Drainage Memorandum - Final

Hohokam Area Drainage Master Study (Phase I) Pilot Study & Sensitivity Analysis

Contract FCD 2009C029

April 2011

Prepared for: **Flood Control District Of Maricopa County**
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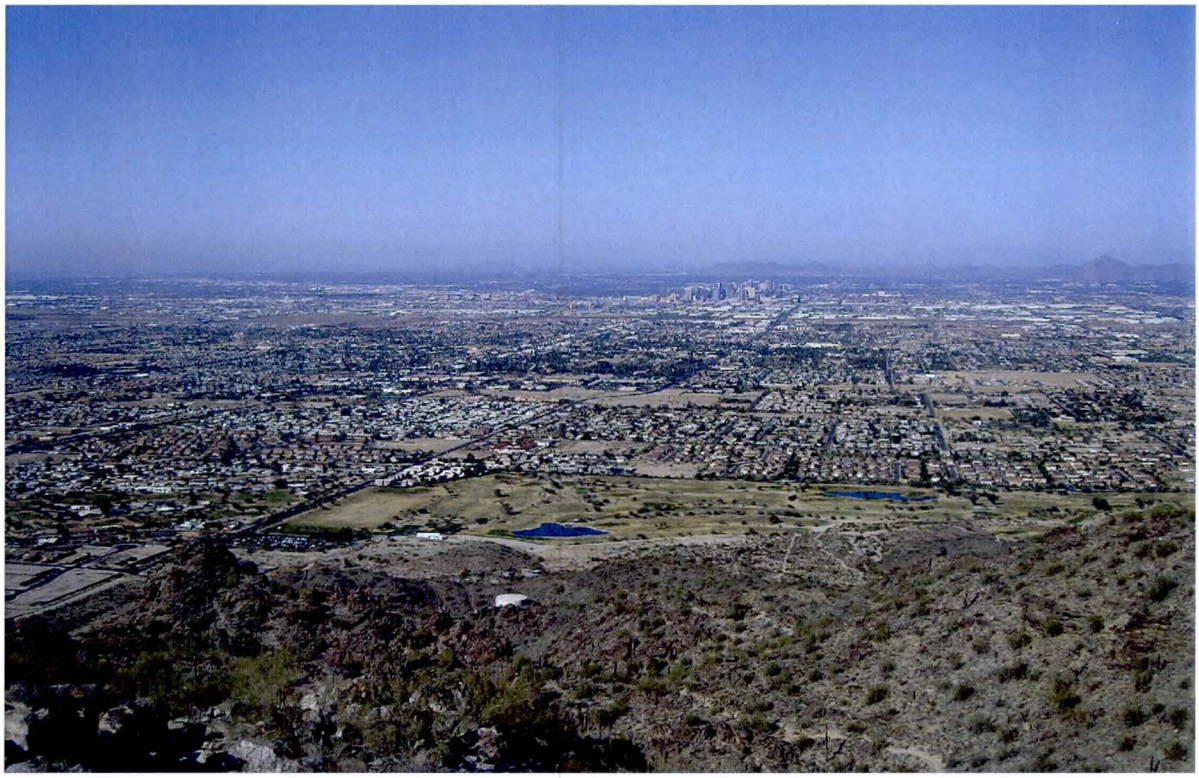

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Expires 3/31/2012

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1 INTRODUCTION

1.1 PURPOSE OF MEMORANDUM

The purpose of this memorandum is to document and summarize the conclusions of the Hohokam Area Drainage Master Study (ADMS) FLO-2D Pilot Study. The pilot study consisted of hydrologic modeling of a smaller representative portion of the Hohokam ADMS study area for the purpose of determining the methodologies and approaches to be used for the development of the final study models for the entire study area. As part of the pilot study, sensitivity analyses were performed to assess the impact of various hydrologic parameters, model variables and hydraulic features.

The results of this study are not necessarily the findings that may result from the complete study area analyses. Similarly, the conclusions, approaches and recommendations for the final study area analyses may change during the remaining course of the Hohokam ADMS.

1.2 STUDY AREA/PILOT STUDY AREA LOCATION

The Hohokam ADMS/ADMP study area is located within the corporate limits of the City of Phoenix and the City of Tempe. The area is approximately 28.1 sq. miles in size and bounded by the I-10 freeway, the Salt River, South Mountain Park and the eastern limits of the Laveen ADMS (see Figure 1-1).

The pilot study area is located in the south central portion of the study area. It is approximately 3.58 sq. miles in size. The area includes typical features found within the overall study area including the steep natural slopes of South Mountain Park, residential properties ranging from low density to high density, a golf course, a regional park undeveloped properties, hydraulic structures, and both the Western and Highline Canals.

While the pipe diameters sizes located in the Pilot Study area are smaller than minimum pipe size to be included in the study (36"), for purposes of the pilot study, hypothetical inlets were placed in the Pilot Study area to develop an approach for modeling the storm drain system.

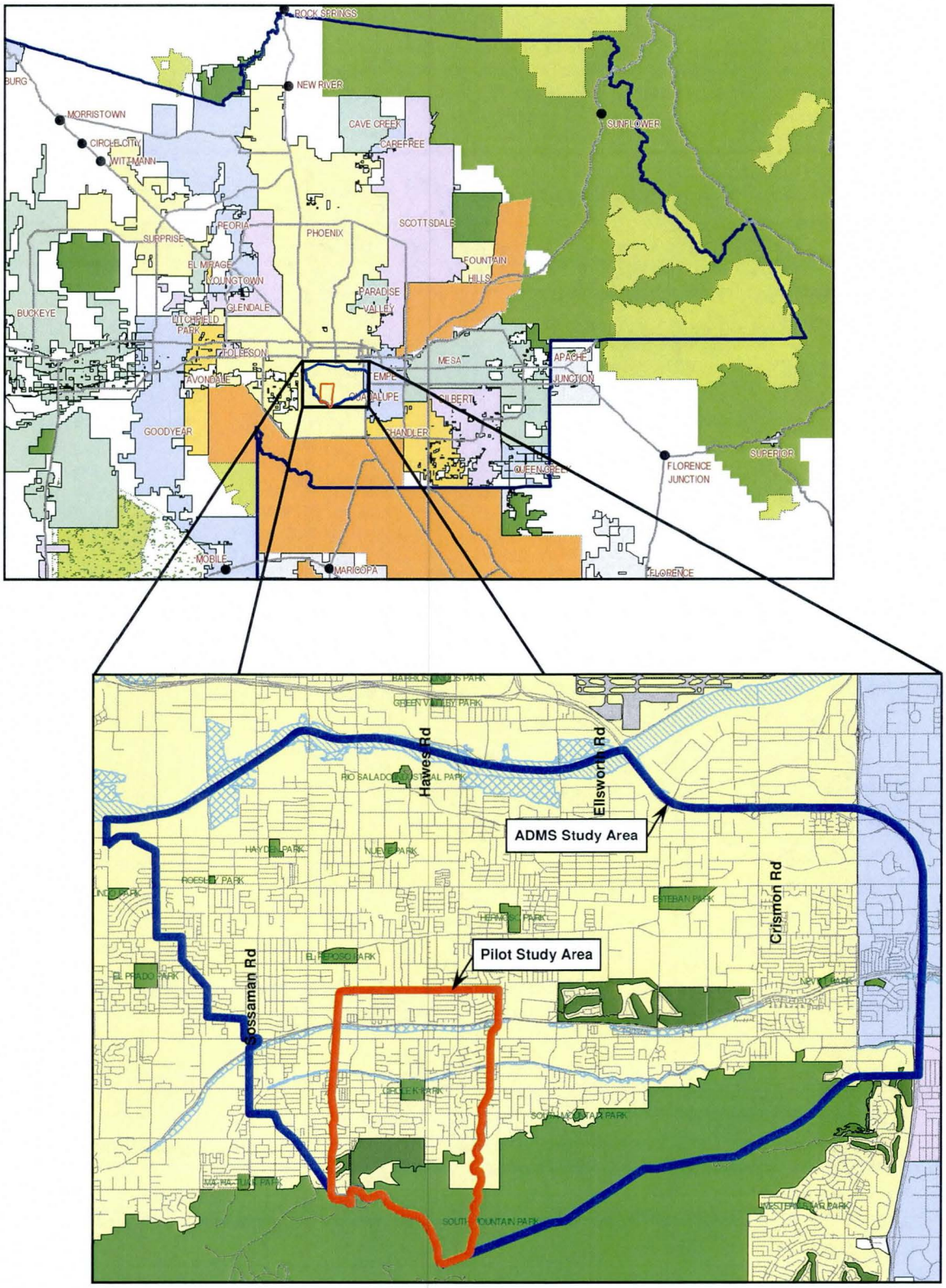


Figure 1-1: Project Location and Vicinity Map

2 FLO-2D

2.1 General

FLO-2D was the selected as the application to develop the study area hydrology for the Hohokam ADMS/ADMP. FLO-2D is a two-dimensional model that routes rainfall runoff and flood hydrographs over flow surfaces or in channels. It can include a number of components to simulate various features and hydrologic/hydraulic conditions including spatially variable rainfall and infiltration, streets, channels, buildings and obstructions, hydraulic structures, levees as well as other flooding, sediment transport and debris flow conditions. FLO-2D also includes pre- and post-processing applications to help produce input parameters and process output data.

2.2 FLO-2D Version

FLO-2D is a continuously being upgraded to increase functionality and correct identified program bugs. During the course of this study, several new executables were released. Different releases may not always yield identical results or retain model stability. As a consequence, to replicate results, it is best to utilize the same FLO-2D version used for the original simulation unless the new release has been demonstrated to produce comparable or improved results.

In developing the FLO-2D simulation grid and grid elevations FLO-2D Version 2009.06 (64-bit FLO.EXE dated 7/26/2010) was utilized. However, for the Pilot Study and sensitivity analyses, FLO-2D Version 2009.06 (64-bit FLO.EXE dated 9/2/2010) was utilized for the model simulations and is provided along with the FLO-2D input and output files. It is expected that the both executable dates would develop the same simulation grid and grid elevations using the same data. More recently released versions and/or executables that include additional functionality that would be beneficial to the project have not yet been fully evaluated by the project team or approved by the FCDMC.

2.3 FLO-2D INPUT

In addition to hydrologic parameters/hydraulic components that are representative of the physical characteristics or hydrologic conditions a watershed area, FLO-2D requires model controls that are computational requirements or related to establishing numerical stability criteria for FLO-2D. Model controls are more likely to be defined by the project scope of work or dictated by the stability requirements of a specific simulation run, however, as part of the sensitivity analysis, both hydrologic/hydraulic parameters and model controls were among the parameters evaluated. The development of input is discussed in Section 3.2.

3 PILOT STUDY

The primary purpose of the pilot study is to determine the methodologies to be used for the development of the final study models for the entire study area. As part of the pilot study, sensitivity analyses were performed to assess the impact of various hydrologic parameters, model variables and hydraulic features.

3.1 PILOT STUDY AREA LOCATION

The pilot study area is approximately 3.4 sq. miles in size and located in the south central portion of the study area (see Figure 1-1). The area includes highly urbanized areas as well as steep mountain slopes which is generally representative of the overall study area. The area includes residential properties ranging from low density to high density, a golf course, a regional park, undeveloped properties, hydraulic structures, and both the Western and Highline Canals.

The pipe diameters are smaller than the minimum pipe size to be included in the study (36"); however, for purposes of the pilot study, hypothetical inlets were placed in the study area to develop an approach for modeling the storm drain system.

3.2 FLO-2D INPUT AND MODEL CONTROLS

3.2.1 Topographic Mapping and Aerial Photography

Topographic mapping used for the FLO-2D grid elevation assignment was provided by the FCDMC from several different mapping contracts. Topographic mapping provided by the FCDMC is typically developed by photogrammetric methods. The mapping products consist of topographic contours, mass points, breaklines, and digital terrain model (DTM) or triangulated irregular network (TIN) boundary polylines or polygons. Table 3-1 lists pertinent information related to each mapping data set.

The two Salt River topographic mapping data sets are based on the National Geodetic Vertical Datum of 1929 (NGVD29) therefore, a conversion factor was obtained from the National Geodetic Survey (NGS) VERTCON tool (http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl). The NGVD29 elevations were adjusted to North American Vertical Datum of 1988 (NAVD88) by adding 2.16 feet. The remaining mapping data sets listed in Table 3-1 are all on the NAVD88.

Digital, ortho-rectified aerial photography was collected for the study area from the FCDMC. The aerial photography is provided at a resolution of 0.8-feet pixels. The flight dates for the photography within the study area range from October 17th to October 31st 2009. This data is commonly referred to as the FCDMC's 2010 aerial photography.

The aerial photography and mapping data sets listed in Table 3-1 were all provided in the Arizona State Plane horizontal coordinate system (NAD 1983 HARN State Plane Arizona Central FIPS 0201 Feet Intl).

Table 3-1: Topographic Mapping Sources

Project	FCDMC Contract No.	Project ID	Flight Date	Contractor	Mapping Scale / C.I. (ft)	Vertical Datum
Salt River Mapping	07-38	1289	6/21/2008	Cooper Aerial of Phoenix	200 / 2 C.I.	NGVD29
Phoenix-Tempe Area Mapping	08-20	1291	12/11/2008	Vertical Mapping Resources	2 C.I.	NAVD88
Hohokam Mapping	08-20	1296	04/07/2009	Vertical Mapping Resources	2 C.I.	NAVD88
Hohokam Mapping (Supplemental)	08-20	1308	05/20/2010	Vertical Mapping Resources	2 C.I.	NAVD88
Salt/Gila River Master Plan	92-01	1030	12/14/1991 & 02/10/1997	Michael Baker Jr., Inc	300&200/ 4 C.I.	NGVD29
Countywide 10- ft Contour Mapping	Unknown	1208	12/17/2000 & 12/27/2000	Landata Airborne Systems, Inc.	500 / 10 C.I.	NAVD88

3.2.2 Grid Elevations (FPLAIN.DAT & CADPTS.DAT)

A grid was developed for FLO-2D (64-bit FLO.EXE file dated 7/26/2010) to simulate rainfall runoff and runoff hydraulics through the pilot study area. The grid cell size selected for the model was 30 feet by 30 feet, previously determined for the entire ADMS. This size is presumed to be small enough to approximate conveyance within small drainage channels, residential streets, and subtle man made diversions or impoundments, while not as small as to cause model run times of several days due to a large total number of model grid elements. The pilot study model contains 110,765 grid elements with a total model area of 3.58 square miles.

The grid element elevations were assigned using a combination of the Hohokam Mapping and the Countywide 10-ft Contour Interval (C.I.) Mapping (see Table 3-1). Figure 3-1 shows the extents of the mapping sources used in development of the pilot study FLO-2D model. The FLO-2D pre-processor application Grid Development System (GDS) was used to assign the grid element elevations based on the digital elevation data. The GDS computes a distance weighted average for each grid element for which the minimum specified number of elevation data points does not fall within a particular grid element. This capability was found to be very useful at the interface

boundary between the county-wide 10-ft C.I. mapping data and the Hohokam Mapping 2-foot C.I. data.

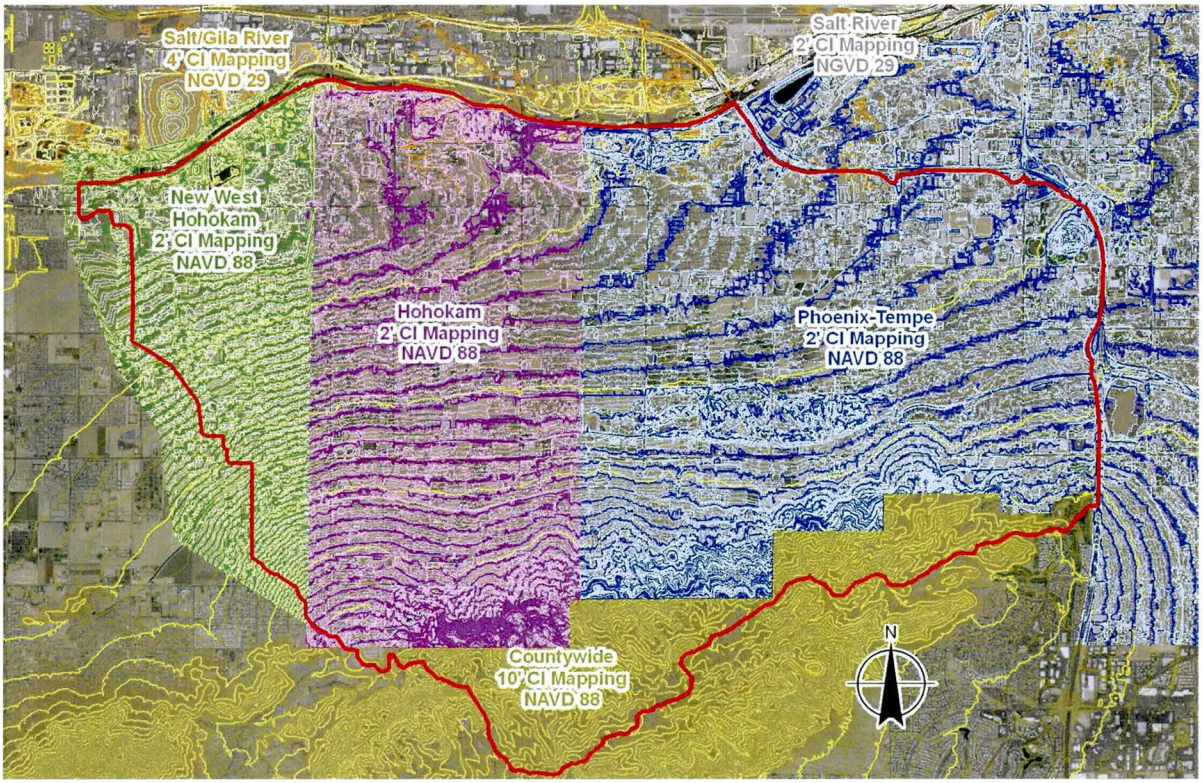


Figure 3-1: Extents of Mapping Sources

One common approach in Maricopa County for developing digital elevation data for the GDS is to convert 3-dimensional breakline data to points (one point at each vertex and endpoint) and combine this with the mass points. However, it was found that there was an exceptionally high density of breakline data for certain features, particularly streets and curbs, in the Hohokam Mapping data set. When combined with a relatively sparse mass point and breakline population in areas adjacent to the streets, this would have the affect of biasing adjacent grid elements towards the elevations in the streets, typically lower in elevation. Therefore, it was determined the best way to overcome this was to develop a surface in ArcGIS in the format of a Triangular Irregular Network (TIN) based on the mass points and break lines, rasterize the TIN to develop a grid of elevation points based on the surface, and then use these points in the GDS.

The Hohokam Mapping elevation rasters were developed at a 5-foot pixel (5-foot grid), and converted to points. These resulting points were then combined with the countywide 10-foot C.I. mapping mass points and breakline points and used for grid element elevation assignment using the GDS. The elevations are assigned in the FPLAIN.DAT input file.

The horizontal location of each FLO-2D model grid element is assigned in the CADPTS.DAT input file. This input file is automatically created in conjunction with the FPLAIN.DAT file when using the GDS to assign elevations. The X and Y coordinates listed in the CADPTS.DAT file were assigned in the project coordinate system, Arizona State Plane, and limited to integer values in multiples of 10 for simplicity (E.G. X=653380.00, Y=857400.00).

3.2.3 Precipitation (RAIN.DAT)

The point precipitation input to the FLO-2D models was taken from NOAA Atlas 14, Volume 1, Version 4.0 as hard coded into the FCDMC's Drainage Design Management System for Windows Version 4.1.8 (DDMSW). Since it is anticipated that many of the existing drainage problems in the ADMS area are a result of localized rainfall runoff rather than offsite runoff, it was determined to use a spatially varied maximum point rainfall based on the NOAA14 statistics. This was accomplished by utilizing the IRAINARF option in the FLO-2D RAIN.DAT file. This option allows each grid element to be assigned a ratio of the specified point precipitation. The precipitation statistic tiles were extracted from DDMSW and intersected with the FLO-2D grid. The maximum precipitation tile for each frequency and duration (typically near the ridge of South Mountain) was specified as the model point precipitation, and each grid element within a NOAA14 precipitation tile with a value lower than the maximum was assigned a ratio to the maximum. NOAA14 point precipitation tiles relative to the pilot study area are provided in Appendix A. Table 3-2 lists the highest or maximum point precipitation tile value for each frequency and duration within the pilot study area

Table 3-2: NOAA 14 Maximum Point Precipitation

Frequency, Duration	Maximum Point Precipitation (in)
2-year, 6-hour	1.138
2-year, 24-hour	1.560
10-year, 6-hour	1.705
10-year, 24-hour	2.361
100-year, 6-hour	2.602
100-year, 24-hour	3.653

The model area or watershed is 3.58 square miles; therefore, the temporal rainfall distribution on the grid network was input as the 6-hour Rainfall Distribution (Pattern 2) and the 24-hour Storm Distribution as detailed in the FCDMC's Drainage Design Manual. No depth-area reduction was accounted for considering the relatively small size of the study area. However, it is anticipated that depth-area reduction may be considered for the full ADMS area FLO-2D model based on a determined average size sub-watershed area. FLO-2D RAIN.DAT input files were developed for the 2-year, 10-year, and 100-year storm recurrence intervals for both the 6-hour and 24-hour durations.

3.2.4 Manning's n-Values (FPLAIN.DAT)

FCDMC provided a shape file identifying existing land uses/features in the pilot study area. The data did not consist of land uses that might correspond to general plan zoning such as commercial or residential but provided detailed information on specific features found within the study area such as vegetation, concrete, asphalt, buildings, or rock outcropping. For each feature, hydrologic and hydraulic parameters were established as shown in Table 3-3. Using the feature shape file and the table data, the FLO-2D GDS will match each feature with its associated n-value and determined an area weighted average n-value for each grid element. Due to the level of feature detail, the data took several days to process. This data is incorporated into the FPLAIN.DAT file.

Table 3-3: Land Use/Feature Parameters for Pilot Study Area

Class ID	Land Use/Feature Types In Pilot Study Area	Parameters for Pilot Study				
		IA	RTIMP	VC	Sat.	n-Value
0	Natural High Vegetation (trees)	0.35	80	100	Dry	0.065
2	Natural Low Vegetation (grass & low shrubs)	0.25	80	100	Dry	0.055
3	Urban High Vegetation (trees)	0.35	10	100	Normal	0.065
5	Urban Low Vegetation (lawns & low shrubs)	0.25	10	100	Normal	0.055
13	Concrete	0.05	98	0	Dry	0.030
14	Asphalt	0.05	95	0	Dry	0.035
15	Buildings	0.05	95	0	Dry	0.035
16	Shade Structures	0.05	98	0	Dry	0.035
17	Water	0.00	100	0	Saturated	0.040
19	Rock 100	0.30	95	0	Dry	0.060
20	Rock 85	0.30	80	0	Dry	0.055

3.2.5 Infiltration (INFIL.DAT)

As with the development of the Manning's n-values for each grid element, the FLO-2D GDS was utilized to process the FCDMC provided feature shape file and the table of hydrologic data (Table 3-3) and develop Green & Ampt rainfall loss parameters for each grid element. Similarly, due to the level of detail in the shape file, the data took several days to process. This data is incorporated into the INFIL.DAT file.

3.2.6 ARF.DAT

The FCDMC provided the ARF.DAT file for the pilot study area. The FCMDC used an automated process to help process the features/land use shape file and develop the ARF.DAT file. ARF.DAT provides the area reduction factor (ARF) and width reduction factors (WRF) to be applied to each grid element. The intention of these factors is to

help represent buildings or other features that either remove available storage area/volume from a grid element or obstruct a percentage of flow in a specific direction.

3.2.7 LEVEE.DAT

Initial analyses of the pilot study area indicated that the distribution of flow throughout the watershed was not being adequately portrayed with the ARF.DAT file alone. Specifically, block walls (for fencing, not structures or buildings) had a significant impact on the distribution of overland flow. To model block walls, the FLO-2D levee option was used (LEVEE.DAT). In conjunction with the ARF.DAT file, the FCDMC is to provide the LEVEE.DAT files. An automated process is under consideration to help develop the LEVEE.DAT file but it has not yet been perfected. For the Pilot Study, the LEVEE.DAT was manually constructed using the FLO-2D GDS and based upon aerial photos, and the block wall shape files. It was assumed that no model walls would fall and no walls would be overtopped. Consequently, a set elevation that exceeded actual wall heights was used for all walls.

3.2.8 HYSTRUC.DAT

A few select large box culverts are modeled in the HYSTRUC.DAT file. The culverts were located within gated communities and golf courses and not readily accessible. Consequently, detailed information on the culverts was not available. For purposes of the pilot study, it was simply assumed the culverts could pass all flow reaching the inlet and an approximate rating table was assumed that would pass the inflow to the structure.

Storm drain catch basins/inlets are also modeled using rating tables in the HYSTRUC.DAT file. The process is described in Section 3.3.9.

3.2.9 CHAN.DAT and CHANBANK.DAT

The Western Canal is modeled using the FLO-2D channel option (CHAN.DAT & CHANBANK.DAT) using a 30-ft wide trapezoidal channel with 1:1 sideslopes. The process of rasterizing elevation data into 30'x30' grids resulted in a wildly fluctuating canal profile that is not representative of the canal profile. To better model the canal, the approximate slope of the channel was estimated between control structures to provide a uniform and continuous downgrade in the direction of channel flow. At control structures, the canal elevation is dropped. The drops and uniform channel slope between drops is representative of the canal water surface elevation delivering water.

The left and right canal bank elevations were estimated by draping lines along the canal maintenance roads located on both sides of the canal on a TIN surface. In CHAN.DAT, a trapezoidal channel invert is set based upon the lowest channel bank elevation minus the channel depth for each grid element. Since the embankment elevations constantly varied, it was necessary to vary the channel depth from grid element to grid element to provide the desired canal slope.

For the sensitivity analysis, the channel option was simply turned off to see what effect modeling the canal has on the overall results.

The Highline Canal is not to be modeled except as reflected in the grid elevation data. (FPLAIN.DAT).

3.2.10 CONT.DAT

CONT.DAT contains a number of model control parameters of particular interest are two parameters included as part of the sensitivity analysis, SHALLOWN and FROUDL.

3.2.10.1 SHALLOWN

SHALLOWN is the flow roughness n-value used for shallow overland flow. The application of SHALLOWN in FLO-2D is based upon the following rules:

0.0 ft < flow depth < 0.2 ft	n = SHALLOWN value
0.2 ft < flow depth < 0.5 ft	n = SHALLOWN / 2
0.5 ft < flow depth < 3 .0 ft	$n = n_b*1.5*e^{-(0.4depth / dmax)}$
3.0 ft < flow depth	n = FPLAIN.DAT n-value

For the sensitivity analysis, SHALLOWN was evaluated for 0.05, 0.10, 0.15 (base model), 0.20, 0.25, and 0.30.

3.2.10.2 FROUDL

The limiting Froude Number (FROUDL) is the maximum Froude Number allowed for overland flow. When FROUDL is exceeded, the floodplain n-value is increased by 0.001 for that grid element for the next time step. Setting FROUDL = 0.0 indicates the model has no Froude Number limitations.

For the sensitivity analysis, FROUDL values of 0.00, 0.85, 0.90, 0.95, and 0.99 (base model value) were evaluated.

3.2.11 TOLER.DAT

3.2.11.1 WAVEMAX

WAVEMAX is a dynamic wave criterion that increments and decrements the computational time steps when WAVEMAX is exceeded. WAVEMAX can vary from 0.1 to 1.00 with a default value of 0.25. The lower the value, the more stable the model, but the simulation runs more slowly. Conversely, the higher the value the less stable but the simulation runs more quickly.

A negative WAVEMAX value (ranging -1.00 to -0.1) turns off the dynamic wave stability criteria. Time steps are then incremented or decremented by DEPTOL or the Courant

stability criteria. Floodplain n-values are adjusted when the WAVEMAX criterion is exceeded but the time step in not increased.

A WAVEMAX>100 turns off the dynamic wave criterion. Time steps are then incremented or decremented by DEPTOL or the Courant stability criteria. Floodplain n-values, however, are not adjusted.

For the sensitivity analysis, WAVEMAX values of -0.25, -1.00, 0.25, 1.00 (base model value), and 101.

3.2.11.2 TOL

TOL is related to surface detention and is the minimum value of flow depth for flood routing in FLO-2D. The scope of work specifies TOL should be set at a value of 0.05 or less. For purposes of the pilot study, the TOL value is set at 0.01. It should be noted that rainfall initial abstraction (IA) should be reduced by the TOL value. This adjustment was made in the table for the various land use/feature tables prior to processing in the GDS. The need to make this adjustment discourages the testing of TOL as a sensitivity parameter due to the need to reprocess the rainfall loss data.

3.2.11.3 DEPTOL

DEPTOL is a tolerance value for the percent change in channel flow for a given time step. When DEPTOL is exceeded, the time step will be reduced. A suggested value for DEPTOL is 0.2 (FLO-2D Data Input Manual), however, the project scope of work specifies DEPTOL be set to 0.1 or less. Both these suggestions were unintentionally overlooked and a value of 0.25 was used for the pilot study. Upon discovery of the conflict, a base model using a DEPTOL of 0.1 was tested and proved unstable. Revisiting DEPTOL would have required rerunning all sensitivity analyses and pilot study models. Given the primary goal of the pilot study is to establish approaches and methodologies for the final analyses and model controls by nature may need to be reconsidered for each model, rerunning all model was not considered necessary. However, for the study area analyses, a DEPTOL of 0.1 or less will be used unless agreement is obtained from the FCDMC.

3.2.11.4 COURANT

The Courant Number is a numerical stability criterion. Previously, the Courant Number has been hard-wired to be set at 1.0. In the release used for the sensitivity analyses, the Courant Number can vary from 0.3 to 1.0. Generally, a Courant Number of 0.3 is a slower running but more stable model. A Courant Number of 1.0 is a faster but a less stable model. Values of 0.3, 0.6, and1.0 were evaluated. The base model utilized the default Courant Number value of 0.6.

3.2.12 FPXSEC.DAT

FPXSEC.DAT identifies all the grid elements that define cross sections placed on the floodplain grid surface to obtain flow information and the general direction flow is expected to cross the cross section. For the pilot study, 33 cross sections were placed throughout the pilot study area. Cross section locations are shown in exhibits in Appendices B and C.

3.2.13 OUTFLOW.DAT

OUTFLOW.DAT identifies the grid elements that serve as outflow. For the pilot study, outflow grid elements were placed along much of the perimeter of the pilot study area.

3.3 SENSITIVITY ANALYSIS

3.3.1 General

The sensitivity analysis was performed to assess the impact of various hydrologic parameters, model variables and hydraulic features. Documentation of the analyses and exhibits are provided in Appendix B. Included in the appendix are tables comparing the peak discharges and flow depths of the each parameter sensitivity analysis to the base model condition and exhibits showing the difference in flow depths between each parameter sensitivity analysis and the base model analysis. For the flow depth exhibits, differences in +/- 0.1 ft were not displayed in order to focus on locations with more significant flow depth differences. In some instances, the difference in flow depths are so insignificant, the exhibits simply appear to be aerials (e.g. FROUDL exhibits).

Also included in the provided CD are Excel spreadsheets that provide hydrographs at each cross section location for both the sensitivity analysis results and the base model results. Hardcopies of these hydrographs are not provided in the report.

3.3.2 Base Model

For purpose of the sensitivity analysis, the existing conditions 100-yr, 6-hr event was selected as the condition to use for the sensitivity analysis. The existing conditions 100-yr, 6-hr base model included all the tested sensitivity model components (CHAN.DAT, LEVEE.DAT, RAIN.DAT, INFIL.DAT, ARF.DAT, and HYSTRUC.DAT) and utilized the significant model control parameters shown in Table 3-4. The results of the base model served as a base line for all the sensitivity analysis results.

Table 3-4: Base Model Control Parameters

SHALLOWN = 0.15	*WAVEMAX = 1.00*	FROUDL = 0.99
TOL = 0.01	*DEPTOL = 0.25**	COURANT = 0.6

**Exceeds range specified in project scope of work. See Section 3.2.11.3 for discussion.*

3.3.3 Shallow Overland Flow Roughness (SHALLOWN)

For the sensitivity analysis, SHALLOWN was evaluated for 0.05, 0.10, 0.15 (base model), 0.20, 0.25, and 0.30.

3.3.3.1 Results and Conclusion

The models are sensitive to SHALLOWN. Values less than the base SHALLOWN (0.15) generally resulted in larger peak discharges and deeper flow depths. Similarly, values larger than the base SHALLOWN resulted in lower peak discharges and more shallow flow depths. It should be noted that SHALLOWN values less than 0.1 simply default to a value of 0.1. The results reflect this in that the output for values of 0.05 and 0.1 are identical.

It was thought that a smooth transition of the SHALLOWN value at the threshold depth of 0.5 ft would help promote model stability. It was therefore decided that SHALLOWN will be back calculated based upon an average FPLAIN.DAT n-value of 0.045 and equating SHALLOWN/2 = $n_b*1.5e^{-(0.4depth/dmax)}$ at the transition depth value of 0.5 feet. The result is a lowering of the SHALLOWN to 0.126 from 0.15. The decrease is expected in increase flow depths and peak discharges from the base model. Table 3-5 provides results for two cross sections located in different topographical settings. Cross Section 4 is located in a flat, urban area downstream of Western Canal. Cross Section 30 is located in the steeper, less developed portion of the upper watershed south of the Highline Canal.

Table 3-5: SHALLOWN Peak Discharges and Flow Depth

Cross Section	SHALLOWN									
	0.10		0.15[1]		0.20		0.25		0.30	
	Q_{max} (cfs)	D_{max} (ft)	Q_{max} (cfs)	D_{max} (ft)	Q_{max} (cfs)	D_{max} (ft)	Q_{max} (cfs)	D_{max} (ft)	Q_{max} (cfs)	D_{max} (ft)
4	115	0.48	95	0.47	80	0.45	69	0.43	53	0.42
30	206	0.23	184	0.25	167	0.28	153	0.28	145	0.28

1. 100yr-6hr base analysis

3.3.4 Limiting Froude Number (FROUDL)

For the sensitivity analysis, FROUDL values of 0.00, 0.85, 0.90, 0.95, and 0.99 (base model value) were evaluated.

3.3.4.1 Results and Conclusion

Peak discharges and flow depth appeared to be relatively insensitive to FROUDL. However, as FROUDL decreased from 0.99 to 0.85, run times correspondingly decreased. Removing the Froude Number limitation (0.00) did not significantly reduce run time.

The Froude Number limitation will not be removed; however, FROUDL will be decreased from the base value of 0.99 to a value of 0.90 or 0.85.

3.3.5 WAVEMAX

For the sensitivity analysis, WAVEMAX values of -0.25, -1.00, 0.25, 1.00 (base model value), and 101.

3.3.5.1 Results and Conclusion

Decreasing WAVEMAX from 1.0 to 0.25 significantly increased simulation run time from 2.6 hours to 8.9 hours. Differences in the results for peak discharges were very modest generally differing only by a few cfs.

Turning off the dynamic wave stability criteria (negative WAVEMAX) further decreased run times with little change in peak discharges. The magnitude of the negative value appeared to have little impact. WAVEMAX >100 results were comparable to the negative WAVEMAX value results with no significant difference simulation run time.

A comparison of simulation flow depths showed some changes in flow depth but the percentage of total grid elements affected was small. A review of some of the cross section hydrographs indicate the larger values may be the results of model surging at problematic locations. The standard deviations of flow depth changes (removing those +/- 0.01) for WAVEMAX was generally <0.1 ft. For a normal distribution, approximately 67% of data falls within plus or minus one standard deviation from the average and 95% falls within two standard deviations.

As with other control parameters, the WAVEMAX parameter should be evaluated for each simulation. However, as a general approach, for initial iterations of study analyses, model runs will be initially run with a negative WAVEMAX. Positive WAVEMAX values will likely be run for the final analyses.

3.3.6 Block Wall Modeling

Block walls (for fencing, not buildings or structures) were modeled using the levee option (LEVEE.DAT). For the Pilot Study, the walls were manually drawn utilizing the GDS. The process was time consuming and would represent a substantial effort for the entire study area. An automated process using mapping for walls and a GDS application is under refinement. It is anticipated that this application will be used for the entire study area.

For the sensitivity analysis, the level of detail to which walls were modeled was varied from "no walls" to "detailed" as modeled in the base condition. This parameter was evaluated to determine if there was a level of detail to which block walls need to be modeled. Varying wall heights were not input for the sensitivity analysis. Wall heights were simply set at an elevation that flow would never overtop.

3.3.6.1 Results and Conclusion

The use of a LEVEE.DAT file to model block walls significantly increased simulation run times. Simulation time increased slightly with the increase in detail of block walls modeled but the increase was not significant.

For obvious reasons, walls have a significant impact on the distribution of flow and will be a necessary component to best assess the study area flow patterns. Particularly walls located within significant flow paths, subdivision perimeter walls, walls perpendicular to the overland flow path (e.g. back alley walls) and walls that help contain flow within streets or channels. Interior residential walls (between homes) generally do not have as significant an impact particularly at a macro level.

