Ruthrauff Basin Management Plan
Technical Data Notebook for Hydrologic Analysis & Floodplain Mapping
Pima County Arizona.

FEMA FIRM Panels 04019C-1667, 1669, 1686, 1687, 1688 & 1689L

Prepared For:
Pima County Regional Flood Control District
97 East Congress Street, Third Floor
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November 2, 2015

Evan Canfield, PhD., P.E.
Project Manager
Pima County Regional Flood Control District
97 East Congress Street, Third Floor
Tucson, Arizona 85701

RE: Technical Data Notebook for 'Ruthrauff Basin Management Plan'

Dear Mr. Canfield:

JE Fuller/Hydrology & Geomorphology, Inc., (JEF) has prepared this report to document our hydrology and hydraulic analysis within the Ruthrauff Basin Management Plan study area. We are submitting digital FLO-2D models, floodplain maps, and assorted shape files along with this report. The flood maps submitted with this report document the 100-year, 3-hour flood depths and the 100-year discharges for the current conditions.

On behalf of JE Fuller, I want to say that we have enjoyed working with you, Terry, and others on this project. Thank you for your review and guidance along the way.

Sincerely,
JE Fuller/Hydrology & Geomorphology, Inc.

Ian P. Sharp, P.E., CFM
Project Engineer

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Exhibits

Attached CD

TDN with supporting models and GIS data.

1 INTRODUCTION

1.1 Purpose

The objective of this Technical Data Notebook (TDN) is to provide 100-yr peak discharges and 100-yr floodplain mapping for locations where 100-year flows exceed 100 cfs and depths exceed 0.2 feet, using the most up-to-date topographic, hydrologic, and hydraulic data available.

This TDN was prepared in accordance with the "Instructions for Organizing and Submitting Technical Documentation for Flood Studies" prepared by the Arizona Department of Water Resources, Flood Mitigation Section (Arizona State Standard, SSA 1) and FEMA Guidelines.

1.2 Project Authority

The State of Arizona has delegated the responsibility to each county flood control district to delineate or require the delineation of floodplains and to regulate development within floodplains (ARS § 48-3609):

1.3 Project Location

The study was performed to provide drainage information for the Ruthrauff Basin. The site includes Sections 08, 15-17, and 20-28 of Township 13 South, Range 13 East, and Sections 19 and 30 of Township 13 South, Range 17 East, Pima County, Arizona. The Ruthrauff Basin is primarily in FEMA Zone X, with small areas of Zone AO and Zone X Shaded as shown on the current Flood Insurance Rate Map (FIRM) number 04019C- 1667L, 1669L, 1686L, 1687, 1688 & 1689L.

The watershed is 8.5 square mile. The study watershed was divided into three domains for purposes of hydrologic modeling using FLO-2D (Figure 1.1).

1.4 Hydrologic and Hydraulic Methods

Hydrologic analysis was performed to estimate 100-yr peak discharges, flood depths and floodplain boundaries using FLO-2D. The Pro version was used for this modeling effort. Parameterization followed Technical Policy 033 developed by Pima County Regional Flood Control District as well as procedures described within Section 4.4 of this report. The proposed regulatory discharge is a flow rate that has a 1-percent chance of being equaled or exceeded each year ("100-year" discharge).

1.5 Acknowledgements

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

1.6 Study Results

The 100-yr discharges were calculated at various locations within the study area. Exhibit 1 includes 21 sheets which display the study area at 1"=200', documenting the existing features along with FLO-2D depths and a delineated floodplain. Calculated discharges are shown at many locations on Exhibit 1 and are summarized in Table 4.8 (page 28). The calculated discharges are compared with TSMS discharges in Table 4.9 (page 28).

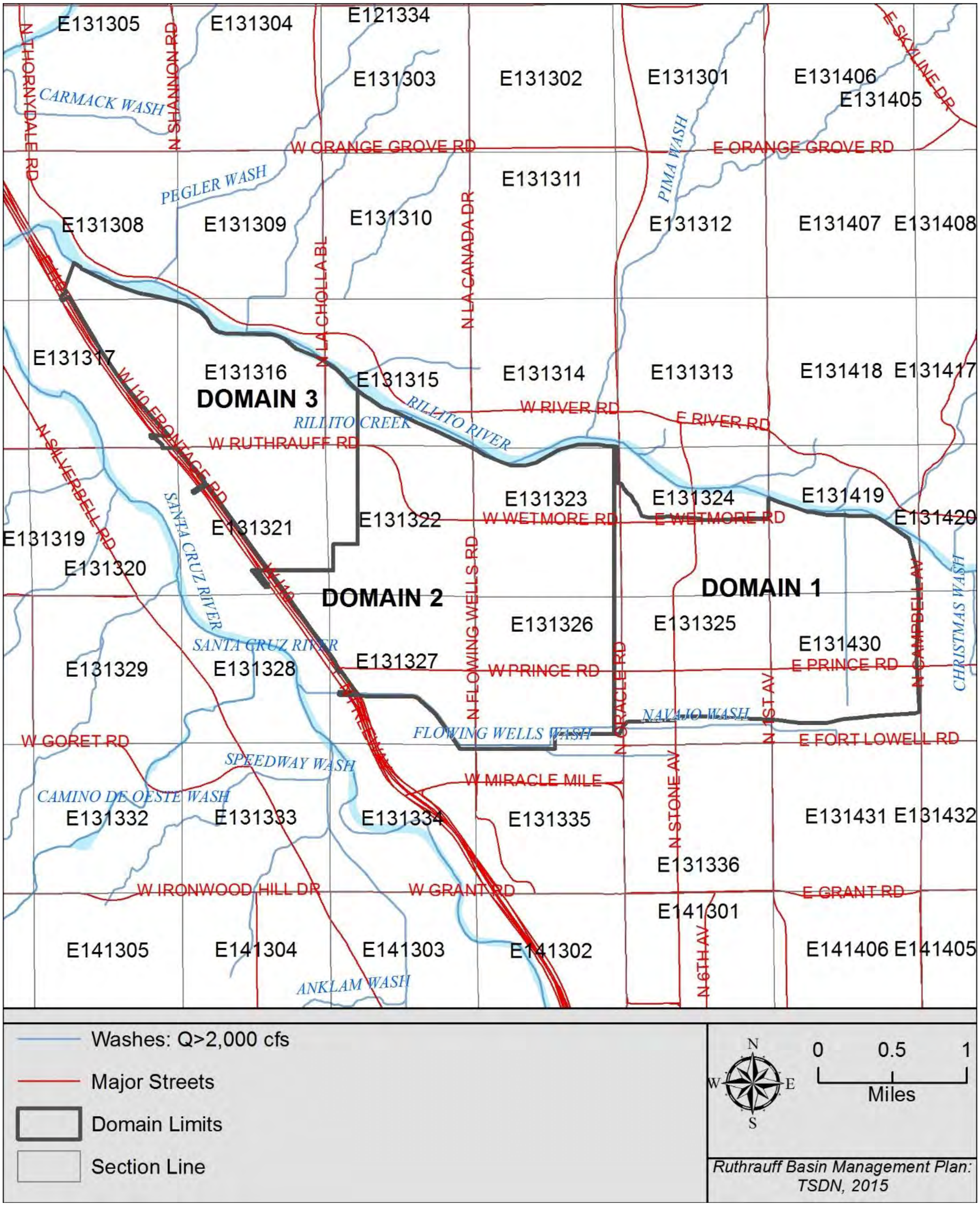

Figure 1.1. Watershed Map

2 Local Government Abstract

2.1 Project Contact Information

<u>Contact Information:</u>
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<u>Local Technical Reviewer</u>:
Evan Canfield and Akitsu Kimoto
Pima County Regional Flood Control District
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Evan.Canfield@pima.gov

Date Study Submitted: ___________________________

Date Study Approved: ____________________________

2.2 General Information

Community: Pima County Regional Flood Control
County: Pima County
River or Stream Name: Ruthrauff Basin
Reach Description: Urban area in near northwest Tucson metropolitan area
Study Type: Hydrology and Hydraulics study of an urban drainage system
Purpose of the Study: Estimate regulatory discharge and map floodplain boundaries

2.3 Survey and Mapping Information

Digital Projection Information: PAG 2008 orthophoto
USGS Quad Sheets if available:
Mapping for Hydrologic Study: LiDAR based on 2008 flight used to derive 2-ft contour interval maps using ArcGIS 10.0
Mapping for Hydraulic Study: LiDAR based on 2008 flight used to derive a DEM (5-ft cell size) for use with FLO-2D.

2.4 Hydrology

Model or Method Used: FLO-2D (Pro version)
Storm Duration: 1-, 3- and 24- hour
Hydrograph Type: SCS Type II 3-hr storm
Frequencies Determined: 10, 25 and 100 yr
List of Gages used in Frequency Analysis or Calibration: None
Rainfall Amounts and Reference: NOAA 14 Upper 90% Confidence Interval

Unique Conditions and Problems: None
Coordination of Q's: Comparison with existing FIS data

2.5 Hydraulics
Model or Method Used: FLO-2D (Pro Version)
Regime: Modeled as subcritical
Frequencies for which Profiles were computed: No profiles
Method of Floodway Calculation: No Floodway
Unique Conditions and Problems: None

2.6 Erosion, Sediment Transport and Geomorphic Analysis
NA

2.7 Additional Study Information
None

3 Survey and Mapping Information

3.1 Digital Projection Information

The data below are included in this TDN (see “GIS” folder)

Aerial Photo: PAG 2008 Orthophotos
Contour: 2 feet interval from PAG 2008 DEM
Topographic Data: 5-ft DEM
Projection: State Plane, Arizona Central Zone
Horizontal Datum: NAD83-92 (HARN)
Vertical Datum: NAVD-88
Units: International Feet

3.2 Field Survey Information

NA

3.3 Mapping

Digital Elevation Model (DEM) derived from 2008 Light Detection and Ranging (LiDAR) data was used for the FLO-2D analysis. The contour interval of the topographic map is 2 feet.

Following data are included in this TDN (see “GIS” folder):

Aerial Photo: PAG 2008 Orthophotos
Contour: 2 feet interval
Topographic Data: 5-ft DEM

4 Hydrology

4.1 Method Description

Hydrologic analysis was performed using FLO-2D (Pro version). The model requires the parameters such as rainfall, topography, soil, vegetation, and land use characteristics to determine runoff and flood depths. Those parameters were determined by following the Pima County Regional Flood Control District Technical Policy 033 (Tech-033). Tech-033 is included in Appendix A. The data processing methods are summarized in Fig. 4.1.

4.2 Parameter Estimation.

4.2.1 Drainage Area Boundaries

The study limit is shown in Figure 1.1. The watershed is 8.5 square mile and consists of an urban area in the north central portion of the City of Tucson and immediately adjacent unincorporated area. The watershed has extensive drainage infrastructure which consists primarily of small channels and storm drains. The study watershed was divided into three domains for purposes of hydrologic modeling using FLO-2D (Figure 1.1).

4.2.2 Watershed Work Maps

A work map showing the FLO-2D modeling domains with background aerial orthophoto is included in Exhibit 2. Exhibit 3 shows the locations of the obstructions within the model and the distribution of the Manning's value within the study area. Resulting floodplain mapping is included in Exhibit 4 and Exhibit 1.

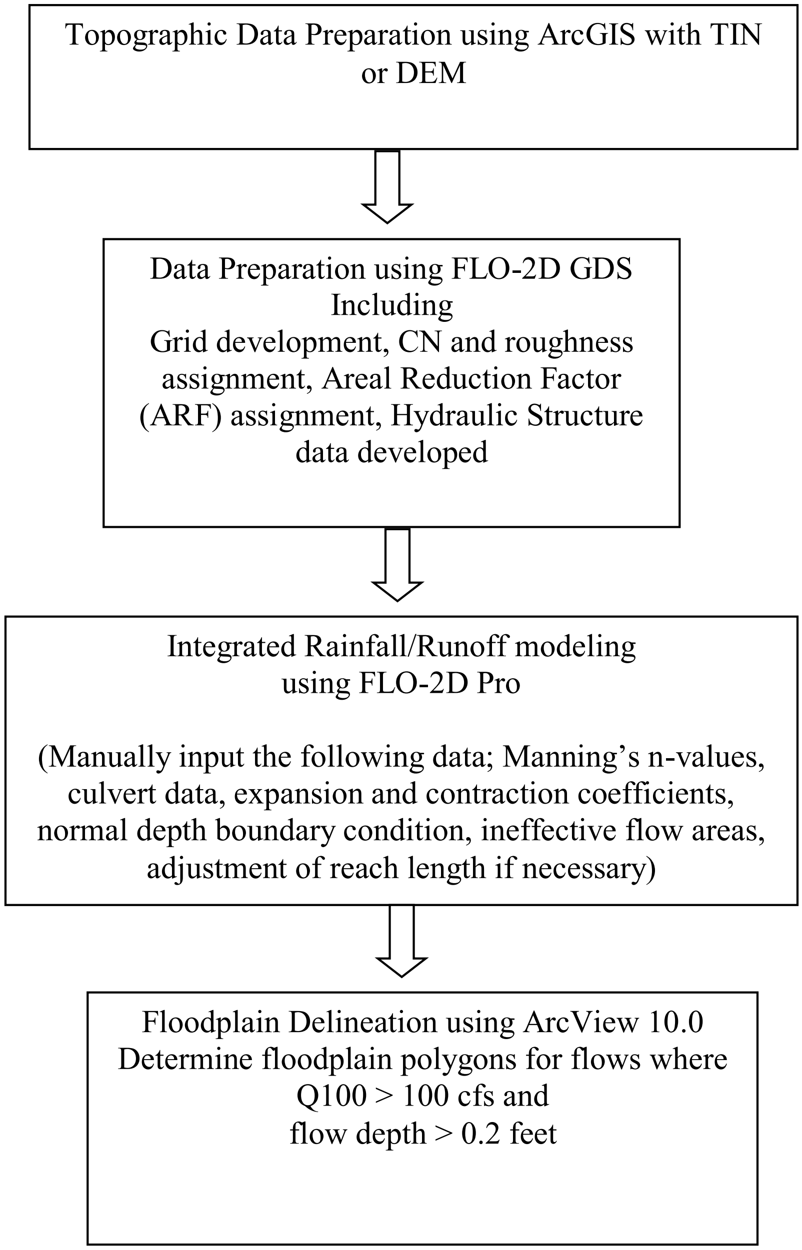


Figure 4.1 – Flow Chart of Mapping Process

4.2.3 Gage Data

NA

4.2.4 Statistical Parameters

NA

4.2.5 Precipitation

The NOAA 14 Atlas 90% upper confidence rainfall depth for the centroid of the study watershed was used for the FLO-2D analysis. No areal reduction factor was applied. The following rainfall distributions were used in the modeling (per Tech-018 unless noted otherwise);

- 1-hr Storm – NOAA depth-duration data were used to symmetrically nest the 5-, 10-, 15-, and 30-min depths within a one hour storm.
- 3-hr Storm - The SCS Type II 3-hr distribution was used per Tech-018.
- 24-hr Storm - The SCS Type I rainfall (NRCS, 1986) was applied per Tech-018.

Rainfall data is included in Appendix A. Discussion of rainfall distributions is included in Section B.3 of Appendix B.

4.2.6 Physical Parameters

Model methods and parameters are summarized in Table 4.1. The development of the parameters is described in the sections following Table 4.1 and also in correspondence letters provided in Appendix B. Please see Section B.4 in Appendix B for photographic documentation of the study area.

Table 4.1. FLO-2D Model Methods and Parameters

Parameter/Data	Description
Topographic Data	Primary Source: Pima Association of Governments (PAG) 2008 DEM data was used to develop a surface model of the project area.
FLO-2D Grid	15-foot grid developed from above described DEM data using FLO-2D GDS program. Data adjusted where needed to eliminate ponding grids and adjust for detail. Model sizes were as follows; • Domain 1 – 347,628 grids covering 2.8 square miles • Domain 2 – 453,152 grids covering 3.7 square miles • Domain 3 – 255,396 grids covering 2.1 square miles
Rainfall Data	NOAA14 Upper 90% confidence interval rainfall data was used (Reference 3) based on watershed centroid at Latitude: 32.2772°, Longitude: -110.9619° Three rainfall distributions were modeled separately as follows; • 1-hr Storm – NOAA depth-duration data were used to symmetrically nest the 5-, 10-, 15-, and 30-min depths within a one hour storm. • 3-hr Storm - The SCS Type II 3-hr distribution was used per Tech-018. • 24-hr Storm - The SCS Type I rainfall (NRCS, 1986) was applied per Tech-018. As a conservative measure, aerial reduction was not applied. The results of the modeling determined that the 3-hour storm generally dominated flood conditions within the model area.
Soils Data	NRCS soil survey data as found in Pima County GIS shape file soilshyd.shp.
SCS Curve Number	The CN was determined using the Curve Number table associated with the PC Hydro User Guide (Arroyo Engineering, 2007) and a Hydrologic Soils Group map. CN values were adjusted for various land uses as determined from Pima County and City of Tucson zoning data.
Roughness Coefficient	Roughness coefficients were assigned based on land use assignments including streets (.020), residential (.065), right-of-way (.030), retail (.055), open space (.045), commercial (.035) and others.
Structures	Hydraulic structures including bridges, culverts and storm drains were modeled using the HYSTRUC.DAT file to model flow leaving and returning to the system. An alternate scenario model was run for the 100-year, 3-hour event whereby the storm drains were omitted from the models.
Special Conditions	The study area was broken into three separate FLO-2D models (domains) to allow for the relatively small grid size (15’) while keeping run times manageable. Outflow from portions of Domain 1 were input into Domain 2, and outflow from portions of Domain 2 were input into Domain 3. Note that no area reduction was applied to estimate the peak discharges.

Infiltration Parameters

The SCS Curve Number (CN) method was utilized in the FLO-2D model. The CN was determined using the Curve Number table associated with the PC Hydro User Guide (Arroyo Engineering, 2007) and the following layers of data:

- Soils type. A hydrologic soils group map for the study watershed is presented in Figure 4.1. The study watershed is mostly covered with Desert Brush. Hydrologic Soil Group B is the dominant soil type in the watershed.
- Impervious cover. A GIS based analysis was performed to delineate areas which are explicitly impervious such as streets and buildings. The remaining study area was determined to be partially impervious, and further analysis was performed to estimate the percentage of impervious area within Pima County and City of Tucson Zoning Areas. It was assumed that streets and buildings are 100 percent impervious. On average, the areas not covered by streets and buildings were estimated to be 37 percent impervious and it was estimated that the watershed as a whole is 56 percent impervious. Further detail is within a July 2014 letter within Appendix B. See also Figure 4.2.
- Vegetative cover density. The cover density, or the percent of a given area covered by vegetation, was estimated by Zoning Area (similar to the impervious cover). On average, the study area not covered by roads and buildings has a 25 percent cover density with streets and buildings assumed to be at zero.
- Calculations were performed to assign an independent curve number for each grid element. Figure 4.4 shows the curve numbers within the study area. Note that the CN was not adjusted for rainfall intensity or antecedent moisture conditions in the FLO-2D model.

The SCS Unit Hydrograph method was used as the transform method.

For further details on how the curve number was computed, please see Section B.2 within Appendix B.

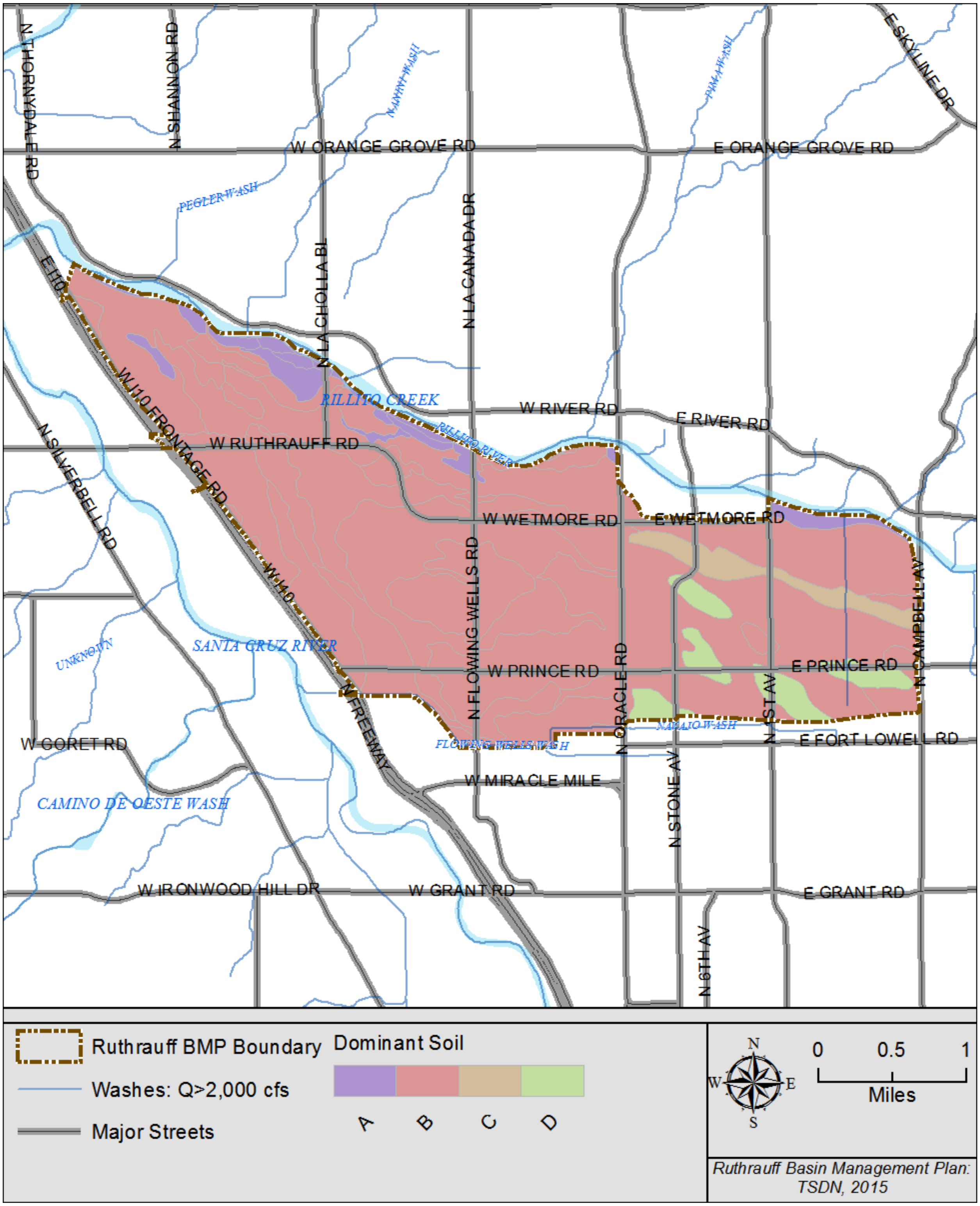


Figure 4.1. Soil Classification

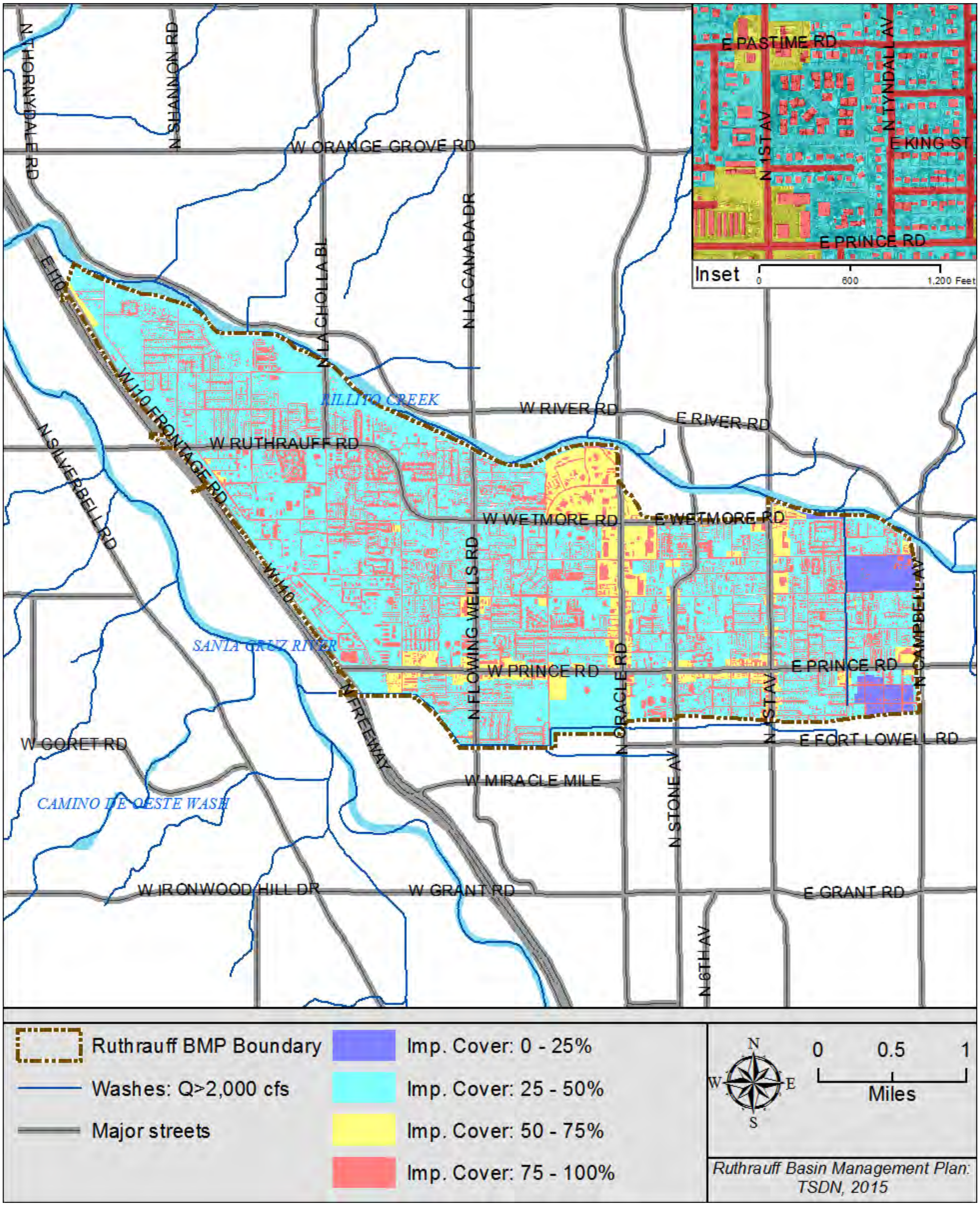


Figure 4.2. Impervious cover within study area.

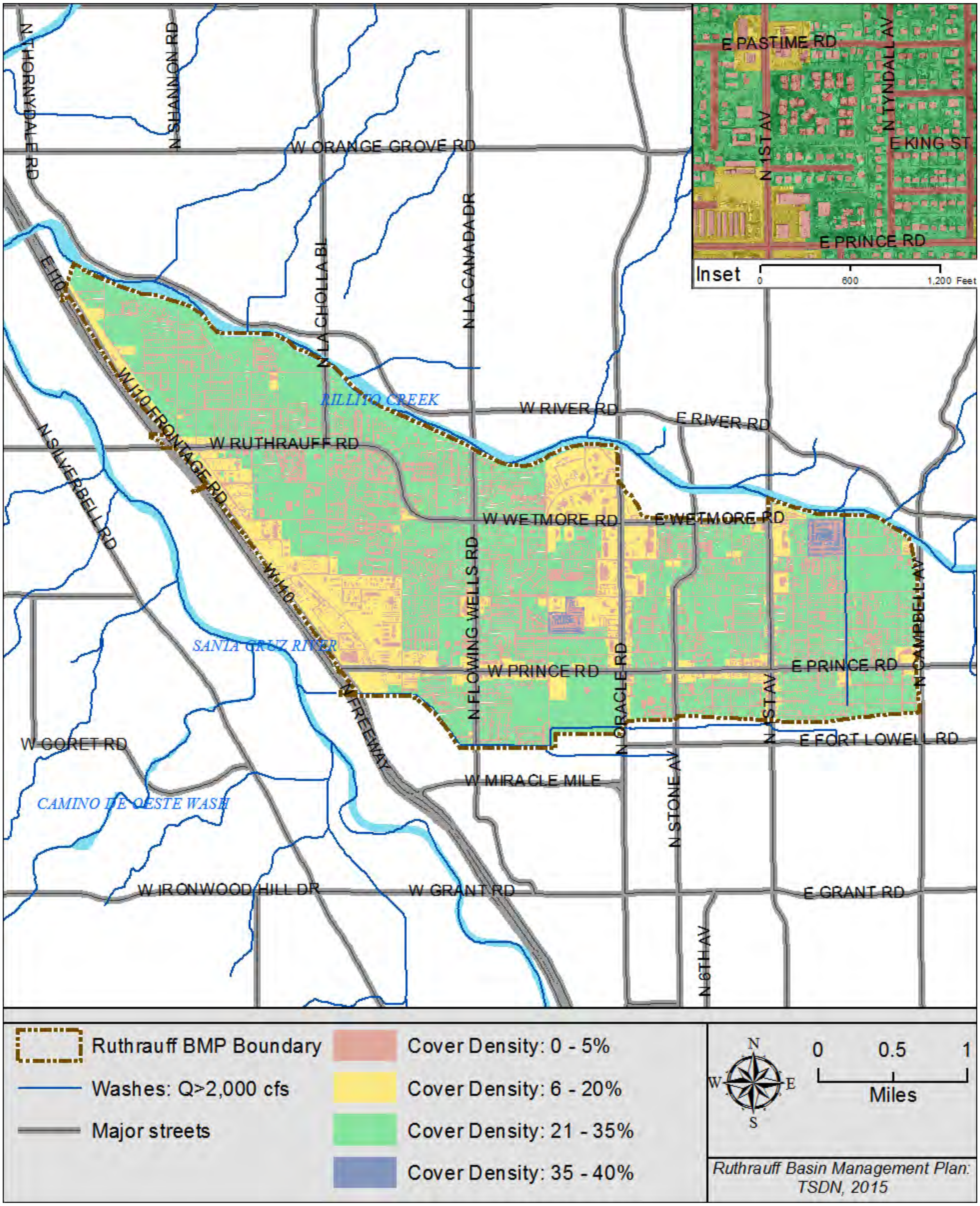


Figure 4.3. Vegetative cover density within study area.

