East 8th Street & North Washington Avenue Floodplain Evaluation Report

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November 23, 2022

Prepared for:

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1 SCOPE AND PURPOSE

The purpose of this Report is to provide details relative to the engineering analyses and concept development performed to support investigations by the City of Douglas, Arizona (City) into reported flooding of residential areas near the intersection of East 8th Street and North Washington Avenue. Aside from the concept descriptions provided within this Report, the scope of this analysis is limited to evaluation of existing drainage and floodplain conditions. JE Fuller/Hydrology & Geomorphology, Inc. (JE Fuller) has prepared this Report to summarize the methods, assumptions, input parameters and relevant output information from analyses performed to support the City's efforts into mitigating the effects of flooding from surface water runoff resulting from rainfall events. The City authorized JE Fuller's efforts for this project via a signed proposal contract, executed May 12, 2022.

This Report pertains to the Washington Avenue Channel, an earthen channel that flows south, situated along the west side of North Washington Avenue, beginning south of East 8th Street. South of East 5th Street, the Washington Channel turns west and flows through a culvert crossing then continues due west towards the Rose Avenue Channel. The project area has historically been a focus point due to the effects of surface water runoff and flooding from the watershed and channel. Efforts to mitigate those effects are evidenced by the presence of flood gates along the western curb line of North Washington Avenue (see image on front cover). Available information related to the purpose, need, intended function, and historical performance of those gates is limited.

This Report pertains to land situated in Sections 16, 17, 18, 19, 20, & 21 of Township 24 South Range 28 East of the Gila and Salt River Meridian (G&SRM). The project focus area is located within the southeast quarter of Section 18 of Township 24 South Range 28 East of the G&SRM. Refer to Figure 1-1 for a map of the project area location within the City of Douglas.

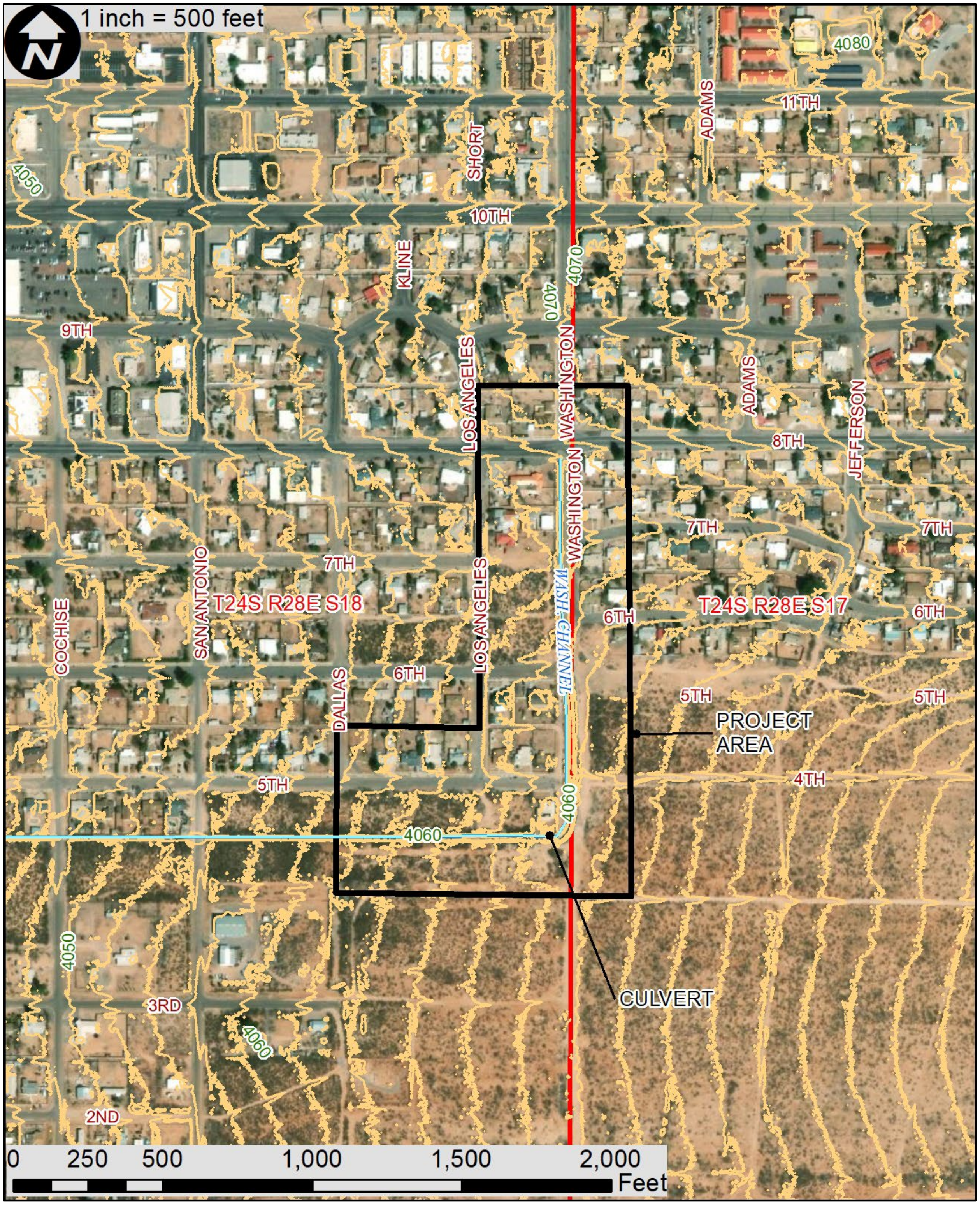

Figure 1-1. Project Location

2 FLOODPLAIN EVALUATION

To evaluate the potential for surface water drainage to affect the project area, rainfall/runoff relationships were modeled using HEC-RAS version 6.1 software, produced by the U.S. Army Corps of Engineers. The analyses and concept layouts performed for this project relied on the digital elevation model (DEM) bare-earth topographic data provided by Cochise County Engineering and Natural Resources Department. That data set, originally provided by the United States Geological Survey (U.S.G.S.) is arranged with a 1.25-foot horizontal spacing, corresponding to year 2021. The DEM is based on the North American Vertical Datum of 1988 (NAVD88) international feet and is on the Cochise County Low Distortion Projection (LDP) coordinate system. From that DEM data, topographic contours at a 2-foot interval were created for the project locations and the surrounding vicinity.

Rainfall/runoff hydrology modeling was performed for the 10- and 100-year precipitation events, corresponding to the 10- and 1-percent Annual Exceedance Probability (AEP) floods, respectively. See below for details on the modeling performed for this project.

2.1 FEMA SPECIAL FLOOD HAZARD AREAS

The project area is affected by Special Flood Hazard Areas (SFHAs) delineated by the Federal Emergency Management Agency (FEMA). The 2D Flow Area spans the following FEMA DFIRM Panels: 04003C2881G, 04003C2882F, 04003C2883G, and 04003C2884G. Panels 2881G, 2883G, and 2884G have an Effective Date of October 20, 2016. Panel 2882F has an Effective Date of August 28, 2008. The project area is located on Panel 2884G.

The project area is affected by SFHAs Zone A and AO3, along with shaded Zone X. Much of the potential watershed is within Shaded Zone X (not a SFHA) indicating 500-year floodplain or flooding with shallow depths less than 1 foot.

Refer to Figure 2-1 for delineation of the effective FEMA SFHAs in the 2D Flow Area.

