TEMPE AREA DRAINAGE MASTER STUDY
CONTRACT FCD 2012C021

FINAL ADMS REPORT

Prepared For:
Flood Control District of Maricopa County
2801 W. Durango Street
Phoenix, Arizona 85009-6399
(602) 506-1501

Prepared by:
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engineering and
environmental design

September 2016

REGISTERED PROFESSIONAL ENGINEER (CIVIL)
CERTIFICATE NO.
23170
JEFFREY J.
HOLZMEISTER
Date Signed 9/12/16
ARIZONA, U.S.A.
Expires 03/31/18

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1.0 EXECUTIVE SUMMARY

The Tempe ADMS/P study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructures including highways, railroads, streets, channels, and canals.

The entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C. The main reasons that the study area is divided into three (3) FLO-2D models are: a) topographic boundaries (features), b) FLO-2D model size, and c) integration of FLO-2D and SWMM models. The FLO-2D modeling boundary delineations take into account factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C. A grid size of 20 feet by 20 feet was applied for this project. The major features for the sub-models are summarized in the following table:

Sub-Model Features				
Model	Model A	Model B	Model C	Total
Drainage Area (mile^2)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

The integration of FLO-2D models (Models A and B, Models B and C) is a key part of the model development processes since the hydrology and hydraulics of the two sub-watersheds are connected by storm drain systems and or surface flows. Consistent input data preparation for all of the three models is also an important part of the integration of the models. The method of one (1) grid overlay along the boundaries was used for the model integration and the impact without rainfall adjustment is less than 0.1% of the drainage area.

Volume conservation is the most important criterion for a successful model simulation. The overall volume conservation for each of the simulation output time step was met very well for all three (3) models.

Measured storm drain outfall hydrographs by City of Tempe and corresponding rainfall data processed and provided by the Flood Control District of Maricopa County (District) for the March 1, 2014 storm were used for model verification (Model A, storm drain outfall SR-8). The outfall SR-8 peak flows from the FLO-2D modeling results and the measured data are comparable. The modeling results of Tempe Drain channel and field observed data for the September 8, 2014 storm were very similar and showed that the FLO-2D modeling results are reasonable.

The Tempe ADMP assignment includes compilation and evaluation of study results to produce a Flood Hazard Assessment report, development and refinement of Low Impact Design (LID) simulation processes using the study models, evaluation of flood mitigation alternative scenarios,

refinement of the Loma Vista Drainage Corridor CIP project (to incorporate feasible LID and rainwater harvesting alternative), and documentation of the study results in a final report.

The main deliverables of this study are Data Collection Report (Volume I), Hydrologic and Hydraulic Modeling Report (Volume II, FLO-2D/SWMM Modeling Report), Flood Hazard Assessment (Volume III), LID Application Review and FLO-2D Modeling Report (Volume IV), Stakeholder Coordination Report (Volume V), and Low Impact Development Concept Plan for Loma Vista Flood Mitigation Study (Volume VI).

2.0 INTRODUCTION

2.1 Project Description

In the past few years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake, major redevelopment of portions of the city is taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various green infrastructures (GI) and low impact development (LID) techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe Area Drainage Master Study and Plan (Tempe ADMS/P).

The major tasks of this ADMS/P includes data collection, hydrologic/hydraulic analyses (FLO-2D) with integrated storm drain analyses (SWMM), preparation for the flood hazard assessment, LID review and modeling, public involvement, stakeholder coordination, and flood mitigation concept for Loma Vista.

2.2 Project Purpose and Goals

The major purposes and goals of the Tempe ADMS/P are to identify flood hazards and develop any needed flood mitigation solutions for effectively addressing the flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

2.3 Project Authorization

J2 Engineering and Environmental Design (J2) has been retained to perform these services as a part of the District On-Call Contract FCD 2012C021. J2 team for the Work Assignment No. 2 includes Black & Veatch and Riada as sub-consultants. The District is located at 2801 West Durango Street, Phoenix, AZ 85009, (602) 506-1501. The Project Manager for the District is Mr. Burke Lokey, P.E., PMP, CFM. J2's Project Manager for this project is Mr. Jeff Holzmeister, P.E.

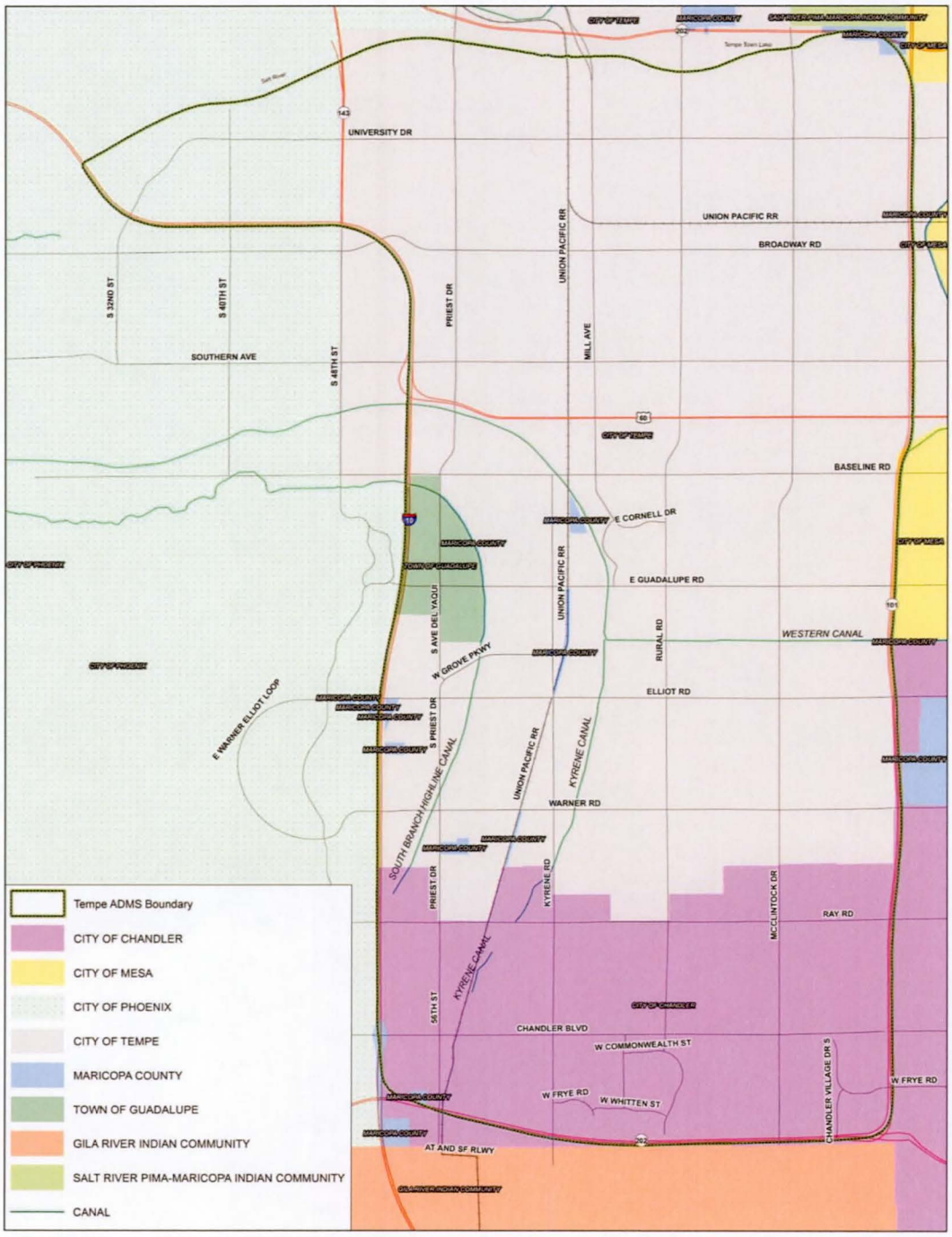
2.4 Project Location, Overview and History

The Tempe ADMS/P study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47

square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructures including highways, railroads, streets, channels, and canals. Figure 2.1 shows the project area boundaries and location.

The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructures including roads and canals. The study area has two (2) major outfalls: the Salt River on the North and the Gila River on the southwest. An important drainage divide/saddle exists within the study area and is located near the intersection of Rural Road and Western Canal which is elevated as shown in the following photos. East of this location surface runoff is generally from east to west; west of this location surface runoff originating from South Mountains is generally from west to east; south of this location surface runoff is generally from northeast to southwest leaving the study area into the Gila River; north of this location surface runoff is generally from east/southeast to west/northwest into the Salt River.

Western Canal Looking West at Rural Road



Tempe ADMS/P FCD 2012C021
Figure 2.1 Project Area Boundaries and Location Map

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

Western Canal Looking East at Rural Road

In addition to Western Canal, Kyrene Canal and Highline Canal have a significant impact on the surface drainage systems of the watersheds as shown in the following photos. Surface runoff is intercepted and flow directions are changed by these canals since they are generally aligned along contour lines and elevated. The alignments of these canals are shown on the Project Area Boundaries and Location Map.

Kyrene Canal Looking South at Elliot Road

Highline Canal Looking North at Guadalupe Road

Transportation infrastructure in the project area is extensive including Loop 101 on the east, SR 202 on the south, I-10 on the west, US60 bisecting the study area, and SR143 serving the boundary of Cities of Tempe and Phoenix as well as the old Southern Pacific railroad system and the new light rail system as shown in the following photos.

UPRR Looking East at Mill Avenue

UPRR Looking North at Broadway Road

Light Rail Looking West at McClintock Drive

Complex drainage systems including open channels/storm drains, detention/retention basins, bridges/culverts, and pump stations were constructed for these highway systems. These drainage systems changed the natural surface flow patterns and become part of the overall drainage systems of the study area. In addition to the highway and railroad systems, surface street/road networks have been developed as well in the study area and are the major surface drainage corridors.

Tempe Drain Looking East at 40th Street

US 60 Basin Looking Southwest

Scudder Park at SEC of Southshore Dr. and Lakeshore Dr.

Complex public drainage systems were constructed with the urbanization of the study area. These drainage systems include open channels of Tempe Drain and Gila Drain, 146-miles of storm drain (with more than 2,800 inlets and 100 outfalls), over 120 detention/retention basins, and 41 bridges/culverts for roadway crossings.

Storm Drain Outfall into Tempe Drain at SR 143 (looking west)

Gila Drain Outfall at SR 202 (looking south)

Storm Drain Outfall into Salt River at Tempe Town Lake (SR08)

2.5 Stakeholder Participation and Interagency Coordination

J2 team supported and documented the Stakeholder Involvement effort that occurred during the project. The *Stakeholder Coordination Report* (Volume V) included the list of stakeholders, meeting minutes of the stakeholder working group meetings, and the record of stakeholder involvement. The primary stakeholders include the COT Public Works, COT Community Relations, and other pertinent COT departments. Other primary stakeholders include PHOENIX, GUADALUPE, CHANDLER, and ASU. Secondary stakeholders may include ADOT, the Salt River Project (SRP), Tempe Elementary School District, and the Tempe Union High School District.

2.6 Acknowledgements

J2 team is very appreciative to have the opportunity to represent the District in the performance of these services. This professional assignment presented many interesting and unique challenges requiring creative teamwork solutions. Mr. Doug Williams, Mr. Burke Lokey, Mr. Jake Serago, Mr. Richard Waskowsky, Mr. Amir Motamedi, Ms. Theresa Pinto, Mr. Thomas Loomis, Mr. Pedro Melo-Rodriguez, and Mr. Joe Wagner of the District; Mr. Gregg Kent and Mr. Richard Dalton of the City of Tempe, Mr. Hasan Mushtaq of the City of Phoenix, Mr. Warren White of the City of Chandler, and Mr. Jim Ricker of the Town of Guadalupe provided critical technical support and decision-making guidance throughout the duration of the study. Their individual and group contributions played a key role in the successful completion of this assignment.

3.0 ASSESSMENT OF EXISTING FLOOD ISSUES

3.1 Assessment of Known Drainage Complaints

Known drainage complaints including flooding complaints, flood insurance claims, and historic flooding data were documented in the *Data Collection Report* (Volume I, Chapter 5).

3.2 Assessment of Existing Flood Control Facilities

The major flood control facilities of the project area were documented in the *Data Collection Report* (Volume I, Chapters 10.0, 11.0, and 12.0). The drainage culverts were evaluated and documented in the *Hydrologic and Hydraulic Modeling Report* (Volume II) and Tempe Drain Channel system were assessed in the *Flood Hazard Assessment Report* (Volume III).

3.3 Assessment of City of Tempe's Existing Storm Drain Systems

This project area has extensive storm drain systems including 146 miles pipe systems with 2,883 inlets. The storm drain systems were modeled and assessed by using EPA's SWMM program. The results were documented in the *Flood Hazard Assessment Report* (Volume III).

TEMPE AREA DRAINAGE MASTER STUDY /PLAN

CONTRACT FCD 2012C021

VOLUME I
DATA COLLECTION REPORT

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August 2014

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1.0 INTRODUCTION

1.1 Study Area and Location

The Tempe Area Drainage Master Study (Tempe ADMS) study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. Figure 1.1 shows the project area boundaries and location.

1.2 Hydrologic Features of the Study Area

The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructure, including roads and canals. The study area has two (2) major outfalls: Salt River on the north and Gila River on the southwest. An important drainage divide/saddle exists within the study area and is located near the intersection of Rural Road and Western Canal. East of this location surface runoff is generally from east to west; west of this location surface runoff originating from south mountains is generally from west to east; south of this location surface runoff is generally from northeast to southwest leaving the study area into the Gila River; north of this location surface runoff is generally from east/southeast to west/northwest into the Salt River.

The following man-made (water supply/irrigation) canals have a significant impact on the surface drainage systems of the watersheds: Tempe Canal, Consolidated Canal, Eastern Canal, and Roosevelt Canal on the east; Kyrene Canal/Western Canal, and Highline Canal on the west. Surface runoff is intercepted and flow directions are changed by these canals since they are generally aligned along contour lines and elevated.

Transportation infrastructure in the project area is extensive, including Loop 101 on the east, SR 202 on the south, I-10 on the west, US60 bisecting the study area, and SR143 serving the boundary of Cities of Tempe and Phoenix as well as the old Southern Pacific railroad system and the new light rail system. Complicated drainage systems including open channels/storm drains, detention/retention basins, bridges/culverts, pump stations were constructed for these highway systems. These drainage systems changed the natural surface flow patterns and become part of the overall drainage systems of the study area. In addition to the highway and railroad systems, surface street/road networks have been well developed as well in the study area and are the major surface drainage corridors.

With the urbanization of the study area complex public drainage systems were constructed including open channels, such as Tempe Drain, over 100 miles of storm drains, regional and neighborhood detention/retention basins, and bridges/culverts for roadway crossings.

1.3 Purpose of Study

Within the last five years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in Tempe. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake major redevelopment of portions of the city is taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various green infrastructure and low impact design techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe ADMS to identify flood hazards and develop any needed flooding mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

The purpose of this report is to document the data collection effort for the Tempe ADMS, summarize the pertinent studies/reports/as-built plans, and facilitate the development of comprehensive FLO-2D hydrologic/hydraulic models, identification of flood hazards, and evaluation of any needed flood mitigation solutions.

1.4 Significance of the Data Collection Effort

As discussed previously, the topographic features in the area is very complex; the study area is primarily developed; and its drainage patterns have been significantly changed by urbanization and man-made infrastructure including streets, highways, railroads, irrigation canals, bridges/culverts, detention/retention basins, and storm drain systems. The majority of the storm water runoff volume is conveyed out of the study area by extensive storm drain systems. A significant portion of the storm water runoff volume is stored in the detention/retention basins within the study area. Only a small portion of the storm water runoff volume is conveyed out of the study area through surface drainage systems. Therefore, data collection effort, especially, data for storm drain systems and drainage structures, is very significant as documented in sections 10, 11, and 12. More than 140-mile pipes, 2,700 inlets, and 110 outfalls of storm drain systems, more than 120 detention/retention basins, and 66 bridges/culverts demonstrate the data collection effort. The accuracy of the collected data determines the success of this project including hydrologic/hydraulic modeling processes, evaluation of flooding issues, and identification of cost/effective flooding mitigation measures.

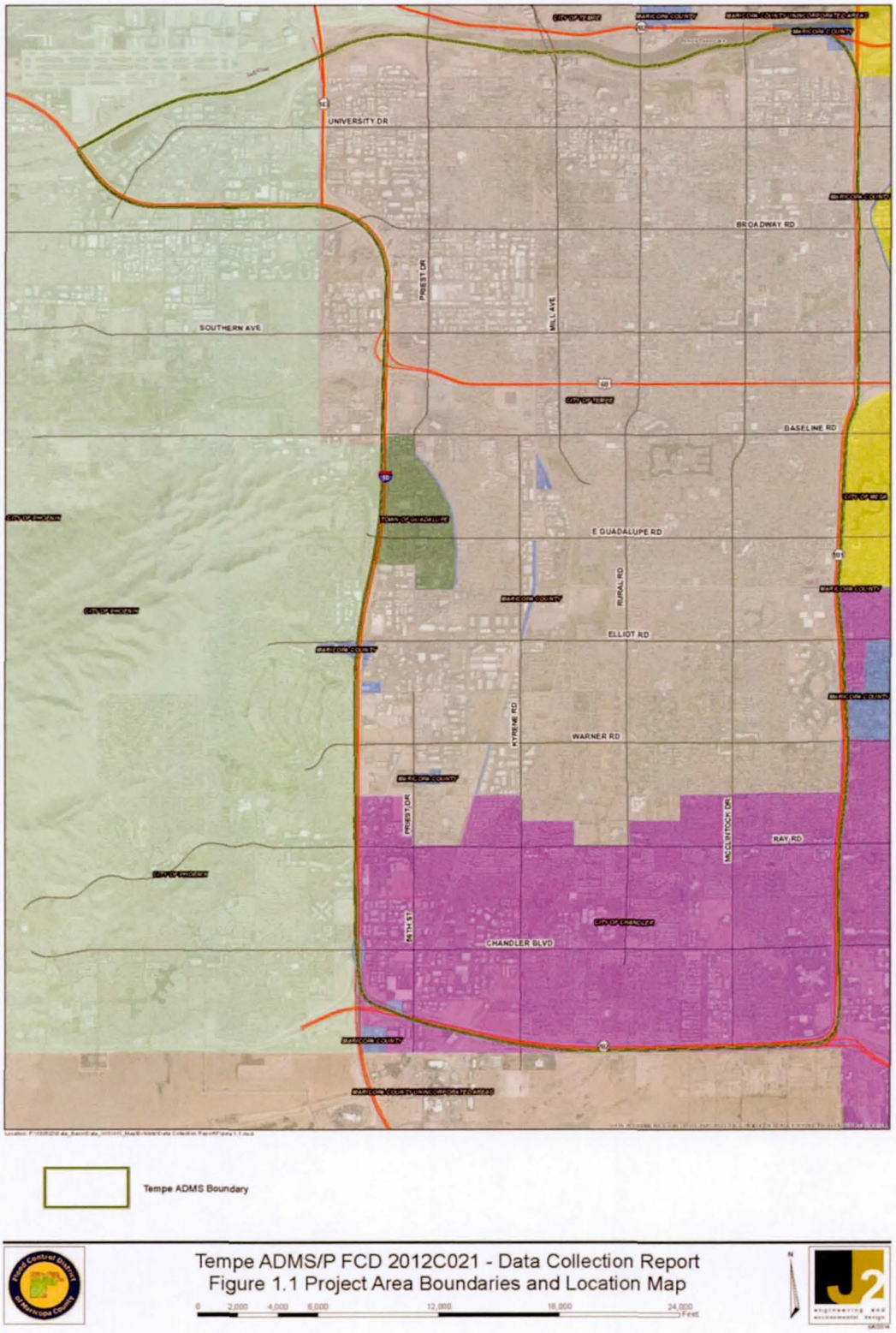

Figure 1.1 Project Area Boundaries and Location Map

2.0 DATA SOURCES AND TYPES

2.1 Data Sources

The data collected as part of the Tempe ADMS/P was from various sources. The majority of the data collected was from major stakeholders on the project: the District, City of Tempe, City of Phoenix, City of Chandler, Town of Guadalupe, Arizona Department of Transportation (ADOT), Arizona State University (ASU), and Salt River Project (SRP). Other sources include Federal Emergency Management Agency (FEMA), US Geologic Survey (USGS), Natural Resources Conservation Service (NRCS), and National Oceanic and Atmospheric Administration (NOAA).

The contact references for the primary sources (major stakeholders) are listed as follows:

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Jamie.ashby@srpnet.com

2.2 Data Types

J2 has collected and reviewed various types of data which are pertinent to the study of the project area. The types of data that were collected included, but were not limited to the following:

- Topographic mapping
- FEMA FIS data
- Historic flooding
- Land use data
- Soil data
- Hydrologic data
- Drainage studies
- Storm drain data
- Drainage structures

3.0 TOPOGRAPHIC AND AERIAL MAPPING

3.1 Aerial Mapping

Aerial mapping for the study area in MrSID format was provided by the District together with the SID file schematic in DGN format. The aerial mapping is shown in Exhibit A.

3.2 Topographic Mapping

Topographic mapping for the study area was provided by the District in both GENERATE format (mass points *.pf and breaklines *.lf files) and DGN format (DTM). The signed and sealed survey reports are included in Appendix 1. The topographic mapping in raster format is shown in Exhibit B. The study area covers several municipalities which are shown in Exhibit C.

3.3 USGS Quadrangle Maps

The USGS Quadrangle Maps covering the study area are tabulated below.

USGS Quad Map Name	Scale	Date	Contour Interval
Tempe, AZ	7.5 minutes 1:24,000	2011	10 ft
Guadalupe, AZ	7.5 minutes 1:24,000	Revised 1982	10 ft
Phoenix, AZ	7.5 minutes 1:24,000	2011	10 ft

4.0 FEMA FIS DATA

4.1 Effective FIS Data

The Tempe ADMS/P study area is located within Maricopa County (FEMA community No. 040037), City of Tempe (FEMA community No. 040054), City of Phoenix (FEMA community No. 040051), City of Chandler (FEMA community No. 040040), and Town of Guadalupe (FEMA community No. 040111). FEMA FIRM panel numbers (effective date: Oct. 16, 2013) located within the study area include: 2220L, 2240L, 2244L, 2245L, 2705L, 2710L, 2715L, and 2720L. The effective FIRM panels are included in Exhibit D – FEMA FIRM Panels. Some of the data from the effective FIS reports are included in Appendix 2 – FIS Data.

4.2 LOMRs/LOMAs

RBF Consult in 2010 performed a flood delineation study that was titled as "Western Canal in Tempe Floodplain Delineation Study Technical Data Notebook (FDS, TDN) for Flood Control District of Maricopa County-FCD, FCD 2008C001."

Other FEMA Letter of Map Revisions (LOMRs) and Letter of Map Amendments (LOMAs) within City of Tempe area are summarized in Appendix 2, LOMRs_LOMAs section.

5.0 KNOWN FLOODING

5.1 Flooding Complaints

Flooding complaints for City of Phoenix are summarized in Appendix 3 which includes about fifty (50) reported cases since 2006. Reported flooding locations and photos for City of Tempe are documented in Exhibit E which shows more than two dozens of flooding cases reported in recent years. Most of the flooding complaints are related to flooding at local streets during significant storm events.

5.2 Flood Insurance Claims

Flood insurance claims were obtained from the District. Total reported claims are 30, 19 out of 30 were paid and 11 of 30 were no paid for the entire City of Tempe up to May 31, 2014. The total payments are $ 211,747.42. The data details are included in Appendix 3.

5.3 Historic Flooding Data

December 22, 1965 – January 2, 1966: Heavy rains caused the first large flow of the Salt River through Phoenix since the dams constructed on the Verde River in 1939 created the Horseshoe and Bartlett reservoirs. All roads crossing the Salt River in Tempe, Phoenix, Scottsdale, and Mesa were washed out. All bridges across the Salt River were at least partially damaged, floodwaters encircled Sun Devil Stadium on the Arizona State University campus, a runway is closed at Sky Harbor Airport in Phoenix and Phoenix International Raceway is threatened by floodwaters. Damage estimated at $10 million.

August 1974, excessive rain causes considerable flooding of streets and highways in the Phoenix area, with water up to eight feet deep at one of the underpasses of the Black Canyon Freeway (I-17). There is substantial flooding over much of Tempe and southeastern Phoenix.

Between October 1977 and February 1980, seven regional floods occur and Phoenix is declared a disaster area three times. There are 18 fatalities and approximately $310 million in property damage.

Jan. 8-20, 1993, an extremely intense El Niño causes heavy rainfall. A large, garbage landfill in Mesa and portions of the new Mill Avenue Bridge that were under construction were washed away by the raging Salt River. The Gillespie Dam west of Phoenix is damaged as high water spreads throughout low-lying areas. One man drowns while trying to cross the Agua Fria River.

Oct. 6, 1993, heavy rain causes Indian Bend Wash to overflow onto city streets and wash over the bridges on Camelback and Indian School roads. A few motorists are rescued from their cars when they become stranded after trying to cross the flooded wash.

Several major storms occurred in Phoenix metro area in 2005. On Feb. 12, rains associated with a mid-winter storm system move slowly across central and southern Arizona. Rainfall intensity increases significantly during the evening of Feb. 11, and Flood Control District ALERT rain gages begin to report excessive rainfall exceeding 1.5 inches per hour during the early morning hours of Feb. 12. The Maricopa County Sheriff's Office rescues 21 individuals in 11 separate floodwater incidents during the weekend. Rock and mud slides along U.S. Highway 60 from Superior to Globe are reported by the afternoon of Feb. 12. Eventually, the Salt River and Verde River start to receive the runoff, with Granite Reef Diversion Dam spilling 35,345 cubic feet per second. Downstream, the river bottom road crossings on the Salt, Verde and Gila rivers are flooded. Tempe Town Lake, located in the Salt River channel, lowers its inflatable dams to allow for increased water flow. This storm system is the final significant 2004-2005 winter event in a season of very heavy rainfall.

July 13, 2008, a surprise, late-afternoon storm hits Tempe, where more than two inches of rain falls in less than two hours. A five-mile section of the U.S. 60 freeway through Tempe is shut down for three hours due to deep standing water across several lanes and beneath underpasses. The Arizona Department of Transportation activates pumps to drain the water.

January 26, 2013, a significant storm occurred within the project area. The measured rainfall data and the flow hydrographs from a few storm drain outfalls are documented in Section 10.

Some other historical flooding events are listed in the following website: www.fcd.maricopa.gov/Education/history.aspx.

6.0 LAND USE DATA

Land use data and GIS shape files generated from the surface feature shape files provided by the District for the Tempe ADMS/P study area are included in Appendix 4 – Land Use Data. The land use map for the study area is included in Exhibit F – Land Use Map. The land use types and their area percentages are summarized in the following table. Note that the land use type classifications are based on their hydrologic features instead of their economic/planning roles, such as residential, commercial, and transportation, etc. The study area is fully developed as shown in the table that hard surfaces (pavement and buildings) account for more than 50% of the total area which has significant impact on the runoff generation. However, some re-developments are expected within the study area including light rail extensions, especially, within ASU properties as shown in Exhibit C.

Land Use Types	% Area
Bare ground	34.58
Pavement	33.47
Buildings	16.97
Urban med/low vegetation	11.44
Water	1.68
Shade structures	1.41
Agriculture	0.40
Wash bottom	0.05

7.0 SOIL DATA

Customized soil data report and GIS shape files generated from National Resource Conservation Service (NRCS, formerly SCS) for the Tempe ADMS/P study area are included in Appendix 5 – Soil Data. The soil data map for the study area is included in Exhibit G – Soil Map. The soil types and their area percentages are summarized in the following table. This table shows that loam including clay and sandy loam accounts for more than 93% of the total area and their average soil depth is around 0.65 ft which has significant impact on the rainfall infiltration. Note that the hard surfaces in the study area account for more than 50% of the total area and the soil hydrologic characteristics do not have any effects on these areas.

Soil Types	% Area
Loam	45.00
Clay loam	39.66
Sandy loam	8.14
Alluvial land	4.26
Loamy sand	2.06
Gravel pit	0.48
Rock land	0.32
Gravelly loam	0.08
Clay	0.01

8.0 HYDROLOGIC DATA

8.1 Temperature and Rainfall Data

Normal Temperatures

(Tempe ASU weather station)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max °F	68.1	72.3	76.9	84.5	92.2	101.4	103.6	102.7	98.7	88.8	76.5	68.2	86.2
Mean °F	54.1	57.6	62.0	68.4	76.3	84.7	89.9	89.0	83.8	73.2	61.0	53.9	71.2
Min °F	40.1	42.9	47.0	52.2	60.3	68.0	76.1	75.2	68.8	57.6	45.5	39.5	56.1

Normal Precipitation

(Tempe ASU weather station)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Inch	1.01	1.04	1.15	0.25	0.21	0.07	0.89	1.20	0.86	0.85	0.80	1.03	9.36

NOAA Atlas 14 Rainfall Data

NOAA Atlas 14, Volume 1, Version 5
Location name: Tempe, Arizona, US*
Coordinates: 33.3625, -111.9285
Elevation: 1184ft*
* source: Google Maps

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Sarah Dietz, Sarah Heim, Lillian Hiner, Kazungu Maitaria, Deborah Martin, Sandra Pavlovic, Ishani Roy, Carl Trypaluk, Dale Unruh, Fenglin Yan, Michael Yekta, Tan Zhao, Geoffrey Bonnin, Daniel Brewer, Li-Chuan Chen, Tye Parzybok, John Yarchoan

NOAA, National Weather Service, Silver Spring, Maryland

PF tabular | PF graphical | Maps & aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.182 (0.153-0.222)	0.239 (0.200-0.290)	0.324 (0.271-0.393)	0.390 (0.324-0.471)	0.479 (0.392-0.575)	0.549 (0.443-0.656)	0.618 (0.490-0.738)	0.681 (0.538-0.823)	0.787 (0.598-0.938)	0.861 (0.640-1.03)
10-min	0.277 (0.233-0.337)	0.363 (0.305-0.441)	0.483 (0.413-0.598)	0.583 (0.494-0.716)	0.729 (0.597-0.876)	0.835 (0.675-0.998)	0.941 (0.746-1.12)	1.05 (0.819-1.25)	1.20 (0.909-1.43)	1.31 (0.974-1.57)
15-min	0.344 (0.289-0.418)	0.450 (0.378-0.547)	0.611 (0.512-0.742)	0.738 (0.612-0.888)	0.904 (0.740-1.09)	1.04 (0.836-1.24)	1.17 (0.925-1.39)	1.30 (1.02-1.55)	1.49 (1.13-1.77)	1.62 (1.21-1.94)
30-min	0.483 (0.389-0.583)	0.605 (0.510-0.737)	0.823 (0.689-0.998)	0.981 (0.824-1.20)	1.22 (0.996-1.46)	1.39 (1.13-1.67)	1.57 (1.25-1.88)	1.78 (1.37-2.09)	2.00 (1.52-2.38)	2.19 (1.63-2.61)
60-min	0.573 (0.482-0.697)	0.749 (0.631-0.912)	1.02 (0.853-1.24)	1.23 (1.02-1.48)	1.51 (1.23-1.81)	1.73 (1.39-2.06)	1.95 (1.54-2.32)	2.17 (1.69-2.59)	2.48 (1.88-2.95)	2.71 (2.01-3.23)
2-hr	0.870 (0.571-0.800)	0.883 (0.741-1.04)	1.18 (0.986-1.39)	1.38 (1.16-1.65)	1.68 (1.40-2.00)	1.93 (1.58-2.27)	2.17 (1.75-2.56)	2.42 (1.91-2.84)	2.75 (2.12-3.24)	3.00 (2.27-3.56)
3-hr	0.728 (0.618-0.874)	0.832 (0.795-1.13)	1.23 (1.04-1.47)	1.48 (1.22-1.75)	1.78 (1.48-2.12)	2.04 (1.66-2.42)	2.31 (1.85-2.74)	2.58 (2.04-3.07)	2.88 (2.27-3.54)	3.30 (2.45-3.92)
6-hr	0.884 (0.748-1.02)	1.09 (0.951-1.29)	1.40 (1.21-1.65)	1.65 (1.42-1.93)	1.89 (1.68-2.31)	2.25 (1.88-2.60)	2.53 (2.07-2.92)	2.81 (2.26-3.25)	3.20 (2.50-3.71)	3.50 (2.68-4.08)
12-hr	0.984 (0.846-1.11)	1.22 (1.07-1.41)	1.55 (1.35-1.78)	1.80 (1.56-2.06)	2.15 (1.84-2.45)	2.41 (2.05-2.75)	2.68 (2.24-3.06)	2.98 (2.44-3.38)	3.33 (2.68-3.83)	3.63 (2.86-4.19)
24-hr	1.14 (1.03-1.26)	1.45 (1.31-1.61)	1.87 (1.69-2.08)	2.21 (1.99-2.45)	2.68 (2.40-2.96)	3.05 (2.71-3.36)	3.44 (3.03-3.78)	3.83 (3.36-4.22)	4.39 (3.79-4.84)	4.82 (4.13-5.33)
2-day	1.22 (1.10-1.36)	1.58 (1.41-1.74)	2.06 (1.85-2.27)	2.43 (2.19-2.69)	2.97 (2.66-3.29)	3.40 (3.03-3.77)	3.88 (3.41-4.27)	4.33 (3.79-4.80)	4.99 (4.32-5.54)	5.51 (4.73-6.15)
3-day	1.29 (1.16-1.43)	1.65 (1.49-1.83)	2.18 (1.95-2.40)	2.58 (2.32-2.85)	3.18 (2.83-3.49)	3.63 (3.23-4.01)	4.13 (3.65-4.57)	4.66 (4.07-5.15)	5.38 (4.65-5.97)	5.97 (5.11-6.65)
4-day	1.35 (1.22-1.50)	1.73 (1.57-1.92)	2.28 (2.06-2.52)	2.72 (2.45-3.01)	3.35 (3.00-3.70)	3.85 (3.43-4.26)	4.38 (3.89-4.86)	4.97 (4.35-5.49)	5.77 (4.99-6.39)	6.43 (5.50-7.14)
7-day	1.49 (1.35-1.65)	1.90 (1.72-2.11)	2.51 (2.26-2.77)	2.99 (2.70-3.31)	3.68 (3.30-4.06)	4.24 (3.77-4.67)	4.83 (4.27-5.32)	5.45 (4.78-6.02)	6.33 (5.47-7.00)	7.04 (6.02-7.80)
10-day	1.82 (1.47-1.80)	2.07 (1.88-2.30)	2.73 (2.47-3.02)	3.26 (2.94-3.60)	4.00 (3.58-4.41)	4.60 (4.09-5.06)	5.22 (4.62-5.76)	5.88 (5.16-6.49)	6.81 (5.89-7.52)	7.55 (6.47-8.36)
20-day	1.99 (1.80-2.21)	2.58 (2.32-2.84)	3.38 (3.05-3.73)	3.99 (3.60-4.41)	4.82 (4.32-5.32)	5.48 (4.88-6.03)	6.10 (5.43-6.75)	6.78 (5.98-7.48)	7.64 (6.70-8.48)	8.32 (7.23-9.25)
30-day	2.32 (2.10-2.57)	2.99 (2.71-3.30)	3.83 (3.56-4.33)	4.85 (4.20-5.11)	5.81 (5.04-6.17)	6.35 (5.68-6.98)	7.11 (6.33-7.81)	7.87 (6.97-8.66)	8.90 (7.82-9.81)	9.69 (8.45-10.7)
45-day	2.71 (2.46-2.99)	3.49 (3.16-3.85)	4.59 (4.15-5.06)	5.40 (4.88-5.96)	6.47 (5.82-7.13)	7.28 (6.53-8.02)	8.08 (7.22-8.92)	8.88 (7.90-9.82)	9.95 (8.78-11.0)	10.7 (9.42-11.9)
60-day	3.01 (2.73-3.31)	3.88 (3.52-4.27)	5.10 (4.62-5.61)	5.98 (5.41-6.58)	7.13 (6.43-7.83)	7.98 (7.17-8.77)	8.84 (7.91-9.72)	9.88 (8.62-10.6)	10.7 (9.52-11.8)	11.5 (10.2-12.8)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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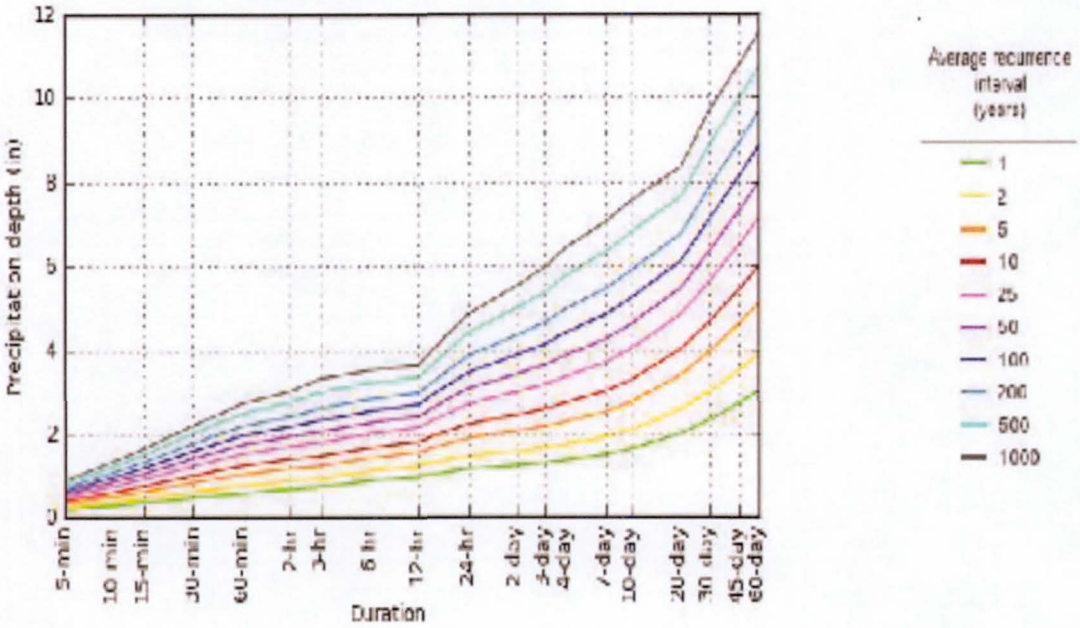
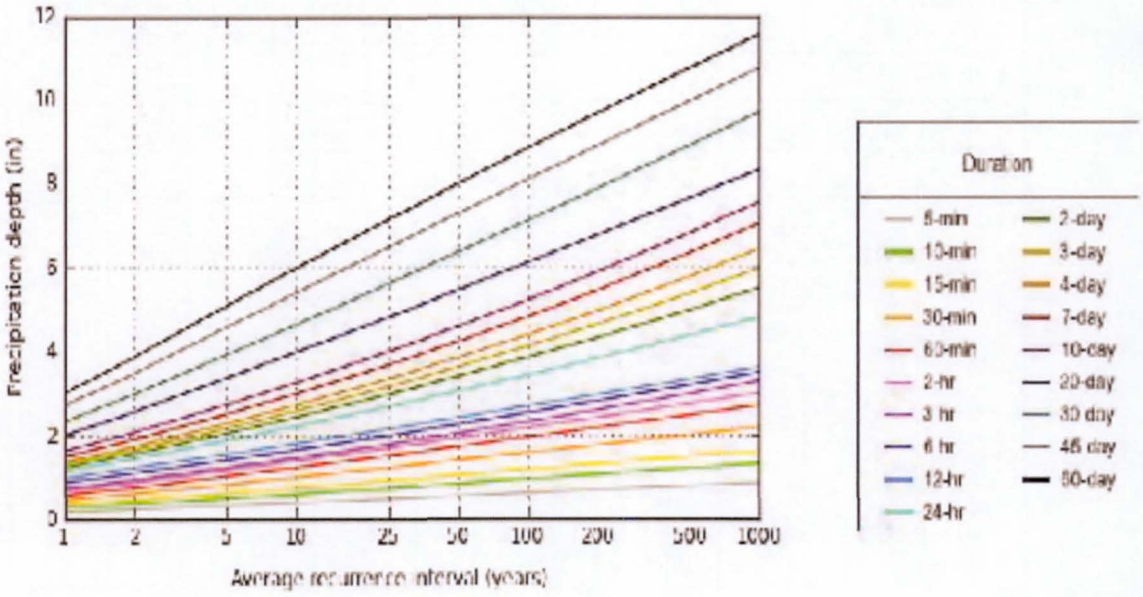
PF graphical

PDS-based depth-duration-frequency (DDF) curves

Coordinates: 33.3625, -111.9285





NOAA/NWS/OHD/HDSC

Created (GMT): Tue Sep 3 20:35:51 2013

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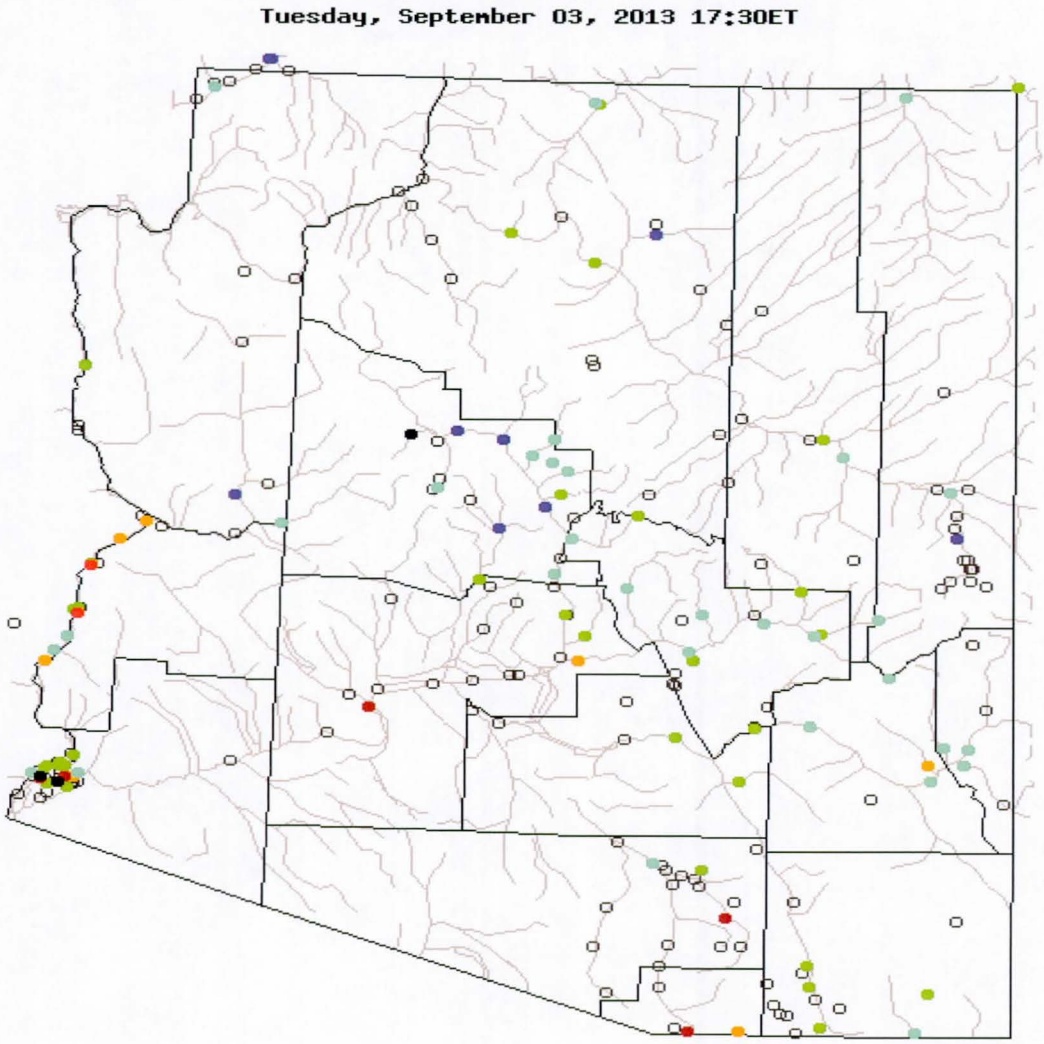
The NOAA 14 rainfall data shapefiles for multiple frequencies are included in Appendix 6.

8.2 Stream Flow Data

US Geological Survey (USGS) has many stream flow gage stations in major rivers/washes within Arizona as shown in the following figure. One USGS stream flow gage near this project area is located in Salt River at Priest Drive (Gage No. 09512165) and its historic stream flow data is summarized in Appendix 6.

USGS Stream Flow Gages in Arizona



The District operates stream flow and precipitation gages within the vicinity of the Tempe ADMS study area. The following figure shows the locations of one stream flow gage and two rainfall gages near the project area.

9.0 PREVIOUS DRAINAGE STUDIES

Many drainage studies have been conducted within or near the project area and their basic data are included in Appendix 7. The following lists the data for some of the project reports reviewed.

9.1 Area Drainage Master Studies

Broadway & Rural Drainage Master Plan: FLO-2D Hydrologic and Hydraulic Analysis, FCDMC Contract #2009035, Cardno WRG, September 2012.

Hohokam Area Drainage Master Study (Phase I), Hydrology/Hydraulics Report, FCDMC Contract # 2009C029, Stanley, April 2012.

Wood, Patel and Assoc., Inc., 1997. Rio Salado Drainage Master Plan, Draft (DMP) for Rio Salado Project and City of Tempe.

Malcolm Pirie, Inc., in Association with Wilson & Company and KVL, December 2000. Integrated Master Plan – Storm Water Master Plan, City of Tempe.

CH2M Hill, 1991. Rio Salado Water Resources Master Plan (Draft), Technical Memorandum 4, Salt River Hydraulics, for City of Tempe.

9.2 Sub-division Drainage Reports

Optimus Civil Design Group, 2004. Final Drainage Report for Tempe Marketplace (Salt River Channel), FCD 2005P004.

Creegan and D'Angelo, 1989. Retention Basin Analysis, Final Report for City of Tempe Drainage Diversion Project Phase II.

9.3 Local Drainage Improvement Reports

RBF Consultant, 2010. Western Canal in Tempe Floodplain Delineation Study Technical Data Notebook (FDS, TDN) for Flood Control District of Maricopa County.

Project Engineering Consultants, Ltd., September 2002. Broadway Road/Rural Road Candidate Assessment Report (CAR).

Sverdrup and Parcel and Assoc., Inc., revised 1985. Drainage Study for 48th Street Storm Sewer, Baseline Road to the Tempe Ditch, for City of Tempe and City of Phoenix

John Carollo Engineering, 1972. Storm Drainage System for West Tempe.

9.4 Highway Drainage Reports

CRSS Sirrine, Inc., 1987. Engineering Report for the Price Road Drainage Tunnel, Tempe, Arizona.

Some of the ADOT drainage reports are listed in Appendix 7.

9.5 Floodplain Use Permits

No floodplain use permits were identified within the study area.

9.6 Violations

There were no complaints and violations found.

10.0 EXISTING STORM DRAIN DATA

10.1 GIS Data

Collected storm drain GIS shapefiles were updated based on as-built plans and site visits and they were used for the development of SWMM input data. Five sets of GIS shapefiles were prepared for Sub-Model areas A, B, and C, and highways I-10 and US-60 storm drain systems. The storm drain summary data is shown in the following table. The updated data for these shapefiles including catch basins are included in Appendix 8 and the storm drain systems are shown in Exhibit H.

Storm Drain Data Summary Table	
Items	Total
No. of conduit segments	4593
Pipe length (ft)	775270
Junctions	1828
Inlets	2767
Outfalls	110
Pumps	6

10.2 As-Built Plans

The summary of collected storm drain as-built plans is shown in the following table and the as-built plans are included in Appendix 8.

As-Built Plans Summary Table	
Items	Total
As-built plans	1000
Plans with relevant data	120
Average sheets/plan set	15

10.3 Measured Hydrographs from Storm Drain Outfalls

District staff contacted with Richard Dalton, the Environmental Compliance Supervisor at the City of Tempe and obtained the data collected by their gages in various formats. An exhibit of the data was prepared to show the locations of the outfall gages, the hydrographs of the outfalls, and rainfall data for the same time periods. This data is included in Appendix 8.

11.0 FIELD COLLECTION OF STORM DRAIN DATA

11.1 Catch Basins and Manholes

472 inlets were field-verified with photos and all other inlets were verified using Google and Bing Street Views. The data is summarized in table format in Appendix 8.

11.2 Photographs

Many photos for storm drain catch basins and manholes were taken in the field and they are located in Appendix 8. A Google Earth KMZ file was developed for the catch basin photos and is located in the Appendix 8.

12.0 EXISTING DRAINAGE STRUCTURES

12.1 Culverts/Bridges

Data for culverts and bridges was collected from both as-built plans and site visits. The culverts crossing I-10 into the project area are shown in Exhibit I, and Exhibit J shows the overall structure location map. The structure data is summarized in the following table and is included in Appendix 9. Many photos for structures were taken in the field and they are located in Appendix 9. The Google Earth KMZ file including some of the structure photos is located in the Appendix 9.

Structure Data Summary Table	
Items	Total
No. of culverts	66
As-built plans for culvert	20
Field visit trips	8
Culvert pictures	152
Inflow locations	7
As-built plans for inflow	10

12.2 Channels/Canals

Several irrigation canals (Tempe Canal, Consolidated Canal, Eastern Canal, and Roosevelt Canal on the east; Kyrene Canal/Western Canal, and Highline Canal on the west) and three channels (Tempe Drain, Gila Ditch, and SR-202 channel) play a very important role in the study area drainage. The irrigation canals are elevated in order to provide gravity flow into the fields and are acting as dividers or blocking flows from upstream to downstream. The Tempe Drain and Gila Ditch are the two major surface flow collectors and convey runoff into either the Salt River or Gila River. The SR-202 channel collects flow from north and east drainage areas and conveys storm water from east to west into Gila Ditch. These channels and canals are shown in the drainage structure map.

12.3 Pump Stations

Six (6) pump stations exist in the study area and their locations and features are summarized in Appendix 9. The pump stations are constructed either for pumping storm water from highway underpass areas (depressed areas) into storm drain systems or for dewatering retention basins.

12.4 Detention/Retention Basins

More than 120 detention and retention basins were constructed within the project area and a GIS shapefile and map were developed that are located in Appendix 9. The total area for the basins is about 380 acres and can retain significant surface runoff volume.

12.5 Overchutes/Siphons

A few overchutes and siphons exist along the canals and channels and are summarized in Appendix 9. Their impact on storm water drainage is not significant.

TEMPE AREA DRAINAGE MASTER STUDY
CONTRACT FCD 2012C021

VOLUME II
FLO-2D/SWMM MODELING REPORT

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December 2015
Revised April 2016

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1.0 EXECUTIVE SUMMARY

The Tempe ADMS/P study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructures including roads, channels, and canals.

The primary objective of this study is to develop detailed hydrologic and hydraulic models (FLO-2D integration with SWMM) for the Tempe ADMS/P. The entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C. The main reason that the study area is divided into three (3) FLO-2D models is: a) topographic boundaries (features), b) FLO-2D model size, and c) integration of FLO-2D and SWMM models. The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C. A grid size of 20 feet by 20 feet was applied for this project. The major features for the sub-models are summarized in the following table:

Sub-Model Features				
Model	Model A	Model B	Model C	Total
Drainage Area (mile^2)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

The integration of two FLO-2D models (Models A and B, Models B and C) is a key part of the model development processes since the hydrology and hydraulics of the two sub-watersheds are connected by storm drain systems and or surface flows. Consistent input data preparation for all of the three models is also an important part of the integration of the models. The method of one (1) grid overlay along the boundaries was used for the model integration and the impact without rainfall adjustment is less than 0.1% of the drainage area.

Volume conservation is the most important criterion for a successful model simulation. The overall volume conservation for each of the simulation output time step was met very well for all three (3) models.

Measured storm drain outfall hydrographs by City of Tempe and corresponding observed rainfall data processes and provided by District for the March 1, 2014 storm were used for model verification (Model A, storm drain outfall SR-8). The outfall SR-8 peak flows from the FLO-2D modeling results and the measured data are comparable. The modeling results of Tempe Drain channel and field observed data for the September 8, 2014 storm were very similar and showed that the FLO-2D modeling results are reasonable.

The following methods were recommended for cost effective preparation of advanced FLO-2D/SWMM input data files based on the Test Area FLO-2D/SWMM sensitivity analysis and modeling results for the entire project:

- **Structures**
  The rating table method should be used for the modeling of bridges/culverts.

- **Streets**
  Grid elevations within streets should be adjusted for the representation of street conveyance due to typical curb and crown cross sections. The elevation adjustment is set to be -0.30 ft.

- **Levees/Embankments**
  Levee input data file, LEVEE.DAT, was used by FLO-2D models to model engineered levees and walls/fences. Levee-like structures such as roadway/railroad embankments and canal overbanks were modeled by adjusting grid elevations. WRFs were not used for this project.

- **1-D Channels**
  The 1-D channel component should be used on channels that require cross sections to define the channel conveyance. If the channel is a swale with poor definition, then the grid element topography and roughness can be used to represent the cross sections. The 1-D channel component was applied for Tempe Drain open channel for this project. Other small washes were modeled using grid elevations.

- **Storm Drain Systems**
  Storm drain systems were modeled using FLO-2D/SWMM integration approach. Procedures for the conversion of GIS shapefiles to SWMM.INP file utilizing geospatial software – Inp.PINS was recommended since it is more cost effective.

Note that the intent of the Tempe ADMS is for regional flood hazard identification and planning purposes.

2.0 INTRODUCTION

2.1 Purpose of Study

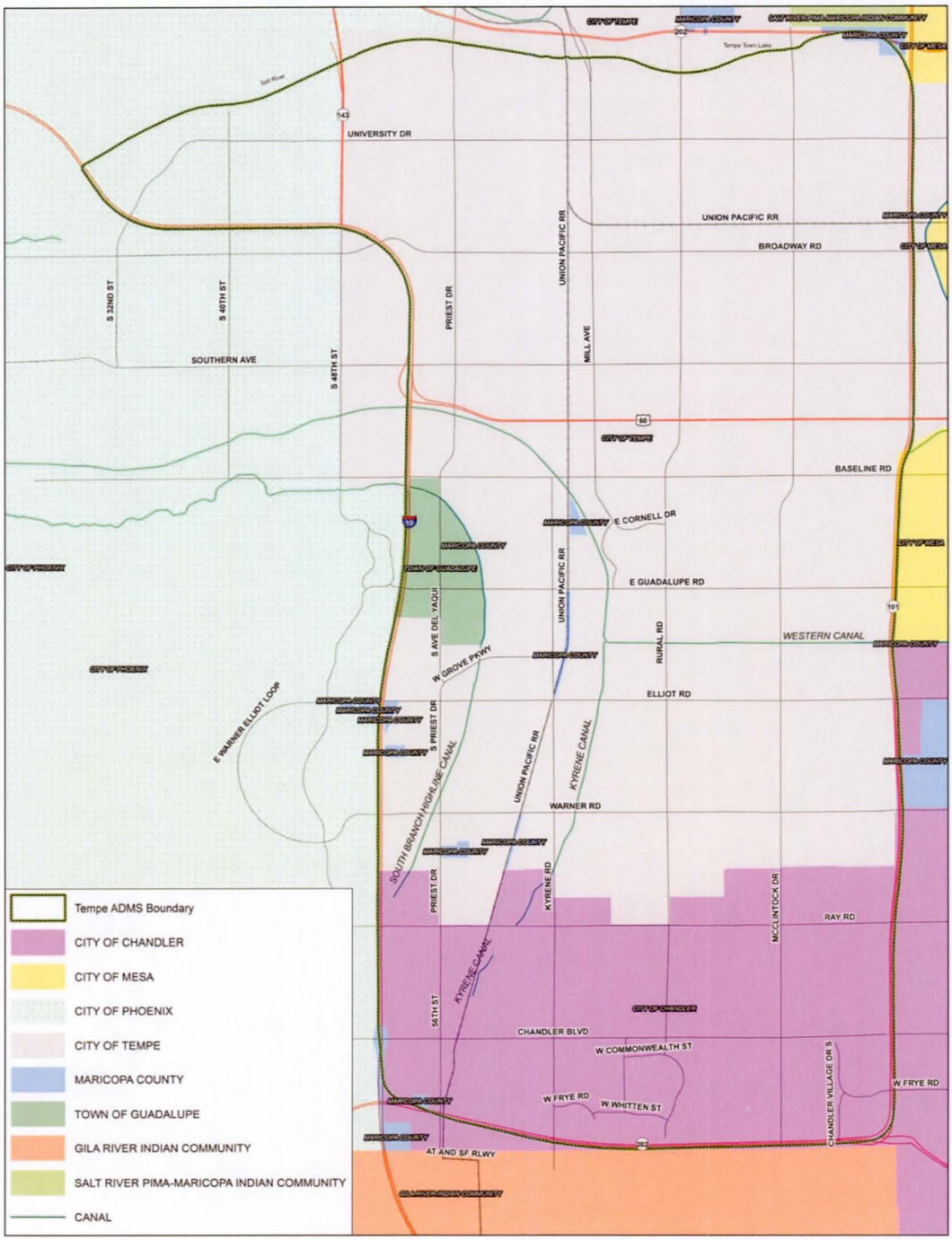
In the past few years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake, major redevelopment of portions of the city is taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various green infrastructures (GI) and low impact development (LID) techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe Area Drainage Master Study and Plan (Tempe ADMS/P) to identify flood hazards and develop any needed flood mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

2.2 Authority for Study

J2 Engineering and Environmental Design (J2) has been retained to perform these services as a part of the District On-Call Contract FCD 2012C021. J2 team for the Work Assignment No. 2 includes Black & Veatch and Riada as sub-consultants. The District is located at 2801 West Durango Street, Phoenix, AZ 85009, (602) 506-1501. The Project Manager for the District is Mr. Burke Lokey, P.E., PMP, CFM. J2's Project Manager for this project is Mr. Jeff Holzmeister, P.E. The contract documents are included in Appendix A.

2.3 Location of Study

The Tempe ADMS study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. Figure 2.1 shows the project area boundaries and location.



Tempe ADMS/P FCD 2012C021
Figure 2.1 Project Area Boundaries and Location Map

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

2.4 Hydrologic Features of the Study Area

The study area is primarily developed and its drainage patterns have been significantly changed by urbanization and man-made infrastructures including roads and canals. The study area has two (2) major outfalls: the Salt River on the North and the Gila River on the southwest. An important drainage divide/saddle exists within the study area and is located near the intersection of Rural Road and Western Canal which is elevated as shown in the following photos. East of this location surface runoff is generally from east to west; west of this location surface runoff originating from South Mountains is generally from west to east; south of this location surface runoff is generally from northeast to southwest leaving the study area into the Gila River; north of this location surface runoff is generally from east/southeast to west/northwest into the Salt River.

Western Canal Looking West at Rural Road

Western Canal Looking East at Rural Road

In addition to Western Canal, Kyrene Canal and Highline Canal have a significant impact on the surface drainage systems of the watersheds as well as shown in the following photos. Surface runoff is intercepted and flow directions are changed by these canals since they are generally aligned along contour lines and elevated. The alignments of these canals are shown on the Project Area Boundaries and Location Map.

Kyrene Canal Looking South at Elliot Road

Highline Canal Looking North at Guadalupe Road

Transportation infrastructure in the project area is extensive including Loop 101 on the east, SR 202 on the south, I-10 on the west, US60 bisecting the study area, and SR143 serving the boundary of Cities of Tempe and Phoenix as well as the old Southern Pacific railroad system and the new light rail system as shown in the following photos.

UPRR Looking East at Mill Avenue

UPRR Looking North at Broadway Road

Light Rail Looking West at McClintock Drive

Complex drainage systems including open channels/storm drains, detention/retention basins, bridges/culverts, and pump stations were constructed for these highway systems. These drainage systems changed the natural surface flow patterns and become part of the overall drainage systems of the study area. In addition to the highway and railroad systems, surface street/road networks have been developed as well in the study area and are the major surface drainage corridors.

Tempe Drain Looking East at 40th Street

US 60 Basin Looking Southwest

Scudder Park at SEC of Southshore Dr. and Lakeshore Dr.

Complex public drainage systems were constructed with the urbanization of the study area. These drainage systems include open channels of Tempe Drain and Gila Drain, 146-miles of storm drain (with more than 2,800 inlets and 100 outfalls), over 120 detention/retention basins, and 41 bridges/culverts for roadway crossings.

Storm Drain Outfall into Tempe Drain at SR 143 (looking west)

Gila Drain Outfall at SR 202 (looking south)

Storm Drain Outfall into Salt River at Tempe Town Lake (SR08)

2.5 Acknowledgements

J2 team is very appreciative to have the opportunity to represent the District in the performance of these services. This professional assignment presented many interesting and unique challenges requiring creative teamwork solutions. Mr. Burke Lokey, Mr. Jake Serago, Mr. Richard Waskowsky, Mr. Amir Motamedi, Mr. Doug Williams, Ms. Theresa Pinto, Mr. Thomas Loomis, Mr. Pedro Melo-Rodriguez, and Mr. Joe Wagner of the District; Mr. Gregg Kent and Mr. Richard Dalton of the City of Tempe, Mr. Hasan Mushtaq of the City of Phoenix, Mr. Warren White of the City of Chandler, and Mr. Jim Ricker of the Town of Guadalupe provided critical technical support and decision-making guidance throughout the duration of the study. Their individual and group contributions played a key role in the successful completion of this assignment.

3.0 SURVEY AND MAPPING INFORMATION

3.1 Digital Projection Information

The District provided the electronic topographic mapping and images for this project. The mapping was provided in shape file format and ASCII format for the break lines and mass points. Image files are in MrSid format at a resolution of 0.8-feet pixels and a flight date of April 2012. The aerial mapping data is included in *Data Collection Report*.

3.2 Field Survey Information

J2 performed field investigations to verify/document existing drainage structures within the project area including data of inlet and outlet conditions and dimensions of the cross sections for culverts.

3.3 Mapping

Detailed mapping was developed for this study area in April 2012 under a separate contract for the District (FCD 2009C043, Task Order 14). The horizontal coordinate system is HARN, Arizona Central with units of international feet referenced to NAD 83. The vertical datum is NAVD 88. Mapping was provided in shape file format and ASCII format for break lines and mass points. The detailed topographic mapping data and survey reports are documented in *Data Collection Report*.

4.0 DEVELOPMENT OF FLO-2D BASIC INPUT DATA

4.1 FLO-2D Program and Application Versions

FLO-2D, integrated with EPA Storm Water Management Model (SWMM Version 5.0) and developed by Riada, Inc., was selected to be applied for this project. FLO-2D routes surface runoff over unconfined flow surfaces/channels using the dynamic wave approximation to the momentum equation while maintaining volume conservation. Finite difference algorithms are utilized to solve the partial differential equations. EPA SWMM is integrated with FLO-2D to simulate storm drain systems. More detailed information about the capabilities and applications of FLO-2D can be found in the references. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the final modeling of the project. Note that the modeling results may be slightly different if different FLO-2D build number program is applied.

4.2 FLO-2D Modeling Sub Models and Boundaries

The entire Tempe ADMS/P study area (47 mile^2) is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C as shown in Figure 4.1. The Test Area is part of the study area of Model A. The main reasons that the entire area is divided into three (3) FLO-2D models are: a) topographic boundaries (features), b) FLO-2D model size, and c) integration of FLO-2D and SWMM models. Since these boundary delineations are fundamental to the development of FLO-2D models and will dictate all of the input data preparation they were determined in the early stage of the project. The study boundaries for the four models are shown in Figure 4.1. The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C.

4.3 FLO-2D Basic Input Data Files

The FLO-2D input data consists of a series of ASCII files organized by model components. A basic FLO-2D model starts with routing an inflow hydrograph (INFLOW.DAT) over an unconfined floodplain surface (FPLAIN.DAT) which includes grid system elevation data and Manning's n-value data. To conduct a basic FLO-2D flood simulation, six basic data files must be created. The six required files for basic overland flow simulation are:

- FPLAIN.DAT
- CADPTS.DAT
- CONT.DAT
- TOLER.DAT
- INFLOW.DAT
- OUTFLOW.DAT

The FPLAIN.DAT and CADPTS.DAT files contain the topographic and grid system data. CONT.DAT and TOLER.DAT contain control and numerical stability data and consist of only a few lines of data. INFLOW.DAT contains the inflow hydrographs and OUTFLOW.DAT contains outflow nodes and optional outflow water surface control. There are two new data files in the Pro Version model to assist with GIS and CAD program integration: TOPO.DAT (coordinates and elevation data) and MANNINGS_N.DAT (grid numbers and roughness n-values).

Flood simulation details can be enhanced by adding rainfall, infiltration, buildings and flow obstructions, and floodplain cross section data. These components are initiated through on-off switches found in the control data file (CONT.DAT). If the component options are "turned on", then the appropriate data files must be created. Such as:

- RAIN.DAT
- INFIL.DAT
- ARF.DAT
- FPXSEC.DAT

The best procedures for the development of complex FLO-2D models are to start simple with a basic overland flow simulation and build the flood simulation details into the model one component at a time to observe the effects of each feature and debug the input data files.

4.4 Methods of Basic Input Data Development

The detailed methods for general input data development was documented in the *Test Area FLO-2D Analysis Report* which is included in Appendix D2. Other manuals that can help FLO-2D input data preparation are listed in the references. The specific methods used to develop the basic input data files in this study are explained in the following:

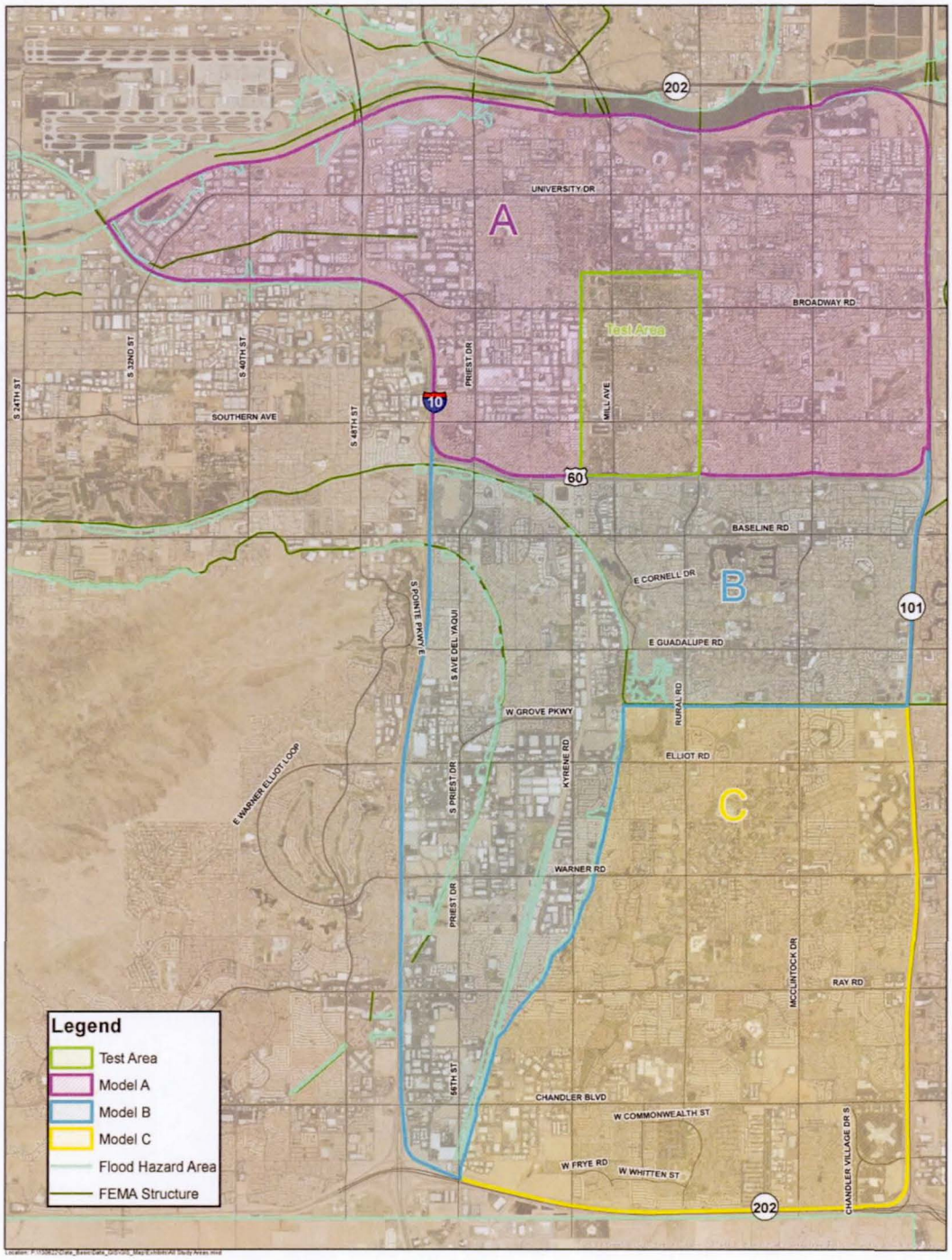
The grid systems for Models A, B, and C were generated using the pre-processor program of GDS (FPLAIN.DAT and CADPTS.DAT) based on the modeling boundary shapefiles. A grid shapefile (MGrid.Shp) was developed for each of the models and was utilized for the development of grid elevations. OUTFLOW.DAT and FPXSEC.DAT files were also developed using GDS pre-processor.

The surface terrain to raster method was used to develop the ground surface elevations for the FLO-2D grids within FPLAIN.DAT by using GIS tools and Manifold program in conjunction with the grid shapefile. The grid elevation data evaluation was documented in the *Test Area FLO-2D Analysis Report.*

INFIL.DAT for rainfall losses and ARF.DAT for buildings and flow obstructions were developed based on the surface feature characterization shapefile provided by the District and soil data shapefile from NRCS. GIS tools and Manifold program in conjunction with the grid shapefiles were used for the development of these two input data files.

CONT.DAT, TOLER.DAT, RAIN.DAT, and INFLOW.DAT were developed by using MS Excel and Notepad programs following FLO-2D input data manuals.

The detailed procedures and supporting data files for the development of these basic FLO-2D input data files are included in Appendix B.



Tempe ADMS/P FCD 2012C021 - Work Assignment #2
Figure 4.1 FLO-2D Study Boundaries for Models A, B, C, and Test Area

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

5.0 DEVELOPMENT OF FLO-2D ADVANCED INPUT DATA

5.1 FLO-2D/SWMM Advanced Input Data Files

A basic FLO-2D model can be expanded to include hydraulic structures, levees, 1-D channels, storm drain systems, or other components to model more complex drainage systems. These components are initiated through on-off switches found in the control data file (CONT.DAT). If the component options are "turned on", then the appropriate data files must be created. The advanced input data files include:

- HYSTRUC.DAT
- STREET.DAT
- LEVEE.DAT
- 1-D Channel Data (CHAN.DAT, XSEC.DAT, and CHANBANK.DAT)
- Storm Drain System Data (SWMM.INP, SWMMFLO.DAT, and SWMMOUTF.DAT)

Existing bridges/culverts have a significant impact on the drainage patterns. Culverts and bridges are modeled using HYSTRUC.DAT by FLO-2D models and rating table method was applied.

Numerous streets exist in the project area and they play a very important role as part of the surface drainage systems. Street features were modeled by adjusting grid elevations within streets for the representation of street conveyance due to typical curb and crown cross sections. The elevation adjustment was -0.30 ft.

Levee input data file, LEVEE.DAT, is used by FLO-2D to model engineered levees, walls/fences, and levee-like structures such as roadway/railroad embankments and canal overbanks.

Hydraulic modeling of open channels/washes using FLO-2D constitutes a serious challenge due to deep water and flow exchange between floodplain and channels. Open channels/washes can be modeled by FLO-2D using either 1-D channel or grid elevation adjustments. Tempe Drain is the only channel that was modeled using the 1-D channel method. Three input data files are needed to model the 1-D open channel system: CHAN.DAT, XSEC.DAT, and CHANBANK.DAT.

Storm drain systems play a very important role in Tempe drainage. The FLO-2D Pro Model has been integrated with the EPA SWMM to simulate the exchange of surface water flow with storm drain systems. Three input data files are needed to model the storm drain systems: SWMM.INP for SWMM model, SWMMFLO.DAT for catch basin geometric data, and SWMMOUTF.DAT for storm drain outfall conditions.

5.2 Methods of Advanced Input Data Development

The *Test Area FLO-2D Analysis Report* documented the detailed methods for general input data development including the Test Area model and is included in Appendix D2.

The detailed procedures and supporting data files for the development of the HYSTRUC.DAT input data files of Models A, B, and C are included in Appendix C1.

The detailed procedures and supporting data files for the development of the LEVEE.DAT input data files of Models A, B, and C are included in Appendix C2.

The detailed procedures and supporting data files for the development of the 1-D channel input data files of the Tempe Drain are included in Appendix C3.

The FLO-2D and SWMM models are integrated and run simultaneously with FLO-2D being the host model which calculates all hydrologic and hydraulic surface-water flood-routing while EPA-SWMM only solves the conduit hydraulics and routing in the storm drain network. The model integration was accomplished by revising the source codes to allow the models to share data on a time-step basis controlled by the FLO-2D model. The FLO-2D model computes the storm drain inflow discharge based on the predicted grid element headwater depth and exchanges this discharge with the EPA-SWMM model to compute the storm drain system pipe discharge and the potential return flow to the surface through downstream outfalls and catch basins.

Major steps for FLO-2D model and SWMM model integration include:

A) Basic FLO-2D model development;
B) Independent SWMM model development; and
C) Integration of FLO-2D model and SWMM model.

Stormdrain data was obtained from as-built plans, along with field verification of inlets. For the stormdrain conduits, data collected includes length, material, geometric properties, and invert elevation data. For the stormdrain nodes, data collected includes invert elevation, rim elevation, and inlet geometry if applicable. These collected data was applied to update the City's storm drain GIS shapefiles which then were converted into SWMM.INP files. The detailed procedures for the development of these input data files for SWMM and integration with FLO-2D and supporting data files are included in Appendix C4. Off-site storm drain inflow hydrographs and storm drain outfall flows from Model B to Models A and C into storm drain systems (SWMM models) were coded into appropriate SWMM models. The inflow hydrographs to SWMM models are documented in Appendix C5.

5.3 Input Data Refinements

After all of the input data files were developed the following input data files have been refined to improve the modeling results. Detailed information for input data refinements can be found in Appendix C6.

FPLAIN.DAT

- Manning's n-Value Revisions for Ponding Areas: In some instances, ponding areas result in "sticky grid elements" in which computational time steps are decreased and thereby slow down the model execution. A recommended means to decrease the potential or magnitude of time decrements is to increase the n-values of the "sticky grid elements". Since ponded grids are essentially static, increasing n-values generally did not impact overall modeling results. Consequently, n-values within ponded grids were adjusted (increased) to improve model run times.

- Elevation Revisions for Pipe Maximum Depth: It occurs very often that a grid element floodplain or street elevation is different from the storm drain inlet rim elevation which is equal to pipe invert elevation plus pipe maximum depth since the FPLAIN.DAT and SWMM.INP are developed independently. When this condition exist the rim elevation is applied in the computations by FLO-2D. However, the floodplain grid elevation data file is not revised automatically by FLO-2D. These grid numbers are listed in the ERROR.CHK file. In order to make the grid elevation and storm drain rim elevation consistent the FPLAIN.DAT was revised according to the ERROR.CHK file.

- Elevation Revisions for Hydraulic Structure Inlet/Outlet Grids: Elevations of the grid elements at hydraulic structure (bridge/culvert) inlet/outlet areas are typically higher than the invert elevations of the inlet/outlet due to the elevation-averaging process. In order to represent the wash/channel elevations and conveyance capacity accurately, the elevations of these grids were refined.

- Elevation Revisions for Wash/Channel Conveyance: Tempe Drain is the only open channel modeled using CHAN.DAT by FLO-2D. Hydraulic conveyance for other channels was represented by modifying the grid elevations within the channel systems. The general guideline is to modify the elevations of the grids within the channel corridor to have a relatively smooth profile and comparable flow conveyance with the existing channel/wash.

- Elevation Revisions for Embankments: Grid elevations along Tempe Drain overbanks were modified to minimize the impact of the 20-foot grids average processes of the FLO-2D model. The FLO-2D model will work better if these grid elevations are at least as high as the 1-D channel cross section overbank elevations. The advantages of this approach are a) it is easy to modify the grid elevations; b) it simplifies the LEVEE.DAT.

- Elevation Revisions for Streets: Street hydraulic conveyance for this project was approximated by modifying the grid elevations within the street network. The elevation adjustment was set to be -0.30 ft based on evaluation results. One of

the advantages of this approach is that it is very cost effective using GIS tools to modify the street grid elevations.

- Elevation Revisions for Catch Basins: In order to improve the modeling accuracy of the storm drain catch basin inflows to the SWMM model the elevations of the grids with catch basins were revised to approximate typical local depression of the catch basins which is ignored due to the grid size and its elevation average process from the surface raster data. If the grid with a catch basin is also a street grid an additional -0.20 ft was adjusted. Otherwise, -0.50 ft was applied for the grid elevations to account for both street and catch basin local elevation adjustments.

INFIL.DAT

- IA Revisions for TOL Value: Surface detention parameter (TOL) is the minimum value of the flow depth for flood routing. Theoretically, the lower value for TOL, the better (more accurate) modeling results since this depth is artificially ponded water. In order to mitigate the negative impact of the TOL data on the accuracy of the modeling results, the initial abstraction value, IA, was adjusted such that new IA = default IA – TOL $\geq$ 0.0 for each grid. IA is one of the input variables for input data file of INFIL.DAT where each grid has a unique IA value based on land uses (surface features).

- RTIMP Revisions for Area Reduction Factors: The default RTIMP values from the District provided surface feature data were reviewed and applied in the FLO-2D modeling. Since INFIL.DAT and ARF.DAT are developed separately and ARF values and street impervious data are not used for additional RTIMP runoff calculations RTIMP values were adjusted to make sure RTIMP $\geq$ ARF for each grid after ARF data is developed. Otherwise, error/warning messages will appear during the model execution.

ARF.DAT

Buildings were modeled for this project using ARF.DAT by FLO-2D models. ARF.DAT for buildings and flow obstructions were developed based on the surface feature characterization shapefile provided by the District. There are two conditions where ARF values were refined: a) when the ARF value is close to 1.0 it is recommended by the FLO-2D Manual that ARF = 1.0 (totally blocked) if ARF $\geq$ 0.95; b) the ARF values were adjusted for some grids that are identified in the output file TIME.OUT as "sticky" grids and make the model simulation very slow.

LEVEE.DAT

Since the walls/fences are complicated and the LEVEE.DAT includes data for engineered levees, walls/fences, and other embankments the basic data file of LEVEE.DAT needs to be refined. Generally, after the FLO-2D models were run with and without walls, the modeling results were compared. The wall data within areas where significant maximum flow depth changes occurred were reviewed and modified accordingly. The revised models ran again with the refined wall data until the modeling results are reasonable. Finally, the wall

overtopping areas were reviewed and levee failure modeling was not performed since no significant overtopping occurs.

SWMM.INP

- Maximum Depth Revisions for Street Elevation Adjustments: The storm drain maximum depth in SWMM.INP is dependent on the grid elevations (street grid elevations in most cases) SWMM.INP file were revised following the street grid elevation adjustment within FPLAIN.DAT. The maximum depth of 100-ft was applied to all non-inlet junctions. The purpose of using a maximum depth of 100-ft is to minimize the ponding/flooding flows (returning flows) at those junctions since this issue is still under revision by Riada (software related phenomenon) at the project time.

- Maximum Depth Revisions for Catch Basin Adjustments: The elevations for the grid elements with storm drain catch basins were adjusted as discussed previously. Since the storm drain maximum depth in SWMM.INP is related to the storm drain catch basin rim elevations SWMM.INP file was revised based on the refinements of FPLAIN.DAT for catch basin grids.

Recently, the District has developed a spreadsheet that can be used for the identification of potential problems among the input data files. A matrix was developed to identify the potential data conflicting issues that are warning or fatal issues. Appendix C6 included the supporting data and results of this evaluation process.

5.4 Integration of Multiple FLO-2D Models

FLO-2D Sub-Models

As discussed previously, the entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C as shown in Figure 4.1.

The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C.

After considering issues associated with the ground surface (mapping accuracy), hydraulic accuracy, complicated street and storm drain systems, complex walls and fences, as well as model size and integration with EPA SWMM model, a grid size of 20 feet by 20 feet was specified by the District and applied for this project. The major features for the sub-models are summarized in the table:

Sub-Model Features				
Model	Model A	Model B	Model C	Total
Drainage Area (mile^2)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

Integration of Multiple FLO-2D Models

The integration of two FLO-2D models (Models A and B, Models B and C) is a key part of the model development processes since the hydrology and hydraulics of the two sub-watersheds are connected by storm drain systems and or surface flows. Consistent input data preparation for all of the three models is also an important part of the integration of the models. The method of one (1) grid overlay along the boundaries was used for the model integration and the impact without rainfall adjustment is less than 0.1% of the drainage area. The detailed steps for the development of flow hydrograph conversions from the upstream model (Model B) to the downstream models (Models A and C) are documented in Appendix C7.

6.0 TEST AREA MODELING

6.1 Purposes of Test Area Modeling

The primary objective of the Test Area modeling is to develop detailed hydrologic and hydraulic models (FLO- 2D integration with SWMM) of the identified Test Area in order to determine the appropriate FLO-2D modeling protocols for Tempe ADMS/P. The major tasks include development/evaluation of cost-effective procedures for preparation of basic FLO-2D input data files, advanced input data files including SWMM input data for storm drain systems, evaluation and refinement of input data, model parameter sensitivity analysis, and evaluation of flow exchanges between FLO-2D and SWMM models.

The Test Area is approximately 2 square miles and located within the Broadway Rural Master Plan (BRMP) study area. It is bounded by Union Pacific Railroad (UPRR) on the west, US-60 on the south, Rural Road on the east, and UPRR on the north. Figure 4.1 shows the Test Area boundaries and location.

The FLO-2D software, Pro Version, Model-Build No. 13.11.06, release date of February 17, 2014, was applied initially for the modeling of the Test Area including sensitivity analysis. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the final modeling of the Test Area. FLO-2D program has been updated many times since the Test Area sensitivity analysis and they may have some impact on the FLO-2D modeling results and recommendations.

6.2 Test Area Modeling Sensitivity Analysis

Evaluation Criteria

The purposes of the sensitivity analysis for the Test Area are to evaluate the impact of uncertainties inherent in the input parameters and system components modeling approaches on peak flow and volume computations, to select proper parameters to improve modeling stability and efficiency, and to identify the most sensitive parameters to help the model calibration process.

The following parameters were utilized as the sensitivity analysis evaluation criteria:

1) Flood volumes (infiltration, floodplain storage, and outflows including surface and storm drains) reported by FLO-2D and SWMM report;
2) Peak flows from floodplain cross sections, total surface flow and storm drain outfall flows;
3) Maximum inundated area; and
4) Computer simulation time.

Sensitivity Analysis Scenarios

Design of sensitivity analysis scenarios is very important in the evaluation of parameters, modeling approaches, and system component on the impact of peak flows and volumes. Total twenty three (23) scenarios were designed and are classified into three (3) types of scenarios as follows:

1) Individual parameter sensitivity analysis;
2) Combined impact with additional system components; and
3) Impact of different modeling approach for system components.

The detailed modeling parameters, system components, modeling results, and evaluations for the modeling sensitivity analysis are documented in *The Test Area Sensitivity Analysis Summary Report*. This report is included in Appendix D1.

6.3 Summary and Conclusions for Test Area Modeling

The Test Area Sensitivity Analysis Summary Report was submitted to the District on March 6, 2014. This report is part of the *Test Area FLO-2D Analysis Report* which is included in Appendix D2. The final modeling results of the Test Area show that the surface inflow to storm drain system through inlets computed by FLO-2D and received by SWMM differs by -5.72%. The total outflows of the storm drain system through outfalls reported by FLO-2D and computed by SWMM are very close.

The following summary and recommendations were derived from the Test Area FLO-2D/SWMM sensitivity analysis and modeling results and applied in this project:

- **Structures**
  The generalized equation method should be used for the modeling of bridges/culverts since it is more consistent in preparing the input data and the modeling results are more stable unless it is confident in performance of bridges/culverts in which more accurate rating tables can be developed. If a culvert has multiple barrels rating table method should be developed and applied for the modeling of this type of culverts. After the Test Area sensitivity analysis, the District found that the generalized equation method in the updated version of FLO-2D program provides incorrect head elevations. Therefore, the rating table method was applied in this project.

- **Streets**
  Street features were not modeled using STREET.DAT in this project based on the recommendations from the Test Area sensitivity analysis. The main reasons are a) it is not cost-effective to prepare the STREET.DAT file using GDS since the street systems are very complex and many miles long; and b) FLO-2D does not work very well with complicated STREET.DAT file.

  Instead, grid elevations within streets have been adjusted for the representation of street conveyance due to typical curb and crown cross sections. The elevation adjustment is set to be -0.30 ft.

- **Levees/Embankments**
  Levee input data file, LEVEE.DAT, was used by FLO-2D models to model engineered levees and walls/fences. Levee-like structures such as roadway/railroad embankments and canal overbanks were modeled by adjusting grid elevations. WRFs were not used for this project.

- **1-D Channels**
  The 1-D channel component should be used on channels that require cross sections to define the channel conveyance. If the channel is a swale with poor definition, then the grid element topography and roughness can be used to represent the cross sections. The 1-D channel component was applied for Tempe Drain open channel for this project. Other small washes were modeled using grid elevations.

- **Storm Drain Systems**
  Storm drain systems should be modeled using FLO-2D/SWMM integration approach whenever a storm drain system is one of the major outfalls of the storm water drainage systems. It has been recommended that FLO-2D/SWMM integration approach be used for this project.

  Procedures for the conversion of GIS shapefiles to SWMM.INP file utilized in this project include geospatial software – Inp.PINS and commercial software – Innoyze's InfoWorks CS. The method of using geospatial software – Inp.PINS is recommended since it is more cost effective.

- **Parameters**
  i. Value of surface detention, TOL, which is a minimum value of the flow depth for flood routing, should be as low as possible to reduce unnecessary flooding volume losses. The target value of 0.0042 ft which represents abstraction on asphalt was applied in this project. The initial abstraction, IA, values in INFIL.DAT used in the model were adjusted for TOL value and are greater than or equal to zero after TOL is subtracted.

  ii. Froude Number was limited to subcritical flow and a value of 0.84 was applied in this study since the flow is unstable if Froude Number value is between 0.86 and 1.13. Since the modeling area of this project is flat (subcritical flow is dominant) the modeling results are similar for minor variations of Froude Number values.

  iii. Courant is a critical stability parameter and should be adjusted between 0.20 and 0.60 to reduce numerical surging. Smaller Courant values increase computation time. A Courant number of 0.20 was applied for channels. Value of 0.35 was applied for Models B and C (without channel) and value of 0.60 were used for floodplains of Model A (with channel).

  iv. SHALLOWN is the flow roughness n-value for shallow overland flow (flow depth <0.2 ft) and has significant impact on both peak flow and volume (at least it is true for the FLO-2D version used for the sensitivity analysis). An equation is applied by the model as default to establish the relationship between the flow depth and the shallow flow roughness. The shallow n-value (SHALLOWN) of 0.0 (AMANN = -99) is applied in this study which means no depth roughness adjustment for all grid elements in this project modeling. Setting AMANN = -99 is to turn off depth integrated roughness in the program and setting SHALLOWN = 0.0 is to use default value of 0.100 for SHALLOWN.

7.0 FLO-2D MODELING RESULTS EVALUATION AND DOCUMENTATION

7.1 Evaluation Criteria for Modeling Results

When a FLO-2D simulation is completed, the modeling results need to be evaluated to make sure that the simulation was successful. The District's *FLO-2D Review Guidelines (July 2, 2012)* were followed for results evaluation and District's post-processing tools were used for the development of deliverables.

Volume conservation is the most important criterion for a successful model simulation. Overall volume conservation should be met for each time step simulation as shown in the SUMMARY.OUT file. The volume conservation should also be met between overland flow, channel flow, and storm drain flow exchanges. If the volume was not conserved, then it is necessary to conduct a detailed review and determine where the volume conservation errors occurred and these errors should be corrected.

After the volume conservation was met, the maximum flow depths and velocities in the channel, on the floodplain or in the streets were reviewed for reasonableness.

The following sub-sections present different ways of evaluating and documenting the FLO-2D/SWMM modeling results.

7.2 Assessment of Various Output Files

The FLO-2D model input data errors and run-time issues were identified and corrected if necessary through review of various FLO-2D output data files:

1) Errors and warning messages check for input data files – ERROR.CHK file was reviewed and input data files with any error messages were corrected and warning messages were evaluated; some of the warning messages were informational only;

2) Volume conservation check for FLO-2D – SUMMARY.OUT file was reviewed for the total flood volume, the infiltration losses, the floodplain/channel/storm drain storage and outflow volumes; volume conservation is the most important criterion for a successful model simulation; the overall volume conservation for each of the simulation output time step was met very well for all three (3) models as evidenced by the SUMMARY.OUT files;

3) Volume conservation check for SWMM – SWMM.RPT file was reviewed under "Flow Routing Continuity" for the total inflow volume, the external outflow, internal outflow, final stored volume, and continuity error. These volumes were compared with the values in SUMMARY.OUT; the total inflow into the storm drain systems and the total outflow from storm drain outfalls were very close for all three (3) models;

4) "Sticky" grid elements Check – TIME.OUT file was reviewed to check the number of time step decreases and determine if anything can be done for these grids to reduce the computer run time. TIME.OUT file was reviewed and the first few grids with the highest number of time step decreases were selected. Either Manning's n-values and/or ARF values were adjusted for these grids.

5) Manning's n-values check – ROUGH.OUT file was reviewed to evaluate the original Manning's n values and their changes; for the next FLO-2D simulation, grid element n-value adjustments were made using the n-values reported in ROUGH.OUT to improve the model simulation;

6) Floodplain cross section hydraulics check including peak flow, peak time, volume, and hydrograph shape – HYCROSS.OUT, CROSSMAX.OUT, and CROSSQ.OUT were reviewed for the predefined cross sections; most of the hydrographs were smooth except the ones near the most upstream and most downstream areas of the Tempe Drain channel where fluctuations for channel hydraulics exist due to significant geometric data variations and storm drain inflows;

7) Hydraulic structure rating curves check including peak flow, peak time, volume, and hydrograph shape – HYDROSTRUCT.OUT was reviewed for each of the hydraulic structures and almost all of them were smooth;

8) Hydraulics for each grid check – MAXQHYD.OUT was reviewed for the hydraulics for the maximum flow and corresponding flow depth, velocity, water surface elevation, and flow direction; the District's GIS post-processing tools were also used for the review of the hydraulics for grids; if unexpected results were noticed changes for some of the input data files were made;

9) Hydraulics for storm drain systems – SWMM.RPT was reviewed:
   a) Under "Node Depth Summary" maximum depth and HGL were reviewed and input data was revised if necessary;

   b) Under "Node Inflow Summary" maximum total inflow was reviewed and catch basin capacity (maximum lateral inflow) was evaluated for selected catch basins;

   c) Under "Node Surcharge Summary" node surcharge maximum height above crown and surcharge duration were reviewed and some high surcharge values were reviewed and addressed;

   d) Under "Node Flooding Summary" maximum flooding rate, volume, and ponded depth were reviewed and some high flooding values were noticed which was one of the reasons that the storm drain returning flow is high;

   e) Under "Outfall Loading Summary" maximum flow and volume for outfalls were reviewed and compared with FLO-2D modeling output values; they were very close;

   f) Under "Link Flow Summary" pipe maximum flow and velocity were reviewed and compared with those values of the junction next to the pipe; most of them were very close except those with significant flooding flows;

   g) Under "Pumping Summary" pump average flow and maximum flow were reviewed to make sure the pump stations were working properly;

h) Under "Node Results" individual node HGL, hydrograph, and flooding flow were reviewed;

i) Under "Link Results" individual pipe hydrograph was reviewed similar to f).

The electronic files for the complete FLO-2D model input and output files of the three (3) models are included in Appendix E1.

7.3 FLO-2D Post-Processing Tools

Mapper

The FLO-2D post-processor – Mapper was applied to develop maps to visually review the modeling results including area of inundation. Several shapefiles can be generated during the modeling results review process. Since most of the shapefiles are included within District GIS tools only the MGrid.shp files were generated and are included in Appendix E2.

District GIS Tools

The District provided GIS Tools were utilized to evaluate the modeling results and a group layer file was created. The FLO-2D modeling results including maximum flow depth, velocity, elevations, combined discharge, and flow directions were reviewed using these GIS tools. These layer files are included in Appendix E2.

District Spreadsheet Tools

The District provided spreadsheet "Hydrographs_Structure_FPXS.XLSM" was used to generate hydrographs for floodplain cross sections based on the HYCROSS.OUT and for hydraulic structures based on HYDROSTRUCT.OUT output files. These hydrographs were utilized to visually identify surging and instability issues. The cross section locations, the spreadsheet, and the generated hydrographs are located in Appendix E2. Most of the hydrographs were smooth except the ones near the most upstream and most downstream areas of the Tempe Drain channel where fluctuations for channel hydraulics exist due to significant geometric data variations and storm drain inflows;

Another District spreadsheet tool is for evaluation of hydrograph plots of catch basins. Catch basin (inlet) inflow and return flow hydrographs computed by FLO-2D into storm drain and received from SWMM (SWMMQIN.OUT) and SWMM received inflow from FLO-2D and computed return flow to FLO-2D (SWMM.RPT) were plotted and compared using these District spreadsheet tools. These hydrographs were used to visually identify surging and instability issues of the catch basins. These hydrographs are located in Appendix E2. Review of the cumulative volume hydrographs for grids showed that some of them have significant differences due to the different calculations of FLO-2D flooding and SWMM flood returning flows.

7.4 Evaluation of Flow Exchange between FLO-2D and SWMM

Purposes and Constraints

The FLO-2D Pro Model has been integrated with the EPA-SWMM to simulate the exchange of surface water flow with storm drain systems. The EPA SWMM model is designed for hydrologic and hydraulic modeling of storm drain systems. This program has its own features and its computational algorithms are different from FLO-2D, such as computation time steps, and definitions of flooding (ponding)/return flows. SWMM

model does not have the dimension information for each of the catch basins (inlets) and assumes that ideal catch basin systems are available for the storm drain systems. The integration of these two programs is very complicated because of these differences.

The purpose of this section is to evaluate the flow exchanges between FLO-2D and SWMM. The complete FLO-2D/SWMM model input and output files are located in Appendix E1. The spreadsheets and tables used for the evaluations are included in Appendix E3 for all of the three models. Model A is used as an example of this evaluation.

Flows Transfer from FLO-2D to SWMM

There are three (3) ways through which surface flows can be transferred into storm drain systems (SWMM): 1) through storm drain inlets (catch basins); 2) through storm drain outfalls (backwater); 3) inflow hydrographs coded in SWMM.INP file for off-site inflows.

These three (3) flows should be reported by both FLO-2D SUMMARY.OUT and SWMM SWMM.RPT files. The differences of the total inflows into storm drain systems reported by FLO-2D (SUMMARY.OUT) and SWMM (SWMM.RPT) for Models A, B, and C are, respectively, -5.36%, -8.00%, and -12.30% (row 4). Tables for Model A are shown below and tables for other two models are included in Appendix E3.

FLO-2D SWMM Flow Exchange Check - A_Model65_Chan (Build No. 15.02.10)					
	FLO-2D - SUMMARY.OUT		SWMM - SWMM.RPT		Difference (%)
1	FLO-2D to SWMM through Inlets	1940.12	Wet Weather Inflow	2067.27	-6.55
2	FLO-2D to SWMM through Outfalls	10.08	External Inflow	3.54	64.88
3	SWMM Coded Inflow Hydrographs	301.50	External Inflow (SWMM.INP HG)	301.50	0.00
4	Total Inflow to SWMM	2251.70	Total Inflow to SWMM	2372.31	-5.36
5	SWMM to FLO-2D from Returning Flow	574.54	Internal Outflow	858.01	-49.34
6	SWMM to FLO-2D from Oufalls	1280.60	External Outflow	1309.45	-2.25
7	SWMM Out of System from Outfalls	906.61	External Outflow	881.30	2.79
8	SWMM Storage	25.59	SWMM Storage	25.59	0.00
9	Total Outflow + Storage from SWMM	2787.34	Total Outflow + Storage from SWMM	3074.35	-10.30
10	Volume Difference (At-Ft)	-535.64	Volume Difference (At-Ft)	-702.04	
11	Volume Difference (%)	-23.79	Volume Difference (%)	-29.59	

Note that these discrepancies are mainly caused by the reported difference of inflows from outfalls (row 2) from these two programs. If the FLO-2D-computed inflow from outfalls is reduced the inflow differences reported by these two programs are all small for Model A as shown in the following table (Adjusted table). The surface inflows to storm drain systems through inlets computed by FLO-2D and received by SWMM (row 1) are close for all of the three models.

FLO-2D SWMM Flow Exchange Check - A_Model65_Chan (Build No. 15.02.10) (Adjusted)					
	FLO-2D - SUMMARY.OUT		SWMM - SWMM.RPT		Difference (%)
1	FLO-2D to SWMM through Inlets	1940.12	Wet Weather Inflow	2067.27	-6.55
2	FLO-2D to SWMM through Outfalls	4.00	External Inflow	3.54	11.50
3	SWMM Coded Inflow Hydrographs	301.50	External Inflow (SWMM.INP HG)	301.50	0.00
4	Total Inflow to SWMM	2245.62	Total Inflow to SWMM	2372.31	-5.64
5	SWMM to FLO-2D from Returning Flow	10.00	Internal Outflow	10.00	0.00
6	SWMM to FLO-2D from Oufalls	1280.60	External Outflow	1309.45	-2.25
7	SWMM Out of System from Outfalls	906.61	External Outflow	881.30	2.79
8	SWMM Storage	25.59	SWMM Storage	25.59	0.00
9	Total Outflow + Storage from SWMM	2222.80	Total Outflow + Storage from SWMM	2226.34	-0.16
10	Volume Difference (At-Ft)	22.82	Volume Difference (At-Ft)	145.97	
11	Volume Difference (%)	1.02	Volume Difference (%)	6.15	

Flows Transfer from SWMM to FLO-2D

There are also three (3) ways through which storm drain (SWMM) flows can be transferred out of or stored in the storm drain systems (SWMM): 1) through storm drain inlets (catch basins, returning flows); 2) through storm drain outfalls; 3) final stored volume by storm drain systems. The flows transferred through storm drain outfalls can be further divided into two (2) categories: flows out of FLO-2D system (through outflow grids and setting outfall conditions to be 0) and flows into FLO-2D system (into floodplain grids, basins, and channels).

These three (3) flows should be reported by both FLO-2D SUMMARY.OUT and SWMM SWMM.RPT files. The differences of the total flows out of the storm drain systems reported by FLO-2D (SUMMARY.OUT) and SWMM (SWMM.RPT) for Models A, B, and C are, respectively, -10.30%, -15.28%, and -17.50% (row 9).

Note that these discrepancies are mainly caused by the reported differences of returning flows from inlets from these two programs. The major reason for this difference is the different definitions of returning flow from SWMM and flooding by FLO-2D. If the returning flow from inlets (Adjusted table, row 5) is reduced, the outflow difference reported by these two programs is small (Model A, -0.16%, Adjusted table, row 9). The total outflows of the storm drain systems through outfalls reported by FLO-2D and computed by SWMM are very close for all of the three models.

7.5 Volume Conservation for Multiple FLO-2D Models

The entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C. Outflow hydrographs including surface flows and storm drain flows from Model B need to be converted to Model A and Model C. Therefore, the storm water volume conservation needs to be maintained among the three models.

Flows Transfer from Model B to Model A

As described in Section 5.4, the method of one (1) grid overlay along the boundaries of Model B and Model A was used for the model integration of surface flow and the detailed methods were documented in Appendix C7. The INFLOW.DAT for Model A includes surface flows from Model B and off-site surface flows outside drainage areas for

Models A and B. If the flow into Model A is from a storm drain this inflow hydrograph needs to be coded in SWMM.INP file, such as off-site inflow from 48th storm drain system into Model A (Appendix C5). The total outflow from Model B should be equal to the sum of the flows to Model A, Model C, and flows out of Model B through "Outflow" grids leaving the system. Detailed summary data is included in Appendix E4.

Flows Transfer from Model B to Model C

Similar to flows from Model B to Model A, the method of one (1) grid overlay along the boundaries of Model B and Model C was used for the model integration of surface flow and the detailed methods were documented in Appendix C7. The INFLOW.DAT for Model C includes surface flows from Model B and off-site surface flows outside drainage areas for Models B and C (flows from east of SR101 and north of SR202). If the flow into Model C is from a storm drain this inflow hydrograph was coded in SWMM.INP file. Detailed summary data is included in Appendix E4.

Volume conservation is the most important criterion for a successful model simulation. Overall volume conservation is very good for all of the three (3) models within one output time step (SUMMARY.OUT) and the maximum difference is 0.05%.

The total flow exchange volumes between FLO-2D and SWMM models are reasonable for all three models. However, the following overall volume conservation discrepancies were observed:

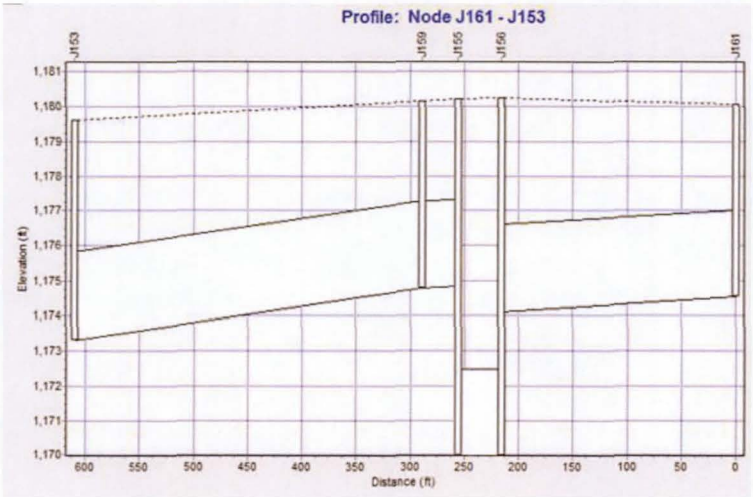
- The computed flow volume into SWMM through storm drain outfalls by FLO-2D and SWMM is not consistent and tends to be high;
- The computed flooding volume through storm drain inlets and manholes by FLO-2D and SWMM (returning flow) is not consistent and appears to be high;
- The computed flow volumes from storm drain outfalls into FLO-2D and out of the system by FLO-2D and SWMM are not consistent;
- The computed flow volumes from FLO-2D into storm drain (SWMM) through storm drain inlets by FLO-2D and SWMM are not consistent.

The inflow hydrographs from some of the inlets show noticeable oscillations. However, these oscillations did not have showed significant impact on the overall flow volume conservations based on the modeling results because these oscillations are due to:

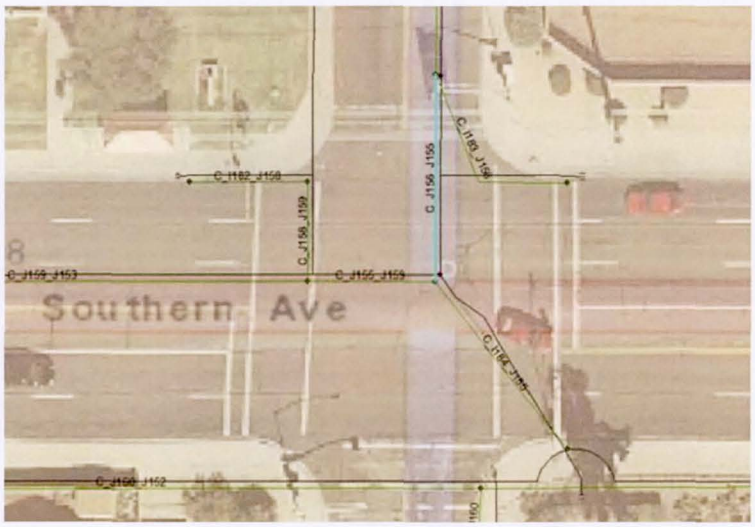
- Inflow depth variations;
- Computation equations (weir flow vs. orifice flow);
- Time steps (FLO-2D vs. SWMM);
- Inlet sizes and types (capacity not always match inflows);
- Pipe capacity vs. inlet flows (small pipes); and
- Pressure flow/no-pressure flow (FLO-2D) vs. flooding/ponding (SWMM) switches.

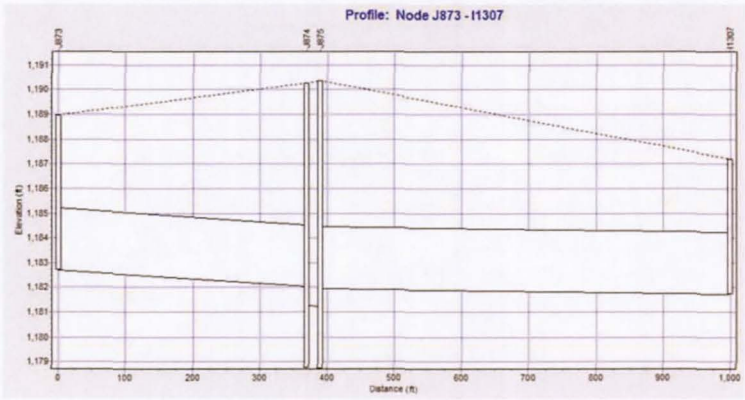
Additional review was conducted for possible pipe sag conditions within storm drain systems. Two pipe sag locations were identified and are shown in the following:

1) C_J874_J875 – McClintock Dr south of Concorda Dr. This sag is dropped for old canal and does not have any impact on the storm drain hydraulics. However, sedimentation could be an issue for small storm flows. Therefore, regular maintenance may be necessary for this location.



2) C_J156_J155 – Southern Ave and Terrace Rd. This pipe sag is dropped to avoid irrigation line. As-built plans confirmed that the outlet invert is higher than the inlet invert to the dropped pipe. This sag does not have any impact on the storm drain hydraulics. However, sedimentation could be an issue for small storm flows. Therefore, regular maintenance may be necessary for this location.





7.6 Documentation of Modeling Results

Various maps for the development of input data files were created and are included in Exhibit A for review and references.