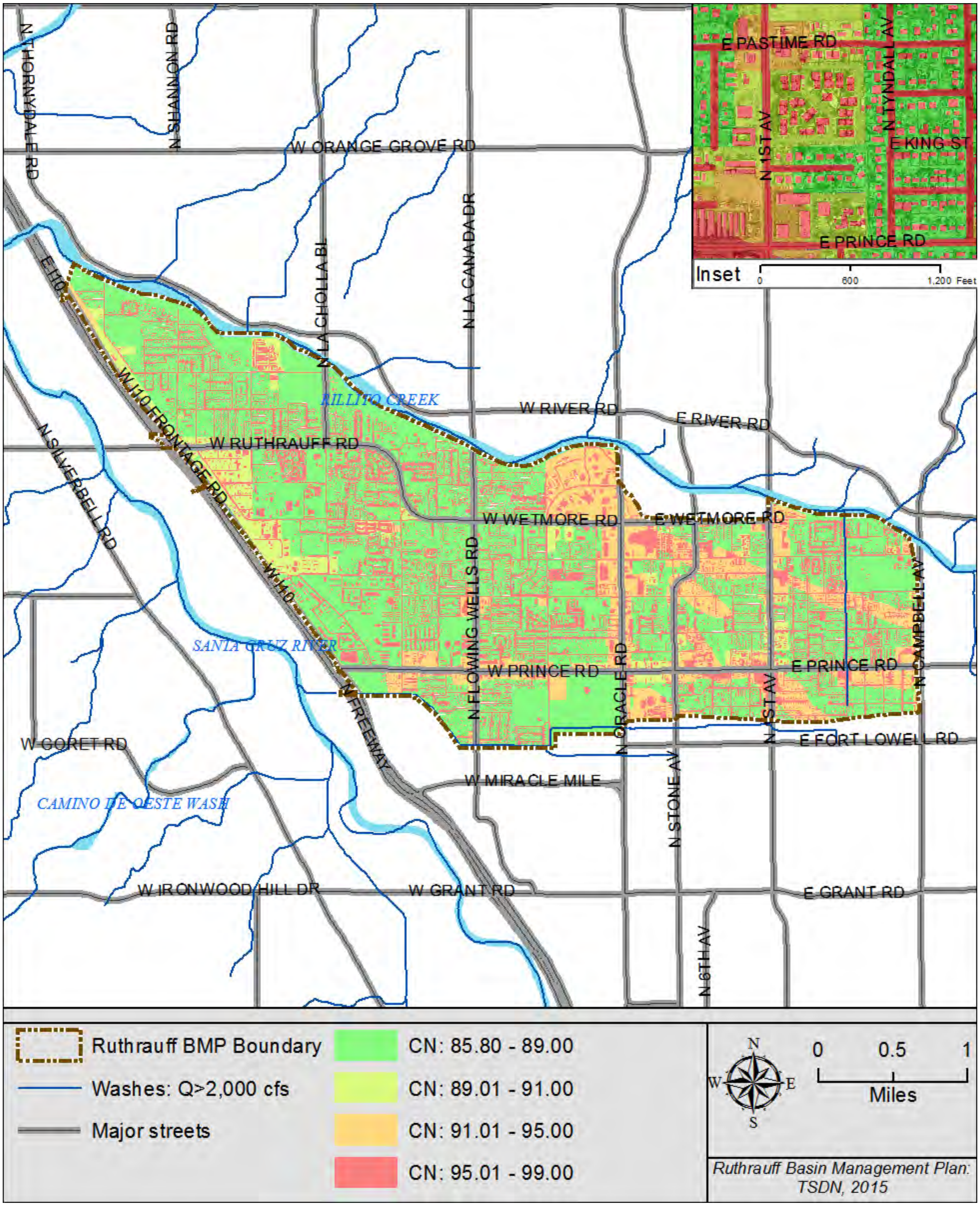


Figure 4.4. Curve numbers within study area.

Roughness Coefficients

The Manning's roughness coefficient is modeled spatially within FLO-2D, with the user assigning a value for each grid. Furthermore, this roughness value may be defined in multiple ways. All grid elements must have a "floodplain" roughness value which describes the roughness of the grid element. By default, the model applies this value to flow depths of 3.0 feet or greater. Depths of 0.5 feet or less are defined by the "shallow" roughness coefficient (SHALLOWN), which is typically in the range of 0.1 to 0.2. The model applies this value to depths below 0.20 feet, and then cuts it in half for depths between 0.20 and 0.50 feet. Values between 0.50 and 3.0 feet are adjusted up from the floodplain roughness value following an equation.

Both the shallow roughness and depth varied roughness equation are default and optional parameters. Early runs were performed using both of these parameters, however it was observed during calibration that the resulting peak discharges were lower than anticipated (see section 4.4). It was decided to turn off the shallow and variable roughness parameters for this project, forcing the model to use the floodplain roughness value at all flow depths. Because this value is typically one third to one half the shallow roughness value, the result was a quicker time to peak and higher discharges.

Figure 4.5 on the following page shows the distribution of the Manning's roughness value throughout the study area. Exhibit 3 also shows the distribution of the Manning's value along with the locations of the buildings modeled.

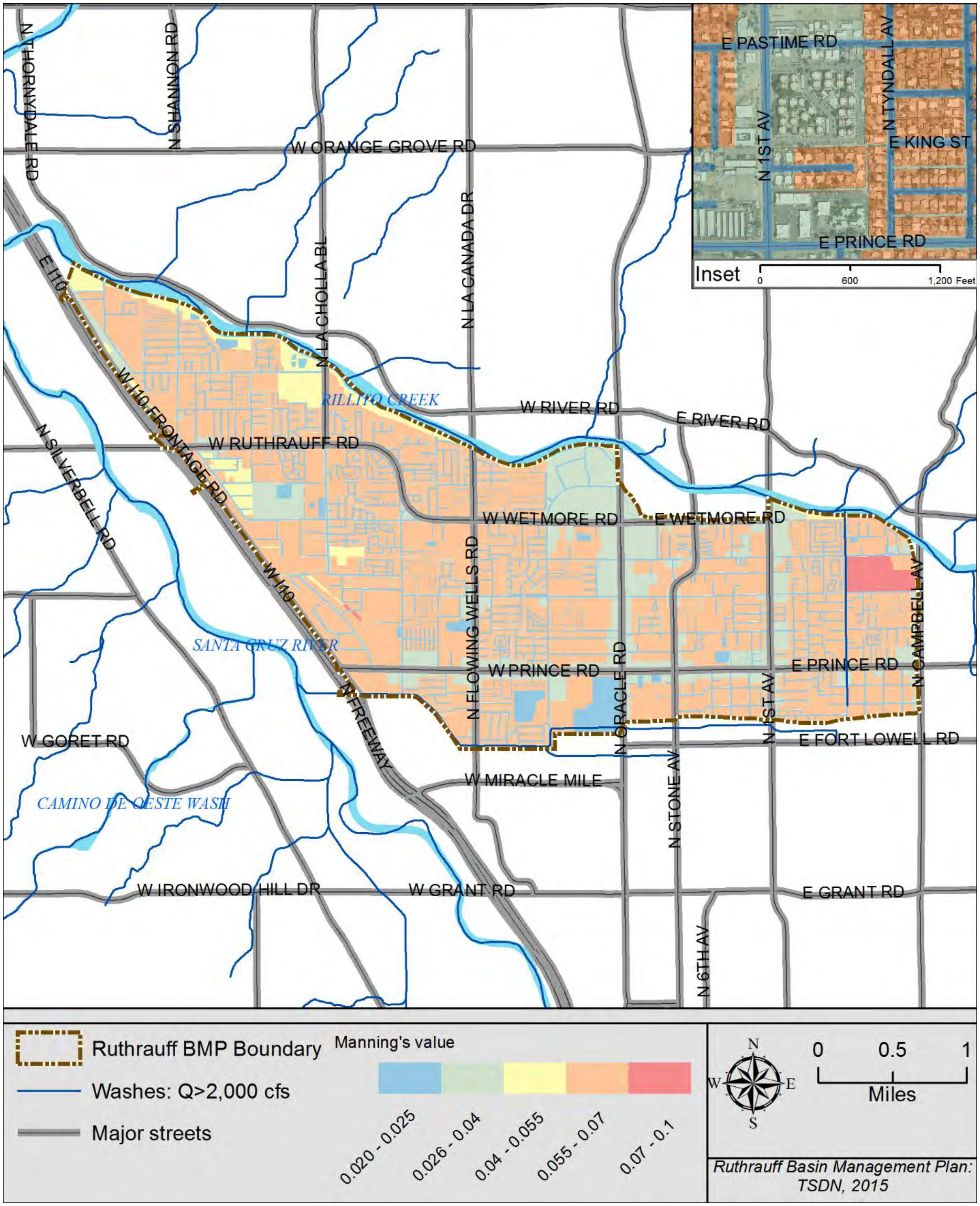


Figure 4.5. Manning's values in study area.

4.2.7 Storm Drain and Culverts

The study area contains many culverts and hundreds of storm drain inlets. These features were modeled within FLO-2D using the HYSTRUC.DAT file. Culvert dimensions were obtained from as-builts and field investigations. Rating tables were developed with HY-8 or the dimensions were entered into FLO-2D to allow it to compute the rating table.

The locations of storm drain inlets and pipes were determined initially through the use of shape files provided by Pima County and the City of Tucson. The locations were further refined through field and aerial inspection and with the use of the as-built plans. The rating tables that were developed for the inlets follow a series of steps described in Section B.5 of Appendix B and summarized as follows:

- Inlet dimensions were entered into a spread sheet. Curb and grate inlets were modeled using applicable equations from the City of Tucson Drainage Manual. Appropriate capture ratios were applied.
- In general, the above rating tables do not match well with the FLO-2D model. For a given depth, the inlet typically will drain a greater discharge than the FLO-2D model is conveying on a grid element at that depth. Therefore, the rating tables were scaled down by computing a stage-discharge relationship for a 15 foot wide (FLO-2D grid size) travel lane.
- Storm drain inlets were joined into systems by assigning common outlets on the HYSTRUC.DAT file (D line). The peak discharge at the outlet was compared to computations of full flow depth and/or hydraulic grade line analyses of storm drain systems to assure that the FLO-2D model was not overestimating the discharge that the system could really convey. Where necessary, the inlet rating tables were scaled back further to reduce the flow to storm drain pipes.
- The above steps result in rating tables which model the storm drain inlets without overestimating flow exiting the study area.

Buildings

The study area contains hundreds of buildings which will obstruct and divert runoff should they encounter flows. Buildings were modeled using the ARF.DAT file. The locations of the buildings were determined through GIS operations. Initially, Pima County provided a shape file showing the building footprints. The building footprints in this file were refined as necessary and were then imported into the FLO-2D GDS program to develop the ARF.DAT file. This process leads to an array which describes cells as either totally obstructed or partially obstructed. Any cell which was 60% obstructed or greater was revised to be completely blocked, all other cells were removed from the file. This procedure simplified the computations and eliminated some FLO-2D runtime errors.

Exhibit 3 shows the locations of the buildings modeled as obstructions.

4.3 Issues Encountered During the Study.

4.3.1 Special problems and solutions

The study area was broken into three separate FLO-2D models (domains) to allow for the relatively small grid size (15’) while keeping model run times manageable. Outflow from portions of Domain 1 were input into Domain 2, and outflow from portions of Domain 2 were input into Domain 3.

4.3.2 Modeling Warning and Error Messages

No error messages. Minor warning messages were received at some hydraulic structures for various runs, typically where outlet control was indicated for limited durations or rating tables were revised during runtime by the model.

4.4 Calibration

Limited calibration was performed to compare runoff rates from a sample portion of the study area to a HEC-1 model developed for the same area. This analysis was performed to determine what impacts may occur by altering the roughness parameters, including:

- SHALLOWN – the basic roughness parameter that FLO-2D uses for depths of 6 inches or less. Reducing the value of, or eliminating this variable, should increase discharges.
- Depth Variable Roughness (DVR) – the equation FLO-2D uses to increase floodplain roughness as depth decreases. Turning off this variable (which must be done while turning off SHALLOWN) should reduce time to peak and thus increase the peak discharge.
- Roughness in the streets. It was speculated that by lowering the roughness value of the grids representing streets, that the velocity will increase in the primary flow paths and the discharges will increase. (Early runs used a roughness value of 0.025 in the streets.)
- Limiting Froude Number. Preliminary models used a limiting Froude number of 0.9 globally. It is possible that supercritical flow may exist in some street segments, therefore this parameter was analyzed.

4.4.1 Calibration Method

A test model was developed to analyze parameters independently. This model is bounded by Prince Road on the south and First Avenue on the west. A topographic divide bounds the model on the east, roughly along Vine Ave., then curving southwest past Roger Road. Figure 4.6 shows the model limits, including three sub-areas. The Roger Road sub-area drains to the intersection of Roger Road and First Avenue. The Via Villas area drains to two locations within a linear basin/channel, one exits to the west and the other to the north. The additional area not analyzed contains a number of small concentration points along 1st Avenue at minor streets.

For each model, the hydrograph, peak discharge, and time of peak were recorded at the three concentration points shown on Figure 4.6. A combined hydrograph was also tabulated, combining the three concentration points.

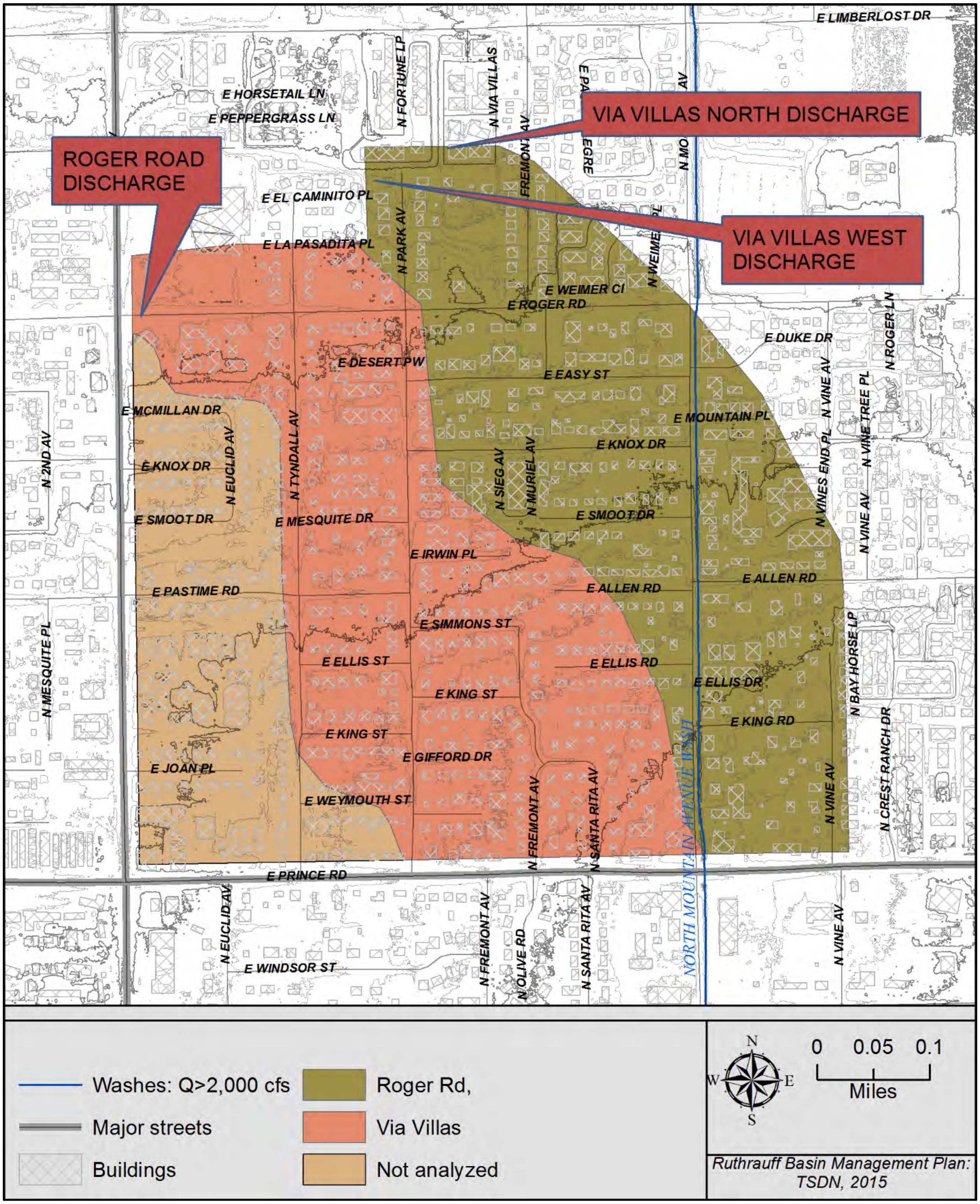


Figure 4.6. Calibration model area.

4.4.2 Comparable HEC-1 model.

In the absence of gage data for calibration, a HEC-1 model was prepared to compare to the FLO-2D models. The Time of Concentration was computed following TECH-018 which references USDS-NRCD TR55. The procedures in TR55 were used to compute the Time of Concentration assuming this watershed contains a sheet flow region and a shallow concentrated flow region. In the sheet flow region, the n value was set to 0.10 based upon matching the lowest SHALLOWN value used. The HEC-1 models yield a discharge of about 350 cfs.

It should be stressed here that HEC-1 is another model and it has its own limitations that make it difficult to use in this study area. For example, it was found that the Sheet Flow time of concentration is extremely sensitive and can have a significant impact upon the predicted peak discharge. Another observation regarding the TR-55 procedure is that it assumes an average velocity for an entire sub-reach based only on slope and whether the path is paved. This does not account for what the total discharge is along the path. Furthermore, HEC-1 relies upon lumped parameter assumptions, has no awareness of flow splits, recombinations, and ponding, and assigns average values from a reference book (in HEC-1) instead of applying equations to terrain (as in FLO-2D). The point is that while the procedures used by HEC-1 are trusted by floodplain modelers and regulators, it is simply another tool. However, given the lack of statistical data, it was decided to calibrate the FLO-2D model to HEC-1.

4.4.3 Models Prepared.

One model was prepared for this analysis. It models the 100-year, 3-hour storm and has many sub-models to test the parameters. Table 4.2 documents the tested parameters and the resulting peak discharge from the combined Roger Road and Via Villas watersheds. This value was compared to the peak discharge of 350 cfs produced by HEC-1.

Table 4.2. Summary of parameters in calibration models.

Variable tested	Model	SHALLOW N	Floodplain N	DVR	TOL (ft)	Limiting FR	Resulting Q (cfs)
SHALLOWN	105	**0.10**	Global n=0.015	On	0.03	Global FR=1.5	**254**
	110	**0.15**	Global n=0.015	On	0.03	Global FR=1.5	**225**
	120	**0.20**	Global n=0.015	On	0.03	Global FR=1.5	**202**
	130	**0.30**	Global n=0.015	On	0.03	Global FR=1.5	**160**
	140	**0.40**	Global n=0.015	On	0.03	Global FR=1.5	**147**
Floodplain n value on a global level	210	0.15	**Global n=0.020**	On	0.03	Global FR=1.5	**213**
	220	0.15	**Global n=0.030**	On	0.03	Global FR=1.5	**189**
	230	0.15	**Global n=0.040**	On	0.03	Global FR=1.5	**172**
	240	0.15	**Global n=0.050**	On	0.03	Global FR=1.5	**160**
	250	0.15	**Global n=0.060**	On	0.03	Global FR=1.5	**151**
	260	0.15	**Global n=0.070**	On	0.03	Global FR=1.5	**141**
n value in streets	310	0.20	**Streets*=0.015**	On	0.03	Global FR=1.5	**188**
	320	0.20	**Streets*=0.020**	On	0.03	Global FR=1.5	**179**
	330	0.20	**Streets*=0.025**	On	0.03	Global FR=1.5	**174**
n value in streets	410	0.15	**Streets*=0.015**	On	0.03	Global FR=1.5	**210**
	420	0.15	**Streets*=0.020**	On	0.03	Global FR=1.5	**200**
	430	0.15	**Streets*=0.025**	On	0.03	Global FR=1.5	**188**
n value in streets	510	0.15	**Streets*=0.015**	On	0.03	0.9 / 1.2**	**209**
	520	0.15	**Streets*=0.020**	On	0.03	0.9 / 1.2**	**199**
	530	0.15	**Streets*=0.025**	On	0.03	0.9 / 1.2**	**198**
n value in streets	610	0.10	**Streets*=0.015**	On	0.03	0.9 / 1.2**	**242**
	620	0.10	**Streets*=0.020**	On	0.03	0.9 / 1.2**	**231**
	630	0.10	**Streets*=0.025**	On	0.03	0.9 / 1.2**	**223**
n value in streets	710	0.10	**Streets*=0.015**	Off	0.03	0.9 / 1.2**	**249**
	720	0.10	**Streets*=0.020**	Off	0.03	0.9 / 1.2**	**241**
	730	0.10	**Streets*=0.025**	Off	0.03	0.9 / 1.2**	**235**
TOL	810	0.10	Streets*=0.015	On	0.001	0.9 / 1.2**	**250**
	820	Off	Streets*=0.015	Off	**0.03**	0.9 / 1.2**	**328**
	830	Off	Streets*=0.015	Off	**0.001**	0.9 / 1.2**	**334**
	840	Off	Streets*=0.015	Off	**0.005**	0.95 / 1.2**	**339**

Notes. * n values assigned via shape file outside streets. ** FR outsides streets / FR in streets.

Test of SHALLOWN. A total of 5 models test the SHALLOWN value, varying it from 0.10 to 0.40. The Limiting Froude number was set to 1.5 and the floodplain roughness is set to 0.015 everywhere.

Table 4.3. FLO-2D calibration: test of SHALLOWN variable

Model	SHALLOWN	Roger Rd.		Villas West		Villas East		Combined		Percent area above 1.0 ft	Percent area above 0.2 ft
		Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)		
105	0.10	97	1.85	26	1.83	150	1.82	**254**	1.90	6.8%	47.0%
110	0.15	84	1.92	21	1.88	131	1.92	**225**	1.90	7.2%	50.4%
120	0.20	74	2.01	18	1.88	120	2.07	**202**	2.00	7.5%	52.9%
130	0.30	63	2.02	15	1.88	109	1.98	**160**	2.00	8.2%	56.8%
140	0.40	52	2.09	16	1.83	103	2.19	**147**	2.20	8.7%	59.6%

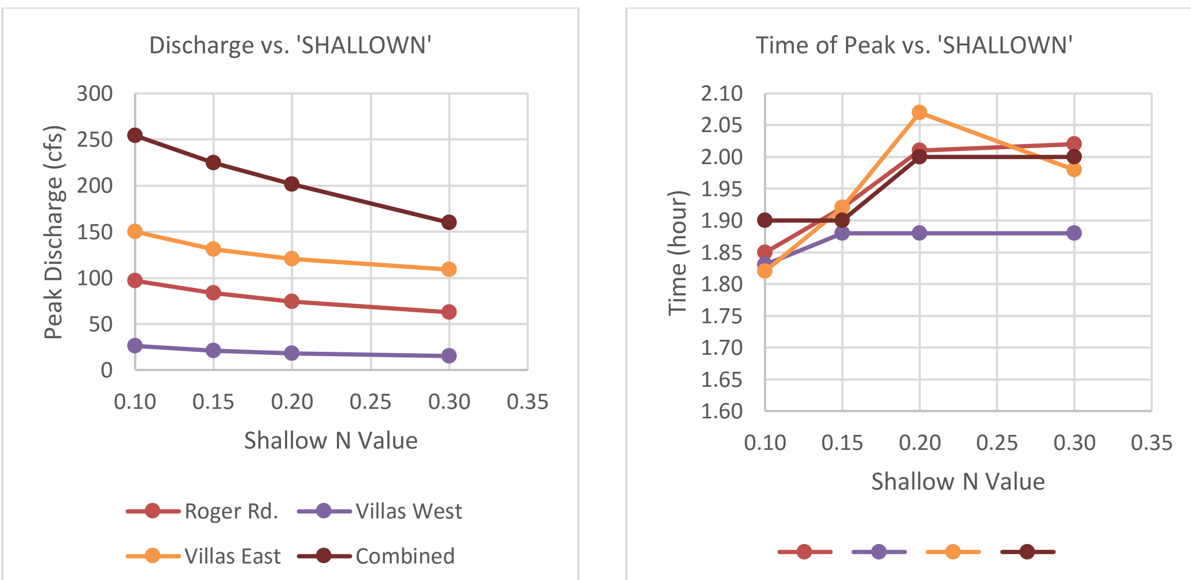


Figure 4.7. Discharge and time of peak versus SHALLOWN

Observation. As would be expected, lower SHALLOWN values lead to higher discharges and quicker times to peak. The default SHALLOWN value in a FLO-2D model is 0.2, however simply reducing this to 0.1 has a significant impact upon reported discharge.

Reducing SHALLOWN also reduces the overall inundation area as shown in the last column of the above table.

Test of globally assigned roughness value. A total of 6 models determine the effect of altering the floodplain roughness value on a global level (all grid elements have the same roughness). The roughness varied from 0.020 to 0.070 while SHALLOWN was set to 0.15 and the Limiting Froude number was set to 1.5. (Note that Model 110 from the previously described series fits into this array with a roughness value of 0.015).

Table 4.4. FLO-2D calibration: test of globally assigned floodplain roughness variable

Model	Global n value	Roger Rd.		Villas West		Villas East		Combined		Percent area above 0.5 ft	Percent area above 0.1 ft
		Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)		
140	0.015	52	2.09	16	1.83	103	2.19	**147**	2.20	8.7%	59.6%
210	0.020	79	2.01	19	1.86	126	2	**213**	2.10	7.3%	50.6%
220	0.030	72	2.12	15	2.06	115	2.12	**189**	2.20	7.4%	51.1%
230	0.040	67	2.3	14	1.98	105	2.05	**172**	2.20	7.6%	51.4%
240	0.050	62	2.44	13	2.03	98	2.07	**160**	2.30	7.9%	51.7%
250	0.060	59	2.58	12	2.12	92	1.99	**151**	2.50	8.1%	52.0%
260	0.070	56	2.67	12	2.16	88	2.14	**141**	2.50	8.3%	52.2%

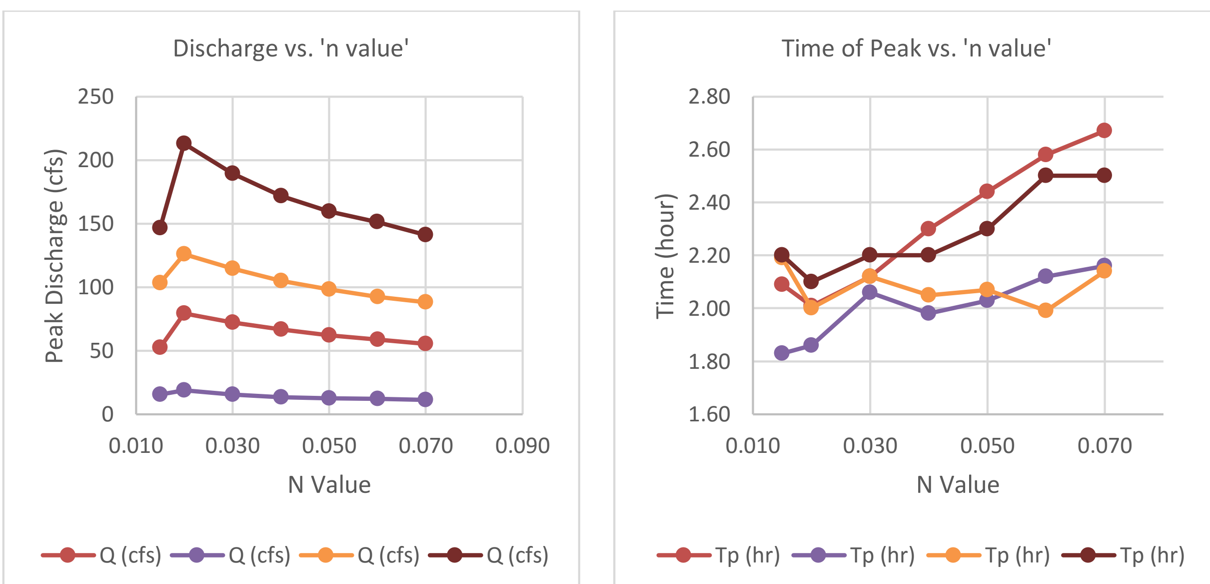


Figure 4.8. Discharge and time of peak versus global floodplain 'n' value

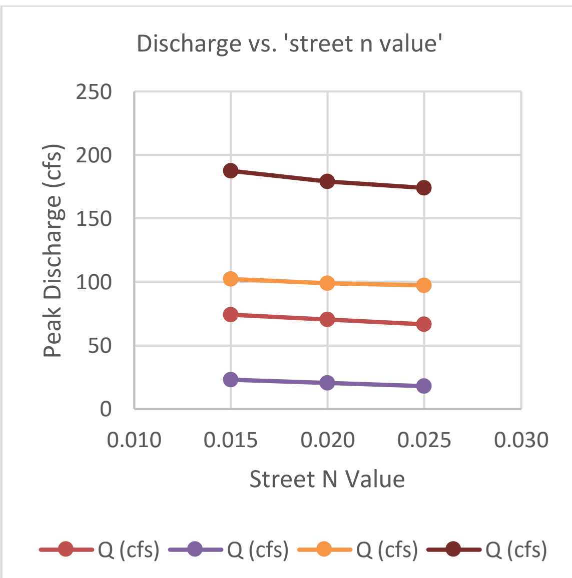
Observation. As expected, the floodplain roughness value has a logical impact upon discharge. Lower values tend to result in a lower time of peak and a higher peak discharge.

With the exception of extremely low floodplain values (Model 140), changing the floodplain roughness value has little impact upon the inundation area.

