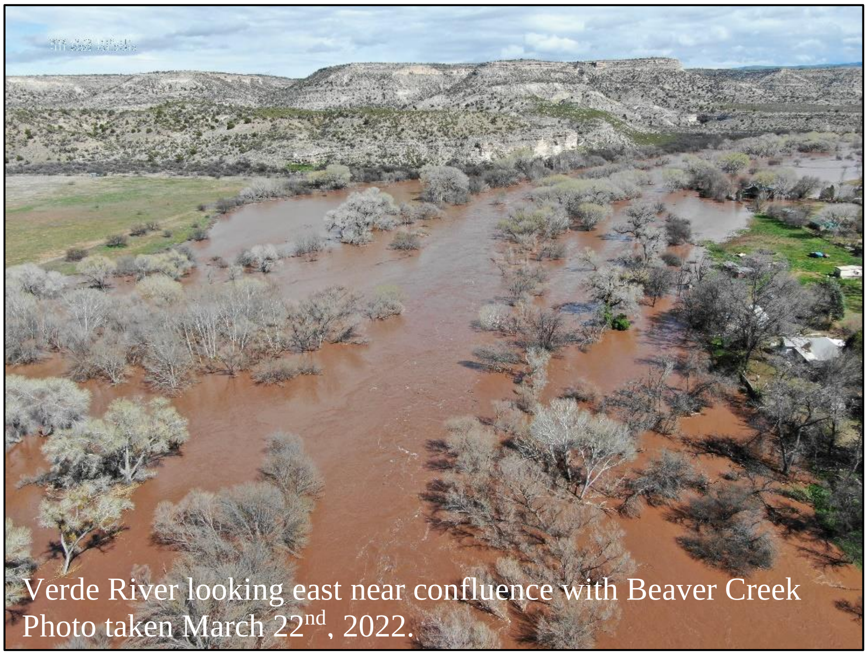
TOWN OF CAMP VERDE
AREA DRAINAGE MASTER STUDY
TECHNICAL SUPPORT DATA NOTEBOOK

JANUARY 2024

Prepared For:
Town of Camp Verde
395 S. Main Street, Camp Verde, AZ 86322

Prepared By:
Wilson & Company, Inc.
410 N. 44th Street, Suite 460, Phoenix, AZ 85008



Verde River looking east near confluence with Beaver Creek
Photo taken March 22nd, 2022.

Registered Professional Engineer (Civil)
Certificate No. 41014
BRIAN NICHOLAS SCHALK
Date Signed 1/25/2024
ARIZONA, U.S.A.

Expires 06/30/2025

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1 INTRODUCTION

1.1 Study Purpose

The Town of Camp Verde (Town) is continuously working to proactively manage stormwater issues and needs. To that end, the Area Drainage Mater Study (ADMS) was conducted to provide best available hydrologic and hydraulic (H&H) data for flood risk assessment, public/stakeholder outreach, stormwater management planning, and design of future flood control measures.

As part of the ADMS, aerial mapping data was collected and detailed H&H analyses were performed to estimate drainage patterns and flood hazard conditions throughout the Town limits. The H&H data resulting from the ADMS includes extent of flooding, depth of flooding, flow magnitudes (discharges), and flow velocities for the 10- and 100-year storms, having both 6- and 24-hour durations.

This Technical Support Data Notebook (TSDN) is intended to document the ADMS technical efforts and findings.

1.2 Project Authorization

The Town retained Wilson & Company, Inc. Engineers & Architects to complete the Town of Camp Verde Aerial Mapping and Area Drainage Master Study. The Town's contact and contract information is provided in Table 1-1. The consulting firm contact information is provided in Table 1-2.

Table 1-1. Town of Camp Verde Contact and Contract Information.

Authorizing Agency	Town of Camp Verde
Contact Information	Jeff Low, Director of Utilities 473 S Main Street, Camp Verde, AZ 86322 Jeff.Low@campverde.az.gov
Contract	Contract No. 23-170

Table 1-2. Consulting Firm Contact Information.

Consulting Firm	Wilson & Company, Inc. Engineers & Architects
Contact Information	Brian Schalk, P.E., CFM; Senior Project Manager 410 N 44th Street, Suite 460, Phoenix, AZ 85008 brian.schalk@wilsonco.com

1.3 Study Area Overview

1.3.1 Location

The Town of Camp Verde is located along Verde River. The Verde River originates from the Big Chino-Williamson Valley watershed (HUC-8 Sub-basin 15060201) and runs 170 miles until its confluence with the Salt River, east of Phoenix. Approximately 18 miles of the Verde River are located within the Town. The Verde River watershed is divided into the Upper Verde (HUC-8

Sub-basin 15060202) and Lower Verde (HUC-8 Sub-basin 15060223) watersheds with the Town sitting across the border between these two watersheds. The tributary watershed for the Town, delineated using USGS Streamstats service, includes the entire Big Chino-Williamson Valley watershed, the Upper Verde watershed, and a portion of the Lower Verde watershed (Figure 1-1). The Contributing Watersheds Overview Exhibit is included in Appendix A for more information.

1.3.2 Study Area Characteristics

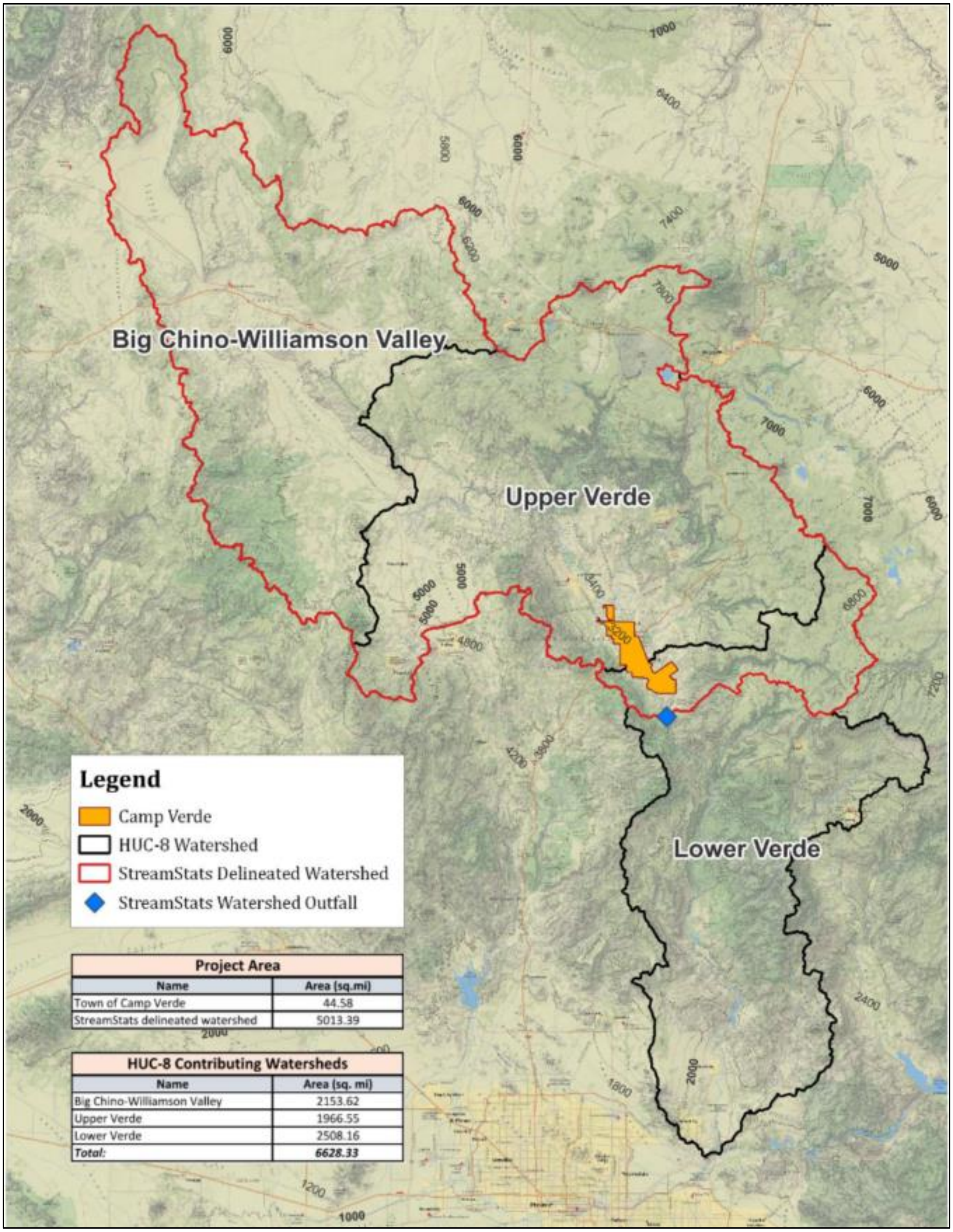
The total incorporated area for the Town is 44.58 square miles which defines the study area. The Verde River and its tributaries, Oak Creek, Beaver Creek and West Clear Creek, combine within the Town limits and periodically flood during major storm events. Figure 1-2 shows the effective FEMA floodplains across the Town. Per the effective FEMA Flood Insurance Study (FIS), the Verde Lakes Estate within the Town experienced severe flooding from West Clear Creek in September 1970, December 1971, October 1972, February 1976, and February 1980. The 1980 flood was so severe that channel alignment and grade were significantly altered.

Significant flooding events typically occur during the spring season. This flooding not only comes from rainfall, but from snowmelt as well. Recently, between March 21st and March 23rd, 2023, the Town experienced severe flooding from heavy rain and snowmelt. The USGS gage station at Verde River reported its 3rd highest flow (78,863 cfs) near Camp Verde and its 5th highest flow (14,592 cfs) at West Clear Creek. Figure 1-3 shows the snow depth as of March 21st, 2023 in relation to the watershed contributing to the Town. The snow data was downloaded from the National Operational Hydrologic Remote Sensing Center (NOHRSC) website. The precipitation and rapid snowmelt brought widespread flooding and elevated flows to the Town.

1.4 Study Limitations and Assumptions

The purpose of this study is to evaluate the existing drainage pattern and assess the flood hazards during the 10- and 100-year, 6- and 24-hour storm events. Assumptions and limitations of this study consist of the following:

- This is a planning level study to identify existing drainage patterns.
- No floodplain delineation is included in this study.
- USGS topography was used outside of the Town boundary for hydrology and hydraulic analysis (Section 2.1.2).
- Frequency storms generated in HEC-HMS were used as the rainfall pattern for this study (Section 4.2).
- Culvert data was collected from as-builts, field observation, aerial imagery, and topographic information (Section 5.8). No professional field survey was conducted to collect culvert information.
- The entire watershed was modeled with HEC-HMS and FLO-2D. Hydrographs from HEC-HMS were scaled to match FIS peak discharges and then coded into FLO-2D as inflow hydrographs (Section 4.8).



Project Area

Name	Area (sq.mi)
Town of Camp Verde	44.58
StreamStats delineated watershed	5013.39

HUC-8 Contributing Watersheds

Name	Area (sq. mi)
Big Chino-Williamson Valley	2153.62
Upper Verde	1966.55
Lower Verde	2508.16
Total:	***6628.33***

