Catalina Foothills Watercourse Studies:
Technical Data Notebook for Hydrologic and Hydraulic Mapping of the Wentworth Wash and its Tributary,
Pima County Arizona.

FEMA FIRM Panel 04019C-2280 and 2290 K

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Approved by

Suzanne Shields, PE
Director

June 2013

Pima County Regional
FLOOD CONTROL
DISTRICT

Pima County Regional Flood Control District
97 E Congress Street
Tucson Arizona, 85701

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Attached CD

Wentworth Wash TDN with supporting models and GIS data.

Section 1: Introduction

1.1 Purpose

The purpose of this study is to provide flood and erosion hazard information for the Wentworth Wash for use by the Pima County Regional Flood Control District (District) in floodplain use permitting and floodplain management. More specifically, it provides:

- discharge values for sub-basins and important concentration points;
- hydrographs for use with floodplain mapping;
- floodplain mapping for channels with contributing areas greater than 1 square mile, and channels with 100-yr discharges greater than 2000 cfs, which are treated differently under the Pima County Ordinance.

1.2 Project Authority

The State of Arizona has delegated the responsibility to each county flood control district to adopt floodplain regulations designed to promote the public health, safety and general welfare of its citizenry as provided under the Arizona Revised Statutes, Title 48, Chapter 21, Article 1, Sections 48-3601 through 3627. More specifically, A.R.S. 3609 directs county flood control districts to adopt floodplain regulations that:

> A. Regulate all development of land, construction of residential, commercial or industrial structures or uses of any kind which may divert, retard or obstruct flood water and threaten public health or safety or the general welfare; and
> B. Establish minimum flood protection elevations and flood damage prevention requirements for uses, structures and facilities which are vulnerable to flood damage; and
> C. Comply with state and local land use plans and ordinances, if any.
> In conformance with A.R.S. 3609, this ordinance provides for protection of the public health safety and welfare by regulation of flood and erosion hazard areas to control flood hazards and prevent repetitive loss from flood damage.
> D. The flood hazard areas of Pima County are subject to periodic inundation which may result in loss of life and property, create health and safety hazards, disrupt commerce and governmental services, require extraordinary public expenditures for flood protection and relief, and impair the tax base, all of which adversely affect the public health, safety, and general welfare.
> E. These flood losses are caused by the cumulative effect of obstructions in areas of special flood hazards which increase flood heights, flow velocities, and cause flood and erosion damage. Uses that are inadequately flood-proofed, elevated, or otherwise protected from flood damage, also contribute to the flood loss. (Ord. 2005 FC-2 § 2 (part), 2005).

Section 16 of the Pima County Ordinance describes the provisions for floodplain regulation in Pima County.

1.3 Project Location

The study was performed to provide drainage information for the Wentworth Wash. Study reach of the Wentworth Wash is in FEMA Zone X, as shown on the current Flood Insurance Rate Map (FIRM) number 04019C-2280K (February 8, 1999).

The watershed is 5.28 square mile. The study watershed was divided into five sub-basins (Fig.1.1). The study limits for the Wentworth Wash extends from a junction with Tanque Verde Wash to the upstream end of Subbasin A (Fig.1.2).

1.4 Methodologies Used for Hydrology and Hydraulics

Topographic, hydrologic and hydraulic analyses were performed to determine drainage conditions in the Wentworth wash. ArcGIS, Version 9.3.1, HEC-HMS version 3.4 (HEC-HMS), HEC-RAS Version 4.0 (HEC-RAS), FLO-2D Version 2007.06, and HEC-GeoRAS, Version 4.2.93 (HEC-GeoRAS) were used for the analyses.

1.5 Acknowledgements

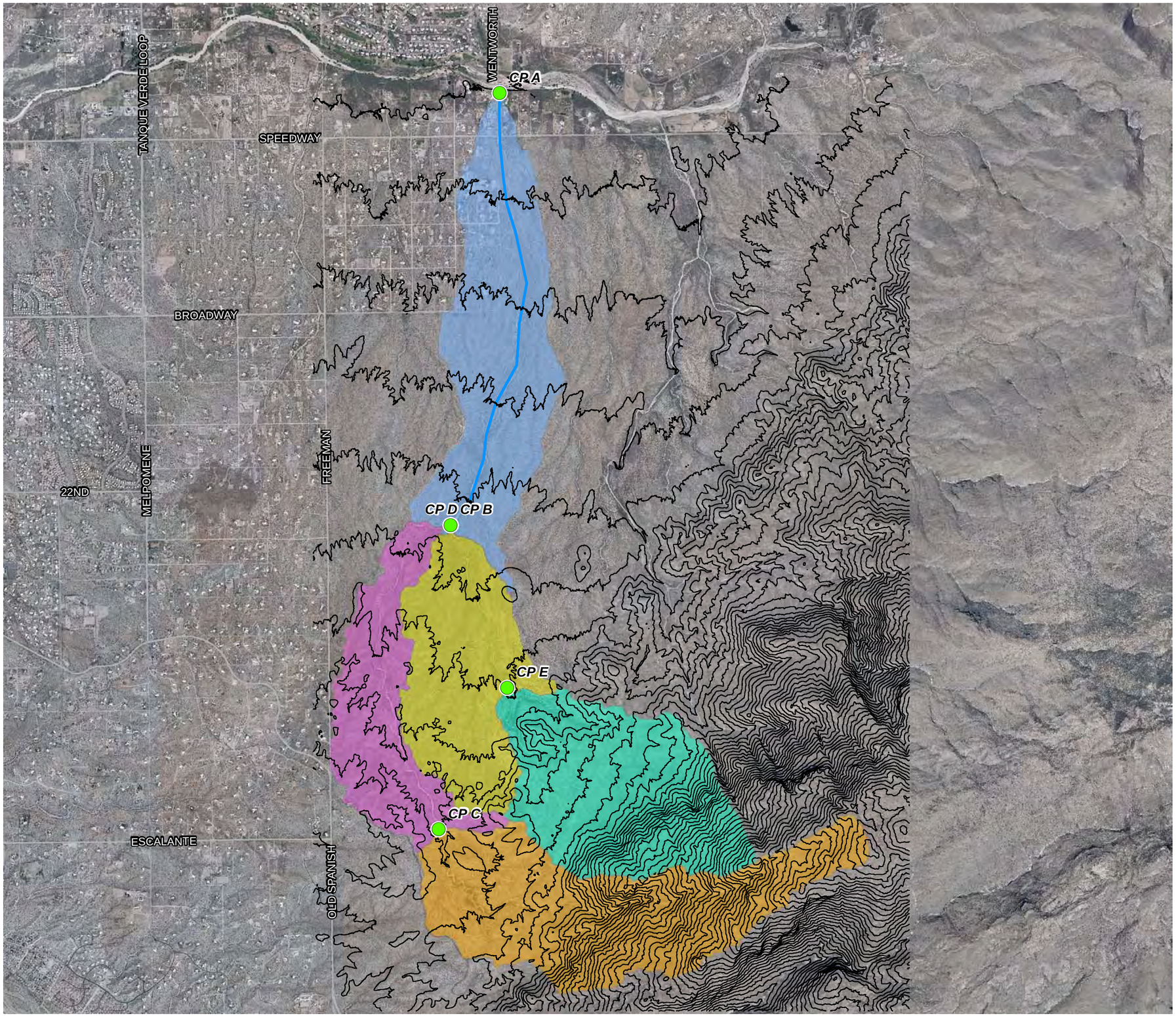
This study relied on assistance of RFCD GIS staff, who were integral to the development of the models and maps.