Test of varying street roughness. Several of the models (300-700) test the effect of changing the roughness value in the streets while holding other variables constant. Their results are very similar. The table and figure below compare the resulting discharge from the 300 series models which used SHALLOWN=0.20 and a limiting Froude Number of 1.5

Table 4.5. FLO-2D calibration: test of varying street roughness values.

Model	Street n	Roger Rd.		Villas West		Villas East		Combined		Percent area above 0.5 ft	Percent area above 0.1 ft
		Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)		
310	0.015	74	1.92	23	1.91	8.7%	59.6%	**188**	2.10	7.7%	53.0%
320	0.020	70	2.03	20	1.99	7.3%	50.6%	**179**	2.00	7.7%	53.2%
330	0.025	67	2.11	18	2.01	7.4%	51.1%	**174**	2.10	7.8%	53.4%



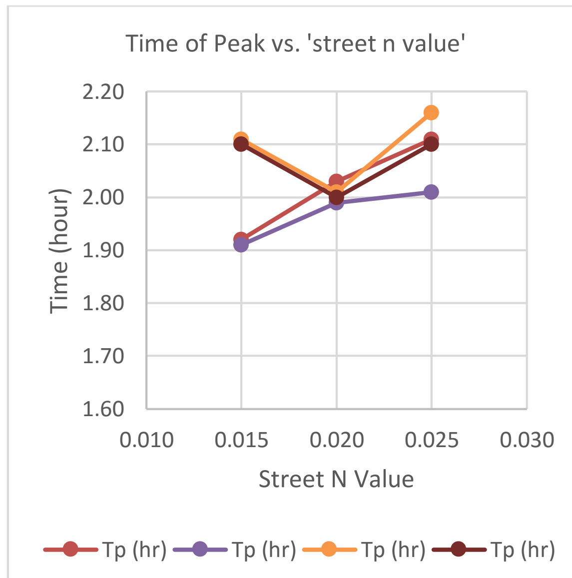


Figure 4.9. Discharge and time of peak versus street 'n' value

Observation. Reducing the street roughness value has the result of increasing peak discharge, although the impact is less significant than adjusting SHALLOWN and overall roughness. The inundation area does not seem to be impacted by changing this variable.

Test of Depth Variable and SHALLOWNN functions. After running the 100-600 series models, it was observed that FLO-2D was still generating discharges lower than a comparable HEC-1 model (see Section 4.4.2). JE Fuller staff have prepared models in other jurisdictions where the SHALLOWN and Depth Variable Roughness parameters were turned off. After discussions with FLO-2D representatives and District staff, it was decided to test turning these parameters off in this study area. The table below shows results at the concentration points and the figure shows peak discharge and time of peak at the combined concentration point.

Table 4.6. FLO-2D calibration: test of varying street roughness values.

Model	DVR / SHALLOWN	Roger Rd.		Villas West		Villas East		Combined		Percent area above 0.5 ft	Percent area above 0.1 ft
		Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)	Q (cfs)	Tp (hr)		
610	ON / ON	97	1.86	35	1.81	7.7%	53.0%	**242**	2.00	7.1	47.2%
710	OFF / ON	97	1.86	35	1.81	7.7%	53.2%	**249**	1.80	6.9	47.0%
820	OFF / OFF	127	1.79	52	1.76	7.8%	53.4%	**328**	1.90	6.2	40.8%

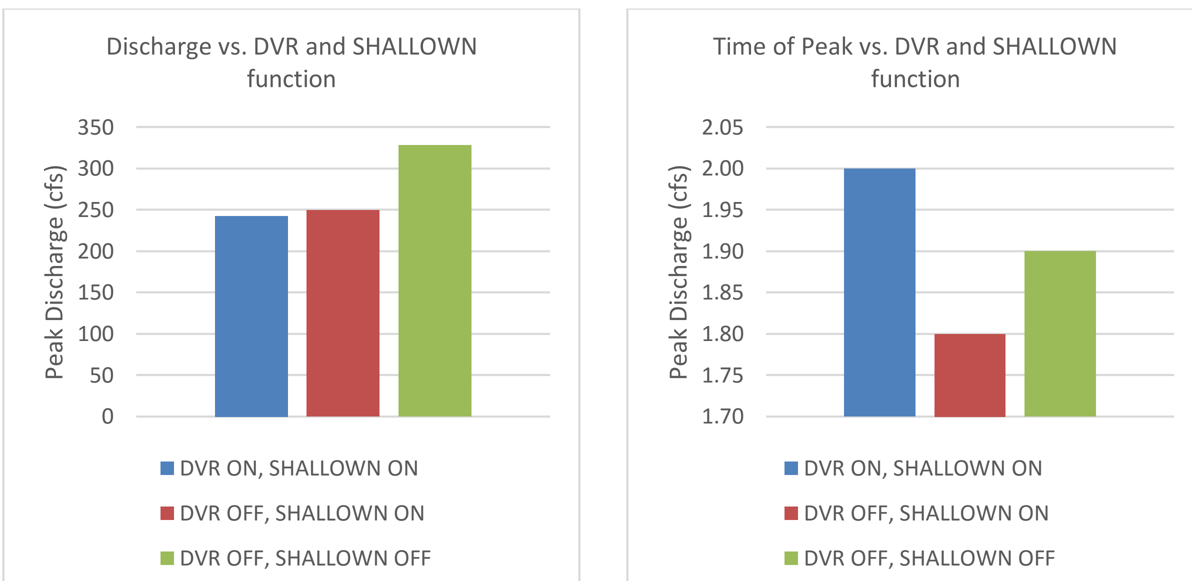


Figure 4.10. Discharge and time of peak versus DVR and SHALLOWN function

Conclusions. The use or exclusion of the Depth Variable Roughness made little impact upon the peak discharge, although turning this variable off reduced the time of peak by about 10 percent. Turning both DVR and SHALLOWN off reduces time of peak by about 5 percent while increasing the peak discharge by 35 percent in the scenario modeled.

Conclusions from Calibration

The reported peak discharge varies significantly within the models prepared. The total inundation area was also impacted by these parameters, although to a lessened extent. Most of these models have parameters which could be justified and have been used in previous studies. However, this indicates how sensitive FLO-2D is to parameterization. See Table 4.7 for further documentation of the inundated area for these and all other calibration models.

Of all of the parameters tested, the use of or exclusion of both the SHALLOWN and Depth Varied Roughness has the greatest impact upon the peak discharge and the overall inundation area. The change in flooded area was not significant until the SHALLOWN and Depth Varied Roughness parameters were turned off. With these off, the inundation area is reduced at shallow depths (those affected by SHALLOWN) and increased for deeper depths (resulting from higher peak discharges).

Based upon the calibration exercise, the following parameters were applied to the study area:

- Limiting Froude Number of 0.95.
- Street ‘n’ of 0.020.
- Turn of Shallow ‘n’, turn off depth variable roughness.
- Set surface detention (variable TOL) to .005 feet

Table 4.7. Summary of input and results for FLO-2D calibration model.

Model	SHALLOWN	DVR	TOL (ft)	Resulting Q (cfs)	Portion of area above depth:				
					0.1 ft	0.2 ft	0.5 ft	1.0 ft	2.0 ft
105	0.10	On	0.03	254	47.0%	30.3%	6.8%	0.73%	0.06%
110	0.15	On	0.03	225	50.4%	32.5%	7.2%	0.68%	0.05%
120	0.20	On	0.03	202	52.9%	34.2%	7.5%	0.64%	0.05%
130	0.30	On	0.03	160	56.8%	36.7%	8.2%	0.57%	0.05%
140	0.40	On	0.03	147	59.6%	38.6%	8.7%	0.56%	0.05%
210	0.15	On	0.03	213	50.6%	32.8%	7.3%	0.72%	0.05%
220	0.15	On	0.03	189	51.1%	33.3%	7.4%	0.81%	0.05%
230	0.15	On	0.03	172	51.4%	33.7%	7.6%	0.90%	0.05%
240	0.15	On	0.03	160	51.7%	34.1%	7.9%	0.98%	0.06%
250	0.15	On	0.03	151	52.0%	34.4%	8.1%	1.06%	0.06%
260	0.15	On	0.03	141	52.2%	34.7%	8.3%	1.14%	0.06%
310	0.20	On	0.03	188	53.0%	34.4%	7.7%	0.73%	0.07%
320	0.20	On	0.03	179	53.2%	34.6%	7.7%	0.76%	0.06%
330	0.20	On	0.03	174	53.4%	34.8%	7.8%	0.78%	0.06%
410	0.15	On	0.03	210	50.5%	32.7%	7.4%	0.78%	0.07%
420	0.15	On	0.03	200	50.8%	33.1%	7.4%	0.81%	0.07%
430	0.15	On	0.03	188	50.9%	33.2%	7.4%	0.84%	0.07%
510	0.15	On	0.03	209	50.5%	32.7%	7.4%	0.78%	0.07%
520	0.15	On	0.03	199	50.8%	33.1%	7.4%	0.81%	0.07%
530	0.15	On	0.03	198	50.9%	33.2%	7.5%	0.84%	0.07%
610	0.10	On	0.03	242	47.2%	30.4%	7.1%	0.84%	0.08%
620	0.10	On	0.03	231	47.5%	30.7%	7.0%	0.89%	0.07%
630	0.10	On	0.03	223	47.7%	30.9%	7.1%	0.91%	0.07%
710	0.10	Off	0.03	249	47.0%	30.2%	6.9%	0.78%	0.07%
720	0.10	Off	0.03	241	47.2%	30.4%	6.9%	0.81%	0.07%
730	0.10	Off	0.03	235	47.3%	30.5%	6.9%	0.84%	0.07%
810	0.10	On	0.001	250	47.2%	30.7%	7.3%	0.90%	0.08%
820	Off	Off	0.03	328	40.8%	25.1%	6.2%	0.94%	0.08%
830	Off	Off	0.001	334	40.7%	25.3%	6.4%	0.98%	0.08%
840	Off	Off	0.005	339	40.7%	25.3%	6.4%	0.98%	0.08%

4.5 Final Results

4.5.1 Hydrologic Analysis Results

The 100-yr peak discharges are summarized in Table 4.8. See the floodplain maps and digital files for further discharge documentation.

Table 4.8. 100-yr peak discharges

Location	Storm Duration	FLO-2D Domain and Section	Peak Discharge	Peak Discharge without Storm Drain
	(hrs)		(cfs)	(cfs)
Roger Road @ Roger Lane	3	1-010	220	222
Stone Ave @ Wetmore Rd	1	1-274	254	495
Prince Rd @ Oracle Rd	3	1-094	90	108
First Ave @ Limberlost Rd	3	1-039	123	135
Wetmore Rd @ Flowing Wells Rd	3	2-118	245	330
Placita Desierto Morado @ UPRR	3	3-008	425	445
Shannon Rd @ UPRR (culvert flow)	3	I10_5213_A	90	390

4.5.2 Verification of Results

Results were compared with Tucson Stormwater Management Study (TSMS) discharges at select locations. The results are shown in Table 4.9. No regulatory discharge point data is available from the effective flood insurance study for the project area.

Table 4.9. Comparison of 100-yr Peak Discharge Values

Location	Q100 FLO-2D (cfs)	TSMS Node	Q100 TSMS (cfs)
Roger Road @ Roger Lane	220	GQ-N0030	531
Stone Ave @ Wetmore Rd	254	HG-N0040	1073
Prince Rd @ Oracle Rd	90	DG-N0326	227
First Ave @ Limberlost Rd	123	GR-N0020	343
Wetmore Rd @ Flowing Wells Rd	245	HR-N0020	911
Placita Desierto Morado @ UPRR	425	EG-N0060	1513
Shannon Rd @ UPRR (culvert entrance)	90	EG-N0080	1440

Note that the TSMS does not model storm drain flow.

5 Hydraulics

5.1 Method Description

FLO-2D was used for both hydrology and hydraulics. For that reason, the method and parameter description for hydraulics has been covered in the preceding Hydrology section. Limited additional information is provided in this section.

5.2 Work Study Maps

Exhibit 1 (Appendix E, 21 sheets) provides the floodplain maps for the project area. These maps show the results of the FLO-2D model by displaying the following:

- The 100-year, 3-hour model flow depths are displayed with symbology described in Tech Policy 033 for flow depths greater than 0.2'.
- 100-year discharges are shown on FLO-2D flow recording cross sections. The discharge shown is the maximum discharge of each run which was nearly always the 100-year, 3-hour storm. These cross sections are also provided as a shape file for digital use.
- Floodplain limits within unincorporated Pima County were prepared in collaboration with the District. The initial flood limits were derived by plotting the area of inundation (with FLO-2D Mapper). The limits were revised using the following guidance provided by the District:
    - Excluded flow or ponding areas that only impacted roadways
    - Excluded flooded areas if upstream contributing watershed was less than 20 acres
    - Excluded flooded areas where the combined Q100 was less than 100 cfs (began mapping where aggregate flow was >100 cfs)
    - Excluded areas of ponding with no connection to flow
    - Included broad sheetflow areas that may have flows less than 100 cfs but where flow diversions could cause adverse impacts to adjacent parcels
    - Included floodprone parcels owned by Pima County without regard for the above.

Exhibit 4 shows much of the same information as Exhibit 1, but at a reduced scale to allow the entire study to fit on a single map. Digital maps of floodplain limits, inundated depths and cross-sections are included (in appendix E).

5.3 Parameter Estimation

5.3.1 Roughness Coefficients

See previous discussion under Hydrology.

5.3.2 Expansion and Contraction Coefficients

NA.

5.4 Cross Section Description

NA.

5.5 Modeling Considerations

5.5.1 Hydraulic Jump and Drop Analysis

NA.

5.5.2 Bridges and Culverts

The model included culverts and bridges existing at the time of report preparation, as well as drainage infrastructure planned for the I-10 corridor, including a new culvert through the railroad embankment for the Flowing Wells Wash which is anticipated to be installed in the very near future.

5.5.3 Levees and Dikes

None.

5.5.4 Non-Levee Embankments

None.

5.5.5 Islands and Flow Splits

None.

5.5.6 Ineffective Flow Areas

This effect is addressed through the use of aerial reduction factors in the ARF.DAT file.

5.5.7 Supercritical Flow

NA

5.6 Floodway Modeling

NA

5.7 Issues Encountered during the Study.

5.7.1 Special Problems and Solutions.

See previous discussion under Hydrology.

5.7.2 Modeling Warning and Error Messages.

See previous discussion under Hydrology.

5.8 Calibration.

See previous discussion under Hydrology.

5.9 Final Results.

5.9.1 Hydraulic Analysis Results.

The following tables (5.1, 5.2, and 5.3) are provided to document the area of inundation during the various events. This area is computed by tabulating the number of FLO-2D grids with maximum flow depths above the prescribed thresholds. The area excludes any areas occupied by structures within the model, therefore it might be interpreted that the inundated area is greater than reported.

Table 5.1. Inundated area by depth during the 10-year, 3-hour event.

Model	Total Acres	Acres of inundation by depth (ft.)				
		0.2	0.5	1	2	3
1	1,796	301.8	90.1	23.9	4.5	0.7
2	2,341	375.2	109.4	32.3	11.2	5.5
3	1,319	260.9	84.2	20.0	4.0	1.4
1-3	**5,455**	**937.9**	**283.7**	**76.2**	**19.8**	**7.6**

Table 5.2. Inundated area by depth during the 25-year, 3-hour event.

Model	Total Acres	Acres of inundation by depth (ft.)				
		0.2	0.5	1	2	3
1	1,796	379.0	124.7	31.4	6.5	1.1
2	2,341	482.2	157.3	44.3	14.2	7.6
3	1,319	323.0	119.5	30.3	5.4	1.9
1-3	**5,455**	**1184.1**	**401.4**	**106.0**	**26.1**	**10.6**

Table 5.3. Inundated area by depth during the 100-year, 3-hour event.

Model	Total Acres	Acres of inundation by depth (ft.)				
		0.2	0.5	1	2	3
1	1,796	500.6	184.4	51.4	10.1	3.4
2	2,341	653.7	252.2	72.7	19.7	10.7
3	1,319	415.7	176.7	51.9	8.1	3.0
1-3	**5,455**	**1569.9**	**613.4**	**176.0**	**38.0**	**17.1**

An alternate run was performed for the 100-year, 3-hour event whereby the storm drains were removed from the model. Table 5.4 lists the inundation area with this scenario in place. This analysis suggests that the storm drains reduce the flooded area by about 30 percent.

Table 5.4. Inundated area by depth during the 100-year, 3-hour event without drains.

Model	Total Acres	Acres of inundation by depth (ft.)				
		0.2	0.5	1	2	3
1	1,796	549.2	235.5	83.2	21.3	8.4
2	2,341	724.8	328.7	109.2	26.3	11.7
3	1,319	440.6	200.5	66.9	11.7	3.8
1-3	**5,455**	**1714.6**	**764.7**	**259.4**	**59.3**	**23.9**

Figure 5.1 below compares the percent of area inundated by the 10-, 25-, and 100-year events with 3-hour rainfall durations. The maximum inundated area is just under 30 percent, again excluding buildings.

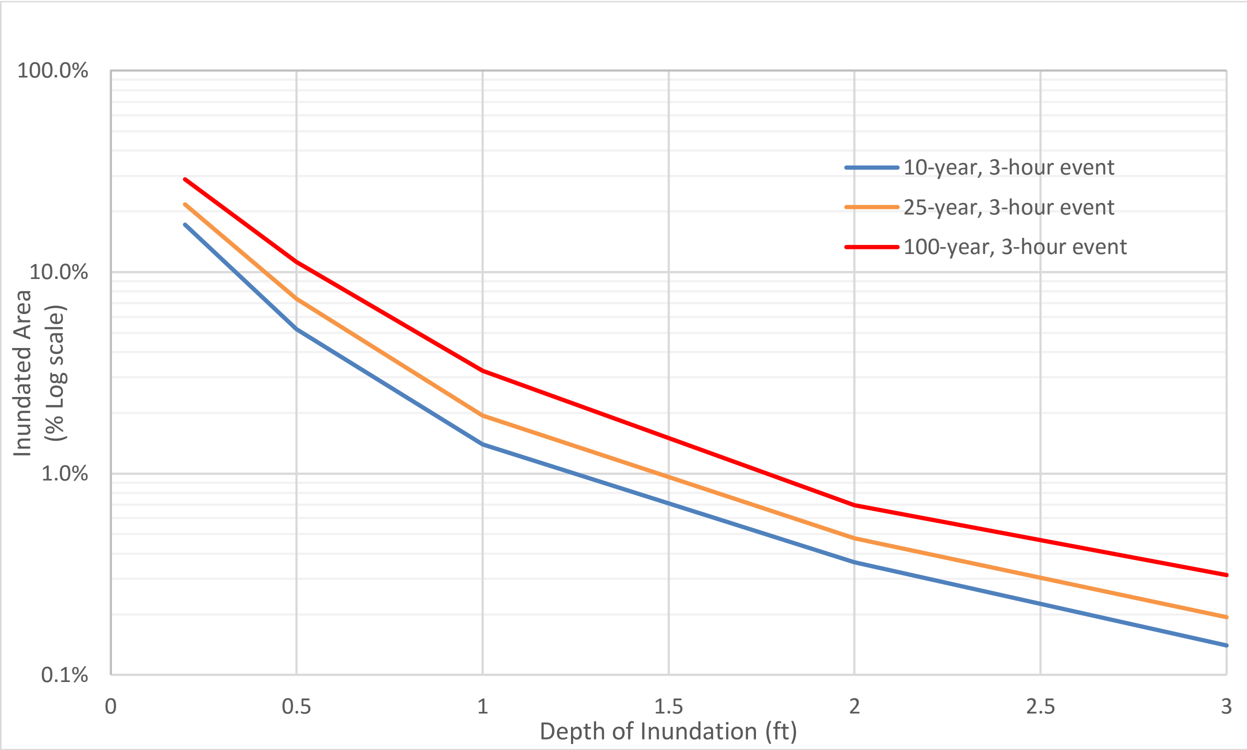


Figure 5.1. Percent of study area inundated above various depths for 3-hour events.

5.9.2 Verification of Results.

See previous discussion under Hydrology.

6 Erosion and Sediment Transport

Not available in this study

7 Ratio of the Top Width of 100-yr and 25-yr Floodplain

NA. "Canyon Wash" criteria does not apply to this urban area study.

Appendix A. References

A.1 Pima County Tech Policy 018 - Acceptable Model Parameterization for Determining Peak Discharges
A.2 Pima County Tech Policy 033 - Criteria for Two-Dimensional Modeling
A.3 NOAA Rainfall Data

Appendix B. General Documentation and Correspondence

Appendix C. Survey Field Notes & As-builts

C.1 Survey Field Notes (NA)
C.2 As-Builts

- Structures & Storm Drain Systems
  - Domain 1
    - Mountain Avenue (D76-001)
    - First Avenue (I-813 & I-828)
    - Limberlost Road (I-84-043)
    - Stone Avenue (I-82-058 & D-95-002)
    - Oracle-Prince-Yavapai-Mohave System (I-67-009, I-76-023, I76-024 & I-79-023)
    - Oracle Road = Prince Rd North to Rillito (I-67-013)
  - Domain 2
    - Auto Mall (I-87-012)
    - Limberlost Drive (I-98-050)
    - Fairview Avenue (D-2003-003)
    - Flowing Wells Road (I-70-047)
    - Wetmore Road – Pomona Ave System (I-2005-009)
  - Domain 3
    - La Cholla Blvd (4BRAUF, 4LCITR & I-2005-009)
    - Sullinger Avenue (4BRAUF)
    - Ruthrauff Road (4BRAUF)
    - I-10 Westbound Frontage Road (JBA-H3038)

Appendix D. FLO-2D Analysis Supporting Documentation (on CD/DVD).

The following models are submitted on the CD/DVD.

Domain	Return Interval	Rainfall Duration	Storm Drains Modeled?	Model Name
1	010	01	Yes	RRBMP_01_F2D_010YR_01HR
2	010	01	Yes	RRBMP_02_F2D_010YR_01HR
3	010	01	Yes	RRBMP_03_F2D_010YR_01HR
1	010	03	Yes	RRBMP_01_F2D_010YR_03HR
2	010	03	Yes	RRBMP_02_F2D_010YR_03HR
3	010	03	Yes	RRBMP_03_F2D_010YR_03HR
1	010	24	Yes	RRBMP_01_F2D_010YR_24HR
2	010	24	Yes	RRBMP_02_F2D_010YR_24HR
3	010	24	Yes	RRBMP_03_F2D_010YR_24HR
1	025	01	Yes	RRBMP_01_F2D_025YR_01HR
2	025	01	Yes	RRBMP_02_F2D_025YR_01HR
3	025	01	Yes	RRBMP_03_F2D_025YR_01HR
1	025	03	Yes	RRBMP_01_F2D_025YR_03HR
2	025	03	Yes	RRBMP_02_F2D_025YR_03HR
3	025	03	Yes	RRBMP_03_F2D_025YR_03HR
1	025	24	Yes	RRBMP_01_F2D_025YR_24HR
2	025	24	Yes	RRBMP_02_F2D_025YR_24HR
3	025	24	Yes	RRBMP_03_F2D_025YR_24HR
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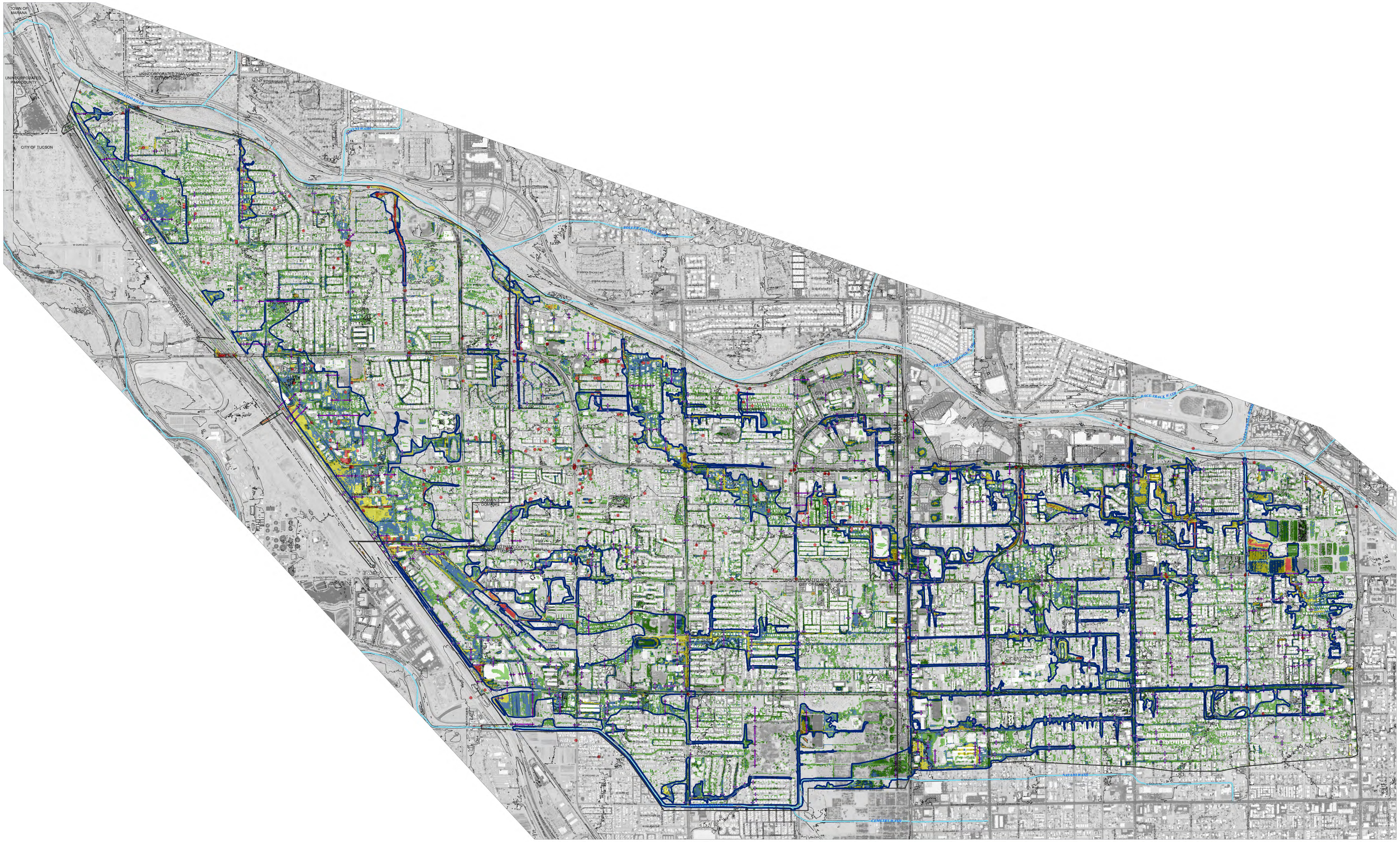
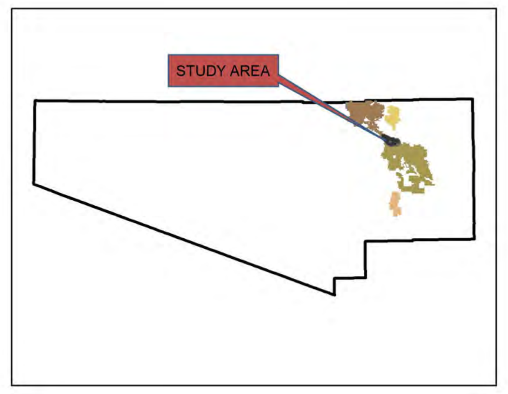
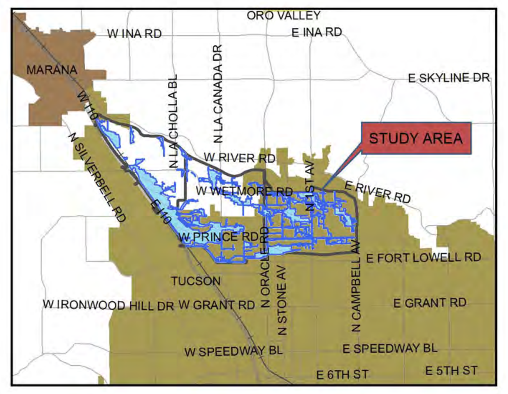
2	100	01	Yes	RRBMP_02_F2D_100YR_01HR
3	100	01	Yes	RRBMP_03_F2D_100YR_01HR
1	100	03	Yes	RRBMP_01_F2D_100YR_03HR
2	100	03	Yes	RRBMP_02_F2D_100YR_03HR
3	100	03	Yes	RRBMP_03_F2D_100YR_03HR
1	100	24	Yes	RRBMP_01_F2D_100YR_24HR
2	100	24	Yes	RRBMP_02_F2D_100YR_24HR
3	100	24	Yes	RRBMP_03_F2D_100YR_24HR
1	100	03	No	RRBMP_01_F2D_100YR_03HR-no-storm-drain
2	100	03	No	RRBMP_02_F2D_100YR_03HR-no-storm-drain
3	100	03	No	RRBMP_03_F2D_100YR_03HR-no-storm-drain

Appendix E. Exhibits

Exhibit 1 – 100-yr Floodplain Maps (21 sheets)
Exhibit 2 – FLO-2D Model Domains and Study Area Overview
Exhibit 3 – Distribution of Manning's Roughness Values and Obstructions
Exhibit 4 – 100-year Floodplain Limit Map







Ruthrauff Basin Management Plan
Exhibit 4: 100-year Floodplain Limit Map

The information depicted on this display is the result of digital analyses performed on a variety of databases provided and maintained by several governmental agencies. The accuracy of the information presented is limited to the collective accuracy of these databases on the date of the analysis. JE Fuller and the Pima County Regional Flood Control District make no claims regarding the accuracy of the information depicted herein.

The predicted flooding presented on this exhibit reflects the outcome of modeling a basinwide 100 storm. Peak discharges shown ont the flow recording cross sections are the highest discharge from the 100-year, 1-, 3-, or 24-hour storm. The FLO-2D flood routing model used the SCS CN procedure with NOAA 14, upper 90% confidence interval rainfall data. This FLO-2D model accounts for the storm drain systems. The flood limits shown were delineated for areas of discharge greater than 100 cfs.