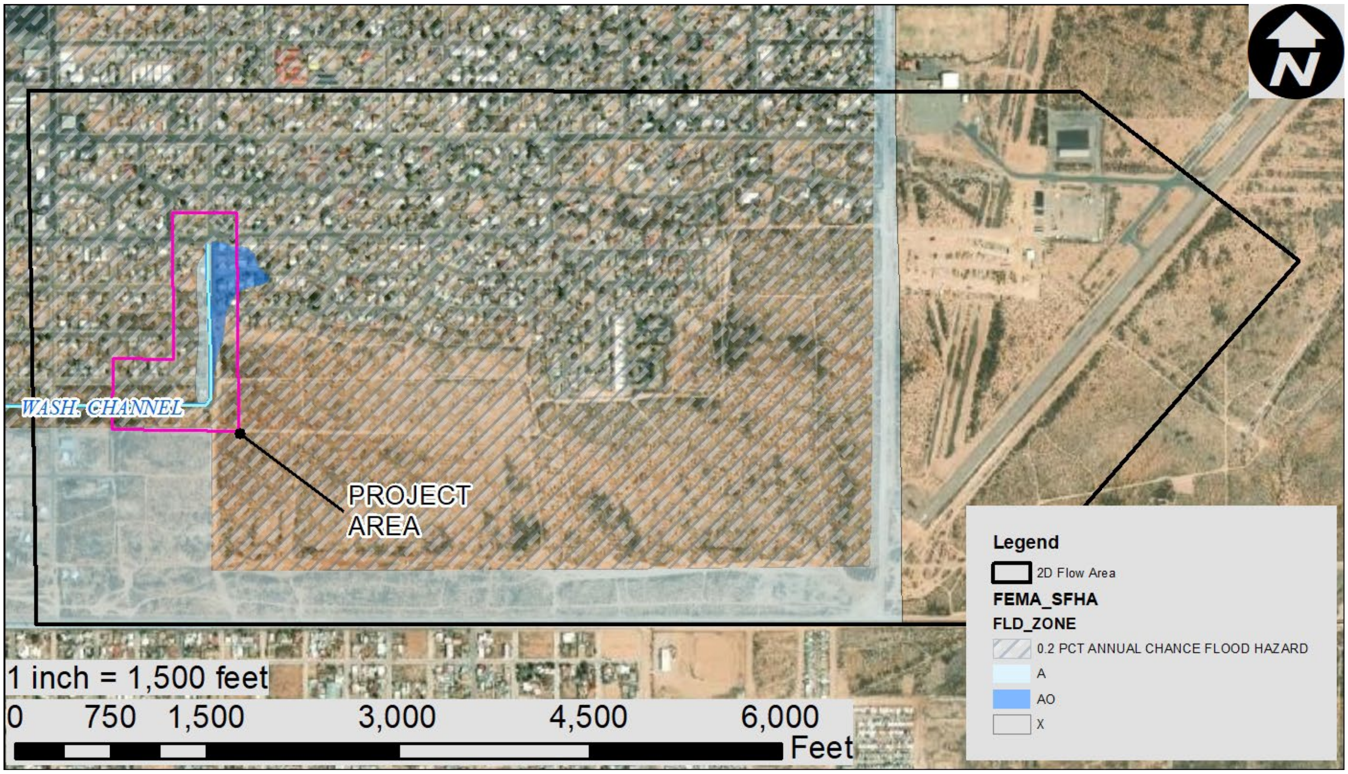

Figure 2-1. FEMA SFHAs

2.2 HEC-RAS Model Input

For all HEC-RAS modeling performed for this project, rainfall/runoff is simulated together within the model, as precipitation is applied to the entire 2D Area and runoff is routed downstream; hydrology and hydraulics are coupled together for the simulations and model output reflects the computed results.

2.2.1 Model Arrangement

The HEC-RAS modeling consists of a 2D Flow Area using a single mesh covering the entire potential watershed limit. Refer to the sections below for additional details. The HEC-RAS project file is named *8TH_WASH.prj*, with an associated terrain file named *TERRAIN_BURN1*, an infiltration file named *INFILTRATION*, and a land cover spatial coverage file named *LANDUSE*. The 2D Flow Area is named 2D_MODEL.

Table 2-1 provides plan, geometry data and unsteady flow data file names used in the 2D modeling.

Table 2-1. HEC-RAS 2D Model Input Files

AEP Flood	Plan File Name	Geometry Data File Name	Unsteady Flow Data File Name
10 Percent	EX2021_10YR	EX_2021	10YR
1 Percent	EX2021_100YR	EX_2021	100YR

2.2.2 Nominal Mesh Spacing

The 2D Flow Area was assigned a nominal mesh grid spacing of 50 feet in both the x and y directions. Breaklines introduced to the 2D Flow Area grid were assigned the default nominal spacing or a lesser value, depending on the location and desired model effect. A notable distinction of using HEC-RAS 2D modeling over other software (e.g. FLO-2D) is that the mesh boundaries sample the underlying terrain to simulate the hydraulics along each boundary face, meaning that the model routes flow independently across all boundary faces between mesh cells.

2.2.3 HEC-RAS 2D Breaklines

Breaklines were used in the 2D mesh to force cell faces to be oriented along the breakline and introduce a finer grid resolution at selected locations to detail features that affect flow patterns such as channel banks, berms, roadway embankments, and excavations. Breaklines were used to impose alignments to cell faces where the orthogonal nature of the mesh grid development did not align well with flow patterns/directions and deflections caused by existing features in the inundated area.

In selected regions where breaklines were used to add finer detail to the model area, depending on the purpose of the breakline and the nature of the feature being detailed, breakline-specific minimum and maximum cell spacing were used with values ranging from as low as 5 feet to as high as 35 feet, respectively. Many breaklines did not have minimum or maximum values assigned, and therefore defaulted to the nominal spacing in regeneration of the 2D mesh at the breakline.

2.2.4 Precipitation

Maximum point-precipitation rainfall depth for the potential watershed boundaries were identified and then applied across the 2D Flow Area using NOAA Atlas 14 rainfall raster data sets. Rainfall intensity was varied by time using the twenty-four-hour storm distribution based upon the NRCS Type 2 event. The 24-hour distribution is shown in Figure 2-2 while the maximum rainfall point values are shown in Table 2-2.