Systematic documentation of modeling results can help the multiple agencies to review the deliverables effectively and make the modeling results more useful to the public. In addition to documentation of modeling results by the post-processing tools as described in previous sections, such as GIS shapefiles, hydrographs, tables, and web-based post-processor tools (District), the following modeling results are documented with hydrographs and tables which are included in Appendix E5:

Hydrographs for 1-D Channel Cross Sections

Tempe Drain is one of the most important surface runoff outfalls for the Model A area. The FLO-2D output file HYCHAN.OUT stores the Tempe Drain 1-D channel various hydrographs for all cross sections. The discharge hydrographs were plotted using the District spreadsheet tool and are included in Appendix E5. Figure 7.1 shows the hydrographs at three critical locations. The channel peak flow values can be utilized to determine if the channel capacity had been exceeded (overtopped).

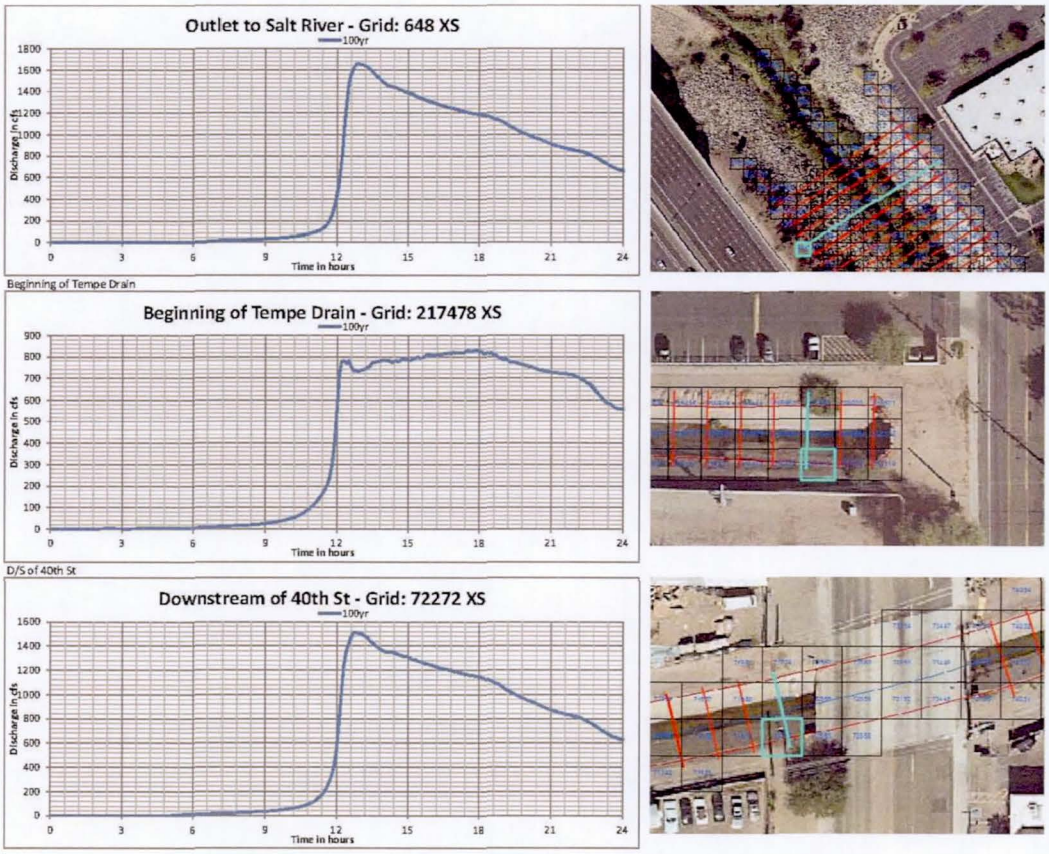


Figure 7.1 Tempe Drain channel example flow hydrographs

Hydrographs for Major Storm Drain Outfalls

Major outfall hydrographs were exported graphically from the SWMM.Rpt file. Figure 7.2 showed six (6) storm drain outfall hydrographs from Model A. Storm drain outfall hydrographs for other locations were included in Appendix E5. The storm drain outfall hydrographs were utilized to determine if the storm drain capacity had been exceeded.

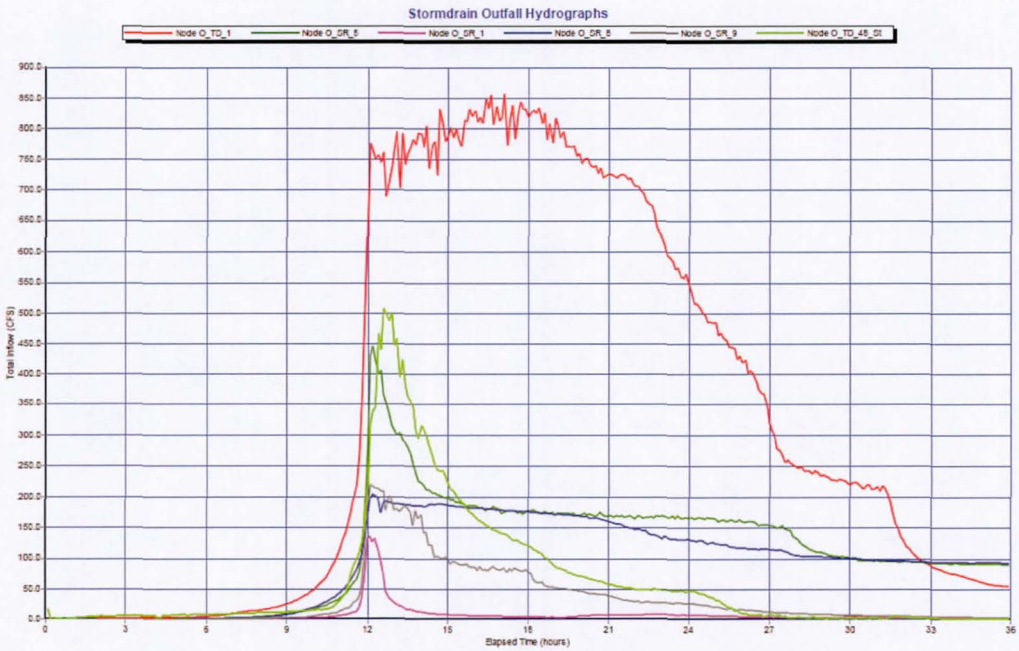


Figure 7.2 Storm drain outfall example hydrographs (Model A)

Flow Depth Hydrographs for Major Detention Basins

Basin stage-time hydrographs were obtained by exporting tabular data from the outfalls of the basins in SWMM.Rpt and graphing them in Excel. These basins include the US-60 basin near Kyrene Rd which receives flow from US-60 and South to Guadalupe Rd; the Ken McDonald Golf Course which receives flow from the neighborhoods near the Western Canal; the Hanger Park which receives flow from the areas of Tempe South of the Western Canal; and the Hanger Park then outlets into the Gila Drain. Figure 7.3 showed these four (4) basin hydrographs.

Note that the water surface elevations in the basins are generally rising after the rainfall stops (24-hour) because the storm drain systems can receive surface runoffs from areas with long time of concentration which indicates the 24-hour storm is the controlling storm event. The flow depth hydrographs for major retention basins were utilized to determine if the basin volume capacity had been exceeded.

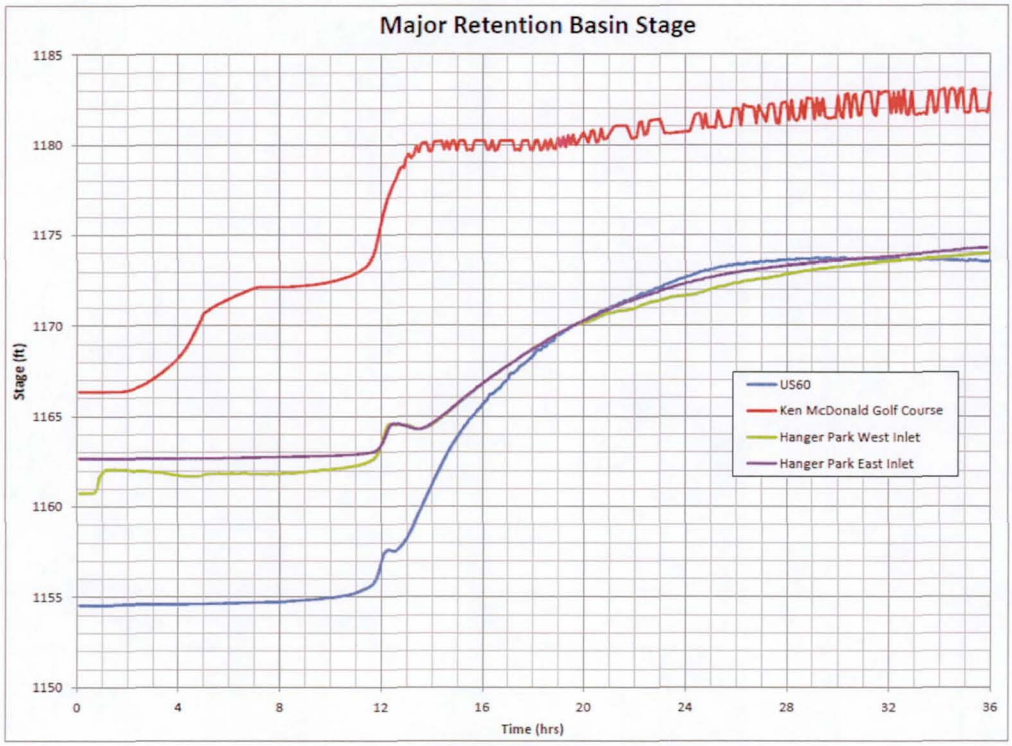


Figure 7.3 Detention basin stage hydrographs

Maximum Discharge and Velocity for Floodplain Cross Sections (Tables)

Floodplain cross section hydrographs were obtained from FLO-2D output file HYCROSS.OUT. The floodplain cross section summary data was documented in the table format including maximum discharges and velocities and is included in Appendix E5. Model A floodplain cross section results are shown in the following table. These cross section locations are shown in the maps located in Appendix B9. The charts of the hydrographs can be found in Appendix E2. The maximum discharge and velocity for floodplain cross sections were used to quantify flood hazard within the study area.

Floodplain Cross Section Results - Model A								
XS No.	Q_p (cfs)	V (acft)	XS No.	Q_p (cfs)	V (acft)	XS No.	Q_p (cfs)	V (acft)
1	33.7	5.66	47	2.7	0.17	93	7.6	0.95
2	51.3	4.32	48	12.2	0.68	94	6.6	0.43
3	51.8	5.23	49	1.8	0.10	95	14.2	1.87
4	24.1	8.25	50	5.8	0.23	96	19.6	2.63
5	53.0	17.62	51	11.8	0.77	97	74.8	4.14
6	45.3	6.59	52	1.2	0.04	98	38.3	3.25
7	51.0	25.29	53	2.9	0.17	99	139.7	62.01
8	3.4	0.41	54	0.9	0.06	100	2.2	0.16
9	28.9	4.17	55	16.5	2.37	101	32.9	5.86
10	7.1	0.46	56	15.0	1.92	102	4.8	0.42
11	7.9	0.72	57	1.7	0.12	103	192.7	63.63
12	22.4	1.63	58	15.3	3.91	104	104.1	21.95
13	3.6	0.04	59	18.6	6.99	105	16.3	0.64
14	5.7	0.32	60	45.7	8.23	106	23.2	2.13
15	3.8	0.23	61	4.8	0.46	107	114.2	29.26
16	60.8	14.15	62	3.5	0.24	108	16.7	9.89
17	57.7	13.17	63	70.8	58.35	109	24.7	8.24
18	10.0	2.64	64	20.0	5.57	110	11.9	1.03
19	22.4	11.44	65	11.9	8.01	111	29.1	10.55
20	16.4	0.49	66	102.9	16.86	112	4.3	1.06
21	42.5	13.89	67	36.5	17.49	113	95.4	51.43
22	24.9	8.38	68	36.4	14.77	114	43.7	6.55
23	1.5	0.07	69	9.8	5.36	115	12.4	2.16
24	25.9	2.19	70	89.8	15.01	116	0.3	0.02
25	36.9	2.19	71	22.0	4.53	117	27.7	10.14
26	16.0	3.34	72	9.2	2.09	118	10.4	0.91
27	67.2	18.48	73	24.4	6.76	119	17.3	3.00
28	65.9	11.93	74	15.3	2.03	120	33.5	8.43
29	27.2	8.72	75	0.5	0.02	121	42.7	12.34
30	18.6	9.79	76	1.8	0.12	122	16.1	2.33
31	2.3	0.21	77	5.2	0.61	123	62.9	8.51
32	6.5	0.43	78	1.9	0.13	124	14.6	2.17
33	4.4	0.33	79	4.9	0.27	125	45.7	3.35
34	14.4	2.45	80	48.9	20.68	126	9.0	0.55
35	32.8	9.92	81	75.8	61.31	127	19.2	1.44
36	21.6	7.14	82	3.7	0.50	128	17.1	6.96
37	78.7	62.44	83	98.8	70.76	129	14.5	1.33
38	35.1	20.36	84	18.7	6.54	130	28.8	4.50
39	56.0	39.17	85	36.3	2.02	131	12.4	0.81
40	17.7	2.35	86	15.9	1.38	132	4.6	0.43
41	7.3	0.34	87	71.7	9.82	133	90.4	14.73
42	8.4	0.38	88	63.0	8.62	134	18.7	1.47
43	3.8	0.04	89	140.2	15.14	135	12.0	1.62
44	28.5	3.53	90	73.5	19.69	136	23.9	3.15
45	1.4	0.28	91	31.9	3.90			
46	2.0	0.08	92	33.0	8.83			

Maximum Water Surface Elevation and Discharge for Hydraulic Structures (Tables)

The hydrographs for drainage structures were obtained from FLO-2D output file HYDROSTRUCT.OUT. The summary data for structures was documented in the table

format including maximum discharges and peak flow time in Appendix E5. Model A hydraulic structure results are shown in the following table. The structure locations are shown in the maps located in Appendix C1. The charts of the hydrographs can be found in Appendix E2. These parameters were used to evaluate the hydraulic structure capacities within the study area.

Hydraulic Structure Modeling Results - Model A			
Name	Structure No.	Qp	Tmax
UPRR-2	1	5.23	12.07
Irr-2	2	18.51	12.13
Irr-4	3	1.25	11.98
SR143-2	5	1.57	12.00
SR143-16	6	32.31	11.93
SR143-18	7	154.50	14.92
SR143-20	8	55.39	13.18
SR143-22	9	29.08	12.19
SR143-24	10	7.61	12.30
SR143-26	11	6.06	12.27
College-2	12	4.59	12.03
I10-4b	14	0.42	11.64
44-1	15	3.40	12.19
44-2	16	0.70	23.93
44-3	17	35.79	14.98

Maximum Flow Depth, Velocity, and Discharge for Floodplain Grids (Maps)

Full size maps for the maximum flow depth, maximum flow velocity, and maximum flow rate for floodplain grids were developed and are included in Exhibit B. These maps can be utilized to identify the base flood hazard areas and develop preliminary flood mitigation alternatives.

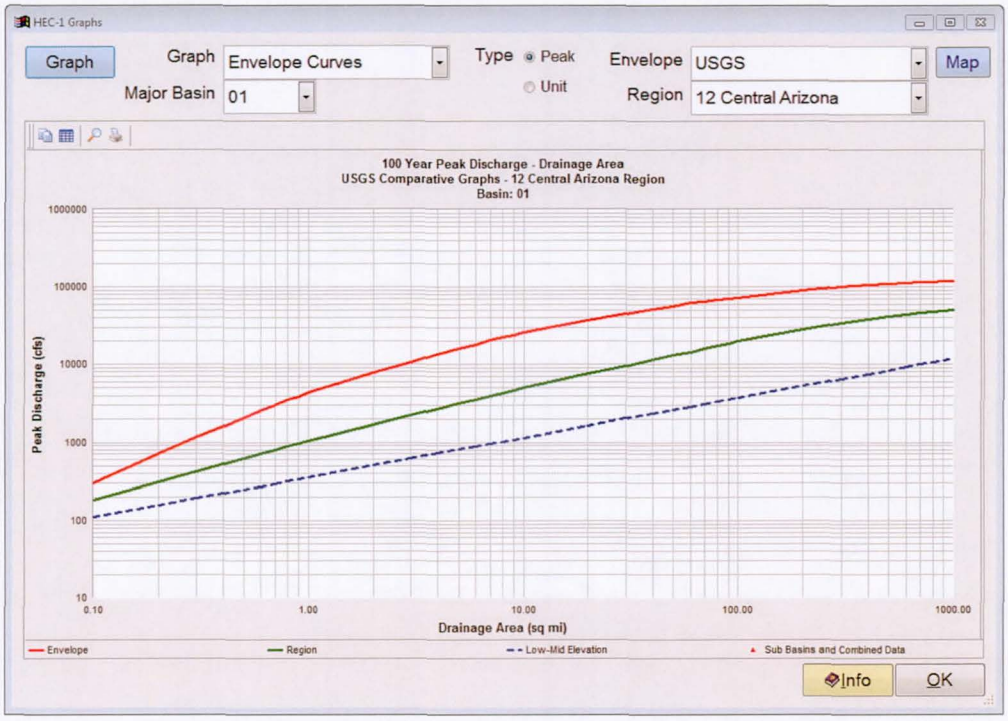
Maximum Storm Drain Pipe Flow, Pipe Utilization, and Velocity (Maps)

Maps showing the storm drain maximum flow rate, maximum flow velocity, and pipe utilization (pipe flow/full flow) were developed and are included in Exhibit B. These maps can be utilized to evaluate the storm drain system capacities and develop preliminary flood mitigation alternatives.

8.0 MODEL VERIFICATION

8.1 Purposes and Constraints

Direct quantitative model verification cannot be performed using the Test Area model because there is no site specific gauged stream flow data available and the Test Area does not have a closed watershed. Instead, indirect model verification methods were first adopted for this project using the peak flow in Tempe Drain channel in Model A. The USGS regression equation envelope curves produced by using the District DDMSW program are shown below. The 100-year peak flow in the Tempe Drain channel near SR-143 is about 1,100 cfs from the FLO-2D modeling results of Model A and the drainage area for this location is approximately 15 square miles. This flow is near the low bound of the envelope curve and is reasonable since the USGS regression equations were developed for general land uses and peak flows for urbanized areas should be lower than the estimated flows by these equations due to the attenuation effects by detention/retention basins, streets, and canals.



Then, the following model verification methods were adopted for this project using the FLO-2D modeling results of Model A: a) storm drain catch basin flow evaluation; and b) comparison of measured storm drain outfall hydrograph with FLO-2D/SWMM computed hydrograph at storm drain outfall SR-8 for gauged rainfall data of March 1, 2014 storm event.

The modeling results of Tempe Drain channel for the September 8, 2014 storm were applied also for the purpose of general FLO-2D model verification since the peak flow depth in the Tempe Drain can be estimated with high confidence based on the field photo

in that morning. This analysis is not intended to be comprehensive, but simply a check of FLO-2D hydrologic and hydraulic calculations.

8.2 Model Verification by Storm Drain Catch Basin and Outfall Hydrographs

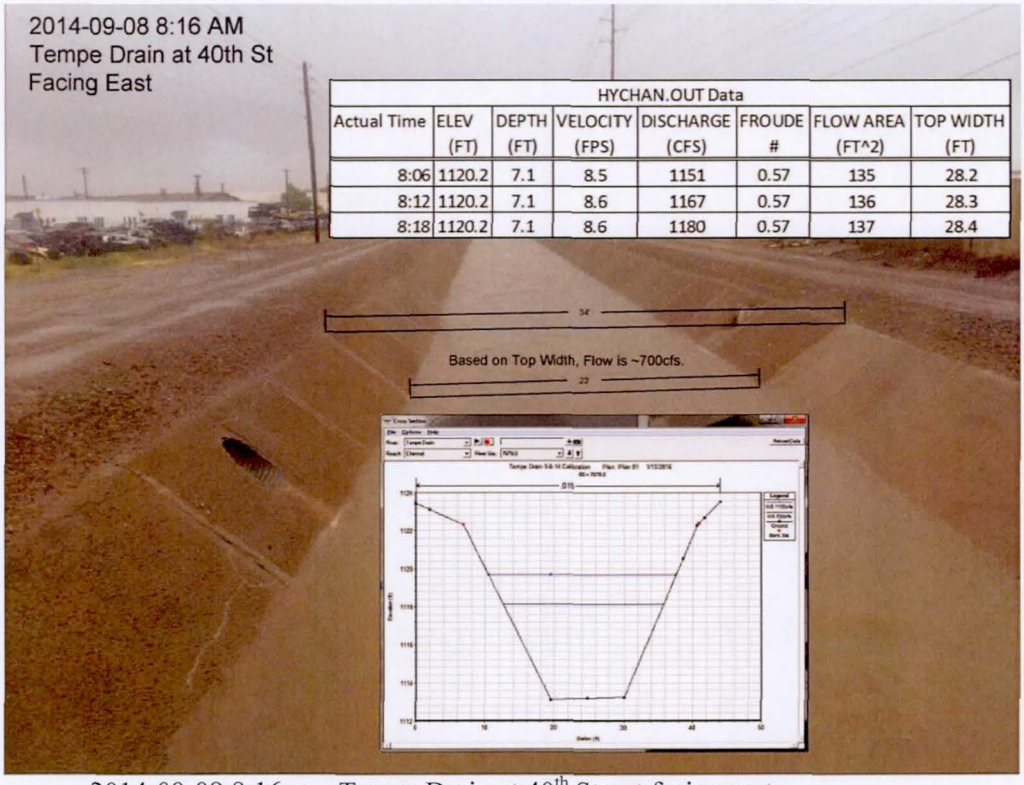
- **Storm drain catch basin inflow hydrographs**
  The maximum flow depths of grids with catch basins and the sizes of catch basins were utilized to estimate the maximum peak flows through these catch basins and they were compared with the SWMM reported peak flows for these catch basins. The peak flow values from selected catch basins (I_I10_136 and I1253) are very close from these two methods as documented in Appendix F1.

- **Storm drain outfall hydrographs**
  Measured storm drain outfall hydrographs by City of Tempe and corresponding observed/processed rainfall data provided by District for the March 1, 2014 storm were used for the model verification (Model A, storm drain outfall SR-8). The outfall SR-8 peak flows from the FLO-2D modeling results and the measured data are very close as documented in Appendix F1. Note that the time to peak is adjusted since the modeling time and reported measurement time is different.

8.3 Model Verification by September 8, 2014 Storm

- **Storm drain catch basin inflow hydrographs**
  The maximum flow depths of grids with catch basins and the sizes of catch basins were utilized to estimate the maximum peak flows through these catch basins and they were compared with the SWMM reported peak flows for these catch basins. The peak flow values from selected catch basins (I_I10_136 and I1253) for the September 8, 2014 storm were very close from these two methods as documented in Appendix F2.

- **Tempe Drain peak flow and maximum flow depth**
  The September 8, 2014 storm was used for model verification. The peak flow depth in Tempe Drain was estimated from field and photo taken in that morning (see photo below). The field photo shows the water surface elevation at Tempe Drain near 40th street at 2014-09-08, 8:16 am. The estimated flow based on HEC-RAS is approximately 700 cfs and the FLO-2D 1-D channel reported flow rate at this time is about 1,150 cfs. The water surface elevations of these two flows for the HEC-RAS cross section are shown in the following photo and they are close. These photos and hydrographs of the Tempe Drain are documented in Appendix F2.



HYCHAN.OUT Data							
Actual Time	ELEV (FT)	DEPTH (FT)	VELOCITY (FPS)	DISCHARGE (CFS)	FROUDE #	FLOW AREA (FT^2)	TOP WIDTH (FT)
8:06	1120.2	7.1	8.5	1151	0.57	135	28.2
8:12	1120.2	7.1	8.6	1167	0.57	136	28.3
8:18	1120.2	7.1	8.6	1180	0.57	137	28.4

2014-09-08 8:16am. Tempe Drain at 40th Street facing east

8.4 Summary and Conclusions

Since direct quantitative model verification cannot be performed for this project due to no site specific gauged stream flow data available and without a closed drainage watershed alternative model verification methods were used for this project for Model A. The modeling results of Tempe Drain channel for the September 8, 2014 storm compared with field observed data were very similar and showed that the FLO-2D modeling results for this project are reasonable and acceptable.

9.0 REFERENCES

1. ESRI, *ArcGIS,* Version 10, 2010.
2. FLO-2D Software Inc., *FLO-2D*, Pro Version, Model-Build No. 13.11.06, 2014.
3. Manifold Software Limited, *Manifold System*, Version 8.0, 2010.
4. U.S. Environmental Protection Agency, *EPA SWMM*, Version 5.0 (Build 5.0.022), April 2011.
5. inpPINS Computer Program, https://sites.google.com/site/inppins/guide
6. Bentley Systems, Inc., *CulvertMaster*, Version 3.2, August 2008
7. Flood Control District of Maricopa County, FLO-2D Review Guidelines, revised version, July 2012.
8. Riada Engineering, FLO-2D Reference Manual.
9. Riada Engineering, FLO-2D Data Input Manual.
10. Riada Engineering, FLO-2D GDS Manual.
11. Riada Engineering, FLO-2D Mapper Manual.
12. Riada Engineering, FLO-2D Limiting Froude Number Application Guidelines.
13. Riada Engineering, FLO-2D Pocket Guide.
14. Riada Engineering, User Assigned Courant Number in TOLER.DAT for Enhanced Model Numerical Stability.
15. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, User's Manual, Version 4.1, June 1998.
16. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Version 4.1, June 1998.
17. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1 January 2010.
18. *Broadway & Rural DMP: FLO-2D Pilot Study*, Cardno WRG, October 1, 2010.
19. *Broadway Road/Rural Road Candidate Assessment Report (CAR)*, Project Engineering Consultants, Ltd. September 2002.

20. *Drainage Policies and Standards for Maricopa County*, Flood Control District of Maricopa County, April 24, 2007.

21. *Drainage Design Manual for Maricopa County, Hydrology*, Flood Control District of Maricopa County, November 18, 2009.

22. *Drainage Design Manual for Maricopa County, Hydraulics*, Flood Control District of Maricopa County, August 15, 2013.

23. *Phoenix-Tempe Area Mapping, Project ID 1291, Contract No. FCD 08-20*, Flood Control District of Maricopa County, August 4, 2009.

24. *SCS_Soil GIS Shape Files,* Flood Control District of Maricopa County, March 10, 2010.

25. *FLO-2D Data Input Manual, Version 2009.06,* FLO-2D Software, Inc., November 30, 2010.

26. *FLO-2D Review Checklist (DRAFT),* Flood Control District of Maricopa County, May 5, 2011.

27. *Broadway-Rural Pilot Study, FLO-2D Hydrograph Analysis,* Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

28. *TOL and Hydraulic Structure Rating Curves Interoffice Memorandum*, Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

29. *Tempe ADMS/P Data Collection Report*, J2, August 2014.

30. *Tempe ADMS/P Test Area Sensitivity Analysis Summary Report*, J2, March 2014.

31. *Tempe ADMS/P Test Area FLO-2D Analysis Summary Report*, J2, June 2015.

TEMPE AREA DRAINAGE MASTER STUDY
CONTRACT FCD 2012C021

VOLUME III
FLOOD HAZARD ASSESSMENT REPORT

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December 2015
Revised January 2016

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1.0 INTRODUCTION

1.1 Purpose of Study

In the past few years, there have been multiple significant storm events causing extensive street drainage problems and localized flooding of several neighborhoods in the City of Tempe. Although Tempe is nearly built-out, the advent of the light rail, ASU expansion plans, and Tempe Town Lake has spurred major redevelopment within the City. As a response to projected urban growth and regulatory requirements, the City of Tempe is considering implementation of various green infrastructures (GI) and low impact development (LID) techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway system (I-10) within this region. The freeway drainage network within Tempe includes several facilities that will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area and has initiated the Tempe Area Drainage Master Study and Plan (Tempe ADMS/P) to identify flood hazards and develop any needed flooding mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

The purpose of this report is to document the flood hazard assessment (FHA) procedures and findings based on the FLO-2D/SWMM modeling results for the 24-hour storm events. The 100-year 24-hour storm was determined to be the controlling storm duration based on the evaluation of the modeling results due to the size of the study area.

An area of flood hazard is generally defined as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year (100-year storm, base flood). Areas of flood hazard are commonly identified on the Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM). Areas of flood hazard are generally determined by flood depth/water surface elevation, discharge, and flow velocity. The FHA in this study consists of the following major steps:

A) Introduction to the FLO-2D/SWMM models, model features, and modeling results for the base flood that were applied in the FHA (Section 2.0);

B) Identification of potential concentrated flooding areas where detailed FHA was performed (Section 3.0);

C) Identification of potential structure/building flooding within the identified concentrated flooding areas using detailed FHA processes (Section 4.0);

D) Evaluation of flood hazard risks within the identified flood hazard areas using multiple frequency modeling results (Section 5.0).

The complete hydrologic and hydraulic modeling of the Tempe ADMS area by FLO-2D/SWMM models was documented in the *Tempe ADMS FLO-2D/SWMM Modeling Report.*

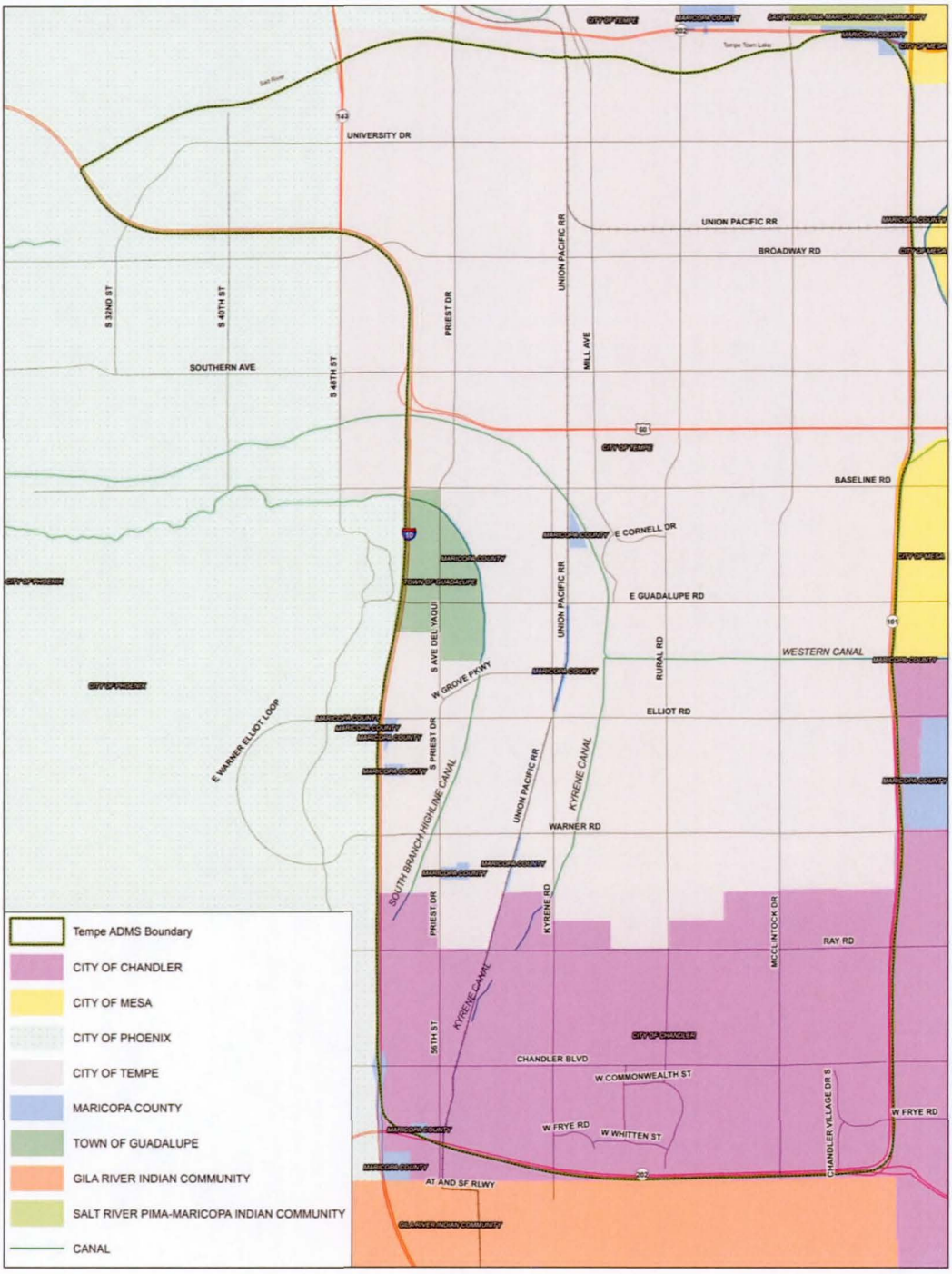
Note that the intent of the Tempe ADMS is for regional flood hazard identification and planning purposes.

1.2 Location of Study

The Tempe ADMS area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. Figure 1.1 shows the project area boundaries and location.

1.3 Acknowledgements

J2 is very appreciative to have the opportunity to represent the District in the performance of these services. This professional assignment presented many interesting and unique challenges requiring creative teamwork solutions. Mr. Burke Lokey, Mr. Richard Waskowsky, Mr. Doug Williams, Ms. Theresa Pinto, Mr. Thomas Loomis, and Mr. Pedro Melo-Rodriguez of the District; Mr. Gregg Kent and Mr. Richard Dalton of the City of Tempe, Mr. Hasan Mushtaq of the City of Phoenix, Mr. Warren White of the City of Chandler, and Mr. Jim Ricker of the Town of Guadalupe provided critical technical support and decision-making guidance throughout the duration of the study. Their individual and group contributions played a key role in the successful completion of this assignment.



Tempe ADMS/P FCD 2012C021 - Flood Hazard Assessment
Figure 1.1 Project Area Boundaries and Location Map

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

2.0 HYDROLOGIC AND HYDRAULIC MODELING

2.1 FLO-2D Program and Application Version

FLO-2D, integrated with EPA Storm Water Management Model (SWMM Version 5.0) and developed by Riada, Inc., was selected to be applied for this project. FLO-2D routes surface runoff over unconfined flow surfaces/channels using the dynamic wave approximation to the momentum equation while maintaining volume conservation. Finite difference algorithms are utilized to solve the partial differential equations. EPA SWMM is integrated with FLO-2D to simulate storm drain systems. More detailed information about the capabilities and applications of FLO-2D can be found in the references. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the final modeling of the project. Modeling results may be slightly different if different FLO-2D build number program is applied.

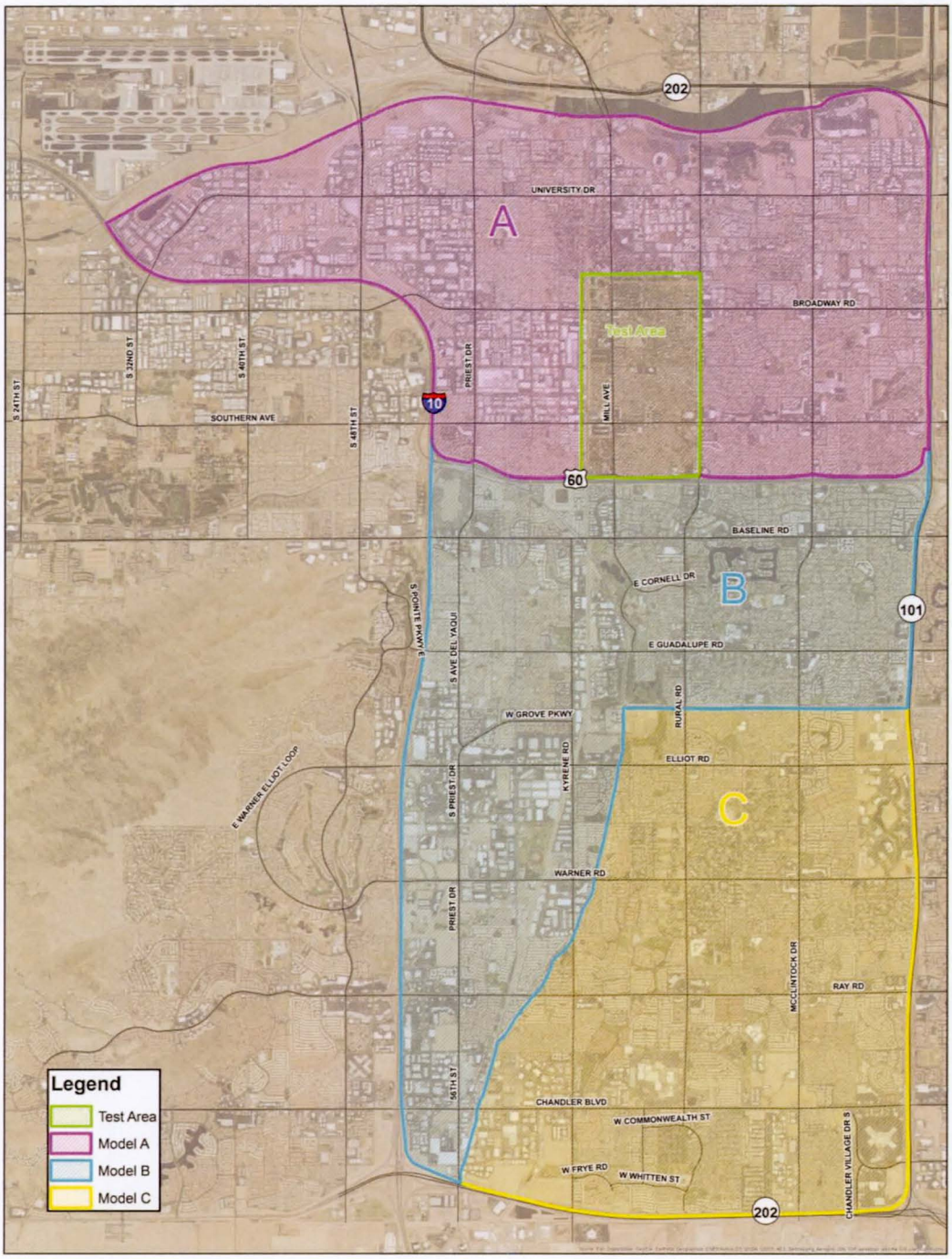
2.2 FLO-2D Modeling Sub Models and Boundaries

The entire Tempe ADMS/P study area (47 mile^2) is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C as shown in Figure 2.1. The Test Area is part of the study area of Model A. The main reason that the study area is divided into three (3) FLO-2D models is: a) topographic boundaries (features), b) FLO-2D model size, and c) integration of FLO-2D and SWMM models. Since these boundary delineations are fundamental to the development of FLO-2D models and dictate all of the input data preparation they were determined in the early stage of the project. The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C. A grid size of 20 ft by 20 ft was applied for this project. The major features for the sub-models are summarized in Table 2.1:

Table 2.1 FLO-2D Sub-Model Features

Model	Model A	Model B	Model C	Total
Drainage Area (mile^2)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

Note that the number of structures in Table 2.1 is the number of drainage structures. The development of the input data files for all three models, model verification, and modeling results were documented in detail in the *Tempe ADMS FLO-2D/SWMM Modeling Report* prepared by J2. In that report, various maps for the development of input data files were created and documented as well.



Tempe ADMS/P FCD 2012C021
Figure 2.1: FLO-2D Study Boundaries for Models A, B, C, and Test Area

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

2.3 FLO-2D Modeling Results for the 100-Year, 24-Hour Storm

Complete documentation of FLO-2D/SWMM modeling results were done first by using the District post-processing tools, and then by using other software and programs as described in detail in the *Tempe ADMS FLO-2D/SWMM Modeling Report.* The formats of the documentation include GIS shapefiles (layers), hydrographs, tables, maps and other exhibits.

For the purpose of flood hazard assessment, the following modeling results including hydrographs and tables are included in Appendix A:

Hydrographs for 1-D Channel Cross Sections

Tempe Drain is one of the most important surface runoff outfalls for the Model A area. The FLO-2D output file HYCHAN.OUT stores the Tempe Drain 1-D channel various hydrographs for all cross sections. The discharge hydrographs were plotted using the District spreadsheet tool and are included in Appendix A. The channel peak flow values were utilized to determine if the channel capacity has been exceeded (overtopped) or has extra capacity. This information enabled team members to better quantify the flood hazard of the Tempe Drain areas and identify possible mitigation solutions.

Hydrographs for Major Storm Drain Outfalls

Major storm drain outfall hydrographs were exported graphically from the SWMM.RPT file. Two phenomena were noticed from the storm drain outfall hydrographs: a) the tailwater in a channel or basin has significant impact on the shape of the storm drain outfall hydrographs as shown by outfall Node O_HP_2 which shows oscillations when the basin water surface elevations start to impact the outfall flows; b) when the basin is almost full additional flow from the basin can be pushed into the by-pass storm drain systems as shown by outfall Node O_GD_1. The storm drain outfall hydrographs were utilized to determine if the storm drain capacity had been exceeded and help team members to better quantify the flood hazard and identify areas of excess storm drain capacity to develop possible flood mitigation solutions.

Flow Depth Hydrographs for Major Detention Basins

Basin stage-time hydrographs were obtained by exporting tabular data from the outfalls of the basins in SWMM.RPT and graphing them in Excel. These basins include the US-60 basin near Kyrene Rd which receives flow from US-60 and South to Guadalupe Rd; the Ken McDonald Golf Course which receives flow from the neighborhoods near the Western Canal; the Hanger Park which receives flow from the areas of Tempe South of the Western Canal; and the Hanger Park then outlets into the Gila Drain.

Note that the water surface elevations in the basins are generally rising after the rainfall stops (24-hour) because the storm drain systems can receive surface runoffs from areas with long time of concentration which indicates the 24-hour storm is the controlling storm event. The flow depth hydrographs for major retention basins were utilized to determine if the basin volume capacity has been exceeded and help team member to better quantify the flood hazard of the basins and identify possible mitigation solutions.

Maximum Discharge and Velocity for Floodplain Cross Sections (Tables)

Floodplain cross section hydrographs were obtained from FLO-2D output file HYCROSS.OUT. The floodplain cross section summary data is documented in the table

format including maximum discharges and velocities. The table and the cross section location maps are located in Appendix A3. The charts of the hydrographs can be found in the *Tempe ADMS FLO-2D/SWMM Modeling Report*. The maximum discharge and velocity for floodplain cross sections were used to quantify hydraulic parameters within the study area to better identify the flood hazard in various street locations.

Maximum Water Surface Elevation and Discharge for Hydraulic Structures (Tables)
The hydrographs for drainage structures were obtained from FLO-2D output file HYDROSTRUCT.OUT. The summary data for drainage structures was documented in the table format including maximum discharges and peak flow time. The table and drainage structure location maps are located in Appendix A3. The charts of the hydrographs can be found in the *Tempe ADMS FLO-2D/SWMM Modeling Report*. The maximum water surface elevation and discharge for hydraulic structures were used to evaluate the drainage structure capacities within the study area and to identify if any structure needs to be modified for possible flood mitigation solutions.

Maps for the following modeling results from the base flood were developed and are included in Exhibit A. Note that the maximum flow depth and discharge for the Tempe Drain channel are included in Appendix A (hydrographs and tables) and Exhibit D4 (maps). These maps are useful tools for the base flood hazard identification and assessment:

Maximum Flow Depth, Velocity, and Discharge for Floodplain Grids; and

Maximum Storm Drain Pipe Flow, Pipe Utilization, and Velocity.

3.0 IDENTIFICATION OF POTENTIAL CONCENTRATED FLOODING AREAS

3.1 Selection Criteria

One of the primary objectives of this study is to identify and characterize the existing flooding hazards for potential mitigation based on the FLO-2D/SWMM modeling results. The potential concentrated flooding areas were identified based on the following three (3) criteria: 1) maximum flow depth based on the FLO-2D modeling results; 2) maximum flow discharge and size of the flooding area based on the FLO-2D modeling results; and 3) drainage complaints and flooding reports obtained as part of the data collection effort.

3.2 Summary of Potential Concentrated Flooding Areas

First, maps of the preliminary 100-year 24-hour storm FLO-2D/SWMM modeling results with existing drainage system conditions were reviewed and presented to the District and the City. These maps are included in Exhibit A. Preliminary review of the modeling results indicated that it was not necessary to perform the detail FHA for the entire study area (47 square miles) since no structure flooding areas were identified in Model C area because the majority of development in Model C area occurred after the implementation of 100-year 2-hour retention requirements and increasing the finished floor elevations to 14" – 17" above top of curb.

In order to identify the potential structure flooding, the concentrated flooding areas were evaluated first following directions from the District and eight (8) potential concentrated flooding locations were identified as shown in Figure 3.1. The same map covering the entire study area is in Exhibit B1. These eight (8) locations consisted of areas having significant ponding areas with depth greater than 1.0 ft, previously reported flooding, and areas of potential interest for a capital improvement program (CIP) project for the City. Supporting data for the identification of potential flooding areas are included in Appendix B which shows how the initial eleven (11) locations were reduced to eight (8) locations. Exhibit B2 includes one index map and seven (7) maps (covers entire Model A area and a small portion of Model B area) showing the 100-year maximum flow depths for the eight (8) potential concentrated flood areas and adjacent areas that were used as the basis for the detailed FHA and evaluation of the potential structure flooding. The summary statistics of these eight (8) potential concentrated flooding areas are documented in Table 3.1 and briefly discussed below:

Area 1 is located at northeast corner of Rural Road and Guadalupe Road and the primary land uses are residential and commercial. Storm drain is the major outlet of the storm runoff and the potential flooding is caused mostly by lack of surface flow outfalls and limited storm drain capacity.

Area 2 is located at southeast corner of Priest Drive and University Drive and the primary land use is residential. Storm drain is the major outlet of the storm runoff and the potential flooding is caused mostly by lack of surface flow outfalls and limited storm drain capacity.

Area 3 is located at northeast corner of McClintock Drive and Southern Avenue and the primary land uses are residential and school. Storm drain is the major outlet of the storm runoff and the potential flooding is caused mostly by lack of surface flow outfalls and limited storm drain capacity.

Area 4 is located at northeast corner of Mill Avenue and Broadway Road and the primary land uses are residential and community center. Storm drain is the major outlet of the storm runoff and the potential flooding is caused mostly by lack of surface flow outfalls (UPRR acts as a levee) and limited storm drain capacity.

Area 5 is located at northeast corner of Priest Drive and Southern Avenue and the primary land use is commercial. Storm drain is the major outlet of the storm runoff and the potential flooding is caused mostly by lack of surface flow outfalls and limited storm drain capacity.

Area 6 is located at Rural Road and north Broadway Road and the primary land uses are residential and commercial. Storm drain is the major outlet of the flood runoff and the potential flooding is caused mostly by lack of surface flow outfalls (UPRR acts as a levee) and limited storm drain capacity.

Area 7 is located near Broadway Road and Mill Avenue and the primary land use is residential. Storm drain is the major outlet of the flood runoff and the potential flooding is caused mostly by lack of surface flow outfalls (UPRR acts as a levee) and limited storm drain capacity.

Area 8 is located at Tempe drain near 40th Street and the primary land use is commercial. The Tempe Drain is the major outfall of the storm runoff and the potential flooding is caused mostly by the surface lower than the channel banks (interior drainage).

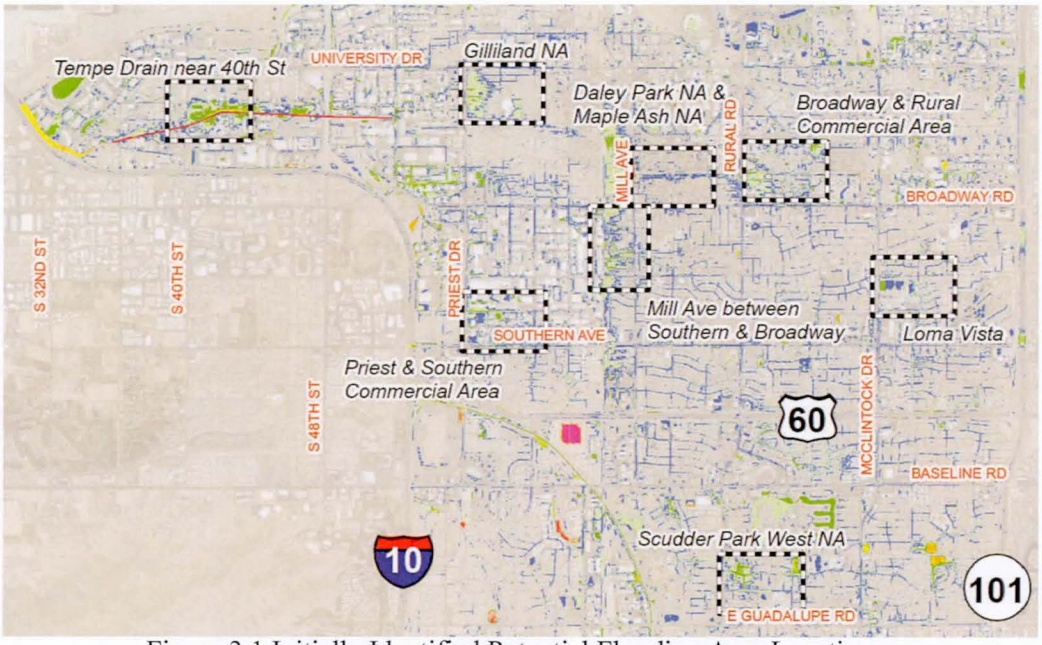


Figure 3.1 Initially Identified Potential Flooding Area Locations

Table 3.1 Initially Identified Potential Flooding Areas Summary Table

Area	Location	HOA/NAs	Primary Landuse	Typical Res. lot size (acre)	Notes	FLO-2D Model	Typical Flooding Depth (ft)
1	NE of Rural & Guadalupe	Scudder Park West NA	Residential/ Community Center	0.20	Stormdrain is the major outlet	B	2.0
2	SE of Priest & University	Gilliland NA	Residential	0.17	Stormdrain is the major outlet	A	1.5
3	McClintock & Alameda	McClintock NA, Alameda Meadows NA	Residential/School	0.17	Loma Vista	A	1.0
4	NE of Mill & Broadway	Maple Ash NA, Daley Park NA	Residential/ Community Center	0.20	UPRR acts as levee	A	1.0
5	NE of Priest & Southern		Commercial		Deep street flooding	A	1.5
6	Broadway & Rural	Hudson Manor	Commercial/ Residential		UPRR acts as levee, Residential flooding	A	1.5
7	Mulitple areas W of Mill	Maple Ash NA, Historic Date Palm Manor NA, Alameda Park HOA	Residential	0.20	UPRR acts as levee, Residential flooding	A	1.5
8	Tempe Drain @ 40th St		Commercial		Area is lower than channel	A	3.0

4.0 IDENTIFICATION OF POTENTIAL STRUCTURE FLOODING

4.1 Identification Processes of Potential Structure Flooding

In addition to the identification of potential concentrated flooding areas, structures (buildings and homes) with potential flooding risks were also evaluated and identified using the District recommended processes. As discussed previously, the eight (8) initially identified concentrated flooding areas were used as the basis for the detailed FHA since the majority of the other areas were not susceptible to flooding. Hydrologic and hydraulic data generated by the FLO-2D models was evaluated with the District's FLO-2D GIS post-processing tools and the GIS layer files were then applied for this process. Initially, all structures with a flooding depth of 0.5 ft and higher were designated as flooded. Then, review of the potential flooded structures eliminated those with trapped flows on hill slopes, adjacent to washes, and erroneous depths near the edges of the boundaries. In areas with clusters of flooded structures, adjacent structures showing depths between 0.4 and 0.5 ft were also designated as flooded.

The preliminary flooded structure identification processes are as follows and the supporting data are included in Appendix C:

1. All ARFs of 1.00 were deleted from the FLO2DGIS features from the post-processed results. These were removed because the results would have skewed the surface for the WSELMax.

2. The FLO2DGIS feature classes were then used to create a WSELMax TIN for the study area.

3. The "Surface Difference" routine was used to create a new TIN that subtracted the Elevation TIN from the WSELMax TIN. This TIN became a surface entirely based on flow depths related to the ground surface and not the grids.

4. The structure polygons were extracted from the land surface characterization shapefile and all structures under 1000 ft^2 were deleted. Most structures under 1000 ft^2 were found to be sheds, garages and mischaracterized features.

5. A 5-foot buffer was created around each of the structures. The initial polygons were removed so there would just the buffer representing the areas immediately adjacent to the structures.

6. The 5-foot buffers were then used to sample the depth TINs. The maximum (Z_Max), minimum (Z_Min) and mean (Z_Mean) depths were obtained for each of the buffer areas representing depths immediately outside the structures.

7. All data from the 5-foot buffers was transferred to the original structure polygons.

8. A column was added to the structure shapefile attribute table to indicate whether the structure was flooding or not.

9. Initially, all structures with a Z_Mean of 0.5 ft and higher were designated as flooded. A review of the potential flooded structures eliminated several based on: trapped flows for homes on hill slopes, structures adjacent to washes and erroneous depths near the edges of the TINs. All structures indicated as "flooded" were also verified with the maximum depth results.

10. In areas with clusters of potential flooded structures, adjacent structures showing depths between 0.4 and 0.5 ft were also designated as flooded.

11. Flood hazard areas were then drawn around strong clusters of structures.

4.2 Flood Hazard Assessment Results

Two types of flood hazard areas were identified and they are defined as:

1) General Flood Hazard Areas:
   -100-year 24-hour storm maximum depth equal to or greater than 1.0 ft;
   -Area of 1.0 ft depth or greater larger than 4000 ft^2 (10 grids);
   -Area not contributing to buildings designated as at risk of flooding;
   -Neighborhood and sectional retention basins not experiencing overtopping were not included (assumed to perform as designed).

2) Structure Flooding Risk Areas:
   -100-year 24-hour storm maximum depth equal to or greater than 0.5 ft;
   -Area contributing to a structure designated as at risk of flooding.

The maps for the potential flood hazard areas defined by this process are included in Exhibit C which contains one index map and seven (7) maps for both types of flooding areas. The supporting data (shapefiles) for identification of potential structure flooding are included in Appendix C. The total potential flood hazard area for the base flood is 1,394 acres (930 acres for buildings and 464 acres for general flooding) and the total number of buildings with potential base flood hazard is 1,043.

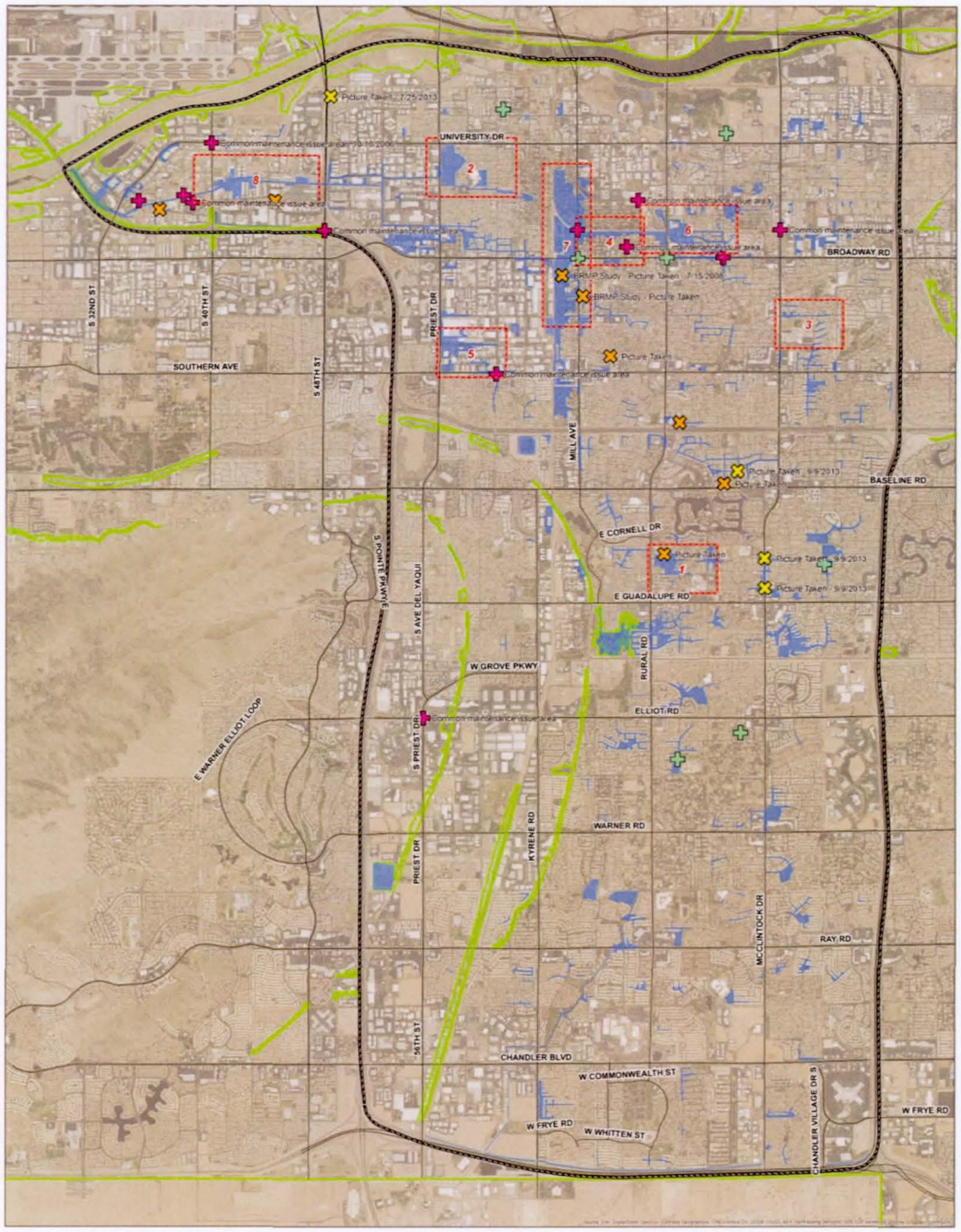
Table 4.1 contains the summary data for the eight (8) clustered flood hazard areas from the eight (8) initially identified concentrated potential flood areas (the largest flood hazard area for each of the eight (8) areas). The area names, nearest street intersection names, HOA and NA map numbers, number of buildings flooded, approximate flooded area, flood hazard assessment map numbers, and brief explanations to the reasons of these potential flooding locations are included in Table 4.1.

Table 4.1 Summary Data for Representative Base Flood Risk Areas

Area No.	Location	HOA/NAs	No. of Buildings Flooded	Approximate Flooded Area (ac)	FHA Map No.	Comment
1	NE of Rural & Guadalupe	Scudder Park West NA	67	22	7	Neighborhood is below street, overwhelmed US-60 stormdrain system is only outlet
2	SE of Priest & University	Gilliland NA	136	38	2	Neighborhood is below street, overwhelmed Tempe Drain 1 stormdrain system is only outlet
3	McClintock & Alameda	McClintock NA, Alameda Meadows NA	9	5	6	Neighborhood is below street, overwhelmed Salt River 8 stormdrain system is only outlet
4	NE of Mill & Broadway	Maple Ash NA, Daley Park NA	122	57	3	Ponding occurs up against UPRR, overwhelmed Salt River 5 stormdrain system is only outlet
5	NE of Priest & Southern		7	34	5	Commercial area is below Priest Dr, overwhelmed Tempe Drain 1 stormdrain system is only outlet
6	Broadway & Rural	Hudson Manor	104	58	3, 4	Ponding occurs up against UPRR, overwhelmed Salt River 5, 6, and 8 stormdrain systems are outlets
7	Mulitple areas W of Mill	Maple Ash NA, Historic Date Palm Manor NA, Alameda Park HOA	237	186	3, 5	Ponding occurs up against UPRR, overwhelmed Salt River 5 and Tempe Drain 1 stormdrain systems are outlets
8	Tempe Drain @ 40th St		12	39	1	Ponding occurs outside of banks of Tempe Drain

4.3 Comparison of Flood Hazard Assessment Results with Reported Flooding

The data collection phase of this study involved obtaining information regarding known flooding locations from property owners, city staff, citizens, and visiting the field during flooding events. Some of the photos within the project area from the September 8, 2014 storm were included in the folder of photo for references. Figure 4.1 shows the locations of all reported flooding obtained in the data collection overlaid with the base flood hazard assessment results. Flood hazard areas within this study are more prevalent in the older-developed portions of Tempe and Phoenix. Almost all of these reported flooding areas are located within the identified potential eight (8) FHA areas. One reported flooding area near Elliot Road and Priest Drive is not within one of the eight (8) identified areas since the reported flooding occurred before the improvements near the area. The reported flooding locations match the model results very well.



- Field Visit
- Marked at Public Meeting
- Property Owner Reported
- Marked by City Staff
- Tempe ADMS Boundary
- Base Flood Hazard
- FEMA Floodplain
- Initially Identified Flood Risk Focus Areas

Tempe ADMS/P FCD 2012C021
Figure 4.1: Identified Potential and Reported Flooding Locations

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

5.0 EVALUATION OF FLOOD HAZARD RISKS

5.1 Method Description – Multiple Frequency Modeling

The evaluation of flood hazard potential risks is related to the existing drainage system capacities. The capacity of individual drainage components can be estimated by using hydraulic modeling for a single structure, such as conveyance systems (open channels and underground pipes), crossing and control structures, such as bridges, culverts, weirs, pump stations, split structures, and outfalls. But for complex drainage systems with both surface and underground drainage systems such as those within this project area, a systematic approach is required. Therefore, multiple frequency FLO-2D/SWMM models (2-yr, 10-yr, 25-yr, and 100-yr design storms) within the study area were developed for the purpose of evaluating the flood protection levels of various existing drainage systems and flood control structures. Special attention was paid to areas where the systems have insufficient capacity as well as those may have excess capacity and/or insufficient interception capacity.

Documentation maps of the multiple frequency modeling results for the three (3) storms other than the 100-year storm are included in Exhibit D1. Supporting data and modeling results documented in other formats, such as tables, figures, and GIS shapefiles are included in Appendix D1.

5.2 Surface Flood Risk Evaluation

Similar to the 100-year storm, the two types of potential flood hazard areas (a. general potential flooding areas; b. structures (homes) with potential flooding risks) were identified using the same processes. Maps of the assessment results are included in Exhibit D2 and supporting data are included in Appendix D2.

Both of the two types of potential flood hazard areas are reduced (smaller areas) with more frequent storm events. The flood hazard assessment was correlated to a comprehensive listing of the areas identified as susceptible to flooding based on maximum flow depth and discharges as well as drainage complaints and flooding reports obtained as part of the data collection effort. Table 5.1 below shows the total areas and number of buildings designated as hazard areas based on the multiple frequency modeling and flood hazard analysis.

Table 5.1 Potential Flood Hazard Data from Multiple Frequency Modeling

Storm Event	Potential Flood Hazard Area (ac)			No. of Buildings Flooded
	Building Hazard*	General Hazard**	Total	
2	59.8	95.9	155.7	39
10	278.9	158.5	437.4	503
25	640.7	285.3	925.9	875
100	929.9	464.5	1394.3	1043
*	0.5'+ Depths Contributing to Building Flooding			
**	1'+ Depths Outside of Retention & Parking Areas			

The number of structures with potential flooding is a function of the storm frequency as shown in Figure 5.1 which shows that the number of structures with potential flooding increases with the increase of the storm magnitude (return interval).

Figure 5.1 Potential Flooded Structures vs. Storm Frequency

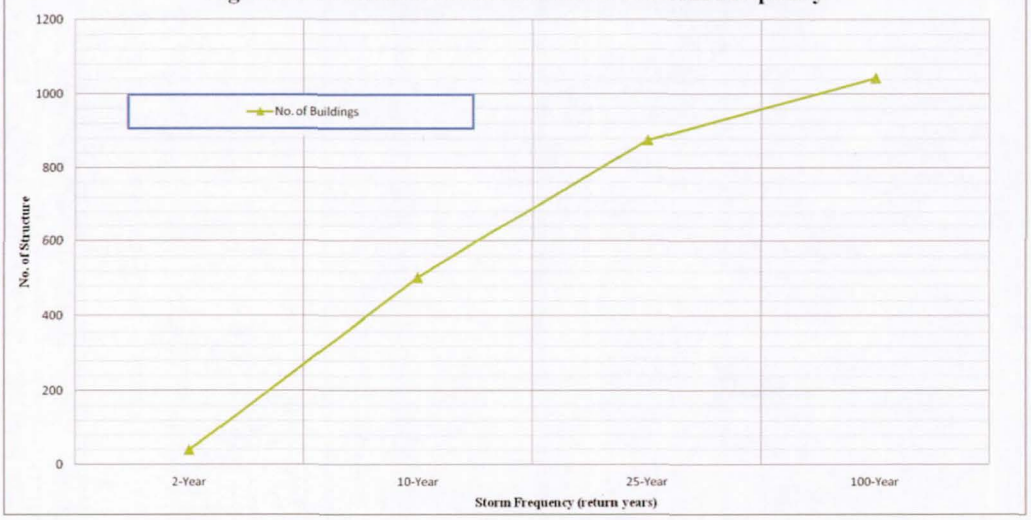


Table 5.1 shows that 39 buildings have potential flood hazard for the 2-year storm event. Structures susceptible to flooding during the the lower return intervals may represent high priority mitigation areas (future CIP), or potential individual parcel acquisition to mitigate flood hazard. More detailed review of the modeling results showed that these 39 buildings are located in about 14 locations as shown in Table 5.2 and mapped in Exhibit D2. The location street names, number of buildings, HOA/NA map numbers, flood hazard assessment map numbers, and possible courses are summarized in Table 5.2 as well. Most of these locations do not have either natural outfalls, or storm drain systems. Some of the building lots are lower than the street elevations.

Table 5.2 Summary Data for Flood Hazard Areas with Less Than 2-Year Protection Level						
Building Group	Location	Model Name	No. of Buildings	HOA/NA Map No.	FHA Map No.	Comments
1	42nd St and Winslow Ave	A	2	-	1	Local topography has no outlet
2	Tempe Drain	A	6	8	1	Ponding occurs outside banks of Tempe Drain
3	5th St and Hardy Dr	A	1	-	2	Local topography has no outlet
4	1st St and Wilson St	A	1	-	3	Local topography has no outlet
5	13th St and Roosevelt St	A	9	-	2	Local topography has no outlet & lots are not above streets
6	University Dr and Alpha Dr	A	1	-	3	Property is below street
7	Orange St and Stanley Pl	A	1	-	4	Local topography has no outlet
8	6th St and Hacienda Dr	A	5	-	4	Local topography has no outlet
9	Mill Ave and UPRR	A	4	7	3	Salt River 5 stormdrain full, lots not above the streets, & ponding against the UPRR
10	Spence Ave and Jen Tilly Ln	A	2	6	3	Local topography has no outlet
11	Rural Rd and Concorda Dr	A	1	-	6	Property is below street
12	Southern Ave and Terrace Rd	A	4	-	6	Local topography has no outlet
13	Pegasus Dr and Hazelton Ln	B	1	-	7	US-60 stormdrain system overwhelmed
14	Concorda Dr and River Dr	A	1	-	4	Local topography has no outlet

5.3 Storm Drain System Flood Risk Evaluation

Maps for maximum storm drain pipe flow, pipe utilization, and maximum velocity were developed for all of the four (4) storms and are included in Exhibit D3. Refer to Exhibit A5 for a map detailing the storm drain system locations. Additional supporting data can be found in Appendix D3.

Approximate capacities for all major storm drain systems are summarized in Table 5.3 which shows that most storm drain systems have 2-year storm capacity only. Four (4) out of 38 storm drain systems have protection level less than 2-year storm and Figure 5.2 shows these storm drain systems:

1) The Salt River 5 system outlets downstream of the Tempe Town Lake dam and the watershed ranges from the ASU campus down to the intersection of Broadway Road and Rural Road. Flooding in this area during the 2-yrear storm occurs near the intersection of Mill Avenue and the UPRR overpass. In larger storms, the UPRR line going north-south inhibits surface flow and results in ponding on the east side of the railroad.

2) The Salt River 8 system outlets into the Tempe Town Lake north of the ASU Karsten Golf Course west of McClintock Drive. This system includes the Dorsey Lane trunk line draining most of Tempe between Rural Road and Price Road south of the UPRR and north of the US-60 highway. Flooding in this area during the 2-year storm occurs on Los Feliz Drive. The neighborhoods along this street are situated in bowl-like topography where the only outlet is through the storm drain. Some of this storm drain

in this area is very flat as it was converted from irrigation lines resulting in reduced capacities.

3) The Tempe Drain 3 system outlets into the Tempe Drain at 40th Street. This system is relatively small and short, however the southern end of the system is situated in bowl-like topography and floods the street in the 2-year event.

4) The US-60 system outlets into the large basin west of Kyrene Road south of the US-60 highway. The watershed covers the east portion of Tempe between the Western Canal and the US-60. There are multiple sections flooding during the 2-year event in this system that causes minor street flooding. There is also a surge basin in this system located at Scudder Park which floods in events greater than the 2-year storm. This area has been observed to flood the adjacent elementary school twice since this project began.

The summary data for storm drain systems with 2-year and lower protection levels are summarized in Table 5.4. The storm drain system outfall names, protection levels, nearest street intersection names, HOA and NA map numbers, flood hazard assessment map numbers, and brief explanations to these potential flooding locations (total 21) are documented in Table 5.4. Storm drains with 2-year or lower protection levels do not have excess capacity available to assist in mitigation of local flooding (i.e., the storm drain is flowing full during these events) and may represent high priority mitigation areas (future CIP).

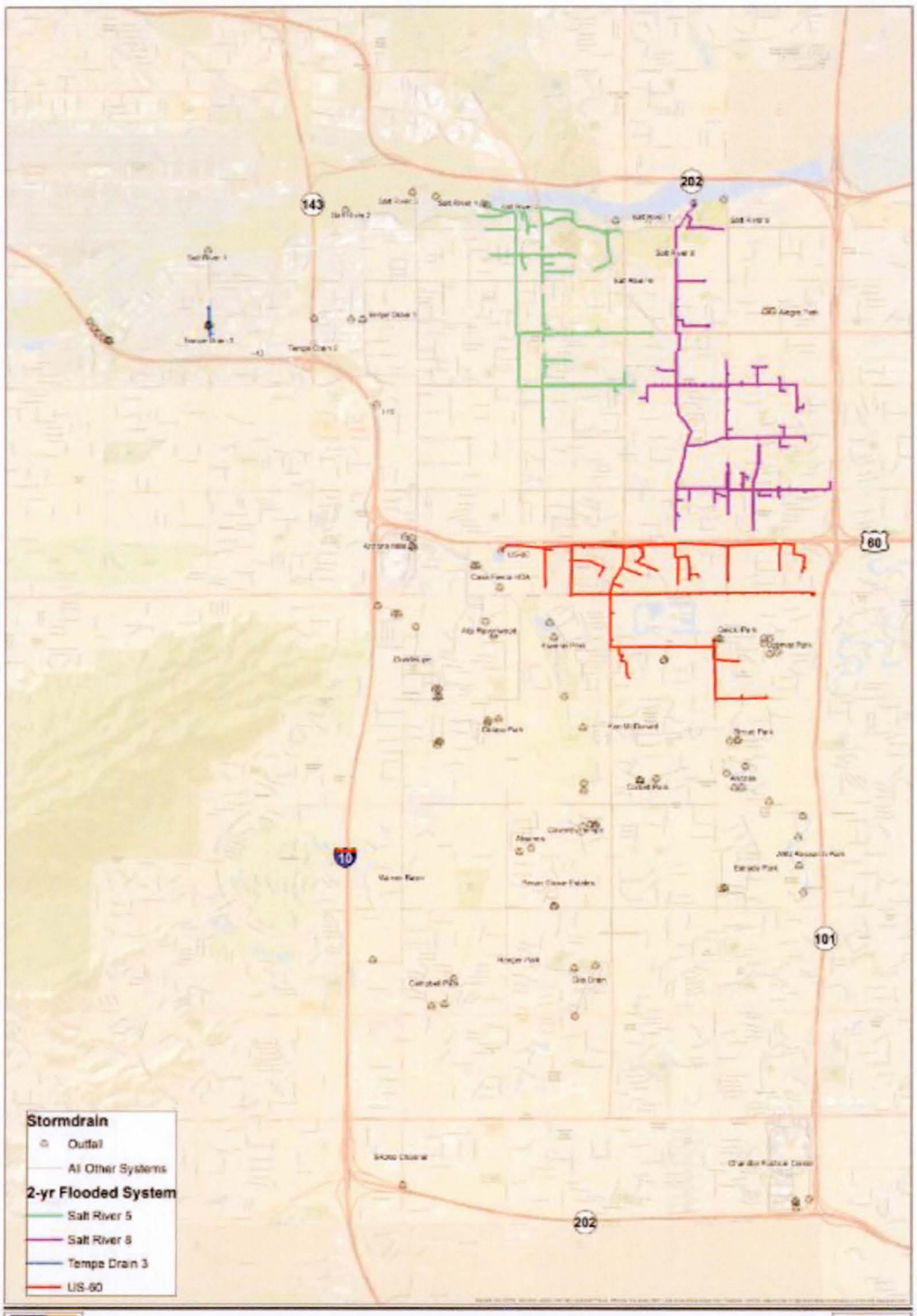


Figure 5.2 - Tempe ADMS/P FCD 2012C021
Stormdrain Systems Flooded in 2-Year 24-Hour Storm

Table 5.3 Stormdrain System Flood Protection Levels			
Stormdrain System	Pipe Length	No. of Junctions/ Inlets	Protection Level
	(ft)		(Year)
Alegre Park	2186	31	2
Alisanos Subdivision	8067	90	25
Alta Ravenwood Apartments	7205	42	2
Anozira Subdivision	5372	65	2
Arizona Mills	7766	66	2
ASU Research Park	5224	39	25
Campbell Park	8196	58	100
Casa Fiesta HOA	1565	18	25
Celaya Park	4806	38	25
Chandler Fashion Center	52167	351	2
Corbell Park	4223	33	2
Coventry Tempe Subdivision	2485	31	25
Estrada Park	10578	61	2
Gaicki Park	990	4	2
Gila Drain	36974	132	10
Guadalupe	15971	170	2
Hanger Park	22851	122	25
I-10	22796	90	100
Ken McDonald Golf Course	24013	161	2
Kiwanis Park	12128	70	2
Optimist Park	1743	17	2
Pecan Grove Estates Subdivision	3292	23	2
Salt River 1	8217	74	25
Salt River 2	4248	27	25
Salt River 3	4822	30	100
Salt River 4	4362	28	25
Salt River 5	72106	436	<2 Yr
Salt River 6	26010	140	2
Salt River 7	8626	133	100
Salt River 8	83877	433	<2 Yr
Salt River 9	19047	154	2
SR202 Channel	3783	20	100
Stroud Park	5300	33	2
Tempe Drain 1	150534	835	2
Tempe Drain 2	9682	74	25
Tempe Drain 3	2632	25	<2 Yr
US-60	80863	285	<2 Yr
Warner Basin	16467	118	10

Table 5.4 Stormdrain Systems with 2-Year or Lower Flood Protection Levels					
Stormdrain System	Protection Level (Year)	Nearest Street Intersection(s)	HOA/NAs No.	FHA sheet No.	Comments/checked
Salt River 5	<2 Yr	2yr: Mill Ave and 14th St, 10yr: Broadway Rd and UPRR	7	3	2yr: Sheet flow in 2yr event less than 1' deep, 10yr: Ponding up against UPRR at or above 2' deep
Salt River 8	<2 Yr	Broadway Rd and Terrace Rd, Los Feliz Dr and Pebble Beach Dr, Los Feliz Dr and Balboa Dr	3	3, 4	Sheet flow in 2yr event at or above 1' deep
Tempe Drain 3	<2 Yr	40th St and Raymond St	8	1	Sheet flow in 2yr event at or above 1' deep
US-60	<2 Yr	Hazelton Ln and Pegasus Dr, Southshore Dr and Lakeshore Dr	1	7	Sheet flow in 2yr event at or above 1' deep
Alegre Park	2	Don Carlos Ave & Smith Rd	-	4	Sheet flow in 10yr event at or above 1' deep
Alta Ravenwood Apartments	2	Mitchell Dr and Rice Dr, Mitchell Dr and Harvard Dr, Cornell Dr and Farmer Ave	-	-	Sheet flow in 10yr event at or above 1' deep
Anozira Subdivision	2	Anozira Pkwy and Los Feliz Dr, McNair Dr and Hazelton Ln	-	7	Sheet flow in 10yr event less than 1' deep
Arizona Mills	2	SW portion of parking lot	-	5	Sheet flow in 10yr event at or above 1' deep
Chandler Fashion Center	2	N portion of parking lot	-	-	Sheet flow in 10yr event less than 1' deep
Corbell Park	2	Dava Dr and Dorsey Ln, Dava Dr and Elm St	-	7	Sheet flow in 10yr event at or above 1' deep
Estrada Park	2	Kachina Dr and Calle de Caballos	-	-	Sheet flow in 10yr event at or above 1' deep
Gaicki Park	2	Cornell Dr and Heather Dr	-	7	Sheet flow in 10yr event at or above 1' deep
Guadalupe	2	Calle Vauo Nawi and Calle Magdalena	-	-	Sheet flow in 10yr event less than 1' deep
Ken McDonald Golf Course	2	Bell de Mar Dr and Rita Ln, Bell de Mar Dr and Newberry Rd, Vaughn St and Jen Tilly Ln	-	7	Sheet flow in 10yr event at or above 1' deep
Kiwanis Park	2	College Ave and Colgate Dr	-	7	Sheet flow in 10yr event at or above 1' deep
Optimist Park	2	Country Club Way and Sesame St, Country Club Way and Oxford Dr	-	7	Sheet flow in 10yr event at or above 1' deep
Pecan Grove Estates Subdivision	2	Buena Vista Dr and Mill Ave, Mill Ave and Calle Monta Vista	-	-	Sheet flow in 10yr event less than 1' deep
Salt River 6	2	Vista del Cerro Dr and Jen Tilly Ln	6	3	Ponding up against UPRR at or above 2' deep
Salt River 9	2	Rockford Dr and 5th St	-	4	Sheet flow in 10yr event at or above 1' deep
Stroud Park	2	Los Feliz Dr and Redfield Rd	-	7	Ponding of Stroud Park onto roadway at or above 2' deep
Tempe Drain 1	2	52nd St & 10th Pl, Priest Dr & 10th St, Dromedary Dr & Palmdale Dr, Dromedary Dr & Concorda Dr, Alameda Dr & UPRR, Southern Ave & Kyrene Rd	3, 7	2, 3, 5	Ponding up against UPRR at or above 2' deep, sheet flow in 10yr event at or above 1' deep

5.4 Tempe Drain Channel Flood Risk Evaluation

The Tempe Drain channel capacities for various locations were estimated by using the HEC-RAS model. The capacities and peak flows for the four (4) frequency storms at the three (3) critical locations were summarized in Table 5.5 which shows that the Tempe Drain channel has the 100-year storm capacity. The Tempe Drain channel capacity was also verified by the September 8, 2014 storm field observed results and documented in the *Tempe ADMS FLO-2D/SWMM Modeling Report.* Exhibit D4 shows hydrographs, plan views, and profile views of the Tempe Drain water surface elevations from the frequency modeling results. The flooding areas near the Tempe Drain corridor was caused by the ground surface elevations are lower than the channel banks (interior drainage) and small storm drain systems may help the local flooding. Appendix D4 included the supporting data.

Table 5.5 Tempe Drain Channel Flood Risk Evaluation

Cross Section No.	Grid No.	Location	Capacity Q	2-Year Q	10-Year Q	25-Year Q	100-Year Q
			(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
1	217478	Beginning at 52nd St	1800	569	752	768	832
2	72772	Downstream of 40th St	1900	648	1041	1277	1509
3	648	Outlet to Salt River	2100	668	1102	1365	1657

6.0 REFERENCES

1. ESRI, *ArcGIS,* Version 10, 2010.
2. FLO-2D Software Inc., *FLO-2D*, Pro Version, Model-Build No. 13.11.06, 2014.
3. Manifold Software Limited, *Manifold System*, Version 8.0, 2010.
4. U.S. Environmental Protection Agency, *EPA SWMM*, Version 5.0 (Build 5.0.022), April 2011.
5. inpPINS Computer Program, https://sites.google.com/site/inppins/guide
6. Bentley Systems, Inc., *CulvertMaster*, Version 3.2, August 2008
7. Flood Control District of Maricopa County, FLO-2D Review Guidelines, revised version, July 2012.
8. Riada Engineering, FLO-2D Reference Manual.
9. Riada Engineering, FLO-2D Data Input Manual.
10. Riada Engineering, FLO-2D GDS Manual.
11. Riada Engineering, FLO-2D Mapper Manual.
12. Riada Engineering, FLO-2D Limiting Froude Number Application Guidelines.
13. Riada Engineering, FLO-2D Pocket Guide.
14. Riada Engineering, User Assigned Courant Number in TOLER.DAT for Enhanced Model Numerical Stability.
15. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, User's Manual, Version 4.1, June 1998.
16. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Version 4.1, June 1998.
17. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1 January 2010.
18. *Broadway & Rural DMP: FLO-2D Pilot Study*, Cardno WRG, October 1, 2010.
19. *Broadway Road/Rural Road Candidate Assessment Report (CAR)*, Project Engineering Consultants, Ltd. September 2002.
20. *Drainage Policies and Standards for Maricopa County*, Flood Control District of Maricopa County, April 24, 2007.

21. *Drainage Design Manual for Maricopa County, Hydrology*, Flood Control District of Maricopa County, November 18, 2009.

22. *Drainage Design Manual for Maricopa County, Hydraulics*, Flood Control District of Maricopa County, August 15, 2013.

23. *Phoenix-Tempe Area Mapping, Project ID 1291, Contract No. FCD 08-20*, Flood Control District of Maricopa County, August 4, 2009.

24. *SCS_Soil GIS Shape Files,* Flood Control District of Maricopa County, March 10, 2010.

25. *FLO-2D Data Input Manual, Version 2009.06,* FLO-2D Software, Inc., November 30, 2010.

26. *FLO-2D Review Checklist (DRAFT),* Flood Control District of Maricopa County, May 5, 2011.

27. *Broadway-Rural Pilot Study, FLO-2D Hydrograph Analysis,* Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

28. *TOL and Hydraulic Structure Rating Curves Interoffice Memorandum*, Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

29. *Tempe ADMS/P Data Collection Report*, J2, August 2014.

30. *Tempe ADMS/P Test Area Sensitivity Analysis Summary Report*, J2, March 2014.

31. *Tempe ADMS/P Test Area FLO-2D Analysis Summary Report*, J2, June 2015.

32. *Tempe ADMS/P FLO-2D/SWMM Modeling Report*, J2, November 2015.

TEMPE AREA DRAINAGE MASTER STUDY
CONTRACT FCD 2012C021

VOLUME IV
LID APPLICATION REVIEW AND FLO-2D MODELING

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January 2016
Revised April 2016

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1.0 INTRODUCTION

1.1 Purposes and Goals

The purpose of this report for the Work Assignment No. 3 (WA3) of the Tempe Area Drainage Master Study and Plan (ADMS/P) is to conduct a comprehensive literature review of the green infrastructures (GI) and low impact development (LID) techniques, their applications, and hydrologic and hydraulic modeling methods to initiate and encourage the implementation of various LID controls and development of simulation tools in order to understand and quantify the individual and cumulative impact of LID controls on drainage and flooding in the arid Southwest. This report is also developed as a guidance document for creating local and regional hydrologic and hydraulic models with the capability to analyze conceptual scenarios of LID used for drainage and flood mitigation and water conservation.

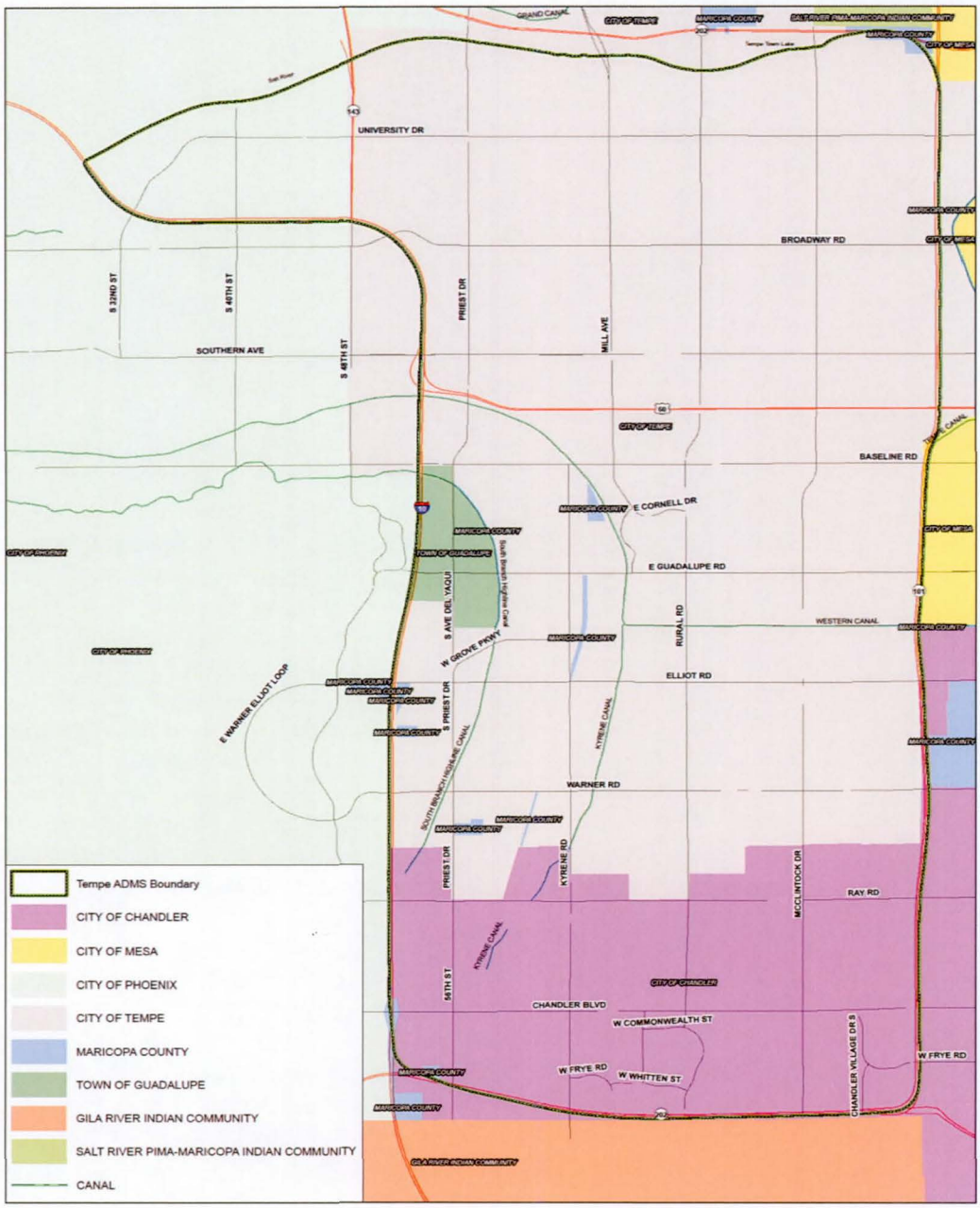
1.2 Background and Context

In the past few years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake, major redevelopment of portions of the city is taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various GI and LID techniques as part of the new General Plan 2040. The Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe ADMS to identify flood hazards and develop any needed flooding mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

The hydrologic and hydraulic modeling of the Tempe ADMS area by FLO-2D/SWMM models was documented in the *Tempe ADMS FLO-2D/SWMM Modeling Report* prepared by J2.

The Tempe ADMS study area is bounded by the Salt River on the north, Loop 101 on the east, SR 202 on the south, and I-10 on the west. The study area is approximately 47 square miles located primarily within the City of Tempe with portions in the adjacent Cities of Phoenix and Chandler as well as the Town of Guadalupe. Figure 1.1 shows the project area boundaries and location.

FLO-2D, integrated with EPA Storm Water Management Model (SWMM Version 5.0) model and developed by Riada, Inc., was selected to be applied for this project for the hydrologic and hydraulic modeling. The entire Tempe ADMS/P study area is divided into three (3) FLO-2D modeling areas: Model A, Model B, and Model C as shown in Figure 1.2. The Test Area model is within the Model A area. The FLO-2D modeling boundary delineations take into account of the factors such as off-site inflow hydrographs and FLO-2D grid hydrographs conversion from Model B to Model A and Model C. A grid size of 20 feet by 20 feet was applied for this project. The major features for the sub-models are summarized in Table 1.1.



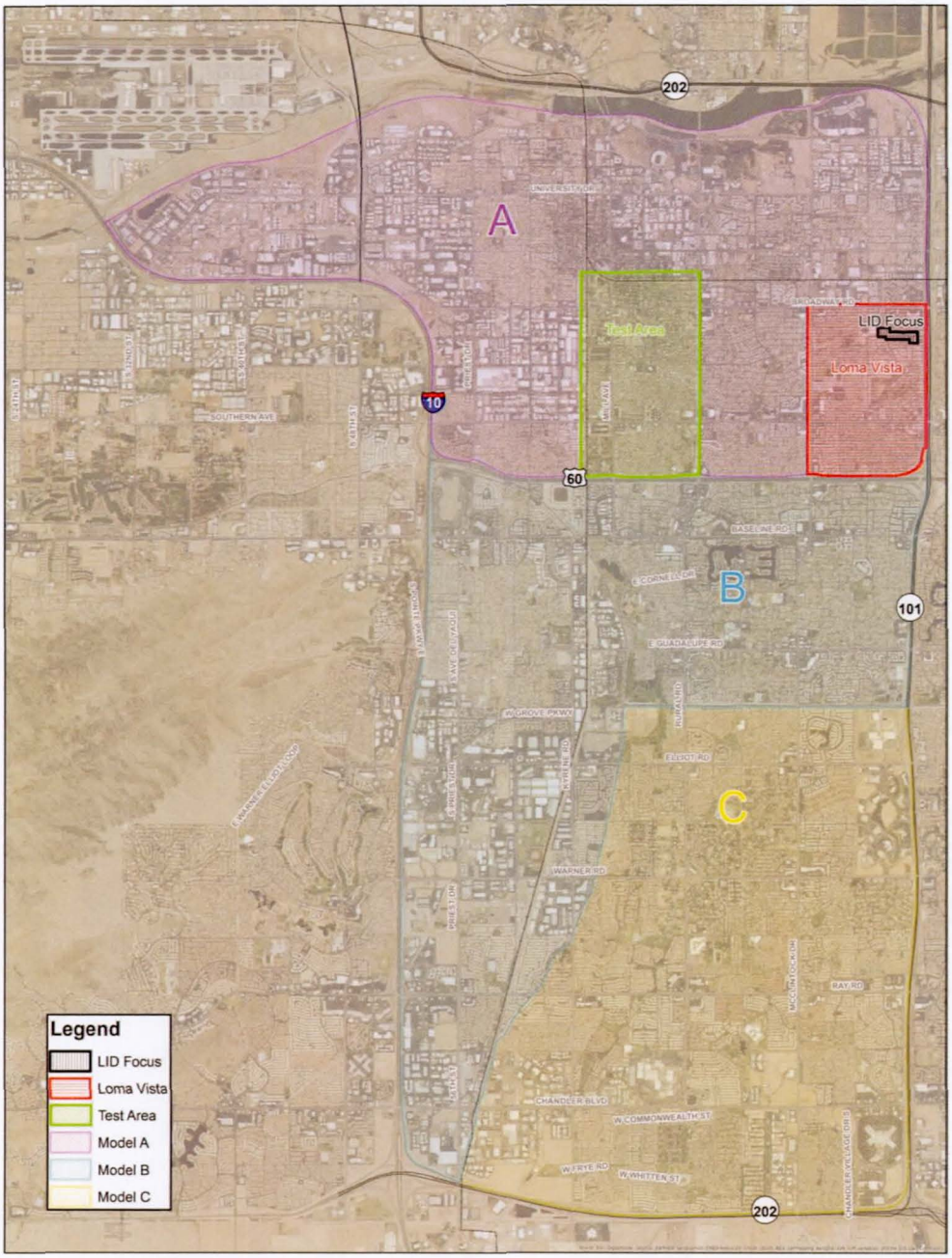
Tempe ADMS/P FCD 2012C021 - Work Assignment #2
Figure 1.1 Project Area Boundaries and Location Map

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

Table 1.1 FLO-2D Sub-Model Features				
Model	Model A	Model B	Model C	Total
Drainage Area (mile^2)	18	15	14	47
Total Number of Grids	1,238,647	1,027,788	1,010,360	3,276,795
Impervious Area (RTIMP, %)	59	56	48	55
Storm Drain Pipe Length (mile)	75	47	24	146
Number of Inlets	1,504	900	479	2,883
Number of Structures	17	2	22	41

The development of the input data files for all three models, model verification, and evaluation of modeling results were documented in detail in the *Tempe ADMS FLO-2D/SWMM Modeling Report*. Various maps for the development of input data files were created and modeling results were documented by the District post-processing tools as well as hydrographs and tables.

The FLO-2D program has a variety of parameters and processes that can be applied to model and quantify the impact of LID practices on the storm water volume and peak flows.



Tempe ADMS/P FCD 2012C021
Figure 1.2: FLO-2D Study Boundaries for Models A, B, C, and Test Area

0 2,000 4,000 6,000 12,000 18,000 24,000 Feet

1.3 Project Team

J2 Engineering and Environmental Design (J2) has been retained to perform these services as a part of the District On-Call Contract FCD 2012C021. J2 team for the WA3 includes Watershed Management Group (WMG) as a sub-consultant. The District is located at 2801 West Durango Street, Phoenix, AZ 85009, (602) 506-1501. The Project Manager for the District is Mr. Burke Lokey, P.E., PMP, CFM. J2's Project Manager for this project is Mr. Jeff Holzmeister, P.E.

J2 team is very appreciative to have the opportunity to represent the District in the performance of these services. This professional assignment presented many interesting and unique challenges requiring creative teamwork solutions. Mr. Burke Lokey, Mr. Richard Waskowsky, Mr. Doug Williams, Mr. Thomas Loomis, and Mr. Pedro Melo-Rodriguez of the District; and Mr. Gregg Kent of the City of Tempe provided critical technical support and decision-making guidance throughout the duration of the study. Their individual and group contributions played a key role in the successful completion of this assignment.

2.0 LOW IMPACT DEVELOPMENT (LID) CONCEPT AND PRACTICES

2.1 Overview of LID General Practices

LID is a sustainable approach to stormwater management that utilizes the landscape to absorb storm runoff and reduce offsite flows that can contribute to flooding and infrastructure costs. The basic principle is to model after nature: manage runoff at the source using distributed micro-scale controls. The goal of LID is to mimic and sustain predevelopment hydrologic conditions by using techniques that store, detain, retain, infiltrate, evaporate, and re-use stormwater runoff to support native and designed landscapes, groundwater recharge, and water quality improvement. They can be utilized to supplement, and sometimes reduce the need for, traditional methods for stormwater management. While conventional methods often channelize and pipe runoff away from development, LID methods utilize this water close to its source, to support vegetation and reduce runoff volume.

LID is adaptable to a wide range of land use types and project scales. Breaking down developed areas into their constituent components – residential areas, commercial properties, and public realm; buildings, paved areas and landscape – presents a way to organize potential controls to implement LID.

Increased stormwater runoff is directly related to the amount of impervious surfaces in a given area and to how land is developed and improved. Improvements in managing stormwater can have multiple benefits for cities, their residents, and businesses. LID actions can be taken by governments, organizations, and private interests. The benefits of LID have been published for many national and local examples, and are supported by the Environmental Protection Agency (EPA) in its Municipal Separate Storm Sewer System (MS4) requirements.

The benefits of LID applications can be summarized as follows:

- Flood control: Detain stormwater close to its sources and reduce runoff volume and peak flows to downstream;
- Maintenance: Collects sediments to reduce drainage facility maintenance costs;
- Environmental: Reduce pollutants in stormwater runoff and improve water quality;
- Water supply: Utilize stormwater to support native vegetation and landscape improvements and reduce irrigation water supply;
- Landscape: Combine with traditional landscape to reduce costs;
- Traffic calming: Modify streets to combine with traffic calming measures.

A literature research and review of potential LID applications has been conducted in order to identify various LID controls for applicability in Tempe and Maricopa County. While LID has been used in limited cases in Tempe, the practice in metropolitan Phoenix and Arizona is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. Other urbanized areas in the United States have been more vigorously implementing LID predominantly due to water quality issues first and volume secondarily. The collected major references are generally classified into five categories: a) Publications for LID general practices; b) Publications of LID applications in Southwest Regions; c) Tempe LID practices; d) LID application Case Studies; and e) Modeling methods of LID practices including hydrologic and hydraulic modeling, and benefit/cost estimations. The major references are included in Appendix A and are discussed in the following sub-sections.

The major publications for the first category are included in Appendix A1and are summarized as follows:

EPA, in December 2007, published a report titled *Reducing Stormwater Costs through Low Impact Development (LID) - Strategies and Practices*. While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it also shows that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life.

In December 2008, EPA released a handbook titled *Managing Wet Weather with Green Infrastructure Municipal Handbook – Green Streets*. The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network provides significant opportunity to decrease infrastructure demands and pollutant transport.

Baker, in June 2011, drafted a Municipal Handbook for EPA as well – *Low Impact Development and Green Infrastructure: Role in Flood Risk Management*. This handbook is trying to demonstrate the functions and benefits of LID applications on flood mitigation.

In January 2015, EPA published *Green Infrastructure Opportunities that Arise during Municipal Operations* which provides approaches local government officials and municipal program managers in small to midsize communities can use to incorporate green infrastructure components into work they are doing in public spaces. This guide demonstrates ways in which projects can be modified relatively easily and at a low cost recognizing that municipal resources can be limited.

In April 2015, EPA published *A Guide for Local Governments – Community Based Public-Private Partnerships (CBP3s) and Alternative Market-Based Tools for Integrated Green Stormwater Infrastructure*. This guide provides communities with an opportunity to review the capacity and potential to develop a P3 program to help "close the gap" between current resources and the funding that will be required to meet stormwater regulatory commitments and community stormwater management needs.

Earlier, in October 2000, EPA published a literature review on LID to determine the availability and reliability of data to assess the effectiveness of LID practices for controlling stormwater runoff volume and reducing pollutant loadings to receiving waters. Background information concerning the uses, ownership and associated costs for LID measures was also compiled. The conclusions are still valid.

In general LID measures are more cost effective and lower in maintenance than conventional, structural stormwater controls. Not all sites are suitable for LID though. Considerations such as soil permeability, depth of water table and slope must be considered, in addition to other factors. Further, the use of LID may not completely replace the need for conventional stormwater controls.

Maintenance issues can be more complicated than for conventional stormwater controls because many LID measures rely on multiple facets including but not limited to permeability, biometrics, sub-grade media, and available area. This can be further complicated if these measures reside on private property. In most instances, homeowners agree to only the first year of maintenance. Homeowner associations could be a mechanism for providing long-term maintenance to these areas. Generally, bio retention facilities require replacement of dead or diseased vegetation, remulching as needed, and replacement of soils after 5–10 years. Bio swales require periodic mowing and removal of sediments. Maintenance of permeable/pervious pavements requires annual high-powered vacuuming of the area to remove sediments.

Several studies have been conducted to analyze the effectiveness of various LID controls based on hydrology and pollutant removal capabilities. **Bio retention areas, bio swales, pervious pavements and green roof were the most common practices studied**. These techniques reduce the amount of Effective Impervious Area (EIA) in a watershed. EIA is the directly connected impervious area to the storm drain system and contributes to increased watershed volumes and runoff rates. There are documented case studies that conclusively link urbanization and increased watershed imperviousness to hydrologic impacts on streams. Existing reports and case studies provide strong evidence that urbanization negatively affects streams and results in water quality problems such as loss of habitat, increased temperatures, sedimentation and loss of fish populations (EPA, 1997).

In general bio retention areas were found to be effective in reducing runoff volume and in treating the first flush (first ½ inch) of stormwater. Results from three different studies indicate that removal efficiencies were quite good for both metals and nutrients. Removal rates for metals were more consistent than for nutrients. Removal rates for metals ranged from 70–97% for lead, 43–97% for copper and 64–98% for zinc. Nutrient removal was more variable and ranged from 0–87% for phosphorus, 37–80% for total nitrogen, 0–92% for ammonium, and 0–26% for nitrate. Effluent volumes were lower than influent volumes. These studies were conducted by means of simulated rainfall events. Analysis of actual long-term rainfall events would produce more reliable data.

The effectiveness of bio swales was also quite good for both pollutant removal and runoff volume reduction. A study of three different sites in the United States reveals similar results despite the differences in location. In general, performance of swales is dependent on not only channel length, but also longitudinal slope and the use of check dams to slow flows and allow for greater infiltration. Further, the removal of metals was found to be directly related to the removal rate of total suspended solids, and the removal rate of metals was greater than removal of nutrients.

Reduction of impervious surfaces can greatly reduce the volume of runoff generated by rainfall. Several methods can be employed to reduce total impervious surface area. Pervious pavements and vegetated rooftops are two methods to accomplish this goal. Vegetated rooftops have been used extensively in Germany for more than 25 years and results show up to 50% reduction in annual runoff in temperate climates. Many opportunities exist to retrofit these systems into older highly urbanized areas of the United States. The Philadelphia project case study provides an example of this practice.

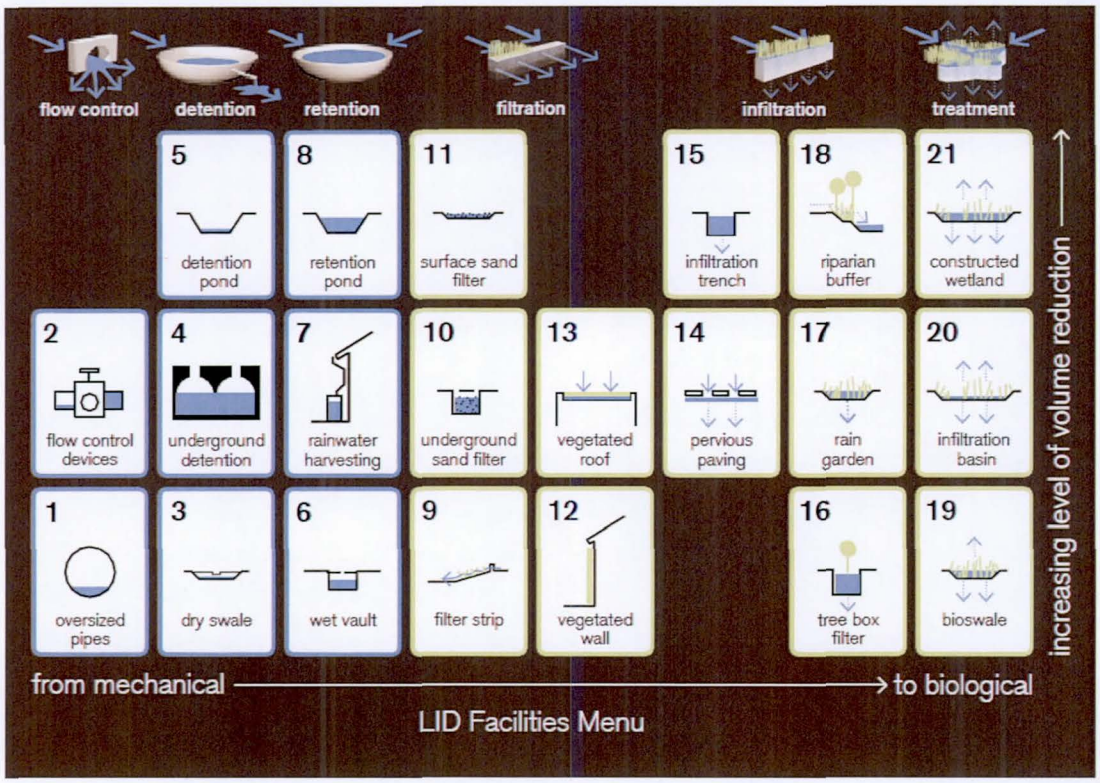
Pervious pavements can also reduce impervious surfaces. However, they are more expensive to construct than traditional asphalt pavements. Costs of these systems may be offset by the reduction of traditional curb and gutter systems to convey stormwater. Benefits of these alternate pavement types include better infiltration, ground water recharge, reduction in runoff volume and treatment of stormwater for pollutants. The study conducted in Tampa, Florida outlines these benefits as well as the opportunity to retrofit pervious pavements into existing parking lots with little or no loss of parking spaces. Less than 20% of rainfall was converted to runoff when using pervious pavements. Study results from the University of Washington, compare several different treatments of varying permeability. The study shows that the higher the amount of pervious area of the treatment, the greater the reduction of runoff volume and pollutant loadings.

Most of the available data are from Prince George's County, Maryland, which pioneered the use of LID. The data available for bio retention analysis were from single simulated storm events in actual bio retention facilities or from laboratory constructed and tested bio retention systems. The data for bio swales were for only a few storm events, collected over a short period of time. The only available data for a long-term study came from the Aquarium parking lot in Tampa, Florida and the Washington pervious pavement project. More long-term analysis is required to more accurately assess the effectiveness of LID and to determine long term trends.

In addition to EPA publications, many manuals and studies related to LID have been published, such as *LID Manual for Michigan* released in 2008; University of Arkansas published a LID manual in 2010 titled *Low Impact Development: a design manual for urban areas*; the BMP Database was also developed by Geosyntec Consultants, Inc. in May 2012 to document the analysis of volume reduction in bio retention BMPs. Oregon State has published specific LID site design practices. Green Nylen, Nell, and Michael Kiparsky, 2015 published a paper titled *Accelerating Cost-Effective Green Stormwater Infrastructure: Learning from Local Implementation*, Center for Law, Energy & the Environment, U.C. Berkeley School of Law.

The following LID controls Menu was developed by University of Arkansas and summarizes the general ideas and relationships of traditional flood control structures and LID facilities. This Menu organizes controls based on increasing level of treatment service (storm water quality) as well as increasing level of volume reduction (storm water quantity). Therefore, number one (1), oversized pipes offer the least amount of treatment services while number twenty-one (21), constructed wetland offers the most. Most municipalities require drainage infrastructure to manage the 100-year storm events. Though one facility alone will not likely satisfy performance requirements, facilities with varying levels of service in a LID system will provide superior levels of storm water treatment and flood volume reduction.

The District has compiled a list of LID studies and publications in a spreadsheet format. A list of website links to LID studies and publications was also prepared for easy usage. All of the references are listed in Appendix A1.



2.2 Survey of Regional and Local LID Practices

2.2.1Regional LID Practices

As discussed previously, other urbanized areas in the United States, especially in the southwest areas, have been more vigorously implementing LID practices predominantly due to water quality issues first and volume secondarily.