Detailed modeling of block walls for the study area would be ideal; however, it would not be practical for the entire study area unless the process could be reliably automated. An application has been developed to automate the development of the wall LEVEE.DAT file based upon mapping data; however, the initial results were poor due to the quality of mapping data and the approach of the application. The application is currently being refined. Ultimately, the level of detail will be limited by the quality of the available mapping and the ability to automate the process. The primary focus will be to assure walls obstructing major flow paths, perimeter subdivision walls, and walls that help contain flow to streets or conveyances are properly reflected in the study models.

3.3.7 Approach to Developing FPLAIN.DAT

The base model approach for developing the grid elevation data in FPLAIN.DAT utilized the Grid Developer System and directly using mass points and break lines from the project mapping. Another approach was tried by first creating a TIN surface and then rasterizing it to produce a 5'x5' uniformly spaced grid of points. The GDS was then used on the data to set the 30'x30' grid elevations. The purpose of the evaluation of the two different approaches was to determine if one approach provided a significant improvement in modeling the concentration of flow in certain locations (e.g. streets, small conveyances etc.).

3.3.7.1 Results and Conclusion

The flow distribution in the base model did not follow the streets as much as expected. In particularly, 16th Street did not contain as much flow as expected based on a video coverage of the July 31, 2010 runoff event. The rasterized approach increased the amount of runoff in 16th Street from 126 cfs to 155 cfs at South Mountain Avenue.

It was generally thought that utilizing the mass point and break lines would provide more accurate results in the steeper mountainous areas while the TIN approach better represented the flatter, urbanized lowland area. Part of this is due to the nature of the mapping break line data. The break lines consisted of densely packed points which was thought could tend to skew data in locations where break lines were more densely

located and where changes in elevations defined by the break lines were less significant such as along roads and in the flatter urban areas.

As a result, a combined approach will be used for the study area with the mass points and break lines used for the mountainous areas and the TIN approach used for the flatter urbanized areas.

3.3.8 Culvert Modeling

A few select large box culverts are modeled in the HYSTRUC.DAT file. The culverts were located within gated communities and golf courses and not readily accessible. Consequently, detailed information on the culverts was not available. For purposes of the pilot study, it was simply assumed the culverts could pass all flow reaching the inlet and an approximate rating table was assumed that would pass the inflow to the structure.

For the sensitivity analysis, the hydraulic structure file was modified to remove several culverts located within the Dobbins Creek subdivision located just north of Dobbins Road and just downstream of the Thunderbird Golf Course. Two large box culverts convey flow from the golf course across Dobbins Road to two separate channels through the subdivision. In each channel there are multiple box culverts to convey flow across local streets and ultimately discharge to a large detention area. This detention area in turn is drained by two outlet box culverts to surface streets downstream. For the sensitivity analysis, the hydraulic structure file for the "fewer culverts model" was modified to remove the interior culverts across the local roads within the subdivision. In addition, the grid elevations at the local street crossings were lowered to provide a means of unobstructed conveyance along the channel. The culverts across Dobbins Road and the detention area outlet culverts, however, continued to be modeled.

3.3.8.1 Results and Conclusion

The inclusion of hydraulic structures at the culvert locations increased incidents of numerical surging. Among the challenges in trying to resolve the surging issues is that the cause may not be readily apparent or singular in nature. The issue may be related to multiple variables which might individually or in combination create a disparity in flow velocities or flow discharges between the rating table and upstream conditions. The resolution of this disparity in conditions can be difficult particularly since culverts are typically located where there are significant changes in hydraulic conditions.

As previously mentioned, since detailed culvert information was lacking, rating tables were developed not necessarily to reflect the expected hydraulic characteristics of the culvert but to pass all flow. Attempts to adjust rating tables, (localized) n-values and elevations to reduce numerical surging were not entirely successful. A contributing factor might also be the reluctance to make significant changes to the model as the changes might also contribute to differences between sensitivity analyses. Consequently, if the culvert model ran to completion despite some numerical surging,

the analysis was considered adequate and compared against the results of the non-culvert model.

The results of the sensitivity analysis primarily limited to the immediate vicinity of the channels and the detention basin as expected. Removing interior culverts however did increase flow depth downstream of the west detention basin outlet culvert up to 0.5 ft. This would not be entirely unexpected given that in the channels are less obstructed and perhaps less attenuated. Numerical surging was particularly problematic at the east Dobbins Road culvert in the base model. It is likely the cause of irregularities seen at cross section 17 (see Figure 3-2).

Given the potential for increased numerical surging, the need to obtained survey/field data on any modeled culverts, and the possibility that the resolution of surging issues might require revision to multiple variables and ultimately may not necessarily be reflective of estimated hydraulic capacities and/or conditions, it is recommended that the modeling of any culverts be limited to those that are hydrologically significant and/or have a have significant impact on flooding conditions. Consideration should be given instead to adjusting floodplain elevations to provide a means of conveyance.

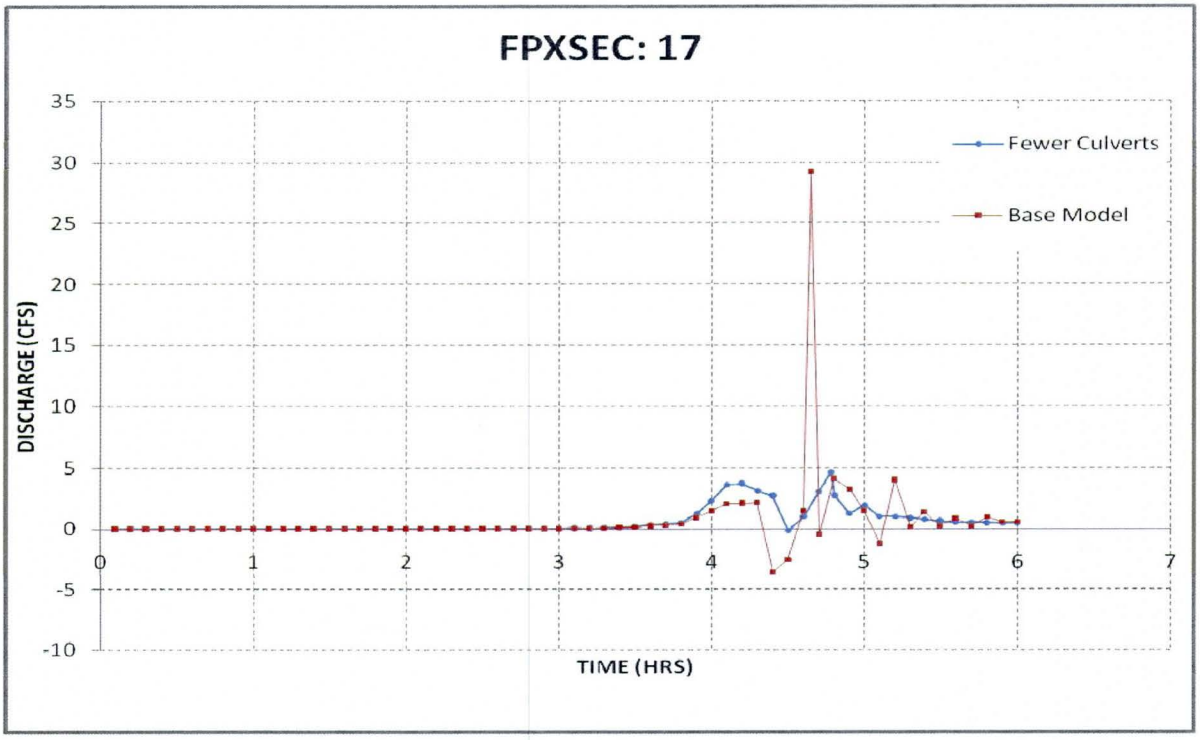


Figure 3-2. Hydrographs at XS 17 (upstream of east culvert in Thunderbird G.C.)

3.3.9 Storm Drain Modeling

This parameter was evaluated to determine the significance of the level of detail in modeling inlets to a storm drain system and to help establish an approach to modeling a storm drain system in FLO-2D.

All the storm drain lines within the pilot study area are less than the modeling threshold of 36" in diameter for the study area. In addition, where the existing storm drain did exist, "exact" inlet locations (based upon GIS data) and storm drain lines were not located were flow was concentrated enough to help develop a storm drain modeling approach. Therefore, for the pilot study, dummy catch basins/inlets were placed along 14th St. between the Highline Canal and Baseline Road which is located in the middle of a wide flood inundation area.

Storm drain catch basins/inlets are modeled using rating tables in HYSTRUC.DAT files. Because of the shallow flow depths, the rating tables were generally modified to try to achieve the same peak discharge removal for all the inlets regardless of the number simulated. For the study area models, the target removal discharge would be the pipe full capacity of all the combined inlets to the outfall storm drain pipe. This process would require several iterations to refine results. For the pilot study an approximate approach was considered adequate to assess and evaluate the approach. Consequently, a specific target discharge was not set or achieved for each model simulation. Rating tables were simply modified based upon the number of inlets simulated. As the number of inlets is reduced, rating tables for the remaining inlets were increased to try to remove the same amount of flow. This did not/could not always achieve the desired result due to the shallow flow depths and the actual maximum flow rate realized at each inlet location. While the pilot study results are not exacting, the process did achieve the desired result by identifying the issues with this approach and provide some insight as to the value of modeling the storm drain infrastructure within the study area.

For the sensitivity analysis, the level of storm drain inlet detail varied from "no catch basins" to seven catch basins spaced along the length of 14th St between the Highline Canal and Baseline Road. The base model assumed seven catch basins along 14th St.

3.3.9.1 Results and Conclusion

Generally, the results indicated that the inlets had little overall impact to the models either in peak discharge or in flow depth. As previously discussed, the results did reveal the difficulty in achieving the desired removal of flow when reducing the inlet number since flow and flow depths are limited to fewer nodes to achieve the same removal amount.

Based upon the pilot study efforts, the modeling of the study area storm drain systems will be accomplished by:

- Ignoring existing/actual catch basin numbers and locations and focusing on peak flow removal. This would assume there are sufficient catch basins inlets to capture flow up to the estimated pipe full capacity;
- Spacing catch basins/inlets along the length of the pipe to distribute captured flow. Placing as few inlets as possible; however, adding inlets to increase the amount of flow captured and/or at desirable locations;
- Performing multiple iterations to attempt to achieve the desired flow removal (pipe full capacity).

3.3.10 Channel Modeling

For the sensitivity analysis, the channel option was turned off to see what effect modeling the canal has on the overall results.

Per the project scope of work, the Highline Canal is not to be modeled except as reflected in the grid elevation data (FPLAIN.DAT). However, given the importance of accurately representing the channel banks along the Western canal in defining upstream ponding and downstream flow distribution, consideration should be given to either modeling the canal or revising grid elevation data along the Highline canal alignment to better and more accurately reflect bank elevations.

3.3.10.1 Results and Conclusion

The SUMMARY.OUT for the base condition indicates the combined channel storage and channel outflow is approximately 10.4 acre-ft. Generally, the results showed that not modeling the canal increased the flow depths downstream of the canal but decreased flow depths upstream of the canal. It is difficult to say that the effective storage provided by the canal is insignificant due to the increase in flow depth downstream of the canal. It is believed that modeling the canal and setting more accurate channel bank elevations creates ponding behind the canal and thereby reduces the amount of flow overtopping the canal. Flows did appear to overtop the canal and given the importance of identifying overtopping locations, an accurate representation of the channel banks is important. A more accurate representation of the channel banks, particularly on the upstream side, would provide better results and consequently the channel option will be used to model the Western Canal in the study area models.

3.3.11 Courant Number

The Courant Number is a numerical stability criterion. Previously, the Courant Number has been hard-wired and set at 1.0. In the release used for the sensitivity analyses, the Courant Number can vary from 0.3 to 1.0. Generally, a Courant Number of 0.3 is a slower running but more stable model. A Courant Number of 1.0 is a faster but less stable model. Values of 0.3, 0.6, and1.0 were evaluated. The base model utilized the default Courant Number value of 0.6.

3.3.11.1 Results and Conclusion

Varying the Courant Number did not appear to have a significant impact on run time, peak discharges or flow depths. The FCDMC has directed that a Courant Number of 1.0 be used until such time as they have fully evaluated newer versions of FLO-2D that allow the Courant Number to vary.

3.4 FUTURE LAND USE CONDITIONS MODELING

3.4.1 General

There are many undeveloped areas within the study area. It is expected some of these areas will be developed in the future. Current regulations require new developments retain the 100-yr, 2-hr developed condition runoff volume for each site. To simulate future land use development and account for future 100-yr, 2-hr retention in FLO-2D, two approaches were considered: an Initial Abstraction (IA) approach and a retention basin approach. The IA approach attempts to model the increased retention volume by increasing the initial abstraction over the development area. The retention basin approach is the physical modeling of the required retention volume within the development area by lowering grid element elevations.

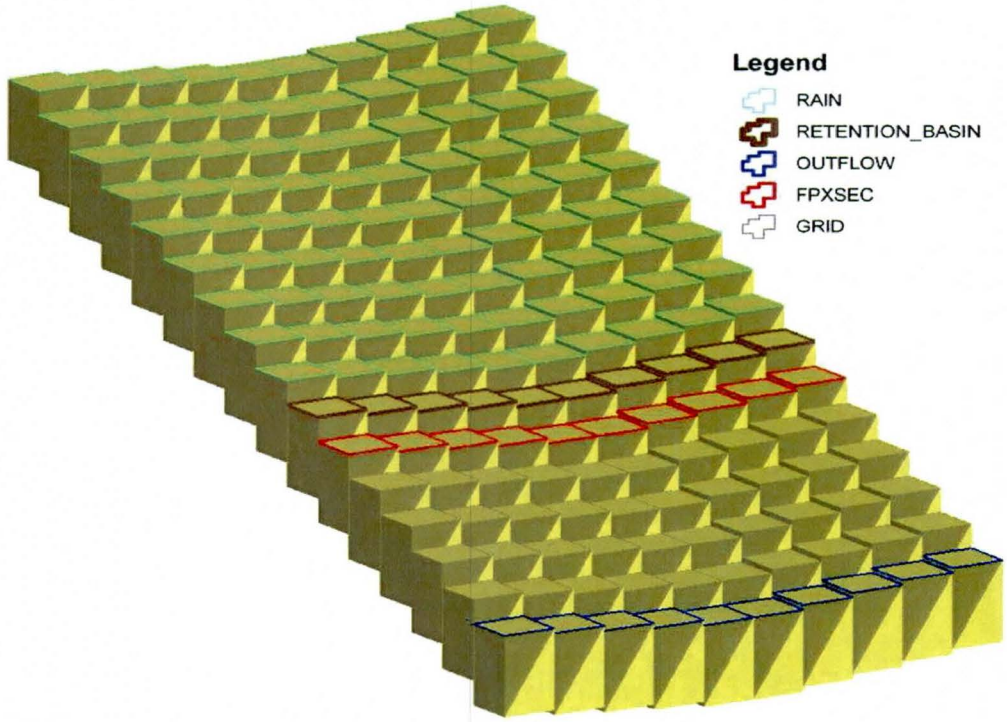


Figure 3-3: Synthetic FLO-2D Model

Both of these approaches were tested on a synthetic medium-sized "undeveloped" area in FLO-2D (see Figure 3-3). The modeling area consisted of 170 grid elements (10x17) with each grid element being 30'x30' in size for a total area of 3.51 acres). The 10x17 grid was given a 0.2 percent cross slope towards the middle and a 1 percent longitudinal slope. The upper-most 10x10 grid elements represented the development site. For the retention basin approach, the last row (row 10) of the development grid was utilized to model the required retention volume. A cross section was placed at the next downstream row (row 11) to capture the flow data. The last row (row 17) served as outflow nodes. The downstream 7 rows were all given an RTIMP of 100% so infiltration would not confuse the results.

The existing or undeveloped conditions for the model area were classified as Urban - Bare Ground and given the Green & Ampt parameters shown in Table 3-6.

Table 3-6: Existing/Undeveloped Conditions Green & Ampt Parameters

XKSAT = 0.4 in/hr	PSIF = 4.08 in	DTHETA = 0.35
IA = 0.2 in	RTIMP = 10%	

Future or developed conditions for the model area was classified Medium Density Residential (6,000 – 12,000 sq. ft. lots) and given the following Green & Ampt parameters and shown in Table 3-7.

Table 3-7: Future/Developed Conditions Green & Ampt Parameters

XKSAT = 0.4 in/hr	PSIF = 4.08 in	DTHETA = 0.35
IA = 0.25 in	RTIMP = 30%	

For both methods, the required 100-yr, 2-hr retention volume was computed using the rational method:

$$V = CPA/12$$

Where:
V = 100-yr, 2-hr retention volume acre-ft
C = roughness coefficient = 0.70
P = 100-yr, 2-hr precipitation = 2.1 in
A = area = (30ft)(30ft)(100)/43560 = 2.066 acres

$$V = (0.70)(2.1)(2.066)/12 = 0.253 \text{ acre-ft}$$

However, when modeling future conditions, the FCDMC conservatively assumes only 80% of the required retention volume is ultimately realized. The retention volume to be modeled for this test future development is therefore (0.80)(0.253) = 0.2025 acre-ft.

3.4.2 IA Approach

The IA approach approximates this retention volume by applying it across each grid element in the form of initial abstraction. Initial abstraction is only applied to the pervious areas of a watershed in FLO-2D as well as in other commonly accepted hydrologic models such as HEC-1. Therefore, the initial abstraction value must be adjusted (increased) to compensate for the percent impervious area assigned to the land use. For the Medium Density Residential (MDR) future land use condition, RTIMP = 30%, there, the adjustment factor would be (100%) / (100%-30%)= 1.429.

To equate the required 100-yr, 2-hr retention volume to an equivalent IA, a unit rainfall depth is determined for each grid element as follows:

$$P_{unit} = (0.80)(1.429)CP$$

Where:
- P_{unit} = unit rainfall depth to be retained per grid element (in)
- 0.80 = the recognized retention volume per FCDMC
- 1.429 = the RTIMP adjustment factor
- C = runoff coefficient = 0.70
- P = 100-yr, 2-hr precipitation = 2.10 in

$$P_{unit} = (0.80)(1.429)(0.70)(2.10) = 1.68 \text{ in}$$

With the IA for a MDR land classification being 0.25 inches, the adjusted IA to include future retention is 1.68 + 0.25 = 1.93 inches. For FLO-2D, a final adjustment has to be made for the surface detention input parameter (TOL) assigned in the TOLER.DAT file. The TOL value to be used for the project is 0.01 feet or 0.12 inches. The final IA to be assigned in the INFIL.DAT file is therefore 1.93 – 0.12 = 1.81 inches. *It should be noted that the actual retention volume does not need to be computed for this approach. As stated above, the percent impervious area (RTIMP) needs to be adjusted from existing conditions (10%) to future conditions (30%) for these grid elements. Therefore, both the IA and the RTIMP need to be reassigned for the future conditions in the INFIL.DAT file.*

3.4.3 Retention Basin Approach

The retention basin approach attempts to physically model the future condition retention basin by lowering elevations assigned to FLO-2D grid elements located along the downstream boundary of the future development area. The grid elements are lowered enough that the collective elevation difference (i.e. volume) equals the recognized future 100-year, 2-hour retention volume. Therefore, the brown grid elements shown in Figure 3-3 have been lowered for this approach to collectively provide 0.2025 acre-feet of storage volume. *With this approach, the required retention volume must be computed for each development area.*

As with the IA approach, the percent impervious area (RTIMP) needs to be adjusted for these future development grid elements. In addition, the IA needs to be assigned to the

default value for the future development land use, 0.25 – 0.12 (for TOL) = 0.13 inches. *Therefore, both the IA and the RTIMP need to be reassigned for the future conditions in the INFIL.DAT file.*

3.4.4 Model Analyses and Results

This test scenario was conducted by developing 2-yr, 10-yr, and 100-yr frequencies and 6-hr and 24-hr durations for the following test scenarios:

- Future Conditions Runoff (no retention) **(FCR)**
- IA Approach Future Conditions (retention simulated by increasing IA) **(IA)**
- Retention Basin Approach Future Conditions (retention simulated by lowering grid element elevations) **(RBA)**

To simplify the test models, rainfall was limited to 100 grid elements shown in Figure 3-3. Furthermore, outflow nodes were placed some distance downstream of the development. A FLO-2D floodplain cross section (FPXSEC.DAT) was placed immediately downstream of the test development area to call a hydrograph and other hydrologic data from the models for comparison.

Runoff volumes, peak discharges, time to peaks, and hydrographs were developed for each scenario and method for all runs.

Table 3-8 lists the key hydrologic data for each model run. Figure 3-4 and Figure 3-5 are hydrograph comparisons of the Future Conditions Runoff (no retention) to both the IA approach and retention basin approach for the 100-yr, 6-hr and the 100-yr, 24-hr frequency runs, respectively. Table 3-9 lists a comparison of effective retention modeled using both methodologies.

Table 3-8: Hydrologic Output

Model	HYCROSS.OUT			SUMMARY.OUT			
	Runoff Vol. (ac-ft)	Peak (cfs)	Time (hr)	Rain Vol[1] (ac-ft)	Infil & Inter (ac-ft)	FP Storage (ac-ft)	Outflow (ac-ft)
2-yr, 6-hr							
Future (no retention)	0.02	0.77	4.14	0.20	0.15	0.03	0.01
IA Approach	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Ret Basin Approach	0.00	0.00	0.00	0.20	0.18	0.02	0.00
2-yr, 24-hr							
Future (no retention)	0.04	1.56	12.08	0.27	0.21	0.03	0.03
IA Approach	0.00	0.00	0.00	0.27	0.27	0.00	0.00
Ret Basin Approach	0.00	0.00	0.00	0.27	0.25	0.02	0.00
10-yr, 6-hr							
Future (no retention)	0.09	1.81	4.08	0.29	0.18	0.03	0.08
IA Approach	0.00	0.00	0.00	0.29	0.29	0.00	0.00
Ret Basin Approach	0.00	0.00	0.00	0.29	0.23	0.07	0.00
10-yr, 24-hr							
Future (no retention)	0.10	3.06	12.05	0.41	0.28	0.03	0.10
IA Approach	0.00	0.00	0.00	0.41	0.39	0.02	0.00
Ret Basin Approach	0.00	0.00	0.00	0.41	0.35	0.05	0.00
100-yr, 6-hr							
Future (no retention)	0.21	3.91	4.03	0.45	0.21	0.03	0.20
IA Approach	0.00	0.25	4.58	0.45	0.42	0.03	0.00
Ret Basin Approach	0.00	0.04	5.08	0.45	0.27	0.18	0.00
100-yr, 24-hr							
Future (no retention)	0.21	6.37	12.03	0.63	0.39	0.03	0.20
IA Approach	0.04	1.75	12.15	0.63	0.56	0.03	0.04
Ret Basin Approach	0.00	0.08	12.88	0.63	0.47	0.16	0.00

1. *(precipitation (in) * 30-ft x 30-ft * 100 grid elements) / (12-in/ft * 43,560 sf / ac)*

Table 3-9: Comparison of Effective Retention Volume Modeled

Frequency, Duration	Rainfall Volume (acre-ft)	Future Conditions Runoff Volume (acre-ft)	Retained Volume	
			IA Approach (acre-ft)	Ret Basin Approach (acre-ft)
2-year, 6-hour	0.20	0.02	0.02	0.02
2-year, 24-hour	0.27	0.04	0.04	0.04
10-year, 6-hour	0.29	0.09	0.09	0.09
10-year, 24-hour	0.41	0.10	0.10	0.10
100-year, 6-hour	0.45	0.21	0.21	0.21
100-year, 24-hour	0.63	0.21	0.17	0.21

1. *Target volume up to is less than maximum/required retention volume of 0.2025 ac-ft.*

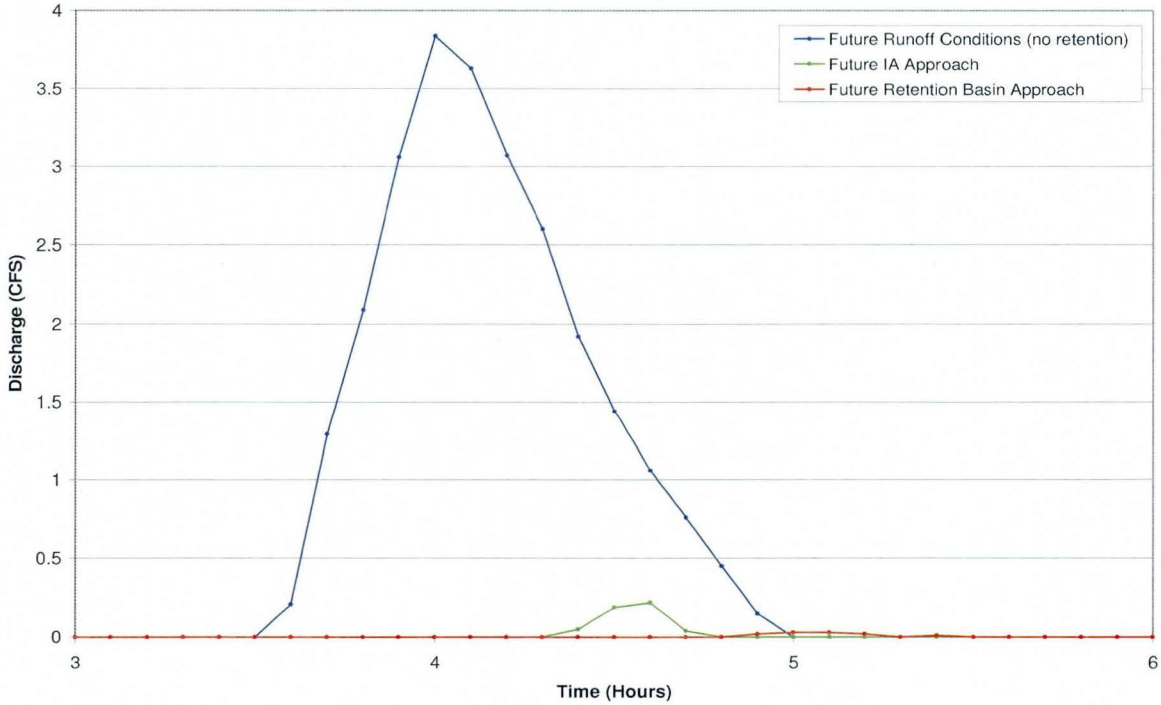


Figure 3-4: 100-yr, 6-hr Hydrograph Comparison

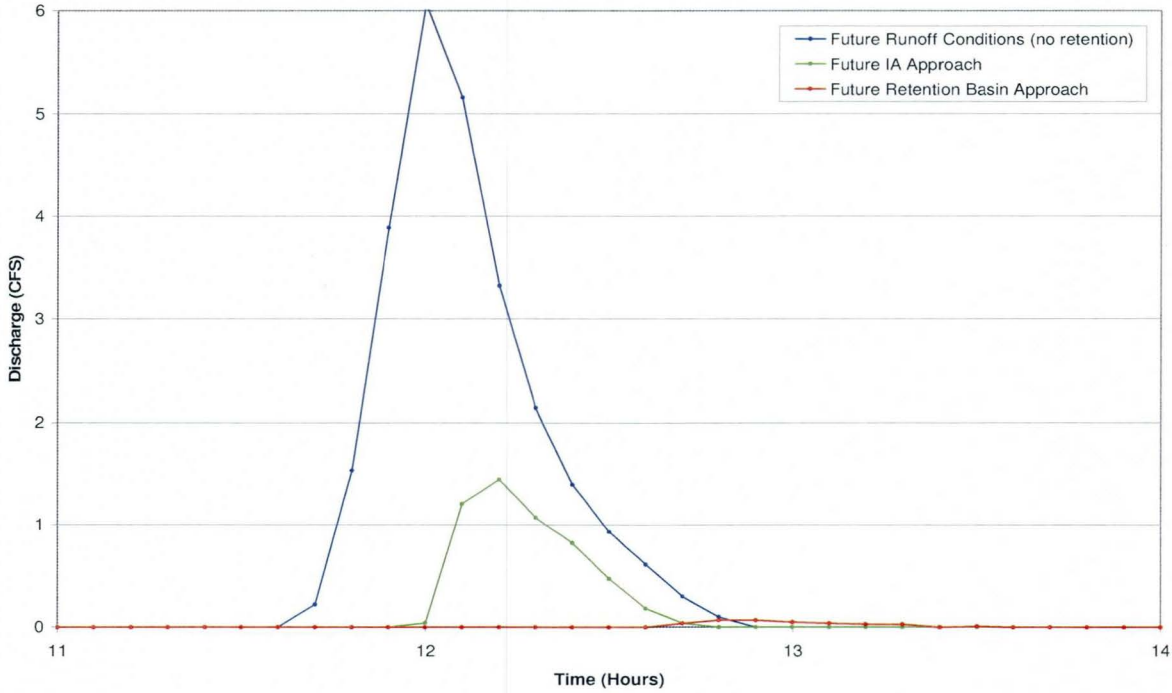


Figure 3-5: 100-yr, 24-hr Hydrograph Comparison

It can be seen that the IA approach results are a very close match to the retention basin approach for the frequencies and durations with the exception of the 100-year, 24-hour storm. The effective retention volume utilized in the retention basin approach is closer to the target retention volume for the 100-year, 24-hour event than the IA approach. Figure 3-4 and Figure 3-5 also show that the rising limb of the resulting hydrograph for the retention basin approach is slightly delayed and much more dampened than the IA approach.

3.4.5 Discussion of Approaches

Both the IA and retention basin approaches have advantages and disadvantages. The IA approach is more abstract and is an indirect method that exploits a hydrologic parameter to model a physical feature. The retention basin approach is more direct and ultimately easier to understand since it is reflects the physical modeling of a physical feature. Both approaches would require revision to the existing conditions parameters to the future land use condition for each development area (RTIMP, n-values, rainfall loss, etc).

Based upon the assessment performed, both approaches seem to reasonably produce expected and desired results. When there is a difference between the approaches, the IA approach seems to be the more conservative in that there is less retention provided and higher downstream peak discharges. Given the similar results, the ease in which the approach can be applied to the project area and the impact to model run times were key factors in selecting an approach.

There are a number of future development areas within the ADMS study area. For the retention basin approach, the required retention volume for each site must first be determined and then an adjustment to the FPLAIN.DAT elevations is necessary for each development site. An assessment of the likely location of any future retention basin is also required. Given the uneven terrain and the possible shape of a development area, it may require coding of more than one basin. For the IA approach, the adjusted IA for each land use can be determined independent of FLO-2D and the parameter can be uniformly applied to all like development areas. Retention volumes for a site need not even be calculated for each site unless to verify results.

The retention basin approach also creates ponding areas within the FLO-2D computational domain. Ponding in FLO-2D can be problematic and increase run times. For the test models, the retention basin approach took approximately 40% longer to run than the IA approach.

Given the ease of application, the conservative results (less retention, higher downstream discharges) and the faster run times, the IA approach will be used for the Future Conditions Hohokam ADMS FLO-2D models.

3.5 PILOT STUDY FLO-2D MODELS

3.5.1 Storm Events and Control Parameters

The pilot study FLO-2D hydrology includes models for the 2-yr, 10-yr, and 100-yr frequency and for both the 6-hr and 24-hr durations. The models include all the tested sensitivity model components (CHAN.DAT, LEVEE.DAT, RAIN.DAT, INFIL.DAT, ARF.DAT, and HYSTRUC.DAT) and utilized the significant model control parameters shown in the table below. Some of these parameters were adjusted based upon the conclusions from the sensitivity analysis.

Table 3-10: Pilot Study Model Control Parameters

SHALLOWN = 0.126	WAVEMAX = -0.25	FROUDL = 0.90
TOL = 0.01	DEPTOL = 0.25*	COURANT = 1.0

**Exceeds range specified in project scope of work. See discussion of DEPTOL in Section 3.2.11.3.*

3.5.2 Results

Documentation for the results of the pilot study models are presented in Appendix C. Included is a summary table of peak discharges at all pilot study cross section locations and run times for all study models and exhibits of flow depths in the pilot study area for all events. For the flow depths exhibits, flow depths of less than 0.1 ft were not displayed in order to focus on the larger and more significant flow depth locations. Also included in the provided CD are Excel spreadsheets that provide hydrographs at each cross section location. Hardcopies of these hydrographs are not provided in the report.

This sub-section briefly describes a qualitative assessment of the overall pilot study results based upon a review of the FLO-2D output.

3.5.2.1 Flow Distribution

Generally, the results of the inundation areas and flow depths is as expected with flow concentrated and deepest in channels, drainages, streets and retention basins. However, in some locations, it appeared street flow was underestimated and flow was just as likely to flow overland as it would down a paved street with curb and gutter. It was expected that more flow would be concentrated and conveyed along streets due to the lack of other means of natural or man-made conveyance. Where street flow appeared to be underestimated, the lack of flow seemed to be at least in part due to the averaging of point and break line data that blurred the definition of the streets resulting in little elevation difference between "street" grid elements and adjacent "residential home" elements. Typically in residential areas with curb and gutter, one would expect pad elevations to be raised at least a foot above the adjacent top of curb elevations. The grid element elevations did not seemed to adequately define the streets as flow paths or distribute or concentrate flow as efficiently as might be expected. The

averaging of feature n-values might also contribute to this lack of street flow but the impact would be considerably less significant than the elevation.

Revising the approach used to develop grid elevation data in urban areas was proposed in an attempt to better define the streets (see Section 3.3.7). In addition, the inclusion of block walls/levees located along streets will help contain and concentration flow in the streets and reduce inappropriate overland flow. ARF/WRFs should also help limit inappropriate overland flow in the more densely developed areas.

3.5.2.2 Ponding Areas

Ponding was found along the Western and Highline Canals, along within the Thunderbird Gold Course, in retention basins, in locations were there were significant obstructions to flow with no means of drainage such as south east perimeter wall around the Dobbins Creek subdivision and north of the Western Canal along 10th Street.

For the final study analyses, significant ponding areas should be reviewed for appropriateness. Ponding behind the Highline Canal might be better defined if the channel bank elevations were defined similar to the Western Canal (see Section 3.2.9). Ponding due to block walls (or other obstructions) should be reviewed to assure the walls area continuous, structurally sound, and do not have sizeable opening that would allow for drainage. Detention basins with large outlets (such as in Dobbins Creek) should evaluated.

3.5.2.3 Velocities

Overall, maximum velocities were reviewed and appeared to be reasonable. Only a handful of grid elements exhibited very high velocities in the range of 10-15 ft/s and these were found in the steep mountainous areas. Velocities of 6-10 ft/s were found along major flow paths in the mountains, along the channels in the Dobbins Creek Subdivision and briefly in some streets where flow was concentrated (15th St north of Euclid near OK Park). Overland flow and street flow generally was less than 3-4 ft/s.

3.5.2.4 Model Surging

In some locations, such as Cross Section 17, hydrographs fluctuate significantly indicating surging is occurring. This could be due to the orientation of the cross sections and flow directions not being parallel to the cross section over time. However, this could also be due to the model having difficulty in resolving discrepancies between flow discharges, velocities, flow area, slopes and/or roughness. Often these locations are also identified as "sticky" grid elements in the TIME.OUT file as the model decreases time steps to reduce or eliminate surging. To resolve issues of surging, the stability criteria may need to be lowered to decrease time steps and/or grid element parameters may need to be adjusted (elevations, depths, slopes or n-values). For the study area models, the TIME.OUT file will be reviewed to identify sticky grid elements and hydrographs will be reviewed for evidence of surging and the models adjusted to

minimize or eliminate model surging. Locations where there are extreme values (peak discharges, velocities) will similarly be reviewed.

3.5.2.5 Model Verification

A comprehensive hydrologic model for the pilot area and/or study area has not been previously developed that might provide a means for a quantitative assessment of project FLO-2D models. Nor are there significant watercourses or gages within the study area that would be useful in evaluating the study results. Verification of the study area models will ultimately be a qualitative assessment based upon knowledge of the study area and professional judgment. Of particular value will be information on historic flooding problems and conditions gathered from the public and local agencies during the data collection and public involvement process. The City of Phoenix has provided a list of historic complaints in the study area some of which are located in the study area. In general, the results of the pilot study FLO-2D analyses do show increased flooding potential and/or flow depths in the complaint locations identified as being potential regional flooding issues in field investigations.

3.5.2.6 Comparison of 24-Hour and 6-Hour Events

With the exception of a few cross sections, the events of 24 hours in duration produced the largest peak discharges at the cross section locations. At the few locations where the 6 hour events did exceed the 24-hour events, the differences were insignificant.

4 SUMMARY OF CONCLUSIONS & APPROACHES

This section summarizes the conclusions derived from the pilot study and identifies the approaches expected to be utilized for the study area models. The conclusions and described approaches are subject to change during the course of the development of the study.

4.1.1.1 Development of the Computational Grid Elevations

Two-foot contour interval data will be used for the urbanized portion of the study area. This data will be supplemented with 10-ft C.I. data provided for the steeper, mountainous portions of the study area found in South Mountain Park (see Section 3.2.1.).

