Cardno WRG

Shaping the Future

BROADWAY & RURAL DRAINAGE MASTER PLAN: FLO-2D HYDROLOGIC AND HYDRAULIC ANALYSIS

FCDMC CONTRACT# 2009035

WORK ASSIGNMENT #2

MARICOPA COUNTY, ARIZONA

SEPTEMBER 12, 2011

Prepared For:

Flood Control District of Maricopa County
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Phoenix, AZ 85009
Phone: 602-506-1501

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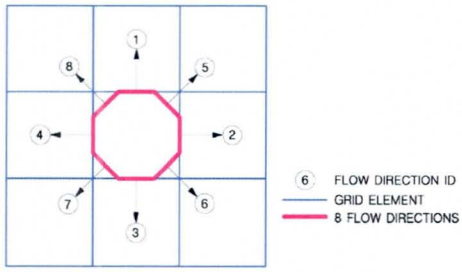
SECTION 1.0 EXECUTIVE SUMMARY

The Flood Control District of Maricopa County (FCDMC) has contracted with Cardno WRG to conduct this *Broadway & Rural Drainage Master Plan: FLO-2D Hydrologic and Hydraulic Analysis* herein referred to as the *Drainage Master Plan*.

The impetus for this *Drainage Master Plan* arose from the *Candidate Assessment Report: Broadway & Rural* prepared by Project Engineering Consultants (PEC) on behalf of the FCDMC in September of 2002 (Ref. 2). This *Candidate Assessment Report (CAR)* assembled and documented current available data, identified historic flooding problems, and made recommendations for future studies and mitigation concepts within the Daley Park Subdivision. For this *Drainage Master Plan*, the FCDMC expanded the project area beyond the Daley Park Subdivision to include identifying the flood hazard potential throughout the Daley Park Subdivision contributing watershed. No other Candidate Assessment Reports are known to have been prepared for areas outside of the Daley Park Subdivision.

FLO-2D, which is a quasi-two-dimensional hydrologic and hydraulic modeling software, was used accordingly for the Broadway Rural DMP Study Area. This software is described by *FLO-2D Software, Inc.* as a simple volume conservation flood routing model, represented as a domain of small grid elements where flood volume is transferred amongst the elements based on topography and resistance to flow. A grid element is characterized with eight (8) distinct flow directions as illustrated below.



This transfer of volume amongst grid elements is based upon the application of the continuity equation and the dynamic wave momentum equation across the individual grid element boundaries. The application of these equations is done so across one grid element boundary at a time.

Using FLO-2D in urbanized areas is relatively new for the FCDMC. Therefore, the FCDMC did not have specific FLO-2D modeling guidelines and criteria established for use in urban areas. The *Broadway Rural DMP: FLO-2D Pilot Study*(herein referred to as the *FLO-2D Pilot Study*) completed in October 2010 by Cardno WRG helped establish some of these criteria and guidelines (Ref. 1). The FCDMC's intent of this Pilot Study was to increase the level of confidence in the accuracy of the ultimate Broadway Rural DMP FLO-2D modeling through identification of modeling protocols. Elements of the *FLO-2D Pilot Study* applied to this *Drainage Master Plan* include the identification of an appropriate grid size, development of a digital terrain model, and two-dimensional modeling protocols for fences/walls, storm drain systems, and streets specific to the Broadway Rural DMP Study Area.

The modeling procedures rigorously investigated as a part of the *FLO-2D Pilot Study* and the directives for use in this *Drainage Master Plan* are discussed in the following sections

Grid Element Size Determination

Both 25- and 50-foot grid element sizes were investigated for use in the *Broadway Rural DMP: FLO-2D Pilot Study*. The larger 50-foot grid element size was found to not provide the level of detail necessary to appropriately characterize an urbanized area. Furthermore, this insufficient level of detail required use of the street and levee coding procedures available within FLO-2D to add more detail to the coarser 50-foot grid element size. This additional effort required a significant amount of additional time to complete.

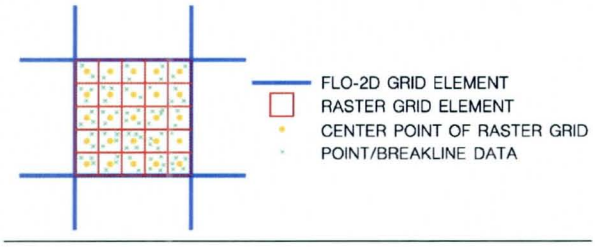
The 25-foot grid element size was identified for use in preparation of this Drainage Master Plan.

Topographic Surface Characteristics

The *FLO-2D Pilot Study* identified a protocol for the characterization of the topographic features within the Study Area and determination of average elevations for each FLO-2D grid element. Two methods for characterizing topographic surface data were initially investigated as a part of the *FLO-2D Pilot Study*.

The first of these procedures included direct incorporation of the data provided by the FCDMC into FLO-2D for calculation of average grid element elevations. This procedure was found to yield biased grid element elevations in many instances due to the variability in the level of mapping detail within the urbanized watershed. FCDMC Mapping guidelines were reviewed as a result of this finding.

The second procedure consisted of a multi-step process in which the data were translated into an elevation raster file. This raster file consisted of a network of small grid elements each with an associated center point elevation. The elevations of these small raster grid elements were then used to determine average elevations for the larger FLO-2D grid elements.



This procedure was found to provide a better characterization of the topography within the Study Area and was identified for use in this *Drainage Master Plan*.

Modeling of Streets using procedures available within FLO-2D

The *FLO-2D Pilot Study* investigated the use of procedures available within FLO-2D to model the conveyance capabilities of street cross-sections. This street analysis capability is facilitated by the STREET.DAT data input file within the FLO-2D program.

A comparison between two FLO-2D models was performed as a part of the *FLO-2D Pilot Study*. The purpose of this comparison was to ascertain any advantage of using a coarser grid element size augmented with street conveyance capabilities over a finer grid element size with no additional street conveyance capabilities. Use of a coarse grid element size model incorporating the STREET.DAT data input file was found to yield hydrograph instabilities and oscillations for cross-sections contiguous to grid elements containing levee and reduction factor coding. Furthermore, identification of cross-sections within grid elements void of levee and reduction factor coding proved difficult given the highly urbanized nature of the Study Area.

Use of a finer 25-foot grid element size with no additional street conveyance modeling was identified for use in this *Drainage Master Plan*.

Modeling of Existing Walls and Fences as Levees

An investigation into the potential for effects of existing walls on hydraulic response was performed as a part of the *FLO-2D Pilot Study*. A portion of an existing wall located along the west side of Rural Road and north of Broadway Road was modeled within the Study Area considered in the *FLO-2D Pilot Study*, using the LEVEE.DAT data input file. Cardno WRG manually coded the existing wall with a fixed height of six (6) feet with preclusion from structural failure. A comparison in the residual flow depths yielded by models both with and without modeled walls/fences yielded increases of up to 0.5 feet in the area generally located downstream of the existing wall.

Use of the LEVEE.DAT data input file and incorporation of select walls/fences within the Study Area based on potential for significant flow depth increases was identified for use in this *Drainage Master Plan*.

Modeling of Existing Storm Drain Facilities

The FLO-2D Pilot Study evaluated the effects of storm drain systems on the FLO-2D model. Two existing storm drain systems located within Rural Road were evaluated as a part of the FLO-2D Pilot Study for the purposes of assessing protocols for forthcoming storm drain analyses. These systems were each located within Rural Road, north of Broadway Road. The pipe flowing full capacity of each storm drain system was modeled with the use of the HYSTRUC.DAT data input file. The effects of the two storm drain systems considered, on residual flow depth were found to be minimal, yielding reductions of two inches or less.

What was the main difference between the two models?

use units in feet, as in the data table

The FCDMC and Cardno WRG however, concluded that the residual effects on flow depth could be more pronounced when subjected to higher frequency storm events. Therefore, the hydraulic capacity of storm drains 36-inches and larger were identified for incorporation into this Drainage Master Plan.

~~include~~ Title this as different section

This hydrologic and hydraulic analysis associated with this *Drainage Master Plan* identified several potential storm water inundation areas within the project study area based on the 100-year frequency event. These inundated areas were graphically identified with the use of FLO-2D and found to consist of flow depths ranging from just inches to several feet within streets, parks, commercial and industrial areas, multi-family residential areas, and single family residential areas. Twelve (12) distinct single-family residential areas were identified on the basis of widespread ponding depths greater than one-half foot. These areas were further parsed to ten (10) to include only those areas with flow depths in excess of one-foot.

The graphical modeling results were then used to select single family residential homes for further finished floor elevation survey for the purposes of direct comparison to grid

element water surface elevations and estimations of inundation depth. Finished floor elevation survey was strictly limited to homes identified to have a potential for inundation during the course of the modeling exercise. The potential for inundation is not necessarily limited to the areas and homes identified herein.

These areas are summarized in Table 1.1 – *Problematic Drainage Areas*.

AREA	GENERAL LOCATION	HOMES INUNDATED
1	Intersection of Broadway Rd and Rural Rd-Northwest Corner	21
2	Intersection of Southern Pacific RailRoad and Mill Avenue-Southeast Corner	13
3	Intersection of Broadway Road and Mill Avenue	11
4	Mill Avenue between Alameda Drive and Geneva Drive	12
5	Alameda Drive between College Avenue and Rural Road	-
6	Intersection of Campus Drive and Terrace Road	1
7	LaJolla Drive between College Avenue and McAllister Avenue	-
8	Intersection of Riviera Drive and Bonarden Lane	9
9	Los Feliz Drive between Southern Avenue and U.S. 60	8
10	Intersection of Riviera Drive and River Drive	0
11	Los Feliz Drive between Southern Avenue and Alameda Drive	2
12	Intersections of Loma Vista Drive/Alameda Drive and McClintock Drive	21

separate word/number

Throughout the study area, 98 homes were identified to have finished floors subject to inundation within the 100-year event. Fifty-three (53) of these homes are expected to have flooding depths greater than 0.5 feet above the finished floor elevation.

A majority of the single family residential homes within the Study Area may be characterized as single family residential homes constructed during the early to mid 1950s. The construction of many may be characterized with slab-on-grade style construction that yields minimal elevation differential between the finished floor elevation and that of the contiguous street.

A 0.5-foot depth of flow can be significant in regard to building and contents loss for these homes. The Federal Emergency Management Agency's (FEMA) *Understanding Your Risks, Identifying Hazards and Estimating Losses*, indicates that a flood depth of 0.5 feet may render up to 12% of a one-story home (without a basement) as damaged and over 17% of the building's contents as damaged.

SECTION 2.0 INTRODUCTION

2.1 Purpose of Study

The *Broadway &Rural Drainage Master Plan: Hydrologic and Hydraulic Analysis* herein referred to as the *Drainage Master Plan,* serves as the succeeding study to the the *Candidate Assessment Report* (CAR) prepared by Project Engineering Consultants on September 30, 2002. This *Drainage Master Plan (DMP)* identified problematic drainage areas within the overall Broadway & Rural Study Area using quasi-two-dimensional hydrologic and hydraulic modeling methodology. The *Broadway Rural FLO-2D Pilot Study* served as the supporting document to this *Drainage Master Plan.*

The purpose of this *Drainage Master Plan* per the FCDMC's Notice to Proceed (NTP) dated October 8, 2010, is reproduced below.

The purpose of this work assignment is to identify and quantify the extent of the flooding in the Daley Park subdivision and its associated contributing watershed. The areal extent, water depth, velocities, and flows of the flood hazards will be identified and quantified throughout the entire Broadway and Rural watershed. Based on the results of this work assignment, the District will determine if a subsequent work assignment is warranted, which would be used to identify solutions to flood hazards. If so, the subsequent work assignment would include identifying flood mitigation solutions for the Daley Park Subdivision and/or the Broadway and Rural Watershed.

The FCDMC initiated the *Broadway Rural FLO-2D Pilot Study* as well as this *Broadway& Rural DMP* due to historic storm water flooding occurrences within the Daley Park Subdivision. The Daley Park neighborhood encompasses approximately 58-acres of the Study Area and consists of 192 households originally built in the early to mid-1950s. Many of the homes within the Daley Park Subdivision as well as elsewhere within the Study Area may be characterized by slab-on-grade construction found to typically yield minimal finished floor elevation differential above the adjacent roadway elevations.