Figure 1-1. Camp Verde and Its Tributary Watershed

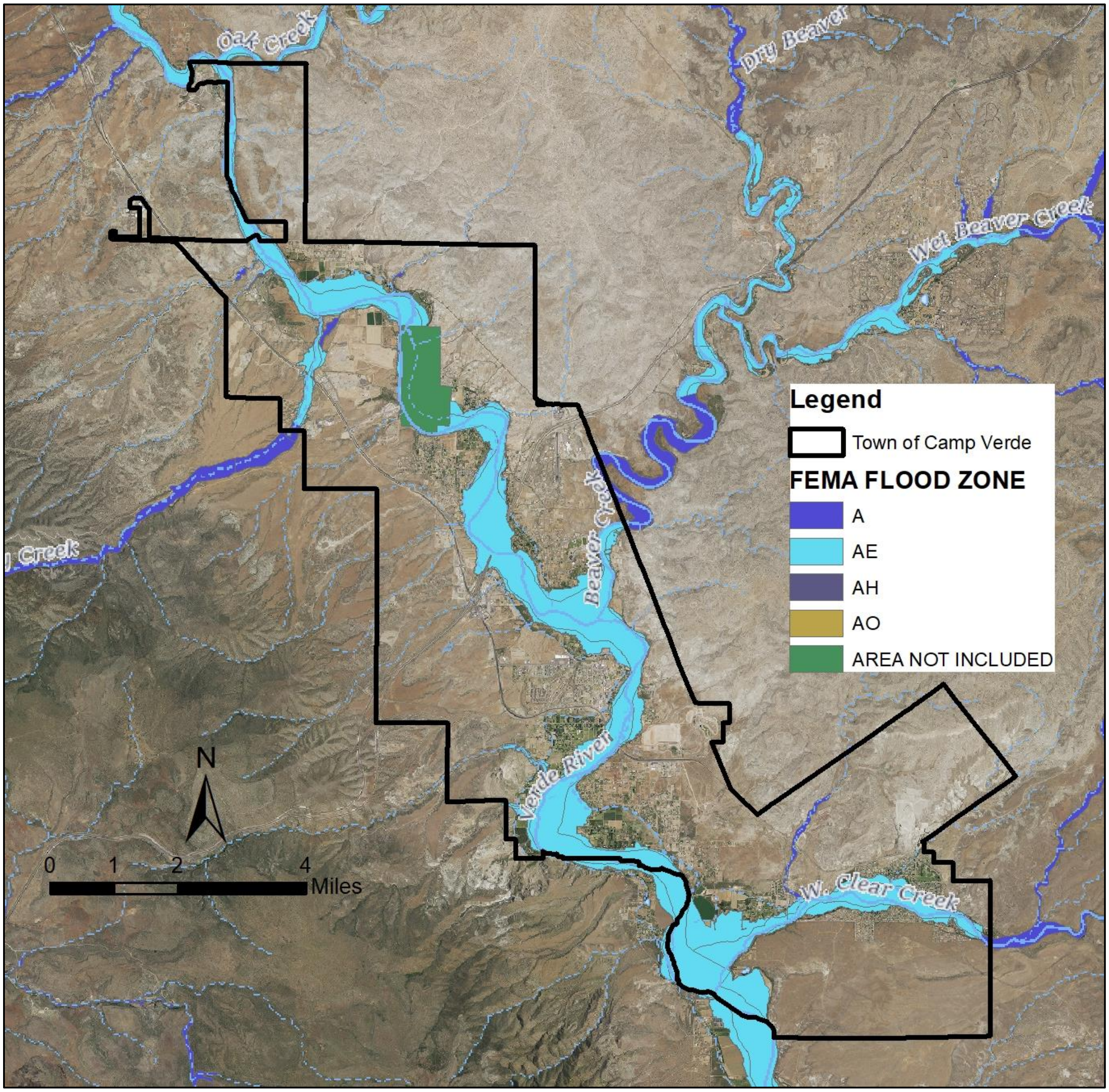


Figure 1-2. Floodplain and Flooding Sources

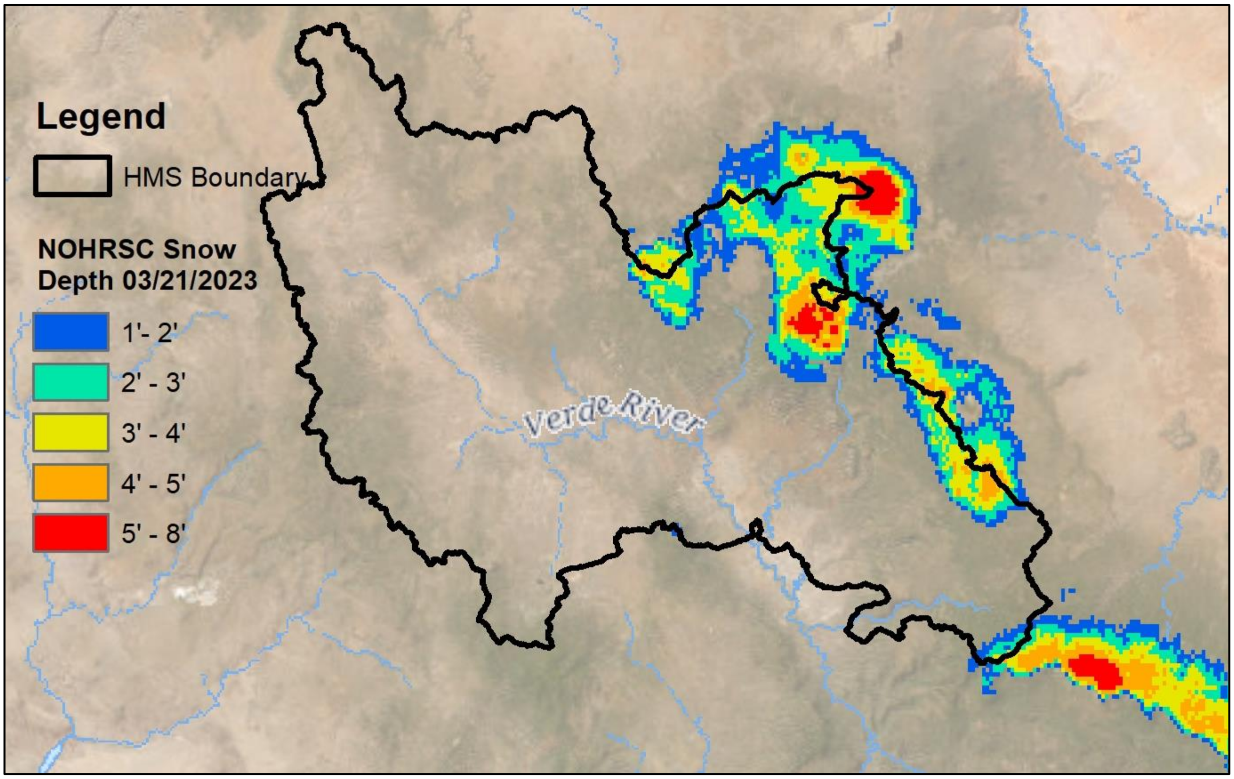


Figure 1-3. Snow Depth as of March 21st 2023

2 DATA COLLECTION

2.1 Topography

2.1.1 Detailed

LiDAR data, collected at a resolution of 30 points per square meter, was acquired by Cooper Aerial Survey Company for the 44.58 square miles of Town limits. LiDAR acquisition was completed from flights flown in March 2023 and was processed to provide bare earth DEMs at 1-foot resolutions. LiDAR point data and 3D AutoCAD files of the DTM are provided in Appendix C.

The aerial mapping was based on the spatial projection as listed in Table 2-1 and on the North American Vertical Datum of 1988 (NAVD88).

Table 2-1. Spatial Projection of Town Topographic Data.

Parameter	Value
Projection Name	NAD_1983_2011_StatePlane_Arizona_Central_FIPS_0202_Ft_Intl
False Easting	700000
False Northing	0
Central Meridian	-111.9166666666667
Scale Factor	0.9999
Latitude of Origin	31
Linear Unit	Foot

The following two control points were used in the aerial mapping:

Control Point #99 (utilized NGS monument ES0457)
Latitude: N34°32'14.38206"
Longitude: W111°49'45.47039"
Ellipsoid height: 3012.960
Description: 3” brass disk in rock outcrop
Arizona State Plane-Central Coordinates:
Northing: 1,286,928.192
Easting: 726,311.086
Elevation: 3098.121

Control Point #98
Latitude: N34°37'54.37391"
Longitude: W111°55'51.65778"
Ellipsoid height: 3146.308
Description: set 1/2” rebar and plastic cap
Arizona State Plane-Central Coordinates:
Northing: 1,321,286.239
Easting: 695,683.601
Elevation: 3231.413

2.1.2 USGS

Additional topographic data was downloaded from the USGS website for use where high-resolution data was unavailable within the FLO-2D study boundary. A USGS dataset with a spatial resolution of 1-meter and 10-meter is used and has a spatial projection summarized in Table 2-2 and Table 2-3, respectively. The vertical datum for the USGS datasets is NAVD88. The USGS data was provided in raster format and is included in Appendix C. The USGS datasets were projected to the spatial reference system summarized in Table 2-1. The spatial extents of the USGS topographic sources are shown in Figure 2-1.

Table 2-2. Spatial Projection of 1-meter USGS Topography Data

Parameter	Value
Projection Name	NAD_1983_UTM_Zone_12N
Linear Unit	Meter (1.000000)
Angular Unit	Degree (0.0174532925199433)
Datum	D_North_American_1983

Table 2-3. Spatial Projection of 10-meter USGS Topographic Data

Parameter	Value
Projection Name	GCS_North_American_1983
Angular Unit	Degree (0.0174532925199433)
Datum	D_North_American_1983
Geographic Coordinate Units	Decimal Degree

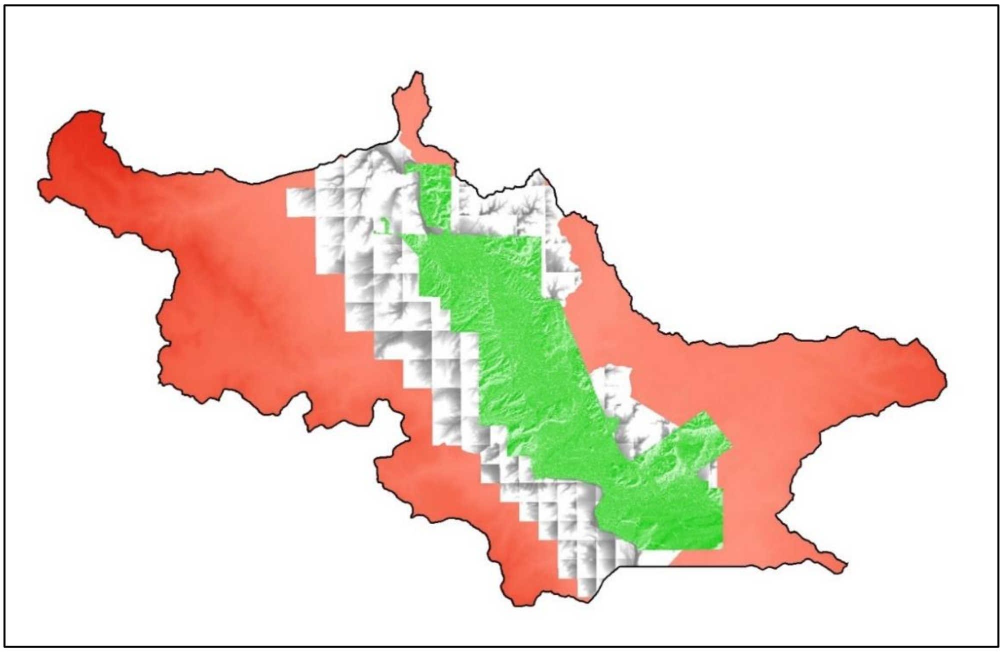


Figure 2-1. Topo Sources within FLO-2D Boundary – Detailed Aerial Mapping (Green), USGS 1-Meter (Black and White Tiles) and USGS 10-Meter (Red)

2.2 Planimetrics

Planimetric data was developed by Cooper Aerial Survey Company from the collected LiDAR data and aerial imagery. The following feature types were delineated and included in the planimetric data:

- Brick (paver)
- Building
- Concrete
- Concrete Ditch
- Culvert Pipe
- Fire Hydrant
- Foundation
- Headwall
- Manhole
- Miscellaneous Building
- Paved Drive
- Paved Parking
- Paved Road
- Sidewalk
- Sports Track
- Storage Container
- Trailer or Mobile Home
- Unpaved Alley
- Unpaved Drive
- Unpaved Parking
- Unpaved Road
- Valve

2.3 Aerial Imagery

Aerial imagery was acquired by Cooper Aerial Survey Company during the flights in March 2023 using PhaseOne camera technology for the 44.58 square mile Town limits. The orthorectified imagery was collected at a pixel resolution of 5 cm ground sampling distance (GSD). For the area outside of the Town limits, 2019 aerial imagery for Yavapai County was obtained from the United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP). The NAIP imagery has a resolution of 2.0 feet.

2.4 Site Visits

Site visits were conducted on March 23rd, 2023, May 30th, 2023, and July 12th, 2023 to evaluate watershed conditions and to obtain information on hydraulically significant culverts.

A heavy rain started during the late evening hours on March 20th, 2023, and continued throughout March 21st, 2003. Widespread flooding occurred in northern Arizona including areas along Verde River. There were multiple reports of flooding in Camp Verde. The crest of the Verde River gage station near Camp Verde was reported to reach 25.0 ft high with an estimated flow of 78,863 cfs, which marked the 3rd highest record in the gage history. The site visit on March 23rd, 2023 documented the flooding impacts at various locations. The site visits on May 30th, 2023 and July

12th, 2023 were to collect culvert information within the Town limits. Field photographs from these site visits are included in Appendix C.

2.5 As-Builts

As-builts of State Route 260 and Interstate 10 within the Town limits were collected from the Arizona State Department of Transportation (ADOT) website. Below is the list of the as-builts that were collected and reviewed to extract culvert information. In addition, Arizona National Bridge Inventory (NBI) was downloaded and reviewed for the culverts with span lengths greater than 20-feet.

- H329501C State Highway Camp Verde – Payson HWY (SR 260), S-326-509, 1998
- H386803C State Highway Cottonwood – Camp Verde Highway (SR 260), AC-STP-326-(012)A, 2008
- H386802C State Highway Cottonwood – Camp Verde – Mogollon Rim HWY (SR 260), 2009
- H470801C State Highway Cordes Jct – Flagstaff Highway (I-17), I-17-2-515, 1999
- H483201C State Highway Camp Verde – Bridgeport Highway (SR 260), STP-326-(13)P, 2000
- H702701C State Highway Cordes Jct – Flagstaff Highway (I-17), HSIP-IM-017-B(211)T, 2014
- H750601C State Highway Cottonwood – Camp Verde – Mogollon Rim HWY (SR 260), 2009
- H869901C State Highway Cottonwood – Camp Verde – Mogollon Rum HWY (SR 206), 2019
- I-17-2(48) State Highway Cordes Junction – Flagstaff, 1980
- IN-003-3(1) State Highway Cordes Jct – Flagstaff, 1957
- S-326(3) State Highway Camp Verde – Bridgeport, 1962
- S-326(5) State Highway Camp Verde – Bridgeport, 1968

2.6 March 2023 Flooding

Flooding occurred during this study on March 16th, March 21st and March 22nd, 2023. Photographs of flooding conditions were obtained from field visits and were provided by the Town staff and residents (see Photograph 2-1 – Photograph 2-5). Additional photographs of the March 2023 flooding are provided in Appendix C.

Photograph 2-1. *Beaver Creek flooding near Lacey Lane during the March 2023 flooding event.*

Photograph 2-2. *Aerial view of Verde River RV Resort during the March 2023 flooding event.*

Photograph 2-3. Aerial view of Verde Lakes Drive and Ripple Road intersection.

Photograph 2-4. Roadway damage at Verde Lakes Drive due to the March 2023 flooding event.

Photograph 2-5. Flooding aftermath at Verde Lakes Drive showing riverbed deposits and severe roadway damage.

2.7 Outreach

A Community Outreach Meeting was conducted on October 12th, 2023 to solicit information on drainage issues from Town residents and business owners. Participants were invited to share their comments and concerns at the in-person outreach meeting or online via a virtual meeting room. A survey form and GIS application were used for residents to provide feedback and to pinpoint specific areas of interest on the interactive map. Additionally, residents were able to view a map of the FLO-2D modeling results over the Town limits. Resident and Town feedback strongly correlated to the FLO-2D modeling results. Community Outreach Meeting information is provided on the accompanying external hard drive (Appendix C).

3 GENERAL HYDROLOGIC AND HYDRAULIC ANALYSES APPROACH

3.1 Modeled Flood Scenarios

Existing condition modeling was completed for the 10- and 100-year storms having durations of 6- and 24-hours.

3.2 Selected Models

3.2.1 HEC-HMS

There are four flood sources to the FLO-2D study area, i.e. Verde River, Oak Creek, Beaver Creek, and West Clear Creek. The tributary areas for these river and creeks range from 240 square miles to 3000 plus square miles, and hence the peak times of flood waves vary across these inflows. Hydrographs to reflect the peak time differences are important for FLO-2D to accurately model the flood wave across the Town. However, there was no existing HEC-1/HEC-HMS model available to provide hydrographs. Therefore, for this study, a HEC-HMS model was developed for the area outside the study area boundary to provide inflow hydrographs into the FLO-2D model. The HMS modeling was prepared following the procedures in the Drainage Design Manual for Yavapai County (2015).

As discussed in Section 1.3.2, the typical flooding during the spring seasons is not only from rainfall but also from snowmelt within the watershed. Although HMS has the capability to model snowmelt, “rain-on-snow” scenarios were not modeled since they require detailed information on snow levels, snowpack conditions and temperature variations. Therefore, only the rainfall-runoff process was modeled. There are several gage stations within the watershed and the gage records cover all storm events including “rain-on-snow” events. The effective FIS peak discharges were also derived from gage records and hence counted in those “rain-on-snow” events. The gage station records were analyzed and compared with FIS data and the HMS model outputs. The hydrographs resulting from the HMS modeling were scaled to the gage record analysis or FIS data to ensure that statistical peak discharges are matched.

3.2.2 FLO-2D

For the study area defined by the limits of the Town and its contributing areas, existing condition H&H modeling was conducted using the Professional Version of FLO-2D (FLO-2D Software, Inc., 2018), Build No. 21.08.23.

FLO-2D is a dynamic, two-dimensional, H&H model that conserves volume as it routes hydrographs over a grid comprised of square elements. The model routes stormwater runoff over the grid using the dynamic wave momentum equation and a central finite difference routing scheme. The flood wave progression is affected by the surface topography (grid element elevations) and roughness values (Manning’s n-values assigned to each grid element) associated with land-use characteristics.

4 HEC-HMS MODEL DEVELOPMENT

4.1 Basin Delineation

HMS basins were delineated using the USGS Streamstats batch processing tool (https://www.usgs.gov/tools/streamstats-batch-processing-tool) based on the selected concentration points. The concentration points include four (4) FLO-2D inflow points and eight (8) selected USGS gage station within the watershed. One of the benefits of choosing USGS gage stations as concentration points is that the historical flow records serve to verify the HMS modeling. The concentration points are shown in Figure 4-1. The eight (8) USGS gage stations are as follows:

1. West Clear Creek Near Camp Verde, AZ (US09505800)
2. Wet Beaver Creek Near Rimrock, AZ (US09505200)
3. Dry Beaver Creek Near Rimrock, AZ (US09505350)
4. Oak Creek Near Sedona, AZ (US09504420)
5. Oak Creek Near Cornville, AZ (US09504500)
6. Verde River Near Clarkdale, AZ (US09504000)
7. Verde River Near Paulden, AZ (US09503700)
8. Big Chino Wash At Paulden, AZ (US09502830)

A total of twelve (12) basins were delineated based on these concentration points. The sizes are listed in Table 4-1.