From the pilot study effort, a combined approach was determined to be best suited to establish the computational grid elevations for the study area models. Directly utilizing mass point and break lines in the GDS was considered the best approach for the steeper mountainous areas, while for the flatter urbanized lowland areas, the mass points and breaklines will be utilized to first create a TIN, the TIN will then be transformed into a raster data set of 5'x5' pixels to create a grid of uniformly spaced point elevations and then the raster data will be used by the GDS to establish the computational grid elevations

4.1.1.2 Precipitation Data (RAIN.DAT)

The spatially varied maximum point precipitation data will be derived from NOAA 14 data as described in Section 3.2.3. For the pilot study, no depth-area reduction adjustments were made to the data. For the study area, precipitation data may be adjusted. A possible means of adjustment would be to adjust all rainfall data based upon an estimate of the average size of sub-basins in the watershed area.

4.1.1.3 Manning's n (FPLAIN) & Infiltration Parameters (INFIL)

Manning's n-values and infiltration parameters for the study area will be generally determined based upon feature characterization shape files provided by the FCDMC and by assigning values to each land use/feature as described in Sections 3.2.4 and 3.2.5 and as presented in Table 3-3. However, due to the amount of it takes to process such a large amount of detailed data using GDS, it may be necessary to process n-values and infiltration parameters using GIS applications. GIS may process the data differently than the GDS and/or the feature data may be rasterized similar to the approach proposed to develop grid elevations for the urbanized areas. The feature data may be rasterized and assigned values based upon either a weighted average within each pixel or by simply utilizing the value at the center of the raster pixel. Given the regional nature of the hydrologic analysis, the relative small pixel size (perhaps 5'x5') and the much larger computation grid element size, it is expected that this approach would not significantly change the study results or findings.

4.1.1.4 Area and Width Reduction Factors (ARF.DAT)

As was done in the Pilot Study, the ARF.DAT file (area reduction factors) for the entire study area will be prepared by the FCDMC as described Section 3.2.6.

4.1.1.5 Modeling of Block Walls (LEVEE.DAT)

Accounting for the impact of block walls on the distribution of flow through the watershed is an essential and necessary component for this study. Block walls (for fencing, not buildings or structures) will be modeled using the levee option (LEVEE.DAT). The modeling of walls will generally be limited to those that have significant impact on regional distribution of flow such as subdivision perimeter walls, walls perpendicular to significant overland flow paths and/or walls that help contain flow within streets or channels. Generally walls will be assumed to be structurally sound and will not be assessed for failure unless results indicate excessive ponding or flow depth along walls in specific areas. Consequently, detailed information on wall heights will not be necessary and wall/levee heights will be set at an elevation that flow will never overtop. Wall failure will be addressed on a case-by-case basis based upon the results of the study models.

4.1.1.6 Modeling of Culverts (HYSTRUC.DAT)

Given the potential for increased numerical surging and the need to obtained survey/field data on any modeled culverts it is recommended that the modeling of culverts be limited to those determined to be those that are hydrologically significant and/or have a significant impact on flooding conditions. Consideration will be given instead to adjusting floodplain elevations to provide an equivalent means of conveyance.

4.1.1.7 Modeling of Storm Drain System (HYSTRUC.DAT)

Based upon the pilot study efforts, the modeling of the study area storm drain systems will be accomplished as described in Section 3.3.9.1.

4.1.1.8 Modeling of Western Canal (CHAN.DAT)

Based upon the pilot study results, modeling the Western Canal (in CHAN.DAT) increased ponding upstream of the canal and decreased flow depths downstream of the canal. These results are thought to be more likely related to a more accurate representation of the channel bank elevations, particularly on the upstream side, than any storage or conveyance provided by the canal itself.

The Western Canal will be modeled using the FLO-2D channel option using the approach discussed in Section 3.2.9. While the Highline Canal is not expected to be modeled with CHAN.DAT, due to the importance of accurately representing the channel

banks along the Western Canal shown in the Pilot Study, consideration should be given to either modeling the canal or revising grid elevation data along the Highline canal alignment to better and more accurately reflect bank elevations.

4.1.1.9 Initial FLO-2D Model Control Parameters

While a range for the values of model control parameters is prudent, definitively setting values for model control parameters may be inappropriate and may need to differ between study models to address issues of volume conservation and numerical surging/stability. In addition, it may be desirable to weigh the need for exacting model results against the practicality of running models with excessively long computational run times and adjust control parameters accordingly. However, based upon Pilot Study results and current modeling criteria established by the FCDMC, the initial control parameters are to be used for the study models are provided in Table 4-1.

Table 4-1: Initial Study Model Control Parameters

SHALLOWN = 0.100[1]	WAVEMAX = -0.25[2]	FROUDL = 0.90
TOL = 0.01[3]	DEPTOL = 0.10[4]	COURANT = 0.6[5]

1. *Discussions subsequent to the pilot study with the FCDMC regarding FLO-2D results from other studies indicated a possibility that high SHALLOWN is contributing to an overestimation of rainfall infiltration, the FCDMC has since expressed a desire to set SHALLOWN = 0.10. Adjustments to shallow n for variable flow depths will still be applied.*
2. *WAVEMAX values will be initially set to a negative value to decrease model run times provided it is verified that the models remain stable and do not significantly impact model results or change the findings of study.*
3. *Model criteria established by the FCDMC specifies a value $\leq$0.05.*
4. *Model criteria established by the FCDMC specifies a value $\leq$0.10.*
5. *A value of 1.0 was previously hardwired into FLO-2D. In recent revisions, the Courant is adjustable and a value of 0.6 is recommended as a starting value.*

4.1.1.10 Future Land Use Conditions.

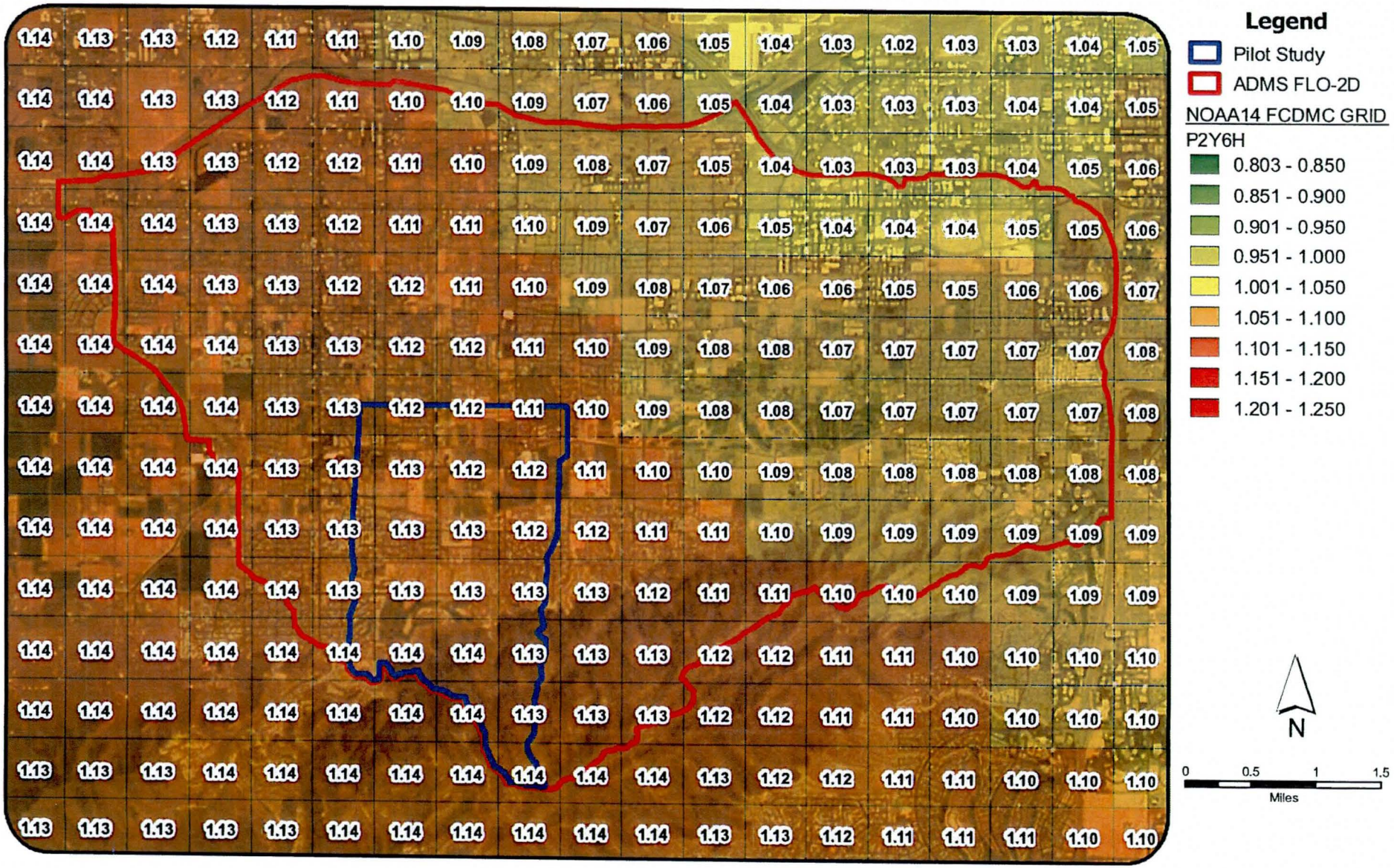
The IA approach as described in Section 3.4 will be used for future land use conditions. The Pilot Study evaluation of two different approaches to model future conditions land use and development indicated that either could be used and produced comparable results but that the IA approach was anticipated having several advantages related to the ease in application and would likely result in models requiring less computational time.

APPENDIX A

NOAA 14 RAINFALL DATA EXHIBITS

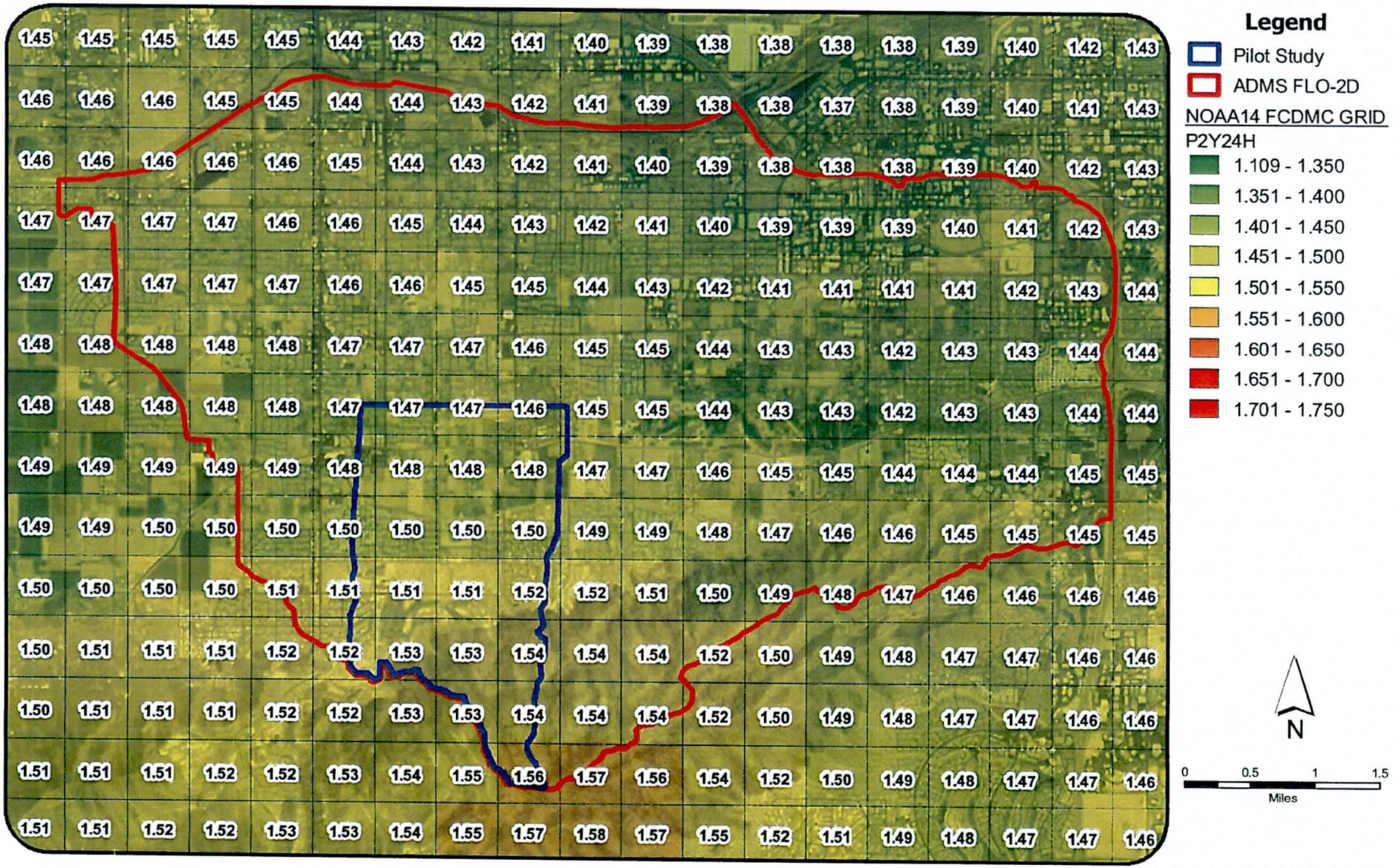
Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 2-Year, 6-Hour Precipitation



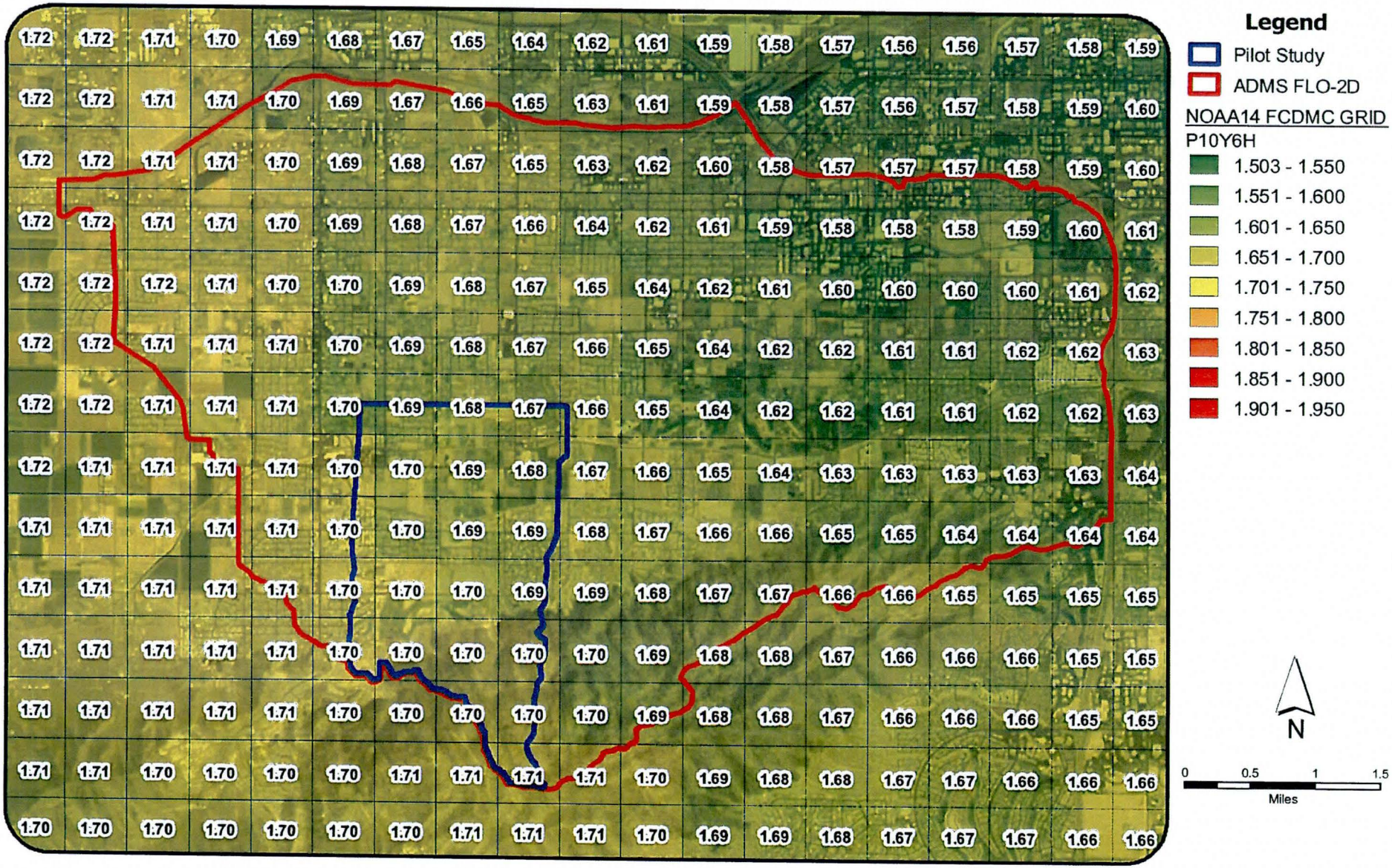
Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 2-Year, 24-Hour Precipitation



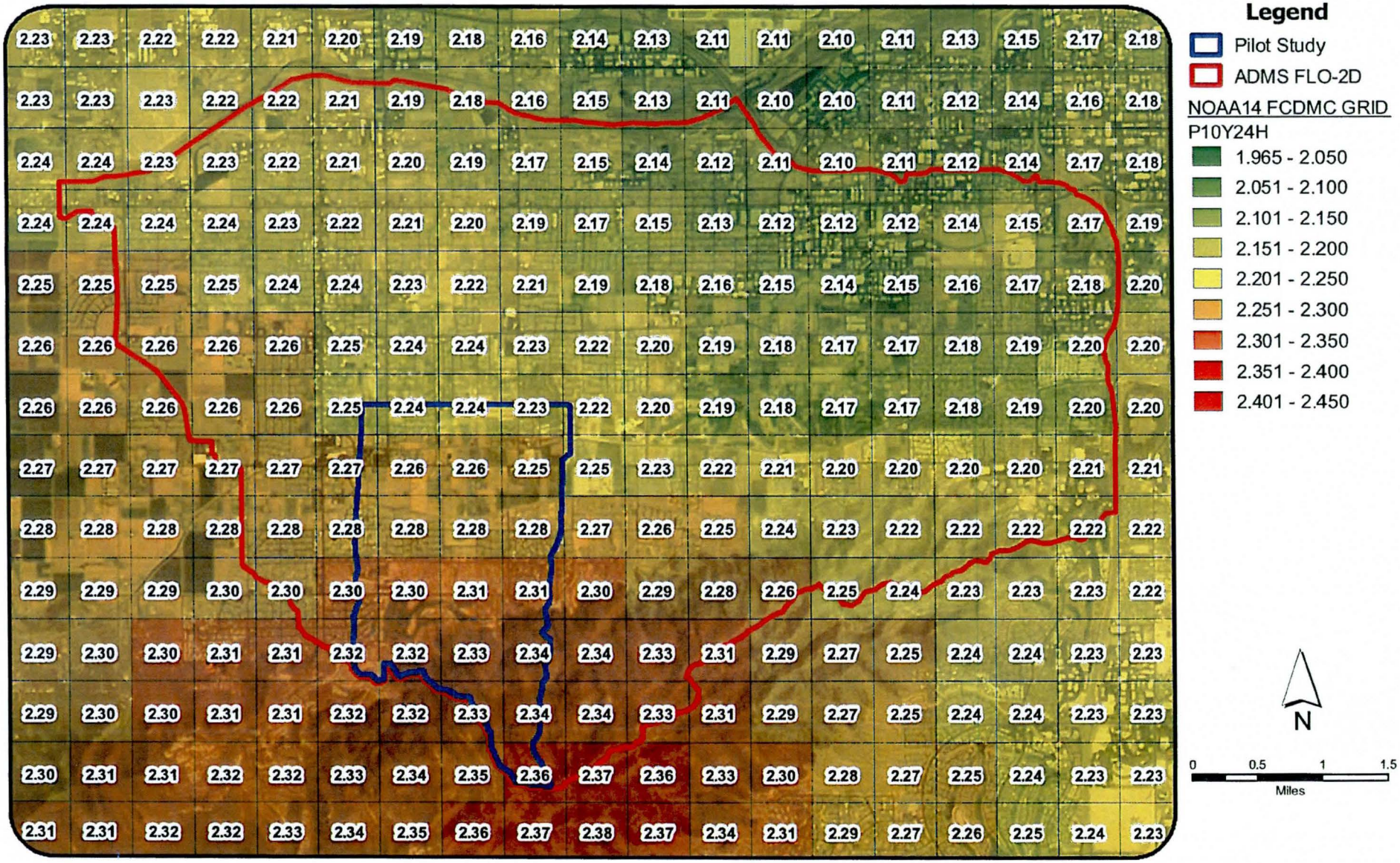
Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 10-Year, 6-Hour Precipitation



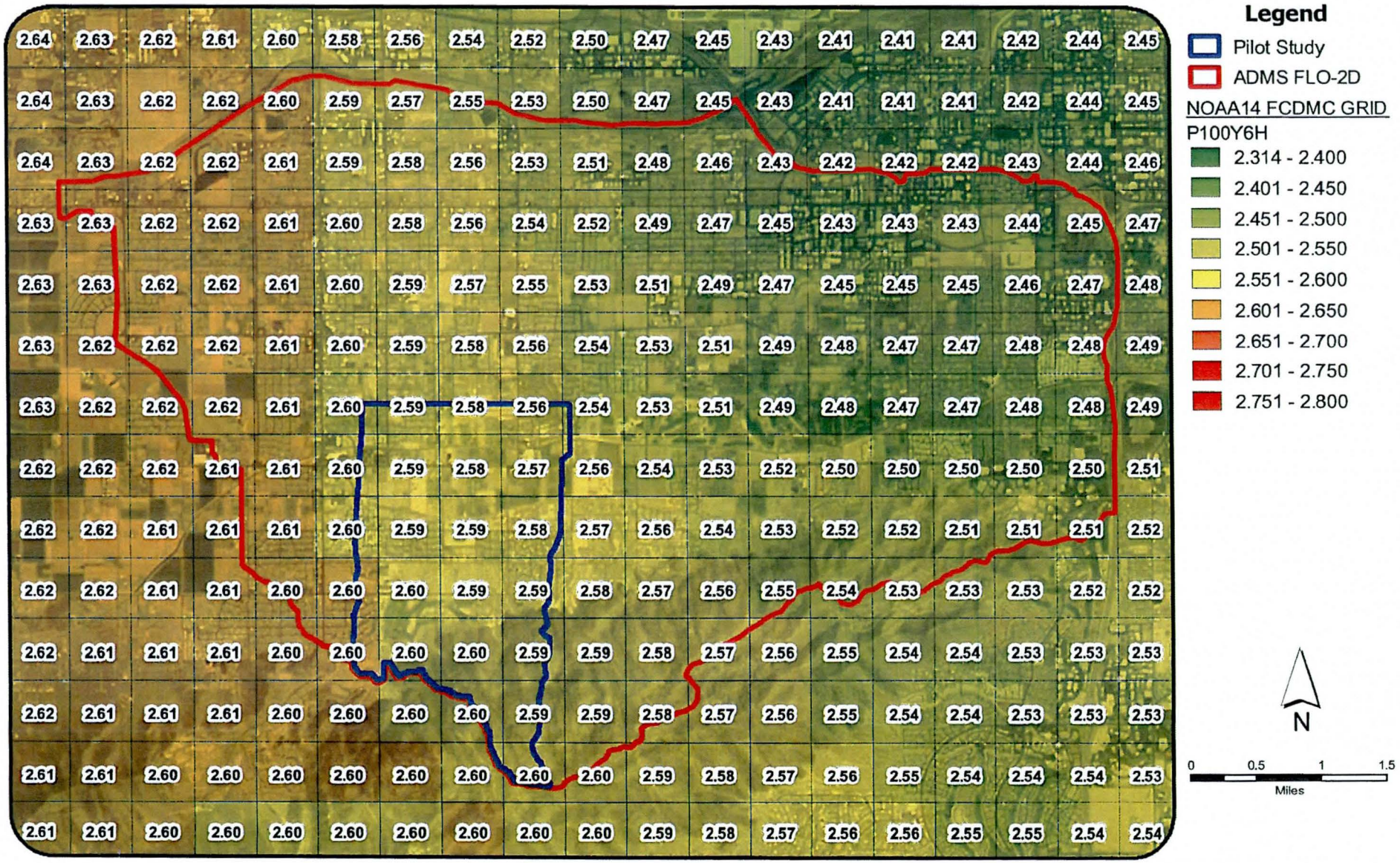
Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 10-Year, 24-Hour Precipitation



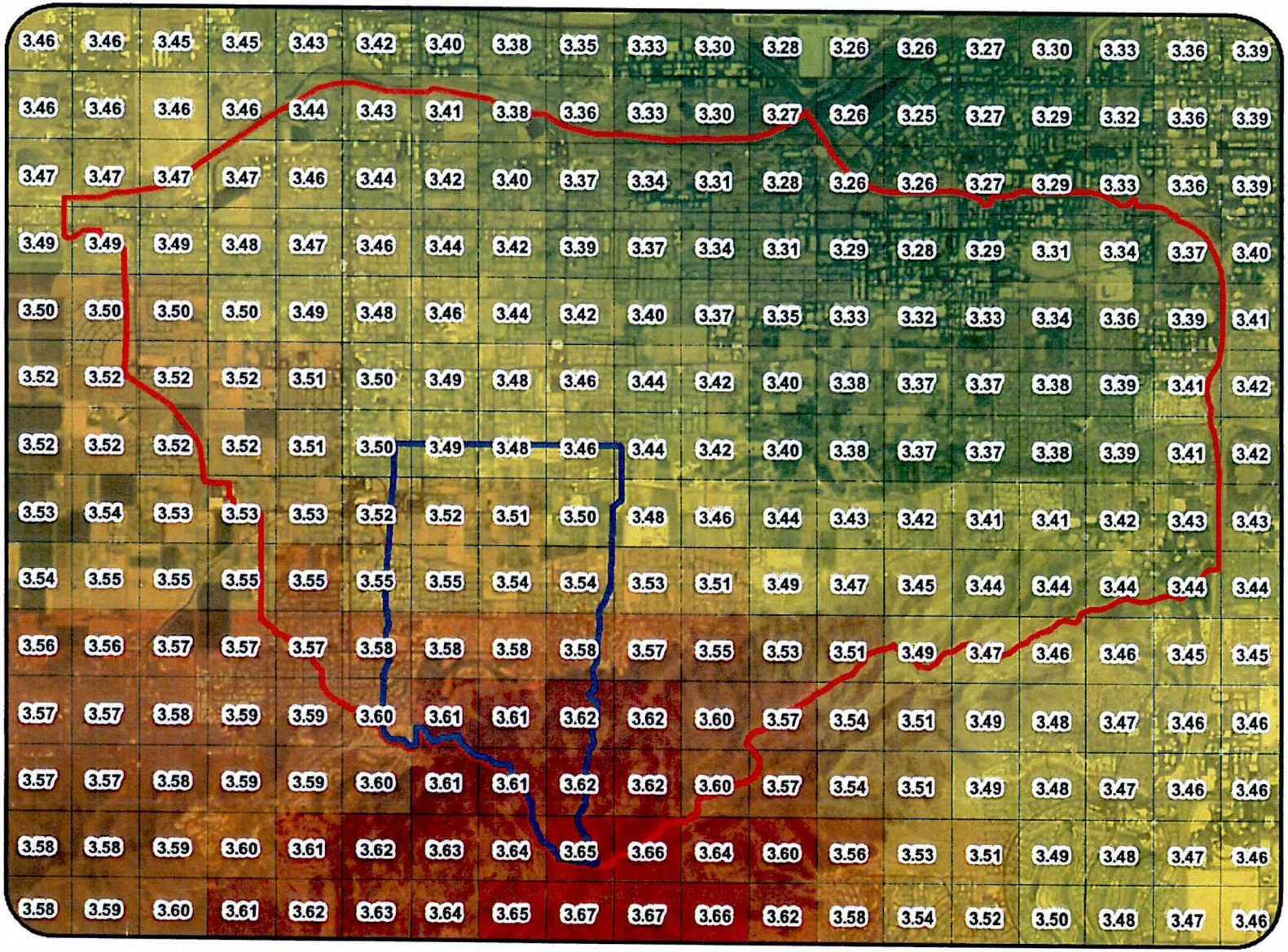
Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 100-Year, 6-Hour Precipitation



Hohokam Area Drainage Master Study

NOAA 14 Rainfall Input: 100-Year, 24-Hour Precipitation



Legend

- Pilot Study
- ADMS FLO-2D

NOAA14 FCDMC GRID
P100Y24H

- 3.080 - 3.300
- 3.301 - 3.350
- 3.351 - 3.400
- 3.401 - 3.450
- 3.451 - 3.500
- 3.501 - 3.550
- 3.551 - 3.600
- 3.601 - 3.650
- 3.651 - 3.700

N

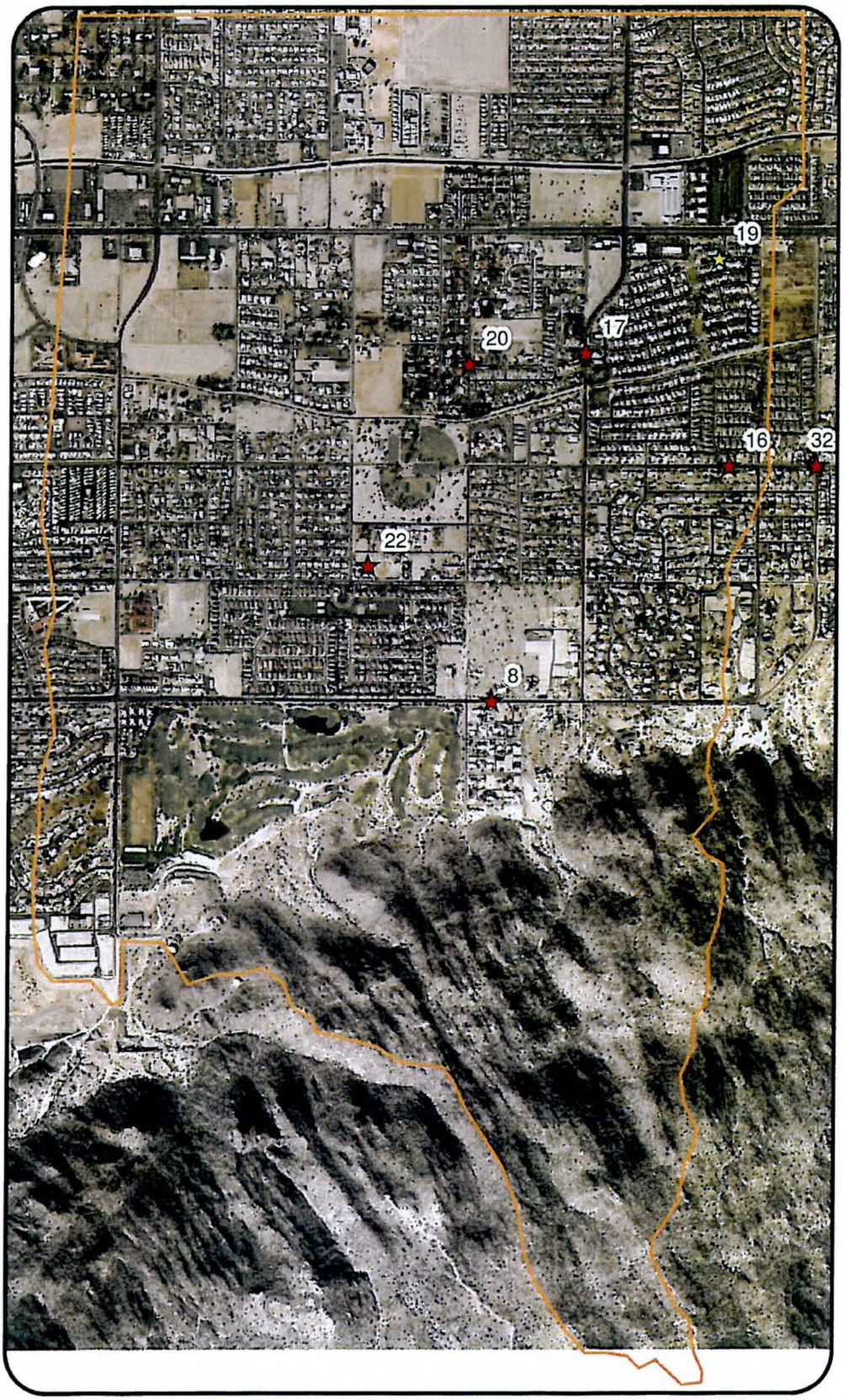
0 0.5 1 1.5
Miles

APPENDIX B

SENSITIVITY ANALYSES

Hohokam Area Drainage Master Study

Pilot Study
Boundary Limits



Legend

- Pilot Study Boundary
- Local Drainage Issue
- Regional Drainage Issue

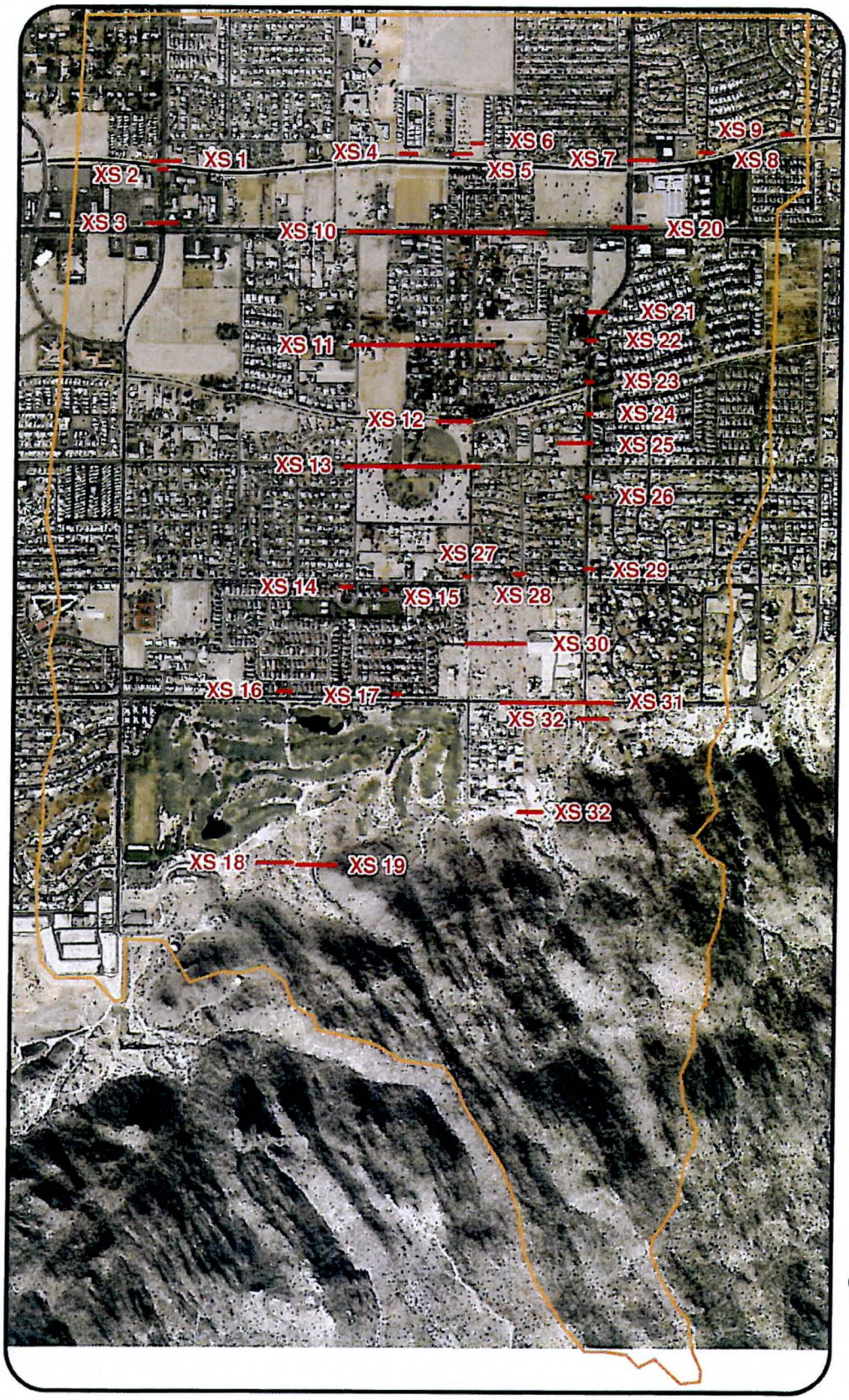
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Cross Section Locations