Several counties, cities, and state government agencies in California State have developed manuals and handbooks to guide and encourage the applications of LID techniques including Los Angeles County and City, San Diego County and City, San Mateo County, Riverside County, City of Riverbank, etc. These manuals and handbooks are included in Appendix A2.

Another state in the southwest region, Nevada, also has applied LID practices. For example, a LID Handbook for the Truckee Meadows Regional Stormwater Quality Management Program was developed in August 2007, and a Final Report for Xeriscape Conversion Study was prepared by Southern Nevada Water Authority in 2005. These publications are included in Appendix A2.

In metropolitan Phoenix and Arizona, Application of LID techniques is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. City of Tucson published Water Harvesting Guidance Manual and Stormwater Quality Ordinance in 2005 as well as Watercourse Maintenance Guidelines in 2007. Specifically, Pima County and City of Tucson developed LID and GI Guidance Manual in 2015.

Watershed Management Group (WMG) develops community-based solutions to ensure the long-term prosperity of people and health of the environment and provides people with the knowledge, skills, and resources for sustainable livelihoods. They have developed many LID newsletters, training sessions, and design standards. These documents are included in Appendix A2. WMG is a sub-consultant to this study and provided the descriptions of the general concepts of basic LID controls in Section 3.2.

City of Scottsdale has developed a LID Techniques Tool Box and applied some of the techniques in Granite Reef Watershed study as implementation demonstrations.

City of Mesa has developed and handbook titled LID Toolkit in 2015. Some of the photos, descriptions, and data have been used in this report. However, the water budget calculation methods documented in this handbook cannot be used for spatially varied hydrologic and hydraulic modeling for the LID applications. All of the references mentioned in the regional LID section are included in Appendix A2.

2.2.2 Tempe LID Practices

LID Applicability in City of Tempe

Since the start of the Tempe ADMS project, J2 team has developed a white paper and several memos related to LID applications and modeling in Tempe under the directions of the District project manager. The white paper was prepared by Black & Veatch in March 2014 and the paper title is *Evaluation of Sustainable Stormwater Management Practices*. The first memo was developed in August 2014 to document the potential LID applications, City of Tempe requirements, and the proposed FLO-2D modeling procedures for selected LID practices. Nine (9) possible LID practices were identified in this memo.

The second memo was prepared in July 2015 to update the first memo including more detailed land use applications and refined FLO-2D modeling approaches. The proposed potential LID practices were further evaluated and the memo outlines the reasons and supporting documentation for the reduction from nine (9) to six (6) basic LID controls.

The third memo was prepared in September 2015 to document the five (5) selected LID controls, identified LID accessories (add-ons), and the proposed FLO-2D modeling procedures for selected LID controls and participation ratios. The Test Area FLO-2D model was utilized for the modeling of LID practices and combinations.

The fourth memo was developed in October 2015 to document the five (5) selected LID controls, identified accessories, and the proposed FLO-2D modeling procedures for selected LID controls and participation ratios. A new FLO-2D model with 4 ft x 4ft grids was developed for a Focus Area in order to simulate the infiltration processes and LID accessories. The study boundaries for FLO-2D models Loma Vista and Focus Area are shown in Figure 2.1. FLO-2D modeling techniques for each of the five selected LID controls were developed and tested. FLO-2D modeling procedures for regional LID application scenarios were also proposed.

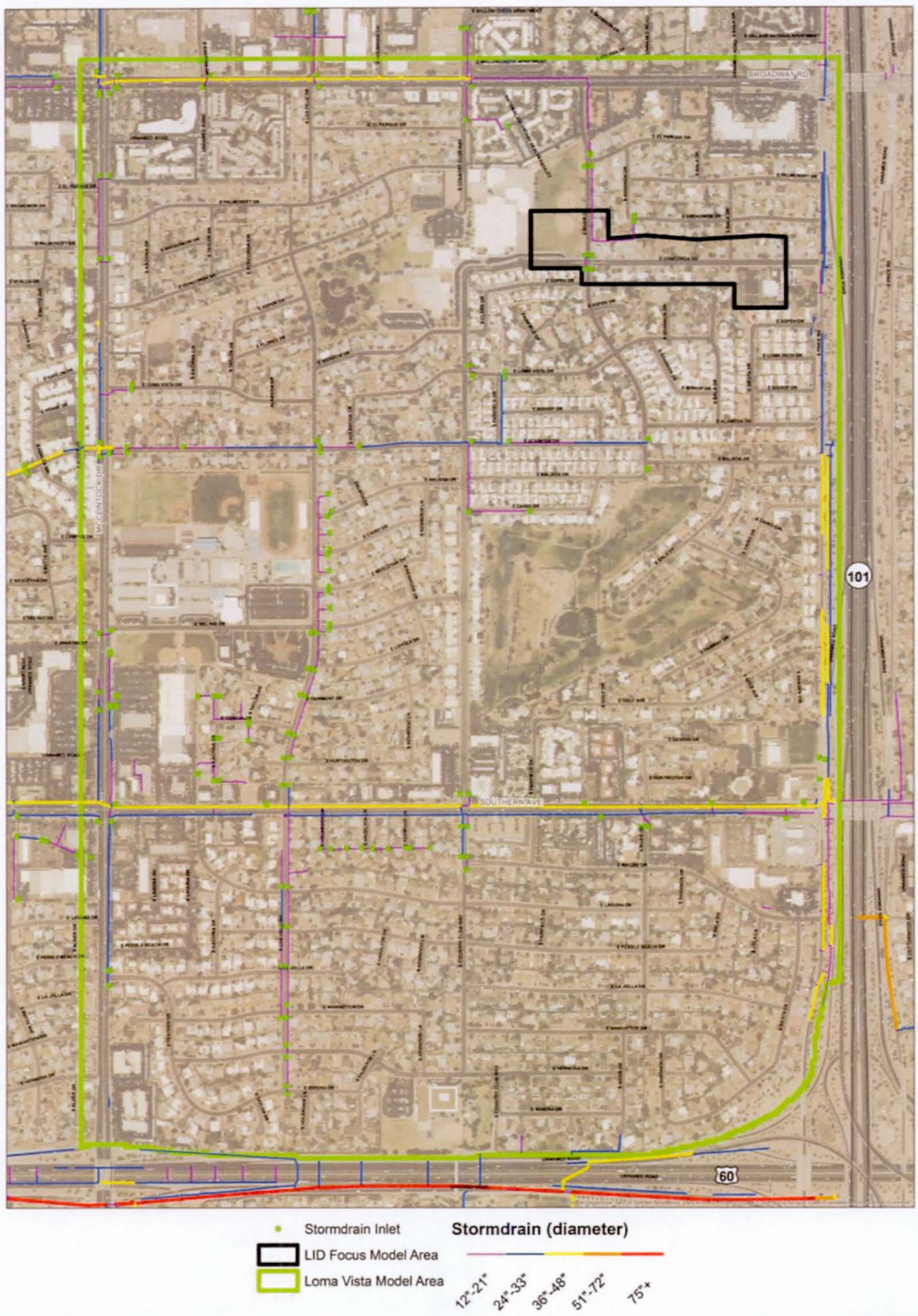


Figure 2.1 Study Boundaries for Models Loma Vista and Focus Area

The four memos and the white paper are included in Appendix A2. Table 2.1 summarizes the five selected basic LID controls (tools) for potential applications in Tempe for various land uses. Where "High" means highly applicable and "N/A" means not applicable for this LID control to the land use type.

Table 2.1 LID Applicability in City of Tempe

LID Basic Controls\ Land Uses	Single Family Residential	Multi-Family Residential	Commercial	Industrial	School	Community Center/Park	Street
Bio Retention	High	High	High	High	High	High	Medium
Bio Swale	Medium	High	High	High	High	High	High
Pervious Pavement	Medium	High	High	High	High	High	High
Rainwater Harvesting	High	High	High	High	High	High	Medium
Green Roof	Low	Low	Medium	Medium	Low	Medium	N/A

LID Evaluation by City of Tempe

The City of Tempe developed a document titled *Low Impact Development Evaluation* in June 2013. This document started LID evaluation with a review of existing stormwater practices related to planning, construction, and redevelopment including review of Tempe Municipal Ordinance and practice examples. Then, LID practices, their applicability, and regulatory hurdles were discussed. Three mechanisms were identified to promote and encourage LID applications including leading/organizational ownership, stormwater quality/quality alignment, and public outreach.

The City of Tempe has identified various types of LID practices that should be further encouraged and a series of LID practices that cannot be embraced by the City:

A. *LID Practices Tempe Will Encourage/Support*
- Alternative retention systems
- Depressed landscaping
- Use of drought tolerant plants (in tandem with street or harvesting projects)
- Stormwater pretreatment systems
- Pervious parking
- Pervious concrete
- Pervious surface treatments
- Xeriscape conversion
- Water harvesting (consistent with retention and vector control)
- Various uses for permeable/pervious pavers
- Impervious area reduction
- Incentive program
  - Public recognition (under evaluation)
  - "C" value reduction, a coefficient for relating the runoff to rainfall in the Rational Method for estimating stormwater runoff
  - Reduction in number of drywells as a result of "C" value modifications

- LID recommendations for redevelopment projects that don't meet the on-site retention triggers (i.e. 25% area of impact and/or value trigger)
- Continued use of LID practices in CIP projects
- LID streetscape projects

B. *LID Practices Tempe Will Not Endorse*

- Practices contrary to conservation efforts
- Practices that could negatively impact operation of the City-owned and operated stormwater system
- Practices that impact on-site retention requirements
- Practices that could impact neighboring property
- Practices that require future increased maintenance and/or monitoring by the City (non-CIP)

As a result of this evaluation, Tempe has made a commitment to continue to promote LID by example by incorporating acceptable practices in CIP projects and subscribing to the LID objectives outlined in the Tempe General Plan 2040. Additionally, Tempe hopes to incorporate LID concepts to address future flooding mitigation efforts.

Potential LID Implementation Strategies

As mentioned previously, Black & Veatch, a sub-consultant to J2 for the Tempe ADMS/P project, prepared a white paper titled *Evaluation of Sustainable Stormwater Management Practices* in order to evaluate the City's existing SWMP and associated ordinances with respect to their MS4 permit requirements. The evaluation included a review of the various programs within the City's existing SWMP, including its Stormwater Retention Ordinance.

Tempe has, for the most part, been completely "built-out" with no new open development parcels remaining in the City. With this in mind the ***Potential LID Implementation Strategies*** will need to be focused on infill redevelopment and the retrofit of existing lands, buildings, developments and roadways. To this end potential implementation strategies for Tempe will look at projects and policies that can be implemented through codes for redevelopments, defined Capital Improvement Projects (CIP) for buildings, sites and roadways owned and operated by the City, partnerships with schools and private businesses and incentive programs for private homes and businesses.

The four general strategies by which projects may be implemented are:

1. Code requirement for new development, renovations and infill projects;
2. Capital Improvement Projects (CIP);
3. Public/Private Partnerships;
4. Incentive Programs.

Code requirement for new development, renovations and infill projects

When new development, renovation or infill development occurs, the opportunity to implement LID practices is available if City codes are in place to require the development to enact strategies to reduce and slow stormwater runoff from the project site. While there are different ways to "codify" the stormwater reduction requirements, one which exists is the stormwater retention requirements (retain on site a 100 year 2 hour storm). This code has been very helpful in reducing flooding in the newer development areas of the City; however the

"pre retention" code areas would be the best opportunity to implement LID as a part of the retention requirement.

Quantification of LID volumes and acceptance by agencies has been a hurdle to overcome in the past. By actively defining the process and quantifications that make it equal to or less burdensome to navigate a project through the development permitting process would enhance the implementation of LID measures. A tool that may help with implementation of LID would be a LID stormwater manual for the City of Tempe. The manual could show example scenarios that may be used on new, renovation and infill projects. The manual would also need the "hard data" quantification formulas for each scenario. In addition to the hard data, there would be examples of how some LID stormwater methods may also overlap with City planning codes for landscape, open space parking and aesthetics. Preliminary evaluation results show that the basic LID controls have code implementation opportunity during new development, renovation, and infill development.

Capital Improvement Projects (CIP)
Throughout the City, CIP projects are continuous occurring providing maintenance rehabilitation and new works. There exists an opportunity to incorporate LID into several of these existing projects, such as streets, parks and buildings, along with future projects. In addition defining and creating new LID CIP specific or overlap projects can be incorporated into the CIP process.

Public/Private Partnerships
Examples of public/private partnerships may include private businesses, schools, churches, the university, utility companies and the railroad. These all have lands that are either disused "forgotten lands" that are serving no particular purpose and are ongoing maintenance for the owner. In addition many of these property owners have open lands that are "non time critical lands" such as open landscape areas, park/school/church open space, and practice fields. All of these lands are prime opportunities to create basins, "rain gardens" and "bio swales."

Incentive Programs
Incentive programs for local runoff reduction may be a good opportunity to not only reduce runoff but engage the public to actively participate in a LID program. The benefits could be increased public support, reduced runoff, reduced potable water consumption for landscapes, increased bio mass, shade, heat island reduction, reduction of materials going to landfills, aesthetic enhancements, and neighborhood stabilization/enhancement.

2.2.3 LID Case Studies

Many LID application projects have been implemented in recent years. A few case studies are reviewed here. Spokane Urban Greenway Ecosystems for Lincoln Street, Washington State, LID practices including bio-infiltration system were constructed to assist traditional inflow reduction technology, such as detention, vortex separators, and treatment plant upgrades.

Three LID case studies by Massachusetts Department of Conservation and Recreation in the Ipswich River Watershed included LID controls of porous pavements, bio retention, and bio swales.

1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas was conducted by Geosyntec Consultant for a drainage area of 368 acres. SWMM program was applied to model the hydrologic and hydraulic impact of LID controls on flood.

Pima County Flood Control District and WMG performed the study for the Airport Wash by solving flooding challenges with green stormwater infrastructure. FLO-2D program was used for the modeling of LID hydrology and hydraulics by adjusting TOL parameters spatially.

The District has collected a list of LID application projects in the local areas and documented in a spreadsheet. These case study reports and the District spreadsheet are included in Appendix A2 for detailed information.

2.3 Review of LID Simulation Methods

Hydrologic and Hydraulic Modeling

Modeling methods of LID applications include hydrologic and hydraulic modeling, and benefit estimations. Quantification of LID practices on flood reductions has been a hurdle to overcome in the past. Therefore, one of the objectives for the Tempe ADMS/P project WA3 is to identify how the ADMS/P hydrologic and hydraulic modeling effort could be utilized to help Tempe in the evaluation of LID controls.

Early in July 1999, Prince George's County, Maryland developed some methods to simulate the hydrologic impact of LID practices using NRCS curve number program, such as reducing Runoff Curve Number, increasing Time of Concentration, adding Retention basin, and Detention basin. This program is a lumped program and cannot model spatially varied LID practices in detail.

Lately, Geosyntec Consultants (2015) applied PCSWMM for 1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas. EPA SWMM can explicitly model five different generic types of LID controls as well. However, it is difficult to apply this program to a parcel level detailed-modeling. The general methodologies for these two programs are summarized in Appendix A3.

In 2009, Guo published a research paper titled *Preservation of Watershed Regime for Low Impact Development* and presented a simplified method by which a LID design can be quantitatively evaluated for a full spectrum control of runoff population. USGS (2010) also published a report (Circular 1361) titled *Effects of Low-Impact-Development (LID) Practices on Streamflow, Runoff Quantity, and Runoff Quality in the Ipswich River Basin, Massachusetts: A Summary of Field and Modeling Studies* and documented the method of modeling the impact of LID practices on flood in watershed scale.

In City of San Diego *Low Impact Development Design Manual,* several methods were recommended for the hydrologic and hydraulic modeling of LID practices including HSPF (Hydrological Simulation Program in Fortran) model Functional Tables.

Central Vermont Regional Planning Commission developed a model which utilized impervious surface data, GIS build-out analysis data and average rainfall amounts to demonstrate the increases in stormwater run-off if development continued to occur without

LID strategies in place. An alternate model was created to illustrate the amount of stormwater runoff if development incorporated LID techniques.

EPA, in 2014, developed a National Stormwater Calculator tool which is a simple to use tool for computing small site hydrology for any location within the US. It estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of LID practices can be employed to help capture and retain rainfall on-site. Future climate change scenarios taken from internationally recognized climate change projections can also be considered. These reports and manuals are included in Appendix A3.

Benefit Estimation Programs

Understanding the economics is as important as understanding the planning and technical mechanics of LID stormwater-water infrastructure design solutions. The Pima County Regional Flood Control District & Pima Association of Governments with the Cooperation of the City of Tucson has developed a tool called AutoCASE™ that was applied for the evaluation of LID benefits in Pima County Environment. This cost-benefit report, tailored with data specific to the arid southwest, is a tool to evaluate the spending of public funds for LID solutions. The report and presentation slides are included in Appendix A3.

General Help Tools

In 2012, Envision™ was developed in joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure. Envision™ rating system is designed to be used not only as a project assessment tool but as a guideline for sustainable infrastructure design including LID practices and integrated education and resource library. This assessment recognizes the need to stretch the traditional design boundaries in which infrastructure projects are judged not only by how they are delivered, but also by how long they last, accounting for durability, flexibility and utility of the constructed works. This new sustainable infrastructure rating system is a cutting-edge development for the world's infrastructure design and built environment.

Desert Water Harvesting Institute also developed a tool which is called Water Harvesting Assessment Toolbox. The goal of the Water Harvesting Assessment Toolbox is to help communities in the Southwest US identify water resource challenges, understand the role water harvesting can play in meeting these challenges as well as providing multiple additional benefits, and implement locally-appropriate water harvesting efforts including LID practices. The Toolbox is intended for use by a wide range of water resource decision-makers and community members. Use of the Toolbox is conducted with the assistance of a local facilitator who oversees the assessment process and utilization of the five tools provided with the Toolbox. The manuals and programs/spreadsheets for these tools are included in Appendix A3.

2.4 Introduction to FLO-2D Modeling of LID Practices

Recently, FLO-2D has been modified to model LID practices. Riada has revised the program to have spatially varied TOL values to model LID controls and released a handout – *FLO-2D Low Impact Development (LID) Modeling* which is included in Appendix A4. Spatially

variable TOL values would be assigned on a grid element basis to represent the composite LID techniques on a given grid element. Depending on the size of the LID feature, multiple grid elements may represent an individual lot or a LID control. Different grid elements may represent different LID techniques. The potential volume of on-site retention storage can be assessed by multiplying the LID control surface area by the retained flow depth (TOL value). This would provide flood hazard mitigation on a lot by lot basis.

This approach has been utilized by Pima Flood Control in Airport Wash Area (Tucson, AZ). The report and emails related to this project are included in Appendix A4. The FLO-2D model developers of this project, Janice Hughes and Evan Canfield have provided insight on their modeling efforts in Pima County. In hindsight, they would have utilized different methodologies (IA adjustment, etc.) to model the impact of LID, but Pima County does not utilize the Green Ampt methodology in their hydrologic analysis. Therefore, they chose to utilize the TOL adjustment for their model. Since the surface detention parameter (TOL) is artificially ponded water and is the minimum value of the flow depth for flood routing (mathematic computations), maintaining the lower TOL value will theoretically produce more accurate results.

FLO-2D, integrated with EPA SWMM Version 5.0 model, routes surface runoff over unconfined flow surfaces/channels using the dynamic wave approximation to the momentum equation while maintaining volume conservation. Finite difference algorithms are utilized to solve the partial differential equations. EPA SWMM is integrated with FLO-2D to simulate storm drain systems. More detailed information about the capabilities and applications of FLO-2D can be found in the references. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the modeling of the LID practices.

2.4.1 Review of Available Model Parameters

The FLO-2D program has a variety of parameters and processes that can be applied to model and quantify the storm water volume and peak flow as documented in previous J2 memos. The following is a preliminary list of the capabilities and parameters of FLO-2D that may be utilized for LID modeling.

A – Grid elevation adjustment: Lowering the grid elevations (on-lot – within the LID area or off-site – near the LID area) can increase the retention/detention storage to mimic the volume reduction of a specific LID control;

B – Initial loss abstraction IA adjustment: Increasing the values of IA for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

C – TOL value adjustment: Increasing the values of TOL for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

D – Infiltration rate adjustment: Increasing the values of infiltration rate for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

E – Limiting soil depth adjustment: Increasing the values of limiting soil depth for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

F – Spatially variable rainfall data: Reducing the values of rainfall depth for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

G – Diversion by a structure: An artificial diversion by a structure can be used to model some LID controls that can transfer concentrated flows;

H – Boundary outflow grid: Additions of boundary outflow grids can be used to account for the losses of runoff volume from a specific LID control area;

I – Use of artificial WRF: Additions of WRF (Width Reduction Factor) around the grids within the LID area to block the flow movement can be used to store the rainfall depth/runoff volume of a specific LID control;

J – Use of artificial levee: Additions of levees around the grids near the LID area to control the flow directions and locations can be used to model the runoff into LID area of a specific LID control;

K – Use of artificial storm drain: Artificial storm drain can be added to LID area to divert runoff into specific locations to model runoff volume reduction of a specific LID control;

L – Others/project specific methods, such as use of IRAINBUILDING variable to turn on/off the runoff contribution from roofs to model green roof and rainwater harvesting LID controls.

2.4.2 Pairing of LID Controls and Model Parameters

The identified five basic LID controls include: 1) Bio Retention, 2) Bio Swale, 3) Pervious Pavement, 4) Rainwater Harvesting, and 5) Green Roof. The applicability of the FLO-2D modeling parameter/methods to the basic LID controls is summarized in Table 2.2. Note that this table shows the possible parameters that could be used for LID control modeling. The evaluation is preliminary and the conclusion could be different for a specific project and application.

Table 2.2 FLO-2D Modeling Parameters for LID Basic Controls

	Method No.	Parameter Name	LID Basic Control				
			Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
			1	2	3	4	5
Potential Modeling Parameters	A	Grid elevation adjustment	X	X	X	X	
	B	Initial loss IA adjustment	X	X	X	X	X
	C	TOL value adjustment	X	X	X	X	X
	D	Infiltration rate adjustment	X	X	X	X	
	E	Limiting soil depth	X	X	X	X	
	F	Spatially variable rainfall	X	X	X	X	X
	G	Diversion by structure	X	X	X	X	X
	H	Boundary outflow grid	X	X	X	X	X
	I	Use of artificial WRF	X	X	X		X
	J	Use of artificial levee	X	X	X		
	K	Use of artificial storm drain	X	X	X	X	X
	L	Others/IRAIN-BUILDING				X	X

2.4.3 Parameter Adjustment Process for Simulation of LID Scenarios

The goal of the LID control evaluation is to develop a process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual LID basic controls can be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple LID basic controls, accessories, and various land use participations. Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios will be discussed in Section 6. The main steps are summarized as follows:

Step 1: Determining LID design capacities for land uses (zoning);
Step 2: Estimating participation rate;
Step 3: Developing FLO-2D input data files based on the design capacities, individual LID basic control modeling results, and selected modeling parameters;
Step 4: Running the regional FLO-2D models and documenting the modeling results.

2.4.4 Model and Simulation Testing Protocols

The key to implementing LID controls into the FLO-2D model is the ability to quantify the impact of LID controls on an individual lot (parcel) basis. Typically, LID controls are independently implemented in relatively small areas – City R/W (parks, green streets, etc.), government R/W (schools, etc.), and private parcels (commercial, industrial, residential). The City of Tempe has provided the design team with GIS files defining the individual parcels within the City of Tempe (Model A area).

Several small area FLO-2D models were developed to evaluate the impact of LID controls on the rainfall/runoff response of a drainage area. The models being utilized are the Test Area model, Loma Vista Area model, and a Focus Area model with small grid (4 ft x 4 ft

grid element size) and two blocks of neighborhood. Iterations may be run on these models much more quickly than on the regional models. Specifically, J2 is modeling individual LID control parameters within the small grid model in order to quantify the impact of the LID control on flood mitigation within a specific parcel area, and populating the methodologies to the Loma Vista Area model for regional LID practices.

A key operational function of the FLO-2D model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. Ultimately, the LID controls will impact the rainfall/runoff response of the watershed by reducing the volume of runoff from an individual parcel. The reductions in volume and peak flows were quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections.

3.0 COMMON LID CONTROLS IN THE SOUTHWEST

3.1 LID Controls, Accessories, and Systems

Many LID controls (also known as tools, practices, techniques, methods, or similar names, **control** is used in this report) have been developed and applied with similar hydrologic and hydraulic functions, but different shapes, materials, locations, and sometimes, with and or without add-ons (accessories). Some of the LID controls are actual combinations (systems) of several basic controls with accessories to improve their functions and capabilities. As discussed previously, five basic LID controls have been identified in this report from literature review. Table 3.1 listed the five LID basic controls and the similar controls with common and traditional names.

Table 3.1 LID Basic Controls and Their Similar Names

Five LID Basic Controls				
Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
Similar names	**Similar names**	**Similar names**	**Similar names**	**Similar names**
Bioretention cell	Downspout disconnection	Pervious concrete	Active rainwater harvesting	Vegetated roof
Chicane	Grass swale	Pervious paving	Above ground cistern	Rooftop garden
Flow-through planter box	Linear vegetated swale	Porous asphalt	Below ground cistern	
In-ground planter box	Meandering vegetated swale	Soft paving	Rain cistern	
On-site bioretention basin	Vegetated channel	Stabilized aggregate	Rain tank	
Planter box		Structural grid system		
Rain barrel		Permeable paver system		
Rain garden				
Raised planter box				
Regional bioretention basin				
Retention basin				

The LID controls can be classified based on their application locations, such as rain barrel, rain garden, rain tank, rain cistern, and bio retention for residential parcels and commercial properties; Chicane, planter box, bio retention, bio swales, and vegetated channel for street landscaping areas; Bio retention, bio swales, grass swale, and vegetated channel for public facilities; Pervious concrete, porous asphalt, soft paving, and pervious pavement for streets and parking areas; Rooftop garden, vegetated roof, and active rainwater harvesting for buildings.

The LID controls can also be classified based on their construction materials and shapes, such as grass, soil, mulch, asphalt, aggregate, sand, basin, swale, box, chicane, barrel, and tank.

The most useful classification of LID controls is based on their hydrologic and hydraulic functions: retention, detention, infiltration/recharge, storage/reuse, and conveyance (evapotranspiration is ignored for single storm event). Increasing infiltration rate is one of the major means by which LID controls are constructed to accomplish their functions. The purpose of classification for LID controls is to identify the LID basic controls for hydrologic and hydraulic modeling purposes. Table 3.2 listed the five LID basic controls and their hydrologic functions.

Table 3.2 LID Basic Controls and Hydrologic Functions					
Basic LID Control Name	Hydrologic Functions				
	Retention	Detention	Infiltration/ Recharge	Storage & Reuse	Conveyance
Bio Retention	X	X	X		X
Bio Swale		X	X		X
Pervious Pavement	X	X	X		X
Rainwater Harvesting	X			X	
Green Roof	X	X		X	

LID accessories are structures that are added or connected to LID basic controls to improve their hydrologic and hydraulic functions and capabilities. LID systems are combinations of one or more LID basic controls and accessories to improve and expand their hydrologic and hydraulic functions and capabilities, such as runoff collection, retention, detention, store, re-use, and conveyance. Table 3.3 shows the summary table for four (4) typical LID systems, possible combinations of basic controls and accessories.

Table 3.3 LID Systems, Basic Controls, and Accessories				
Typical LID Systems	On-Lot Treatment System	Green Parking System	Green Street System	Active Rainwater Harvesting
Basic Controls	Bio Retention, Bio Swale, Pervious Pavement, Green Roof	Bio Retention, Bio Swale, Pervious Pavement	Bio Retention, Bio Swale, Pervious Pavement	Rainwater Harvesting, Green Roof
Accessories	Downspout, Roof drain, Paving blocks, Porous pavements, Curb cut, underdrain	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain, Wheelstop curb	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain	Downspout, Rain tank, Above ground cistem, Below ground cistem, Roof drain

3.2 General Concepts of Basic LID Controls

The general concepts of the five (5) LID basic controls are illustrated in this sub-section. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. Appendix B1 includes a detailed design guidance manual developed by Rhode Island for LID roadway and parking lot design and design specifications for the basic LID controls developed by Virginia.

3.2.1 Bio Retention

Description:

Bio retention areas are small-scale, vegetated depressions designed to provide stormwater storage and filtration through engineered media. Using detention, sedimentation, filtration and adsorption, bio retention enhances the removal of contaminants from stormwater by both plants and soils. Bio retention can also incorporate pretreatment (i.e., vegetated filter strips, vegetated swales) allowing increased sedimentation and capture of debris from heavily trafficked areas.

Bio retention is applicable and encouraged for any landscape area to manage stormwater and provide an irrigation benefit for native vegetation. Bio retention areas can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed.

Bio retention can have various names for different materials, shapes and locations, such as rain garden, vegetated retention basin, bio retention cell, and planter box:

Vegetated Retention Basin, Rain Garden

- Shallow depressions in the landscape that include plants, a mulch layer and ground cover
- Healthy soils allow stormwater to infiltrate and supply plants with needed water, recharge groundwater and improve water quality
- Can accept runoff from a roof, other impervious surface or adjacent landscape
- Supports native landscape without the need for supplemental irrigation after plant establishment

Bio retention Cell

- Shallow depressions with a designed soil mix and plants adapted to the local climate and soil conditions
- Capture and infiltrate stormwater into the ground below the cell and have an overflow that carries excess stormwater to a discharge point

Bio retention Planters

- Do not infiltrate stormwater into the ground and include an underdrain
- Landscape planters that also store stormwater in porous planting soils and above the soil surface
- Planters may be raised above ground or can be set flush with or even below the ground surface
- They capture runoff from downspouts or overflow from cisterns
- There are several types of bio retention planters including:
    - Structural soils or Silva Cells
    - Raised flow-through planter boxes
    - In-ground planter boxes

Pictures:

Bioretention areas detain stormwater while enhancing the landscape.

Bioretention cells fit into constrained urban site.

Bioretention planters provide stormwater storage and promote healthy growth of trees and plants.

Benefits:

Bio retention (rain garden) has been shown to reduce peak flooding events when implemented throughout neighborhoods and communities. For every 100 square feet of bio retention, over $5,000 of benefits are created over the life of the bio retention as a result of increased property values, water conservation, shading of buildings and street pavement as well as other quality of life improvements (City of Tucson & WMG[1], 2015). Well-designed and constructed facilities receiving appropriate maintenance can increase infiltration rates over time by allowing natural processes to maintain soil porosity and increasing soil organic matter.

Limitations:

- Bio retention should be located at least 5-10 feet away from building foundations depending on relevant building codes. Locating bio retention less than 5 feet away from a building foundation should be carefully determined by local professional guidance and codes based on bio retention design, site conditions and soil types.
- In arid environments native plants must be established by irrigation system, water truck or by hand for the first 1-3 years. After the establishment period, plants will thrive on stormwater alone.
- Bio retention facilities must be maintained in order to achieve design performance.
- Experienced designers and construction managers are necessary to ensure bio retention performs as intended and can exceed design performance criteria.

Maintenance:

Regular maintenance is essential to maintain runoff infiltration capacity. Seasonal activities, especially around rainfall events, are necessary to ensure bio retention facilities are performing as expected. Sediment traps should be inspected before rainy seasons, native vegetation should be pruned for safety and healthy, natural plant growth, cuttings should be mulched on site and left in bio retention basin bottoms to increase soil organic matter, and undesirable plants not serving an infrastructure and aesthetic benefit should be removed completely including the roots. Sediment removed from sediment traps and basin bottoms can be disposed of onsite if sufficient area exists where sediment can be placed in landscaping areas, outside of basin bottoms and under mulch to maintain the site aesthetic. Excess sediment can be disposed offsite. Bio retention or adjacent areas should never be sprayed with chemicals, herbicides or pesticides, raked or mowed. These practices will degrade the functionality of the bio retention system. Leaving organic matter to decompose is an essential function to maintain and enhance system performance.

Costs:

Costs vary greatly depending on size, plant materials, and site considerations. Bio retention basins are generally less expensive when used in place of traditional stormwater conveyance. Watershed Management Group's experience is primarily with retrofit projects. Constructing and installing new landscapes and infrastructure with bio retention often results in a reduction of capital and maintenance costs by 10-20% relative to conventional infrastructure[2] Based on WMG's experience with bio retention retrofits for residential and commercial facilities, costs range from $0.85/gallon installed capacity for facilities installed in existing landscapes without

[1] Watershed Management Group
[2] Natural Resources Defense Council

major inlet structures needed to $2.30/gal when inlet structures such as curb cuts are necessary. Some variables that can increase costs significantly are engineered soils, underdrains, infiltration trenches and asphalt/concrete removal. For street and parking lot retrofits where concrete and asphalt removal and replacement was necessary, costs exceeded $12/gal of installed capacity.

Recommended Uses:

Bio retention is applicable and encouraged for any landscape area to manage stormwater and provide an irrigation benefit for native vegetation. Bio retention areas can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed. Bio retention area should be maximized before stormwater reaches traditional stormwater conveyance in order to reduce costly maintenance of in-ground infrastructure and to maximize water quality benefits and stormwater peak flow reductions.

Literature Referenced:

Low Impact Development Toolkit. City of Mesa. April 2015.

Natural Resources Defense Council. http://nrdc.org/water/commercial-value-green-infrastructure.asp.

Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Watershed Management Group. May 2015. http://watershedmg.org/document/gi-report-2015.

3.2.2 Bio Swale

Description:

Bio swales are shallow, open channels that are designed to reduce runoff volume through infiltration. Additionally, bio swales remove pollutants such as trash and debris by filtering water through vegetation within the channel. Swales can serve as conveyance for stormwater and can be used in combination with traditional curbs and gutters; however, when compared to traditional conveyance systems the primary objective of a bio swale is infiltration and water quality enhancement rather than conveyance. In addition to reducing the mass of pollutants in runoff, properly maintained bio swales can enhance the aesthetics of a site.

Bio swales are highly versatile stormwater Integrated Management Practices (IMPs) that effectively reduce pollutants. With a narrow width, bio swales can be integrated into site plans with various configurations and components. Ideal sites for bio swales include the right-of-way of linear transportation corridors and along borders or medians of parking lots. In heavily trafficked areas, curb cuts can be used to delineate boundaries. Bio swales can be combined with other basic and stormwater runoff Best Management Practices (BMPs) to form a treatment train to reduce the required size of a single IMP unit.

Bio swales can be utilized in place of conventional stormwater conveyance where flow velocities will not overwhelm the structural integrity of the established vegetation and rock structures. If space, runoff volumes and velocities permit, bio swales should meander in order to lengthen the flow path and slow runoff velocities. Bio swales can serve as connections between stormwater management features. Ideally, Bio swales would connect several different bio retention areas before discharging the overflow into a storm sewer inlet.

Vegetated Channel, Vegetated Swale

- Stormwater runoff conveyance systems that provide an alternative to piped storm sewers;
- Absorb low flows, direct runoff from heavy rains to bio retention facilities, then to storm sewer inlets;
- Improve water quality by enhancing infiltration of the first flush of stormwater runoff.

Pictures:

Vegetated swales accept stormwater for conveyance, storage and infiltration.

Benefits:

Bio swales can provide multiple benefits when designed to both convey and infiltrate runoff. Bio swales can reduce peak flooding events when implemented throughout neighborhoods and communities. For every 100 square feet of bio swale planted with native trees, over $5,000 of benefits are created over the life of the bio swale as a result of increased property values, water conservation, shading of buildings and street pavement as well as other quality of life

improvements (City of Tucson & WMG, 2015). Well-designed and constructed facilities receiving appropriate maintenance can increase infiltration rates over time by allowing natural processes to maintain soil porosity and increasing soil organic matter.

Limitations:

- Space, velocity and volume considerations may limit applications in constrained spaces
- In arid environments native plants must be established by irrigation system, water truck or by hand for the first two warm seasons. After the establishment period, plants will thrive on stormwater alone.
- Bio swales must be maintained in order to achieve design performance.
- Experienced designers and construction managers are necessary to ensure bio swales perform as intended and can exceed design performance criteria.

Maintenance:

Regular maintenance is essential to maintain runoff conveyance and infiltration capacity. Seasonal activities, especially around rainfall events, are necessary to ensure bio swale facilities are performing as expected. Sediment in bio swales should be removed before rainy seasons, native vegetation should be pruned for safety and healthy, natural plant growth, cuttings should be mulched on site in order to increase soil organic matter of the adjacent landscape if areas outside of swales exist where flow velocities will not wash mulch away, and undesirable plants not serving an infrastructure and aesthetic benefit should be removed completely including the roots. Bio swales or adjacent areas should never be sprayed with chemicals, herbicides or pesticides, raked or mowed. These practices will degrade the functionality of the bio swale system. Leaving organic matter to decompose is an essential function to maintain and enhance system performance.

Costs:

Costs vary greatly depending on size, plant materials, and site considerations. Vegetated swales are generally less expensive when used in place of underground piping. Watershed Management Group's experience is primarily with retrofit projects. Constructing and installing new landscapes and infrastructure with bio swales often results in a reduction of capital and maintenance costs by 10-20% relative to conventional infrastructure[3]. Based on WMG's experience with bio swale retrofits for residential and commercial facilities, costs range from $0.85/gallon installed capacity for facilities installed in existing landscapes without major inlet structures needed to $2.30/gal when inlet structures such as curb cuts are necessary.

Recommended Uses:

Bio swales can serve as conveyance Bio swales should be planted with native grasses and groundcovers that can thrive when inundated with stormwater runoff, but will not create a flooding hazard by obstructing flow. Vegetation will allow for infiltration of low flows and retain soil in high flow events. Rock structures can enhance infiltration by slowing, spreading and sinking runoff into the soil. If space allows, rock structures and the bio swale can be shaped to meander and increase the length of the flow path for maximum flood reduction and water conservation benefit. Bio swales can receive runoff from roofs, parking lots, roads, adjacent landscapes, athletic fields, agricultural areas and other areas where stormwater quantity and quality improvements are needed.

[3] Natural Resources Defense Council

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Natural Resources Defense Council. http://nrdc.org/water/commercial-value-green-infrastructure.asp.

Solving Flooding Challenges with Green Stormwater Infrastructure in the Airport Wash Area. Watershed Management Group. May 2015. http://watershedmg.org/document/gi-report-2015.

3.2.3 Pervious Pavement

Description:

Pervious pavement can have various names for different materials, shapes and locations, such as:

Stabilized aggregate - a mixture of compacted stone aggregate and a binder;

Porous asphalt - standard asphalt pavement in which the fines have been screened and removed, creating void spaces that make it highly permeable to water;

Porous concrete - single size, screened aggregate consists of a special mix design with void spaces that make it highly permeable;

Structural grid systems - consist of plastic, concrete or metal interlocking units that allow water to infiltrate through large openings filled with aggregate stone, or topsoil and turf grass;

Permeable pavers - precast concrete unit pavers designed to be set on a compacted base and highly permeable setting bed with joints filled with sand or fine gravel.

Pervious pavement allows for percolation of stormwater through subsurface aggregate and offers an alternative to conventional concrete and asphalt paving. Typically, stormwater that drains through the pervious surface is allowed to infiltrate underlying soils and excess runoff drains through perforated underdrain pipes. Pervious pavement can be designed as a self-treating or self-retaining area.

The use of pervious pavement is encouraged for sites such as parking lots, driveways, pedestrian plazas, rights-of-way, and other lightly traveled areas. Numerous types and forms of pervious pavers exist and offer a range of utility, strength, and permeability. Pervious pavement must be designed to support the maximum anticipated traffic load but should not be used in highly trafficked areas. For designs that include infiltration, surrounding soils must allow for adequate infiltration. Precautions must be taken to protect soils from compaction during construction. Pervious pavement is typically designed to treat storm water that falls on the pavement surface area and run on from other impervious surfaces. It is most commonly used at commercial, institutional, and residential locations in area that are traditionally impervious. Pervious pavement should not be used in high-traffic areas.

Pictures:

Stabilized aggregate reduces storm runoff from low-traffic paving areas.

Porous asphalt paving is a runoff-reducing in paving areas and driveways.

Porous concrete can reduce runoff sustaining in sidewalks and plaza areas.

Structural grid paving reduces runoff in parking areas and firelanes.

Permeable paving is an attractive way to provide runoff reduction in paving and pedestrian areas.

Benefits:
Pervious pavements provide stormwater runoff reduction through infiltration, reducing ponding and flooding.

Limitations:

- Maintenance may be a challenge in areas with adjacent landscapes that are not stabilized, high airborne dust concentrations and/or sediments in stormwater.
- Stabilized aggregate and engineered soils are required to achieve stormwater infiltration benefits often leading to higher costs than for landscape based LID practices where native soils and plants provide and support design infiltration rates.
- Pervious pavements do not provide multiple benefits unless infiltrated water meets tree irrigation needs.
- Not appropriate for cold climates due to frost heave.

Maintenance:
Regular maintenance is essential to maintain runoff infiltration capacity. Specialized equipment is required to remove accumulated materials that clog porous surfaces with vacuuming or pressure washing.

Costs:
Based on research from the EPA the range of costs are:

Pavement	Paved Area (sq ft)	Quote ($)	Quote ($)	Quote ($/sq yd)	Quote ($/sq yd)	Quote ($/Sq ft)	Quote ($/sq ft)
		Highest	Lowest	Highest	Lowest	Highest	Lowest
Hot Mix Asphalt	36,225	98,600	92,620	24.50	23.01	2.72	2.56
Porous Asphalt	5,328	28,650	18,352	4,840	31.00	5.38	3.44
Porous Pavers	5,328	67,960	61,755	114.80	104.32	12.76	11.59
Porous Concrete	7,988	63,200	53,919	71.21	60.75	7.91	6.75

Recommended Uses:
Pervious pavement materials are recommended for commercial and residential applications where the capacity of landscape areas is not available or sufficient to handle desired runoff volumes. If possible, grade soil sub-grade below pervious pavement to direct infiltrated water from pervious surfaces to landscape root zone to achieve multiple benefits from trees.

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

Pervious Pavement Research--Edison New Jersey, Amy Rowe, EPA National Risk Management Research Laboratory. http://nyccpc.org/Documents/2010/RoweNYCCPC.pdf.

University of Maryland Extension Fact Sheet. Pervious Pavement Fact Sheet Information for Howard County, Maryland Homeowners. Accessed Oct 8, 2015.

3.2.4 Rainwater Harvesting

Description:

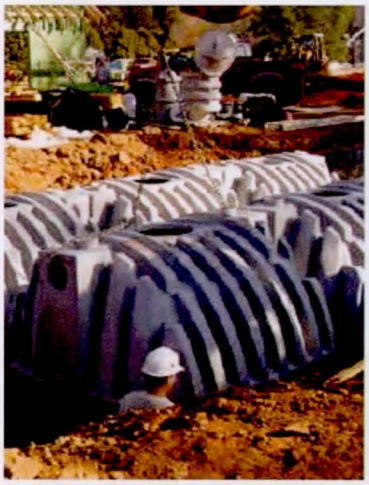
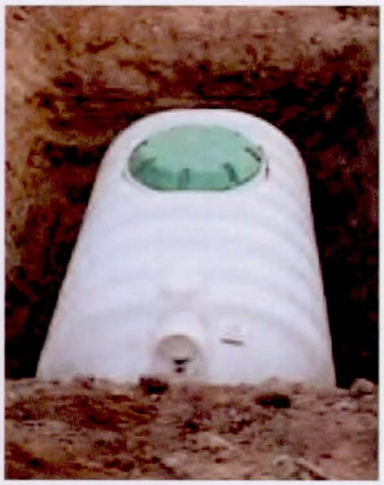
Rain Tank, Cistern, Rain Barrel

- An aboveground rain tank captures stormwater runoff, often from a rooftop, and stores the water for later use
- A rain tank consists of the following main components including a gutter system that collects runoff from the rooftop and directs it into the rain tank for later use, a rain head to prevent large debris from entering the tank plumbing system, a first-flush to capture the first flow of dirty water and sediment from a roof, an overflow pipe that allows excess runoff to leave the rain tank in a controlled manner, and an outlet pipe that distributes water to a garden or landscape by gravity or pump from the bottom of the rain tank
- If rain tanks are utilized for potable water storage, test the source water from the rain tank, utilize conveyance plumbing designed for drinking water standards, treatment should include a sand filter, carbon filter, ultraviolet disinfection and can include a reverse osmosis filter for extra precaution
- An underground rain tank may be preferable where surface space is limited
- Rain tanks may be constructed of various materials including plastic, cinder blocks, reinforced concrete, fiberglass or steel.

Rain tanks work best harvesting stormwater off of relatively clean surfaces like building rooftops. Rain tanks can be used to store stormwater off of other surfaces when landscape space is limited and appropriate filtration strategies and maintenance are planned. Rain tanks work well in residential, commercial and industrial settings.

Pictures:

Cisterns can store rainwater to be re-used for future landscape irrigation.

Underground cisterns provide storage areas for rainwater reuse.

Benefits:

Rain tanks provide storage of stormwater for use during dry periods. Rain tanks can be utilized for a variety of needs including outdoor uses, indoor non-potable water needs and drinking water. Rain tanks function most effectively when designed as an integrated system that includes bio swales and bio retention for managing rain tank overflows and harvesting runoff from non-roof surfaces.

Limitations:

- Rain tanks are the most costly storage option per gallon of capacity;
- If tanks are not utilized in between storm events, stormwater harvesting capacity may be limited or non-existent unless a bleed pipe is utilized to maintain tank capacity;
- Water use requires regular human interaction with systems, costly automated systems and generally has many parts that can fail if not well-maintained.

Maintenance:

- Regularly check the gutters and rain head to make sure debris is not entering the tank;

- Inspect the screens annually to make sure debris is not collecting on the surface and that there are not holes allowing mosquitoes or other insects to enter the tank;
- Clean the inside of the cistern twice a year to prevent buildup of debris. Clean out debris twice a year, preferably prior to the beginning of each rainy season;
- Check screens and tank fittings are sealed to prevent mosquito breeding;
- Ensure first-flush diverter is functioning properly;
- Check gutter connections every three to four months and after intense rainfall to check for leaking or damage;
- Check gravity feed irrigation system and/or maintain pumps or filters in accordance with manufacturer's recommendations.

Costs:
Costs for rain tanks vary greatly depending on size, material, site conditions, tank uses and whether the tank is above ground or underground. Smaller tanks have a higher $/gal cost. Small (less than 800 gallons) above ground tanks can cost $1.5+/gal installed. Larger (greater than 800 gallons) above ground tanks typically range from $1-1.5/gal installed. Underground tanks are typically $2+/gal installed.

Recommended Uses:
Rain tanks work best when site goals include irrigating high water use landscapes, food production, meeting indoor water demand, and/or offsetting or eliminating municipal/ groundwater sources. If flood mitigation is a goal, an appropriately designed bleed piped should drain to a bio swale and/or bio retention to ensure there is rain tank capacity to store subsequent storm event flows.

Literature Referenced:
Low Impact Development Toolkit. City of Mesa. April 2015.

3.2.5 Green Roof

Description:

Green Roof or Vegetated Roof

- A green roof or Xeriscape living roof is when the roof of a building or structure is at least partially covered with a growing medium and vegetation planted over a waterproofing membrane. It may also include a root barrier, drainage mat and irrigation system.
- There are two types of green roofs: Intensive and Extensive. The difference is in the depth of soil and the ability to support simple groundcover planting (extensive, 3-5 in of soil) versus larger materials such as trees and shrubs (intensive, 5-24+ in of soil).
- Green roofs provide stormwater storage and absorption, reduce runoff from buildings, and insulate buildings from solar gain and heat loss.

Green roofs are not common in the arid southwest due to construction and plant establishment challenges. The Tempe Transportation Center and University of Arizona College of Architecture, Planning and Landscape Architecture are two examples of established intensive green roofs. A few residential applications exist in Tucson and Phoenix. Green roofs have worked in residential, commercial and industrial settings.

Pictures:

Green roofs store and utilize stormwater to reduce runoff from building sites.

Benefits:

Green roofs serve to slow roof runoff, filter pollutants and provide additional benefits from habitat creation as well as reductions in urban noise, heat island, local temperatures and building energy consumption. Green roofs have also been shown to extend the life up to 200% of existing roof material.

Limitations:

- Retrofits can be difficult and costly due to structural roof requirements both intensive and extensive green roofs;
- Professionals must be consulted for the design and construction of the green roof. A qualified architect, structural engineer, landscape architect and facility maintenance personnel (commercial) are critical to the success of a green roof project;
- The plant establishment period is critical to ensure survival in the harsh environment;
- Roofs must be protected from retained plant moisture to eliminate roof damage.

Maintenance:

- Vegetation will require supplemental irrigation and only very hardy plants should be used in our desert environment. Depending on whether the green roof is extensive or intensive, required plant maintenance will range from two to three yearly inspections to check for weeds or damage, to weekly visits for irrigation, pruning, and replanting;
- Both plant maintenance and maintenance of the waterproofing membrane are required;
- To ensure continuity in the warranty and the maintenance requirements, the building architect, structural engineer and/or owner should specify and maintain everything up to and including the waterproof membrane. The green roof designer and installer are only responsible for those items above the waterproof membrane, including soils, drainage and plantings.

Costs:

Data from other climates show a well designed and installed extensive green roof can cost \$10-12/ft^2. Intensive green roofs can cost \$33-220/ft^2. Costs vary widely based on the design, building type, use of reclaimed materials, retrofit or new construction and climate.

Recommended Uses:

Green roofs work well in urban environments where existing landscape area is minimal and visual or physical access to the site is possible to enjoy the green roof environment. Green roof retrofits are more cost effective for extensive green roofs due to less structural roof requirements and intensive green roofs can more easily be incorporated into new construction and design. Stormwater benefits can be achieved more cost effectively by other LID controls, however, the benefits of habitat creation as well as reductions in urban noise, heat island, local temperatures and building energy consumption.

Plants that work well in Tempe:

Rocky Point Ice Plant (Malephora lutea), Slipper Plant (Pedilanthus macrocarpus), Red Yucca (Hesperaloe parviflora), Bear Grass (Nolina microcarpa) and Candelilla (Euphorbia antisyphilitica).

Plants that worked well in Tucson:

Red Yucca (Hesperaloe parviflora), Fairy Duster (Calliandra eriophylla), Dogweed (Dyssodia pentachaeta).

Literature Referenced:

Low Impact Development Toolkit. City of Mesa. April 2015.

Tempe Transportation Center: http://www.greenroofs.com/projects/pview.php?id=935.

3.3 General Concepts of Basic LID Accessories

The general concepts of selected LID accessories are illustrated in this sub-section. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. More LID accessories can be found in Appendix B2 which includes a detailed LID design manual for urban areas developed by University of Arkansas.

Standard Curb Cut

Description:

Curb cuts are openings created in a curb to allow stormwater from an impervious surface, such as roads, parking lots, or hardscape areas, to flow into a lower landscaped storage and LID control area. The curb cut is a useful tool for retrofitting existing development with LID practices without major reconstruction. Since curb cut openings are perpendicular to the flow of stormwater on the street, they will usually collect only a portion of the water flowing along the gutter. If attenuating stormwater flows along the street is the goal, place multiple curb cuts at intervals along the street.

Pictures:

Curb cuts control stormwater flow from streets to LID facilities.

Installation and Maintenance:

Openings should be at least 18 inches wide, but up to 36 inches is preferred for ease of maintenance. Openings should be at low points and spaced based on amount of water being received along curb, and the area available for detention, infiltration, and access to overflow systems. The curb cut can either have vertical or angled sides. The design intent is to create a smooth transition from the paved surface to full curb height.

Curb cuts work well with relatively shallow stormwater facilities that do not have steep side slopes that might erode. Set the elevation of the bottom of the curb cut to maximize flow into the landscape area. A drop in grade should occur between the curb cut entry point and the finish grade of the landscape area to allow for passage of sediment. Small amounts of hand placed rip-rap can be used on the LID facility side of the curb cut opening to reduce the potential for erosion in landscaped areas.

Regularly clear curb cuts of any debris and sediment that prevents the free flow of stormwater into LID facility (1-2 times per year and after major storm events). Periodically check rip rap areas for signs of erosion damage. Repair and reinforce as necessary (annually and after major storm events).

Curb Cut with Sidewings

Description:

The sidewing addition to curb cut conveys stormwater a greater distance, and can reduce the potential for erosion behind the curb or close to the paved surface.

Pictures:

Curb cuts direct stormwater from street to landscape areas.

Installation and Maintenance:

Sidewings work well to guide stormwater greater distances and with stormwater facilities that have steep side slopes. Openings should be at least 18 inches wide, and sidewings can be parallel or tapered.

Slope the bottom of the curb cut and trench toward the landscape area. The slope should be flat enough to keep flow velocities low and steep enough to keep sediment moving (between 1% and 5% slope). A drop in grade should occur between the curb cut entry point and the finished grade of the landscape area to allow for passage of sediment. Small amounts of hand placed rip-rap can be used outside the curb cut opening to reduce the potential for erosion in landscaped areas.

Regularly clear curb cuts and sidewings of any debris and sediment that prevents the free flow of stormwater into LID facility (1-2 times per year and after major storm events). Periodically check rip rap areas for signs of erosion damage. Repair and reinforce as necessary (annually and after major storm events).

Grated Curb Cut

Description:

Grated curb cuts allow stormwater to be conveyed into LID area under a pedestrian walkway. Curb-cut openings are described in previous sections to allow stormwater from impervious surfaces to flow into a LID area. The grated curb cut is a useful tool for urban areas where there is heavy pedestrian traffic and the need for handicap accessible routes adjacent to streets and parking areas.

Grated curb cuts should only be used where there is not enough vertical distance to install a scupper. Where they are used, only decorative heavy duty, accessible, precast gratings should be permitted.

Pictures:

Grates allow stormwater to pass through while proving an accrossing pedestrian route.

Installation and Maintenance:

The grated curb cut opening should ideally be 18 inches wide; enough to minimize the potential for clogging. Grates should be compliant with the Americans with Disabilities Act (ADA) and have adequate slip resistance. Grates should be anchored in a way that deters removal or theft.

A drop in grade should occur between the grated curb cut channel and the finish grade of the landscaped area to allow for the passage of sediment. Permanent or temporary erosion control may be necessary where concentrated runoff from the channel is deposited into the landscaped area.

Regularly clear grated curb cuts of debris and sediment that may prevent the free flow of stormwater (1-2 times per year and after storm events). Periodically check for damage to grate and structural support system that may cause ponding of water or impede accessible pedestrian routes. It may be necessary to remove grates to clear sediment and debris.

Curb Cut with Sediment Capture

Description:

Sediment removal poses a considerable challenge in the maintenance of LID control area. In the arid Southwest, high proportions of bare soil are common, resulting in high rates of erosion and sedimentation. Sediment capture can address this issue. Sediment catchments capture and collect sand and fine soils at the entrance to bio retention areas, removing them from stormwater and allowing periodic removal. Sediment removal can significantly extend the functional life of these features.

Pictures:

Sediment capture can be open or covered.

Installation and Maintenance:

Use sediment capture in areas where higher than normal sediment loads are expected. Excavate at least 12 inches from the inside of the curb cut, and at least 2 feet square by 8 inches deep. The capture device can either be open or covered with a grate. A concrete curb, or steel edge, several inches in height, may be used to separate the capture area from the adjacent landscape detention area or basin, and anchor the grate.

A berm, several inches in height, may be used to separate the capture area from the adjacent LID area or basin. Plant the berm with native groundcover plantings to stabilize it and allow it to filter stormwater pollutants.

Check sediment capture device to ensure that the stormwater inlet does not become blocked (before and after rainy seasons and after large storm event). Regularly remove sediment from the bottom of the facility (frequency depends on sedimentation rates, but at least once a year). Check apron, slopes, edges, etc. for erosion and repair/reinforce as needed (annually and after storm events).

Concrete Flush Curb

Description:

Concrete flush curbs allow stormwater to runoff impervious surfaces directly into LID control areas and stormwater facilities. Stormwater flow is distributed more evenly which reduces the potential for erosion and clogging along a pavement edge.

Pictures:

Flush curbs allow stormwater to sheet drain to landscape areas.

Installation and Maintenance:
Top of concrete curb should be installed flush with the pavement surface, with allowances for subgrade compaction and future settlement. A drop in grade should occur between the top of the flush curb and the finished grade of the landscaped area to allow for passage of sediment and debris to drop out.

Utilize temporary erosion control measures when seeding or planting adjacent areas to reduce the potential for erosion. A wider surface area and contrasting color for the flush curb provides an important visual cue when used on roads, driveways and bicycle paths. This tool will be considered on a case by case basis for street rights-of-way.

Check the flush curb for signs of damage or settlement causing ponding or concentration of stormwater runoff. Check landscape edge condition for signs of rilling or erosion and repair or reinforce as needed (annually). Remove sediment and debris from landscape area outside of flush curb that may cause water to pond or backup.

Wheelstop Curb
Description:
Wheelstop Curbs are formed sections of curb with gaps between them. They allow stormwater from adjacent impervious surfaces, like parking lots, to flow into adjacent LID control areas.

In flush, or no curb parking areas, poured-in-place wheelstop curbs can be used to define openings and protect LID control areas.

Pictures:

Wheelstops allow sheet drainage to pass into landscape areas.

Installation and Maintenance:

Space poured-in-place wheel stop curbs as needed for parking/traffic conditions while allowing water to flow into LID areas. Poured-in-place wheel stop curbs are most common in parking lot applications, but they can also be applied in certain street conditions.

Provide a minimum of 6 inches of space between the poured-in-place wheelstop curb edge and edge of asphalt paving to provide structural support for the wheel stop. Securely anchor poured-in-place wheelstop curbs using foundations or other support to ensure that they resist vehicle impact and overturning. A concrete flush curb is advised along the edge of pavement for structural support of poured-in-place wheel stop curbs and visual demarcation of parking area or driveway edge.

Poured-in-place wheelstop curbs have similar maintenance requirements as other poured concrete curbs. Unless they are firmly anchored they can be dislodged creating unsightly and dangerous conditions. They should be check regularly for cracking and settlement and repaired or replaced as necessary.

Downspout

Description:

Downspout is used to direct rainwater from the rooftop into a LID control instead of into a piped system or into the street. Downspouts can direct stormwater to LID control where it is stored and used to irrigate landscape plants or infiltrate into the ground.

Pictures:

Installation and Maintenance:

Direct downspout extensions away from building foundations or adjacent properties to avoid structural damage or nuisance flooding. Firmly anchored splash blocks or hand placed rock can be installed to direct downspout drainage to LID areas.

Ensure that the offsite overflow is sufficiently lower than the building floor elevation to reduce the potential for building flooding.

Clean gutter at least twice a year, and more often if there are overhanging trees. Make sure gutters are pitched to direct water to downspouts. Caulk leaks and holes. Make sure roof flashing directs water into the gutters. Look for low spots or sagging areas along the gutter line and repair with spikes or place new hangers as needed.

Check and clear elbows or bends in downspouts to prevent clogging. Each elbow or section of the downspout should funnel into the one below it. All parts should be securely fastened together. Maintain landscaping so that there is positive drainage away from all structures. Don't build up grade, soils, groundcover mulches, or other materials near the building that might inhibit positive drainage.

Roof Drain

Description:

Roof Drain is used to help collect and convey runoff from green roof LID control area into rain tanks, cisterns above/below ground or piped systems.

Pictures:

Installation and Maintenance:

Roof Drain should be located at lower spots to collect runoff from the green roof and firmly anchored and tightly sealed to avoid leakage.

Ensure that the pipes are connected to downspouts and into rain tanks, cisterns above/below ground or piped systems to either store the runoff or irrigate vegetated areas.

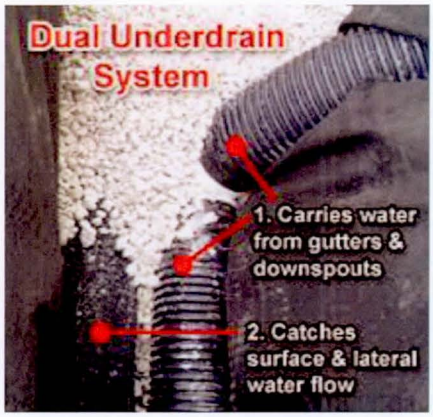
Clean inlets at least twice a year, and more often if there are overhanging trees. Check and clear elbows or bends in downspouts to prevent clogging.

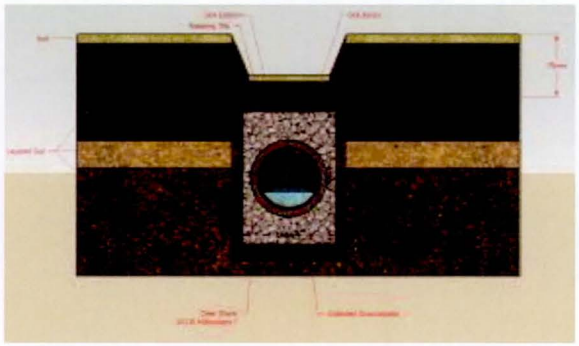
Underdrain

Description:

A perforated pipe, typically 4-6 inches in diameter placed longitudinally at the invert of a bio retention, bio swale, or pervious pavement LID control for the purposes of achieving a desired discharge rate or runoff volume reduction.

Pictures:





Installation and Maintenance:

Pipe underdrain should be installed with trench. The perforated pipe shall be bedded on 4 in coarse aggregate material and carefully backfilled with the remaining coarse aggregate cover material to 6 in above the top of pipe.

Clean outlets at least twice a year and after each major storm event.

4.0 FLO-2D MODELING PROCEDURES FOR INDIVIDUAL LID CONTROLS

4.1 FLO-2D Model for the Focus Area and LID Modeling Methods

The primary objective of the Focus Area modeling is to develop detailed hydrologic and hydraulic modeling procedures for LID basic controls in order to determine the appropriate FLO-2D modeling processes for regional modeling. The FLO-2D model for the Focus Area covers two blocks of neighborhood with an area of about 21 acres which forms a relatively closed drainage watershed (minimal off-site inflows). The Focus Area model has 4 ft x 4ft grid size and 56,693 total number of grid. The optimal grid size should be estimated based on the topographic mapping accuracy (grid size ~ mapping accuracy/surface slope), size of the modeling area, types of LID controls and accessories, and modeling objectives.

Appendix C0 includes the base model input and output data files, and Exhibit A shows the Focus Area boundaries and modeling results for the base model.

As discussed previously and documented in previous memos, the proposed possible modeling methods for five LID basic controls are summarized in Table 4.1.

Table 4.1 FLO-2D Modeling Methods for LID Basic Controls

LID Basic Control	Possible Modeling Methods			
	Grid elevation adjustment	Initial loss IA adjustment	Infiltration rate/Soil depth adjustment	Use of artificial storm drain
Bio Retention	X	X	X	X
Bio Swale	X	X	X	X
Pervious Pavement	X	X	X	X
Rainwater Harvesting		X	X	X
Green Roof		X		X

In addition to grid elevation adjustments for areas with significant retention and detention volume, infiltration rate and limiting soil depth adjustments were used for increased infiltration capacities of LID controls on the computation of runoff reduction. Initial loss IA adjustment was used for the modeling of LID controls of Rainwater Harvesting and Green Roof. Artificial storm drain system was used for modeling bio swale and pervious pavement with underdrain systems.

The advantages of FLO-2D models with smaller grid cells (in this study, 4 ft x4 ft grids, high accuracy of topographic mapping required) are:

1) For small LID areas, the hydrologic processes, such as topographic differences (grid elevation adjustments), infiltration rate and limiting soil depth changes, surface runoff movement within bio swales, etc. can be modeled;

2) With the small grid FLO-2D model, higher resolution hydraulic modeling parameters can be obtained, such as flow depths and velocities within streets and bio swales;
3) Runoff collection and diversion processes by LID accessories with small dimensions (typically, 18 in to 48 in long), such as curb cut, flush curb, curb cut with sidewing, wheelstop curb, etc. can be represented and modeled adequately.

4.2 FLO-2D Modeling Procedures for Bio Retention

In addition to grid elevation adjustments for the grids within the Bio Retention areas, spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of Bio Retention on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

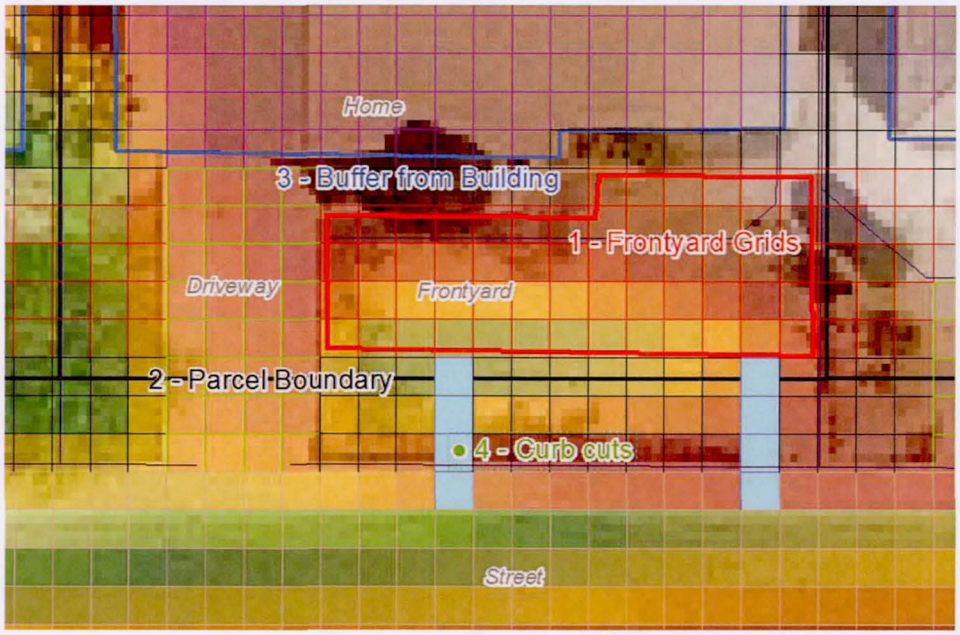
In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements (i.e., utilize the 100-year, 2-hour on-site retention requirement as a practical upper limit) which will be demonstrated in Section 6. In the Focus Area modeling for the bio retention LID control, the parcel specific bio retention application areas were developed based on parcel pervious areas within the modeling areas as shown in Exhibit B1. The total number of grids within Bio Retention area is 2436. A typical bio retention LID control has two layers of areas where storm water can be stored: top open basin and bottom coarse permeable material for increased infiltration. For Focus Area model, the bio retention basin depth and infiltration depth of 6 in was modeled with total bio retention design capacity of 0.89 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Grid Assignment
   a) Bio retention grids - Grid assignment for the bio retention began with identifying the front yard (No. 1 in the following map) grids. These grids were then narrowed down to those that were contained within the parcel (No. 2 in the following map). Grids adjacent to a building were also ignored from the selection (No. 3 in the following map).

   b) Accessory grids - Grids were then assigned for curb cuts to help route flow to the bio retention areas. The curb cut grids (No. 4 in the following map) were placed on the grid adjacent to the lowest roadway grid and extended to the bio retention area. Each bio retention area was given 2 connections to the street.



2) Input Data Files

a) FPLAIN.DAT – The bio retention area grids were grouped by unit; each front yard was treated separately. Elevations to be applied across all grids per front yard were determined by subtracting 0.5 ft from the low grid on roadway elevation to create the top open basin. Each bio retention grid was also assigned an N-value of 0.1 to both represent increased vegetation and reduce simulation runtime.

Curb cut grids attributed to the same parcel were all given the same elevation which was approximately the lowest street grid elevation adjacent to the property rounded down to the nearest tenth.

b) INFIL.DAT – The bio retention area grid infiltration parameters were modified as if they were a loamy sand soil amendment with an additional 6 in of infiltration-loss capacity with the following modified parameter values:

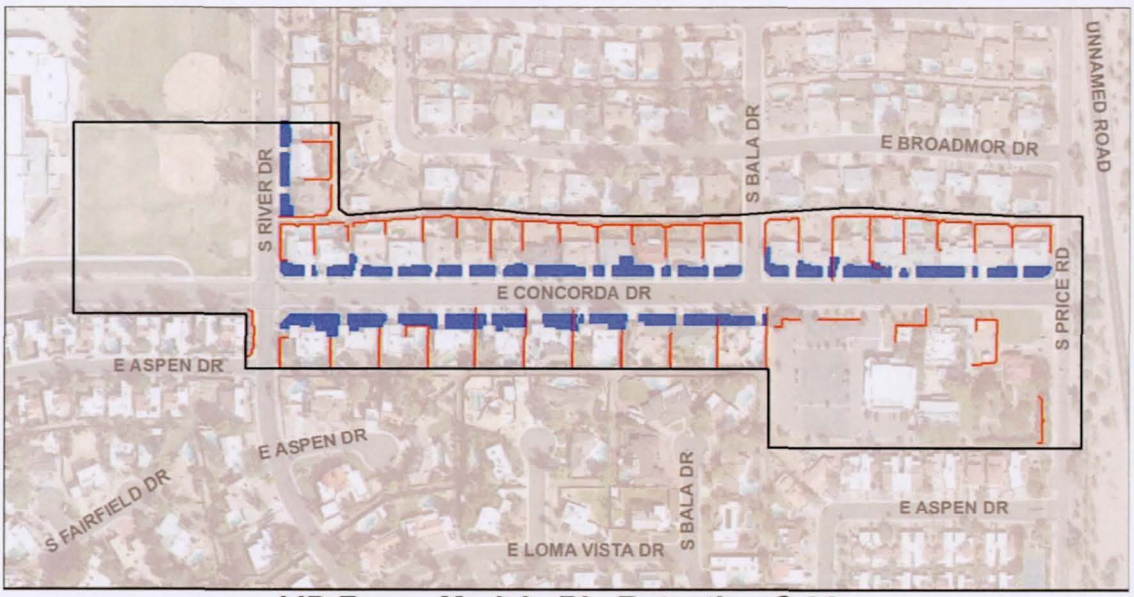
i) HYDC – The hydraulic conductivity, in inches/hr: A value of 1.2 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2;
ii) SOILS – The soil suction head, in inches: a value of 2.4 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2;
iii) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
iv) ABSTRINF - The initial abstraction in inches: a value of 0 was used for the bio retention area grids for the purpose of estimating infiltration volume;
v) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 (no impervious area within bio retention areas) was used to allow full infiltration;

vi) SOILD – The limiting soil depth in feet: A value of 1.667 was added on top of the original limiting soil depth used. This was determined by using our design depth of 6 in divided by DTHETA (0.3) and converted to feet (0.5 ft/0.3 = 1.667 ft).

Step 3: Running FLO-2D Models and Documenting Results

A base model (Model LID2.1) was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Retention LID control (Model LID 6.5) for all parcels was developed to simulate the effects of LID applications. The summary modeling results were documented in Table 4.2a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.2a and the numbers used were highlighted (These files were also included in Appendix C1). The LID control grids and their close-up map are shown in the following.

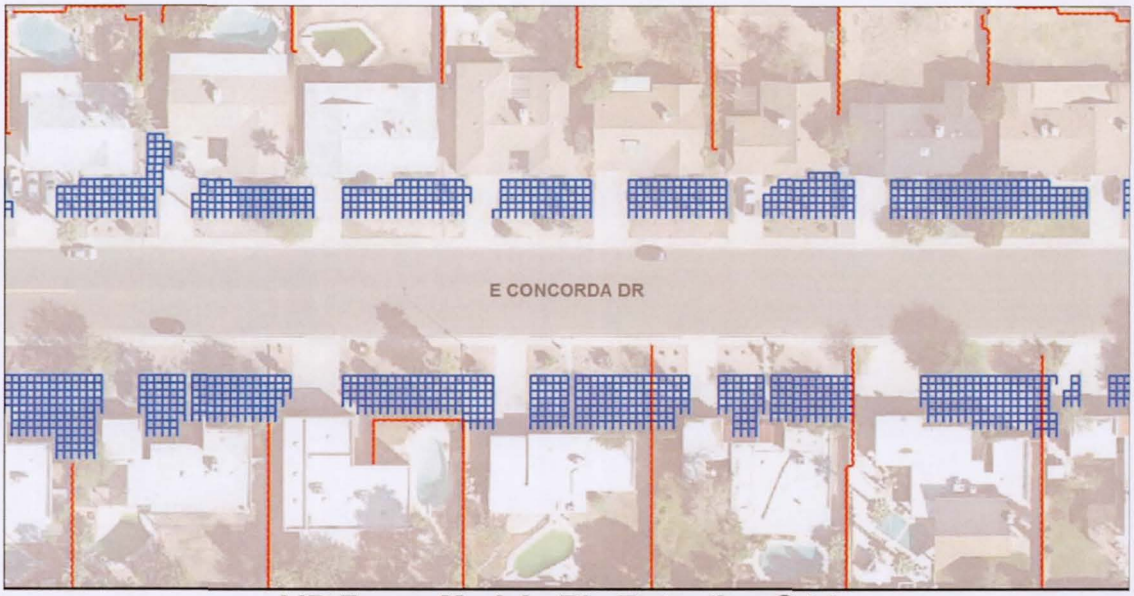


LID Focus Model - Bio Retention Grids

Model Boundary — Walls — Bio Retention

N

1 inch = 400 feet



LID Focus Model - Bio Retention Grids

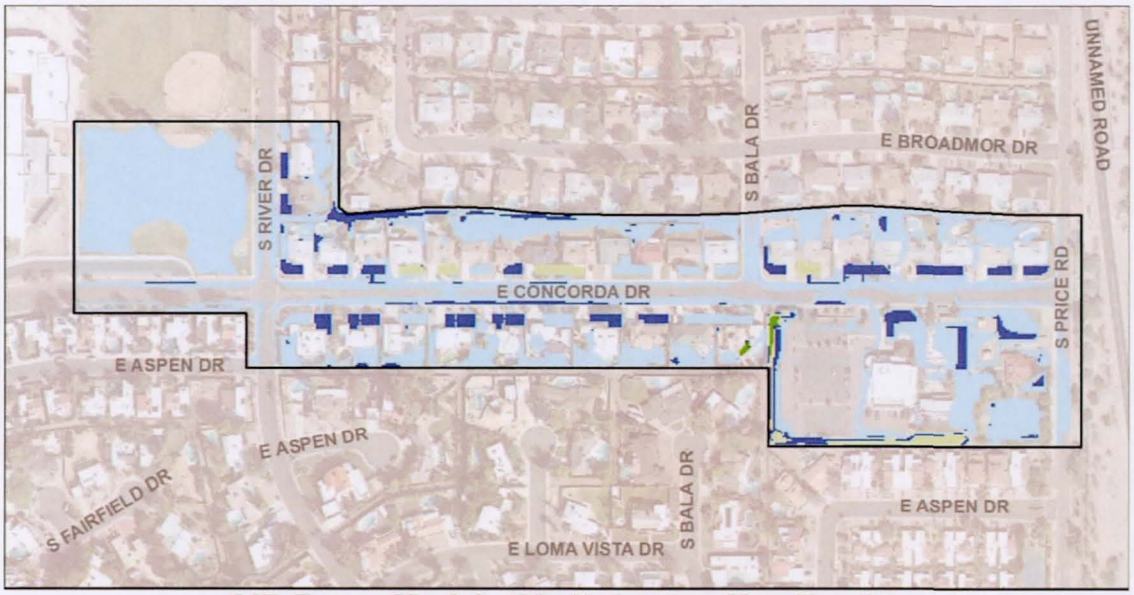
Model Boundary — Walls — Bio Retention

N

1 inch = 100 feet

Table 4.2a Bio Retention Modeling				
Output File Names	Parameter Names	Parameters	FLO-2D Models	
			LID 2.1	LID 6.5
			Base	Bio Retention
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	4.70
	Wet weather inflow	V (acft)	1.19	0.64
	Return flow	V (acft)	0.04	0.00
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.32
		%	*21*	*30*
	Floodplain storage	V (acft)	1.47	1.83
		%	*34*	*42*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.58
		%	*17*	*13*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.64
		%	*28*	*15*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.75
	Target volume capture	V (acft)	-	0.89
	Utilization of Bio Retention volume	%	-	84.3
	Bio Retention grids	2436		
	Elevation difference volume	0.447	acft	
	Infiltration depth added	0.5	ft	
	Infiltration volume	0.447	acft	
	Total volume capacity	0.89	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



LID Focus Model - Bio Retention Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

LID Focus Model - Bio Retention Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

Abbreviated SUMMARY.OUT FILE

```
                    Pro Model - Build No. 15.02.10
==================================================================
                         *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                 2.5200 INCHES
                                                     WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                        0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
==================================================================
                         *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER         1.12 INCHES
          OVERLAND FLOW                              WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.32
FLOODPLAIN STORAGE                                     1.83
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.58
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.72
TOTAL SURFACE OUTFLOW AND STORAGE                      2.41
==================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          0.64
SWMM TO FLO-2D FROM RETURNING FLOW                     0.00
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             0.64
==================================================================
                                 *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.58
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                          18.23 ACRES
==================================================================
     COMPUTER RUN TIME IS:  3.25830 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/26/2015 AT:  19:26:30
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
*************************          Volume         Depth
Runoff Quantity Continuity       acre-feet        inches
Total Precipitation ......           0.000         0.000
Evaporation Loss .........           0.000         0.000
Infiltration Loss ........           0.000         0.000
Surface Runoff ...........           0.000         0.000
Final Surface Storage ....           0.000         0.000
Continuity Error (%) .....           0.000

*************************          Volume        Volume
Flow Routing Continuity          acre-feet      10^6 gal
Dry Weather Inflow .......           0.000         0.000
Wet Weather Inflow .......           0.644         0.210
Groundwater Inflow .......           0.000         0.000
RDII Inflow ..............           0.000         0.000
External Inflow ..........           0.000         0.000
External Outflow .........           0.636         0.207
Internal Outflow .........           0.000         0.000
Storage Losses ...........           0.000         0.000
Initial Stored Volume ....           0.000         0.000
Final Stored Volume ......           0.002         0.001
Continuity Error (%) .....           0.803

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      0.72       4.70       0.207
--------------------------------------------------------------
System                88.67      0.72       4.70       0.207

Analysis begun on:  Mon Oct 26 16:10:43 2015
Analysis ended on:  Mon Oct 26 19:26:12 2015
Total elapsed time: 03:15:29
```

The following statements explain how and where the values in the tables were obtained from the FLO-2D modeling output files:

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of bio retention grids (2436)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective storage depth (1 ft from 0.5 ft of elevation below curb and 0.5 ft infiltration)].

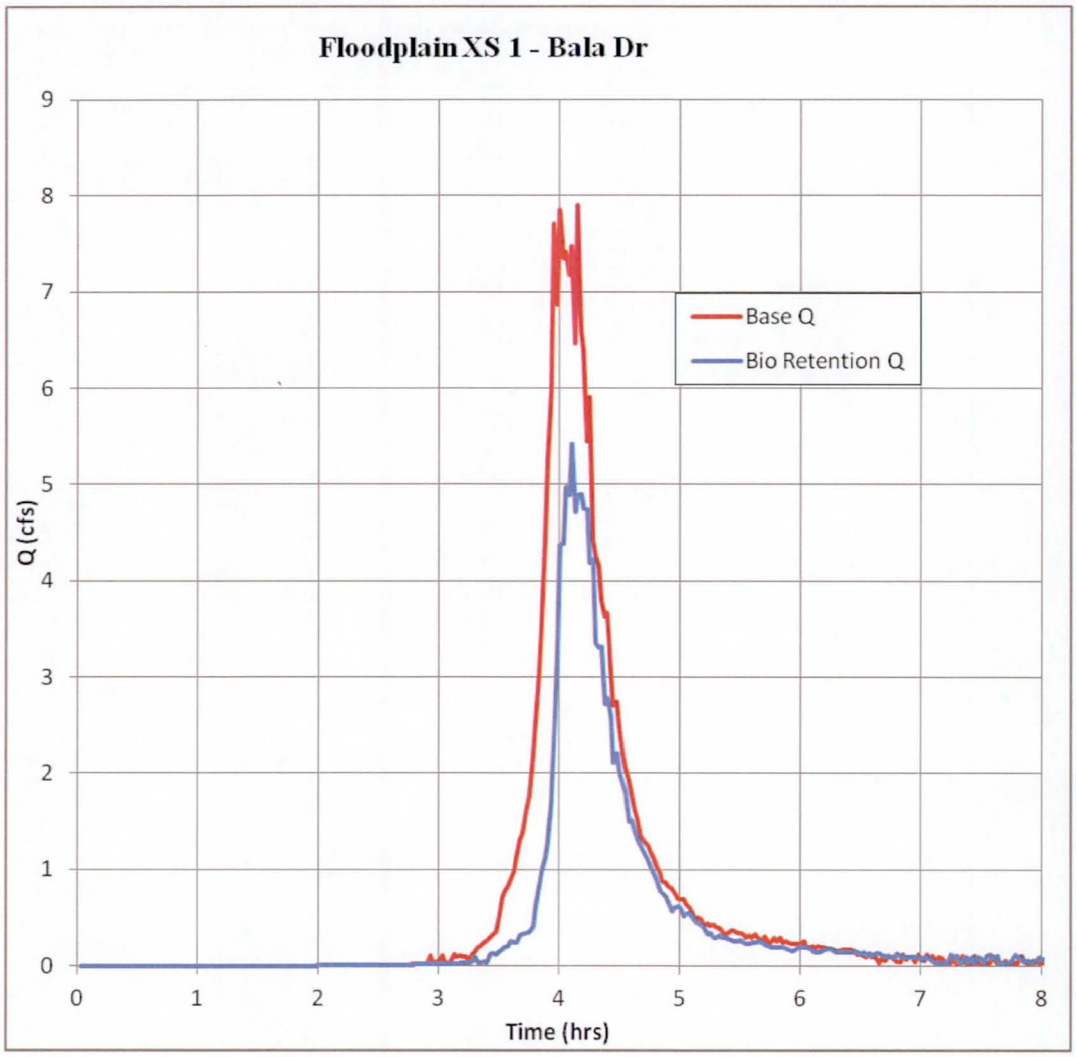
Under "Volume captured", the volume is defined (in acre feet) as:
[Bio retention Infiltration & interception] – [Base Infiltration & interception] + [Bio retention Floodplain storage] – [Base Floodplain storage]

Under "Utilization of Bio retention volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.2a show that if bio retention LID control is constructed in the front yards within the Focus Area with a total capacity of about 20.4% of the rainfall volume (0.89/4.37 = 20.4%) using FPLAIN.DAT and INFIL.DAT parameter adjustment both the surface outflow and the stormdrain outflow were reduced significantly. Of a potential 0.89 ac-ft capacity, the LID control captures 0.75 ac –ft (0.36 ac-ft stored in the open basin and 0.39 ac-ft infiltrated into the bottom). The average infiltration depth is about 5.23 in. out of possible 6.0 in. The utilization of the bio retention LID control capacity is 84.3%. There are multiple reasons why the utilization value is not 100%: flow does not automatically route to the bio retention grids and this model used grid elevation adjustments to connect the street to collect flow onto the bio retention grids to approximate real design conditions. The effectiveness of the bio retention LID control on flood mitigation is also presented by a floodplain maximum depth difference raster with and without LID applications and is shown in Exhibit B1.

The peak flow and volume values for the cross sections are documented in Table 4.2b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.2b shows that both the total surface peak flow and volume reduction with bio retention is about 39%. All of the floodplain hydrographs are included in Appendix C1.

Table 4.2b - Floodplain Cross Section Results								
	Base Model		Bio Retention		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	6.03	0.29	3.18	35	0.16	36
2	0.54	0.03	0.33	0.01	0.21	39	0.02	67
3	2.42	0.10	2.38	0.10	0.04	2	0.00	0
4	6.95	0.46	2.47	0.21	4.48	65	0.25	54
5	1.28	0.04	1.26	0.04	0.02	2	0.00	0
6	5.24	0.65	1.94	0.28	3.30	63	0.37	57
7	2.84	0.37	1.49	0.24	1.35	48	0.13	35
8	8.98	0.42	5.51	0.26	3.47	39	0.16	38
9	1.78	0.05	1.10	0.04	0.68	38	0.01	20
10	0.84	0.05	1.10	0.05	-0.26	-31	0.00	0
11	1.91	0.20	1.83	0.20	0.08	4	0.00	0
Total	41.99	2.82	25.44	1.72	16.55	39	1.10	39


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Bio Retention Q
0
1
2
3
4
5
6
7
8
9

4.3 FLO-2D Modeling Procedures for Bio Swale

In addition to grid elevation adjustments for the grids within the Bio Swale areas, spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of Bio Swale on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Bio Swale LID control, the parcel specific Bio Swale application areas were developed based land uses and topographic features within the modeling areas as shown in Exhibit B2. The total number of grids within Bio Swale area is 1038 with total storage capacity of 0.31 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Grid Assignment

   a) Bio swale grids – Grids were placed in areas that were already collecting flow. In this model, portions of the streets where access and parking were not critical were used to model 4 grid-wide bio swales. Grids along the lowest part of the curb were assigned as the bio swale thalweg grids while the rest of them were just assigned as bio swale grids.

2) Input Data

   a) FPLAIN.DAT
      i) Elevations – The thalweg grids were given a uniform adjustment of -0.5 ft and the bio swale grids were given a uniform adjustment of -0.25 ft. Positive slope already existed throughout the selected grids and was maintained through the adjustment.
      ii) N values – All modified grids were given an n-value of 0.075 to conservatively estimate added vegetation and rock added to the swale.

   b) INFIL.DAT – The bio retention area grid infiltration parameters were modified as if they were a loamy sand soil amendment with an additional 6 in of infiltration-loss capacity:

      i) HYDC – The hydraulic conductivity, in inches/hr: A value of 1.2 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2
      ii) SOILS – The soil suction head, in inches: a value of 2.4 was used based on the 1995 FCDMC Drainage Design Manual, Table 4.2
      iii) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3.
      iv) ABSTRINF - The initial abstraction in inches: a value of 0 was used for the bio swale area grids.

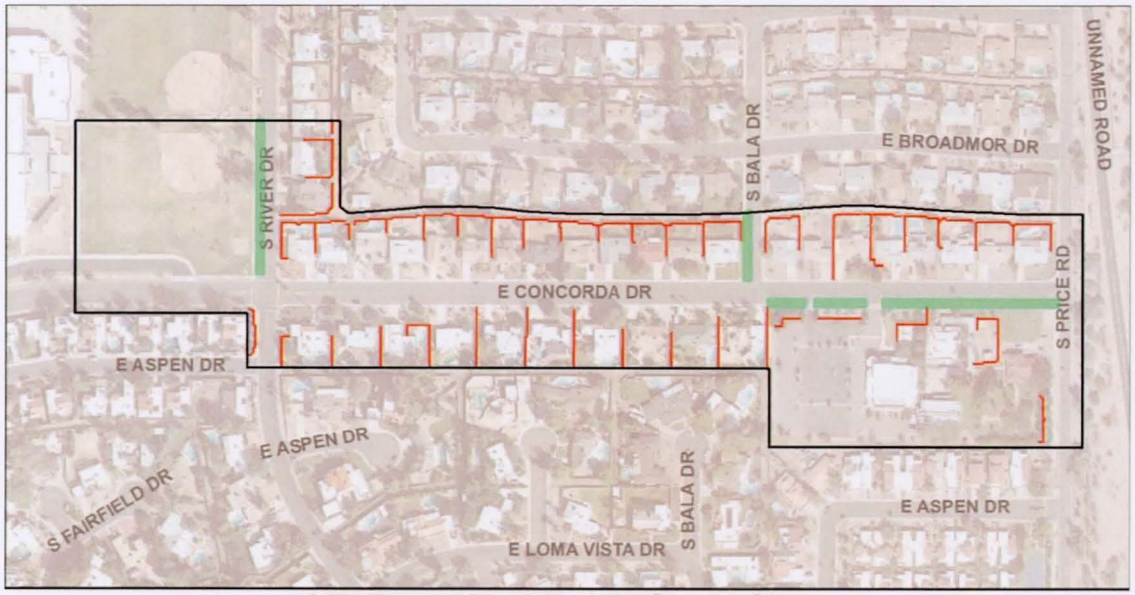
v) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 was used to allow full infiltration.
vi) SOILD – The limiting soil depth in feet: A value of 1.667 was added on top of the original limiting soil depth used. This was determined by using our design depth of 6 in divided by DTHETA and converted to feet.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Swale LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.3a.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.3a and the numbers used were highlighted (These files were also included in Appendix C2):

	Table 4.3a Bio Swale Modeling	Model	LID 2.1	LID 13
			Base	Bio Swale
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	8.45
	Wet weather inflow	V (acft)	1.19	1.11
	Return flow	V (acft)	0.04	0.03
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	0.99
		%	*21*	*23*
	Floodplain storage	V (acft)	1.47	1.5
		%	*34*	*34*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.79
		%	*17*	*18*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.1
		%	*28*	*25*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.02
Check	Sum of volumes	V (acft)	4.36	4.36
	Volume captured	V (acft)	-	0.09
	Target volume capture	V (acft)	-	0.31
	Utilization of Bioswale volume	%	-	29.1
	Street swale grids	1038		
	Elevation difference volume	0.119	acft	
	Infiltration depth added	0.5	ft	
	Infiltration volume	0.191	acft	
	Total volume capacity	0.310	acft	

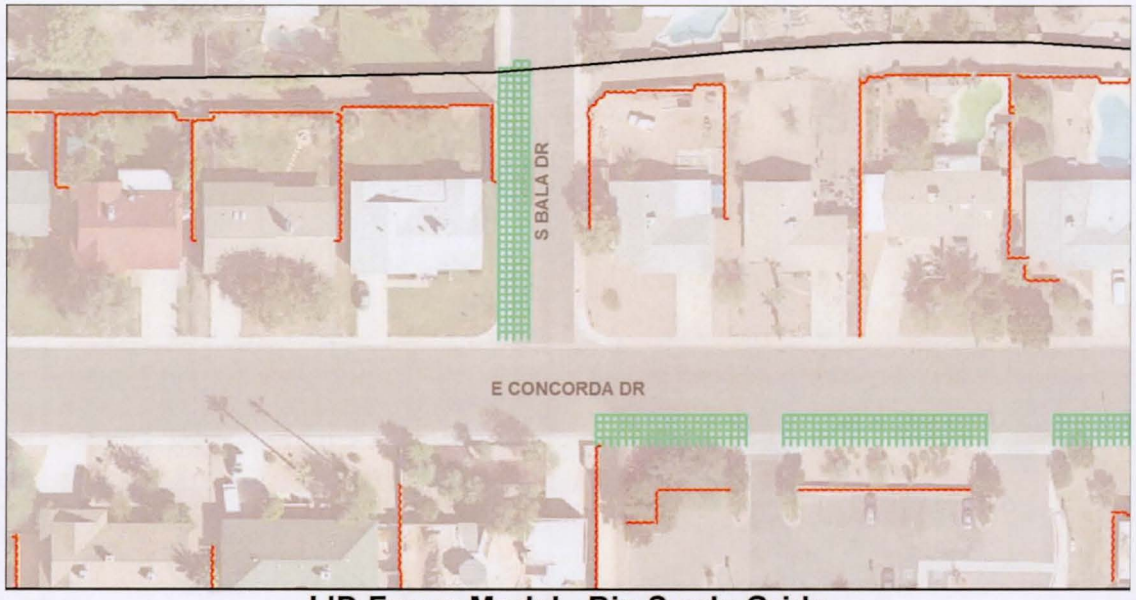


LID Focus Model - Bio Swale Grids

Model Boundary — Walls — Bio Swale

N

1 inch = 400 feet



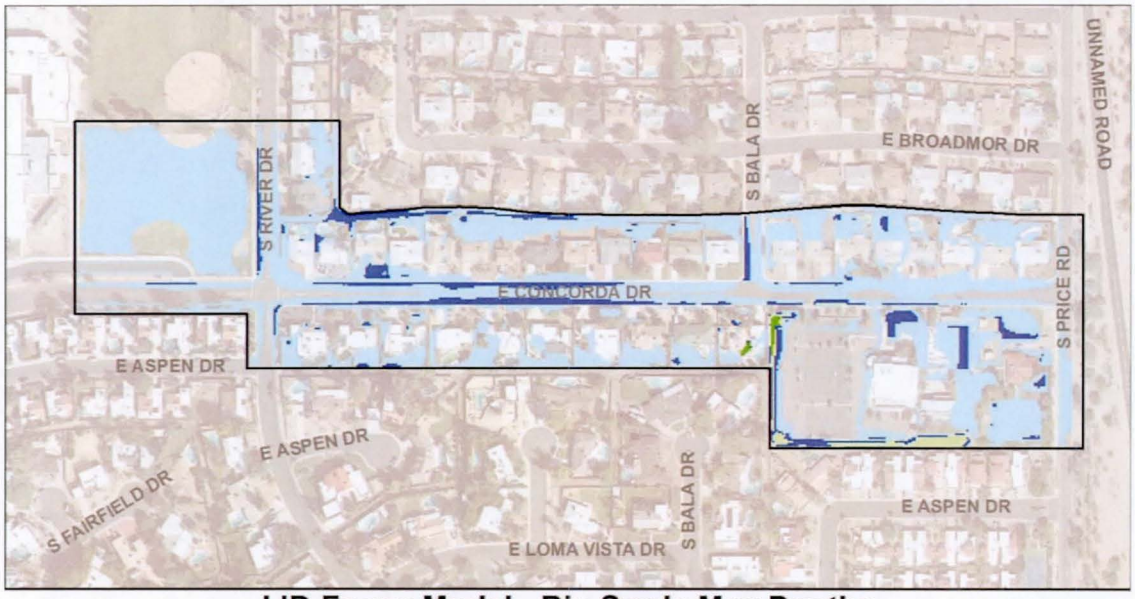
LID Focus Model - Bio Swale Grids

Model Boundary — Walls — Bio Swale

N

1 inch = 100 feet

The maximum flow depth for the focus area and a close-up area are shown below.



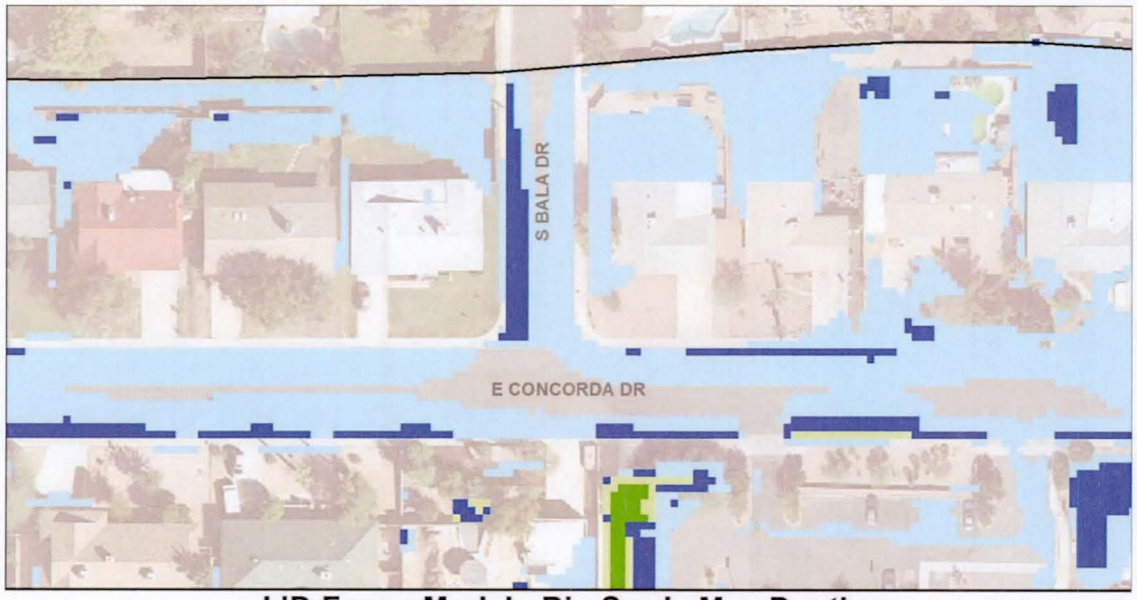
LID Focus Model - Bio Swale Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 fee



LID Focus Model - Bio Swale Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 fee

```
                    Abbreviated SUMMARY.OUT FILE

                 Pro Model - Build No. 15.02.10
================================================================
                    MASS BALANCE   INFLOW - OUTFLOW VOLUME
================================================================
                         *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                       0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
================================================================
                         *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER      0.90 INCHES
          OVERLAND FLOW                            WATER
WATER LOST TO INFILTRATION & INTERCEPTION              0.99
FLOODPLAIN STORAGE                                     1.50
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.79
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.28
TOTAL SURFACE OUTFLOW AND STORAGE                      2.29
================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          1.10
SWMM TO FLO-2D FROM RETURNING FLOW                     0.02
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             1.08
================================================================
                                 *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.79
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)
THE MAXIMUM INUNDATED AREA IS:                          18.23 ACRES
================================================================
     COMPUTER RUN TIME IS:  3.57471 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/23/2015  AT:  20:28:18
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------
Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
*************************          Volume         Depth
Runoff Quantity Continuity       acre-feet        inches
Total Precipitation ......           0.000         0.000
Evaporation Loss .........           0.000         0.000
Infiltration Loss ........           0.000         0.000
Surface Runoff ...........           0.000         0.000
Final Surface Storage ....           0.000         0.000
Continuity Error (%) .....           0.000

*************************          Volume        Volume
Flow Routing Continuity          acre-feet      10^6 gal
Dry Weather Inflow .......           0.000         0.000
Wet Weather Inflow .......           0.644         0.210
Groundwater Inflow .......           0.000         0.000
RDII Inflow ..............           0.000         0.000
External Inflow ..........           0.000         0.000
External Outflow .........           0.636         0.207
Internal Outflow .........           0.000         0.000
Storage Losses ...........           0.000         0.000
Initial Stored Volume ....           0.000         0.000
Final Stored Volume ......           0.002         0.001
Continuity Error (%) .....           0.803

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      0.72       4.70       0.207
--------------------------------------------------------------
System                88.67      0.72       4.70       0.207

Analysis begun on:  Mon Oct 26 16:10:43 2015
Analysis ended on:  Mon Oct 26 19:26:12 2015
Total elapsed time: 03:15:29
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of bio swale grids(1038)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective storage depth (0.5 ft or 0.25 ft depending on location in bio swale and 0.5 ft infiltration)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Bio swale Infiltration & interception] – [Base Infiltration & interception] + [Bio swale Floodplain storage] – [Base Floodplain storage]

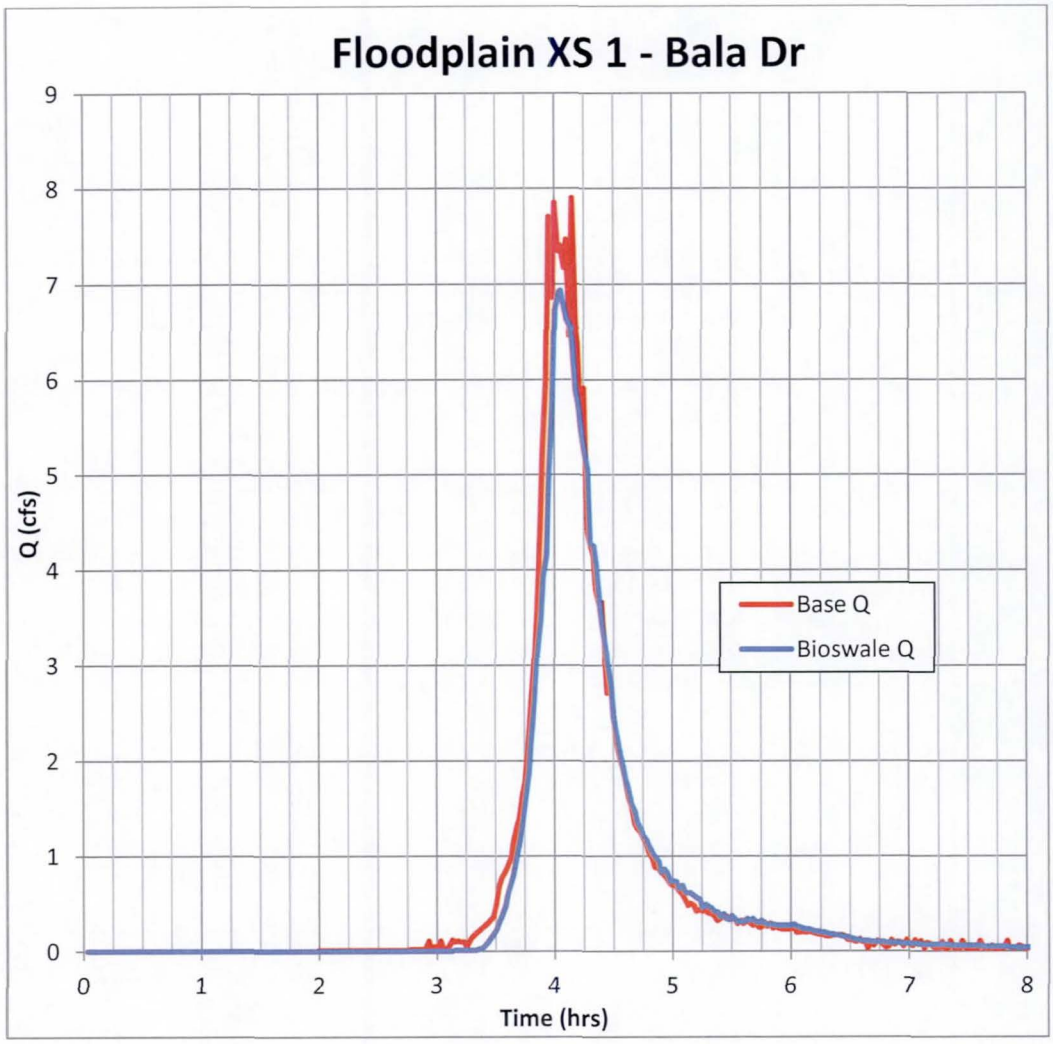
Under "Utilization of Bio swale volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.3a show that modeling small bio swales within the small grid model (total capacity is about 7.1% of the rainfall volume) using FPLAIN.DAT and INFIL.DAT parameter adjustment as outlined in this memo increases the volume infiltrated, stored on the floodplain, as well as the stormdrain outflow. Of a potential 0.31 ac-ft, the model captures 0.09 ac –ft. This value is lower than expected because the grids are already located in areas that collect and convey flow, so not much remains in its storage. A floodplain maximum depth difference raster is shown in Exhibit B2.

The peak flow and volume values for the cross sections are documented in Table 4.3b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.3b showed that the total surface peak flow reduction with bio swale is about 15% and that the total volume reduction is about 5%. All of the floodplain hydrographs are included in Appendix C2.

Table 4.3b Floodplain Cross Section Results

	Base Model		Bio Swale		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	7.37	0.41	1.84	20	0.04	9
2	0.54	0.03	0.83	0.11	-0.29	-54	-0.08	-267
3	2.42	0.10	2.28	0.10	0.14	6	0.00	0
4	6.95	0.46	6.20	0.45	0.75	11	0.01	2
5	1.28	0.04	1.30	0.04	-0.02	-2	0.00	0
6	5.24	0.65	4.94	0.64	0.30	6	0.01	2
7	2.84	0.37	2.13	0.29	0.71	25	0.08	22
8	8.98	0.42	7.27	0.37	1.71	19	0.05	12
9	1.78	0.05	0.76	0.03	1.02	57	0.02	40
10	0.84	0.05	0.83	0.05	0.01	1	0.00	0
11	1.91	0.20	2.01	0.20	-0.10	-5	0.00	0
Total	41.99	2.82	35.92	2.69	6.07	15	0.13	5


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Bioswale Q
0
1
2
3
4
5
6
7
8
9

4.4 FLO-2D Modeling Procedures for Pervious Pavement

Spatially varied infiltration rates and limiting soil depths method was applied by the FLO-2D model to evaluate the impact of pervious pavement on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Pervious Pavement LID control, the parcel specific Pervious Pavement application areas were developed based driveways and parking lots within the modeling areas as shown in Exhibit B3. The total number of grids within pervious pavement area is 5802 with 4.8 in storage capacity. The capacity is based on a typical depth of 12 in for parking lots and residential uses, with a porosity of 0.4. These values were obtained from a Belgard Commercial memo (page 14) on Sustainable & Pervious Pavement Systems which was included in Appendix A3. Generally, the surface of the pervious pavement will limit the infiltration rate. Pavers with a typical void opening of 5% will limit the infiltration to 50-75 in/hr. Porous concretes can generally infiltrate 100-400 in/hr. An infiltration rate of 500in/hr was used in order to remove it as a limitation on the potential for the volume capture under the direction of the FCDMC.

Step 2: Developing INFIL.DAT files

The steps for revising the INFIL.DAT file are as follows starting with a working base model:

1) Grid assignment for pervious pavement - In our model, grids overlaying driveways and parking lots were assigned as pervious pavement grids. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for pervious pavement grids:
   a) HYDC – The hydraulic conductivity in inches/hr: a value of 500 was used;
   b) SOILS – The soil suction head in inches: a value of 1 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
   c) DTHETA – The volumetric soil moisture deficit, a coefficient that determines available volume within a depth of soil: a value of 0.3 was used based on the 1995 FCDMC Drainage Design Manual Figure 4.3;
   d) ABSTRINF – The initial abstraction in inches: a value of 0 was used for the pervious pavement.
   e) RTIMP – A coefficient representing the imperviousness of the surface: a value of 0 was used to allow full infiltration;
   f) SOILD – The limiting soil depth in feet: A value of 1.333 was used. This was determined by using our design depth of 4.8 in divided by DTHETA and converted to feet.

3) Collection of runoff
   Modifying infiltration parameters on grids to model LID features will not guarantee that their effects will be reflected in the results. If the effective storage capacity of the pervious pavement is greater than the rainfall depth, steps need to be taken to collect flow to the LID areas to measure the full effect. There are multiple ways to

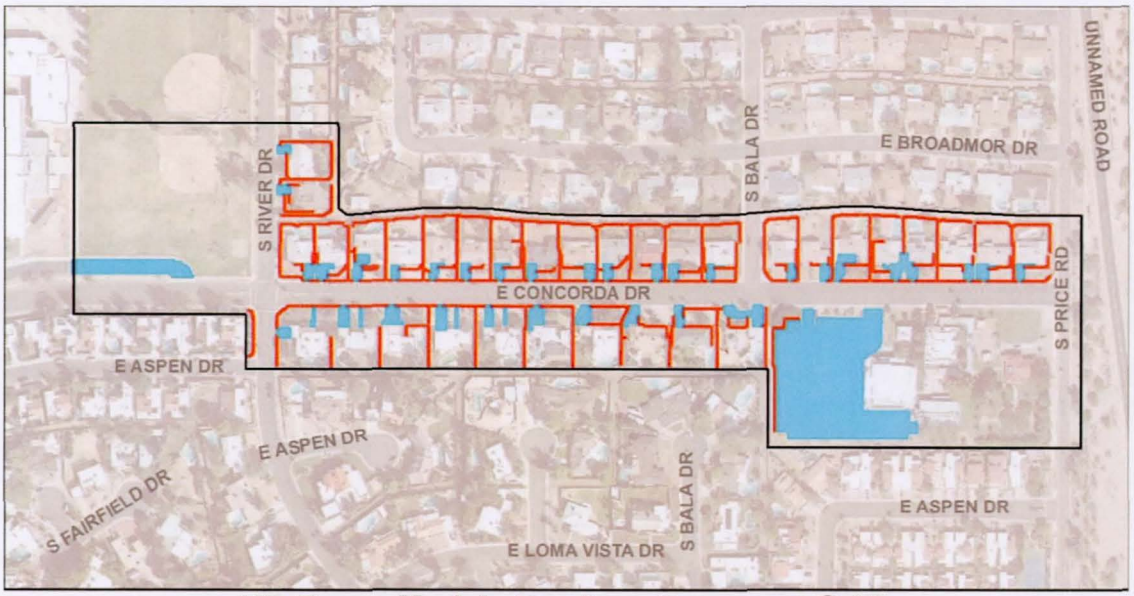
modify the input files in FLO-2D to route the flow (Exhibit B3 shows the pervious pavement modeling area with artificial walls):

a) Walls as modeled in LEVEE.DAT – This can be used to restrict where water flows and can be used to force water to flow towards feature grids. This method is the easiest to implement on a larger scale and is not recommended when looking at one particular parcel. This was used for all residential parcels within the LID Focus Area model due to its ease of implementation;
b) Hydraulic structures using HYSTRUC.DAT –This can be used to transfer water that is ponding or flowing over a particularly low spot on a parcel to the feature (Pervious Pavement) grids. This method can also be used to model a French drain or used in conjunction with walls to most realistically simulate a roof gutter and downspout.
c) Manipulation of elevation data in FPLAIN.DAT: This method is the most realistic but requires more effort. It is ideal as it will most realistically mimic any grading involved. This was done for the church site on the southeast corner of the model in order to inundate the large parking lot.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with pervious pavement LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.4a. A floodplain maximum depth difference raster is shown in Exhibit B3.

The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.4a and the numbers used were highlighted (These files were also included in Appendix C3):



LID Focus Model - Pervious Pavement Grids

Model Boundary — Walls for P. Pavement — Pervious Pavement

N

1 inch = 400 feet

LID Focus Model - Pervious Pavement Grids

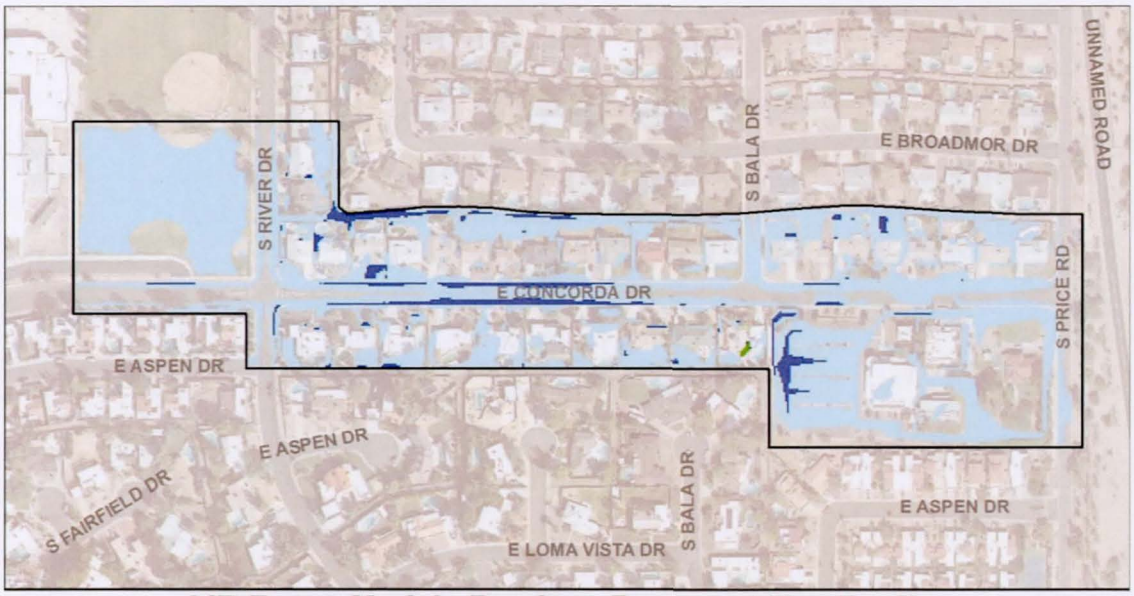
Model Boundary — Walls for P. Pavement — Pervious Pavement

N

1 inch = 100 feet

Table 4.4a Pervious Pavement Modeling		Model	LID 2.1	LID 7.3
			Base	P. Pavement
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	7.52
	Wet weather inflow	V (acft)	1.19	1.02
	Return flow	V (acft)	0.04	0.02
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.67
		%	*21*	*38*
	Floodplain storage	V (acft)	1.47	1.09
		%	*34*	*25*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.59
		%	*17*	*14*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.02
		%	*28*	*23*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.74
	Target volume capture	V (acft)	-	0.85
	Utilization of pervious pavement volume	%	-	86.81
	Rainfall Depth	2.52	in	
	Total Grids in Model (4'x4')	56693		
	Total Model Area	20.8	ac	
	Number of Pervious Pavement Grids (4'x4')	5802		
	Effective Pervious Pavement Depth	0.4	ft	
	Pervious Pavement Volume Capacity	0.852	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



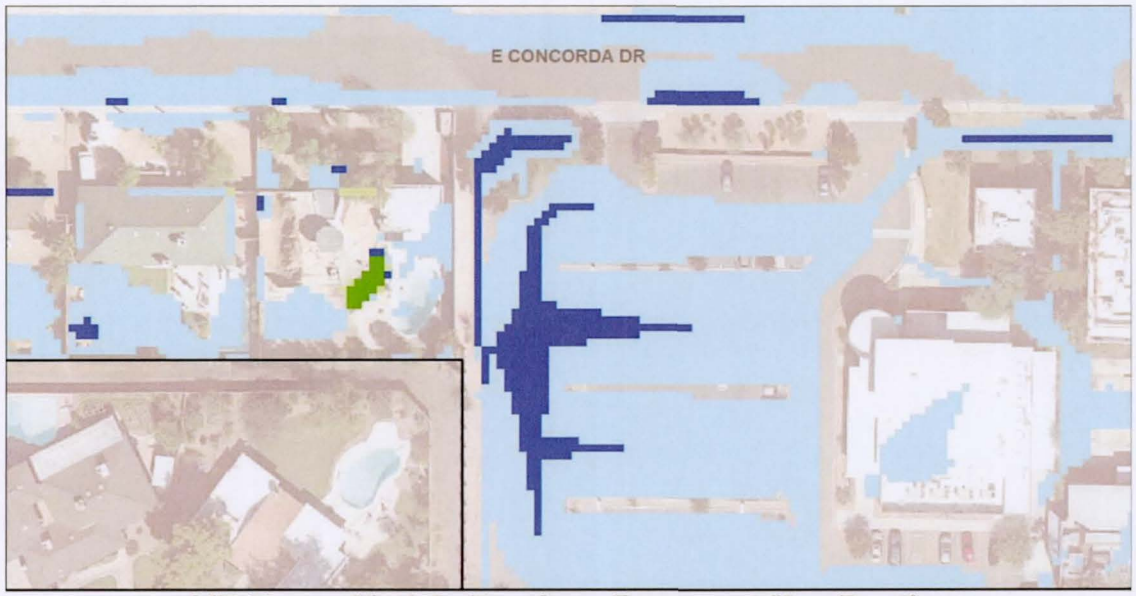
LID Focus Model - Pervious Pavement Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Pervious Pavement Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

Abbreviated SUMMARY.OUT FILE

```
                    Pro Model - Build No. 15.02.10
==================================================================
                      MASS BALANCE   INFLOW - OUTFLOW VOLUME
==================================================================
                           *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES

                                                     WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                        0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
==================================================================
                           *** SURFACE OUTFLOW (ACRE-FT) ***

OVERLAND INFILTRATED AND INTERCEPTED WATER       1.28 INCHES

          OVERLAND FLOW                              WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.67
FLOODPLAIN STORAGE                                     1.09
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.59
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.35

TOTAL SURFACE OUTFLOW AND STORAGE                      1.68
==================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***

FLO-2D TO SWMM THROUGH INLETS                          1.02
SWMM TO FLO-2D FROM RETURNING FLOW                     0.00
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             1.02
==================================================================
                                  *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.59
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                          17.85 ACRES
==================================================================
     COMPUTER RUN TIME IS :  3.32617 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/19/2015  AT:  15: 6:47
```

```
                                   Abbreviated SWMM.RPT

EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
 --------------------------------------------------------------

 ********************************************************
 NOTE: The summary statistics displayed in this report are
 based on results found at every computational time step,
 not just on results from each reporting time step.
 ********************************************************

 **************************          Volume         Depth
 Runoff Quantity Continuity       acre-feet        inches
 **************************       ---------       -------
 Total Precipitation ......           0.000         0.000
 Evaporation Loss .........           0.000         0.000
 Infiltration Loss ........           0.000         0.000
 Surface Runoff ...........           0.000         0.000
 Final Surface Storage ....           0.000         0.000
 Continuity Error (%) .....           0.000


 **************************          Volume         Volume
 Flow Routing Continuity          acre-feet       10^6 gal
 **************************       ---------      ---------
 Dry Weather Inflow .......           0.000         0.000
 Wet Weather Inflow .......           1.023         0.333
 Groundwater Inflow .......           0.000         0.000
 RDII Inflow ..............           0.000         0.000
 External Inflow ..........           0.000         0.000
 External Outflow .........           0.986         0.321
 Internal Outflow .........           0.018         0.006
 Storage Losses ...........           0.000         0.000
 Initial Stored Volume ....           0.000         0.000
 Final Stored Volume ......           0.002         0.001
 Continuity Error (%) .....           1.673

 ************************
 Outfall Loading Summary
 ************************

 ------------------------------------------------------------
                       Flow       Avg.       Max.       Total
                       Freq.      Flow       Flow      Volume
 Outfall Node          Pcnt.       CFS        CFS    10^6 gal
 ------------------------------------------------------------
 I388                  88.67      1.12       7.52       0.321
 ------------------------------------------------------------
 System                88.67      1.12       7.52       0.321

 Analysis begun on:  Mon Oct 19 11:46:52 2015
 Analysis ended on:  Mon Oct 19 15:06:28 2015
 Total elapsed time: 03:19:36
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of pervious pavement grids(5802)] * [grid area (4 ft*4 ft=16ft²)] * [Effective pervious pavement storage depth (0.4 ft = 4.8 in)].