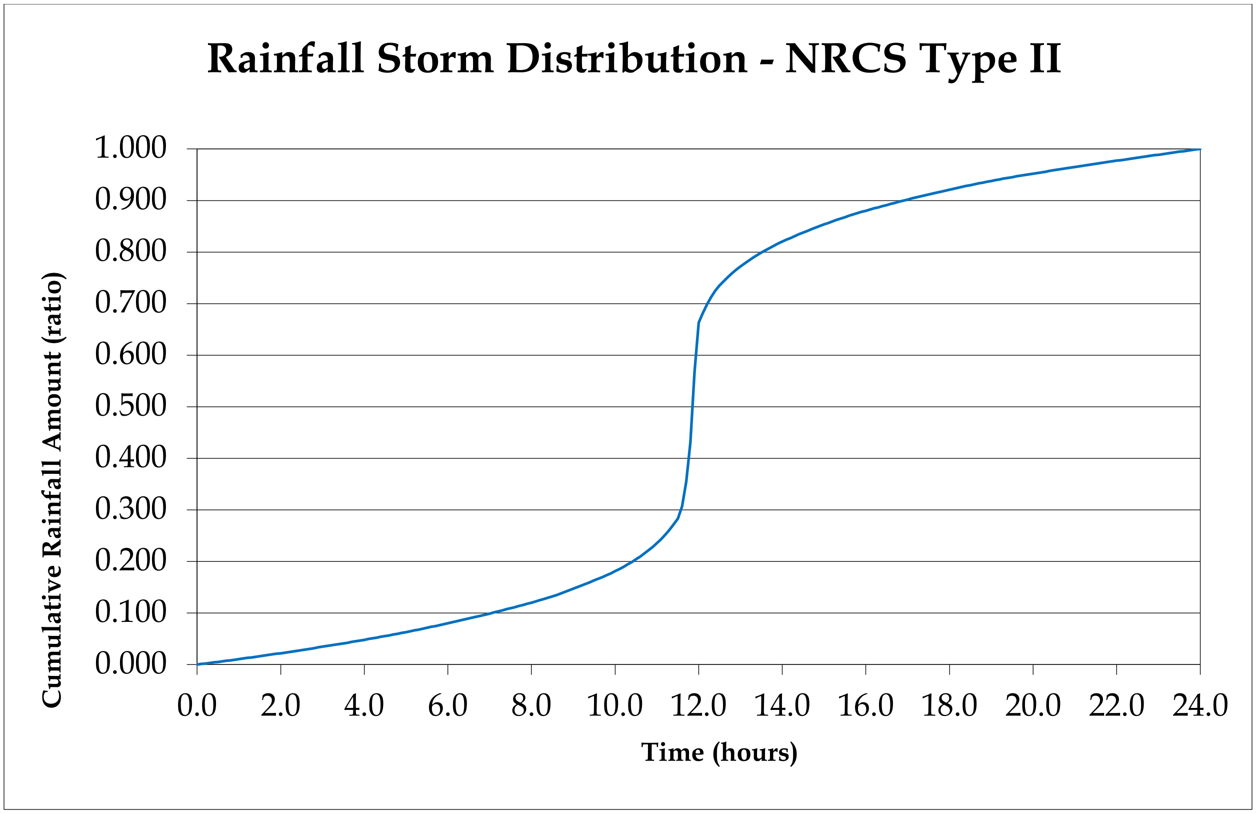

Figure 2-2. 24-Hour Precipitation Distribution (NRCS Type II)

Table 2-2. NOAA Atlas 14 Precipitation Values

LATITUDE (degrees)	LONGITUDE (degrees)	NOAA 14 PRECIP (in.) RETURN PERIOD (24 hr.) 10-Year	100-Year
31.3402	-109.519	2.68	3.90

2.2.5 Boundary Conditions

The 2D Flow Area was simulated to receive the precipitation uniformly distributed across the model area, as described above. A downstream boundary condition line, named DOWNSTREAM is located along the western extent of the 2D Flow Area, to allow discharge to exit the 2D Flow Area. That boundary condition line was set to Normal Depth and given a friction slope of 0.005 ft./ft.

Following development of the 2D Flow Area and initial model setup, runoff flow collecting and ponding along the southeastern limits of the 2D Flow Area was observed in the results. Accordingly, boundary condition lines named SE_RUNOFF and E_RUNOFF were introduced along the 2D Flow Area limit to allow flow to discharge from the 2D area. Those boundary condition lines were set to Normal Depth and given a friction slope of 0.010 ft./ft.

Given the discontinuous nature of the flooding observed at the downstream boundary condition lines, the options to compute separate water surface elevations per face along the BC lines were selected.

2.2.5.1 Initial Conditions

For all plans the initial conditions time was set to 1 hour to allow the model to warm up prior to the simulation. Following the initial conditions period, the model then runs the unsteady simulation beginning from the wetted initial conditions.

2.2.6 Equation Set

All HEC-RAS 2D simulations used the Full Momentum equation set (option SWE-ELM in HEC-RAS v6.1).

2.2.7 Time Step

While the user is able to specify a fixed time step for the simulation, all HEC-RAS 2D simulations were set to adjust the time step based on the Courant Number. Minimum and maximum values for the Courant Number were assigned values of 0.49 and 1.0 respectively. The simulation time was set to 48 hours to allow the 24-hour storm duration to pass through and runoff to discharge from the 2D Flow Area.

2.2.8 Bridges and Culverts

For this project, one culvert crossing is located in the 2D Flow Area, modeled as a 2D Flow Area Connection in the HEC-RAS geometry. Field survey was not performed nor provided in support of this project. Field reconnaissance provided measurements of the culvert openings and available headwater depth at the inlet. The culvert crossing identified in the field is a combination parallel corrugated metal pipe and box culvert configuration. Invert elevations were estimated from the DEM data. The terrain above the culvert was entered as a broad crested weir with a weir coefficient of 3.0. Debris loading and sedimentation were not considered in the culvert model.

Refer to Table 2-3 for a summary of the culvert crossing modeled in the HEC-RAS 2D model. The location of the culvert crossing is shown on Figure 1-1.

Table 2-3. Culvert Configuration

		Invert Elevations			
Culvert ID	Configuration	Inlet	Outlet	Length (ft)	Skew Angle (Degrees)
SOUTH	1-48” Corrugated Metal Pipe (CMP)	4058.0	4057.6	85’	0
NORTH	1-8.0’ x 3.0’ Concrete Box	4058.0	4057.6	85’	0

2.2.9 Levees, Dikes, and Non-Levee Embankments

Levees, dikes, and non-levee embankments are present in the watershed of the Washington Channel modeled using HEC-RAS 2D. Levee lines are shown within the study area on the effective DFIRMs/NFHL dataset. As the 2D modeling reflected topography provided by the 2021 DEM, levees, dikes, and non-levee embankments evident by the topography data were included in the 2D model area terrain for existing conditions. Potential levee failure was not evaluated for this project.

2.2.10 Islands, Flow Splits, and Ineffective Flow Areas

Islands, flow splits, and ineffective flow areas are present in the reach modeled using HEC-RAS 2D. As the 2D modeling method accounts for such phenomena and is expected to accurately reflect the resulting flow dynamics, islands, flow splits, and ineffective areas resulting from the 2D model area simulations are reflected in the mapping.

2.2.11 Impervious Cover

Impervious cover including buildings, parking lots, and paved roads were identified and digitized based on aerial photography data. A polygon shapefile was created for the impervious coverage in the model area, and was used in creation of the LANDUSE layer that supplied the impervious cover and surface roughness values. Refer to Section 2.2.12 below for additional details.

2.2.12 Manning's n Values

Manning's roughness values used for this project range from 0.017 to 0.040. The Manning's roughness value for each LANDUSE class was determined based on the ADOT Hydrology Manual. Manning's n values and percent imperviousness for each LANDUSE classification are summarized in Table 2-4.

Table 2-4. Manning's n Values and Percent Impervious by Landuse Classifications

Landuse Classification	Manning's n Value	Percent Impervious
BUILDINGS	0.017	100
STREETS	0.017	100
RESIDENTIAL	0.035	0
UNDEVELOPED	0.040	0

Refer to Figure 2-3 for mapping of the land use classifications in the 2D Flow Area.