1.6 Study Results

The modeled discharge for the Wentworth Wash at the confluence with the Tanque Verde Wash is 4719 cfs, where the area is 5.28 square miles.

Preliminary floodplain boundaries for areas less than one square mile are also shown in this study. The Wentworth Wash watershed is mostly located within Federal land (national forest, FEMA Zone D). The floodplain was mapped in the downstream area of the Wentworth Wash. The study found some homes at risk for flooding during the 100-yr flood.

Figure 1.1
Watershed Map
Wentworth Wash



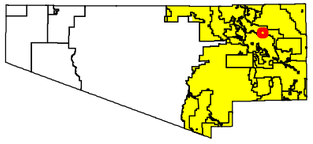
- Discharge Point
- Contour 50ft
- River

Subbasin

- WEW A
- WEW B
- WEW C
- WEW D
- WEW E

Areial Photo 2008 Pima Association of Governments
Topo: 2008 Pima Association of Governments
Vertical Datum: NAVD 1988

Pima County Index Map



Index Map Scale 1:5,250,000

Pima County Regional Flood Control District

Pima County Regional FLOOD CONTROL DISTRICT

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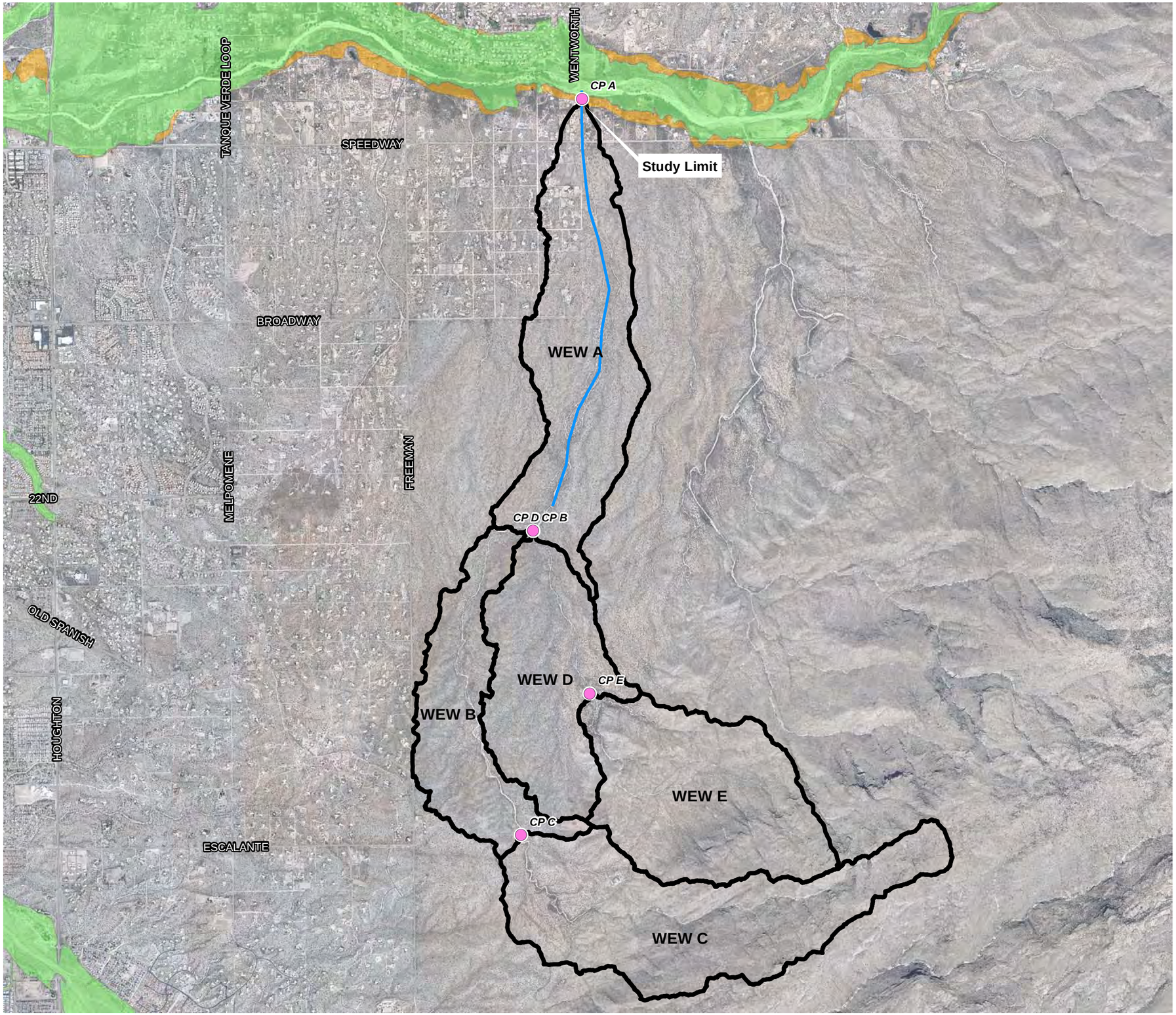
Figure 1.2
Study Limit Map
WentworthWash