Table 4-1. Basin Sizes

Basin ID	Drainage Area (sq mi)
Verde_1	1,798.1
Verde_2	350.8
Verde_3	993.7
Verde_4	132.0
Oak_1	232.7
Oak_2	122.3
Oak_3	107.5
DryBeaver	142.1
WetBeaver_1	109.3
WetBeaver_2	170.2
WestClear_1	241.4
WestClear_2	14.2
Total	**4,414.3**

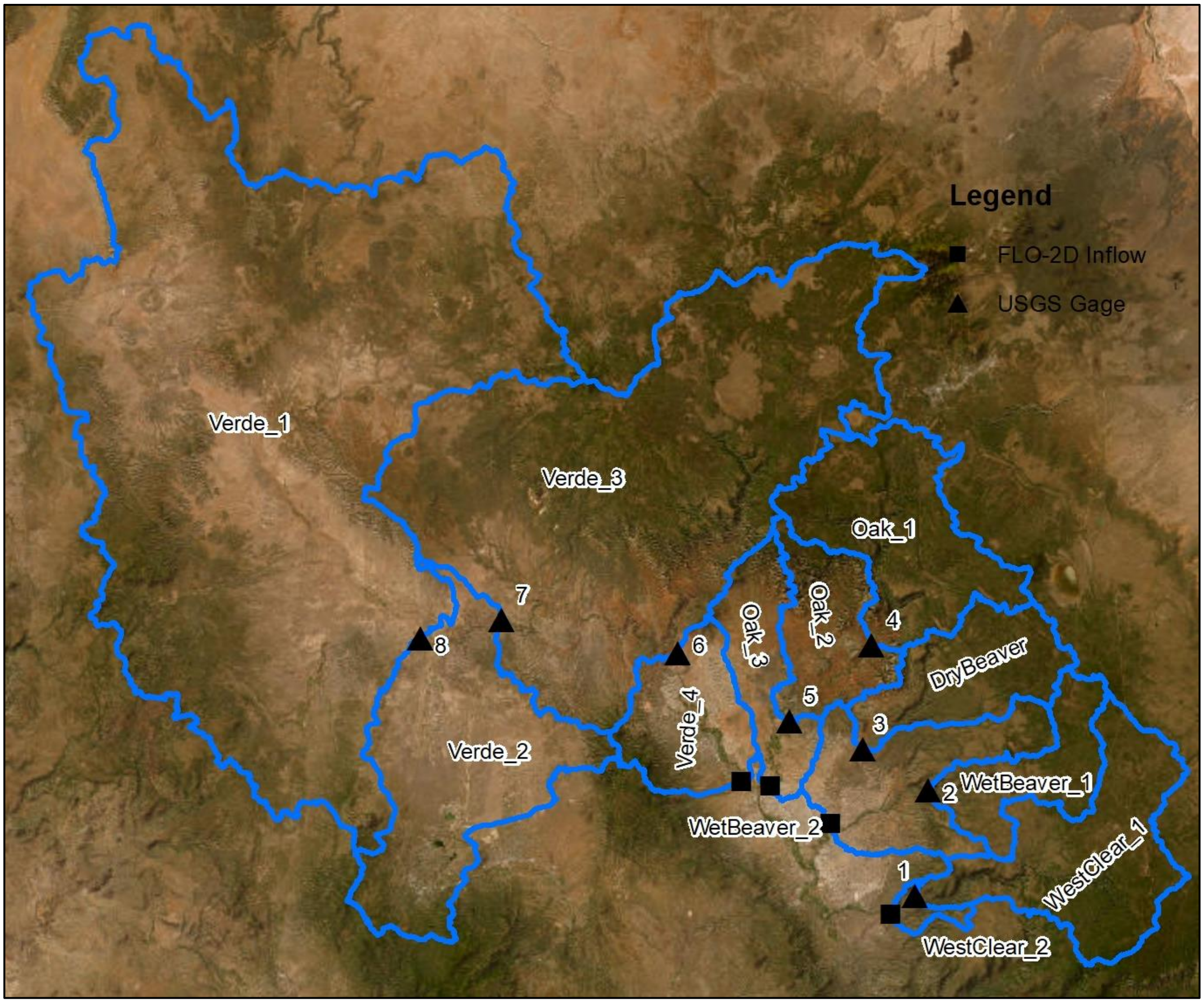


Figure 4-1. HMS Concentration Points and Basin Delineation

4.2 Rainfall

The rainfall was determined per the Drainage Design Manual for Yavapai County (2015). The median rainfall values of 5- and 15-minutes with durations of 1-, 2-, 3-, 6-, 12- and 24-hours, were downloaded from the NOAA website in raster file formats. The Zonal Statistics function in ArcMap was used to obtain the average rainfall values over the entire HMS study area (Table 4-2). Frequency storms were developed based on these precipitation values in HMS. The temporal patterns of the frequency storms were extracted from HMS modeling and provided as one of the FLO-2D modeling inputs. TP40 was selected in the HMS modeling for the area-depth reduction.

Table 4-2. NOAA Area Average Precipitation Depths

Duration	**Precipitation Depth (in)**	
	10-Year	**100-Year**
5-minute	0.488	0.819
15-minute	0.922	1.546
1-hour	1.536	2.577
2-hour	1.722	2.874
3-hour	1.800	2.946
6-hour	2.047	3.217
12-hour	2.454	3.622
24-hour	3.005	4.486

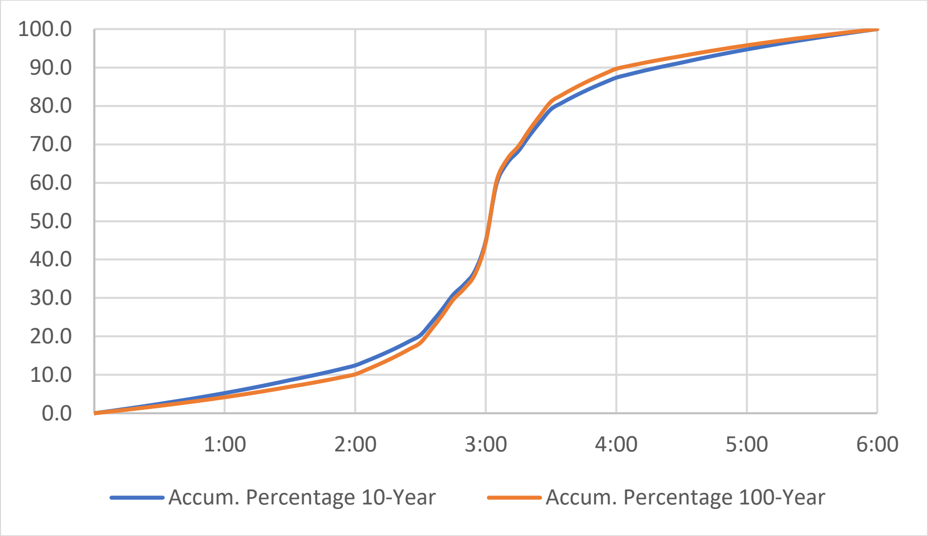


Figure 4-2. Temporal Distribution of 6-Hour Event from HMS Frequency Storm

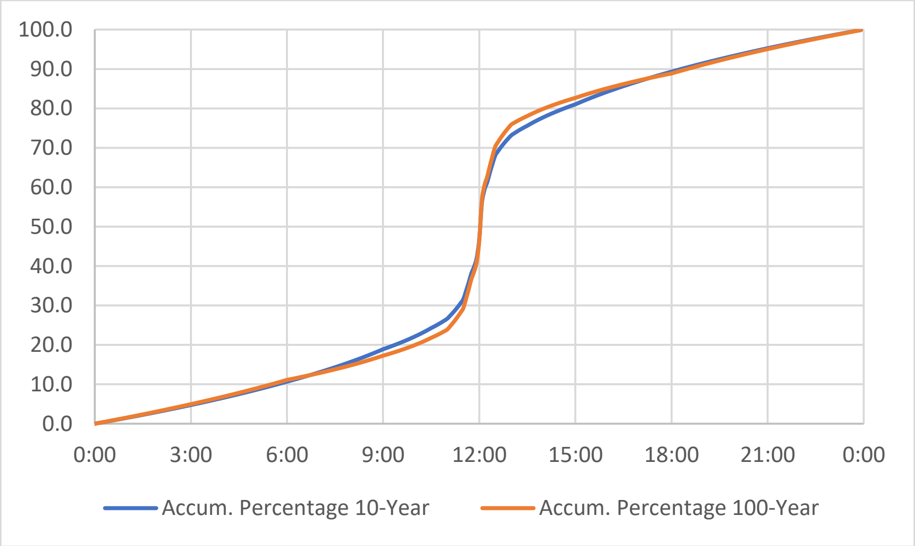


Figure 4-3. Temporal Distribution of 24-Hour Event from HMS Frequency Storm

4.3 Rainfall Loss

Per the Drainage Design Manual for Yavapai County (2015), the simple surface method was selected for the surface retention loss and the Green and Ampt method was selected for infiltration estimation in the HMS modeling. Two parameters were required for the simple surface method, initial storage in percentage and maximum storage in inch. The initial storage was taken as 0 percent. The maximum storage is the sum of all initial losses including surface depression storage and interception losses. Table 7.7 in the Drainage Design Manual for Yavapai County (2015) lists detailed land use types and the corresponding surface retention loss and impervious percentage ranges. To simplify the analysis, only two land use types were selected for the HMS modeling (Table 4-3).

Table 4-3. Surface Retention Loss and Effective Impervious Area Estimates

Land-use	Surface retention loss, inches	Impervious, percent
Mountain, steep slopes (vegetated)	0.25	Varies (Rock outcrop percentage from soil data)
Urban area / clusters	0.25	50

The urban area/cluster area were based on the 2010 Census data and was shown in Figure 4-4. The percentages of urban area/cluster for each basin are listed in Table 4-4.

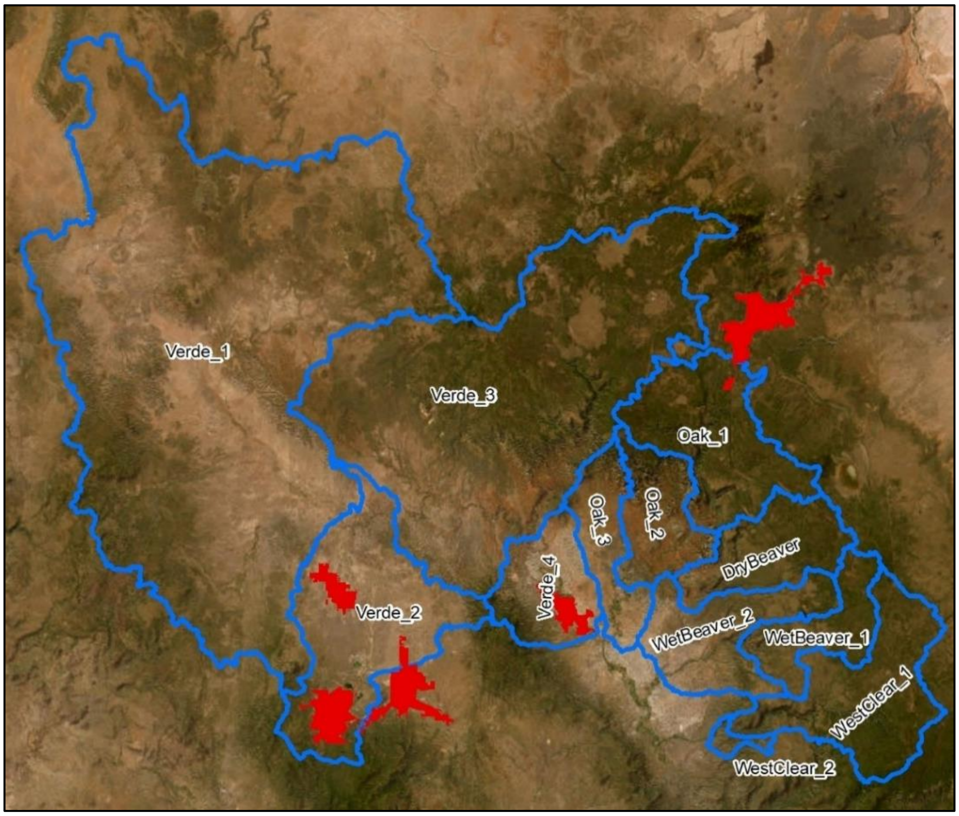


Figure 4-4. Urban Area/Cluster (in red) of Watershed

Table 4-4. Urban Area/Cluster Percentages

Basin ID	Urban Area/Cluster Percentage (%)
Verde_1	0
Verde_2	11.3
Verde_3	0
Verde_4	11.0
Oak_1	0.9
Oak_2	3.6
Oak_3	0
DryBeaver	2.0
WetBeaver_1	0
WetBeaver_2	1.7
WestClear_1	0
WestClear_2	0

Four (4) parameters are needed for Green and Ampt calculations: initial soil moisture content deficit, hydraulic conductivity at natural saturation, wetting front capillary suction, and impervious area percentages. Soils data was downloaded from the ADOT website (https://azdot.gov/business/engineering-and-construction/roadway-engineering/drainage-design/manuals-drainage-design). Detailed soils data was used where available and general soils data was used to supplement the remaining modeled area (Figure 4-5). The initial soil moisture content deficit was calculated based on dry conditions. Both initial soil moisture deficit and wetting front capillary suction were calculated using the area weight equation, i.e. Equation 7.11 in the Drainage Design Manual for Yavapai County (2015).

The saturated conductivity was calculated using Equation 7.10 in the Drainage Design Manual for Yavapai County (2015). Then the value was adjusted based on vegetation per Figure 7.10 and Equation 7.13 in the Drainage Design Manual for Yavapai County (2015). The vegetation cover was calculated based on the National Land Cover Database (NLCD) 2019 data (Figure 4-6). Three categories (deciduous forest, evergreen forest, and mixed forest) in the NLCD data were added up to get the vegetation cover for each basin (Table 4-5).

The impervious area for urban area/cluster is 50% per Table 4-3. After reviewing the rock outcrop data through the watershed, it was determined that the rock outcrops are continuous in general, and therefore it should be counted as effective impervious area. The rock outcrop areas for each basin were calculated and summed up with the urban impervious area to get the total impervious percentage for each basin. The total impervious percentage and other parameters are listed in Table 4-6.