Under "Volume captured", the volume is defined (in acre feet) as:
[P.Pavement Infiltration & interception] – [Base Infiltration & interception]

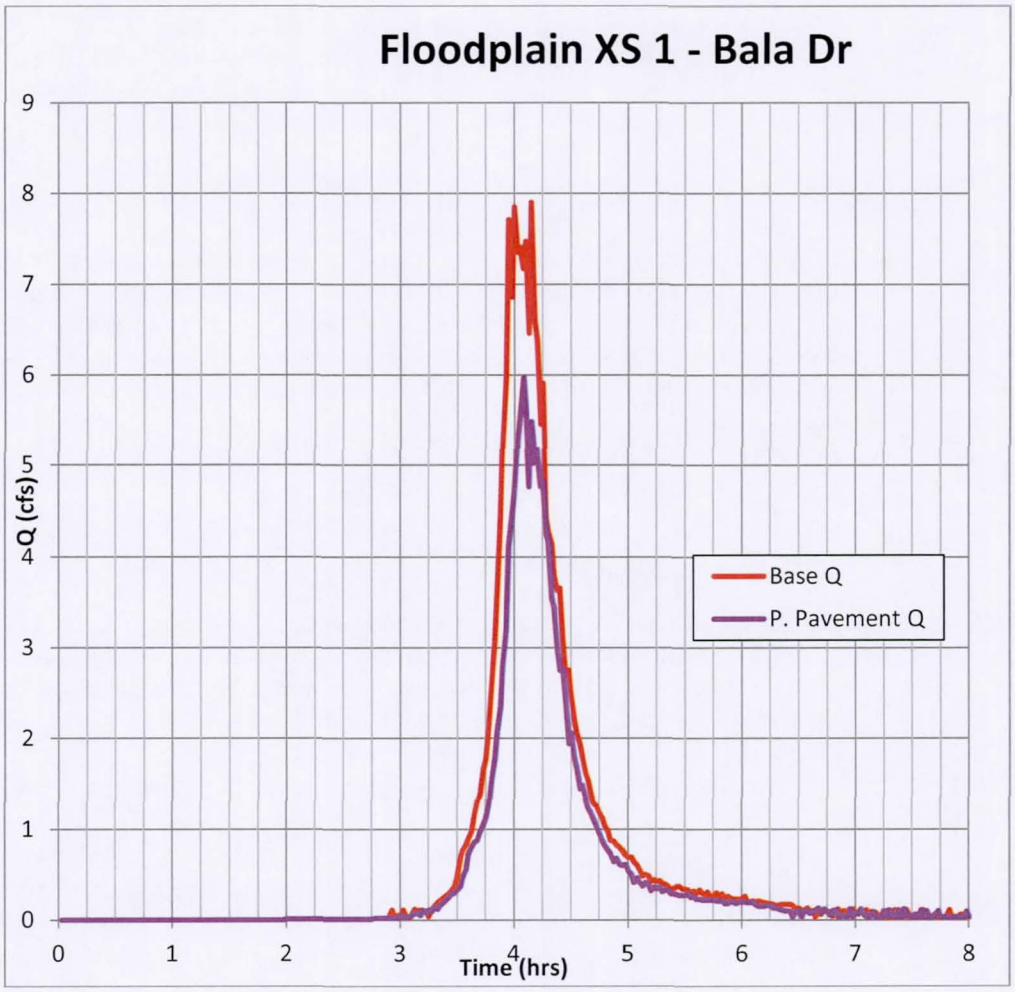
Under "Utilization of pervious pavement volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.4a show that modeling the driveways and parking lots within the small grid model (total capacity is about 19.5% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage (25.8%) and outflow (22.4%), as well as the stormdrain outflow. Of a potential 0.85 ac-ft, the model infiltrates 0.74 ac –ft. There are multiple reasons why this value is not 100%. Flow does not automatically route to the pervious pavement grids. This model used artificial walls and site grading to help guide flow onto the pervious pavement grids to approximate real design conditions. These walls and the grading could be refined in iterations along with possible modifications to hydraulic structures to achieve 100%, which would be more feasible if looking at a smaller model or a single parcel.

The peak flow and volume values for the cross sections are documented in Table 4.4b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.4b shows that the total surface peak flow reduction with pervious pavement is about 29% and that the total volume reduction is about 19%. All of the floodplain hydrographs are included in Appendix C3.

Table 4.4b Floodplain Cross Section Results

	Base Model		P. Pavement Model		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	6.45	0.33	2.76	30	0.12	27
2	0.54	0.03	0.47	0.02	0.07	13	0.01	33
3	2.42	0.10	1.66	0.07	0.76	31	0.03	30
4	6.95	0.46	5.19	0.41	1.76	25	0.05	11
5	1.28	0.04	1.20	0.04	0.08	6	0.00	0
6	5.24	0.65	3.89	0.62	1.35	26	0.03	5
7	2.84	0.37	1.94	0.26	0.90	32	0.11	30
8	8.98	0.42	5.78	0.30	3.20	36	0.12	29
9	1.78	0.05	0.70	0.02	1.08	61	0.03	60
10	0.84	0.05	0.71	0.03	0.13	16	0.02	40
11	1.91	0.20	1.78	0.18	0.13	7	0.02	10
Total	41.99	2.82	29.77	2.28	12.22	29	0.54	19


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
P. Pavement Q
0
1
2
3
4
5
6
7
8
9

4.5 FLO-2D Modeling Procedures for Rainwater Harvesting

Spatially varied Initial Abstraction values, IA, were applied by the FLO-2D model to evaluate the impact of Rainwater Harvesting LID control on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Rainwater Harvesting LID control, the parcel specific Rainwater Harvesting application areas were developed based building roof features within the modeling areas as shown in Exhibit B4. The total number of grids within Rainwater Harvesting area is 8392 with total storage capacity of 0.12 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Assign roof grids. In our model, grids overlaying building features as characterized in the surface feature data shapefile provided by FCDMC were assigned as roof grids and then spot checked. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for roof grids

   a) ABSTRINF – The initial abstraction in inches: This value was modified based on 1000 gallons of volume spread across a roof area. Grids were individually attributed with the area of the building they overlaid. The depth adjustment to IA was then calculated:

[New IA(in)] = [Exist. IA(in)] + {[Grid area (ft^2)]* [1000 (gal)] * [1/7.48 (ft^3/gal)] / [Roof area (ft^2)] * [12 (in/ft)]}.

Collection of runoff:

Rain tanks and cisterns generally only collect water from a roof. In this modeling scenario, only roof grids were modified, so no additional routing was necessary.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Rainwater Harvesting LID control for all buildings (40) was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.5a.

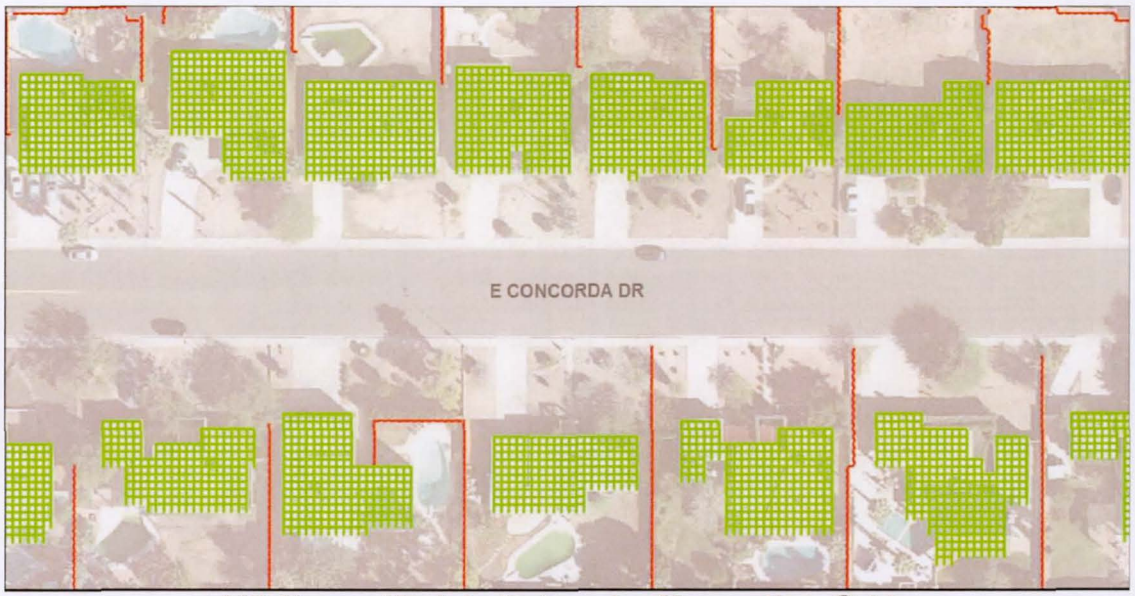
The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.5a and the numbers used were highlighted (These files were also included in Appendix C4):

LID Focus Model - Rainwater Harvesting Grids

Model Boundary — Walls — Rainwater Harvesting

N

1 inch = 400 feet



LID Focus Model - Rainwater Harvesting Grids

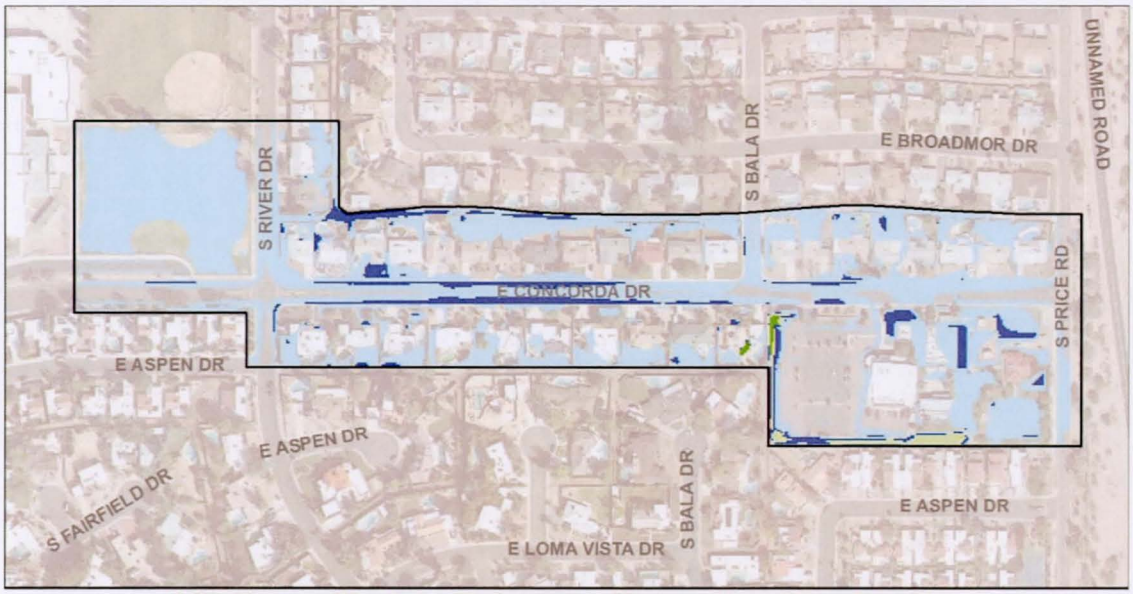
Model Boundary — Walls — Rainwater Harvesting

N

1 inch = 100 feet

Table 4.5a Rainwater Harvesting Modeling		Model	LID 2.1	LID 9.3
			Base	Rainwater Harvesting
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	8.62
	Wet weather inflow	V (acft)	1.19	1.15
	Return flow	V (acft)	0.04	0.04
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.05
		%	*21*	*24*
	Floodplain storage	V (acft)	1.47	1.44
		%	*34*	*33*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.73
		%	*17*	*17*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	1.17
		%	*28*	*27*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.02
Check	Sum of volumes	V (acft)	4.36	4.37
	Volume captured	V (acft)	-	0.12
	Target volume capture	V (acft)	-	0.12
	Utilization of Rain Tank volume	%	-	97.7
	Roof grids	8392		
	Roof Area	3.08	ac	
	Roofs	40		
	Σ1000-gal tanks volume	0.123	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



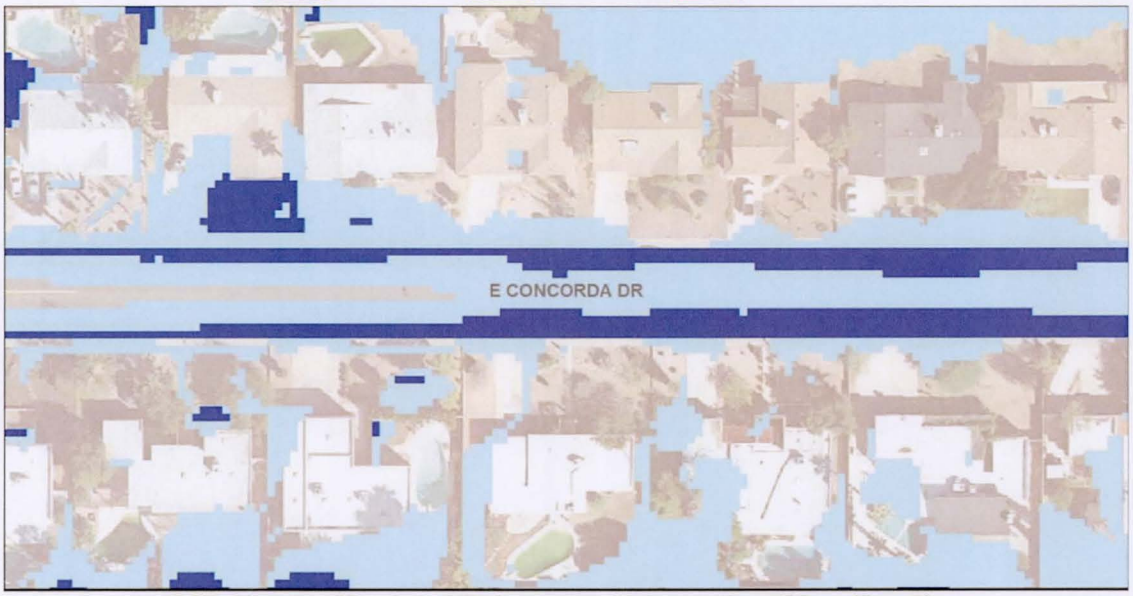
LID Focus Model - Rainwater Harvesting Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Rainwater Harvesting Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

```
                    Abbreviated SUMMARY.OUT FILE
              Pro Model - Build No. 15.02.10

                    *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                2.5200 INCHES
                                                    WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                      0.00
                                                  ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
=====================================================================
                    *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER        0.95 INCHES
         OVERLAND FLOW                              WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.05
FLOODPLAIN STORAGE                                     1.44
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.73
                                                  ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.22
TOTAL SURFACE OUTFLOW AND STORAGE                      2.17
=====================================================================
         *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          1.17
SWMM TO FLO-2D FROM RETURNING FLOW                     0.02
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                  ---------
NET VOLUME                                             1.15
=====================================================================
                          *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.73
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                        18.23 ACRES
=====================================================================
     COMPUTER RUN TIME IS:  3.83838 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/15/2015  AT:  18:55:35
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------

Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
*************************          Volume         Depth
Runoff Quantity Continuity       acre-feet        inches
Total Precipitation ......           0.000         0.000
Evaporation Loss .........           0.000         0.000
Infiltration Loss ........           0.000         0.000
Surface Runoff ...........           0.000         0.000
Final Surface Storage ....           0.000         0.000
Continuity Error (%) .....           0.000

*************************          Volume        Volume
Flow Routing Continuity          acre-feet      10^6 gal
Dry Weather Inflow .......           0.000         0.000
Wet Weather Inflow .......           1.152         0.376
Groundwater Inflow .......           0.000         0.000
RDII Inflow ..............           0.000         0.000
External Inflow ..........           0.000         0.000
External Outflow .........           1.109         0.362
Internal Outflow .........           0.035         0.011
Storage Losses ...........           0.000         0.000
Initial Stored Volume ....           0.000         0.000
Final Stored Volume ......           0.002         0.001
Continuity Error (%) .....           0.534

Outfall Loading Summary
***********************
                      Flow       Avg.       Max.       Total
                      Freq.      Flow       Flow      Volume
Outfall Node          Pcnt.       CFS        CFS    10^6 gal
I388                  88.67      1.26       8.62       0.361
-------------------------------------------------------------
System                88.67      1.26       8.62       0.361

Analysis begun on:  Thu Oct 15 15:04:57 2015
Analysis ended on:  Thu Oct 15 18:55:16 2015
Total elapsed time: 03:50:19
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of roof grids(8392)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective roof storage depth (Obtained by converting 1000gal to ft^3 and dividing it by the individual roof area in ft^2)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Rainwater Harvesting Infiltration & interception] – [Base Infiltration & interception]

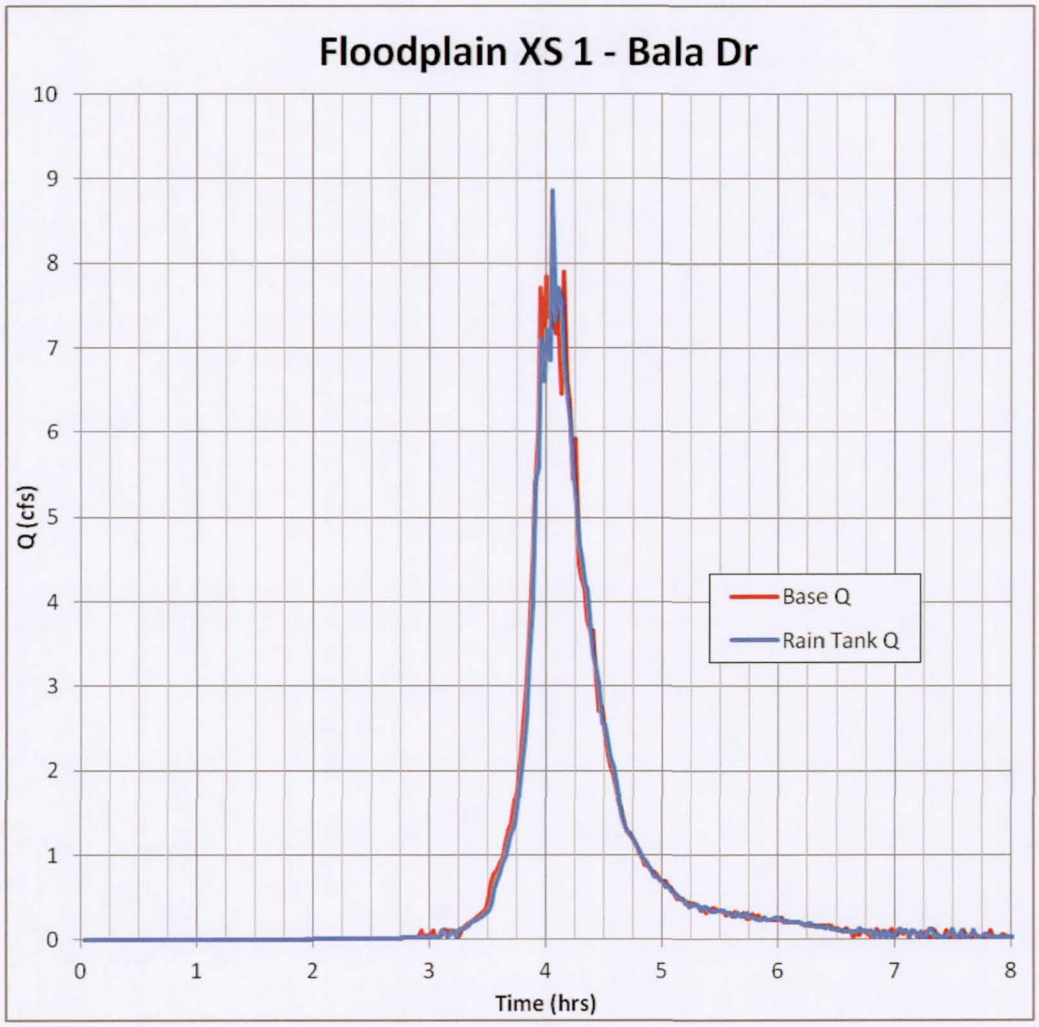
Under "Utilization of Rainwater Harvesting volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.5b show that modeling the roofs within the small grid model (total capacity is about 2.7% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage and outflow. All of the potential 0.12 ac-ft LID volume is intercepted. A floodplain maximum depth difference raster is shown in Exhibit B4.

The peak flow and volume values for the cross sections are documented in Table 4.5b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.5b shows that the total surface peak flow reduction with Rainwater Harvestings is about 4% and that the total volume reduction is about 5%. All of the floodplain hydrographs are included in Appendix C4.

Table 4.5b Floodplain Cross Section Results

	Base Model		Rainwater Harvesting		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	8.89	0.44	0.32	4	0.01	2
2	0.54	0.03	0.52	0.02	0.02	4	0.01	33
3	2.42	0.10	2.29	0.10	0.13	5	0.00	0
4	6.95	0.46	6.07	0.44	0.88	13	0.02	4
5	1.28	0.04	1.28	0.04	0.00	0	0.00	0
6	5.24	0.65	5.12	0.62	0.12	2	0.03	5
7	2.84	0.37	2.64	0.35	0.20	7	0.02	5
8	8.98	0.42	8.94	0.40	0.04	0	0.02	5
9	1.78	0.05	1.89	0.05	-0.11	-6	0.00	0
10	0.84	0.05	0.79	0.04	0.05	6	0.01	20
11	1.91	0.20	1.76	0.19	0.15	8	0.01	5
Total	41.99	2.82	40.19	2.69	1.8	4	0.13	5


Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Rain Tank Q
0
1
2
3
4
5
6
7
8
9
10

4.6 FLO-2D Modeling Procedures for Green Roof

Spatially varied Initial Abstraction values, IA, were applied by the FLO-2D model to evaluate the impact of Green Roof LID control on the study area hydrology and hydraulics. The detailed steps are:

Step 1: Determining Parcel Design Capacities for LID Controls

In general, total LID design capacities for all the parcels within the modeling area should be estimated based on land uses and sizes according to land use zoning and the City's on-site retention requirements, such as 100-year, 2-hour on-site retention requirement. For the Green Roof LID control, the parcel specific Green Roof application areas were developed based building roof features within the modeling areas as shown in Exhibit B5. The total number of grids within Green Roof area is 8392 with total storage capacity of 0.65 ac-ft.

Step 2: Developing FLO-2D Input Data files

The steps for revising the FLO-2D input data files are as follows starting with a working base model:

1) Assign roof grids. In our model, grids overlaying building features as characterized in the surface feature data shapefile provided by FCDMC were assigned as roof grids and then spot checked. This was performed in GIS using the MGRID shapefile that can be exported from FLO-2D GDS/Mapper.

2) Parameters for INFIL.DAT – modifying the spatial parameters for roof grids

   a) ABSTRINF – The initial abstraction in inches: This value was modified based on a limitation of not being able to take more than the rainfall that falls on it. With a rainfall of 2.52 in for this simulation, the roof grids were given an IA of 2.52 in.

Collection of runoff:

Green roofs generally only collect water from a roof. In this modeling scenario, only roof grids were modified, so no additional routing was necessary.

Step 3: Running FLO-2D Models and Documenting Results

A base model was developed without any LID applications (100-year, 6-hour storm model) and a model with Bio Swale LID control for all parcels was developed to simulate the effects of LID applications. The modeling results were documented in Table 4.6a.

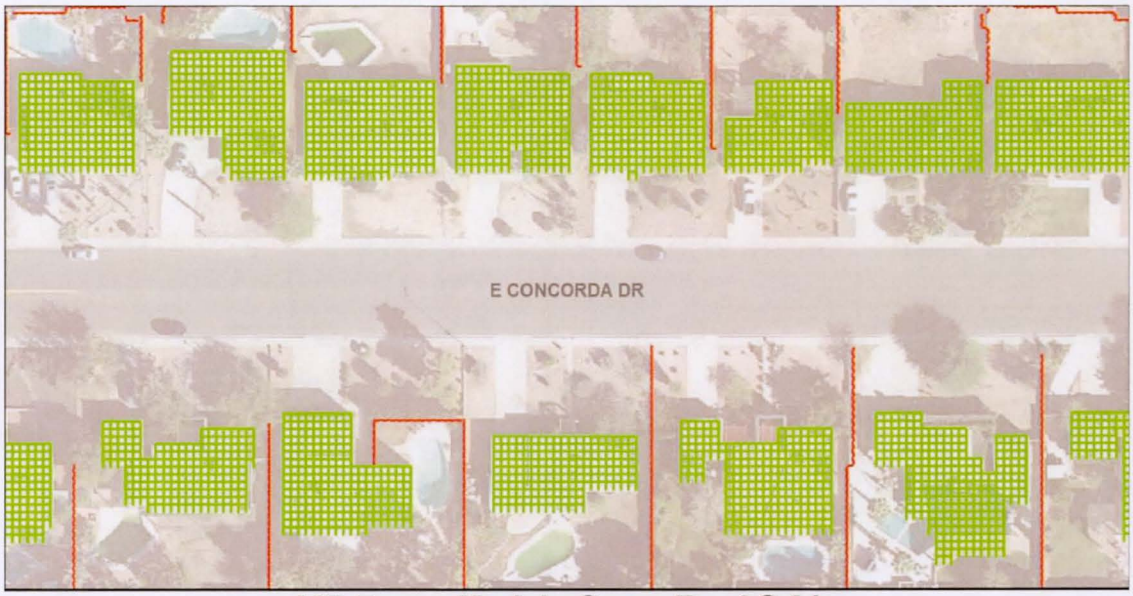
The total LID design volume is the LID system capacity within the modeling area. The surface flow comparison values were from "SUMMARY.OUT" file and the storm drain flow comparison values were from SWMM.RPT file as shown in Table 4.6a and the numbers used were highlighted (These files were also included in Appendix C5):

LID Focus Model - Green Roof Grids

Model Boundary — Walls — Green Roof

N

1 inch = 400 feet



LID Focus Model - Green Roof Grids

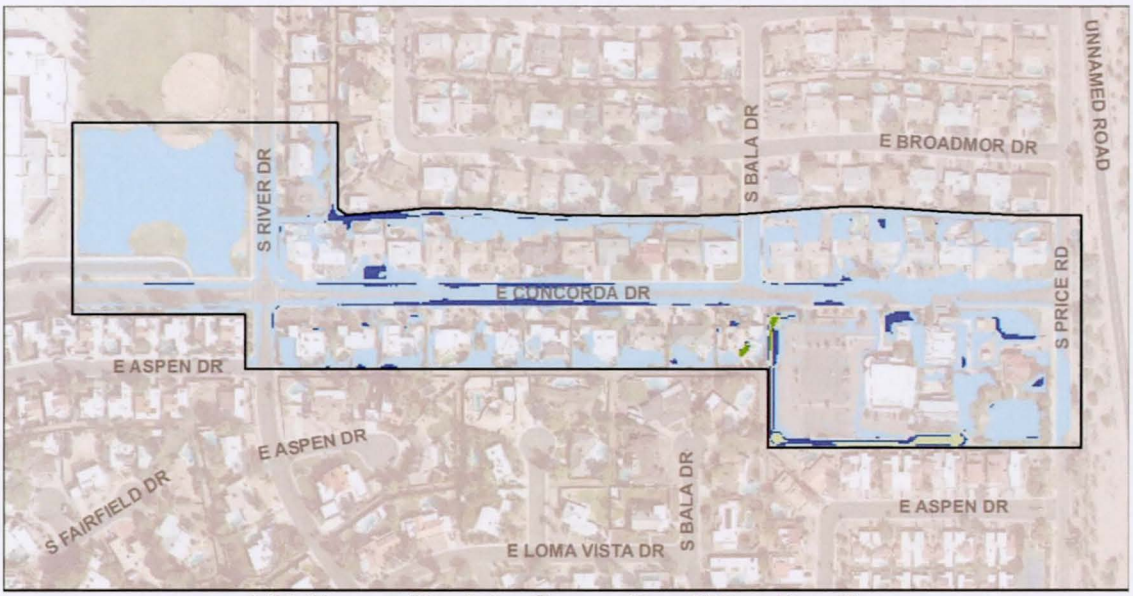
Model Boundary — Walls — Green Roof

N

1 inch = 100 feet

Table 4.6a Green Roof Modeling		Model	LID 2.1	LID 9.6
			Base	Green Roof
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	7.85
	Wet weather inflow	V (acft)	1.19	0.93
	Return flow	V (acft)	0.04	0.02
SUMMARY OUT	Rainfall Volume	V (acft)	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.54
		%	*21*	*35*
	Floodplain storage	V (acft)	1.47	1.27
		%	*34*	*29*
	TOL storage	V (acft)	0.07	0.07
		%	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.64
		%	*17*	*15*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.92
		%	*28*	*21*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.01
Check	Sum of volumes	V (acft)	4.36	4.36
	Volume captured	V (acft)	-	0.61
	Target volume capture	V (acft)	-	0.63
	Utilization of Green Roof volume	%	-	96.4
	Roof grids	8392		
	Roof Area	3.08	ac	
	Roofs	40		
	Green roof volume	0.633	acft	

The maximum flow depth for the focus area and a close-up area are shown below.



LID Focus Model - Green Roof Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

LID Focus Model - Green Roof Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

Abbreviated SUMMARY.OUT FILE

```
                    Pro Model - Build No. 15.02.10
=========================================================================
                      MASS BALANCE   INFLOW - OUTFLOW VOLUME
=========================================================================
                           *** INFLOW (ACRE-FEET) ***
TOTAL POINT RAINFALL:                                  2.5200 INCHES
                                                     WATER
RAINFALL VOLUME                                        4.37
SURFACE WATER INFLOW HYDROGRAPH                       0.00
                                                   ---------
INFLOW HYDROGRAPHS + RAINFALL                          4.37
=========================================================================
                           *** SURFACE OUTFLOW (ACRE-FT) ***
OVERLAND INFILTRATED AND INTERCEPTED WATER         1.27 INCHES
          OVERLAND FLOW                              WATER
WATER LOST TO INFILTRATION & INTERCEPTION              1.54
FLOODPLAIN STORAGE                                     1.27
OVERLAND STORAGE DUE TO TOL                            0.07
FLOODPLAIN OUTFLOW HYDROGRAPH                          0.64
                                                   ---------
FLOODPLAIN OUTFLOW, INFILTRATION & STORAGE             3.46
TOTAL SURFACE OUTFLOW AND STORAGE                      1.91
=========================================================================
          *** FLO-2D STORM DRAIN EXCHANGE VOLUME (ACRE-FT) ***
FLO-2D TO SWMM THROUGH INLETS                          0.92
SWMM TO FLO-2D FROM RETURNING FLOW                     0.01
SWMM TO FLO-2D FROM OUTFALL                            0.00
FLO-2D TO SWMM FROM OUTFALL                            0.00
                                                   ---------
NET VOLUME                                             0.91
=========================================================================
                                  *** TOTALS ***
TOTAL OUTFLOW FROM GRID SYSTEM                         0.64
TOTAL VOLUME OF OUTFLOW AND STORAGE                    4.37

  SURFACE AREA OF INUNDATION REGARDLESS OF THE TIME OF OCCURRENCE:
(FOR FLOW DEPTHS GREATER THAN THE "TOL" VALUE TYPICALLY 0.1 FT OR 0.03 M)

THE MAXIMUM INUNDATED AREA IS:                          17.96 ACRES
=========================================================================
     COMPUTER RUN TIME IS:  3.14502 HRS
     THIS OUTPUT FILE WAS TERMINATED ON:  10/16/2015  AT:  11:37:48
```

Abbreviated SWMM.rpt

```
EPA STORM WATER MANAGEMENT MODEL - VERSION 5.0 (Build 5.0.022)
--------------------------------------------------------------

Element Count
*************
Number of nodes ........... 6
Number of links ........... 5

Control Actions Taken
*************************
```

**********	Volume	Depth
Runoff Quantity Continuity	acre-feet	inches
Total Precipitation	0.000	0.000
Evaporation Loss	0.000	0.000
Infiltration Loss	0.000	0.000
Surface Runoff	0.000	0.000
Final Surface Storage	0.000	0.000
Continuity Error (%)	0.000	

**********	Volume	Volume
Flow Routing Continuity	acre-feet	10^6 gal
Dry Weather Inflow	0.000	0.000
Wet Weather Inflow	0.933	0.304
Groundwater Inflow	0.000	0.000
RDII Inflow	0.000	0.000
External Inflow	0.000	0.000
External Outflow	0.901	0.294
Internal Outflow	0.021	0.007
Storage Losses	0.000	0.000
Initial Stored Volume	0.000	0.000
Final Stored Volume	0.002	0.001
Continuity Error (%)	0.986	

Outfall Loading Summary
****

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CFS	Max. Flow CFS	Total Volume 10^6 gal
I388	88.67	1.03	7.85	0.294
System	88.67	1.03	7.85	0.294