Legend

Cross Sections

Pilot Study Boundary

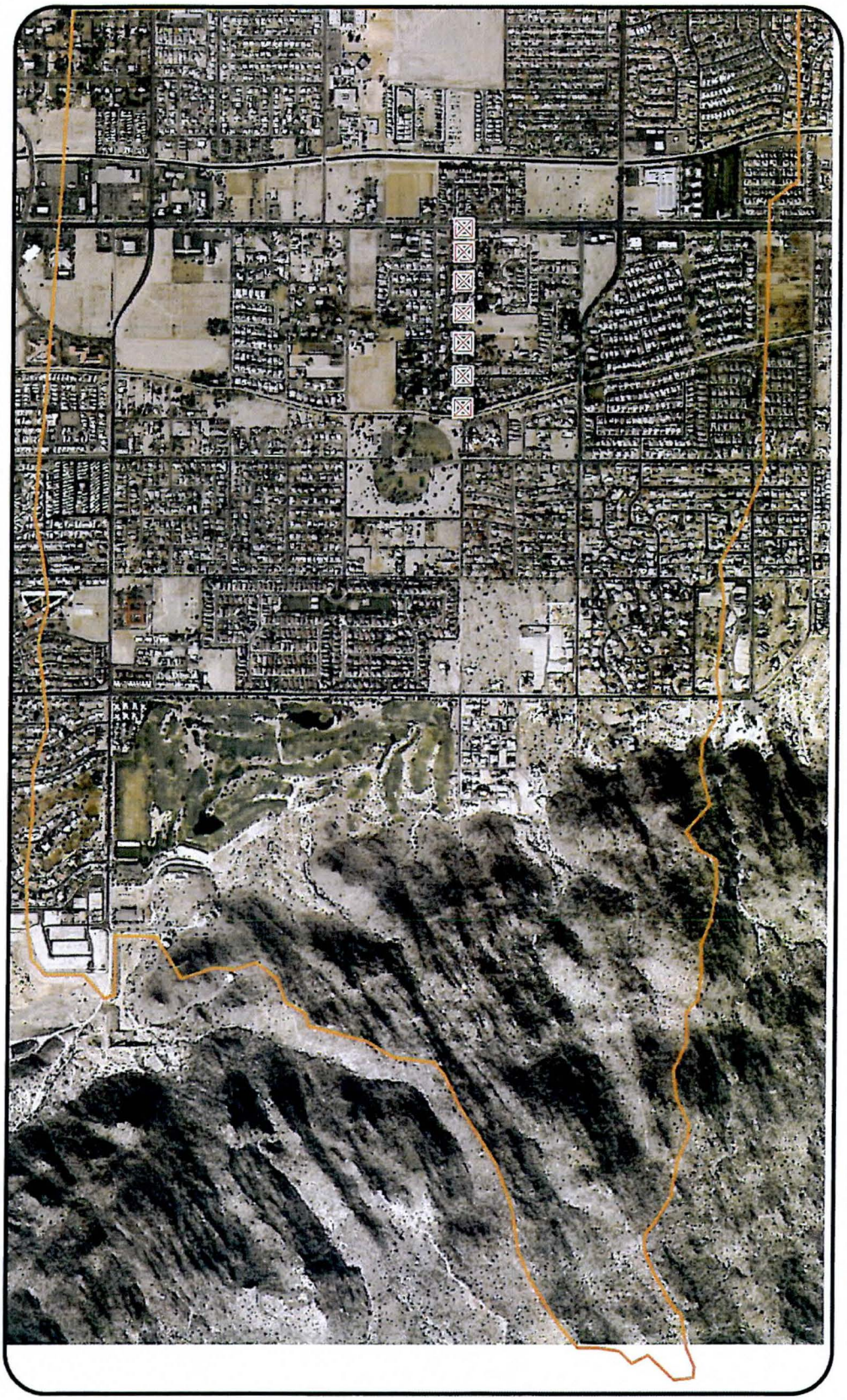
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Pilot Study Catch Basin Locations



Legend

- Pilot Study Boundary
- CatchBasins

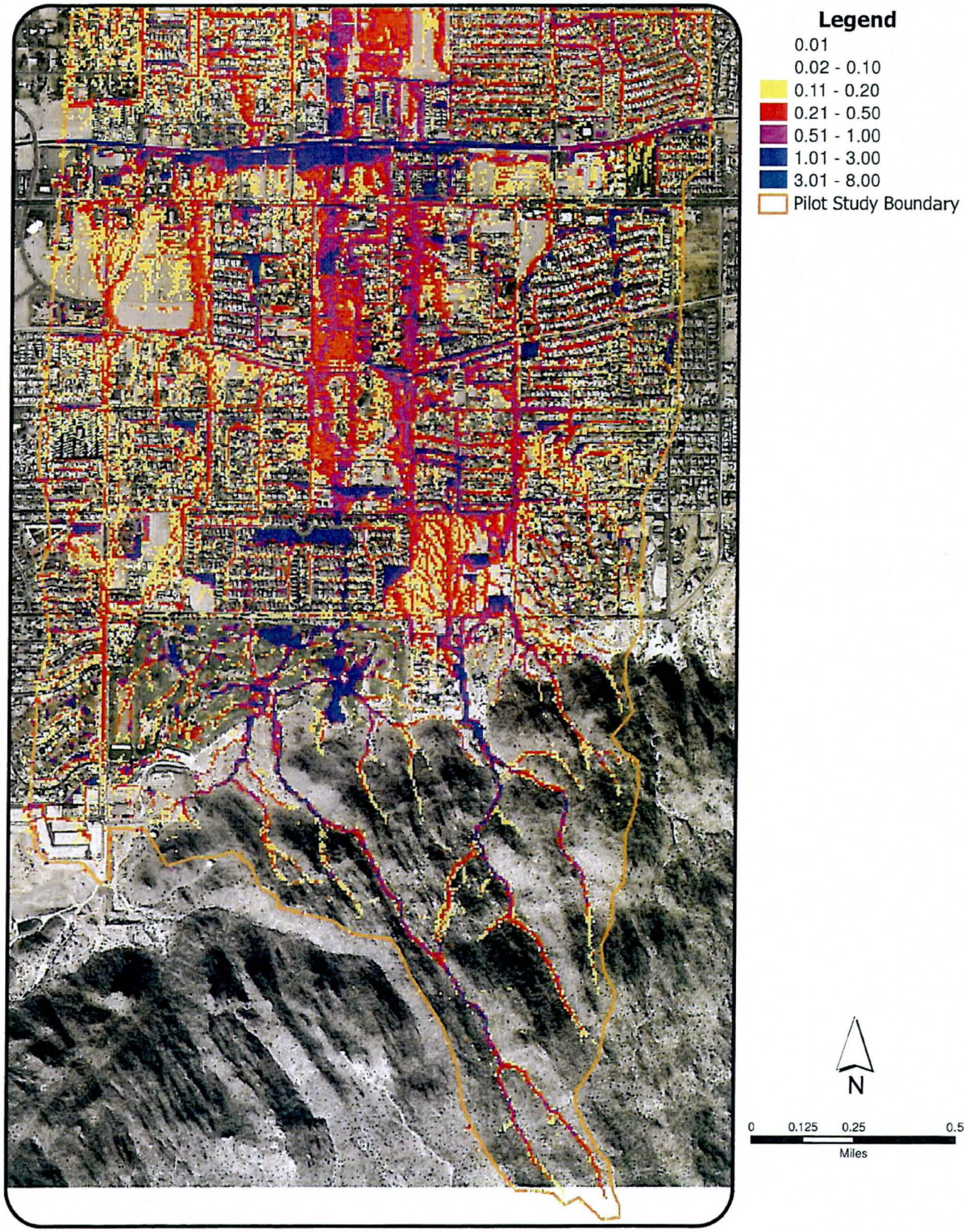
N

0 0.125 0.25 0.5

Miles

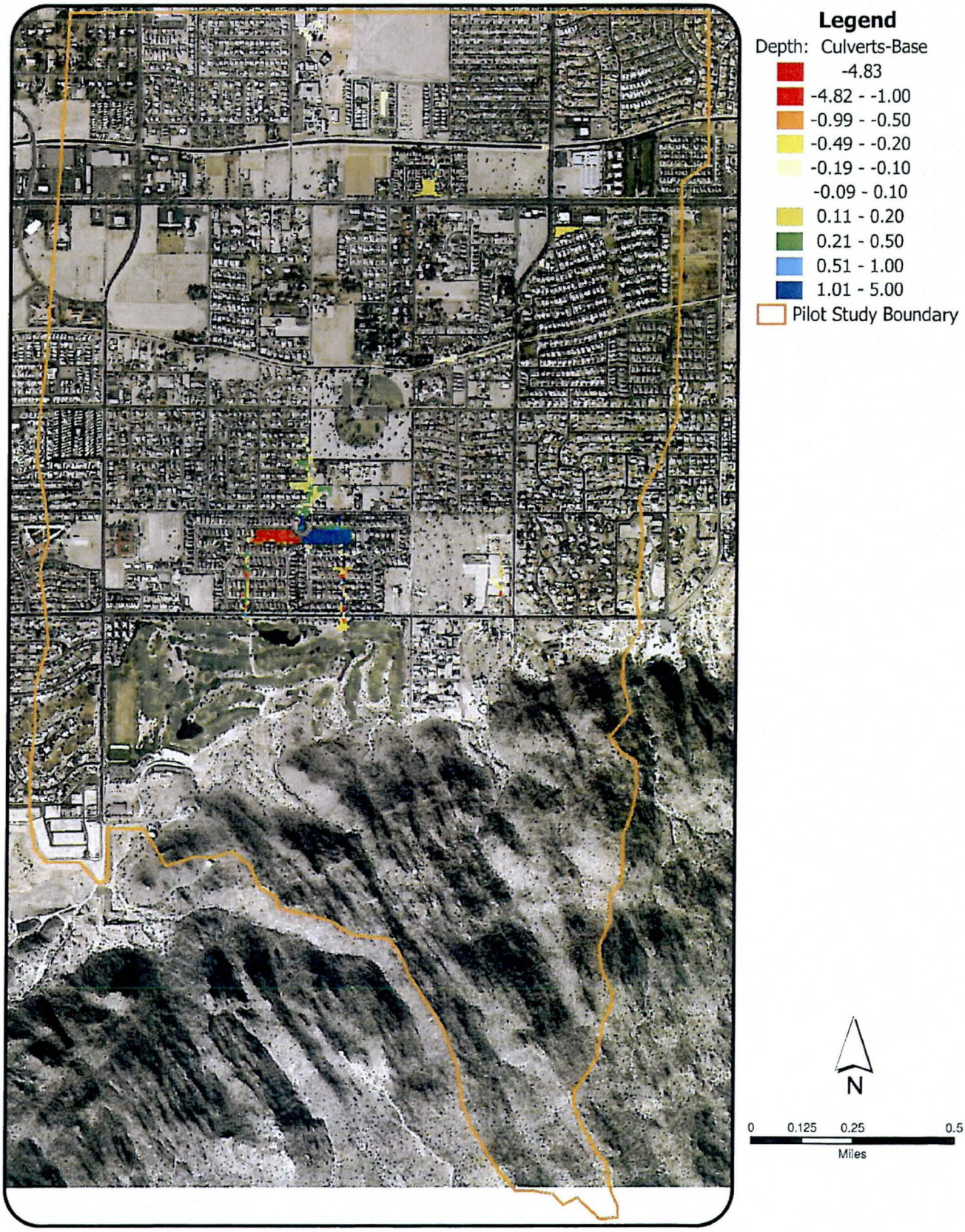
Hohokam Area Drainage Master Study

Sensitivity Analysis:
Exhibit 1: 100-Yr, 6-Hr Base Model Flow Depths



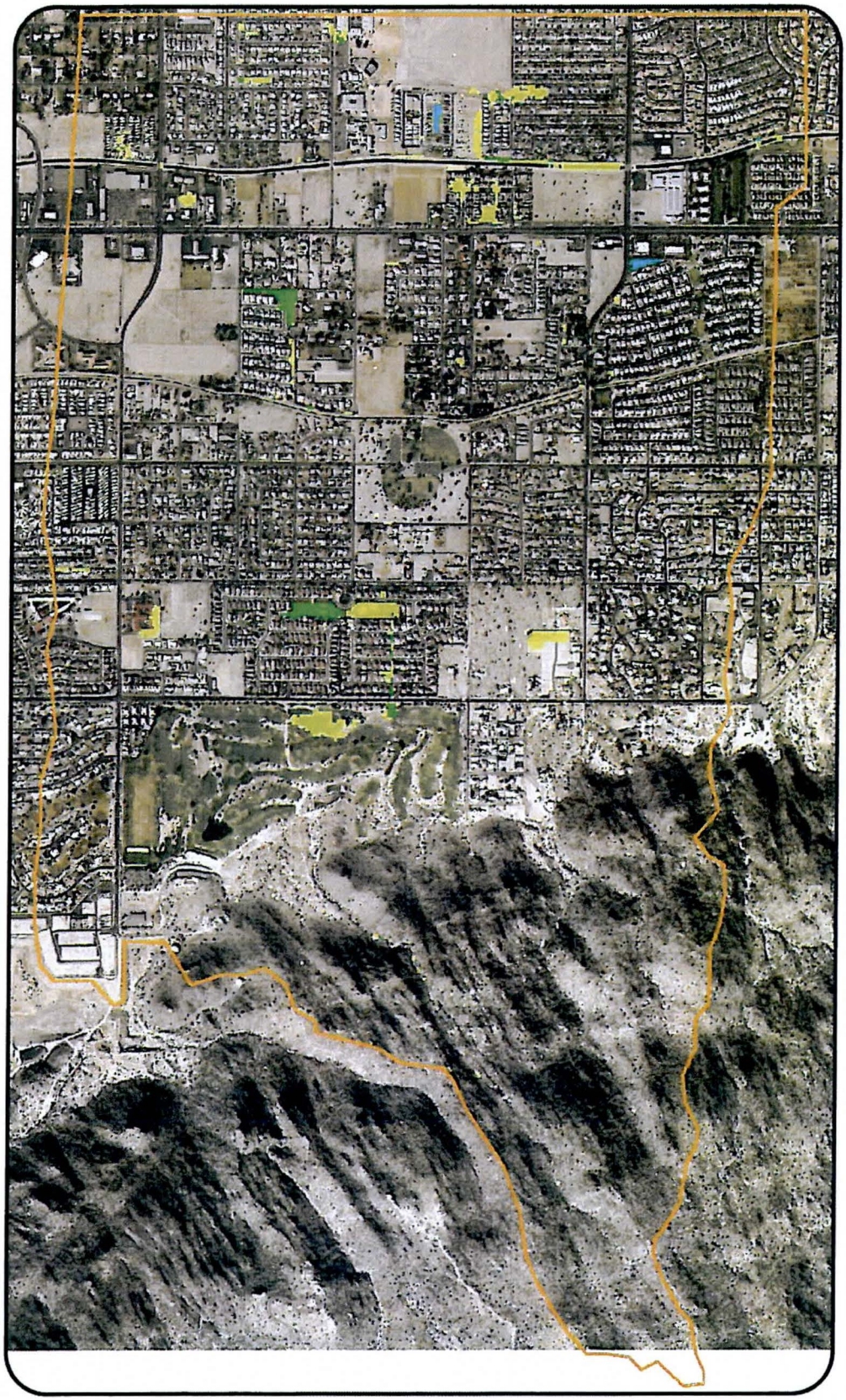
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 2: Culverts (Fewer) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 3A: SHALLOWN (0.05) - Base



Legend

Depth: 0.05-base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

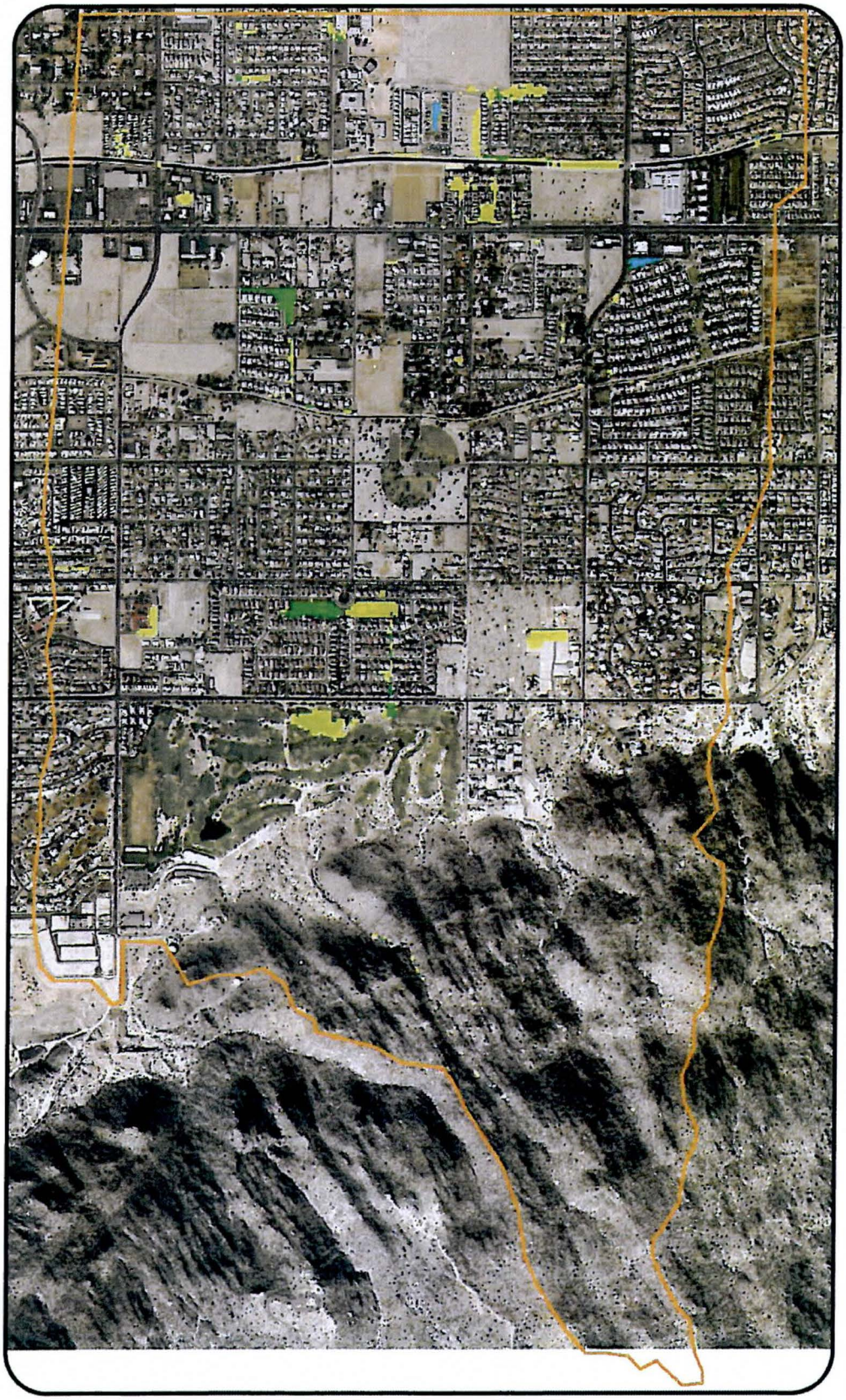
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 3B: SHALLOWN (0.10) - Base



Legend

Depth: 0.10-base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

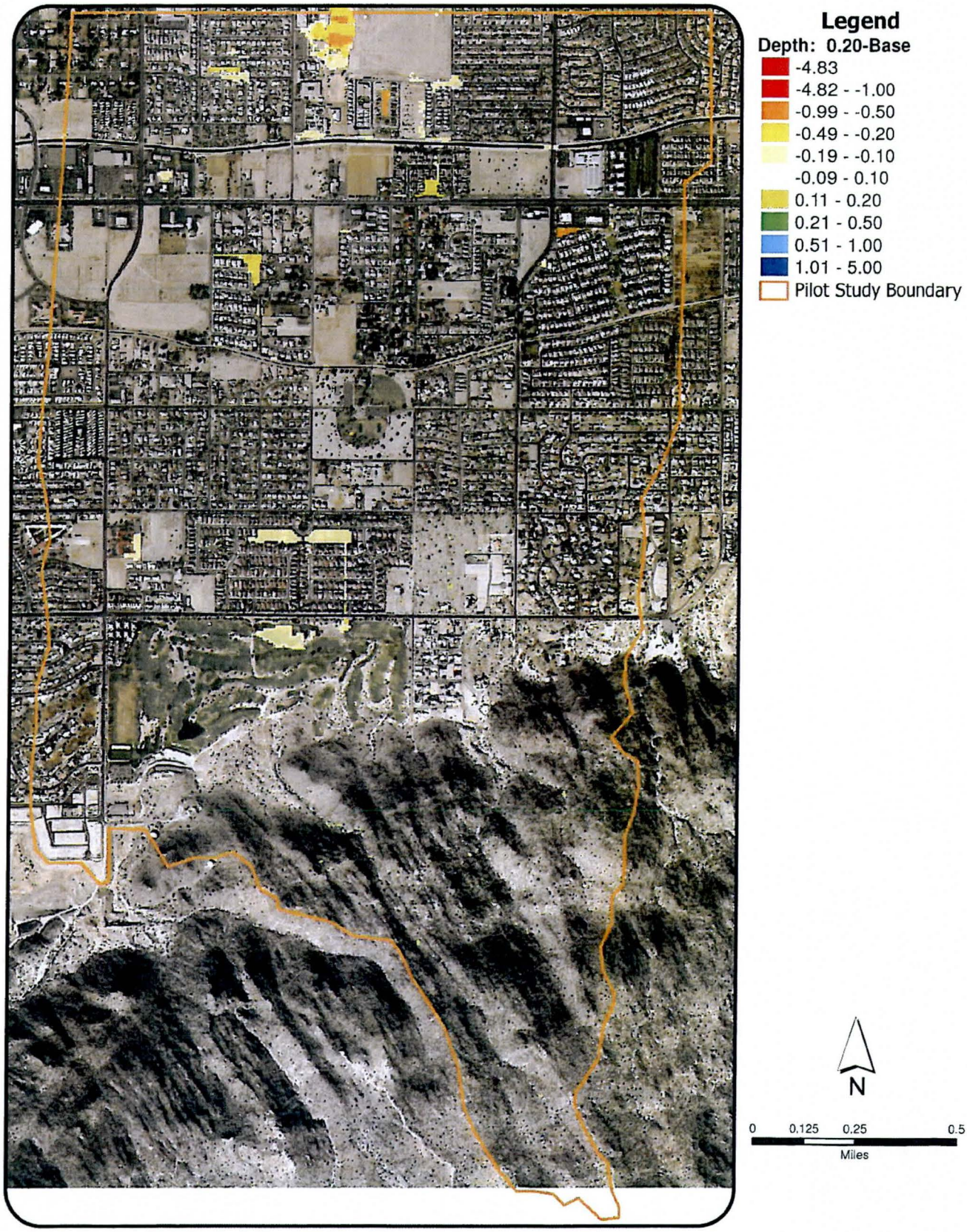
N

0 0.125 0.25 0.5

Miles

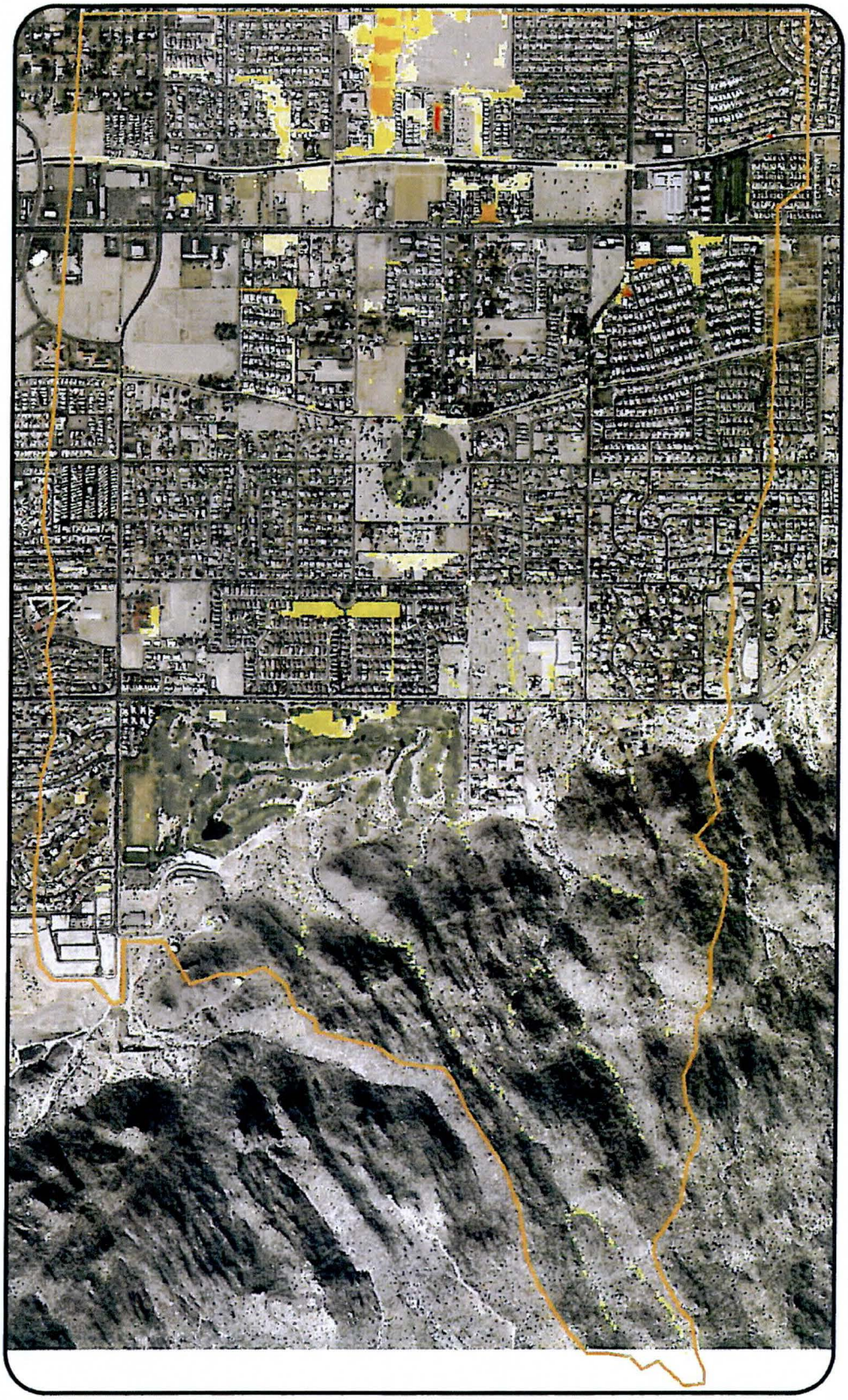
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 3C: SHALLOWN (0.20) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 3D: SHALLOWN (0.25) - Base



Legend

Depth: 0.25-base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

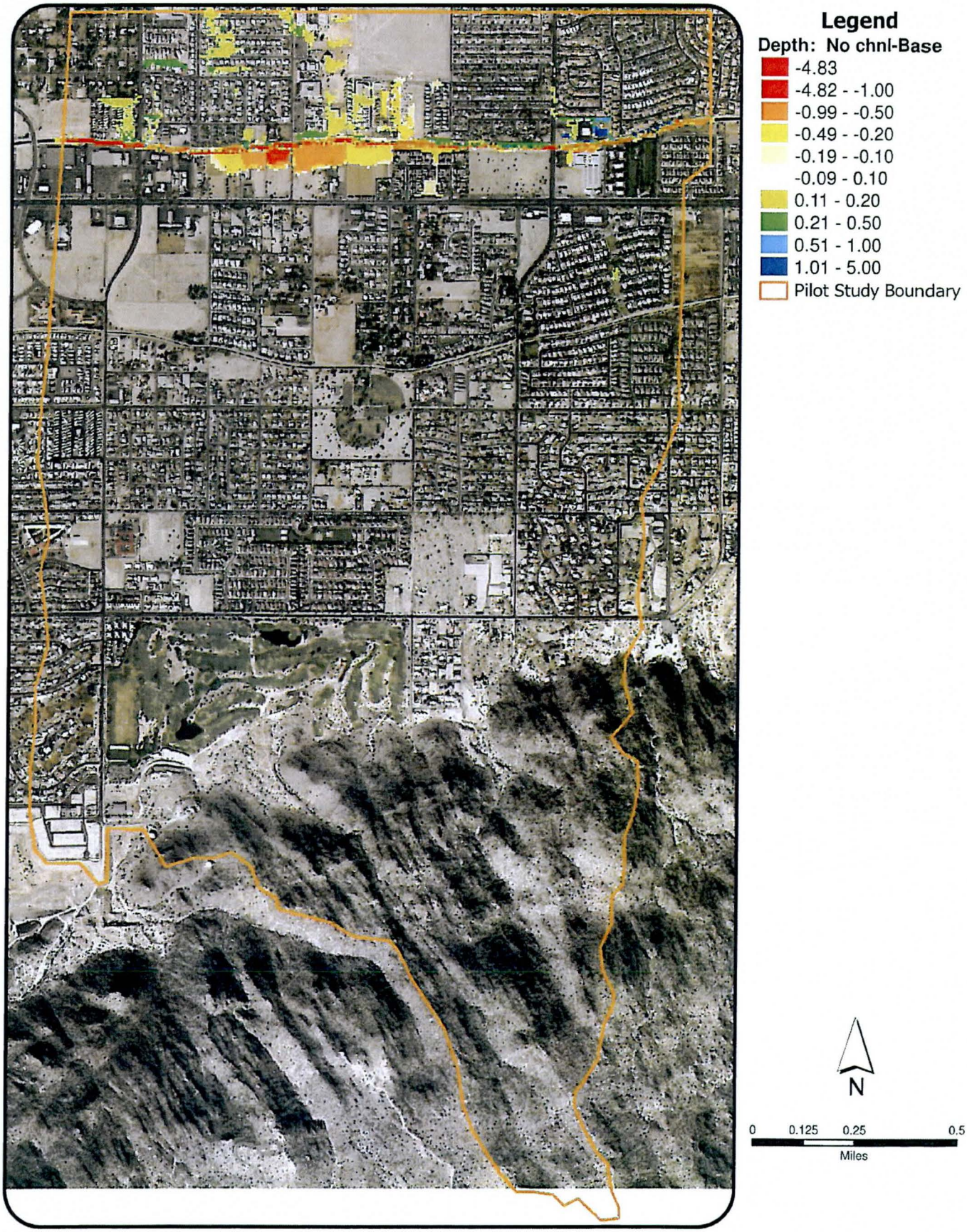
N

0 0.125 0.25 0.5

Miles

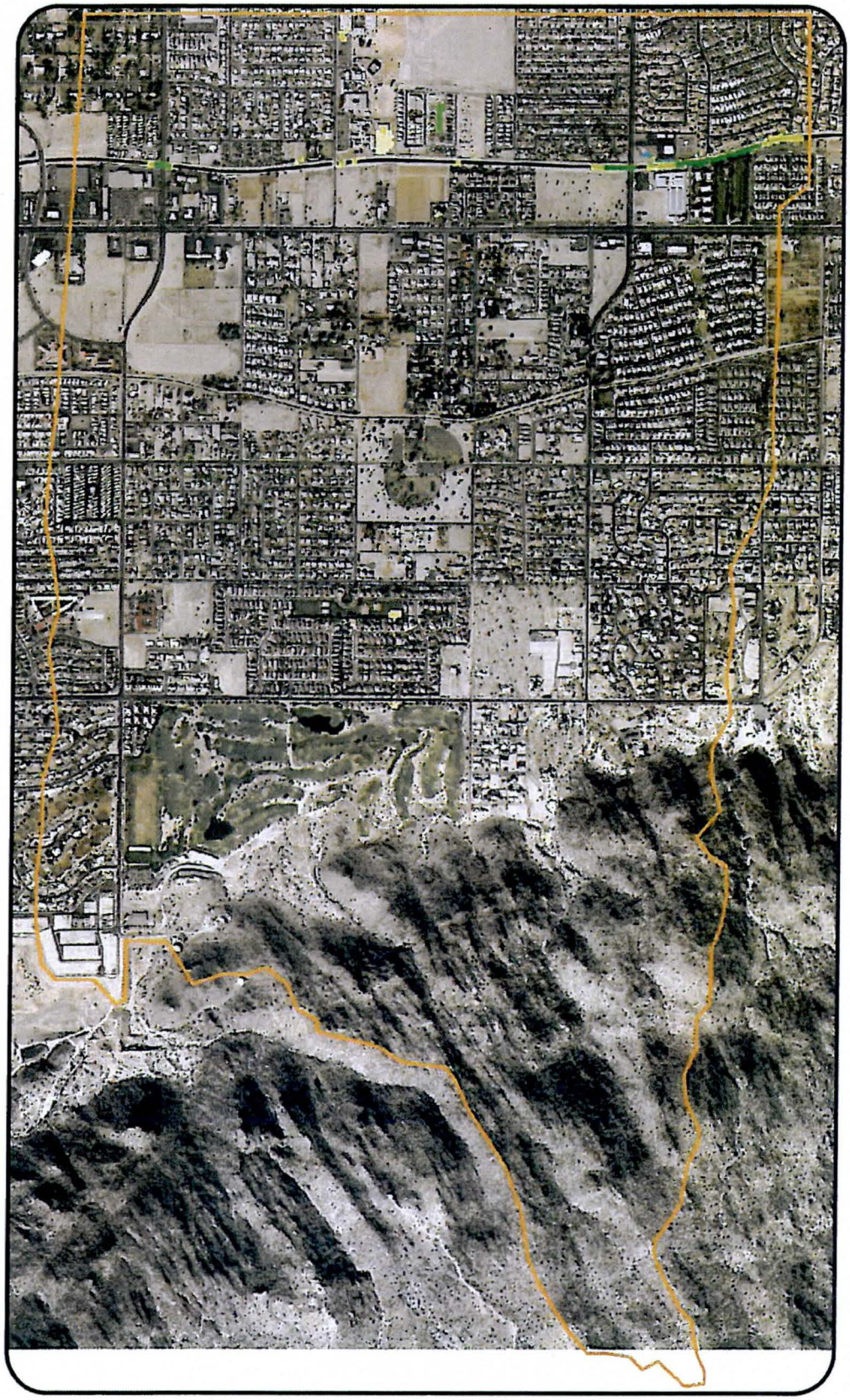
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 4: No CHAN.DAT - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 5A: WAVEMAX (0.25) - Base