While initial emphasis was placed on flooding within the Daley Park Subdivision, this *Drainage Master Plan* identified flood hazards throughout the remaining Broadway Rural DMP Study Area.

Cardno WRG was retained to prepare the *Broadway & Rural Drainage Master Plan: Hydrologic and Hydraulic Analysis* as a part of the Flood Control District of Maricopa County's (FCDMC) On-Call Contract FCD2009C035, Work Assignment #2 (See Appendix A for the complete scope of work).

2.2 Location of Study

The overall study area associated with the *Broadway & Rural DMP* consists of approximately 5.176 square miles. It is located within the City of Tempe corporate boundaries and is generally bounded by the U.S. 60 on the south, the Union Pacific Railroad on the north, the Price Road/Loop 101 Freeway on the east, and the railroad spur west of College Avenue on the west. The location of the Broadway & Rural DMP Study Area is graphically illustrated on Exhibit 2.2 – *Location Map*.

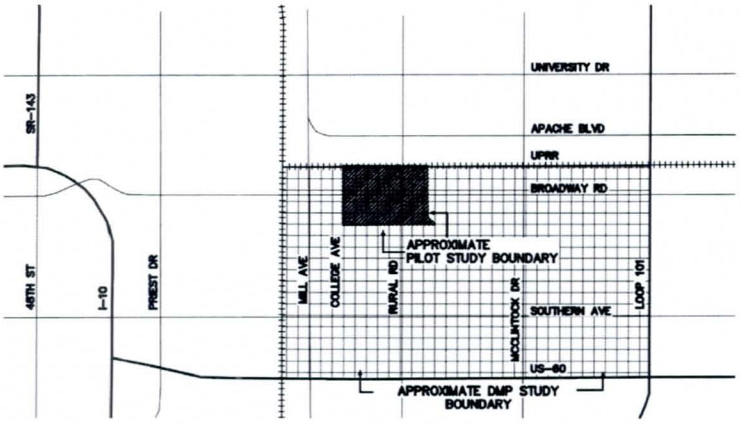


Exhibit 2.2– *Location Map*

The entire Broadway Rural DMP Study Area perimeter is augmented with an additional buffer area, representing the area modeled with FLO-2D. This FLO-2D Model Boundary is discussed in more detail in subsequent sections of this report.

2.3 Site Description

The Study Area associated with this *Drainage Master Plan* is located entirely within the City of Tempe Corporate boundaries. The Broadway Rural DMP Study Area may generally be characterized by a mix of well-established single and multi-family residential neighborhoods, commercial centers, general industrial, and schools. The Daley Park/University Heights Subdivision generally consists of homes constructed in the 1950s. The remainder of the Broadway Rural Study Area consists of single family

residential buildings and commercial-industrial structures primarily built in the 1960s, 1970s, and 1980s.

City of Tempe zoning categories along with their respective area component of the Broadway Rural DMP Study Area are tabulated below in Table 2.3.1 – *Study Area Zoning Categories* for the purpose of characterizing the land use within its boundaries. While this data serves to characterize the general land use within the watershed, a more detailed breakdown of the existing land surface features found throughout the Study Area was incorporated into the two-dimensional models. These existing surface features, such as asphalt, concrete, asphalt, grass, vegetation, bare ground, and buildings are discussed in subsequent sections of this report.

Table 2.3.1 – *Broadway Rural DMP Study Area Zoning Categories*

City of Tempe Zone Code	Description	Area Component[1] [%]
R1-6	Single Family Residential	58.8
R-3	Multi-Family Residential	10.6
CSS	Commercial Shopping and Services	5.4
PCC-1	Planned Commercial Center-Neighborhood	4.2
RO	Residential/Office	3.2
GID	General Industrial District	3.0
R-2	Multi-Family Residential	2.7
PCC-2	Planned Commercial Center-General	2.2
R1-4	Single Family Residential	2.2
R-4	Multi-Family Residential	2.0
AG	Agriculture	1.8
R-3R	Multi-Family Residential-Restricted	1.4
R1-10	Single Family Residential	0.8
MU-2	Mixed Use, Medium Density	0.4
R1-PAD	Single Family Residential Planned Area Development	0.2
R1-7	Single Family Residential	0.1
MU-ED	Mixed Use-Educational	0.03
RO	Residential/Office	0.02

Notes:

1. Balance of area consists of right-of-way

SECTION 3.0 FEMA/ADWR COORDINATION

The purpose of this work assignment is to identify and quantify the flooding hazards within the Study Area. The results of the hydrologic and hydraulic modeling presented herein are intended to serve as a planning tool for use by the FCDMC. Submittal of this *Drainage Master Plan* to the Federal Emergency Management Agency for the purposes of any flood hazard area delineation was not included as a part of this Scope of Services.

SECTION 4.0 MAPPING & SURVEY INFORMATION

The FCDMC provided Cardno WRG with recent digital topographic mapping data procured as a part of Contract No. FCD 08-20, Project ID 1291-*Phoenix-Tempe Area Mapping*. Specific details regarding this mapping data as provided by the FCDMC are listed below in Table 4.1 – *Topographic Mapping Parameters*.

Table 4.1 – *Topographic Mapping Parameters*

Phoenix-Tempe Area Mapping – FCD 08-20	
Flight Date	12/11/2008
Contour Interval	2-foot
Vertical Datum	NAVD88
Horizontal Datum	State plane NAD83, Arizona Central

Topographic information provided by the FCDMC included mass point and breakline file data in an X, Y, Z format, which was utilized for the development of the digital terrain model discussed in subsequent sections of this report.

Additional field survey services were authorized by the FCDMC as a part of Task 3.9-Optional Services, during the course of preparation of this *Drainage Master Plan*.. This additional data included finished floor elevations, curb/gutter, and catch basin elevations. This data was obtained based on Geodetic Densification and Cadastral Survey (GDACS) points with published elevations based on NAVD88 vertical datum.

SECTION 5.0 HYDROLOGIC AND HYDRAULIC MODELING

The entire Broadway Rural Study Area was characterized with a system of over 278,000 25-foot square grid elements. The 25-foot grid element size was selected for use in this *Drainage Master Plan* based on analysis presented in the *FLO-2D Pilot Study*. The 25-foot grid element size afforded additional ability to characterize existing and/or irregular buildings and did not require additional detail for the characterization of roadways with the use of 1D street elements.

Each grid element was associated with a representative elevation, applicable existing building blockage factor, and surface feature characteristics. A runoff response was modeled for the grid system based on application of a rainfall depth and temporal distribution for the 2-, 10-, and 100-year frequency events, each with a 6-hour duration. The 6-hour duration is typically used for flood studies and design of storm water drainage facilities in Maricopa County of drainage areas less than 20 square miles. Details regarding each of the parameters and the processes used in their determination are discussed in the following sections.

FLO-2D version 2009.06, Build No. 2009.17.02, in conjunction with a FLO.exe executable file dated November 17, 2010 were used to obtain the results presented herein.

5.1 FLO-2D Modeling Input Parameters

The following sections discuss the identification of the Broadway Rural Study Area boundary and the development of FLO-2D data input files for the Broadway Rural Study Area. The FLO-2D data input files included the determination of precipitation data, soil infiltration parameters, and impact on hydraulic performance due to land surface features and existing building blockages.

5.1.1 Study Area Boundaries

As mentioned previously, the physical boundaries of the Broadway Rural Study Area are formed by the SPRR alignments on the west and the north and by freeway alignments on the east (Loop 101) and the south (U.S. 60), respectively. The Broadway Rural DMP Study Area is identified to contain approximately 5.176 miles^2 in area.

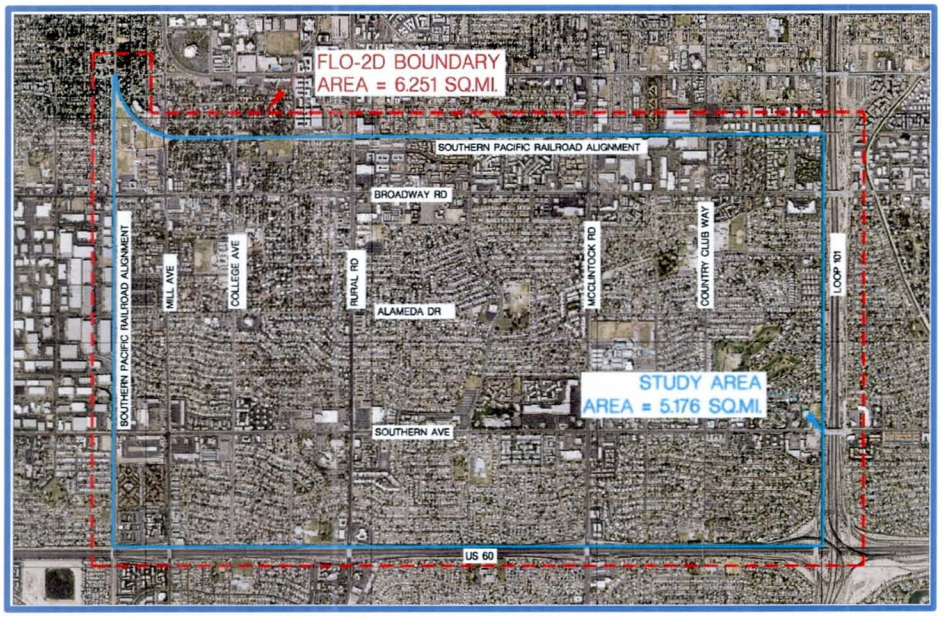


Exhibit 5.1.1.1 – *Broadway Rural Study Area Boundary*

The FCDMC in conjunction with Cardno WRG performed field reconnaissance within the Broadway Rural watershed on November 15, 2010 in effort to document this Study Area boundary. Concerns were raised during this reconnaissance regarding the potential for additional contributing watershed area into the Study Area from north of the existing Southern Pacific Railroad alignment. The FCDMC authorized the execution of a preliminary FLO-2D model for a 7.5 miles^2 area located north of the existing railroad tracks, based entirely on a digital elevation model and rainfall. A coarse 100-foot grid element size was used in effort to reduce run time and believed to be sufficient for the assessment of potential inflow points.

The execution of this preliminary model revealed two locations capable of contributing storm water to the Study Area.

- Northwest Corner of Mill Avenue and the SPRR alignment
- Northeast Corner of Rural Road and the SPRR alignment

Potential inflow at the northwest corner of Mill Avenue and the SPRR alignment would be expected to impact the Tempe High School athletic fields located in the northwest corner of the Study Area.

Potential inflow at the northeast corner of Rural Road and the SPRR alignment would not be expected to impact the Daley Park Subdivision and overflow Rural Road due to its elevated nature.

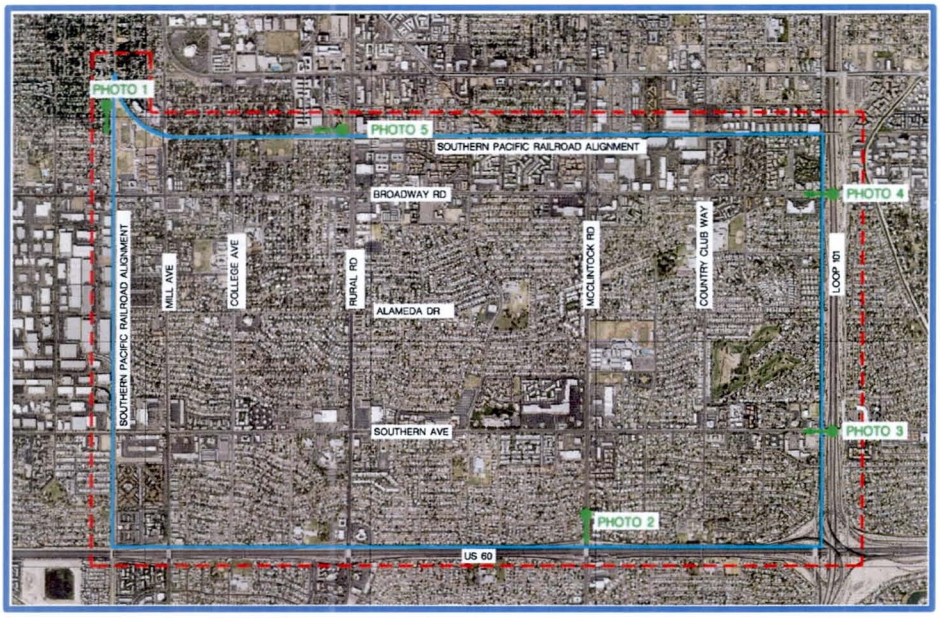
A memorandum entitled *Broadway & Rural DMP Watershed & Study Boundary,* prepared by the FCDMC, documenting the decisions made in regard to the study boundary is included in the Appendix. check

Cardno WRG performed further field reconnaissance along the perimeter of the Study Area in effort to identify the presence of potential incoming offsite flow. Specifically, this reconnaissance was performed along the northern and western railroad alignments and in the vicinity of the existing traffic interchanges located along the U.S. 60 and Loop 101 freeway alignments (southern and eastern study boundaries respectively).