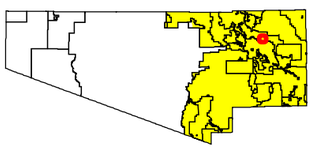


Discharge Point
River
Subbasin

Existing Floodplain
ZONE A
ZONE AE
ZONE X - SHADED

Areial Photo 2008 Pima Association of Governments

Pima County Index Map



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Pima County Regional Flood Control District

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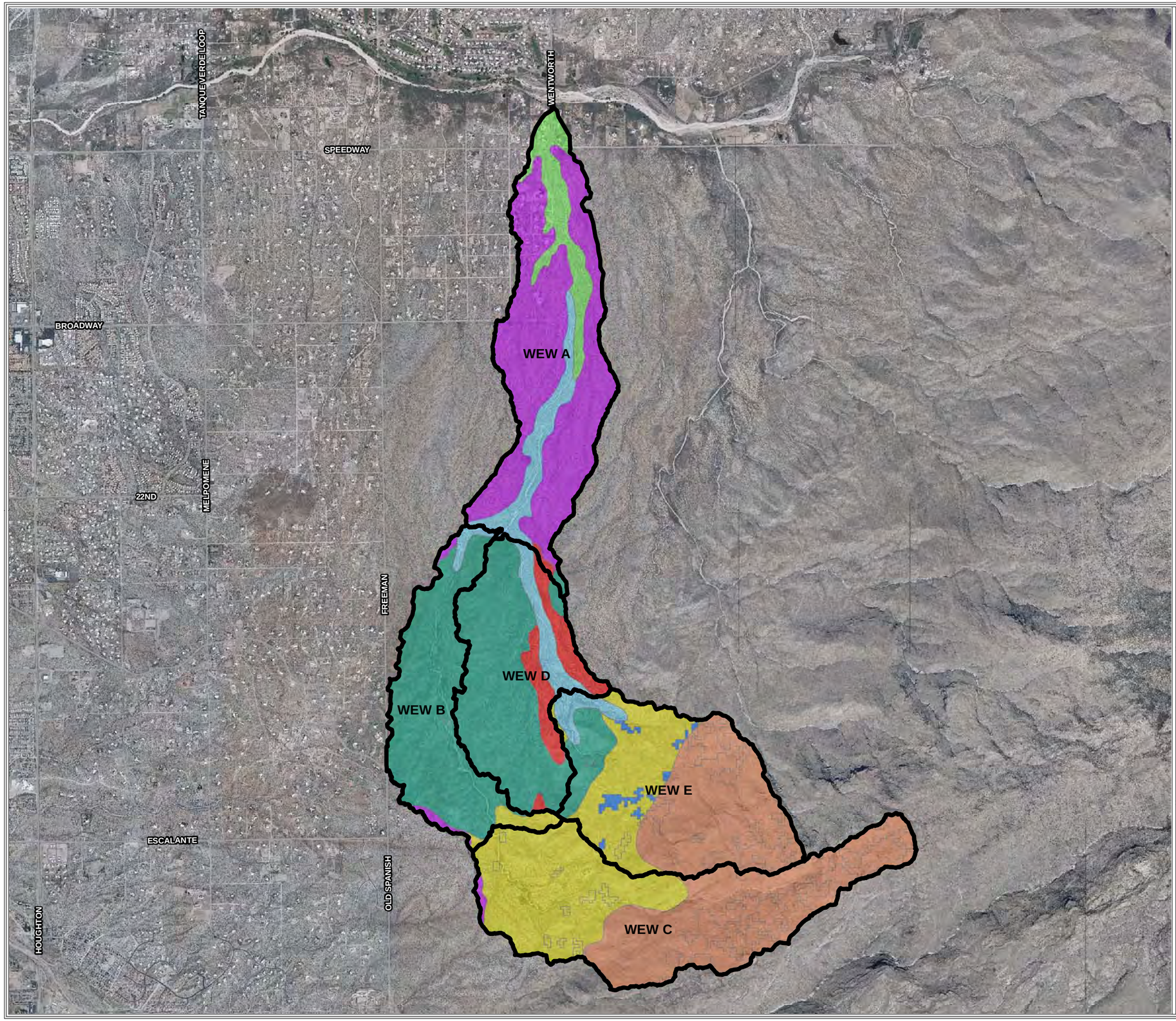
Figure 1.3
Soil Classification
Wentworth Wash



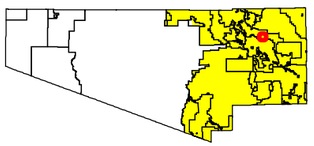
Subbasins

Soil Classification

- Soil Group: A (100%), ARIZO-RIVERWASH COMPLEX, 0 TO 3 PERCENT SLOPES
- Soil Group: B (100%), ANTHONY FINE SANDY LOAM, 0 TO 3 PERCENT SLOPES
- Soil Group: C (25%) D (75%),LAMPSHIRE-ROMERO-ROCK OUTCROP COMPLEX, 10 TO 65 % SLOPES
- Soil Group: C (47%) D (53%),PANTANO-GRANOLITE COMPLEX, 5 TO 25 PERCENT SLOPES
- Soil Group: C (53%) D (47%), PALOS VERDES-JAYNES COMPLEX, 2 TO 8 PERCENT SLOPES
- Soil Group: D (100%), CELLAR-LEHMANS COMPLEX, 5 TO 25 PERCENT SLOPES
- Soil Group: D (100%), CELLAR-ROCK OUTCROP COMPLEX, 30 TO 65 PERCENT SLOPES
- Soil Group: D (100%), CHIMENEA VERY GRAVELLY FINE SANDY LOAM, 5 TO 15 PERCENT SLOPES

Areial Photo 2008 Pima Association of Governments

Pima County Index Map



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Pima County Regional Flood Control District

Pima County Regional FLOOD CONTROL DISTRICT

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Section 2.0 Summary of Key Facts