Legend

Depth: 0.25-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

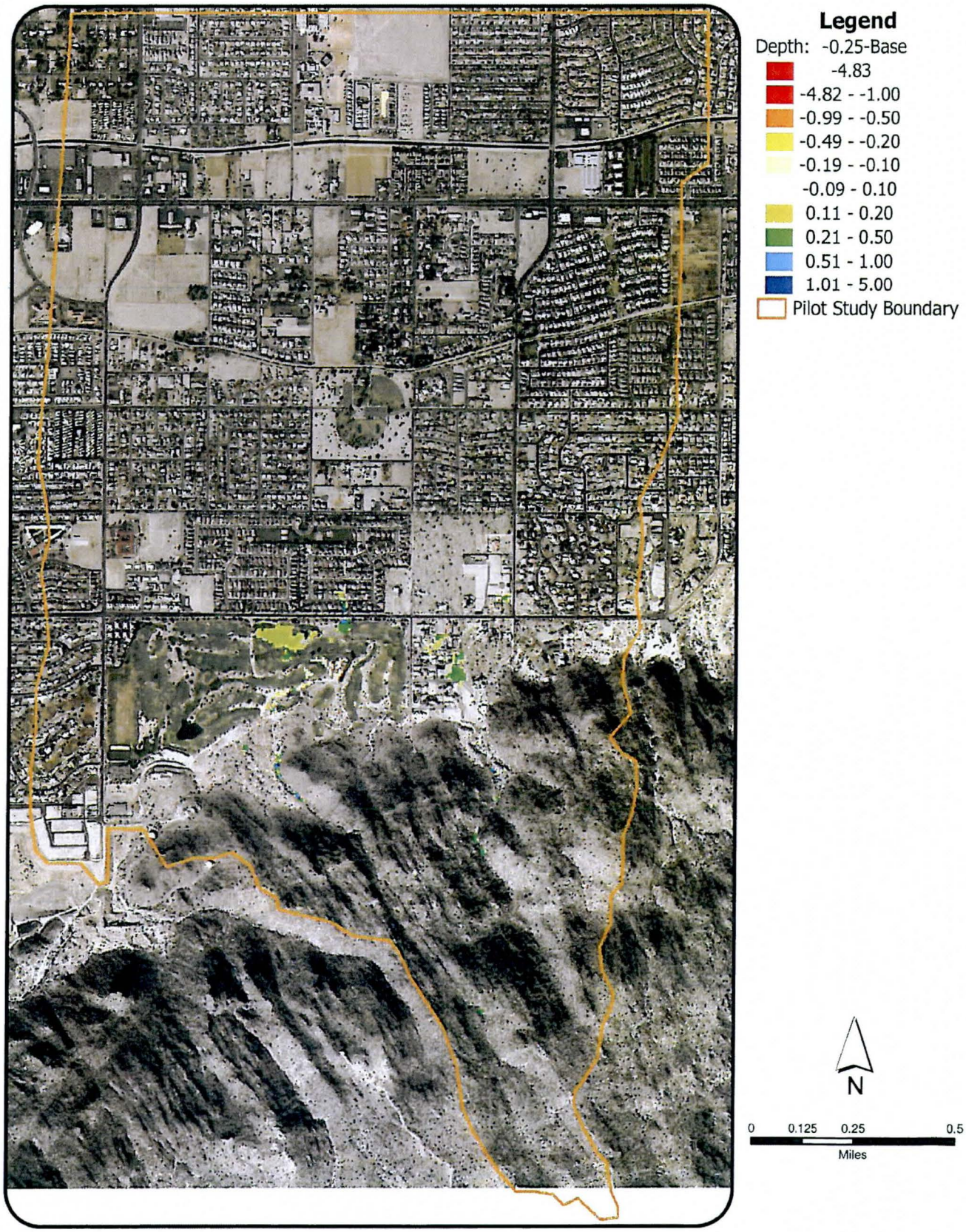
N

0 0.125 0.25 0.5

Miles

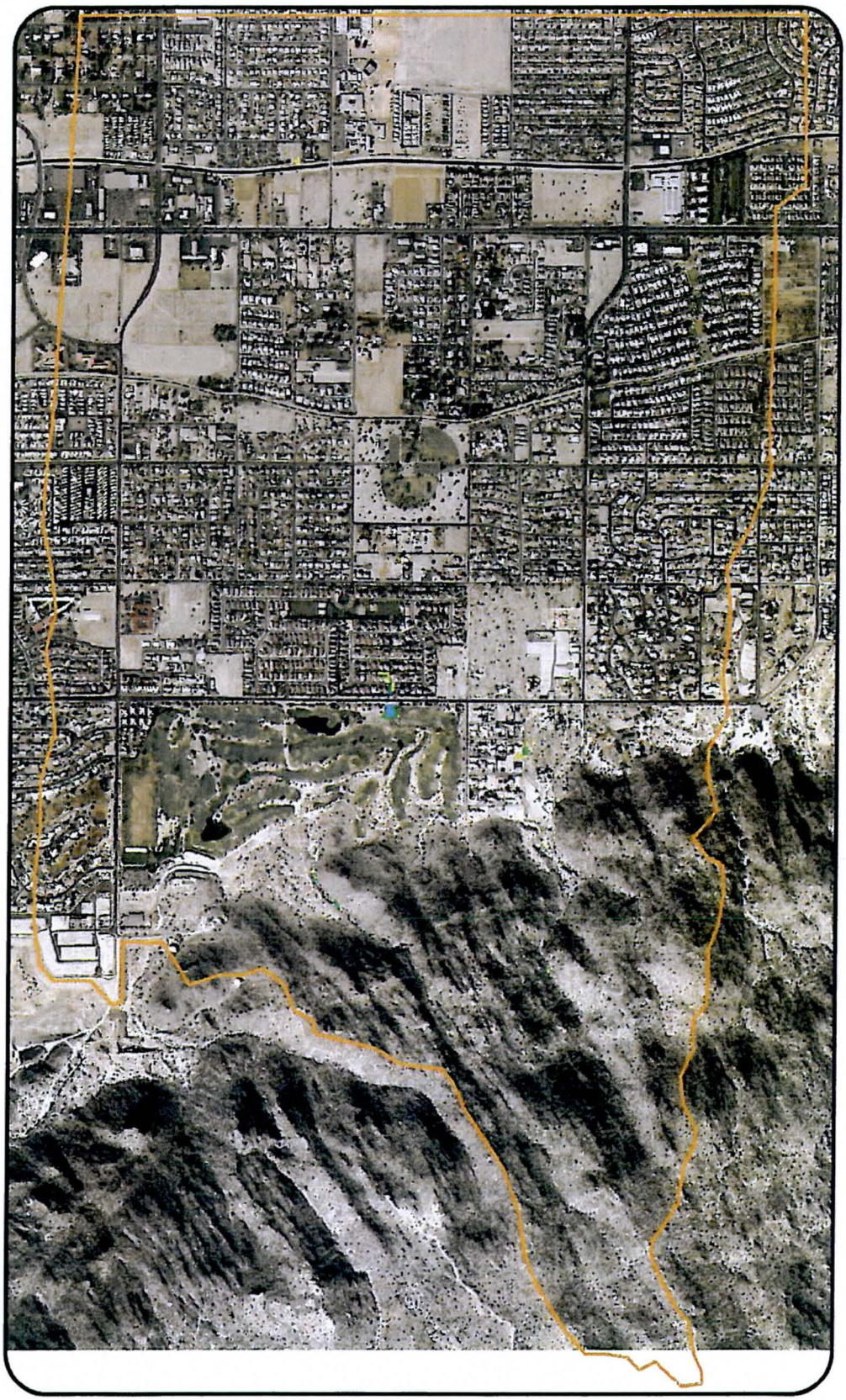
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 5B: WAVEMAX (-0.25) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 5C: WAVEMAX (-1.00) - Base



Legend

Depth: -1.00-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

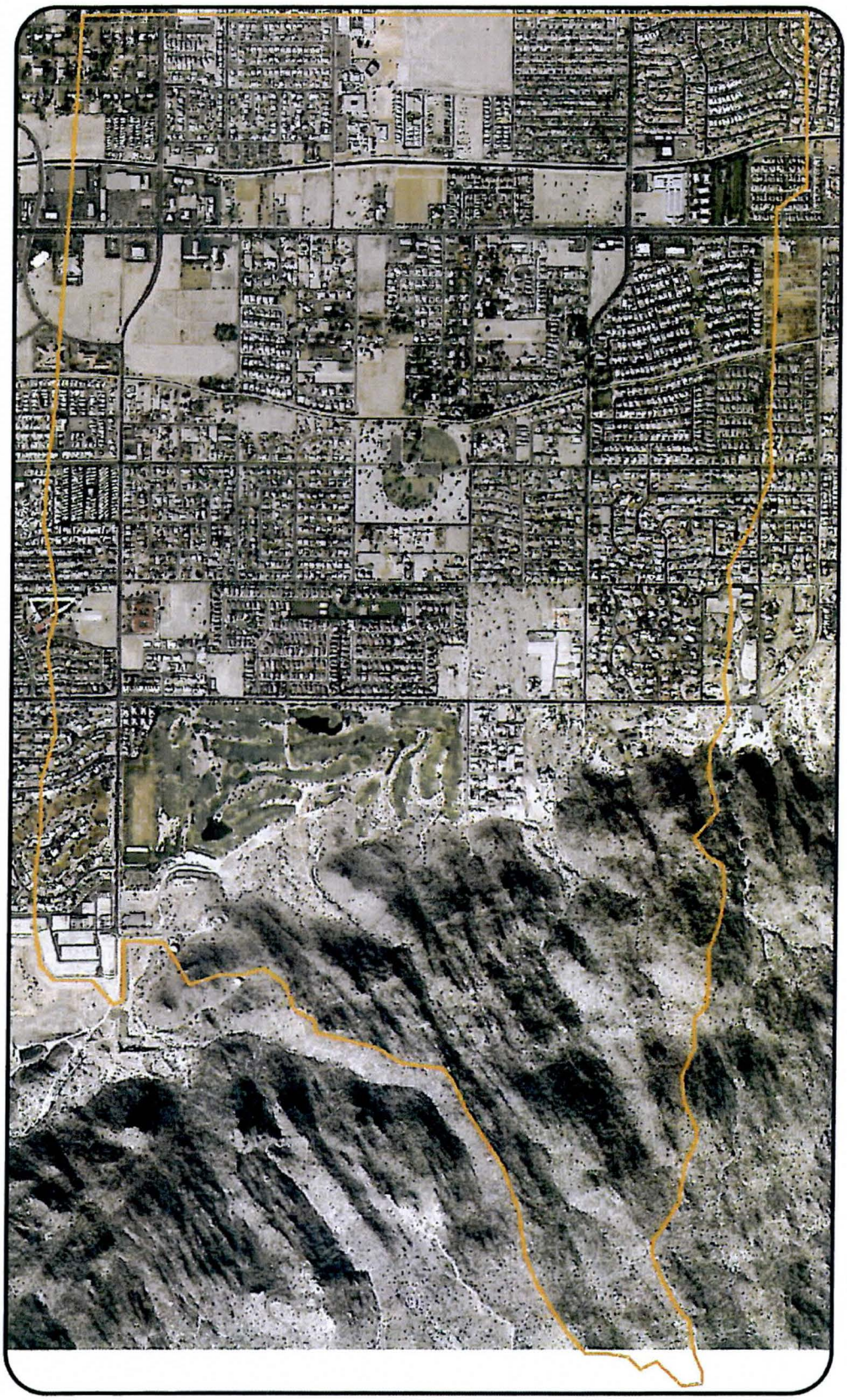
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 5D: WAVEMAX (101) - Base



Legend

Depth: 101-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

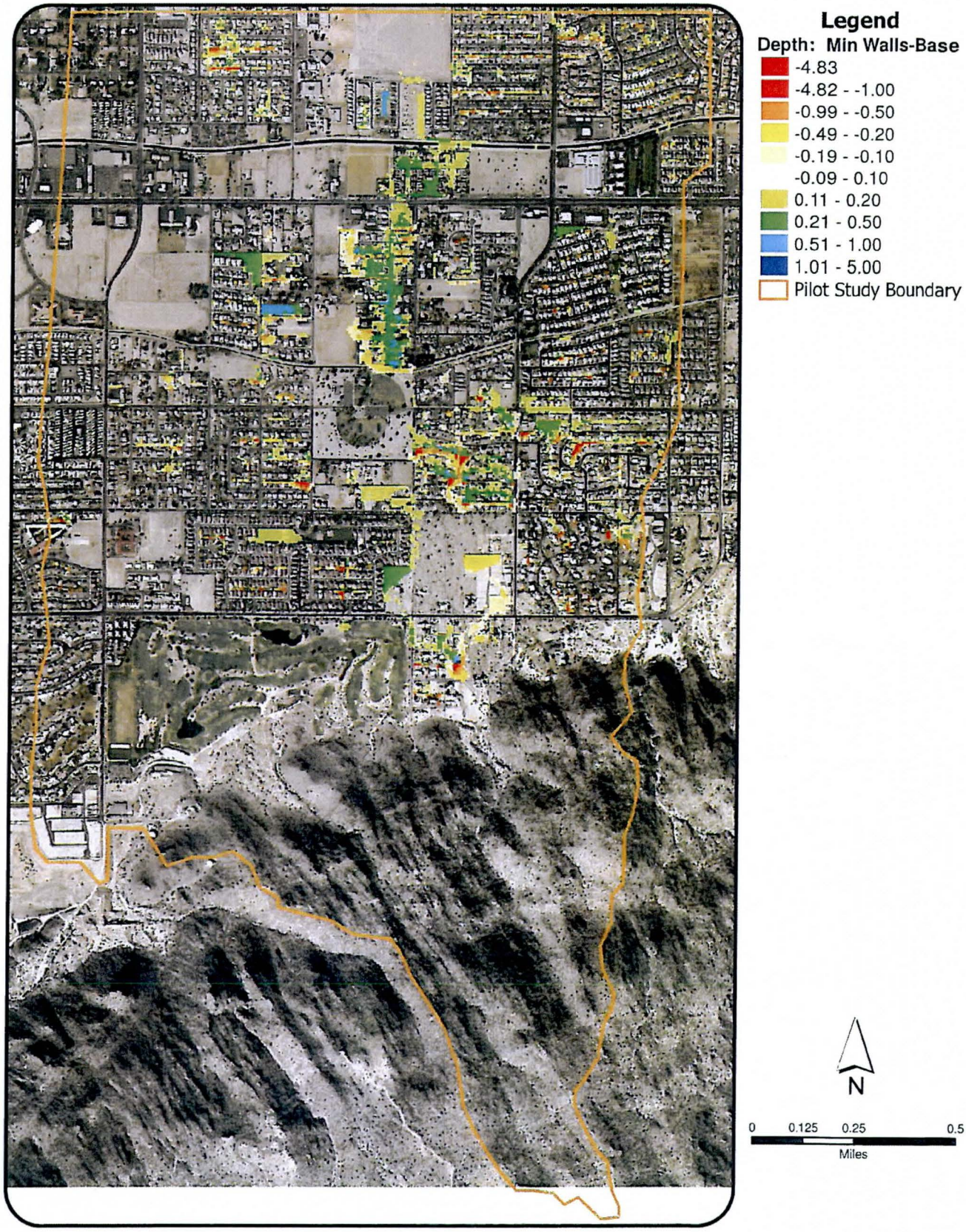
N

0 0.125 0.25 0.5

Miles

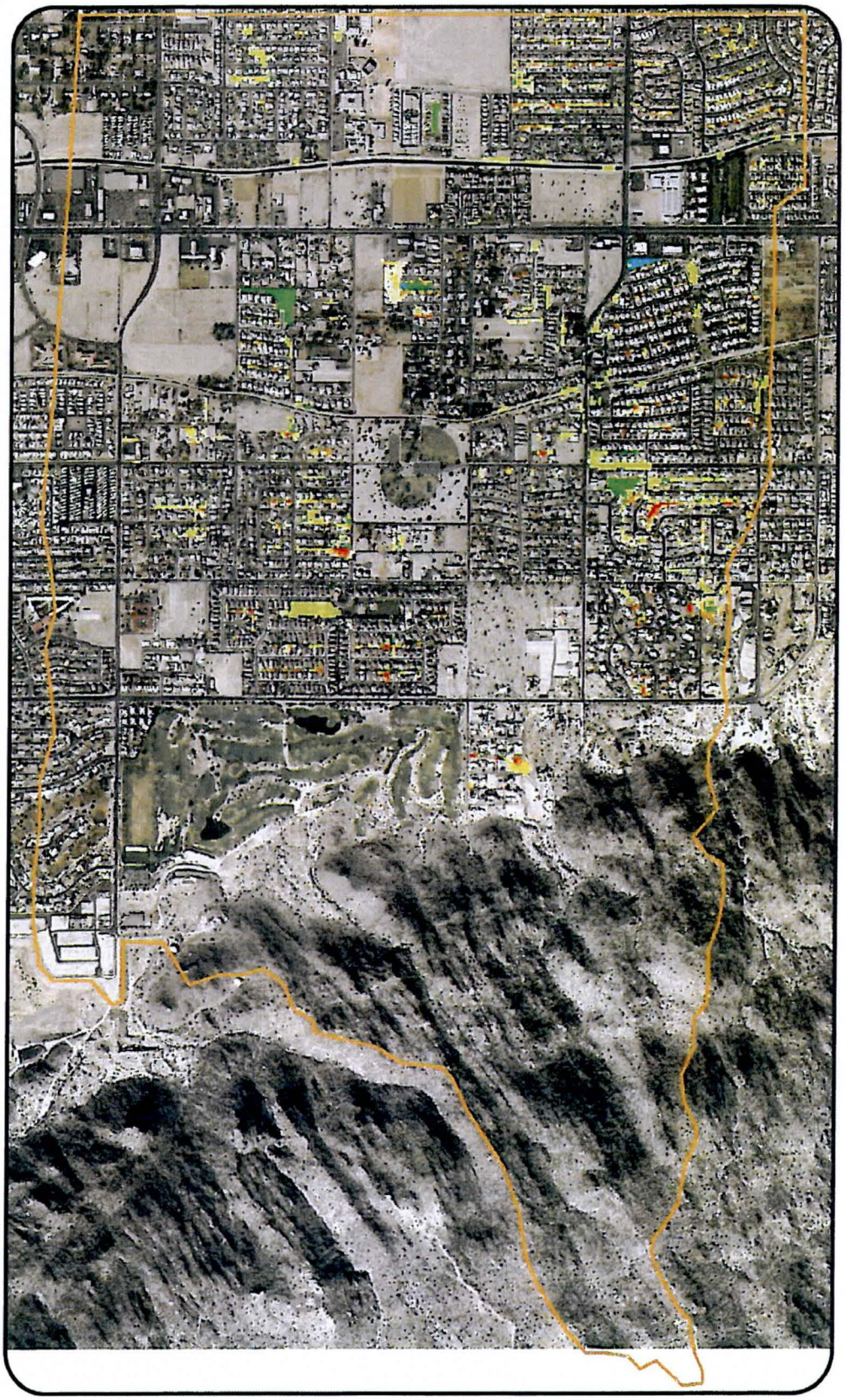
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 6A: Walls (Min. Detail) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 6B: Walls (Mod. Detail) - Base



Legend

Depth: Moderate Wall-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

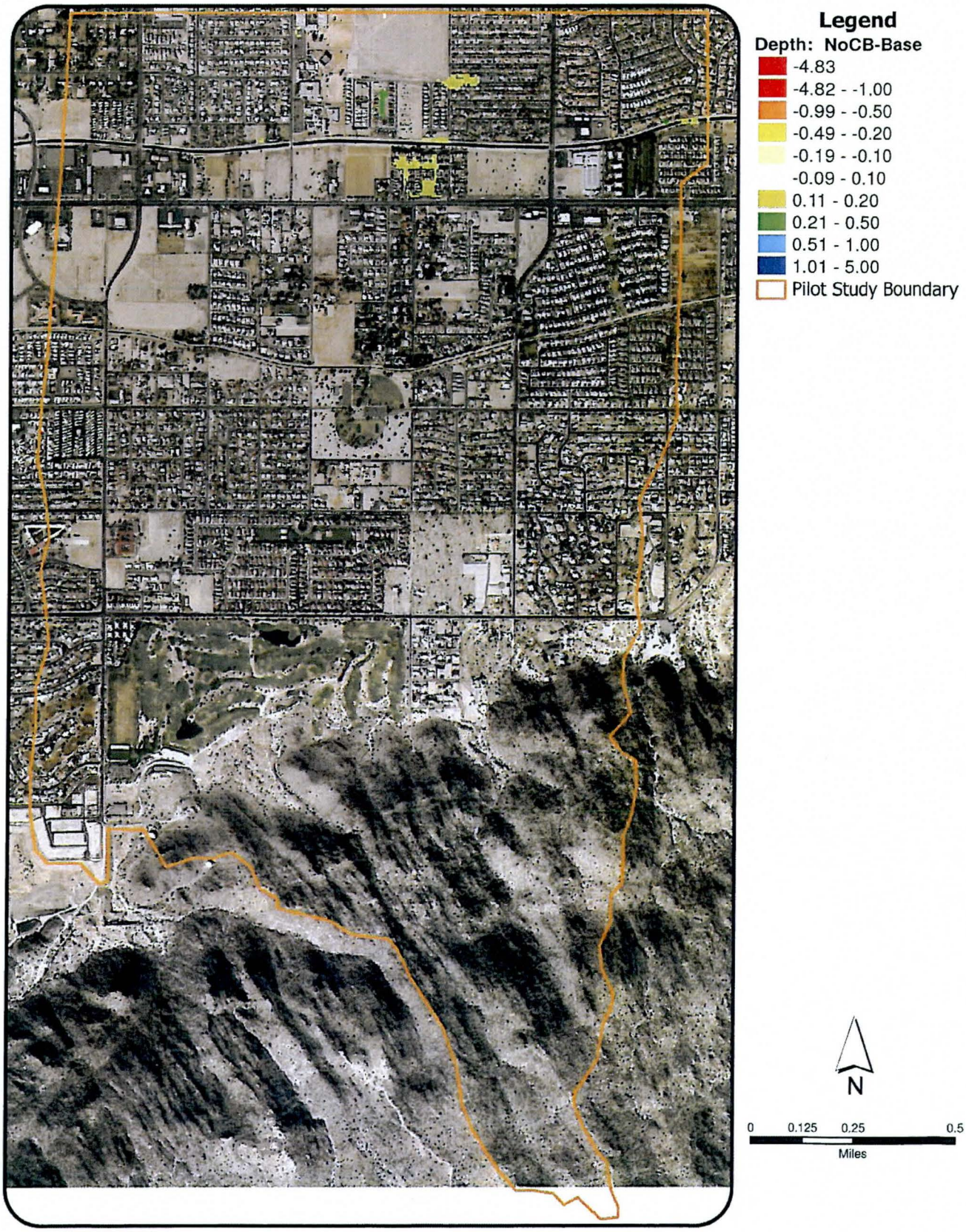
N

0 0.125 0.25 0.5

Miles

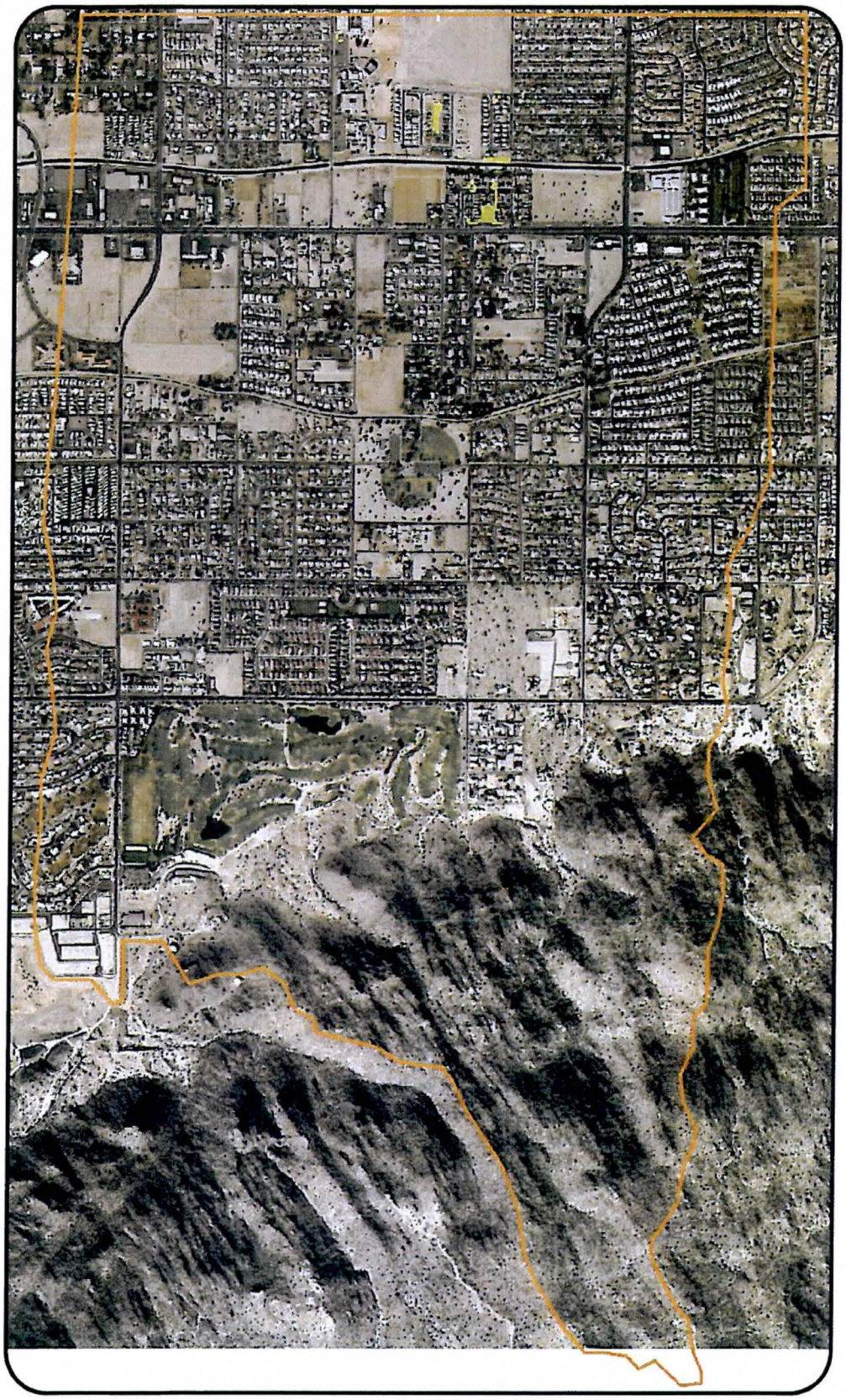
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 7A: Catch Basins (None) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 7B: Catch Basins (1) - Base



Legend

Depth: 1 CB-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

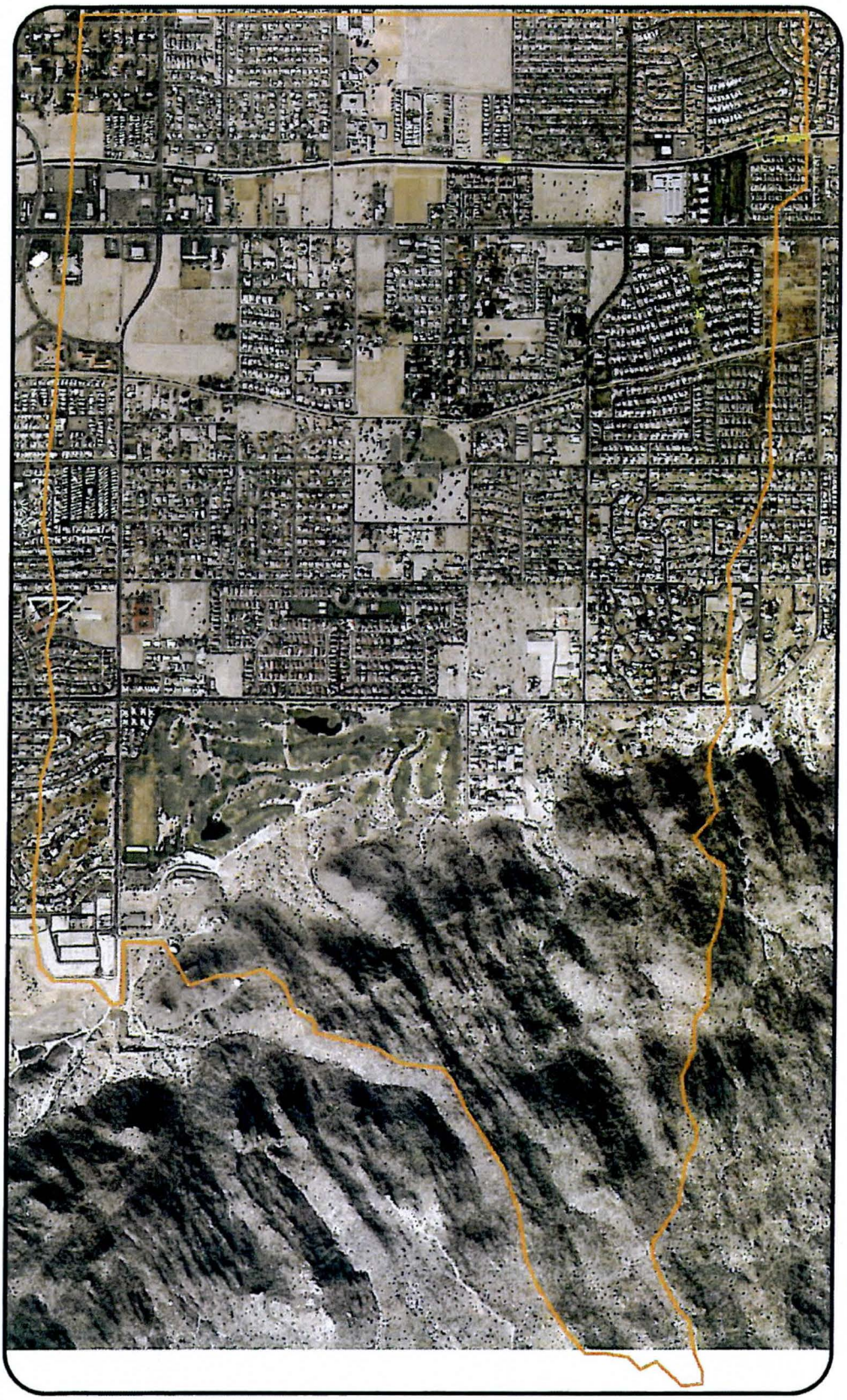
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 7C: Catch Basins (3) - Base



Legend

Depth: 3 CBs-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

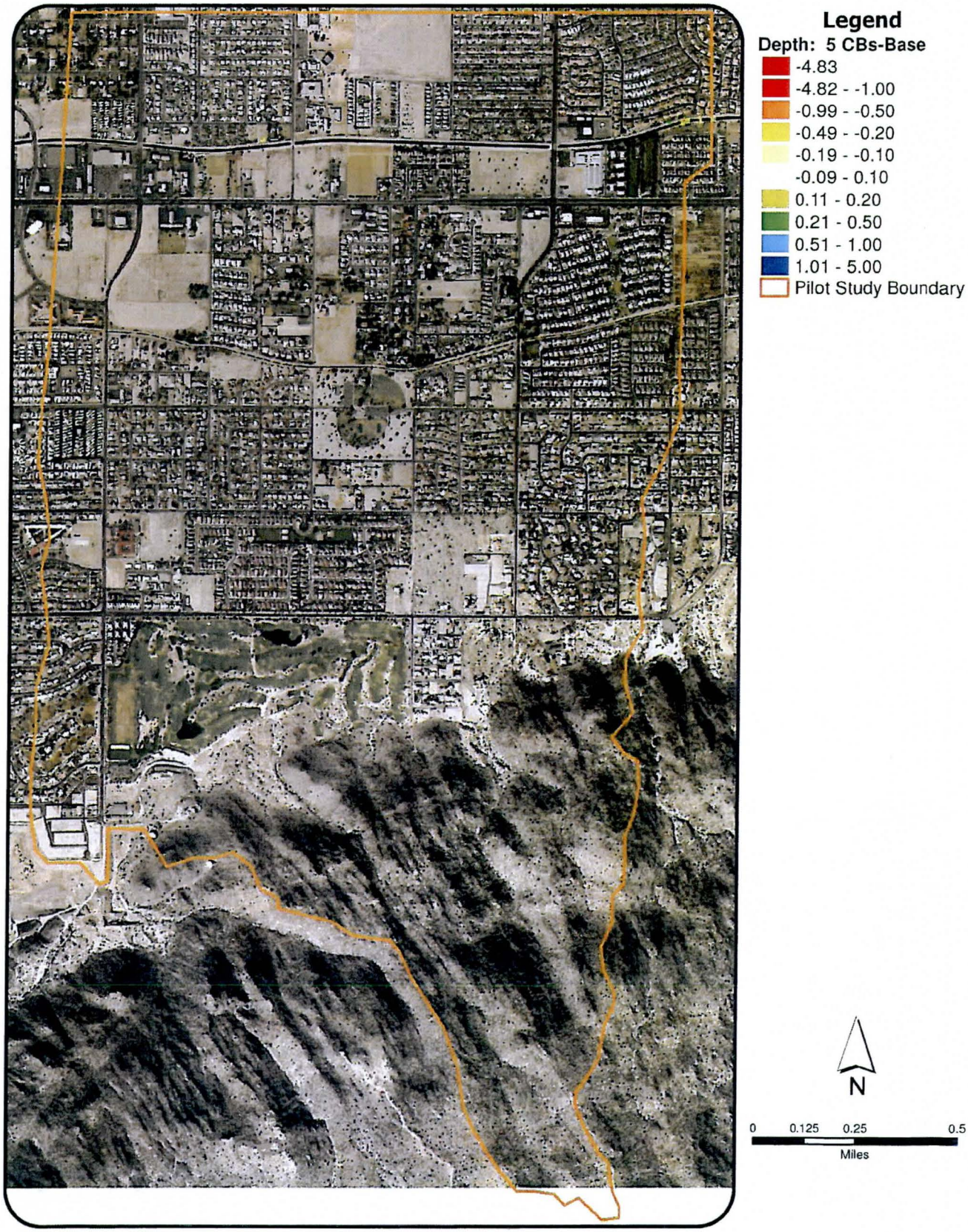
N

0 0.125 0.25 0.5

Miles

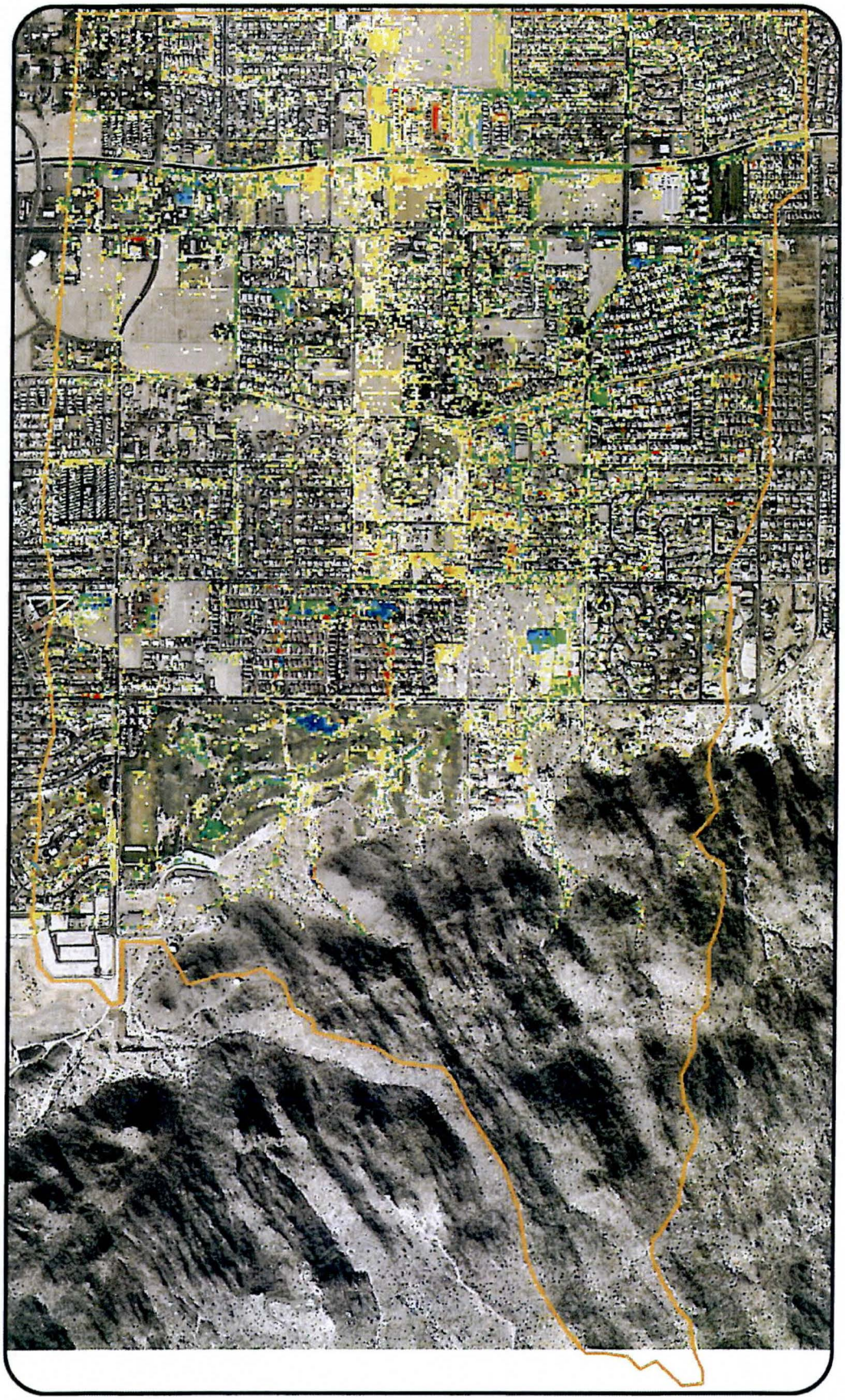
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 7D: Catch Basins (5) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 8: Revised FPLAIN.DAT - Base