0 400 800 1,600 2,400 3,200 Feet

1 inch = 800 feet (when printed to 48" x 36")

N E S W

Exhibit prepared for:
Pima County Regional Flood Control District
97 E Congress Street
Tucson Arizona, 85701

PIMA COUNTY FLOOD CONTROL

Exhibit prepared by:
JE Fuller Hydrology & Geomorphology
40 E. Helen Street
Tucson, AZ 85705

IPS | Fall 2015

JE FULLER HYDROLOGY & GEOMORPHOLOGY, INC.

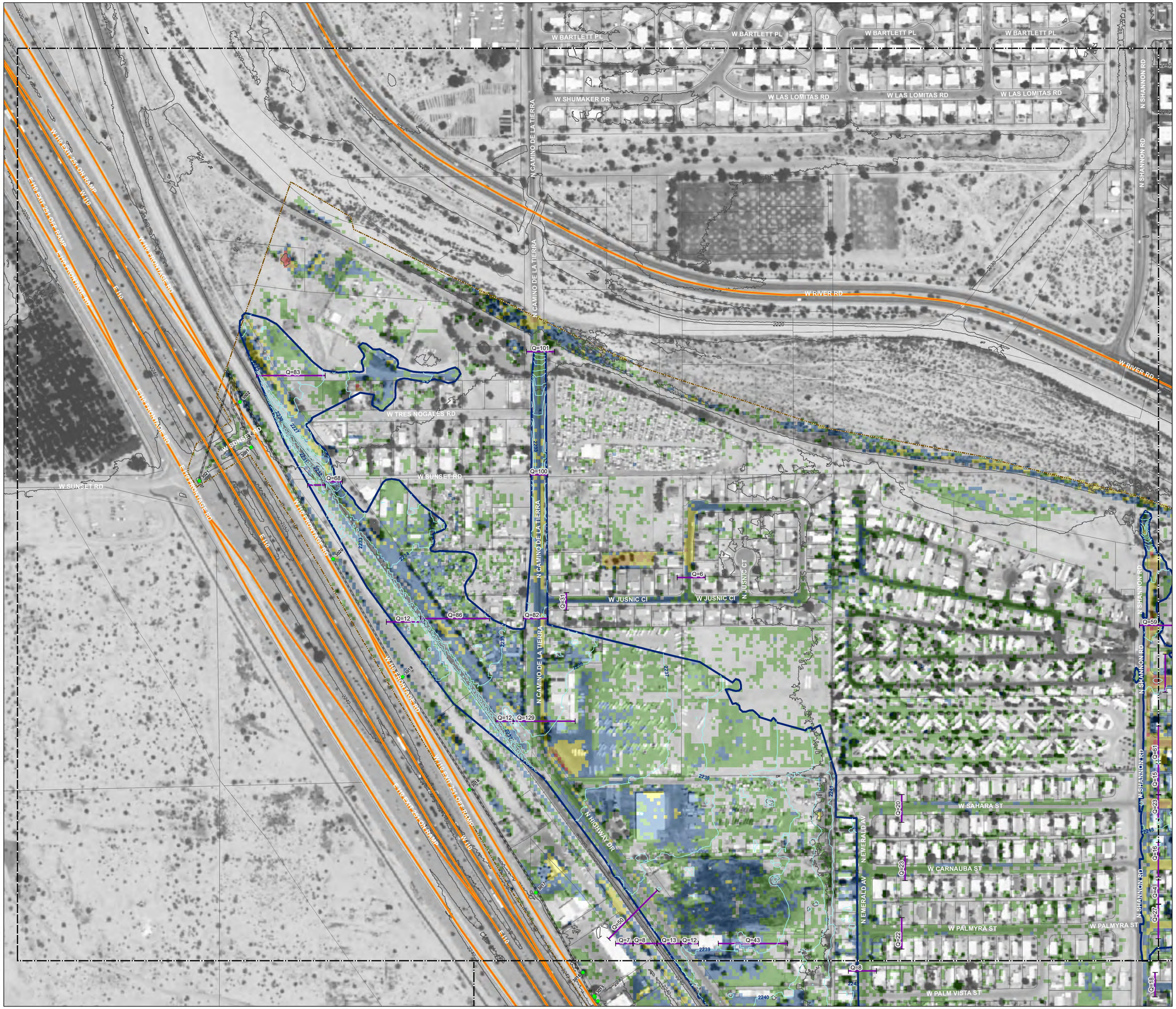
Legend

- Corporate Limit Boundary
- Domain Limits (1, 2, 3)
- Flood Limits (Q100>100 cfs)
- Major Washes
- Storm Drain Pipes (approx.)
- Flow Record With Design Discharge (cfs)
- Storm Drain Inlets
- Reported Drainage Complaint

Underlying aerial image is a 2013 image from NAIP (National Agriculture Imagery Program)

Flow Depth (ft), 100-year 3-hour

- < 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1.0 - 2
- 2.0 - 3.0
- > 3.0



Ruthrauff Basin Management Plan

Exhibit 1 - 100-yr Floodplain Maps:

Generation 'a': Fall 2015

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(3) Flood limits were extended upstream of 100 cfs concentration points where they were greater than 6 inches in depth.

0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

Streets (Major)
10-ft Contours (PAG 2008)
Parcels (Approximate)
Sheet Line
Ruthrauff BMP Boundary

FLO-2D Symbols

Flood Limits
Q=150 / 2-112 Flow Record With Design Discharge (cfs)
Water Surface Elev. Contour (ft)
Culverts
Storm Drain Pipes (approx.)
Storm Drain Inlets (with ID)
Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

Aerial images: 2015 NAIP, <<http://gis.apfo.usda.gov/arcgis/services>>
Topographic contours developed from 2008 PAG LIDAR data.

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Pima County Regional Flood Control District
97 East Congress Street, Third Floor
Tucson, Arizona 85701
Contact: Evan Canfield, PhD., P.E.

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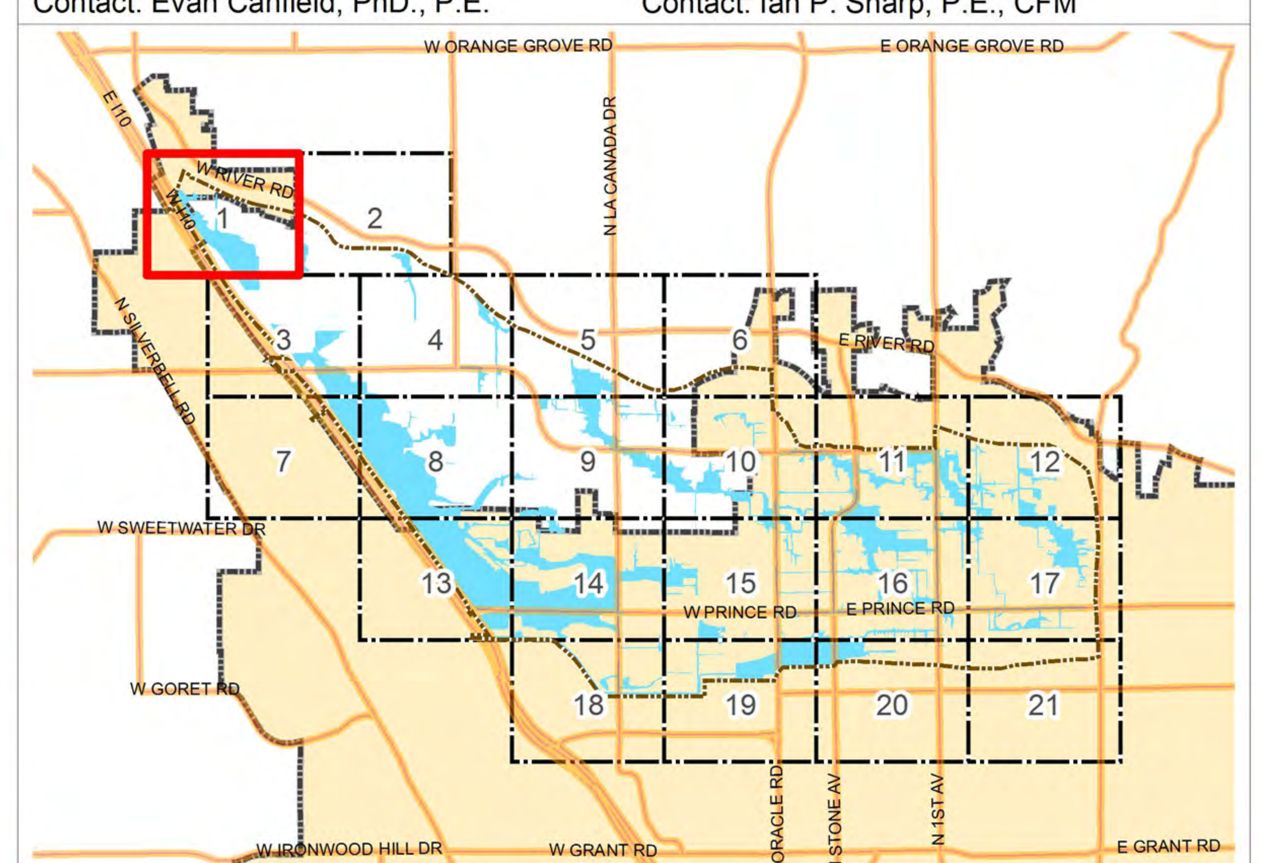

Legend

Flood Limits
Sheet Line
City of Tucson
Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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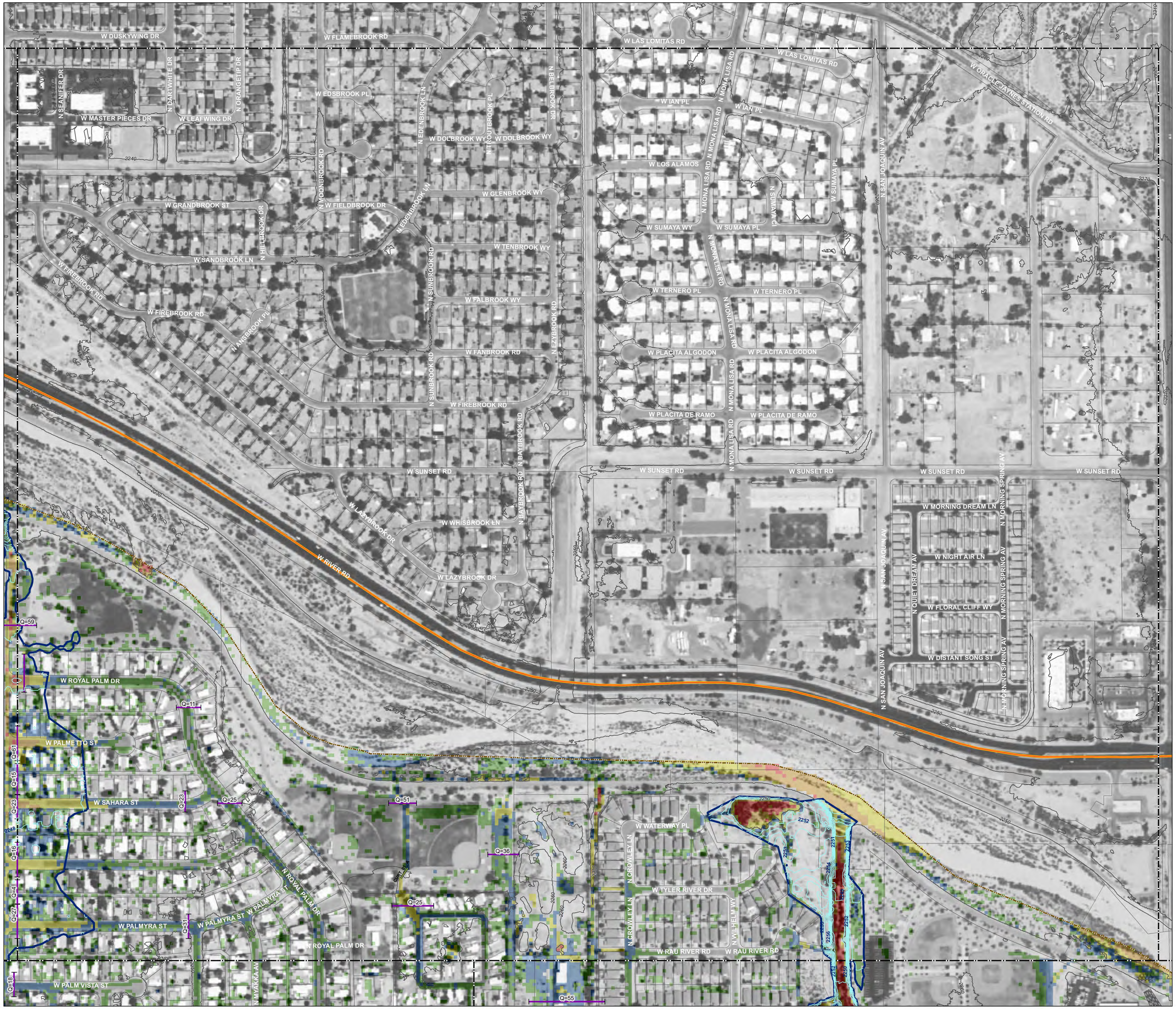
Expires 3/31/2018

Sheet 1 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Q=150 / 2-112 Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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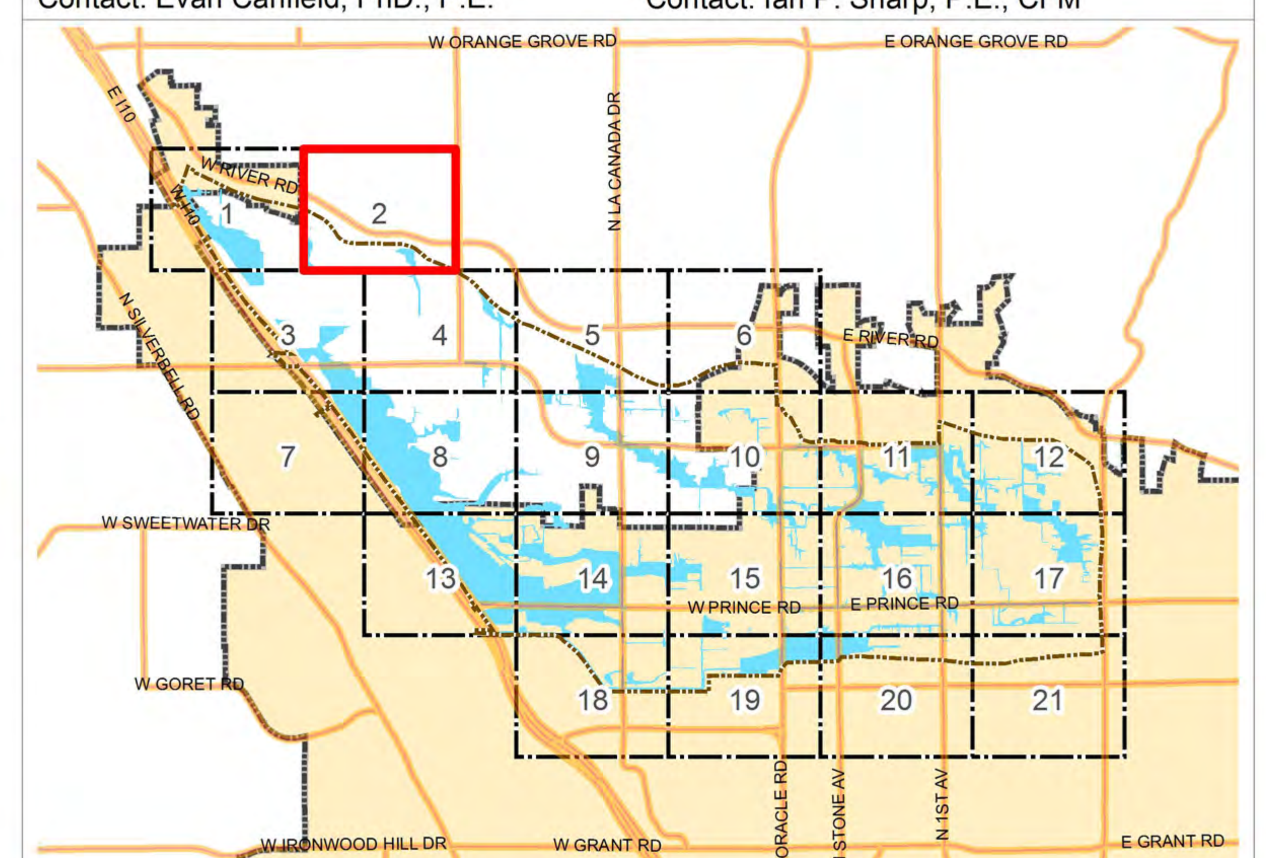

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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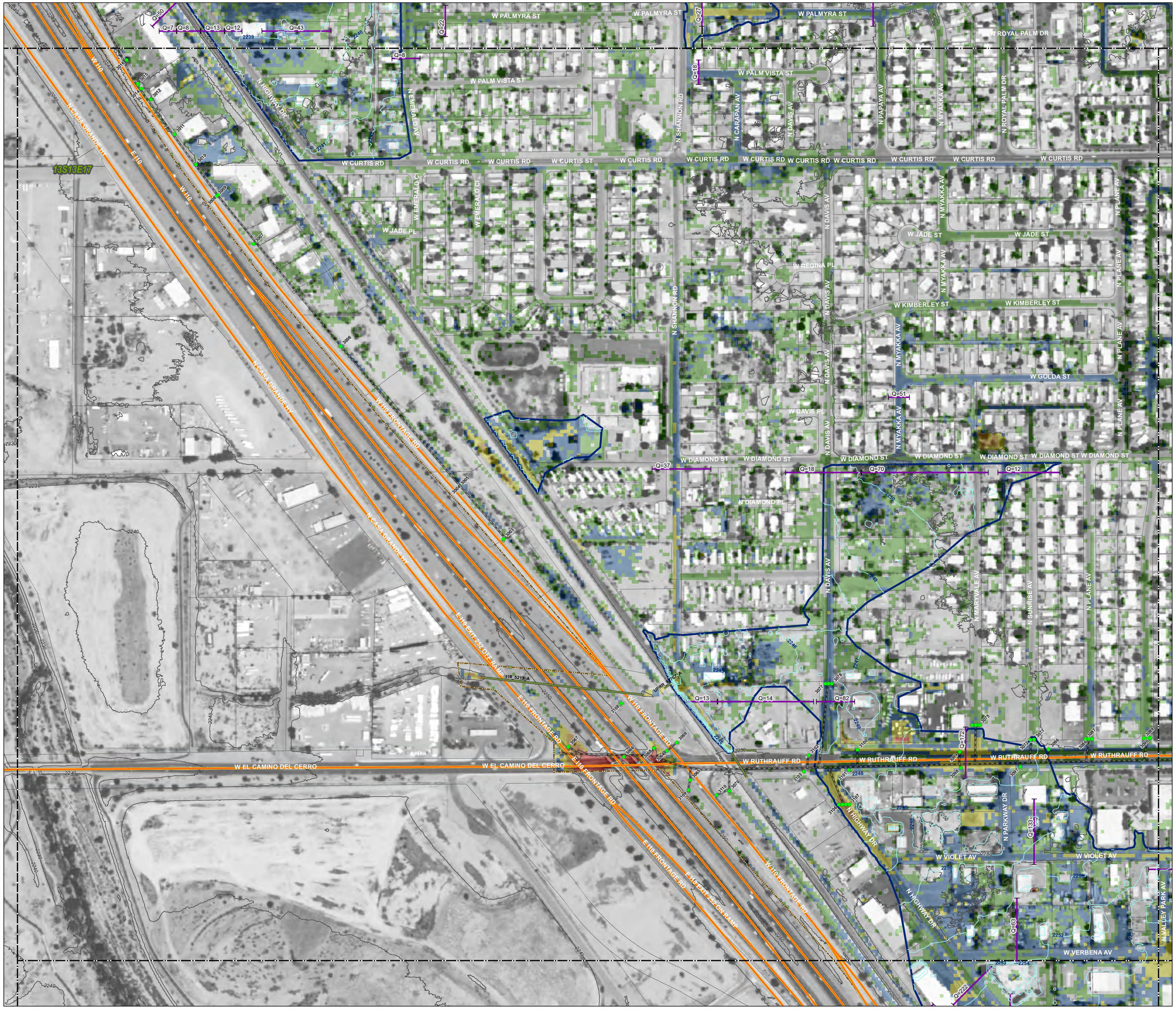
Sheet 2 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Flow Record With Design Discharge (cfs) (Q=150, 2-112)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

<0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | >3.0

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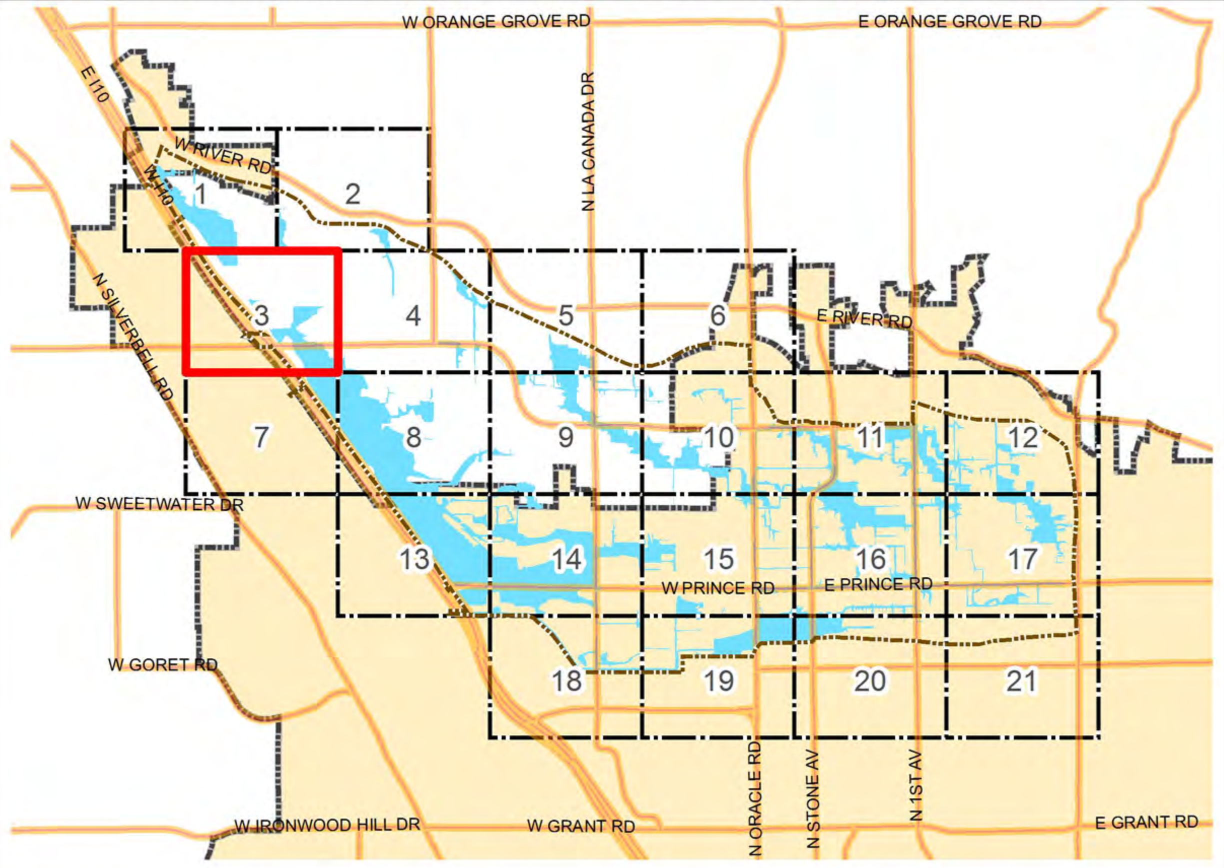

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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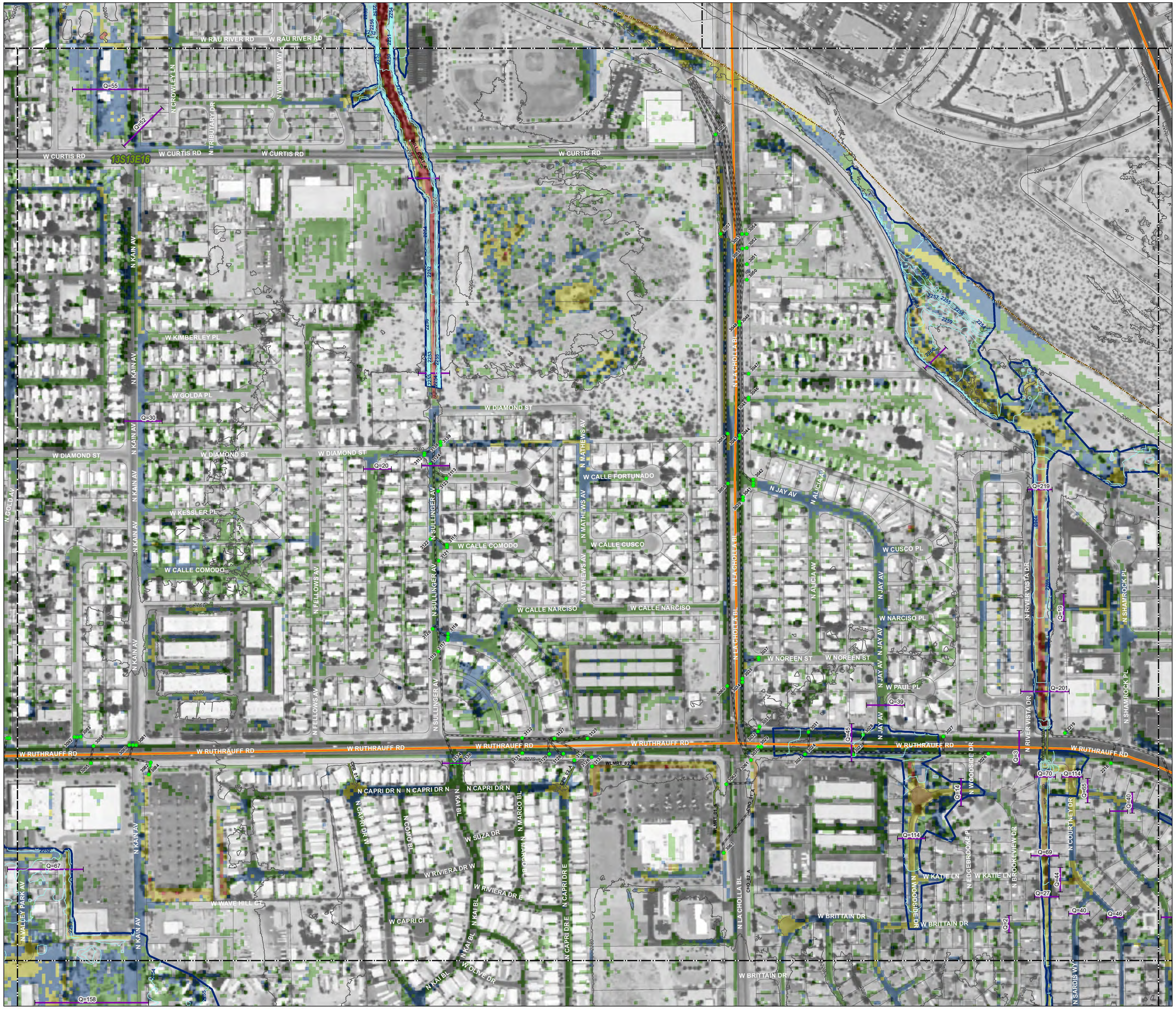
Sheet 3 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Q=150 / 2-112 Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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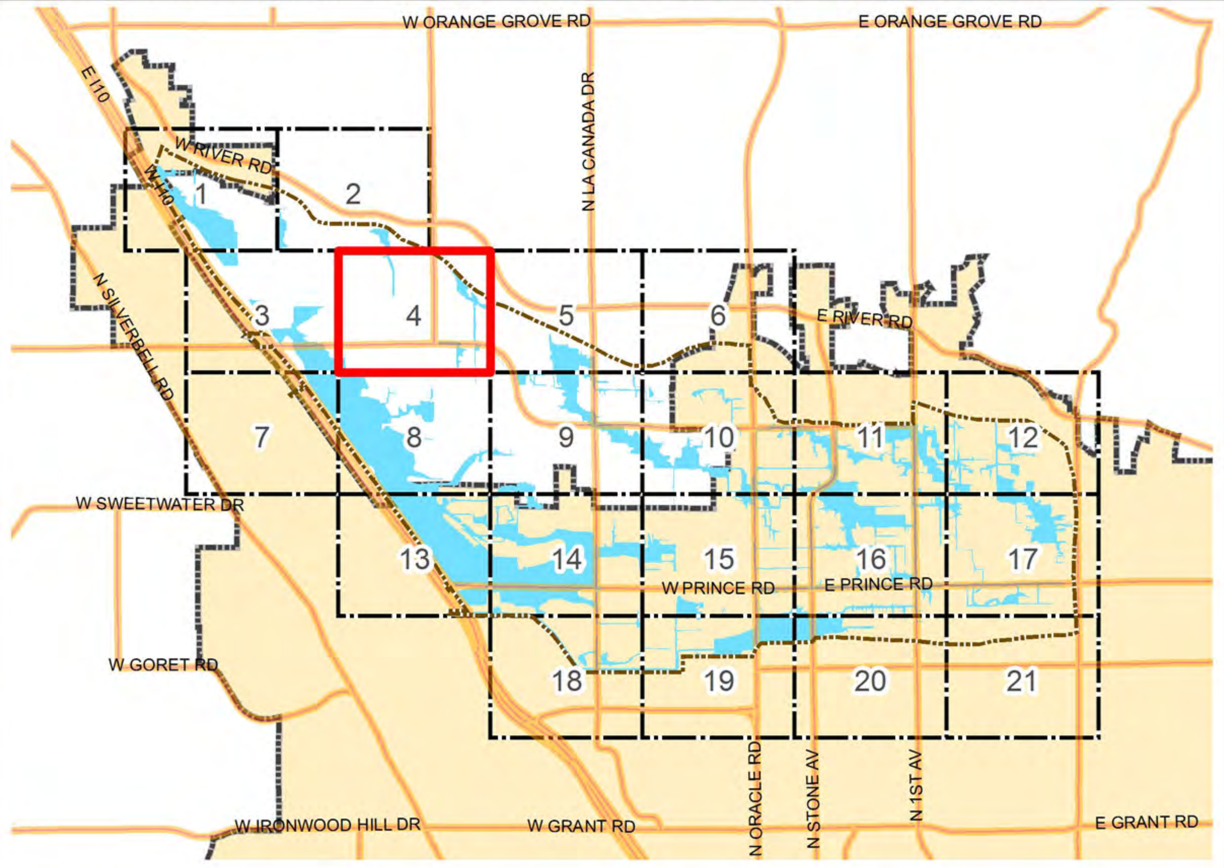