```
Analysis begun on:  Fri Oct 16 08:28:45 2015
Analysis ended on:  Fri Oct 16 11:37:28 2015
Total elapsed time: 03:08:43
```

Under "Sum of volumes", the volume is defined (in acre feet) as:
[Infiltration & interception] + [Floodplain storage] + [TOL storage] + [Floodplain outflow] + [Stormdrain]. This value should match the rainfall volume. Any difference within 0.01ac-ft may be due to rounding error.

Under "Target volume capture", the volume is defined (in acre feet) as:
[# of roof grids (8392)] * [grid area (4 ft*4 ft=16ft^2)] * [Effective green roof storage depth (rainfall depth = 2.52 in)].

Under "Volume captured", the volume is defined (in acre feet) as:
[Green Roof Infiltration & interception] – [Base Infiltration & interception]

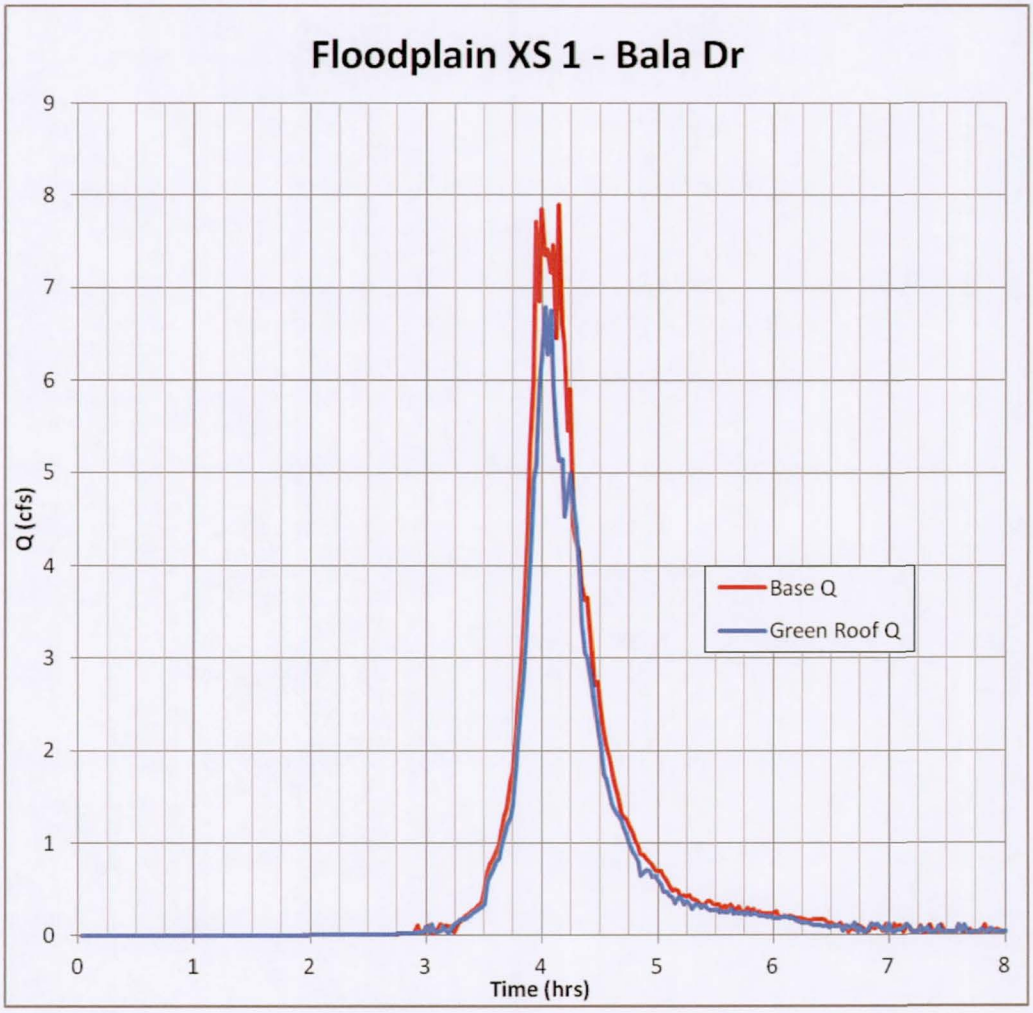
Under "Utilization of green roof volume", the utilization is defined (in %) as:
[Volume captured] / [Target volume capture]

The modeling results in Table 4.6a show that modeling the roofs within the small grid model (total capacity is about 14.8% of the rainfall volume) using INFIL.DAT parameter adjustment as outlined in this memo reduce the floodplain storage, outflow, as well as the stormdrain outflow. Of a potential 0.65 ac-ft, the model infiltrates 0.61 ac –ft (95%). A floodplain maximum depth difference raster is shown in Exhibit B5.

The peak flow and volume values for the cross sections are documented in Table 4.6b below and a typical floodplain cross section hydrograph is plotted below as well. Table 4.6b shows that the total surface peak flow reduction with green roofs is about 20% and that the total volume reduction is about 22%. All of the floodplain hydrographs are included in Appendix C5.

Table 4.6b Floodplain Cross Section Results

	Base Model		Green Roof		Reduction			
XS	Qp	Vol	Qp	Vol	Qp		Vol	
	cfs	ac-ft	cfs	ac-ft	cfs	%	ac-ft	%
1	9.21	0.45	7.88	0.38	1.33	14	0.07	16
2	0.54	0.03	0.40	0.02	0.14	26	0.01	33
3	2.42	0.10	2.48	0.10	-0.06	-3	0.00	0
4	6.95	0.46	5.46	0.35	1.49	21	0.11	24
5	1.28	0.04	1.30	0.04	-0.02	-2	0.00	0
6	5.24	0.65	3.64	0.50	1.60	31	0.15	23
7	2.84	0.37	2.10	0.27	0.74	26	0.10	27
8	8.98	0.42	7.51	0.35	1.47	16	0.07	17
9	1.78	0.05	1.16	0.04	0.62	35	0.01	20
10	0.84	0.05	0.54	0.03	0.30	36	0.02	40
11	1.91	0.20	1.29	0.13	0.62	33	0.07	35
Total	41.99	2.82	33.76	2.21	8.23	20	0.61	22

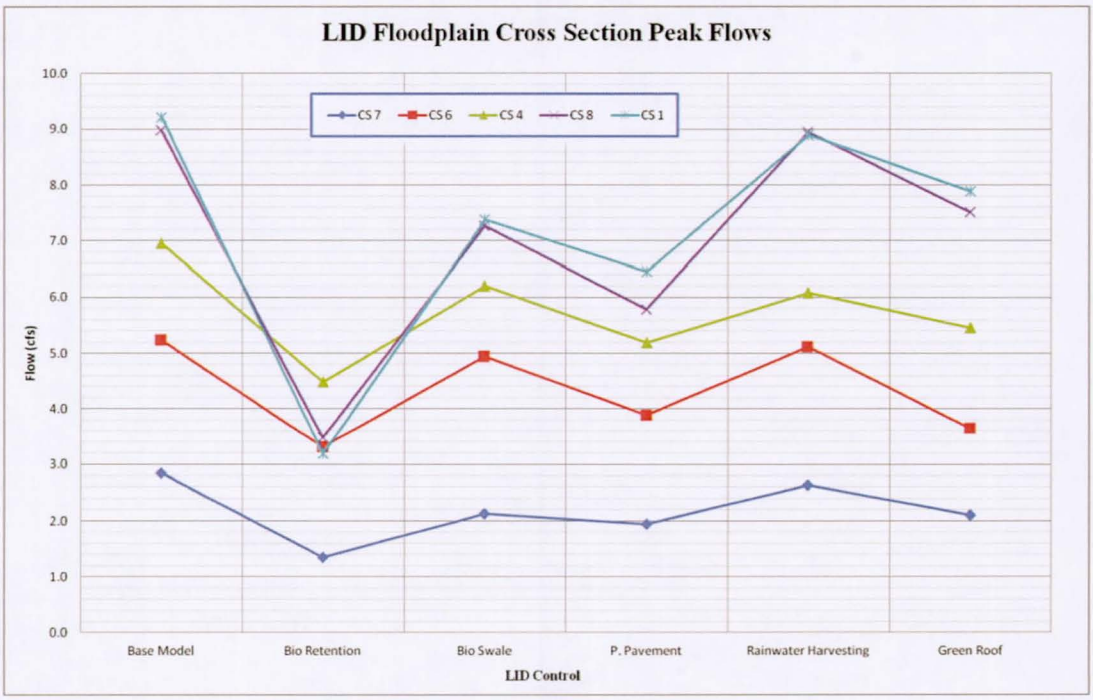

Floodplain XS 1 - Bala Dr
Q (cfs)
Time (hrs)
Base Q
Green Roof Q
0
1
2
3
4
5
6
7
8
9

4.7 Summary of Modeling Results for Five LID Controls

The FLO-2D modeling results for the base model and the LID five basic controls are summarized in Table 4.7. Table 4.7 shows that Rainwater Harvesting and Green Roof have highest utilization rates as expected; Pervious Pavement and Bio Retention have high utilization rates as well; and Bio Swale has lowest utilization in terms of storm volume reduction. These utilization effectiveness factors will be applied for the determination of the LID design capacities in the regional FLO-2D modeling of the LID application scenarios. Bio Retention has the highest peak flow reductions in all cross sections as shown in the following chart. The modeling results further strengthened the conclusion that Initial Loss IA Adjustment is the most appropriate method among the potential modeling techniques.

Table 4.7 Summary Table for LID Basic Control Modeling Results

		Model	LID 2.1	LID 6.5	LID 13	LID 7.3	LID 9.3	LID 9.6
			Base	Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	4.70	8.45	7.52	8.62	7.85
	Wet weather inflow	V (acft)	1.19	0.64	1.11	1.02	1.15	0.93
	Return flow	V (acft)	0.04	0.00	0.03	0.02	0.04	0.02
SUMMARY OUT	Rainfall volume (2.52" depth)	V (acft)	4.37	4.37	4.37	4.37	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.32	0.99	1.67	1.05	1.54
		%	21	30	23	38	24	35
	Floodplain storage	V (acft)	1.47	1.83	1.5	1.09	1.44	1.27
		%	34	42	34	25	33	29
	TOL storage	V (acft)	0.07	0.07	0.07	0.07	0.07	0.07
		%	2	2	2	2	2	2
	Floodplain outflow	V (acft)	0.76	0.58	0.79	0.59	0.73	0.64
		%	17	13	18	14	17	15
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.64	1.1	1.02	1.17	0.92
		%	28	15	25	23	27	21
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00	0.02	0.00	0.02	0.01
Vol Comparison	Sum of volumes	V (acft)	4.36	4.37	4.36	4.37	4.37	4.36
	LID volume captured	V (acft)	-	0.75	0.09	0.74	0.12	0.61
	LID design volume capacity	V (acft)	-	0.89	0.31	0.85	0.12	0.63
	Utilization of LID volume	%	-	84	29	87	98	96

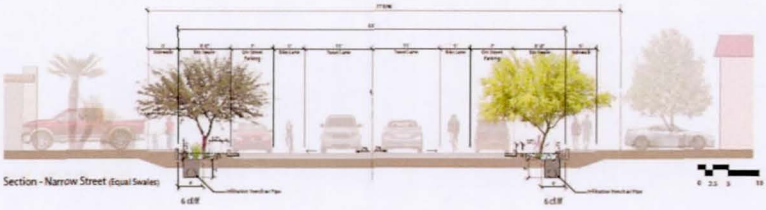

LID Floodplain Cross Section Peak Flows
CS 7
CS 6
CS 4
CS 8
CS 1
Flow (cfs)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Base Model
Bio Retention
Bio Swale
P. Pavement
Rainwater Harvesting
Green Roof
LID Control

5.0 SIMULATION OF LID CONTROL COMBINATIONS

5.1 Selection of LID Control Combinations/Systems

A LID control system is defined as a combination of at least one LID control with LID accessories and certain parcel participation rate (percentage of properties joining LID practices).

Many LID application options were evaluated for the Focus Area as well as within Loma Vista Area. Several examples are shown in the following plans and pictures, and they are also included in Exhibit C0. These applications include LID practices along Concorda Drive within the Focus Area and Country Club Way within Loma Vista Area. The effectiveness of the LID system is dependent on the types of controls as well as parcel participation rate.



Plan View - Narrow Street (Equal Swales)

Country Club Way
Option 2 - Narrow Street
(Equal Swales)

Loma Vista Flood Mitigation and Stormwater Re-Use
Project Number: 4603216

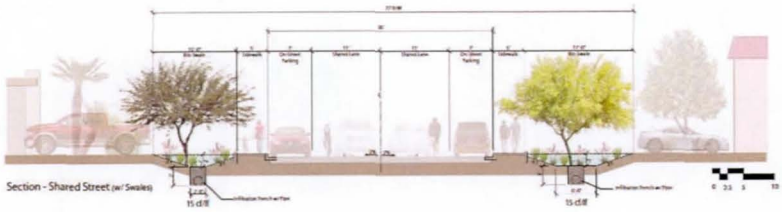
Tempe, Arizona
August 10, 2015

Plan View - Narrow Street (Wide Swale One Side)

Country Club Way
Option 3 - Narrow Street
(Wide Swale One Side)

Loma Vista Flood Mitigation and Stormwater Re-Use
Project Number: 4603216

Tempe, Arizona
August 10, 2015



Plan View - Shared Street (w/ Swales)

Country Club Way
Option 4 - Shared Street
(w/ Swales)

Loma Vista Flood Mitigation and Stormwater Re-Use
Project Number: 4603216

Tempe, Arizona
August 10, 2015

Bio Retention along Concorda Drive

Bio Swale along Concorda Drive

Pervious Pavement along Concorda Drive

Rainwater Harvesting example along Concorda Drive

Green Roof example along Concorda Drive

LID Combination example along Concorda Drive

J2 evaluated numerous LID combinations for the project. They selected three (3) LID control combinations to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation. These three LID systems are common and acceptable practices for Tempe and they are: On-Lot Treatment System, Green Park System, and Green Street System. The following sub-sections document the modeling procedures and results for these three systems. The FLO-2D model for the Focus Area was used for the modeling of these three systems.

5.2 On-Lot Treatment System

On-Lot Treatment System consists of a series of bio retention, bio swale, and rainwater harvesting (rain tanks) with various accessories. The land uses for this system are primarily residential. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

On-Lot Treatment System Concept along Concorda Drive

On Lot Treatment System FLO-2D Modeling Procedures:
In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for On Lot Treatment LID System:
   - Building roofs for rainwater harvesting – same as rainwater harvesting control selection
   - Bio retention – same as bio retention control grids for storage areas and curb cuts as hydraulic structures
   - Bio swale – single row of grids nearest the street to connect the bio retention grid groups

2) FLO-2D Input Parameter Modifications:
   - Roof grids – INFIL.DAT – IA given value to reflect 100yr-2hr storm (2.16 in capacity for all roof grids
   - Bio retention – FPLAIN.DAT, INFIL.DAT, HYSTRUC.DAT – same as bio retention control grids
   - Bio swale – FPLAIN.DAT, INFIL.DAT – Elevations at endpoints of the rows were set at 0.5 ft above the bio retention elevation and grid elevations are interpolated between these. Since the regional drainage flows from east to west and from south to north in this area, checks were made to prevent negative slope profiles in those directions

3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

The exhibit showing the on lot treatment system LID areas and FLO-2D grids is included in Exhibit C1. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D1. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.

LID Focus Model - On Lot Treatment System Grids

Bio Retention
Rainwater Harvesting
Bio Swale
Model Boundary
Walls

N

1 inch = 400 feet

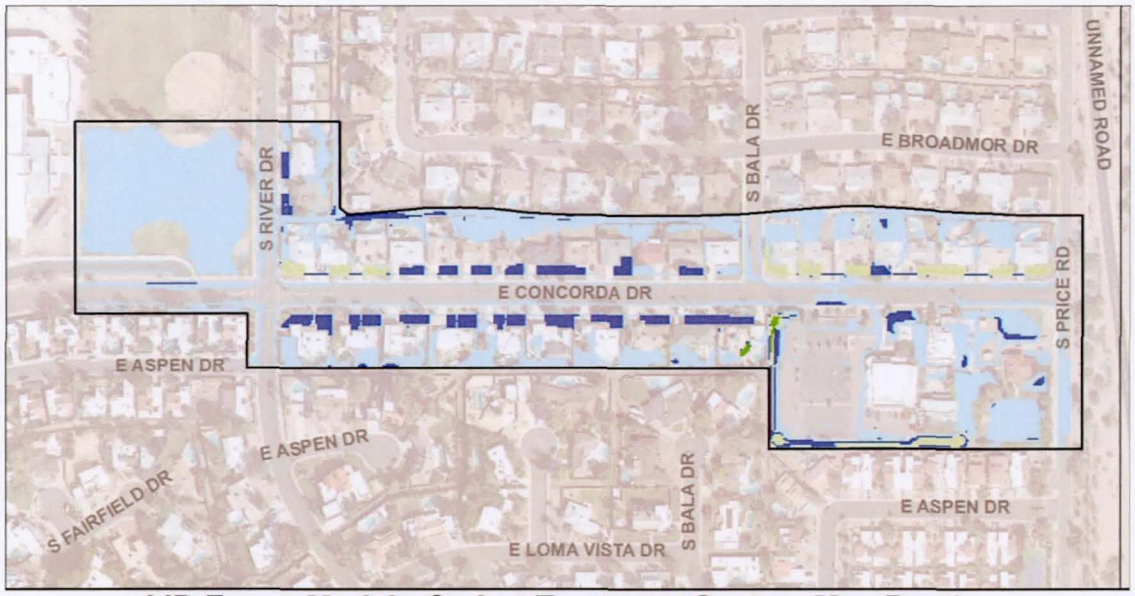
LID Focus Model - On Lot Treatment System Grids

Bio Retention
Rainwater Harvesting
Bio Swale
Model Boundary
Walls

N

1 inch = 100 feet

The maximum flow depth for the on lot treatment area and a close-up area are shown below.



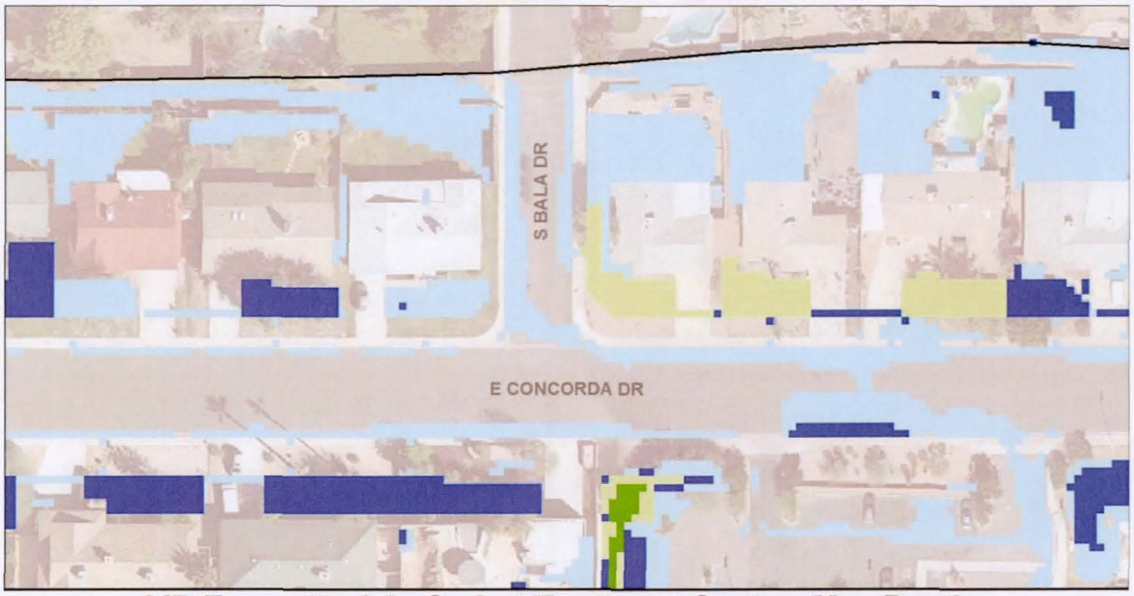
LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

5.3 Green Parking System

Green Parking System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily commercial, community parking lots, and residential driveways. The general concept of this system Concorda Drive within the Focus Area is shown in the following photo.

Green Parking System Concept along Concorda Drive

Green Parking System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Parking LID System:
   - Residential driveways – same as pervious pavement control selection, with added walls too
   - Church site and school driveway were used as pervious pavement
   - Bio retention – manually selected areas near the church parking lot and school driveway
   - Routing to bio retention – grids connecting street drainage to bio retention area

2) FLO-2D Input Parameter Modification:
   - Residential driveways INFIL.DAT – same as LID controls

- Church site and school driveway – INFIL.DAT – same as LID controls

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 2 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 1 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

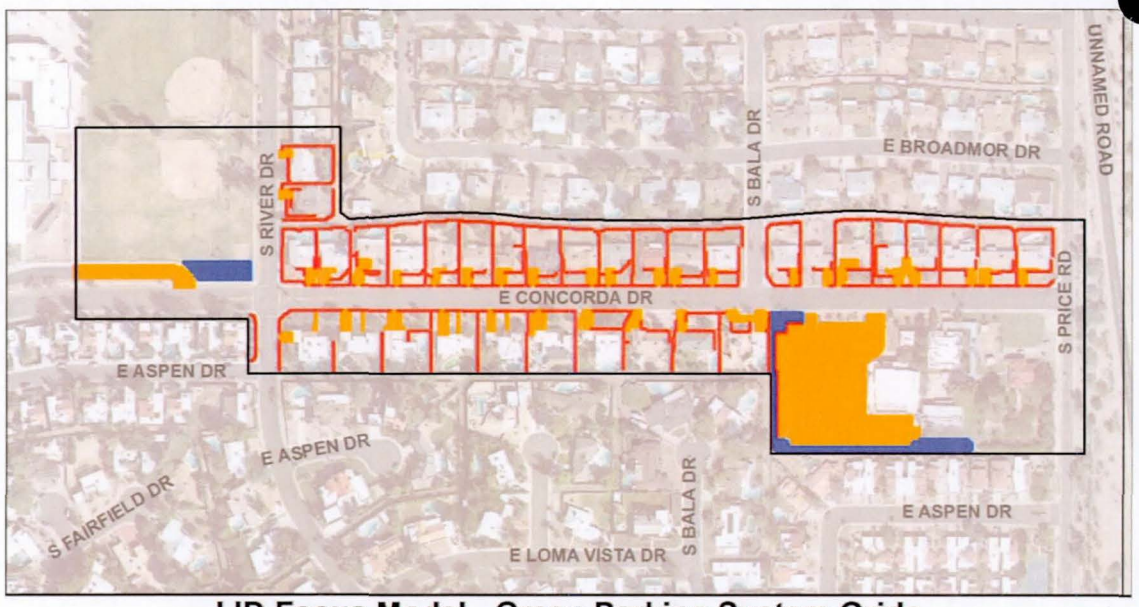
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

The exhibit showing the green parking system LID areas and FLO-2D grids is included in Exhibit C2. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D2. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.

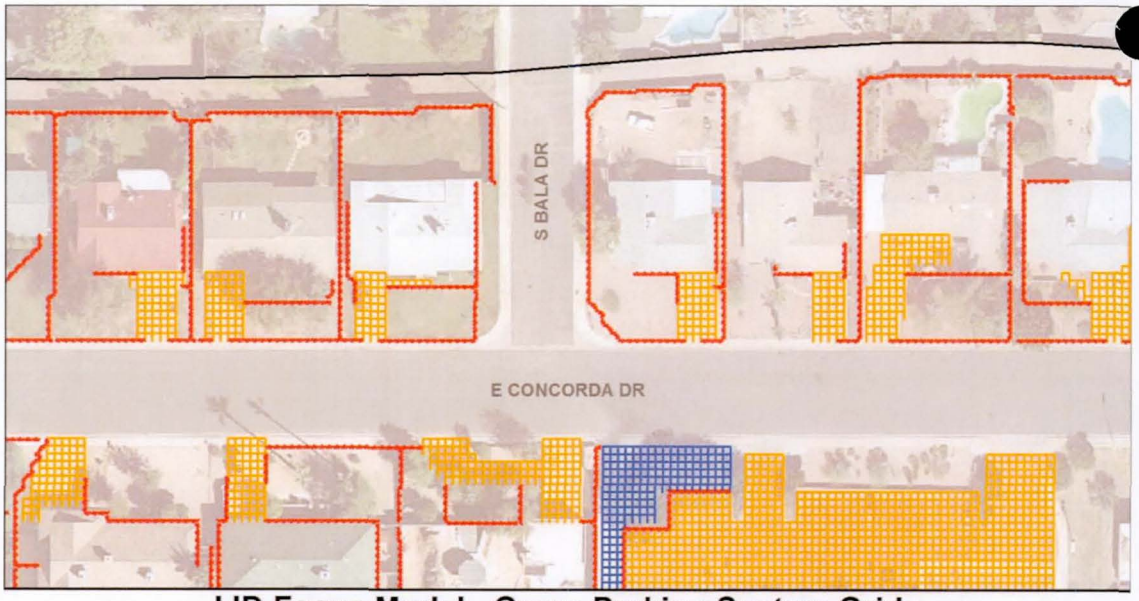


LID Focus Model - Green Parking System Grids

Pervious Pavement | Model Boundary
Bio Retention | Walls

N

1 inch = 400 feet



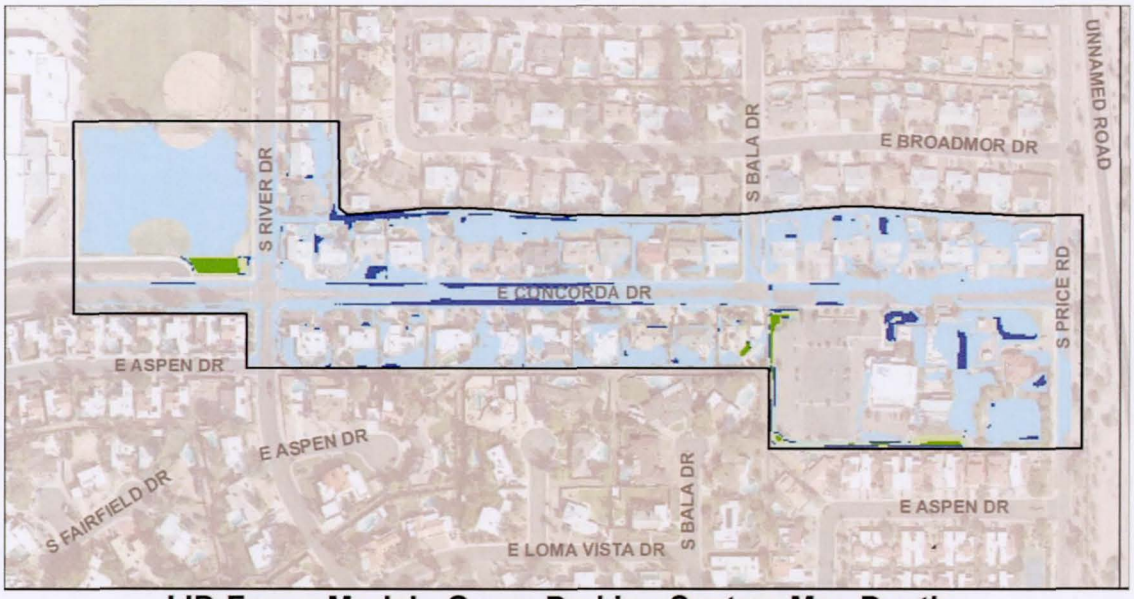
LID Focus Model - Green Parking System Grids

Pervious Pavement | Model Boundary
Bio Retention | Walls

N

1 inch = 100 feet

The maximum flow depth for the green parking area and a close-up area are shown below.



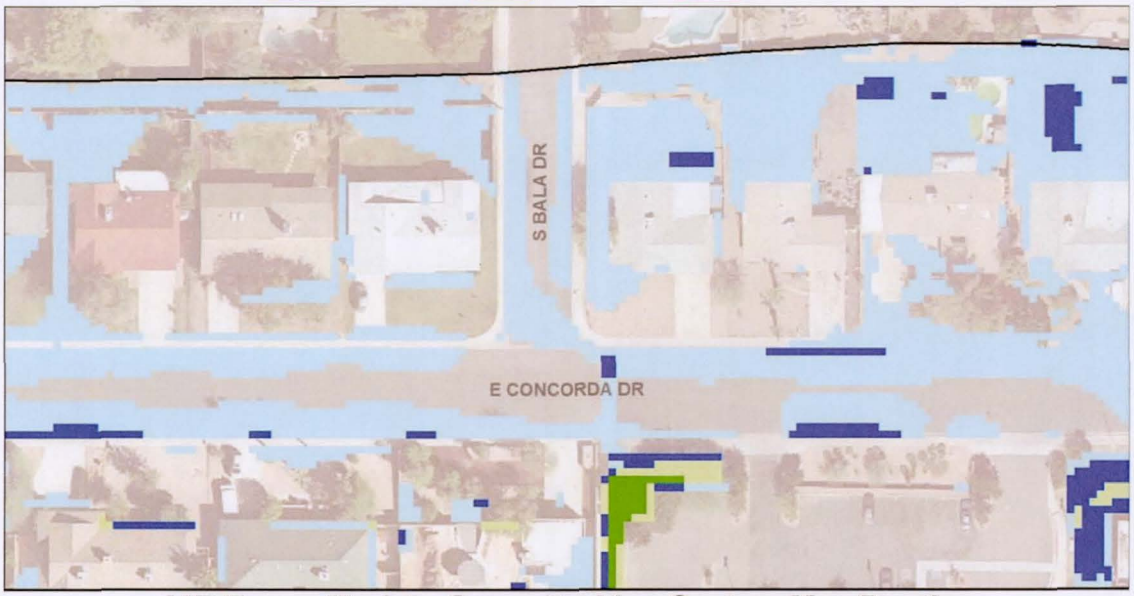
LID Focus Model - Green Parking System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Green Parking System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

5.4 Green Street System

Green Street System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily streets, public right-of-ways, and some residential land adjacent to streets. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

Green Street System Concept along Concorda Drive

Green Street System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments for the grids within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Street LID System:
   - Bio swale – double row of grids on the curbs of the streets – broken up by driveways
   - Pervious pavement – double row of grids adjacent to the bio swales and double rows of grids between bio swales that are broken up by driveways
   - Bio retention – same grids used in green parking system model

2) FLO-2D Input Parameter Modification:
   - Bio swale – Grid elevations dropped by 1 ft, infiltration matches control model parameters
   - Pervious pavement – matches control model parameters

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 1 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 0.5 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

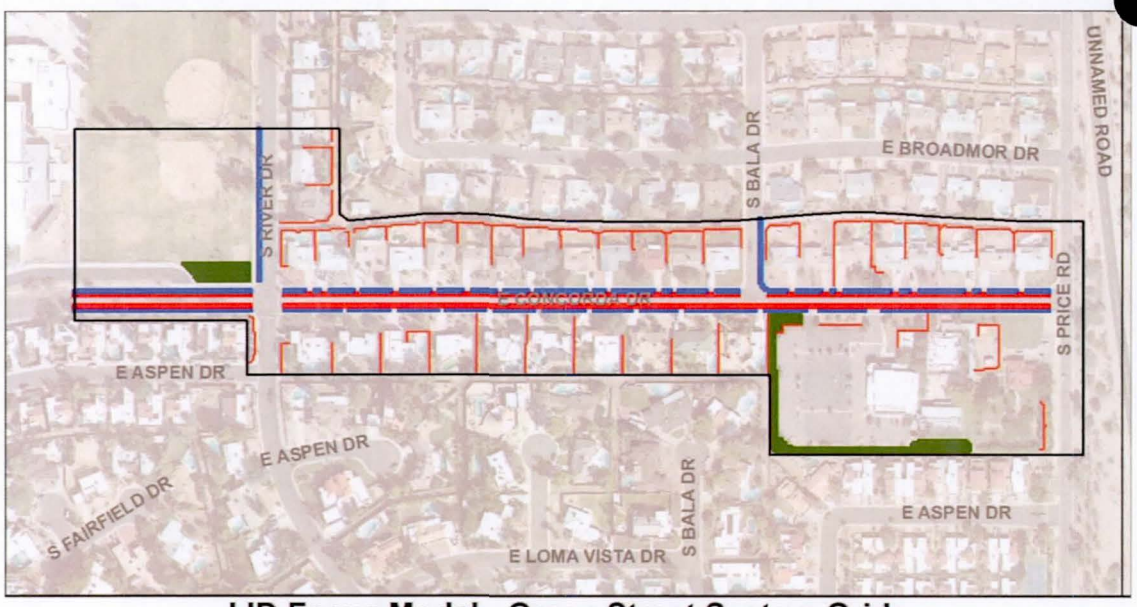
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

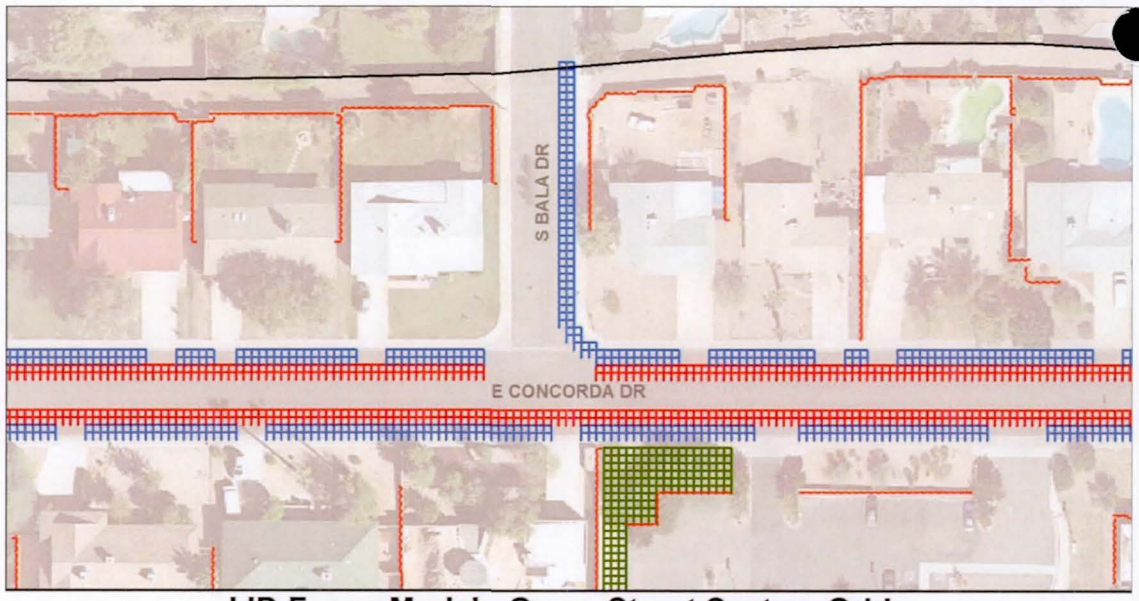
The exhibit showing the green street system LID areas and FLO-2D grids is included in Exhibit C3. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix D3. The FLO-2D modeling results summary data is documented in Table 5.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 5.1.



LID Focus Model - Green Street System Grids

Bio Swale
Model Boundary
Pervious Pavement
Walls
Bio Retention

N
1 inch = 400 feet

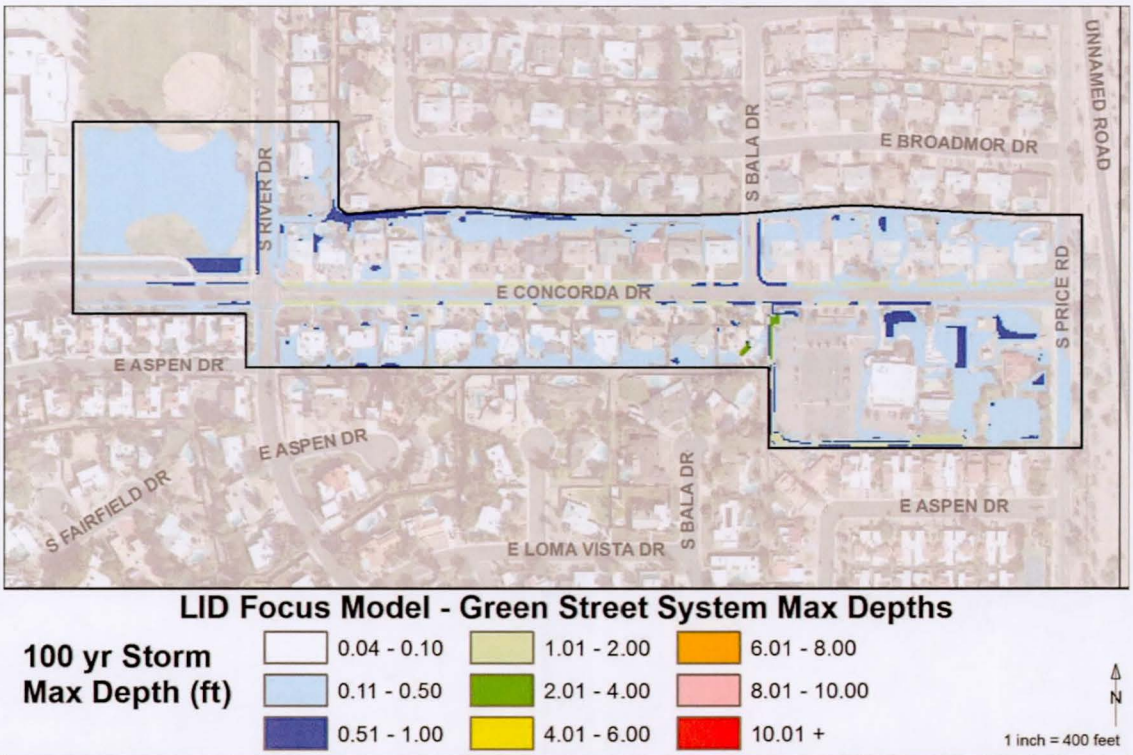


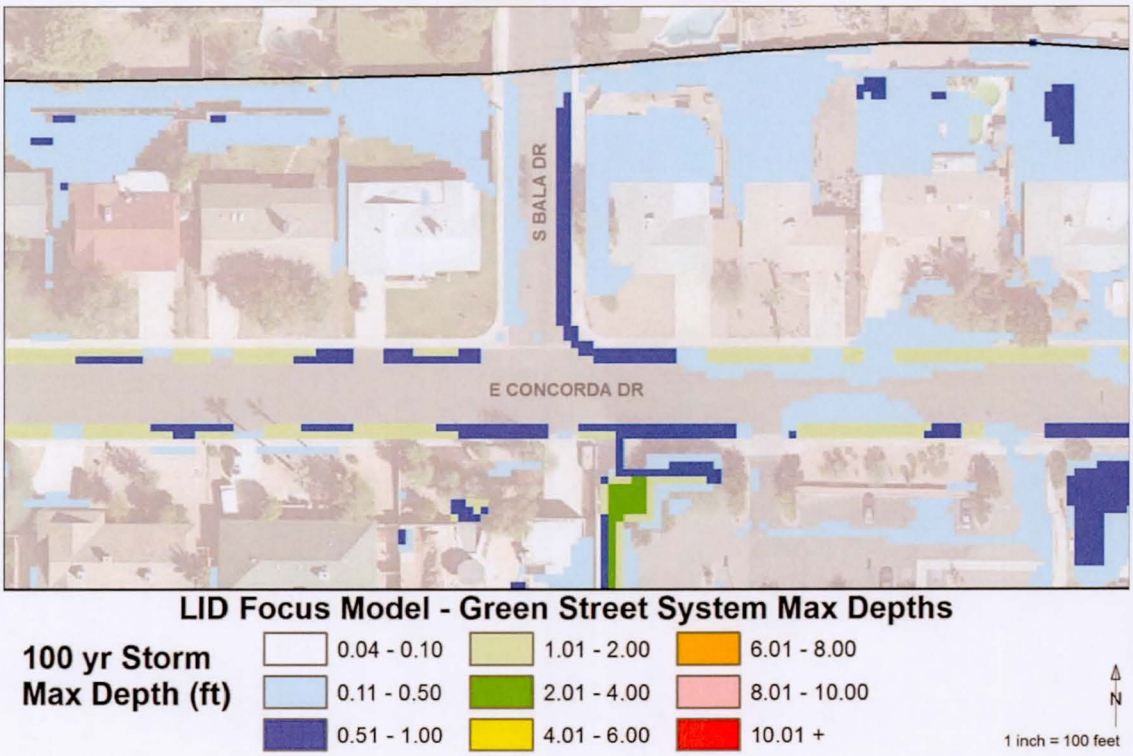
LID Focus Model - Green Street System Grids

Bio Swale
Model Boundary
Pervious Pavement
Walls
Bio Retention

N
1 inch = 100 feet

The maximum flow depth for the green street area and a close-up area are shown below.





5.5 Summary of Modeling Results for Three LID Control Systems

The FLO-2D modeling results for the base model as well as the three LID systems are summarized in Table 5.1. Table 5.1 shows that Green Street System has the highest utilization of LID design volume (55.2%). The other two systems have similar utilization percentage (~47.5%). Figure 5.1, as an example of the cross section hydrographs, shows that on lot treatment system has the highest peak flow reduction in all three LID systems. The peak flow of 7.9 cfs for the base model at floodplain cross section of Bala Drive is reduced to 1.1 cfs for the on lot treatment LID system, 1.8 cfs for the green parking LID system, and 3.3 cfs for the green street LID system. The on lot treatment LID system has the highest peak flow reduction due to its high LID target (design) volume (3.11 ac-ft, see table 5.1). The modeling results show that all three LID systems are very effective in flood mitigation (reducing the downstream storm water peak flows and volumes).

Table 5.1 Summary Table for LID System Modeling Results

			Base Model	On-Lot Treatment	Green Parking	Green Street
		Model	LID 2.1	LID 20	LID 21	LID 22
	Target volume capture	V (acft)	-	3.107	1.807	1.830
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	3.17	5.27	2.14
	Wet weather inflow	V (acft)	1.192	0.146	0.756	0.397
	Return flow	V (acft)	0.041	0	0.002	0
SUMMARY OUT	Total point rainfall	in	2.52	2.52	2.52	2.52
	Overland infiltration & interception	in	0.88	1.75	1.25	1.36
	Rainfall volume	V (acft)	4.37	4.37	4.37	4.37
	Infiltration & interception	V (acft)	0.93	2.31	1.62	1.79
		%	*21*	*53*	*37*	*41*
	Floodplain storage	V (acft)	1.47	1.56	1.64	1.62
		%	*34*	*36*	*38*	*37*
	TOL storage	V (acft)	0.07	0.07	0.07	0.07
		%	*2*	*2*	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.36	0.36	0.57
		%	*17*	*8*	*8*	*13*
	To stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.14	0.75	0.39
		%	*28*	*3*	*17*	*9*
	Stormdrain return flow (SWMM to FLO-2D)	V (acft)	0.03	0	0	0
		%	*1*	*0*	*0*	*0*
Check	Sum of volumes	V (acft)	4.36	4.37	4.37	4.37
	Utilization of LID volume	%	-	47.3	47.6	55.2
Storage Additions	Grading	V (ft^3)	-	79035	44364	45421
	Initial abstraction	V (ft^3)	-	22969	-590	-492
	Increased soil depth	V (ft^3)	-	33329	34932	34775
	Sum	V (ft^3)	-	135332	78707	79704
		V (acft)	-	3.11	1.81	1.83

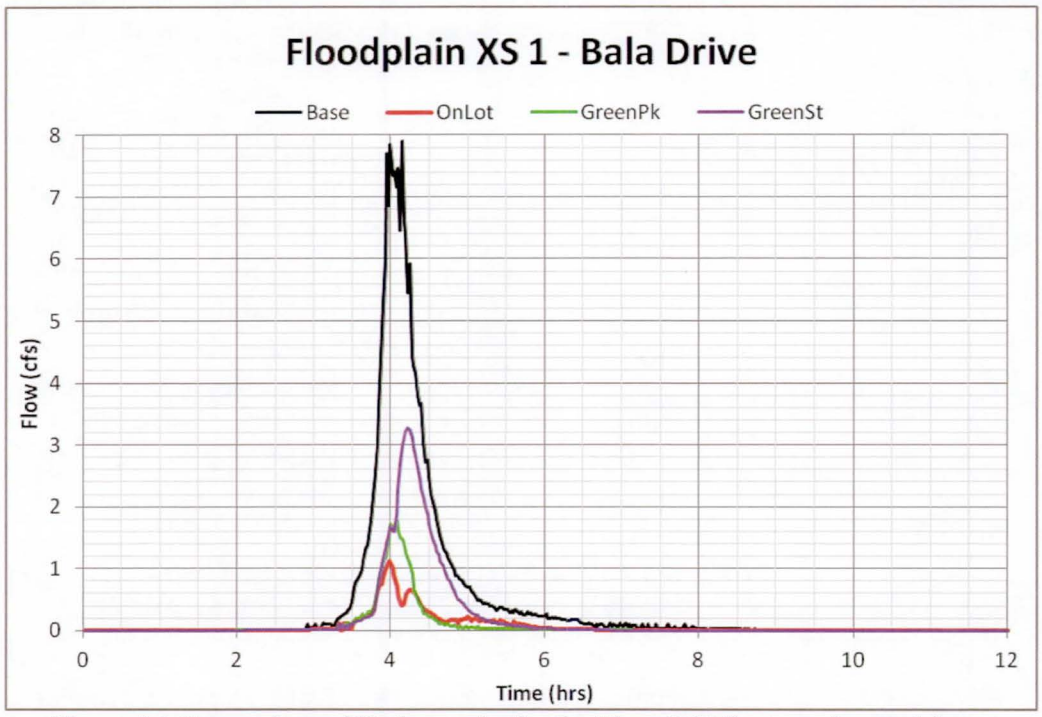


Figure 5.1 Comparison of Hydrographs for the Three LID Systems (example)

6.0 SIMULATION OF LID SCENARIOS BY REGIONAL MODELS

6.1 Identification of Modeling Strategies

One of the goals of the individual LID basic control evaluation is to develop a modeling process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual LID basic controls from the Focus Area model (4 ft x 4 ft grid size) should be adjusted to be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple LID basic controls, accessories, and various land uses with certain parcel participation rate. The Loma Vista FLO-2D model was used for the regional modeling of LID application scenarios. Figure 2.1 shows the Loma Vista FLO-2D modeling boundaries.

The direct impact of LID practices on flood mitigation is the reduction of surface runoff volume to the downstream areas due to the rainfall/runoff responses of many localized LID controls (retention, detention, infiltration, storage and re-use, high surface roughness). A key operational function of the FLO-2D model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. The reductions in volume are quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections. One of the advantages in the evaluation of LID scenarios in a regional FLO-2D model is that it is able to accurately depict impacts on a parcel by parcel basis and conservation of volume, though the 20 ft x 20 ft grids may be too coarse of a resolution to model some of the actual physical processes that are occurring at some LID accessories.

Further evaluations concluded that Initial Loss IA Adjustment is the most appropriate method among the potential techniques since this method has the following advantages over other approaches:

a. It is already a distributed parameter (grid dependent) and no new input data file is needed;
b. It is easy to be estimated and directly related to runoff volume and depth;
c. Changes of IA values represent best the LID basic control impact on hydrologic and hydraulic performance, such as rainfall/runoff timing and spatial variations;
d. It is a physical hydrologic parameter;
e. It can be used for all of the five LID basic controls.

Other methods do not have all of the advantages. For example, Grid Elevation Adjustment method does not work very well for variations of grid elevations (runoff may not be able to flow into the LID areas). TOL method has significant impact on hydraulic computations. Therefore, Initial Loss IA Adjustment was recommended for the modeling of LID scenarios in the regional modeling.

Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios are discussed in the following sections.

6.2 Estimation of LID Design Capacities for Various Land Uses

All the parcels within the modeling area are classified based on land use zoning provided by the City. For this example modeling, eight (8) zoning numbers were used, but streets were assumed not to have LID applications. Each land use zoning was evaluated by using the following spreadsheet to estimate the composite design LID volume capability (V_d).

Spreadsheets for all seven (7) land uses were included in Appendix E1. The composite capacity for each land use is estimated based on the five basic LID controls modeling results as well as the utilization effectiveness which is a correction factor with value less than 1.0 for individual LID controls. The utilization effectiveness factor for each of the five basic LID controls obtained from the Focus Area modeling is a very important parameter in the determination of the LID modeling volumes. The 100-year, 2-hour storm rainfall volume (V_2) was assumed to be the maximum LID design volume for a parcel. If the possibly constructed LID volume (Vc) for a parcel is greater than the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was applied ($V_d = V_2/ U_e <= V_c$). If the possibly constructed LID volume (Vc) for a parcel is less than or equal to the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was not applied and the design volume is the same as the 100-year, 2-hour storm volume ($V_d = V_2$). Where V_d is the composite LID design volume and the FLO-2D LID modeling volume.

The estimated composite design capacities for the eight (8) zooming numbers are listed in Table 6.1. These values for each parcel can be refined or revised based on real project area land use conditions and other factors. The values utilized for the Loma Vista model have been quantified through the Focus Area modeling efforts. In addition, the proposed procedure allows the modeler to easily refine the values to be utilized if modifications are required.

Table 6.1 Land Use Zoning and LID Design Capacities

Land Use Zoning No.	LID Land Use		LID Design Capacity	
	Zoning Name	Description	Value	Unit
1	AG	Parks & Golf Course	3500	ft^3/ac
2	CSS	Commercial	6000	ft^3/ac
3	R-2	Adjoined homes/duplexes	500	ft^3
4	R-3	Apartments	4000	ft^3/ac
5	R1-6	Medium-lot homes	1000	ft^3
6	RO	Church	5000	ft^3/ac
7	MU-2	School	4500	ft^3/ac
8	ST	Street	0	ft^3/ac

	Design Capacity Estimation for Individual Lot LID Controls	By:	**JJH**
		Date:	**1/18/16**
Project Name:	**Tempe ADMS - FLO-2D Modeling of LID Applications**	Checked:	
		Project No.:	**130.622**

Reference: Drainage Design Manual for Maricopa County, Arizona, Vol. 1, Hydrology

INPUT:

Rainfall

Return Interval = 100-year 2-hour = 2.16 inches = 0.180 ft

Criteria Equations

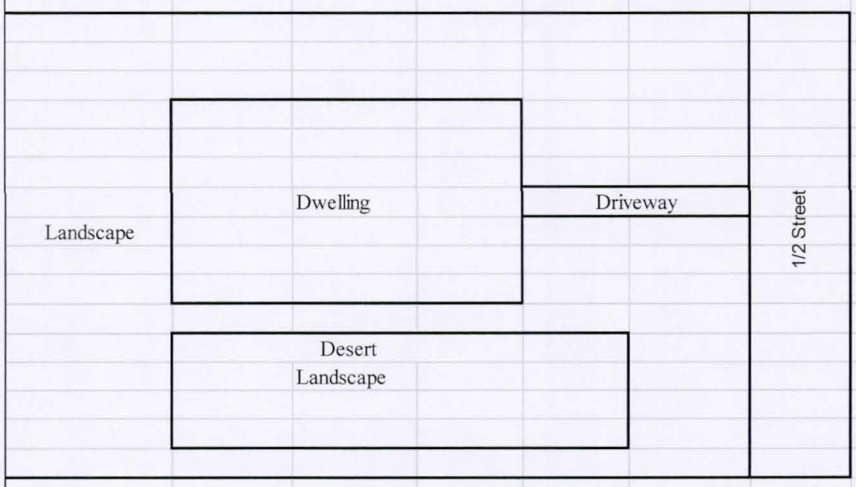
Volume, V = C * P* A (C = runoff coefficient, P = precipitation, A area)

Zoning = R1-6

Lot Size = 8250 square feet

0.19 acres

Landuse	Area (Sq. ft.)	C	C*A	
Structure Size	3766	0.95	3578	
1/2 Street (w = 20 ft, and assume 2 sides of lot adjacent to road)	0	0.95	0	
Desert Landscaping	3884	0.50	1942	
Landscaping	0	0.35	0	
Driveway	600	0.95	570	
Total	8250	0.74	6089.70	OK



Lot Size = 0.189 Acres

Runoff Volume

Generated by Lot = 0.025 Acre-ft

1096 cu ft

Low Impact Development (LID) Controls

Bio Retention	652	cu ft
Bio Swale	0	cu ft
Pervious Pavement	240	cu ft
Rainwater Harvesting	100	cu ft
Green Roof	0	cu ft
Total LID Volume	992	cu ft

Green Roof

Portion of Roof Contained =	0.00	
Contributing Roof Area =	0	sq ft
Roof Volume =	0	cu ft

Rainwater Harvesting

Portion of Roof Contained =	0.50	
Contributing Roof Area =	1883	sq ft
Roof Vol. Contributing to Tank =	339	cu ft
Rain Tank Volume =	100	cu ft
Controlling Volume =	100	cu ft

Bio Retention

bottom length	30.00	ft
bottom width	10.00	ft
Depth	1.00	ft
Side Slope	4.00	ft/ft
Top Length	38	ft
Top Width	18	ft
Stored Volume	481	cu ft
Stored Volume	0.01	ac-ft
Infiltration Rate	1.00	in/hr
Duration	6.00	hr
Additional Limiting Depth	3.00	
Infiltration Volume	171	cu ft

Bio Swale

bottom length	0.00	ft
bottom width	0.00	ft
Depth	0.00	ft
Side Slope	0.00	ft/ft
Top Length	0	ft
Top Width	0	ft
Stored Volume	0	cu ft
Stored Volume	0.00	ac-ft
Infiltration Rate	0.00	in/hr
Duration	0.00	hr
Infiltration Volume	0	cu ft

Pervious pavement

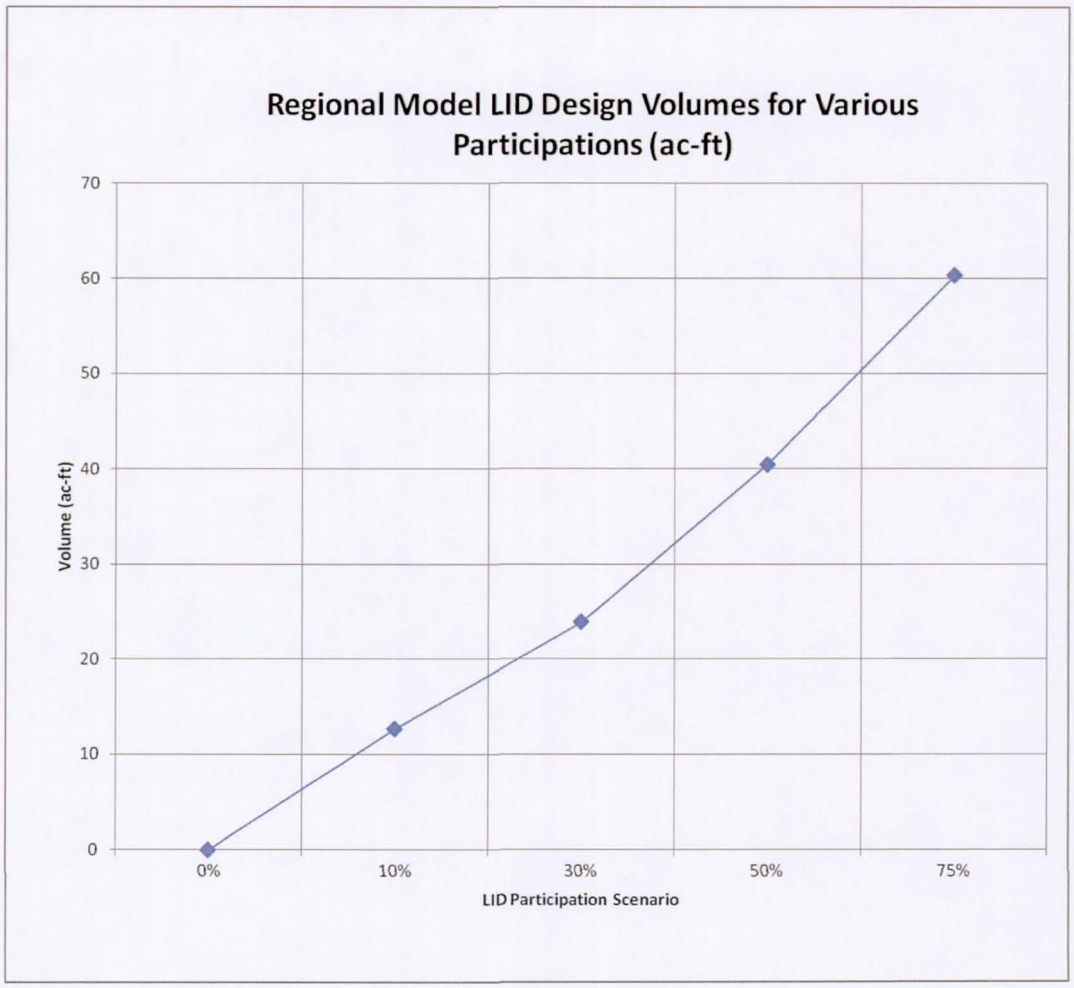
Area	600	sq ft
Volume	240	cu ft

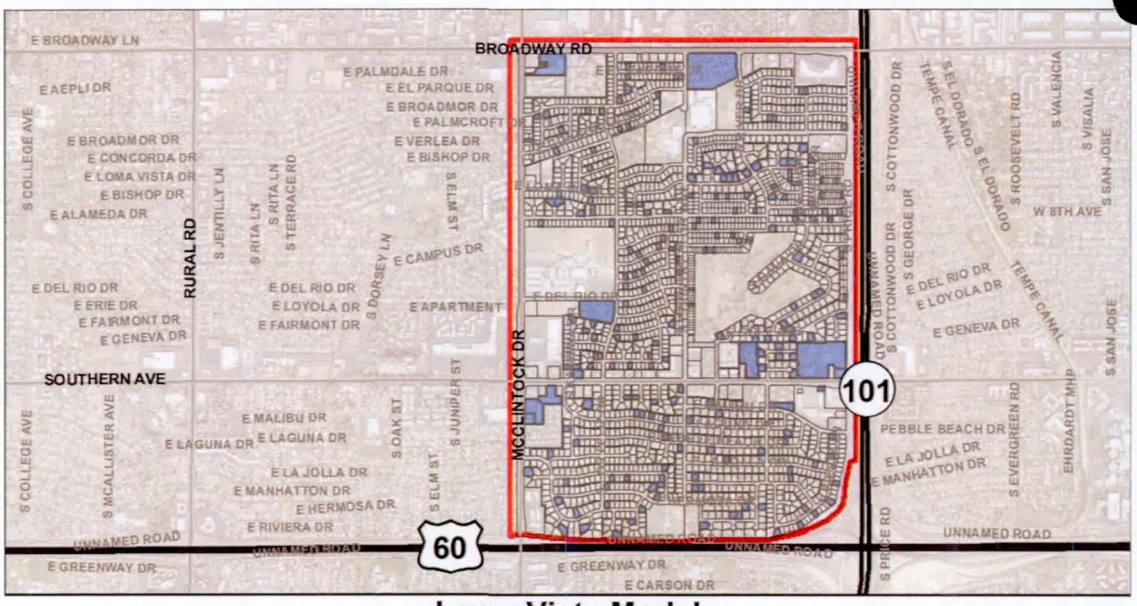
6.3 Determination of LID Application Scenarios

A LID scenario is defined as a LID practice system that includes multiple LID basic controls, accessories, and various land uses with certain parcel participation rate. Different LID application scenarios can be developed by combining several LID controls and storm drain system may be added to enhance the performance of the LID practices. Since the number of scenarios is numerous four (4) LID application scenarios were selected for this study to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation:

1) Scenario I: 10% parcel participation rate;
2) Scenario II: 30% parcel participation rate;
3) Scenario III: 50% parcel participation rate;
4) Scenario IV: 75% parcel participation rate.

Parcels were randomly assigned to be used for each scenario as shown in the following maps (see Exhibit D also). The estimated LID design volumes for the four (4) proposed participation scenarios are shown in the following chart. These values were applied in the development of FLO-2D input data files.





Loma Vista Model
10% LID Participation Parcels

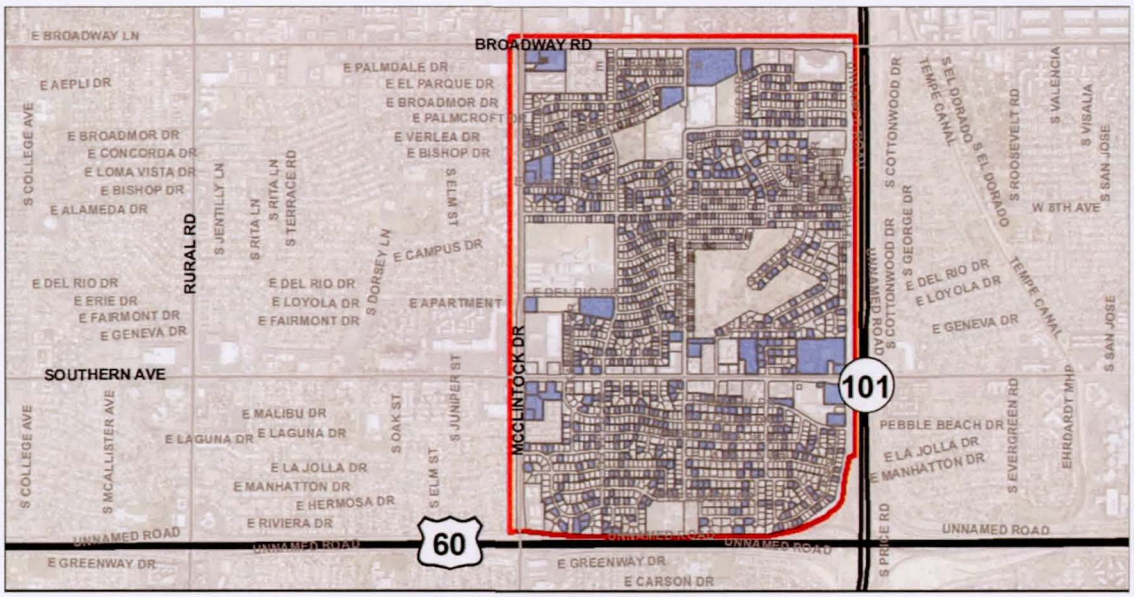
Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
10% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



Loma Vista Model
30% LID Participation Parcels

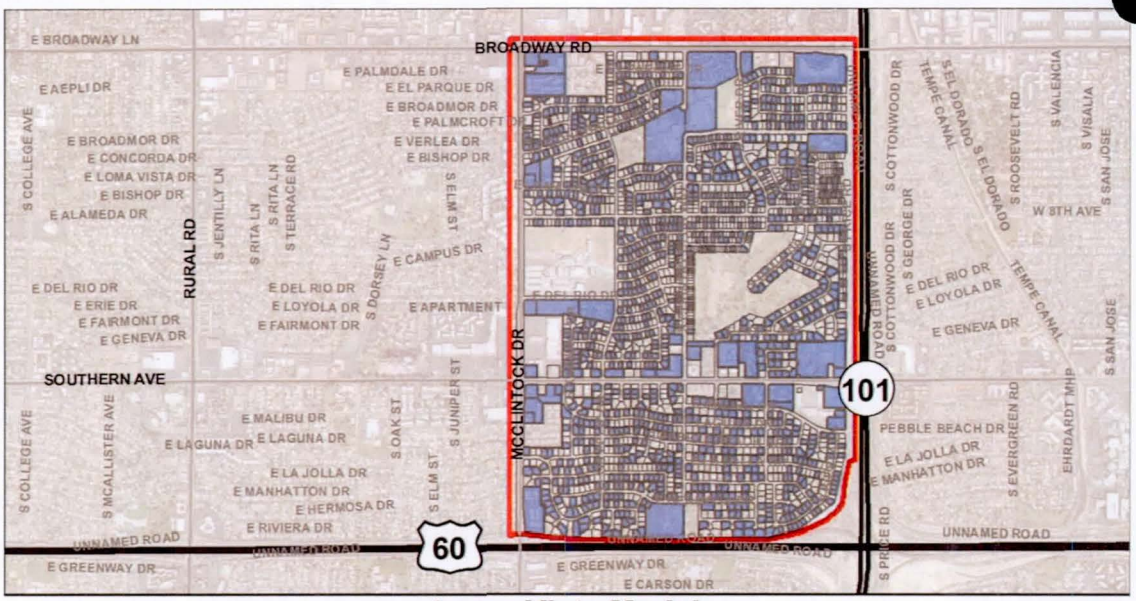
Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
30% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

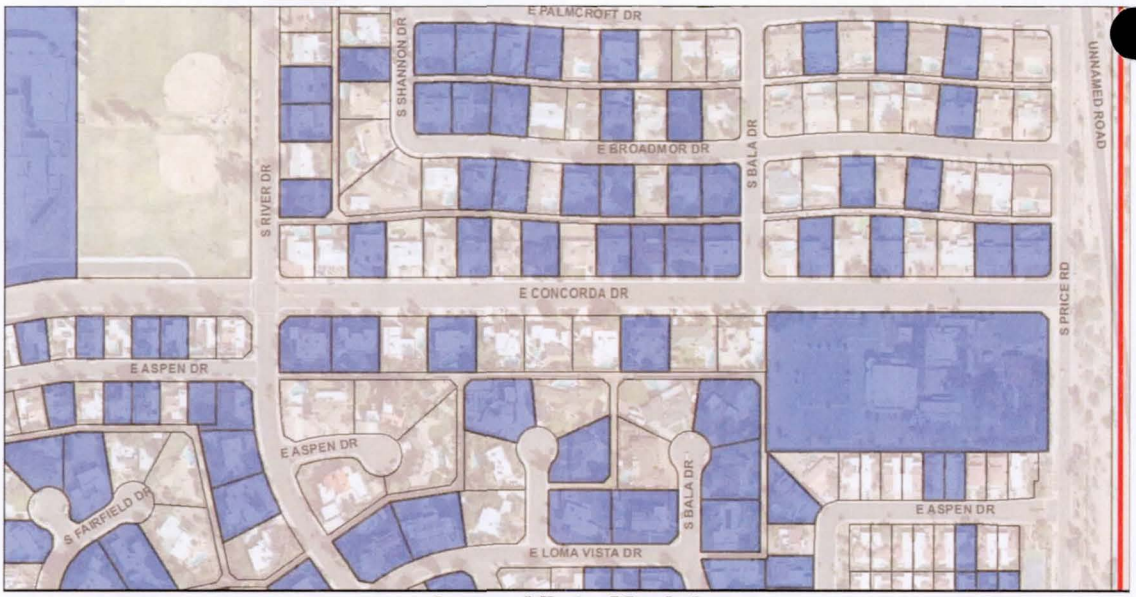
N
1 inch = 400 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

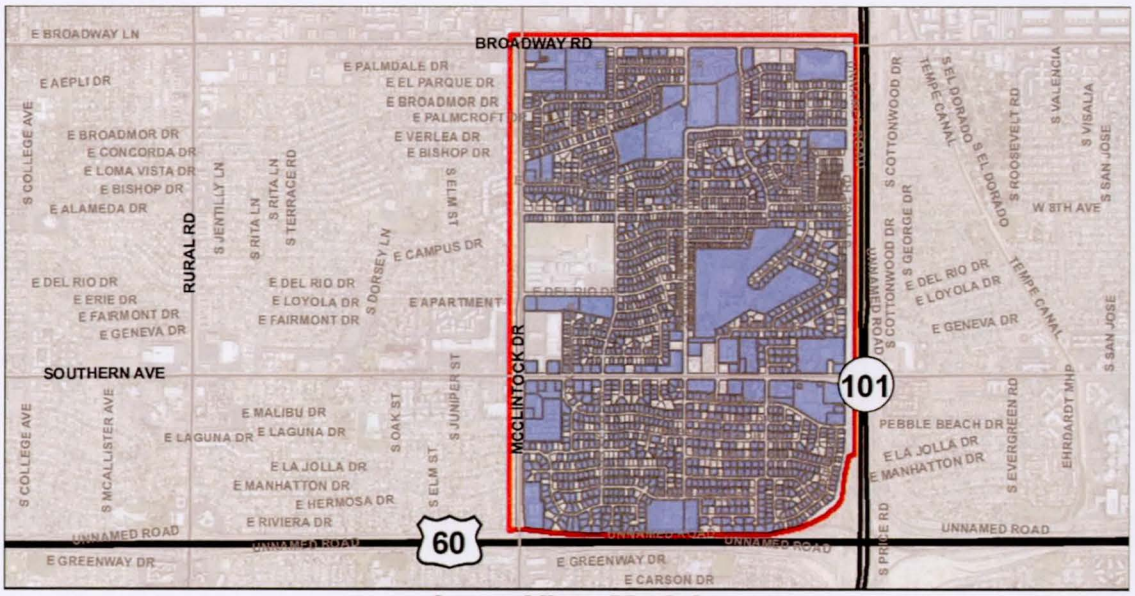
N
1 inch = 3,000 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



Loma Vista Model
75% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
75% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet

6.4 Development of FLO-2D Input Data Files

The specific steps for the development of INFIL.DAT are as follows:

1) Create a new shapefile consisting parcels only;
2) Remove parcels with area below minimum criteria (Example: 100 ft^2);
3) Classify parcels by zoning numbers in terms of LID volume capabilities;
4) Calculate a parcel zoning-specific IA adjustment based on the classified volume and the parcel contributing area (A), added IA = Vol/A;
5) Determine scenarios for participation levels by percent of parcels. For example: 10% parcels participate in LID scenario 1, 30% in scenario 2, 50% in scenario 3, and 75% in scenario 4. Randomly assign which parcels to use for each scenario (see Exhibit D);
6) Create rasters (4 ft resolution or smaller) using selected parcels for each scenario based on the IA adjustment values;
7) Associate IA adjustment values to grid number shapefile using Manifold;
8) Add IA adjustment values to original IA values and create new INFIL.DAT file.

Five (5) FLO-2D models were developed and executed for the base model and the four (4) LID scenarios. The base model is the model with 0% LID participation. The FLO-2D model input and output files and modeling results are included in Appendix E.

6.5 Evaluation of FLO-2D Modeling Results for LID Scenarios

The recommended FLO-2D modeling techniques and LID applications were incorporated into Loma Vista model to quantify the impact of LID on storm water runoff. The Loma Vista FLO-2D model was developed for possible evaluation of various LID systems and scenarios within the project area and can serve as a preliminary approach for developing LID CIP projects within the Tempe ADMS watersheds. The final design will require development and refinement of more detailed LID alternatives. Hopefully, this project will allow LID to become one of the mainstream flood control measures in urbanized watersheds.

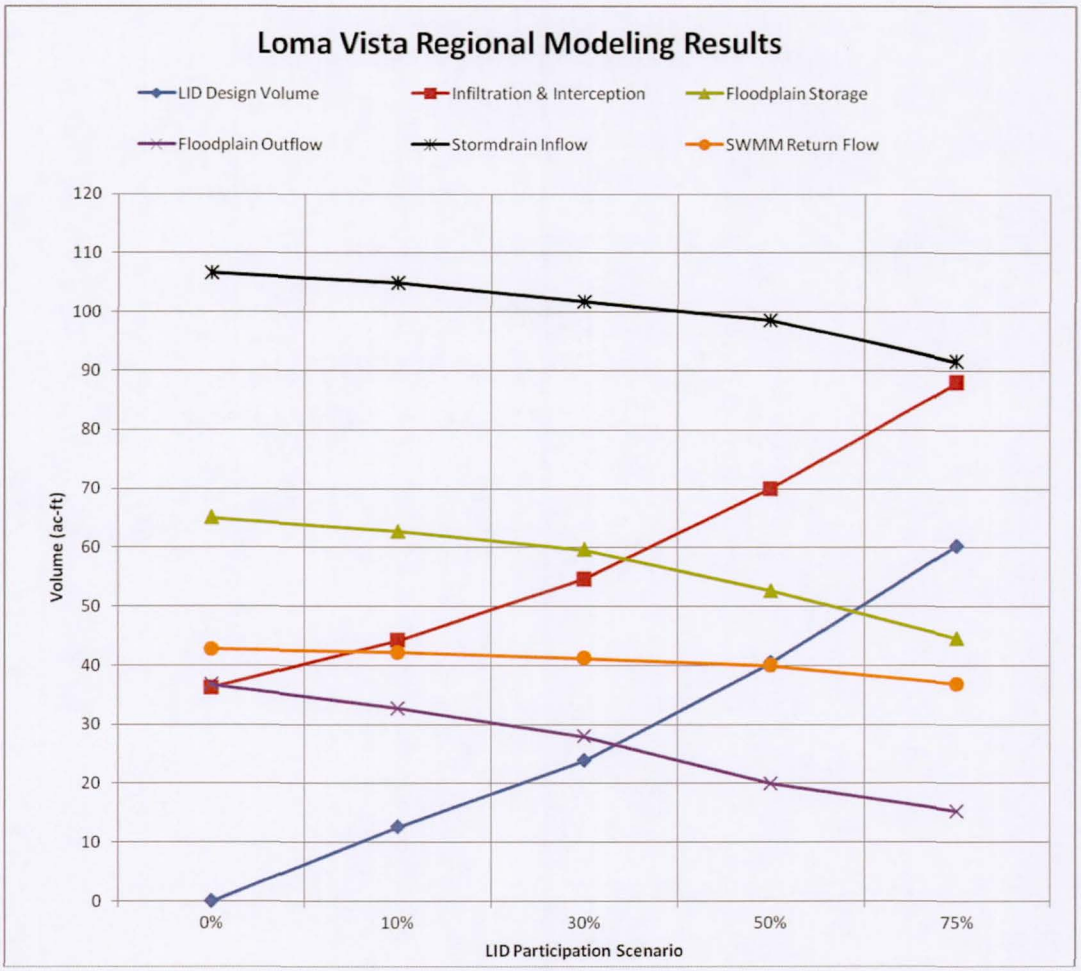
The FLO-2D/SWMM modeling results for the regional model (Loma Vista Area) and four (4) LID participation scenarios are summarized in Table 6.2 and the following charts.

Table 6.2 Loma Vista Regional Modeling Results

Participation Rate	LID Design Volume	Infiltration & Interception	Floodplain Storage	Floodplain Outflow	Stormdrain Inflow	SWMM Return Flow	SWMM Total Outflow
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
0%	0.0	36.3	65.0	36.8	106.7	42.8	100.1
10%	12.6	44.2	62.7	32.8	105.0	42.1	98.3
30%	23.8	54.7	59.6	28.0	101.7	41.2	95.3
50%	40.4	70.0	52.6	19.9	98.6	40.0	90.8
75%	60.3	88.0	44.6	15.2	91.5	36.8	84.4

The LID design volume and FLO-2D reported watershed infiltration & interception volume increase with the increase of the LID participation rate as expected. Floodplain (watershed) storage, surface outflow, storm drain inflow, storm drain outflow, and storm drain return flow (flooding) decrease with the increase o the LID participation rate. The reduction of storm

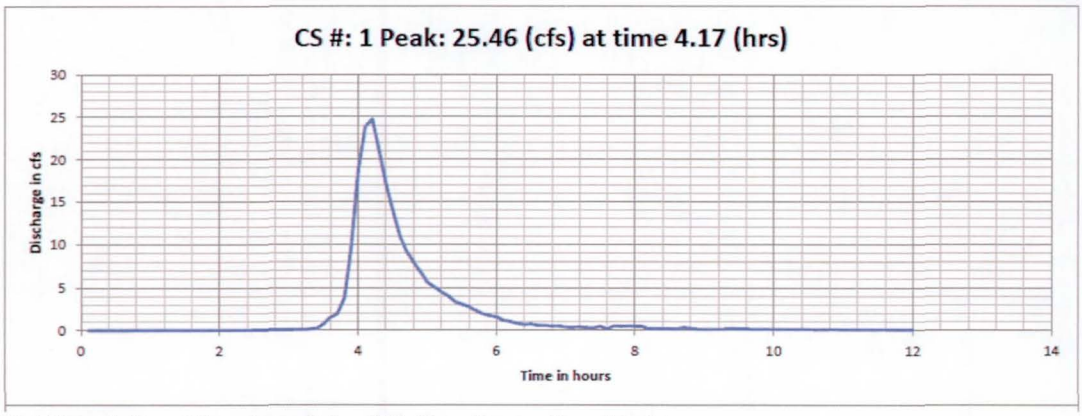
drain return flows is not very significant due to the small storm drain capacity compared to the 100-year storm runoff. The following charts show these patterns.



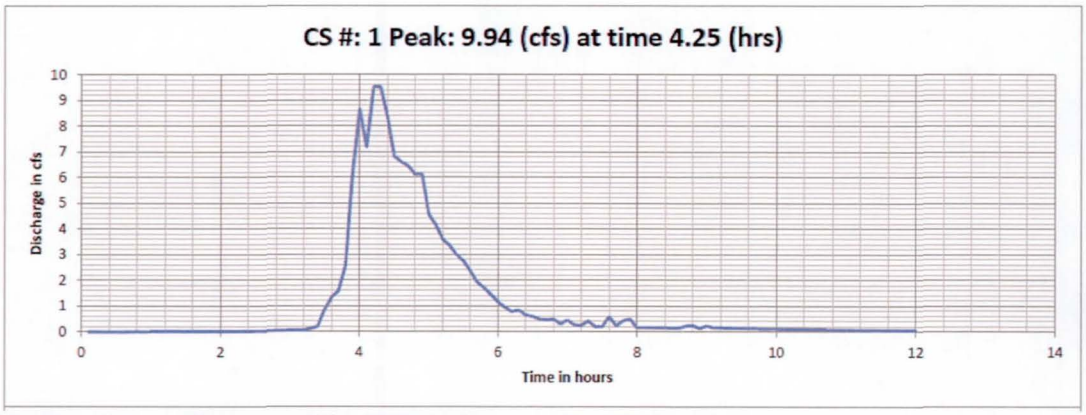
In order to show the effectiveness of LID applications on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts (all cross section (CS) hydrographs are included in Appendix E4):

CS #1 is located at McClintock Dr. and Broadway Rd and the peak flow is reduced from 25.5 cfs to 9.9 cfs (61% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.17 hours to 4.25 hours which has some effects on the peak flows at the downstream reaches.

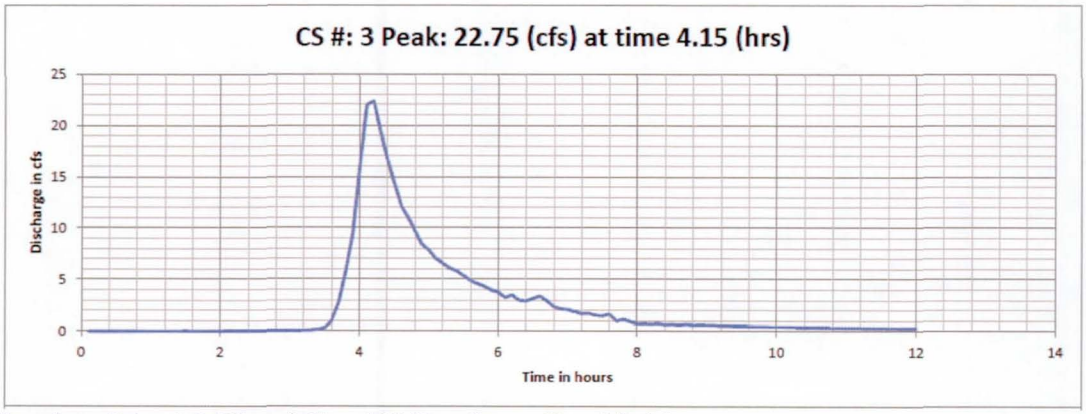
CS #3 is located at Broadway Rd. and McClintock Dr. and the peak flow is reduced from 22.8 cfs to 15.8 cfs (31% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.15 hours to 4.36 hours which has some effects on the peak flows at the downstream reaches.



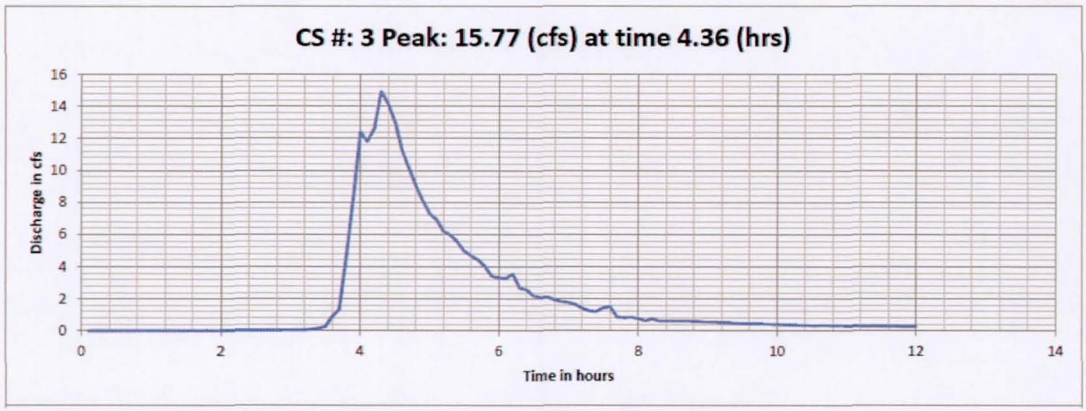
McClintock Dr. at Broadway Rd. - 100-Year Storm, Base Model



McClintock Dr. at Broadway Rd. - 100-Year Storm, 50% LID Participation

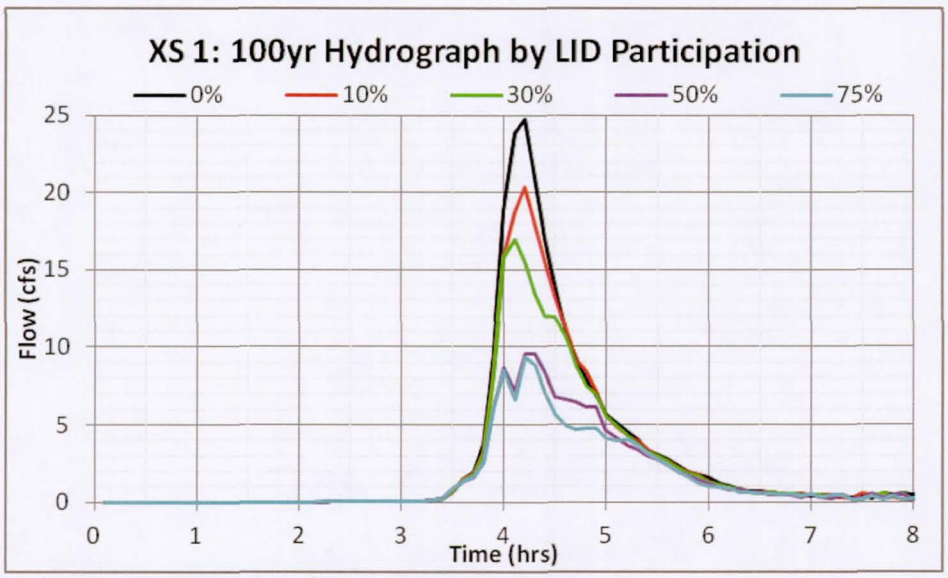


Broadway Rd. at McClintock Dr. - 100-Year Storm, Base Model

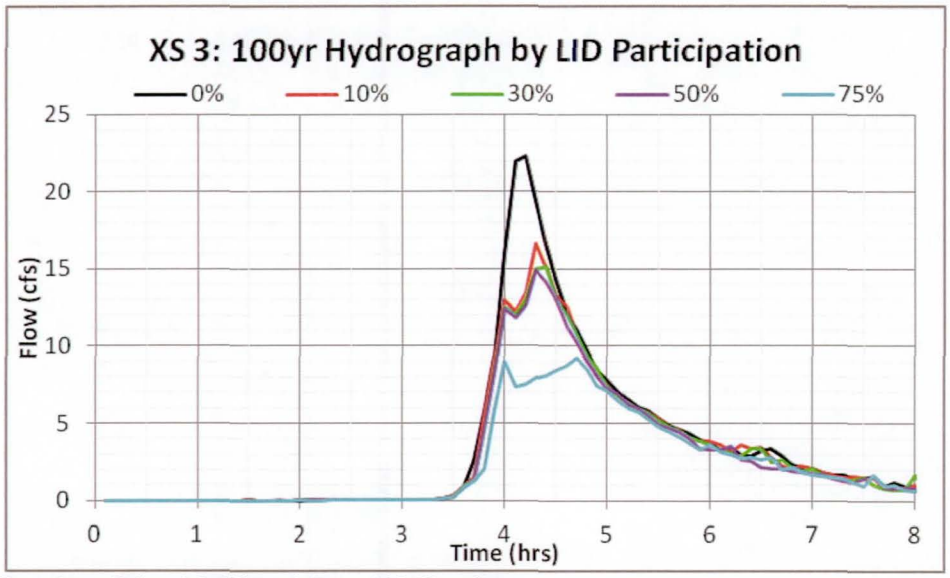


Broadway Rd. at McClintock Dr. - 100-Year Storm, 50% LID Participation

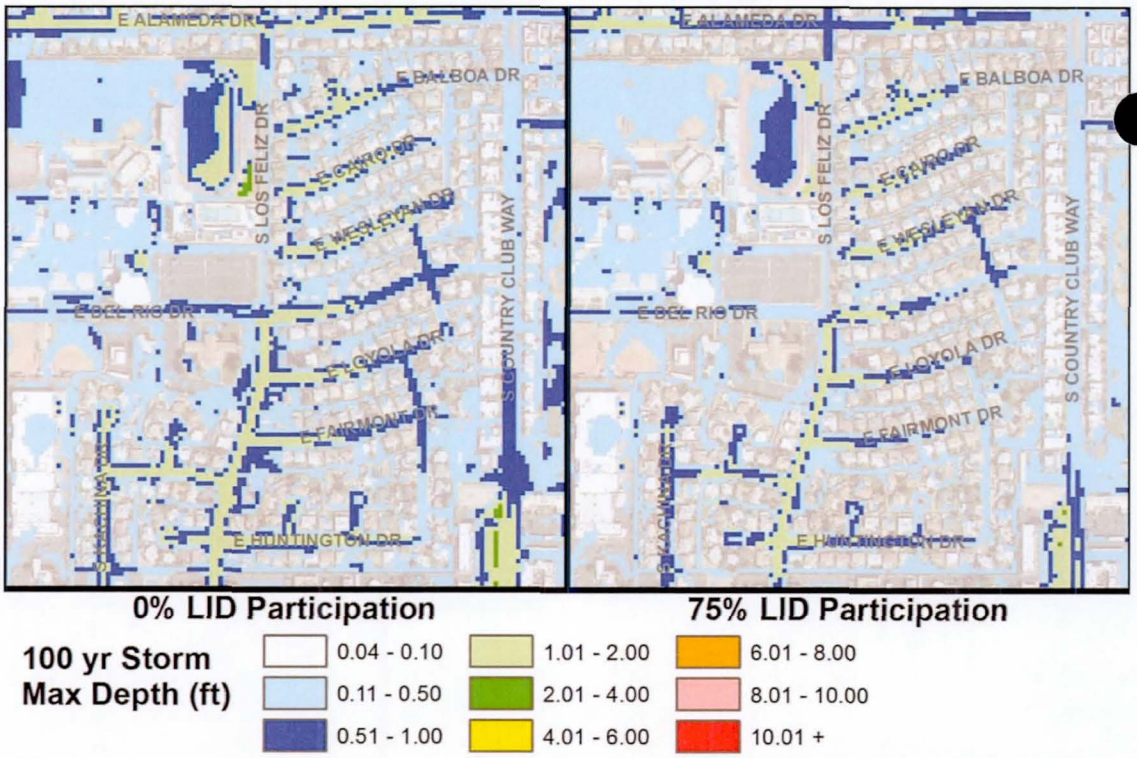
In order to show the impact of LID participation rate on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all of the four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate as expected.



McClintock Dr. at Broadway Rd. - 100-Year Storm



Broadway Rd. at McClintock Dr. - 100-Year Storm



McClintock High: Comparison of maximum depths between 0% and 75% LID participation scenarios

7.0 LID IMPLEMENTATION IMPACT ON FLOOD MITIGATION

The impact of LID practices on flood mitigation depends on many factors, such as LID composite design capacity (individual LID sizes), LID parcel participation rate (community participation rate – total LID sizes), and storm event frequency (flooding potential/risk).

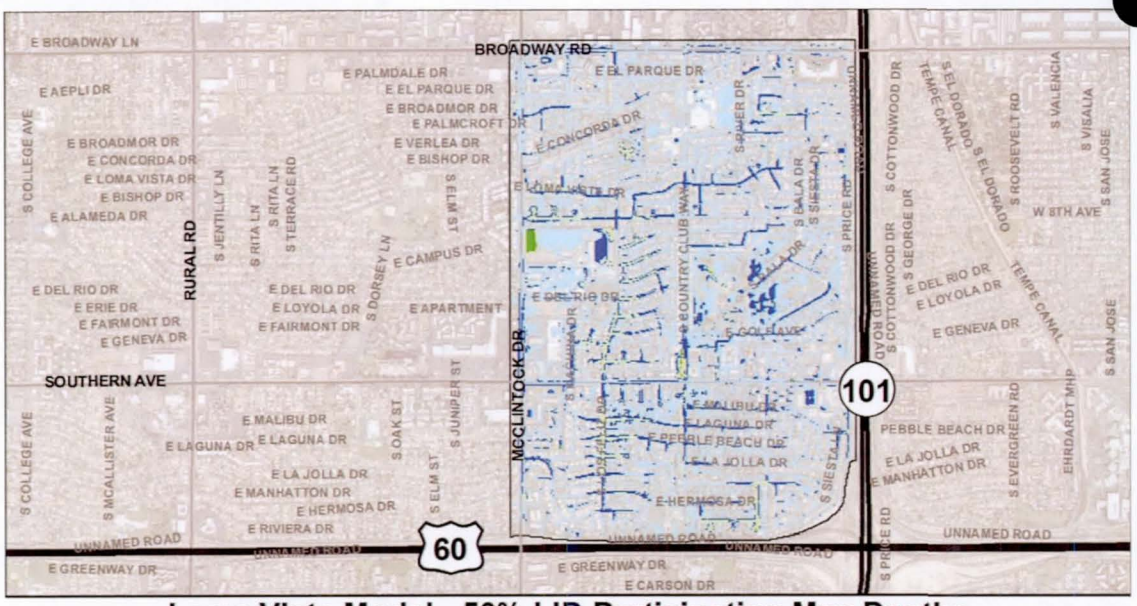
The impact of LID composite design capacity (individual LID sizes) and LID participation scenarios (community participation rate – total LID sizes) on flood mitigation was evaluated in previous section. Theoretically, the larger the LID design capacity and LID participation rate are, the more significant of the impact on flood mitigation is due to LID applications.

Multiple frequency modeling (2-yr, 10-yr, 25-yr, and 100-yr design storms) was conducted to evaluate the LID application effectiveness on flood mitigation for given design LID scenarios using Loma Vista FLO-2D models in the following sub-sections. The four (4) LID application scenarios were evaluated for each of the four (4) storm events to demonstrate the effectiveness of LID applications on flood mitigation for various sizes of storm events:

- Scenario I: 10% parcel participation rate;
- Scenario II: 30% parcel participation rate;
- Scenario III: 50% parcel participation rate;
- Scenario IV: 75% parcel participation rate.

7.1 100-Year Storm Event

The 100-year storm FLO-2D modeling results for the five (5) models were documented in Appendix E and Exhibit D including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendices E3 and E4. Evaluation of the modeling results was documented in Section 6.5. The following map showed the 50& participation rate. The modeling results for CR #1 and CS #3 show that surface runoff reduction increases with the increase of LID participation rate.



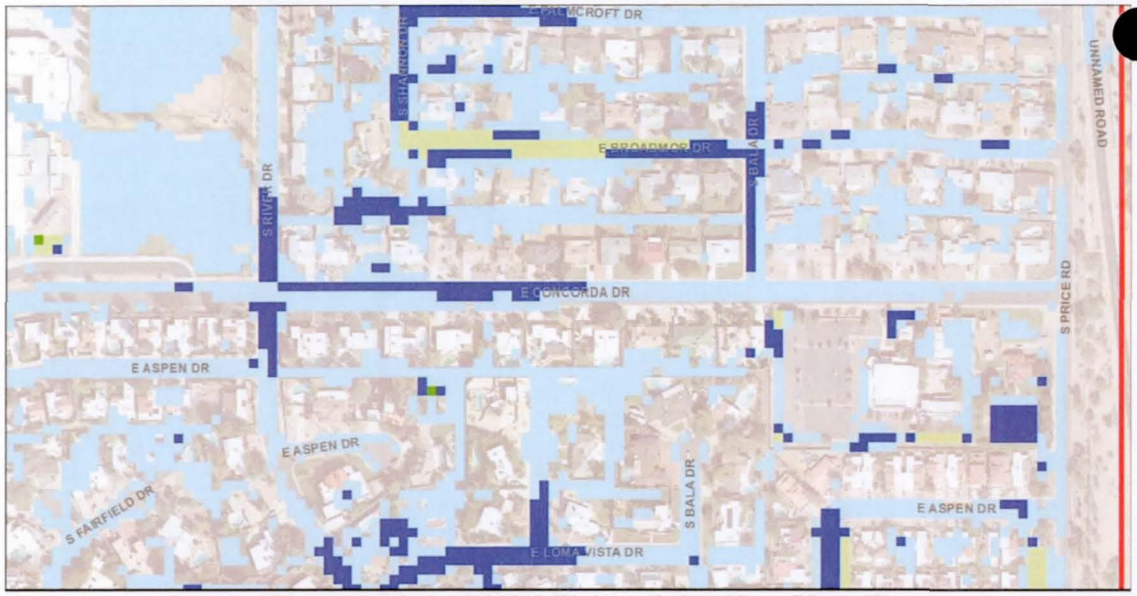
Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

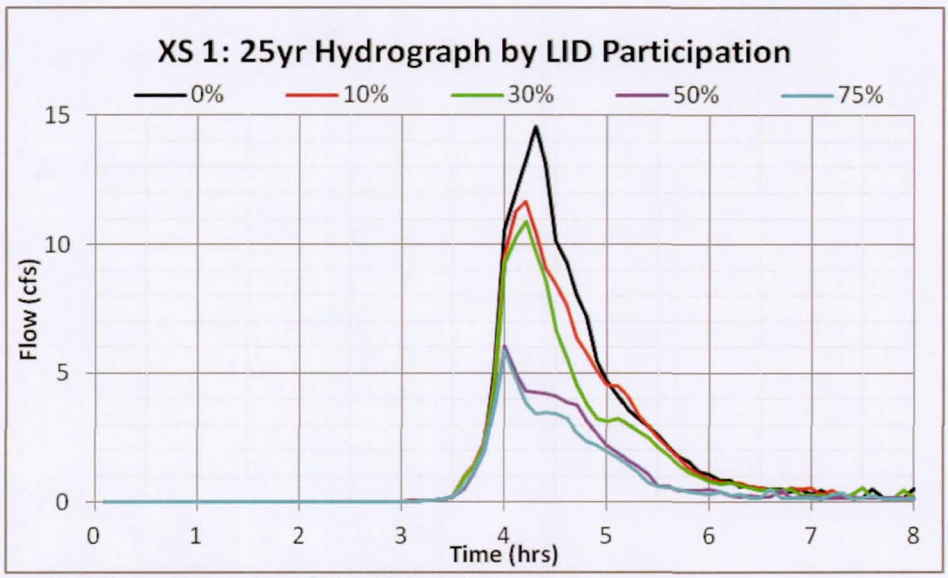
N

1 inch = 400 feet

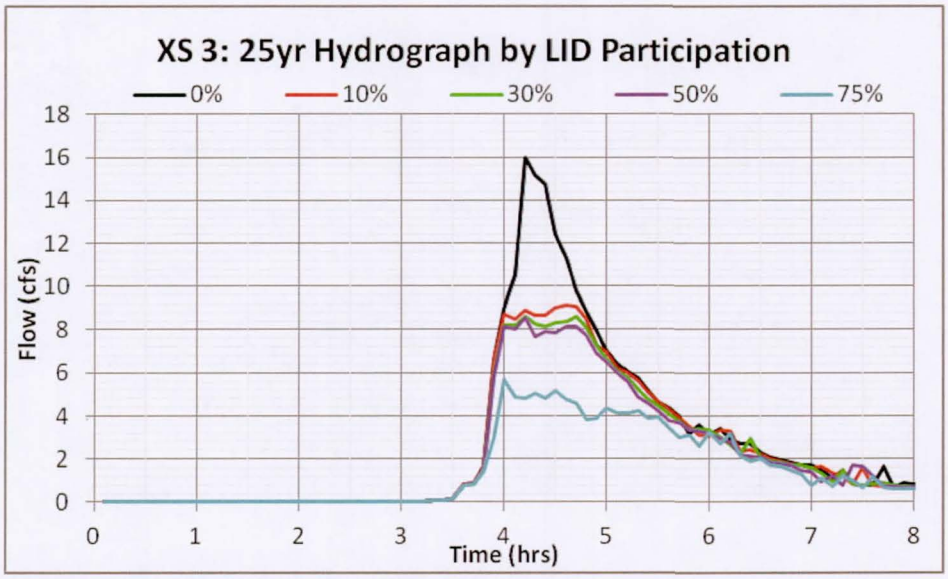
7.2 25-Year Storm Event

The 25-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

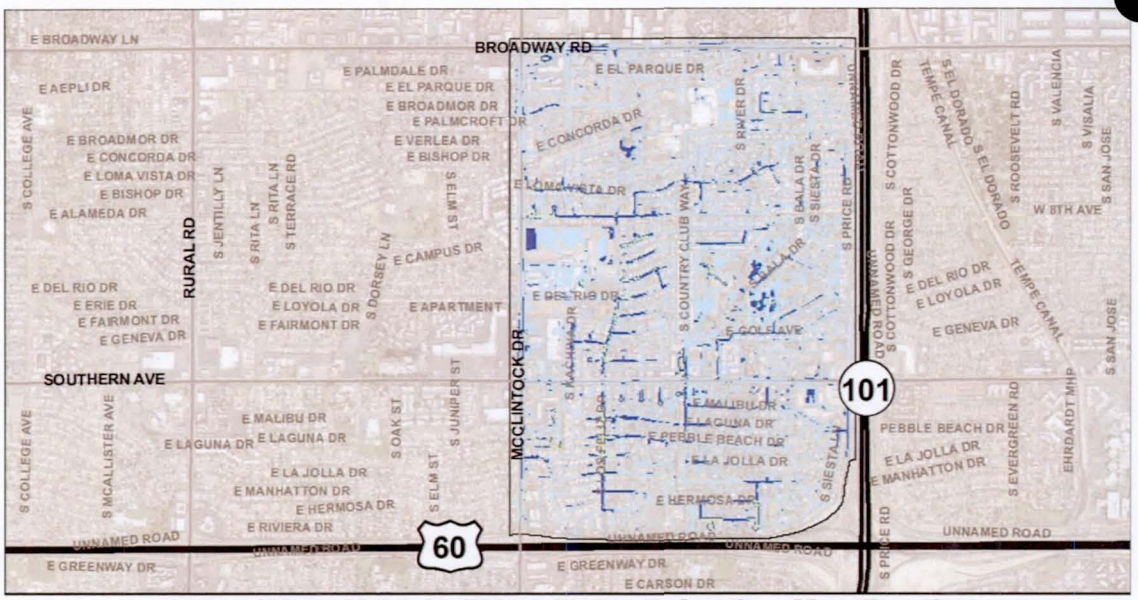
In order to show the impact of LID participation rate on the surface peak flow reduction for the 25-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 25-Year Storm



Broadway Rd. at McClintock Dr. – 25-Year Storm



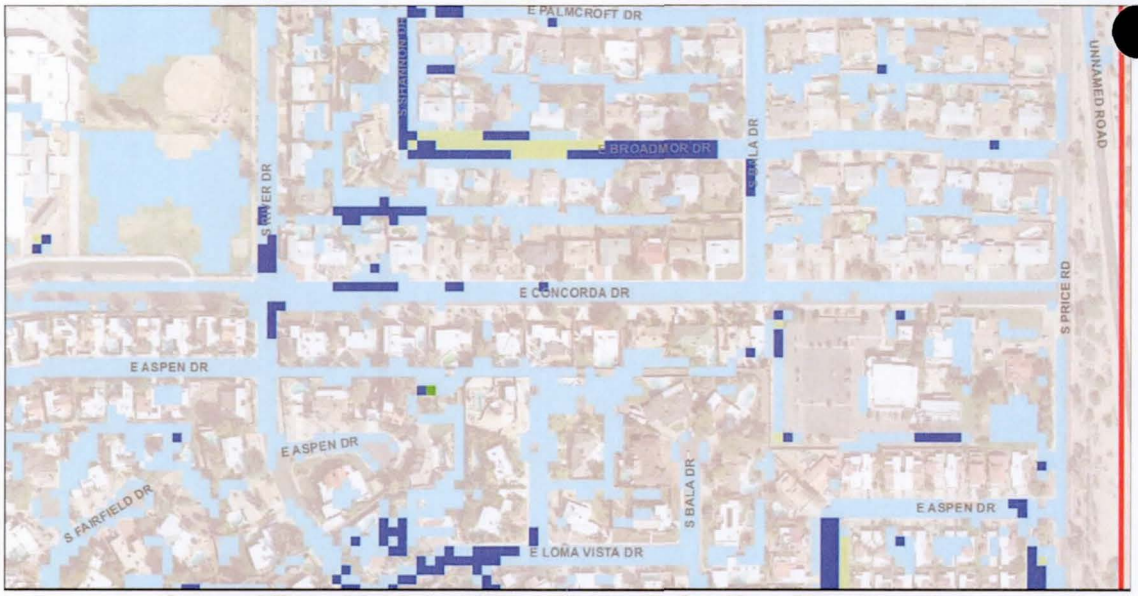
Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

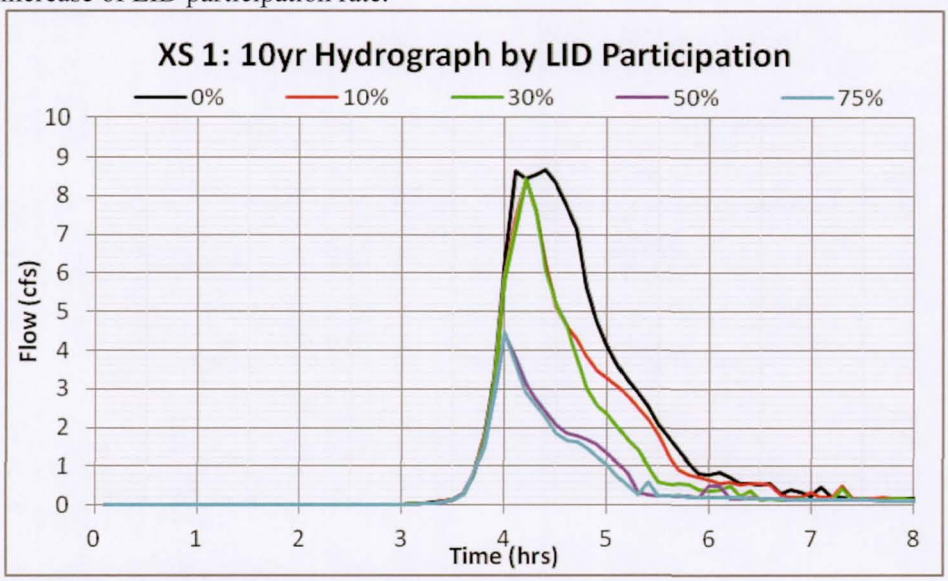
N

1 inch = 400 feet

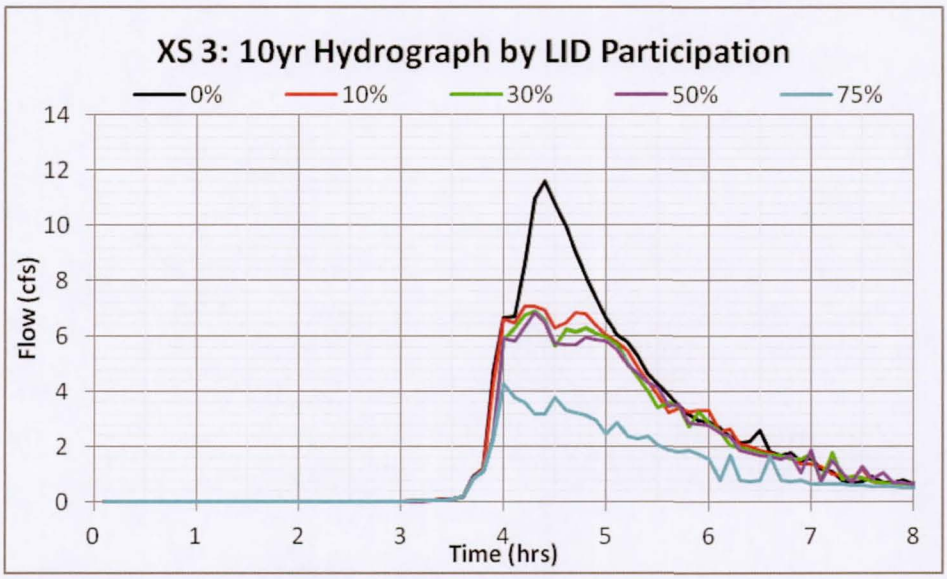
7.3 10-Year Storm Event

The 10-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

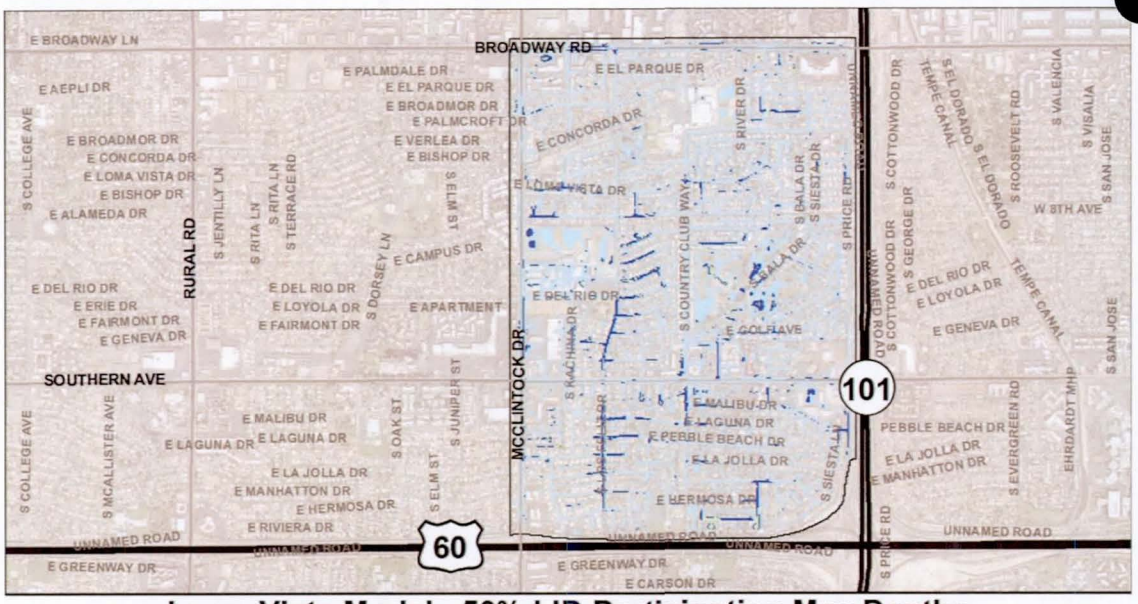
In order to show the impact of LID participation rate on the surface peak flow reduction for the 10-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 10-Year Storm



Broadway Rd. at McClintock Dr. – 10-Year Storm



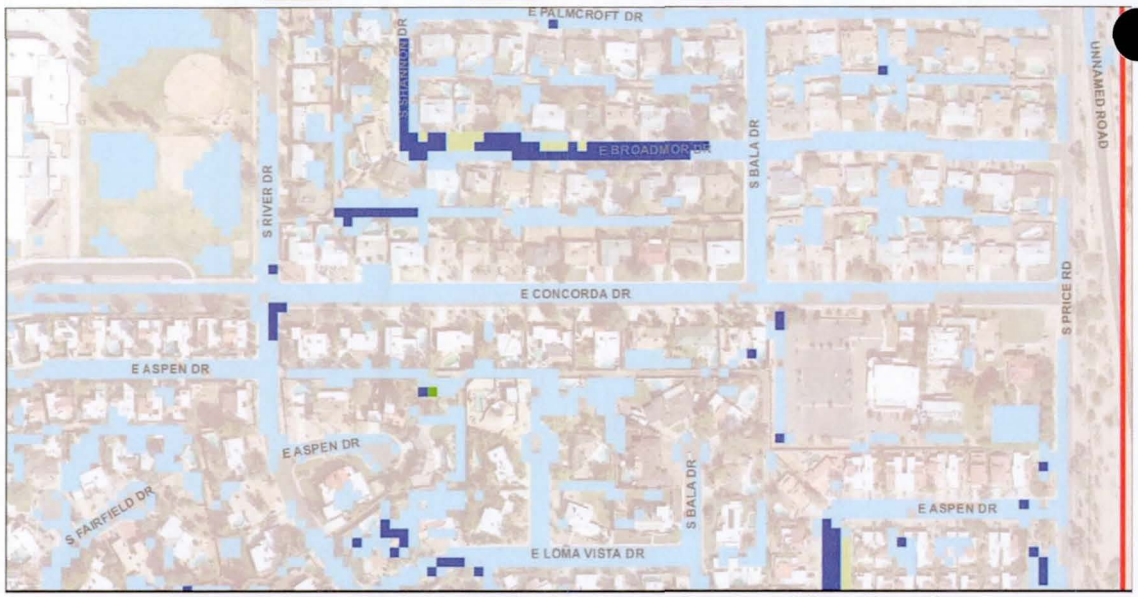
Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

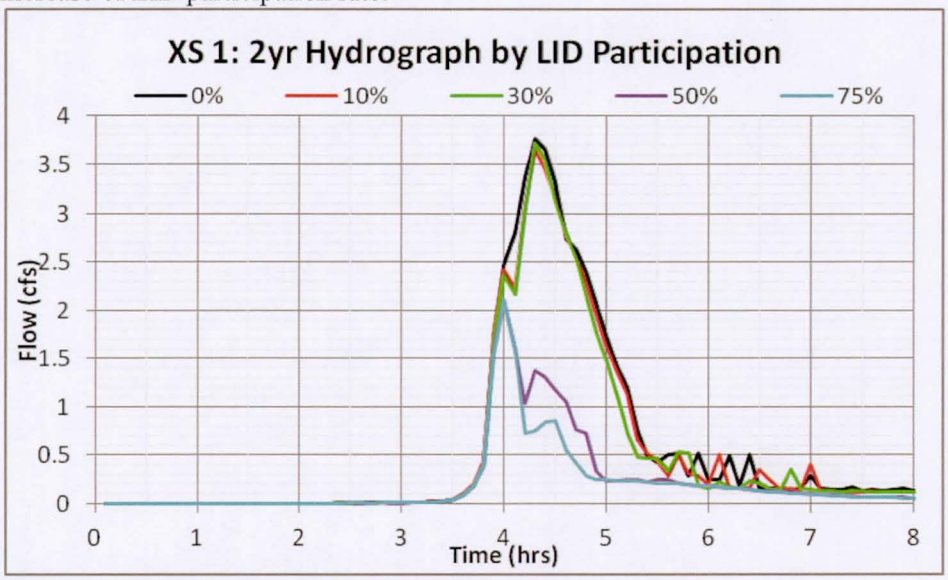
N

1 inch = 400 feet

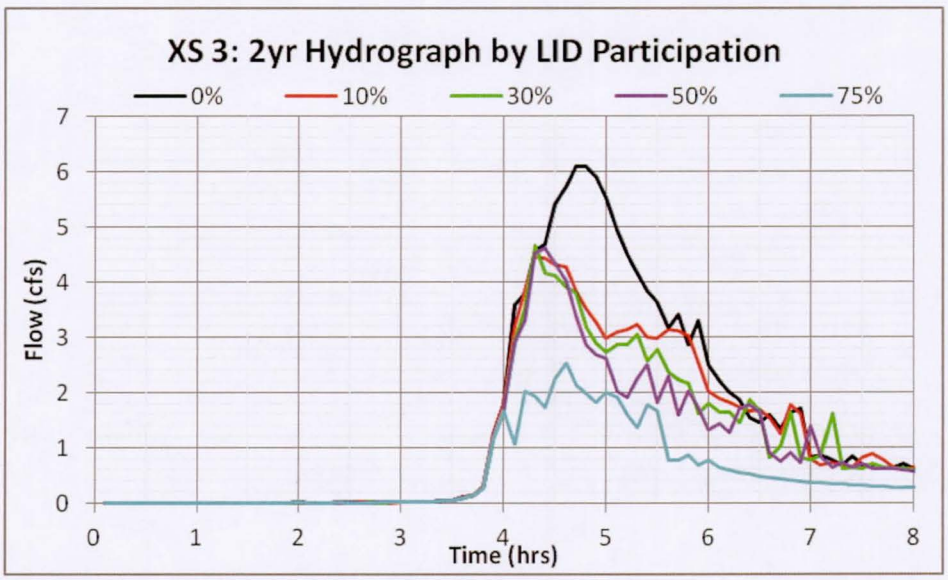
7.4 2-Year Storm Event

The 2-year storm FLO-2D modeling results for the four (5) models were documented in Appendix F and Exhibit E including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix F.

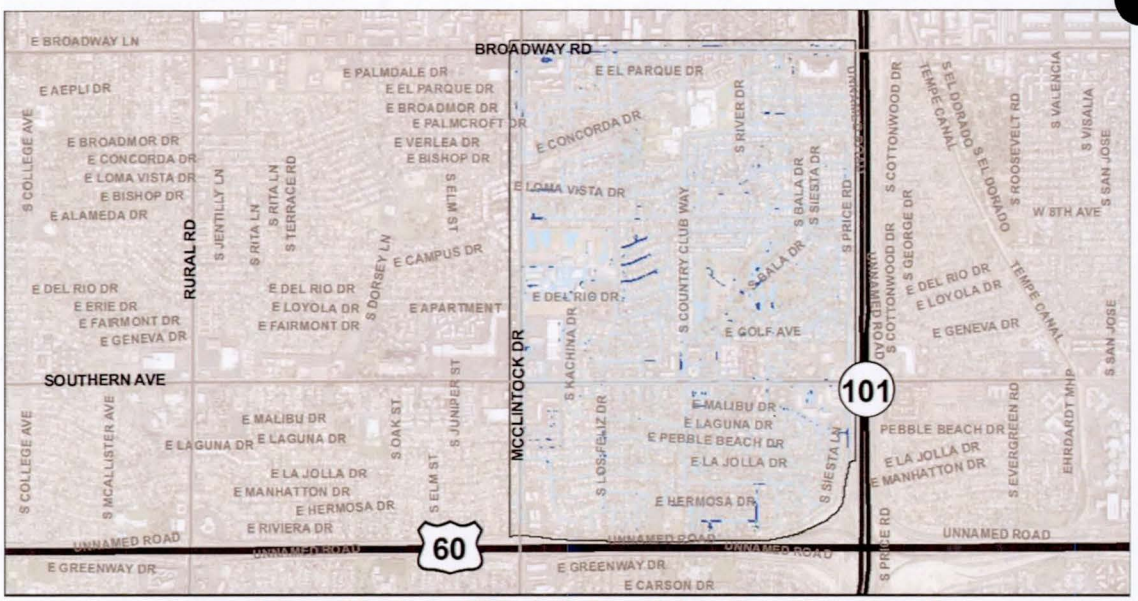
In order to show the impact of LID participation rate on the surface peak flow reduction for the 2-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 2-Year Storm



Broadway Rd. at McClintock Dr. – 2-Year Storm



Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet

Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

7.5 Summary of Multiple Frequency FLO-2D Modeling Results

The FLO-2D modeling results for the multiple frequency storms with the four (4) parcel participation rates were summarized in Tables 7.1 to 7.6:

Table 7.1 documents the modeling results for infiltration and interception variables;
Table 7.2 documents the modeling results for surface floodplain storage variable;
Table 7.3 documents the modeling results for floodplain outflow volume;
Table 7.4 documents the modeling results for stormdrain inflow volume;
Table 7.5 documents the modeling results for stormdrain returning flow;
Table 7.6 documents the modeling results for stormdrain total outfall peak flows.
The values in the tables as functions of the storm size and parcel participation rate were also shown in the charts following each table.

The modeling results show that LID applications are very effective in flood mitigation in reducing the storm runoff volumes.

Table 7.1 Loma Vista Multiple Frequency Results

Infiltration & Interception (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.3	34.3	32.8	28.9
	10%	44.2	42.2	40.2	34.2
	30%	54.7	52.4	49.9	40.8
	50%	70.0	67.3	63.9	50.2
	75%	88.0	84.8	80.0	60.6

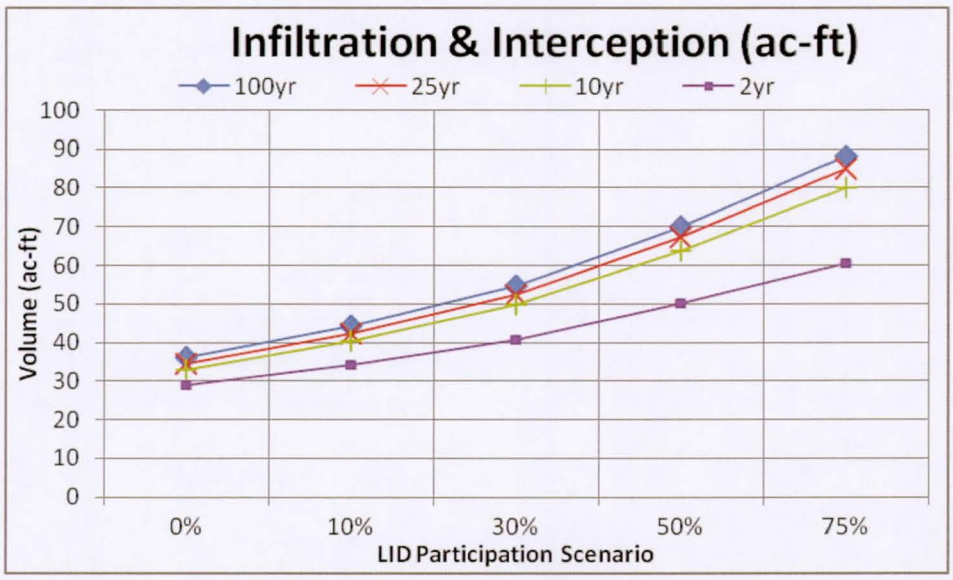


Table 7.2 Loma Vista Multiple Frequency Results					
Floodplain Storage (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	65.0	51.5	41.0	28.0
	10%	62.7	47.3	38.0	25.9
	30%	59.6	43.6	35.1	23.4
	50%	52.6	36.9	29.6	18.7
	75%	44.6	30.1	22.7	12.8

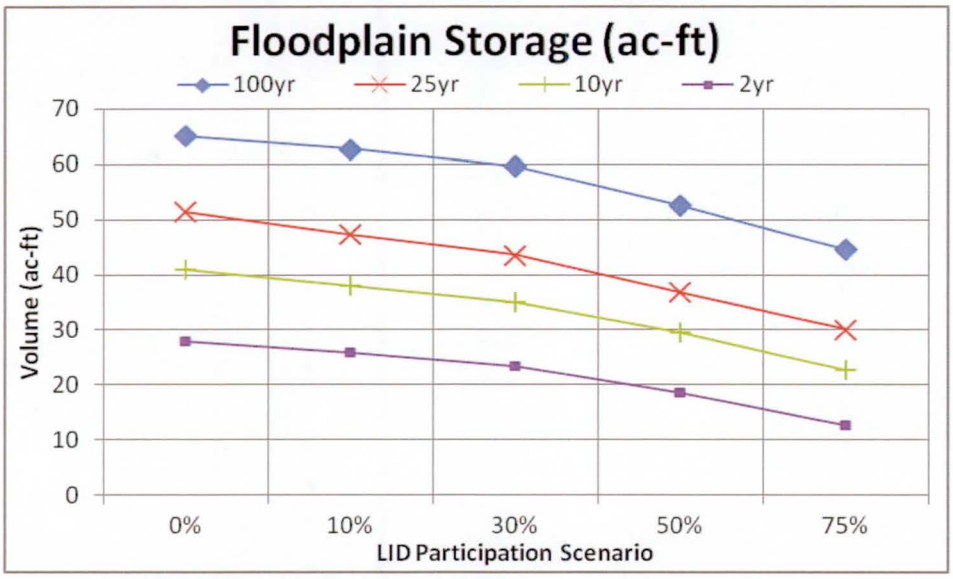


Table 7.3 Loma Vista Multiple Frequency Results					
Floodplain Outflow (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.8	16.3	9.3	3.6
	10%	32.8	14.7	8.4	3.4
	30%	28.0	11.8	7.3	3.1
	50%	19.9	8.7	5.7	2.5
	75%	15.2	6.7	4.5	2.2

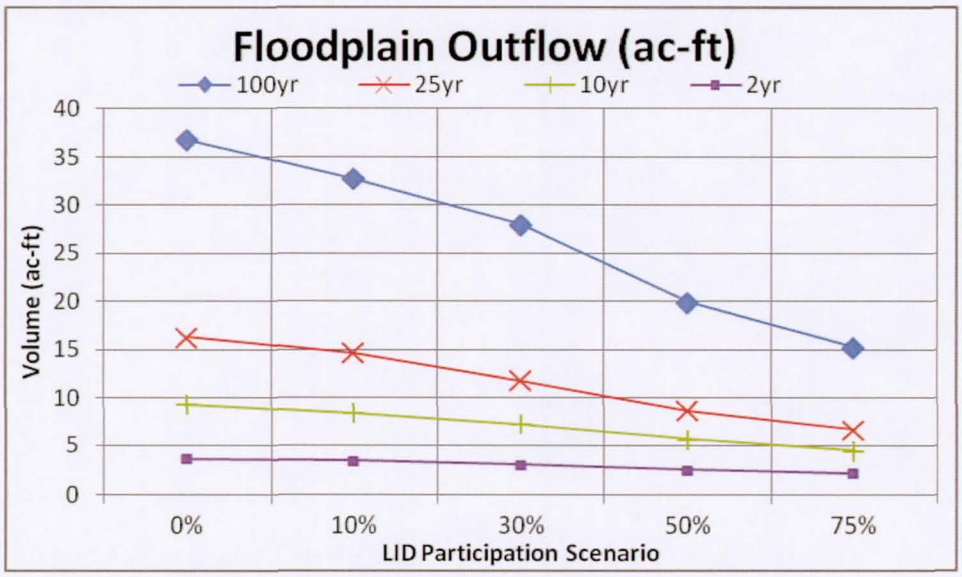


Table 7.4 Loma Vista Multiple Frequency Results						
Stormdrain Inflow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	106.7	95.3	82.4	45.5
		FLO2D	99.8	88.5	75.8	40.3
	10%	SWMM	105.0	91.2	76.8	40.8
		FLO2D	97.9	84.5	70.1	35.9
	30%	SWMM	101.7	86.1	67.6	33.6
		FLO2D	94.5	79.2	61.3	29.8
	50%	SWMM	98.6	76.8	58.4	26.5
		FLO2D	92.5	70.5	51.9	23.4
	75%	SWMM	91.5	65.0	44.2	14.0
		FLO2D	84.7	58.4	38.8	13.6

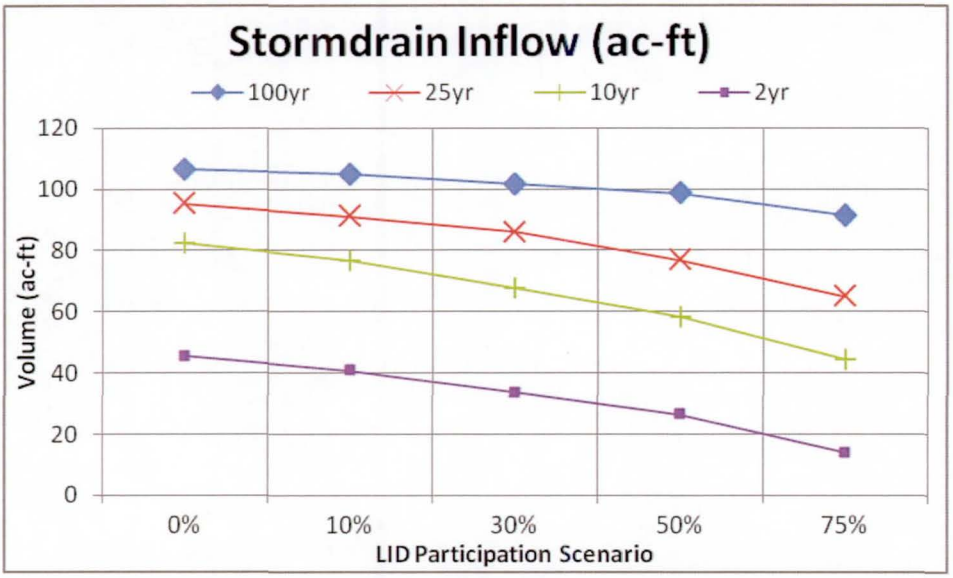


Table 7.5 Loma Vista Multiple Frequency Results						
Stormdrain Return Flow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	42.8	38.9	33.0	16.3
		FLO2D	33.5	30.0	25.1	12.4
	10%	SWMM	42.1	36.6	30.2	14.6
		FLO2D	33.1	28.0	22.9	11.0
	30%	SWMM	41.2	34.2	26.1	10.8
		FLO2D	32.3	26.3	19.7	8.7
	50%	SWMM	40.0	30.3	22.6	8.2
		FLO2D	30.6	22.8	17.2	6.4
	75%	SWMM	36.8	25.7	16.4	0.5
		FLO2D	28.1	19.5	12.1	0.8

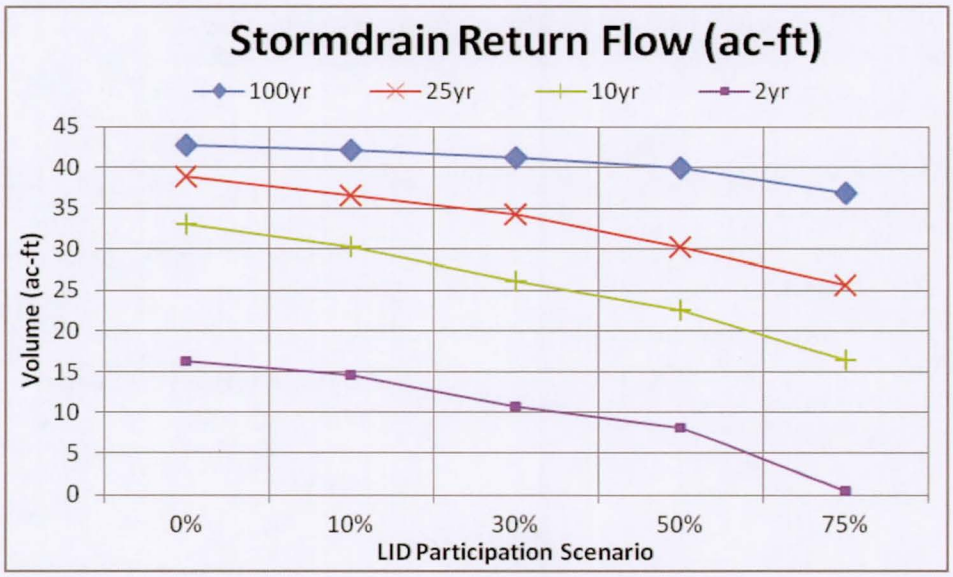
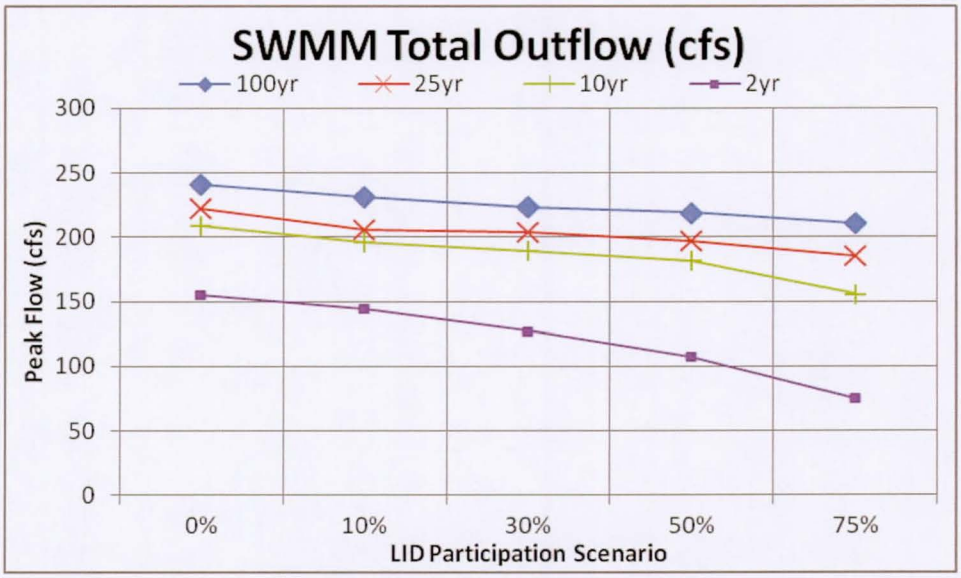
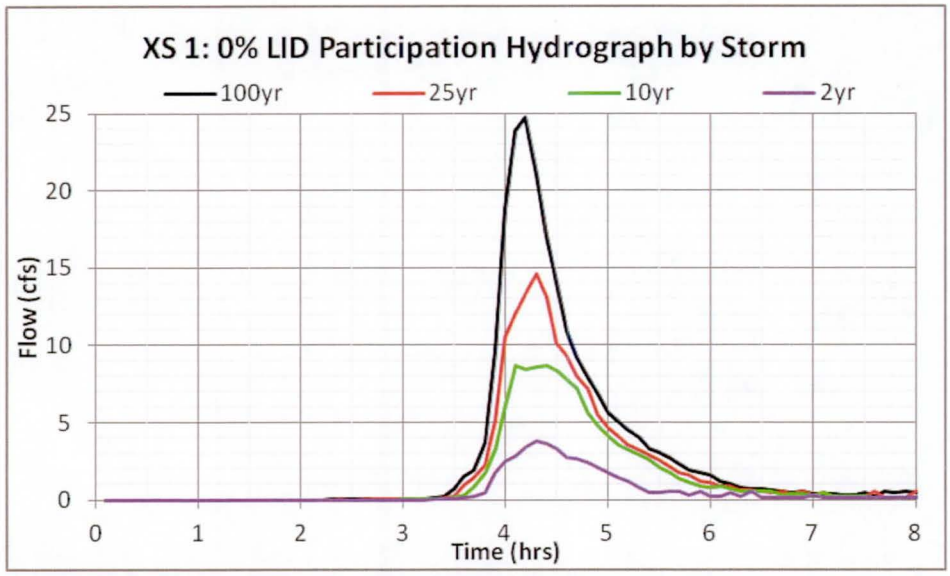


Table 7.6 Loma Vista Multiple Frequency Results					
SWMM Total Outflow (cfs)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	241.0	222.2	208.9	155.3
	10%	231.3	205.8	196.2	144.6
	30%	223.6	203.9	189.3	127.1
	50%	218.8	196.9	181.4	107.3
	75%	210.4	184.9	155.4	75.3

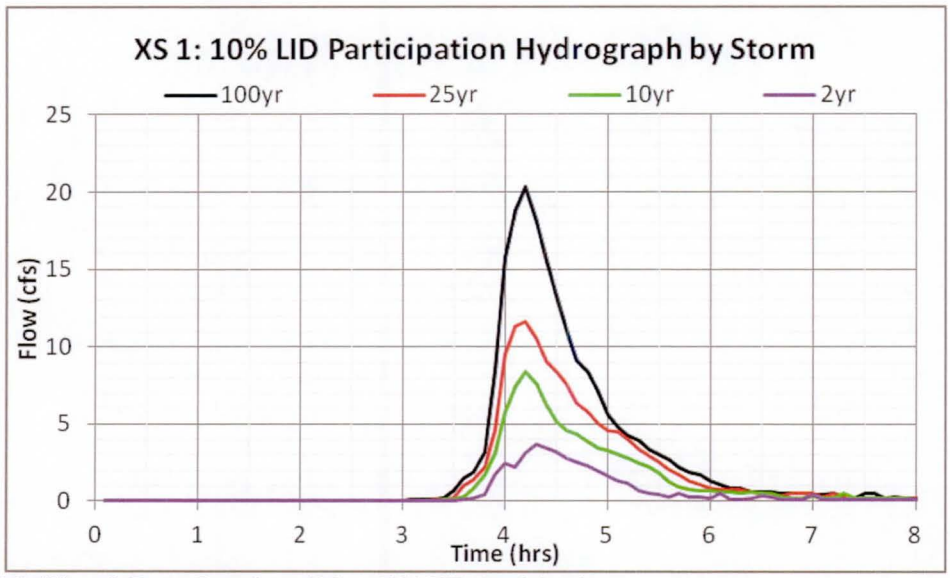


The surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts in order to show the effectiveness of LID applications on the surface peak flow reduction (all cross section hydrographs are included in Appendix F):

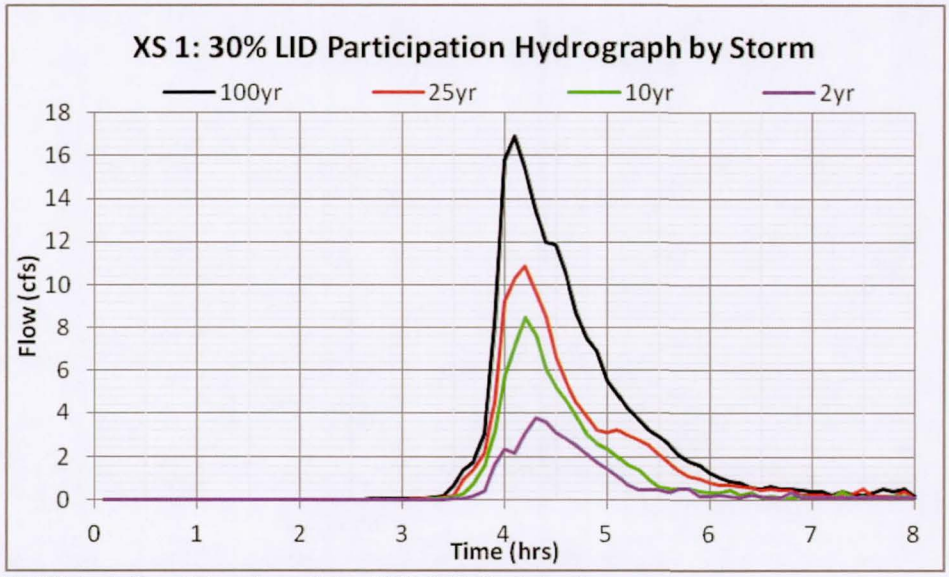
CS #1 is located at McClintock Dr. and Broadway Rd. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces with more frequent storms.



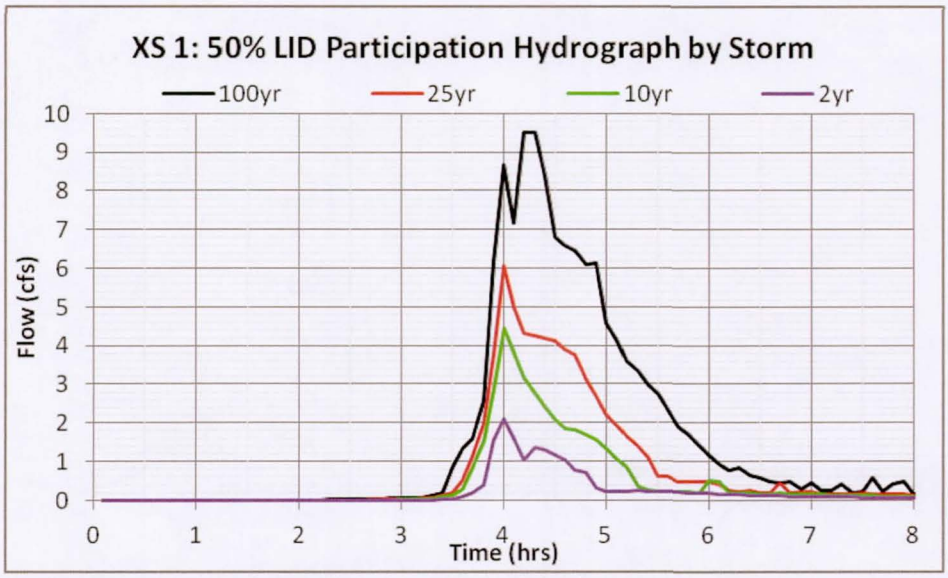
McClintock Dr. at Broadway Rd. – 0% LID Participation



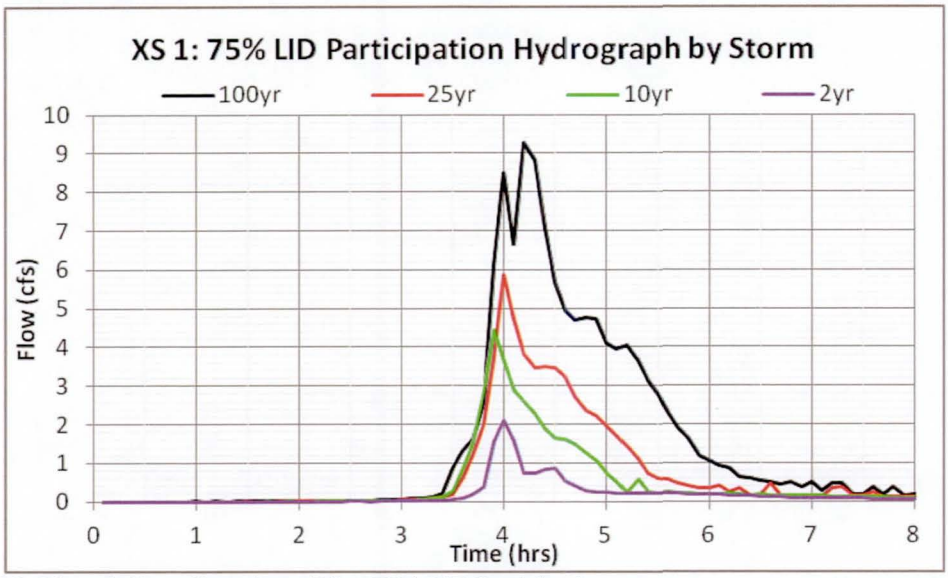
McClintock Dr. at Broadway Rd. – 10% LID Participation



McClintock Dr. at Broadway Rd. – 30% LID Participation

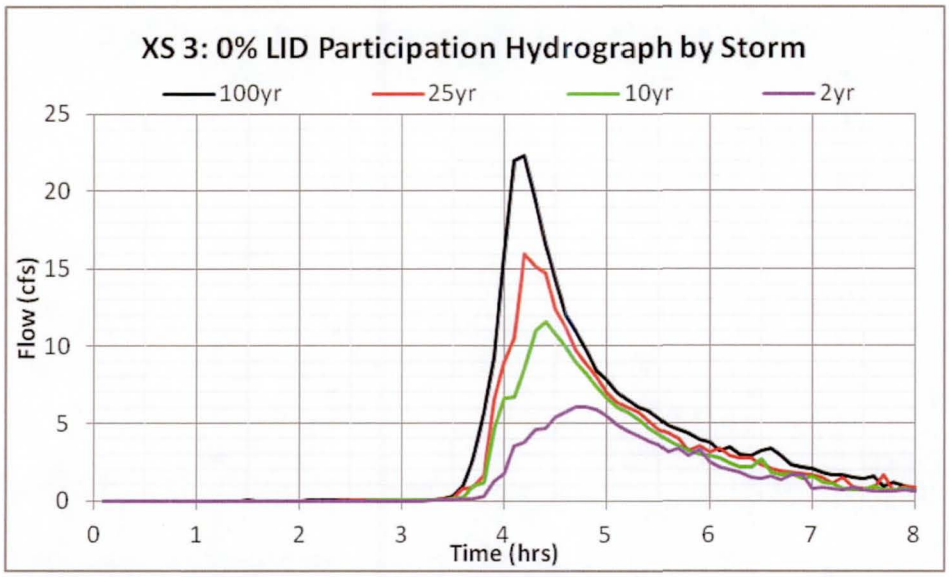


McClintock Dr. at Broadway Rd. – 50% LID Participation

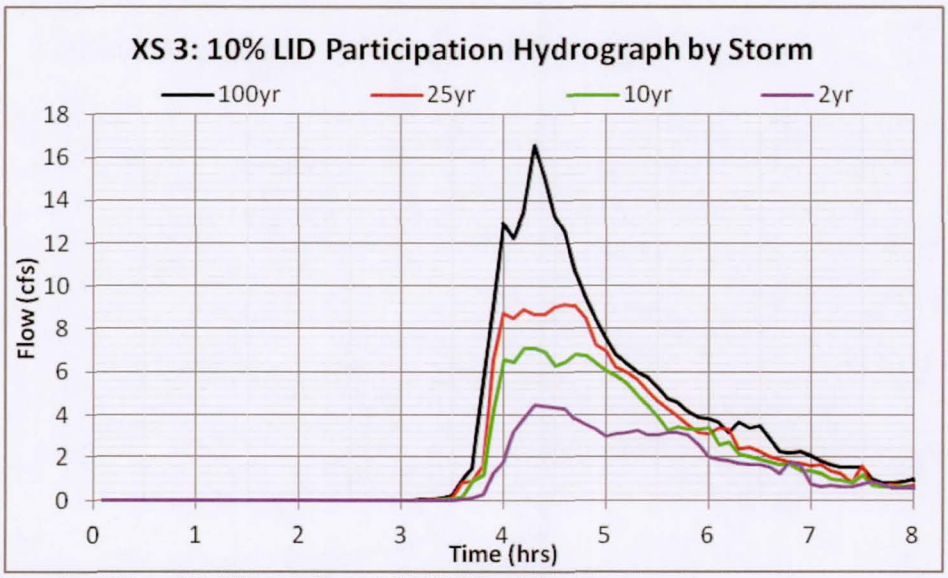


McClintock Dr. at Broadway Rd. – 75% LID Participation

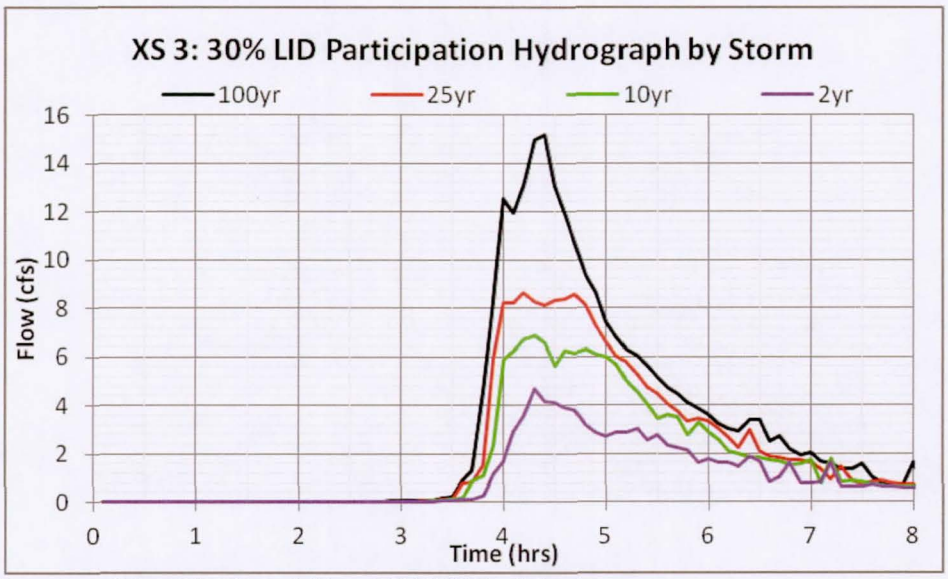
CS #3 is located at Broadway Rd. and McClintock Dr. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces more with more frequent storms.



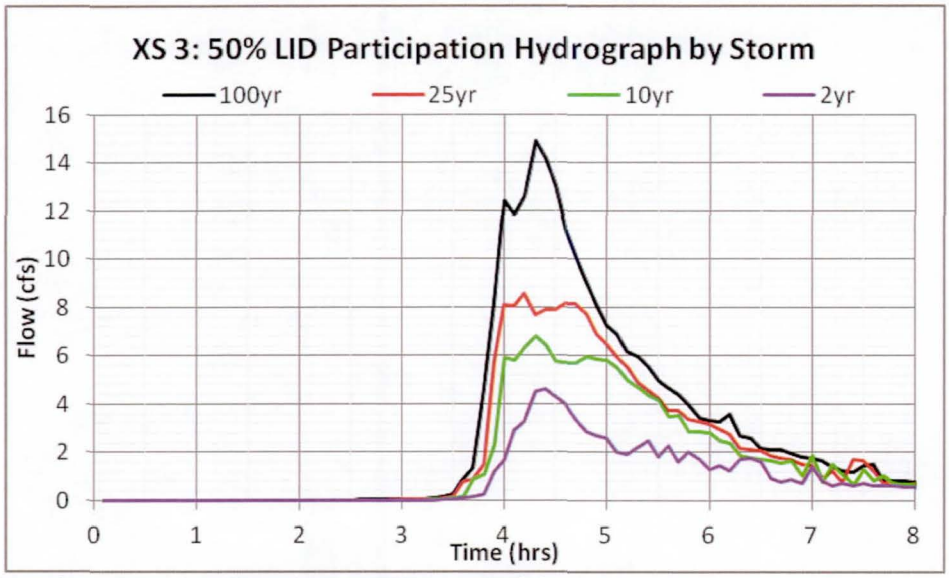
Broadway Rd. at McClintock Dr. – 0% LID Participation



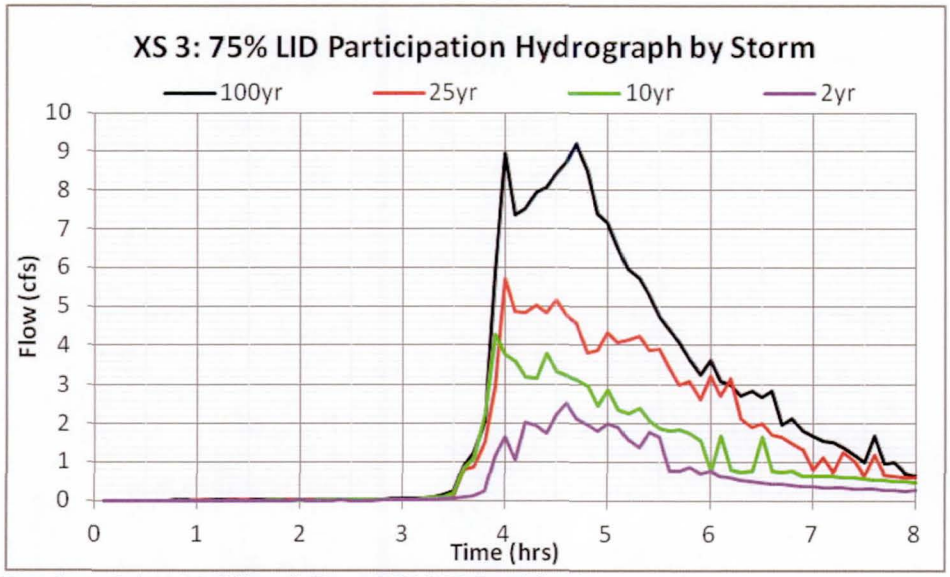
Broadway Rd. at McClintock Dr. – 10% LID Participation



Broadway Rd. at McClintock Dr. – 30% LID Participation



Broadway Rd. at McClintock Dr. – 50% LID Participation



Broadway Rd. at McClintock Dr. – 75% LID Participation

8.0 REFERENCES

1. ESRI, *ArcGIS,* Version 10, 2010.
2. FLO-2D Software Inc., *FLO-2D*, Pro Version, Model-Build No. 13.11.06, 2014.
3. Manifold Software Limited, *Manifold System*, Version 8.0, 2010.
4. U.S. Environmental Protection Agency, *EPA SWMM*, Version 5.0 (Build 5.0.022), April 2011.
5. inpPINS Computer Program, https://sites.google.com/site/inppins/guide
6. Bentley Systems, Inc., *CulvertMaster*, Version 3.2, August 2008
7. Flood Control District of Maricopa County, FLO-2D Review Guidelines, revised version, July 2012.
8. Riada Engineering, FLO-2D Reference Manual.
9. Riada Engineering, FLO-2D Data Input Manual.
10. Riada Engineering, FLO-2D GDS Manual.
11. Riada Engineering, FLO-2D Mapper Manual.
12. Riada Engineering, FLO-2D Limiting Froude Number Application Guidelines.
13. Riada Engineering, FLO-2D Pocket Guide.
14. Riada Engineering, User Assigned Courant Number in TOLER.DAT for Enhanced Model Numerical Stability.
15. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, User's Manual, Version 4.1, June 1998.
16. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Version 4.1, June 1998.
17. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1 January 2010.
18. *Broadway & Rural DMP: FLO-2D Pilot Study*, Cardno WRG, October 1, 2010.
19. *Broadway Road/Rural Road Candidate Assessment Report (CAR)*, Project Engineering Consultants, Ltd. September 2002.
20. *Drainage Policies and Standards for Maricopa County*, Flood Control District of Maricopa County, April 24, 2007.

21. *Drainage Design Manual for Maricopa County, Hydrology*, Flood Control District of Maricopa County, November 18, 2009.

22. *Drainage Design Manual for Maricopa County, Hydraulics*, Flood Control District of Maricopa County, August 15, 2013.

23. *Phoenix-Tempe Area Mapping, Project ID 1291, Contract No. FCD 08-20*, Flood Control District of Maricopa County, August 4, 2009.

24. *SCS_Soil GIS Shape Files,* Flood Control District of Maricopa County, March 10, 2010.

25. *FLO-2D Data Input Manual, Version 2009.06,* FLO-2D Software, Inc., November 30, 2010.

26. *FLO-2D Review Checklist (DRAFT),* Flood Control District of Maricopa County, May 5, 2011.

27. *Broadway-Rural Pilot Study, FLO-2D Hydrograph Analysis,* Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

28. *TOL and Hydraulic Structure Rating Curves Interoffice Memorandum*, Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

29. *Tempe ADMS/P Data Collection Report*, J2, August 2014.

30. *Tempe ADMS/P Test Area Sensitivity Analysis Summary Report*, J2, March 2014.

31. *Tempe ADMS/P Test Area FLO-2D Analysis Summary Report*, J2, June 2015.

32. *Tempe ADMS/P FLO-2D/SWMM Modeling Report*, J2, November 2015.

TEMPE AREA DRAINAGE MASTER STUDY
CONTRACT FCD 2012C021

VOLUME V
STAKEHOLDER COORDINATION

Prepared For:
Flood Control District of Maricopa County
2801 W. Durango Street
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Phoenix, Arizona 85040
(602) 438-2221

August 2016

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- B2 Homeowners and Neighborhood Associations Information
- B3 Public Meeting Comments and Attendance

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- 2014-03-26 Tempe Unified High School District
- 2014-03-27 Downtown Tempe Community
- 2014-04-02 Tempe Chamber of Commerce
- 2014-04-03 City of Chandler
- 2014-05-01 Town of Guadalupe
- 2014-05-12 City of Phoenix
- 2014-05-14 Arizona State University
- 2014-05-20 Salt River Project
- 2014-05-21 Tempe Homeowners and Neighborhood Associations
- 2014-06-09 City of Tempe General Plan 2040
- 2014-09-29 Tempe Unified High School District
- 2014-11-17 Arizona State University
- 2015-04-10 City of Tempe
- 2015-06-03 Tempe Unified High School District

Appendix A

Tempe ADMS Key Stakeholders

a. City of Tempe
   1. Mr. Gregg Kent (480) 350-2738 gregg_kent@tempe.gov
   2. and Public Involvement Team: Ms. Shauna Warner (480) 350-8883 shauna_warner@tempe.gov and
   3. Ms. Amanda Nelson (480)350-2707 amanda_nelson@tempe.gov

b. City of Chandler
   1. Dan Cook
      Interim City Engineer
      PH: (480) 782-3403
      Dan.cook@chandleraz.gov

   2. Martin Perez
      Acting Building Development Engineer
      PH: 480-782-3138
      Martin.perez@chandleraz.gov

   3. Don Kirby
      Development Services Engineer
      Ph - (480) 782 3128
      Email: donald.kirby@chandleraz.gov

   4. Warren White
      Principle Engineer
      Ph - (480) 782 3337
      Email: warren.white@chandleraz.gov
      To set up meetings with this group please call Gina Foreman @ 480 782 3300

c. Town of Guadalupe Public Works:
   1. Bill Hernandez (480) 505-5399 bhernandez@guadalupeaz.org

d. SRP Public Relations:
   1. Public Relations: Peter Hayes (602) 236-5900

e. Arizona Department of Transportation (ADOT)
   Communication and Community Partnerships Office: Teresa Welborn
   (602) 712-7399 twelborn.azdot.gov

f. City of Phoenix
   1. Environmental Services – Storm water Program (602) 256-3190
   2. and Public Outreach: Toni Maccarone (602) 262-7176
      toni.maccarone@phoenix.gov

3. Hasan Mushtaq – Floodplain Administrator (602) 262-4026 hasan.mushtaq@phoenix.gov

g. Arizona State University (ASU)
   1. Media Relations: Sharon Keeler (480) 965-4012 sharon.keeler@asu.edu

h. Tempe Union High School - District Community Relations
   1. Dr. Linda Littell: 480-345-3716 llittell@tempeunion.org
   2. Bob Anderson – Director of Plant Operations (480) 345-3727
   3. Jessica Hauer, Envision Energy Coach (480) 345-3726

i. Mill Avenue District (Downtown Tempe Community, Inc) (480) 355-6060
   1. Nancy Hormann nancy@downtowntempe.com
   2. Spike Lawrence Chairman of the Board: (480)897-4422 spike@lawrenceandgeyser.com

j. Tempe Chamber of Commerce (480) 967-7891
   1. Jack Pisano Chair (480) 858-7760 jack.pisano@veoliatransdev.com
   2. Sean Donovan: VP Media and Program Development sean@tempechamber.org

k. Town of Guadalupe
   1. Rose Mary Arellano (480)505-5367,(480)567-5253 rarellano@guadalupeaz.org
   2. Nancy Holguin nholguin@guadalupeaz.org
   3. Jim Ricker (480)505-5380 jricker@guadalupeaz.org

Appendix B – Public Outreach

Appendix B1 - Public Information Flyers and Exhibits

Tempe Area Drainage Master Study Update

Issue Date 08-20-15

Supervisor Denny Barney, District 1
Supervisor Steve Gallardo, District 5

Project Description

Within the last five years, multiple significant storm events have caused extensive street drainage problems and flooding in several Tempe neighborhoods.

In response to these problems, the Flood Control District of Maricopa County (FCDMC) recognized a need to assess flooding in the area, and is nearing completion of the Tempe Area Drainage Master Study and Plan (Tempe ADMS/P) to identify flood hazards and develop flooding mitigation solutions.

The study included collecting extensive data and developing a comprehensive two-dimensional hydrology/hydraulic model with integrated storm drain analytics. The study also includes an evaluation of the impacts to storm water flows when using various Low Impact Development (LID) techniques and green infrastructure approach.

Project Area

The study area is bounded by the Salt River (Rio Salado) (north), Loop 101 (east), SR 202 (south) and I-10 (west). The study includes approximately 47 square miles located primarily within Tempe, with portions in Phoenix, Chandler and Guadalupe.

Project Outreach

By reviewing flood history, conducting field work, completing a two-dimensional model and reviewing existing storm drainage systems, project staff have identified areas in Tempe that have a high probability of experiencing excessive storm water as a result of significant storm events.

The project team is available to present the preliminary results of this study and answer any questions. (See other side.)

Project Results - *"What does this mean to me?"*

The general areas identified in the graphic on the reverse side are the areas within the study boundary where storm water flooding continues to be a challenge. The FCDMC and Tempe are targeting these specific areas, but would like to hear from residents about storm water flooding throughout the study area. Study highlights include:

1. Model results are in alignment with historic storm flooding problems identified by the City.

2. Model results will allow the FCDMC and the City to develop mitigation solutions to these challenges, including, but not limited to, identifying specific Capital Improvement Projects (CIP) that mitigate storm water conveyance problems.

3. Projects to improve storm water conveyance within these specific areas could include improvements to existing storm drainage systems and potentially implementing Low Impact Development (LID) techniques and a green infrastructure approach to help reduce flooding.

Tempe Area Drainage Master Study Update

Opportunities for Input - ***Where can I learn more?***

The Team would like to present the results of this study and answer questions:

1. **Home Owners Association (HOA) & Neighborhood Association (NA) Meetings** - Team members by invitation only, are available to participate in regularly scheduled HOA/NA Board/Committee Meetings to discuss the project.

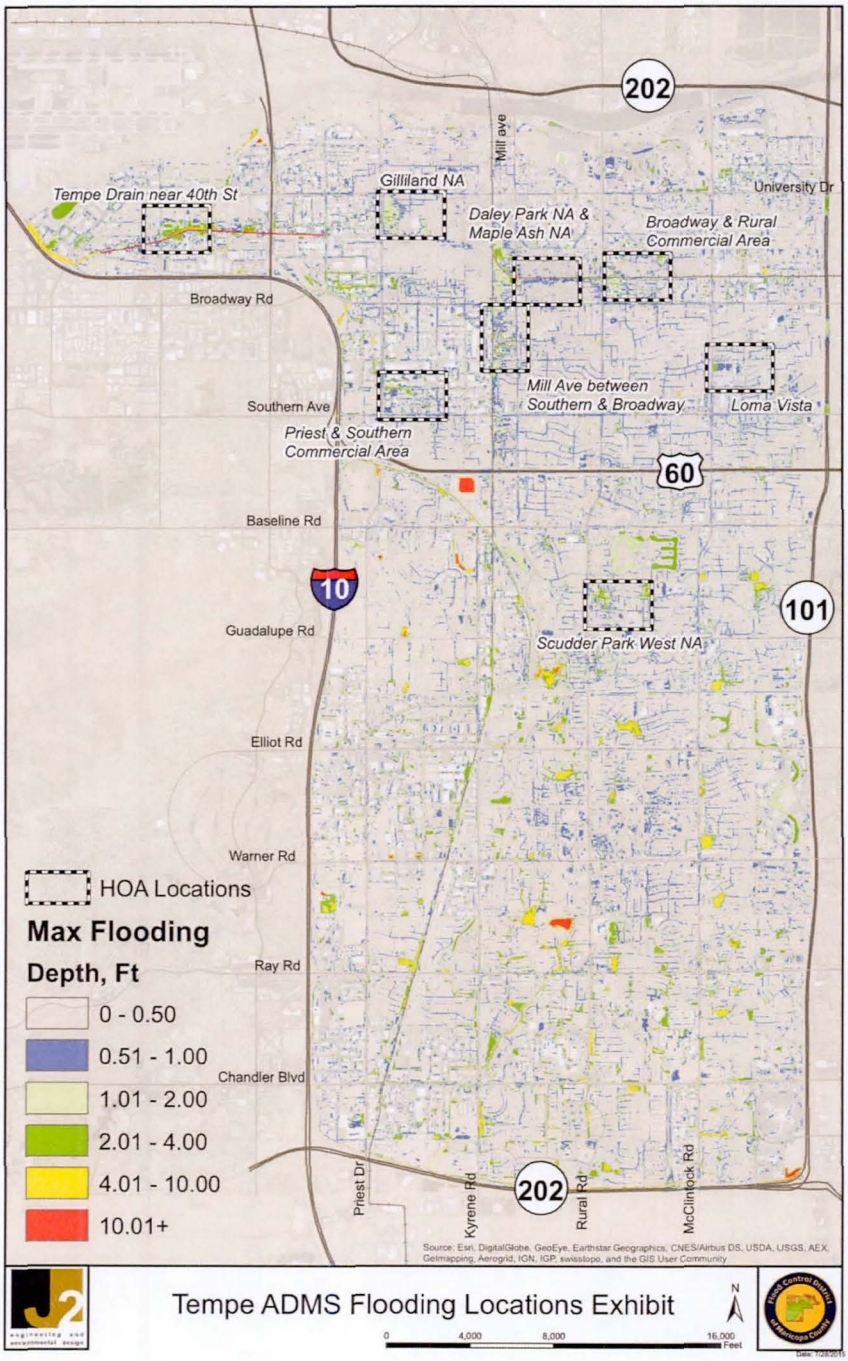
2. **GAIN Event Participation Oct. 17, 2015** - Team members by HOA/NA invitation only, would have an informational table at a neighborhood GAIN scheduled event.

3. **General Open House Event** - Open for all residents of the study area to discuss the project and the steps moving forward.
   Date: Nov. 18, 2015
   Time: 6:00-7:30 p.m.
   Location: Tempe History Museum
   809 E. Southern Ave.

Requests for hearing assistance (sign language interpreter, listening devices, alternative-format materials) require a 72-hour notice and can be made by calling (480) 967-1343. Additional reasonable accommodations will be made if possible and if given 72-hour notice.

Any questions or issues concerning this project can be directed to:

Mr. Burke Lokey, P.E., CFM, PMP
Project Manager - FCDMC
602-506-0867
burkelokey@mail.maricopa.gov
www.fcd.maricopa.gov



Tempe Area Drainage Master Study

Project Description

Within the last five years, there have been multiple significant storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe (City). Although Tempe is nearly built-out, the advent of the light rail, ASU expansion plans, and the attraction of the Tempe Town Lake is expected to lead to major redevelopment of portions of the City. As a response to projected growth and regulatory requirements, the City is considering implementation of various green infrastructure and low impact design techniques such as part of the new General Plan 2040. The Arizona Department of Transportation also has several large drainage infrastructure projects related to the freeways throughout this region, many of which are undersized and will require major investments in advance of projected freeway projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe Area Drainage Master Study and Plan (Tempe ADMS/P) to identify flood hazards and develop any needed flooding mitigation solutions.

The study area is bounded by the Salt River (north), Loop 101 (east), SR 202 (south) and I-10 (west). The study includes approximately 45 square miles located primarily within the City of Tempe with portions in the Cities of Phoenix and Chandler as well as the Town of Guadalupe. The first phase of the study includes data collection, development of a comprehensive two-dimensional hydrology model with integrated storm drain analytics, and preparation of a Flood Hazard Assessment with estimates of economic damages caused by flooding. An extensive stakeholder coordination and public outreach effort will be incorporated to help compile information (records and anecdotes, dated photos and videos of flooding and drainage incidents, and any other historic information available) as well as to help focus on acceptable mitigation alternatives.

To facilitate collection of flooding incidence information, the District has developed a web-based tool called Report A Flood (www.ReportAFlood.org). The tool includes an interactive map of the county and allows anyone to locate a point on the map and upload photos or videos of flooding events that occurred at that location.

Status

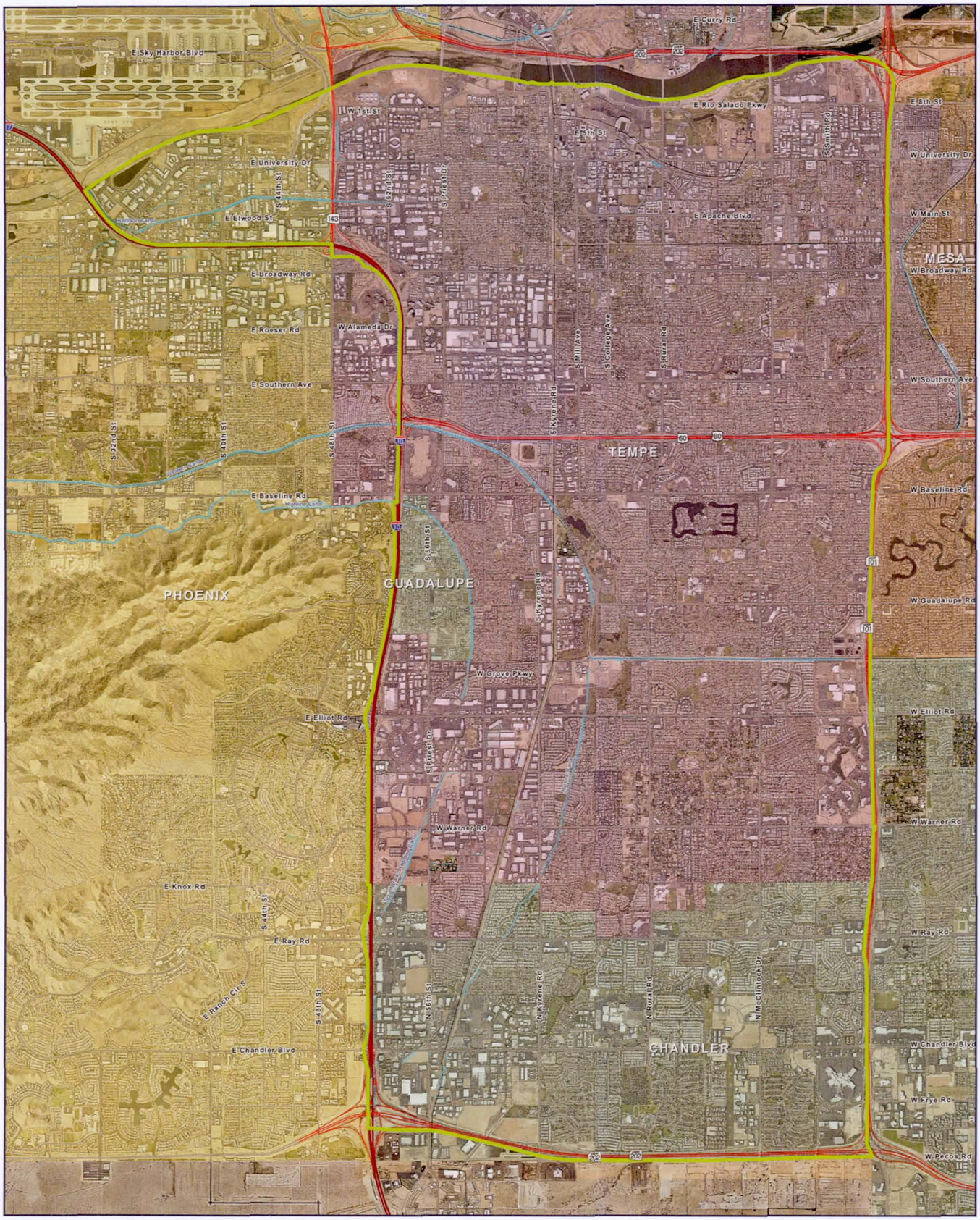
The District initiated the ADMS in June 2013, and data collection is currently underway. Development of the regional hydrology model is scheduled to begin in September and should be complete by June 2014. The Flood Hazard Assessment will be finished by November 2014.

Contact

Burke Lokey, P.E., CFM, PMP
Project Manager
602-506-0867
burkelokey@mail.maricopa.gov

Flood Control District of Maricopa County

Tempe Area Drainage Master Study



Tempe ADMS/P Study Boundary

Canal

The Flood Control District of Maricopa County (District) is conducting a series of public meetings for the City of Tempe Area Drainage Master Study Plan (Tempe ADMS). The Tempe ADMS is intended to identify drainage and flooding problems in the City of Tempe study area and to develop alternative measures to mitigate identified concerns. At each public meeting, the study team will present the status of the study, the data collection that is underway and solicit your comments and feedback. The District and City of Tempe will evaluate the identified areas and develop a long range plan to address the issues that this study identifies. You are encouraged to attend one of the three scheduled meetings to learn more about the Tempe ADMS. Requests for hearing assistance (sign-language interpreter, listening devices, alternative-format materials) require 72-hour notice and can be made by calling (480) 967-1343 Additional reasonable accommodations will be made if possible and if given 72-hour notice. A brief presentation will begin at 6:30 p.m at each of the scheduled meetings.

The Flood Control District of Maricopa County is tasked to provide regional flood hazard identification, regulation, remediation, and education to Maricopa County residents so that they can reduce their risk of injury, death, and property damage from flooding, while still enjoying the natural and beneficial values served by floodplains.

Tempe
Area Drainage Master Study

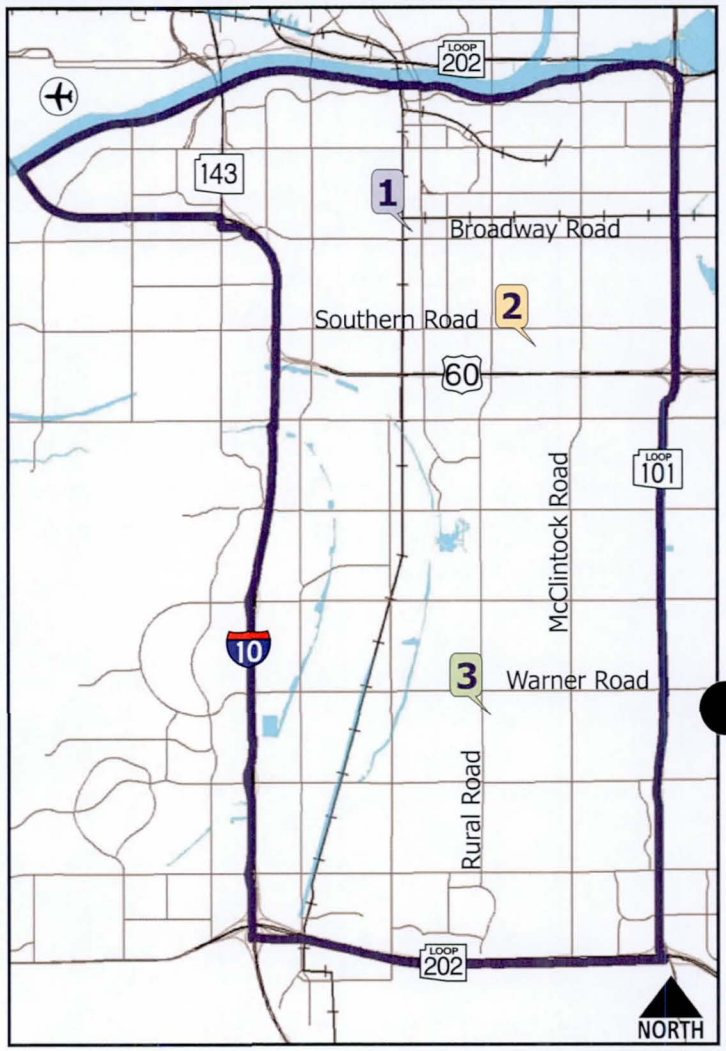
Supervisor Denny Barney, District 1
Supervisor Mary Rose Wilcox, District 5

The Flood Control District of Maricopa County is conducting a series of public meetings for the City of Tempe Area Drainage Master Study (Tempe ADMS). The Tempe ADMS is intended to identify drainage and flooding problems in the City of Tempe study area and to develop alternative measures to mitigate identified concerns.

At each public meeting, the study team will present the status of the study, the data collection that is underway and solicit your comments and feedback. Once the areas are identified the team will develop a long range plan to address the issues that this study identifies.

Also at these meetings we will be presenting updated FEMA Flood Insurance Rate Maps. Although most of these maps remain unchanged from the current maps, they show zones of potential flooding in the City of Tempe, where the risk of flooding is to the level that requires the property owners to purchase flood insurance.

You are encouraged to attend one of the three scheduled meetings to share your flooding photos and videos, and to learn more about the Tempe ADMS.



Map not to scale.

Contact

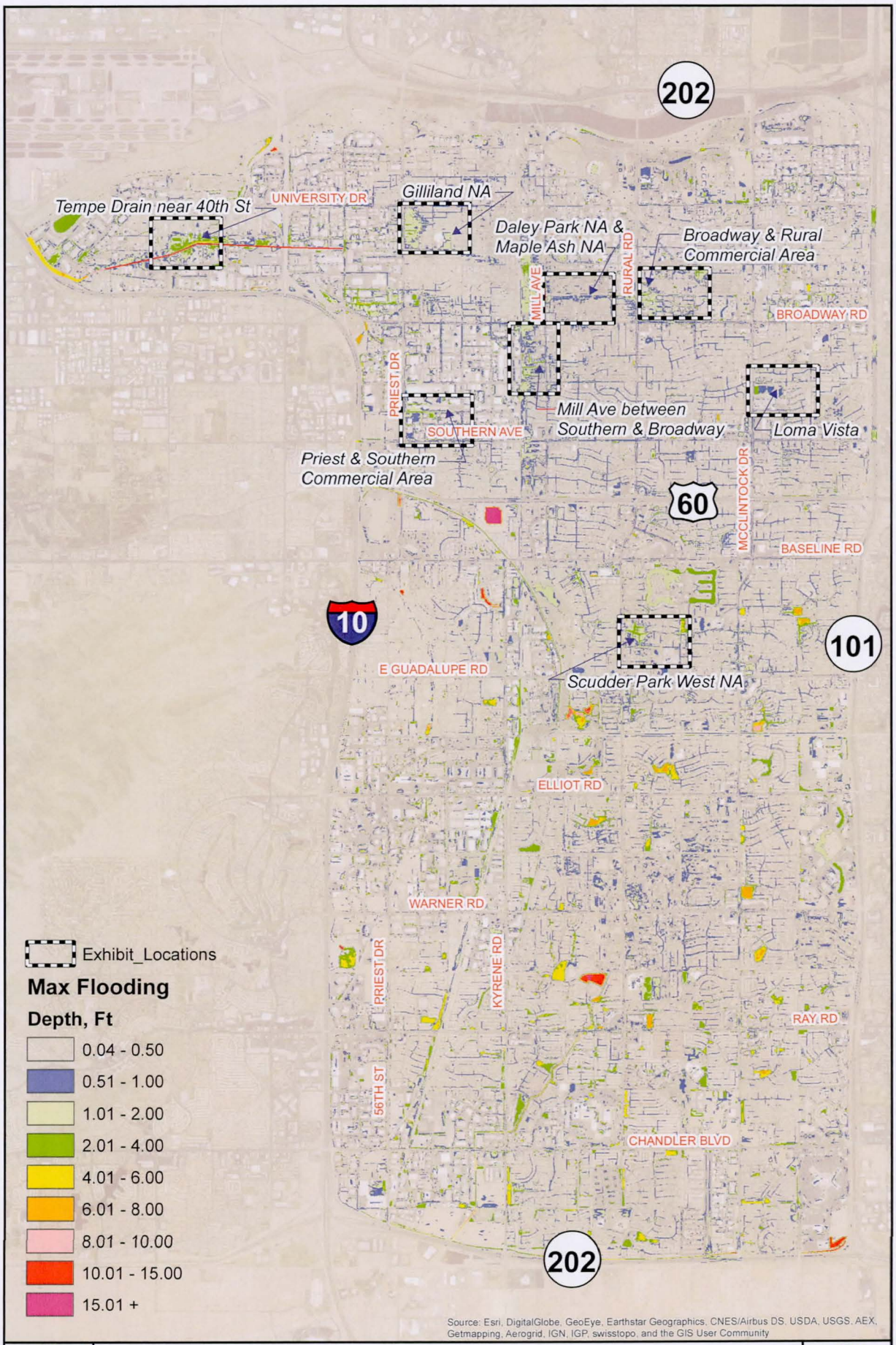
Burke Lokey, P.E., CFM, PMP, Project Manager
602-506-0867
burkelokey@mail.maricopa.gov

Public Meeting 1	Public Meeting 2	Public Meeting 3
Thursday, August 15, 2013	Tuesday, August 20, 2013	Thursday, August 22, 2013
6:00–7:30PM	6:00–7:30PM	6:00–7:30PM
Tempe High School Auditorium	Hudson Elementary School Cafeteria/Multi-purpose Room	Corona Del Sol High School Auditorium
1730 S. Mill Ave	1325 E. Malibu Drive	1001 E. Knox Road

A brief presentation will begin at 6:30 p.m. at each of the scheduled meetings.

Requests for hearing assistance (sign-language interpreter, listening devices, alternative-format materials) require 72-hour notice and can be made by calling (480) 967-1343. Additional reasonable accommodations will be made if possible and if given 72-hour notice.

www.fcd.maricopa.gov



J2 engineering and environmental design

Tempe ADMS Flooding Locations Exhibit

N

0 4,000 8,000 16,000 Feet

Flood Control District of Maricopa County

Date: 7/8/2015

Tempe Area Drainage Master Study

Flood Occurrence Details

Date of flooding occurrence:_____

Where did the flooding take place? (Check all that apply)

- ❍ House or other building
- ❍ Yard or property
- ❍ Road/Street
- ❍ Has this site flooded before : _____Yes_____No
- ❍ Other noted flooding areas (e.g. wash, culvert, etc.)_____

Which Part of the house or building was flooded?	Approximately how deep was the water?	Approximately how long did the water stay in your home?
❍ Garage only	❍ Less than 2 inches	❍ Less than 1 hour
❍ One – two rooms	❍ 2-6 inches	❍ 1-2 hours
❍ Half the house	❍ 6-12 inches	❍ 2-4 hours
❍ Entire house	❍ 1-2 feet	❍ 4-12 hours
❍ Other please specify	❍ Over 2 feet	❍ 12-24 hours
		❍ 1-3 days
		❍ More than 3 days

Did the flood water cause any of the following problems?

- ❍ Soil erosion
- ❍ Significant debris or soil accumulation
- ❍ Neither do not know

Do you have photos or videos of the flooding and/or erosion?

- ❍ Yes (Please sign release form attached) Photo Log/ID Number_____
- ❍ No

Please specify if you can be contacted for additional flooding information?

- ❍ Yes. Please provide contact information below
- ❍ No

Name:_____

Address:_____

❍ Major Cross Streets: _____

E-mail address:_____

Phone Number:_____

Mail This Completed Form To:
J2 Engineering & Environmental Design, LLC
4649 East Cotton Gin Loop Suite B-2
Phoenix, AZ 85040
On-Line Forms [illegible]able at www.reportaflood.org **or** www.fcd.maricopa.gov

Other information that you would like to share relative to any drainage and/or flooding issues in your neighborhood and or within the City of Tempe:

Appendix B2 - Homeowners and Neighborhood Associations Information

Contact	Title	Association	Contact Address	Text7	Association Address	Submodel Area	Key	website
Lyseth Mitchell	Ms.	Concord Village, Inc. HOA	2658 N. Champlain Ave.	Tempe, AZ 85281	Continental to Fillmore; McAllister to Bull Run	x	H1	
Ed Towill	Mr.	University Ranch HOA	760 S. Stapley Drive	Mesa, AZ 85204	University to Orange; Lola to Price	a	H10	
Anna Collins-Christie	Ms.	Questa Vida HOA	16704 E. Ave of the Fountains, #101	Fountain Hills, AZ 85268	University River	a	H10A	
Tom Murhphy	Mr.	Questa Vida HOA	1901 E. University Dr. Suite 440	Mesa, AZ 85203	University River	a	H10A	
Frank Landeros	Mr.	Oaks II & III HOA	2862 W Ironwood Dr	Chandler AZ 85224	University to Tempe Canal; Evergreen	x	H10B	
Erin Valles	Ms.	Oaks II & III HOA	PO Box 27476	Tempe, AZ 85285-7476	University to Tempe Canal; Evergreen	x	H10B	
James Clark	Mr.	Oaks HOA	15434 S. 23rd St.	Phoenix, AZ 85048	University Evergreen	x	H10C	
Ken Falltrick	Mr.	University Shadows HOA	4645 E. Cotton Gin Loop	Tempe, AZ 85281	5th Street to University; George to Evergreen	x	H10D	
Thomas Brace	Mr.	Las Brisas HOA	1819 S. Torre Molinos Circle	Tempe AZ 85281	Railraod Tracks to Broadway; Rvier Drive to Shannon Drive	a	H11	
Sarah Colby	Ms.	Las Brisas HOA	1533 S. River Dr.	Tempe, AZ 85281	Railraod Tracks to Broadway; Rvier Drive to Shannon Drive	a	H11	
Elsie Szecsy	Ms.	Broadmor Place HOA	PO Box 26300	Tempe, AZ 85285	Fiest Dr. to Redondo; Mill to Forest	a	H12	
Cary DeBarry		Broadmor II HOA	9 E. La Diosa Dr.	Tempe, AZ 85282	Fiesta Dr. to Redondo; Mill to Forest	a	H12A	http://www.facebook.com/pages/Broadmor-II-Homeowners-Association/170212129436
Jon Smith	Mr.	Broadmor II HOA	10 E. La Diosa Drive	Tempe, AZ 85282	Fiesta Dr. to Redondo; Mill to Forest	a	H12A	http://www.facebook.com/pages/Broadmor-II-Homeowners-Association/170212129436
Bill Stone	Mr.	Alameda Estates HOA	110 E. Concorda	Tempe, AZ 85282	Broadmor to Alameda; Mill to College	a	H13	
Cassie Bowman	Ms.	Alameda Estates HOA	111 E. Loma Vista	Tempe, AZ 85282	Broadmor to Alameda; Mill to College	a	H13	
Chuck Plake	Mr.	Alameda Park HOA	115 W. Loma Vista Dr. #104	Tempe, AZ 85282	Concorda to Loma Vista; Dromedary to Maple	a	H13A	http://www.alamedapark.org/
Bob Ghan	Mr.	Alameda Park HOA	326 E. Laugna Dr.	Tempe, AZ 85282	Concorda to Loma Vista; Dromedary to Maple	a	H13A	http://www.alamedapark.org/
Rita Hagel	Ms.	Villa Patrician HOA	315 E. Patrician Dr.	Tempe, AZ 85282	Geneva to Southern; College to El Camino	a	H14	
Lawrence Massa	Mr.	La Sombra HOA	835 E. Redondo Dr.	Tempe AZ 85282	Redondo Rural	a	H14A	
Claudia Morales	Ms.	Brentview HOA	3031 S. Rural Rd. #3	Tempe, AZ 85282	Loyola to Geneva; Rural to Jentilly	a	H14B	
Mike Gerson	Mr.	Brentview HOA	2409 S. Rural Rd. Suite D	Tempe, AZ 85282	Loyola to Geneva; Rural to Jentilly	a	H14B	
Mark McWhirter	Mr.	Joshua Square HOA	237 E. Minton Dr.	Tempe AZ 85282	Broadway Granada to Rural Road	a	H14D	
Rhonda Alegria	Ms.	Broadway Terrace HOA	1600 W. Broadway Road Ste. 200	Tempe, AZ 85282	Broadway to Hammond to Forest	a	H14E	
Steven Yee	Mr.	Broadway Terrace HOA	1600 W. Broadway Rd. Ste. 200	Tempe, AZ 85282	Broadway to Hammond to Forest	a	H14E	
Justin Johnson	Mr.	Premier Condominiums HOA	3320 N. 63rd Place	Scottsdale, AZ 85251	Broadway Dorsey to Elm	a	H14F	
Kellie Woetzel	Ms.	Premier Condominiums HOA	1445 E. Broadway Rd. #208	Tempe, AZ 85282	Broadway Dorsey to Elm	a	H14F	
Cliff Adams	Mr.	Chesapeake HOA	21448 N. 75th Avenue #6	Glendale, AZ 85308	Huntington to Southern; Mill to College	a	H14G	
Doug Price	Mr.	Chesapeake HOA	2151 E. Broadway Road #116	Tempe, AZ 85282	Huntington to Southern; Mill to College	a	H14G	
Scott Darnall	Mr.	Circle G Ranches IV HOA	PO Box 25466	Tempe, AZ 85284	Warner to Knox; Fairfield to Price	a	H14G	
Darryl Barnes	Ms.	Circle G Ranches IV HOA	2009 E Caroline Ln	Tempe AZ 85284	Warner to Knox; Fairfield to Price	a	H14G	
Yin Pang		Broadway Townhomes HOA	3431 E. Mission Lane	Phoenix, AZ 85028	Broadway to Aepli; Sierra Vista to La Rosa	a	H14H	
P.J. Heiden		Broadway Townhomes HOA	455 E. Broadway Rd. #2	Tempe, AZ 85282	Broadway to Aepli; Sierra Vista to La Rosa	a	H14H	
Christopher Gass	Mr.	Presidential Estates HOA	123 E. Concorda Dr.	Tempe, AZ 85282	Broadmor College	a	H14I	
Daniel Schugurensky	Mr.	Presidential Estates HOA	125 E. Concorda Dr.	Tempe, AZ 85282	Broadmor College	a	H14I	
Jim Bubik	Mr.	Colonia Del Sur I HOA	2710 S. Azalea Dr.	Tempe, AZ 85282	Gaylon to Azalea/Alder; Azalea to McClintock	a	H15	
Carol Howell	Ms.	Colonia Del Sur III HOA	2040 E. Riviera Dr.	Tempe, AZ 85282	Alameda to Southern; Country Club	a	H15A	
Floyd Stewart	Mr.	Colonia Del Sur III HOA	2307 N. Gentry	Mesa, AZ 85213	Alameda to Southern; Country Club	a	H15A	
JR Cummard	Mr.	Shalimar East HOA	3123 S. Fairfield Dr.	Tempe, AZ 85282	Golf to Southern; Fairfield	a	H15B	
Mary Leason	Ms.	Shalimar East HOA	3205 S. Fairfield Drive	Tempe, AZ 85282	Golf to Southern; Fairfield	a	H15B	
Kathleen Lindquist	Ms.	Village at Shalimar HOA	2171 E. Aspen Dr.	Tempe AZ 85282	Aspen to Alameda; Siesta to Price	a	H15C	
Lorraine Broshears	Ms.	Village at Shalimar HOA	2170 E. Aspen Dr.	Tempe, AZ 85282	Aspen to Alameda; Siesta to Price	a	H15C	
Jack Leibert	Mr.	Tempe Village HOA	8686 N. Central Ave. Ste. 206	Phoenix, AZ 85020	Southern to La Jolla; Edward to Village Way	a	H16	
Jack Leibert	Mr.	Fiesta Villages HOA	8686 N. Central Ave., Suite 206	Phoenix, AZ 85020	Southern to La Jolla; Clementine to Priest	a	H16A	
Holly Dorman	Ms.	Southern Village Estates HOA	3406 S. Hardy	Tempe, AZ 85282	Southern to Laguna; Parkside to Judd	a	H17	http://www.southernvillageestates.com/
Frank Peake	Mr.	Southern Village Estates HOA	4657 E. Cotton Gin Loop, Ste. 102	Phoenix, AZ 85040	Southern to Laguna; Parkside to Judd	a	H17	http://www.southernvillageestates.com/
Brian Kelly	Mr.	Springdale HOA	1222 W. Baseline Rd. #163	Tempe, AZ 85283	Baseline Beck	b	H17A	
Laura Lane	Ms.	Springdale HOA	PO Box 22074	Mesa, AZ 85277	Baseline Beck	b	H17A	
Linda Koch	Ms.	Laguna Estates HOA	3500 S. Wilson	Tempe AZ 85282	Malibu to Pebble Beach; Roosevelt to Kyrene	a	H18	
Gene Cooley	Mr.	Laguna Estates HOA	3500 S. Wilson	Tempe, AZ 85282	Malibu to Pebble Beach; Roosevelt to Kyrene	a	H18	
Dennis Shaff	Mr.	Mistwood HOA	1514 W. Todd Dr. Ste. B-103	Tempe, AZ 85283	Southern to Manhatton; Roosevelt	a	H18A	
Linda Marie Perreault	Ms.	Casa Fiesta HOA	PO Box 14767	Scottsdale, AZ 85267	Carter to Minton Hardy to Roosevelt	b	H18C	
Tony Cristanelli	Mr.	Casa Fiesta HOA	4675 S. Judd St.	Tempe, AZ 85282	Carter to Minton Hardy to Roosevelt	b	H18C	
Sentry Management		Tempe Gardens Townhomes HOA	7955 S. Priest Drive #105	Tempe, AZ 85284	Pebble Beach to US 60; Mill to Grandview	ab	H19	
Shari Hamblin	Ms.	Butler Tempe HOA	2104 N. Squire Ave.	Tempe, AZ 85281	Embassy to McKellips; College to Squire	x	H2	
Lisa Beech	Ms.	Butler Tempe HOA	313 E. Ambassador Dr.	Tempe, AZ 85281	Embassy to McKellips; College to Squire	x	H2	
Everett Scott	Mr.	Puerta Del Sol HOA	942 E. Laguna Dr.	Tempe, AZ 85282	Laguna Rural to Rita	a	H20	
Jeannine Berg	Ms.	Park Riviera Townhouse HOA	1515 E. Newport	Tempe, AZ 85282	Southern to Coronado; Oak to Juniper	a	H20A	

Bill Wagner	Mr.	Park Premiere HOA	423 E. Carson Drive	Tempe, AZ 85282	Fremont to Dunbar; Terrance to Dorsey	b	H21	
Marney Glancy	Ms.	Park Riviera South T.H. I/II HOA	1609 E. Dunbar	Tempe, AZ 85282	Minton to Baseline; Juniper to McClintock	b	H22	