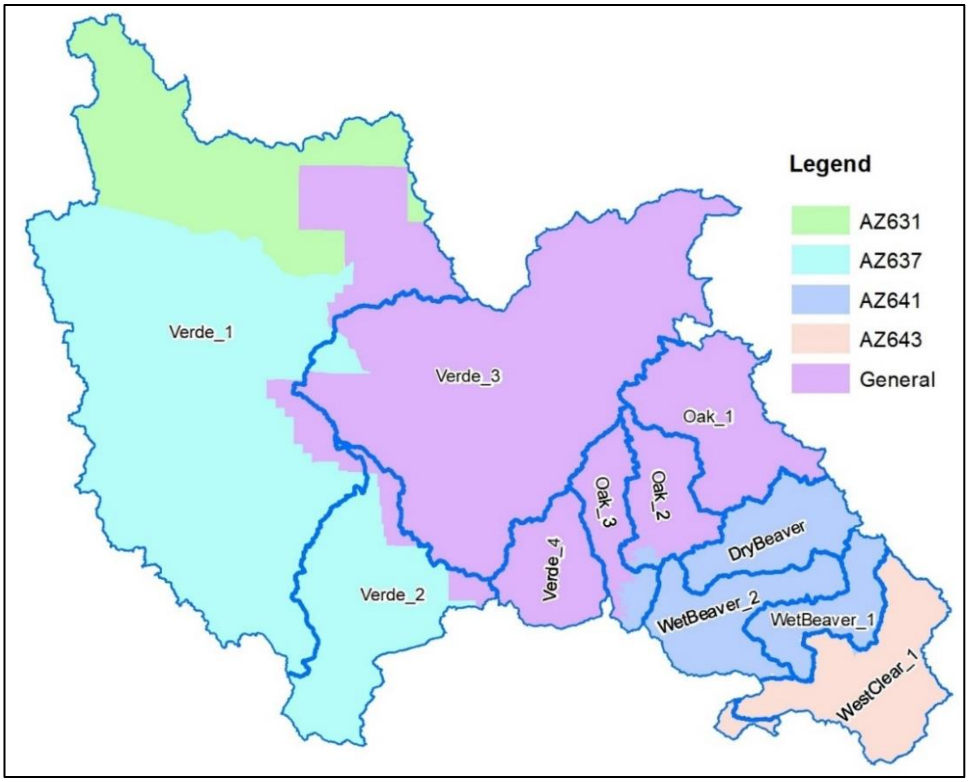


Figure 4-5. Soil Data Sources for HMS Modeling

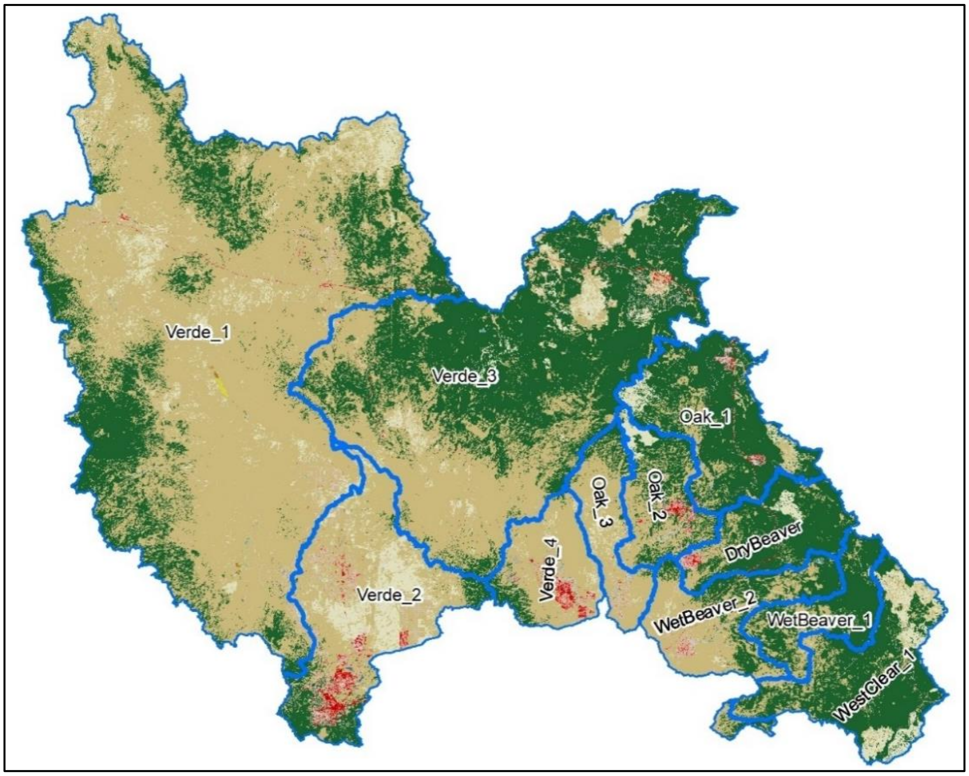


Figure 4-6. Vegetation Cover from 2019 NLCD Data

Table 4-5. Vegetation Cover for Basins

Basin ID	Vegetation Cover (%)
Verde_1	21.2
Verde_2	12.8
Verde_3	55.1
Verde_4	10.4
Oak_1	73.9
Oak_2	38.5
Oak_3	13.7
DryBeaver	75.5
WetBeaver_1	73.8
WetBeaver_2	33.4
WestClear_1	65.9
WestClear_2	41.8

Table 4-6. Green-Ampt Parameters for Basins

Basin ID	Initial Deficit	Suction (in)	Conductivity (in/hr)	Impervious (%)
Verde_1	0.27	10.62	0.12	4.4
Verde_2	0.29	7.69	0.21	8.1
Verde_3	0.29	9.47	0.22	11.8
Verde_4	0.29	6.73	0.19	13.5
Oak_1	0.29	11.05	0.2	18.1
Oak_2	0.27	11.52	0.11	43.2
Oak_3	0.27	12.19	0.1	21.1
DryBeaver	0.25	10.8	0.08	22.6
WetBeaver_1	0.25	12.33	0.06	16.7
WetBeaver_2	0.24	11.67	0.05	18.8
WestClear_1	0.28	9.16	0.18	0.6
WestClear_2	0.27	8.98	0.18	0.3

4.4 Unit Hydrographs

The Clark unit hydrograph was selected for the HMS modeling. Three parameters were required for the Clark unit hydrograph: the time of concentration, the storage coefficient, and a time-area relation. The longest flow paths and length measured from concentration points to centroids were shown in Figure 4-7. The time of concentrations and storage coefficients were calculated based on Equation 7.15 and 7.18 in the Drainage Design Manual for Yavapai County (2015) and are shown in Table 4-7. The default time-area histogram in the HMS program was selected for the modeling.

Table 4-7. Time of Concentration (Tc) and Storage Coefficient (R)

Basin ID	**A (sq mi)**	**L (mi)**	**Lca (mi)**	**S (ft/mi)**	**Tc (hr)**	**R (hr)**
Verde_1	1798.1	94.3	29.8	24.5	19.5	5.3
Verde_2	350.8	47.5	25.0	57.3	11.3	4.2
Verde_3	993.7	64.5	22.9	140.3	11.0	2.9
Verde_4	132.0	19.9	10.1	197.4	5.1	1.5
Oak_1	232.7	29.0	13.4	98.0	7.3	2.2
Oak_2	122.3	38.1	18.7	101.8	8.0	4.4
Oak_3	107.5	37.3	20.9	99.8	8.1	4.7
DryBeaver	142.1	34.3	18.2	112.8	7.7	3.6
WetBeaver_1	109.3	31.4	13.4	132.5	6.5	3.2
WetBeaver_2	170.2	31.2	11.6	144.1	6.5	2.5
WestClear_1	241.4	55.8	24.9	87.1	10.4	5.4
WestClear_2	14.2	9.4	4.2	299.4	2.5	1.3

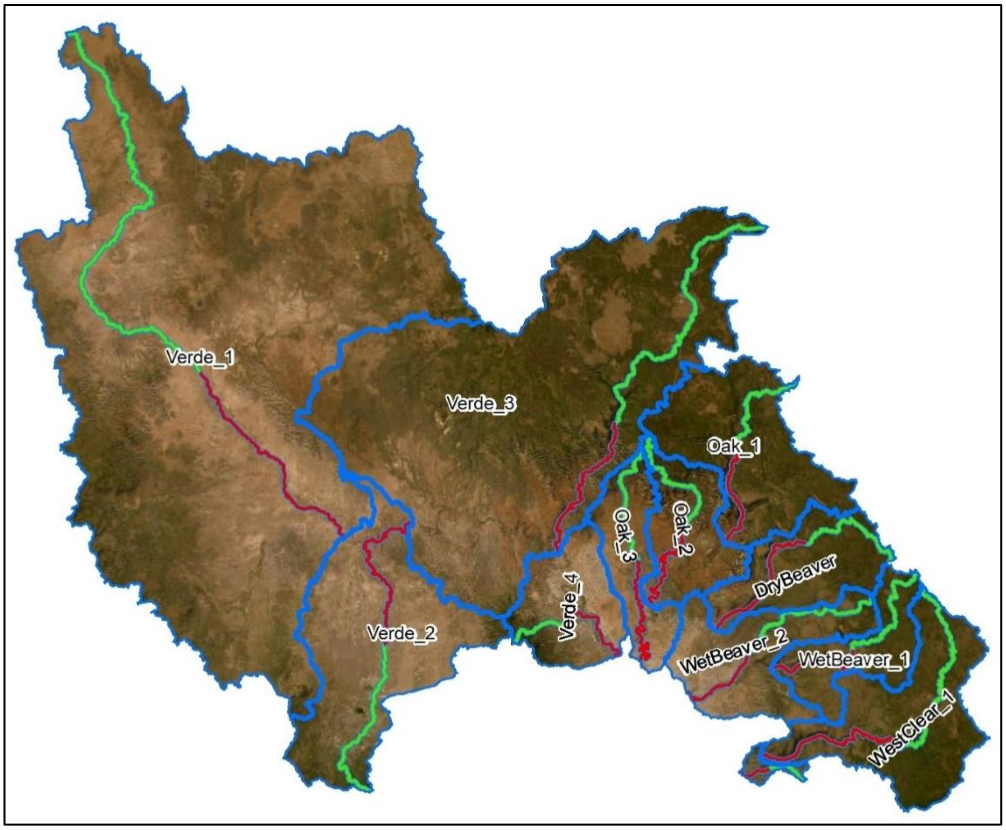


Figure 4-7. Longest Flow Paths (L, in green) and Length from Centroid (Lca, in red)

4.5 Channel Routing

The Muskingum-Cunge method was selected for channel routing. The required inputs for the Muskingum-Cunge method include routing reach length, energy grade line slope, Manning's roughness for channels, cross sections of channels, and the space-time method. The routing reaches are shown in Figure 4-8. The energy grade line slope was assumed to be the same as the calculated channel bed slope. A trapezoidal cross-section for each reach was selected with the bottom width and side slope estimated based on the USGS topography. Auto DX and Auto DT method in the HMS program were selected with an index celerity of 5 ft/s for the program to automatically select space and time intervals that maintain numeric stability. Most of the parameters are listed in Table 4-8. No transmission loss was selected for the channel routing.

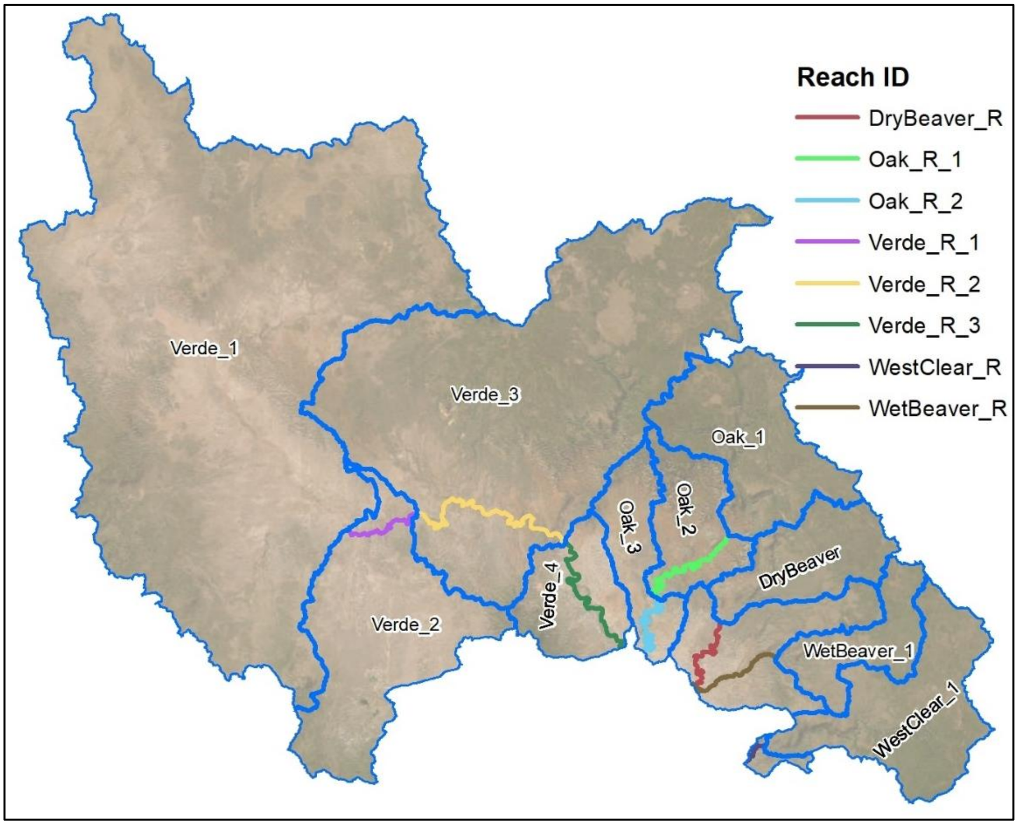


Figure 4-8. Channel Routing Reaches

Table 4-8. Muskingum-Cunge Routing Parameters

Reach	Length (ft)	Slope (ft/ft)	Manning's n	Bottom Width (ft)	Side Slope (H:V)
Verde_R_1	59479	0.0039	0.05	400	3
Verde_R_2	153081	0.0040	0.05	400	3
Verde_R_3	113050	0.0027	0.05	1000	10
Oak_R_1	99686	0.0072	0.05	300	6
Oak_R_2	83649	0.0033	0.05	600	6
WetBeaver_R	69313	0.0114	0.05	600	8
DryBeaver_R	73974	0.0068	0.05	400	6
WestClear_R	18852	0.0127	0.05	200	4

4.6 HEC-HMS Modeling Outputs

The HMS modeling was run for the 10- and 100-year, 6- and 24-hour events. The peak discharges from the HMS modeling are listed in Table 4-9.

Table 4-9. HMS Modeling Outputs

ID	Peak Discharges (cfs)			
	10-Yr 6-Hr	10-Yr 24-Hr	100-Yr 6-Hr	100-Yr 24-Hr
Verde_1	14534	27455	66150	85299
Verde_R_1	14528	27446	66128	85272
Verde_2	3266	6170	17460	22720
Verde_J_1	15699	30429	73978	96321
Verde_R_2	15688	30408	73936	96269
Verde_3	13294	19976	54387	72031
Verde_J_2	16656	35972	96957	132313
Verde_R_3	16636	35918	96390	131661
Verde_4	6460	8882	20914	24644
Verde_J_3	16636	35954	96393	132480
Oak_1	6711	8804	21466	26897
Oak_R_1	6702	8794	21436	26861
Oak_2	7535	9294	15201	17555
Oak_J_1	13674	17707	36364	44242
Oak_R_2	13577	17617	36180	44053
Oak_3	4223	5651	10529	12502
Oak_J_2	15947	21403	44034	54025
Verde_J_4	26921	45500	121222	166033
DryBeaver	7365	9421	17347	20163
DryBeaver_R	7357	9413	17332	20147
WetBeaver_1	6582	8334	15715	18145
WetBeaver_R	6579	8329	15708	18137

ID	Peak Discharges (cfs)			
	10-Yr 6-Hr	10-Yr 24-Hr	100-Yr 6-Hr	100-Yr 24-Hr
WetBeaver_2	12037	14936	27429	31414
WetBeaver_J	16555	21305	40606	46984
Beaver_J	21750	28583	54473	63592
WestClear_1	840	2650	10043	13413
WestClear_R	840	2650	10042	13412
WestClear_2	1510	2035	4673	5459
WestClear_J	1547	2651	10042	13415

4.7 HEC-HMS Modeling Verification

The HMS modeling results were compared with gage records and the effective FIS peak discharges for verification. The HEC-SSP program (version 2.2) was selected to analyze gage records following the USGS Bulletin 17C procedures. The Bulletin 17C superseded the Bulletin 17B in 2019 and updated the procedure with the Expected Moments Algorithm (EMA) to estimate the P-III distribution parameters. The update allows the user to use a wide range of historical flood and threshold-exceedance information collected by gages. The USGS gages analyzed by the HEC-SSP are shown in Figure 4-9.