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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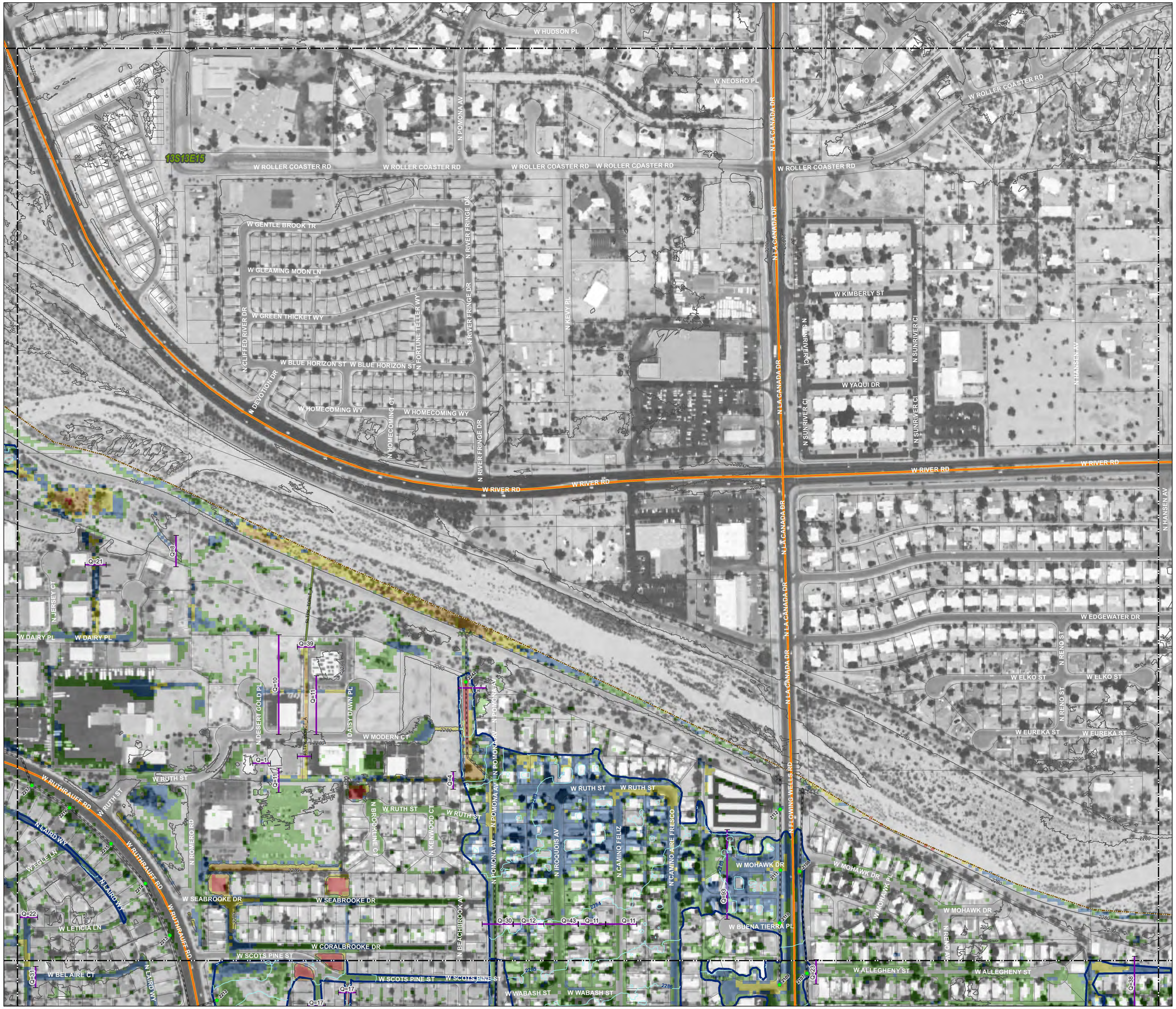
Sheet 4 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
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N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Flow Record With Design Discharge (cfs) (Q=150, 2-112)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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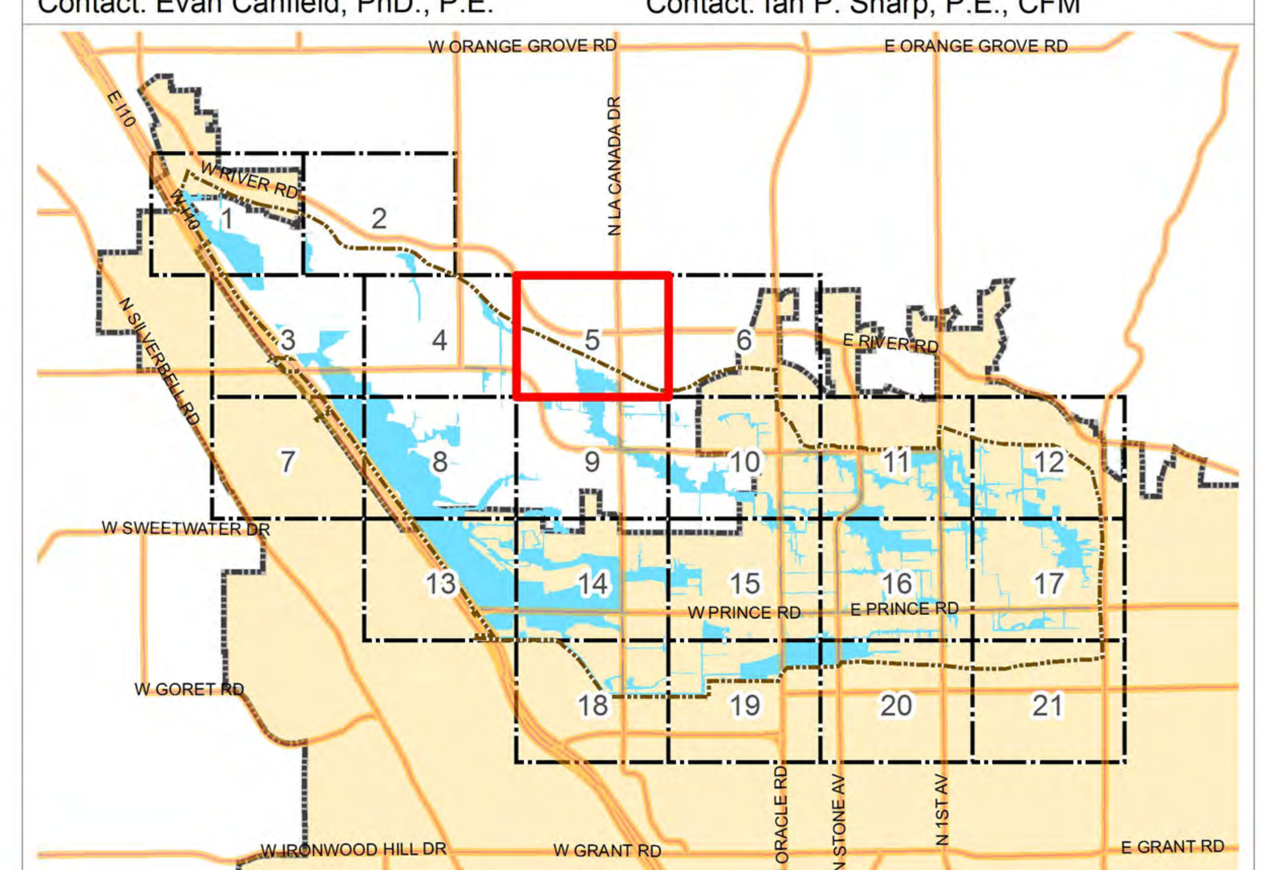

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

Sheet 5 of 21

Ruthrauff Basin Management Plan

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- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
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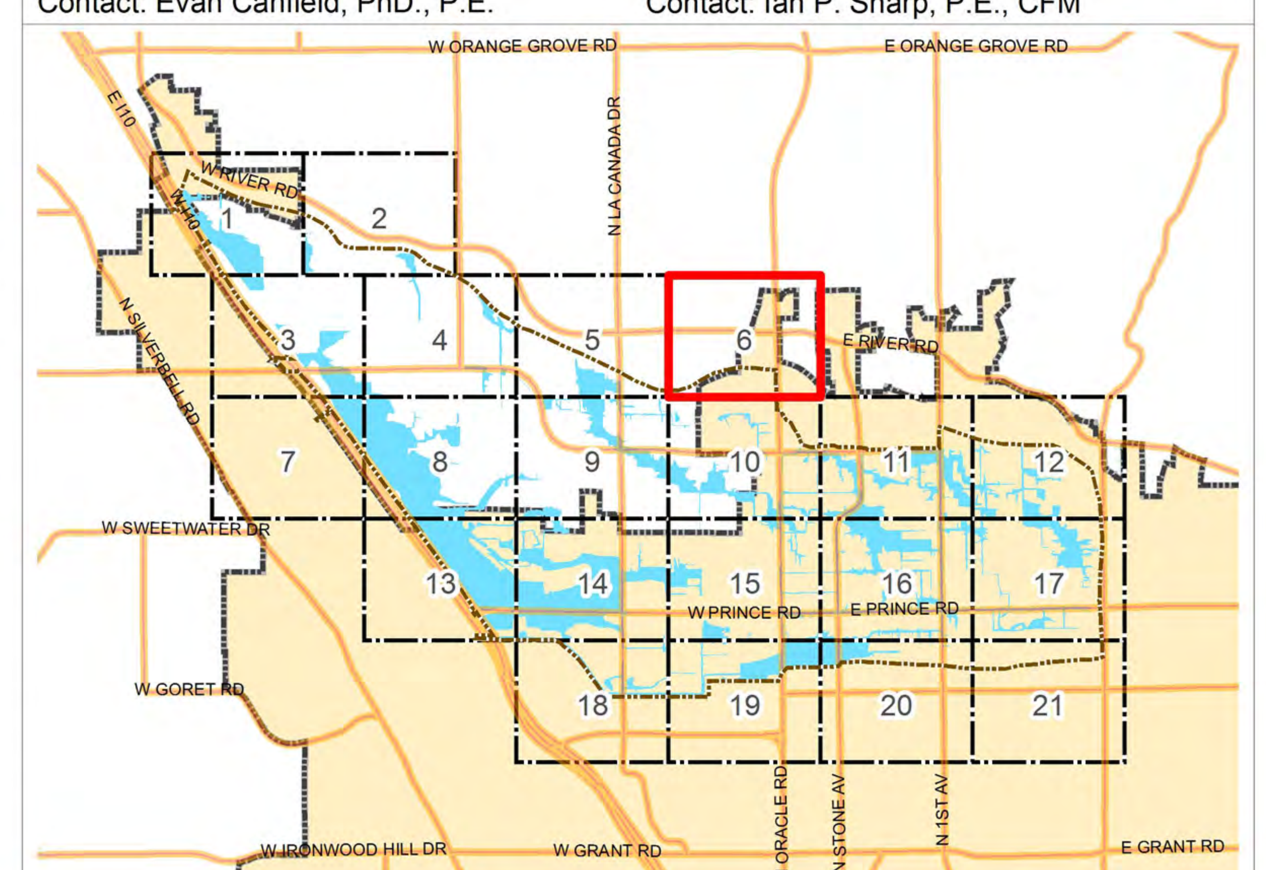

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

Registered Professional Engineer (Civil) Certificate No. 43845 IAN PATRICK SHARP Date Signed Arizona U.S.A.
Expires 3/31/2018

Ruthrauff Basin Management Plan

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- Sheet Line
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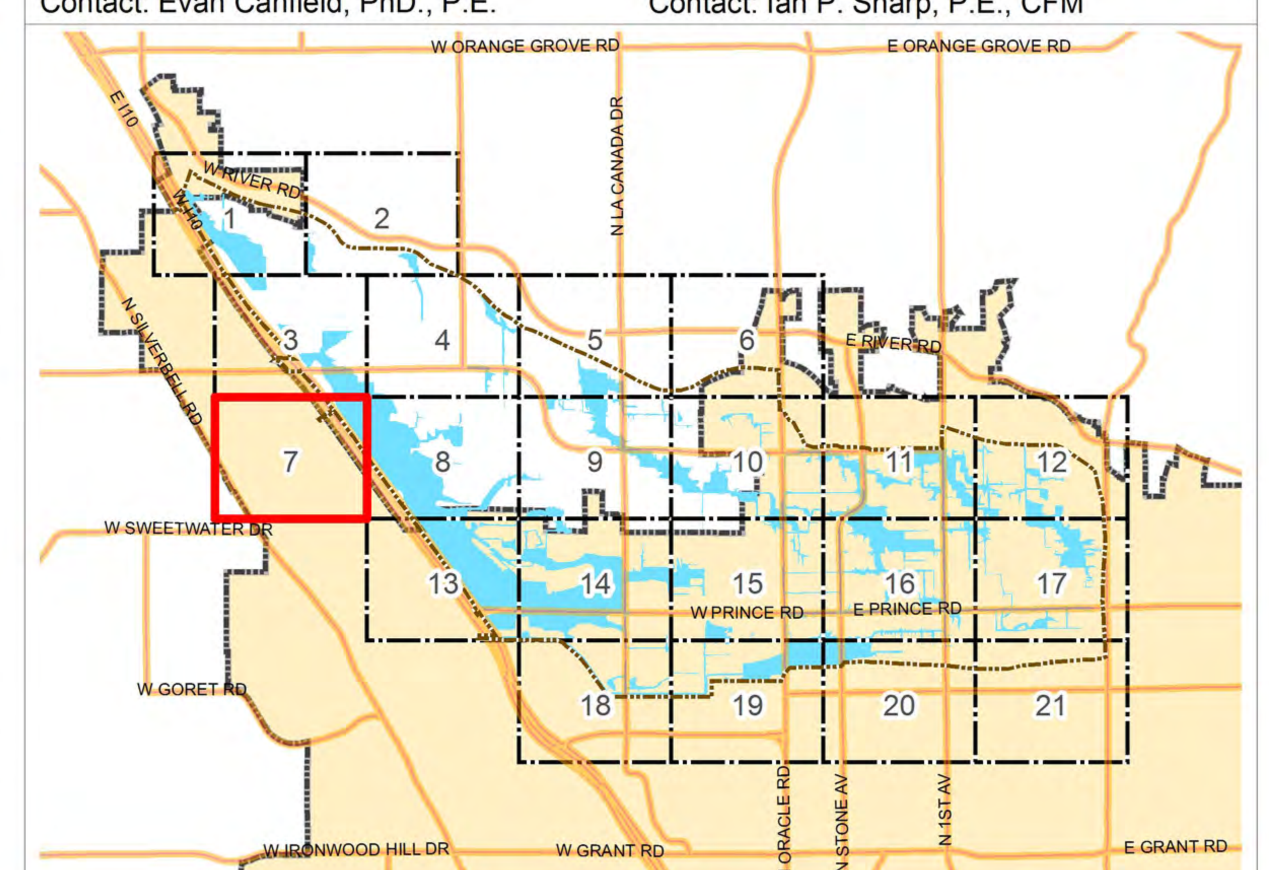

Legend

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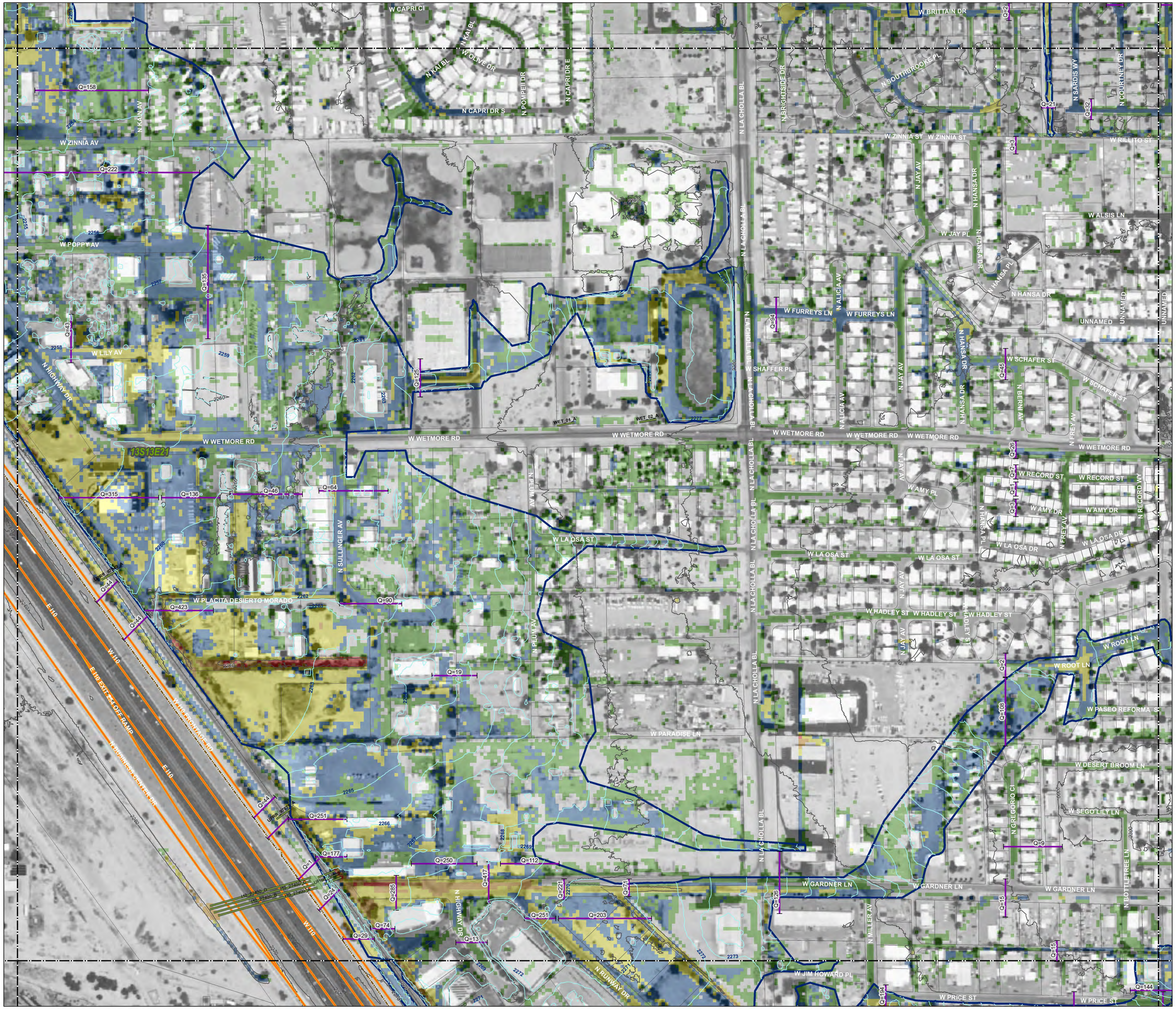
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

Sheet 7 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
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N

Plan Set Legend

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Parcels (Approximate)
Sheet Line
Ruthrauff BMP Boundary

FLO-2D Symbols

Flood Limits
Flow Record With Design Discharge (cfs) (Q=150, 2-112)
Water Surface Elev. Contour (ft)
Culverts
Storm Drain Pipes (approx.)
Storm Drain Inlets (with ID)
Storm Drain Outlets

Flow Depth (ft)

< 0.2, 0.2 - 0.5, 0.5 - 1, 1.0 - 2, 2.0 - 3.0, > 3.0

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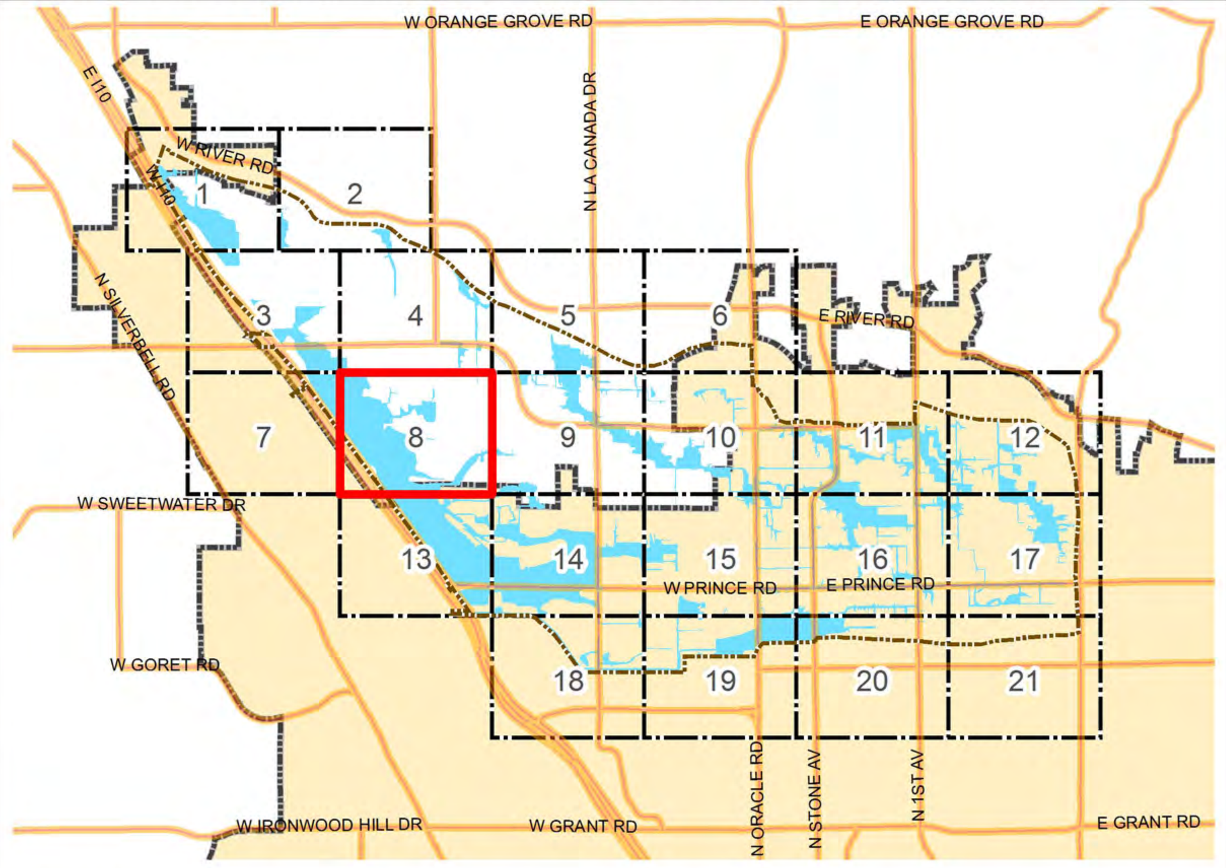
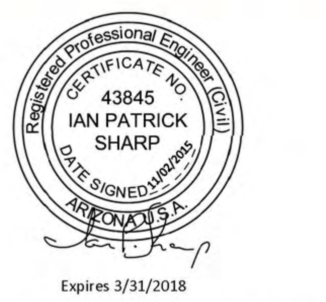


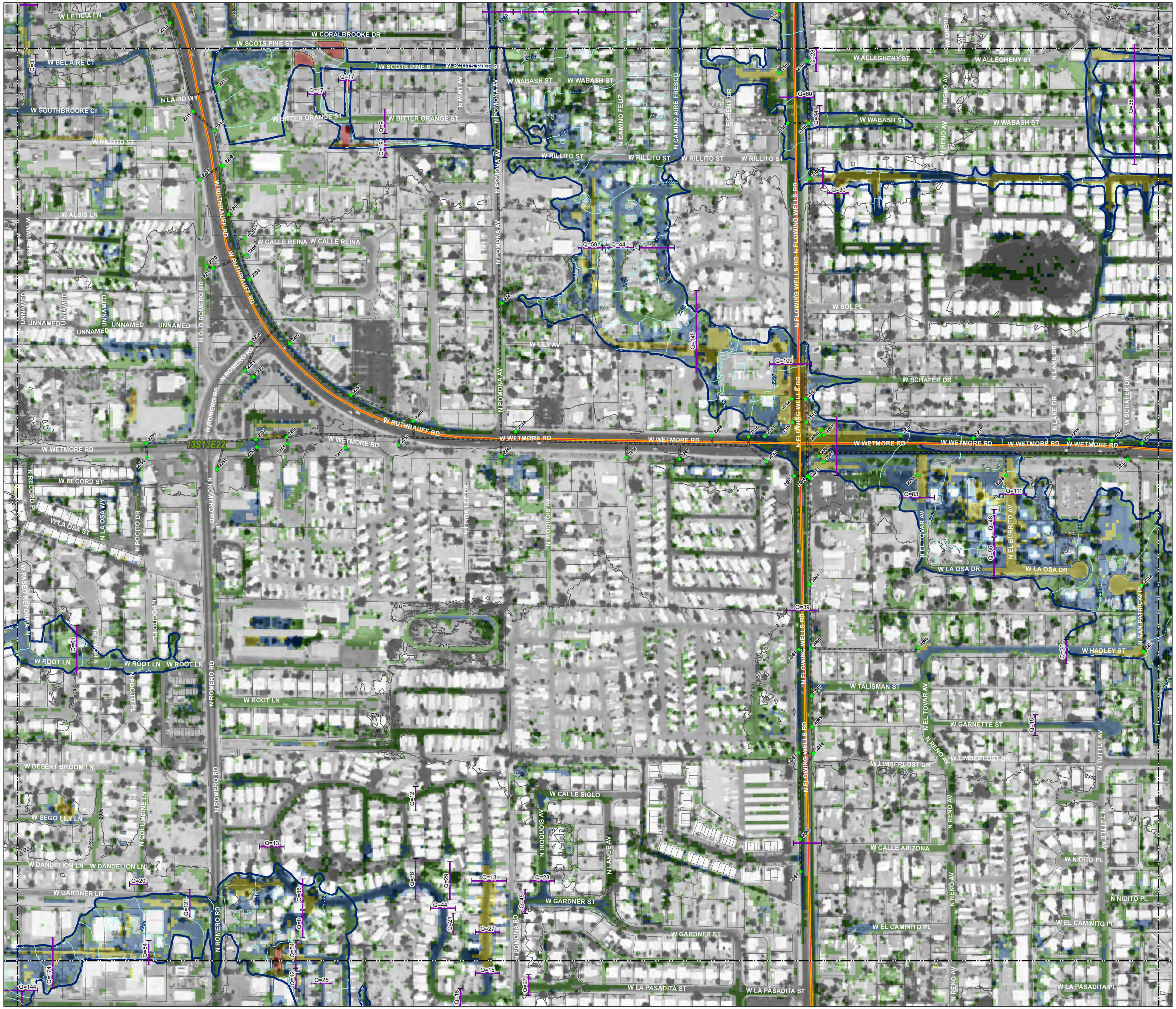
Legend

Flood Limits
Sheet Line
City of Tucson
Ruthrauff BMP Boundary

0 0.5 1 2
Miles



Sheet 8 of 21



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Feet
1 inch = 200 feet

N

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- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2, 0.2 - 0.5, 0.5 - 1, 1.0 - 2, 2.0 - 3.0, > 3.0

Aerial images: 2015 NAIP, <<http://gis.apfo.usda.gov/arcgis/services>>
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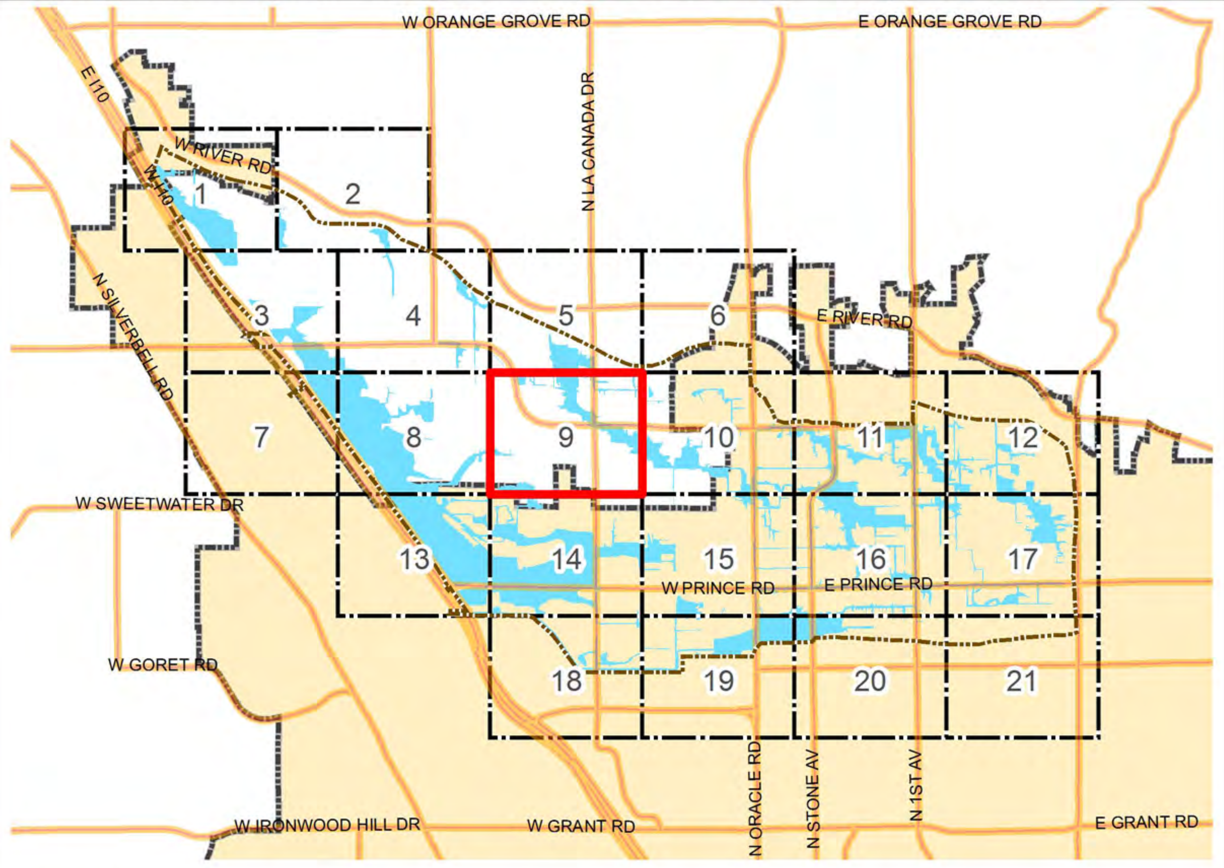