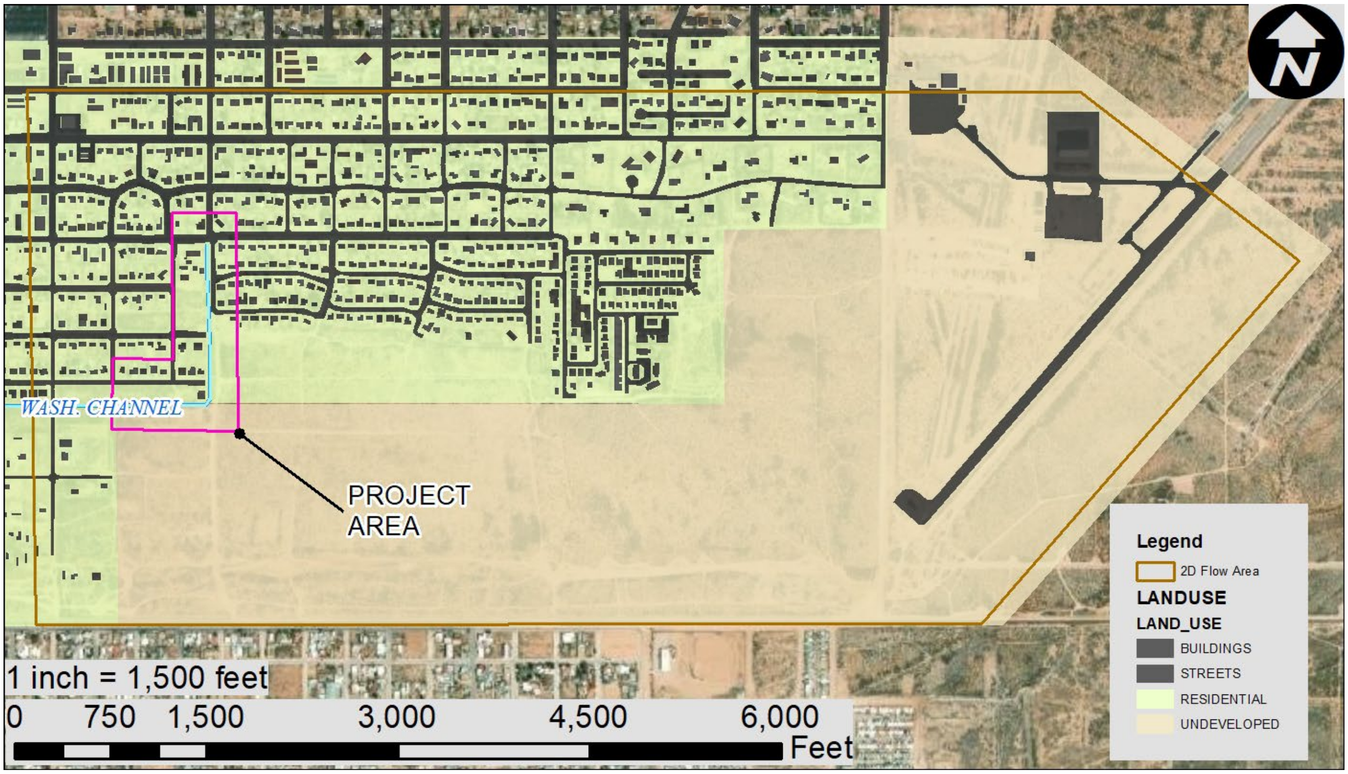

Figure 2-3. Land Use Classifications

2.2.13 Infiltration

The Green & Ampt precipitation loss methodology was employed to evaluate the rainfall losses associated with watershed storage and infiltration. Necessary input parameters for use of this method in HEC–RAS include the initial and saturated moisture content, hydraulic conductivity, and suction for the watershed soils. The parameters were determined using the Green & Ampt soils database developed for use with the ADOT methodology. After initial collection of these values, the hydraulic conductivity was corrected for vegetative cover using Figure 3-1 of the ADOT Manual and considering 20 percent vegetative cover. The parameter for surface retention loss for the watershed model was not included in the model as HEC-RAS provides no way to directly enter that variable. Table 2-5 below summarizes the input parameter values utilized for the rainfall loss methodology.

Table 2-5. Infiltration Parameters by Soil Mapping Unit

Soil Mapping Unit	Initial Soil Water Content	Saturated Hydraulic Conductivity (in/hr)	Saturated Soil Water Content	Wetting Front Suction (in)
8	0.07	0.6549	0.39	5.02
136	0.08	0.5217	0.42	3.96
70	0.19	0.111	0.45	12.07
97	0.18	0.0999	0.44	10.28
99	0.13	0.1998	0.41	8.6
125	0.1	0.1776	0.42	22.13

Refer to Figure 2-4 for depiction of the soil mapping units in the HEC-RAS 2D Flow Area.

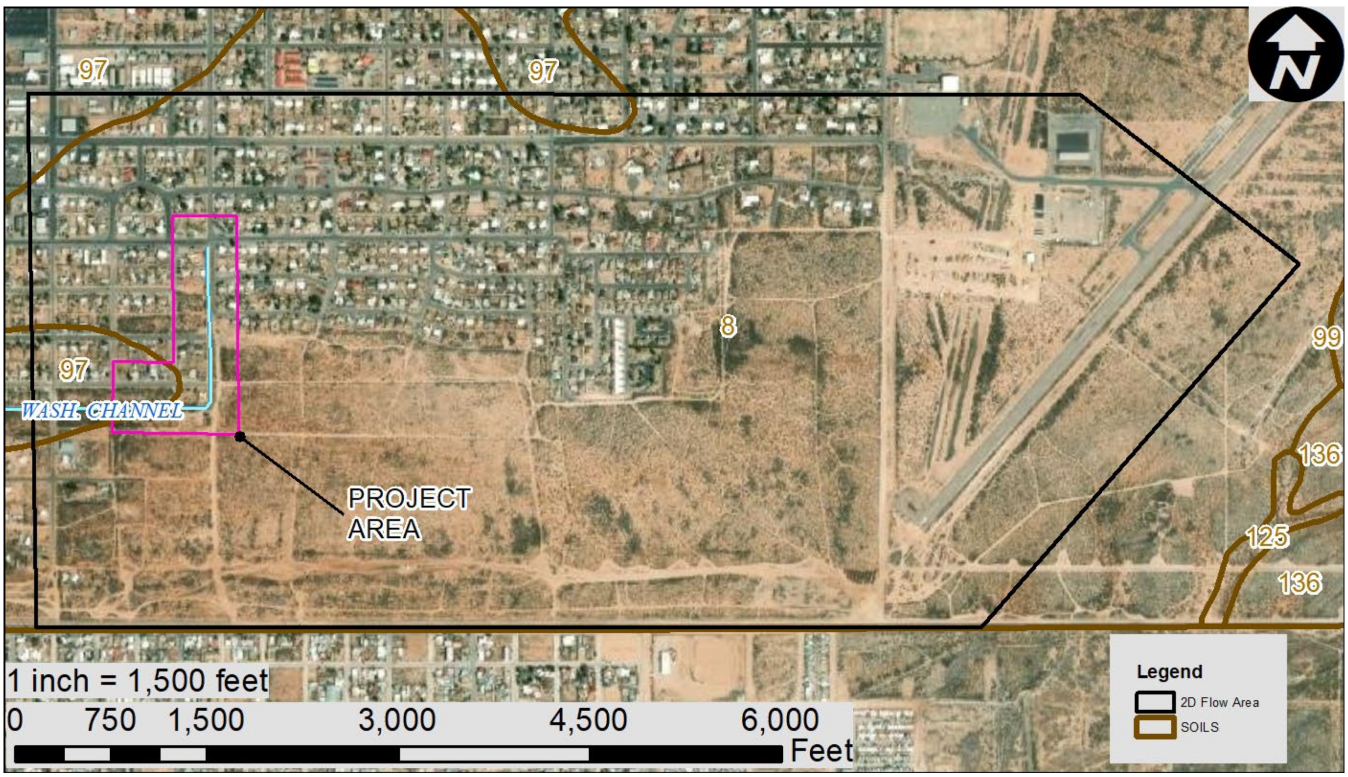

Figure 2-4. Soil Mapping Units

2.3 HEC-RAS Model Results

Following completion of the 10-year and 100-year storm simulations, output data was extracted from those model results. See Figure 2-5 and Figure 2-7 for depiction of the resulting flow depth mapping across the 2D Flow Area for 10- and 100-year floods, respectively. Refer to Figure 2-6 and Figure 2-8 for depiction of the resulting flow depth mapping in the project area for 10- and 100-year floods, respectively.

Resulting peak hydrograph discharges are provided in Table 2-6, corresponding to the Cross Section lines shown on Figure 2-6 and Figure 2-8. Additional details such as flow velocities and water surface elevations are available from the HEC-RAS model file output.