Cardno WRG also reviewed the existing railroad track alignments located along the downstream northern and western boundaries of the Broadway Rural Study Area. The existing track alignments were found to consistently be elevated in nature, above adjacent grade, generally precluding storm flow from entering the study area from the north or west. Two (2) culvert locations were observed along the northern boundary, which allow accumulated storm flow to drain to the north and out of the study area.

The traffic interchanges were initially believed to provide the only potential points for offsite flow to enter the Study Area. Cardno WRG determined that the two freeway alignments and their associated infrastructure form substantial physical barriers to storm water that may have historically entered the study area from the east and the south. Furthermore, the typical design of the interchanges in conjunction with their cambered nature is believed to preclude storm flow from entering the Study Area.

The following field photographs illustrate the conditions found along each of the study area boundaries mentioned previously. The locations of the photographs are shown on Exhibit 5.1.1.2 – *Study Area Boundary Photo Locations*.



Where is Photo 6?

Exhibit 5.1.1.2 – *Study Area Boundary Photo Locations*

Exhibit 5.1.1.3 – *[Photo 1] - Northwestern Portion of Study Area Boundary*
(Looking south along railroad tracks; note elevated nature of railroad tracks)

Exhibit 5.1.1.4 – *[Photo 2] – Southern Portion of Study Area Boundary*
(Looking south along McClintock Road at US 60 traffic interchange; note elevated characteristic yielded by the camber of the interchange)

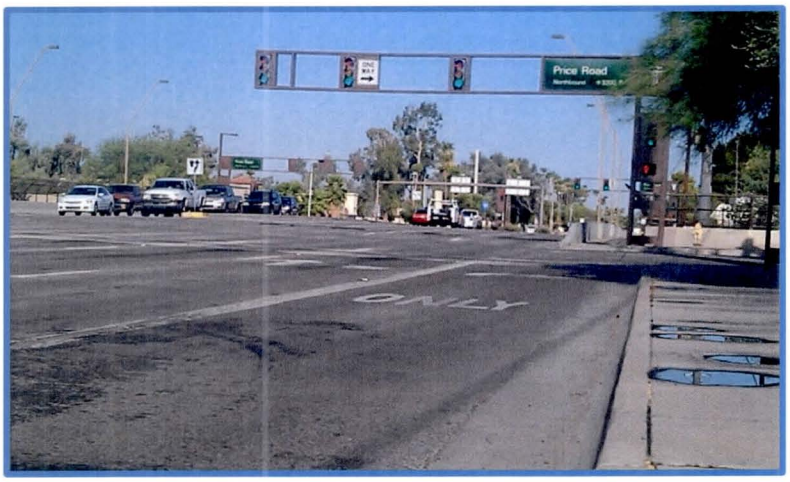


Exhibit 5.1.1.5 – *[Photo 3] – Eastern Portion of Study Area Boundary*
(Looking west along Southern Avenue at Loop 101 traffic interchange; note elevated characteristic yielded by the camber of the interchange)

Exhibit 5.1.1.6 – *[Photo 4] – Eastern Portion of Study Area Boundary*
(Looking east along Broadway Road at Loop 101 traffic interchange; note elevated characteristic yielded by the camber of the interchange)

Exhibit 5.1.1.7 – *[Photo 5] – Northern Portion of Study Area Boundary*
(Looking west along railroad track alignment just east of Rural Road; note elevated nature of railroad tracks)

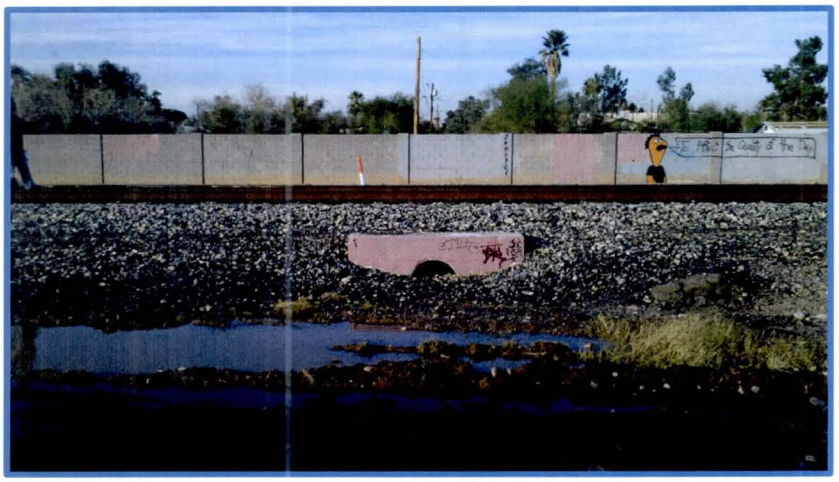


Exhibit 5.1.1.6 – *[Photo 6] – Existing Culvert along Northern Portion of Study Area Boundary*
(Looking north from south side of railroad track alignment near Rita Lane alignment; note elevated nature of railroad tracks)

Cardno WRG therefore determined that no significant watershed areas drain into the Study Area from outside of its boundary. No inflow hydrographs were incorporated into

the boundary of the Study Area. The peak flows estimated throughout the Study Area are based solely on precipitation modeled to fall upon the system of grid elements only.

The 5.176 mi^2Broadway Rural DMP Study Area perimeter was further augmented with an additional 500-footwide buffer area. The resulting 6.251 mi^2comprehensive area, referred to as the FLO-2D Model Boundary, represents the area modeled with the FLO-2D program. This buffer area was added to the Study Area based upon the conclusions presented in the *FLO-2D Pilot Study*, which identified the coincident placement of a Study Area, FLO-2D Model Boundary, and outflow node(s) as problematic. This was particularly relevant in the case of the Broadway Rural Study Area where the downstream boundary was formed by the elevated railroad track alignment. The alignment of the FLO-2D Model Boundary (and corresponding outflow nodes) along the elevated railroad track alignment (Study Area Boundary) was found to ignore the ability for storm water to collect and then be conveyed westerly along the upstream side of the elevated railroad track berm.

5.1.2 FLO-2D Data Input Files

A series of eleven (11) FLO-2D data input files were developed for use in the hydrologic and hydraulic modeling presented herein. These input files are summarized in Table 5.1.2 – *FLO-2D Data Input Files*. Development of each of the files is discussed in detail in subsequent sections.

Table 5.1.2 – *FLO-2D Data Input Files*[1]

FILE NAME	DESCRIPTION	VARIABLES
ARF.DAT	Area and Width Reduction Variables	Area Reduction Factor (ARF)
CADPTS.DAT	Topographic and Grid System Data	Grid element coordinates
CONT.DAT	System Control Variables	Maximum Froude Number (FROUDL) Shallow overland flow n-value (SHALLOWN) Simulation time (SIMUL)
FPLAIN.DAT	Floodplain Elements Variables	Grid element number Grid element roughness coefficient Grid element elevation
FPXSEC.DAT	Floodplain Cross-Section Variables	Floodplain cross section (IFLO) Grid elements within cross section (NNXSEC) Grid element array (NODX)
HYSTRUC.DAT	Hydraulic Structure Variables	Headwater depth (HDEPTH) Hydraulic structure discharge (QTABLE)
INFIL.DAT	Infiltration Variables	Grid element hydraulic conductivity (HYDC) Grid element capillary suction head (SOILS) Grid element soil moisture deficit (DTHETA) Grid element rainfall abstraction (ABSTRINF) Grid element impervious area (RTIMPF)
LEVEE.DAT	Levee and Levee Failure Variables	Grid no. containing levee segment (LGRIDNO) Levee crest elevation (LEVCREST) Flow direction cut off by levee (LDIR)
OUTFLOW.DAT	Output Variables	Outflow grid elements (NODDC)
RAIN.DAT	Rainfall Variables	Total storm rainfall (RTT) Rainfall intensity distribution (R_DISTR)
TOLER.DAT	Numerical Stability Control Data	Tolerance for % change in flow depth (DEPTOL) Surface detention (TOL) Numerical stability coefficient (WAVEMAX)

Notes:
1. Data input files are listed in alphabetical order.
2. The CADPTS.DAT, CONT.DAT, TOLER.DAT, FPLAIN.DAT, are each required for any flood simulation.

5.1.2.1 Precipitation (*RAIN.DAT* Data Input File)

Precipitation values used for this *Drainage Master Plan* were determined with the use of the FCDMC's *Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology* (Ref. 4). A 6-hour duration rainfall event for the 2-, 10-, and 100-year frequencies were modeled for the purposes of this *Drainage Master Plan*. Precipitation values were based on National Oceanic and Atmospheric Administration (NOAA) Atlas 14 data.

A 6-hour rainfall distribution pattern number of 2.35 was used for the purposes of this *Drainage Master Plan*. Interpolation between 6-hour distribution pattern numbers 2 and 3 yields a distribution which was directly incorporated into the RAIN.DAT data input file used by the FLO-2D software program. This rainfall pattern is tabulated below in Table 5.1.2.1 – *Broadway Rural DMP 6-Hour Rainfall Distribution Pattern*. The 100-year, 6-hour rainfall depth utilized for the purposes of this *Drainage Master Plan* is 2.513 inches.

Table 5.1.2.1 – *Broadway Rural DMP 6-Hour Rainfall Distribution Pattern*

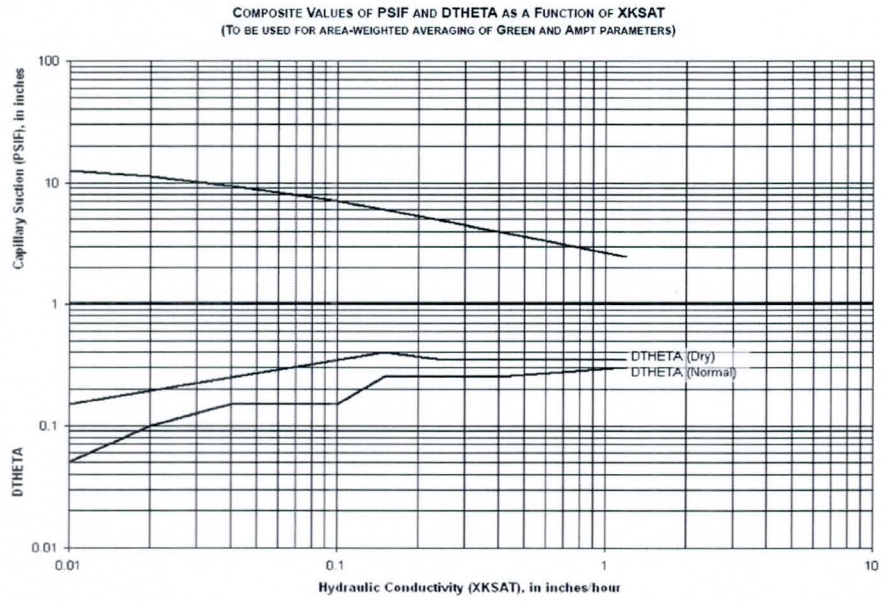
TIME [hours]	PERCENT OF RAINFALL DEPTH		
	PATTERN 2	*PATTERN 2.35*	PATTERN 3
0.00	0.00	*0.00*	0.00
0.25	0.90	*1.11*	1.50
0.50	1.60	*1.74*	2.00
0.75	2.50	*2.68*	3.00
1.00	3.40	*3.89*	4.80
1.25	4.20	*4.94*	6.30
1.50	5.10	*5.98*	7.60
1.75	5.90	*6.99*	9.00
2.00	6.70	*8.03*	10.50
2.25	7.60	*9.11*	11.90
2.50	8.70	*10.38*	13.50
2.75	10.00	*11.82*	15.20
3.00	12.00	*13.93*	17.50
3.25	16.30	*18.37*	22.20
3.50	25.20	*27.02*	30.40
3.75	45.10	*45.84*	47.20
4.00	69.40	*68.56*	67.00
4.25	83.70	*82.27*	79.60
4.50	90.00	*88.88*	86.80
4.75	93.80	*92.89*	91.20
5.00	95.00	*94.86*	94.60
5.25	96.30	*96.20*	96.00
5.75	97.50	*97.43*	97.30
5.75	98.80	*98.77*	98.70
6.00	100.00	*100.00*	100.00

5.1.2.2 Soil Infiltration (*INFIL.DAT* Data Input File)

The FCDMC recommends usage of the Green and Ampt soil infiltration equation within Maricopa County. Green and Ampt infiltration data were incorporated into FLO-2D's INFIL.DAT data input file for the purposes of this *Drainage Master Plan*. Green and Ampt infiltration parameters modeled within FLO-2D include the following:

- Hydraulic Conductivity (XKSAT)
- Wetting front capillary suction (PSIF)
- Volumetric soil moisture deficit (DTHETA)

Composite values of hydraulic conductivity (XKSAT) based on data for individual soils, are used to determine wetting front capillary suction (PSIF) and volumetric soil moisture deficit (DTHETA) based on *Figure 4.3 – Composite Values of PSIF and DTHETA as a Function of XKSAT*, reproduced from the *Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology* (Ref. 4).