Section 2.1: General Information

2.1.1 Community: Pima County Regional Flood Control
2.1.2 Community Number: NFIP Community Number 04019C
2.1.3 County: Pima
2.1.4 State: Arizona
2.1.5 Date Study Accepted: Not Accepted –
2.1.6 Study Contractor: Pima County Regional Flood Control District – Akitsu Kimoto
2.1.7 State Technical Reviewer: Not Applicable
2.1.8 Local Technical Reviewer: Suzanne Shields
2.1.9 River or Stream Name: Wentworth Wash
2.1.10 Reach Description: Wentworth Wash
2.1.11 Study Type: Hydrology and Hydraulics study of a Riverene System

Section 2.2: Mapping Information

2.2.1 FIRM Panels: 04019C-2280K
2.2.2 Mapping for Hydrologic Study: Lidar based on 2008 flight used to derive 2' contour interval maps using ARC-GIS 9.3.1
2.2.3 Mapping for Hydraulic Study: Lidar based on 2008 flight used to derive a DEM (5-ft cell size) for use with GeoRAS

Section 2.3: Hydrology

2.3.1 Model or Method Used: HEC-HMS (v. 3.4) model parameterized using methods of RFCD Draft Tech Policy 018
2.3.2 Storm Duration: 3-hr
2.3.3 Hydrograph Type: SCS Unit Hydrograph
2.3.4 Frequencies Determined: 100 yr
2.3.5 List of Gages used in Frequency Analysis or Calibration: None
2.3.6 Rainfall Amounts and Reference: SCS Type II, NOAA 14 Upper 90% Confidence Interval
2.3.7 Unique Conditions and Problems: None
2.3.8 Coordination of Q's: Comparison with previous studies on file with RFCD and discharge estimates

Section 2.4: Hydraulics

2.4.1 Model or Method Used: HEC-RAS 4.0, FLO-2D version 2007.06.
2.4.2 Regime: Modeled as subcritical
2.4.3 Frequencies for which Profiles were Computed: 100 yr
2.4.4 Method of Floodway Calculation: No Floodway
2.4.5 Unique Conditions and Problems: Boundary set at normal depth.

Section 2.5: Additional Study Information:

None

Section 3: Survey and Mapping Information

3.1 Field Survey Information

No field survey was used.

3.2 Mapping

The 2008 Light Detection and Ranging (LiDAR) data was used for the analysis. Coordinates were in Pima County projection:

Projection = State Plane, Arizona Central Zone
Datum = NAD83 HARN
Units = International Feet
North American Vertical Datum of 1988 (NAVD, 1988)

The LiDAR was used to derive a Digital Elevation Model (DEM) and a contour map. DEM derived on 2' centers provided the basis for delineating the watershed and sub-basins. DEM was also used to characterize the topography along channels used for the floodplain mapping process. Contour map derived from the DEM allowed modelers to visualize topographic differences in making decisions on how to model different areas.

Section 4: Hydrology

4.1 Method description.

The 100-year peak discharges for the Wentworth Wash (WEW A, B, C, D and E; Fig 1.1) were calculated using U.S. Army Corps of Engineers Computer Hydrologic Modeling System, (HEC-HMS) version 3.4. The HEC-HMS model requires the parameters regarding rainfall, topography, soil, vegetation, and channel characteristics to determine runoff volume and peak discharge. Those parameters were determined by following the Pima County Regional Flood Control District Technical Policy 018 (Tech-018). Tech-018 is included in Appendix A. The HEC-HMS model is included in Appendix D.

4.2 Parameter estimation.

Methods are summarized in Table 4.1. The data processing methods are summarized in Fig. 4

Table 4.1 - Methods used for a Hec-HMS analysis

	Selected Method
Rainfall Depth	NOAA 14, upper 90% Confidence Interval
Rainfall Distribution	3-hr SCS Type II Storm
Rainfall Loss	SCS Curve number
Time of Concentration	SCS Segmental Method
Transform	SCS Unit Hydrograph
Routing	Modified-Puls and Kinematic Wave