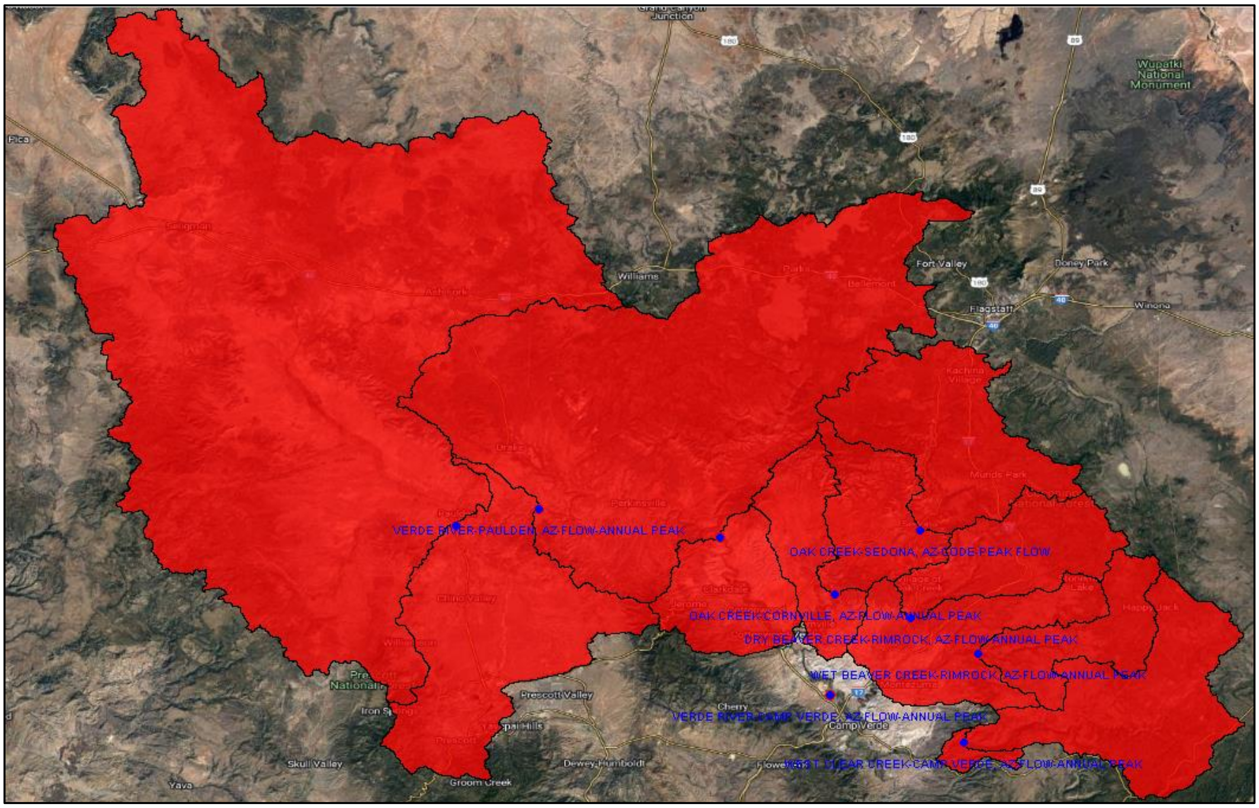


Figure 4-9. HEC-SSP Analysis on USGS Station Records

Gage data from the USGS website was imported into HEC-SSP. The Multiple Grubbs-Beck method was selected to detect low outlier records and remove these records to avoid distortion in results. To simplify efforts, Station Skew instead of Regional Skew was used for parameter estimation. For the years with missing gage records, the upper limits were set at the historical high flows. The HEC-SSP results are listed in Table 4-10.

The effective FIS was reviewed, and the 100-year peak discharges were listed in Table 4-10 for comparison. Per the FIS, gage records were sources of these peak discharges.

Table 4-10. 100-Year Peak Discharge Comparison of HMS Outputs with HEC-SSP and FIS Data

Location	**HMS**		**HEC-SSP**		**FIS**
	ID	**Flow (cfs)**	**USGS Gage**	**Flow (cfs)**	**Flow (cfs)**
Verde River at US R89	Verde_1	85,299	09502830	N/A*	79,600
Verde River near Paulden	Verde_J_1	96,321	09503700	34,565	N/A
Verde River at Clarkdale	Verde_J_2	132,313	09500400	70,289	N/A
Verde River below confluence with Oak Creek	Verde_J_4	166,033	09504950	133,131	100,000
Oak Creek at Sedona	Oak_1	26,897	09504420	28,810	26,900
Oak Creek at Cornville	Oak_J_1	44,242	09504500	36,935	43,350
Oak Creek at Verde River	Oak_J_2	54,025	N/A	N/A	51,200
Dry Beaver near Rimrock	DryBeaver	20,163	09505350	31,869	N/A
Wet Beaver near Rimrock	WetBeaver_1	18,145	09505200	14,608	19,330
West Clear Creek at Camp Verde	WestClear_1	13,413	09505800	25,795	35,400

The 100-year peak discharges from the HMS modeling are reasonably close to the HEC-SSP results and FIS discharges except for West Clear Creek. As discussed in Section 1.3.2, this could be due to the snow melting contributing significantly to West Clear Creek’s flooding while not modeled in HEC-HMS. While both HEC-SSP analysis in this study and the FIS peak discharges are from statistical analysis of the gage records within the watershed, the HEC-SSP analysis in this study uses the latest gage data and follows the latest statistical methodology of Bulletin 17C. The results from both methods are reasonably close.

4.8 Hydrograph Inputs to FLO-2D

There are four outflows from the HMS modeling that are inflows to the FLO-2D modeling: Verde River, Oak Creek, Wet Beaver Creek and West Clear Creek. Their HMS ids are Verde_J_3, Oak_J_2, Beaver_J and WestClear_J, respectively. These four hydrographs from the HMS modeling were scaled to match the FIS peak discharges before being coded into the FLO-2D model. The FIS peak discharges were determined using cross-sections from the FIS effective HEC-RAS models located where the waterways intersect the model boundary. See Table 4-11 for peak discharges used as input to the FLO-2D model for the 10- and 100-year storm events.

Table 4-11. FIS Peak Discharges (10- and 100-Year) as Input to the FLO-2D Model

Name	10-Year Peak Q (cfs)	100-Year Peak Q (cfs)
Verde River	25,485	79,640
Oak Creek	19,430	44,185
Beaver Creek	28,776	59,950
West Clear Creek	16,165	30,500

The FIS effective HEC-RAS models do not provide the 10-year peak discharges at all locations. From the HEC-SSP results, 10-year-to-100-year flow ratios were determined using the USGS gauge stations data (Table 4-12). The determined flow ratios were then used to generate 10-year peak discharges from the FIS 100-year peak flows for input into the FLO-2D model. Hydrographs generated from HMS for the 10-year event were scaled to the 10-year peak discharges using the 10- over 100-year flow ratios. Scaled hydrographs for the 100- and 10-year events are provided graphically in Figure 4-10, Figure 4-11, Figure 4-12, and Figure 4-13.

Table 4-12. 10- Over 100-year Peak Discharge Ratios

Name	USGS Gage	HEC-SSP Peak Flows (cfs)		Ratio
		10-Yr	100-Yr	
Verde River	Verde River at Clarkdale, Az	22231.4	70289.2	0.32
Oak Creek	Oak Creek at Cornville, AZ	16337.7	36934.8	0.44
Wet Beaver Creek	Wet Beaver Creek at Rimrock, AZ	7913.7	14607.9	0.54*
Dry Beaver Creek	Dry Beaver Creek at Rimrock, AZ	12982.0	31868.8	0.41*
West Clear Creek	West Clear Creek at Camp Verde, AZ	13788.2	25794.8	0.53

** It should be noted that the average of Wet Beaver Creek and Dry Beaver Creek, i.e. 0.48, was used for the Beaver Creek.*

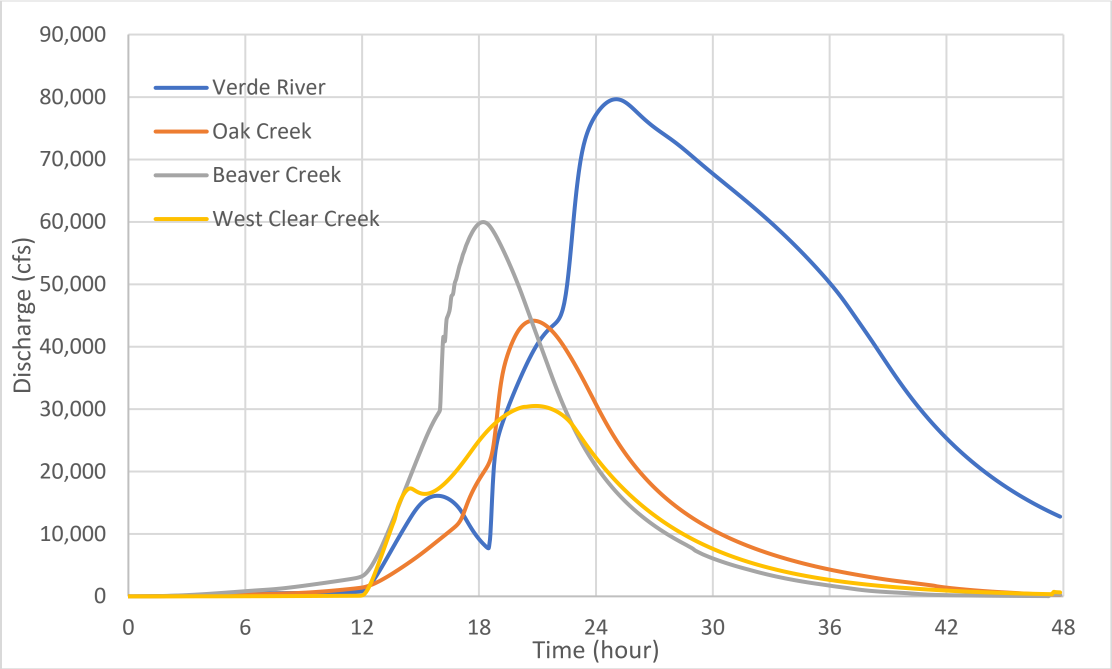


Figure 4-10. 100-Year 24-Hour Inflow Hydrographs for FLO-2D

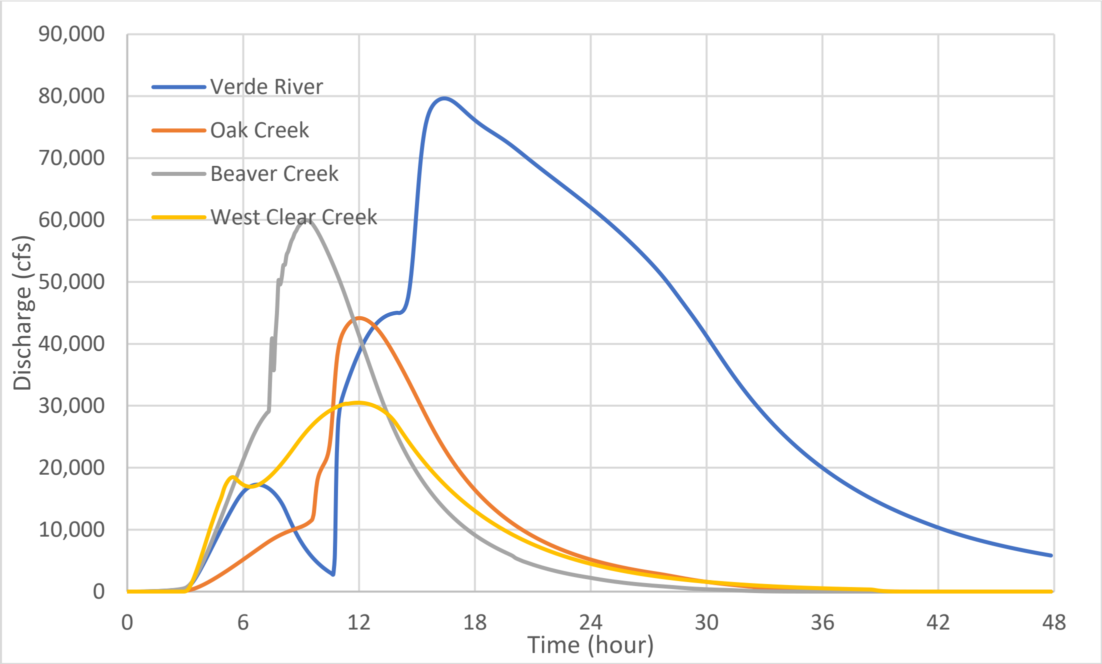


Figure 4-11. 100-Year 6-Hour Inflow Hydrographs for FLO-2D

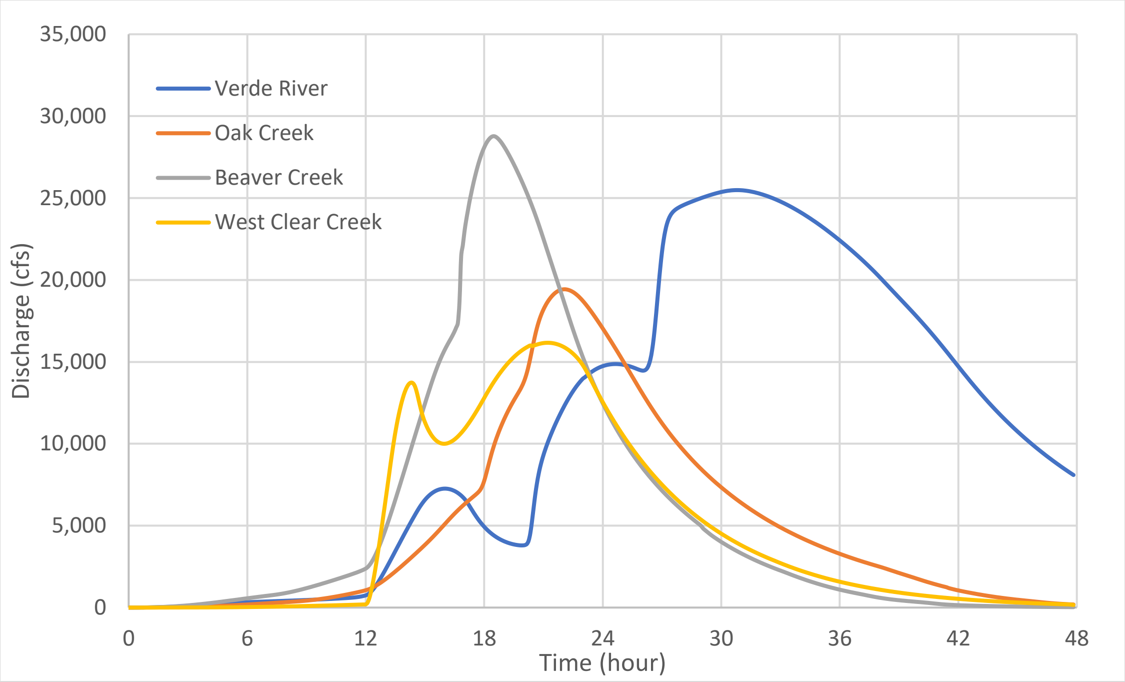


Figure 4-12. 10-Year 24-Hour Inflow Hydrographs for FLO-2D

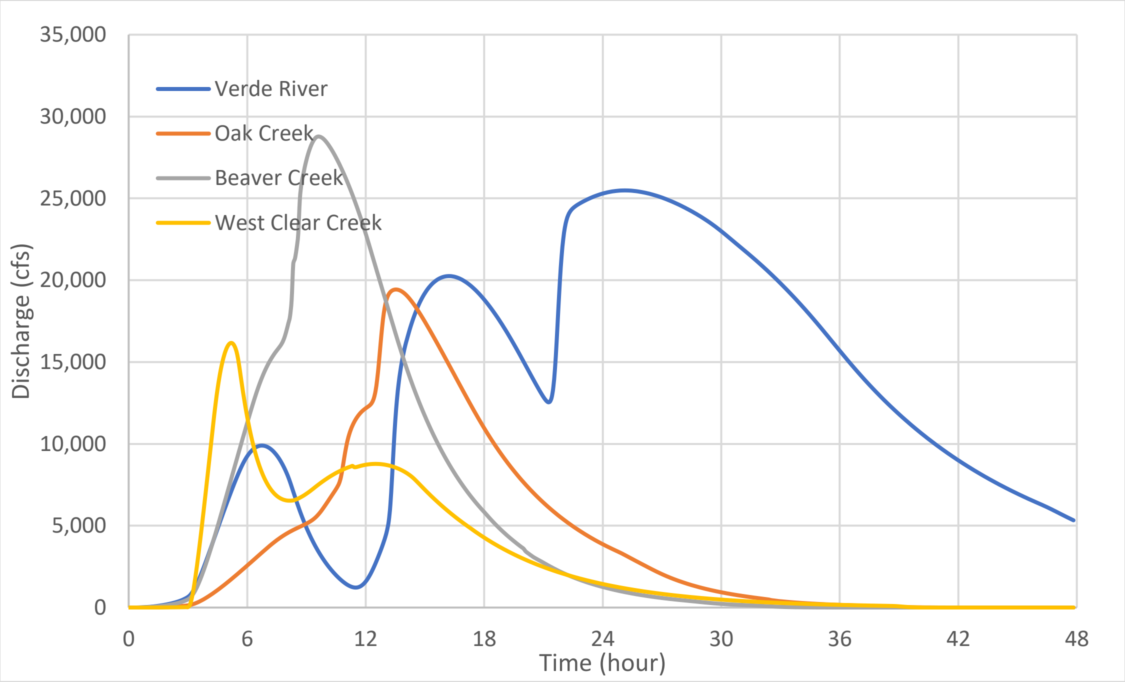


Figure 4-13. 10-Year 6-Hour Inflow Hydrographs for FLO-2D

5 FLO-2D MODEL DEVELOPMENT

The following sections discuss the typical data/information, assumptions, and methodologies used to develop the hydrologic and hydraulic (H&H) models for the Town of Camp Verde Area Drainage Master Study (ADMS).