Green and Ampt soil infiltration parameter data within the Broadway Rural Study Area was provided by the FCDMC. This data, which included Geographic Information

Systems (GIS) Shape and database files for hydraulic conductivity [XKSAT], wetting front suction [PSIF], and volumetric moisture deficit [DTHETA], was directly incorporated into the FLO-2D Grid Developer System (GDS).Green and Ampt soil infiltration parameters were then developed for each of the grid elements within the Study Area.

The Green and Ampt soils infiltration data found throughout the Broadway Rural DMP Study Area is listed in Table 5.1.3.1 – *Green and Ampt Soils Data*. It should be noted that the entire Broadway Rural Study Area is characterized by urban development constructed upon compacted soil. Therefore, the soil hydraulic conductivity or (XKSAT) values were not corrected for the effects of vegetated cover in the landscaped areas. Accordingly, the values for PSIF and DTHETA were also not corrected based on *Figure 4.3 – Composite Values of PSIF and DTHETA as a Function of XKSAT.* This approach is generally conservative in nature. It is however, believed to be a reasonable approach due to arid landscaping practices in the area.

Table 5.1.3.1 – *Green and Ampt Soils Data*

Soil Data ID	Soil Map Unit Symbol	Soil Description	XKSAT [inches/hour]	DTHETA	PSIF [inches]	Rock Outcrop [%]	Effective Impervious Area
6552063	Av	Avondale Clay Loam	0.400	0.15	9.46	0	100
655422120	LaA	Laveen Loam	0.250	0.25	4.87	0	100
655422920	LeA	Laveen Clay Loam	0.040	0.15	9.46	0	100
655504720	PnA	Pinal Gravelly Loam	0.040	0.25	3.99	0	100
6555049	Po	Pinal Loam	0.250	0.25	4.87	0	100
655543720	RiA	Rillito Gravelly Loam	0.400	0.25	3.99	0	100

The selection of additional parameters used in modeling rainfall losses, including initial abstraction [IA] and percent of effective impervious area [RTIMP] were also established based on land surface feature data GIS shape and database files provided by the FCDMC. The land surface feature categories identified by the FCDMC within the Broadway Rural DMP Study Area are listed in Table 5.1.3.2 – *Land Use Feature Categories*. GIS was

used to determine the contributing portion of each land use component for every grid element. A spreadsheet calculation was then used for the determination of aerially weighted values of [IA] and [RTIMP] for each grid element.

Table 5.1.3.2 – *Land Use Surface Feature Categories*

Existing Land Feature	Initial Abstraction [inches]	RTIMP [%]
Buildings	0.05	95
Asphalt sidewalk curb	0.05	95
Concrete	0.05	95
Vegetation	0.20	0
Grass Park	0.20	0
Bare Ground	0.10	0

check it

The value utilized for the TOL parameter (0.05 ~~feet)~~ incorporated into FLO-2D was established with consideration given to the initial abstraction values [IA] and recommended for use by the FCDMC. Subsequent review and recommendations by the FCDMC shall require any supplement to this *Drainage Master Plan* to utilize a value of 0.0042 feet (0.05 inches). This value is based on the initial abstraction value for the *Pavement and Rooftops* Land Use Category within Maricopa County, which is the minimum value indicated in *Table 4.2-IA, RTIMP, and Vegetative Cover for Representative Land Uses within Maricopa County*, reproduced below from the *Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology* (Ref. 4).

Table 4.2
***IA, RTIMP,* AND VEGETATIVE CANOPY COVER FOR REPRESENTATIVE LAND USES IN MARICOPA COUNTY**

Land Use[1] Code	Land Use Category	Description	IA[2] inches	RTIMP[2,3] %	Vegetation Cover[2,4] %
VLDR	Very Low Density Residential[3]	40,000 sq. feet and greater lot size	0.30	5	30
LDR	Low Density Residential[3]	12,000 – 40,000 sq. feet lot size	0.30	15	50
MDR	Medium Density Residential[3]	6,000 – 12,000 sq. feet lot size	0.25	30	50
MFR	Multiple Family Residential[3]	1,000 – 6,000 sq. feet lot size (# du/ac)	0.25	45	50
I1	Industrial 1[3]	Light and General	0.15	55	60
I2	Industrial 2[3]	General and Heavy	0.15	55	60
C1	Commercial 1[3]	Light, Neighborhood, Residential	0.10	80	75
C2	Commercial 2[3]	Central, General, Office, Intermediate	0.10	80	75
P	Pavement and Rooftops	Asphalt and Concrete, Sloped Rooftops	0.05	95	0
GR	Gravel Roadways & Shoulders	Graded and Compacted, Treated and Untreated	0.10	5	0
AG	Agricultural	Tilled Fields, Irrigated Pastures, slopes < 1%	0.50	0	85
LPC	Lawns/Parks/Cemeteries	Over 80% maintained lawn	0.20	Varies[5]	80
DL1	Desert Landscaping 1	Landscaping with impervious under treatment	0.10	95	30
DL2	Desert Landscaping 2	Landscaping without impervious under treatment	0.20	0	30
NDR	Undeveloped Desert Rangeland	Little topographic relief, slopes < 5%	0.35	Varies[5]	Varies[6]
NHS	Hillslopes, Sonoran Desert	Moderate topographic relief, slopes > 5%	0.15	Varies[5]	Varies[6]
NMT	Mountain Terrain	High topographic relief, slopes > 10%	0.25	Varies[5]	Varies[6]

Notes:
1. Other land use or zoning classifications, such as Planned Area Development and Schools must be evaluated on a case by case basis.
2. These values have been selected to fit many typical settings in Maricopa County; however, the engineer/hydrologist should always evaluate the specific circumstances in any particular watershed for hydrologic variations from these typical values.
3. RTIMP = Percent Effective Impervious Area, including right-of-way. Effective means that all impervious areas are assumed to be hydraulically connected. The RTIMP values may need to be adjusted based on an evaluation of hydraulic connectivity.
4. Vegetation Cover = Percent vegetation cover for pervious areas only.
5. RTIMP values must be estimated on a case by case basis.
6. Vegetation Cover values must be estimated on a case by case basis

5.1.2.3 Floodplain Elements (*FPLAIN.DAT* Data Input File)

The following sections discuss the selection and development of the FPLAIN.DAT Data Input File for use in the FLO-2D modeling of the Broadway & Rural Study Area. These include the development of a digital terrain model and the manipulation of surface feature characteristics to determine Manning's roughness coefficients throughout the Broadway & Rural Study Area.

Digital Terrain Model

The digital topographic mapping data procured as a part of the FCDMC's Contract No. FCD 08-20, Project ID 1291-*Phoenix-Tempe Area Mapping* was utilized as the basis for the elevation model on which this FLO-2D hydrologic and hydraulic analysis is based. Specifically, for the purposes of this *Drainage Master Plan*, Cardno WRG utilized the breakline and mass point data (.lf and .pf data files) in conjunction with a multi-step approach to develop an elevation model consisting of an average or representative elevation for each grid element within the Broadway Rural Study Area.

The *FLO-2D Pilot Study* revealed that sole usage of point file and breakline data obtained from aerial mapping and used as a series of digital terrain model points, may tend to yield

an inaccurate representation of average grid element elevations. This was found to be particularly true in urbanized areas with a higher frequency of planar surfaces such as roadways and parking lots. In these instances, aerial mapping may obtain a minimum yet sufficient number of points necessary to characterize a surface, while simultaneously obtaining dense topographic detail for a superfluous feature such as a landscaping mound. This superfluous topographic detail was found to bias the average elevation computation of a grid element and not provide a representative grid element elevation.

In-lieu of sole usage of aerial mapping data, Cardno WRG utilized a multi-step approach for the development of an elevation model to provide an improved representation of average grid element elevations throughout the Broadway & Rural Study Area. The primary steps associated with this approach are detailed below.

- Assemble mass point and breakline file data
- Creation of Triangulated Irregular Network (TIN) from data
- Conversion of TIN to a Raster Image
- Conversion of Raster Image to an ASCII Grid File
- Direct incorporation of ASCII Grid File into FLO-2D
- Computation of representative elevations for each grid element in system

This approach consisted of creation of a TIN from the mass point and breakline file data. The resulting TIN was then converted to a raster image with a 5-foot grid or pixel size for the purposes of this *Drainage Master Plan*, based on discussions with the FCDMC. An ASCII grid file, a file consisting of elevations for each small 5-foot pixel was then created from the resulting raster image. This ASCII grid file was then directly incorporated into FLO-2D's Grid Developer System (GDS) for computation of a representative elevation for each 25-foot grid element based on the series of smaller 5-foot pixel elevations within it. This assignment of an average elevation for each grid element was performed by using the interpolate elevation points command available within the Grid pull-down menu within FLO-2D.

A comparison between the two digital terrain model approaches was prepared for an alignment along Mill Avenue. Exhibit 5.1.2.3 – *Mill Avenue Profile* illustrates the enhanced profile yielded by the ASCII Grid File approach.

show more examples here and in the appendix

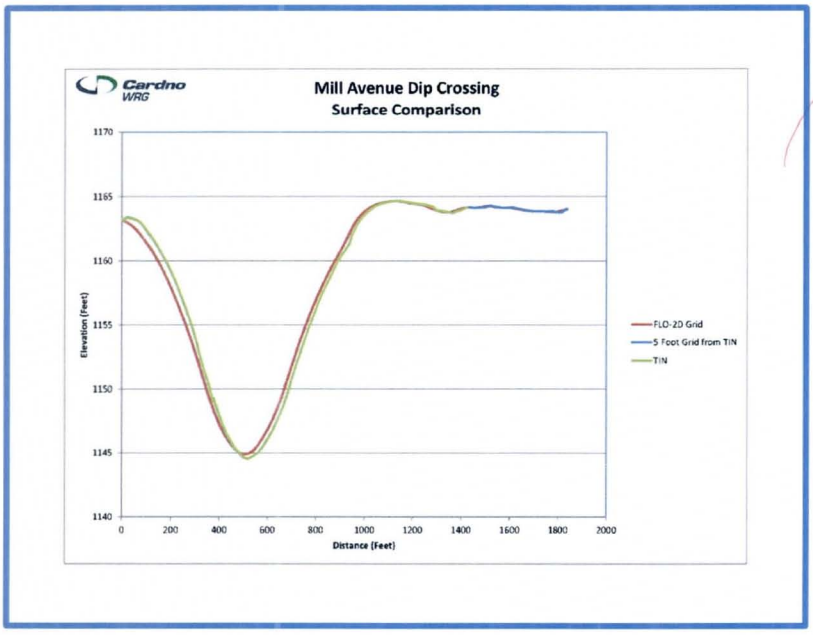


Exhibit 5.1.2.3.1 – *Mill Avenue Profile*

The resulting average grid element elevations were reported in the FPLAIN.DAT data input file.