Melanie Baas	Ms.	Park Riviera South T.H. I/II HOA	760 S. Stapley Dr.	Mesa, AZ 85204	Minton to Baseline; Juniper to McClintock	b	H22	
Ginny Gapen	Ms.	Park Riviera South T.H. III/IV HOA	760 S. Stapley Dr.	Mesa, AZ 85204	Minton to Dunbar; Juniper to McClintock	b	H23	
Anthony Saulina	Mr.	Continental Villas East III HOA	2139 E. Minton Dr.	Tempe, AZ 85282	Minton to Baseline; River to Price	b	H24	
Robin Scott		Continental Villas East III HOA	9000 E. Pima Center Pkway Ste. 300	Scottsdale, AZ 85258	Minton to Baseline; River to Price	b	H24	
Cate Cotier	Ms.	Hudson Trace HOA	2333 E. Southern Ave. #2056	Tempe, AZ 85282	Southern to Malibu; Price to George	x	H25	
Deborah Larson	Ms.	Hudson Trace HOA	2333 E. Southern #2058	Tempe, AZ 85282	Southern to Malibu; Price to George	x	H25	
Marcia Mickle	Ms.	Pepperwood Townhomes HOA	819 W. Duke Dr.	Tempe, AZ 85283	Rice to Cornell; Hardy to Kyrene	b	H26	http://www.pepperwoodhoa.com/
Jennifer Conner	Ms.	Pepperwood Townhomes HOA	760 S. Stapley Dr. #3	Mesa, AZ 85204	Rice to Cornell; Hardy to Kyrene	b	H26	http://www.pepperwoodhoa.com/
Lido Albillar		Stonegate HOA	1004 W Pisces Dr	Tempe, AZ 85283	Waston to Guadalupe; Colonial Way to Hardy	b	H26A	
Kachina Management		Stonegate HOA	21448 N 75 Ave #6	Glendale, AZ 85308	Waston to Guadalupe; Colonial Way to Hardy	b	H26A	
Jeff Broman	Mr.	Alterra HOA	5400 S. Hardy Dr. #124	Tempe, AZ 85283	Colgate to Oxford; - Hardy	b	H26B	
Cliff Adams	Mr.	Alterra HOA	21448 N. 75th Avenue	Glendale, AZ 85308	Colgate to Oxford; - Hardy	b	H26B	
Joan Eberly	Ms.	University Royal Garden Hms HOA	519 E. Colgate Drive	Tempe, AZ 85283	Colgate to Oxford; Rosa to Rural	b	H27	
Daniel Comer	Mr.	University Royal Garden Hms HOA	4645 E. Cotton Gin Loop	Phoenix, AZ 85040	Colgate to Oxford; Rosa to Rural	b	H27	
Steve Cheff	Mr.	Harbour Village HOA	42 S. Hamilton Pl., Suite 101	Gilbert, AZ 85233	Baseline to Lake; Lakeshore	b	H28C	
Linda Artac	Ms.	Runaway Point HOA	1209 E. Northshore Dr. #239	Tempe, AZ 85283	Baseline to Lake; Lakeshore	b	H28D	
Steve Cheff	Mr.	Runaway Point HOA	42 S. Hamilton Pl. #101	Gilbert, AZ 85233	Baseline to Lake; Lakeshore	b	H28D	
Chuck Collins	Mr.	Lake Park Villas HOA	P.O. Box 62073	Phoenix, AZ 85082	Driftwood to Southshore; Compass to Lakeshore	b	H28E	
Christine Baldanza	Ms.	Lakes (The) HOA	5501 S. Lakeshore Dr.	Tempe AZ 85283	Baseline to Southshore; Rural to McClintock	b	H28E	
Annette Milauskas	Ms.	La Tierra HOA	1801 S. Extension Rd., Ste. 124	Mesa, AZ 85210	Libra to Guadalupe; Lakeshore to Juniper	b	H28F	
Mike Kinsey	Mr.	Festiva Tempe HOA	1042 W. Dava	Tempe, AZ 85283	Grove Parkway to Chilton; Highline Canal to Hardy	b	H29	
Dave Greany	Mr.	Marlborough Park Estates HOA	407 E. Susan Ln.	Tempe, AZ 85281	McKellips to Marny; College Avenue to La Rosa/Palm	x	H3	
Brad Bochart	Mr.	Marlborough Park Estates HOA	405 E. Barbara Dr.	Tempe, AZ 85281	McKellips to Marny; College Avenue to La Rosa/Palm	x	H3	
Susan Woods	Ms.	Brittany Lane HOA	42 S. Hamilton Place	Gilbert, AZ 85233	Carmen to Lodge; Wilson to Kyrene	b	H30	
Jonathan Passey	Mr.	Brittany Lane HOA	42 S. Hamilton Pl. #101	Gilbert, AZ 85233	Carmen to Lodge; Wilson to Kyrene	b	H30	
Eddie Padilla	Mr.	Terrace Walk HOA	4645 E. Cotton Gin Loop	Phoenix, AZ 85040	Carmen to Canal; Dennis to Roosevelt	b	H30A	
Tom Abril	Mr.	Tempe Royal Estate HOA	PO Box 11617	Tempe, AZ 85284	Paseo Way to Vaughn; Highline Canal to Kyrene	b	H30B	
Ray Putnam	Mr.	Tempe Royal Estates NA	6820 S. Mitchell Dr.	Tempe, AZ 85283	Paseo Way to Vaughn; Highline Canal to Kyrene	b	H30B	
Ken Falltrick	Mr.	Park Premiere South II HOA	4645 E. Cotton Gin Loop	Phoenix, AZ 85040	Guadalupe to Fleet Drive; El Camino to Rural	b	H31	
John Drucker	Mr.	Park Premiere South HOA	6729 S. Jen Tilly Ln.	Tempe, AZ 85283	Lodge to Bell De Mar; Rural to Terrace	b	H32	
Tom Anglin	Mr.	Bradley Manor HOA	16441 N. 91st St. #104	Scottsdale, AZ 85260	Guadalupe to Vaughn; Newberry to Lakeshore	b	H33	
Harry Allen	Mr.	Juniper Village HOA	1606 E. Vaughn St.	Tempe, AZ 85283	Redmon to Vaughn; Willow to Butte	b	H33A	
Ashley Todd	Ms.	Juniper Village HOA	4657 E. Cotton Gin Loop #102	Phoenix, AZ 85040	Redmon to Vaughn; Willow to Butte	b	H33A	
Millie Maxton	Ms.	Knoell Garden Villas HOA	2254 W. Fremont Dr.	Tempe, AZ 85282	Vineyard to Fremont; Calle Los Cerros to Wendler	b	H33A	
Sentry Management		Galleria HOA	7955 S. Priest Drive Suite 105	Tempe, AZ 85284	Western Canal to Stephens/Todd; Rural to Stanley	c	H34	
Rosalina Baldonado	Ms.	Parkside at the Galleria HOA	969 E. Chilton Dr.	Tempe, AZ 85283	Stephens to Elliot; Rural to Rita	c	H34A	
Barbara Rine Butler	Ms.	Parkside at the Galleria HOA	4645 E. Cotton Gin Loop	Phoenix, AZ 85040-8885	Stephens to Elliot; Rural to Rita	c	H34A	
Mike Woolf	Mr.	Chelsea Manor HOA	7425 S. Rita Lane	Tempe, AZ 85283	Chilton to Elliot; Rita to Lakeshore	c	H34B	
Darlene Pany	Ms.	Chelsea Manor HOA	7445 S. Rita Lane	Tempe, AZ 85283	Chilton to Elliot; Rita to Lakeshore	c	H34B	
Linda Martin	Ms.	Cottonwoods of Tempe HOA	6411 S. River Dr. #10	Tempe, AZ 85283	Guadalupe to Water Treatment Plant; River to Price	b	H35	
Kirsten Locke	Ms.	Cottonwoods of Tempe HOA	P.O. Box 25466	Tempe, AZ 85285	Guadalupe to Water Treatment Plant; River to Price	b	H35	
Ed Grabowski	Mr.	Oasis at Anozira HOA	7103 S. Hazelton Ln.	Tempe, AZ 85283	Western Canal to Elliot; McClintock to Country Club	c	H35A	
Debbie Tribioli	Ms.	Oasis at Anozira HOA	6303 S. Rural Rd #3	Tempe, AZ 85283	Western Canal to Elliot; McClintock to Country Club	c	H35A	
Steve Cook	Mr.	Camelot Park Villas HOA	1848 E. Redfield Drive	Tempe, AZ 85283	Bell de Mar to Redfield; McClintock to Los Feliz	b	H35B	
Debbie Tribioli	Ms.	Camelot Park Villas HOA	6303 S. Rural	Tempe, AZ 85283	Bell de Mar to Redfield; McClintock to Los Feliz	b	H35B	
Jesse Keeler	Mr.	Capistrano I HOA	1838 E. Oasis Drive	Tempe, AZ 85283	Oasis to Elliot; McClintock to Los Feliz	c	H35C	http://caphoa.com/
Toni Celsy	Ms.	Capistrano I HOA	17787 N. Permeter D. #111	Scottsdale, AZ 85255	Oasis to Elliot; McClintock to Los Feliz	c	H35C	http://caphoa.com/
Steve Roehling	Mr.	Pecan Grove Estates II HOA	8534 S. Maple Ave.	Tempe, AZ 85284	Carver to Warner; Maple to Mill	c	H36	
Sentry Management		Pecan Grove Estates II HOA	7955 S. Priest Dr. Suite 105	Tempe, AZ 85284	Carver to Warner; Maple to Mill	c	H36	
Brendon Stratton	Mr.	Homestead HOA	8216 S. Homestead	Tempe, AZ 85284	Carver Homestead	c	H36A	
Phil Vaney	Mr.	Graystone HOA	8526 S. Myrtle Ave.	Tempe, AZ 85284	Buena Vista to Warner; Garndview to Forest	c	H36B	
Peggy Stockford	Ms.	Graystone HOA	8405 S. Forest Ave.	Tempe, AZ 85284	Buena Vista to Warner; Garndview to Forest	c	H36B	
Sentry Management		Alisanos HOA	7955 S. Priest Drive	Tempe, AZ 85284	Elliot to Carver; Kyrene to Kyrene Canal	b	H36C	
Bob Rauperstrauch	Mr.	Parke Tempe HOA	248 W. Calle De Caballos	Tempe, AZ 85284	Buena Vista to Warner; Kyrene to Poplar	b	H36D	
Laurie Roberts	Ms.	Parke Tempe HOA	PO Box 1847	Queen Creek, AZ 85142	Buena Vista to Warner; Kyrene to Poplar	b	H36D	
Suzi Conrad	Ms.	Pecan Grove Village II HOA	760 S. Stapley Dr.	Mesa, AZ 85204	El Freda to Warner; Ash to Bolero	c	H36E	

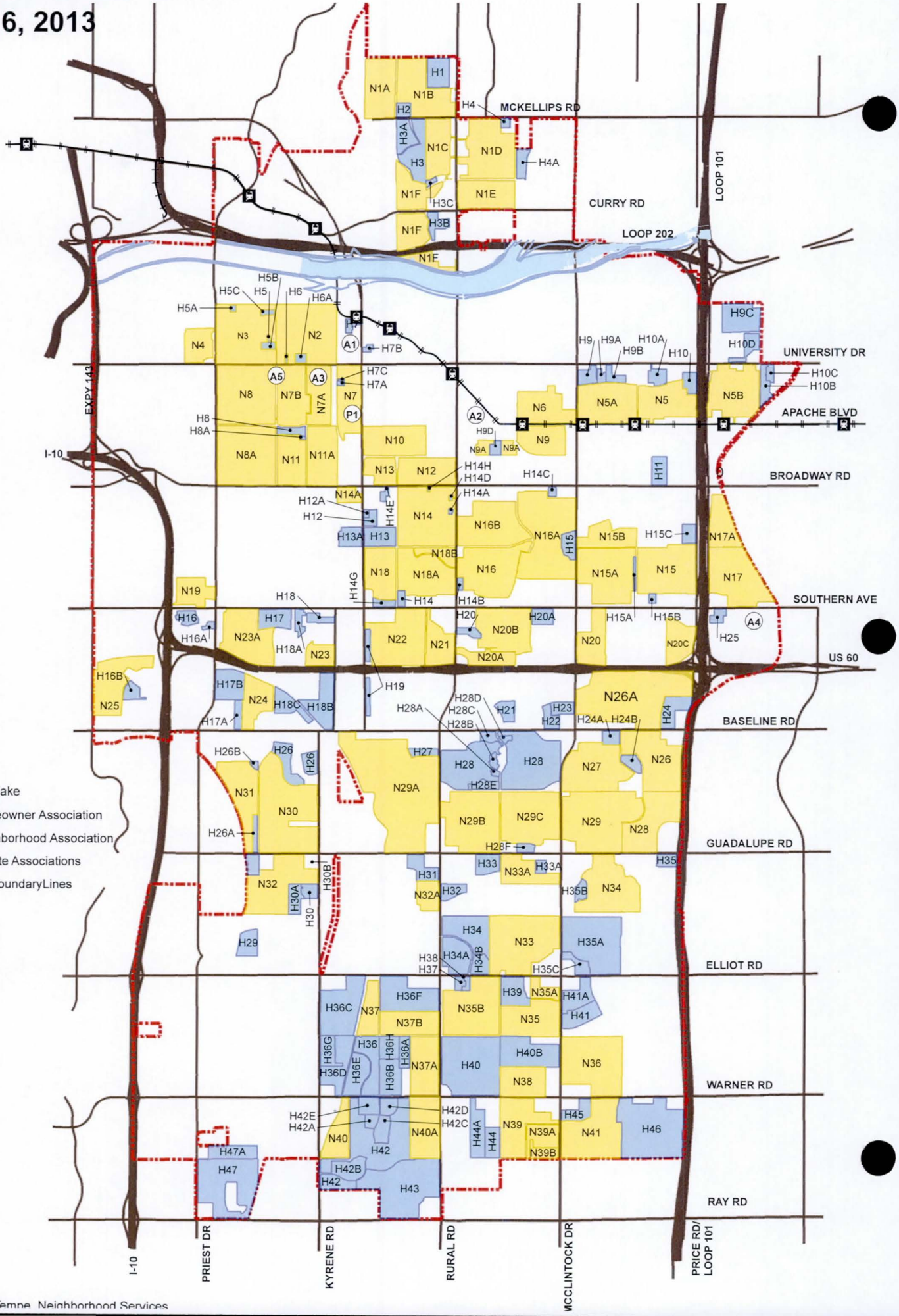
Carissa Phelps	Ms.	Coventry Tempe HOA	1600 W. Broadway Rd. Suite 200	Tempe, AZ 85282	Elliot to Carver; Mill to Rural	c	H36F	
Laurie Roberts	Ms.	Pecan Grove Village III HOA	P.O. Box 1847	Queen Creek 85142	Buena Vista to Palomino; Kyrene to Dromedary	b	H36G	
Highly Falkner	Mr.	Carver Ranch Estates HOA	8268 S. Pecan Grove Cr.	Tempe, AZ 85284	Carver to Pecan Grove Circle to	c	H36H	
Dayna McGrady	Ms.	Carver Ranch Estates HOA	8243 S. Pecan Grove Circle	Tempe, AZ 85284	Carver to Pecan Grove Circle to	c	H36H	
Carolyn Allen	Ms.	Terra HOA	1047 E. Sunburst	Tempe, AZ 85284	Elliot to Louis Way Bonarden	c	H37	
Debbie Triboli	Ms.	Terra HOA	PO Box 25466	Tempe, AZ 85285	Elliot to Louis Way Bonarden	c	H37	
Noreen Hurd	Ms.	Hamilton Homes Tempe HOA	1324 E Krista Way	Tempe, AZ 85284	Elliot to Vinedo; Lakeshore to Juniper	c	H39	
Geri Wentz	Ms.	Hamilton Homes Tempe HOA	7720 S. Oak St.	Tempe, AZ 85284	Elliot to Vinedo; Lakeshore to Juniper	c	H39	
Sage Grossi		Marlborough Park Villas HOA	1733 N. Sierra Vista Dr.	Tempe, AZ 85281	McKellips to Marigold; College Avenue to La Rosa	x	H3A	
Kim		Marlborough Park Villas HOA	7255 E. Hampton Ave., Suite 101	Mesa, AZ 85209	McKellips to Marigold; College Avenue to La Rosa	x	H3A	
Shelley Arnold	Ms.	Papago Park Village HOA	9362 E. Raintree Dr.	Scottsdale, AZ 85260	Curry to Gilbert; College	x	H3B	
Erin Valles	Ms.	Parkview Hacienda HOA	2409 S. Rural Rd. Suite D	Tempe, AZ 85282	Weber; McAllister	x	H3C	
Tim Farley	Mr.	Buena Vista Ranchos HOA	1041 E. El Freda Rd.	Tempe, AZ 85284	Carver to Warner; Rural to Stanley	c	H40	
Edward Fredericks	Mr.	Buena Vista Ranchos HOA	1026 E. Buena Vista Drive	Tempe, AZ 85284	Carver to Warner; Rural to Stanley	c	H40	
Stanley Nicpon	Mr.	Calle De Caballos HOA	1307 E. Calle de Caballos	Tempe, AZ 85284	Calle De Caballos to Lakeshore to McClintock	c	H40B	
Ellen Kirk	Ms.	Calle De Caballos HOA	1307 E. Calle de Caballos	Tempe, AZ 85284	Calle De Caballos to Lakeshore to McClintock	c	H40B	
Patti Gutos	Ms.	Tempe Royal Palms HOA	1808 E. Velvet Dr.	Tempe, AZ 85284	Secretariat to Citation; McClintock to Los Feliz	c	H41	http://temperoyalpalmshoa.com/
David Pheanis	Mr.	Villas Las Palmas HOA	938 E. Ranch Road	Tempe, AZ 85284	Elliot to Secretariat; McClintcok to Los Feliz	c	H41A	
Shelley Ebert	Ms.	Villas Las Palmas HOA	760 S. Stapley Dr.	Mesa, AZ 85204	Elliot to Secretariat; McClintcok to Los Feliz	c	H41A	
Christal Crain	Ms.	Warner Ranch HOA	7955 S. Priest Drive Suite 105	Tempe, AZ 85284	Warner to Knox; Dateland to College	c	H42	
Melanie Zimmer	Ms.	Warner Ranch HOA	147 W. Myrna Lane	Tempe, AZ 85284	Warner to Knox; Dateland to College	c	H42	
Jon Passey	Mr.	Warner Ranch Landing HOA	42 S. Hamilton Pl. #101	Gilbert, AZ 85233	Sarah to La Vieve; Maple to Warner Ranch Drive	c	H42A	
Lolly Boyle	Ms.	Colonia Del Sur IV HOA	1996 E. Oxford Drive	Tempe, AZ 85283	Colgate to Oxford; Kenwood to Country Club Way	c	H42B	
Woody Wilson	Mr.	Colonia Del Sur IV HOA	1982 E. Oxford Dr.	Tempe, AZ 85283	Colgate to Oxford; Kenwood to Country Club Way	c	H42B	
Mitch Hamlin	Mr.	Warner Ranch Landing II HOA	9557 S. Dateland Dr.	Tempe, AZ 85284	Knox to Warner Ranch Drive; Dromedary to Warner Ranch Drive	c	H42B	
Christal Crain	Ms.	Warner Ranch Manor I HOA	7955 S. Priest Drive Suite 105	Tempe, AZ 85284	Sarah to Caroline; Warner Ranch Drive to Forest	c	H42C	
Med Alban		Warner Ranch Manor II HOA	8870 S. Myrtle Ave.	Tempe, AZ 85284	Warner to Sarah; Warner Ranch Drive to Forest	c	H42D	
Will Sternberg	Mr.	Warner Ranch Manor II HOA	8861 S. Myrtle Ave.	Tempe, AZ 85284	Warner to Sarah; Warner Ranch Drive to Forest	c	H42D	
Diane Moran	Ms.	Warner Ranch Village HOA	88 W. Ranch Rd.	Tempe, AZ 85284	Warner to Ranch Road; Drea to Warner Ranch Drive	c	H42E	
Melissa Brassow	Ms.	Warner Ranch Phase II HOA	1600 W. Broadway Rd. Suite 200	Tempe, AZ 85282	Knox to Ray; Ash to Rural	c	H43	
Carol Mohon	Ms.	Warner Ranch Phase II HOA	1600 W. Broadway Rd. Suite 200	Tempe, AZ 85282	Knox to Ray; Ash to Rural	c	H43	
Tamra Zukewycz	Ms.	Corona Ranch HOA	9362 E. Raintree Drive	Scottsdale, AZ 85260	Warner to Knox; Rural to Lakeshore	c	H44	
Larry Heywood	Mr.	Las Estadas HOA	42 South Hamilton Place, Suite 101	Gilbert, AZ 85233	Warner to Knox; Terrace to Stanley	c	H44A	
John Janssen	Mr.	Alta Mirada HOA	1914 E. Ranch Road	Tempe, AZ 85284	Warner to Sarah; McClintock to Los Feliz	c	H45	http://www.altamirada.org/
Steve Evans	Mr.	Sierra Tempe HOA	9646 S. Darrow Drive	Tempe, AZ 85284	Knox to Ray; Priest to Railroad Tracks	b	H47	
Jessica Tennant	Ms.	Sierra Tempe HOA	4645 E. Cotton Gin Loop	Phoenix, AZ 85040-8885	Knox to Ray; Priest to Railroad Tracks	b	H47	
Eric Emmert	Mr.	Sierra Tempe Unit #4 HOA	1074 W. Myrna Lane	Tempe, AZ 85284	Knox to Myrna; Priest to Hardy	b	H47A	
Glenn Richardson		Indian Bend Gardens HOA	1251 E. Bluebell Lane	Tempe, AZ 85281	McKellips to Bluebell; Scovel to Miller	x	H4A	
Erin Valles	Ms.	Rio Salado HOA	2409 S. Rural Rd. Suite D	Tempe, AZ 85282	1st St.	a	H5A	
Louis Diambrosio	Mr.	University Garden Villas HOA	1336 W. Elna Rae St.	Tempe, AZ 85281	5th Street to 6th Street; Westfall	a	H5A	
James Teichert	Mr.	Worthington Place HOA	616 S. Hardy Dr. #235	Tempe, AZ 85281	5th Street Hardy	a	H5B	
Sherri Youngblood	Ms.	Worthington Place HOA	9362 E. Raintree Dr.	Scottsdale, AZ 85260	5th Street Hardy	a	H5B	
Valerie Hart	Ms.	Hacienda Del Rio HOA	150 E. Alamo Dr. #3	Chandler, AZ 85225	2nd st; Hardy	a	H5C	
Jeff White	Mr.	Scene One HOA	42 S. Hamilton Pl. #101	Gilbert, AZ 85233	7th Street to University	a	H6A	
Kristen Bakalis	Ms.	Wilson Place HOA	548 S. Wilson #103	Tempe, AZ 85282	5th Street to 6th Street; Wilson	a	H6B	
Jennifer Miller	Ms.	Wilson Place HOA	331 E. Fremont Dr.	Tempe, AZ 85282	5th Street to 6th Street; Wilson	a	H6B	
Lissa Johnson	Ms.	Hayden Square HOA	9633 S. 48th Street, Suite 150	Phoenix, AZ 85044	3rd Street to 5th Street; Ash to Maple	a	H7	
Fred Neal	Mr.	Lofts (The) at Orchidhouse HOA	21 E. 6th St.	Tempe, AZ 85281	6th Street to 7th Street; Mill Ave. to Myrtle	a	H7B	
Scott Darnall	Mr.	Lofts (The) at Orchidhouse HOA	P.O. Box 25466	Tempe, AZ 85285	6th Street to 7th Street; Mill Ave. to Myrtle	a	H7B	
Rhonda Harding	Ms.	Los Prados HOA	4455 E. Camelback Rd. Ste. E-100	Phoenix, AZ 85018	13th Street to 14th Street; Hardy to Roosevelt	a	H8	
Darrin Maurer	Mr.	Casitas Tempe HOA	4836 E. McDowell Rd., Suite 102	Tempe, AZ 85008	University to Kirkland; McClintock to Hacienda	a	H9	
Kelly Szymanski		Casitas East HOA	150 E. Alamo Dr.	Chandler, AZ 85225	University to Kirkland; Hacienda to Melody	a	H9A	
Brad Lundmark	Mr.	Villagio at Tempe HOA	1600 W. Broadway Rd. #200	Tempe, AZ 85282	Rio Salado to 5th Street; Price to Evergreen	x	H9C	
Darlene Justus	Ms.	North Tempe NA	315 E. Garfield	Tempe, AZ 85281	Continental to Salt River; Papago to Indian Bend Wash	x	N1	
Kathy Tershowski	Ms.	North Tempe NA	351 E. Bluebell Ln.	Tempe, AZ 85281	Continental to Salt River; Papago to Indian Bend Wash	x	N1	
Paul Kent	Mr.	University Park NA	23 E. 15th Street	Tempe, AZ 85281	Apache to Railroad Tracks; Mill to McAllister	a	N10	https://www.facebook.com/home.php?sk=group_182014545178369
Julie Kent	Ms.	University Park NA	23 E. 15th Street	Tempe, AZ 85281	Apache to Railroad Tracks; Mill to McAllister	a	N10	https://www.facebook.com/home.php?sk=group_182014545178369
Valerie Ramos	Ms.	Marilyn Ann NA	822 W. 18th St.	Tempe, AZ 85281	13th Street to Broadway; Hardy to Roosevelt	a	N11	

Aaron Golub	Mr.	Marilyn Ann NA	815 W. 18th St.	Tempe, AZ 85281	13th Street to Broadway; Hardy to Roosevelt	a	N11	
Peter Hodgson	Mr.	Clark Park NA	520 W. 16th Street	Tempe, AZ 85281	13th St. to Broadway; Roosevelt to Railroad Tracks	a	N11A	
Barbara Lloyd	Ms.	Clark Park NA	515 W. Parkway	Tempe, AZ 85281	13th St. to Broadway; Roosevelt to Railroad Tracks	a	N11A	
Steven Kisiel	Mr.	Daley Park NA	1748 S. Sierra Vista Dr.	Tempe, AZ 85281	Railroad tracks to Broadway; College to Rural	a	N12	
Justin Roth	Mr.	Daley Park NA	1750 S. El Camino Dr.	Tempe, AZ 85281	Railroad tracks to Broadway; College to Rural	a	N12	
Tom Martin	Mr.	University Estates NA	PO Box 23785	Tempe, AZ 85285	Vista del Cerro to Broadway; Mill to College	a	N13	
Kim Barr		Broadmor NA	225 E. Broadmor	Tempe, AZ 85282	Broadway to Alameda; College to Rural	a	N14	http://on.fb.me/MzQxVZ
Manjula Vaz		Historic Date Palm Manor NA	120 W. Palmcroft Dr.	Tempe, AZ 85282	Palmdale to Palmcroft; Railroad tracks to Mill	a	N14A	
Carolyn Jenkins	Ms.	Historic Date Palm Manor NA	116 W. Palmcroft Dr.	Tempe, AZ 85282	Palmdale to Palmcroft; Railroad tracks to Mill	a	N14A	
Mary Ann Dillon	Ms.	Shalimar NA	2005 E. Cairo Dr.	Tempe, AZ 85282	Alameda to Golf; Country Club to Price	a	N15	
Joyce Reigelsberger	Ms.	McClintock NA	1923 E. Del Rio Dr.	Tempe, AZ 85282	Alameda to Southern; Kachina to Country Club Way	a	N15A	http://www.facebook.com/pages/Maple-Ash-Neighborhood/129921400371528?ref=ts
Lori Baer	Ms.	Alameda Meadows NA	1972 E. Alameda Dr.	Tempe, AZ 85282	Aspen to Alameda; McClintock to Country Club Way	a	N15B	
Melissa Revel	Ms.	Rural/Geneva NA	1057 E Loyola Drive	Tempe, AZ 85282	Alameda to Southern; Rural to Dorsey	a	N16	
Wayne Shippy	Mr.	Rural/Geneva NA	1140 E. Geneva Drive	Tempe, AZ 85282	Alameda to Southern; Rural to Dorsey	a	N16	
Jaime Arredondo		Meyer Park NA	1319 E. Broadmor	Tempe, AZ 85282	Palmdale to Del Rio Dorsey to McClintock	a	N16A	http://www.facebook.com/pages/Maple-Ash-Neighborhood/129921400371528?ref=ts
Vince Murray	Mr.	Hughes Acres NA	1155 E. Bishop Drive	Tempe, AZ 85282	Palmcroft to Alameda; Rural to Doresey	a	N16B	
Peter Means	Mr.	Hughes Acres NA	1162 E. Alameda Dr.	Tempe, AZ 85282	Palmcroft to Alameda; Rural to Doresey	a	N16B	
Michele Meyer	Ms.	Evergreen NA	2610 E. Balboa Dr.	Tempe, AZ 85282	Blaboa to Southern; Cottonwood to Evergreen	x	N17	http://www.neighborhoodlink.com/Evergreen_NA
Walter Olson	Mr.	Evergreen NA	2447 E. Huntington Drive	Tempe, AZ 85282	Blaboa to Southern; Cottonwood to Evergreen	x	N17	http://www.neighborhoodlink.com/Evergreen_NA
Wendy Marshall	Ms.	Broadway Palms NA	2312 E. Concorda Dr.	Tempe, AZ 85282	Broadway to Alameda; Price to Tempe Canal	x	N17A	
Neil Miller	Mr.	Brentwood Cavalier NA	306 E. Del Rio Dr.	Tempe, AZ 85282	Alameda to Southern; College to Rural	a	N18A	
Paul Hubbell	Mr.	Brentwood Cavalier NA	739 E. Loyola Dr.	Tempe, AZ 85282	Alameda to Southern; College to Rural	a	N18A	
Julia Hardy	Ms.	Peterson Park NA	1611 W. Geneva Dr.	Tempe, AZ 85282	Fairmont to Southern; Edwards to Priest	a	N19	
Lane Carraway		Cavalier Hills NA	1422 N. Sunset Dr.	Tempe, AZ 85281	McKellips to Weber; McAllister to Scottsdale	x	N1C	
Paul Dunham	Mr.	Cavalier Hills NA	1422 N. Sunset Dr.	Tempe, AZ 85281	McKellips to Weber; McAllister to Scottsdale	x	N1C	
Gene Andres	Mr.	NTNA - Indian Bend NA	1717 N. Camellia	Tempe, AZ 85281	McKellips to Weber; Scottsdale to Miller	x	N1D	
Darlene Tussing	Ms.	East Rio NA	1156 E. Henry St.	Tempe, AZ 85281	Weber to Curry; Scottsdale Rd. to Miller	x	N1E	
Alyson Star	Ms.	East Rio NA	1239 E. Tempe Dr.	Tempe, AZ 85281	Weber to Curry; Scottsdale Rd. to Miller	x	N1E	
Mary Anne Green	Ms.	Riverside NA	508 W. 5th St.	Tempe, AZ 85281	1st Street to University; Hardy to Farmer	a	N2	
Candace Toler	Ms.	Hollis Park NA	1262 E. Pebble Beach Dr.	Tempe, AZ 85282	Southern to Manhatton; Terrace to Oak	a	N20B	
Katherine Crewe	Ms.	Hollis Park NA	1259 E. Pebble Beach Dr.	Tempe, AZ 85282	Southern to Manhatton; Terrace to Oak	a	N20B	
Kim Naig		Superstition NA	808 E. La Jolla Drive	Tempe, AZ 85282	Southern to US60; McAllister to Rural	a	N21	http://on.fb.me/Lz76UF
Chris Rogers	Mr.	Superstition NA	635 E. La Jolla Dr.	Tempe, AZ 85282	Southern to US60; McAllister to Rural	a	N21	http://on.fb.me/Lz76UF
Robin Nelson		Tempe Gardens NA	532 E. Manhatton Dr.	Tempe, AZ 85282	Southern to US60; Mill to McAllister	a	N22	
Sandy Hume	Mr.	Tempe Gardens NA	302 E. La Jolla Dr.	Tempe, AZ 85282	Southern to US60; Mill to McAllister	a	N22	
Linda Evans	Ms.	Southern Palms NA	1120 W. Manhatton Dr.	Tempe, AZ 85282	Southern to US60; Hardy to Priest	a	N23A	
Bonnie Amelotte	Ms.	Baseline Hardy NA	5046 S. Beck Ave.	Tempe, AZ 85282	Western Canal to Baseline; Beck to Hardy	b	N24	
Burton Cagen	Mr.	Baseline Hardy NA	6321 S. Shannon Dr.	Tempe, AZ 85283	Western Canal to Baseline; Beck to Hardy	b	N24	
Ed Parker	Mr.	Tempe Palms NA	2172 E. La Jolla Dr.	Tempe, AZ 85282	Malibu to US60; River to Price	b	N24A	http://www.tempepalms.org/
Barbara Raisanen	Ms.	Tempe Palms NA	2119 E. Pebble Beach Dr.	Tempe, AZ 85282	Malibu to US60; River to Price	b	N24A	http://www.tempepalms.org/
Trish Jasinski	Ms.	Tempe South Mountain NA	2605 W. Vineyard Rd.	Tempe, AZ 85282	Riviera to Dunbar Fair to Calle de Los Cerros	x	N25	
Marion Brownell	Ms.	Tempe South Mountain NA	2702 W. Dunbar	Tempe, AZ 85282	Riviera to Dunbar Fair to Calle de Los Cerros	x	N25	
Rochelle Wells	Ms.	Optimist Park Northeast NA	2022 E. Radcliffe Dr.	Tempe, AZ 85283	Baseline to Yale; Kenwood to Price	b	N26	
Duane Washkowiak	Mr.	Optimist Park Northwest NA	1861 E. Colgate Dr.	Tempe, AZ 85283	Harvard to Yale; McClintock to Kenwood	b	N27	
Gene Ganssle	Mr.	Optimist Park Southeast NA	2128 E. Gemini Dr.	Tempe, AZ 85283	Sesame to Guadalupe; Country Club Way to Price	b	N28	
Richard Rickel	Mr.	Optimist Park Southeast NA	2027 E. Magdalena Dr.	Tempe, AZ 85283	Sesame to Guadalupe; Country Club Way to Price	b	N28	
Cindy Kominska	Ms.	Kiwanis Park NA	237 E. Sesame St.	Tempe, AZ 85283	Rice to Guadalupe; Kiwanis Park to Rural Rd.	b	N29A	
Patti Imperia	Ms.	Kiwanis Park NA	5308 S. Bradley Dr.	Tempe, AZ 85283	Rice to Guadalupe; Kiwanis Park to Rural Rd.	b	N29A	
Kathleen Clark	Ms.	Scudder Park West NA	1112 E. Magdalena Dr.	Tempe, AZ 85283	Southshore to Guadalupe; Rural to Lakeshore	b	N29B	
Elizabeth Thielen	Ms.	Juniper Watson NA	1628 E. Westchester Dr.	Tempe, AZ 85283	Southshore to Guadalupe; Lakeshore to McClintock	b	N29C	
Lori Snow	Ms.	Juniper Watson NA	6006 S. Juniper	Tempe, AZ 85283	Southshore to Guadalupe; Lakeshore to McClintock	b	N29C	
Bill Butler	Mr.	Sunset NA	1227 W. 4th St.	Tempe, AZ 85281	1st Street to University; Priest to Hardy	a	N3	
Betty Garcia-Pendley	Ms.	Pepperwood NA	801 W. Julie Dr.	Tempe, AZ 85283	McKemy to Guadalupe; Hardy to Kyrene	b	N30	
Chris & Melissa Urwiller		Dava-Lakeshore NA	1357 E. Chilton Dr.	Tempe, AZ 85283	Western Canal to Elliot; Lakeshore to McClintock	c	N33	
Randy & Beth Zima		Dava-Lakeshore NA	1352 E. Chilton Dr.	Tempe, AZ 85283	Western Canal to Elliot; Lakeshore to McClintock	c	N33	
Cory Tyszka		Bradley Place NA	6401 S. Pine Street	Tempe, AZ 85283	Guadalupe to Carmen; Lakeshore to McClintock	b	N33A	http://www.facebook.com/BradleyPlace
Crush Estrada		Bradley Place NA	6401 S. Pine Street	Tempe, AZ 85283	Guadalupe to Carmen; Lakeshore to McClintock	b	N33A	http://www.facebook.com/BradleyPlace
Sid Frede	Mr.	Camelot Village NA	6716 S. Martin Lane	Tempe, AZ 85283	Guadalupe to Western Canal; Los Feliz to Country Club	b	N34	http://camelotvillage.org/

Carla Smith	Ms.	Camelot Village NA	1886 E. Carmen	Tempe, AZ 85283	Guadalupe to Western Canal; Los Feliz to Country Club	b	N34	http://camelotvillage.org/
Jill Cohen	Ms.	Carver Terrace NA	903 E. Derby Dr.	Tempe, AZ 85284	Elliot to Carver; Rural to Lakeshore	c	N35B	
Cindy Burkhart	Ms.	Carver Terrace NA	917 E. Knight Lane	Tempe, AZ 85284	Elliot to Carver; Rural to Lakeshore	c	N35B	
Lynn Danielewicz		Estate La Colina NA	1924 E. El Freda Rd.	Tempe, AZ 85284	Carver to Warner; McClintock to Kenwood	c	N36	http://www.neighborhoodlink.com/Estate_La_Colina
Bob Elliott	Mr.	Estate La Colina NA	1925 E. Palomino	Tempe, AZ 85284	Carver to Warner; McClintock to Kenwood	c	N36	http://www.neighborhoodlink.com/Estate_La_Colina
Virginia Jackson	Ms.	Duskfire NA	1 W. Krista Way	Tempe, AZ 85284	Elliot to Carver; Kyrene Canal to Mill	c	N37	
Janie Shelton	Ms.	Tally Ho Farms North NA	11639 S. 71st St.	Tempe, AZ 85284	Carver to Warner; 70th Street to Rural	c	N37A	
Lee Albertson		Tally Ho Farms North NA	12219 S. 71st St.	Tempe, AZ 85284	Carver to Warner; 70th Street to Rural	c	N37A	
Russ Courtney	Mr.	Raintree NA	524 E. Citation Ln.	Tempe, AZ 85284	Louis Way to Carver; Mill to Rural	c	N37B	
Gail Majors	Ms.	Raintree NA	615 E. Citation Ln.	Tempe, AZ 85284	Louis Way to Carver; Mill to Rural	c	N37B	
Mark Kaiser	Mr.	Corona Del Sol Estates NA	8850 S. Juniper	Tempe, AZ 85284	Warner to Knox; Lakeshore to McClintock	c	N39	http://cdsena.org/
Gina Phalen	Ms.	Corona Del Sol Estates NA	9320 S. Lakeshore Drive	Tempe, AZ 85284	Warner to Knox; Lakeshore to McClintock	c	N39	http://cdsena.org/
Lisa Lewandowski	Ms.	Mission Ridge NA	1716 E. Caroline	Tempe, AZ 85284	La Vieve to Jeanine Juniper to McClintock	c	N39A	http://www.facebook.com/pages/Maple-Ash-Neighborhood/129921400371528?ref=ts
Don Huisinga	Mr.	Los Tesoros NA	1745 E. Knox Rd.	Tempe, AZ 85284	Knox to Jeanine; Willow to McClintock	c	N39B	
Vikram Shah		Los Tesoros NA	1726 E. Knox Rd.	Tempe, AZ 85284	Knox to Jeanine; Willow to McClintock	c	N39B	
Emily Gersema	Ms.	Lindon Park NA	1517 W. 5th Place	Tempe, AZ 85281	5th St. to University; Lindon Ln. to Priest	a	N4	
Debbie Keller	Ms.	Tally Ho Farms NA	12831 S. 71st St.	Tempe, AZ 85284	Warner to Knox; 71st Street to Rural	c	N40A	
Steve Woodward	Mr.	Tally Ho Farms NA	13025 S. 71st St.	Tempe, AZ 85284	Warner to Knox; 71st Street to Rural	c	N40A	
Judy Tapscott	Ms.	Alta Mira NA	1914 E. Caroline Ln.	Tempe, AZ 85284	Warner to Jeanine; McClintock to Kenwood	c	N41	http://www.neighborhoodlink.com/Alta_Mira
Gretchen Reinhardt	Ms.	Escalante NA	1019 S. Lola Ln.	Tempe, AZ 85281	University to Apache; Smith to Price	a	N5	https://www.facebook.com/EscalanteCommunityGarden
Raul Puente-Martinez	Mr.	Escalante NA	1019 S. Lola Lane	Tempe, AZ 85281	University to Apache; Smith to Price	a	N5	https://www.facebook.com/EscalanteCommunityGarden
Erin Gonzales	Ms.	Victory Acres NA	2337 E. Laird Street	Tempe, AZ 85281	University to Apache; Price to Evergeen	x	N5B	
Carol Cabrera	Ms.	Victory Acres NA	2331 E. Laird St.	Tempe, AZ 85281	University to Apache; Price to Evergeen	x	N5B	
Chuck Buss	Mr.	University Heights NA	1364 E. Lemon St.	Tempe, AZ 85281	8th Street to Apache Dorsey to McClintock	a	N6	
Chris McKee	Mr.	University Heights NA	1026 S. Una Avenue	Tempe, AZ 85281	8th Street to Apache Dorsey to McClintock	a	N6	
Justin Garbinski	Mr.	Maple Ash NA	1010 S. Maple Ave.	Tempe, AZ 85281	University to Hudson; Railroad Tracks to Mill	a	N7	http://www.facebook.com/pages/Maple-Ash-Neighborhood/129921400371528?ref=ts
Ginny Sandstedt	Ms.	Maple Ash NA	1117 S. Ash Ave.	Tempe, AZ 85281	University to Hudson; Railroad Tracks to Mill	a	N7	http://www.facebook.com/pages/Maple-Ash-Neighborhood/129921400371528?ref=ts
Stephanie Haworth	Ms.	Mitchell Park East NA	422 W. 11th St.	Tempe, AZ 85281	University to 13 St; Roosevelt to Farmer	a	N7A	
Alice Bimrose	Ms.	Mitchell Park East NA	502 W. 11th Street	Tempe, AZ 85281	University to 13 St; Roosevelt to Farmer	a	N7A	
Larry Djinis	Mr.	Gililland NA	938 W. 14th St.	Tempe, AZ 85281	University to 13th; Priest to Hardy	a	N8	
Larry Djinis	Mr.	Holdeman NA	938 W. 14th St.	Tempe, AZ 85281	13th St. to Broadway; Priest to Hardy	a	N8A	
Phil Amorosi	Mr.	Hudson Manor NA	1432 E. Cedar St.	Tempe, AZ 85281	Apache to Railroad Tracks; Cedar to McClintock	a	N9	http://www.hudsonmanor.org/
Dan Mayer	Mr.	Hudson Manor NA	1532 E. Cedar St.	Tempe, AZ 85281	Apache to Railroad Tracks; Cedar to McClintock	a	N9	http://www.hudsonmanor.org/
Lena Felder	Ms.	Jen Tilly Terrace NA	1224 E. Spence	Tempe, AZ 85281	Apache to Railroad Tracks; Rural to Kenneth Place	a	N9A	
Courtney Quesada	Ms.	Cole Park NA	1967 E. Fremont Dr.	Tempe, AZ 85282	US 60 to McClintock;Baseline to Price, AZ	b	NEW	http://www.coleparkneighbors.org/
Mary Wilkosz	Ms.	Cole Park NA	1851 E. Fremont Dr.	Tempe, AZ 85282	US 60 to McClintock;Baseline to Price, AZ	b	NEW	http://www.coleparkneighbors.org/
Maureen Hymel	Ms.	Cyprus Southwest NA	P.O. Box 24624	Tempe, AZ 85285		a		
Nancy Hormann	Ms.	Downtown Tempe Community, Inc.	310 S. Mill Ste. A-201	Tempe, AZ 85281		a		
Valerie Hart	Ms.	El Adobe Condominiums HOA	150 E Alamo #3	Chandler, AZ 85225		a		
Mitch Kellogg	Mr.	El Adobe Condominiums HOA	150 E Alamo #3	Chandler, AZ 85225		a		
Ruth Kearns	Ms.	Friendship Village	2625 E. Southern Ave. C-51	Tempe, AZ 85282		x		
Matt Hassett	Mr.	Friendship Village	2645 E. Southern Ave. Apt. 588	Tempe, AZ 85282		x		
Dave Heywood	Mr.	Knoell Ville Monaco HOA	425 S. Hamilton Pl.	Gilbert, AZ 85233				
Pete DeMott	Mr.	Los Vecinos	1440 E. Cedar Street	Tempe, AZ 85281				
		Los Vecinos	2624 S Bonarden Lane	Tempe, AZ 85281				
Steven Tseffos	Mr.	Maple-Ash Prop./Land. Entity	1724 S. Ventura Dr.	Tempe, AZ 85281		a		
Bill Bunger	Mr.	Maple-Ash Prop./Land. Entity	1936 E. Calle de Arcos	Tempe, AZ 85284		a		
Penny Wilson	Ms.	Mitchell Park West NA	612 W. Howe St.	Tempe, AZ 85281		a		
Justin Stewart	Mr.	Mitchell Park West NA	814 W. Howe St.	Tempe, AZ 85281		a		
Kimberle Grise	Ms.	Newberry Terrace HOA	7255 E. Hampton Ave. #101	Mesa, AZ 85209				
Pat Barker		Newberry Terrace HOA	15615 N. 71st St. #208	Scottsdale, AZ 85254				
Allen Carlson	Mr.	Newtown CDC	511 W. University Dr. #4	Tempe, AZ 85281		a		
Eva Zukotynski	Ms.	Tempe Apache Blvd Assn.	1700 E. Apache Blvd.	Tempe, AZ 85281				
Don Mortensen	Mr.	Tempe Apache Blvd Assn.	637 S. 48th street #201	Tempe, AZ 85281				
Maryann Miller	Ms	Tempe Chamber of Commerce	909 E. Apache Blvd.	Tempe, AZ 85281		abc		
Gary Roberts	Mr.	Tempe Neighbors Helping Neighbors	PO Box 25494	Tempe, AZ 85285				
David Kay	Ms.	Tempe Town Lake Condos HOA	1005 W. 5th Street	Tempe, AZ 85281				
Benjamin Drevet	Mr.	Warner Ranch Meadows HOA	9772 S. La Rosa Drive	Tempe, AZ 85284		c		

Sentry Management Warner Ranch Meadows HOA 7955 S. Priest Drive Suite 105 Tempe, AZ 85284 c

Tempe Neighborhoods
April 16, 2013



Source: City of Tempe, Neighborhood Services

Key to Associations

Listed by Map Number

Neighborhood Associations

N1	North Tempe NA
N1A	NTNA - Canal Park NA
N1B	NTNA - College NA
N1C	Cavalier Hills NA
N1D	NTNA - Indian Bend NA
N1E	East Rio NA
N1F	NTNA - West Rio NA
N2	Sunset NA
N2	Riverside NA
N4	Lindon Park NA
N5	Escalante NA
N5A	Alegre Community NA
N5B	Victory Acres NA
N6	University Heights NA
N7	Maple Ash NA
N7A	Mitchell Park East NA
N7B	Mitchell Park West NA
N8	Gililland NA
N8A	Holdeman NA
N9	Hudson Manor NA
N9A	Jen Tilly Terrace NA
N10	University Park NA
N11	Marilyn Ann NA
N11A	Clark Park NA
N12	Daley Park NA
N13	University Estates NA
N14	Broadmor NA
N14A	Historic Date Palm Manor NA
N15	Shalimar NA
N15A	McClintock NA
N15B	Alameda Meadows NA
N16	Rural/Geneva NA
N16A	Meyer Park NA
N16B	Hughes Acres NA
N17	Evergreen NA
N17A	Broadway Palms NA
N18	MACH 8 NA
N18A	Brentwood Cavalier NA
N18B	Alameda Campus NA
N19	Peterson Park NA
N20	McClintock Manor NA
N20A	Cyprus Southwest NA
N20B	Hollis Park NA
N20C	Tempe Palms NA
N21	Superstition NA
N22	Tempe Gardens NA
N23	Kyrene Superstition NA
N23A	Southern Palms NA
N24	Baseline Hardy NA
N25	Tempe South Mountain NA
N26	Optimist Park Northeast NA
N27A	Cole Park NA
N27	Optimist Park Northwest NA
N28	Optimist Park Southeast NA
N29	Optimist Park Southwest NA
N29A	Kiwanis Park NA
N29B	Scudder Park West NA
N29C	Juniper Watson NA
N30	Pepperwood NA
N31	Wood Park NA
N32	Tempe Royal Estates NA
N32A	Bell De Mar Crossing NA
N33	Dava-Lakeshore NA
N33A	Bradley Place NA
N34	Camelot Village NA
N35	Sunburst Farms NA
N35A	Pheasant Ridge NA
N35B	Carver Terrace NA
N36	Estate La Colina NA
N37	Duskfire NA
N37A	Tally Ho Farms North NA
N37B	Raintree NA
N38	Warner Estates NA
N39	Corona Del Sol Estates NA
N39A	Mission Ridge NA
N39B	Los Tesoros NA
N40	Duskfire II NA
N40A	Tally Ho Farms NA
N41	Alta Mira NA

Homeowners Associations

H1	Concord Village, Inc. HOA
H2	Butler Tempe HOA
H3	Marlborough Park Estates HOA
H3A	Marlborough Park Villas HOA
H3B	Papago Park Village HOA
H3C	Parkview Hacienda HOA
H4	River Run HOA
H4A	Indian Bend Gardens HOA
H5	University Garden Villas HOA
H5A	Rio Salado HOA
H5B	Worthington Place HOA
H5C	Hacienda Del Rio HOA
H6	Rosen Place HOA
H6A	Scene One HOA
H6B	Wilson Place HOA
H7	Hayden Square HOA
H7A	Ash Court HOA
H7B	Lofts (The) at Orchidhouse HOA
H7C	Sienna Court Lofts HOA
H8	Los Prados HOA
H8A	Solar Energy Synergy HOA
H9	Casitas Tempe HOA
H9A	Casitas East HOA
H9B	Papago Park II HOA
H9C	Villagio at Tempe HOA
H9D	Newberry Terrace HOA
H10	University Ranch HOA
H10A	Questa Vida HOA
H10B	Oaks II & III HOA
H10C	Oaks HOA
H10D	University Shadows HOA
H11	Las Brisas HOA
H12	Broadmor Place HOA
H12A	Broadmor II HOA
H13	Alameda Estates HOA
H13A	Alameda Park HOA
H14	Villa Patrician HOA
H14A	La Sombra HOA
H14B	Brentview HOA
H14C	Springtree HOA
H14D	Joshua Square HOA
H14E	Broadway Terrace HOA
H14F	Premier Condominiums HOA
H14G	Chesapeake HOA
H14H	Broadway Townhomes HOA
H14I	Presidential Estates HOA
H15	Colonia Del Sur I HOA
H15A	Colonia Del Sur III HOA
H15B	Shalimar East HOA
H15C	Village at Shalimar HOA
H16	Tempe Village HOA
H16A	Fiesta Villages HOA
H16B	Knoell Garden Villas HOA
H17	Southern Village Estates HOA
H17A	Springdale HOA
H17B	Rancho Tempe HOA
H18	Laguna Estates HOA
H18A	Mistwood HOA
H18B	Chaparral HOA
H18C	Casa Fiesta HOA
H19	Tempe Gardens Townhomes HOA
H20	Puerta Del Sol HOA
H20A	Park Riviera Townhouse HOA
H21	Park Premiere HOA
H22	Park Riviera South T.H. I/II HOA
H23	Park Riviera South T.H. III/IV HOA
H24	Continental Villas East III HOA
H24A	Knoell Ville Monaco HOA
H24B	Colonia Del Sur IV HOA
H25	Hudson Trace HOA
H26	Pepperwood Townhomes HOA
H26A	Stonegate HOA
H26B	Alterra HOA
H27	University Royal Garden Hms HOA
H28	Lakes (The) HOA
H28A	Sandcastle HOA
H28B	Village Landings HOA
H28C	Harbour Village HOA
H28D	Runaway Point HOA
H28E	Lake Park Villas HOA
H28F	La Tierra HOA
H29	Festiva Tempe HOA
H30	Brittany Lane HOA
H30A	Terrace Walk HOA
H30B	Tempe Royal Estate HOA
H31	Park Premiere South II HOA
H32	Park Premiere South HOA
H33	Bradley Manor HOA
H33A	Juniper Village HOA
H34	Galleria HOA
H34A	Parkside at the Galleria HOA
H34B	Chelsea Manor HOA
H35	Cottonwoods of Tempe HOA
H35A	Oasis at Anozira HOA
H35B	Camelot Park Villas HOA
H35C	Capistrano I HOA
H36	Pecan Grove Estates II HOA
H36A	Homestead HOA
H36B	Graystone HOA
H36C	Alisanos HOA
H36D	Parke Tempe HOA
H36E	Pecan Grove Village II HOA
H36F	Coventry Tempe HOA
H36G	Pecan Grove Village III HOA
H36H	Carver Ranch Estates HOA
H37	Terra HOA
H38	Terramere HOA
H39	Hamilton Homes Tempe HOA
H40	Buena Vista Ranchos HOA
H40B	Calle De Caballos HOA
H41	Tempe Royal Palms HOA
H41A	Villas Las Palmas HOA
H42	Warner Ranch HOA
H42A	Warner Ranch Landing HOA
H42B	Warner Ranch Landing II HOA
H42C	Warner Ranch Manor I HOA
H42D	Warner Ranch Manor II HOA
H42E	Warner Ranch Village HOA
H43	Warner Ranch Phase II HOA
H44	Corona Ranch HOA
H44A	Las Estadas HOA
H45	Alta Mirada HOA
H46	Circle G Ranches IV HOA
H47	Sierra Tempe HOA
H47A	Sierra Tempe Unit #4 HOA

Affiliate Associations

	Tempe Neighbors Helping Neighbors
A1	Downtown Tempe Community, Inc.
A2	Tempe Apache Blvd Assn.
A3	Newtown CDC
A4	Friendship Village
A5	Los Vecinos

.Property Owners Associatic

P1	Maple-Ash Prop./Land. Entity

Appendix B3 - Public Meeting Comments and Attendance

Tempe Area Drainage Master Study
COMMENTS

PUBLIC MEETING

August 20, 2013

Name: B. Raisanen

Address:

Phone Number: 480-839-9360 E-mail:

Please provide your comments on the project presented in the meeting.

Meeting Survey

1. How did you learn about this meeting?

☐ Newspaper ☒ Mailer ☐ Friend/Neighbor ☐ Signage/Other

Please check the level of importance you feel applies to each of the items listed below.

	Very Unsatisfied	Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied
2. How satisfied were you with the **helpfulness** of the staff members?	☐	☐	☐	☒	☐
3. How satisfied were you with the **knowledge** of the staff members on the topic of the meeting?	☐	☐	☐	☒	☐
4. How satisfied were you with the **professionalism** of the staff members?	☐	☐	☐	☐	☒
5. How satisfied were you with the **information** you received?	☐	☐	☐	☐	☒

Please submit this comment sheet at the meeting or send to PIO, Flood Control District of Maricopa County, 2801 W. Durango St., Phoenix, AZ 85009; gantwegner@mail.maricopa.gov; or fax (602) 506-4389.

Tempe Area Drainage Master Study
COMMENTS

PUBLIC MEETING

August 22, 2013

Name: Steve Bass

Address:

Phone Number: E-mail:

Please provide your comments on the project presented in the meeting.

I will use the ReportAFlood.org tool.

Meeting Survey

1. How did you learn about this meeting?

☑ Newspaper ☐ Mailer ☐ Friend/Neighbor ☐ Signage/Other

Please check the level of importance you feel applies to each of the items listed below.

	Very Unsatisfied	Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied
2. How satisfied were you with the **helpfulness** of the staff members?	☐	☐	☐	☐	☑
3. How satisfied were you with the **knowledge** of the staff members on the topic of the meeting?	☐	☐	☐	☐	☑
4. How satisfied were you with the **professionalism** of the staff members?	☐	☐	☐	☐	☑
5. How satisfied were you with the **information** you received?	☐	☐	☐	☐	☑

Please submit this comment sheet at the meeting or send to PIO, Flood Control District of Maricopa County, 2801 W. Durango St., Phoenix, AZ 85009; gantwegner@mail.maricopa.gov; or fax (602) 506-4389.

Tempe Area Drainage Master Study
COMMENTS

PUBLIC MEETING

August 22, 2013

Name: Noreen Hurd

Address: 1324 E Krista Way Tempe 85284

Phone Number: 480-820-3788 E-mail: joyfulinarizona@att.net

Please provide your comments on the project presented in the meeting.

Meeting Survey

1. How did you learn about this meeting?

☐ Newspaper ☒ Mailer ☐ Friend/Neighbor ☒ Signage/Other email as an ~~HOA~~ Bd member

Please check the level of importance you feel applies to each of the items listed below.

	Very Unsatisfied	Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied
2. How satisfied were you with the **helpfulness** of the staff members?	☐	☐	☐	☐	☒
3. How satisfied were you with the **knowledge** of the staff members on the topic of the meeting?	☐	☐	~~☐~~	☒	☐
4. How satisfied were you with the **professionalism** of the staff members?	☐	☐	☐	☐	☒
5. How satisfied were you with the **information** you received?	☐	☐	~~☐~~	☒	☐

Please submit this comment sheet at the meeting or send to PIO, Flood Control District of Maricopa County, 2801 W. Durango St., Phoenix, AZ 85009; gantwegner@mail.maricopa.gov; or fax (602) 506-4389.

Tempe Area Drainage Master Study
COMMENTS

PUBLIC MEETING

August 22, 2013

Name: Katherine Mord

Address: 1404 E McNair Dr. Tempe AZ 85283

Phone Number: 602-568-8705 E-mail: Katherine@TempeAgents.com

Please provide your comments on the project presented in the meeting.

Advertise: "Open Forum @ 6 pm. Presentation begins at — p.m

Thank you for the dessert!

Meeting Survey

1. How did you learn about this meeting?

☐ Newspaper ☐ Mailer ☐ Friend/Neighbor ☐ Signage/Other email from City of Tempe

Please check the level of importance you feel applies to each of the items listed below.

	Very Unsatisfied	Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied
2. How satisfied were you with the **helpfulness** of the staff members?	☐	☐	☐	☐	☒
3. How satisfied were you with the **knowledge** of the staff members on the topic of the meeting?	☐	☐	☐	☐	☒
4. How satisfied were you with the **professionalism** of the staff members?	☐	☐	☐	☐	☒
5. How satisfied were you with the **information** you received?	☐	☐	☐	☐	☒

Please submit this comment sheet at the meeting or send to PIO, Flood Control District of Maricopa County, 2801 W. Durango St., Phoenix, AZ 85009; gantwegner@mail.maricopa.gov; or fax (602) 506-4389.

Tempe Area Drainage Master Study

Public Meeting – August 15, 2013 – Tempe High School, Tempe, Arizona

SIGN IN SHEET

This sign-in sheet will be saved as one of the documents related to the project.

Name	Address	Phone	E-mail
Wm. Son Magallanez	5230 S. Clark Dr. Tempe, 85283	480.839.0474	
Patrick Ingram	4401 S. ELM ST Tempe 85282		
Darlene Tussing	1156 E Henry Tempe 85281	480-968-5931 *	Notify 4 Scottsdale Review
Don Kirby	(City of Chandler staff member)	480.782-3128	

Tempe Area Drainage Master Study

Public Meeting – August 20, 2013 – Hudson Elementary School, Tempe, Arizona

SIGN IN SHEET

This sign-in sheet will be saved as one of the documents related to the project.

Name	Address	Phone	E-mail
Bob Matthews	Tempe Fire Dept.	858-7223	robert_matthews@tempe.gov
Barbara Raisanen	2119 E. Pebble Beach	480-839-9360	
Kevin Cullens / Jim Laughlin	1808 East Fremont Drive	623 764 4223	Kevin_cullens@msn.com
Candice Cripple	BOS D#1		

Tempe Area Drainage Master Study

Public Meeting – August 22, 2013 – Corona Del Sol High School, Tempe, Arizona

SIGN IN SHEET

This sign-in sheet will be saved as one of the documents related to the project.

Name	Address	Phone	E-mail
Doug Williams	601 E. Bishop Dr. Tempe AZ 85283	480 921-0419	—
Catherine Moore	1404 E McNair Dr Tempe 85283	602-568-8705	Catherine@TempeAgents.com
Pat Quinn	1007 E. Verde Ln. Tempe, AZ 85284	602-214-2536	Patrick Quinn
Noreen Hurd	1324 E Krista Way " " "	480-820-3788	Noreen Hurd
Steve Bass	1203 E. Harbor View Dr. Tempe 85283		steve.bass@mesacc.edu

Appendix C – Stakeholder Meeting Minutes

MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
City of Tempe Stakeholders
Planning Staff

Date: March 20, 2014
Time: 2:30 -4:00
Place: City of Tempe Public Works Conference Room

I. Introductions/Sign In Sheet

A. See attached sign in sheet

II. Project Overview (FCDMC)

A. Project Limits: North Boundary Rio Salado South Boundary SR-202L Freeway, East Boundary SR-101L Freeway, and West Boundary I-10
B. Tempe ADMS Schedule
   a. Phase 1: Data Collection – Mostly finished
   b. Phase 2: Modeling Efforts – To be finished around August
   c. Phase 3: All LID Associated Impacts – To be finished around November

III. Ultimate Product of Study (FCDMC/J2)

A. Overview of model and report provided by FCDMC

IV. Stakeholder Input

A. Identify known areas of flooding in the City
   a. No specific areas identified
B. Identify known areas of storm water conveyance issues in the City
   a. Areas of Guadalupe and Tempe Marketplace that are old county islands may not convey flows in the streets like the rest of Tempe. These and similar areas should be investigated further to determine if these conditions warrant specific modifications in the model to accurately represent storm water runoff.
C. Identify known areas of storm water erosion issues in the City
   a. No specific areas of erosion problems identified

D. Does the City currently utilize or considering implementing any of the following to assist in storm water management from a planning/policy standpoint
   a. Storm water utility fee
      i. Currently no dedicated funding source but starting to investigate developer impact fees to include a storm water fee.
   b. Storm water credits to businesses, or residential lots to retain store storm water on site and lower fee
      i. This idea has not been forwarded for consideration
   c. Low Impact Development Standards that focus on storm water retention, storm water reuse or recycling to lower fee
      i. The idea of fees has not been forwarded for consideration. However LID scenarios have been implemented recently on College Avenue and at the City's Transit Center along with the green roof technology that has been developed at that site. The City would like to see what drainage impacts these developments have had on storm water runoff (peak or volume reductions).
   d. Requirements for storm water management with any new development
      i. The City currently requires that any and all new development retain on site the 100-year storm event. The City has not instituted any fees associated specifically with storm water retention credits.
   e. Other planning or zoning codes specific and or focused on storm water management within the City
      i. No new ideas relative to storm water management have been forwarded for consideration to City management

E. Pilot projects
   a. Loma Vista area has been noted for its potential to be a demonstration (potential for rainwater harvesting) or pilot project
   ~~a.~~b. The City would like to better understand the ADOT pit Southeast of I-10 and Warner Rd. Currently the City has a maintenance agreement that expires in 2015. The City wants a better understanding of how much water is entering this site and from where. The City would also appreciate how much of the contributing water in this basin is coming from Phoenix. And then some creative ideas of what this basin could be used for and perhaps a way to showcase the storm water so that it perhaps can be treated as an amenity to be celebrated.

~~b.~~c. The City noted that the College Avenue LID techniques ~~should~~ could be reviewed to see if they are having any positive impact to storm water drainage flows. Evaluating the prior storm flows with current storm flows after development may need to be investigated.

~~c.~~d. The City has had in place for some time the green roof technology at the Tempe Transit Center at 5th Street and Forest and does not have any data on how effective this has been at decreasing storm water runoff. ~~Could this project assist in gaining some of that information?~~The City would appreciate a discussion with the District to see if this could be considered a pilot project.

~~d.~~e. ~~The City would like to better understand the ADOT pit Southeast of I-10 and Warner Rd. Currently the City has a maintenance agreement that expires in 2015. The City wants a better understanding of how much water is entering this site and from where. The City would also appreciate how much of the contributing water in this basin is coming from Phoenix. And then some creative ideas of what this basin could be used for and perhaps a way to showcase the storm water so that it perhaps can be treated as an amenity to be celebrated.~~

F. How could this project assist the City staff
   a. Addition of pollutant modeling would be a significant improvement for the water quality department and to help the City deal with the new EPA Guidelines.
   b. The City would like the model to reflect if possible the degradation of the City's storm water infrastructure so that a means and method could be developed to target CIP funding to specific reaches or areas within the City for storm drain replacement/improvement.
   c. Modeling individual LID projects including bioswales and reduced pavement projects and comparing results would be helpful as well. This could be based on evaluating the past and current storm water runoff of College Avenue where LID scenarios have been recently implemented.

V. Open Discussion

A. Public Outreach meetings would be best scheduled after the summer, monsoon season, but not in October. Also the City holds major events in March and this month should be avoided for any public outreach efforts.
B. Reportaflood.org marketing material will be available from the district soon to the City

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Planning Staff
March 20, 2014

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* covered on behalf

MEETING MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
City of Tempe Stakeholders – O&M Staff

Date: March 20, 2014
Time: 1:30 -2:30
Place: City of Tempe Public Works Conference Room

I. Introductions/Sign In Sheet
A. (See attached)

II. Project Overview (FCDMC/J2)
A. Project overview provided by FCDMC

III. Stakeholder Input
A. Note that the City of Tempe Fire and or Police services do not track street flooding issues. Tempe Fire stated that the reports that they respond to are not storm water flooding but flooding from broken water mains etc.

B. Identify known areas of drainage and flooding problems
   a. A list of the following intersections and or roadway issues relative to flooding/drainage issues
      i. McClintock/University Drive
      ii. McClintock/US-60 (Note that the City and ADOT are actively working on understanding this issue better and trying to make sure that access points to work on any problems are identified)
      iii. Broadway Road/Terrace
      iv. Broadway Road/Eastbound East of Mill Avenue
      v. McClintock Southbound north of Guadalupe
      ~~v.~~vi. Broadway & Mill Intersection Note that a connection point on Broadway creates head for pump system at underpass of Mill and the railroad. When pumping water re-circulates due to connection method and SRP use of main on Broadway for water delivery. The line on Mill appears to be connected by a tee connection where a 45 degree transition would be a better transition. Also if possible determine best location for a drain point for SRP from

"George Ditch" is an irrigation ditch running east west down the middle of Parkway Boulevard approximately 600 feet south of Apache Blvd.

b. SRP irrigation delivery lines or flood irrigation basins can and often do back up during storm events due to the lines delivering flood irrigation to properties or basins during storm events. Daley Park and Scudder parks are two such cases where storm events coincided with flood irrigation deliveries resulting in flooding.
c. Alleys (Tempe has 165 miles of alleys typically 16-20 feet in width) are unpaved and allow sediment into adjacent street drains and blockage occurs easily. Cutler north of Broadway road near the alley has been an ongoing issue for the City. The treatment of alleys has been an on-going maintenance issue for the City even though the City code states that ownership and maintenance responsibilities for the alley is the adjacent property owners historically that has not been enforced and the City has been maintaining.
d. Residents placing trash for collection on top of catch basins cause debris to enter storm drains and block outfalls, resulting in water backing up (particularly noted in the Sierra Tempe lots near Ray and Priest)
e. Corbell Park drains very slowly and is an issue that contributes to issues at Lakeshore and Elliott.
f. Kiwanis Lake levels become an issue during peak storms due to the limited capacity and the drainage area that contributes to this lake.
g. The City does not enforce the BMP's that are part of the current City code that dictates 100-year storm water retention is supposed to be retained on each individual property

IV. Identify known areas of storm drain conveyance issues in the City
A. The Gila Drain if not maintained becomes a very big issue for the City and drainage related issues.

V. Identify known areas of storm water erosion issues in the City
A. No specific areas of erosion problems identified

VI. Open Discussions
A. How can this project assist City staff
B. Other ideas/issues
i. Flooding pictures/videos can be uploaded to reportaflood.org using PC or mobile devices.

ii. Mike noted that a certain percentage of Tempe storm drains are inspected with videos every year and the videos could be made available for this study if they would be of any assistance.

iii. ADOT pit Southeast of I-10 and Warner Rd. has a maintenance agreement between City of Tempe and ADOT that expires in 2015. The City wants a better understanding of how much water is entering this site and from where. The City would also appreciate how much of the contributing water in this basin is coming from Phoenix.

iv. City may be able to grant access to J2/FCDMC to Flowlink storm drain conveyance measurement data

v. The City's current budget for storm drainage maintenance is set currently at $50,000/year to both maintain and track issues relative to new EPA MS4 regulations.

vi. Coordination and joint use with any of the school district parcels is a good idea to pursue but closer coordination between the City and the School District/specific school sites will be required if that is implemented due to school events and the possibility that temporary pumps may be required to drain a facility after a storm for a programmed school event.

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Maintenance Staff
March 20, 2014

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Google Earth Pro

feet 1000

meters 400

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Maintenance Staff
March 20, 2014

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MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Tempe Union High School District

Date: March 26, 2014
Time: 10:00am
Place: Tempe Union High School: District Community Relations -- 500 W. Guadalupe Rd. Tempe

I. Introductions/Sign In Sheet

A. See attached sign in sheet

II. Project Overview (FCDMC/J2)

A. Project Limits: North Boundary Rio Salado South Boundary SR-202L Freeway, East Boundary SR-101L Freeway, and West Boundary I-10
B. Tempe ADMS Schedule
   i. Phase 1: Data Collection – Mostly finished
   ii. Phase 2: Modeling Efforts – To be finished around August
   iii. Phase 3: All LID Associated Impacts – To be finished around November

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. Speed bumps installed on McKemy St have diverted storm water into one of the TUHSD facilities and resulted in some flooding of one of their buildings – The foreman of the building may have pictures of the (2012) flooding. The TUHSD will check to see if any other pictures of this flooding exist.
   b. Kyrene and Ray Road – behind Intel – drains appear to be blocked. This flooding issue is not related to TUHSD facilities but noted by Jessica Hauer TUHSD staff that lives in this area and has issued this complaint to the City and uploaded her photos to reportaflood.org.

B. Discuss available opportunities to improve storm water management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

a. The TUHSD is very much in favor of being a partner with the District in developing alternative storm water management practices and techniques at all of their 4 campuses. TUHSD would like to investigate how this effort could be expanded into the classroom to engage and interact with both the teaching staff and student population regarding these efforts.

b. The Flood Control District is searching for grants, particularly a Water Infrastructure Finance Authority (WIFA) grant to fund the pilot project at Loma Vista that would showcase several of these techniques.

c. The TUHSD noted that flood irrigation can often increase their costs due to the additional maintenance issues associated with herbicide treatments necessary to control invasive species of weeds and other elements such as chemicals from farm fields that can be detrimental to turf growth that are often associated with the use of flood irrigation.

d. FCDMC would appreciate getting irrigation water use volumes from TUHSD for each sites turf fields. TUHSD stated that this data can be collected and provided.

e. TUHSD stated that Mr. Doug Osborn at Hess Roundtree has all of the campus information relative to buildings, grading, drainage and infrastructure. The FCDMC team is welcome to call Hess Roundtree to gather information if needed.

f. TUHSD uses most of its water for the turf irrigation, and the 2nd most for cooling towers.

g. TUHSD campuses for the most part either currently or in the past utilized flood irrigation delivery so the grading done to accommodate this aspect has resulted in the sites retaining most if not all of its own storm water runoff. This offers a great benefit to investigating other "green" infrastructure projects such as rain gardens, water harvesting and alternative retention concepts.

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices

a. Loma Vista is the target for the initial pilot project. Beyond storm water alternatives the FCDMC would be open to discussing with TUHSD the conversion of its surrounding landscape treatments to a lower wateruse desert adapted planting regime.

b. The impact of developing storm water alternatives at any of the TUHSD sites on the surrounding SWMM and FLO2D models needs to be demonstrated to the District if any benefits are derived from implementing these storm water techniques.
c. Tempe High is also a potential pilot project site but has less acreage to provide alternative storm water management examples.
d. Although Tempe Elementary is not part of TUHSD, there may be additional potential projects with this district as they too are pursuing "green" technologies at all of their campuses. Contact for follow up is Steve Palmer TUHSD will provide contact information for Steve.
e. Burke is interfacing with ASU sustainability groups on several pilot projects including a "Heat Island" study. The TUHSD would be interested in joining up with that study to evaluate how strategic landscape placement could help to reduce heat island effect relative to several of their buildings located on their campuses.
f. Jessica is in contact and potentially planning outreach with GIS teachers, possibly involving students with green projects. There are currently 5 teachers that have initiated GIS training within the classroom and this project could be used as a model for how GIS can be applied to a "real world" issue. TUHSD would like to investigate if this project could be interfaced with the schools STEM (Science, Technology, Engineering, and Mathematics) curriculum.

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. J2 will provide Jessica with some PDF files of the exhibits used in the meeting for her use in describing and gaining support from the TUHSD team to look at integrating a part of the study into the curriculum and into their campuses.

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Tempe Union High School District
3/26/2014

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Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Tempe Union High School District
3/26/2014

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MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Mill Avenue District
Downtown Tempe Community

Date: March 27, 2014
Time: 2:00pm
Place: 310 S. Mill Avenue, Suite A-201 Tempe, AZ

I. Introductions/Sign In Sheet

A. See attached sign in sheet

II. Project Overview (FCDMC/J2)

A. Project Limits: North Boundary Rio Salado South Boundary SR-202L Freeway, East Boundary SR-101L Freeway, and West Boundary I-10
B. Tempe ADMS Schedule
   i. Phase 1: Data Collection – Nearing Completion
   ii. Phase 2: Modeling Efforts – To be finished around August
   iii. Phase 3: All LID Associated Impacts – To be finished around November

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. No specific areas identified but will investigate further with Board and their connections to their constituents and members.

B. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)
   a. No specific ideas presented but will investigate further with Board and their connections to their constituents and members.

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices

a. No specific ideas identified as "pilot projects" but will investigate further with Board and their connections to their constituents and their members.

IV. Open Discussions

A. Other ideas/thoughts regarding this project?

i. DTC operates over 52 square blocks

ii. Send a "1-pager" to the businesses in the district (see attached)

iii. USA Basketball/Convention Center/Hotel plans in the works and may include some LEED certifications including site work but is not certain.

iv. Additional meeting(s) may be needed with the Mill Avenue District Board and or its members if it is determined that there are questions and or clarifications needed.

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Mill Avenue District Downtown Tempe Community
Thursday, March 27, 2014

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Spike Lawrence				

MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Tempe Chamber of Commerce

Date: April 2, 2014
Time: 7:30am
Place: 909 E Apache Blvd

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

A. Study area bounded by Salt River, I-10, 202 and 101 highways
B. Highways and Canals generally serve as boundaries for our modeling
C. Salt River can convey 200 year flood including inflows from Tempe
D. This study will not update floodplain mapping
E. Once results are ready, stakeholders and the public will be notified and informed through involvement meetings

III. Stakeholder Input

A. Will this study needs to tie into the City's 2040 plan currently underway? The linkage between this ADMS and the City's 2040 plan will be the relationship of the City's efforts instituting LID and Green Infrastructure into the City's codes and ordinances. The implementation of these elements and features could have a direct effect on storm water runoff.

B. Project wide questions from attendees included:
   a. Will the City's eventual build out effect this ADMS? Yes the buildout of any area can increase the impervious area and potentially increase runoff however the implementation of LID (Low Impact Development) and Green infrastructure (rain gardens, water harvesting, Bio Swales etc.) can decrease and minimize that runoff.
   b. Will this project create any new flood plains? No this project will not result in any flood plain modifications. This project is only a study of the surface flow of storm water within the boundaries

described above and has no relationship to FEMA established flood hazard maps.

c. Will this project have any effect on sinkholes? This project is only a study of the surface flow of storm water within the boundaries described above and has no relationship to subterranean or geomorphology and sink holes. The team is not aware of any sinkholes in the study area.
d. What effect will this study have on groundwater subsidence? This project is only a study of the surface flow of storm water within the boundaries described above and has no relationship to ground water subsidence issues.
e. What is the relationship between the FCDMC and SRP? This relationship is very close dealing with damn releases and flood control in Arizona's rivers. FCDMC and SRP maintain a very close working relationship
f. Will this study have any relationship to flood insurance requirements? This project is only a study of the surface flow of storm water within the boundaries described above and has no relationship to establishing any new flood plains or flood insurance maps used by FEMA in establishing insurance limits.
g. Will this study have any effect on property values? This project is only a study of the surface flow of storm water within the boundaries described above and has no relationship to establishing property values. It may indicate areas within the study area where known and repeated flooding issues could be addressed and that may have an indirect effect of increasing value when an identified issue is addressed.
h. What dictates storm water retention ordinances? The City ordinances establish the storm water retention requirements.

C. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. Septic Systems can cease functioning during storms
   b. Homeowners who've remodeled may have raised their lots increasing runoff and volumes into adjacent homeowners who maintain the flood irrigation depth. This has resulted in the increased potential for flooding of surrounding homes. This issue appears to be a code enforcement issue between the HOA and the City of Tempe. Tempe current code requires onsite retention from all residential areas which can be individual lots or community retention areas designed for the expected runoff.

D. Discuss available opportunities to improve storm water management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)
   a. Green infrastructure can include the use of storm water cisterns to capture and hold water for later use, the use of Permeable pavement that decreases storm water runoff , rain gardens that capture storm water, bio swales used to help clean the first flush of storm events and other techniques can be used to decrease storm water flows and runoff.