4.2.1 Drainage area boundaries.

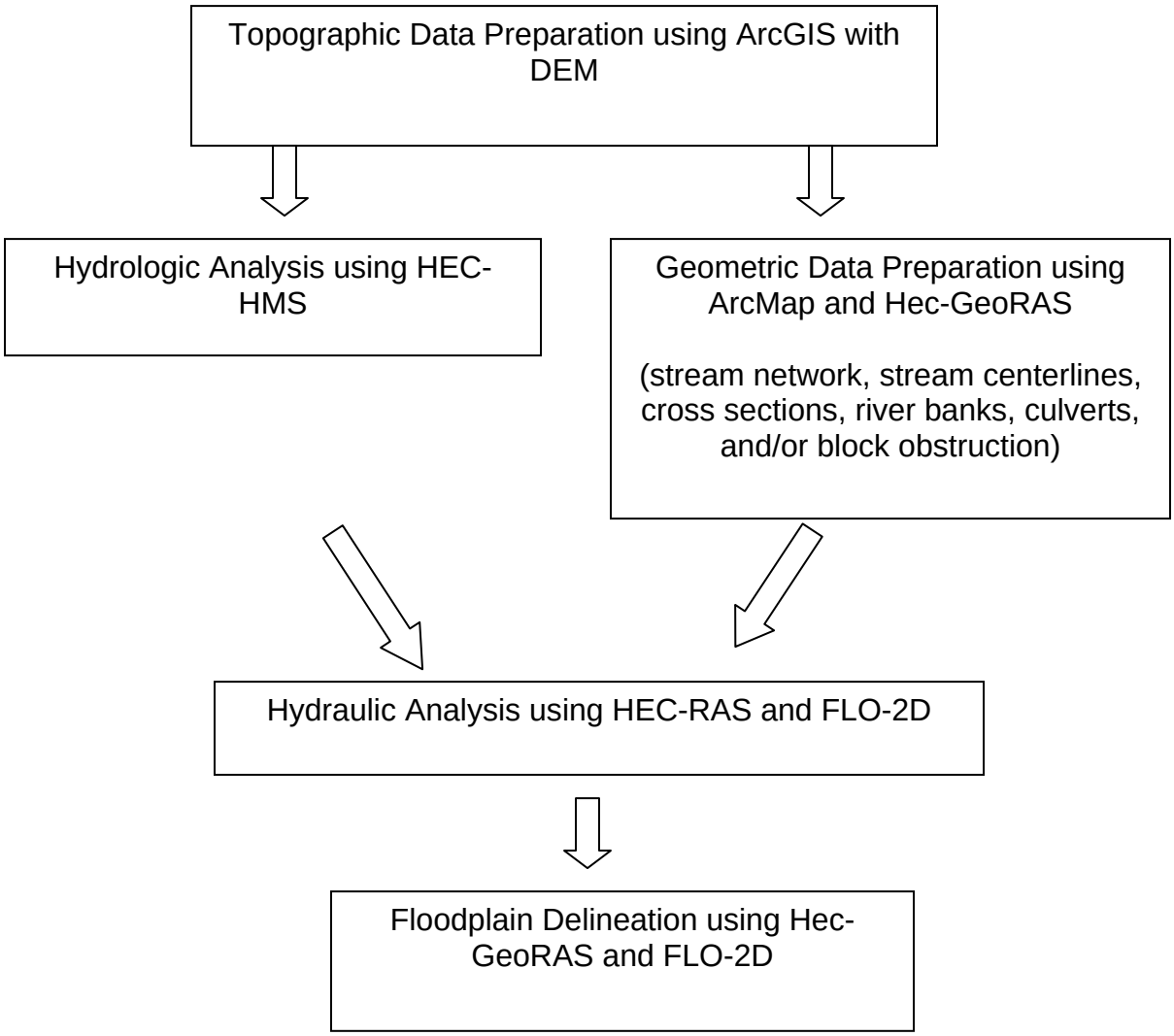
The limits of this study are shown in Fig.1.2. The Wentworth Wash watershed is mostly located within Federal land (national forest, FEMA Zone D). The floodplain was mapped in the downstream area of the Wentworth Wash. The downstream of the Wentworth Wash is mostly mapped as Zone D, as shown on the current Flood Insurance Rate Map (FIRM) number 04019C-2280K. However, several properties in the downstream area are privately owned. This study focuses on a drainage condition in Subbasin A, which includes the private lands in the downstream.

The watershed is 5.28 square mile. The study watershed was divided into five sub-basins (Fig.1.1). The upstream study limits is the upstream end of the Subbasin A, while the downstream limit is the confluence with the Tanque Verde Wash (Fig.1.2).

4.2.2 Watershed work maps

A watershed work map is included in Exhibit 1. Eight subbasins were delineated for the HEC-HMS hydrologic analysis. A 100-yr peak discharge at CP A was estimated in this study. The peak discharge was used as input for the HEC-RAS and FLO-2D analysis.

Figure 4.1 – Flow Chart of Mapping Process



4.2.3 Gage Data.

None Available

4.2.4 Statistical parameters

None Available

4.2.5 Precipitation.

According to the Tech-018, the 3-hour storm shall be used as rainfall data in the HEC-HMS model in case that a time of concentration (Tc) is equal or less than three hours. A 3-hour storm was selected for a peak discharge calculation for the Wentworth Wash, since Tc was less than 3 hours in all the subbasins.

A point 3-hour rainfall depth at the coordinates of the centroid of the watershed was obtained from NOAA Atlas 14, upper 90% confidence interval precipitation frequency estimate (NOAA 14 rainfall). Areal reduction factor was applied to watersheds larger than 1 square mile, as described in Tech-018.

4.2.6 Physical parameters.

A hydrologic soils group map for the study watershed is presented in Fig.3.1. The study watershed is mostly covered with Desert brush. Hydrologic Soil Groups C and D are the dominant soil types in the Wentworth Wash watershed. The SCS Curve Number was determined using maps obtained from NRCS (http://soildatamart.nrcs.usda.gov/) as a basis for preparing a Hydrologic Soil Group Map for Pima County. The CN charts in the PC Hydro Manual (Arroyo Engineering, 2007) were the basis for CN selection. A vegetation cover density of 30% was used to select the SCS Curve Number for the hydrologic calculation of the mountainous watersheds. Impervious cover percentage from 5-15%, were selected based on lot size, the fraction of the sub-basin that is developed and the tables in the PC Hydro manual. Sub-basin characteristics are summarized in Table 4.2 The detail of the CN calculation is included in Appendix D.

Table 4.2 - Sub-basin Characteristics

Sub-Basin	Area (sq mi)	CN	Impervious Area (%)	Vegetation Cover (%)	Lag Time (min)
WEW A	1.24	88.0	10	30	42.1
WEW B	0.71	88.9	5	30	25.2
WEW C	1.36	89.7	5	30	22.7
WEW D	0.87	88.7	5	30	18.3
WEW E	1.12	88.6	5	30	15.8

The SCS TR-55 segmental Time of Concentration (Tc) method with a combination of kinematic wave method was used. The hydraulically most distant point on the sub-basin

was identified. The length of sheetflow was estimated at 100', the distance from the end of the sheetflow to a well-defined channel was selected as the shallow concentrated portion of the flow path, and the channel portion was the path from the well-defined channel to the sub-basin outlet was the 'channel flow' portion of the flow path.

Tc is the sum of the travel time for sheetflow, shallow concentrated flow and channel flow. The travel time for sheetflow was calculated using kinematic wave method. The travel time for shallow concentrated flow was calculated using the methods described in the TR-55 manual (USDA-1986). The travel time for channels used estimates from a HEC-RAS model. The lag time was calculated as 0.6 Tc. The detail of the Tc calculation is included in Appendix D (Table D2).

The SCS unit hydrograph method was used to produce hydrographs at the outlet of the sub-basin in HEC-HMS. Runoff from sub-basins was routed using the Modified-Puls method. A storage discharge table for the channel routing was developed using the cross sections and slopes derived from HEC-HMS. Modified puls routing employed the methods described in the HMS manual. The detail of the calculation of the number of subreach is included in Appendix D. Sub-basin discharges are summarized on Table 4.3.