Manning's Roughness Coefficients

The FLO-2D program can assign a manning's roughness coefficient to each grid element. A comprehensive series of roughness coefficients for typical land surface feature characteristics found within the study area were developed for the purposes of this *Drainage Master Plan*.

The Special Projects Branch of the FCDMC has analyzed the 0.8 ft pixel 2009 aerial images with the *Feature Analyst* software program and, in combination with existing cartography files, characterized the surfaces present in the study area. *Feature Analyst 4.2* is an automated feature extraction extension, developed by *Overwatch Geospatial*, that allows GIS to interpret images and extract lines and polygons, such as buildings, vegetation, roads, rock, etc. The Broadway-Rural DMP study area is heavily urbanized. The following surface features were collected: vegetation, bare ground, concrete and asphalt. Vegetation consists of palms, shrubs, trees, grass, and large surfaces with vegetation like colors. Bare ground consists of those surfaces that are tan or brown. Concrete is attained by using bright surfaces such as sidewalks and driveways. Asphalt consists of dark surfaces such as streets and parking lots. It is important to highlight that the color scheme ranges for some surfaces vary, such as the low vegetation, bare ground and asphalt, which affect the accuracy of the extracted features. The results however seemed to generate a good depiction of the general surface conditions in the study area. The results from *Feature Analyst*, were used to complement existing mapping cartographic files, which had a higher level of detail for streets, sidewalks, buildings and driveways.

Exhibit 5.1.2.3.2 – *Final Mapping Example for Surface Analysis*

The roughness coefficients are notably increased over those typically published for and associated with prismatic channel values. This is to be expected over surfaces subjected to the effects of shallow unconfined flow, variable flow paths, surface obstructions, and vegetation. A tabulation of the existing land features and their associated roughness coefficients are included below.

Table 5.1.2.3 – *Manning's Roughness Coefficients*

Existing Land Feature	Manning's n value
Buildings	0.025
Asphalt sidewalk curb	0.025
Concrete	0.025
Swimming Pools	0.020
Vegetation	0.100
Grass Park	0.030
Bare Ground	0.035

The GDS was used to compute comprehensive Manning's roughness coefficients for each grid element. These were reported along with the representative grid element elevation, in the FPLAIN.DAT data input file.

5.1.2.4 Area Reduction Factors (*ARF.DAT* Data Input File)

Cardno WRG utilized the reduction factor coding procedures available in FLO-2D to characterize the blockages created by existing buildings throughout the Broadway & Rural Study Area. These blockages were incorporated in the ARF.DAT data input file within FLO-2D. The comprehensive land feature GIS shape files provided by the FCDMC included line work for existing building footprints found throughout the Broadway & Rural Study Area. This building footprint line work was incorporated directly into FLO-2D's GDS for development of the Area Reduction Factor ARF.DAT data input file.

Cardno WRG and the FCDMC concluded during the development of the FLO-2D Pilot Study that usage of the Area Reduction Factor procedures would be utilized in lieu of the Width Reduction Factor (WRF) procedures provided by the FLO-2D program. This decision was made due to the more streamlined ability to characterize building blockages with ARF procedures and the inherent level of additional effort associated with definition of building blockage direction (N, NE, E, and SE) in WRF procedures. The FLO-2D version used for this study precludes the generation of rainfall runoff from grid elements identified to yield ARF values of 0.95 or those elements identified to be completely

blocked. Furthermore, an ARF value of 95% used to characterize existing building blockages yields a 5% residual opening that affords a grid element the ability to drain accumulated volume from the building area. The ARF protocol utilized for the purposes of this Drainage Master Plan therefore consists of assigning grid elements identified as completely blocked with ARF values of 0.94 in effort to allow the computation of rainfall runoff from the respective grid elements. Width Reduction Factors within the ARF.DAT data input file were set to a value of 0.

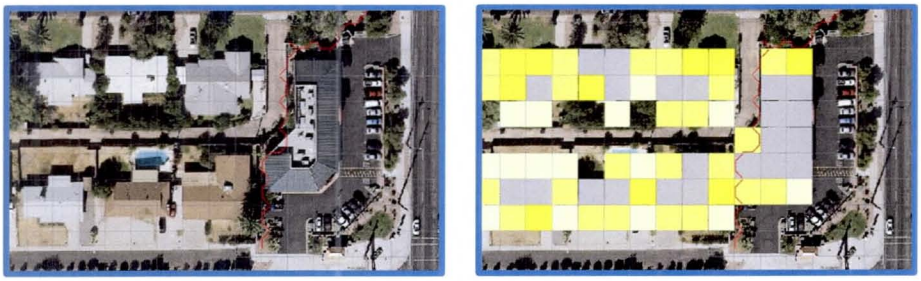


Exhibit 5.1.2.4.1 – *Typical FLO-2D Grid Elements with Area Reduction Factor Coding*
(LEFT: ARF components are turned off - RIGHT: ARF components are turned on)

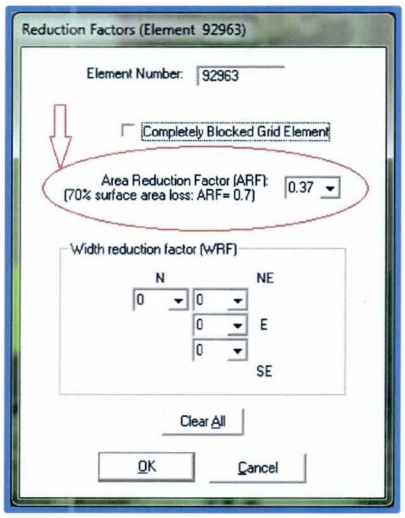


Exhibit 5.1.2.4.2 - *Reduction Factor Coding Dialogue Box within FLO-2D.*

5.1.2.5 Existing Wall/Fence Levee Analysis (*LEVEE.DAT* Data Input File)

Cardno WRG incorporated the influence on storm flow direction of select existing urban and flood walls and fences found within the Broadway Rural Study Area, with the use of the LEVEE.DAT data input file within FLO-2D. The FCDMC provided Cardno WRG with a comprehensive GIS shape file with line work for existing walls and fences found throughout the Broadway Rural Study Area. Cardno WRG prepared a qualitative analysis of these existing walls and fences to determine the appropriateness of their incorporation into the two-dimensional hydraulic model. This qualitative analysis included multiple steps which are detailed below.

- Review of preliminary FLO-2D model flow direction and velocity results for initial identification of key obstructions.
- Review of comprehensive GIS shape file line work for existing walls/fences
- Field reconnaissance within study area to corroborate selection of walls and fences for incorporation into the two-dimensional model.
- Preparation and refinement of a comprehensive GIS shape file for direct incorporation into FLO-2D for development of a LEVEE.DAT data input file.
- Initial model execution and subsequent troubleshooting and revision to the LEVEE.dat data input file.

Preliminary modeling results including maximum flow depth and velocity vector plots were reviewed in order to qualitatively identify existing walls/fences capable of withstanding potential hydrostatic loading and influencing the direction and magnitude of storm flow. A significant portion of the existing wall/fencing materials observed within the Broadway Rural Study Area consist of the pilaster masonry walls and wooden fencing associated with the predominantly single family residential land use. Cardno WRG performed several field reconnaissance visits within the Broadway & Rural Study Area based on these preliminary modeling results, to observe these existing wall/fencing

materials, and to incorporate their effects on storm water. Consideration was given to areas reflecting directional flow across a respective wall or fence as well as larger impinging velocity vectors. The following exhibits illustrate typical existing walls and fences observed within the Broadway Rural Study Area.

Exhibit 5.1.2.5.1 – *Existing Wall at Northwest corner of Broadway Road and Rural Road*

Exhibit 5.1.2.5.2 – *Alley at Broadmor Drive and El Parque Drive*

Exhibit 5.1.2.5.3 – *Intersection of Hazelton Lane and Hermosa Drive*
(Note presence of lot specific gates)

Exhibit 5.1.2.5.4 – *Existing Walls Modeled as Levees in FLO-2D* illustrates the location of existing walls/fences incorporated into the LEVEE.DAT data input file.

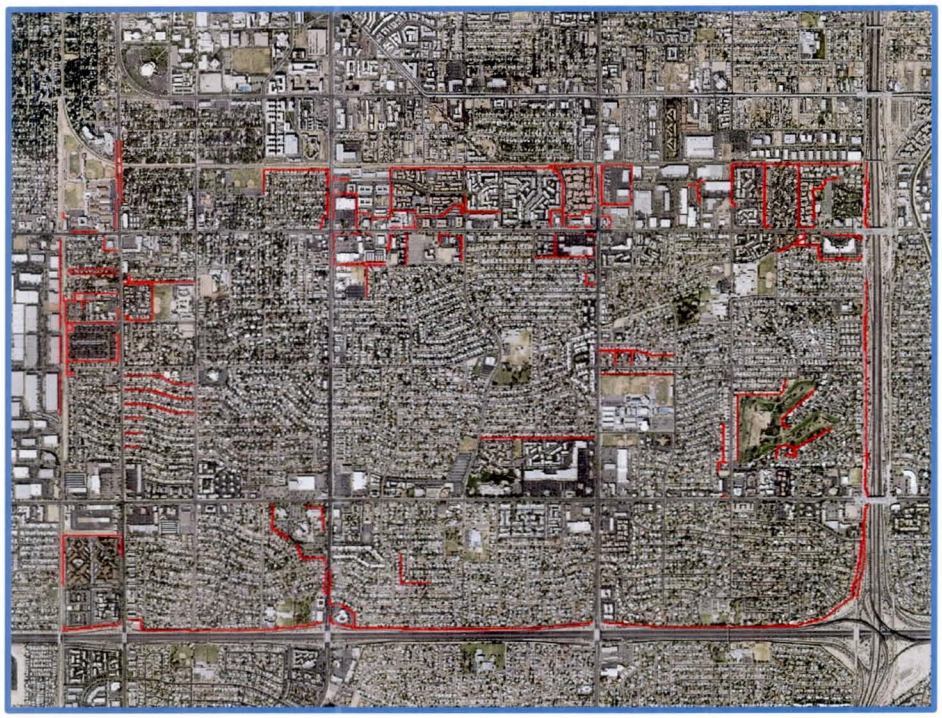


Exhibit 5.1.2.5.4 – *Existing Walls Modeled as Levees in FLO-2D*

ok
Include the location of the previous images
Label streets shown ~~to 2D~~ study Boundary

As mentioned, the GIS data provided by the FCDMC included comprehensive line work for all existing fence/wall structures found throughout the Broadway Rural Study Area. This GIS shape file data was reviewed extensively and used to create a residual shape file for use in creation of the FLO-2D LEVEE.DAT data input file. This residual shape file consisted of only the line work representing those fence/wall structures that had potential to affect the flow direction and magnitude for the purposes of this *Drainage Master Plan*. Line work for structures expected to have a minimal effect on flow or in areas with flow depths and velocities generally less than 0.5 feet and 1 foot per second respectively, were

determined to be inconsequential and removed. Examples of inconsequential structures include wooden fences typically found in a state of disrepair and those offering pass through conveyance capabilities or superfluous decorative landscape walls.

The elevations of the remaining fence/wall line work were then adjusted to be a minimum of six (6) feet above the immediately adjacent ground elevations developed from the elevation model discussed previously. These adjusted ground elevations were then compared to and verified to be above the elevations of their respective 25-foot grid elements.

The levee failure variables and methodology available in the FLO-2D program were not used for the purposes of this *Drainage Master Plan*. The walls were modeled to represent flow obstructions only.

The residual fence/wall GIS shape file was then incorporated directly into FLO-2D's GDS for development of the LEVEE.DAT data input file. Photographs taken throughout the Broadway & Rural Study Area of existing walls and fences are included in Appendix D – *Existing Wall/Fence Photographic Documentation for Levee Analysis*.