Table 2-6. Peak Discharges

Cross Section	10-Year Discharge Q_{10} (cfs)	10-Year Volume (acre-feet)	100-Year Discharge Q_{100} (cfs)	100-Year Volume (acre-feet)
CULVERT_INLET	92.9	15.1	157.9	23.1
7TH_STREET	175.9	15.6	364.1	29.3
4TH_STREET	35.1	3.4	68.9	5.9
NORTH_BREAKOUT	106.2	4.3	261.3	13.2

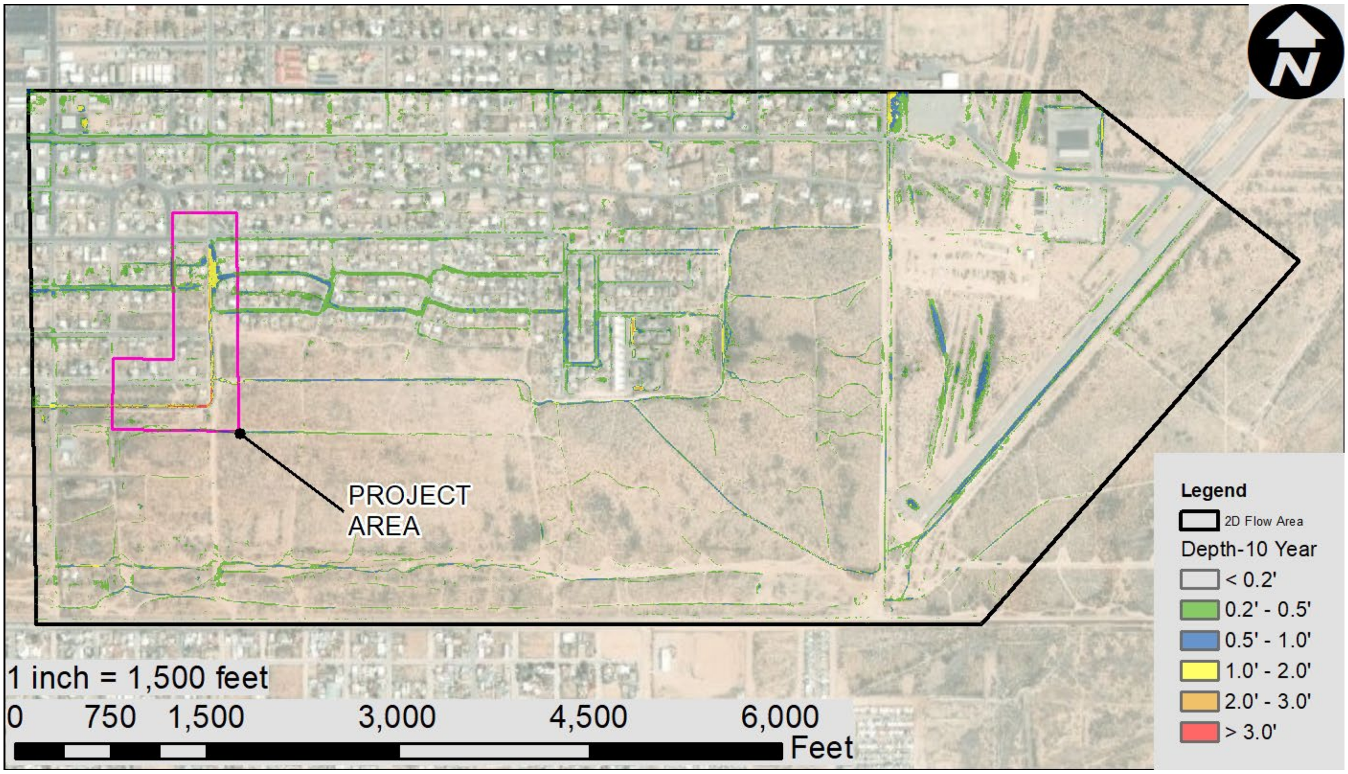

Figure 2-5. 10-Year Flow Depth Mapping

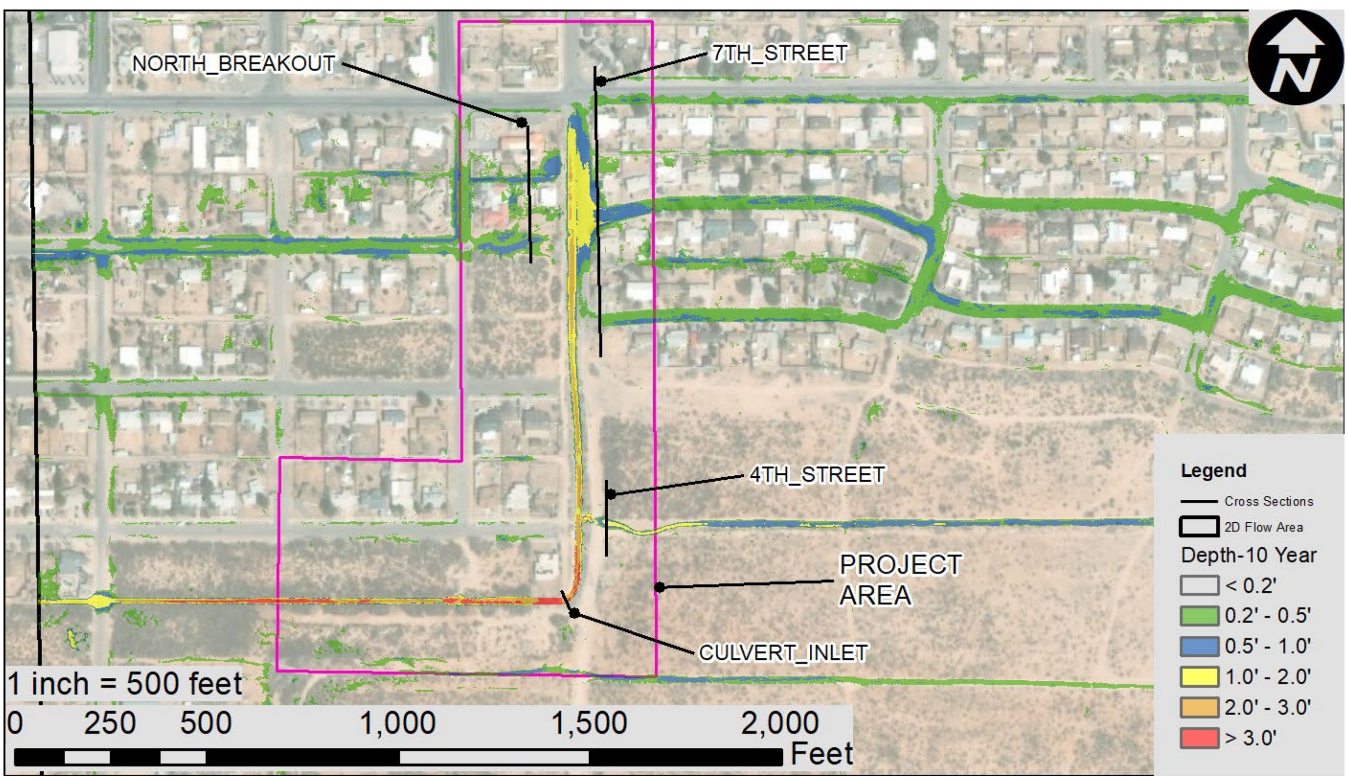

Figure 2-6. 10-Year Flow Depth Mapping (Project Area)