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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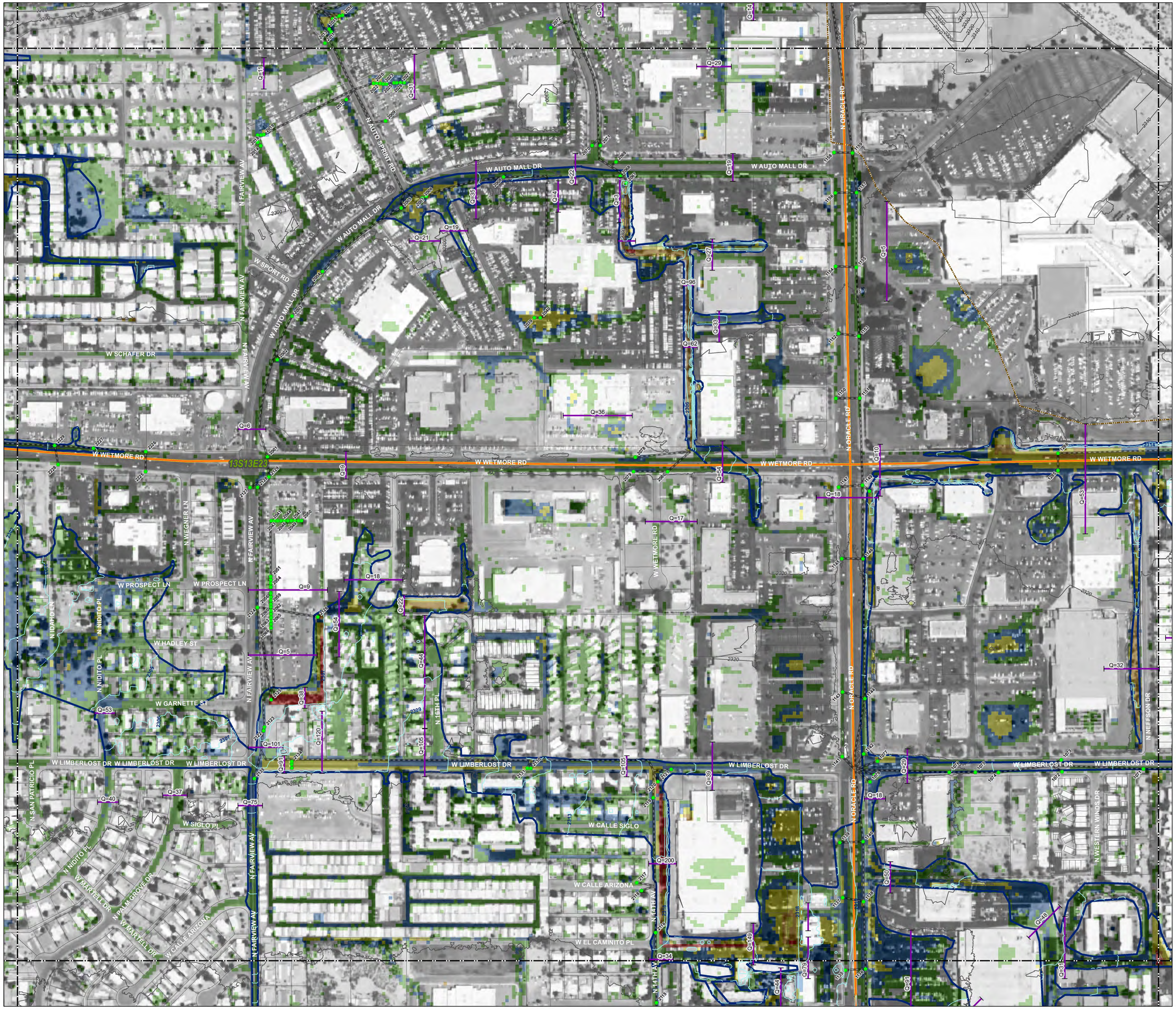
Sheet 9 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Q=150 / 2-112 Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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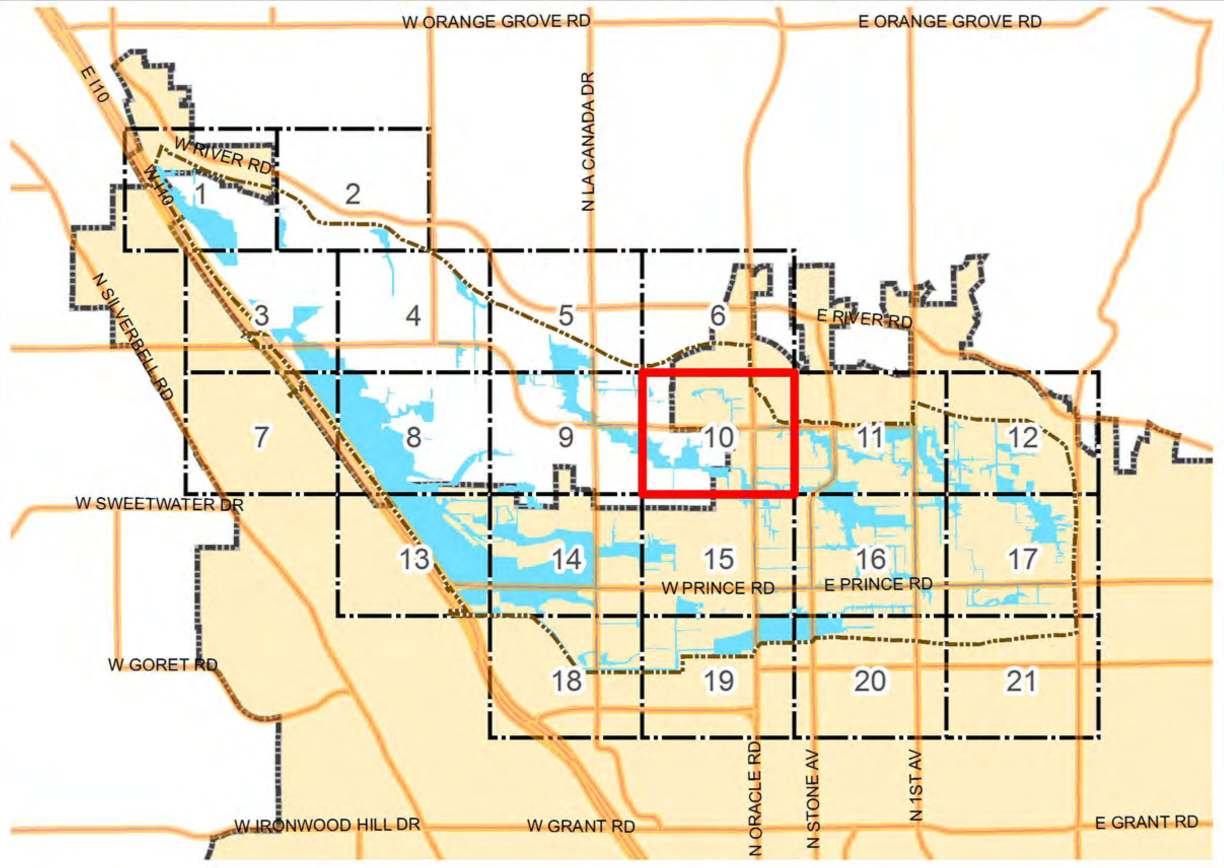

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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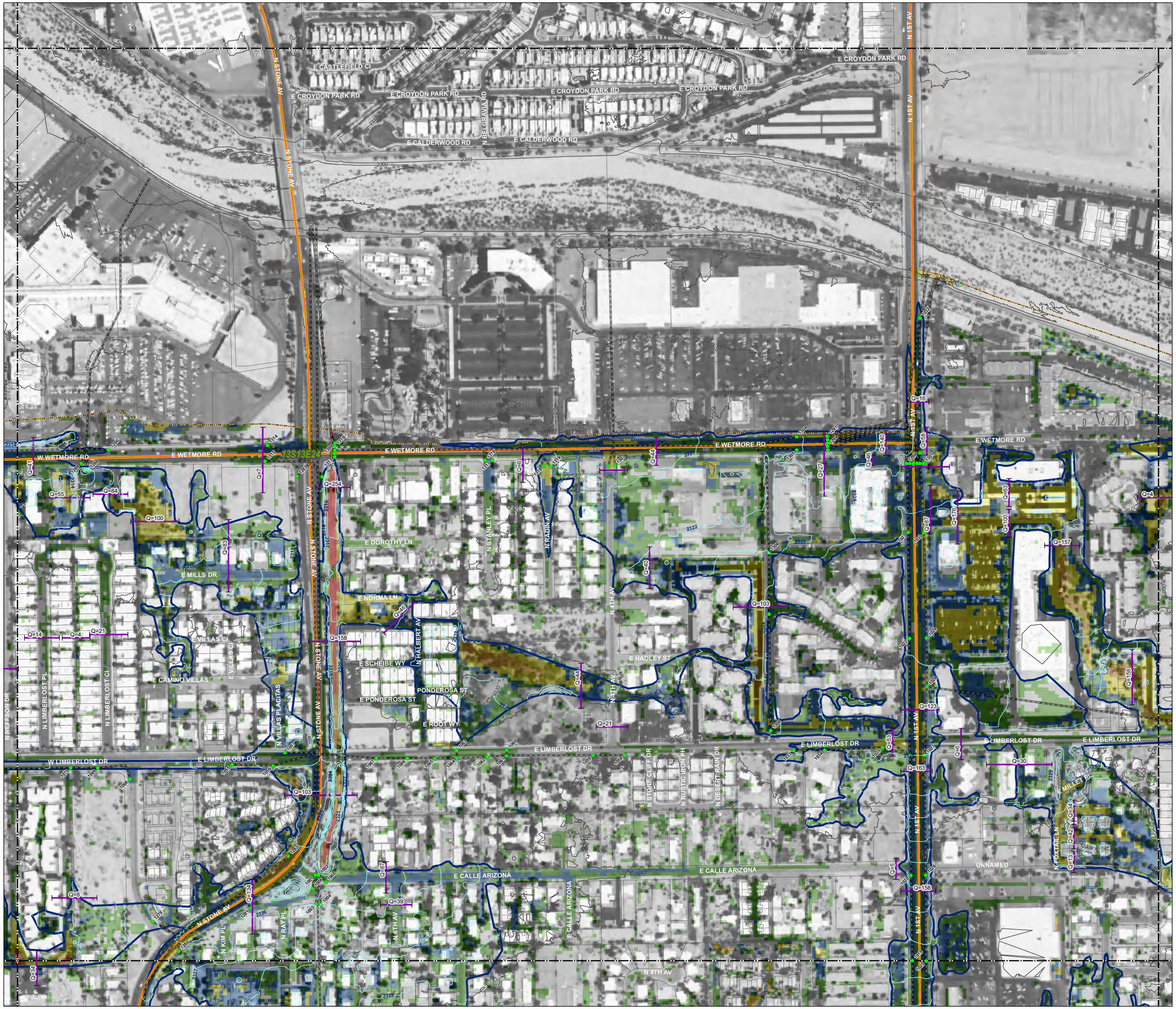
Sheet 10 of 21



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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Q=150 / 2-112 Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
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Flow Depth (ft)

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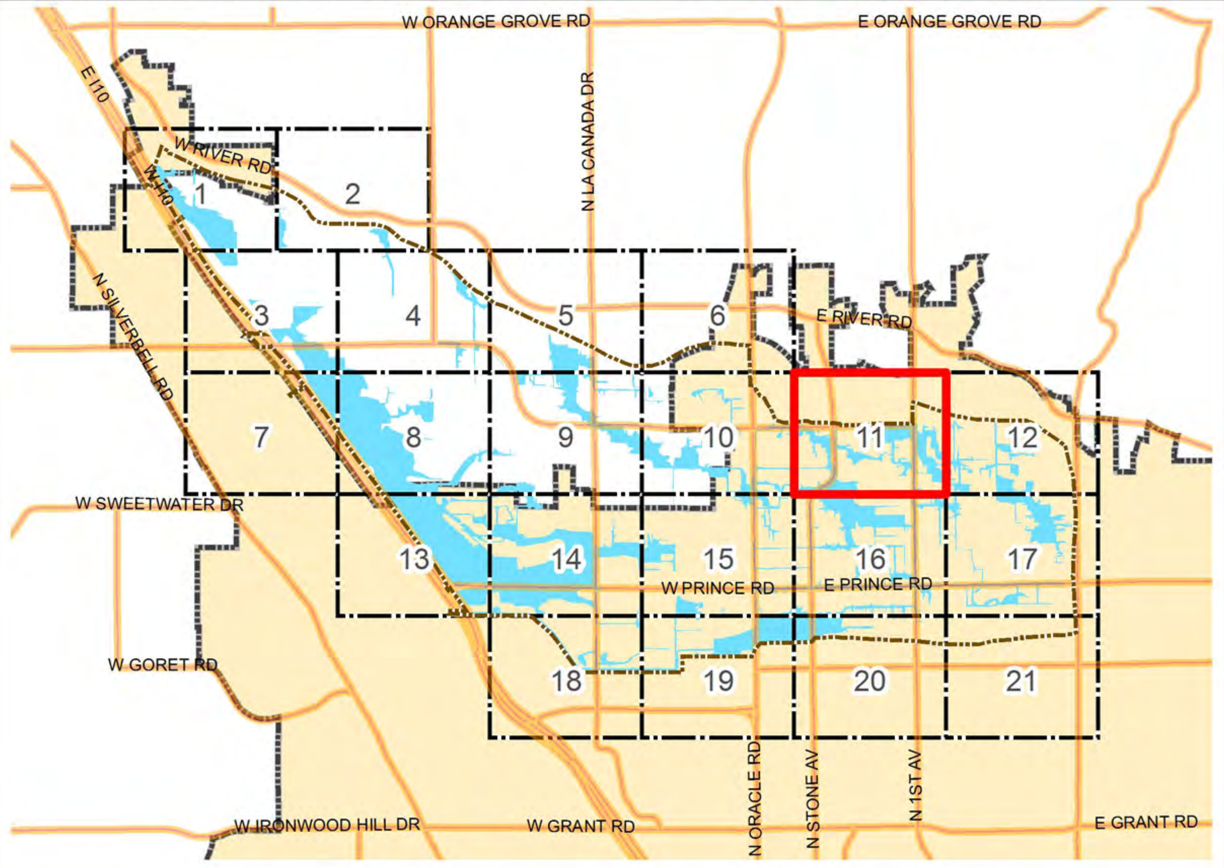

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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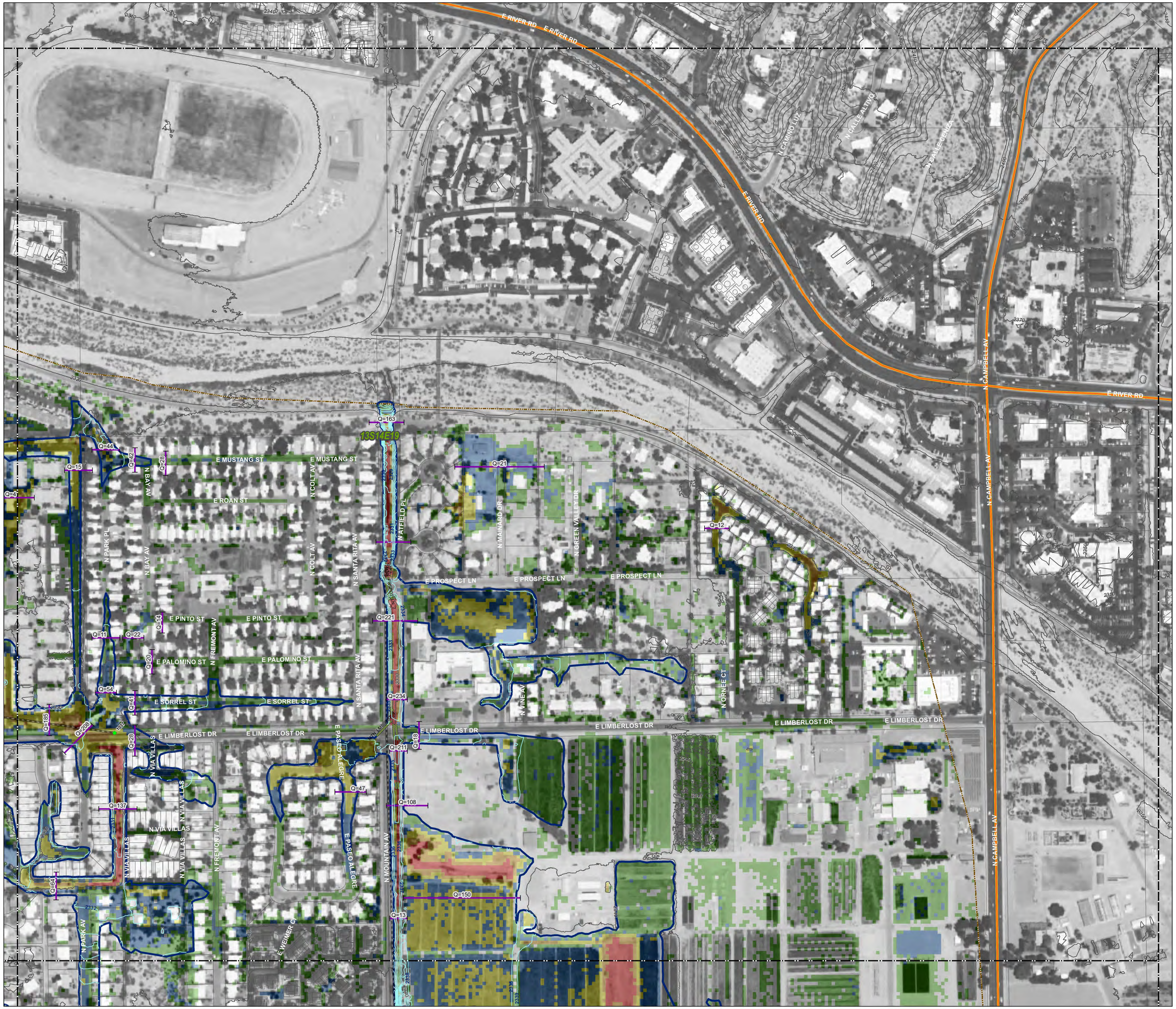
Sheet 11 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Flow Record With Design Discharge (cfs) (Q=150, 2-112)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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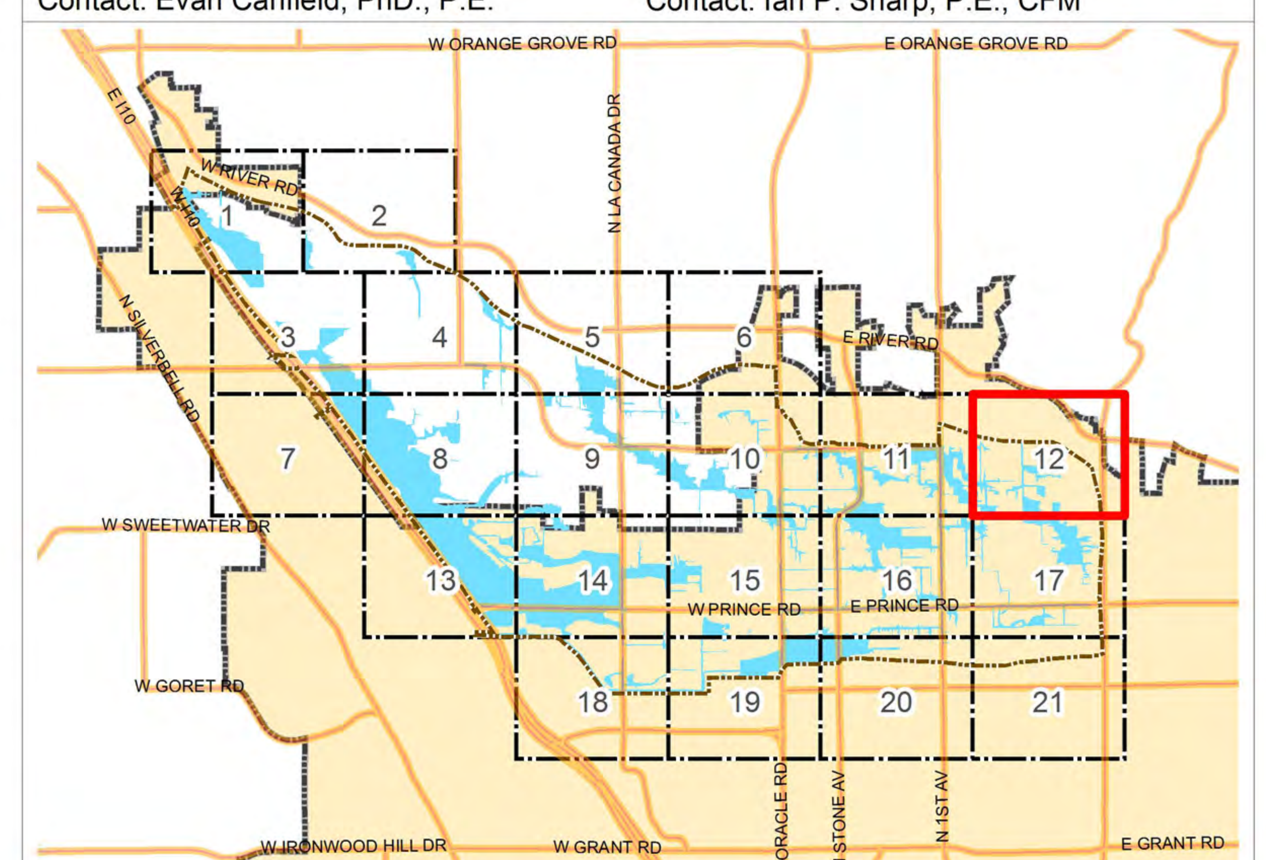

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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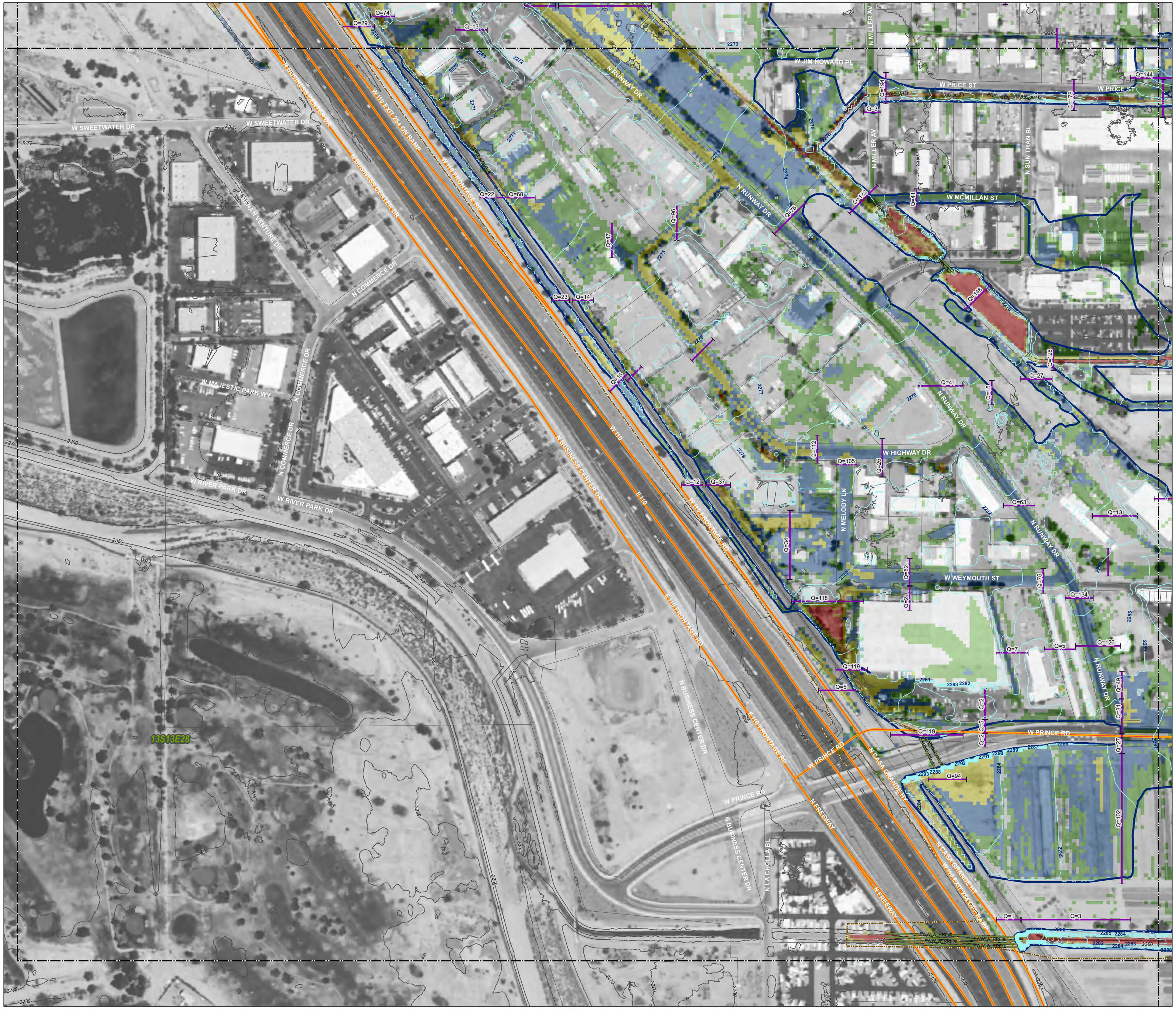
Sheet 12 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

Streets (Major)
10-ft Contours (PAG 2008)
Parcels (Approximate)
Sheet Line
Ruthrauff BMP Boundary

FLO-2D Symbols
Flood Limits
Q=150 / 2-112 Flow Record With Design Discharge (cfs)
Water Surface Elev. Contour (ft)
Culverts
Storm Drain Pipes (approx.)
Storm Drain Inlets (with ID)
Storm Drain Outlets

Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

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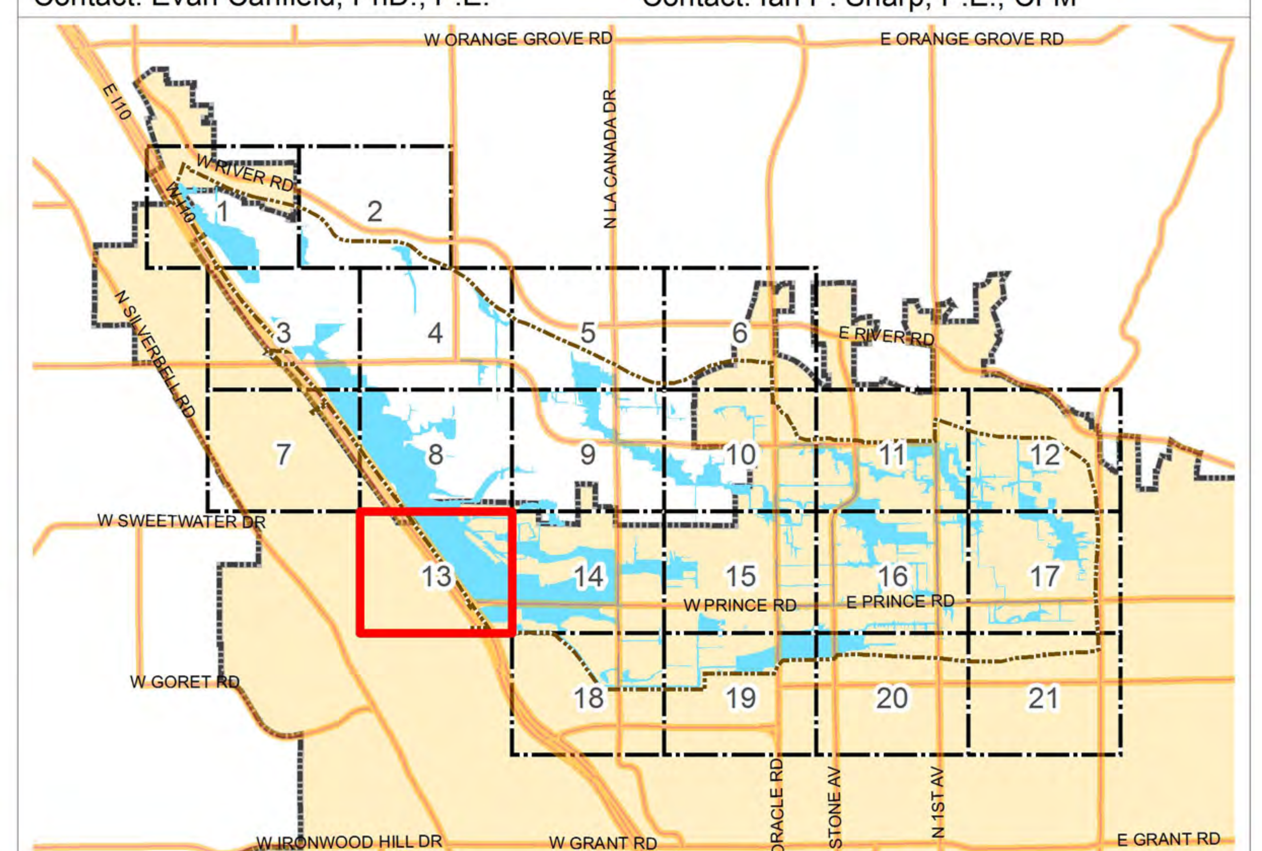