   b. Tuscon regulations have recently been updated with very strict requirements in regards to storm water retention, and implementation of green infrastructure. Their policies and guidelines have been serving as a template for many other municipalities in regards to implementing green infrastructure policies.

E. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices
   a. Flood Control District has Capitol Improvement Project funding available for targeted pilot projects and is working closely with the City of Tempe and the Tempe Union High School District towards developing a pilot project for this study area.
   b. Loma Vista area North of McClintock High School has been identified as a potential site for one of the first pilot project

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Most HOAs only have 1 meeting every year so closer coordination between the HOA's the City and the FCDMC will need to be implemented to assist in that outreach effort.
   ii. Homes with basements might be worth obtaining information on to determine if there are areas within the limits of this study that may require special attention.
   iii. Consider meeting with representatives of the ASU Research Park as they are a large stakeholder in this study.
   iv. reportaflood.org allows residents of Maricopa County to submit pictures and descriptions of experienced flooding to the Flood Control District of Maricopa County which helps the county develop a better understanding of where the flooding issues are

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Tempe Chamber of Commerce
4/2/2014

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AGENDA
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
City of Chandler

Date: April 3, 2014
Time: 10:00am
Place: City of Chandler - 215 E. Buffalo Street, Chandler, AZ 85225

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. Most Chandler drainage issues lie East of the 101 highway
   b. Most drainage is self contained, except for Chandler Mall and Stellar Airpark which drain into other facilities
   c. Gila Drain has had issues before but is under the operation of SRP

B. Discuss available opportunities to improve storm water management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)
   a. No specifics identified

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices
   a. No specific areas identified

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Chandler maintenance staff will be consulted for any issues they've experience with drainage.
   ii. Frye Rd will be extended and built over Gila Drain
   iii. Reportaflood.org allows anyone to upload a picture and meta data for any flooding events experienced in Maricopa County

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - City of Chandler
4/3/2014

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Warren White, Principal Engineer/Data & Mapping Services;	COC			
Jason Richardson, Principal Plans Examiner;	COC	480-782-3141		jason.richardson@chandlieraz.gov
Kim Clark, Development Project Administrator;	COC			
Jack Mikelson, Development Project Administrator.	COC			

AGENDA
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Guadalupe

Date: 5/1/14
Time: 9:30
Place: Guadalupe Town Hall

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. No annual flooding issues
   b. 1 large event in last 15 years caused flooding near Guadalupe Rd/I-10 overpass
   c. Curbing alleviated former flooding issues mostly

B. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Report flooding to the Flood control district at www.reportaflood.org using a desktop or mobile device

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Town of Guadalupe
May 1st, 2014

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AGENDA
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
CITY OF PHOENIX

Date: 5/12/2014
Time: 1:00 PM
Place: City of Phoenix, 200 W Washington Street, Conference Room 5 East.

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. Jack to bring exhibit to supervisor meeting to pinpoint maintenance requests and known areas and return marked up exhibit to J2.

B. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Ho Ho Kam ADMP displayed hydraulic cross sections labeled with peak flow and velocity

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - City of Phoenix
5/12/2014

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Jack Noble	Street			

MEETING MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
ASU

Date: 5/14/14
Time: 9:00 AM
Place: J2 Conference Room

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

A. Project Timeline:
June 2013 – Nov 2013 – Data Collection
Nov 2013 – Sep 2014 – Modeling
Sep 2014 – LID study

B. Long Term Implications
a. Regional Model to be used to address flooding issues
b. Model to be kept up to date to reflect current conditions
c. Model to be used to quantify changes in results based on proposed conditions

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
a. There are known issues – Mel White of ASU would be the person to contact
b. Drywells are inspected/cleaned yearly as per ADEQ (CAD files with locations are available)

B. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

a. There are a couple buildings utilizing rainwater harvesting currently
b. ASU Karsten golf course is slated to be redeveloped in the near future

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Reportaflood.org – Upload pictures and flooding experiences to this website to help the flood control district
   ii. Request for information – ASU boundaries, Drywell locations, Water/Irrigation usage
   iii. Does ASU need concurrence from Tempe on developments

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - ASU
5/14/2014

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MINUTES
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
SRP

Date: 5/20/2014
Time: 1:30 PM
Place: J2 Conference Room

I. Introductions/Sign In Sheet

See sign-in sheet

II. Project Overview (FCDMC/J2)

Burke gave a brief review of the project, purpose of the meeting and status of the project.

III. Stakeholder Input

A. Identify known problem areas related to drainage or flooding within study area (such as flooding damage to structures or landscaping, restricted use, lack of access, vector (mosquito) issues, Etcetera)
   a. No concerns of ponding behind canals
   b. There are numerous locations where SRP irrigation lines are directly connected to existing City storm drains. The known (note not all are known) connections are shown on SRP Zanjero Maps. These maps will be provided to design team.
   c. Storm runoff is entering the SRP canal system at these cross connection points throughout the system. SRP would like to eliminate these cross connections and are targeting their elimination and reconstruction during major infrastructure projects.
   d. Highline Canal was reported to have overtopped near Avenida del Yaqui in Guadalupe. SRP as part of their aesthetic funds is fencing the canal in this area and adding a trail system along its western bank. The fencing will run from Priest to ½ way between Elliot Road and Guadalupe Road

B. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

a. SRP maintains and active groundwater recharge program throughout the state. They are not aware of any of those wells in the Tempe study area.
b. SRP maintains a sustainability coordinator Mr. John Hedrick who heads up that program for SRP. This program could be a potential resource for pilot projects and alternative retention evaluations.

C. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices
   a. SRP interested in knowing more see notes above about sustainability contact.

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Reportaflood.org – Flood Control District flood reporting website/database allows users to upload georeferenced flood photos/videos
   ii. J2 and FCD to obtain latest SRP Zanjero maps, known locations of irrigation/stormdrain connections are noted
   iii. J2 to request SRP GIS data
   iv. J2 to provide GIS data to SRP for Tempe storm drainage system for use as part of their GIS mapping

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - SRP
5/20/2014

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Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - SRP
5/20/2014

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MINUTES
HOA/NA Discussion
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021

Date: 5/21/14
Time: 1:00 PM
Place: City of Tempe Engineering Conference Room

I. Introductions/Sign In Sheet
See sign-in sheet

II. Project Overview (FCDMC/J2)
Burke gave a brief introduction about this project including its objectives, schedule, and status.

III. Home Owners Associations / Neighborhood Associations

A. Review draft plots of model results and HOA area targets
B. GIS data requirements
   i. Tempe to send HOA/NA boundary GIS shapefiles to J2 after technical release is signed and sent back. Gregg will track down release and provide to J2.

C. Association Boundaries (Grouping for effective outreach)
   i. Grouping will be based on identified problem areas once HOA boundaries are overlaid with preliminary model results by sub-model area.

D. Schedule for future HOA Meetings to discuss Project
   i. Advertisement – Who and How?
      1. Industrial groups have been hard to reach. The City has contacts with the major players in this area and will reach out to them and provide contact to the Team regarding this outreach effort.
      2. Water Bill newsletter could be used to advertise project status and upcoming meetings. To get advertisement into water bill information to be included has to be provided a minimum of 2 months prior to billing cycle.

ii. Graphic Displays - What?
   1. Preliminary modeling results and HOA boundaries overlaid on one graphic
   2. Potential graphic animation of model results
   3. Print of aerial of entire project boundaries and limits
   4. Print of aerial and sub-model areas
   5. Other graphics will be determined as design moves through process

iii. Locations of Meetings – Where?
   1. Where significant flooding potentials exist within HOA boundaries a public facility near the area will be identified by City staff as a location for the HOA and Neighborhood Association meetings.

iv. Timing – When?
   1. Preliminary model results – approximately the second week in July will be presented to City staff. At this meeting target areas/HOA's identified for potential meetings will be discussed and a plan of action developed with both City outreach and District outreach efforts.
   2. Target HOA meetings will be in month of October (not the second week of October as that is fall break for ASU and Tempe Schools). The City will reach out to their contacts at the registered HOA's to make sure that meeting schedule in October will work for the HOA individual boards and or commissions, and will coordinate information dissemination for HOA newsletters.

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Some Tempe alleyways were recently paved over with recycled asphalt pavement – Gregg will send J2 a map showing the areas;
   ii. Clark Park pool was converted to a community garden

Tempe ADMS/P, FCD 2012C021
HOA Discussion Meeting - J2/City of Tempe/Flood Control District
5/21/2014

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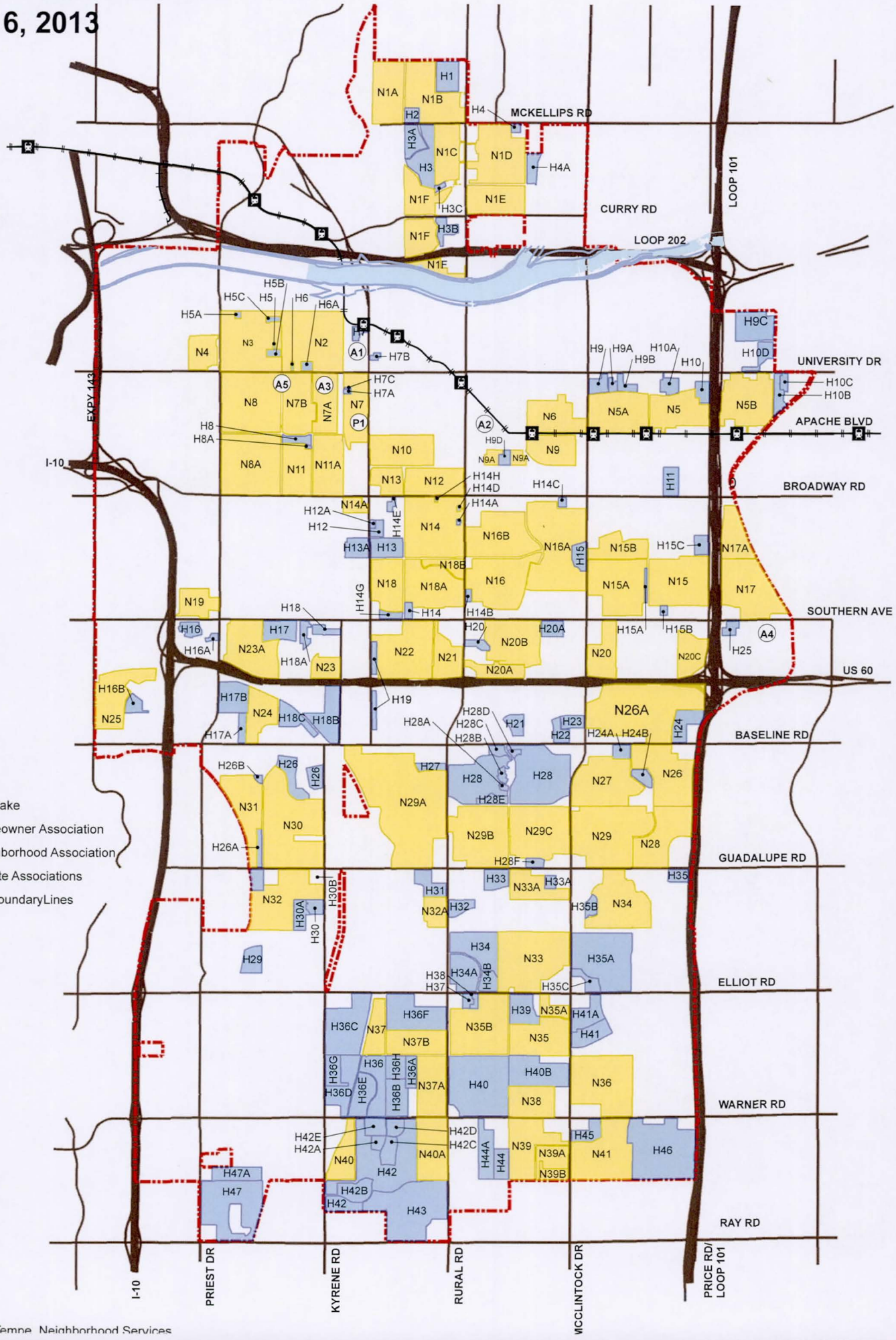
Tempe Neighborhoods
April 16, 2013



Source: City of Tempe, Neighborhood Services

Tempe ADMS/P, FCD 2012C021
HOA Discussion Meeting - J2/City of Tempe/Flood Control District
5/21/2014

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AGENDA
City of Tempe General Plan 2040
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021

Date: 6/9/2014
Time: 3:00 PM
Place: City of Tempe Community Development Garden Level Lobby Conference Room

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

A. Phase II: Modeling effort scheduled to complete around August/September
B. Phase III: Low Impact Development (LID) effort scheduled to wrap up around next April/May
C. Final Public Outreach meeting scheduled to occur next spring

III. Implementation of City General Plan 2040

A. Discuss available opportunities to improve stormwater management (modify existing storm drains/inlets and basins, re-grade landscapes, construct alternative retention facilities, implement rainwater harvesting)

B. Suggestions for Pilot or Demonstration Project(s) to demonstrate means and methods contributing to improved storm water management practices
   a. McClintock High School

IV. Open Discussions

A. Other ideas/thoughts regarding this project?
   i. Tree Canopy – Walton Sustainability is modeling heat island effects
   ii. Potential for Public Private Partnerships to fund certain initiatives
   iii. Original LID idea list amongst Tempe City staff has been expanded and has been turned into a white paper-like document. Jeremy will provide to Gregg to pass along to J2
   iv. Tempe Character Areas – coincide well with our modeling boundaries – pertinent details available on Tempe city website.

Tempe ADMS/P, FCD 2012C021
Tempe General Plan 2040 Meeting
6/9/2014

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AGENDA
Stakeholder Participation
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Tempe Union High School District

Date: September 29, 2014
Time: 2:00 pm
Place: McClintock High School

I. Introductions/Sign In Sheet

II. Project Overview (FCDMC/J2)

III. Stakeholder Input

A. Information Gathering
   a. Team to gain a better understanding of the existing irrigation system overview and operations
   b. Team to gain a better understanding of the existing water meters dedicated to landscape watering
   c. Team to gain a better understanding of the water use for landscape watering how best to retrieve data for water use
   d. Team to gain a better understanding of the options available for any LID practices on McClintock High School site

IV. Open Discussions

A. Other ideas/thoughts regarding this project?

Tempe ADMS/P, FCD 2012C021
Stakeholder Meeting - Tempe Union High School District
9/29/2014

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MINUTES
LID Practices
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Work Assignment No. 3

Date: November 17, 2014
Time: 3:00 p.m. – 4:30 p.m.
Place: ASU University Services Building room 2105

I. Introductions

II. FCD – Tempe ADMS Project Overview

a. Identifying existing flooding and drainage issues
   i. Tempe has the oldest storm drain system in the region

b. Developing a high definition/regional hydrology model that includes the stormdrain systems
   i. This is the first regional study done for Tempe
   ii. Using recent technology (FLO-2D software) that allows modeling the ground at a 20' grid resolution (or smaller, but can be limited by computing power) along with the stormdrain. Each 20' grid contains numerous parameters.
   iii. Previous drainage studies used HEC-1 software, which doesn't model flat, urban areas like Tempe as well

c. Expect that model results will provide opportunities to optimize existing infrastructure, provide Tempe with more and better options for dealing with stormwater
   i. Model results expected to be available mid-January

d. Looking for ways to support and advance LID practices as a cost effective mitigation tool
   i. ASU has 19 MW power generation from solar panels

ii. Permeable pavers/pavement

e. Looking for additional opportunities and real life (re)development case studies to proof modeling techniques, identify and refine relevant (to Tempe/metro Phoenix area) LID component designs, and encourage "green" installations (track construction and maintenance costs, performance data)

   i. The Loma Vista subdivision near McClintock High School has received a WIFA grant for drainage improvements. Original plan was to dig a 13' deep basin, but this project will use green infrastructure

f. Encourage "transformation" of urban areas from current (auto oriented, intensive water consumption, urban heat islands) to a more sustainable model that can be replicated throughout the metro Phoenix area.

III. Status of ASU initiatives

a. Main Campus Drainage study

   i. Last study was a partial study in 1997

   ii. No current overall master plan, however the timing is convenient with the current Tempe ADMS

b. USA Place – 10.5 acres w/ convention center, Omni Hotel, USA Basketball

   i. 2 below-ground parking levels

   ii. Under complicated negotiation with November deadline on financing

   iii. Commitment to conference center

c. Athletic Facilities District – 330 acres (Catellus planning study)

   i. 25 year project

   ii. Tempe ADMS modeling may be useful as well as the mapping

d. Marina Heights – State Farm building construction

IV. City of Tempe Interests and Concerns

a. Direct jurisdiction over ASU?
   i. Verify USA Place requirements
   ii. MUED special zoning category for ASU to handle zoning internally

b. MS4 permits issues (alternative retention)

c. Tempe Town Lake (outfall, pollution vs. usability and aesthetics)

d. Application and utility of LID methods and future integration into design criteria to allow developers to use it

V. Open Discussions – Where can/do we go from here?

VI. Action Items

a. Set meeting in January with ASU and FCDMC planning personnel
   i. Show preliminary modeling results using newest software
   ii. Find out what they are thinking about/envisioning
   iii. Figure out who they are going to engage

b. Verify USA place requirements

Tempe ADMS/P, FCD 2012C021
LID Practices Meeting
November 17, 2014

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AGENDA
HOA Outreach Coordination Meeting
Tempe Area Drainage Master Study/Plan
Contract No. FCD 2012C021
Work Assignment No. 2

Date: April 10, 2015
Time: 9:00 a.m. – 10:00 a.m.
Place: City of Tempe Public Works Conference Room

I. Brief overview of project

A. Scoping of WA#3 underway will include a heavier effort of LID incorporation than previously anticipated. The District is redeveloping the scope of work to include the LID efforts. The use of LID needs technical support and this project could potentially provide that technical backup.

II. Preliminary Modeling Results Review/Discussion

A. Preliminary Results align with the drainage issue areas according to Tempe

B. Particular areas of issue that could be focused on in HOA outreach include

- **i.** Scudder Park – This offline or surge basin needs to be reviewed to see if it is effective and not contributing to the Magdalena Dr. issue.
- **ii.** Alley connected to Rural Rd drains East and may act as overflow, adding to issue at Magdalena neighborhood
- **iii.** Hardy Rd Improvements North of Broadway – Speed tables may cause additional issues blocking storm water flows
- **iv.** APS power line corridor near ASU Karsten – site currently has drainage issues but the future development of this site will need to address
- **v.** Daley Park area has significant drainage issues
- **vi.** Mill Avenue from Southern to University is an issue

III. Public Outreach Date Selection

A. Current dates available for meeting per City of Tempe

a) 5/11
b) 5/12
c) 5/18
d) 5/19
e) 5/20
f) 5/26
g) 5/27
h) 5/28

These highlighted dates are the preferred dates; Gregg to get with City of Tempe PIO to determine who the team needs to contact to establish meeting. Potential sites for the meeting could be at the library or historical museum. Note that the district does not currently have a PIO so will need to coordinate closely on meeting preperations when date selected.

B. J2 would recommend that the best dates on this lists would be May 11, 12, 18, 19 or 20 the remaining dates in May are around the memorial day weekend and holiday and there is potential that many people may be out of town that week to take advantage of the Monday holiday

IV. Other Task for Outreach Coordination

Notices
City Effort and Dates what information needed?
a. City will get back with team on meeting information and dates needed.
District Efforts and Dates what information needed?
a. District does not currently have a PIO so coordination with District will need to take place on what efforts they may or may not be able to provide.

Exhibit Board(s) 24" x 36" (FCD)
a. District has graphic person but timing and sequence of any graphics may be an issue and potential for these exhibits may fall to J2.

Materials (FCD)
Comment Sheets
Sign-in sheets
Directional signage
Name tags for project team members
Misc. supplies

Equipment
Easels (4) - FCD
Projector – J2
Laptop – J2
Scanner - J2

Refreshments for Public Guests (J2 Design)
Bottles of water (iced if possible) and cookies

V. Open Discussion

A. Gregg to discuss with staff if updates to the City Council are necessary will get back to the team
B. Strom drainage capacity to be reviewed to see if there exists a way to optimize the system

VI. Action Items

A. Discuss assignments developed at meeting

City of Tempe Loma Vista Flood Mitigation and Stormwater Re-Use Project
Design Team Coordination Meeting
April 10, 2015
City Project No. 4603216

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City of Tempe Loma Vista Flood Mitigation and Stormwater Re-Use Project

Tempe Union High School District Meeting

Minutes

City of Tempe Contract No. 4603216

J2 Job Number 15-0785

Meeting Minutes

June 8, 2015

To: Project Team & Stakeholders
Copy: See Distribution on Cover Sheet
From: Jeff Engelmann - J2

Color Represents items that have been completed and will be removed from future Minutes and Minutes.

Color Represents items that have been updated from Meeting Notes provided to team.

Color Represents items that have been completed and will be worked into final report

ITEM NO.	TOPIC	ACTION REQUIRED	BY	GOAL	STATUS/COMPLETED
	Sign In				
	See list at end of these notes				
	New Business				
1.01	Burke Lokey of FCDMC Gave overview of Tempe Area Drainage Master Study and new Low Impact Development (LID) applications that can be used to help control local flooding	None Information Only	None Information Only	None Information Only	None Information Only
1.02	The City of Tempe has secured a grant to look at concepts to address the Loma Vista Flood Mitigation and Stormwater Re-Use. The area of study associated with the Grant includes McClintock High School site	None Information Only	None Information Only	None Information Only	None Information Only
1.03	The City of Tempe Grant and Study **does not involve any expenditures by TUHSD** but may require evaluation of potential impacts to McClintock High School Site to adapt or accept potential LID techniques relative to Flood Mitigation and Storm Water Re-Use in the Loma Vista area.	None Information Only	None Information Only	None Information Only	None Information Only
1.04	The Grant includes evaluation of different LID techniques for the entire Loma Vista Study area. The first steps are information gathering on the current drainage issues in the Loma Vista area, development of LID scenarios that fit the different landuse of the area, development of concepts for the LID scenarios and then route the preliminary	None Information Only	None Information Only	None Information Only	None Information Only
1.05	The outcome of the grant will be the evaluation of different LID techniques in the Loma Vista study area. The evaluation will include impacts to localized flooding, options for LID on neighborhood streets, individual lots and McClintock High School Site that may be considered as potential LID options to address the localized drainage issues. It will also provide opportunities for the neighborhood and TUHSD to weigh in on the various LID techniques that are being evaluated as well as look for opportunities to merge the LID techniques with class room study. Included with the Study will be conceptual drawings and estimates for construction costs of any LID techniques.	None Information Only	None Information Only	None Information Only	None Information Only
1.06	The capitol expenditures for any selected LID techniques that are determined through the study as potential for implementation would be offset through a combination of City of Tempe funds and Flood Control District of Maricopa County funds. Long term operations and maintenance of these LID facilities would have to be worked out as part of an IGA between the School District and The City of Tempe.	None Information Only	None Information Only	None Information Only	None Information Only

ITEM NO.	TOPIC	ACTION REQUIRED	BY	GOAL	STATUS/COMPLETED
1.07	TUHSD made it clear that prior to any investigation or discussion about possible LID techniques that may be investigated at McClintock High would require that the TUHSD Executive Committee be informed of the process underway and then to the full TUHSD Board to again inform these two groups as to the status and process that will be undertaken during this preliminary study. There is sensitivity to this issue relative to the bond election slated for this November.	TUHSD Staff to inform Executive Committee and Full Board of project.	**Bob Anderson and Anna Battle to Brief TUHSD Exec. Committee and Board about Study**	**Presentation to Exec. Committee Wednesday June 10, 2015 8:00am**	

ITEM NO.	TOPIC	ACTION REQUIRED	BY	GOAL	STATUS/COMPLETED

Next Meeting : To be Determined (TBD)

Time: TBD

Location: TBD

If you have any comments or disagreements with the meeting notes or comments please contact Jeff Engelmann at jengelmann@j2design.us
J2 Engineering and Environmental Design, LLC 602-438-2221

All meeting notes will be distributed via email or fax.

Please set your goals to complete the action items on time to avoid project delays!

Color represents key point of contact

☒ Icon at Meeting

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ITEM NO.	TOPIC	ACTION REQUIRED	BY	GOAL	STATUS/COMPLETED
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ITEM NO.	TOPIC	ACTION REQUIRED	BY	GOAL	STATUS/COMPLETED
	ATTENDEES NOT LISTED ABOVE	EMAIL ADDRESS		OFFICE/ CELL	FAX

LOMA VISTA FLOOD MITIGATION STUDY

Contract Project No. 4603216

LOW IMPACT DEVELOPMENT (LID) CONCEPT PLAN

Prepared for:
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engineering and
environmental design

April 2016

REGISTERED PROFESSIONAL ENGINEER (CIVIL)
CERTIFICATE NO.
23170
JEFFREY J.
HOLZMEISTER
Date Signed 4/22/16
ARIZONA, U.S.A.
Expires 03/31/18

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1.0 INTRODUCTION

1.1 Purposes and Goals

The City of Tempe was awarded a grant from the "Water Infrastructure Finance Authority" (WIFA) to assist in evaluating existing storm water infrastructure features in the Loma Vista neighborhood of Tempe. The purpose of this report for the Loma Vista flood mitigation study is to conduct a comprehensive review of low impact development (LID) techniques, their applications, and hydrologic and hydraulic modeling methods and to apply various LID controls and scenarios in order to understand and quantify the individual and cumulative impact of LID controls and systems on drainage and flooding in the Loma Vista area. This report is also developed as a guidance document for creating local and regional hydrologic and hydraulic models with the capability to analyze conceptual plans of LID used for drainage and flood mitigation and water conservation.

1.2 Background and Context

In the past few years, there have been multiple storm events causing extensive street drainage problems and flooding of several neighborhoods in the City of Tempe including the Loma Vista area. Although Tempe is nearly built-out, with the advent of the light rail, ASU expansion plans, and the attraction around and associated with Tempe Town Lake, major redevelopment throughout the City is actively taking place. As a response to projected growth and regulatory requirements, the City of Tempe is considering implementation of various Green Infrastructure (GI) and LID techniques as part of a comprehensive approach to storm water mitigation as described in the City's new General Plan 2040. In addition to the planned improvements within the City the Arizona Department of Transportation (ADOT) also has several large drainage infrastructure projects related to improving the existing freeway network throughout this region. The freeway drainage network within Tempe includes several facilities that are undersized and will require major reinvestments in advance of projected freeway expansion projects. In response to these issues, the Flood Control District of Maricopa County (District) recognized a need to assess flooding in the area, and has initiated the Tempe Area Drainage Master Study (ADMS) to identify flood hazards and develop any needed flooding mitigation solutions for effectively addressing those flooding issues in a regional context and protecting the public and property owners while coordinating with community needs and future plans for the area.

The hydrologic and hydraulic modeling of the Tempe ADMS area was completed through the use of FLO-2D/SWMM models and the results were documented in the *Tempe ADMS FLO-2D/SWMM Modeling Report* prepared by J2.

Early in July 2013, the City of Tempe prioritized the Loma Vista Corridor Flood Mitigation Project through the Capital Improvement Program. The submittal pack from the City to the District was included in Appendix A. The Loma Vista project was identified by the District as part of the study of the *Broadway and Rural Drainage Master Plan (2010).* The total estimated cost included in this previously completed plan, to improve storm water drainage in the Loma Vista area was estimated to be approximately $2.67 million.

During the development of Work Assignment No. 3 (WA3) of the Tempe ADMS/P J2 was scoped to conduct a comprehensive literature review of GI and LID techniques, their applications, and hydrologic and hydraulic modeling methods to initiate and encourage the implementation of various GI and LID controls and development of simulation tools in order

to understand and quantify the individual and cumulative impact of both GI and LID controls on drainage and flooding in the arid Southwest. A report titled *Tempe ADMS, LID Application Review and FLO-2D Modeling* was prepared by J2 in January 2016 to document the LID review and FLO-2D modeling results for both the Loma Vista Area and a Focus Area within the Loma Vista Area. The Loma Vista study area and FLO-2D modeling areas are shown in Figure 1.1.

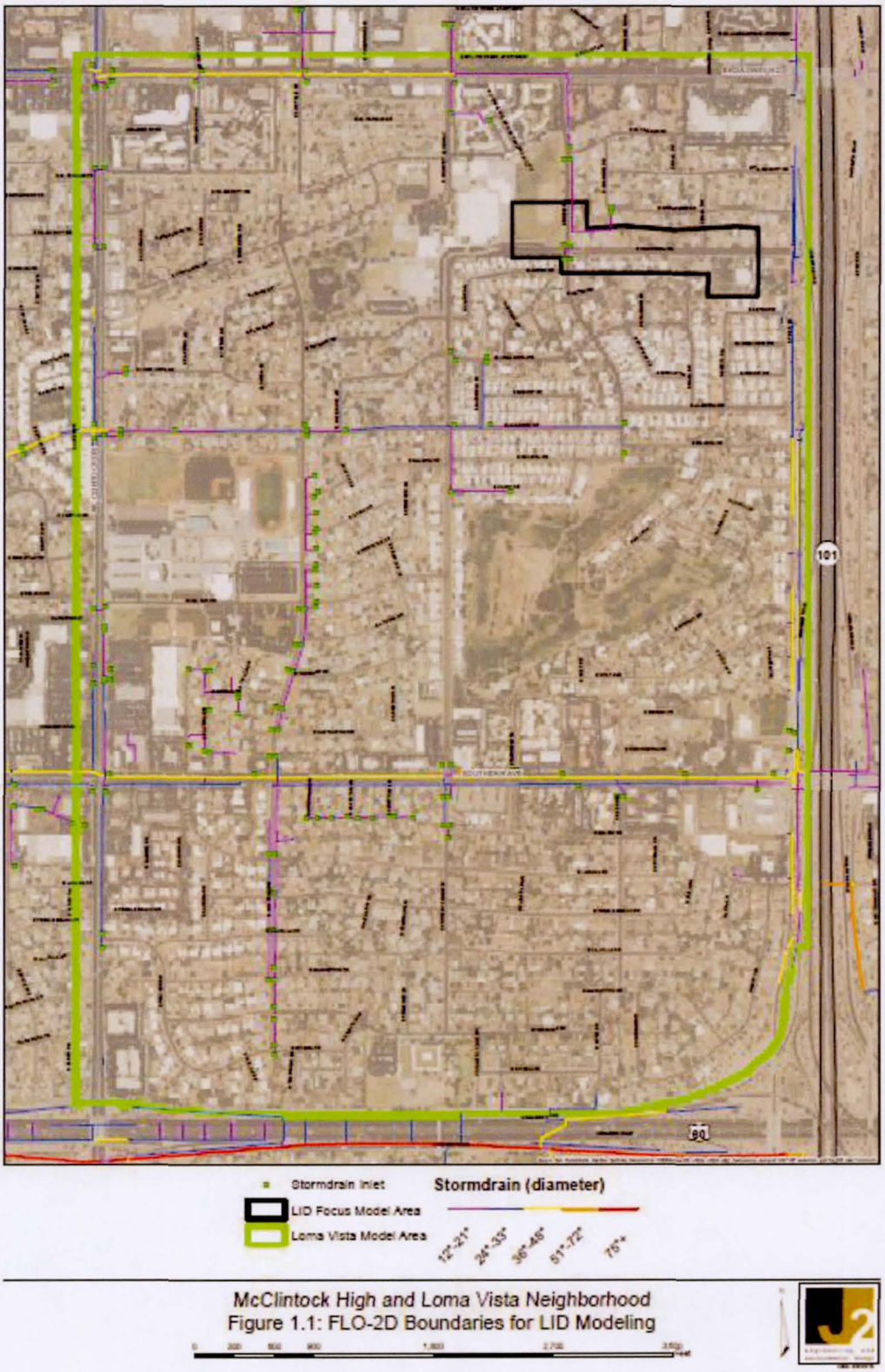


Figure 1.1 Study Boundaries for Models Loma Vista and Focus Area

During the completion of the Tempe ADMS project in 2014, The City of Tempe was awarded a grant by Water Infrastructure Finance Authority of Arizona (WIFA) and J2 was contracted by the City to use this grant to evaluate LID applications and their cumulative effect addressing the Loma Vista area flood mitigation. This report is an extension of the *Tempe ADMS, LID Application Review and FLO-2D Modeling* report prepared by J2 in January 2016. This report is to document a review of GI and LID techniques, their respective FLO-2D modeling results applied to both the Loma Vista Area and a Focus Area within the Loma Vista Study Area, and evaluate their potential impacts to the the flood mitigation of Loma Vista area.

1.3 Authority for Study

J2 has been retained to perform these services as part of the City of Tempe contract project No. 4603216 – Loma Vista Flood Mitigation and Stormwater Re-use. City of Tempe is located at 31 East Fifth Street, Tempe, Arizona 85281, (480) 350-2738. The Project Manager for the City is Mr. Gregg Kent, P.E., Principal Civil Engineer, Public Works Department. J2's Project Manager for this project is Mr. Jeff Engelmann, RLA, ASLA., Principal Landscape Architect. J2's project no. is 15.0785.

2.0 LOW IMPACT DEVELOPMENT (LID) CONCEPT AND PRACTICES

2.1 Overview of LID General Practices

LID is a sustainable approach to stormwater management that utilizes the landscape to absorb storm runoff and reduce offsite flows that can contribute to flooding and infrastructure costs. The basic principle is to model after nature: manage runoff at the source using distributed micro-scale controls. The goal of LID is to mimic and sustain predevelopment hydrologic conditions by using techniques that store, detain, retain, infiltrate, evaporate, and re-use stormwater runoff to support designed landscapes, provide groundwater recharge, and improve water quality. They can be utilized to supplement, and sometimes reduce or modify the approach to traditional stormwater management. While conventional methods often channelize and pipe runoff away from development, LID methods utilize this water close to its source, to support vegetation and reduce overall site runoff volume.

LID is adaptable to a wide range of land use types and project scales. Breaking down developed areas into their constituent components – residential areas, commercial properties, and public realm; buildings, paved areas and landscape areas – presents a way to organize potential controls to implement LID.

Increased stormwater runoff is directly related to the amount of impervious surfaces in a given area and to how land is developed and improved. Improvements in managing stormwater can have multiple benefits for cities, their residents, and businesses. LID actions can be taken by governments, organizations, and private interests. The benefits of LID have been published for many national and local examples, and are supported by the Environmental Protection Agency (EPA) in its Municipal Separate Storm Sewer System (MS4) requirements.

The benefits of LID applications can be summarized as follows:

- Flood control: Detain stormwater close to its sources and reduce runoff volume and peak flows to any downstream stormdrain, retention basin, or stormwater system;
- Maintenance: Collects sediments at the source to reduce drainage facility maintenance costs;
- Environmental: Reduce pollutants in stormwater runoff and improve water quality;
- Water supply: Utilize stormwater to support native and non-native vegetation and landscape improvements and reduce potable irrigation water demand;
- Landscape: Combine with traditional landscape to reduce costs;
- Traffic calming: Modify streets to combine with traffic calming measures.

A literature research and review of potential LID applications has been conducted in order to identify various LID controls for applicability in Tempe and Maricopa County. While LID has been used in limited cases in Tempe, the practice in metropolitan Phoenix and Arizona is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. Other urbanized areas in the United States have been more vigorously implementing LID predominantly due to water quality issues first and volume secondarily. The collected major references are generally classified into five categories: a) Publications for LID general practices; b) Publications of LID applications in Southwest Regions; c) Tempe LID practices; d) LID application Case Studies; and e) Modeling methods of LID practices including hydrologic and hydraulic modeling, and benefit/cost estimations. All of the collected references were documented in the report - *Tempe ADMS, LID Application Review and FLO-*

2D Modeling prepared by J2 in January 2016. Some of the major references are included in Appendix B and are discussed in the following sub-sections.

EPA, in December 2007, published a report titled *Reducing Stormwater Costs through Low Impact Development (LID) - Strategies and Practices*. While this study focuses on the cost reductions and cost savings that are achievable through the use of LID practices, it also shows that communities can experience many amenities and associated economic benefits that go beyond cost savings. These include enhanced property values, improved habitat, aesthetic amenities, and improved quality of life.

In December 2008, EPA released a handbook titled *Managing Wet Weather with Green Infrastructure Municipal Handbook – Green Streets*. The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network provides significant opportunity to decrease infrastructure demands and pollutant transport.

Baker, in June 2011, drafted a Municipal Handbook for EPA as well – *Low Impact Development and Green Infrastructure: Role in Flood Risk Management*. This handbook is trying to demonstrate the functions and benefits of LID applications on flood mitigation.

In January 2015, EPA published *Green Infrastructure Opportunities that Arise during Municipal Operations* which provides approaches local government officials and municipal program managers in small to midsize communities can use to incorporate green infrastructure components into work they are doing in public spaces. This guide demonstrates ways in which projects can be modified relatively easily and at a low cost recognizing that municipal resources can be limited.

In April 2015, EPA published *A Guide for Local Governments – Community Based Public-Private Partnerships (CBP3s) and Alternative Market-Based Tools for Integrated Green Stormwater Infrastructure*. This guide provides communities with an opportunity to review the capacity and potential to develop a CBP3 program to help "close the gap" between current resources and the funding that will be required to meet stormwater regulatory commitments and community stormwater management needs.

Earlier, in October 2000, EPA published a literature review on LID to determine the availability and reliability of data to assess the effectiveness of LID practices for controlling stormwater runoff volume and reducing pollutant loadings to receiving waters. Background information concerning the uses, ownership and associated costs for LID measures was also compiled. The conclusions are still valid.

In general LID measures are more cost effective and lower in maintenance than conventional, structural stormwater controls. Not all sites are suitable for LID though. Considerations such as soil permeability, depth of water table and slope must be considered, in addition to other factors. Further, the use of LID may not completely replace the need for conventional stormwater controls.

Maintenance issues associated with LID can be more complicated than for conventional stormwater controls because many LID measures rely on multiple facets including but not limited to permeability, biometrics, sub-grade media, and available area. This can be further complicated if these measures reside on private property. In most instances, homeowners agree to only the first year of maintenance. Homeowner associations could be a mechanism for providing long-term maintenance to these areas. Generally, bio retention facilities require replacement of dead or diseased vegetation, remulching as needed, and replacement of soils after 5–10 years. Bio swales if installed in a turf situation would require periodic mowing, if a more organic approach is taken the removal of sediments will be required to maintain storm water volume and capacity. Maintenance of permeable/pervious pavements requires annual high-powered vacuuming of the area to remove sediments to maintain the porosity of the pavement.

Several studies have been conducted to analyze the effectiveness of various LID controls based on hydrology and pollutant removal capabilities. **Bio retention areas, bio swales, pervious pavements and green roof were the most common practices studied**. These techniques reduce the amount of Effective Impervious Area (EIA) in a watershed. EIA is the directly connected impervious area to the storm drain system and contributes to increased watershed volumes and runoff rates. There are documented case studies that conclusively link urbanization and increased watershed imperviousness to hydrologic impacts on streams and rivers. Existing reports and case studies provide strong evidence that urbanization negatively affects streams and rivers resulting in water quality problems such as loss of habitat, increased temperatures, sedimentation and loss of fish populations (EPA, 1997).

In general bio retention areas were found to be effective in reducing runoff volume and in treating the first flush (first ½ inch) of stormwater. Results from three different studies indicate that removal efficiencies were quite good for both metals and nutrients. Removal rates for metals were more consistent than for nutrients. Removal rates for metals ranged from 70–97% for lead, 43–97% for copper and 64–98% for zinc. Nutrient removal was more variable and ranged from 0–87% for phosphorus, 37–80% for total nitrogen, 0–92% for ammonium, and 0–26% for nitrate. Effluent volumes were lower than influent volumes. These studies were conducted by means of simulated rainfall events. Analysis of actual long-term rainfall events would produce more reliable data.

The effectiveness of bio swales was also quite good for both pollutant removal and runoff volume reduction. A study of three different sites in the United States reveals similar results despite the differences in location. In general, performance of swales is dependent on not only channel length, but also longitudinal slope and the use of check dams to slow flows and allow for greater infiltration. Further, the removal of metals was found to be directly related to the removal rate of total suspended solids, and the removal rate of metals was greater than removal of nutrients.

Reduction of impervious surfaces can greatly reduce the volume of runoff generated by rainfall. Several methods can be employed to reduce total impervious surface area. Pervious pavements and vegetated rooftops are two methods to accomplish this goal. Vegetated rooftops have been used extensively in Germany for more than 25 years and results show up to 50% reduction in annual runoff in temperate climates. Many opportunities exist to retrofit

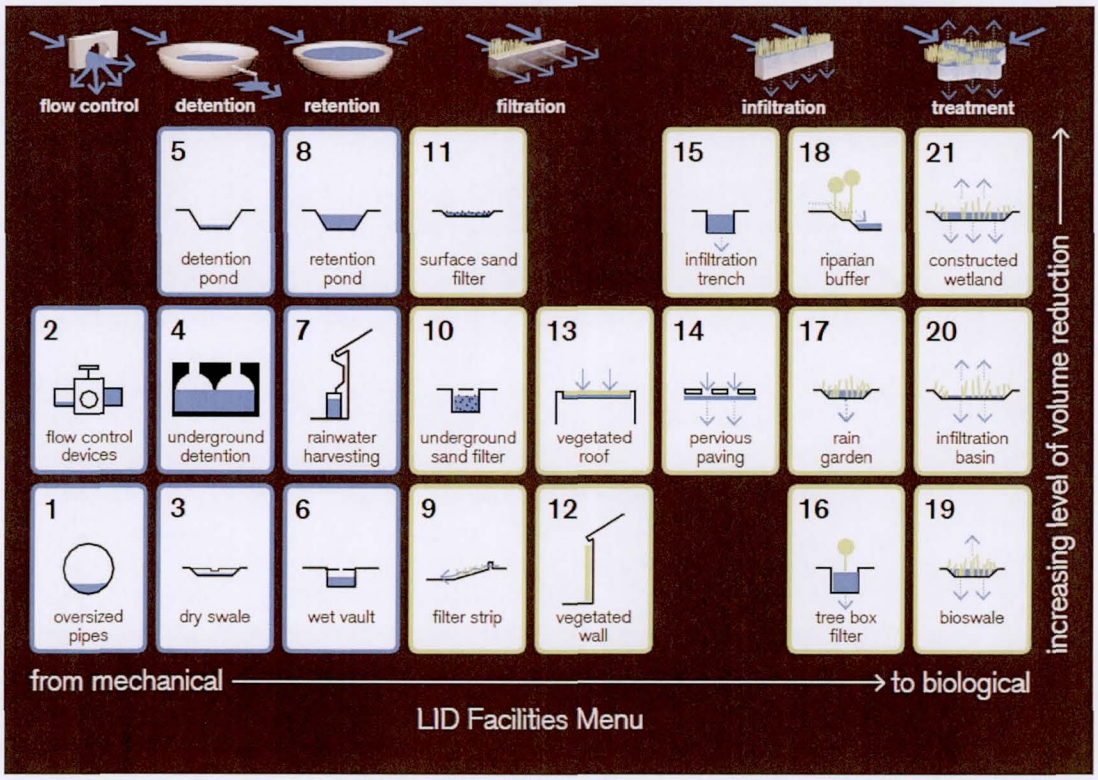
these systems into older highly urbanized areas of the United States. The Philadelphia project case study provides an example of this practice.

Pervious pavements can also reduce impervious surfaces. However, they are more expensive to construct than traditional asphalt pavements. Costs of these systems may be offset by the reduction of traditional curb and gutter systems to convey stormwater. Benefits of these alternate pavement types include better infiltration, ground water recharge, reduction in runoff volume and treatment of stormwater for pollutants. The study conducted in Tampa, Florida outlines these benefits as well as the opportunity to retrofit pervious pavements into existing parking lots with little or no loss of parking spaces. Less than 20% of rainfall was converted to runoff when using pervious pavements. Study results from the University of Washington, compare several different treatments of varying permeability. The study shows that the higher the amount of pervious area of the treatment, the greater the reduction of runoff volume and pollutant loadings.

Most of the available data are from Prince George's County, Maryland, which pioneered the use of LID. The data available for bio retention analysis were from single simulated storm events in actual bio retention facilities or from laboratory constructed and tested bio retention systems. The data for bio swales were for only a few storm events, collected over a short period of time. The only available data for a long-term study came from the Aquarium parking lot in Tampa, Florida and the Washington pervious pavement project. More long-term analysis is required to more accurately assess the effectiveness of LID and to determine long term trends.

In addition to EPA publications, many manuals and studies related to LID have been published, such as *LID Manual for Michigan* released in 2008; University of Arkansas published a LID manual in 2010 titled *Low Impact Development: a design manual for urban areas*; the BMP Database was also developed by Geosyntec Consultants, Inc. in May 2012 to document the analysis of volume reduction in bio retention BMPs. Oregon State has published specific LID site design practices. Green Nylen, Nell, and Michael Kiparsky, 2015 published a paper titled *Accelerating Cost-Effective Green Stormwater Infrastructure: Learning from Local Implementation*, Center for Law, Energy & the Environment, U.C. Berkeley School of Law.

The following LID controls Menu was developed by University of Arkansas and summarizes the general ideas and relationships of traditional flood control structures and LID facilities. This Menu organizes controls based on increasing level of treatment service (storm water quality) as well as increasing level of volume reduction (storm water quantity). Therefore, number one (1), oversized pipes offer the least amount of treatment services while number twenty-one (21), constructed wetland offers the highest level of treatment. Most municipalities require drainage infrastructure to manage the 100-year storm events. Though one facility alone will not likely satisfy performance requirements, facilities with varying levels of service in a LID system will provide superior levels of storm water treatment and flood volume reduction.



2.2 Survey of Regional and Local LID Practices

2.2.1Regional LID Practices

As discussed previously, other urbanized areas in the United States, especially in the southwest areas, have been more vigorously implementing LID practices predominantly due to water quality issues first and volume secondarily.

Several counties, cities, and state government agencies in California have developed manuals and handbooks to guide and encourage the applications of LID techniques including Los Angeles County and City, San Diego County and City, San Mateo County, Riverside County, City of Riverbank, and other municipal agencies.

Another state in the southwest region, Nevada, also has implemented the use of LID practices. For example, a LID Handbook for the Truckee Meadows Regional Stormwater Quality Management Program was developed in August 2007, and a Final Report for Xeriscape Conversion Study was prepared by Southern Nevada Water Authority in 2005.

In metropolitan Phoenix and Arizona, Application of LID techniques is gaining ground as one of the viable controls available to reduce stormwater runoff, provide water quality improvement along with other environmental and quality of life benefits. City of Tucson published Water Harvesting Guidance Manual and Stormwater Quality Ordinance in 2005 as well as Watercourse Maintenance Guidelines in 2007. Specifically, Pima County and City of Tucson developed LID and GI Guidance Manual in 2015.

Watershed Management Group (WMG) develops community-based solutions to ensure the long-term prosperity of people and health of the environment and provides people with the knowledge, skills, and resources for sustainable livelihoods. They have developed many LID newsletters, training sessions, and design standards.

City of Scottsdale has developed a LID Techniques Tool Box and applied some of the techniques in Granite Reef Watershed study as implementation demonstrations.

City of Mesa in 2015 developed a handbook titled LID Toolkit. Some of the photos, descriptions, and data have been used in this report. However, the water budget calculation methods documented in this handbook cannot be used for spatially varied hydrologic and hydraulic modeling for the LID applications. All of the references mentioned in the regional LID section are included in Appendix B1.

2.2.2 LID Case Studies

Many LID application projects have been implemented in recent years. A few case studies are reviewed here. Spokane Urban Greenway Ecosystems for Lincoln Street, Washington State, LID practices including bio-infiltration system were constructed to assist traditional inflow reduction technology, such as detention, vortex separators, and treatment plant upgrades.

Three LID case studies by Massachusetts Department of Conservation and Recreation in the Ipswich River Watershed included LID controls of porous pavements, bio retention, and bio swales.

1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas was conducted by Geosyntec Consultant for a drainage area of 368 acres. SWMM program was applied to model the hydrologic and hydraulic impact of LID controls on flood.

In City of Tempe, LID measures were incorporated into CIPs, such as Maple Ash/Mitchell Park East Traffic Calming Improvements and College Avenue Traffic Calming Projects. Pima County Flood Control District and WMG performed the study for the Airport Wash by solving flooding challenges with green stormwater infrastructure. FLO-2D program was used for the modeling of LID hydrology and hydraulics by adjusting TOL parameters spatially. The case study reports are included in Appendix B1 for detailed information.

2.3 Review of LID Simulation Methods

Modeling methods of LID applications include hydrologic and hydraulic modeling, and benefit estimations. Quantification of defensible results of LID practices on flood reductions has been an issue that had not been adequately addressed by previous studies. . Therefore, one of the objectives for the Tempe ADMS/P project WA3 is to identify how the ADMS/P hydrologic and hydraulic modeling effort could be utilized to help Tempe in the evaluation of LID controls and provide both quantifiable and defensible results.

Early in July 1999, Prince George's County, Maryland developed some methods to simulate the hydrologic impact of LID practices using NRCS curve number program, such as reducing the Runoff Curve Number, increasing Time of Concentration, adding Retention basins, and Detention basins. This program is a lumped program and cannot model spatially varied LID practices in detail.

Lately, Geosyntec Consultants (2015) applied PCSWMM for 1D/2D Modeling of Decentralized Stormwater Control Measures for Flood Mitigation in Austin, Texas. EPA SWMM can explicitly model five different generic types of LID controls as well. However, it is difficult to apply this program to a parcel level detailed-modeling. The general methodologies for these two programs are summarized in Appendix B2.

In 2009, Guo published a research paper titled *Preservation of Watershed Regime for Low Impact Development* and presented a simplified method by which a LID design can be quantitatively evaluated for a full spectrum control of runoff population. USGS (2010) also published a report (Circular 1361) titled *Effects of Low-Impact-Development (LID) Practices on Streamflow, Runoff Quantity, and Runoff Quality in the Ipswich River Basin, Massachusetts: A Summary of Field and Modeling Studies* and documented the method of modeling the impact of LID practices on flood in watershed scale.

In the City of San Diego *Low Impact Development Design Manual,* several methods were recommended for the hydrologic and hydraulic modeling of LID practices including HSPF (Hydrological Simulation Program in Fortran) model Functional Tables.

Central Vermont Regional Planning Commission developed a model which utilized impervious surface data, GIS build-out analysis data and average rainfall amounts to demonstrate the increases in stormwater run-off if development continued to occur without LID strategies in place. An alternate model was created to illustrate the amount of stormwater runoff if development incorporated LID techniques.

EPA, in 2014, developed a National Stormwater Calculator tool which is a simple to use tool for computing small site hydrology for any location within the US. It estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of LID practices can be employed to help capture and retain rainfall on-site. Future climate change scenarios taken from internationally recognized climate change projections can also be considered. These reports and manuals are included in Appendix B2.

3.0 BASIC LID CONTROLS AND ACCESSORIES

3.1 LID Controls, Accessories, and Systems

Many LID controls (also known as tools, practices, techniques, methods, or similar names, **control** is used in this report) have been developed and applied with similar hydrologic and hydraulic functions, but different shapes, materials, locations, and sometimes, with and or without add-ons (accessories). Some of the LID controls are actual combinations (systems) of several basic controls with accessories to improve their functions and capabilities. Five basic LID controls have been identified in this study from the literature review conducted. Table 3.1 listed the five basic LID controls and the similar controls with common and traditional names.

Table 3.1 LID Basic Controls and Their Similar Names

Five LID Basic Controls				
Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
Similar names	**Similar names**	**Similar names**	**Similar names**	**Similar names**
Bioretention cell	Downspout disconnection	Pervious concrete	Active rainwater harvesting	Vegetated roof
Chicane	Grass swale	Pervious paving	Above ground cistern	Rooftop garden
Flow-through planter box	Linear vegetated swale	Porous asphalt	Below ground cistern	
In-ground planter box	Meandering vegetated swale	Soft paving	Rain cistern	
On-site bioretention basin	Vegetated channel	Stabilized aggregate	Rain tank	
Planter box		Structural grid system	Rain barrel	
Rain garden		Permeable paver system		
Raised planter box				
Regional bioretention basin				
Retention basin				

The LID controls can be classified based on their application locations, such as rain barrel, rain garden, rain tank, rain cistern, and bio retention for residential parcels and commercial properties; Chicane, planter box, bio retention, bio swales, and vegetated channel for street landscaping areas; Bio retention, bio swales, grass swale, and vegetated channel for public facilities; Pervious concrete, porous asphalt, soft paving, and pervious pavement for streets and parking areas; Rooftop garden, vegetated roof, and active rainwater harvesting for buildings.

The LID controls can also be classified based on their construction materials and shapes, such as grass, soil, mulch, asphalt, aggregate, sand, basin, swale, box, chicane, barrel, and tank.

The most useful classification of LID controls is based on their hydrologic and hydraulic functions: retention, detention, infiltration/recharge, storage/reuse, and conveyance (evapotranspiration is ignored for single storm event). Increasing infiltration rate is one of the major means by which LID controls are constructed to accomplish their functions. The purpose of classification for LID controls is to identify the basic LID controls for hydrologic and hydraulic modeling purposes. Table 3.2 listed the five basic LID controls and their hydrologic functions.

Table 3.2 LID Basic Controls and Hydrologic Functions					
Basic LID Control Name	Hydrologic Functions				
	Retention	Detention	Infiltration/ Recharge	Storage & Reuse	Conveyance
Bio Retention	X	X	X		X
Bio Swale		X	X		X
Pervious Pavement	X	X	X		X
Rainwater Harvesting	X			X	
Green Roof	X	X		X	

LID accessories are structures that are added or connected to basic LID controls to improve their hydrologic and hydraulic functions and capabilities. LID systems are combinations of one or more basic LID controls and accessories to improve and expand their hydrologic and hydraulic functions and capabilities, such as runoff collection, retention, detention, store, re-use, and conveyance. Table 3.3 shows the summary table for four (4) typical LID systems, possible combinations of basic controls and accessories.

Table 3.3 LID Systems, Basic Controls, and Accessories				
Typical LID Systems	On-Lot Treatment System	Green Parking System	Green Street System	Active Rainwater Harvesting
Basic Controls	Bio Retention, Bio Swale, Pervious Pavement, Green Roof	Bio Retention, Bio Swale, Pervious Pavement	Bio Retention, Bio Swale, Pervious Pavement	Rainwater Harvesting, Green Roof
Accessories	Downspout, Roof drain, Curb cut, underdrain	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain, Wheelstop curb	Concrete flush curb, Curb cut with sediment capture, Curb cut with sidewing, Grated curb cut, Standard curb cut, Underdrain	Downspout, Roof drain

3.2 General Concepts of Basic LID Controls

The general concepts of the five (5) basic LID controls including descriptions, photos, benefits, costs, limitations, and maintenance are documented in Appendix C1. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. Appendix C1 includes a detailed design guidance manual developed by Rhode Island for LID roadway and parking lot design, and design specifications for the basic LID controls developed by Virginia.

3.3 General Concepts of Basic LID Accessories

The general concepts of selected LID accessories including descriptions, pictures, installation and maintenance are illustrated in Appendix C2. Most of the pictures and descriptions were from the report titled *Low Impact Development Toolkit* prepared for the City of Mesa. More

LID accessories can be found in Appendix C2 which includes a detailed LID design manual for urban areas developed by University of Arkansas.

4.0 LID APPLICATIONS IN CITY OF TEMPE

4.1 LID Applicability in City of Tempe

Since the start of the Tempe ADMS project, the J2 team has developed a white paper and memos related to LID applications and modeling in Tempe under the directions of the District project manager. The white paper was prepared by Black & Veatch in March 2014 and the paper title is *Evaluation of Sustainable Stormwater Management Practices*. The first memo (Appendix D) was developed in August 2014 to document the potential LID applications, City of Tempe requirements, and the proposed FLO-2D modeling procedures for selected LID practices. Nine (9) possible LID practices were identified in that memo.

Table 4.1 summarizes the five selected basic LID controls (tools) for potential applications in Tempe for various land uses. Where "High" means highly applicable and "N/A" means not applicable for this LID control to the land use type.

Table 4.1 LID Applicability in City of Tempe

LID Basic Controls\ Land Uses	Single Family Residential	Multi-Family Residential	Commercial	Industrial	School	Community Center/Park	Street
Bio Retention	High	High	High	High	High	High	Medium
Bio Swale	Medium	High	High	High	High	High	High
Pervious Pavement	Medium	High	High	High	High	High	High
Rainwater Harvesting	High	High	High	High	High	High	Medium
Green Roof	Low	Low	Medium	Medium	Low	Medium	N/A

4.2 LID Evaluation by City of Tempe

The City of Tempe developed a document titled *Low Impact Development Evaluation* in June 2013. This document started LID evaluation with a review of existing stormwater practices related to planning, construction, and redevelopment including review of Tempe Municipal Ordinance and practice examples. Then, LID practices, their applicability, and regulatory hurdles were discussed. Three mechanisms were identified to promote and encourage LID applications including leading/organizational ownership, stormwater quantity/quality alignment, and public outreach.

The City of Tempe has identified various types of LID practices that should be further encouraged and a series of LID practices that cannot be embraced by the City:

A. LID Practices Tempe Will Encourage/Support

- Alternative retention systems
- Depressed landscaping
- Use of drought tolerant plants (in tandem with street or harvesting projects)
- Stormwater pretreatment systems
- Pervious parking
- Pervious concrete
- Pervious surface treatments
- Xeriscape conversion

- Water harvesting (consistent with retention and vector control)
- Various uses for permeable/pervious pavers
- Impervious area reduction
- Incentive program
  - Public recognition (under evaluation)
  - "C" value reduction, a coefficient for relating the runoff to rainfall in the Rational Method for estimating stormwater runoff
  - Reduction in number of drywells as a result of "C" value modifications
- LID recommendations for redevelopment projects that don't meet the on-site retention triggers (i.e. 25% area of impact and/or value trigger)
- Continued use of LID practices in CIP projects
- LID streetscape projects

B. LID Practices Tempe Will Not Endorse

- Practices contrary to conservation efforts
- Practices that could negatively impact operation of the City-owned and operated stormwater system
- Practices that increase on-site retention requirements
- Practices that could impact neighboring property
- Practices that require future increased maintenance and/or monitoring by the City (non-CIP)

As a result of this evaluation, Tempe has made a commitment to continue to promote LID by example by incorporating acceptable practices in CIP projects and subscribing to the LID objectives outlined in the Tempe General Plan 2040. Additionally, Tempe hopes to incorporate LID concepts to address future flooding mitigation efforts.

4.3 Potential LID Implementation Strategies

As mentioned previously, Black & Veatch, a sub-consultant to J2 for the Tempe ADMS/P project, prepared a white paper titled *Evaluation of Sustainable Stormwater Management Practices* in order to evaluate the City's existing Storm Water Management Plan (SWMP) and associated ordinances with respect to their MS4 permit requirements. The evaluation included a review of the various programs within the City's existing SWMP, including its Stormwater Retention Ordinance.

Tempe has, for the most part, been completely "built-out" with no new open development parcels remaining in the City. With this in mind the ***Potential LID Implementation Strategies*** will need to be focused on infill redevelopment and the retrofit of existing lands, buildings, developments and roadways. To this end potential implementation strategies for Tempe will look at projects and policies that can be implemented through codes for redevelopments, defined Capital Improvement Projects (CIP) for buildings, sites and roadways owned and operated by the City, partnerships with schools and private businesses and incentive programs for private homes and businesses.

The four general strategies by which projects may be implemented are:

1. Code requirement for new development, renovations and infill projects;

2. Capital Improvement Projects (CIP);
3. Public/Private Partnerships;
4. Incentive Programs.

Code requirement for new development, renovations and infill projects