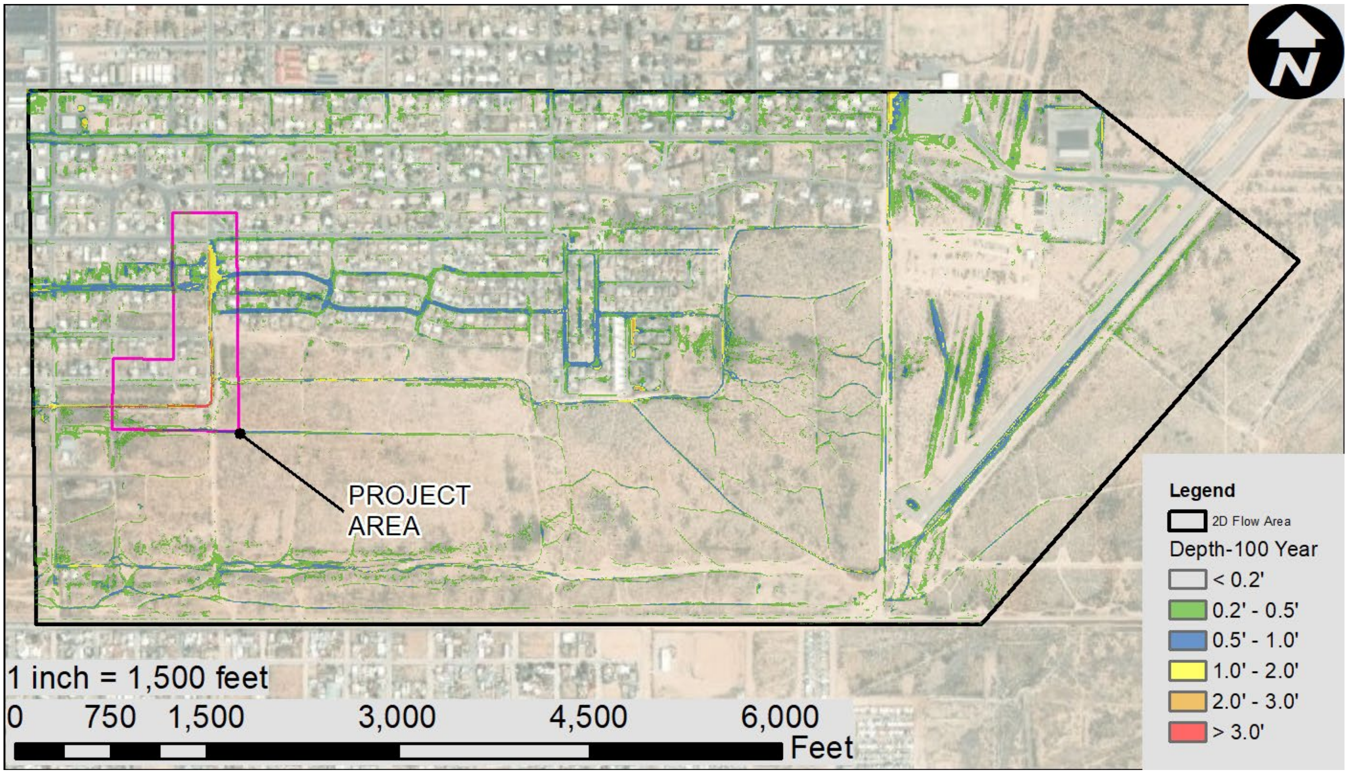

Figure 2-7. 100-Year Flow Depth Mapping

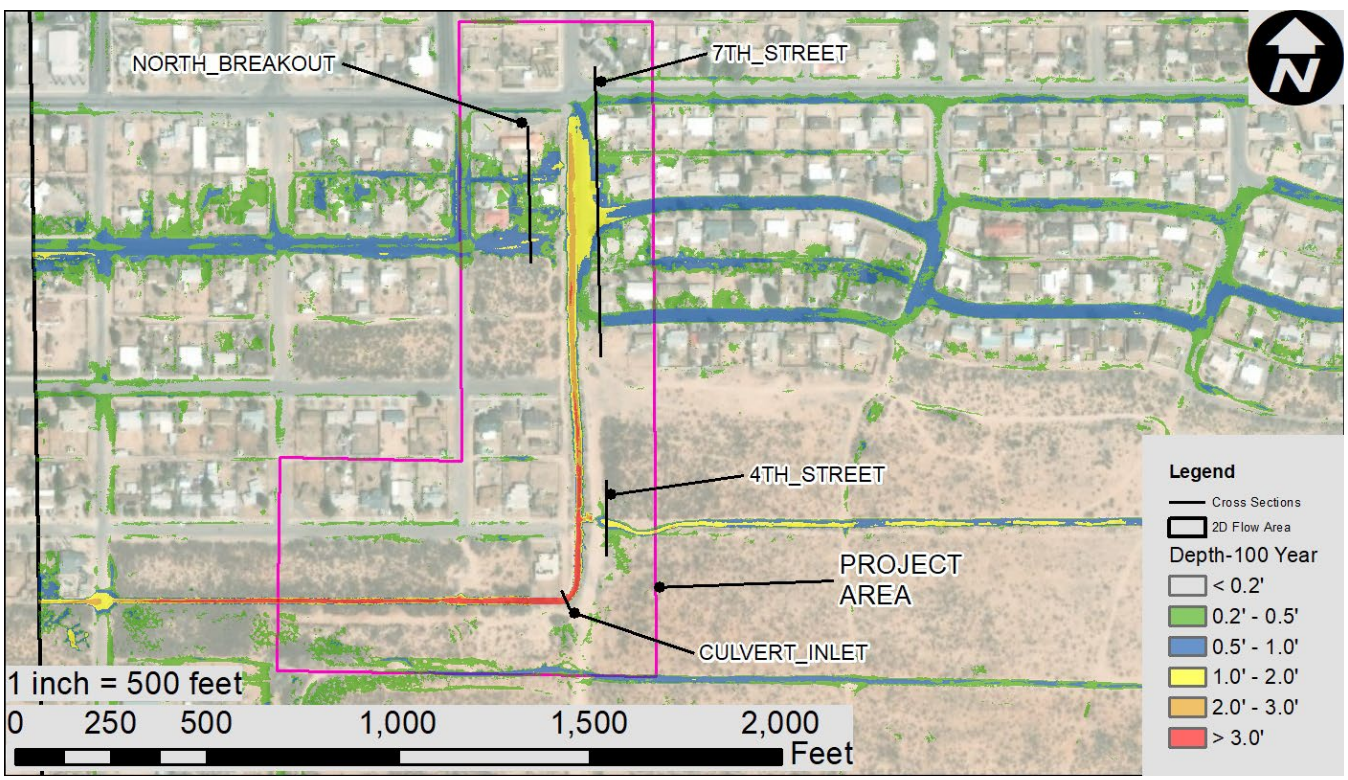

Figure 2-8. 100-Year Flow Depth Mapping (Project Area)

2.4 Channel and Culvert Hydraulics

To evaluate the existing channel and culvert configurations, hydraulic rating curves were developed for the culvert and a channel cross section as depicted on Figure 2-9 below, independent of the HEC-RAS modeling. Reports from previous flood events provide observations of debris, sediment and other material becoming deposited at the inlet of the culvert and obstructing the passage of flood flows. The following discussion relates to analyses of the culvert and channel in fully functional (e.g. clean, maintained) conditions.