Legend

Flood Limits
Sheet Line
City of Tucson
Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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Ian Patrick Sharp
Date Signed
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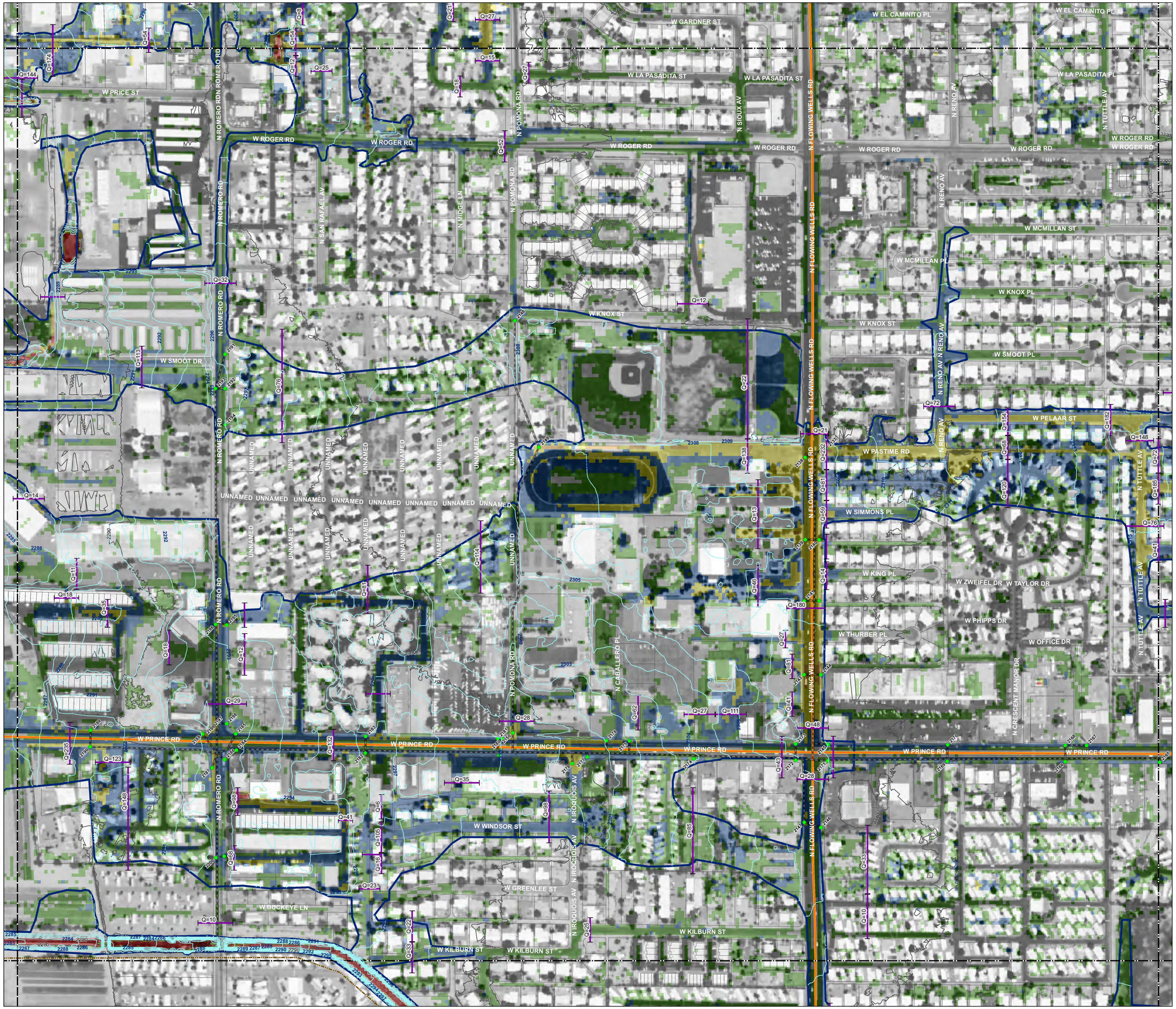
Sheet 13 of 21



Ruthrauff Basin Management Plan

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

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- 10-ft Contours (PAG 2008)
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FLO-2D Symbols

- Flood Limits
- Q=150 / 2-112 Flow Record With Design Discharge (cfs)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
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Flow Depth (ft)

<0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | >3.0

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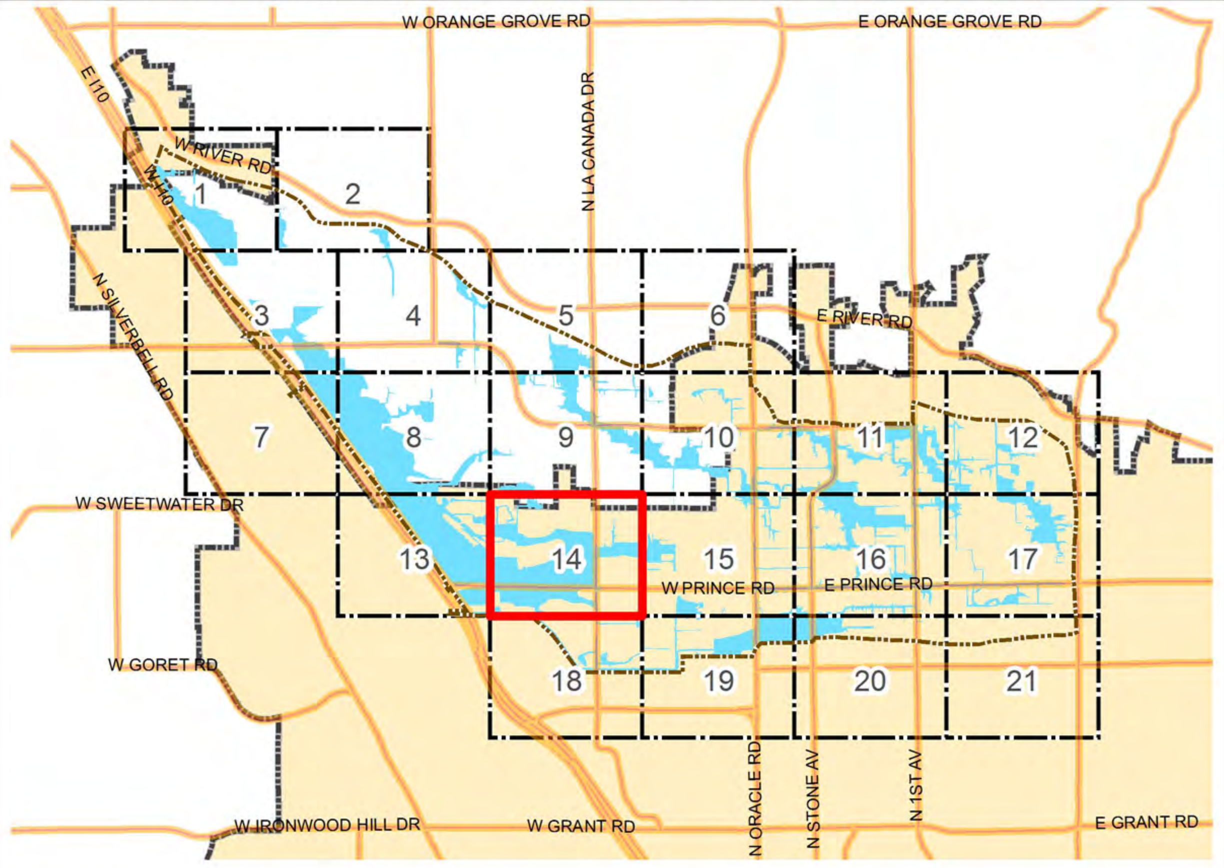

Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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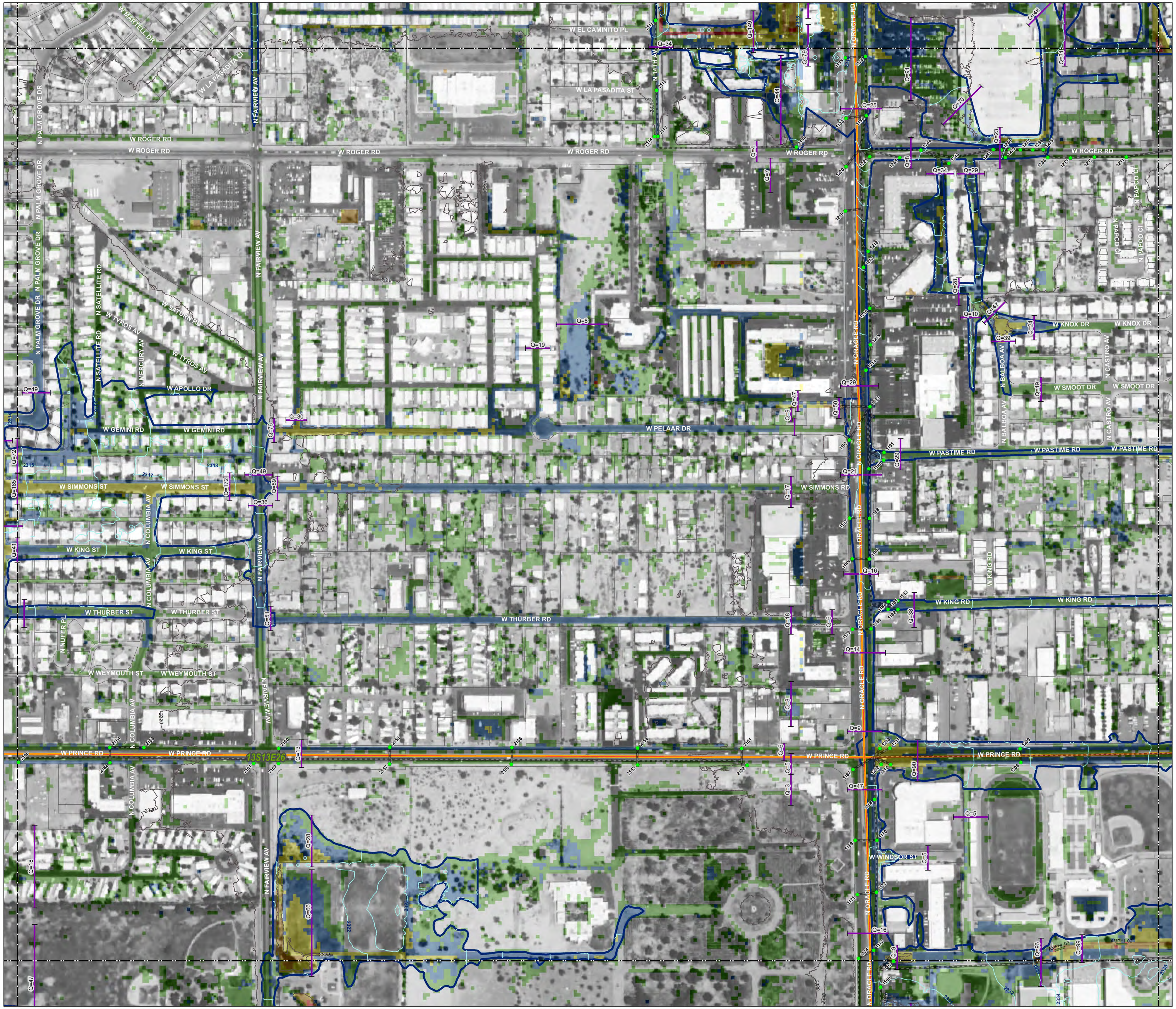

Ruthrauff Basin Management Plan

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0 400 800
Feet
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N

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FLO-2D Symbols

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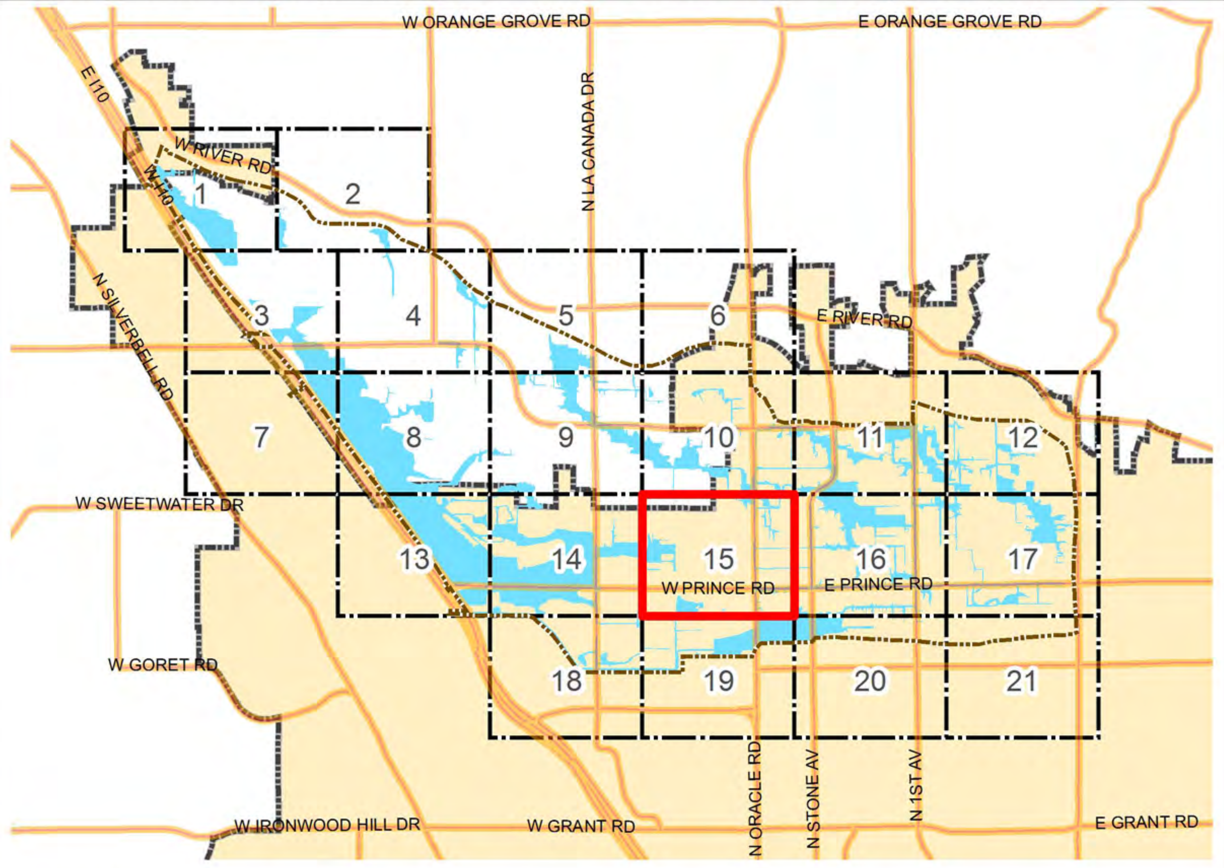

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0 0.5 1 2
Miles

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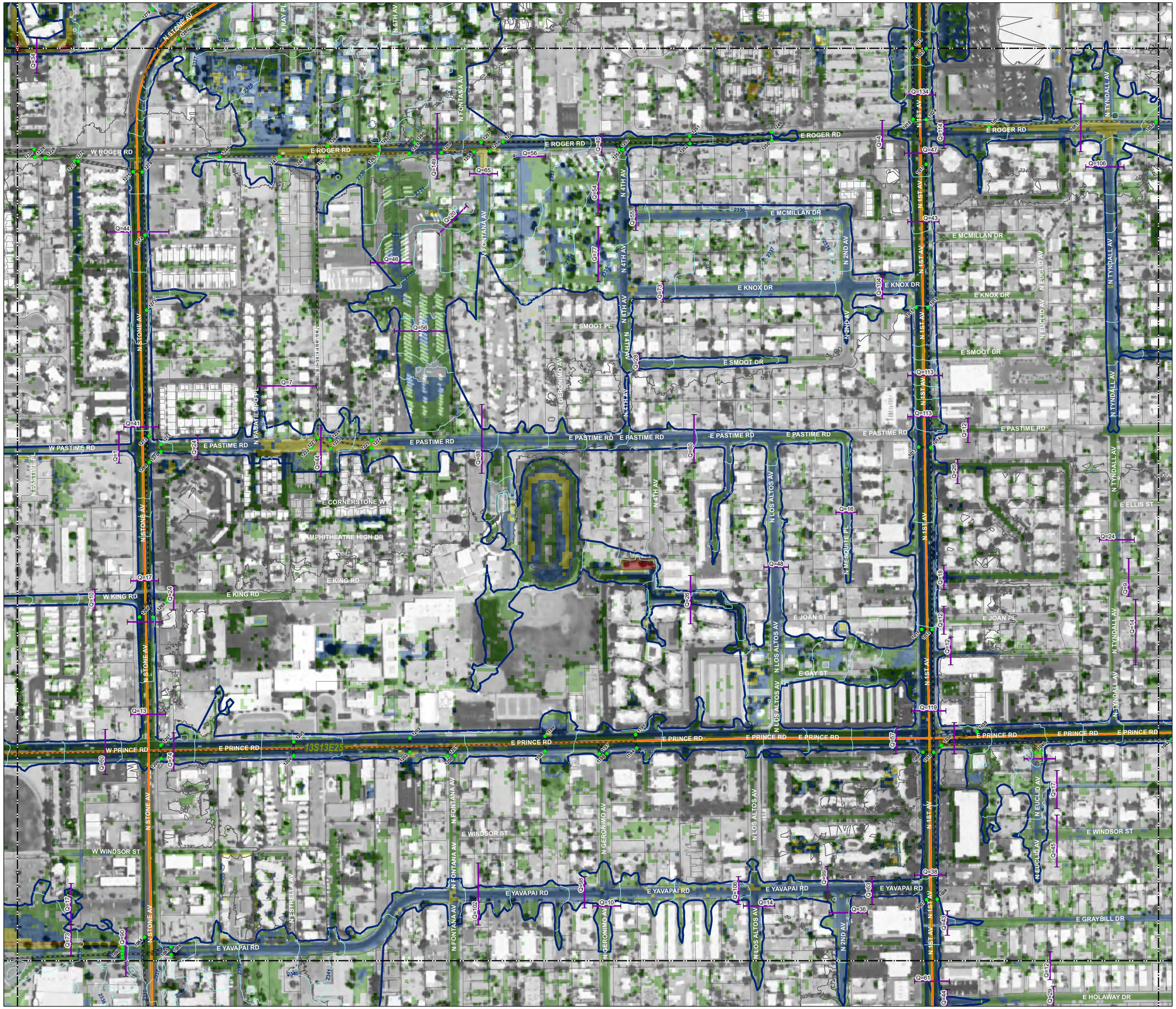

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0 400 800
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N

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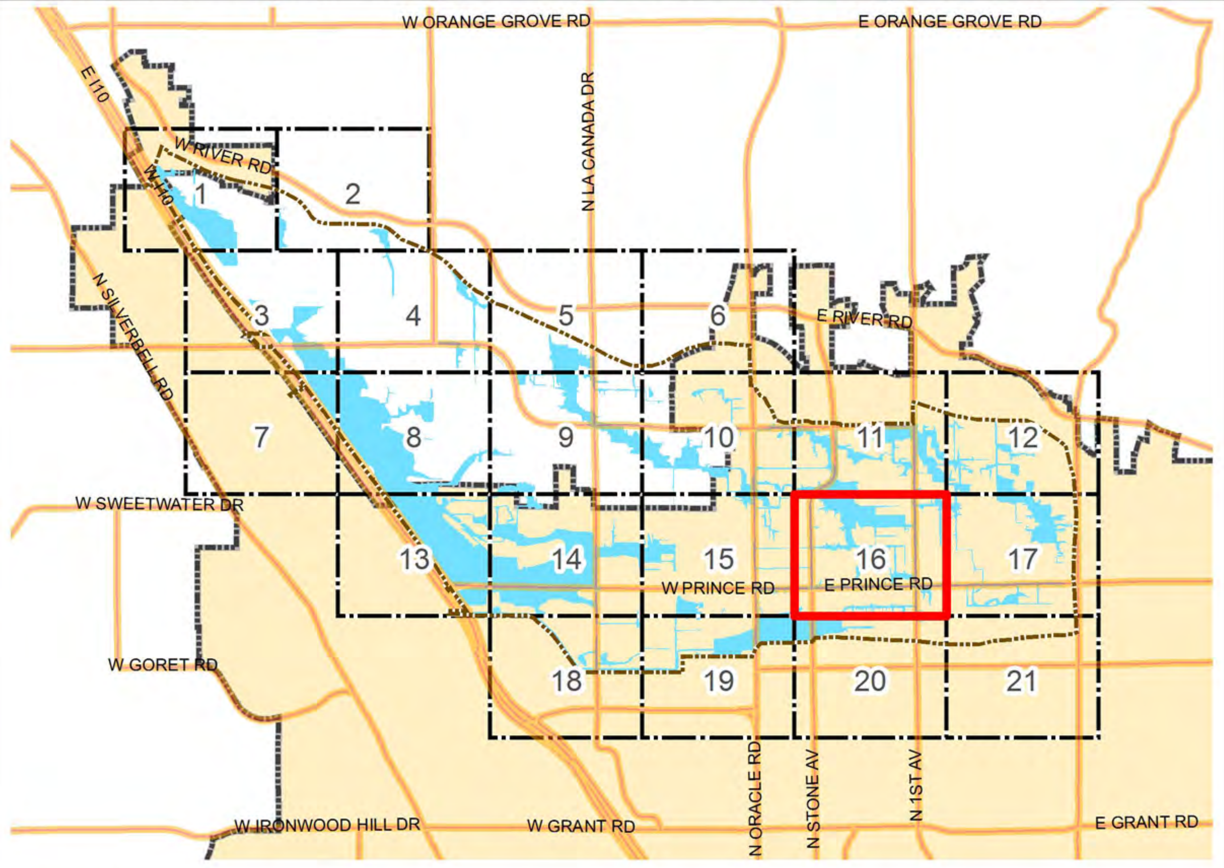

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0 0.5 1 2
Miles

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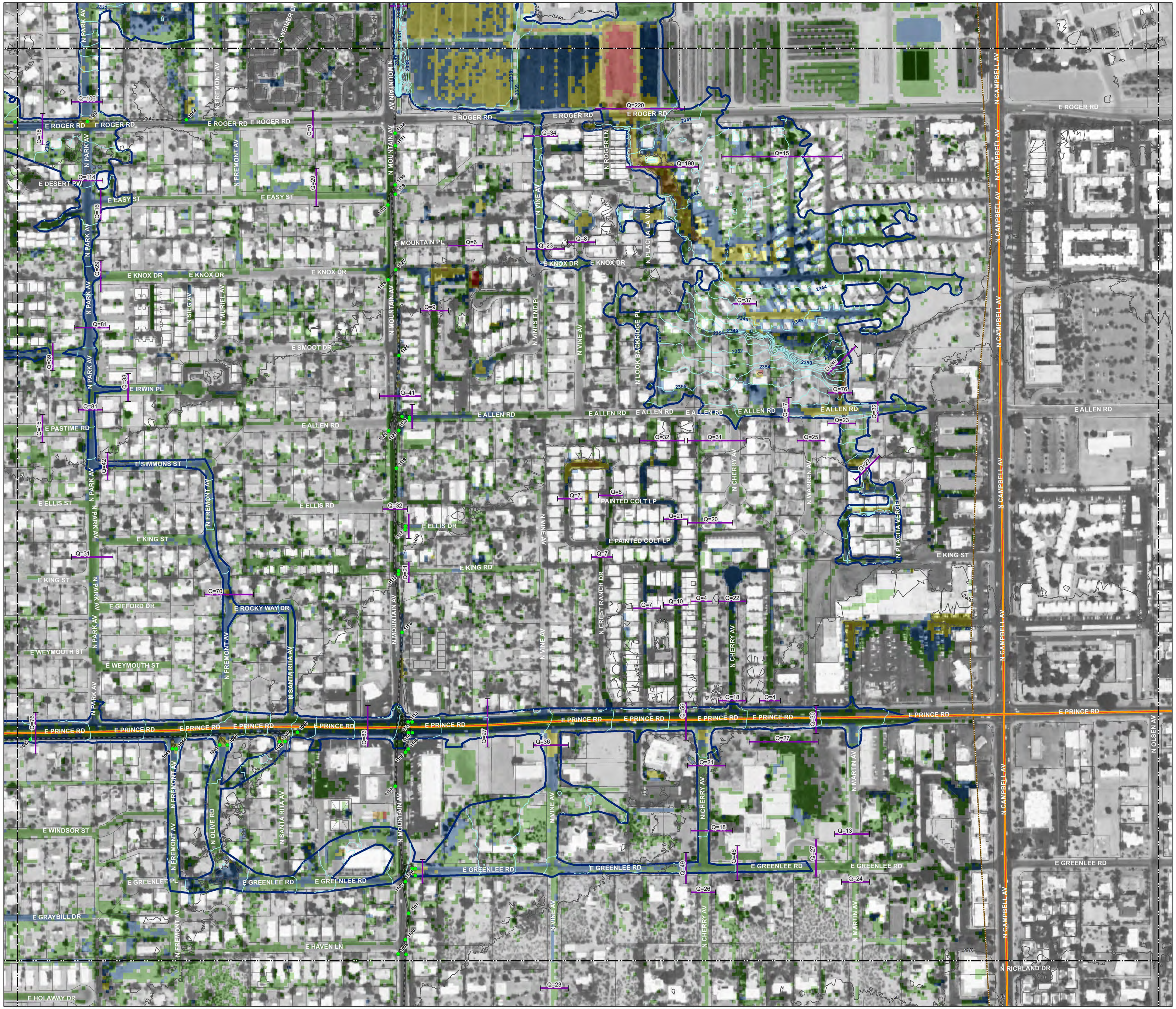

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0 400 800
Feet
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Sheet Line
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FLO-2D Symbols
Flood Limits
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Water Surface Elev. Contour (ft)
Culverts
Storm Drain Pipes (approx.)
Storm Drain Inlets (with ID)
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Flow Depth (ft)
< 0.2, 0.2 - 0.5, 0.5 - 1, 1.0 - 2, 2.0 - 3.0, > 3.0

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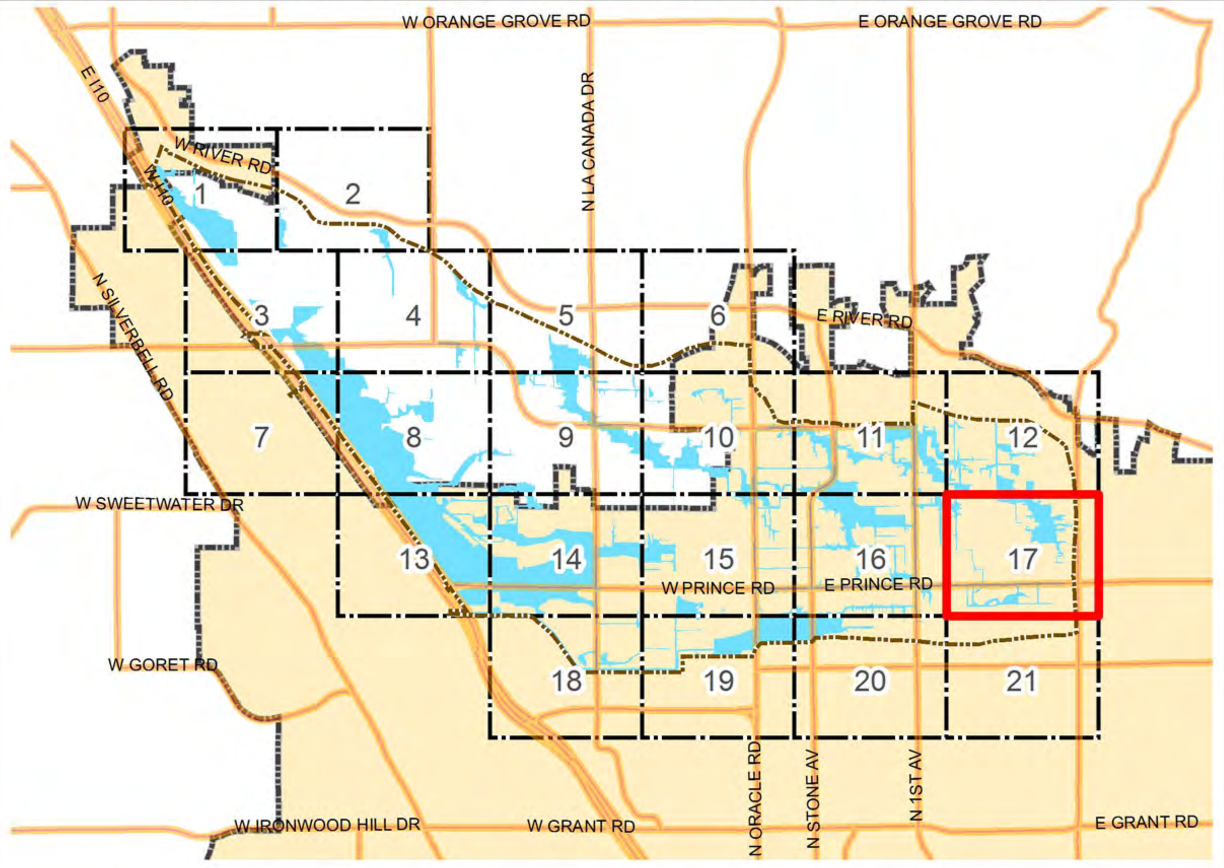

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Flood Limits
Sheet Line
City of Tucson
Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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Expires 3/31/2018