5.1 Sub-Domains

The fully modeled area (Town limits and adjacent contributing watersheds) is approximately 200 square miles in size. This relatively large modeled area was divided into eight (8) different computation domains (sub-domains), summarized in Table 5-1 and shown in Figure 5-1. An overview of the computational sub-domains is provided in full exhibit format as part of Appendix A. Flow from several sub-domains contribute to their respective downstream sub-domains, requiring sequential running of sub-domains. Sub-domains were strategically delineated for efficient model runs. In this project, Sub-domains 1, 3, 5, 7 were run in parallel since they have no dependency on other sub-domains. Then sub-domains 4, 6 and 8 were run in parallel. Finally, Sub-domain 2 was run.

Computational domains are represented in FLO-2D as a grid comprised of square elements. To achieve reasonable run time while preserving details for the Town, a 20’x20’ grid element size was selected for Sub-domains 2, 3, 4, 6 and 8 which cover or touch the Town and a 40’x40’ grid was used for Sub-domains 1, 5 and 7. The total number of elements for each sub-domain is limited to not exceed 2 million.

Table 5-1. Computational Domain ID and Attributes.

Computational Domain ID	Size (sq. mi.)	Grid Element Size	Number of Elements	U/S Comp. Domain	D/S Comp. Domain
1	69.2	40’ x 40’	1,205,414	N/A	4
2	27.5	20’ x 20’	1,915,467	1, 3, 4, 5, 6, 8	N/A
3	23.2	20’ x 20’	1,618,706	N/A	2
4	5.3	20’ x 20’	366,958	1	2
5	26.6	40’ x 40’	463,818	N/A	2,6
6	10.8	20’ x 20’	752,528	5	2
7	12.7	40’ x 40’	222,143	N/A	8
8	20.8	20’ x 20’	1,447,790	7	2
	196.1		**7,992,824**		

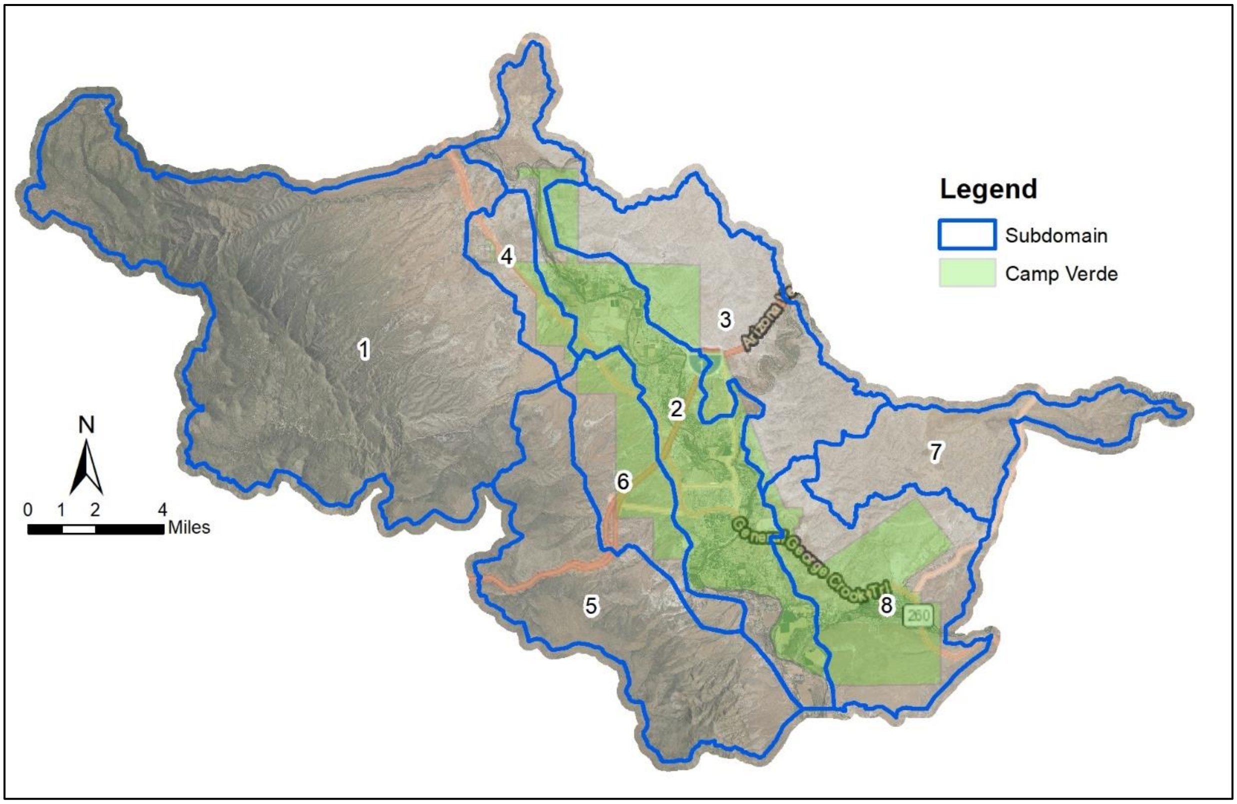


Figure 5-1. Sub-domain Overview of FLO-2D Modeling Extents

5.2 Land Categorization

Based on the aerial imagery, several land categories were delineated: low density residential, agricultural, lawn parks cemetery, medium vegetation urban channel, water body, desert rangeland, Sonoran desert, vegetated mountain terrain and open space. Features from the planimetric delivery such as pavement and building were burned into the land categorization delineation.

Land categorization parameters required for Green and Ampt infiltration include the following: rainfall initial abstraction (IA), percent of impervious area (RTIMP), volumetric soil moisture deficit condition (DTHETA, dry or normal), and surface roughness (Manning's n-values). These parameters were assigned to each land category, as summarized below in

Table 5-2. The land categorizations were developed using polygons in GIS. An overview of the land categorizations across the fully modeled area is shown in Figure 5-2 and provided in exhibit format in Appendix A.

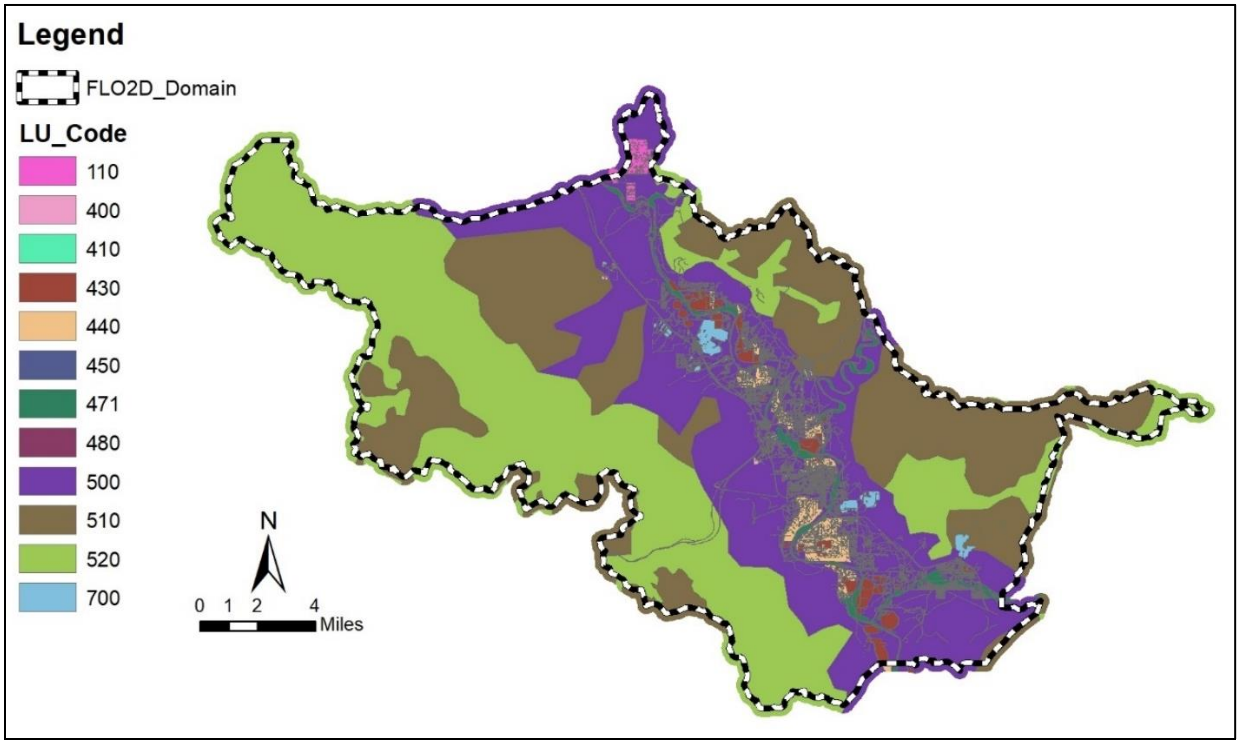


Figure 5-2. Land Categories within FLO-2D Domain

Table 5-2. General Land Categorization.

Code	General Land Category	IA (in)	RTIMP (%)	DTHETA Condition	Manning's n-value
110	Low Density Residential: 12000-40000 sq. feet lot size	0.3	10	Normal	0.04
400	Pavement: Streets and Transportation	0.05	95	Normal	0.02
410	Buildings: Buildings	0.05	95	Normal	0.025
430	Agricultural: Tilled fields, Irrigated pastures, slopes <1%	0.5	0	Normal	0.06
440	Lawns Parks Cemeteries: Over 80% maintained lawn	0.2	5	Normal	0.035
450	Landscaping with impervious under treatment	0.1	95	Normal	0.04
471	Medium Vegetation Urban Channel	0.2	0	Normal	0.06
480	Water Body	0.01	100	Normal	0.025
500	Undeveloped Desert Rangeland: Little topo relief, slopes <5%	0.35	0	Dry	0.04
510	Hillslopes, Sonoran Desert: Moderate topo relief, slopes >5%	0.15	0	Dry	0.08
520	Vegetated Mountainous Terrain	0.25	0	Dry	0.2
700	Open Space:	0.1	0	Normal	0.035

5.3 Soils

Following guidance from the Yavapai County Drainage Design Manual, soils data was obtained from the ADOT Drainage Design website as a GIS shapefile. The soils data was from the Soil Survey Geographic (SSURGO) database for Beaver Creek Area, Arizona (AZ641), Long Valley Area, Arizona (AZ643) and from the general soil information, the State Soil Geographic Database (STATSGO) where detailed soil survey is not available. The attribute table for the polygon shapefile includes a unique identifier (MUKEY) for each soil classification. Each MUKEY has an associated Hydrologic Soil Group defined in the tabular data downloaded along with the spatial coverage. Soil types and infiltration parameters used for FLO-2D modeling are listed in Table 5-3 and shown in Figure 5-3. See Appendix A for the provided Soils Overview exhibit.

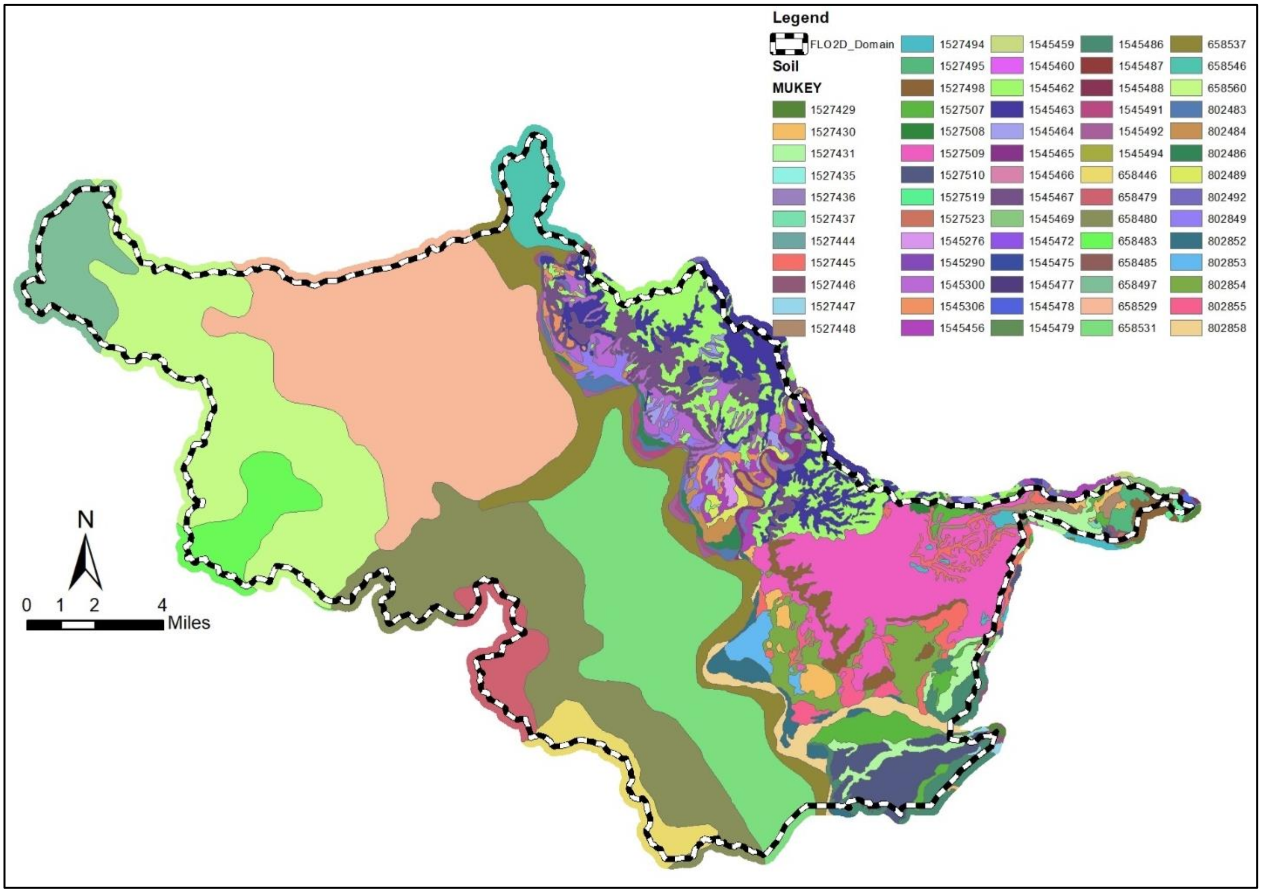


Figure 5-3. Soil within FLO-2D Domain

Table 5-3. Soil Types and Infiltration Parameters.