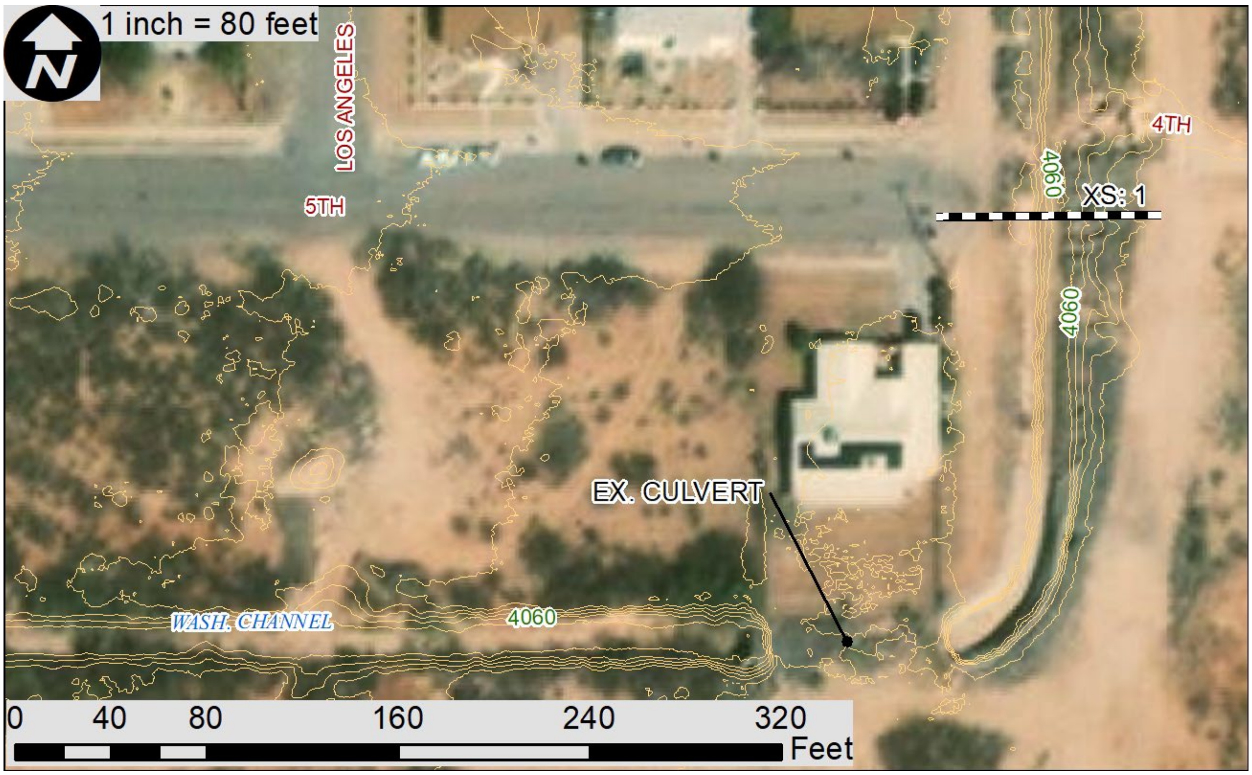

Figure 2-9. Existing Culvert and Channel Cross Section

The channel cross section (XS1) was analyzed using Manning's equation for uniform flow, with the following input parameters. Cross section station-elevation relationships were derived from the DEM, the longitudinal slope was also estimated from the DEM and Manning's n was set to 0.035 reflecting partially vegetated conditions. The maximum channel depth was set to 8.5 feet reflecting the depth where flow overtops the channel banks. A rating curve was established from the cross section analysis to tabulate the estimated discharge varied by flow depth.

Independent of the culvert analysis within the HEC-RAS 2D model, the existing culvert crossing was analyzed using HY-8, considering a structure configuration similar to that presented in Table 2-3. The maximum depth was estimated as the depth of overtopping of the weir crest. A rating curve was established from the cross section rating to illustrate the estimated discharge varied by flow depth.

Refer to Figure 2-10 for depiction of the hydraulic rating curves for the existing culvert and channel cross section.

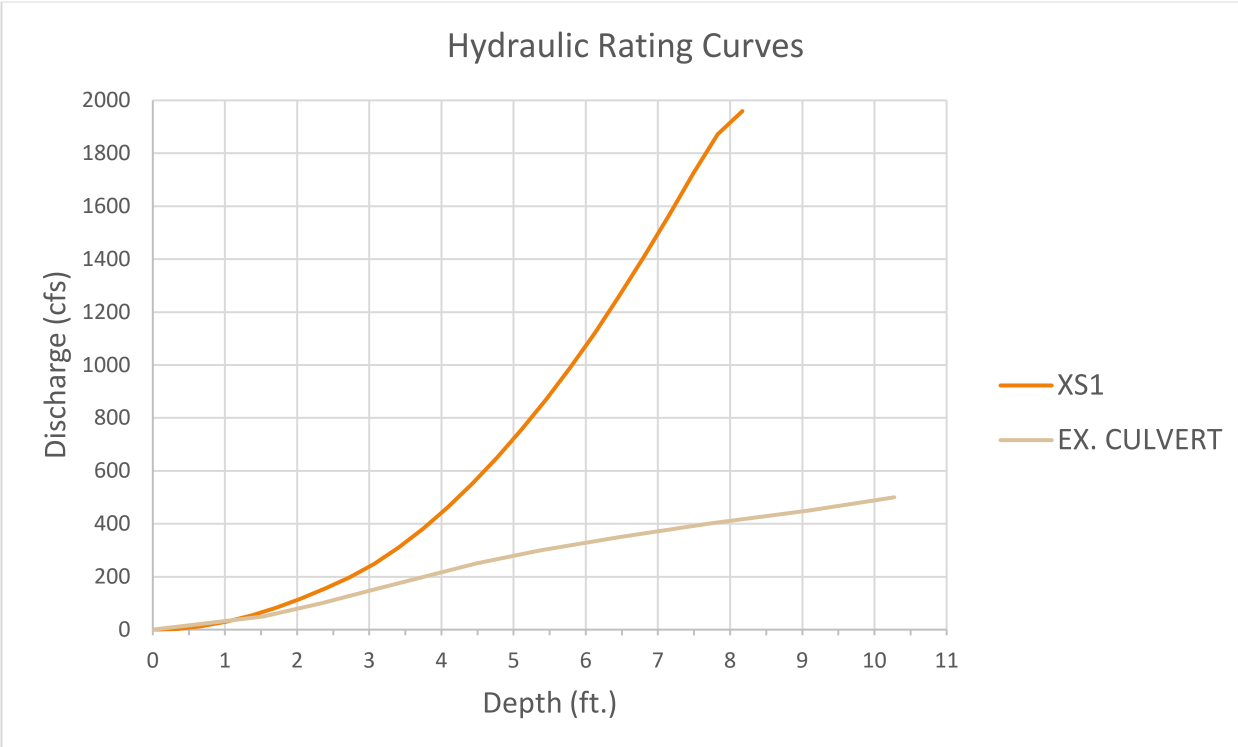

Figure 2-10. Hydraulic Rating Curves for Culvert and Channel Cross Section

As shown on Figure 2-10, the existing channel at cross section XS1 conveys considerably more discharge than the existing culvert for given flow depths above 2 feet. In general, debris and sediment deposition can be expected at locations such as the existing culvert inlet where abrupt constrictions to the flow rate occur. Removal of the existing culvert should be considered by the City to increase flow capacities and mitigate observed debris and sediment accumulation along the Washington Channel, especially if the culvert is not necessary for pedestrian or vehicular traffic flow. Given the sharp nature of the channel bend just upstream of the culvert inlet location, extension of the channel bank erosion protection is recommended to coincide with culvert removal, if performed.

3 CONCEPT PROJECTS

The following sections describe potential projects that could be further investigated to reduce the flooding threat to residential structures in the area. Underground utilities in the project area likely will be affected by the concept projects discussed below. The initial layout of the concepts was performed without the benefit of land survey data that will be required for further investigations. Information such as: property boundaries and right of way (ROW) extents is approximate.