Legend

Depth: FP2-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

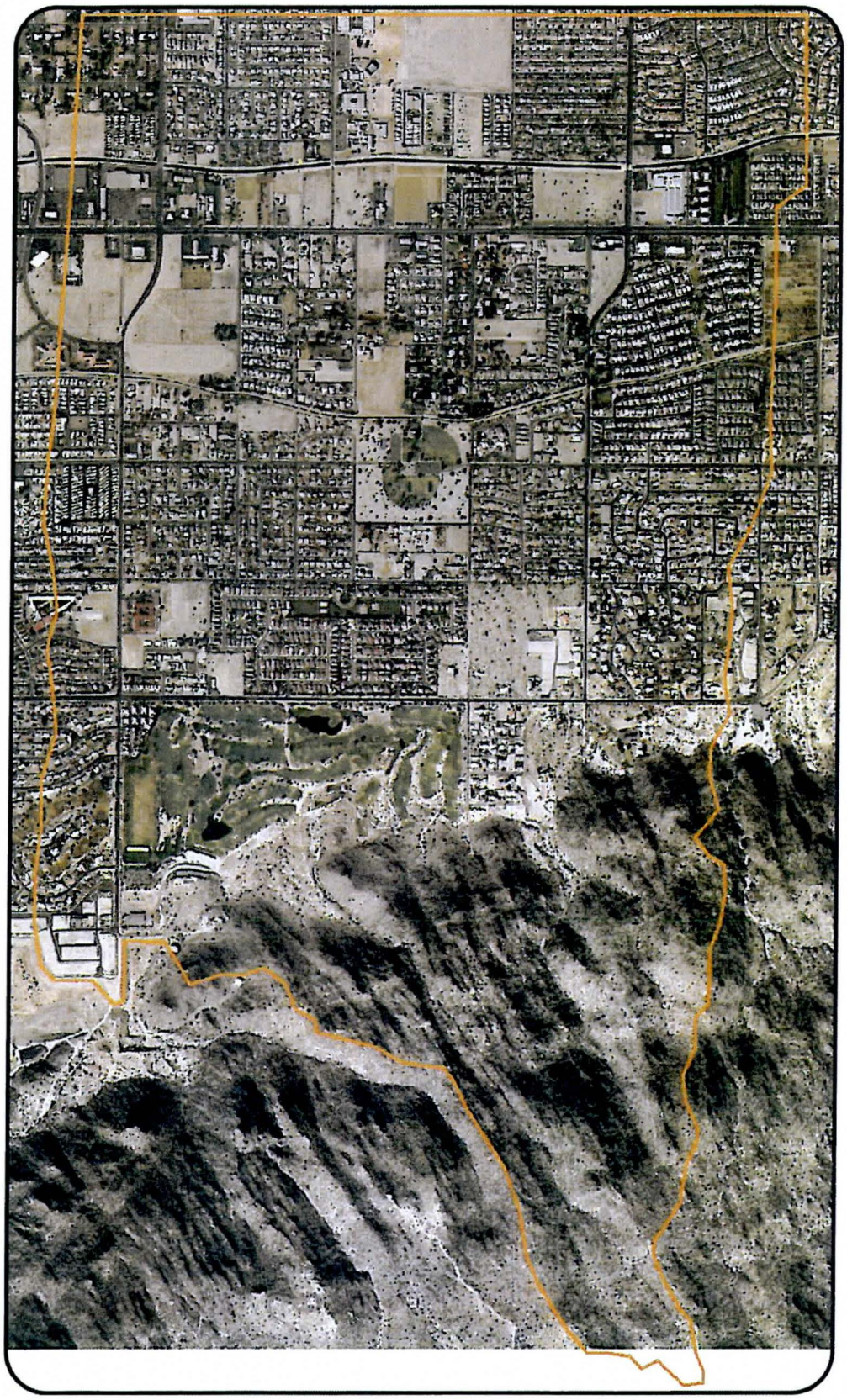
N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 9A: FROUDL (0.95) - Base



Legend

Depth: 0.95-Base

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

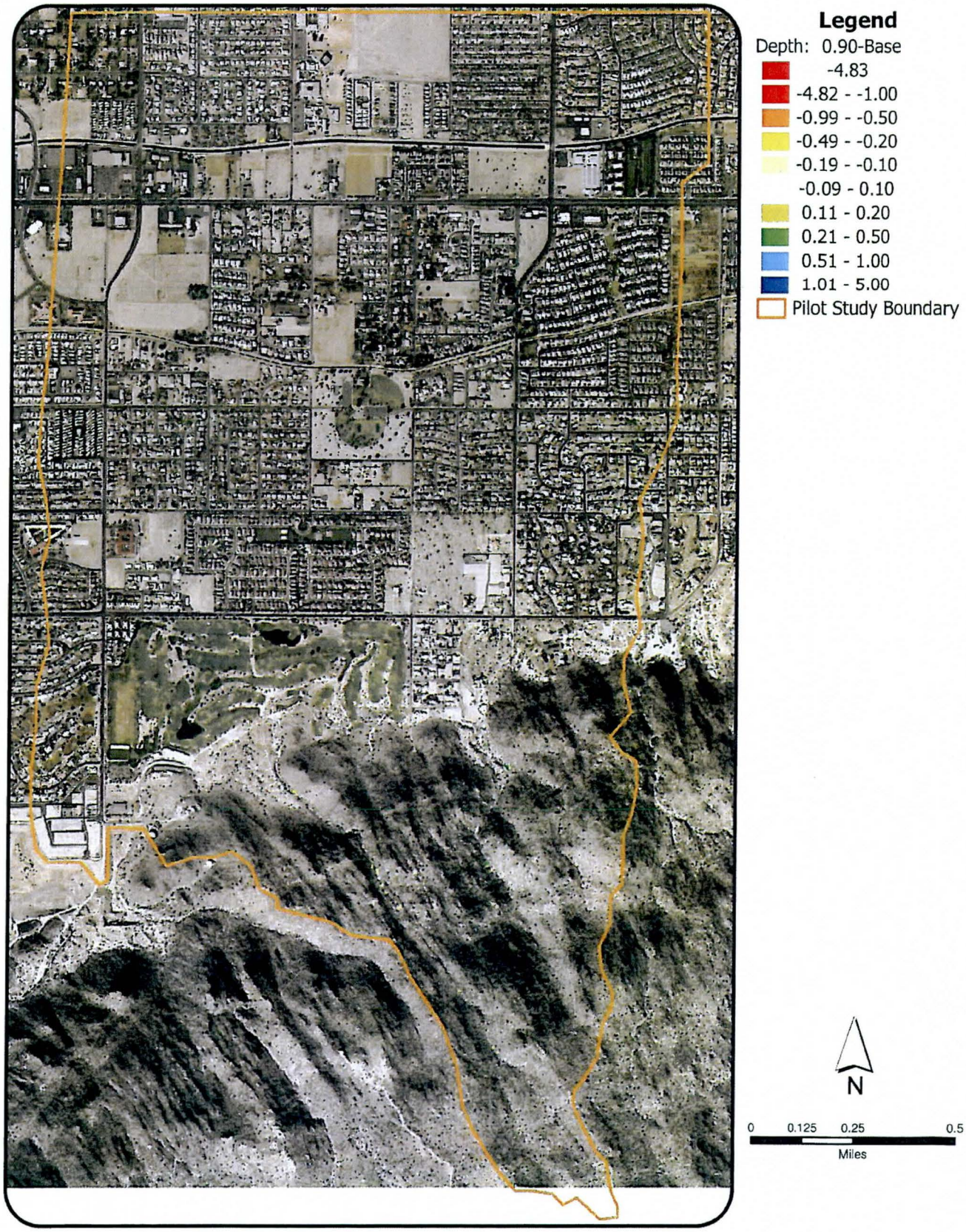
N

0 0.125 0.25 0.5

Miles

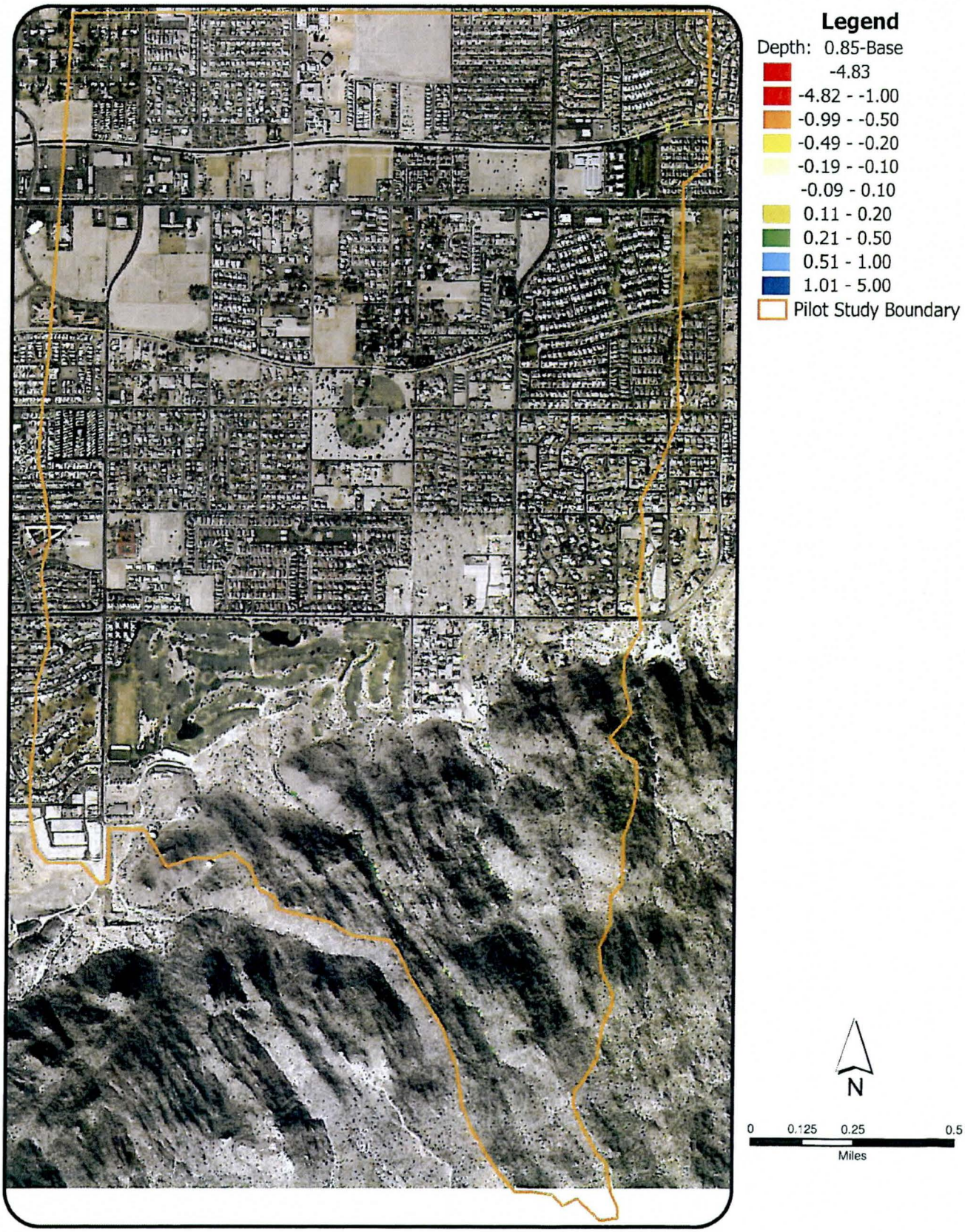
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 9B: FROUDL (0.90) - Base



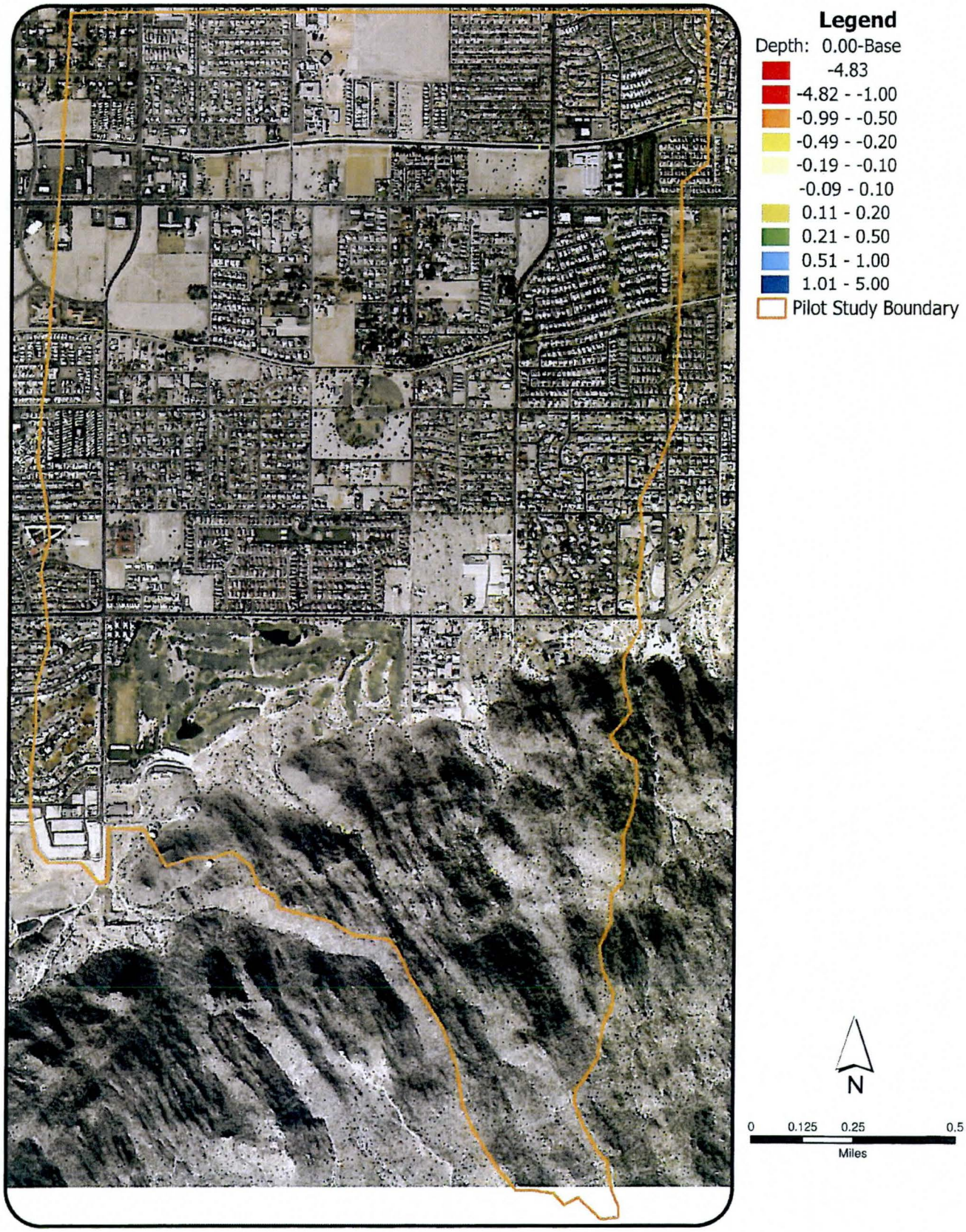
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 9C: FROUDL (0.85) - Base



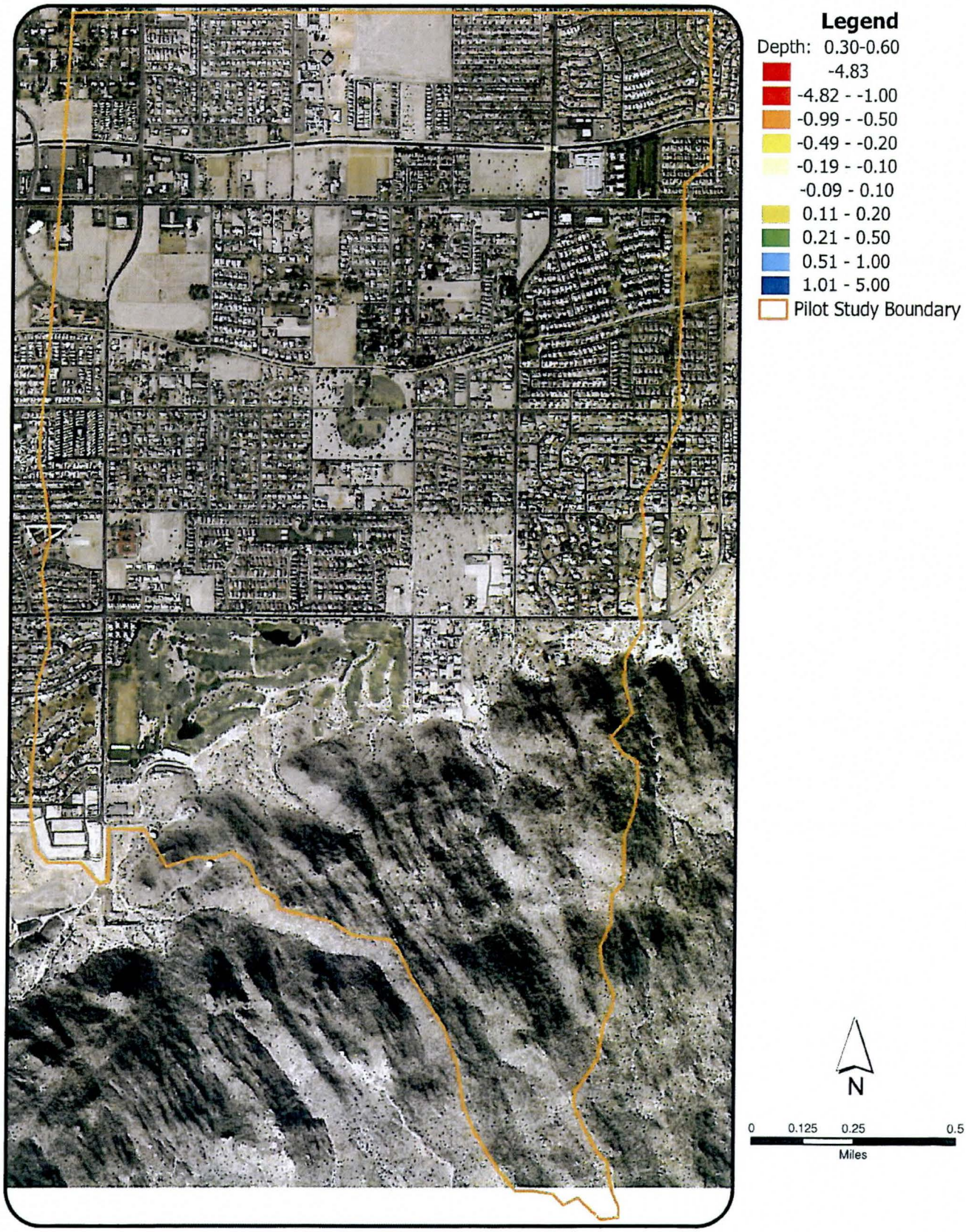
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 9D: FROUDL (0.00) - Base



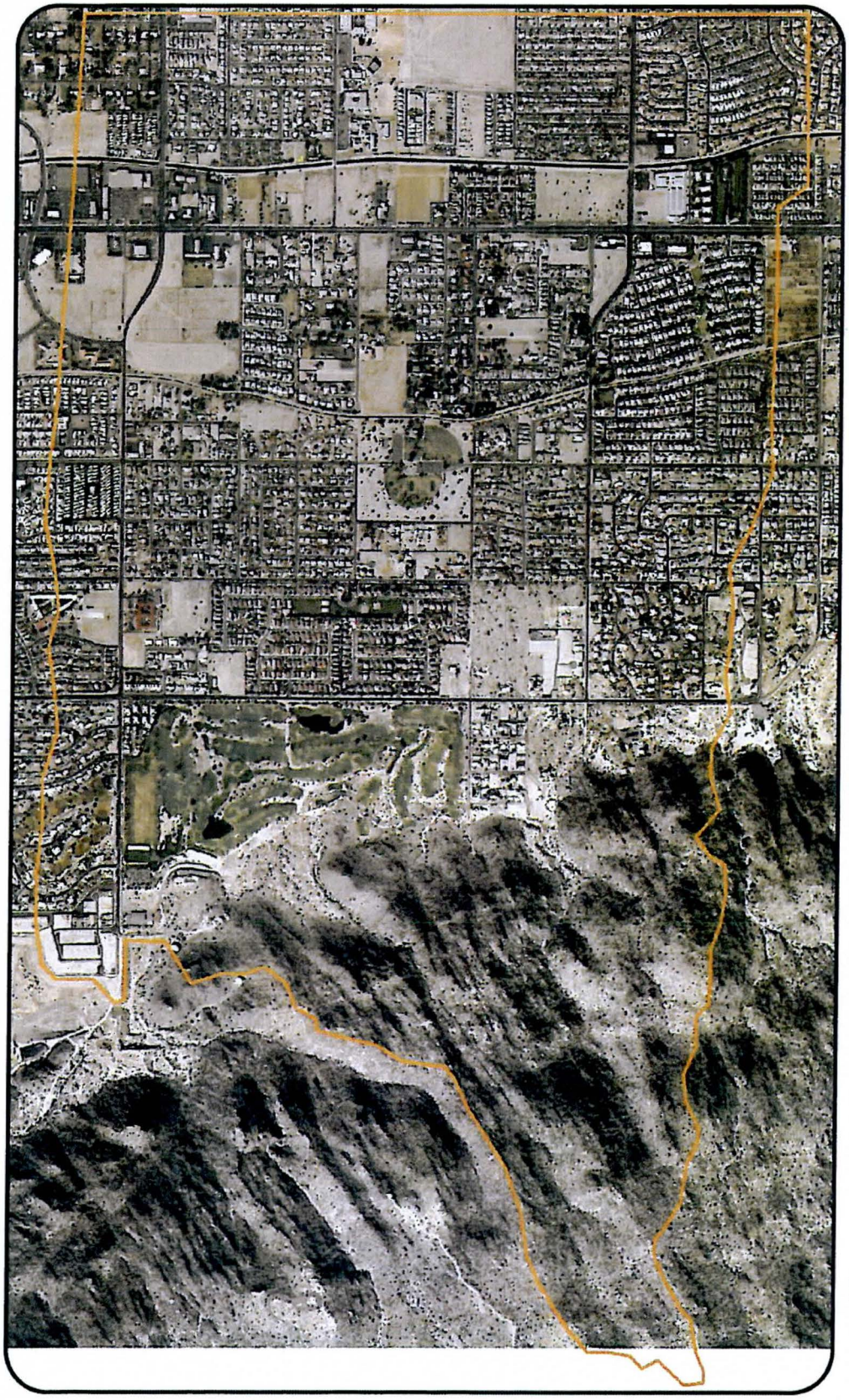
Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 10A: Courant (0.30) - Base



Hohokam Area Drainage Master Study

Sensitivity Analysis: Difference in Flow Depths
Exhibit 10B: Courant (1.00) - Base



Legend

Depth: 1.00-0.60

- -4.83
- -4.82 - -1.00
- -0.99 - -0.50
- -0.49 - -0.20
- -0.19 - -0.10
- -0.09 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 5.00
- Pilot Study Boundary

N

0 0.125 0.25 0.5

Miles

FLO-2D Parameter Sensitivity Analysis (Changes to HYSTRUC, CHAN.DAT & FPLAIN.DAT)

Cross Section	Location	Peak Q Base (Q_{Base}) (cfs)	Fewer Culverts[1] Peak Q (cfs)	Fewer Culverts[1] ΔQ ($Q-Q_{Base}$) (cfs)	Fewer Culverts[1] ΔQ/(Q_{Base}) (%)	No CHAN.DAT for Western Canal[2] Peak Q (cfs)	No CHAN.DAT for Western Canal[2] ΔQ ($Q-Q_{Base}$) (cfs)	No CHAN.DAT for Western Canal[2] ΔQ/(Q_{Base}) (%)	Revised FPLAIN.DAT[3] Peak Q (cfs)	Revised FPLAIN.DAT[3] ΔQ ($Q-Q_{Base}$) (cfs)	Revised FPLAIN.DAT[3] ΔQ/(Q_{Base}) (%)	DEPTOL = 0.1[4] Peak Q (cfs)	DEPTOL = 0.1[4] ΔQ ($Q-Q_{Base}$) (cfs)	DEPTOL = 0.1[4] ΔQ/(Q_{Base}) (%)
	Run Time (hours)	2.6	2.1			2.4			2.8			2.8		
1	7th St N of Western Canal	0.9	0.9	0.0	0.0%	23.3	22.4	2457.1%	1.0	0.1	13.2%	0.9	0.0	0.0%
2	7th St S of Western Canal	38.6	39.1	0.6	1.5%	37.1	-1.4	-3.7%	42.7	4.1	10.7%	38.5	0.0	-0.1%
3	7th St & Baseline (N of)	28.5	28.3	-0.2	-0.8%	28.4	-0.1	-0.3%	28.6	0.1	0.3%	28.7	0.2	0.6%
4	12th Pl N of Western Canal	95.0	91.1	-3.8	-4.1%	140.1	45.1	47.5%	65.9	-29.1	-30.6%	96.3	1.4	1.4%
5	13th Way N of Western Canal	108.1	110.4	2.3	2.1%	36.2	-71.8	-66.5%	139.3	31.3	28.9%	114.8	6.7	6.2%
6	14th St N of Western Canal	102.4	106.5	4.1	4.0%	111.6	9.2	9.0%	168.5	66.2	64.6%	104.5	2.1	2.1%
7	16th St N of Western Canal	1.6	1.6	0.0	0.0%	12.6	10.9	666.5%	1.5	-0.1	-8.5%	1.6	0.0	0.0%
8	17th St N of Western Canal	1.2	1.5	0.4	30.4%	2.1	0.9	81.7%	1.0	-0.2	-14.8%	1.2	0.0	0.0%
9	18th St n of Western Canal	0.9	0.9	0.0	0.0%	1.9	1.0	116.1%	3.2	2.4	271.3%	0.9	0.0	0.0%
10	Baseline (12th St to 15th St)	551.9	508.1	-43.8	-7.9%	551.6	-0.4	-0.1%	497.4	-54.5	-9.9%	553.4	1.5	0.3%
11	Beverly (12th St to 14th St)	571.1	535.3	-35.8	-6.3%	571.5	0.4	0.1%	488.0	-83.1	-14.5%	573.0	1.9	0.3%
12	14th St N of Circle K Park	246.8	245.0	-1.8	-0.7%	246.7	-0.1	-0.1%	222.4	-24.4	-9.9%	247.9	1.1	0.4%
13	Circle K Park (S. Mountain Ave)	527.6	518.8	-8.8	-1.7%	527.3	-0.3	-0.1%	401.7	-125.9	-23.9%	527.9	0.3	0.1%
14	12th St & Euclid (DB West outfall)	0.4	35.8	35.4	10120.0%	0.4	0.0	0.0%	0.2	-0.1	-34.3%	0.4	0.0	0.0%
15	~13th St & Euclid (DB East outfall)	314.2	317.5	3.3	1.1%	315.4	1.2	0.4%	297.6	-16.6	-5.3%	314.5	0.3	0.1%
16	Dobbins & golf course (West)	20.7	20.0	-0.7	-3.3%	20.7	0.0	-0.1%	22.5	1.8	8.5%	20.7	0.0	0.1%
17	Dobbins & golf course (East)	29.3	4.6	-24.6	-84.2%	41.6	12.3	42.1%	24.2	-5.0	-17.1%	26.7	-2.5	-8.6%
18	S of golf course (West)	119.5	119.5	0.0	0.0%	119.6	0.1	0.1%	117.1	-2.4	-2.0%	119.5	-0.1	-0.1%
19	S of golf course (East)	220.5	220.5	0.0	0.0%	220.4	0.0	0.0%	220.2	-0.3	-0.1%	220.4	0.0	0.0%
20	16th St N of Baseline	9.9	9.8	-0.2	-1.6%	9.9	0.0	0.1%	15.6	5.7	57.2%	9.9	-0.1	-0.6%
21	~16th St & Beautiful Ln	30.9	24.4	-6.6	-21.2%	30.7	-0.2	-0.7%	49.1	18.1	58.6%	31.7	0.7	2.4%
22	~16th St & Harwell	9.9	8.7	-1.3	-12.9%	10.0	0.0	0.2%	20.1	10.1	102.1%	9.9	0.0	-0.3%
23	16th St N of Highline Canal	41.8	33.6	-8.2	-19.7%	41.8	0.0	0.0%	62.4	20.5	49.1%	41.6	-0.3	-0.6%
24	16th St S of Highline Canal	44.0	38.1	-6.0	-13.5%	44.4	0.4	0.9%	59.7	15.6	35.5%	43.8	-0.2	-0.5%
25	N of S. Mtn ((15th St to 16th St)	130.9	113.7	-17.3	-13.2%	130.1	-0.8	-0.6%	160.9	30.0	22.9%	130.2	-0.8	-0.6%
26	16th St S of Winston	87.7	73.7	-14.0	-16.0%	87.8	0.0	0.0%	124.1	36.4	41.5%	87.9	0.1	0.2%
27	14th St & Euclid	99.1	96.9	-2.2	-2.2%	98.7	-0.4	-0.4%	96.8	-2.3	-2.4%	98.4	-0.7	-0.7%
28	15th St & Euclid	249.7	258.3	8.6	3.4%	249.6	-0.1	0.0%	251.2	1.5	0.6%	247.3	-2.3	-0.9%
29	16th St & Euclid	137.6	136.0	-1.7	-1.2%	137.2	-0.5	-0.3%	154.2	16.6	12.1%	137.6	0.0	0.0%
30	Field W of MVE Subdivision	183.9	182.7	-1.2	-0.7%	183.4	-0.5	-0.3%	133.0	-50.9	-27.7%	185.1	1.2	0.7%
31	Dobbins (15th St to 17th Pl)	512.7	513.4	0.6	0.1%	518.0	5.3	1.0%	526.2	13.5	2.6%	515.2	2.5	0.5%
32	16th St S of Dobbins	130.1	130.2	0.1	0.0%	129.9	-0.2	-0.1%	131.0	0.8	0.7%	130.3	0.2	0.2%
33	15th St S of Dobbins (wash)	446.6	446.1	-0.5	-0.1%	449.9	3.3	0.7%	445.1	-1.5	-0.3%	448.9	2.3	0.5%

1. *Roadway culverts in subdivisions removed and conveyance instread modeled by lowering grid floodplain elevations to provide conveyance.*
2. *CHAN.DAT for Western Canal turned off. Canal presence simply reflected in grid floodplain elevations.*
3. *Revised approach used to set floodplain elevations. Approach rasterized TINs to produce a 5'x5' uniformly spaced grid of points that then used GDS to set elevations. Base approach utilized breakline vertex points and mass points in the GDS.*
4. *DEPTOL not an initial sensitivity parameter and simulated after the sensitivity analyses. The simulation was performed because the project SOW specifies a DEPTOL<=0.10. All sensitivity analyses unintentionally used DEPTOL=0.25.*

FLO-2D Parameter Sensitivity Analysis (Block Wall Modeling Detail)

Cross Section	Location	Peak Q Base (Q_{Base}) (most detail) (cfs)	No Block Walls			Minimum Block Walls			Moderate Block Walls			Range of Values		
			Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Minimum	Maximum	Spread
	Run Time (hours)	2.6	1.5			2.2			2.5					
1	7th St N of Western Canal	0.9	7.9	7.0	768.1%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	8	7
2	7th St S of Western Canal	38.6	43.6	5.0	12.9%	39.1	0.5	1.3%	38.9	0.3	0.8%	39	44	5
3	7th St & Baseline (N of)	28.5	27.2	-1.3	-4.6%	28.9	0.4	1.4%	28.9	0.5	1.6%	27	29	2
4	12th Pl N of Western Canal	95.0	45.7	-49.3	-51.9%	98.5	3.5	3.7%	98.2	3.2	3.4%	46	98	53
5	13th Way N of Western Canal	108.1	118.5	10.4	9.6%	118.9	10.8	10.0%	117.3	9.3	8.6%	108	119	11
6	14th St N of Western Canal	102.4	86.4	-16.0	-15.6%	138.2	35.8	35.0%	120.1	17.7	17.3%	86	138	52
7	16th St N of Western Canal	1.6	1.5	-0.2	-10.4%	1.6	0.0	0.0%	1.6	0.0	0.0%	1	2	0
8	17th St N of Western Canal	1.2	1.4	0.2	20.9%	1.2	0.0	0.0%	1.2	0.0	0.0%	1	1	0
9	18th St n of Western Canal	0.9	0.9	0.0	-2.3%	0.9	0.0	1.1%	0.9	0.0	0.0%	1	1	0
10	Baseline (12th St to 15th St)	551.9	673.1	121.2	22.0%	583.9	32.0	5.8%	573.8	21.9	4.0%	552	673	121
11	Beverly (12th St to 14th St)	571.1	650.2	79.1	13.8%	589.3	18.2	3.2%	579.4	8.3	1.5%	571	650	79
12	14th St N of Circle K Park	246.8	340.0	93.2	37.8%	333.2	86.4	35.0%	252.5	5.6	2.3%	247	340	93
13	Circle K Park (S. Mountain Ave)	527.6	645.8	118.2	22.4%	561.1	33.5	6.4%	529.9	2.3	0.4%	528	646	118
14	12th St & Euclid (DB West outfall)	0.4	0.6	0.2	57.1%	0.4	0.0	0.0%	0.4	0.0	0.0%	0	1	0
15	~13th St & Euclid (DB East outfall)	314.2	395.6	81.4	25.9%	320.6	6.4	2.0%	319.0	4.8	1.5%	314	396	81
16	Dobbins & golf course (West)	20.7	18.2	-2.5	-11.9%	20.6	-0.1	-0.4%	20.7	0.0	0.1%	18	21	2
17	Dobbins & golf course (East)	29.3	12.4	-16.9	-57.7%	34.0	4.7	16.1%	29.1	-0.2	-0.7%	12	34	22
18	S of golf course (West)	119.5	119.5	0.0	0.0%	119.5	0.0	0.0%	119.4	-0.1	-0.1%	119	120	0
19	S of golf course (East)	220.5	220.2	-0.3	-0.1%	220.1	-0.4	-0.2%	220.7	0.2	0.1%	220	221	1
20	16th St N of Baseline	9.9	24.5	14.6	147.1%	10.8	0.9	8.7%	13.6	3.7	36.9%	10	25	15
21	~16th St & Beautiful Ln	30.9	83.9	52.9	171.2%	36.9	6.0	19.4%	46.2	15.3	49.5%	31	84	53
22	~16th St & Harwell	9.9	14.5	4.6	46.3%	10.4	0.4	4.2%	13.2	3.2	32.4%	10	15	5
23	16th St N of Highline Canal	41.8	8.1	-33.7	-80.6%	44.6	2.8	6.7%	57.3	15.5	37.0%	8	57	49
24	16th St S of Highline Canal	44.0	16.3	-27.7	-63.0%	40.5	-3.5	-8.0%	57.3	13.3	30.2%	16	57	41
25	N of S. Mtn ((15th St to 16th St)	130.9	157.8	26.9	20.5%	134.2	3.2	2.5%	59.5	-71.5	-54.6%	59	158	98
26	16th St S of Winston	87.7	54.7	-33.0	-37.6%	64.6	-23.2	-26.4%	165.9	78.2	89.1%	55	166	111
27	14th St & Euclid	99.1	32.5	-66.6	-67.2%	134.0	34.9	35.3%	91.7	-7.4	-7.4%	33	134	102
28	15th St & Euclid	249.7	192.8	-56.9	-22.8%	171.3	-78.3	-31.4%	103.2	-146.4	-58.6%	103	250	146
29	16th St & Euclid	137.6	68.8	-68.8	-50.0%	108.9	-28.8	-20.9%	250.4	112.8	82.0%	69	250	182
30	Field W of MVE Subdivision	183.9	77.8	-106.1	-57.7%	253.8	69.9	38.0%	145.5	-38.4	-20.9%	78	254	176
31	Dobbins (15th St to 17th Pl)	512.7	411.1	-101.6	-19.8%	492.6	-20.1	-3.9%	192.0	-320.7	-62.5%	192	513	321
32	16th St S of Dobbins	130.1	130.2	0.1	0.1%	130.2	0.1	0.1%	518.4	388.3	298.5%	130	518	388
33	15th St S of Dobbins (wash)	446.6	445.6	-0.9	-0.2%	449.4	2.8	0.6%	130.2	-316.4	-70.9%	130	449	319

FLO-2D Parameter Sensitivity Analysis (Storm Drain Modeling Detail)