When new development, renovation or infill development occurs, the opportunity to implement LID practices is available if City codes are in place to require the development to enact strategies to reduce and slow stormwater runoff from the project site. While there are different ways to "codify" the stormwater reduction requirements, one which exists is the stormwater retention requirements (retain on site a 100 year 2 hour storm). The City also has Alternative Retention Criteria Areas (ARCA) which are required to retain on site a 2 year 2 hour storm. This code has been very helpful in reducing flooding in the newer development areas of the City. The "pre retention" code areas would be the best opportunity to implement LID as a part of the retention requirement to reduce runoff volume.

Quantification of LID volumes and acceptance by agencies has been a hurdle to overcome in the past. By actively defining the process and quantifications that make it equal to or less burdensome to navigate a project through the development permitting process would enhance the implementation of LID measures. A tool that would support implementation of LID would be a LID stormwater manual for the City of Tempe. The manual could show example scenarios that may be used on new, renovation and infill projects. The manual would also need the "hard data" quantification formulas for each scenario so that they could be verified and defended. In addition to the hard data, there would be examples of how some LID stormwater methods may also overlap with City planning codes for landscape, open space parking and aesthetics. Preliminary evaluation results show that the basic LID controls have code implementation opportunity during new development, renovation, and infill development.

Capital Improvement Projects (CIP)
Throughout the City, CIP projects are continuous occurring providing maintenance rehabilitation and new works. There exists an opportunity to incorporate LID into several of these existing projects, such as streets, parks and buildings, along with future projects. In addition defining and creating new CIP specific LID projects would dictate that LID be incorporated into the design and construction process.

Public/Private Partnerships
Examples of public/private partnerships may include private businesses, schools, churches, the university, utility companies and the railroad. These all have lands that are either disused "forgotten lands" that are serving no particular purpose and can be an ongoing maintenance issue for the owner. In addition many of these property owners have open lands that are "non time critical lands" such as open landscape areas, park/school/church open space, golf course areas that are out of play, and practice fields. All of these lands are prime opportunities to create basins, "rain gardens" and "bio swales" that can help address storm water issues while increasing the viability and aesthetic of the areas.

Incentive Programs
Incentive programs for local runoff reduction may be a good opportunity to not only reduce runoff but engage the public to actively participate in a LID program. The benefits could result in increased public support, reduced runoff, reduced potable water consumption for

landscapes, increased bio mass, shade, heat island reduction, reduction of materials going to landfills, aesthetic enhancements, and neighborhood stabilization/enhancement.

The City currently has an incentive program for single-family residents to convert grass lawns to xeriscape on a square footage basis. This program would be a prime opportunity to combine with an LID incentive program.

5.0 FLO-2D MODELING PROCEDURES FOR INDIVIDUAL LID CONTROLS

5.1 Introduction to FLO-2D Modeling of LID Practices

Recently, FLO-2D has been modified to model LID practices. Riada has revised the program to have spatially varied TOL values to model LID controls and released a handout – *FLO-2D Low Impact Development (LID) Modeling* which is included in Appendix E1. Spatially variable TOL values would be assigned on a grid element basis to represent the composite LID techniques on a given grid element. Depending on the size of the LID feature, multiple grid elements may represent an individual lot or a LID control. Different grid elements may represent different LID techniques. The potential volume of on-site retention storage can be assessed by multiplying the LID control surface area by the retained flow depth (TOL value). This would provide flood hazard mitigation on a lot by lot basis.

This approach has been utilized by Pima Flood Control in Airport Wash Area (Tucson, AZ). The report and emails related to this project are included in Appendix E1. The FLO-2D model developers of this project, Janice Hughes and Evan Canfield have provided insight on their modeling efforts in Pima County. In hindsight, they would have utilized different methodologies (IA adjustment, etc.) to model the impact of LID, but Pima County does not utilize the Green Ampt methodology in their hydrologic analysis. Therefore, they chose to utilize the TOL adjustment for their model. Since the surface detention parameter (TOL) is artificially ponded water and is the minimum value of the flow depth for flood routing (mathematic computations), maintaining the lower TOL value will theoretically produce more accurate results.

FLO-2D, integrated with EPA SWMM Version 5.0 model, routes surface runoff over unconfined flow surfaces/channels using the dynamic wave approximation to the momentum equation while maintaining volume conservation. Finite difference algorithms are utilized to solve the partial differential equations. EPA SWMM is integrated with FLO-2D to simulate storm drain systems. More detailed information about the capabilities and applications of FLO-2D can be found in the references. The FLO-2D software, Pro Version, Model-Build No. 15.02.10, release date of March 19, 2015, was applied for the modeling of the LID practices.

Review of Available Model Parameters

The FLO-2D program has a variety of parameters and processes that can be applied to model and quantify the storm water volume and peak flow. The following is a preliminary list of the capabilities and parameters of FLO-2D/SWMM that may be utilized for LID modeling.

A – Grid elevation adjustment: Lowering the grid elevations (on-lot – within the LID area or off-site – near the LID area) can increase the retention/detention storage to mimic the volume reduction of a specific LID control;

B – Initial loss abstraction IA adjustment: Increasing the values of IA for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

C – TOL value adjustment: Increasing the values of TOL for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

D – Infiltration rate adjustment: Increasing the values of infiltration rate for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

E – Limiting soil depth adjustment: Increasing the values of limiting soil depth for the grids within the LID area can be used to model the rainfall depth/volume reduction of a specific LID control;

F – Spatially variable rainfall data: Reducing the values of rainfall depth for the grids within the LID area can be used to mimic the rainfall depth/volume reduction of a specific LID control;

G – Diversion by a structure: An artificial diversion by a structure can be used to model some LID controls (for example, rainwater harvesting) that can transfer concentrated flows;

H – Boundary outflow grid: Additions of boundary outflow grids can be used to account for the losses of runoff volume from a specific LID control area;

I – Use of artificial WRF: Additions of WRF (Width Reduction Factor) around the grids within the LID area to block the flow movement can be used to store the rainfall depth/runoff volume of a specific LID control;

J – Use of artificial levee: Additions of levees around the grids near the LID area to control the flow directions and locations can be used to model the runoff into LID area of a specific LID control;

K – Use of artificial storm drain: Artificial storm drain can be added to LID area to divert runoff into specific locations to model runoff volume reduction of a specific LID control;

L – Others/project specific methods, such as use of IRAINBUILDING variable to turn on/off the runoff contribution from roofs to model green roof and rainwater harvesting LID controls.

Pairing of LID Controls and Model Parameters

The identified five basic LID controls include: 1) Bio Retention, 2) Bio Swale, 3) Pervious Pavement, 4) Rainwater Harvesting, and 5) Green Roof. The applicability of the FLO-2D modeling parameter/methods to the basic LID controls is summarized in Table 5.1. Note that this table shows the possible parameters that could be used for LID control modeling. The evaluation is preliminary and the conclusion could be different for a specific project and application.

Table 5.1 FLO-2D Modeling Parameters for LID Basic Controls							
	Method No.	Parameter Name	LID Basic Control				
			Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
			1	2	3	4	5
Potential Modeling Parameters	A	Grid elevation adjustment	X	X	X	X	
	B	Initial loss IA adjustment	X	X	X	X	X
	C	TOL value adjustment	X	X	X	X	X
	D	Infiltration rate adjustment	X	X	X	X	
	E	Limiting soil depth	X	X	X	X	
	F	Spatially variable rainfall	X	X	X	X	X
	G	Diversion by structure	X	X	X	X	X
	H	Boundary outflow grid	X	X	X	X	X
	I	Use of artificial WRF	X	X	X		X
	J	Use of artificial levee	X	X	X		
	K	Use of artificial storm drain	X	X	X	X	X
	L	Others/IRAIN-BUILDING				X	X

Parameter Adjustment Process for Simulation of LID Scenarios

The goal of the LID control evaluation is to develop a process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual LID basic controls can be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land use participations. Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios will be discussed in Section 7. The main steps are summarized as follows:

Step 1: Determining LID design capacities for land uses (zoning);
Step 2: Estimating participation rate;
Step 3: Developing FLO-2D input data files based on the design capacities, individual basic LID control modeling results, and selected modeling parameters;
Step 4: Running the regional FLO-2D models and documenting the modeling results.

Model and Simulation Testing Protocols

The key to implementing LID controls into the FLO-2D model is the ability to quantify the impact of LID controls on an individual lot (parcel) basis. Typically, LID controls are independently implemented in relatively small areas – City R/W (parks, green streets, etc.), government R/W (schools, etc.), and private parcels (commercial, industrial, residential). The City of Tempe has provided the design team with GIS files defining the individual parcels within the Loma Vista area.

A small area FLO-2D model (Focus Area) was developed to evaluate the impact of LID controls on the rainfall/runoff response of a drainage area. The Focus Area model has small grid (4 ft x 4 ft grid element size) and two blocks of neighborhood (approximately 20 acres). The Focus Area model is used to model individual LID control parameters to quantify the impact of the LID control on flood mitigation within a specific parcel area,

and populating the methodologies to the Loma Vista Area model for regional LID practices.

A key operational function of the FLO-2D/SWMM model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. Ultimately, the LID controls will impact the rainfall/runoff response of the watershed by reducing the volume of runoff from an individual parcel. The reductions in volume and peak flows were quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections.

5.2 LID FLO-2D Modeling Methods for the Focus Area

The primary objective of the Focus Area modeling is to develop detailed hydrologic and hydraulic modeling procedures for basic LID controls in order to determine the appropriate FLO-2D modeling processes for regional modeling. The FLO-2D model for the Focus Area covers two blocks of neighborhood with an area of about 21 acres which forms a relatively closed drainage watershed (minimal off-site inflows). The Focus Area model has 4 ft x 4ft grid size and 56,693 total number of grid. The optimal grid size should be estimated based on the topographic mapping accuracy (grid size ~ mapping accuracy/surface slope), size of the modeling area, types of LID controls and accessories, and modeling objectives.

Appendix E2 includes the base model input and output data files, and Exhibit A shows the Focus Area boundaries and modeling results for the base model. The proposed modeling methods for five basic LID controls are summarized in Table 5.2.

Table 5.2 FLO-2D Modeling Methods for LID Basic Controls

LID Basic Control	Possible Modeling Methods			
	Grid elevation adjustment	Initial loss IA adjustment	Infiltration rate/Soil depth adjustment	Use of artificial storm drain
Bio Retention	X	X	X	X
Bio Swale	X	X	X	X
Pervious Pavement	X	X	X	X
Rainwater Harvesting		X	X	X
Green Roof		X		X

In addition to grid elevation adjustments for areas with significant retention and detention volume, infiltration rate and limiting soil depth adjustments were used for increased infiltration capacities of LID controls on the computation of runoff reduction. Initial loss IA adjustment was used for the modeling of LID controls of Rainwater Harvesting and Green Roof. Artificial storm drain system was used for modeling bio swale and pervious pavement with underdrain systems.

The advantages of FLO-2D models with smaller grid cells (in this study, 4 ft x4 ft grids, high accuracy of topographic mapping required) are:

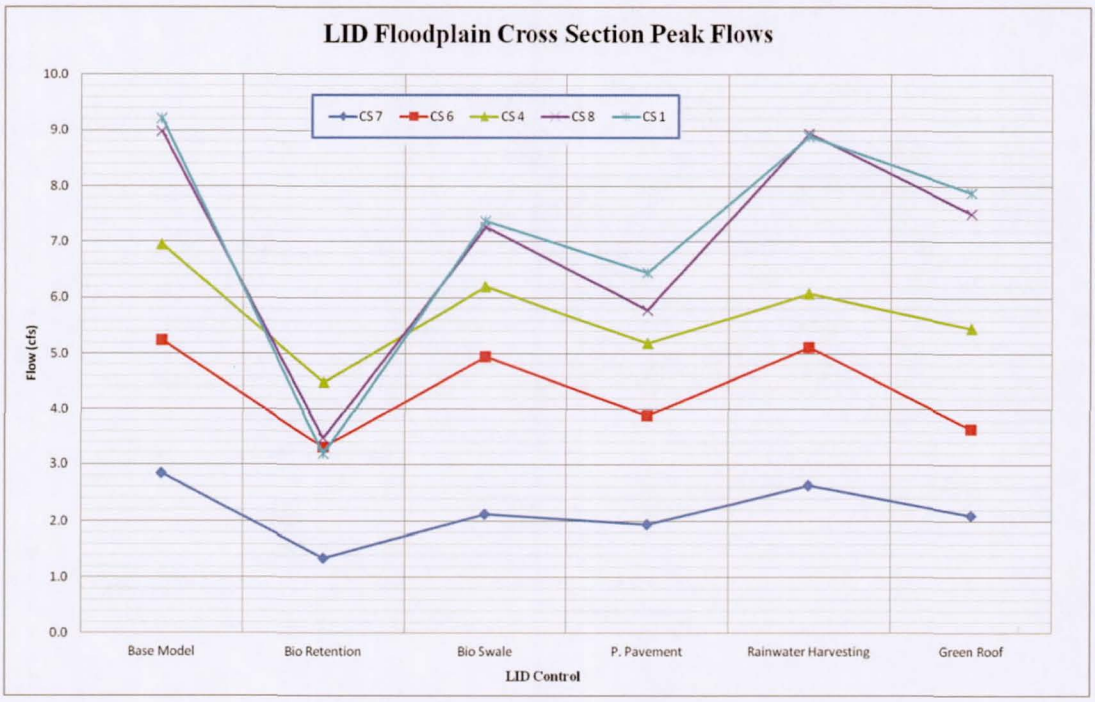
1) For small LID areas, the hydrologic processes, such as topographic differences (grid elevation adjustments), infiltration rate and limiting soil depth changes, surface runoff movement within bio swales, etc. can be modeled;
2) With the small grid FLO-2D model, higher resolution hydraulic modeling parameters can be obtained, such as flow depths and velocities within streets and bio swales;
3) Runoff collection and diversion processes by LID accessories with small dimensions (typically, 18 in to 48 in long), such as curb cut, flush curb, curb cut with sidewing, wheelstop curb, etc. can be represented and modeled adequately.

As one of the major tasks of WA3 of the Tempe ADMS/P, a report titled *Tempe ADMS, LID Application Review and FLO-2D Modeling* was prepared by J2 in January 2016 which has documented the LID review and FLO-2D modeling results for the Focus Area within the Loma Vista Area. The five (5) selected basic LID controls, identified accessories, and the proposed FLO-2D modeling procedures for selected LID controls and participation ratios were documented. A new FLO-2D model with 4 ft x 4ft grids was developed for a Focus Area in order to simulate the infiltration processes and LID accessories. FLO-2D modeling techniques for each of the five selected LID controls were developed and tested. Appendix E3 and Exhibit B documented the FLO-2D modeling results for the five (5) basic LID controls.

5.3 Summary of Modeling Results for the Five Basic LID Controls

The FLO-2D modeling results for the base model and the five basic LID controls are summarized in Table 5.3. Table 5.3 shows that Rainwater Harvesting and Green Roof have highest utilization rates as expected; Pervious Pavement and Bio Retention have high utilization rates as well; and Bio Swale has lowest utilization in terms of storm volume reduction. These utilization effectiveness factors will be applied for the determination of the LID design capacities in the regional FLO-2D modeling of the LID application scenarios. Bio Retention has the highest peak flow reductions in all cross sections as shown in the following chart. The modeling results further strengthened the conclusion that Initial Loss IA Adjustment is the most appropriate method among the potential modeling techniques.

Table 5.3 Summary Table for LID Basic Control Modeling Results								
		Model	LID 2.1	LID 6.5	LID 13	LID 7.3	LID 9.3	LID 9.6
			Base	Bio Retention	Bio Swale	Pervious Pavement	Rainwater Harvesting	Green Roof
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	4.70	8.45	7.52	8.62	7.85
	Wet weather inflow	V (acft)	1.19	0.64	1.11	1.02	1.15	0.93
	Return flow	V (acft)	0.04	0.00	0.03	0.02	0.04	0.02
SUMMARY OUT	Rainfall volume (2.52" depth)	V (acft)	4.37	4.37	4.37	4.37	4.37	4.37
	Infiltration & interception	V (acft)	0.93	1.32	0.99	1.67	1.05	1.54
		%	*21*	*30*	*23*	*38*	*24*	*35*
	Floodplain storage	V (acft)	1.47	1.83	1.5	1.09	1.44	1.27
		%	*34*	*42*	*34*	*25*	*33*	*29*
	TOL storage	V (acft)	0.07	0.07	0.07	0.07	0.07	0.07
		%	*2*	*2*	*2*	*2*	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.58	0.79	0.59	0.73	0.64
		%	*17*	*13*	*18*	*14*	*17*	*15*
	Stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.64	1.1	1.02	1.17	0.92
		%	*28*	*15*	*25*	*23*	*27*	*21*
	Return flow (SWMM to FLO-2D)	V (acft)	0.03	0.00	0.02	0.00	0.02	0.01
Vol Comparison	Sum of volumes	V (acft)	4.36	4.37	4.36	4.37	4.37	4.36
	LID volume captured	V (acft)	-	0.75	0.09	0.74	0.12	0.61
	LID design volume capacity	V (acft)	-	0.89	0.31	0.85	0.12	0.63
	Utilization of LID volume	%	-	84	29	87	98	96

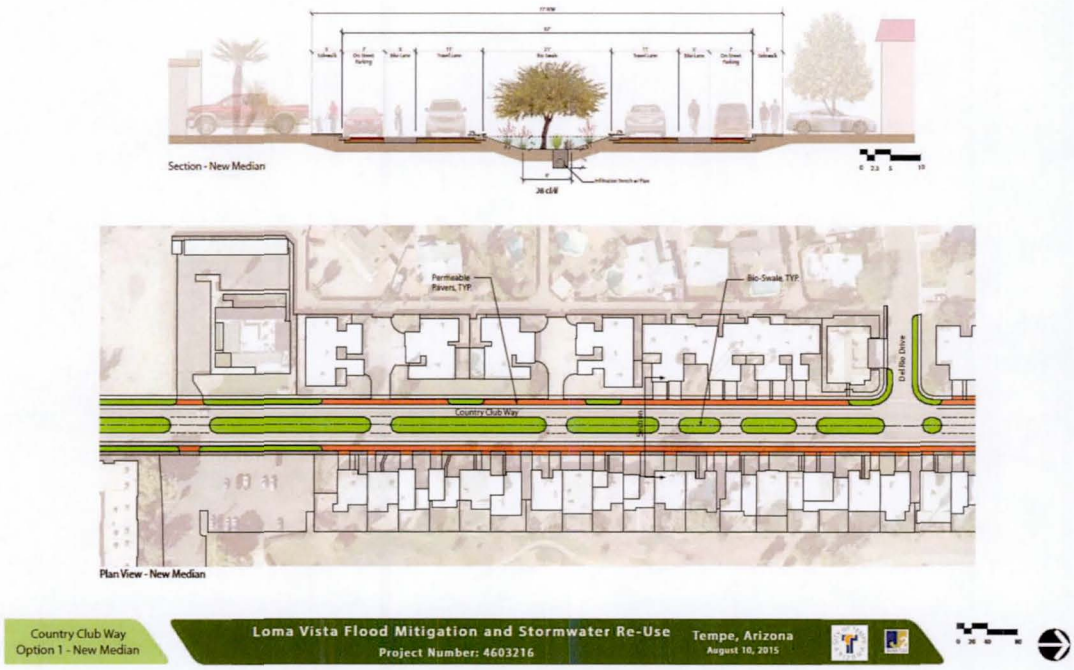

LID Floodplain Cross Section Peak Flows
CS 7
CS 6
CS 4
CS 8
CS 1
Flow (cfs)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Base Model
Bio Retention
Bio Swale
P. Pavement
Rainwater Harvesting
Green Roof
LID Control

6.0 SIMULATION OF LID SYSTEMS IN THE FOCUS AREA

6.1 Selection of LID Control Systems

A LID control system is defined as a combination of at least one LID control with LID accessories and certain parcel participation rate (percentage of properties joining LID practices).

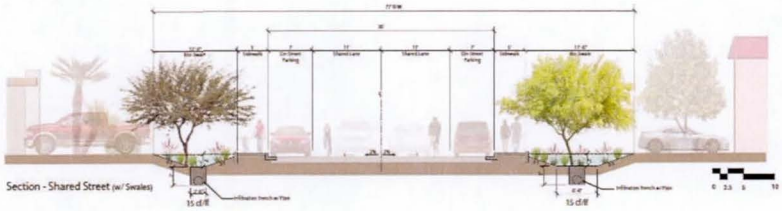
Many LID application options were evaluated for the Focus Area as well as within Loma Vista Area. Several excerpts from Exhibit C0 are shown in the following plans and pictures. These applications include LID practices along Concorda Drive within the Focus Area and Country Club Way within Loma Vista Area. The effectiveness of the LID system is dependent on the types of controls as well as parcel participation rate.



Excerpt from Exhibit C0

Excerpt from Exhibit C0

Excerpt from Exhibit C0



Plan View - Shared Street (w/ Swales)

Excerpt from Exhibit C0

Bio Retention along Concorda Drive

Bio Swale along Concorda Drive

Pervious Pavement along Concorda Drive

Rainwater Harvesting example along Concorda Drive

Green Roof example along Concorda Drive

LID Combination example along Concorda Drive

J2 evaluated many LID combinations for the project. They selected three (3) LID control combinations to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation. These three LID systems are common and acceptable practices for Tempe and they are: On-Lot Treatment System, Green Park System, and Green Street System. The following sub-sections document the modeling procedures and results for these three systems. The FLO-2D model for the Focus Area was used for the modeling of these three systems.

6.2 On-Lot Treatment System

On-Lot Treatment System consists of a series of bio retention, bio swale, and rainwater harvesting (rain tanks) with various accessories. The land uses for this system are primarily residential. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

On-Lot Treatment System Concept along Concorda Drive

On Lot Treatment System FLO-2D Modeling Procedures:
In addition to grid elevation adjustments within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for On Lot Treatment LID System:
   - Building roofs for rainwater harvesting – same as rainwater harvesting control selection
   - Bio retention – same as bio retention control grids for storage areas and curb cuts as hydraulic structures
   - Bio swale – single row of grids nearest the street to connect the bio retention grid groups

2) FLO-2D Input Parameter Modifications:
   - Roof grids – INFIL.DAT – IA given value to reflect 100yr-2hr storm (2.16 in capacity for all roof grids
   - Bio retention – FPLAIN.DAT, INFIL.DAT, HYSTRUC.DAT – same as bio retention control grids
   - Bio swale – FPLAIN.DAT, INFIL.DAT – Elevations at endpoints of the rows were set at 0.5 ft above the bio retention elevation and grid elevations are interpolated between these. Since the regional drainage flows from east to west and from south to north in this area, checks were made to prevent negative slope profiles in those directions

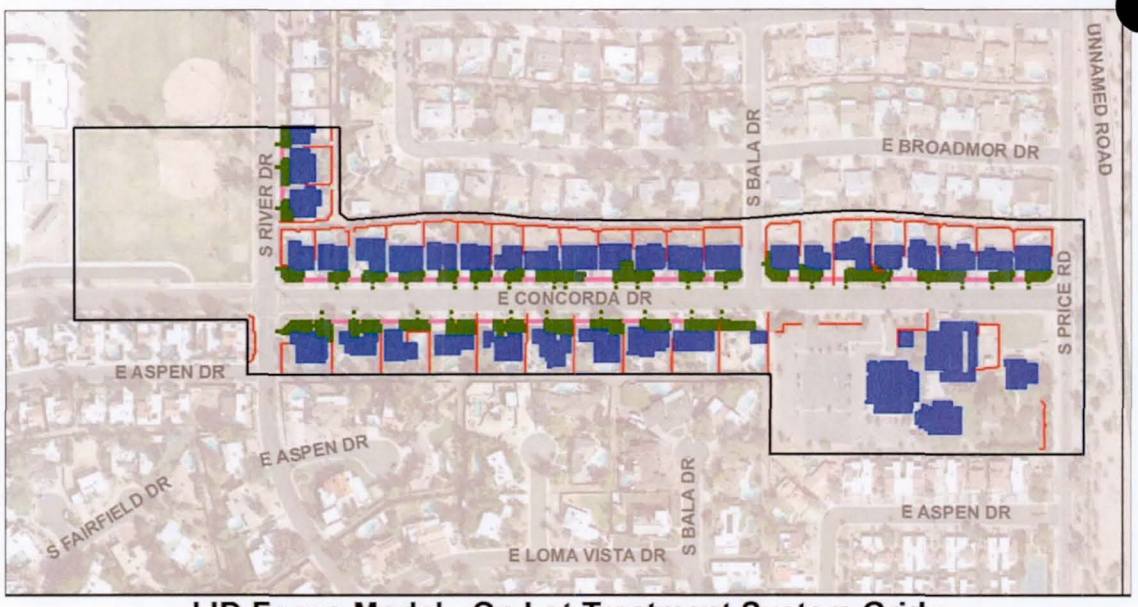
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

The exhibit showing the on lot treatment system LID areas and FLO-2D grids is included in Exhibit C1. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix F1. The FLO-2D modeling results summary data is documented in Table 6.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 6.1.



LID Focus Model - On Lot Treatment System Grids

Bio Retention
Rainwater Harvesting
Bio Swale
Model Boundary
Walls

N

1 inch = 400 feet

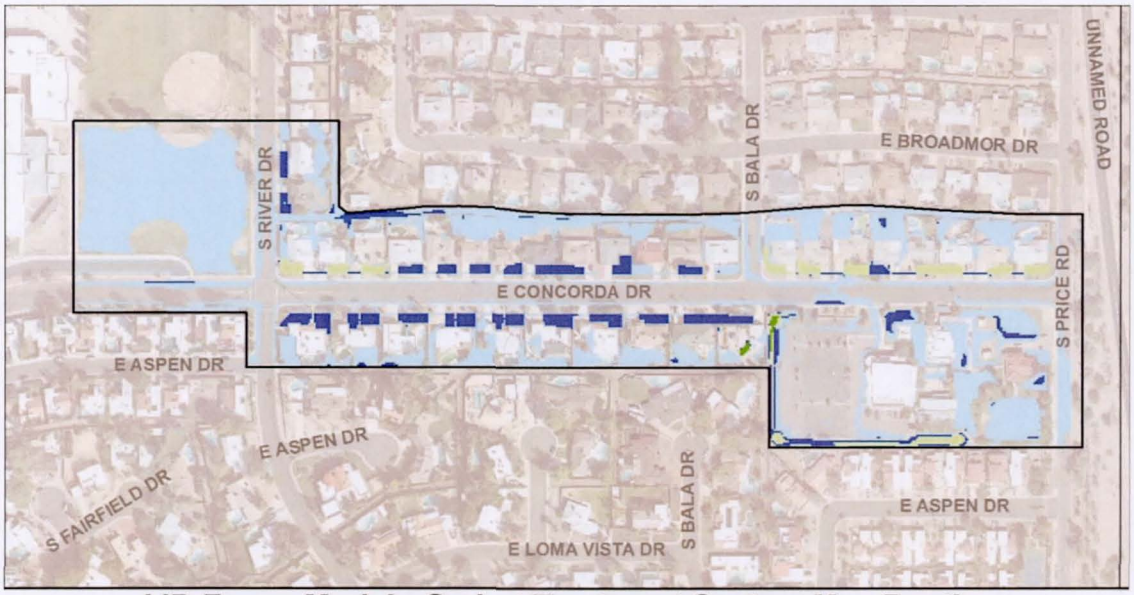
LID Focus Model - On Lot Treatment System Grids

Bio Retention
Rainwater Harvesting
Bio Swale
Model Boundary
Walls

N

1 inch = 100 feet

The maximum flow depth for the on lot treatment area and a close-up area are shown below.



LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

LID Focus Model - On Lot Treatment System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

6.3 Green Parking System

Green Parking System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily commercial, community parking lots, and residential driveways. The general concept of this system Concorda Drive within the Focus Area is shown in the following photo.

Green Parking System Concept along Concorda Drive

Green Parking System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Parking LID System:
   - Residential driveways – same as pervious pavement control selection, with added walls too
   - Church site and school driveway were used as pervious pavement
   - Bio retention – manually selected areas near the church parking lot and school driveway
   - Routing to bio retention – grids connecting street drainage to bio retention area

2) FLO-2D Input Parameter Modification:
   - Residential driveways INFIL.DAT – same as LID controls
   - Church site and school driveway – INFIL.DAT – same as LID controls

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 2 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 1 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

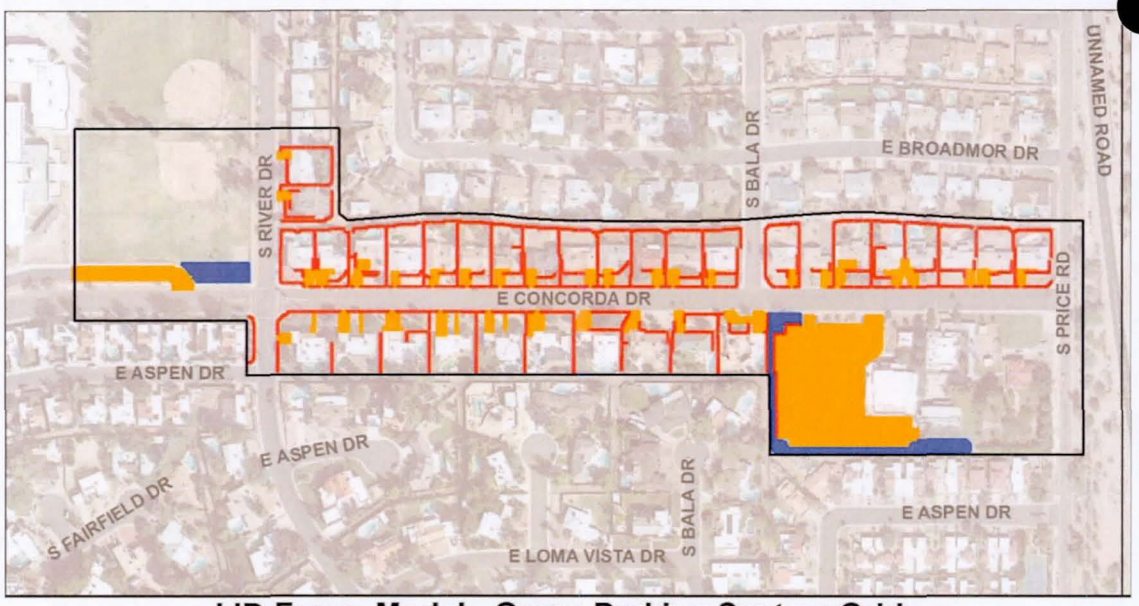
3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

The exhibit showing the green parking system LID areas and FLO-2D grids is included in Exhibit C2. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix F2. The FLO-2D modeling results summary data is documented in Table 6.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 6.1.

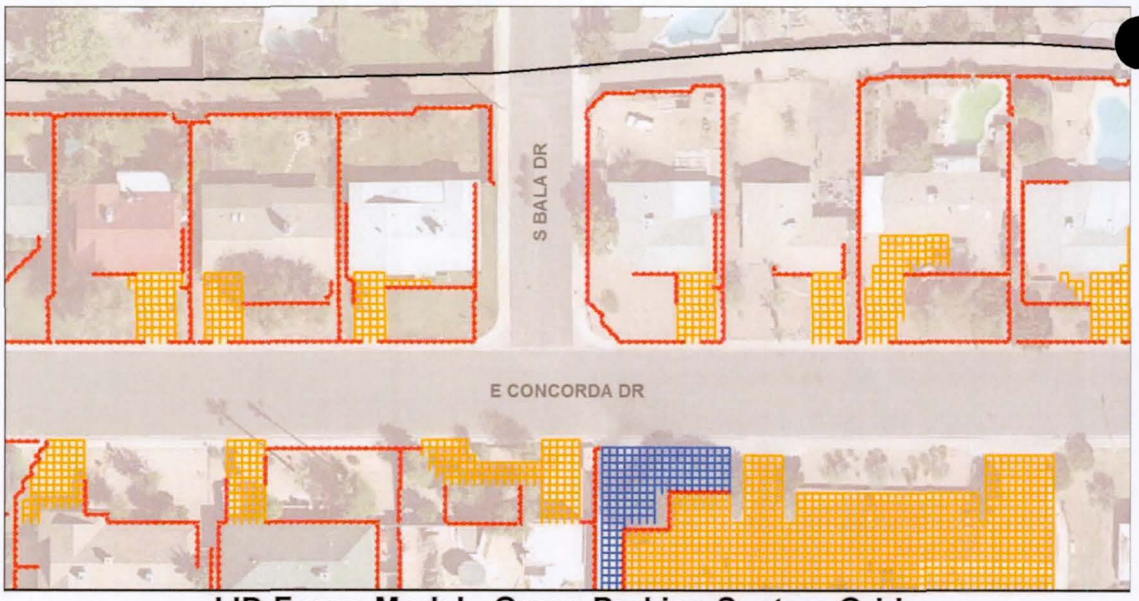


LID Focus Model - Green Parking System Grids

Pervious Pavement
Model Boundary
Bio Retention
Walls

N

1 inch = 400 feet



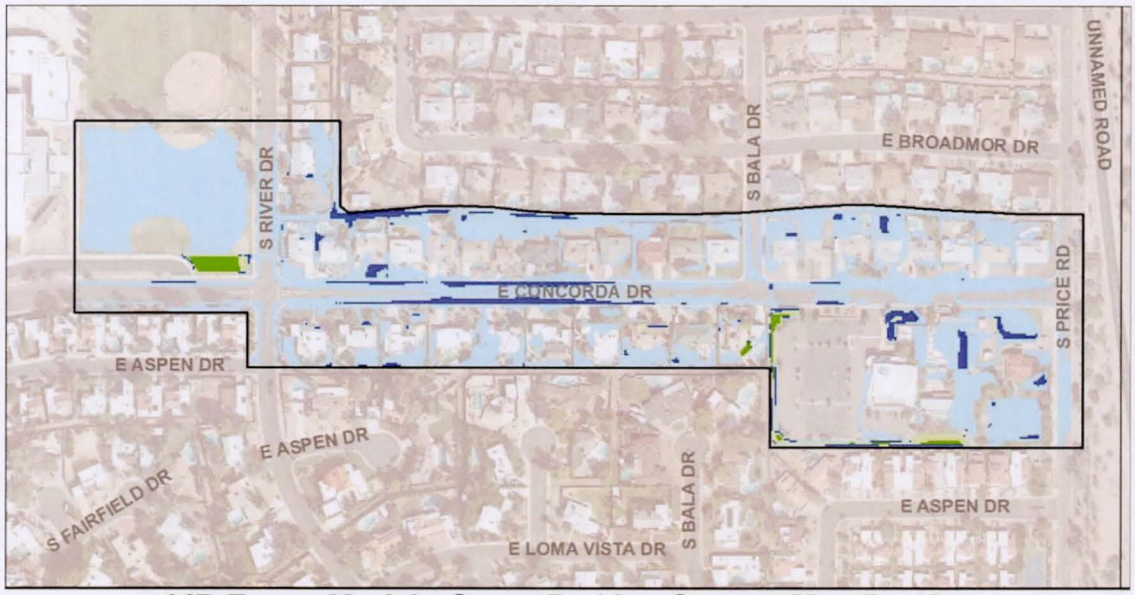
LID Focus Model - Green Parking System Grids

Pervious Pavement
Model Boundary
Bio Retention
Walls

N

1 inch = 100 feet

The maximum flow depth for the green parking area and a close-up area are shown below.



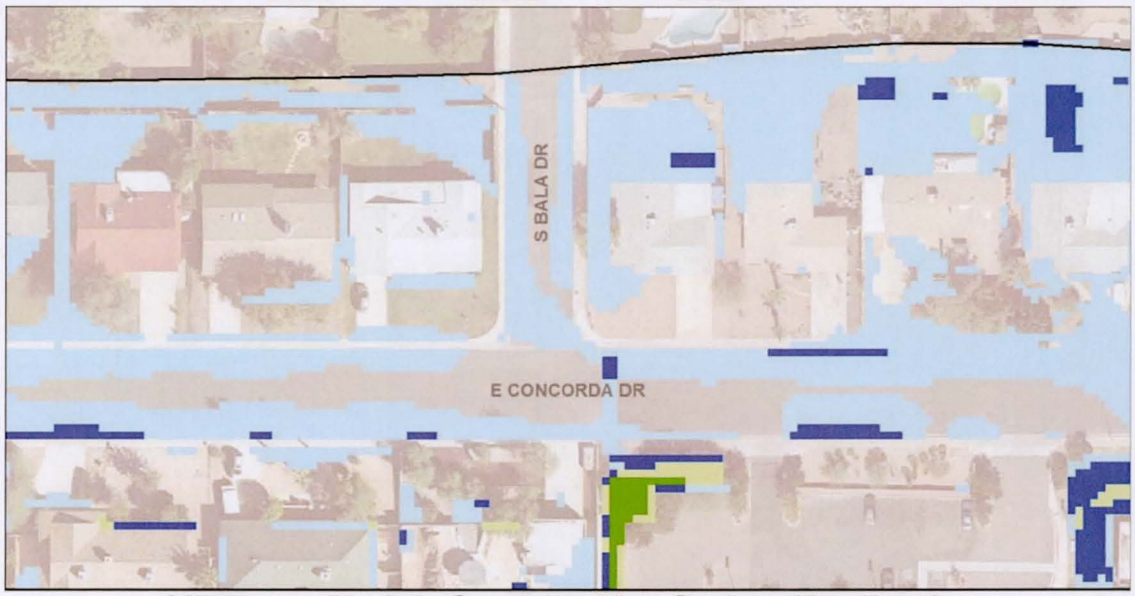
LID Focus Model - Green Parking System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet



LID Focus Model - Green Parking System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

6.4 Green Street System

Green Street System consists of a series of bio retention, bio swale, and pervious pavement with various accessories. The land uses for this system are primarily streets, public right-of-ways, and some residential land adjacent to streets. The general concept of this system along Concorda Drive within the Focus Area is shown in the following photo.

Green Street System Concept along Concorda Drive

Green Street System FLO-2D Modeling Procedures:

In addition to grid elevation adjustments within the LID system areas, spatially varied initial abstractions, infiltration rates, and limiting soil depths were applied by the FLO-2D model to evaluate the impact of this system on the study area hydrology and hydraulics. The detailed steps are:

1) Selection of FLO-2D Grids for Green Street LID System:
   - Bio swale – double row of grids on the curbs of the streets – broken up by driveways
   - Pervious pavement – double row of grids adjacent to the bio swales and double rows of grids between bio swales that are broken up by driveways
   - Bio retention – same grids used in green parking system model

2) FLO-2D Input Parameter Modification:
   - Bio swale – Grid elevations dropped by 1 ft, infiltration matches control model parameters
   - Pervious pavement – matches control model parameters

- Bio retention – INFIL.DAT, FPLAIN.DAT – Bio retention areas were defined with interior, exterior, and connection grids. Interior grids were those not on perimeters of the basins, and were lowered by 1 ft, n-value increased to 0.1, and infiltration capacity was increased by 0.5 ft similar to the infiltration parameters used in the bio retention control model. Exterior grids were only lowered by 0.5 ft and n-values were increased to 0.1. Connector grids were manually lowered in order to provide a route to the basin

3) Estimation of Added Volume Capacity:

- Increase in initial abstraction depths:
  Sum of Depths ($\Delta\Sigma$ [ABSTRINF]) * Grid Area (16 ft^2)

- Increase in limiting soil depths:
  Sum of Depths ($\Delta\Sigma$ [SOILD*DTHETA]) * Grid Area (16 ft^2)

- Increase in volume on surface storage:
  Sum of Depths ($-\Delta\Sigma$ [Elevation]) * Grid Area (16 ft^2)

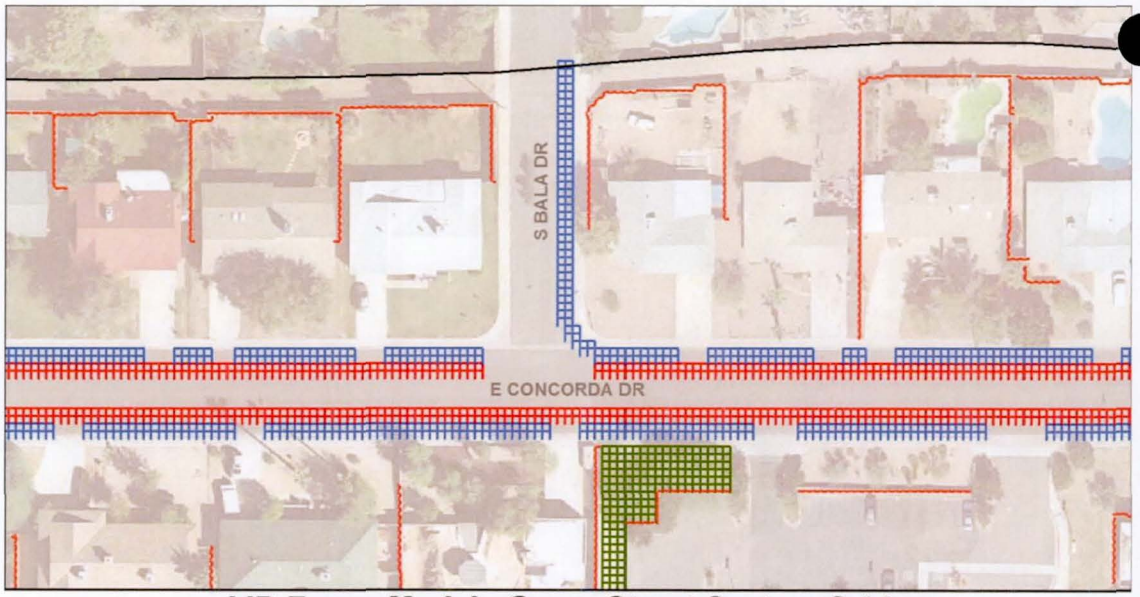
The exhibit showing the green street system LID areas and FLO-2D grids is included in Exhibit C3. The FLO-2D model input and output files, hydrographs, GIS post-processing, and output files used for modeling summary results are included in Appendix F3. The FLO-2D modeling results summary data is documented in Table 6.1 and the comparison of cross section hydrographs from the three (3) LID systems is shown in Figure 6.1.

LID Focus Model - Green Street System Grids

Bio Swale
Model Boundary
Pervious Pavement
Walls
Bio Retention

N

1 inch = 400 feet



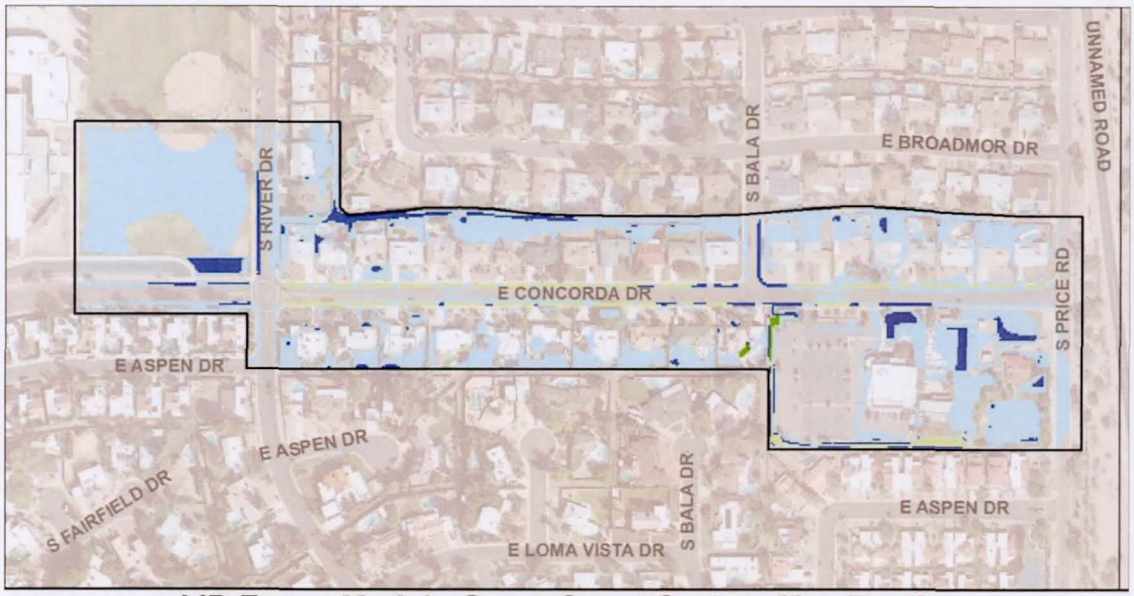
LID Focus Model - Green Street System Grids

Bio Swale
Model Boundary
Pervious Pavement
Walls
Bio Retention

N

1 inch = 100 feet

The maximum flow depth for the green street area and a close-up area are shown below.



LID Focus Model - Green Street System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

LID Focus Model - Green Street System Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 100 feet

6.5 Summary of Modeling Results for Three LID Control Systems

The FLO-2D modeling results for the base model as well as the three LID systems are summarized in Table 6.1. Table 6.1 shows that Green Street System has the highest utilization of LID design volume (55.2%). The other two systems have similar utilization percentage (~47.5%). Figure 6.1, as an example of the cross section hydrographs, shows that on lot treatment system has the highest peak flow reduction in all three LID systems. The peak flow of 7.9 cfs for the base model at floodplain cross section of Bala Drive is reduced to 1.1 cfs for the on lot treatment LID system, 1.8 cfs for the green parking LID system, and 3.3 cfs for the green street LID system. The on lot treatment LID system has the highest peak flow reduction due to its high LID target (design) volume (3.11 ac-ft, see table 6.1). The modeling results show that all three LID systems are very effective in flood mitigation (reducing the downstream storm water peak flows and volumes).

Table 6.1 Summary Table for LID System Modeling Results						
			Base Model	On-Lot Treatment	Green Parking	Green Street
		Model	LID 2.1	LID 20	LID 21	LID 22
	Target volume capture	V (acft)	-	3.107	1.807	1.830
SWMM RPT	Outflow (Outfall node I338)	Qp (cfs)	8.58	3.17	5.27	2.14
	Wet weather inflow	V (acft)	1.192	0.146	0.756	0.397
	Return flow	V (acft)	0.041	0	0.002	0
SUMMARY OUT	Total point rainfall	in	2.52	2.52	2.52	2.52
	Overland infiltration & interception	in	0.88	1.75	1.25	1.36
	Rainfall volume	V (acft)	4.37	4.37	4.37	4.37
	Infiltration & interception	V (acft)	0.93	2.31	1.62	1.79
		%	*21*	*53*	*37*	*41*
	Floodplain storage	V (acft)	1.47	1.56	1.64	1.62
		%	*34*	*36*	*38*	*37*
	TOL storage	V (acft)	0.07	0.07	0.07	0.07
		%	*2*	*2*	*2*	*2*
	Floodplain outflow	V (acft)	0.76	0.36	0.36	0.57
		%	*17*	*8*	*8*	*13*
	To stormdrain (FLO-2D to SWMM)	V (acft)	1.23	0.14	0.75	0.39
		%	*28*	*3*	*17*	*9*
	Stormdrain return flow (SWMM to FLO-2D)	V (acft)	0.03	0	0	0
		%	*1*	*0*	*0*	*0*
Check	Sum of volumes	V (acft)	4.36	4.37	4.37	4.37
	Utilization of LID volume	%	-	47.3	47.6	55.2
Storage Additions	Grading	V (ft^3)	-	79035	44364	45421
	Initial abstraction	V (ft^3)	-	22969	-590	-492
	Increased soil depth	V (ft^3)	-	33329	34932	34775
	Sum	V (ft^3)	-	135332	78707	79704
		V (acft)	-	3.11	1.81	1.83

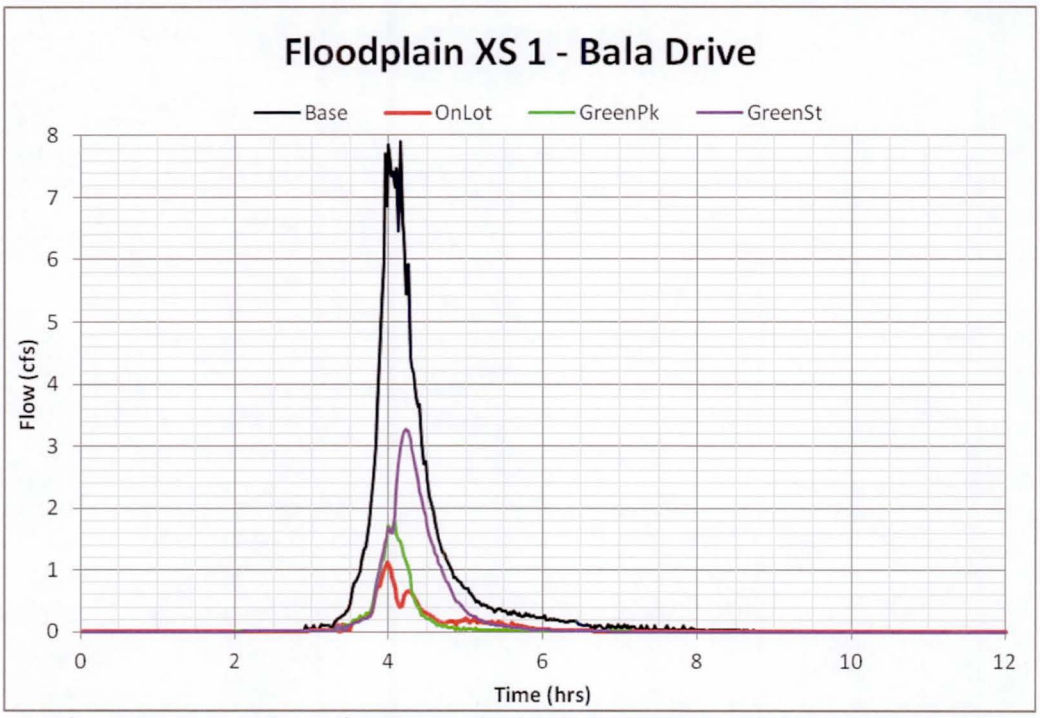


Figure 6.1 Comparison of Hydrographs for the Three LID Systems (example)

7.0 SIMULATION OF LID ALTERNATIVES IN LOMA VISTA AREA

7.1 Identification of Modeling Strategies

One of the goals of the individual basic LID control evaluation is to develop a modeling process that can be incorporated into the regional FLO-2D models. The FLO-2D modeling procedures for individual basic LID controls from the Focus Area model (4 ft x 4 ft grid size) should be adjusted to be applied to regional modeling of LID scenarios. A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land uses with certain parcel participation rate. The Loma Vista FLO-2D model was used for the regional modeling of LID application scenarios.

The direct impact of LID practices on flood mitigation is the reduction of surface runoff volume to the downstream areas due to the rainfall/runoff responses of many localized LID controls (retention, detention, infiltration, storage and re-use, high surface roughness). A key operational function of the FLO-2D model is the conservation of volume. The model accounts for volume in several ways including: surface storage, surface flow, storm drain flow, and infiltration. The reductions in volume are quantified in the model outflow hydrographs, model output summaries, and from placed floodplain cross sections. One of the advantages in the evaluation of LID scenarios in a regional FLO-2D model is that it is able to accurately depict impacts on a parcel by parcel basis and conservation of volume, though the 20 ft x 20 ft grids may be too coarse of a resolution to model some of the actual physical processes that are occurring at some LID accessories.

Further evaluations concluded that Initial Loss IA Adjustment is the most appropriate method among the potential techniques since this method has the following advantages over other approaches:

a. It is already a distributed parameter (grid dependent) and no new input data file is needed;
b. It is easy to be estimated and directly related to runoff volume and depth;
c. Changes of IA values represent best the basic LID control impact on hydrologic and hydraulic performance, such as rainfall/runoff timing and spatial variations;
d. It is a physical hydrologic parameter;
e. It can be used for all of the five basic LID controls.

Other methods do not have all of the advantages. For example, Grid Elevation Adjustment method does not work very well for variations of grid elevations (runoff may not be able to flow into the LID areas). TOL method has significant impact on hydraulic computations. Therefore, Initial Loss IA Adjustment was recommended for the modeling of LID scenarios in the regional modeling.

Detailed procedures for parameter adjustment from basic LID control modeling processes for simulation of LID scenarios are discussed in the following sections.

7.2 Estimation of LID Design Capacities for Various Land Uses

All the parcels within the modeling area are classified based on land use zoning provided by the City. For this example modeling, eight (8) zoning numbers were used, but streets are not parcel-based. Each parcel-based land use zoning was evaluated by using the following spreadsheet to estimate the composite design LID volume capability (V_d). Spreadsheets for the seven (7) parcel-based land uses were included in Appendix G1. The composite capacity

for each land use is estimated based on the five basic LID controls modeling results as well as the utilization effectiveness which is a correction factor with value less than 1.0 for individual LID controls. The utilization effectiveness factor for each of the five basic LID controls obtained from the Focus Area modeling is a very important parameter in the determination of the LID modeling volumes. The 100-year, 2-hour storm rainfall volume (V_2) was assumed to be the maximum LID design volume for a parcel. If the possibly constructed LID volume (Vc) for a parcel is greater than the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was applied ($V_d = V_2/ U_e <= V_c$). If the possibly constructed LID volume (Vc) for a parcel is less than or equal to the 100-year, 2-hour storm volume, the utilization effectiveness factor (U_e) was not applied and the design volume is the same as the 100-year, 2-hour storm volume ($V_d = V_2$) where V_d is the composite LID design volume and the FLO-2D LID modeling volume.

Street LID design capacities greatly depend on the functional classification of the roadway. Minor residential streets do not have as much right-of-way, which limits LID opportunities generally to small bio swales and pervious pavement. As the functional classification goes up towards arterials, bio swales can be more prominent while pervious pavement becomes less viable. The LID Design Capacity for streets is defined in cubic feet per lineal foot. Estimates of these capacities were obtained based on the applicability of LID applications on Country Club Way and Concorda Drive as shown in Exhibit C0.

The estimated composite design capacities for the eight (8) zooming numbers are listed in Table 7.1. These values for each parcel can be refined or revised based on real project area land use conditions and other factors. The values utilized for the Loma Vista model have been quantified through the Focus Area modeling efforts. In addition, the proposed procedure allows the modeler to easily refine the values to be utilized if modifications are required.

Table 7.1 Land Use Zoning and LID Design Capacities

Land Use Zoning No.	LID Land Use		LID Design Capacity	
	Zoning Name	Description	Value	Unit
1	AG	Parks & Golf Course	3500	ft^3/ac
2	CSS	Commercial	6000	ft^3/ac
3	R-2	Adjoined homes/duplexes	500	ft^3
4	R-3	Apartments	4000	ft^3/ac
5	R1-6	Medium-lot homes	1000	ft^3
6	RO	Church	5000	ft^3/ac
7	MU-2	School	4500	ft^3/ac
8	ST	Street	5-30	ft^3/lf

	Design Capacity Estimation for Individual Lot LID Controls	By:	**JJH**
		Date:	**1/18/16**
Project Name:	**Tempe ADMS - FLO-2D Modeling of LID Applications**	Checked:	
		Project No.:	**130.622**

Reference: Drainage Design Manual for Maricopa County, Arizona, Vol. 1, Hydrology

INPUT:

Rainfall

Return Interval = 100-year 2-hour = 2.16 inches = 0.180 ft

Criteria Equations

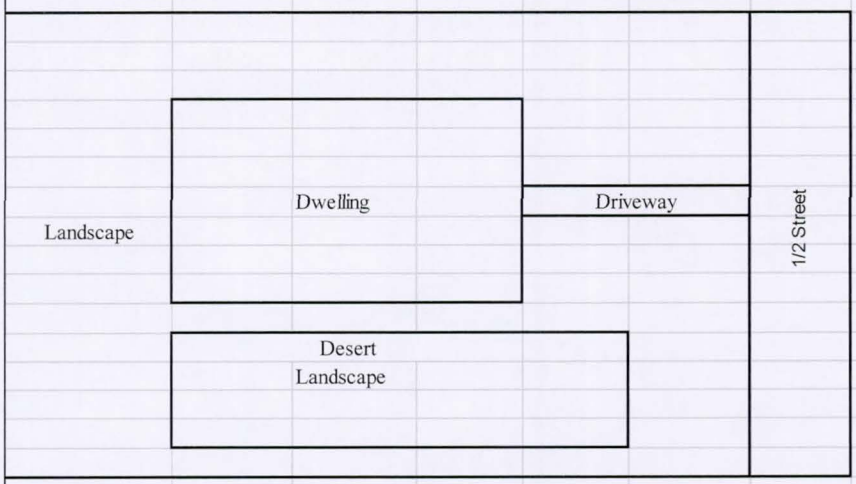
Volume, V = C * P* A (C = runoff coefficient, P = precipitation, A area)

Zoning = R1-6

Lot Size = 8250 square feet

0.19 acres

Landuse	Area (Sq. ft.)	C	C*A	
Structure Size	3766	0.95	3578	
1/2 Street (w = 20 ft, and assume 2 sides of lot adjacent to road)	0	0.95	0	
Desert Landscaping	3884	0.50	1942	
Landscaping	0	0.35	0	
Driveway	600	0.95	570	
Total	8250	0.74	6089.70	OK



Lot Size = 0.189 Acres

Runoff Volume

Generated by Lot = 0.025 Acre-ft

1096 cu ft

Low Impact Development (LID) Controls

Bio Retention	652	cu ft
Bio Swale	0	cu ft
Pervious Pavement	240	cu ft
Rainwater Harvesting	100	cu ft
Green Roof	0	cu ft
Total LID Volume	992	cu ft

Green Roof

Portion of Roof Contained =	0.00	
Contributing Roof Area =	0	sq ft
Roof Volume =	0	cu ft

Rainwater Harvesting

Portion of Roof Contained =	0.50	
Contributing Roof Area =	1883	sq ft
Roof Vol. Contributing to Tank =	339	cu ft
Rain Tank Volume =	100	cu ft
Controlling Volume =	100	cu ft

Bio Retention

bottom length	30.00	ft
bottom width	10.00	ft
Depth	1.00	ft
Side Slope	4.00	ft/ft
Top Length	38	ft
Top Width	18	ft
Stored Volume	481	cu ft
Stored Volume	0.01	ac-ft
Infiltration Rate	1.00	in/hr
Duration	6.00	hr
Additional Limiting Depth	3.00	
Infiltration Volume	171	cu ft

Bio Swale

bottom length	0.00	ft
bottom width	0.00	ft
Depth	0.00	ft
Side Slope	0.00	ft/ft
Top Length	0	ft
Top Width	0	ft
Stored Volume	0	cu ft
Stored Volume	0.00	ac-ft
Infiltration Rate	0.00	in/hr
Duration	0.00	hr
Infiltration Volume	0	cu ft

Pervious pavement

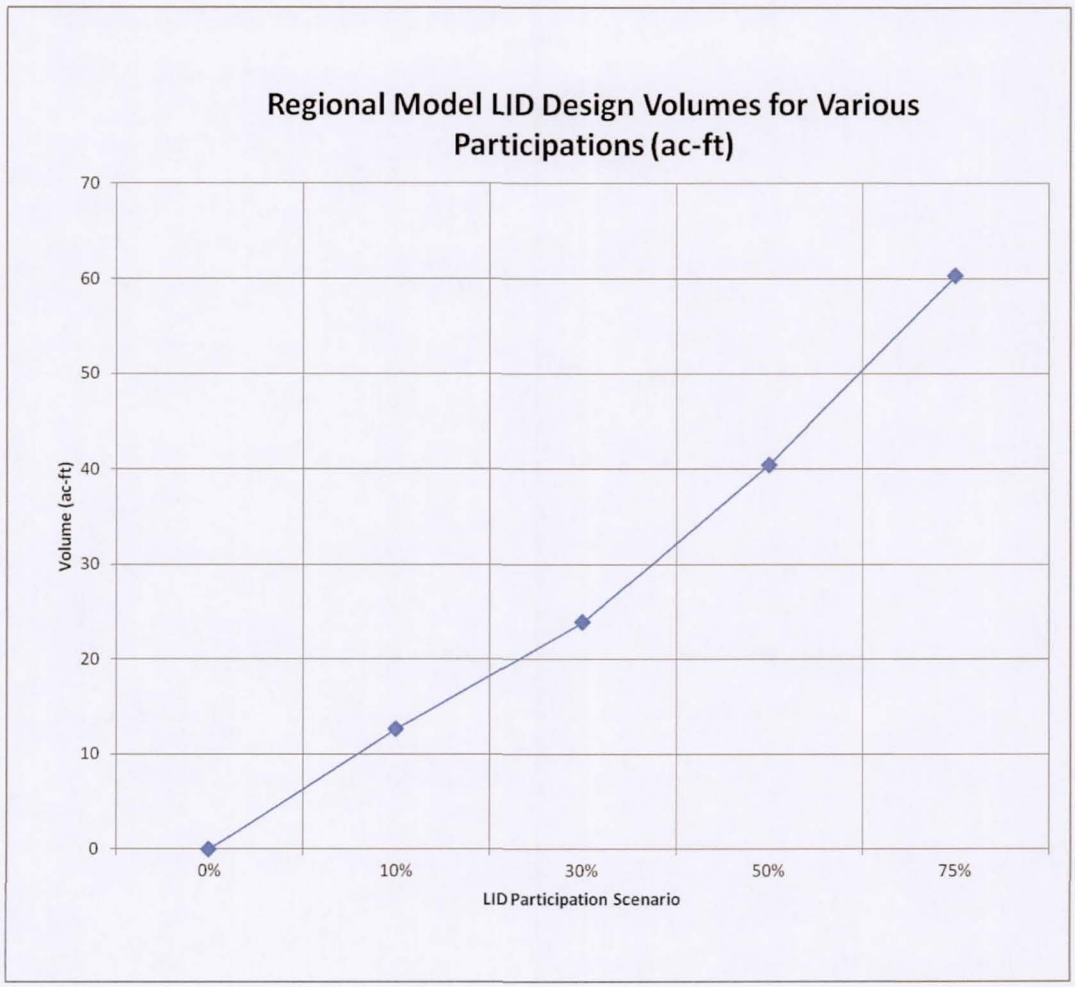
Area	600	sq ft
Volume	240	cu ft

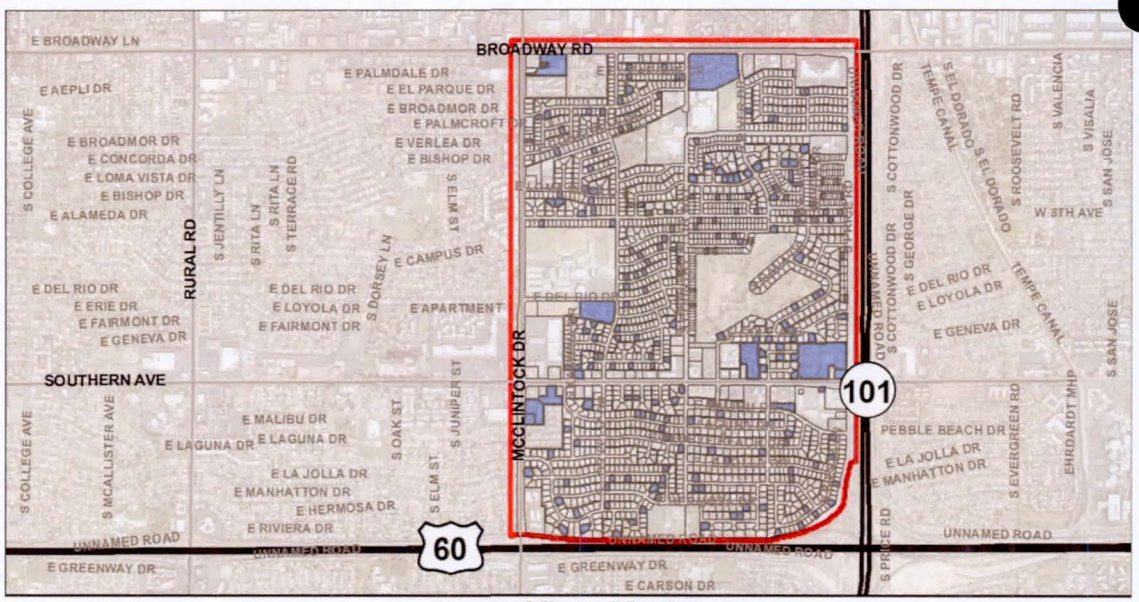
7.3 Determination of LID Application Scenarios

A LID scenario is defined as a LID practice system that includes multiple basic LID controls, accessories, and various land uses with certain parcel participation rate. Different LID application scenarios can be developed by combining several LID controls and storm drain system may be added to enhance the performance of the LID practices. Since the number of scenarios is numerous four (4) LID application scenarios were selected for this study to demonstrate the FLO-2D modeling techniques and the effectiveness of LID applications on flood mitigation:

1) Scenario I: 10% parcel participation rate;
2) Scenario II: 30% parcel participation rate;
3) Scenario III: 50% parcel participation rate;
4) Scenario IV: 75% parcel participation rate.

Parcels were assigned to be used for each scenario as shown in the following maps (see Appendix G2 also). The estimated LID design volumes for the four (4) proposed participation scenarios are shown in the following chart. These values were applied in the development of FLO-2D input data files.





Loma Vista Model
10% LID Participation Parcels

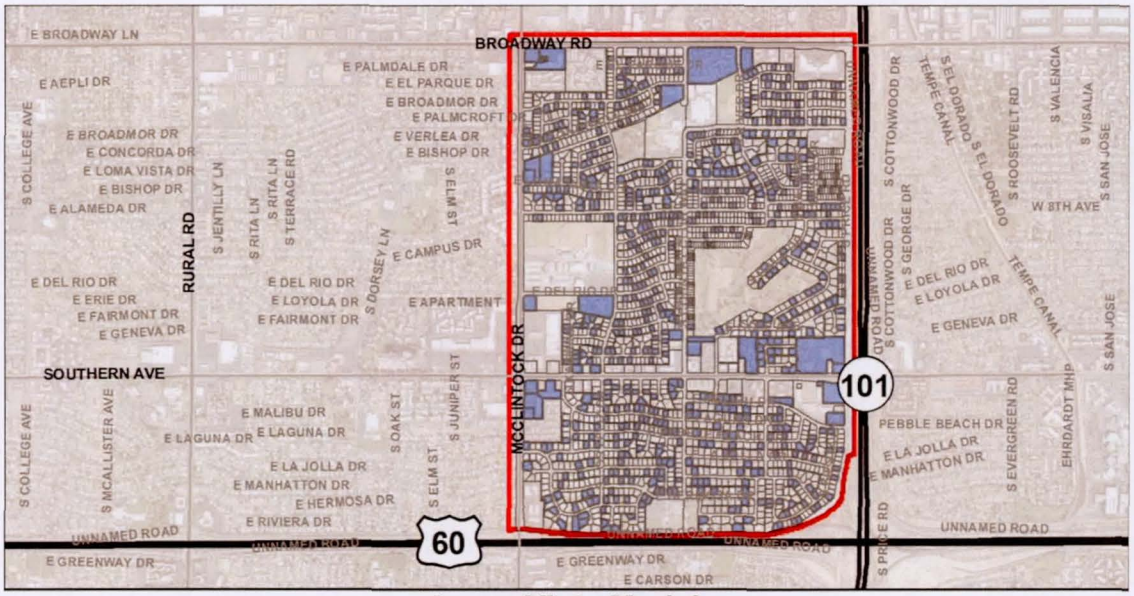
Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
10% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



Loma Vista Model
30% LID Participation Parcels

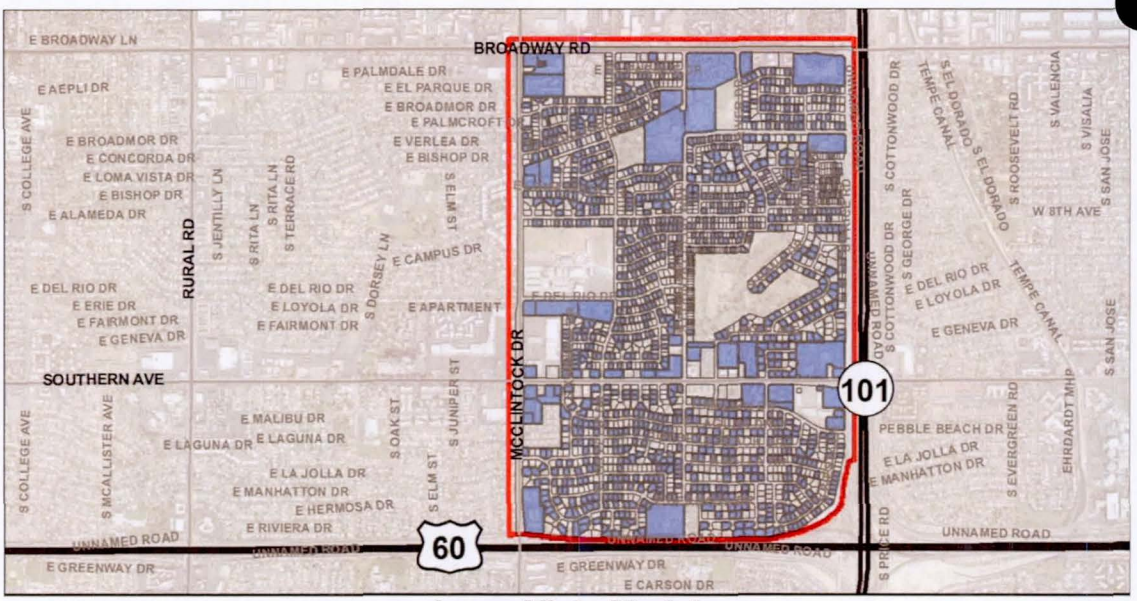
Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
30% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

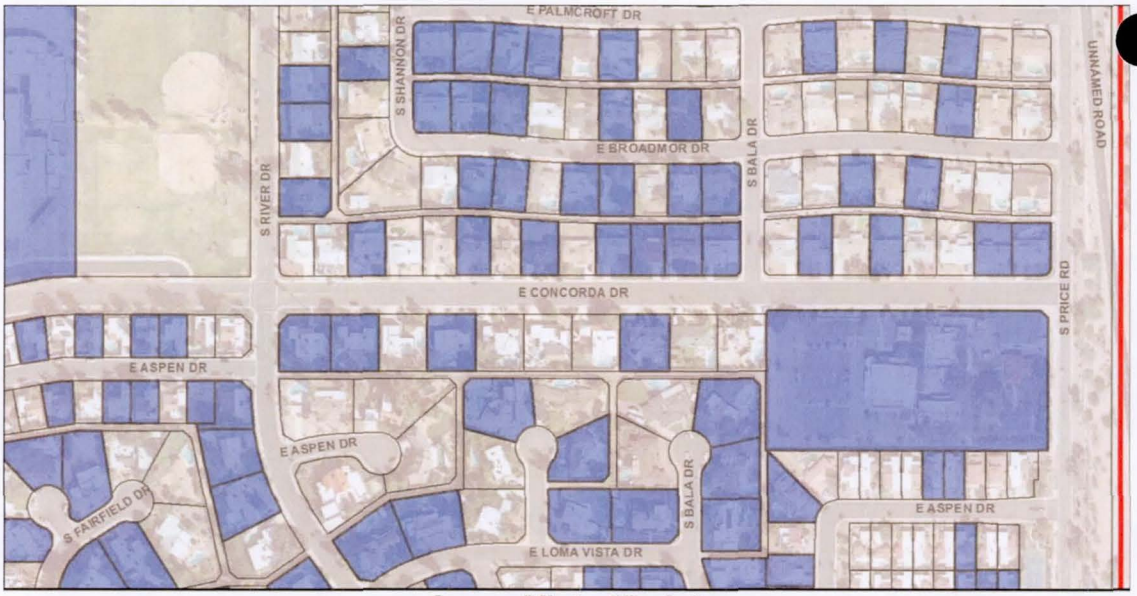
N
1 inch = 400 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

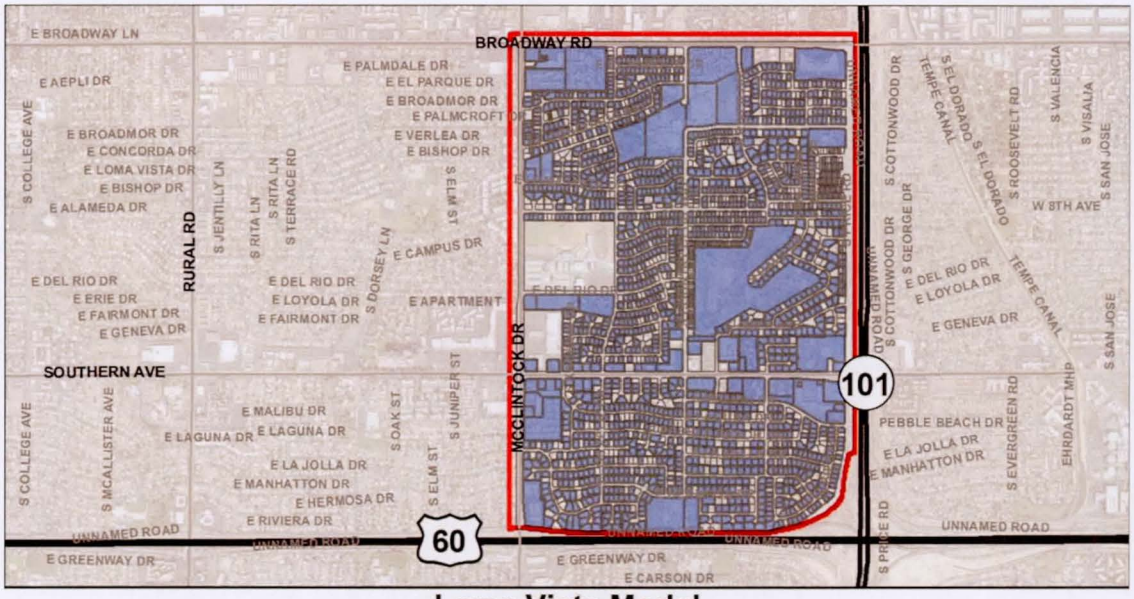
N
1 inch = 3,000 feet



Loma Vista Model
50% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet



Loma Vista Model
75% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 3,000 feet

Loma Vista Model
75% LID Participation Parcels

Parcels
Model Boundary
Participating Parcels

N
1 inch = 400 feet

7.4 Development of FLO-2D Input Data Files

The specific steps for the development of INFIL.DAT are as follows:

1) Create a new shapefile consisting parcels only;
2) Remove parcels with area below minimum criteria (Example: 100 ft^2);
3) Classify parcels by zoning numbers in terms of LID volume capabilities;
4) Calculate a parcel zoning-specific IA adjustment based on the classified volume and the parcel contributing area (A), added IA = Vol/A;
5) Determine scenarios for participation levels by percent of parcels. For example: 10% parcels participate in LID scenario 1, 30% in scenario 2, 50% in scenario 3, and 75% in scenario 4. Assign parcels to be used for each scenario (see Appendix G2);
6) Create rasters (4 ft resolution or smaller) using selected parcels for each scenario based on the IA adjustment values;
7) Associate IA adjustment values to grid number shapefile using Manifold;
8) Add IA adjustment values to original IA values and create new INFIL.DAT file.

The input files for the five (5) FLO-2D models were developed (Appendix G3) and executed for the base model and the four (4) LID scenarios. The base model is the model with 0% LID participation. The FLO-2D model input and output files and modeling results are included in Appendix G4.

7.5 Evaluation of FLO-2D Modeling Results for LID Scenarios

The recommended FLO-2D modeling techniques and LID applications were incorporated into Loma Vista model to quantify the impact of LID on storm water runoff. The Loma Vista FLO-2D model was developed for possible evaluation of various LID systems and scenarios within the project area and can serve as a preliminary approach for developing LID CIP projects within the Tempe ADMS watersheds. The final design will require development and refinement of more detailed LID alternatives. Hopefully, this project will allow LID to become one of the mainstream flood control measures in urbanized watersheds.

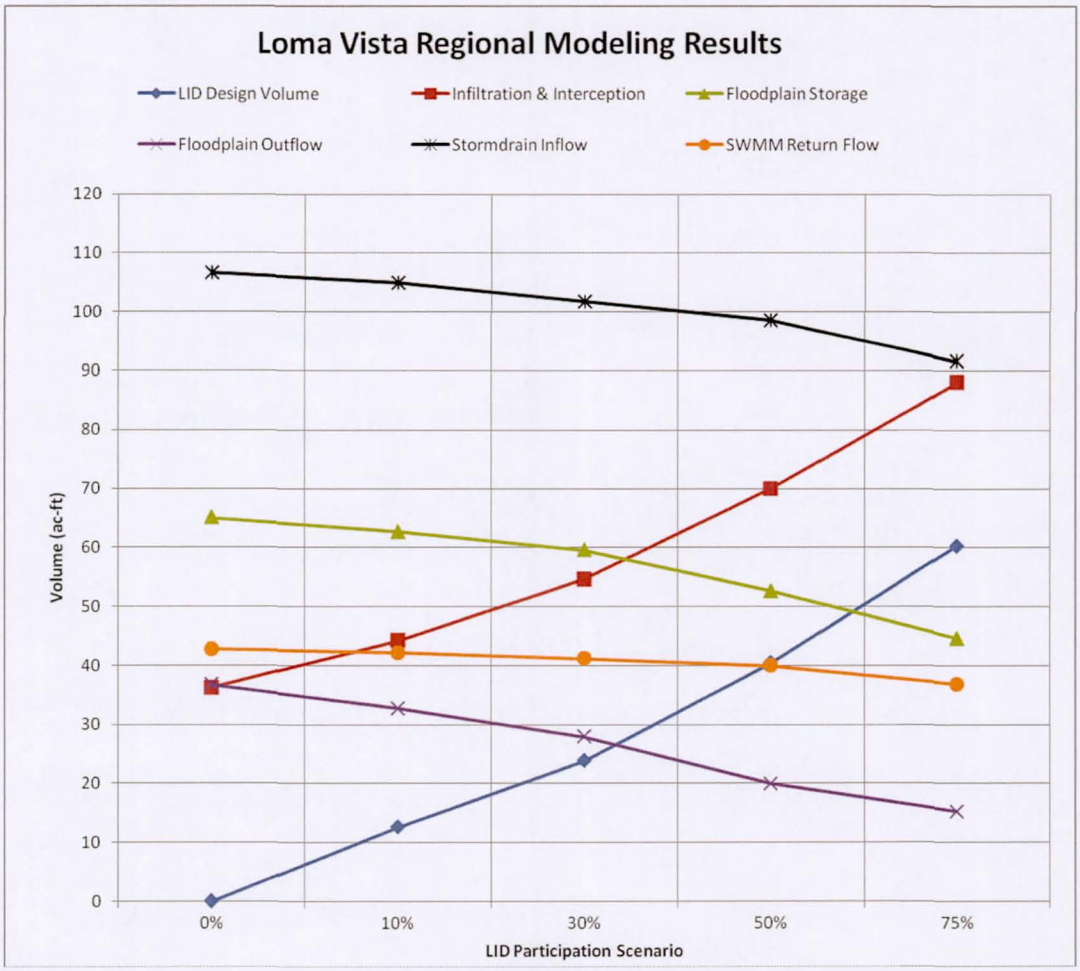
The FLO-2D/SWMM modeling results for the regional model (Loma Vista Area) and four (4) LID participation scenarios are summarized in Table 7.2 and the following charts.

Table 7.2 Loma Vista Regional Modeling Results

Participation Rate	LID Design Volume	Infiltration & Interception	Floodplain Storage	Floodplain Outflow	Stormdrain Inflow	SWMM Return Flow	SWMM Total Outflow
	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)	(ac-ft)
0%	0.0	36.3	65.0	36.8	106.7	42.8	100.1
10%	12.6	44.2	62.7	32.8	105.0	42.1	98.3
30%	23.8	54.7	59.6	28.0	101.7	41.2	95.3
50%	40.4	70.0	52.6	19.9	98.6	40.0	90.8
75%	60.3	88.0	44.6	15.2	91.5	36.8	84.4

The LID design volume and FLO-2D reported watershed infiltration & interception volume increase with the increase of the LID participation rate as expected. Floodplain (watershed) storage, surface outflow, storm drain inflow, storm drain outflow, and storm drain return flow (flooding) decrease with the increase of the LID participation rate. The reduction of storm

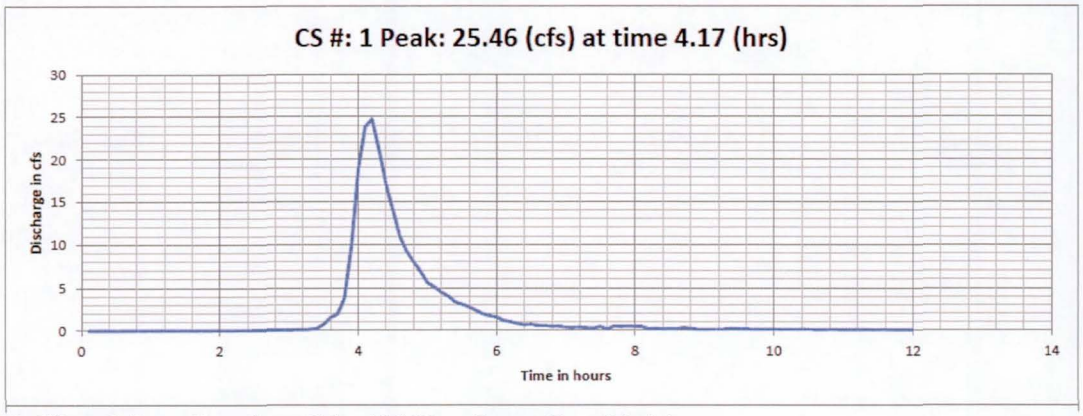
drain return flows is not very significant due to the small storm drain capacity compared to the 100-year storm runoff. The following charts show these patterns.



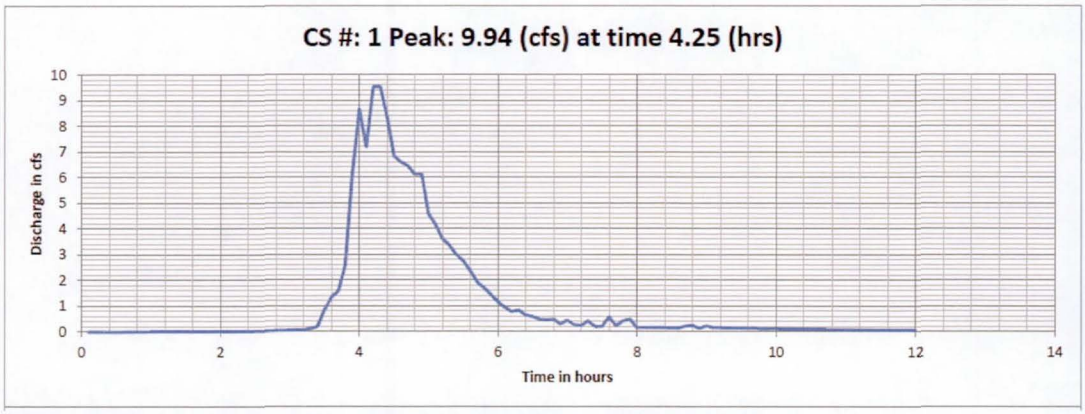
In order to show the effectiveness of LID applications on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts (all cross section (CS) hydrographs are included in Appendix G4):

CS #1 is located at McClintock Dr. and Broadway Rd and the peak flow is reduced from 25.5 cfs to 9.9 cfs (61% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.17 hours to 4.25 hours which has some effects on the peak flows at the downstream reaches.

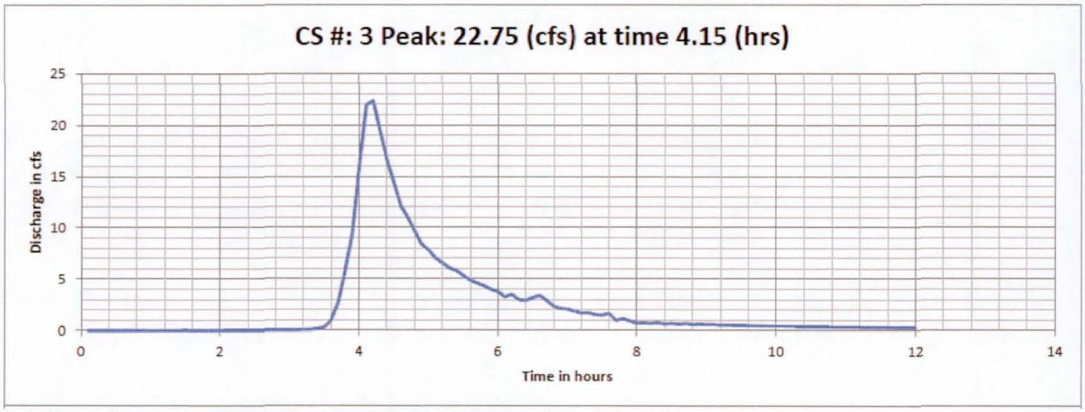
CS #3 is located at Broadway Rd. and McClintock Dr. and the peak flow is reduced from 22.8 cfs to 15.8 cfs (31% reduction) for the 50% LID participation rate. The time to peak is also delayed from 4.15 hours to 4.36 hours which has some effects on the peak flows at the downstream reaches.



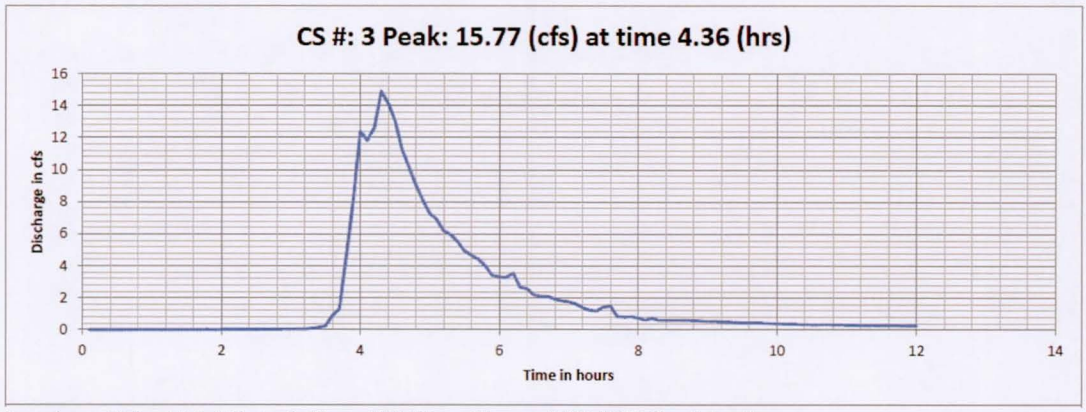
McClintock Dr. at Broadway Rd. - 100-Year Storm, Base Model



McClintock Dr. at Broadway Rd. - 100-Year Storm, 50% LID Participation

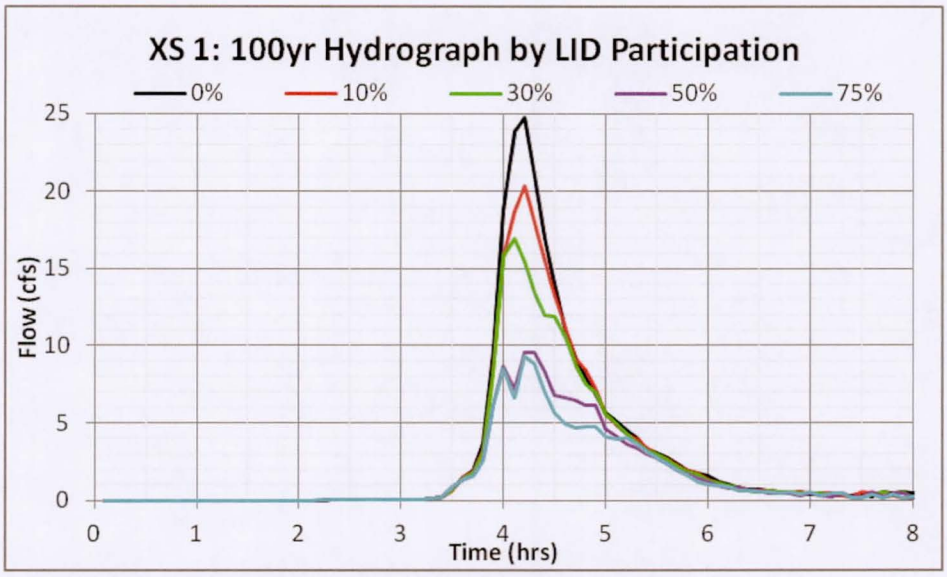


Broadway Rd. at McClintock Dr. - 100-Year Storm, Base Model

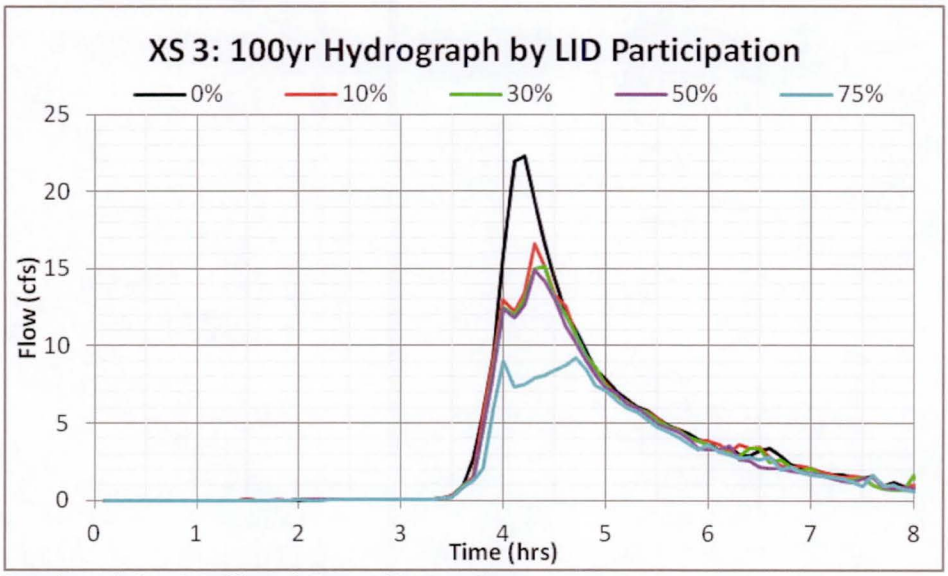


Broadway Rd. at McClintock Dr. - 100-Year Storm, 50% LID Participation

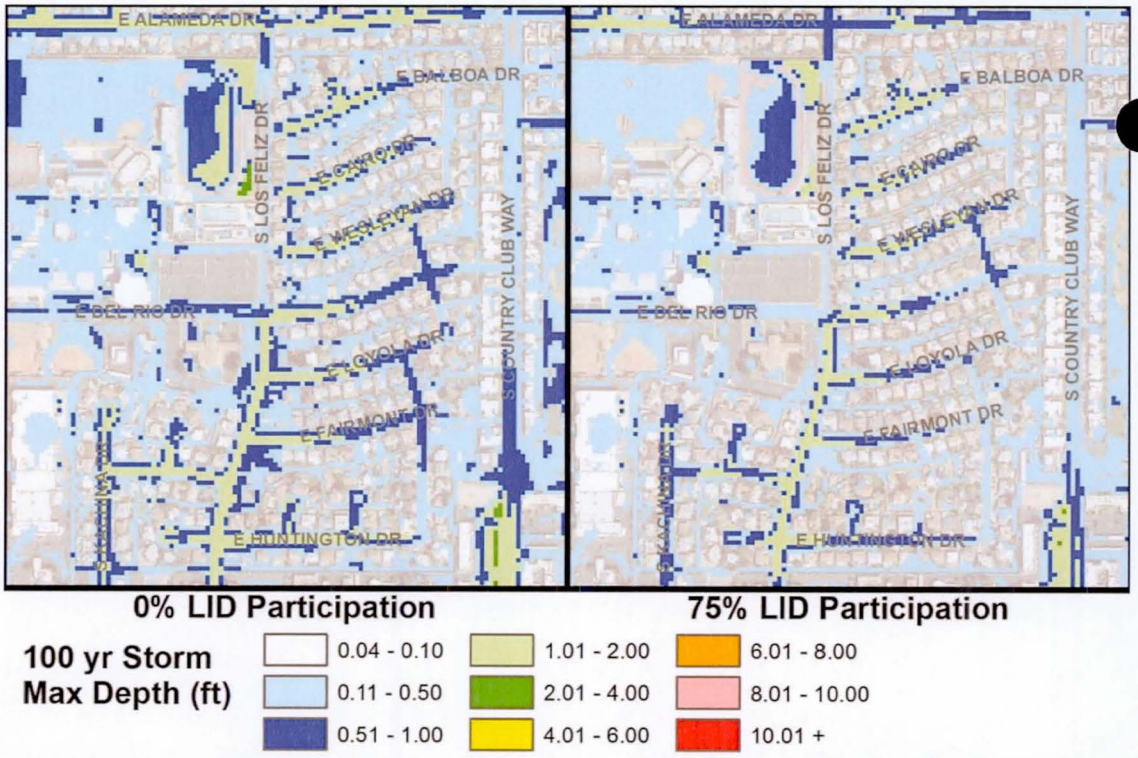
In order to show the impact of LID participation rate on the surface peak flow reduction surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all of the four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate as expected.



McClintock Dr. at Broadway Rd. - 100-Year Storm



Broadway Rd. at McClintock Dr. - 100-Year Storm



McClintock High: Comparison of maximum depths between 0% and 75% LID participation scenarios

7.6 Evaluation of Flood Mitigation Alternatives

BRDMP Original Plan

The Loma Vista Corridor, bounded on the west by McClintock Drive, on the north by Loma Vista Drive, on the east by Los Feliz Drive, and on the south by the McClintock High School Campus, was identified as a potential area for storm water mitigation improvements during the course of the District's preparation of the Broadway & Rural Drainage Master Plan which was performed in 2009. Twenty one (21) homes were identified to be flooded in the 100-year storm event as shown in Exhibit E1. The CIP concept included a storm drain system and retention basin within the McClintock High School campus that impacted a football practice field and baseball field. The total retention basin volume within the school site was approximately 20 ac-ft. The proposed CIP concept is included in Appendix A. The total estimated cost by this plan for the Loma Vista project was about $2.67 million. The updated cost estimate with the same concept is about $3.5 million as shown in Appendix H4.

Loma Vista FLO-2D Modeling Results

The overall FLO-2D modeling results for Loma Vista area were documented in Section 7.5. Nine (9) homes within the Loma Vista Corridor were identified to be flooded in the 100-year storm event as shown in Exhibit E2. The comparison of the modeling results within this corridor was documented in Appendix H1 which showed that maximum flow depths from the Loma Vista FLO-2D model were generally lower than those from BRDMP FLO-2D model. The main differences between these two models are the modeling methods for storm drain systems. BRDMP model used pipe full capacity and Loma Vista model applied SWMM model which can account for pressure flow conditions. Therefore, Loma Vista model storm drain can convey more surface runoff out of this corridor and reduce the flooding depth.

Alternative A

Four alternatives were evaluated (Alternatives A, B, C, and D) based on four parcel participation rates (30%, 50%, 75%, and 0%) for the 100-year storm event. Potential areas within McClintock High were considered for possible retention/detention basins as shown in Exhibit E3. The summary statistics for these four alternatives including number of participated parcels, LID design volumes, peak flows and volumes for inflow hydrographs at Alameda Drive and Los Feliz Drive into the basin, and additional basin volume requirements was documented in Appendix H2. The general alternative drainage concept is similar to the BRDMP concept which has a storm drain system to collect extra surface runoff from north and east and the McClintock High basin to store the collected runoff. The main differences are the inflows to the basin were reduced significantly due to the applications of LID scenarios and the McClintock Basin is a combination detention/retention facility. The storm drain outfall from the basin may connect with either of two existing storm drain systems located in Alameda Drive. One storm drain system routes water to the north and the other storm drain system routes water to the west. The preferred configuration will be determined during the final design process. The conceptual plan is shown in Appendix H3.

Exhibit E4 showed the Alternative A storm drain and basin systems with 30% parcel participation rate. For this alternative, additional 2.9 ac-ft of storage was needed.

Alternative B
Exhibit E5 showed the Alternative B storm drain and basin systems with 50% parcel participation rate. For this alternative, additional 1.1 ac-ft of storage was needed.

Alternative C
Exhibit E6 showed the Alternative C storm drain and basin systems with 75% parcel participation rate. For this alternative, no additional storage was needed.

Alternative D
Exhibit E7 showed the Alternative D storm drain and basin systems with 0% parcel participation rate. For this alternative, the storm drain system is similar to Alternative A and additional 5.2 ac-ft of storage was added. This alternative is capable of providing protection up to the 50-year storm , as 5.2 ac-ft is the approximate maximum storage that can be added and maintain a basin bleed-off into the nearby stormdrain at McClintock Drive and Alameda Drive.

Summary and Conclusions
The quantities and probable cost estimates were documented in Appendix H4 including the updated costs for the concept by BRDMP ($3.5 million). The increase of the BRDMP costs is due to the baseball field of the McClintock High basin improvement which cost approximately $750,000.

The most sensitive parameter for the probable cost estimation is the amount of the LID incentive program. Further study and evaluation are needed with the help from the City for these values. Three possible incentive values were evaluated ($500, $1,000, and $1,500 for each parcel) and the total probable costs for the four alternatives with the highest possible LID incentives were estimated to be $2.06 million for Alternative A, $2.19 million for Alternative B, $1.85 million for Alternative C, and $1.70 million for Alternative D, respectively. The total costs from the LID applications are lower than the total cost by BRDMP CIP project. The most significant cost reduction (due to the LID applications) is due to the savings created by not impacting the existing baseball field of the McClintock High basin which is not required for storm water storage because the inflow was significantly reduced by the LID applications. Another major significant cost reduction is due to not impacting the existing practice field and basin which reduces the turf and irrigation replacement as shown in Alternative C.

The underground storage pipe system (48" to 60" would be determined based on the LID participation rate) can store approximately 134,000 to 210,000 gallons of storm water that could be used for turf or landscape irrigation and an irrigation pump and filter system would have to be included to allow the storm water to be reused for irrigation purposes. However, if the City/School prefers that no storm water re-use is necessary the proposed storm drain pipe can be linked to the existing storm drain system at the intersection of Alameda Drive and Los Feliz Drive. This split structure will allow the depth of the proposed storm drain to be raised and a gravity outfall to the basin can be achieved. The FLO-2D model needs to be refined in the design phase to simulate these conditions. The detailed modeling will be performed during the final design process.

8.0 LID IMPLEMENTATION IMPACT ON FLOOD MITIGATION

The impact of LID practices on flood mitigation depends on many factors, such as LID composite design capacity (individual LID sizes), LID parcel participation rate (community participation rate – total LID sizes), and storm event frequency (flooding potential/risk).

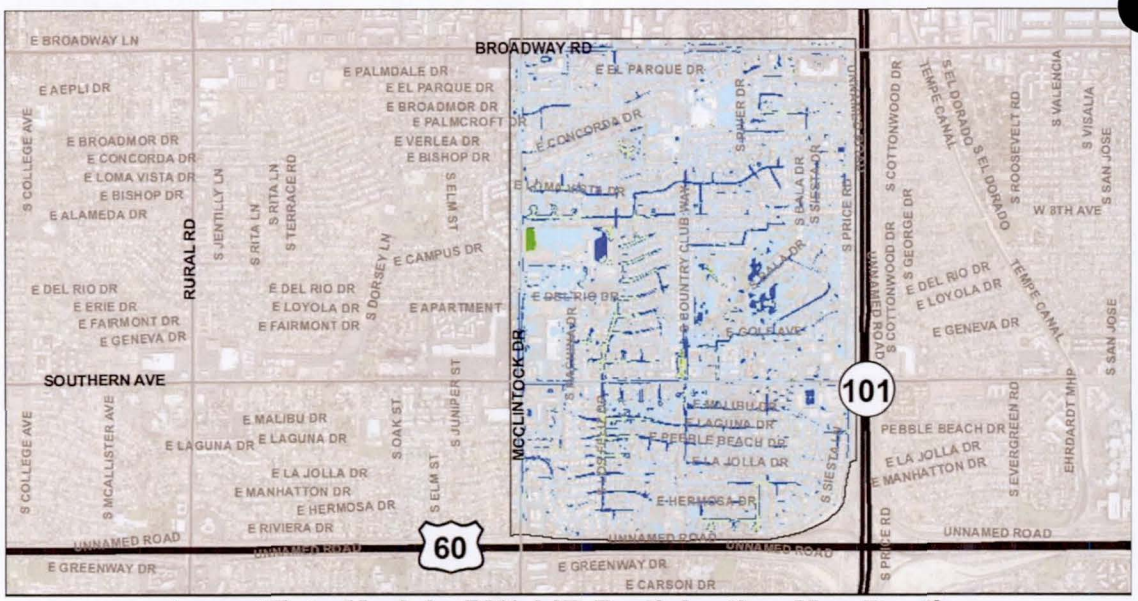
The impact of LID composite design capacity (individual LID sizes) and LID participation scenarios (community participation rate – total LID sizes) on flood mitigation was evaluated in previous section. Theoretically, the larger the LID design capacity and LID participation rate are, the more significant of the impact on flood mitigation is due to LID applications.

Multiple frequency modeling (2-yr, 10-yr, 25-yr, and 100-yr design storms) was conducted to evaluate the LID application effectiveness on flood mitigation for given design LID scenarios using Loma Vista FLO-2D models in the following sub-sections (McClintock High Basin and storm drain system were not modeled). The four (4) LID application scenarios were evaluated for each of the four (4) storm events to demonstrate the effectiveness of LID applications on flood mitigation for various sizes of storm events:

- Scenario I: 10% parcel participation rate;
- Scenario II: 30% parcel participation rate;
- Scenario III: 50% parcel participation rate;
- Scenario IV: 75% parcel participation rate.

8.1 100-Year Storm Event

The 100-year storm FLO-2D modeling results for the five (5) models were documented in Appendix G and Exhibit D including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendices G3 and G4. Evaluation of the modeling results was documented in Section 7.5. The following map showed the 50% participation rate. The modeling results for CR #1 and CS #3 show that surface runoff reduction increases with the increase of LID participation rate.



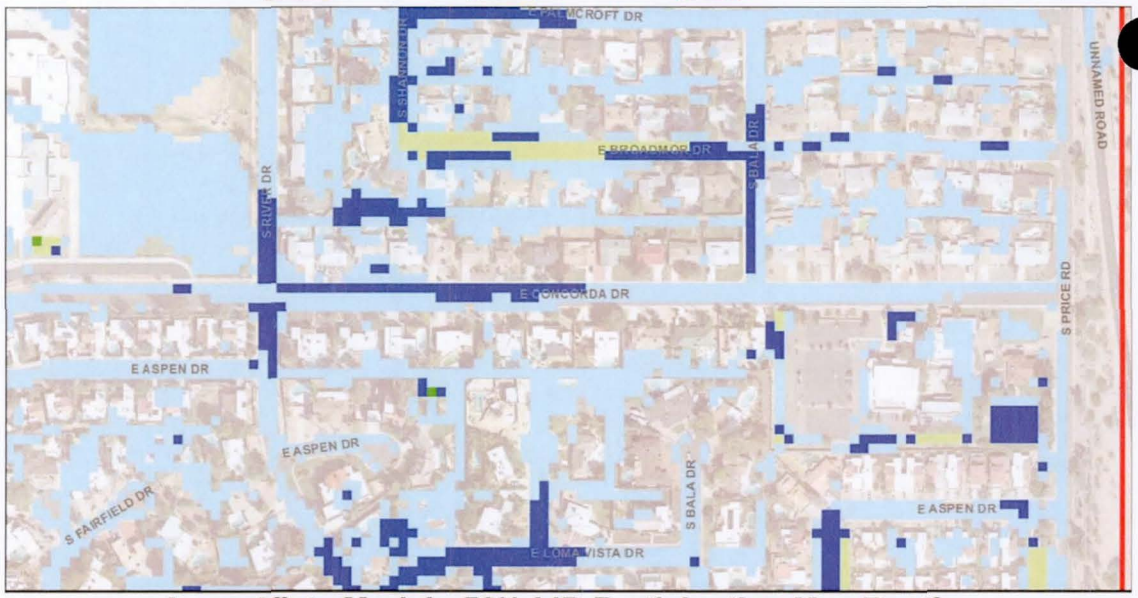
Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

100 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

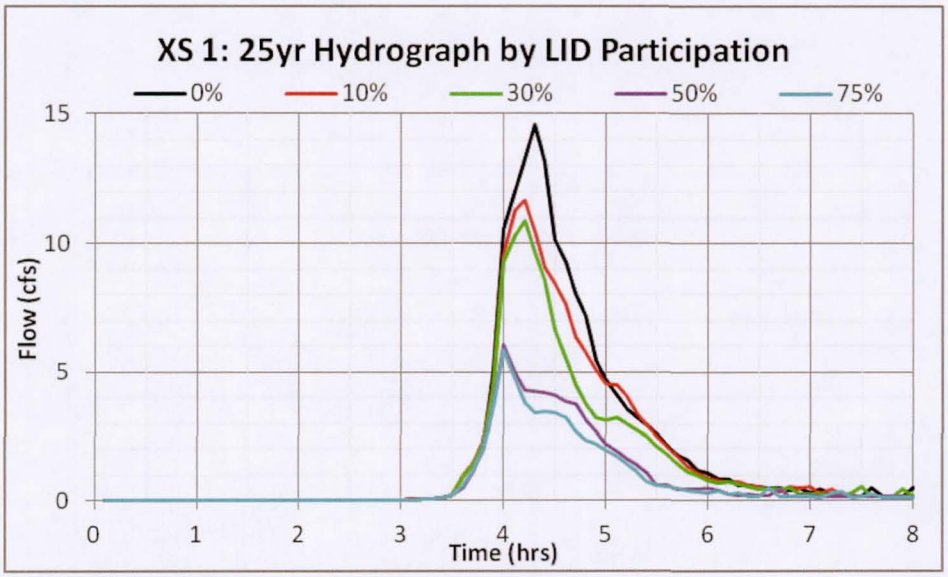
N

1 inch = 400 feet

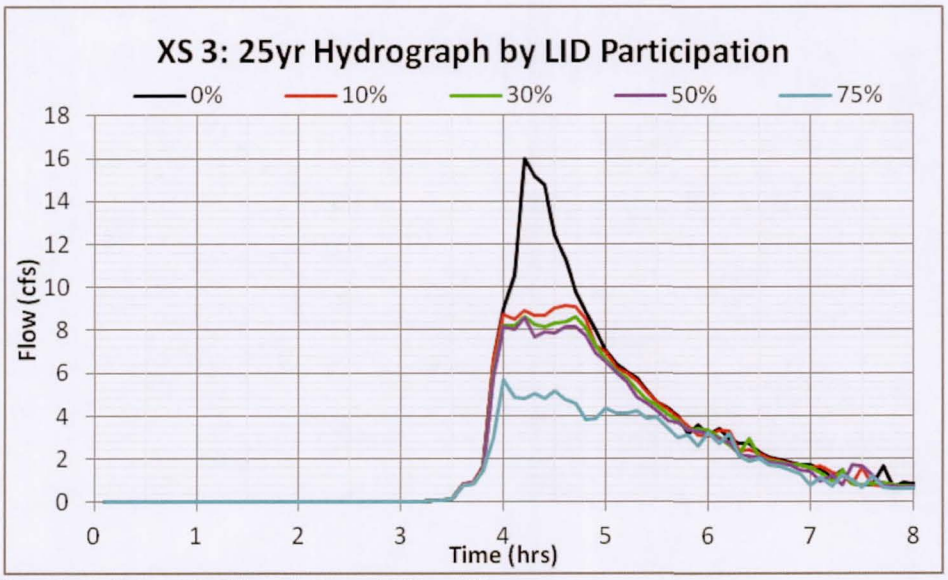
8.2 25-Year Storm Event

The 25-year storm FLO-2D modeling results for the four (5) models were documented in Appendix I and Exhibit F including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix I.

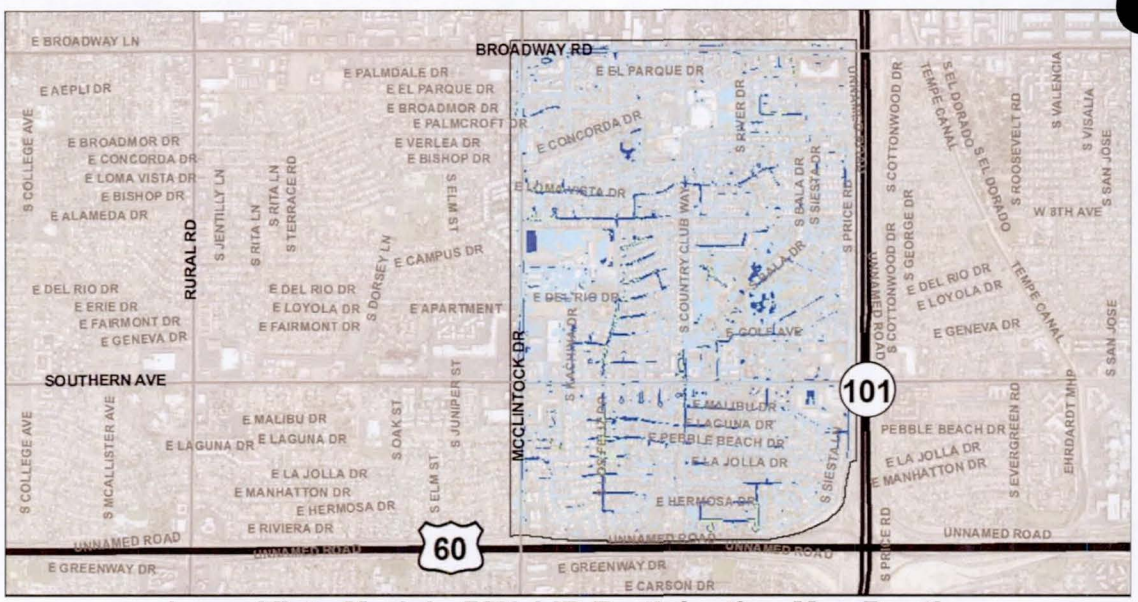
In order to show the impact of LID participation rate on the surface peak flow reduction for the 25-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 25-Year Storm



Broadway Rd. at McClintock Dr. – 25-Year Storm



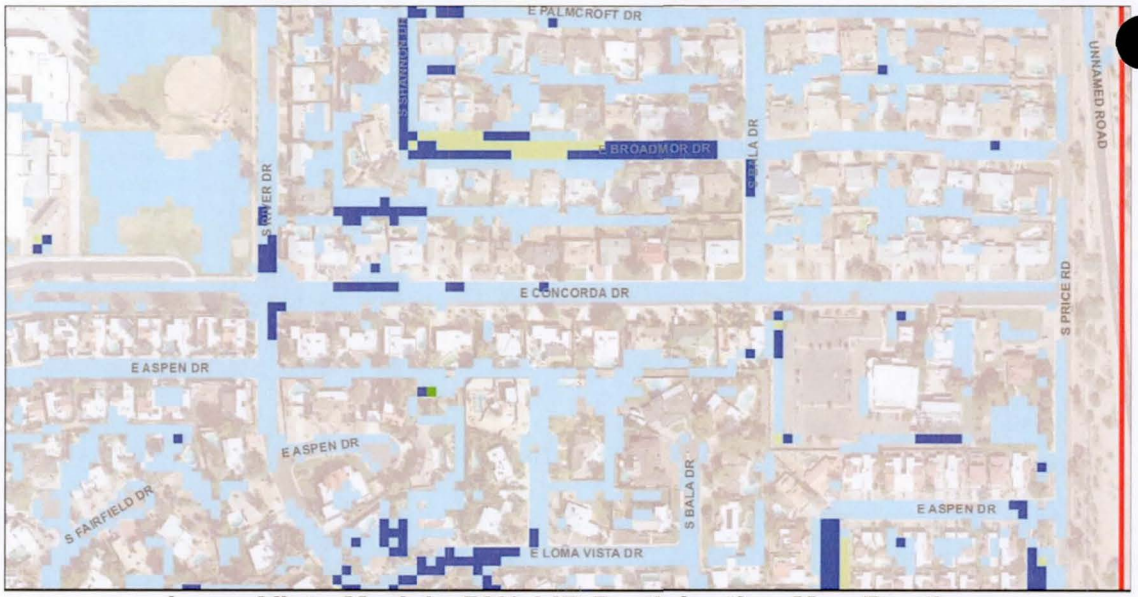
Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

25 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

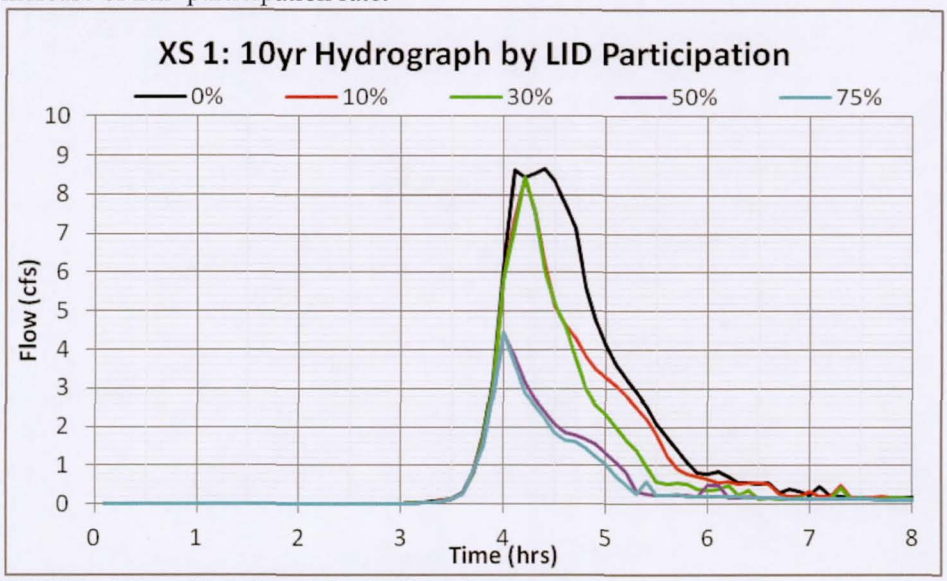
N

1 inch = 400 feet

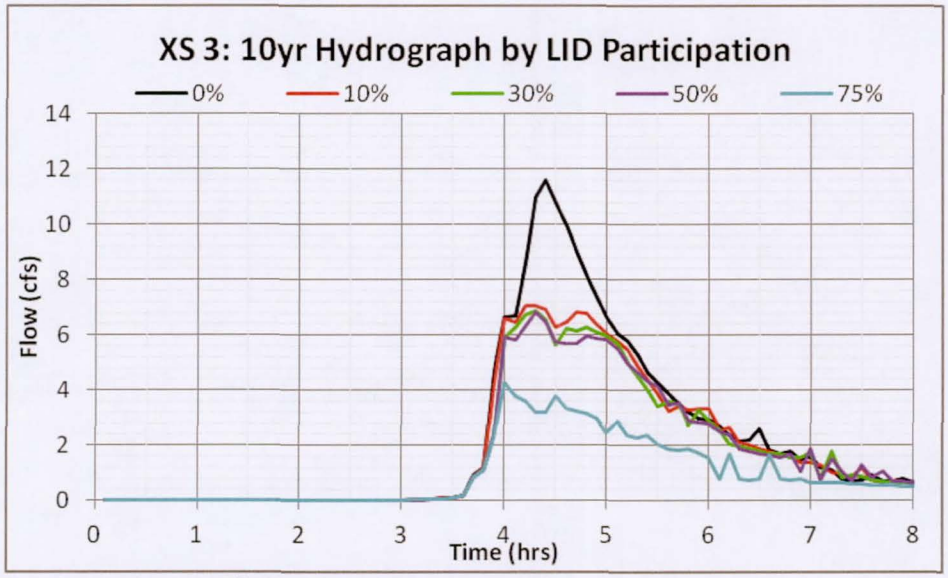
8.3 10-Year Storm Event

The 10-year storm FLO-2D modeling results for the four (5) models were documented in Appendix I and Exhibit F including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix I.

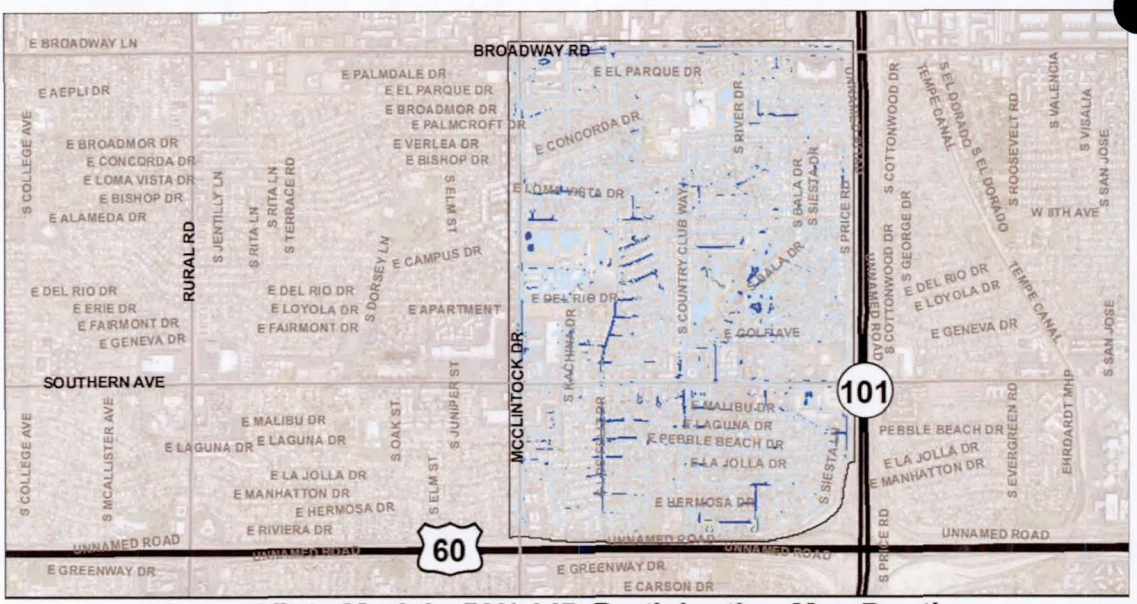
In order to show the impact of LID participation rate on the surface peak flow reduction for the 10-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 10-Year Storm



Broadway Rd. at McClintock Dr. – 10-Year Storm



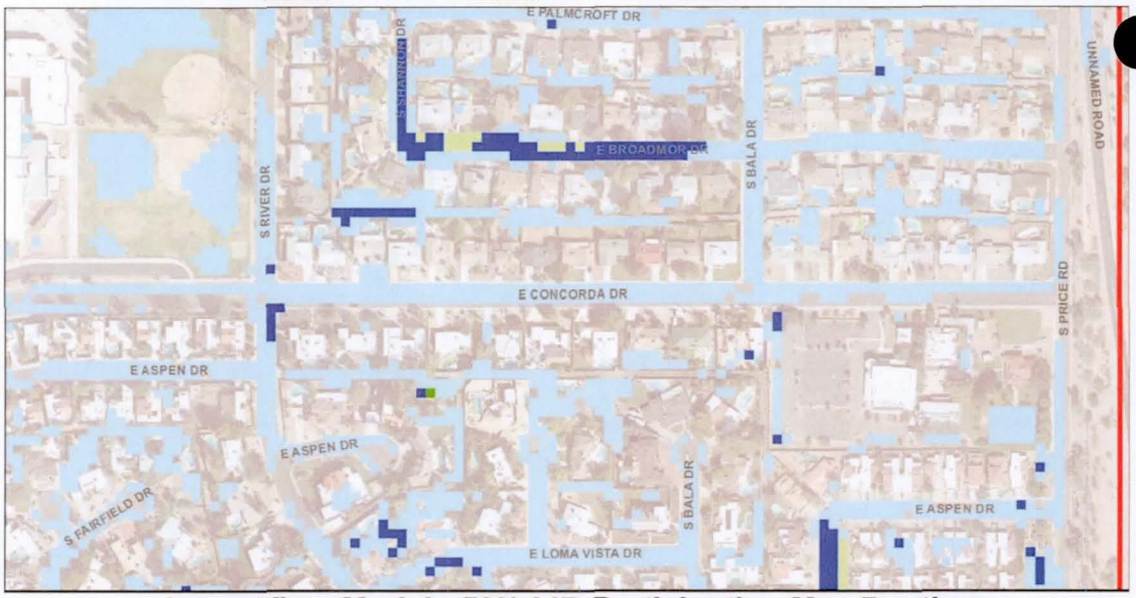
Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

10 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

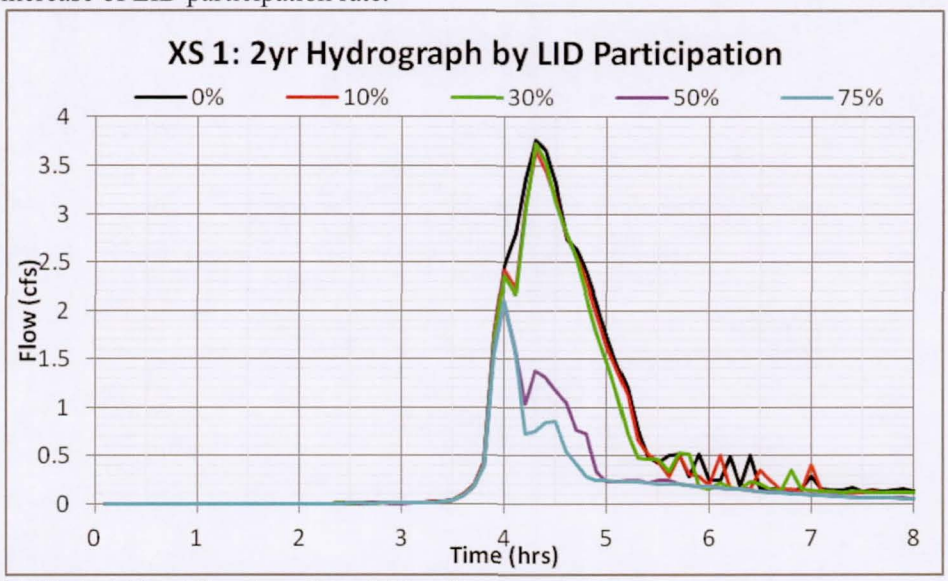
N

1 inch = 400 feet

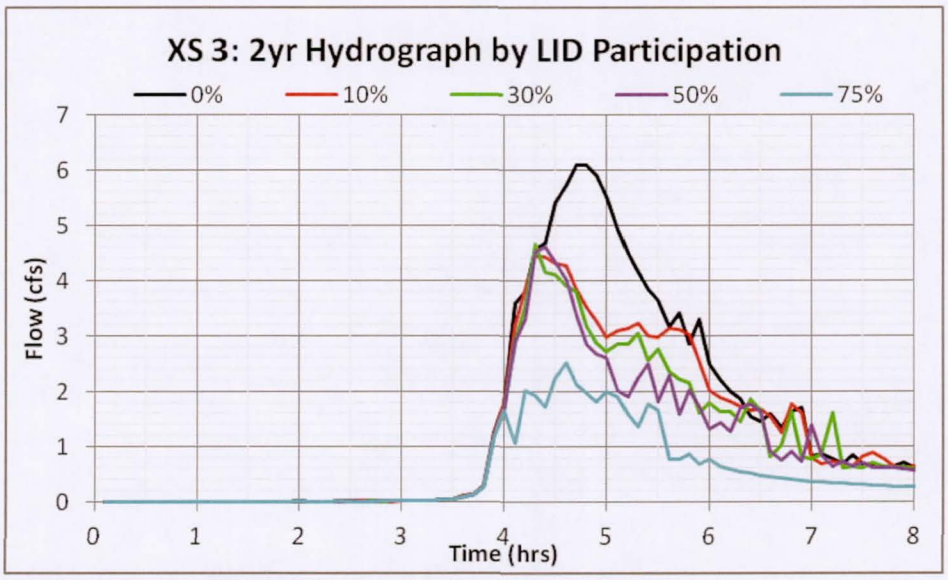
8.4 2-Year Storm Event

The 2-year storm FLO-2D modeling results for the four (5) models were documented in Appendix I and Exhibit F including the base model and the four (4) LID scenarios. The FLO-2D model input and output files and modeling results are included in Appendix I.

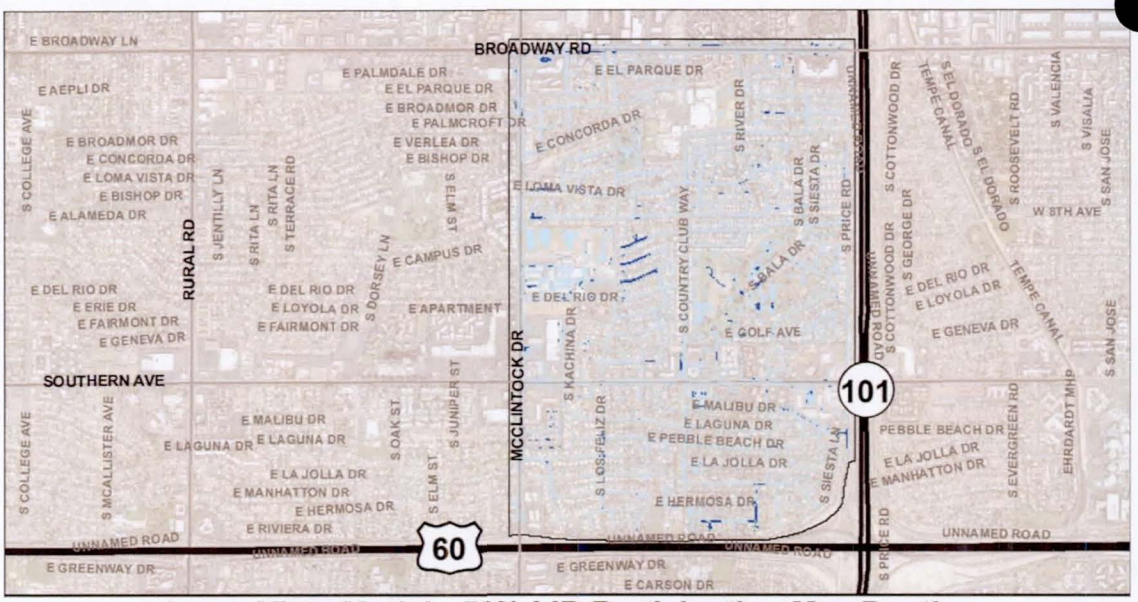
In order to show the impact of LID participation rate on the surface peak flow reduction for the 2-year storm event surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts with all four (4) LID participation rates. These two charts show that surface runoff reduction increases with the increase of LID participation rate.



McClintock Dr. at Broadway Rd. - 2-Year Storm



Broadway Rd. at McClintock Dr. – 2-Year Storm



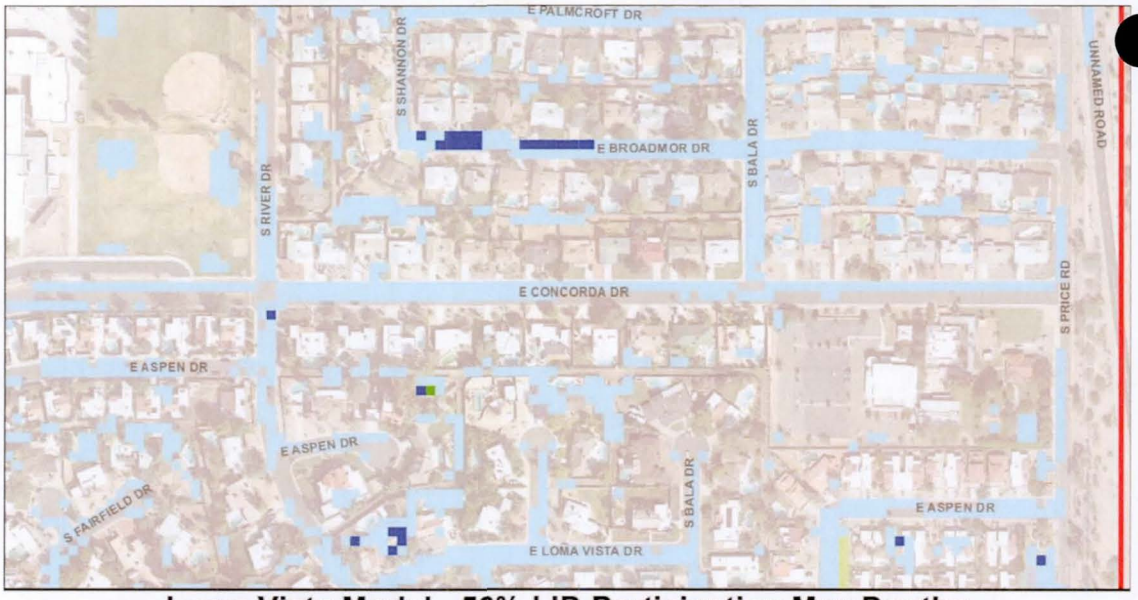
Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 3,000 feet



Loma Vista Model - 50% LID Participation Max Depths

2 yr Storm Max Depth (ft)

0.04 - 0.10	1.01 - 2.00	6.01 - 8.00
0.11 - 0.50	2.01 - 4.00	8.01 - 10.00
0.51 - 1.00	4.01 - 6.00	10.01 +

N

1 inch = 400 feet

8.5 Summary of Multiple Frequency FLO-2D Modeling Results

The FLO-2D modeling results for the multiple frequency storms with the four (4) parcel participation rates were summarized in Tables 7.1 to 7.6:

Table 7.1 documents the modeling results for infiltration and interception variables;
Table 7.2 documents the modeling results for surface floodplain storage variable;
Table 7.3 documents the modeling results for floodplain outflow volume;
Table 7.4 documents the modeling results for stormdrain inflow volume;
Table 7.5 documents the modeling results for stormdrain returning flow;
Table 7.6 documents the modeling results for stormdrain total outfall peak flows.
The values in the tables as functions of the storm size and parcel participation rate were also shown in the charts following each table.

The modeling results show that LID applications are very effective in flood mitigation in reducing the storm runoff volumes.

Table 7.1 Loma Vista Multiple Frequency Results

Infiltration & Interception (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.3	34.3	32.8	28.9
	10%	44.2	42.2	40.2	34.2
	30%	54.7	52.4	49.9	40.8
	50%	70.0	67.3	63.9	50.2
	75%	88.0	84.8	80.0	60.6

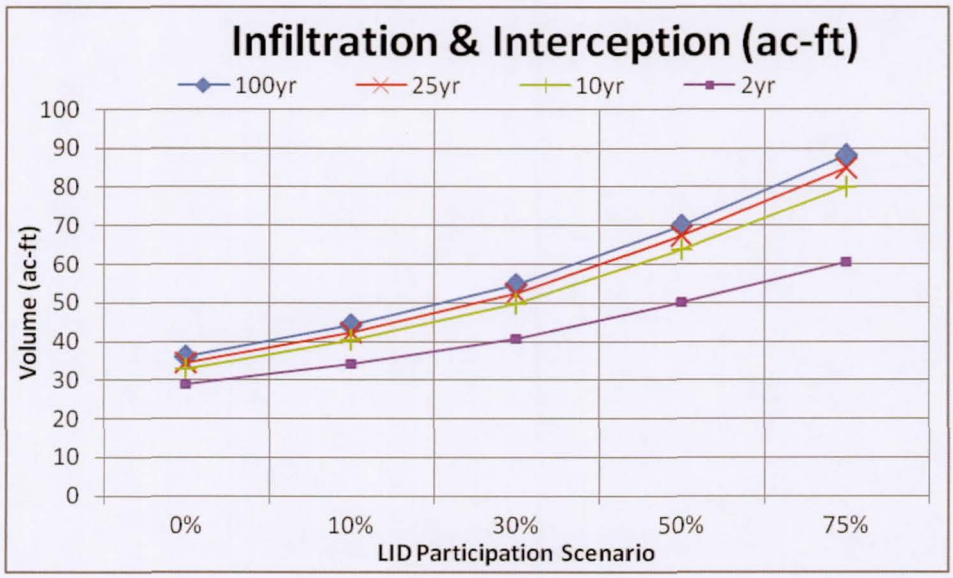


Table 7.2 Loma Vista Multiple Frequency Results					
Floodplain Storage (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	65.0	51.5	41.0	28.0
	10%	62.7	47.3	38.0	25.9
	30%	59.6	43.6	35.1	23.4
	50%	52.6	36.9	29.6	18.7
	75%	44.6	30.1	22.7	12.8

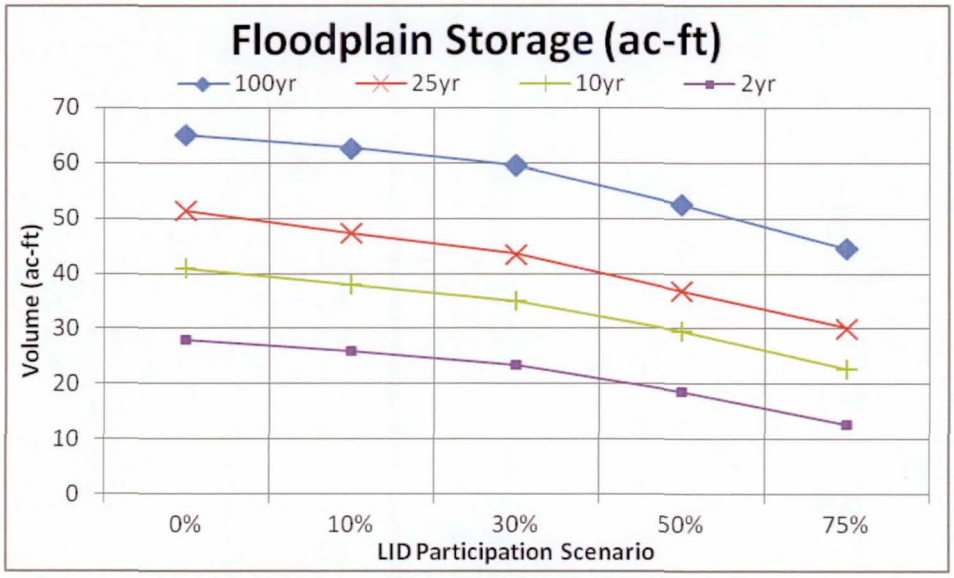


Table 7.3 Loma Vista Multiple Frequency Results					
Floodplain Outflow (ac-ft)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	36.8	16.3	9.3	3.6
	10%	32.8	14.7	8.4	3.4
	30%	28.0	11.8	7.3	3.1
	50%	19.9	8.7	5.7	2.5
	75%	15.2	6.7	4.5	2.2

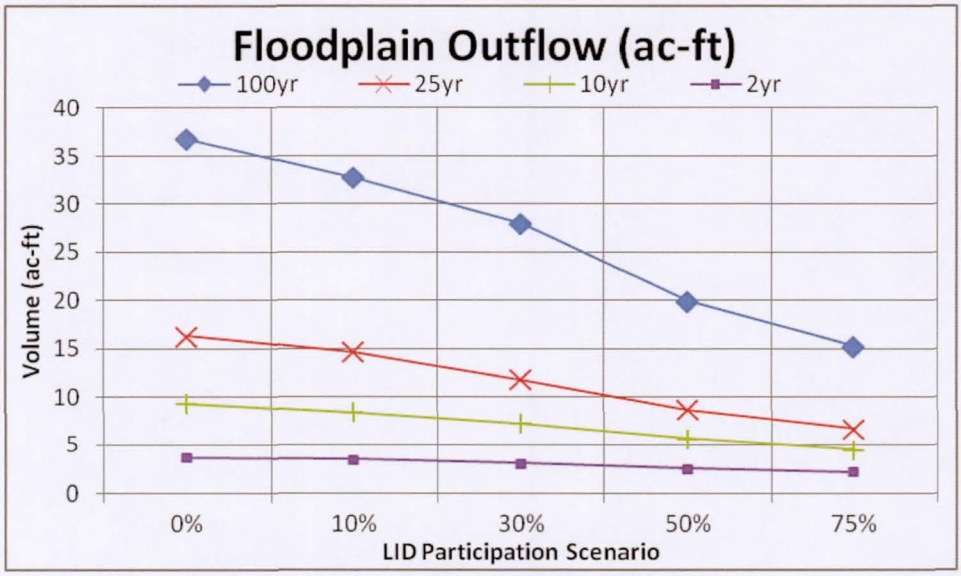


Table 7.4 Loma Vista Multiple Frequency Results						
Stormdrain Inflow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	106.7	95.3	82.4	45.5
		FLO2D	99.8	88.5	75.8	40.3
	10%	SWMM	105.0	91.2	76.8	40.8
		FLO2D	97.9	84.5	70.1	35.9
	30%	SWMM	101.7	86.1	67.6	33.6
		FLO2D	94.5	79.2	61.3	29.8
	50%	SWMM	98.6	76.8	58.4	26.5
		FLO2D	92.5	70.5	51.9	23.4
	75%	SWMM	91.5	65.0	44.2	14.0
		FLO2D	84.7	58.4	38.8	13.6

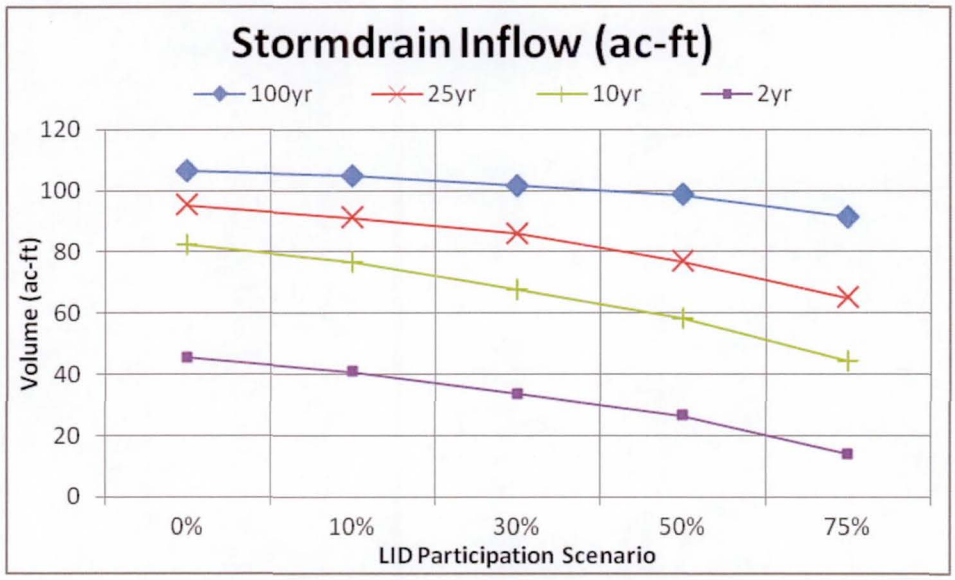


Table 7.5 Loma Vista Multiple Frequency Results						
Stormdrain Return Flow (ac-ft)			Storm			
			100yr	25yr	10yr	2yr
Participation	0%	SWMM	42.8	38.9	33.0	16.3
		FLO2D	33.5	30.0	25.1	12.4
	10%	SWMM	42.1	36.6	30.2	14.6
		FLO2D	33.1	28.0	22.9	11.0
	30%	SWMM	41.2	34.2	26.1	10.8
		FLO2D	32.3	26.3	19.7	8.7
	50%	SWMM	40.0	30.3	22.6	8.2
		FLO2D	30.6	22.8	17.2	6.4
	75%	SWMM	36.8	25.7	16.4	0.5
		FLO2D	28.1	19.5	12.1	0.8

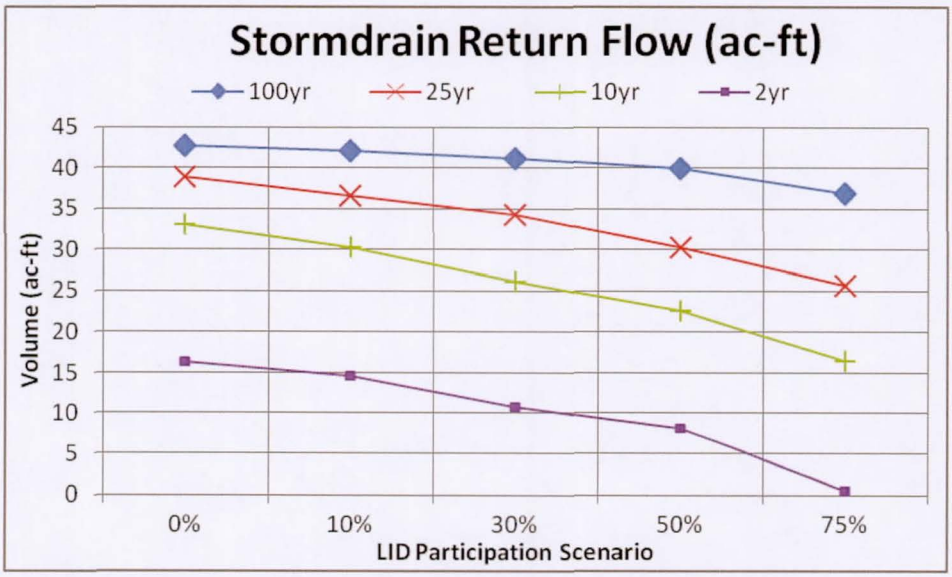
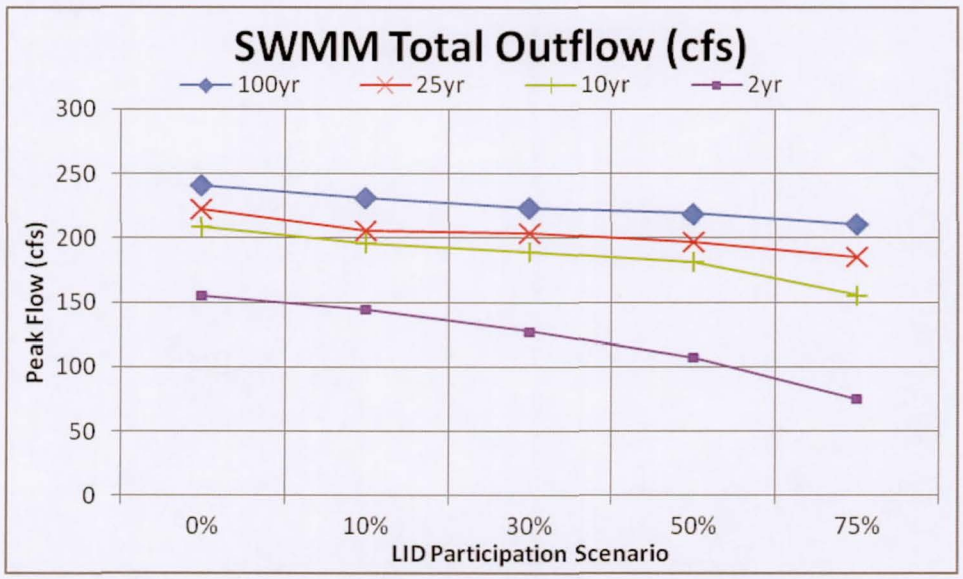


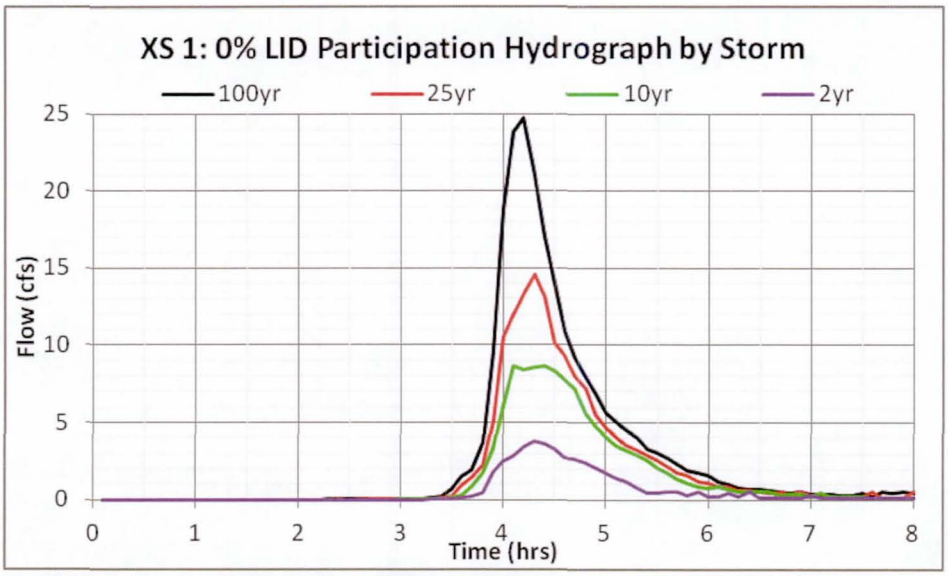
Table 7.6 Loma Vista Multiple Frequency Results					
SWMM Total Outflow (cfs)		Storm			
		100yr	25yr	10yr	2yr
Participation	0%	241.0	222.2	208.9	155.3
	10%	231.3	205.8	196.2	144.6
	30%	223.6	203.9	189.3	127.1
	50%	218.8	196.9	181.4	107.3
	75%	210.4	184.9	155.4	75.3



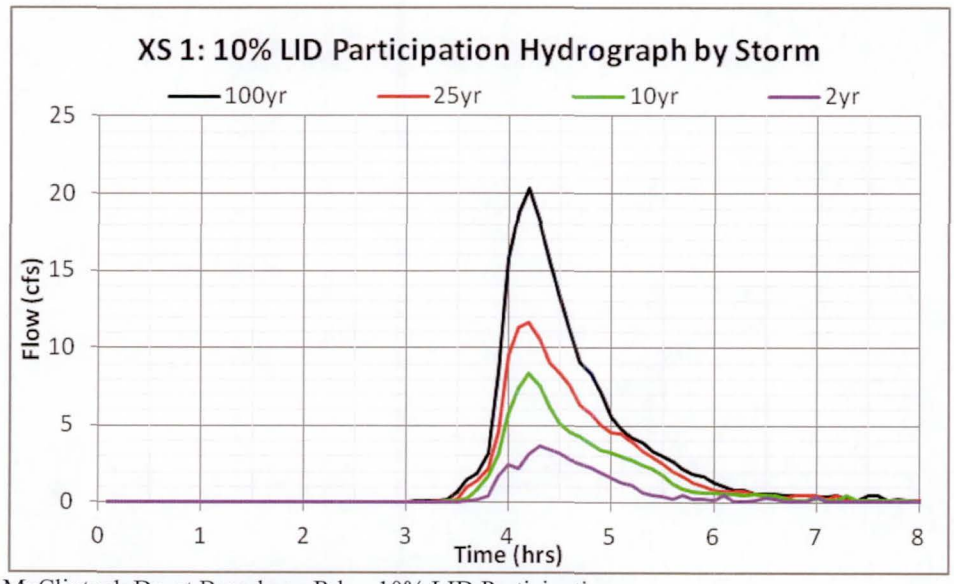
The surface flow hydrographs at two of the floodplain cross sections at the downstream of the modeling area were shown in the following charts in order to show the effectiveness of LID

applications on the surface peak flow reduction (all cross section hydrographs are included in Appendix I):

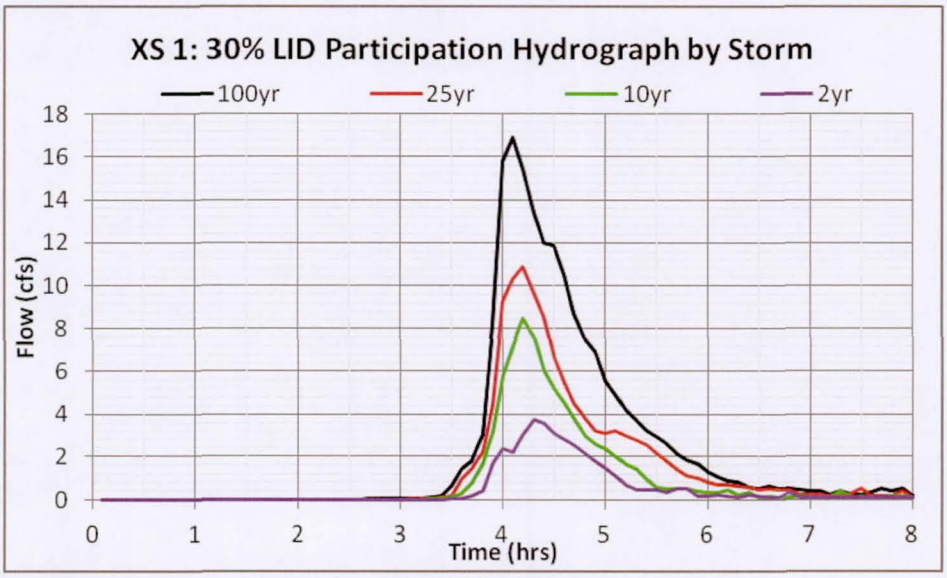
CS #1 is located at McClintock Dr. and Broadway Rd. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces with more frequent storms.



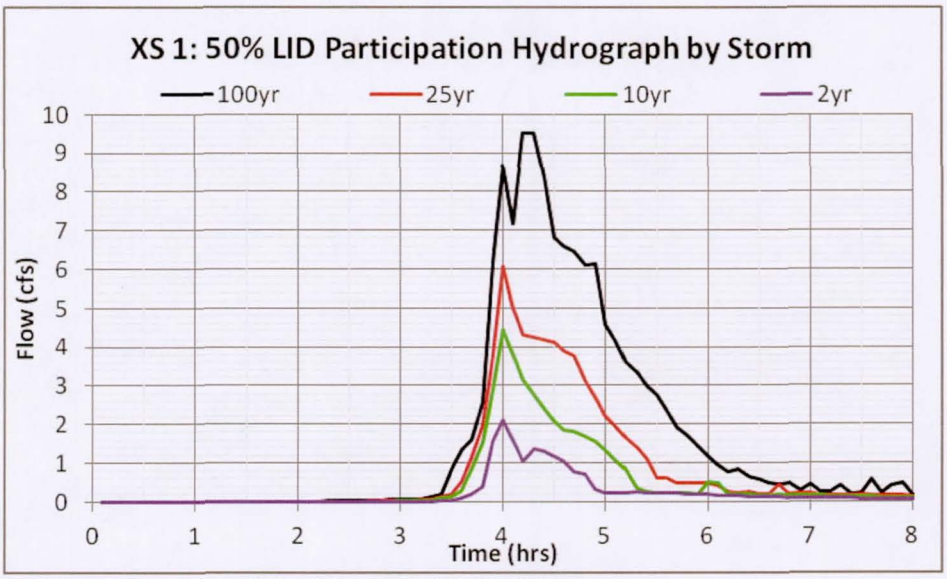
McClintock Dr. at Broadway Rd. – 0% LID Participation



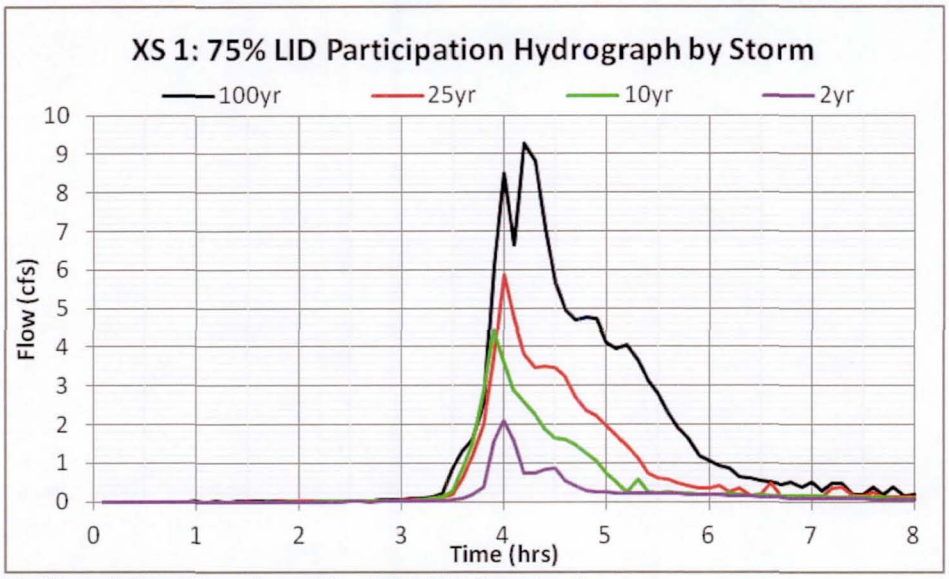
McClintock Dr. at Broadway Rd. – 10% LID Participation



McClintock Dr. at Broadway Rd. – 30% LID Participation

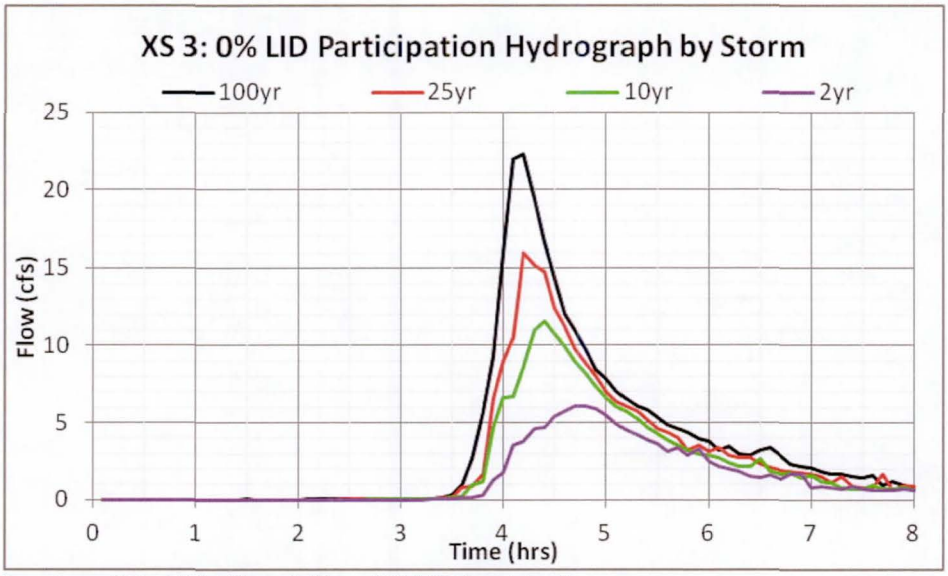


McClintock Dr. at Broadway Rd. – 50% LID Participation

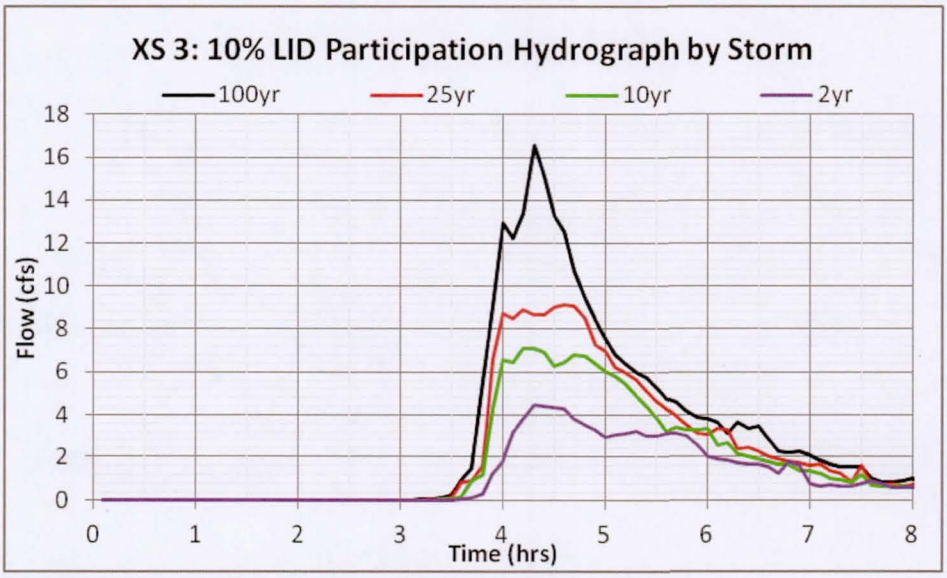


McClintock Dr. at Broadway Rd. – 75% LID Participation

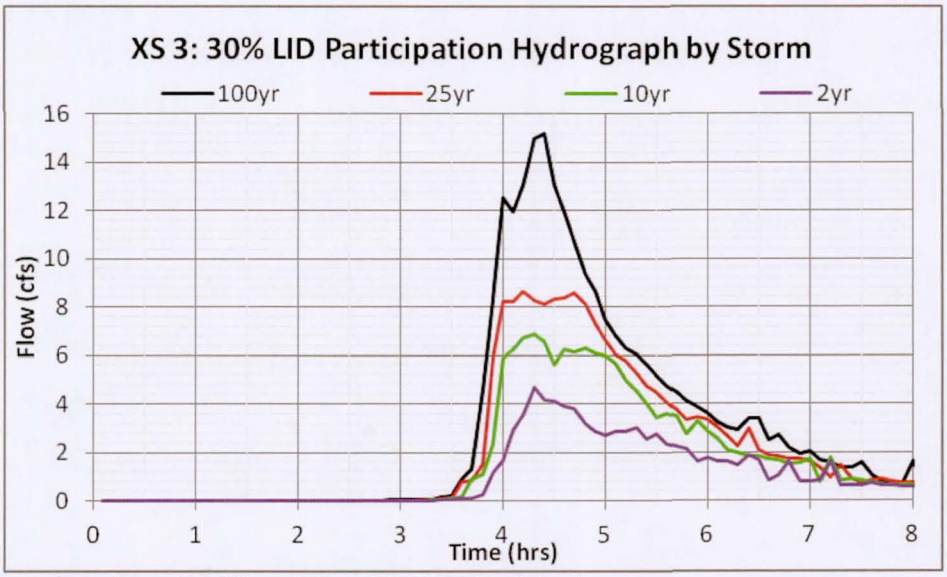
CS #3 is located at Broadway Rd. and McClintock Dr. and the hydrographs charts are listed in the order of LID participation rate. These charts show that the peak flow reduction increases with the increase of parcel participation rate. The peak flow reduces more with more frequent storms.



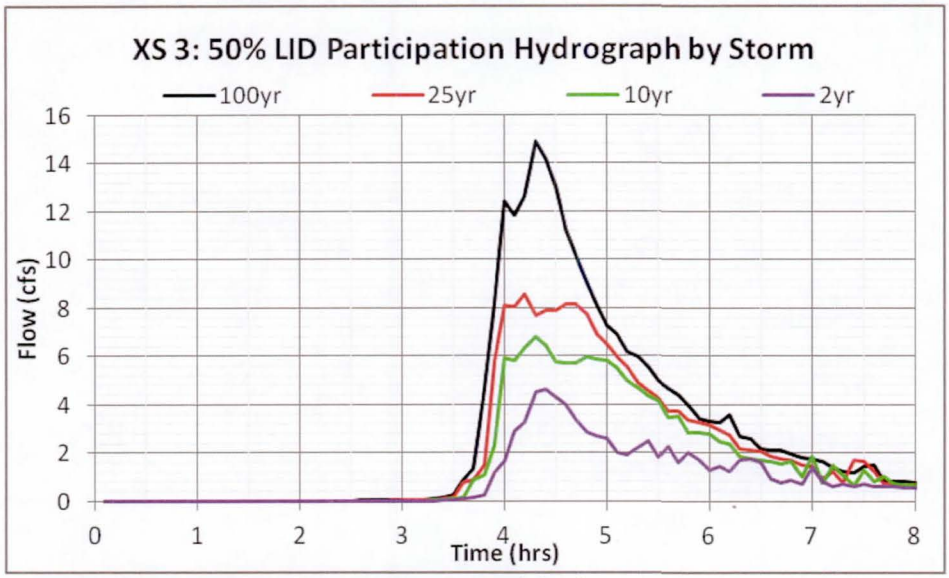
Broadway Rd. at McClintock Dr. – 0% LID Participation



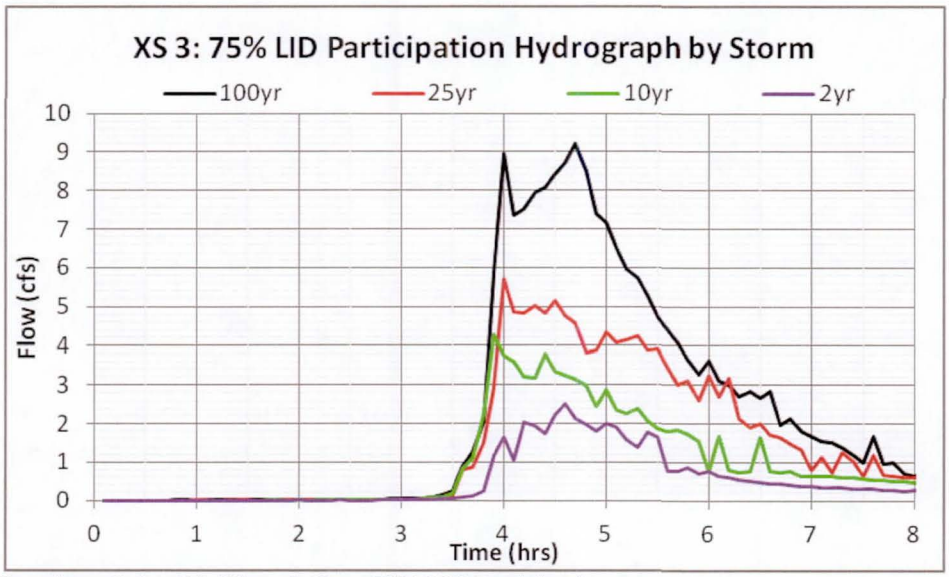
Broadway Rd. at McClintock Dr. – 10% LID Participation



Broadway Rd. at McClintock Dr. – 30% LID Participation



Broadway Rd. at McClintock Dr. – 50% LID Participation



Broadway Rd. at McClintock Dr. – 75% LID Participation

9.0 REFERENCES

1. ESRI, *ArcGIS,* Version 10, 2010.
2. FLO-2D Software Inc., *FLO-2D*, Pro Version, Model-Build No. 13.11.06, 2014.
3. Manifold Software Limited, *Manifold System*, Version 8.0, 2010.
4. U.S. Environmental Protection Agency, *EPA SWMM*, Version 5.0 (Build 5.0.022), April 2011.
5. inpPINS Computer Program, https://sites.google.com/site/inppins/guide
6. Bentley Systems, Inc., *CulvertMaster*, Version 3.2, August 2008
7. Flood Control District of Maricopa County, FLO-2D Review Guidelines, revised version, July 2012.
8. Riada Engineering, FLO-2D Reference Manual.
9. Riada Engineering, FLO-2D Data Input Manual.
10. Riada Engineering, FLO-2D GDS Manual.
11. Riada Engineering, FLO-2D Mapper Manual.
12. Riada Engineering, FLO-2D Limiting Froude Number Application Guidelines.
13. Riada Engineering, FLO-2D Pocket Guide.
14. Riada Engineering, User Assigned Courant Number in TOLER.DAT for Enhanced Model Numerical Stability.
15. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, User's Manual, Version 4.1, June 1998.
16. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package, Version 4.1, June 1998.
17. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1 January 2010.
18. *Broadway & Rural DMP: FLO-2D Pilot Study*, Cardno WRG, October 1, 2010.
19. *Broadway Road/Rural Road Candidate Assessment Report (CAR)*, Project Engineering Consultants, Ltd. September 2002.
20. *Drainage Policies and Standards for Maricopa County*, Flood Control District of Maricopa County, April 24, 2007.

21. *Drainage Design Manual for Maricopa County, Hydrology*, Flood Control District of Maricopa County, November 18, 2009.

22. *Drainage Design Manual for Maricopa County, Hydraulics*, Flood Control District of Maricopa County, August 15, 2013.

23. *Phoenix-Tempe Area Mapping, Project ID 1291, Contract No. FCD 08-20*, Flood Control District of Maricopa County, August 4, 2009.

24. *SCS_Soil GIS Shape Files,* Flood Control District of Maricopa County, March 10, 2010.

25. *FLO-2D Data Input Manual, Version 2009.06,* FLO-2D Software, Inc., November 30, 2010.

26. *FLO-2D Review Checklist (DRAFT),* Flood Control District of Maricopa County, May 5, 2011.

27. *Broadway-Rural Pilot Study, FLO-2D Hydrograph Analysis,* Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

28. *TOL and Hydraulic Structure Rating Curves Interoffice Memorandum*, Flood Control District of Maricopa County, Engineering Division, Special Projects Branch, October 25, 2010.

29. *Tempe ADMS/P Data Collection Report*, J2, August 2014.

30. *Tempe ADMS/P Test Area Sensitivity Analysis Summary Report*, J2, March 2014.

31. *Tempe ADMS/P Test Area FLO-2D Analysis Summary Report*, J2, June 2015.

32. *Tempe ADMS/P FLO-2D/SWMM Modeling Report*, J2, November 2015.

33. *Tempe ADMS LID Application Review and FLO-2D Modeling, J2, January 2016.*