Table 4.3 - Sub-basin discharges

Sub-Basin	Area (sq mi)	Rainfall Depth (in)	Runoff Volume (in)	Peak Discharge (cfs)
WEW A	1.24	3.39	2.17	1499
WEW B	0.71	3.39	2.25	1181
WEW C	1.36	3.39	2.32	2511
WEW D	0.87	3.39	2.23	1759
WEW E	1.12	3.39	2.22	2487

4.3 Problems encountered during the study.

None

4.3.1 Special problems and solutions

4.3.2 Modeling warning and error messages

The time interval of the rainfall data used in this study is 5 minutes, while the simulation time interval is 1 minute. The HEC-HMS model interpolated the 5-minute time interval of the rainfall data to 1-minute time interval.

4.4 Calibration

No Calibration

4.5 Final results

4.5.1 Hydrologic analysis results

As described above, this study mainly focuses on drainage information in the downstream of the Wentworth Wash. The 100-year peak discharge at CP A was determined using the HEC-HMS. Seven hours were simulated on a 1 minute time step with rainfall occurring in the first three hours. The following discharge was obtained from the hydrologic analysis:

Table 4.4 – Summary of 100-yr Peak Discharge Values

Concentration Point	Location	Area (sq mile)	Rainfall Depth (in)	Runoff Volume (in)	Q100 HMS (cfs)	Time to Peak
CP A	South of Speed way	5.3	2.90	1.80	4719	2:28

Table 4.5 – Summary of 25-yr Peak Discharge Values

Concentration Point	Location	Area (sq mile)	Rainfall Depth (in)	Runoff Volume (in)	Q25 HMS (cfs)	Q25 RRE (cfs)	Time to Peak
CP A	South of Speed way	5.3	2.6	1.2	2878	1933	2:47

Table 4.6 – Summary of 500-yr Peak Discharge Values

Concentration Point	Location	Area (sq mile)	Rainfall Depth (in)	Runoff Volume (in)	Q500 HMS (cfs)	Time to Peak
CP A	South of Speed way	5.3	3.8	2.6	7347	2:25

4.5.2 Verification of results.

Peak discharge estimated using a HEC-HMS model was compared with an existing 100-year regulatory discharge at CP A. The comparison showed that the HMS-derived peak discharge was higher than the one derived from the Regression Equation. The higher HMS-derived peak discharge compared to the RRE-derived peak discharge would be expected, because these steep watersheds could be expected to produce higher than average at the sub-basin scale. No regulatory discharge point data is available along the Wentworth Wash.

Table 4.7 – Comparison of 100-yr Peak Discharge Values

Concentration Point	Location	Area (sq mile)	Q100 HMS (cfs)	Q100 RRE (cfs)
CP A	South of Speed way	5.28	4719	3452

Section 5: Hydraulics

5.1 Method description.

The hydraulic modeling for the Sweetwater was performed using HEC-RAS, Version 4.0 (HEC-RAS), HEC-GeoRAS, Version 4.1.1 (HEC-GeoRAS), ArcGIS, Version 9.3, and FLO-2D (Version 2007-6). A floodplain within Subbasin A is mapped in this study.

Steady flow analysis was performed using HEC-RAS in order to determine a floodplain limit for the upstream of the Wentworth Wash (from the upstream end of the subbasin A to approximately 2190 feet upstream of the Speedway BL.). The locations of the stream centerline, flowpath, and cross sections of the Sweetwater Wash were determined using a 2-ft contour map and 2008 PAG aerial photos. The physical attributes of the wash were digitized in ArcGIS using the HEC-GeoRAS extension and exported to HEC-RAS to create geospatially referenced geometric data (cross section, reach profile). Other parameters for the steady-state analysis, such as Manning's n-values, expansion and contraction coefficients, boundary condition, and ineffective flow areas were manually input into HEC-RAS. Normal-depth with a slope of 0.016 was assumed for the downstream boundary condition. The hydraulic data obtained from HEC-RAS were imported into HEC-GeoRAS to delineate a floodplain boundary for the Wentworth Wash.

FLO-2D was used for the downstream distributary area (from approximately 2190 feet upstream of the Speedwar BL. to a confluence with the Tanque Verde Creek). Geometric data for the FLO-2D model were derived from the 2008 Lidar data. Grid cell size of 50 feet was used to map a floodplain in the distributary area. The time interval used for the computation was 1 minutes. The model does not include infiltration or rainfall. A hydrograph from the HMS at CP A (at the confluence with the Tanque Verde Creek) was used as inflow data at 2190 feet upstream of the Speedway BL.

5.2 Work study maps

The work study map for the Wentworth Wash is included in Exhibit 2.

5.3 Parameter estimation.

The watershed was modeled using methods consistent with District Tech Policy 019.

5.3.1 Roughness coefficients.

Manning's roughness coefficients for the channel and the over-bank areas were determined by using a 2008 aerial photo. In the HEC-RAS model, Manning's n value of 0.055 was assigned for the overbank with desert brush, and the value of 0.045 was assigned to a channel. In the FLO-2D model, selected Manning's n values are 0.045-0.06 for a floodplain and overbank, 0.03-0.035 for roads (Speedway BL. and Wentworth RD.).

5.3.2 Expansion and contraction coefficients.

Default HEC RAS expansion (0.3) and contraction (0.1) coefficients were used for the most cross sections.

5.4 Cross section description.

A 2-foot interval contour map derived from 2008 LiDAR data was used to select the location of cross sections. Cross-section locations were determined primarily based on the channel topography. The cross-section lines were drawn to be perpendicular to flow paths in HEC-GeoRAS.

5.5 Modeling considerations.

5.5.1 Hydraulic Jump and drop analysis.

No hydraulic, drop analyses or adjustment of the floodplain was conducted in this study.

5.5.2 Bridges and culverts.

There are no culverts.

5.5.3 Levees and dikes.

None.

5.5.4 Islands and flow splits.

None.

5.5.5 Ineffective flow areas.

In the HEC-RAS model, ineffective flow option was modeled in the following situations. In general these ineffective flow areas were disconnected overbank areas that would not convey flow to the next downstream cross-section.

5.5.6 Supercritical flow.

No supercritical reaches.

5.6 Floodway modeling

No encroachment calculations were performed.