The following are recommended next steps for further evaluation of any work in the project area:

1. Acquisition of utility base maps from appropriate agencies;
2. Surface marking and/or potholing to better understand the presence of existing underground utilities;
3. Land survey of the project area, including topography, planimetrics, and property/ROW boundaries;
4. Detailed evaluation of the need for the culvert present south of the East 5th Street alignment;
5. Detailed evaluation of the need for the flood gates present along the western curb line of North Washington Avenue;
6. Detailed hydraulic modeling of one or more alternative(s);
7. Design Concept Report (DCR) for one preferred alternative.

Two concepts that were not considered for reducing flood threats are: 1.) levee and 2.) storm drain pipe network. The levee option was not considered due to the allowable ROW width of North Washington Avenue. A storm drain network along the Washington Channel was not considered due to the vertical space constraints.

All concepts presented should include consideration of removal of the culvert based on the results of the recommendation (#4) above, and should include consideration of removal of the Washington Avenue curb line flood gates based on the results of the recommendation (#5) above.

3.1 FLOODWALL

This Concept calls for a concrete block floodwall along the western ROW of North Washington Avenue. It is recommended to place the floodwall from the intersection of East 8th Street and North Washington Avenue to the inlet of the culvert south of East 4th Street, unless flood modeling demonstrates the capacity of the existing Washington Channel meets the design discharge directed to it.

This option would have the effect of blocking the breakout flow at the NORTH BREAKOUT Cross Section, and confining flows to the Washington Channel alignment for the extent of the floodwall. Therefore, downstream of the concept floodwall the Washington Channel alignment will receive runoff flow greater than under existing conditions. Hydrologic modeling will be required to evaluate potential adverse impacts of increasing discharge downstream of the concept floodwall.

Refer to Figure 3-1 for depiction of the floodwall concept.

Figure 3-1. Concept Floodwall

3.2 CHANNEL RE-GRADING

The Channel Re-Grading Concept involves the enlargement and deepening of the existing Washington Channel alignment, within the North Washington Avenue ROW. In general, the concept channel cross section is trapezoidal with a 14 foot bottom width. Channel side slopes were set as 4 horizontal to 1 vertical, and longitudinal slope was set to 0.004 ft./ft. Manning's n roughness was set to 0.030 reflecting a well-maintained earthen channel. Considering a discharge of 500 cfs, the channel flows subcritical at a depth of approximately 3.4 feet. Minimum freeboard is recommended to be 1.0 foot. Refer to Figure 3-2 for depiction of the concept channel cross section. Refer to Figure 3-3 for depiction of the concept channel alignment.

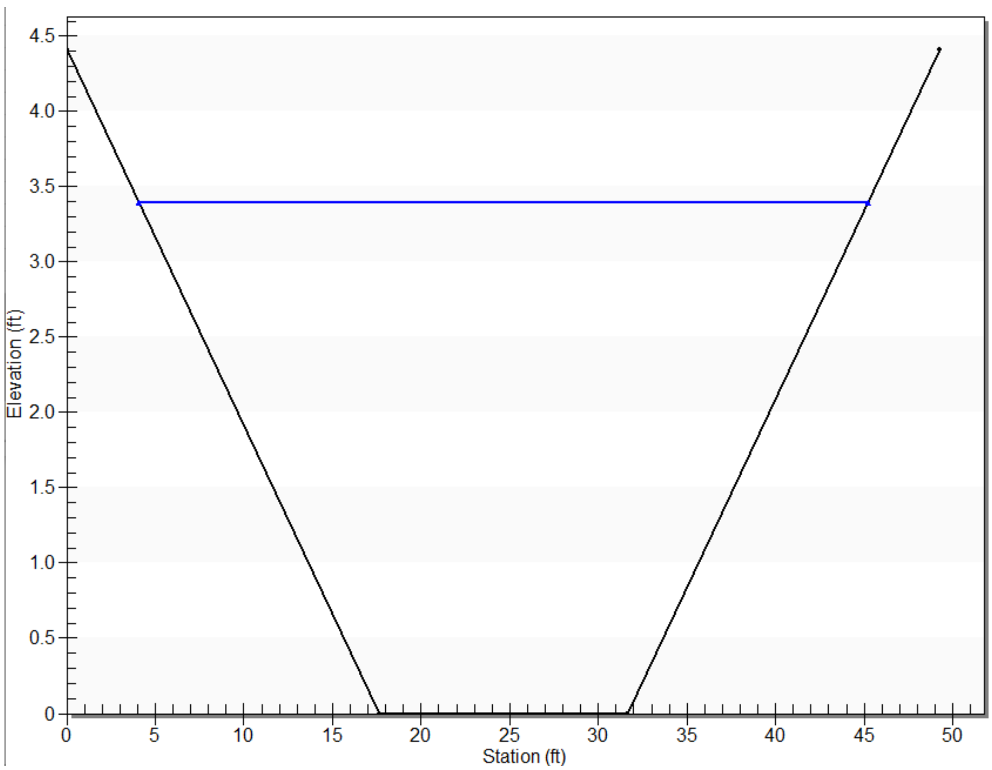

Figure 3-2. Concept Channel Cross Section

It is recommended to enlarge the channel from the intersection of East 8th Street and North Washington Avenue to the inlet of the culvert south of East 4th Street, unless flood modeling demonstrates the capacity of the existing Washington Channel meets the discharge directed to it. Based on the available approximate data, there is approximately 45 feet of width between the western edge of pavement along North Washington Avenue and the properties adjacent to the west. Top width of flow is estimated to be 41 feet without the recommended freeboard.

This option would also have the effect of blocking the breakout flow at the NORTH BREAKOUT Cross Section, and confining flows to the Washington Channel alignment for the extent of the enlarged channel. Therefore, downstream of the concept channel the Washington Channel alignment will receive runoff flow greater than under existing conditions. Hydrologic modeling will be required to evaluate potential adverse impacts of increasing discharge downstream of the concept channel.

Figure 3-3. Concept Channel

3.3 OFF-LINE DETENTION BAIN

The Off-Line Detention Basin Concept leverages existing undeveloped property and ROW west of North Washington Avenue to provide a preferential flow path into the basin as opposed to towards the developed properties west of the Washington Channel. This concept requires the acquisition of the following properties: 409-27-027A, 409-27-027, 409-27-028, and 409-27-029A.

The Concept would lower the grade of the northeastern corner of the concept basin to provide an inlet for flows arriving from the east to the intersection of East 7th Street and North Washington Avenue. The basin would provide storage of runoff in an excavated basin with an overflow spillway located in the southeastern corner of the concept basin. The concept basin as depicted on Figure 3-4 measures approximately 4.1 acres.

A potential additional alternative for this Concept would be to construct transverse trench grates in East 7th Street with a storm drain network discharging into the basin, to promote inflows to the basin by reducing overland flows.

Presumably the concept basin would serve to reduce the discharge along the Washington Channel downstream of the concept basin. Hydrologic modeling will be required to evaluate potential adverse impacts of increasing discharge downstream of the concept basin.

Refer to Figure 3-4 for depiction of the concept detention basin.

Figure 3-4. Concept Basin

4 REFERENCES

Brunner, G. W. (2016). *HEC-RAS, River Analysis System Hydraulic Reference Manual.* Davis, CA: US Army Corps of Engineers.

NOAA. (2014). *Precipitation Frequency Atlas of the United States.* Silver Spring, MD: National Oceanic and Atmospheric Agency.

Pima County. (2013). *TECH-033: Criteria for Two Dimensional Modeling.*

DIGITAL ATTACHMENTS:

- **A. HEC-RAS MODELS & POST-PROCESSED OUTPUT DATA FILES**
- **B. HYDRAULIC TOOLBOX FILE**
- **C. HY-8 FILE**