Cross Section	Location	Peak Q Base (Q_{Base}) CBs=7 (cfs)	CBs=5 Peak Q (cfs)	CBs=5 ΔQ ($Q-Q_{Base}$) (cfs)	CBs=5 ΔQ/(Q_{Base}) (%)	CBs=3 Peak Q (cfs)	CBs=3 ΔQ ($Q-Q_{Base}$) (cfs)	CBs=3 ΔQ/(Q_{Base}) (%)	CBs=1 Peak Q (cfs)	CBs=1 ΔQ ($Q-Q_{Base}$) (cfs)	CBs=1 ΔQ/(Q_{Base}) (%)	No CBs Peak Q (cfs)	No CBs ΔQ ($Q-Q_{Base}$) (cfs)	No CBs ΔQ/(Q_{Base}) (%)	Range of Values Minimum	Range of Values Maximum	Range of Values Spread
	Run Time (hours)	2.6	2.5			2.5			2.5			2.5					
1	7th St N of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
2	7th St S of Western Canal	38.6	38.7	0.1	0.4%	39.0	0.5	1.2%	38.6	0.0	0.1%	38.8	0.3	0.7%	39	39	0
3	7th St & Baseline (N of)	28.5	28.5	0.0	-0.1%	28.4	-0.1	-0.2%	28.9	0.4	1.4%	28.6	0.1	0.4%	28	29	0
4	12th Pl N of Western Canal	95.0	96.5	1.5	1.6%	97.4	2.4	2.5%	97.2	2.3	2.4%	97.7	2.8	2.9%	95	98	3
5	13th Way N of Western Canal	108.1	107.6	-0.5	-0.5%	110.1	2.0	1.9%	110.1	2.0	1.9%	115.3	7.2	6.7%	108	115	8
6	14th St N of Western Canal	102.4	103.0	0.6	0.6%	109.6	7.2	7.1%	120.5	18.1	17.7%	123.9	21.5	21.0%	102	124	22
7	16th St N of Western Canal	1.6	1.6	0.0	0.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	2	2	0
8	17th St N of Western Canal	1.2	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1	1	0
9	18th St n of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
10	Baseline (12th St to 15th St)	551.9	555.2	3.3	0.6%	558.5	6.6	1.2%	576.4	24.5	4.4%	584.7	32.8	5.9%	552	585	33
11	Beverly (12th St to 14th St)	571.1	572.7	1.5	0.3%	581.8	10.7	1.9%	575.2	4.1	0.7%	586.1	15.0	2.6%	571	586	15
12	14th St N of Circle K Park	246.8	247.0	0.2	0.1%	247.0	0.1	0.1%	246.8	0.0	0.0%	246.9	0.1	0.0%	247	247	0
13	Circle K Park (S. Mountain Ave)	527.6	525.9	-1.7	-0.3%	529.0	1.4	0.3%	528.1	0.5	0.1%	527.5	-0.1	0.0%	526	529	3
14	12th St & Euclid (DB West outfall)	0.4	0.4	0.0	0.0%	0.4	0.0	0.0%	0.4	0.0	0.0%	0.4	0.0	0.0%	0	0	0
15	~13th St & Euclid (DB East outfall)	314.2	314.2	0.0	0.0%	314.6	0.4	0.1%	314.4	0.2	0.1%	314.8	0.6	0.2%	314	315	1
16	Dobbins & golf course (West)	20.7	20.7	0.0	0.0%	20.7	0.0	0.0%	20.7	0.0	0.0%	20.7	0.0	0.0%	21	21	0
17	Dobbins & golf course (East)	29.3	29.3	0.0	0.0%	40.6	11.3	38.7%	29.3	0.0	0.0%	29.3	0.0	0.0%	29	41	11
18	S of golf course (West)	119.5	119.5	0.0	0.0%	119.5	0.0	0.0%	119.5	0.0	0.0%	119.5	0.0	0.0%	120	120	0
19	S of golf course (East)	220.5	220.5	0.0	0.0%	220.5	0.0	0.0%	220.5	0.0	0.0%	220.5	0.0	0.0%	220	220	0
20	16th St N of Baseline	9.9	10.0	0.1	0.5%	9.9	0.0	0.0%	10.3	0.3	3.3%	10.1	0.2	1.6%	10	10	0
21	~16th St & Beautiful Ln	30.9	30.8	-0.1	-0.5%	30.3	-0.6	-1.9%	30.4	-0.5	-1.6%	31.1	0.2	0.6%	30	31	1
22	~16th St & Harwell	9.9	9.8	-0.1	-0.9%	9.9	0.0	0.0%	10.0	0.0	0.4%	9.9	0.0	0.1%	10	10	0
23	16th St N of Highline Canal	41.8	41.7	-0.1	-0.4%	41.8	0.0	0.0%	42.2	0.3	0.8%	41.9	0.1	0.2%	42	42	0
24	16th St S of Highline Canal	44.0	44.1	0.0	0.1%	44.0	0.0	0.0%	44.1	0.0	0.1%	44.1	0.0	0.1%	44	44	0
25	N of S. Mtn ((15th St to 16th St)	130.9	131.0	0.0	0.0%	130.8	-0.1	-0.1%	131.1	0.1	0.1%	131.0	0.0	0.0%	131	131	0
26	16th St S of Winston	87.7	87.7	0.0	0.0%	87.7	0.0	0.0%	87.7	0.0	0.0%	87.7	0.0	0.0%	88	88	0
27	14th St & Euclid	99.1	99.1	0.0	0.0%	97.8	-1.3	-1.3%	99.1	0.0	0.0%	99.1	0.0	0.0%	98	99	1
28	15th St & Euclid	249.7	249.7	0.0	0.0%	249.7	0.0	0.0%	249.7	0.0	0.0%	249.7	0.0	0.0%	250	250	0
29	16th St & Euclid	137.6	137.6	0.0	0.0%	137.6	0.0	0.0%	137.6	0.0	0.0%	137.6	0.0	0.0%	138	138	0
30	Field W of MVE Subdivision	183.9	183.9	0.0	0.0%	182.9	-1.0	-0.6%	183.9	0.0	0.0%	183.9	0.0	0.0%	183	184	1
31	Dobbins (15th St to 17th Pl)	512.7	512.7	0.0	0.0%	512.7	0.0	0.0%	512.7	0.0	0.0%	512.7	0.0	0.0%	513	513	0
32	16th St S of Dobbins	130.1	130.1	0.0	0.0%	130.1	0.0	0.0%	130.1	0.0	0.0%	130.1	0.0	0.0%	130	130	0
33	15th St S of Dobbins (wash)	446.6	446.6	0.0	0.00%	446.6	0.0	0.0%	446.6	0.0	0.0%	446.6	0.0	0.0%	447	447	0

FLO-2D Parameter Sensitivity Analysis (Shallow n Value)

Cross Section	Location	Peak Q Base (Q_{Base}) SHALLOWN=0.15 (cfs)	SHALLOWN=0.05			SHALLOWN=0.10			SHALLOWN=0.20			SHALLOWN=0.25			SHALLOWN=0.30			Range of Values		
			Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Minimum	Maximum	Spread
	Run Time (hours)	2.6	2.8			2.8			2.4			2.3			2.2					
1	7th St N of Western Canal	0.9	0.9	0.0	2.2%	0.9	0.0	2.2%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	-1.1%	1	1	0
2	7th St S of Western Canal	38.6	53.5	14.9	38.7%	53.5	14.9	38.7%	31.5	-7.0	-18.3%	26.5	-12.0	-31.2%	24.3	-14.3	-37.1%	24	53	29
3	7th St & Baseline (N of)	28.5	37.0	8.5	29.8%	37.0	8.5	29.8%	24.3	-4.2	-14.6%	21.0	-7.5	-26.4%	18.6	-9.9	-34.9%	19	37	18
4	12th Pl N of Western Canal	95.0	115.1	20.1	21.2%	115.1	20.1	21.2%	80.4	-14.5	-15.3%	68.5	-26.5	-27.9%	53.4	-41.6	-43.8%	53	115	62
5	13th Way N of Western Canal	108.1	121.5	13.4	12.4%	121.5	13.4	12.4%	97.3	-10.7	-9.9%	90.8	-17.3	-16.0%	77.1	-31.0	-28.7%	77	121	44
6	14th St N of Western Canal	102.4	138.0	35.7	34.9%	138.0	35.7	34.9%	78.0	-24.3	-23.8%	58.6	-43.8	-42.8%	48.9	-53.4	-52.2%	49	138	89
7	16th St N of Western Canal	1.6	1.7	0.0	1.8%	1.7	0.0	1.8%	1.6	0.0	-1.2%	1.6	0.0	-3.0%	1.6	-0.1	-4.9%	2	2	0
8	17th St N of Western Canal	1.2	1.2	0.0	2.6%	1.2	0.0	2.6%	1.3	0.1	11.3%	1.1	0.0	-0.9%	1.1	-0.1	-7.0%	1	1	0
9	18th St n of Western Canal	0.9	1.4	0.6	65.5%	1.4	0.6	65.5%	0.8	-0.1	-9.2%	0.7	-0.2	-17.2%	0.7	-0.2	-21.8%	1	1	1
10	Baseline (12th St to 15th St)	551.9	639.6	87.6	15.9%	639.6	87.6	15.9%	490.9	-61.1	-11.1%	448.5	-103.4	-18.7%	411.6	-140.4	-25.4%	412	640	228
11	Beverly (12th St to 14th St)	571.1	638.5	67.4	11.8%	638.5	67.4	11.8%	514.8	-56.3	-9.9%	476.5	-94.6	-16.6%	441.6	-129.5	-22.7%	442	639	197
12	14th St N of Circle K Park	246.8	272.3	25.5	10.3%	272.3	25.5	10.3%	224.3	-22.5	-9.1%	206.4	-40.4	-16.4%	189.5	-57.3	-23.2%	190	272	83
13	Circle K Park (S. Mountain Ave)	527.6	580.8	53.2	10.1%	580.8	53.2	10.1%	493.4	-34.2	-6.5%	462.5	-65.1	-12.3%	440.2	-87.4	-16.6%	440	581	141
14	12th St & Euclid (DB West outfall)	0.4	0.4	0.1	14.3%	0.4	0.1	14.3%	0.3	0.0	-2.9%	0.3	0.0	-2.9%	0.3	0.0	-5.7%	0	0	0
15	~13th St & Euclid (DB East outfall	314.2	344.2	30.0	9.5%	344.2	30.0	9.5%	290.9	-23.3	-7.4%	271.7	-42.5	-13.5%	255.3	-58.9	-18.8%	255	344	89
16	Dobbins & golf course (West)	20.7	21.7	1.0	4.9%	21.7	1.0	4.9%	19.7	-1.0	-4.9%	19.5	-1.2	-5.6%	20.0	-0.7	-3.6%	20	22	2
17	Dobbins & golf course (East)	29.3	48.7	19.4	66.4%	48.7	19.4	66.4%	23.0	-6.2	-21.3%	18.3	-10.9	-37.3%	18.6	-10.7	-36.6%	18	49	30
18	S of golf course (West)	119.5	122.2	2.7	2.3%	122.2	2.7	2.3%	115.6	-3.9	-3.3%	112.5	-7.0	-5.8%	109.5	-10.0	-8.4%	110	122	13
19	S of golf course (East)	220.5	228.1	7.6	3.5%	228.1	7.6	3.5%	214.7	-5.8	-2.6%	208.2	-12.3	-5.6%	207.6	-12.9	-5.8%	208	228	21
20	16th St N of Baseline	9.9	15.3	5.4	54.5%	15.3	5.4	54.5%	8.6	-1.3	-13.0%	7.7	-2.3	-22.8%	6.7	-3.2	-32.4%	7	15	9
21	~16th St & Beautiful Ln	30.9	42.1	11.2	36.2%	42.1	11.2	36.2%	21.5	-9.5	-30.6%	16.5	-14.5	-46.8%	12.4	-18.5	-59.8%	12	42	30
22	~16th St & Harwell	9.9	11.9	2.0	19.6%	11.9	2.0	19.6%	8.5	-1.4	-14.0%	7.1	-2.8	-28.2%	6.6	-3.4	-33.8%	7	12	5
23	16th St N of Highline Canal	41.8	51.4	9.6	22.9%	51.4	9.6	22.9%	35.9	-5.9	-14.1%	29.7	-12.2	-29.1%	25.9	-15.9	-38.1%	26	51	26
24	16th St S of Highline Canal	44.0	51.6	7.6	17.3%	51.6	7.6	17.3%	39.3	-4.7	-10.7%	36.0	-8.1	-18.3%	34.4	-9.6	-21.8%	34	52	17
25	N of S. Mtn ((15th St to 16th St)	130.9	144.4	13.5	10.3%	144.4	13.5	10.3%	126.6	-4.3	-3.3%	119.0	-11.9	-9.1%	116.9	-14.1	-10.7%	117	144	28
26	16th St S of Winston	87.7	90.8	3.1	3.5%	90.8	3.1	3.5%	87.6	-0.2	-0.2%	86.8	-0.9	-1.0%	84.9	-2.8	-3.2%	85	91	6
27	14th St & Euclid	99.1	114.2	15.1	15.3%	114.2	15.1	15.3%	83.2	-15.9	-16.0%	74.0	-25.1	-25.3%	68.3	-30.8	-31.1%	68	114	46
28	15th St & Euclid	249.7	258.7	9.0	3.6%	258.7	9.0	3.6%	235.2	-14.5	-5.8%	219.9	-29.8	-11.9%	210.4	-39.2	-15.7%	210	259	48
29	16th St & Euclid	137.6	145.6	7.9	5.8%	145.6	7.9	5.8%	131.4	-6.2	-4.5%	127.2	-10.4	-7.5%	125.0	-12.7	-9.2%	125	146	21
30	Field W of MVE Subdivision	183.9	206.0	22.1	12.0%	206.0	22.1	12.0%	167.4	-16.5	-9.0%	153.3	-30.6	-16.7%	144.9	-39.0	-21.2%	145	206	61
31	Dobbins (15th St to 17th Pl)	512.7	526.4	13.7	2.7%	526.4	13.7	2.7%	497.0	-15.7	-3.1%	484.5	-28.2	-5.5%	470.8	-41.9	-8.2%	471	526	56
32	16th St S of Dobbins	130.1	133.6	3.5	2.7%	133.6	3.5	2.7%	128.8	-1.3	-1.0%	124.4	-5.7	-4.4%	119.1	-11.0	-8.5%	119	134	15
33	15th St S of Dobbins (wash)	446.6	458.3	11.7	2.6%	458.3	11.7	2.6%	431.8	-14.8	-3.3%	425.7	-20.9	-4.7%	404.2	-42.4	-9.5%	404	458	54

FLO-2D Parameter Sensitivity Analysis (WAVEMAX - Dynamic Wave Numerical Stability Coefficient)

Cross Section	Location	Peak Q Base (Q_{Base}) WAVEMAX=1.00[1] (cfs)	WAVEMAX = 0.25[2] Peak Q (cfs)	WAVEMAX = 0.25[2] ΔQ ($Q-Q_{Base}$) (cfs)	WAVEMAX = 0.25[2] ΔQ/(Q_{Base}) (%)	WAVEMAX = -0.25[3] Peak Q (cfs)	WAVEMAX = -0.25[3] ΔQ ($Q-Q_{Base}$) (cfs)	WAVEMAX = -0.25[3] ΔQ/(Q_{Base}) (%)	WAVEMAX = -1.00[4] Peak Q (cfs)	WAVEMAX = -1.00[4] ΔQ ($Q-Q_{Base}$) (cfs)	WAVEMAX = -1.00[4] ΔQ/(Q_{Base}) (%)	WAVEMAX = 101[5] Peak Q (cfs)	WAVEMAX = 101[5] ΔQ ($Q-Q_{Base}$) (cfs)	WAVEMAX = 101[5] ΔQ/(Q_{Base}) (%)	Range of Values Minimum	Range of Values Maximum	Range of Values Spread
	Run Time (hours)	2.6	8.9			1.3			1.3			1.2					
1	7th St N of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
2	7th St S of Western Canal	38.6	39.6	1.0	2.6%	38.6	0.0	0.1%	38.8	0.3	0.6%	39.0	0.4	1.1%	39	40	1
3	7th St & Baseline (N of)	28.5	29.5	1.0	3.4%	27.8	-0.7	-2.4%	27.8	-0.7	-2.5%	28.0	-0.5	-1.8%	28	29	2
4	12th Pl N of Western Canal	95.0	95.0	0.0	0.0%	95.8	0.8	0.8%	96.7	1.7	1.8%	95.6	0.7	0.7%	95	97	2
5	13th Way N of Western Canal	108.1	118.3	10.3	9.5%	104.4	-3.7	-3.4%	104.6	-3.4	-3.2%	103.7	-4.4	-4.0%	104	118	15
6	14th St N of Western Canal	102.4	105.5	3.1	3.0%	103.7	1.3	1.3%	105.5	3.2	3.1%	104.8	2.4	2.4%	102	106	3
7	16th St N of Western Canal	1.6	3.9	2.2	136.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	2	4	2
8	17th St N of Western Canal	1.2	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1	1	0
9	18th St n of Western Canal	0.9	3.2	2.4	272.4%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	3	2
10	Baseline (12th St to 15th St)	551.9	551.3	-0.7	-0.1%	541.0	-11.0	-2.0%	547.7	-4.3	-0.8%	550.3	-1.7	-0.3%	541	552	11
11	Beverly (12th St to 14th St)	571.1	581.1	10.0	1.8%	554.0	-17.1	-3.0%	560.0	-11.1	-1.9%	568.1	-3.0	-0.5%	554	581	27
12	14th St N of Circle K Park	246.8	248.7	1.9	0.8%	247.2	0.3	0.1%	246.2	-0.7	-0.3%	246.4	-0.4	-0.2%	246	249	3
13	Circle K Park (S. Mountain Ave)	527.6	542.2	14.6	2.8%	508.8	-18.8	-3.6%	512.0	-15.6	-3.0%	522.6	-5.0	-0.9%	509	542	33
14	12th St & Euclid (DB West outfall)	0.4	0.4	0.0	0.0%	0.4	0.0	2.9%	0.4	0.0	2.9%	0.4	0.0	2.9%	0	0	0
15	~13th St & Euclid (DB East outfall)	314.2	319.0	4.8	1.5%	304.2	-10.1	-3.2%	311.5	-2.7	-0.8%	310.4	-3.8	-1.2%	304	319	15
16	Dobbins & golf course (West)	20.7	20.8	0.1	0.6%	20.8	0.1	0.4%	20.4	-0.3	-1.6%	20.5	-0.3	-1.3%	20	21	0
17	Dobbins & golf course (East)	29.3	18.7	-10.6	-36.2%	34.2	5.0	17.1%	33.4	4.1	14.2%	38.1	8.8	30.2%	19	38	19
18	S of golf course (West)	119.5	119.2	-0.3	-0.2%	119.4	-0.1	-0.1%	119.5	-0.1	0.0%	119.4	-0.1	-0.1%	119	120	0
19	S of golf course (East)	220.5	220.8	0.3	0.1%	216.0	-4.5	-2.0%	218.2	-2.2	-1.0%	219.7	-0.8	-0.4%	216	221	5
20	16th St N of Baseline	9.9	9.6	-0.3	-3.4%	10.4	0.5	4.5%	10.0	0.1	1.1%	10.5	0.6	6.1%	10	11	1
21	~16th St & Beautiful Ln	30.9	30.4	-0.5	-1.7%	30.0	-0.9	-3.0%	30.3	-0.7	-2.2%	30.2	-0.7	-2.4%	30	31	1
22	~16th St & Harwell	9.9	10.0	0.1	0.9%	9.8	-0.1	-1.3%	9.8	-0.1	-0.9%	9.9	-0.1	-0.6%	10	10	0
23	16th St N of Highline Canal	41.8	42.5	0.7	1.6%	40.5	-1.3	-3.2%	40.7	-1.1	-2.7%	40.7	-1.1	-2.7%	40	43	2
24	16th St S of Highline Canal	44.0	43.9	-0.2	-0.4%	43.8	-0.2	-0.5%	44.4	0.4	0.9%	44.6	0.6	1.3%	44	45	1
25	N of S. Mtn ((15th St to 16th St)	130.9	131.1	0.2	0.1%	129.4	-1.5	-1.2%	130.0	-1.0	-0.7%	130.6	-0.3	-0.3%	129	131	2
26	16th St S of Winston	87.7	87.6	-0.2	-0.2%	85.1	-2.7	-3.0%	87.5	-0.3	-0.3%	87.6	-0.1	-0.1%	85	88	3
27	14th St & Euclid	99.1	98.4	-0.7	-0.7%	99.2	0.1	0.1%	98.5	-0.6	-0.6%	96.6	-2.6	-2.6%	97	99	3
28	15th St & Euclid	249.7	251.2	1.6	0.6%	239.8	-9.9	-4.0%	250.1	0.5	0.2%	251.2	1.5	0.6%	240	251	11
29	16th St & Euclid	137.6	138.0	0.4	0.3%	135.0	-2.7	-1.9%	136.3	-1.3	-0.9%	136.5	-1.1	-0.8%	135	138	3
30	Field W of MVE Subdivision	183.9	185.7	1.8	1.0%	192.1	8.2	4.4%	185.0	1.1	0.6%	182.7	-1.2	-0.7%	183	192	9
31	Dobbins (15th St to 17th Pl)	512.7	515.2	2.5	0.5%	509.7	-3.0	-0.6%	509.9	-2.8	-0.6%	512.5	-0.3	-0.1%	510	515	6
32	16th St S of Dobbins	130.1	130.2	0.1	0.0%	130.4	0.3	0.2%	130.4	0.3	0.2%	130.4	0.3	0.2%	130	130	0
33	15th St S of Dobbins (wash)	446.6	445.4	-1.2	-0.3%	440.4	-6.1	-1.4%	446.8	0.2	0.04%	448.3	1.8	0.4%	440	448	8

1. *At 1.00, dyanmic wave stability criteria is less stringent. Decrements time step if exceeded. Less stable but model runs faster.*
2. *At 0.25, the dynamic wave stability criteria is more stringent. Decrements time step if exceeded. More stringent, more stable, but model runs slower.*
3. *At -0.25, the dynamic wave stability criteria does not decrement time step, but increments Manning's n values when exceeded.*
   Time step decrements affected only by depth tolerance and Courant stability criteria. Less stable than positive WAVEMAX values but model runs faster.
4. *At -1.00, the dynamic wave stability criteria does not decrement time step, but increments Manning's n values when exceeded. T*
   Time step decrements affected only by depth tolerance and Courant stability criteria. Even less stable that positive WAVEMAX, but model runs even faster.
5. *At 101, the dynamic wave stability criteria turned off. Does not decrement time step or increment Manning's n values.*
   Time step decrements affected only by depth tolerance and Courant stability criteria. Least stable but the fastest run time.

FLO-2D Parameter Sensitivity Analysis (Limiting Froude Number)

Cross Section	Location	Peak Q Base (Q_{Base}) (FROUDL=0.99) (cfs)	FROUDL=0.95			FROUDL=0.90			FROUDL=0.85			FROUDL=0.00 (not Limited)			Range of Values		
			Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Peak Q (cfs)	ΔQ ($Q-Q_{Base}$) (cfs)	$\Delta Q/(Q_{Base})$ (%)	Minimum	Maximum	Spread
	Run Time (hours)	2.6	2.5			2.2			2.3			2.5					
1	7th St N of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
2	7th St S of Western Canal	38.6	38.9	0.3	0.9%	39.2	0.6	1.7%	38.8	0.2	0.5%	38.7	0.2	0.4%	39	39	1
3	7th St & Baseline (N of)	28.5	29.5	1.0	3.4%	29.7	1.2	4.3%	28.3	-0.2	-0.8%	28.6	0.1	0.3%	28	30	1
4	12th Pl N of Western Canal	95.0	97.3	2.4	2.5%	96.8	1.8	1.9%	95.3	0.3	0.3%	96.1	1.1	1.2%	95	97	2
5	13th Way N of Western Canal	108.1	109.1	1.0	1.0%	107.3	-0.7	-0.7%	109.8	1.7	1.6%	107.3	-0.8	-0.7%	107	110	3
6	14th St N of Western Canal	102.4	106.0	3.7	3.6%	104.8	2.4	2.4%	103.5	1.2	1.2%	103.6	1.2	1.2%	102	106	4
7	16th St N of Western Canal	1.6	1.6	0.0	0.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	1.6	0.0	0.0%	2	2	0
8	17th St N of Western Canal	1.2	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1.2	0.0	0.0%	1	1	0
9	18th St n of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
10	Baseline (12th St to 15th St)	551.9	551.8	-0.2	0.0%	552.2	0.3	0.1%	553.0	1.0	0.2%	552.3	0.3	0.1%	552	553	1
11	Beverly (12th St to 14th St)	571.1	572.4	1.3	0.2%	571.4	0.3	0.0%	571.0	-0.1	0.0%	573.1	2.0	0.4%	571	573	2
12	14th St N of Circle K Park	246.8	246.7	-0.2	-0.1%	246.8	0.0	0.0%	248.1	1.3	0.5%	247.0	0.2	0.1%	247	248	1
13	Circle K Park (S. Mountain Ave)	527.6	528.6	1.0	0.2%	527.8	0.2	0.0%	527.8	0.2	0.0%	529.2	1.6	0.3%	528	529	2
14	12th St & Euclid (DB West outfall)	0.4	0.4	0.0	0.0%	0.4	0.0	0.0%	0.4	0.0	0.0%	0.4	0.0	0.0%	0	0	0
15	~13th St & Euclid (DB East outfall)	314.2	315.5	1.3	0.4%	314.7	0.5	0.2%	315.6	1.4	0.4%	315.2	1.0	0.3%	314	316	1
16	Dobbins & golf course (West)	20.7	20.7	0.0	-0.1%	20.5	-0.2	-0.9%	20.6	-0.2	-0.7%	20.8	0.1	0.5%	21	21	0
17	Dobbins & golf course (East)	29.3	37.5	8.2	28.2%	23.9	-5.4	-18.3%	29.7	0.4	1.5%	28.5	-0.8	-2.6%	24	37	14
18	S of golf course (West)	119.5	119.6	0.0	0.0%	119.3	-0.2	-0.2%	119.3	-0.2	-0.2%	119.4	-0.1	-0.1%	119	120	0
19	S of golf course (East)	220.5	219.3	-1.2	-0.6%	217.4	-3.1	-1.4%	216.6	-3.9	-1.8%	224.4	3.9	1.8%	217	224	8
20	16th St N of Baseline	9.9	9.9	0.0	-0.3%	9.9	0.0	-0.5%	9.9	0.0	-0.1%	9.9	-0.1	-0.6%	10	10	0
21	~16th St & Beautiful Ln	30.9	31.1	0.2	0.5%	32.0	1.1	3.6%	30.6	-0.4	-1.2%	29.8	-1.1	-3.6%	30	32	2
22	~16th St & Harwell	9.9	9.9	0.0	0.1%	9.9	0.0	0.0%	9.9	0.0	-0.1%	9.9	0.0	0.0%	10	10	0
23	16th St N of Highline Canal	41.8	41.8	-0.1	-0.2%	42.0	0.2	0.5%	41.8	-0.1	-0.2%	41.6	-0.2	-0.5%	42	42	0
24	16th St S of Highline Canal	44.0	44.6	0.6	1.3%	44.3	0.3	0.6%	43.9	-0.1	-0.3%	43.8	-0.2	-0.5%	44	45	1
25	N of S. Mtn ((15th St to 16th St)	130.9	130.7	-0.2	-0.1%	129.9	-1.0	-0.8%	131.3	0.4	0.3%	130.9	-0.1	0.0%	130	131	1
26	16th St S of Winston	87.7	87.8	0.1	0.1%	87.6	-0.2	-0.2%	87.3	-0.4	-0.5%	87.9	0.2	0.2%	87	88	1
27	14th St & Euclid	99.1	99.1	0.0	0.0%	98.9	-0.2	-0.2%	99.7	0.6	0.6%	99.0	-0.1	-0.1%	99	100	1
28	15th St & Euclid	249.7	248.1	-1.6	-0.6%	249.9	0.2	0.1%	250.3	0.6	0.2%	249.6	0.0	0.0%	248	250	2
29	16th St & Euclid	137.6	137.4	-0.2	-0.1%	136.7	-1.0	-0.7%	136.5	-1.1	-0.8%	137.9	0.3	0.2%	137	138	1
30	Field W of MVE Subdivision	183.9	184.0	0.1	0.1%	184.0	0.1	0.1%	186.1	2.2	1.2%	182.6	-1.3	-0.7%	183	186	3
31	Dobbins (15th St to 17th Pl)	512.7	512.9	0.2	0.0%	511.7	-1.0	-0.2%	511.2	-1.5	-0.3%	515.7	3.0	0.6%	511	516	5
32	16th St S of Dobbins	130.1	130.2	0.1	0.0%	130.1	0.0	0.0%	130.2	0.1	0.1%	130.0	-0.1	-0.1%	130	130	0
33	15th St S of Dobbins (wash)	446.6	445.4	-1.2	-0.3%	449.8	3.2	0.7%	444.8	-1.7	-0.4%	449.8	3.2	0.7%	445	450	5

FLO-2D Parameter Sensitivity Analysis (Courant Numerical Stability Criteria)

Cross Section	Location	Peak Q Base (Q_{Base}) (C=0.6)[1] (cfs)	Courant = 0.3[2] Peak Q (cfs)	Courant = 0.3[2] ΔQ ($Q-Q_{Base}$) (cfs)	Courant = 0.3[2] ΔQ/(Q_{Base}) (%)	Courant = 1.0[3] Peak Q (cfs)	Courant = 1.0[3] ΔQ ($Q-Q_{Base}$) (cfs)	Courant = 1.0[3] ΔQ/(Q_{Base}) (%)	Range of Values Minimum	Range of Values Maximum	Range of Values Spread
	Run Time (hours)	2.6	2.5			2.5					
1	7th St N of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
2	7th St S of Western Canal	38.6	38.6	0.0	-0.1%	38.7	0.1	0.4%	39	39	0
3	7th St & Baseline (N of)	28.5	28.4	-0.1	-0.3%	28.2	-0.3	-1.1%	28	28	0
4	12th Pl N of Western Canal	95.0	95.4	0.4	0.4%	95.2	0.2	0.2%	95	95	0
5	13th Way N of Western Canal	108.1	107.8	-0.2	-0.2%	109.8	1.7	1.6%	108	110	2
6	14th St N of Western Canal	102.4	105.6	3.2	3.1%	106.2	3.8	3.7%	102	106	4
7	16th St N of Western Canal	1.6	1.7	0.0	0.6%	1.6	0.0	0.0%	2	2	0
8	17th St N of Western Canal	1.2	1.2	0.0	0.0%	1.2	0.0	0.0%	1	1	0
9	18th St n of Western Canal	0.9	0.9	0.0	0.0%	0.9	0.0	0.0%	1	1	0
10	Baseline (12th St to 15th St)	551.9	552.9	0.9	0.2%	551.0	-0.9	-0.2%	551	553	2
11	Beverly (12th St to 14th St)	571.1	572.7	1.6	0.3%	571.3	0.2	0.0%	571	573	2
12	14th St N of Circle K Park	246.8	247.8	1.0	0.4%	246.7	-0.1	0.0%	247	248	1
13	Circle K Park (S. Mountain Ave)	527.6	528.3	0.7	0.1%	526.9	-0.7	-0.1%	527	528	1
14	12th St & Euclid (DB West outfall)	0.4	0.4	0.0	0.0%	0.4	0.0	0.0%	0	0	0
15	~13th St & Euclid (DB East outfall)	314.2	315.4	1.2	0.4%	314.5	0.3	0.1%	314	315	1
16	Dobbins & golf course (West)	20.7	20.7	0.0	0.0%	20.7	0.0	0.0%	21	21	0
17	Dobbins & golf course (East)	29.3	29.5	0.2	0.8%	35.2	5.9	20.2%	29	35	6
18	S of golf course (West)	119.5	119.4	-0.1	-0.1%	119.5	0.0	0.0%	119	120	0
19	S of golf course (East)	220.5	220.3	-0.2	-0.1%	220.5	0.0	0.0%	220	220	0
20	16th St N of Baseline	9.9	9.8	-0.1	-1.0%	10.0	0.1	1.0%	10	10	0
21	~16th St & Beautiful Ln	30.9	31.2	0.3	0.9%	31.2	0.3	0.8%	31	31	0
22	~16th St & Harwell	9.9	9.9	0.0	-0.2%	9.9	0.0	-0.3%	10	10	0
23	16th St N of Highline Canal	41.8	41.9	0.1	0.2%	41.8	-0.1	-0.2%	42	42	0
24	16th St S of Highline Canal	44.0	43.6	-0.4	-0.9%	44.0	0.0	0.0%	44	44	0
25	N of S. Mtn ((15th St to 16th St)	130.9	130.1	-0.8	-0.6%	131.3	0.4	0.3%	130	131	1
26	16th St S of Winston	87.7	88.1	0.4	0.4%	87.7	0.0	0.0%	88	88	0
27	14th St & Euclid	99.1	99.0	-0.1	-0.1%	99.0	-0.1	-0.1%	99	99	0
28	15th St & Euclid	249.7	249.8	0.1	0.0%	250.5	0.8	0.3%	250	250	1
29	16th St & Euclid	137.6	137.6	0.0	0.0%	137.4	-0.2	-0.2%	137	138	0
30	Field W of MVE Subdivision	183.9	185.5	1.6	0.9%	183.7	-0.2	-0.1%	184	186	2
31	Dobbins (15th St to 17th Pl)	512.7	515.0	2.3	0.4%	514.5	1.8	0.3%	513	515	2
32	16th St S of Dobbins	130.1	129.9	-0.2	-0.1%	130.1	0.0	0.0%	130	130	0
33	15th St S of Dobbins (wash)	446.6	446.4	-0.2	0.0%	445.7	-0.9	-0.2%	446	447	1

1. "Default" value. Courant can vary from 0.3 to 1.0. Along with DEPTOL and WAVEMAX the Courant helps control numerical surging.

2. The lowest value for range of Courant Numbers. A Courant Number of 0.3 is slower running but provides the most stability.

3. The highest value for range of Courant Numbers. A Courant of 1.0 is faster running but provides less stability.

FLO-2D Parameter Sensitivity Analysis (Changes to Flow Depths Compared to Base FLO-2D Analysis)

Parameter Analysis	Maximum Difference in Flow Depths Compared to Base FLO-2D Analysis (Parameter Sensitivity Flow Depths - Base FLO-2D Flow Depths)								Number of Elements		
	All Elements				All Elements > 0.01 or <-0.01				x < -0.01 or x > 0.01	-0.01 ≤ x and x ≤ 0.01	Total Count
	Minimum (ft)	Maximum (ft)	Mean (ft)	Standard Deviation (ft)	Minimum (ft)	Maximum (ft)	Mean (ft)	Standard Deviation (ft)			
No Culverts	-4.51	3.92	-0.00106	0.079694	-4.51	3.92	-0.016875	0.33783	6,144	104,621	110,765
No CHAN.DAT	-2.87	4.64	0.005117	0.095803	-2.87	4.64	-0.093621	0.395386	6,173	104,587	110,760
Revised FPLAIN.DAT	-3.72	2.74	-0.005549	0.153235	-3.72	2.74	-0.012212	0.224219	51,612	59,153	110,765
Walls											
None	-4.83	2.52	-0.004537	0.230619	-4.83	2.52	-0.011858	0.35973	45,482	65,280	110,762
Minimum	-3.51	1.56	-0.000707	0.103355	-3.51	1.56	-0.005518	0.230554	22,227	88,535	110,762
Moderate	-3.35	1.56	0.000165	0.078699	-3.35	1.56	-0.003137	0.217055	14,534	96,228	110,762
Storm Drain Detail											
No CBs	-0.11	0.27	0.001157	0.009341	-0.11	0.27	0.044371	0.042841	2,512	108,252	110,764
One CB	-0.12	0.18	0.000627	0.006822	-0.12	0.18	0.034117	0.041488	1,705	109,059	110,764
Three CBs	-0.11	0.37	0.000366	0.004734	-0.11	0.37	0.024509	0.03778	1,080	109,684	110,764
Five CBs	-0.1	0.23	0.000072	0.003148	-0.1	0.23	0.007241	0.045931	406	110,358	110,764
SHALLOWN											
0.05	-0.28	0.99	-0.006854	0.032413	-0.28	0.99	-0.011407	0.057604	34,030	76,734	110,764
0.10	-0.28	0.99	-0.006854	0.032413	-0.28	0.99	-0.011407	0.057604	34,030	76,734	110,764
0.20	-0.74	0.19	0.002772	0.032943	-0.74	0.19	-0.00323	0.069736	23,920	86,844	110,764
0.25	-1.38	0.34	0.003693	0.05605	-1.38	0.34	0.000266	0.088088	44,468	66,296	110,764
0.30	-2.26	0.29	0.003948	0.078115	-2.26	0.29	0.00148	0.106802	59,053	51,711	110,764
FROUDL											
0.95	-0.11	0.13	0.000042	0.003432	-0.11	0.13	0.008958	0.040025	576	110,188	110,764
0.90	-0.11	0.25	0.000206	0.004295	-0.11	0.25	0.021472	0.040194	795	109,969	110,764
0.85	-0.1	0.36	0.000206	0.005815	-0.1	0.36	0.023639	0.054263	948	109,816	110,764
0.00	-0.36	0.16	0.000042	0.004714	-0.36	0.16	-0.001369	0.044884	1,023	109,741	110,764
WAVEMAX											
-1.00	-0.1	0.97	0.000505	0.012233	-0.1	0.97	0.030953	0.095724	1,574	109,190	110,764
-0.25	-0.21	1.31	0.000342	0.01831	-0.21	1.31	0.014823	0.095136	3,919	106,845	110,764
0.25	-0.45	0.85	0.000003	0.015667	-0.45	0.85	0.003492	0.090756	3,216	107,548	110,764
101	-0.08	0.34	0.000334	0.004951	-0.08	0.34	0.017678	0.035338	1,352	109,412	110,764
Courant											
1.00	-0.09	0.15	0.00007	0.002908	-0.09	0.15	0.01018	0.031228	557	110,207	110,764
0.30	-0.42	0.09	-0.000145	0.003972	-0.42	0.09	-0.015379	0.037546	831	109,933	110,764

Summary of Parameter Sensitivity Analysis

Parameter	Description	Results / Conclusion	Resolution
SHALLOWN	SHALLOWN is the flow roughness n-value for shallow overland flow. The application of SHALLOWN in FLO-2D is based upon the following rules: 0.0 ft < flow depth < 0.2 ft — n = SHALLOWN value 0.2 ft < flow depth < 0.5 ft — n = SHALLOWN / 2 0.5 ft < flow depth < 3 .0 ft — $n = nb*1.5*e^{-(0.4depth / dmax)}$ 3.0 ft < flow depth — n = FPLAIN.DAT n-value	The models are sensitive to SHALLOWN. Values less than the base SHALLOWN (0.15) generally resulted in larger peak discharges and deeper flow depths. Similarly, values larger than the base SHALLOWN resulted in lower peak discharges and more shallow flow depths.	SHALLOWN will be back calculating SHALLOWN based upon an average FLPLAIN.DAT n-value of 0.045 and equating $SHALLOWN/2 = n_b*1.5e^{-(0.4depth/dmax)}$ at the transition depth value of 0.5 (see separate calculation). The result is a lowering of the SHALLOWN to 0.126 from 0.15. the decrease is expected in increase flow depths and peak discharges from the base model.
WAVEMAX	WAVEMAX is dynamic wave criteria that increments and decrements the computational time step when WAVEMAX is exceeded. The range is from 0.1 to 1.00 with a default value of 0.25. The lower the value, the more stable but the model runs more slowly. The higher the value the less stable but the model runs more quickly. Negative WAVEMAX values (ranging -1.00 to -0.1) turns off the dynamic wave stability criteria. Time steps are then incremented or decremented by DEPTOL or the Courant stability criteria. Floodplain n-values are adjusted when the WAVEMAX criteria is exceeded but the time step in not increased. A WAVEMAX>100 turns off the dynamic wave criteria. Time steps are then incremented or decremented by DEPTOL or the Courant stability criteria. Floodplain n-values, however, are not adjusted.	Decreasing WAVEMAX from 1.0 to 0.25 increased run time from 2.6 hours to 8.9 hours. Differences in the results for peak discharges were very modest. Typically only a few cfs. Turning off the dynamic wave stability criteria (negative WAVEMAX) further decreased run times with little change in peaks discharges. The magnitude of the negative value appeared to have little impact. WAVEMAX >100 results were comparable to the negative WAVEMAX value results. There was no significant further decrease in run time. There were some changes in flow depths but the percentage of total grid elements affected was small. The standard deviations of flow depth changes (removing those +/- 0.01) for WAVEMAX was generally <0.1 ft. (for normal distribution, ~67% of data fall within +/-1 SD, ~95% fall within +/- 2SD)	For the iterative study analyses, model runs will be initially run with a negative WAVEMAX. Positive WAVEMAX values will likely be run for the final analyses.