5.1.2.6 Existing Storm Drain and Culvert Analysis (*HYSTRUC.DAT* Data Input File)

Cardno WRG incorporated the effects of existing storm drain and culvert systems found within the Broadway Rural Study Area, into the quasi-two-dimensional hydrologic and hydraulic model in accordance with the original Scope of Work and subsequent work assignment revisions. The effects of these existing structures were incorporated into the HYSTRUC.DAT data input file within FLO-2D. The storm drain analysis component of this *Drainage Master Plan* was originally intended to encompass storm drain conduits with diameters equal to or greater than 36-inches. Preliminary two-dimensional modeling results, however, yielded ponding depths in public right-of-way areas with known storm drain facilities smaller than 36-inches. The FCDMC subsequently issued a revision to the

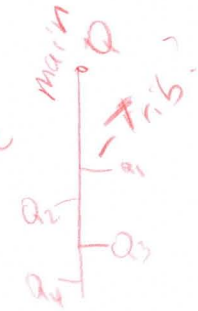
work assignment directing Cardno WRG to incorporate the effects of storm drain facilities ranging in size from 12-inch to 30-inch, in these areas.

Storm Drain Analysis

The effects of the storm drain facilities were modeled utilizing the hydraulic structure component of the FLO-2D program. The hydraulic structure modeling procedures available in FLO-2D allow the user to characterize storm drain inlets at discrete locations and capture flows using rating curves that relate flow capacity and hydraulic head.

For the purposes of this *Drainage Master Plan*, the flow rate modeled for a particular storm drain network was based on the ratio of the full flow capacity of the most downstream segment of a given storm drain network and the number of upstream appurtenances identified on the network for modeling. For a pipe, i, the capacity was estimated based on the equation given below.

Show schematic



$$Q_{modeled\ capcity,i} = \frac{Q_{downstream\ pipe\ cap}}{n_{upstream\ appurtenances}}$$

This flow capacity quotient was applied to each upstream storm drain segment while considering the upstream area serviced by the segment and ensuring that the flow does not exceed the full flow capacity of the respective segment. Individual storm drain inlets were not modeled as a part of this analysis in effort to reduce the modeling time that would be associated with characterizing individual inlets varying in size. Pipe flowing full capacities were estimated with the use of normal depth methodology.

Existing storm drain conduits were identified from the available GIS shape file data obtained from the City of Tempe and provided by the FCDMC. The information provided by the City of Tempe is shown on Exhibit 5.1.2.6 – *City of Tempe Storm Drain Data*. These storm drain conduits were then organized into a pipe network for determination of flow direction and outfall. Storm drain data consisting of size, material, and invert elevations were obtained when available, from the data provided by the FCDMC. In

some cases, storm drain data was limited or unavailable due to the age of a given system. In these instances, Cardno WRG then reviewed topographic data to access a longitudinal street slope for use as a pipe slope. The topographic point file data (*.pf data files) provided by the FCDMC were used in this effort.

Grid elements were strategically selected for inclusion of a hydraulic rating curve, at points throughout the storm drain network. These hydraulic structure rating curve grid elements were generally selected at changes in pipe size and at the storm drain inlets in the uppermost portion of a storm drain network. It is important to note that the rating curves used within the FLO-2D model were not intended to reflect site specific hydraulic analysis or an actual relationship between hydraulic head and flow capacity. The rating curves were instead intended to reflect removal of constant flow rates at random hydraulic head depths.

Data points were incorporated into the rating curves for hydraulic head depths of less than 0.2 feet in an effort to minimize hydrograph anomalies and run-time errors in the model. A sample rating curve is included below in Table 5.1.2.6.1 – *HYSTRUC.DAT Rating Curve*.

Table 5.1.2.6.1 – *HYSTRUC.DAT Rating Curve*

HYDRAULIC HEAD DEPTH [feet]	FLOW CAPACITY [ft^3/sec]
0	0
0.06	0
0.10	0.20
0.20	0.50
0.25	1.00
0.35	6.0
0.75	6.0
1.00	6.0
2.00	6.0
3.00	6.0
5.00	6.0

A tabulation of the storm drain facility rating curves and their associated peak flows is included below.

Table 5.1.2.6.2 – *HYSTRUC.DAT Storm Drain Peak Flow Summary*

RATING CURVE ID	MODELED STORM DRAIN CAPACITY [ft^3/sec]	RATING CURVE ID	MODELED STORM DRAIN CAPACITY [ft^3/sec]
SD1	6	SD10B	8
SD1B	5	SD11	12
SD2	11	SD12	12
SD3	6	SD13	4
SD3A	1	SD13A	5
SD3B	1	SD14	11
SD3C	1	SD14A	3
SD4	5	SD15	14
SD4A	1	SD16A	5
SD5	5	SD16B	2
SD5A	0.5	SD16C	1
SD5B	0.5	SD18	10
SD5C	0.5	SD18A	1
SD5D	0.5	SD18B	1
SD5E	0.5	SD19	12
SD5F	0.5	SD20	12
SD5G	0.5	SD21	12
SD5H	0.5	SD22	2
SD5I	0.5	SD22A	2
SD5J	0.5	SD22B	2
SD5K	0.5	SD22C	2
SD5L	0.5	SD22D	2
SD5N	0.5	SD22E	2
SD5O	0.5	SD23	7
SD5P	0.5	SD23A	5
SD5Q	0.5	SD24	9
SD5S	1	SD24A	3
SD5T	1	SD26A	2
SD6	5	SD27	2
SD7	9	SD28	2
SD8	9	SD29	2
SD9	9	SD29A	2
SD9A	1	SD31	24
SD9B	1	SD32	5
SD9C	1	SD33	2
SD10	17	SD34	1
SD10A	5	SD35	3

Culvert Analysis

Cardno WRG also incorporated the effects of two (2) existing culverts located underneath the existing railroad track alignment along the northern boundary of the Broadway Rural Study Area. Field reconnaissance revealed that each of the culvert locations is significantly encumbered by sediment deposits. The potential for sedimentation and clogging of the existing culvert locations is shown in the following exhibits.

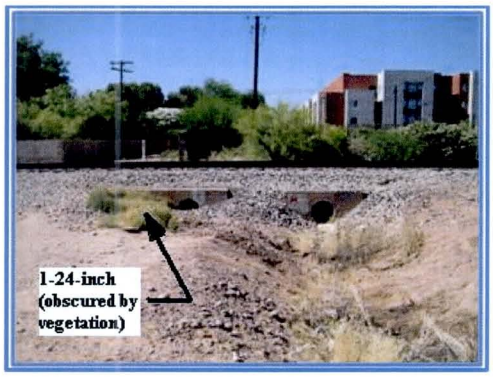


Exhibit 5.1.2.6.1 – *Existing Culvert Crossing at Northeast Corner of Daley Park*
(CLVT2: 3-24-inch culverts)

Exhibit 5.1.2.6.2 – *Existing Culvert Crossing near Rita Lane Alignment*
(CLVT1: 1-24-inch culvert)

Table 5.1.2.6.3 – *HYSTRUC.DAT Culvert Flow Summary* lists the rating curves prepared for each of the two culvert locations. The rating curves were developed with the use of Dodson's HLW computer program. The capacity of Culvert CLVT1 near the Rita Lane alignment was based on 1-24-inch diameter culvert with flow capacity reduced by 50%. The capacity of CLVT2 was modeled based on two (2) 24-inch diameter culverts with the capacity of each reduced by a clogging factor of 50%.

Table 5.1.2.6.3 – *HYSTRUC.DAT Culvert Flow Summary*

HYDRAULIC HEAD [feet]	CULVERT RATING CURVES	
	CLVT1 FLOW CAPACITY [ft^3/sec]	CLVT2 FLOW CAPACITY [ft^3/sec]
0	0	0
0.52	0.5	1
0.92	1.5	3
1.22	2.5	5
1.47	3.5	7
1.69	4.5	9
1.9	5.5	11
2.11	6.5	13
2.33	7.5	15
2.55	8.5	17
2.81	9.5	19
3.11	10.5	21
3.47	11.5	23
3.85	12.5	25
4.27	13.5	27
4.73	14.5	29
5.21	15.5	31

The Storm drain and culvert locations considered in this *Drainage Master Plan* are graphically illustrated on Exhibit 5.1.2.6.3 – *Storm Drain and Culvert Locations*.

5.1.2.7 Modeling Controls (*TOLER.DAT* Data Input File)

Modeling controls utilized for the purposes of this *Drainage Master Plan* include, in part, the following numerical stability parameters in the TOLER.DAT input file:

- Courant number = 0.6
- Dynamic wave stability coefficient [WAVEMAX] = 0.25
- Surface detention depth[TOL]= 0.05 foot
- Percent change in flow depth[DEPTOL] = 0.1

Courant number numerical stability criteria was incorporated into the FLO-2D models to reduce numerical surging and enhance model stability.

The dynamic wave stability coefficient [WAVEMAX] of -0.25 was utilized for the initial FLO-2D models to reduce run-time. Final FLO-2D model executions were performed with the use of a WAVEMAX value of 0.25.

The surface detention depth [TOL] variable dictates a threshold below which no routing of flow takes place between grid elements, and can be considered analogous to depression storage rainfall abstraction or initial abstraction as is coded within the INFIL.DAT data input file. As indicated previously, initial abstraction values were assigned within the INFIL.DAT data input file to reflect each of the land use surface features found within the Broadway Rural Study Area. The surface detention depth [TOL] was maintained at the indicated minimal value of 0.05 foot based on recommendations from the FCDMC. Subsequent review and recommendations by the FCDMC shall require any supplement to this *Drainage Master Plan* to utilize a value of 0.0042 foot (0.05 inches). This value is based on the initial abstraction value for the *Pavement and Rooftops* Land Use Category within Maricopa County, which is the minimum value indicated in *Table 4.2-IA, RTIMP, and Vegetative Cover for Representative Land Uses within Maricopa County*, reproduced below from the *Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology* (Ref. 4). This relationship is exemplified below.

$$P_{EFFECTIVE\ RAINFALL\ RUNOFF\ DEPTH} = P_{RAINFALL\ DEPTH} - IA - TOL$$

$$1.71\ inches = 2.513\ inches - 0.20\ inch - 0.60 inch$$

The change in flow depth percentage value [DEPTOL] was maintained at the value indicated as recommended by the FCDMC.

5.1.2.8 Modeling Controls (*CONT.DAT* Data Input File)

Additional modeling controls utilized during the course of this FLO-2D Pilot Study include the following parameters in the CONT.DAT input file:

- Floodplain limiting Froude Number [FROUDL] = 0.95
- Simulation time and output interval – 24 hours / 0.5 hours
- Shallow flow n-value [SHALLOWN] = 0.10

A limiting Froude number of 0.95 was used to maintain a subcritical flow regime within the model.

The 24-hour simulation time was determined based on the execution of an initial preliminary model utilizing a 40-hour simulation time. The preliminary model included FLO-2D data input files for grid element elevation and roughness coefficient, building blockage, infiltration, and rainfall parameters (FPLAIN.DAT, ARF.DAT, INFIL.DAT, and RAIN.DAT). Floodplain cross-sections were assigned throughout the Broadway Rural Study Area and the resulting hydrographs associated with each were reviewed to determine an optimal simulation time at which peak flow had occurred and runoff volume was dissipated.

Cardno WRG used a shallow flow n-value of 0.10 based on discussions with the FCDMC and previous modeling experience with FLO-2D.

5.2.7 Erosion and Sediment Transport

No erosion and sediment transport services are included as a part of the Scope of Service associated with this Drainage Master Plan.

SECTION 6.0 MODEL RESULTS INTERPRETATION

The comparison of hydrologic and hydraulic results prepared by Cardno WRG was facilitated with the use of hydrographs associated with interior cross-sections incorporated into the FLO-2D models.

6.1 Floodplain Cross-Sections

The locations of forty-nine (49) cross-sections are illustrated on Exhibit 6.1.1 – *Interior Hydrograph Locations* included in the back of this *Drainage Master Plan*. The cross-sections were established with the use of FLO-2D's FPXSEC.DAT data input file. This data input file allows the user to define a cross-section across a flow conveyance with a series of grid elements. Care was exercised to not incorporate grid elements encumbered by existing building blockage or levee coding as well as to be perpendicular to the direction of combined maximum flow reported in the MAXQHYD.OUT output file.