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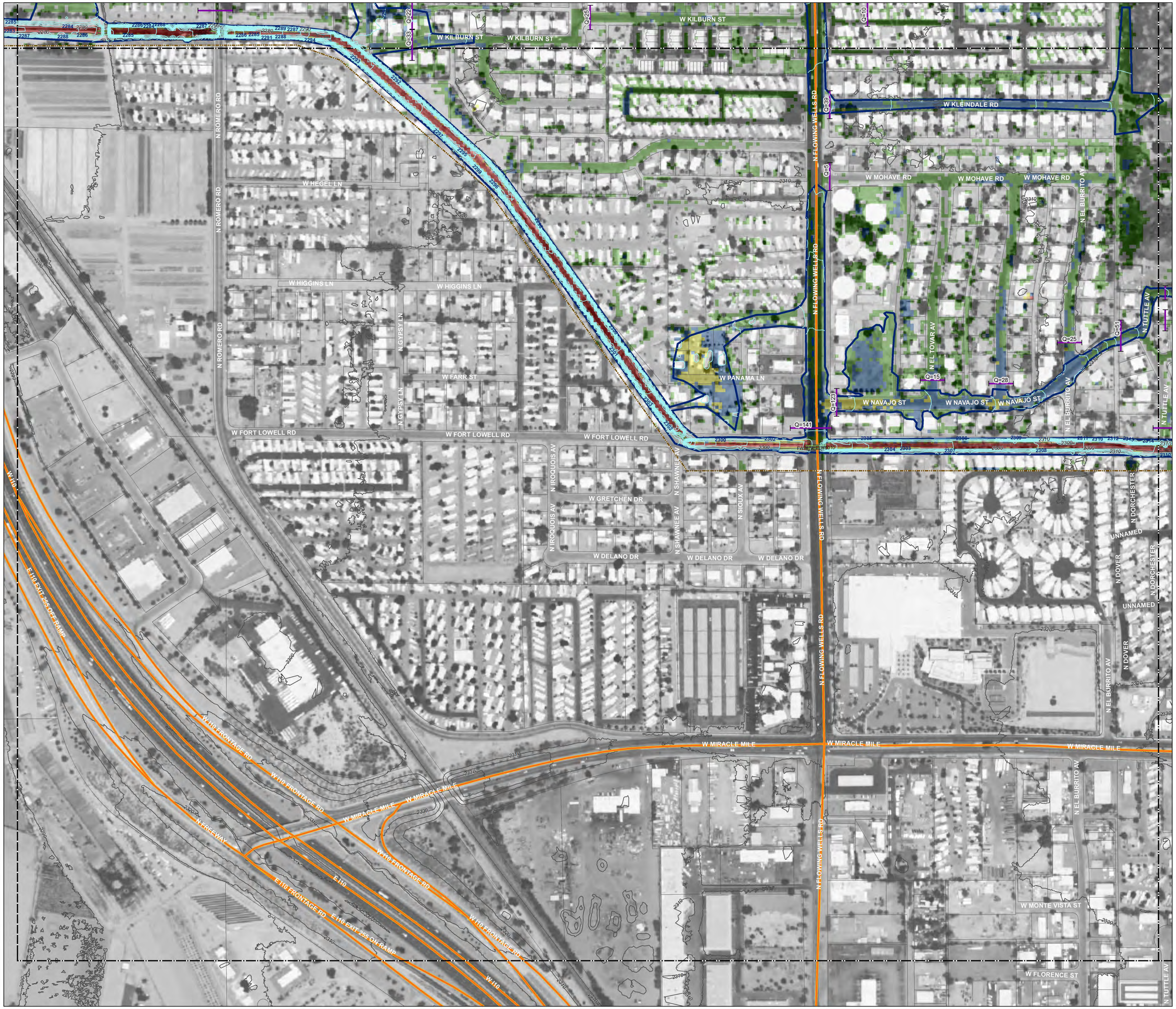

Ruthrauff Basin Management Plan

Exhibit 1 - 100-yr Floodplain Maps:

Generation 'a': Fall 2015

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0 400 800
Feet
1 inch = 200 feet

N

Plan Set Legend

- Streets (Major)
- 10-ft Contours (PAG 2008)
- Parcels (Approximate)
- Sheet Line
- Ruthrauff BMP Boundary

FLO-2D Symbols

- Flood Limits
- Flow Record With Design Discharge (cfs) (Q=150, 2-112)
- Water Surface Elev. Contour (ft)
- Culverts
- Storm Drain Pipes (approx.)
- Storm Drain Inlets (with ID)
- Storm Drain Outlets

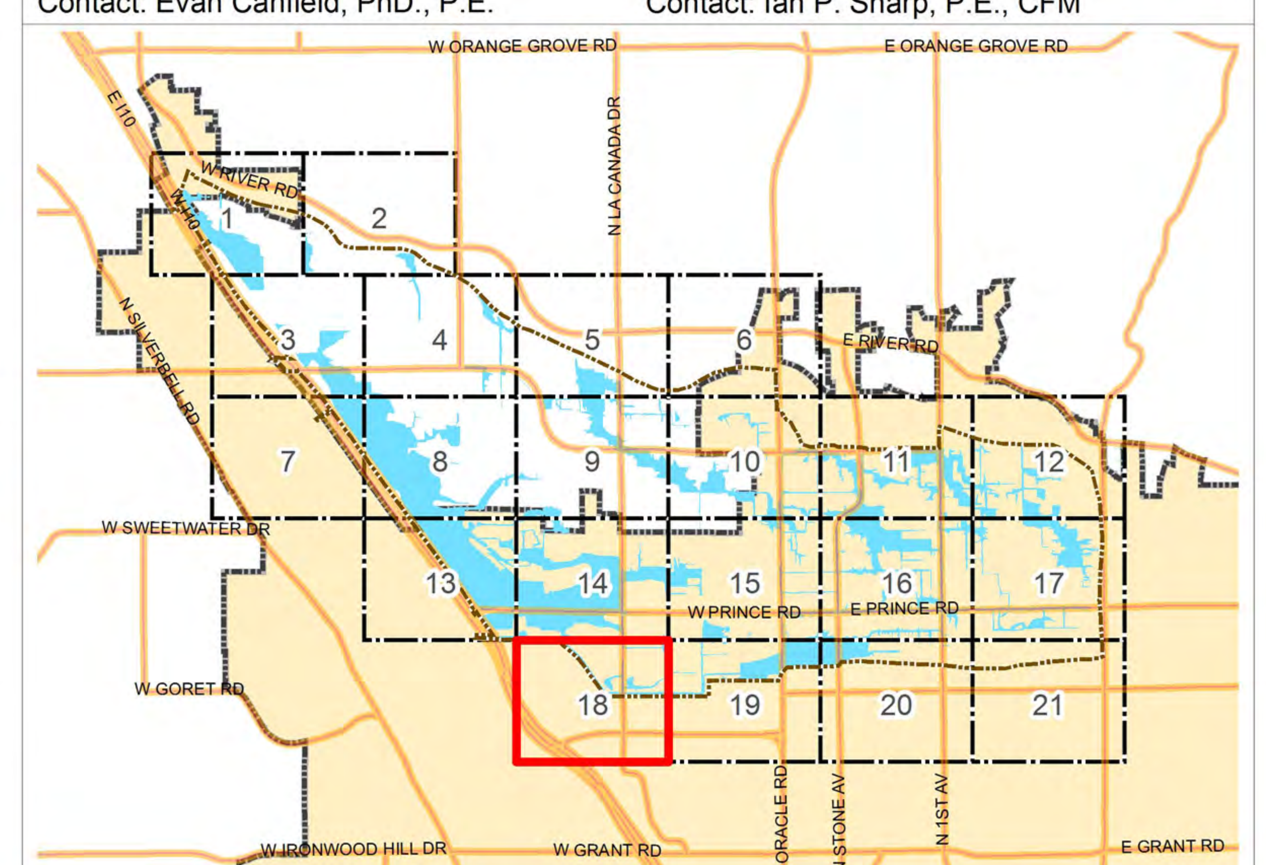
Flow Depth (ft)

< 0.2 | 0.2 - 0.5 | 0.5 - 1 | 1.0 - 2 | 2.0 - 3.0 | > 3.0

Aerial images: 2015 NAIP, <<http://gis.apfo.usda.gov/arcgis/services>>
Topographic contours developed from 2008 PAG LIDAR data.

Maps prepared for:
Pima County Regional Flood Control District
97 East Congress Street, Third Floor
Tucson, Arizona 85701
Contact: Evan Canfield, PhD., P.E.

Maps prepared by:
JE Fuller Hydrology & Geomorphology Inc.
40 East Helen Street
Tucson, Arizona 85705
Contact: Ian P. Sharp, P.E., CFM



Legend

- Flood Limits
- Sheet Line
- City of Tucson
- Ruthrauff BMP Boundary

0 0.5 1 2
Miles

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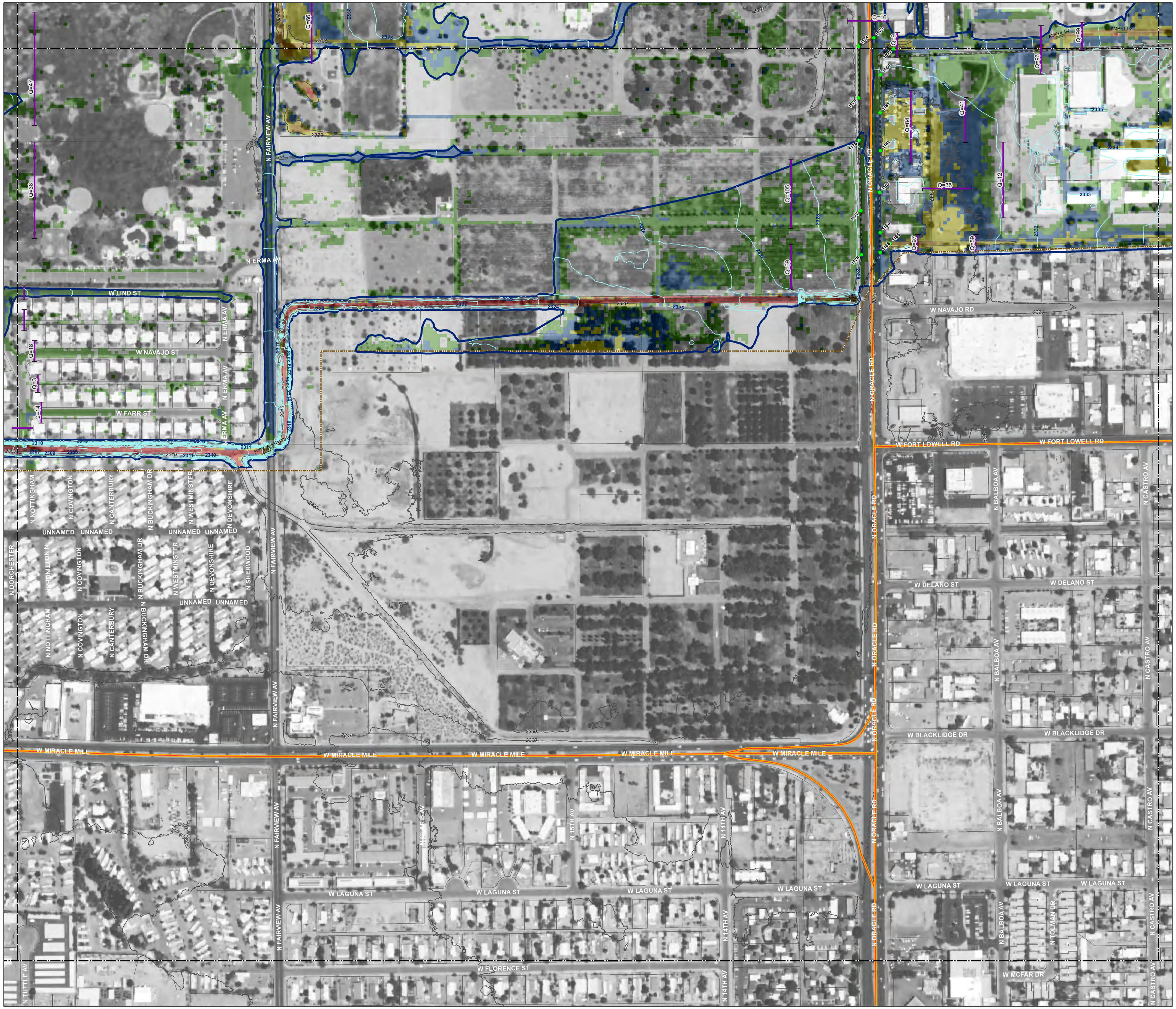

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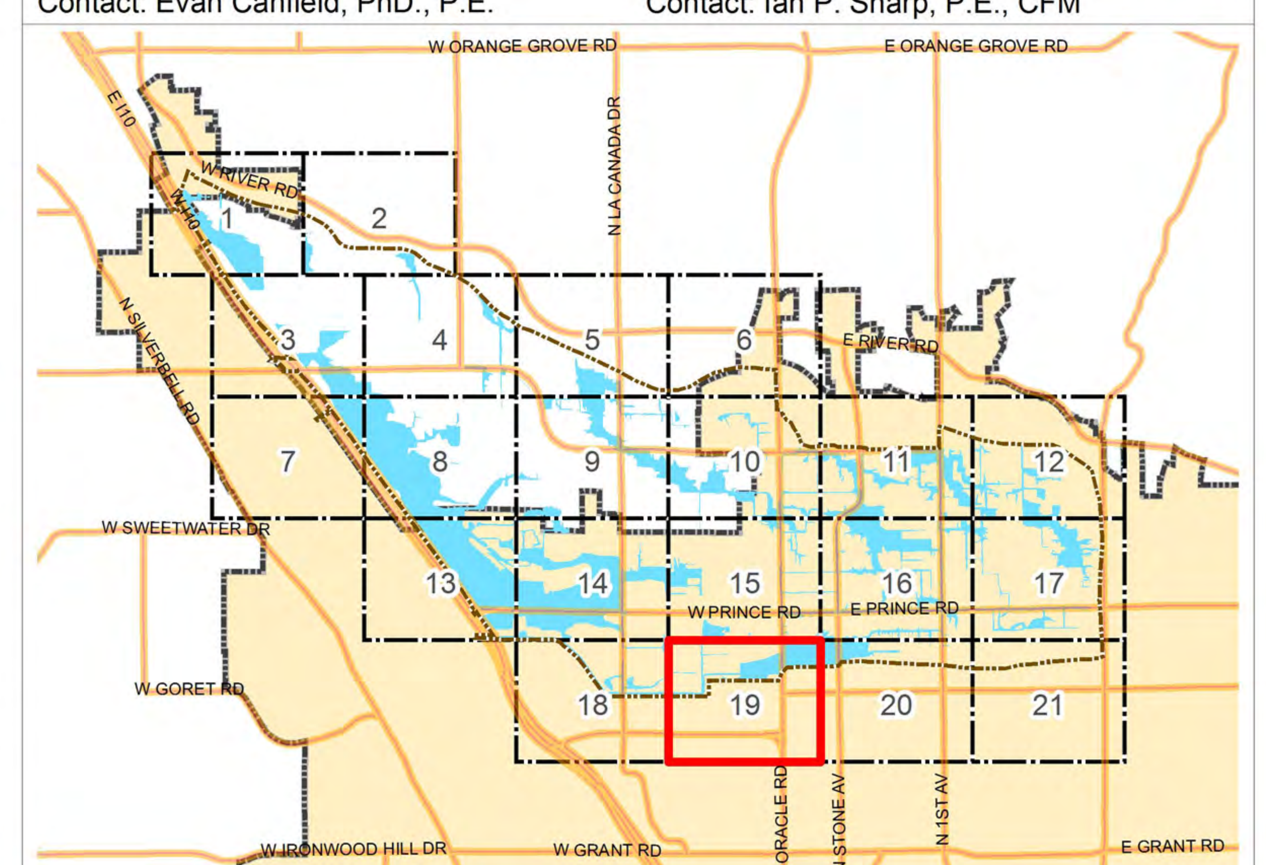

Legend

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0 0.5 1 2
Miles

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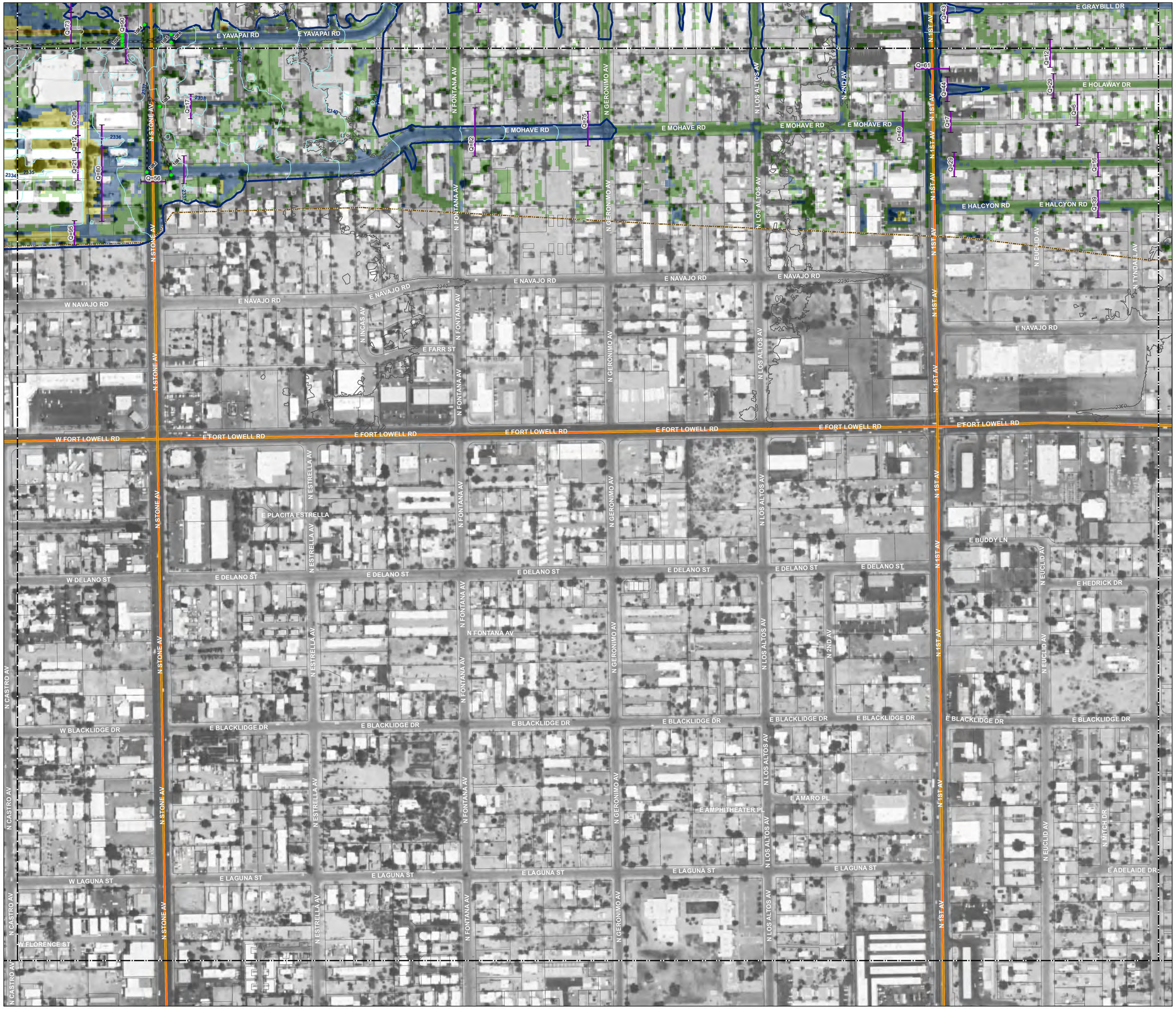

Ruthrauff Basin Management Plan

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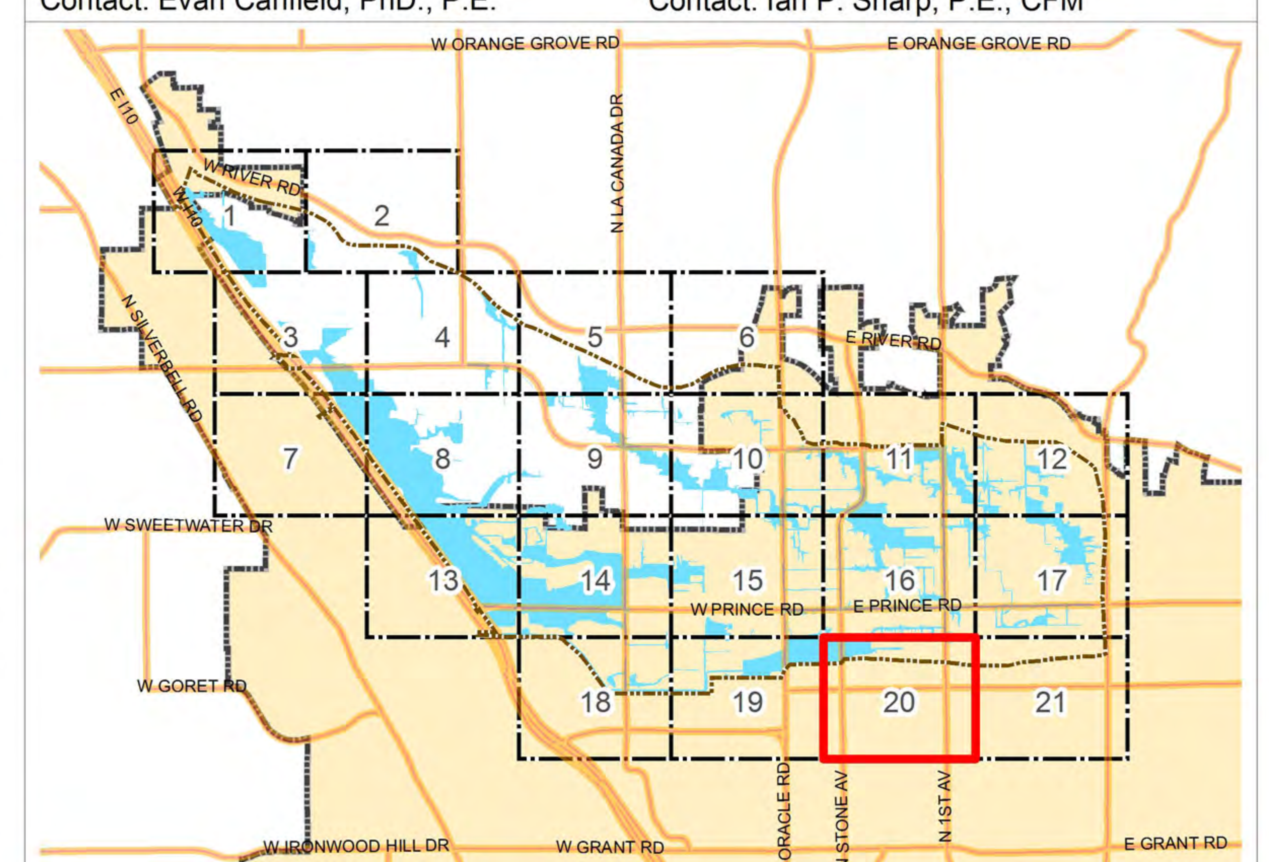

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0 0.5 1 2
Miles

43845
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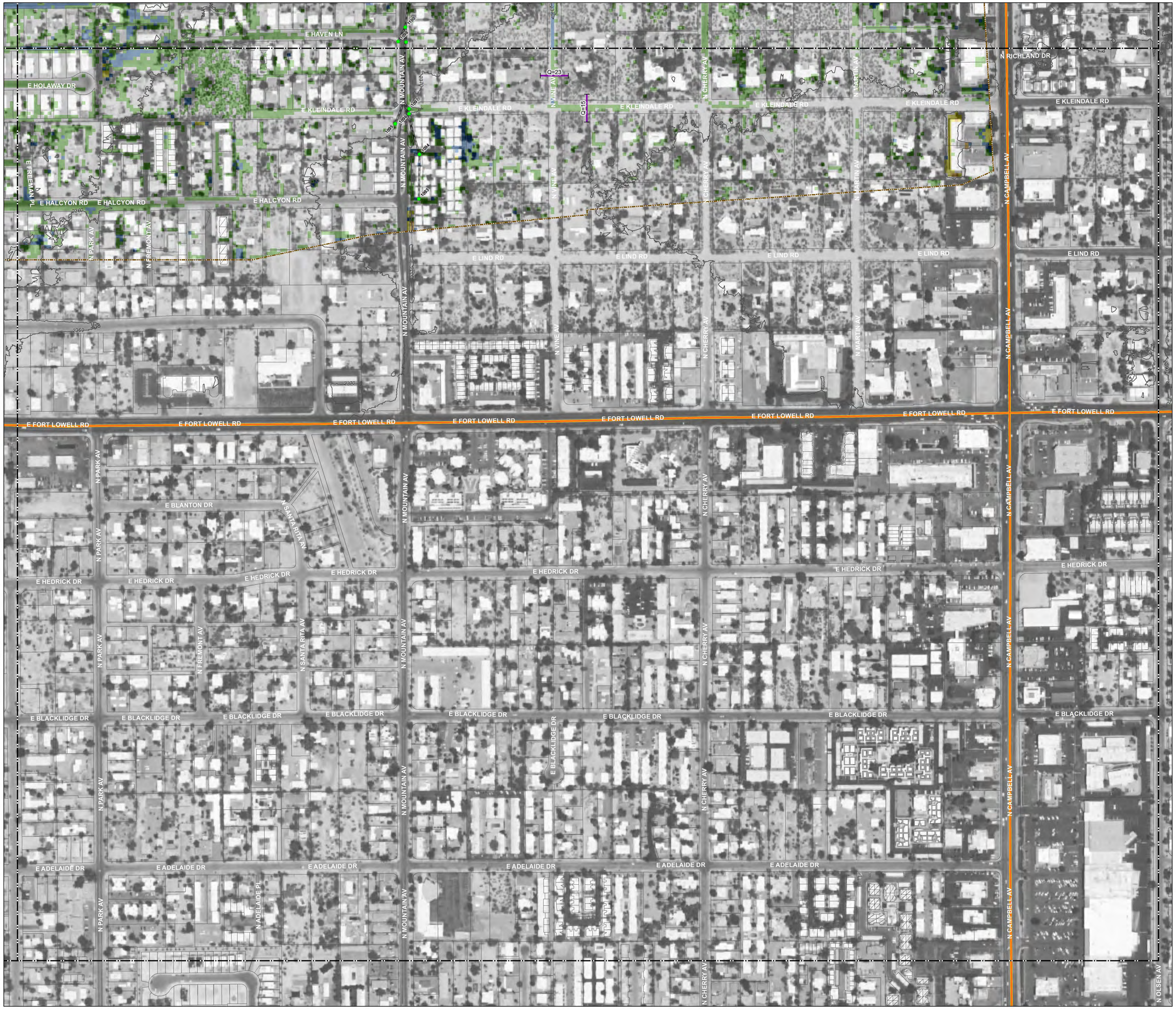

Ruthrauff Basin Management Plan

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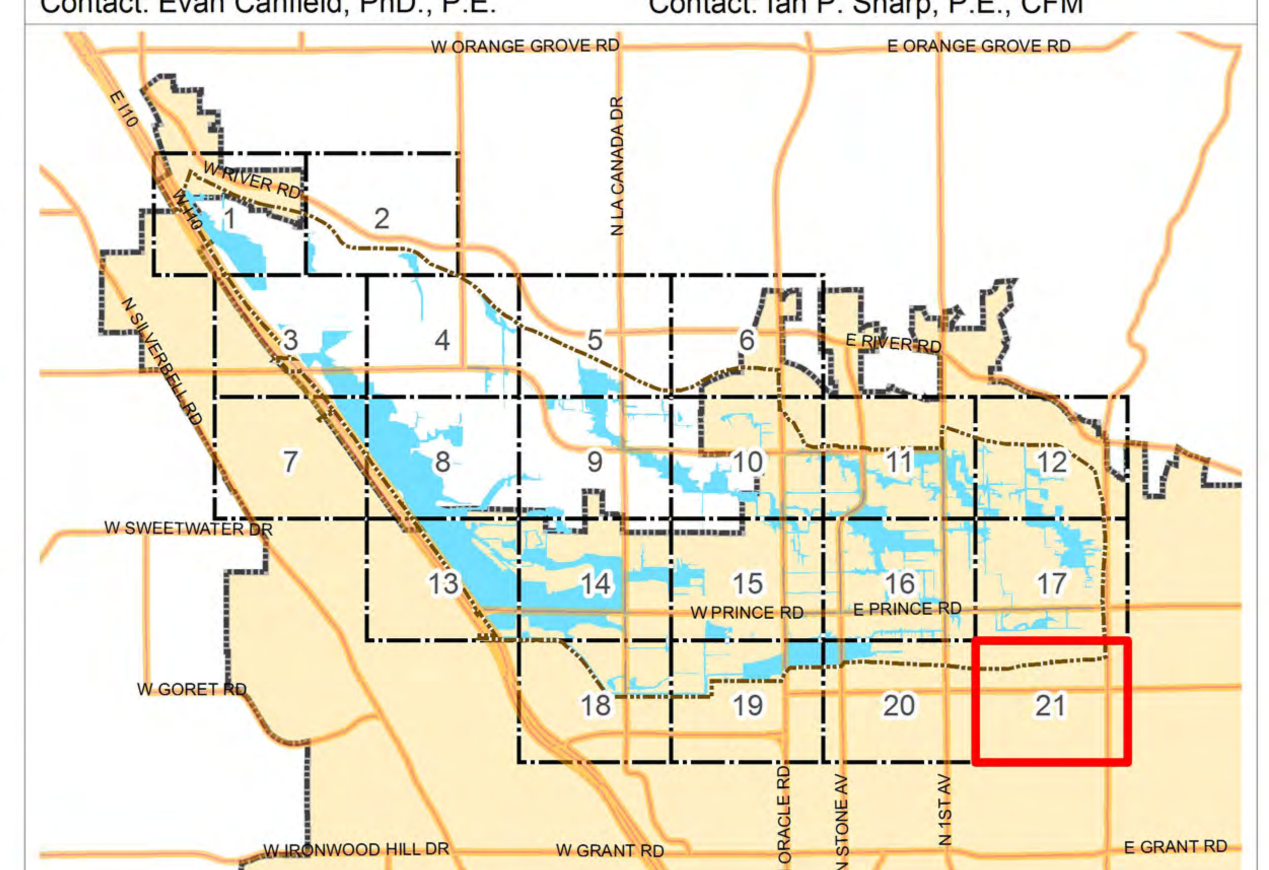

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