Summary of Parameter Sensitivity Analysis

Parameter	Description	Results / Conclusion	Resolution
Walls	Block walls (for fencing, not structures) were modeled using LEVEE.DAT files. The level of detail to which walls modeled was varied from "no walls" to "detailed" as modeled in the base condition. This parameter was evaluated to determine if there was a level of detail to which block walls need to be modeled. For the sensitivity analysis, the walls were manually drawn/determined in GDS. An automated process using mapping for walls and a GDS application is under refinement and it is anticipated it will be used for the entire study area.	More detailed modeling of walls increased run times, but additional detail did not significantly increase run times (compared to no walls). Walls have a significant impact on the distribution of flow, particularly walls located within significant flow paths, subdivision perimeter walls, walls perpendicular to the overland flow path (e.g. back alley walls) and/or walls that help contain flow within streets or channels. Interior residential walls (between homes) generally do not have as significant an impact. Detailed modeling of the walls is not practical given the level of effort that would be required to do so. Consequently, the level of detail will be limited by the quality of the available mapping and the ability to automate the wall modeling process.	The level of detail will be dependent upon the ability to automate the wall modeling process and the quality for the level of detail that results. Focus should be on perimeter walls located in significant flow paths, walls perpendicular to significant flow and/or walls that help contain flow within channels and/or streets.
Storm Drain	Storm drain catch basins/inlets were modeled using rating tables in HYSTUC.DAT files. For a sample area along 14th St, inlets were modeled (no storm drain >36" exist in study are and where storm drain does exist, flow depths are too shallow). The level of detail varied from "no catch basins" to seven CBs (base) spread along the length of 14th St between the Highline Canal and Baseline Road. As the number of inlets were reduced, rating tables for the remaining inlets were increased so that roughly the same amount of flow was removed. This parameter was evaluated to determine the significance of the level of detail in modeling inlets to a storm drain system.	Generally the results indicated that the inlets had little overall impact to the models either in peak discharge or in flow depth. The results did reveal the difficulty in achieving the desired removal of flow when severely reducing the inlet number since flow and flow depths are limited to fewer nodes to achieve the same removal amount.	To better distribute flow along the length of the storm drain system, the inlets will be spaced along the main storm drain lines (pipe diameters ≥36") The inlets will not necessarily be located were existing inlets are located. Likely there will be ~3 inlets for each change in pipe size located at the upstream end, middle and downstream end of the pipes with the intention of the summation of the flow captured by the inlets being equivalent to the pipe capacity). Additional inlets may be placed at locations of significance as necessary.
FROUDL	The limiting Froude Number (FROUDL) is the maximum Froude Number for overland flow. When FROUDL is exceeded, the floodplain n-value is increased by 0.001 for that grid element for the next tim step. Setting FROUDL = 0.0 indicates the model has no Froude Number limitations. Values of 0.99 (base), 0.95, 0.90, 0.85 and 0.00 were evaluated for the sensitivity analysis.	Generally, as FROUDL decreased from 0.99 to 0.85, run times correspondingly decreased. Removing the Froude Number limitation (0.00) did not significantly reduce run time. Peak discharge and flow depth appeared to be relatively insensitive to FROUDL.	The Froude Number limitation will not be removed however, FROUDL will be decreased from the base value of 0.99 to a value of 0.90 or 0.85.

Summary of Parameter Sensitivity Analysis

Parameter	Description	Results / Conclusion	Resolution
Courant	The Courant Number is a numerical stability criteria that can vary from 0.3 to 1.0. Generally, a Courant Number of 0.3 is a slower running but more stable model. A Courant Number of 1.0 is a faster but less stable model. Values of 0.3, 0.6 and1.0 were evaluated for the sensitivity analysis.	The Courant Number did not appear to have a significant impact on run time, peak discharges or flow depths.	The default value of 1.0 will be used for model analyses.
Revised FPLAIN.DAT	The base FPLAIN.DAT file was developed using GDS and mass point and break lines vertices from the project mapping. The revised approach TINS will be rasterized to produce a 5'x5' uniformly spaced grid of points that then used GDS to set elevations. The purpose of the evaluation was to determine if one approach provided a significant improvement in modeling the concentration of flow in certain locations (e.g. streets, small conveyances etc...)	The different approach to creating the FPLAIN.DAT had some impact some impact on results. The results will be reviewed with the FCDMC to determine the approach to creating the FPLAIN.DAT file.	A composite approach will be used for the study area. For the mountainous areas, the GDS approach using mass points and break lines will be used. In the flatter and urbanized low land areas, TINs will be rasterized to create a grid of uniformly spaced elevations points (tentatively 5'x5'). These mass points will then be processed using GDS.
No CHAN.DAT	The analysis was to determine how significant it was to model the Western Canal using the CHAN.DAT versus simply utilizing the results of the floodplain elevations data (by turning off CHAN.DAT)	The modeling of the channel had some impact on results downstream of the canal. The results will be reviewed with the FCDMC to determine the value of modeling the Western Canal for the purposes of this project.	The Western Canal will be modeled using CHAN.DAT a conducted in the Pilot Study.
Fewer Culverts	This analysis was performed to see if there was a difference in modeling select culverts located in channels in the HYSTRUC.DAT file versus removing the culverts (in HYSTRUC.DAT) and modifying the floodplain elevations at the culvert locations to provide a continuously flowing channel.	The modeling of the culverts have some impact on results in the local vicinity of the culverts and, in some instance, further downstream as well. Given the limited access to the pilot study area culverts and the lack of information, no true assessment of culvert capacities was performed. It was simply assumed that all culverts passed all inflow. This was considered realistic in most instances. The culvert locations, however, also tended to be "sticky" points in the FLO-2D analyses increasing instabilities and run times.	Modeling of study area culverts will be assessed on an individual basis depending on the size, significance and availability of information on the structures.
DEPTOL	DEPTOL is a tolerance value for the percent change in channel flow for a given time step. When DEPTOL is exceeded, the time step will be reduced. A value of 0.25 was used for the pilot study analyses, however, the suggested values for DEPTOL were 0.1 (FCDMC SOW) and 0.2 (FLO-2D manual). This analysis with DEPTOL =0.1 was performed to verify that unintentionally using the larger DEPTOL value did not compromise the results and conclusions of the Pilot Study.	A comparison of results indicate that the DEPTOL value had little impact on the final results and the model run time. Consequently, utilizing a higher DEPTOL for Pilot Study analyses would not appear to compromise the results or conclusions.	While a larger DEPTOL did not appear to compromise the results of the pilot study, a DEPTOL value consistant with the FCDMC recommendations (0.01 or less) will be used for the final study models.

APPENDIX C

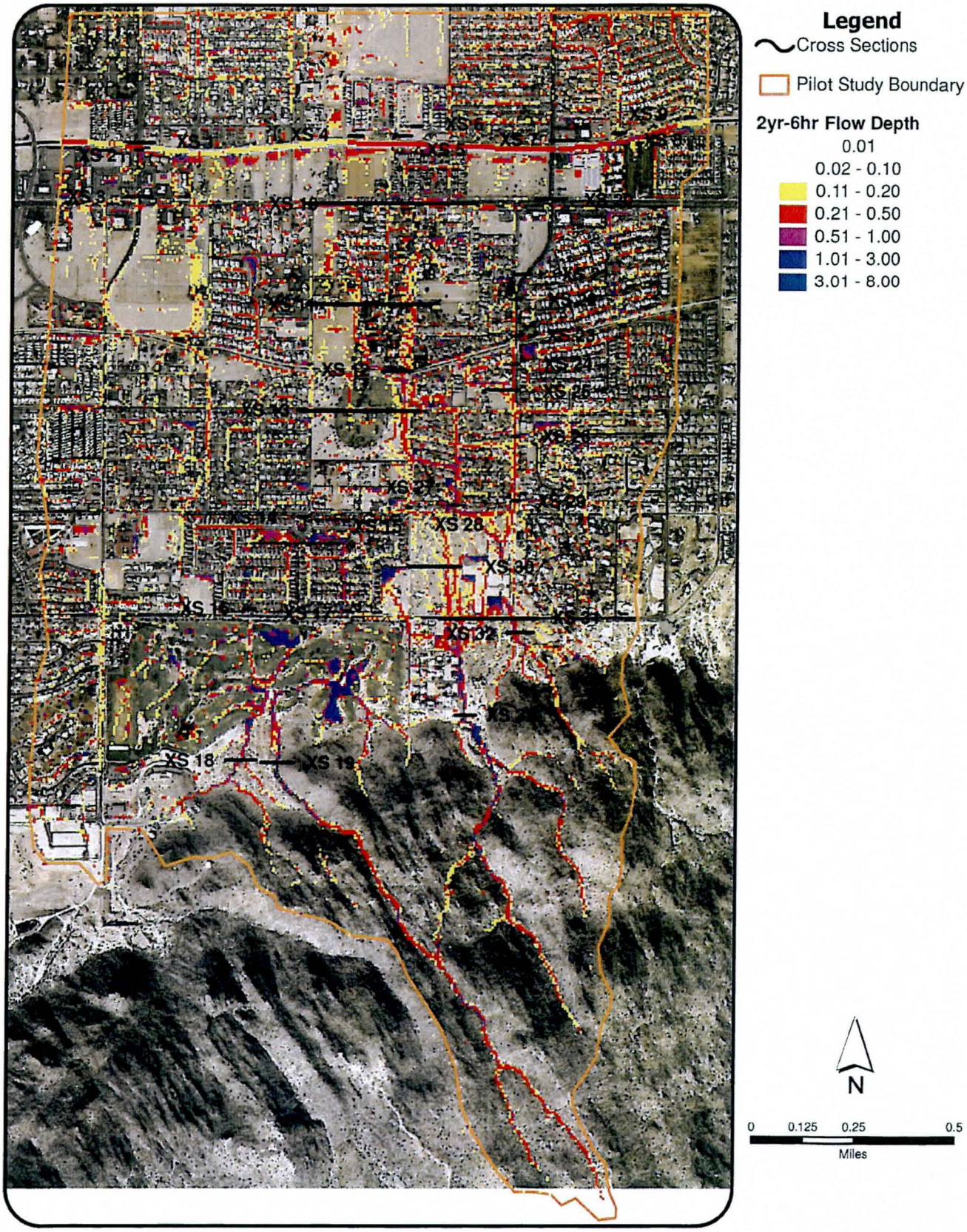
PILOT STUDY ANALYSES

FLO-2D Pilot Study Cross Section Peak Discharges

	Frequency	2 Year			10 Year			100 Year		
Cross Section	Location	Peak Discharge 2yr, 6hr (cfs)	Peak Discharge 2yr, 24hr (cfs)	Duration of Highest Discharge	Peak Discharge 10yr, 6hr (cfs)	Peak Discharge 10yr, 24hr (cfs)	Duration of Highest Discharge	Peak Discharge 100yr, 6hr (cfs)	Peak Discharge 100yr, 24hr (cfs)	Duration of Highest Discharge
	Run Time (hours)	0.6	2.0		0.8	2.9		1.2	3.8	
1	7th St N of Western Canal	0.4	0.6	24hr	0.6	0.9	24hr	0.9	1.5	24hr
2	7th St S of Western Canal	0.1	0.4	24hr	5.6	8.2	24hr	43.9	43.1	6hr
3	7th St & Baseline (N of)	1.9	1.9	6hr	7.1	6.6	6hr	31.6	30.0	6hr
4	12th Pl N of Western Canal	0.2	0.3	24hr	9.7	23.2	24hr	102.3	105.9	24hr
5	13th Way N of Western Canal	0.2	0.3	24hr	0.4	19.4	24hr	113.6	122.7	24hr
6	14th St N of Western Canal	0.4	0.6	24hr	0.8	8.9	24hr	113.9	120.4	24hr
7	16th St N of Western Canal	0.6	1.0	24hr	1.0	1.6	24hr	1.7	2.7	24hr
8	17th St N of Western Canal	0.4	0.6	24hr	0.7	1.1	24hr	1.2	2.0	24hr
9	18th St n of Western Canal	0.3	0.4	24hr	0.5	0.7	24hr	1.0	1.4	24hr
10	Baseline (12th St to 15th St)	5.2	19.8	24hr	114.0	117.1	24hr	573.8	594.4	24hr
11	Beverly (12th St to 14th St)	24.5	29.2	24hr	139.9	144.0	24hr	579.1	594.7	24hr
12	14th St N of Circle K Park	24.9	30.6	24hr	103.2	108.7	24hr	257.0	287.8	24hr
13	Circle K Park (S. Mountain Ave)	30.4	33.9	24hr	133.5	142.3	24hr	525.8	537.4	24hr
14	12th St & Euclid (DB West outfall)	0.2	0.3	24hr	0.3	0.4	24hr	0.4	0.6	24hr
15	~13th St & Euclid (DB East outfall)	0.1	0.1	24hr	76.1	72.0	6hr	312.3	314.2	24hr
16	Dobbins & golf course (West)	3.3	3.6	24hr	8.5	9.2	24hr	20.9	23.0	24hr
17	Dobbins & golf course (East)	0.3	0.3	6hr	2.5	1.8	6hr	33.4	38.1	24hr
18	S of golf course (West)	37.5	55.2	24hr	69.1	103.7	24hr	119.3	187.3	24hr
19	S of golf course (East)	62.8	72.8	24hr	126.1	143.5	24hr	217.6	263.3	24hr
20	16th St N of Baseline	1.5	1.5	24hr	4.5	5.1	24hr	12.3	13.8	24hr
21	~16th St & Beautiful Ln	0.5	0.7	24hr	1.9	2.3	24hr	34.7	36.6	24hr
22	~16th St & Harwell	1.0	1.1	24hr	3.7	3.8	24hr	10.5	10.6	24hr
23	16th St N of Highline Canal	3.2	3.3	24hr	10.7	10.9	24hr	44.1	43.0	6hr
24	16th St S of Highline Canal	5.1	5.4	24hr	19.0	19.5	24hr	47.4	50.2	24hr
25	N of S. Mtn ((15th St to 16th St)	16.2	19.1	24hr	59.1	60.8	24hr	135.2	142.9	24hr
26	16th St S of Winston	14.1	15.5	24hr	47.2	49.1	24hr	88.0	95.3	24hr
27	14th St & Euclid	8.0	10.3	24hr	31.3	38.3	24hr	106.1	139.9	24hr
28	15th St & Euclid	40.2	44.2	24hr	112.0	125.2	24hr	248.5	272.9	24hr
29	16th St & Euclid	19.7	22.1	24hr	72.1	76.1	24hr	138.9	154.1	24hr
30	Field W of MVE Subdivision	24.8	29.2	24hr	77.3	94.8	24hr	196.8	259.9	24hr
31	Dobbins (15th St to 17th Pl)	139.8	184.9	24hr	293.9	369.8	24hr	506.6	655.4	24hr
32	16th St S of Dobbins	34.1	52.2	24hr	78.0	111.0	24hr	132.3	207.8	24hr
33	15th St S of Dobbins (wash)	124.6	180.0	24hr	252.4	359.7	24hr	442.2	637.3	24hr

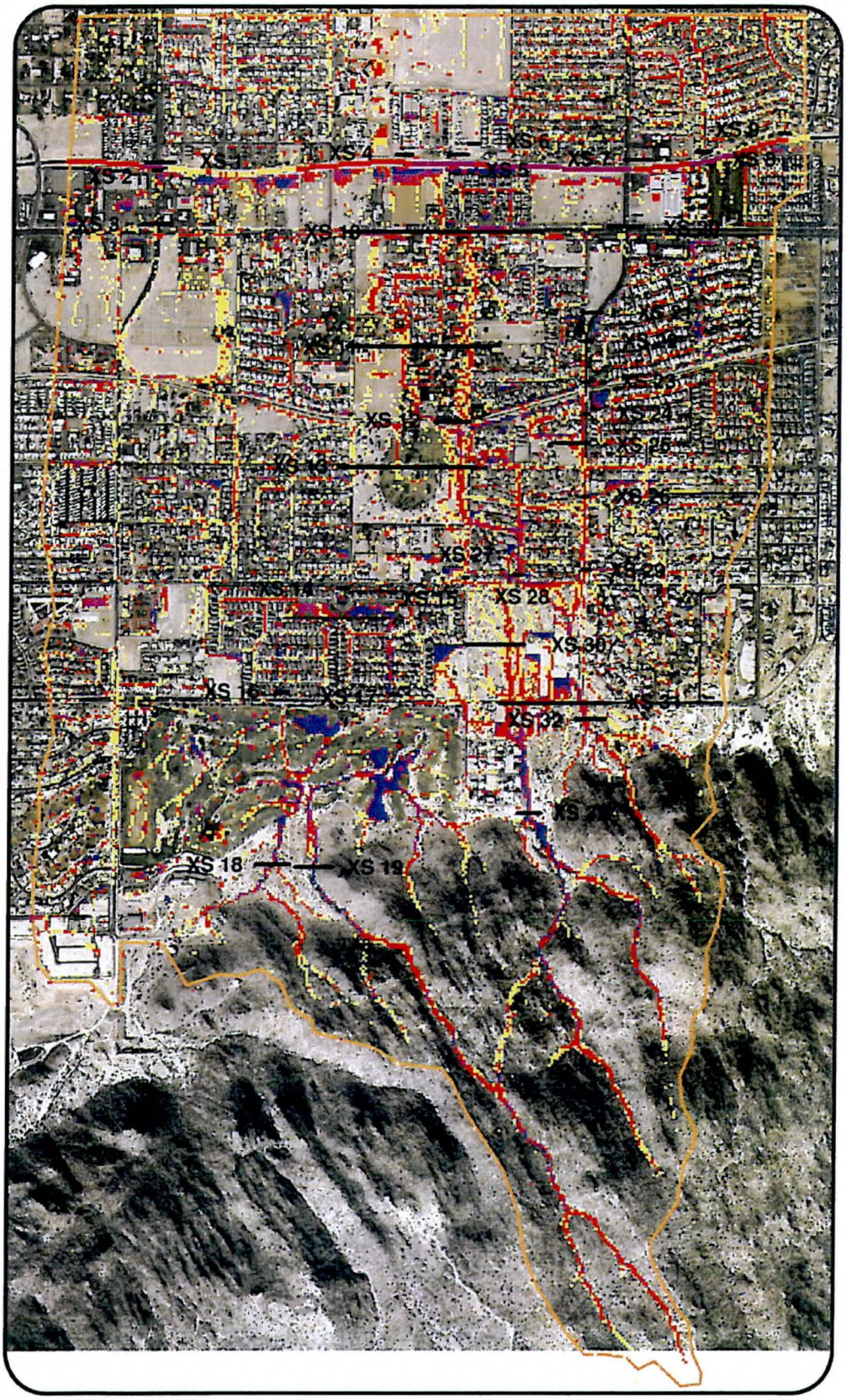
Hohokam Area Drainage Master Study

Pilot Study:
Exhibit 1: 2-Yr, 6-Hr Flow Depths



Hohokam Area Drainage Master Study

Pilot Study:
Exhibit 2: 2-Yr, 24-Hr Flow Depths



Legend

Cross Sections

Pilot Study Boundary

2yr-24hr Flow Depth

- 0.01
- 0.02 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 3.00
- 3.01 - 8.00

N

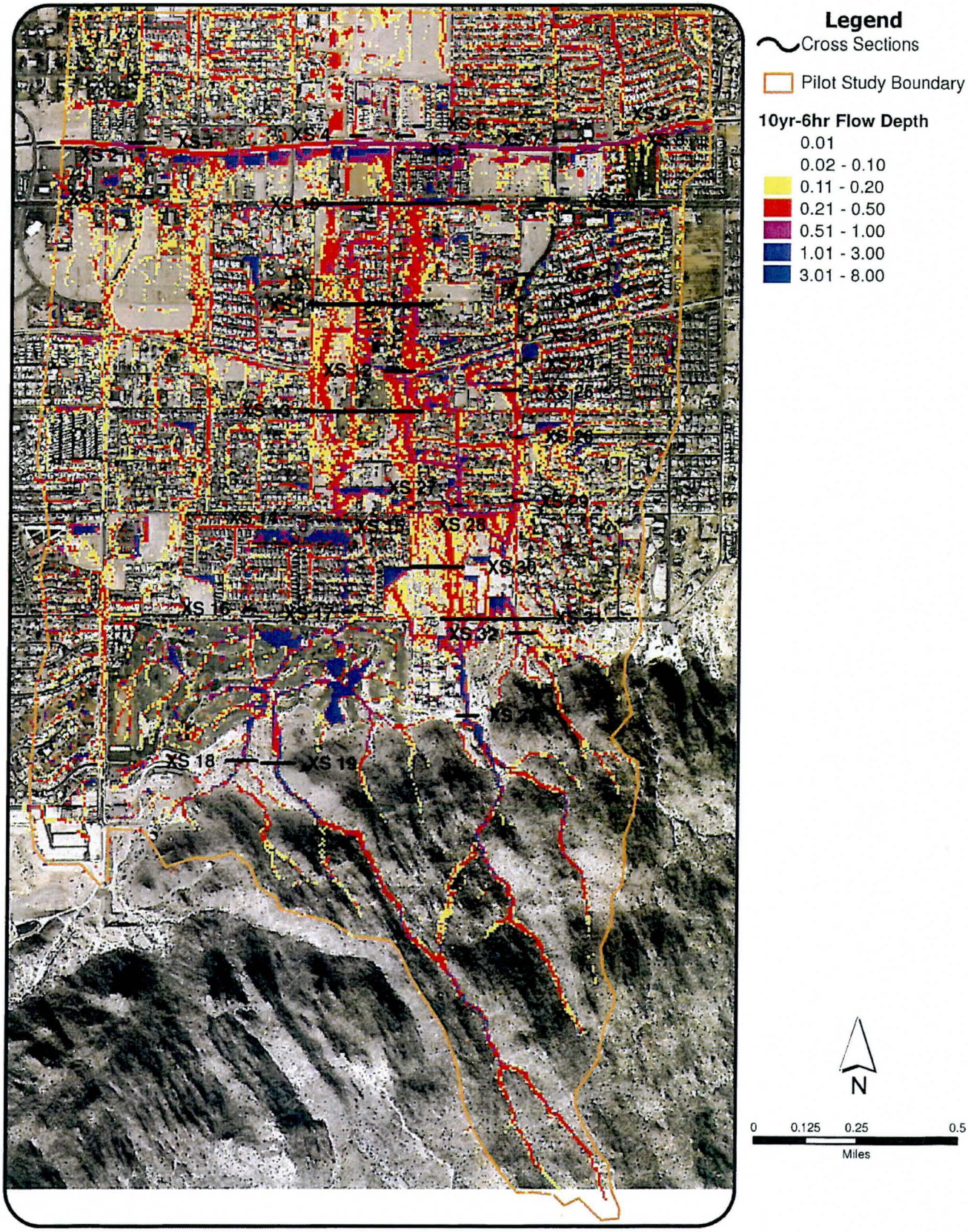
0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

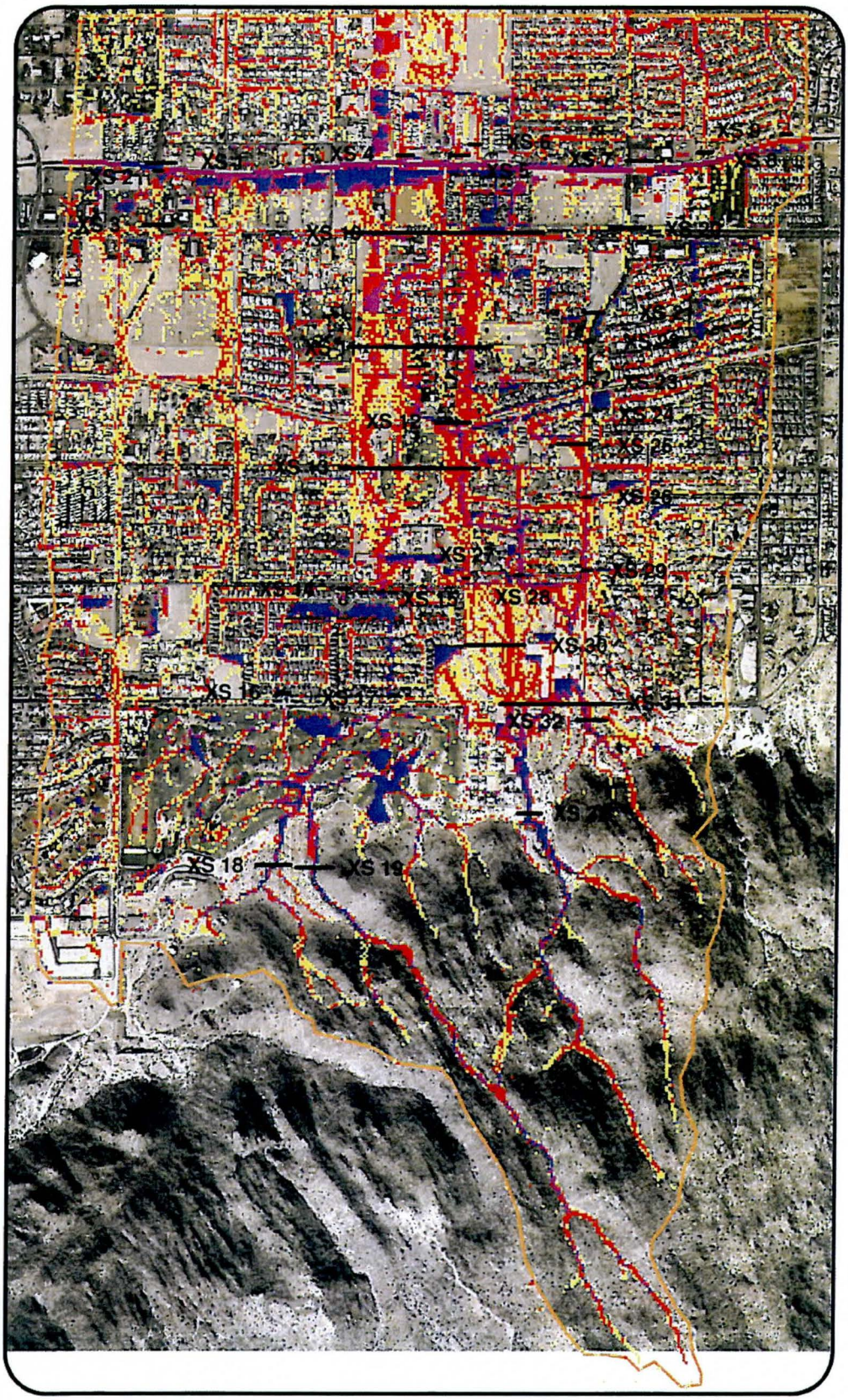
Pilot Study

Exhibit 3: 10-Yr, 6-Hr Flow Depths



Hohokam Area Drainage Master Study

Pilot Study:
Exhibit 4: 10-Yr, 24-Hr Flow Depths



Legend

Cross Sections

Pilot Study Boundary

10yr-24hr Flow Depth

- 0.01
- 0.02 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 3.00
- 3.01 - 8.00

N

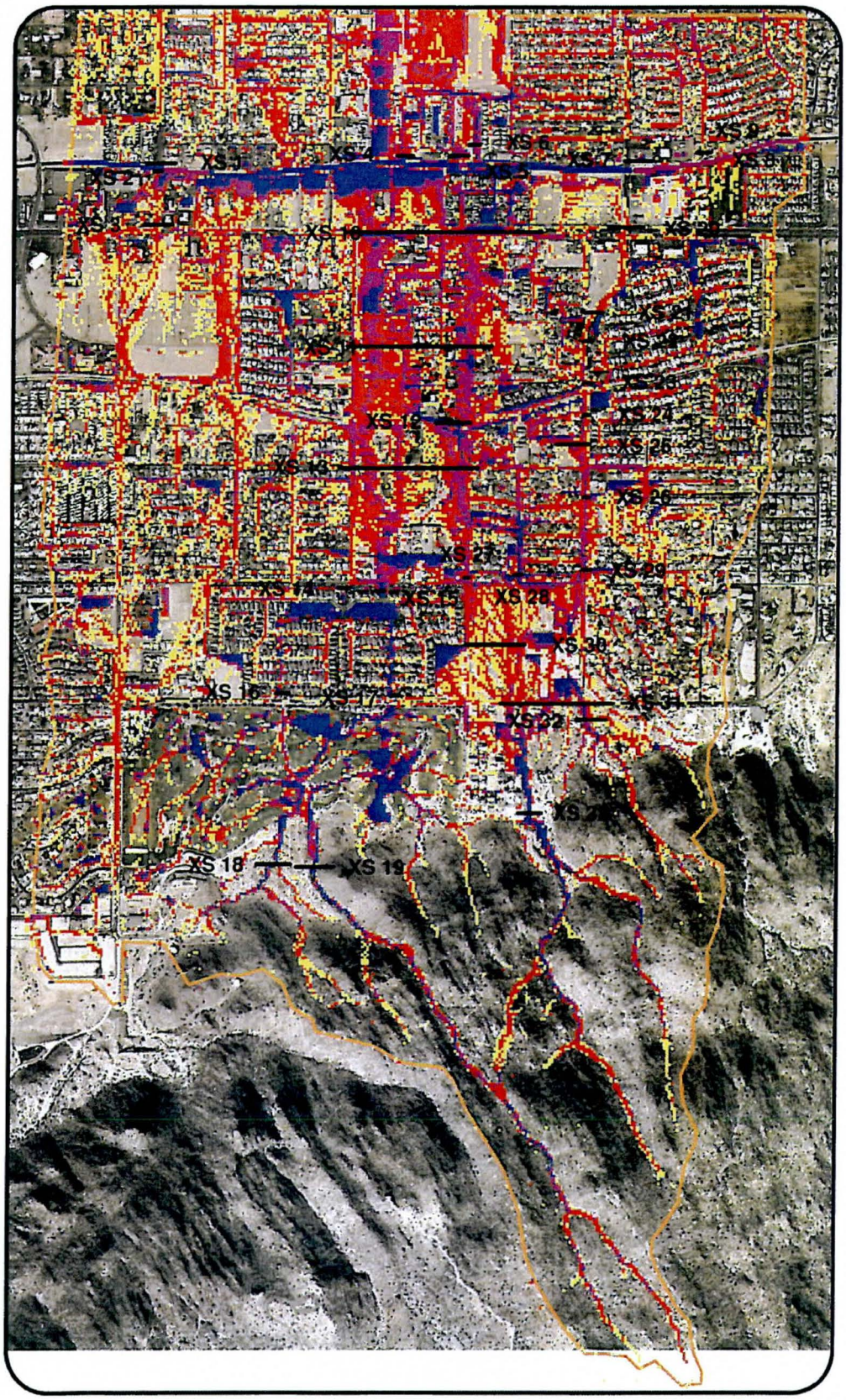
0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Pilot Study

Exhibit 5: 100-Yr, 6-Hr Flow Depths



Legend

Cross Sections

Pilot Study Boundary

100yr-6hr Flow Depth

- 0.01
- 0.02 - 0.10
- 0.11 - 0.20
- 0.21 - 0.50
- 0.51 - 1.00
- 1.01 - 3.00
- 3.01 - 8.00

N

0 0.125 0.25 0.5

Miles

Hohokam Area Drainage Master Study

Pilot Study

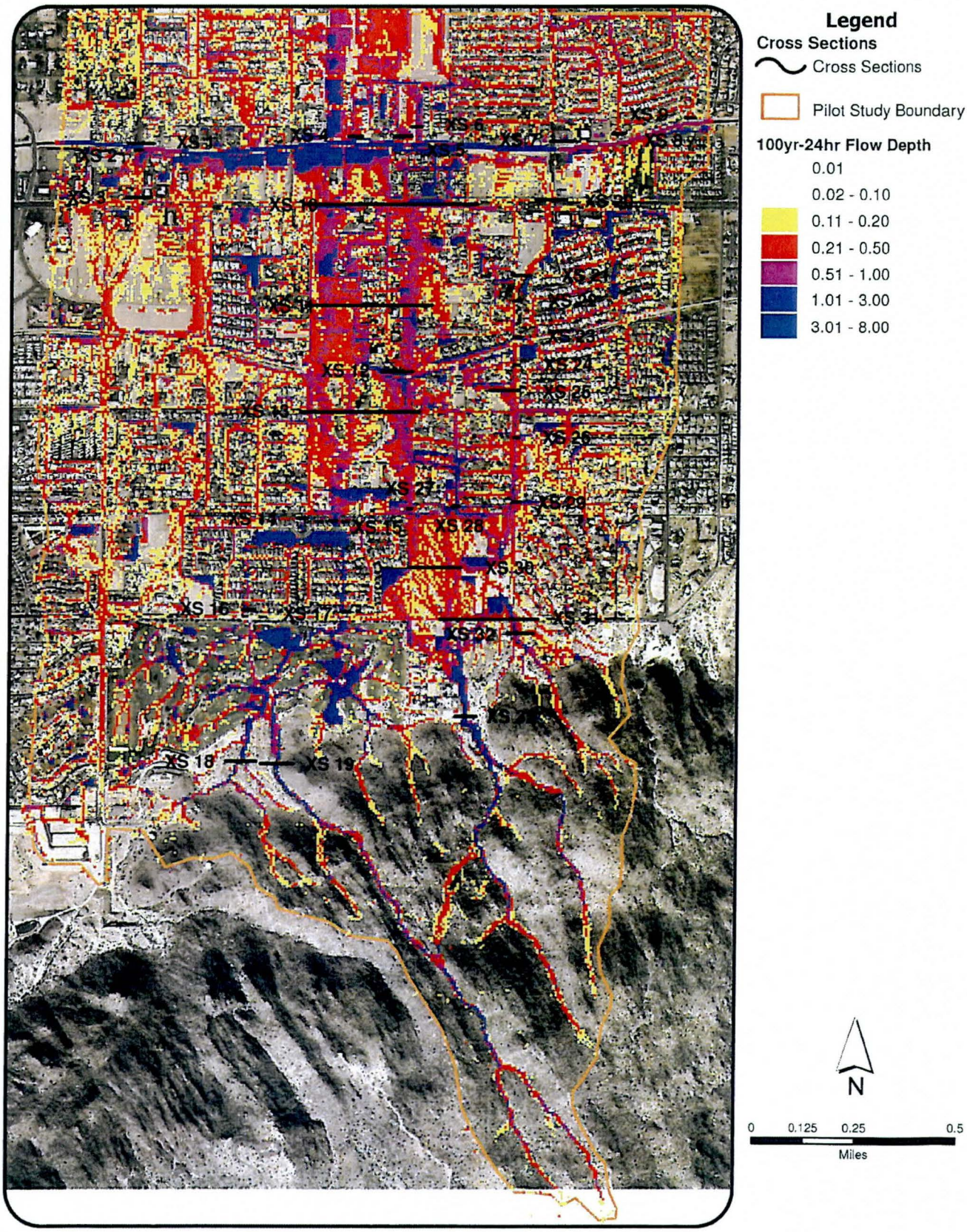



Exhibit 6: 100-Yr, 24-Hr Flow Depths