The hydrographs associated with each cross-section were obtained from FLO-2D's HYCROSS.OUT data output file for the 2-, 10-, and 100-year frequency events. The 100-year peak flows, time of peak flow, and runoff volumes for each of these cross-sections are tabulated in Table 6.1 – *Hydrograph100-Year Event Peak Flow Summary*.

map

Table 6.1 – *Hydrograph100-Year, 6-Hour Event Peak Flow Summary*

INTERIOR CROSS-SECTION ID	$Q_{100\text{-}YEAR}$ [ft^3/sec]	T_{PEAK} [hours]	$VOL_{100\text{-}YEAR}$ [acre-feet]	DESCRIPTION	INTERIOR CROSS-SECTION ID	$Q_{100\text{-}YEAR}$ [ft^3/sec]	T_{PEAK} [hours]	$VOL_{100\text{-}YEAR}$ [acre-feet]	DESCRIPTION
CS-1	9	4.05	3.38	Broadway Rd & Country Club Way	CS-26	1	9.45	0.11	Broadway Rd & SPRR
CS-2	19	4.74	2.03	Broadway Rd & McClintock Dr	CS-27	9	4.12	1.63	Broadway Rd & Mill Ave
CS-3	32	5.36	5.23	Alameda Dr & McClintock Dr	CS-28	1	4.00	0.04	Broadway Rd & Farmer Ave
CS-4	9	4.19	0.93	Southern Ave west of Loop 101	CS-29	3	3.92	0.15	13th St & Farmer Ave
CS-5	3	4.24	0.97	Southern Ave and Holbrook Ln	CS-30	29	4.59	6.09	Daley Park & College Ave
CS-6	30	4.64	11.08	Malibu Dr and Dorsey Ln	CS-31	49	5.28	10.69	Broadway Rd & Jentilly Ln
CS-7	10	4.48	6.52	Southern Ave and Dorsey Ln	CS-32	30	5.34	6.69	Broadway Rd & Rural Rd
CS-8	19	4.72	3.08	Alameda Dr & Dorsey Ln	CS-33	18	5.87	5.24	Vista Del Cerro Dr & Jentilly Ln
CS-9	9	5.24	2.51	Broadway Rd & Dorsey Ln	CS-34	7	6.39	0.97	Terrace Rd (Desert Palm Village Apts)
CS-10	23	5.58	8.8	Rural Rd & Encanto Dr	CS-35	1	3.99	0.07	Mill Ave & UPRR
CS-11	36	7	19.72	Southern Avenue & Rural Rd	CS-36	2	6.53	1.24	Laguna Dr & Kyrene Rd
CS-12	19	4.48	3.41	College Ave & Laguna Dr	CS-37	9	4.72	3.03	NE Cor Daley Park
CS-13	22	15.18	10.77	Southern Ave & College Ave	CS-38	16	8.56	4.90	NE Cor Daley Park
CS-14	15	4.90	4.58	Pebble Beach Dr & Mill Ave	CS-39	0	0	0	Mill Ave & UPRR
CS-15	18	4.48	7.68	Southern Ave & Mill Ave	CS-40	3	5.94	0.82	Mill Ave & UPRR
CS-16	5	7.5	2.8	Kyrene Rd & Laguna Dr	CS-41	1	4.06	0.29	CLVT1
CS-17	1	3.85	0.01	Southern Ave & SPRR	CS-42	26	4.33	3.67	Broadway Rd & Kachina Dr
CS-18	7	4.25	1.41	Rural Rd & Loyola Dr	CS-43	6	5.56	1.94	Vista Del Cerro Dr
CS-19	10	4.76	4.35	Alameda Dr & Campus Dr	CS-44	6	4.36	1.26	Mill Ave & UPRR near Alley
CS-20	15	4.5	2.71	Balboa Dr & College Ave	CS-45	8	6.45	1.64	Broadway Rd & Kachina Dr
CS-21	37	5.34	14.15	Alameda Dr & College Ave	CS-46	11	6.27	3.53	Broadway Rd & Kachina Dr
CS-22	12	5.07	1.88	Mill Ave & Del Rio Dr	CS-47	28	4.27	3.58	River Dr near Riviera Dr
CS-23	26	5.54	5.88	Mill Ave & Alameda Dr	CS-48	13	4.27	2.83	River Dr near Riviera Dr
CS-24	25	5.74	4.92	Alameda Dr & SPRR	CS-49	9	4.6	1.56	Riviera Dr near Country Club Way
CS-25	2	9.26	0.67	Broadway Rd West of Farmer Ave					

The hydrographs for the 100-year as well as the 2- and 10-year events are included in Appendix E – *Broadway & Rural DMP Hydrograph Analysis*.

6.2 Flow Depth

Maximum flow depths within the Broadway Rural Study Area were computed throughout the Broadway Rural Study Area for the 2-, 10-, and 100-year frequency events. Exhibit 6.2.1 – *Maximum 100-Year Flow Depth* illustrates the ranges of storm water ponding depths found within the Broadway Rural Study Area.

Review of the maximum flow depth estimates reveals several residential areas that may be subject to significant inundation. Cardno WRG identified a series of twelve (12) problematic drainage areas based on the results of the two-dimensional modeling. The areas were identified based on identification of large expanses of ponding within single family residential land use areas. These twelve areas were subsequently reduced to a series of ten (10) based on consideration of only those problematic areas subject to maximum ponding depths greater than or equal to 1 foot per discussions with the FCDMC.

Additional structure survey was obtained for each of these ten problematic areas. Survey data obtained included finished floor elevations for approximately 160 existing single family residential structures found to be adjacent to areas of ponding depth in excess of one (1) foot. The results of these surveys allow grid element specific water surface elevations adjacent to potentially affected single family residential structures to be directly compared to surveyed finished floor elevations.

This exercise was relevant for the purposes of direct comparison between finished floor elevation and grid element water surface elevation. Actual finished floor elevations were not obtained during the aerial mapping process and were therefore not represented during the course of grid element elevation computations. Furthermore, water surface elevations

for grid elements that encompassed a single family residential building footprint were not representative of existing conditions and were therefore not appropriate for use in inundation depth estimates.

Each of these areas are discussed in more detail in Section 7.0 of this report. The finished floor elevations and their relationships to grid element water surface elevations for each problematic drainage area are graphically illustrated on Exhibits 6.2.4 through 6.2.13 – *Problematic Area Drainage Maps*.

6.3 Flow Velocity

Maximum flow velocities within the Broadway Rural Study Area were computed throughout the Broadway Rural Study Area. Exhibits 6.3.1 – *Maximum 100-Year Flow Velocities,* 6.3.2 – *Maximum 10-Year Flow Velocities,* and 6.3.3 – *Maximum 2-Year Flow Velocities* illustrates the ranges of flow velocities found within the Broadway Rural Study Area for the storm events modeled. The maximum velocities for each event are listed below, in Table 6.3 – *Maximum Flow Velocities*.

Table 6.3 – *Maximum Flow Velocities*

STORM EVENT	MAXIMUM FLOW VELOCITY [ft/sec]
100-Year	3.58
10-Year	2.24
2-Year	2.15

The FLO-2D TIME.OUT data output file was reviewed during the model troubleshooting task, for excessive timestep decrements. Grid elements identified with a high number of time step decrements were manually adjusted to typically reflect an increased Manning's roughness coefficient or change in elevation to mitigate velocity. These manually coded revisions typically occurred in the vicinity of recessed areas, storm water basins, buildings with elevation anomalies, and storm drain inlets artificially lowered to enhance inlet capacity. Changes made to grid element roughness coefficients varied from a

decrease of 0.075 to an increase of 0.070. Changes made to grid element elevations varied from a decrease of 3.11 feet to an increase of 12.7 feet.

Exhibit 6.3.4 – *Grid Element N-Value and Elevation Revision Locations* illustrates locations of grid elements manually revised to reflect differences in Manning's roughness coefficient and/or elevation.

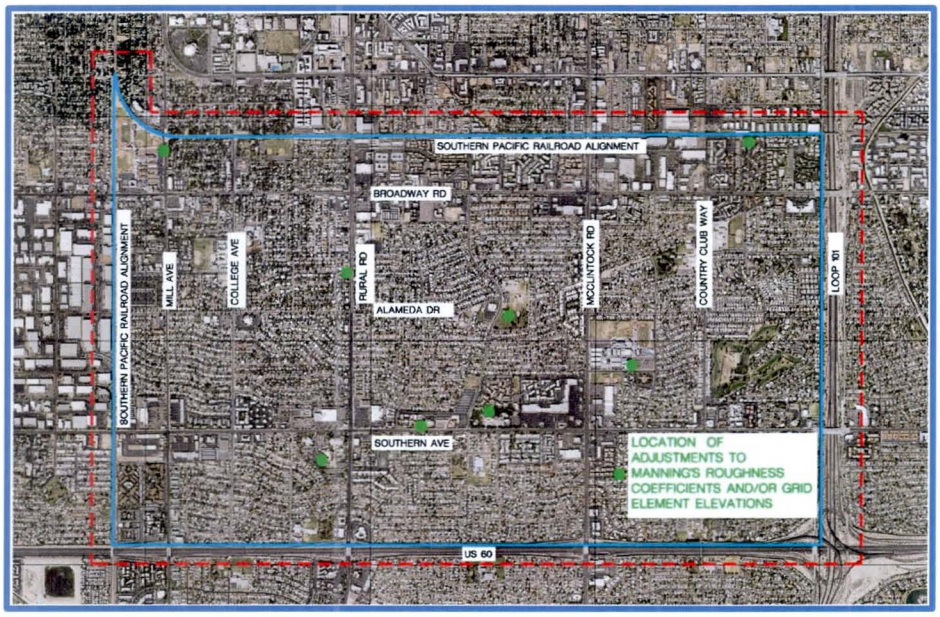


Exhibit 6.3.4 – *Grid Element N-Value and Elevation Revision Locations*

6.4 Calibration and Verification

No existing precipitation or flow gages are known to exist within the Broadway Rural Study Area and therefore the hydrologic and hydraulic results presented herein are not calibrated with actual gage data.

The results presented herein have been reviewed with consideration given to actual storm events. The *Candidate Assessment Report* (CAR) presented photographic evidence of a

storm that occurred in the vicinity of the Daley Park Subdivision on and around July 2001. Furthermore, the CAR estimated the historic storm to be similar in frequency to a 2-year to 5-year event based on available precipitation data yielded by ASU South ALERT Gage 4525 located north of the Broadway Rural Study Area at Parkway Blvd and McAllister Ave.

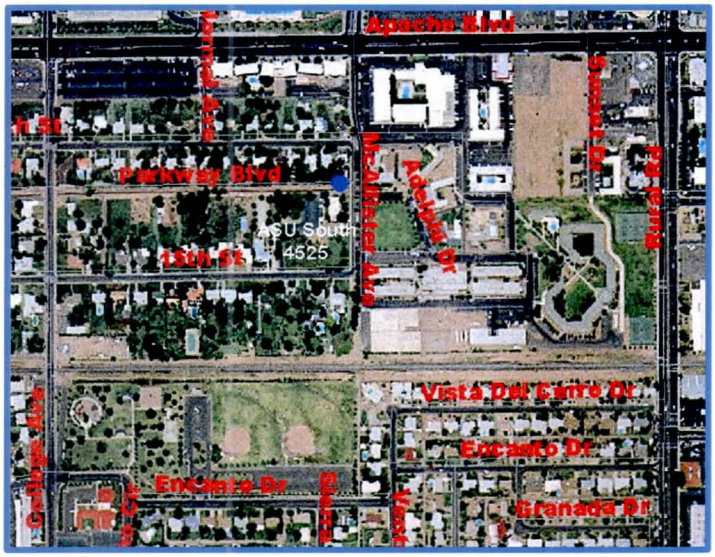


Exhibit 6.4.1 – *ASU South Gage 4525 Location*

The photographic evidence illustrated significant storm water ponding in the vicinity of the intersection of Rural Road and Encanto Drive. The photographic evidence, while characterized as a more frequent event (2-year to 5-year), appears to be similar in magnitude to the 100-year frequency hydrologic and hydraulic modeling results presented herein.

Photographic evidence of residential street inundation provided by individual homeowners within the Broadway Rural Study Area also provides forensic evidence we can use to compare the results presented herein. Photographic evidence of the aftermath

of the storm occurring in July 2008 was provided by a homeowner situated near Campus Drive and Terrace Road.