Soil Map Book Number	MUSYM	MUKEY	XKSAT (in/hr)	Rock Outcrop (%)
General	s368	658446	0.25	9
General	s401	658479	0.07	0
General	s402	658480	0.26	30
General	s405	658483	0.18	0

Soil Map Book Number	MUSYM	MUKEY	XKSAT (in/hr)	Rock Outcrop (%)
General	s407	658485	0.14	20
General	s419	658497	0.22	0
General	s451	658529	0.13	0
General	s453	658531	0.09	0
General	s459	658537	0.68	0
General	s468	658546	0.19	0
General	s482	658560	0.18	30
AZ641	An	802483	0.66	0
AZ641	Cd	802484	0.55	0
AZ641	Gs	802486	0.52	0
AZ641	Gu	802489	0.03	0
AZ641	Ka	802492	0.66	0
AZ641	Ha	802849	0.04	0
AZ643	AnA	802852	0.72	0
AZ643	CoB	802853	0.72	0
AZ643	GeB	802854	0.04	0
AZ643	HaB	802855	0.03	0
AZ643	Cr	802858	1.60	0
AZ643	Ba	1527429	0.28	0
AZ643	BdC	1527430	0.56	0
AZ643	BeD	1527431	0.13	0
AZ643	CaF	1527435	0.05	0
AZ643	CbD	1527436	0.05	0
AZ643	CeD	1527437	0.18	40
AZ643	GcD	1527444	0.06	0
AZ643	GdC	1527445	0.04	0
AZ643	GhD	1527446	0.06	0
AZ643	GhF	1527447	0.06	0
AZ643	GuB	1527448	0.02	0
AZ643	HmD	1527494	0.18	0
AZ643	JaD	1527495	0.89	0
AZ643	Ls	1527498	0.28	0
AZ643	PeC	1527507	0.06	0
AZ643	ReC	1527508	0.24	0
AZ643	RsD	1527509	0.14	0
AZ643	RtC	1527510	0.01	0
AZ643	SrC	1527519	0.02	0
AZ643	WaD	1527523	0.06	0
AZ641	Bg	1545276	0.33	0

Soil Map Book Number	MUSYM	MUKEY	XKSAT (in/hr)	Rock Outcrop (%)
AZ641	Cc	1545290	0.04	0
AZ641	Gt	1545300	0.12	0
AZ641	Hm	1545306	0.05	0
AZ641	La	1545456	0.47	0
AZ641	Ms	1545459	0.16	0
AZ641	Pc	1545460	0.04	0
AZ641	RrC	1545462	0.11	0
AZ641	RrD	1545463	0.11	0
AZ641	Re	1545464	0.19	0
AZ641	Rw	1545465	1.16	0
AZ641	Rx	1545466	0.06	0
AZ641	Ry	1545467	0.01	100
AZ641	Sd	1545469	0.01	100
AZ641	Sf	1545472	0.22	0
AZ641	SnC	1545475	0.01	0
AZ641	SnD	1545477	0.01	0
AZ641	SnB	1545478	0.01	0
AZ641	Sl	1545479	0.02	0
AZ641	St	1545486	0.01	100
AZ641	Su	1545487	0.01	100
AZ641	Sv	1545488	0.01	100
AZ641	To	1545491	1.70	0
AZ641	Tx	1545492	1.55	0
AZ641	Wc	1545494	0.10	0

5.4 FLO-2D Grid

5.4.1 Grid Element Elevations

FLO-2D model grid element elevations were computed from the available topographic data discussed in Section 2.1. Elevations for each grid were generated using the procedure described below:

1) The provided high-resolution elevation raster dataset from Cooper Aerial, 2023, has a spatial resolution of 1’x1’. Therefore, each 1’x1’ grid was assigned an elevation, determined from the provided dataset.
2) The “intermediate” elevation raster dataset was aggregated to a 20’x20’ raster dataset, with each grid representing the average elevation of the twenty 1’x1’ grid elements comprised in each 20’x20’ grid element. The 20’x20’ raster dataset was created to match the grid element size of 20’x20’ for each computational domain.

3) The low-resolution (10-m) elevation raster dataset obtained from USGS was resampled from a 10-m x 10-m resolution to a 2’x2’ resolution raster dataset, which is provided in Appendix C.
4) The medium-resolution (1-m) elevation raster dataset obtained from USGS was resampled from a 1-m x 1-m resolution to a 2’x2’ resolution raster dataset, which is provided in Appendix C.
5) The two 2’x2’ resolution USGS rasters were aggregated to 20’x20’ raster datasets for Sub-domains 2,3,4,6 and 7 with a 20’ grid size.
6) The three elevation raster datasets were mosaicked into one 20’x20’ raster dataset. The USGS 1 meter data was only used where there was no topographic coverage from the Cooper Aerial, 2023 topographic dataset. The USGS 10-meter data was only used where there was no topographic coverage from the high or medium resolution datasets.
7) The 20’x20’raster dataset was aggregated to 40’x40’ raster dataset, which was used for Sub-domains 1,5 and 8 with a 40’ grid size.

This final elevation raster/grid was used as the base elevation data for FLO-2D model development.

Local topographic adjustments to the FLO-2D grid element elevations were necessary to maintain natural flow patterns and prevent over attenuation from impediments to flow. For example, elevation adjustments are necessary to maintain natural flow conveyance upstream/downstream of culverts. Areas of topographic adjustments are provided as a GIS shapefile in Appendix C.

5.4.2 Grid Element Roughness

Grid element roughness values (roughness coefficients/Manning’s n-values/n-values) were assigned to each grid element according to land categorizations and were aerially weighted as the polygon was converted to a 20’x20’ raster and a 40’x40’ raster to match the FLO-2D model grid elements (Section 5.1). Land categorization roughness values were based on vegetation (type, density, etc.), surface characteristics (roughness and irregularities), and topography (variations in slope). Aerial photographs, topographic data, field reconnaissance and Yavapai County Drainage Design Manual guidelines were used for assigning land categorization roughness coefficients (Figure 5-2).

Table 5-2 lists the roughness coefficient assigned to each land categorization.

Based on preliminary modeling, grid element roughness values were increased above the typical land categorization value at various locations to prevent model surging and instability. In general, Manning’s n-values were increased along the washes with excessively high flow velocities (> 20 ft/s), determined from preliminary modeling results. These natural washes were not anticipated to sustain such high flow velocities; and therefore, Manning’s n values were increased to reduce flow velocities to more realistic levels. Grid elements with a Manning’s n-value adjustment that differs from

Table 5-2 are provided in GIS shapefile format in Appendix C.

5.4.3 Grid Element Area Reduction and Width Reduction Factors

The grid cell Area Reduction Factor (ARF) component of FLO-2D is used to model flow obstruction resulting from buildings and other structures. Buildings and structures that have the potential to impede flow were provided by Cooper Aerial in the planimetric deliverable, which are provided in Appendix C. An ARF value of 0 to 1 represents the fraction of the grid cell that is blocked by these obstructions – for example, an ARF value of 0.5 represents 50 percent of a grid element is obstructing flow and not available for flood storage. The portion of the cell blocked is determined using GIS and applied to the model using the ARF.DAT input file.

5.4.4 Rainfall

5.4.4.1 Direct Rainfall

Existing condition hydrologic and hydraulic analyses were conducted using FLO-2D for the 10- and 100-year storms having a 6- and 24-hour duration. In accordance with the Drainage Design Manual for Yavapai County, spatial rainfall distribution depth data was downloaded directly from the NOAA Atlas 14 website. Rainfall coverages for the modeled storms were obtained in DEM ASCII grid format. The DEM ASCII grid data was discretized to generate grid-based rainfall data at a 20’ x 20’ and a 40’x40’ resolution for use in FLO-2D, using the RAIN.DAT input file. The spatial distribution of the rainfall was applied using the RAINARF parameters within FLO-2D. The maximum modeled point precipitation depth per sub-domain for the modeled storm frequencies and durations are provided in Table 5-4. An exhibit showing the spatial distribution over each sub-domain is provided in Appendix A.

Table 5-4. Maximum Point Precipitation Values per Sub-Domain

Sub-Domain	10-Yr, 6-Hr (inches)	100-Yr, 6-Hr (inches)	10-Yr, 24-Hr (inches)	100-Yr, 24-Hr (inches)
1	2.297	3.587	3.291	4.930
2	1.835	2.900	2.672	3.981
3	1.891	2.979	2.701	4.024
4	1.872	2.958	2.685	4.014
5	2.044	3.210	3.177	4.768
6	1.917	3.019	2.805	4.187
7	1.953	3.072	2.823	4.207
8	2.251	3.514	3.338	4.997

5.4.4.2 Temporal Rainfall Distribution

Per the Yavapai County Drainage Design Manual, a single hypothetic rainfall distribution shall be used for the entire study area and the hypothetical distribution shall be generated using HEC-1 (HEC-HMS). Given the frequency storm for 10- and 100-year 6- and 24-hour have been developed for the HEC-HMS modeling (Section 4.2), these hypothetic rainfall distributions (Figure 4-2 and Figure 4-3) were directly used in the FLO-2D modeling for temporal rainfall distribution.

5.4.5 Rainfall Losses (Infiltration)

5.4.5.1 Rainfall Losses (Infiltration) Approach

Rainfall losses were applied in FLO-2D using Green and Ampt infiltration parameters. Parameter values were derived from land categorization and soils coverages (Sections 5.2 and 5.3, respectively). The computed Green and Ampt infiltration parameters were obtained directly from the ADOT Drainage Design web page in GIS shapefile and tabular formats, as outlined in the Yavapai County Drainage Design Manual. The GIS coverages contain the Green and Ampt parameters for each soil map unit using the Saxton & Rawls method. The Green and Ampt parameters are sampled from the land categorization and soils classification coverages at grid element centers, which are then used to generate the INFIL.DAT file. A limiting infiltration depth of 3 inches was applied in the FLO-2D sub-domains. Equation parameters, based on land categorization and soil characteristics, include the following, which are described in more detail below:

- Initial loss due to surface retention (IA).
- Volumetric soil moisture deficit at the start of rainfall (DTHETA).
- Wetting front capillary suction (PSIF).
- Hydraulic conductivity (XKSAT).
- Percent of impervious area (RTIMP).

5.4.5.2 Initial Abstraction (IA)

Initial abstraction values were based on land categorization. However, FLO-2D software increases initial losses by including an additional depression storage value (TOL value), assigned in the TOLER.DAT input file. Depression storage occurs prior to the beginning of infiltration. Therefore, to eliminate the TOL value increase in initial losses, IA values were reduced by the TOL value. The TOL value was set to 0.004 feet (0.048 inches).

5.4.5.3 Volumetric Soil Moisture Deficit (DTHETA)

As discussed in Section 5.2, DTHETA is an infiltration parameter dependent on land categorization. Per the Drainage Manual, one of the following three DTHETA conditions should be selected based on land categorization:

- DTHETA Dry – for non-irrigated lands such as desert and rangeland.
- DTHETA Normal – for irrigated lawn, turf, and permanent pasture.
- DTHETA Saturated – for irrigated agricultural lands.

5.4.5.4 Wetting Front Capillary Suction (PSIF)

Wetting Front Capillary Suction (PSIF) values were obtained from the ADOT Green and Ampt parameters for each soil map unit using the Saxton & Rawls method, as specified in the Yavapai County Drainage Design Manual.

5.4.5.5 Hydraulic Conductivity (XKSAT)

Hydraulic Conductivity (XKSAT) values were obtained from the ADOT Green and Ampt parameters for each soil map unit using the Saxton & Rawls method, as specified in the Yavapai County Drainage Design Manual.

5.4.5.6 Percent of Impervious Area (RTIMP)

The percent of impervious contributing area is based on land categorization (paved roadways, parking lots, etc.) and soil type (percentage of rock outcrop within soil classification). Percent of impervious area for each land use classification and soil type are listed in

Table 5-2 and

Table 5-3, respectively.

5.4.6 Inflow/Outflow

5.4.6.1 External Source Inflows to Sub-Domains

As discussed in Section 4.8, the HEC-HMS output hydrographs were scaled to FIS peak discharges for the 100-year event and adjusted based on the ratio in Table 4-12 for the 10-year event, before being processed into the INFLOW.DAT for the associated sub-domains. The inflow hydrographs are shown in Figure 4-10, Figure 4-11, Figure 4-12 and Figure 4-13.

5.4.6.2 Flow Transfer Between Sub-Domains

Computational domains were delineated to ensure flow is conveyed from upstream sub-domains to downstream sub-domains with no significant outflow discharges occurring in the reverse direction (downstream to upstream). Thus, the sub-domain run simulations are performed starting from upstream sub-domains (Section 5.1). Outflow hydrographs from the upstream sub-domains were used as inflow hydrographs for the downstream sub-domains. This is accomplished by setting the line identifier (OUTCHAR) variable in the OUTFLOW.DAT file to O1 or O4, based on downstream sub-domains #1 or #4. The sub-domains at the outflow-inflow transfer locations have a one-cell overlap (20 feet) to adequately achieve the flow transfer between two sub-domains. The inflow hydrographs from all upstream sub-domains are combined into a single INFLOW.DAT file for the downstream sub-domain. Sub-domains were delineated with the intent to run upstream models simultaneously, with no dependencies on one another, to reduce overall model run time.

Outer limits of each sub-domain are lined with outflow nodes to allow flow to appropriately exit sub-domains and are represented in the OUTFLOW.DAT input file.

5.5 One-Dimensional Channel Modeling

The one-dimensional (1-D) channel modeling routine within FLO-2D was not used for this study's modeling efforts. Channels were reflected in the FLO-2D modeling via grid element elevations.

5.6 Levees and Property Walls

No property walls were identified hydraulically significant in this study, and therefore property walls were not modeled in this study. A few berms were identified hydraulically significant during field visits and by topographic examination, and therefore were modeled as levees in this study.

5.7 Storm Drains

No storm drain was identified to be hydraulically significant in the study area, therefore no storm drain was modeled.

5.8 Hydraulic Structures

A total of 233 culverts were identified hydraulically significant and modeled within the FLO-2D sub-domains. These culverts include:

- 40 culverts along State Route 260 and Interstate 17 with size, material and headwall information from ADOT as-builts (Section 2.5).
- 52 culverts with size, material and headwall information from field visit (Section 2.4).
- 110 culverts visible from aerial images with size, material and headwall information estimated from aerial images and topography.
- 31 culverts not visible from aerial images but identified from topography or ponding in the modeling results. Size, material and headwall information were estimated based on topography and adjacent culverts if available.

Culvert inverts were set to the grids which its inlet or outlet fall into. The grid elevations were adjusted when necessary to provide positive drainage across culverts.

Culverts were modeled in FLO-2D using two different approaches: (1) Generalized culvert equations; and (2) Rating tables generated using the HY-8 Culvert Analysis Program developed by the Federal Highway Administration (FHWA). A GIS shapefile with all modeled culverts is provided in Appendix C.

5.8.1 Generalized Culvert Routine

Generalized culvert equations were used as an option within FLO-2D for all culverts whose inlets do not span over two grid elements. The generalized culvert equations require the following culvert information: shape, length, slope, size, Manning's n-value, and entrance loss coefficient. The Manning's n-value and entrance loss coefficient are dependent on culvert material and inlet configuration. In total, 211 culverts were modeled using the generalized culvert equation methodology.