5.7 Problems encountered during the study.

5.7.1 Special problems and solutions.

Flow in the area from approximately 2190 feet upstream of Speedway BL. to the confluence with the Tanque Verde Creek was modeled with FLO-2D. For a floodplain mapping with FLO-2D, shallow flow depth less than 0.2 feet is considered to be negligible and cells with flood depth less than 0.2 feet were removed from a 100-year flood hazard area. In other words, cells with flow depth deeper than 0.2 feet were considered as a floodplain in this study.

5.7.2 Modeling warning and error messages.

No errors occurred. The following warning messages occurred:

Divided flow
Energy loss greater than 1.0
Energy equation could not be balanced and defaulted to critical.
Cross-section extended vertically.
Multiple critical depths calculated.
Conveyance ratio is less than 0.7 or greater than 1.4.

Inspection indicated that the modeling is accurate given the steep channel conditions. Most of these errors force a critical solution which is reasonable for these steep watercourses. A summary of the HEC-RAS errors is available in Appendix E.

5.8 Calibration.

None.

5.9 Final results.

5.9.1 Hydraulic analysis results.

The HEC-RAS and FLO-2D modeling results are shown in Exhibit 2.

5.9.2 Verification of results.

Existing floodplain maps are not available along the Wentworth Wash. The new map tends to follow the floodplain topography. The results suggest that the mapping is reasonable.

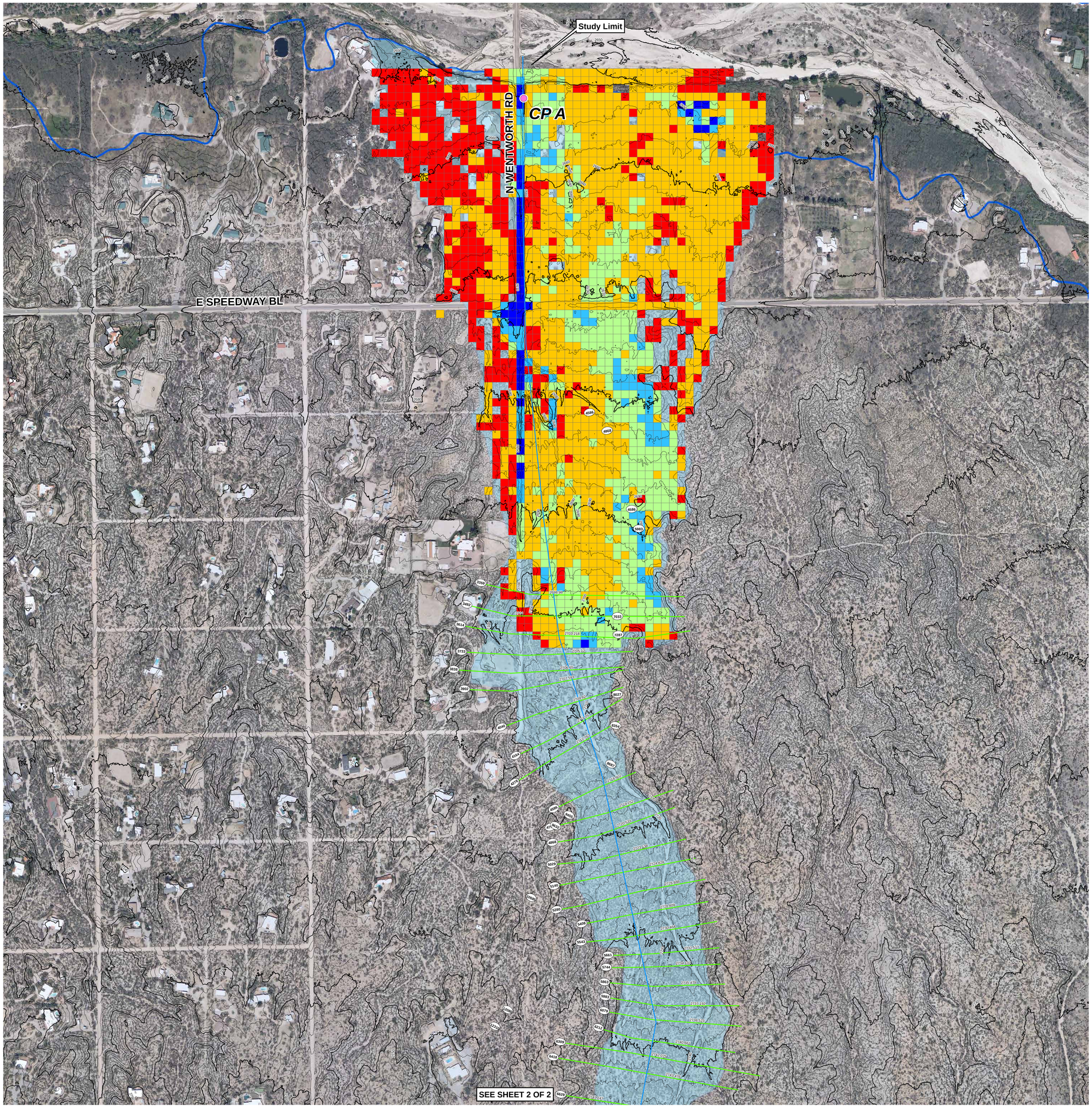
Section 6: Erosion and Sediment Transport

6.1 Method description.
None – not applicable
6.2 Parameter estimation.
None – not applicable
6.4 Modeling considerations.
None – not applicable
6.5 Problems encountered during the study.
6.5.1 Special problems and solutions.
None – not applicable
6.5.2 Modeling warning and error messages.
None – not applicable
6.6 Calibration.
None – not applicable.
6.7 Final results.
6.7.1 Erosion and sediment transport analysis results.
None – not applicable
6.7.2 Verification of results.
None – not applicable

Section 7: Ratio of the top width of 100-yr and 25-yr floodplain

A map showing the cross sections with the ratio of the topwidth less than 1.25 is included in Addendum 1. The average ratio of 100-yr to 25-yr floodplain topwidth for the HEC-RAS study reach is 1.09. Cross sections with the ratio less than 1.25 are defined as "Canyon Wash".