Exhibit 6.4.2 – *Photo looking north onto Campus Drive*

Exhibit 6.4.3 – *Photo looking north and west onto Campus Drive*

A forensic analysis entitled *R&B – Frequency Analysis of Four Storms at FCD Rain Gage 4525,* prepared by the FCDMC indicates that the storm may have been similar in magnitude to a 20-year, 1-hour frequency event. This analysis is included in Appendix C - *R & B - Frequency Analysis of Four Storms at FCD Rain Gage 4525.*

The FCDMC's *Drainage Design Manual for Maricopa County, Arizona, Volume I – Hydrology* (Ref. 4) identifies indirect methods for estimation of peak flows within Maricopa County. These methods however, are generally based on contributing area and are therefore difficult to use a verification tool for FLO-2D results. This difficulty lies in the indeterminate area generally associated with a peak flow estimated with FLO-2D.

SECTION 7.0 PRELIMINARY FLOOD HAZARD IDENTIFICATION

Cardno WRG and the FCDMC have identified 12 areas that have a significant potential for flooding to affect residents of the community. Several factors were used to identify these problematic drainage areas, including land use, frequency of flooding, depth of flooding and other factors. The team identified 12 single family residential areas that had a potential for significant flooding in a 100-year event. These were further evaluated and identified 10 of the 12 areas that had an average 100-year flooding depth of one foot or greater. These 10 areas were further assessed by gathering 160 finished floor elevations using detailed survey methods throughout these problematic drainage areas. Cardno WRG reviewed the results of the Flo-2D model to identify the homes in these 10 areas that were in the close proximity of 100-year flooding depths greater than one foot. The Finished Floor Elevations were surveyed and compared to the modeled water surface elevations on adjacent grid elements. This information was utilized to identify the homes that are expected to be subject to inundation in various storm events. Additionally, the depth of inundation over the finished floor was estimated for the homes that were surveyed. The number of homes in each area that are expected to be inundated in a given event, as well as the expected depth of flooding, can be used to identify potential structure and content loss as a percent of value. Published tables of estimated building loss and content loss were obtained from FEMA and are presented below in Table 7.1 – *Flood Building Loss Estimation Table* and Table 7.2 – *Flood Contents Loss Estimation Table*.

Expand on this.

Table 7.1 - *Flood Building Loss Estimation Table*

FLOOD DEPTH (feet)	**ONE STORY NO BASEMENT** (%Building Damage)	**TWO STORY NO BASEMENT** (% Building Damage)	**ONE OR TWO STORY WITH BASEMENT** (% Building Damage)	**MANU-FACTURED HOME** (%Building Damage)
-2	0	0	4	0
-1	0	0	8	0
0	9	5	11	8
1	14	9	15	44
2	22	13	20	63
3	27	18	23	73
4	29	20	28	78
5	30	22	33	80
6	40	24	38	81
7	43	26	44	82
8	44	29	49	82
>8	45	33	51	82

Table 7.2 - *Flood Contents Loss Estimation Table*

FLOOD DEPTH (feet)	**ONE STORY NO BASEMENT** (%Contents Damage)	**TWO STORY NO BASEMENT** (% Contents Damage)	**ONE OR TWO STORY WITH BASEMENT** (% Contents Damage)	**MANU-FACTURED HOME** (%Contents Damage)
-2	0	0	6	0
-1	0	0	12	0
0	13.5	7.5	16.5	12
1	21	13.5	22.5	66
2	33	19.5	30	90
3	40.5	27	34.5	90
4	43.5	30	42	90
5	45	33	49.5	90
6	60	36	57	90
7	64.5	39	66	90
8	66	43.5	49	90
>8	67.5	49.5	51	90

must be

It was noted that not all homes were surveyed in each area and in some cases a house with significant floor inundation was adjacent to a house that was not surveyed. It can be assumed that there is a reasonable likelihood that the adjacent house could be subject to inundation as a result of the subject storm. Therefore it is believed that there are additional unidentified houses within the study area that are subject to inundation in the 100-year flood event and it is not practical to estimate the number of these houses without extensive additional survey.

The 12 potential flooding areas are identified as follows along with a description of the areas and depths of expected flooding are described as follows:

Area 1: *Daley Park Subdivision, northwest of Broadway Road and Rural Road*

This is the Daley Park subdivision, a residential subdivision located northwest of the intersection of Broadway Road and Rural Road and is the original impetus for this study. The flooding in this area is the result of the elevated railroad tracks to the north of the subdivision. The general fall of the land is from the southeast toward the northwest. The Union Pacific Railroad forms the northern boundary of the study area and impedes the flow from leaving the Daily Park subdivision. The majority of the flooding occurs along Vista del Cerro Drive located immediately adjacent to the railroad. Much of this flooding has a 100-year depth of 0.5 to 1.0 foot above the average grid element elevation, with a few grid elements with depths over one foot. The study identified 23 of the 47 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to be below 0.5 feet above the finished floor.

Area 2: *Southeast of Mill Avenue and the Union Pacific Railroad*

This area is old residential subdivision located east of Mill Avenue and south of the Union Pacific Railroad. The flooding in this area is the result of the elevated railroad tracks to the north of the subdivision and the elevated retaining walls adjacent to the Mill Avenue underpass to the west. The general fall of the land is from the southeast toward the northwest. The Union Pacific Railroad forms the northern boundary of the study area

and impedes the flow from leaving the subdivision to the north, while the retaining walls for the underpass contain the flood waters to the west. The flooding is the greatest where Vista del Cerro Drive forms a knuckle as it makes a 90 degree turn at the northwest corner of the subdivision. The floodwaters concentrate in this low point with insufficient relief toward an already inundated underpass. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation, with a significant area with depths over two feet. The study identified all 13 of the 13 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to range between 1.0 and 1.8 feet above the finished floor. This is the most serious flooding issue within the study area.

Area 3: *Southeast of Mill Avenue and Broadway Road*

This area is a residential subdivision located between Mill Avenue and the north-south leg of the railroad, and south of Broadway road across from Tempe High School. The flooding in this area is the result of the elevated railroad tracks to the west of the subdivision and the sump in Broadway Road to the north. The general fall of the land is from the southeast toward the northwest. The railroad forms the western boundary of the study area and impedes the flow from leaving the subdivision to the west, while the high school impedes flow from continuing to the north. The flooding is the greatest at the sump in Broadway Road and in Palmdale Drive. The floodwaters concentrate in this low point and are initially captured by a storm drain system. This storm drain system does not have the capacity to convey the runoff produced by a major rainfall event and there is insufficient relief to the north through the high school. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified all 11 of the 11 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to range between 0.5 and 1.5 feet above the finished floor.

Area 4: South of Alameda Drive near Mill Avenue

This area is a residential subdivision located South of Alameda Drive near Mill Avenue and is comprised of two distinct inundation areas. The western of these two flooding areas is the result of the elevated railroad tracks to the west of the subdivision. The general fall of the land is from the southeast toward the northwest. The railroad forms the western boundary of the study area and impedes the flow from leaving the subdivision to the west, while the building pads impede flow from continuing to the north. The flooding is the greatest at the intersection of Dromedary Drive and Balboa Drive. The easterly of these two flooding areas is the result of Mill Avenue being elevated to the west of the subdivision. The general fall of the land is from the southeast toward the northwest. Mill Avenue impedes the flow from leaving the subdivision to the west, while the building pads impede flow from continuing to the north. The flooding is the greatest at the local street intersections with Mill Avenue these streets are Balboa Drive, Cairo Drive, Del Rio Drive, and Erie Drive. The floodwaters concentrate in these low points immediately east of Mill Avenue and are initially captured by storm drain systems. This storm drain systems do not have the capacity to convey the runoff produced by a major rainfall event and therefore the stormwater ponds in the local streets until it can overflow into Mill Avenue. Both of these area result in flooding to the adjacent homes. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified all 12 of the 12 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to range from 0.4 to over 1.0 feet above the finished floor.

Area 5: South of Alameda Drive between College Avenue and Rural Road

This area is a residential subdivision located between College Avenue and Rural Road immediately south of Alameda Drive. The flooding in this area is the result of heavy street flow and minimal street slope. The general fall of the land is from the southeast toward the northwest. The flooding is mostly identified as street flooding with depth ranging from 0.5 to 1.0 foot. This area was not identified as a significant flooding problem area and therefore no finished floors were identified to be surveyed.

Area 6: Southeast of Alameda Drive and Rural Road

This area is a residential subdivision located between Rural Road and Dorsey Lane on the south side of Alameda Drive. The flooding in this area is the result of significant street flows and a sump in Campus Drive east of Terrace Road. The floodwaters concentrate in this low point and are initially captured by a storm drain system. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified only 1 of the 10 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to be only 0.2 feet above the finished floor.

Area 7: South of Southern Avenue east of College Avenue

This area is a residential subdivision located between College Avenue and McAllister Avenue south of Southern Avenue. The flooding in this area is the result of heavy street flow and minimal street slope. The general fall of the land is from the southeast toward the northwest. The flooding is mostly identified as street flooding with depth ranging from 0.5 to 1.0 foot. This area was not identified as a significant flooding problem area and therefore no finished floors were identified to be surveyed.

Area 8: Northeast of Rural Road and U.S. 60

This area is a residential subdivision located immediately north of the U.S. 60 and east of Rural Road. The general fall of the land is from the east to west with a slight southeasterly slope. The flooding in this area is the result of the Superstition Freeway (U.S. 60) impeding the outfall of the area. Stormwater concentrates in Riviera Drive and flows east to a knuckle intersection at Bonarden Lane. There is a sump at this intersection with a storm drain system to outfall the flow to the U.S. 60 drainage system. The floodwaters concentrate in this low point in Riviera Drive and are initially captured by the storm drain system, however it does not have the capacity to convey the runoff produced by a major rainfall event and there is insufficient relief to the north. Much of

this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified 8 of the 9 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected to be below 0.8 feet above the finished floor. It should be noted that field observation during the study identified some of the houses in this area were split level and had below grade floors that could not be measured by the non-intrusive survey. Therefore, the flooding to these homes could be far greater than identified.

Area 9: *Southeast of Southern Avenue and McClintock Drive*

This area is a residential subdivision located between McClintock Drive and Country Club Way on the south side of Southern Avenue. The flooding in this area is the result of significant street flows with little relief to the west. The flow concentrates in Los Feliz Drive at the intersections with Laguna Drive, Pebble Beach Drive, La Jolla Drive, and Manhattan Drive. The floodwaters concentrate in these low points and are initially captured by a storm drain system; however, the storm drain system does not have the capacity to relieve the flow from the significant storm events. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified 8 of the 17 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected be below 0.6 feet above the finished floor.

Area 10: *Northwest of Loop 101 and U.S. 60*

This area is a residential subdivision located immediately north of the Superstition Freeway (U.S. 60) between Country Club Way and the Loop 101. The general fall of the land is to the south toward the U.S. 60. The flooding in this area is the result of the street flows concentrating into the cul-de-sacs at Fairfield Drive and River Drive. The flood waters concentrate in these low points and are initially captured by a storm drain system that convey the flow to the U.S. 60 drainage system. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation; however, the

houses are elevated. The study identified that none of the 13 homes surveyed are likely have finished floor inundation in an expected 100-year event.

Area 11: *Northeast of Southern Avenue and McClintock Drive*

This area is a residential subdivision located between McClintock Drive and Country Club Way on the north side of Southern Avenue. The flooding in this area is the result of significant street flows with little relief to the west. The flow concentrates in Los Feliz Drive at the intersections with Huntington Drive and Geneva Drive, with some shallow flooding at intersections to the north. The floodwaters concentrate in these low points and are initially captured by a storm drain system; however, the storm drain system does not have the capacity to relieve the flow from the significant storm events. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified only 2 of the 8 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected range from 0.1 feet to 0.4 feet above the finished floor.

Area 12: *Northeast of Alameda Drive and McClintock Drive*

This area is a residential subdivision located between McClintock Drive and Country Club Way on the north side of Alameda Drive. The flooding in this area is the result of significant street flows with little relief to the west. The flow concentrates in Alameda Drive and Loma Vista Drive in a sump condition immediately east of McClintock Drive. The floodwaters concentrate in these low points and are initially captured by a storm drain system; however, the storm drain system does not have the capacity to relieve the flow from the significant storm events. Much of this flooding has a 100-year depth of more than 1.0 foot above the average grid element elevation. The study identified all 21 of the 21 homes surveyed to likely have finished floor inundation in an expected 100-year event. This inundation is expected range from 0.2 feet to 1.2 feet above the finished floor.

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