Exhibit 1
100-year Floodplain with cross sections Wentworth Wash
Sheet 1 of 2



- Discharge Points
- River
- Cross Sections
- Contour 2ft
- Contour 10ft
- Proposed 100yr Flooding
- Existing Zone AE

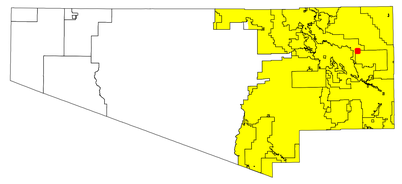
Flow Depth at Cell

Var

- = > 0.200
- = > 0.500
- = > 1.500
- = > 2.500
- = > 3.500

Areial Photo 2008 Pima Association of Governments
Topo: 2008 Pima Association of Governments
Vertical Datum: NAVD 1988

Pima County Index Map



Index Map Scale 1:1,500,000

Pima County Regional Flood Control District

N

0 200 400 Feet

Pima County Regional Flood Control
97 East Congress Street - 3rd Floor
Tucson. Arizona 85701-1207
(520)243-1800 - FAX (520)243-1821
http://www.rfcd.pima.gov

11/2010

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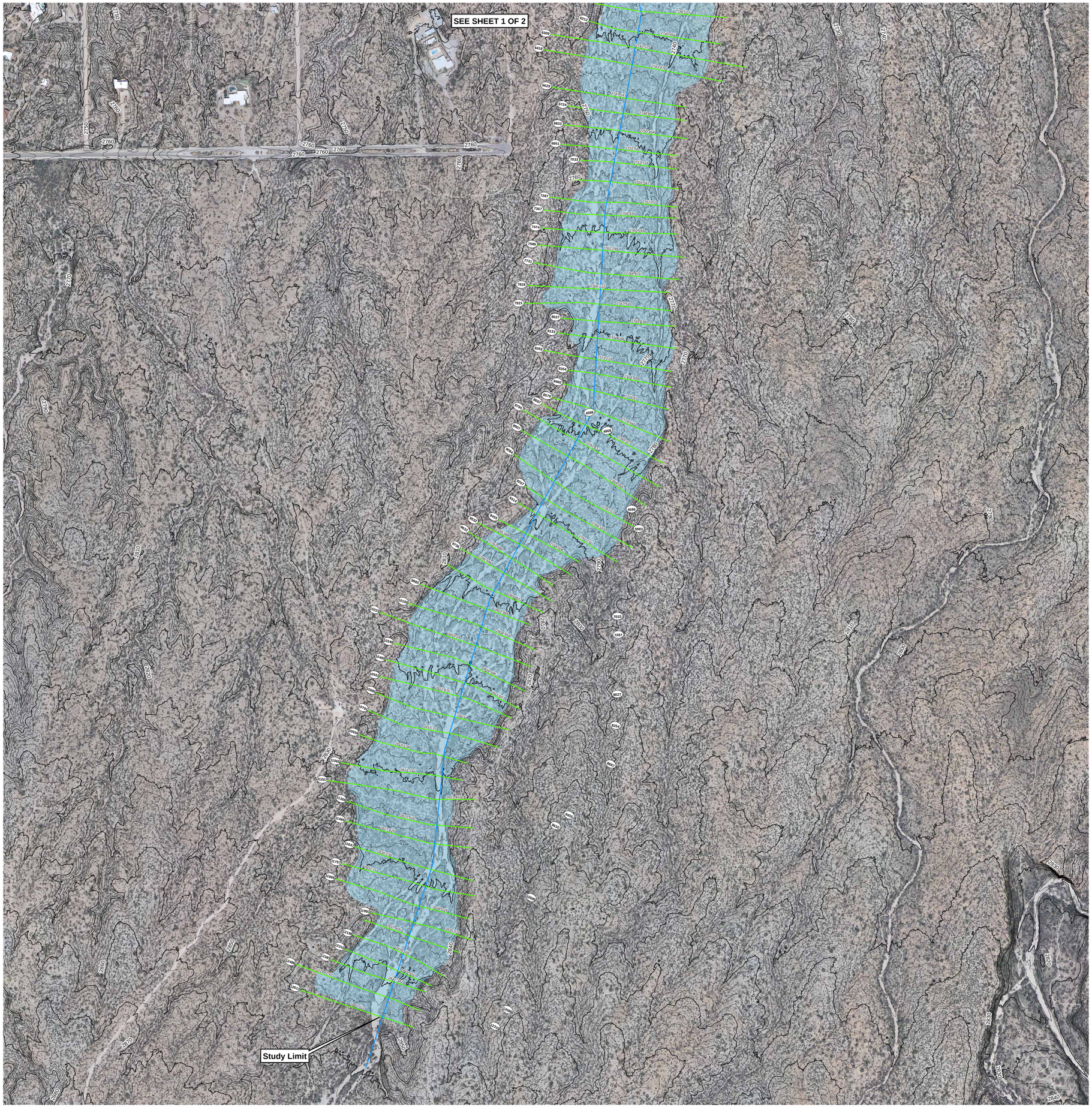
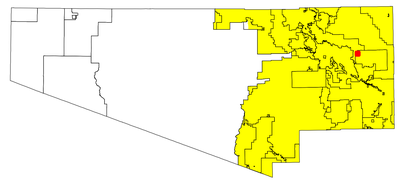
Exhibit 1
100-year Floodplain with cross sections
Wentworth Wash
Sheet 2 of 2



- Discharge Points
- River
- Cross Sections
- Contour 2ft
- Contour 10ft
- Proposed 100yr Flooding
- Existing Zone AE

Areial Photo 2008 Pima Association of Governments
Topo: 2008 Pima Association of Governments
Vertical Datum: NAVD 1988

Pima County Index Map



Index Map Scale 1:1,500,000

N

0 200 400 Feet

Pima County Regional FLOOD CONTROL DISTRICT

THE SEAL OF PIMA COUNTY ARIZONA

Pima County Regional Flood Control
97 East Congress Street - 3rd Floor
Tucson. Arizona 85701-1207
(520)243-1800 - FAX (520)243-1821
http://www.rfcd.pima.gov

11/2010

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Appendix A: References

A.1 Data collection summary.

Include a list of previous studies, other applicable studies, published and unpublished historical
flood information, and research contacts.

A.2 Referenced documents.

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