5.8.2 HY-8 Rating Table

For multi-barrel culverts whose inlets span over two grid elements, HY-8 was used to generate rating tables. The inlet, outlet, and overtopping elevations were determined using topographic data. Inlet control was assumed for each culvert. The HY-8 software requires the following culvert information to generate a rating table: shape, material, size, inlet configuration, Manning's n-value, and number of barrels. HY-8 files for each culvert are provided in Appendix C. In total, 11 culverts were modeled using the HY-8 methodology. The rating table of each culvert was divided by two and applied to each half of the culvert configuration. The divided rating tables were combined with the generalized culvert equation data to populate the HYSTRUC.DAT input file.

5.9 Floodplain Cross-Sections

Floodplain cross-sections were added to all sub-domains to identify hydrographs and peak flows at specific locations. All the cross-sections were adjusted to be perpendicular to the river or creek flow directions. The data was reviewed to ensure that flows across the floodplain cross-sections have a positive magnitude. Floodplain cross-section data has been provided in Appendix C, the accompanying external hard drive.

5.10 Model Control Parameters

5.10.1 Froude Number

A Limiting Froude Number of 0.90 was applied. Once the Froude number exceeds 0.90, the Manning's n of that grid will be increased.

5.10.2 Shallow n-Values

The option to vary Manning's n-value with depth was used with a Shallow n-value of 0.2.

5.10.3 Courant Number

A Courant number value of 0.7 was used for the floodplain flows and was determined to provide adequate numerical stability.

5.10.4 TOLGLOBAL Parameter

Surface detention TOLGLOBAL is set at 0.0040 ft. As discussed in Section 5.4.5.2, the initial abstraction (IA) values were reduced by this value to avoid double counting.

5.10.5 TIMEACCEL Parameter

The coefficient to increase the rate of the incremental timestep change TIMEACCEL is set at 0.1 to ensure stable simulation.

5.10.6 DEPTOL Parameter

The tolerance value for the flow depth change in a given timestep DEPTOL is set to 0 so that the time step is controlled by Courant values.

5.11 Special FLO-2D Modeling Considerations

5.11.1 DEM Seam Treatment

As discussed in Section 2.1, there are three topographic sources to cover the FLO-2D modeling boundary: the detailed aerial mapping for the Town, USGS 1-meter DEM, and USGS 10-meter DEM. By merging three sources, the elevations along seams have been reviewed and ramps were added along seams to stich different sources and ensure positive drainage across seams.

5.11.2 Verde River DEM Patch

As stated in Section 2.1.1, the LiDAR data was collected in March 2023 immediately after a storm event. The LiDAR data captured the bank-full flow within the Verde River but not the river bottom elevations. To reflect the capacity of the Verde River, the USGS 1-meter DEM between banks of Verde River was used to patch the FLO-2D grid elevations.

5.11.3 FLO-2D Sub-domains

A different sub-domain configuration was run initially in which Verde River crossed 3 sub-domains in sequence. However, discrepancies were found in the water surface elevations along Verde River across the sub-domain borders. Therefore, the sub-domain configuration as shown in Figure 5-1 was adopted finally to cover Verde River in a single sub-domain.

5.12 FLO-2D Modeling Warnings and Errors Messages

There were no error messages associated with the FLO-2D modeling. However, the following warning messages are listed in the ERROR.CHK output file. This file lists the general error and warning messages for FLO-2D. Responses to the warning messages are in italics below each warning.

INITIAL ABSTRACTION (IA) IS DEFINED AS RAINFALL INTERCEPTION PLUS DEPRESSION STORAGE (REPRESENTED BY THE TOL VALUE). AVOID DOUBLE ACCOUTING ASSIGN IA EQUAL TO ONLY INTERCEPTION

> *Response: As discussed in Section 5.4.5.2, the TOL value is subtracted from the full Land Use associated IA value to avoid double counting the depression storage. This is a general warning and not a data input error and does not require a change.*

*** THERE ARE DRY OUTFLOW NODES FOR THE FOLLOWING DOWNSTREAM GRID SYSTEM: *** GRID CELL: ***

> *Response: This is a warning that indicates that there is a grid that receives flow from no adjacent grids and is likely located on a topographic ridgeline. This can also occur in smaller events where small contributing areas that might have flow in larger events (500- and 100-year storms) but might not have flow in smaller events (10-year) due to infiltration and a reduced rainfall. Rather than remove outflow nodes and have different*

> *OUTFLOW.DAT files for different events, it is left as-is. This is a general warning and does not indicate a data input error and does not require a change.*

WARNING: THE PEAK DISCHARGE/SURFACE AREA OF GRID ELEMENT EXCEEDS 10.0 CFS/SQ.FT OR 3.00 CMS/SQ.M. THE GREATER THIS RATIO IS, THE SLOWER THE MODEL MAY RUN.

> *Response: The ratio has been reviewed and it is appropriate given the significant flow in Verde River entering the model domain.*

REVIEW THE EVACUATEDFP.OUT FILE FOR COMPLETE EVACUATION OF VOLUME IN THE LISTED GRID ELEMENTS - IMPROVE ROUTING STABILITY BY REDUCING THE OUTFLOW FROM THE ELEMENT

> *Response: The file is reviewed, and the locations of each evacuated grid is reviewed for hydraulic significance. Additionally, the model is reviewed for instability and if the number of evacuations is low, no action is required. The overall model volume conservation is excellent.*

The following warnings are listed in the HYDRAULIC STRUCTURE_RUNTIME WARNINGS.OUT output file. This file lists the associated errors and warnings associated with the HYSTRUC.DAT and hydraulic structure modeling. Responses are in italic below each listed warning.

WARNING: AT TIME (HR) HYDRAULIC STRUCTURE NO. AND NAME DISCHARGE (CFS OR CMS) EXCEEDS THE INFLOW DISCHARGE (CFS OR CMS) TO THE INLET NODE BY 50% (1.5 X).

> *Response: This warning is related to a depth/discharge disparity between the flow entering a structure inlet grid and the flow through the structure as referenced by the structure rating table data. For example, an inlet grid might have 0.25 feet of depth and 1 cfs discharge, however, the hydraulic structure rating table might reference a discharge of 1.5 cfs at 0.25 feet of depth based on the resulting HY-8 developed rating table. Almost all of these generated warnings relate to the leading and/or receding limbs of the hydrographs and flows are relatively minor and negligible, these warnings do not impact the results or affect the peak of the hydrograph.*

WARNING: THE DOWNSTREAM WATER SURFACE GETS HIGHER THAN THE UPSTREAM WATER SURFACE AT TIME: THERE IS POTENTIAL FOR UPSTREAM FLOW THROUGH THE STRUCTURE: CONSIDER SETTING THE UPSTREAM FLOW SWITCH INOUTCONT = 1

> *Response: This warning indicates that the water surface is higher at the outlet than the inlet and that there is potential of backwards flow at the culvert (Note: the INOUTCONT parameter is set to "1" in the FLO-2D model to allow the model to consider tailwater submergence. The FLO-2D Data Input Manual states that INOUTCONT should be set to 2 for allowing backwards flow). All culverts in the Project are set to allow downstream flow only. Locations where upstream flow is possible were individually investigated for hydraulic significance if backwards flow were allowed. In all cases, it was not considered to have any significance on model results if backwards flow were allowed.*

WARNING: THE RATING TABLE FOR HYDRAULIC STRUCTURE: WAS ADJUSTED TO BETTER MATCH THE STREAM FLOW CONDITIONS.

> *Response: This warning is a notification that the rating curve has been adjusted in order to stabilize and adjust the structure due to tailwater conditions; revised ratings are typically written to a separate output file REVISED_RATING_TABLES.OUT. However, for this Project, revisions were not written to the REVISED_RATING_TABLES.OUT so it is assumed that the adjustments to the structure were minor and did not require a full revision to the rating table. Each structure with this warning was individually reviewed to ensure that there was a positive outfall slope at the culvert outlet and did not have an artificial tailwater submergence due to elevation aggregation.*

5.13 FLO-2D Modeling Validation

According to Yavapai County Drainage Design Manual guidance, discharges computed by analytical methods should always be validated, to the extent possible, to guard against erroneous modeling assumptions and/or faulty model input. FLO-2D discharges at select locations were compared to discharges identified in FIS Number 04025CV001H, Version Number 2.3.3.0.

Discharge validation locations were taken from the FIS study for Cherry Creek, Oak Creek, Beaver Creek, and West Clear Creek, and the Verde River. Table 5-5 provides a comparison between the 0.1%-annual-chance discharges from the FIS and the 100-year, 24-hour FLO-2D discharges at the select locations. Overall, FLO-2D discharges are reasonably similar to the discharges reported in the FIS. In general, flows from tributary creeks are slightly underestimated, whereas flows in the Verde River are slightly overestimated. Refer to Section 4.8 for a description of FLO-2D modeling input discharges determined from the FIS. The detailed FIS reports are provided in Appendix C.

Table 5-5. Comparison of 100-Year Discharges at FIS Locations.

Flooding Source Information per FEMA (08/24/2021) FIS Table 10: Summary of Discharges					**FLO-2D Discharges**	
Flooding Source	**Location**	**Drainage Area (sq. mi.)**	**100-Yr, 24-Hr Q (cfs)**	**Q / Area (cfs/mi^2)**	**100-Yr, 24-Hr Q (cfs)**	**Q / Area (cfs/mi^2)**
Cherry Creek	Above Confluence with Verde River	25	14,497	580	19,417	777
Beaver Creek	At confluence with Verde River	423	74,000	175	60,446	143
Oak Creek	At confluence with Verde River	460	51,200	111	43,961	96

Flooding Source Information per FEMA (08/24/2021) FIS Table 10: Summary of Discharges					FLO-2D Discharges	
Flooding Source	**Location**	**Drainage Area (sq. mi.)**	**100-Yr, 24-Hr Q (cfs)**	**Q / Area (cfs/mi^2)**	**100-Yr, 24-Hr Q (cfs)**	**Q / Area (cfs/mi^2)**
West Clear Creek	Upstream of confluence with Verde River	293	35,400	121	31,833	109
Verde River	Below confluence with Oak Creek	3,776	100,000	26	108,849	29
Verde River	Below confluence with Beaver Creek	4287	121,200	28	128,442	30
Verde River	Below confluence with West Clear Creek	4,619	135,600	29	148,281	32

6 HYDROLOGIC & HYDRAULIC MODELING RESULTS AND FINDINGS

6.1 General Overview of Modeling Results

Given the significant level of detail provided with FLO-2D model results, the results are provided as exhibits in PDF format in Appendix B and as GIS spatial data (rasters, shapefiles, etc.) in Appendix C.

The study area is characterized by three distinct regions: the mountainous regions on the outskirts, rural and urban Town areas, and riverine sections including the Verde River and its tributaries. Sub-domains 1, 5, 6, and 8 are primarily mountainous and have flow patterns that are typically confined in natural wash corridors. Sub-domains 2, 3, and 7 are primarily riverine, containing flows from the Verde River, Beaver Creek, and West Clear Creek, respectively. An overview exhibit of each FLO-2D sub-domain has been provided in Appendix A. See Figure 6-1 below for an overview of flow depths across the Town for the 100-year, 24-hour storm event.

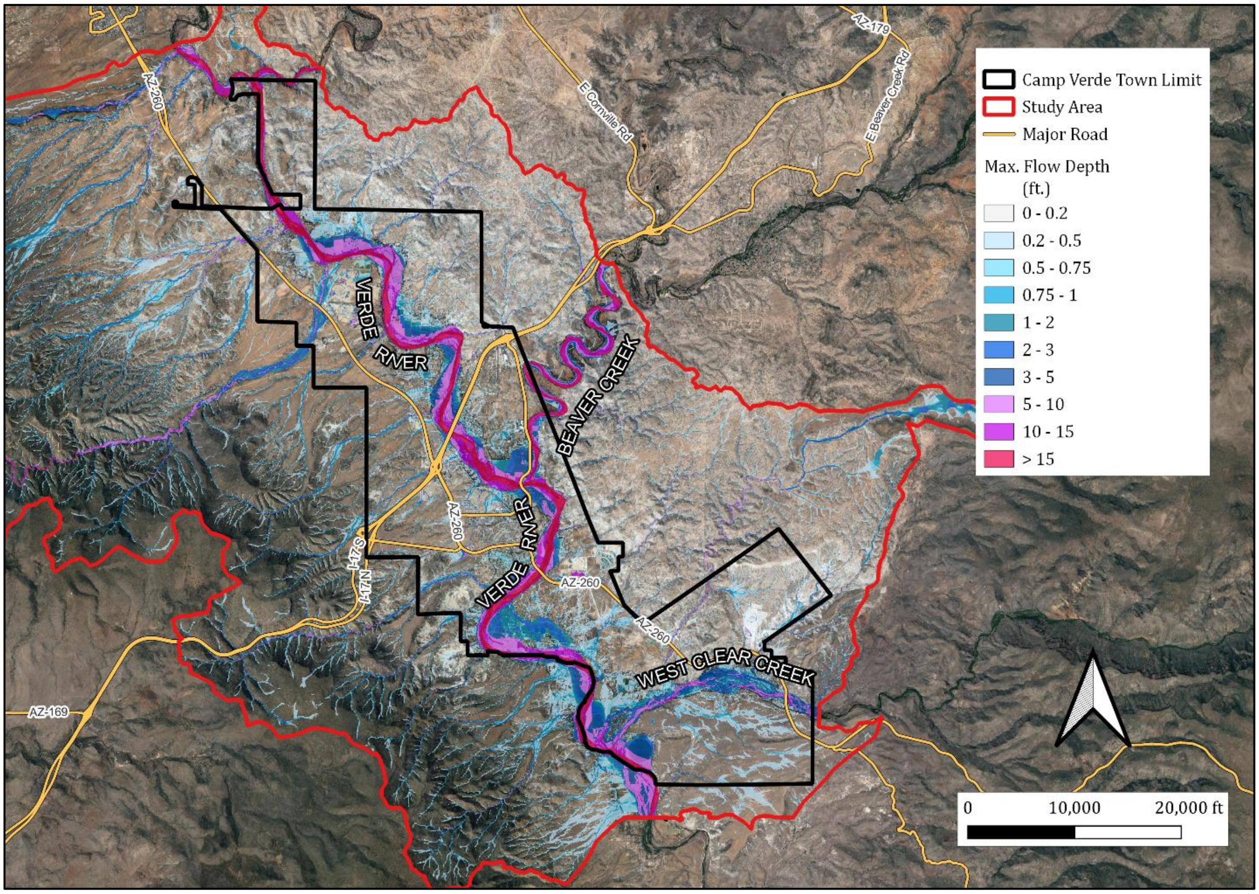


Figure 6-1: FLO-2D Flow Depths Overview of the 100-Year, 24-Hour Storm Event.

6.1.1 **Pluvial Drainage and Flooding Conditions**

Pluvial flows from the mountains are collected and conveyed through natural washes. Flows located in steep terrain and natural washes are typically well contained. Figure 6-2 showcases pluvial flows in the upper study area. Flows that generate inside of the Town are typically not channelized and freely make their way overland. Areas of Town with flat slopes are susceptible to significant ponding since there is a lack of major storm drainage infrastructure. The more developed and commercial areas of Town experience less flooding, compared to the more rural areas, due to the having more culverts to convey flow and storage basins to capture flow. It should be noted that a majority of the Town is primarily in a rural setting, and flooding is generally widespread during large events.

Field reconnaissance, historical data, and Town resident experience suggests large amounts of sediment transport through the washes over time. Sediment transport was not part of the modeling. However, the detailed topographic data captured the elevation of any deposited sediment at the time of data collection.

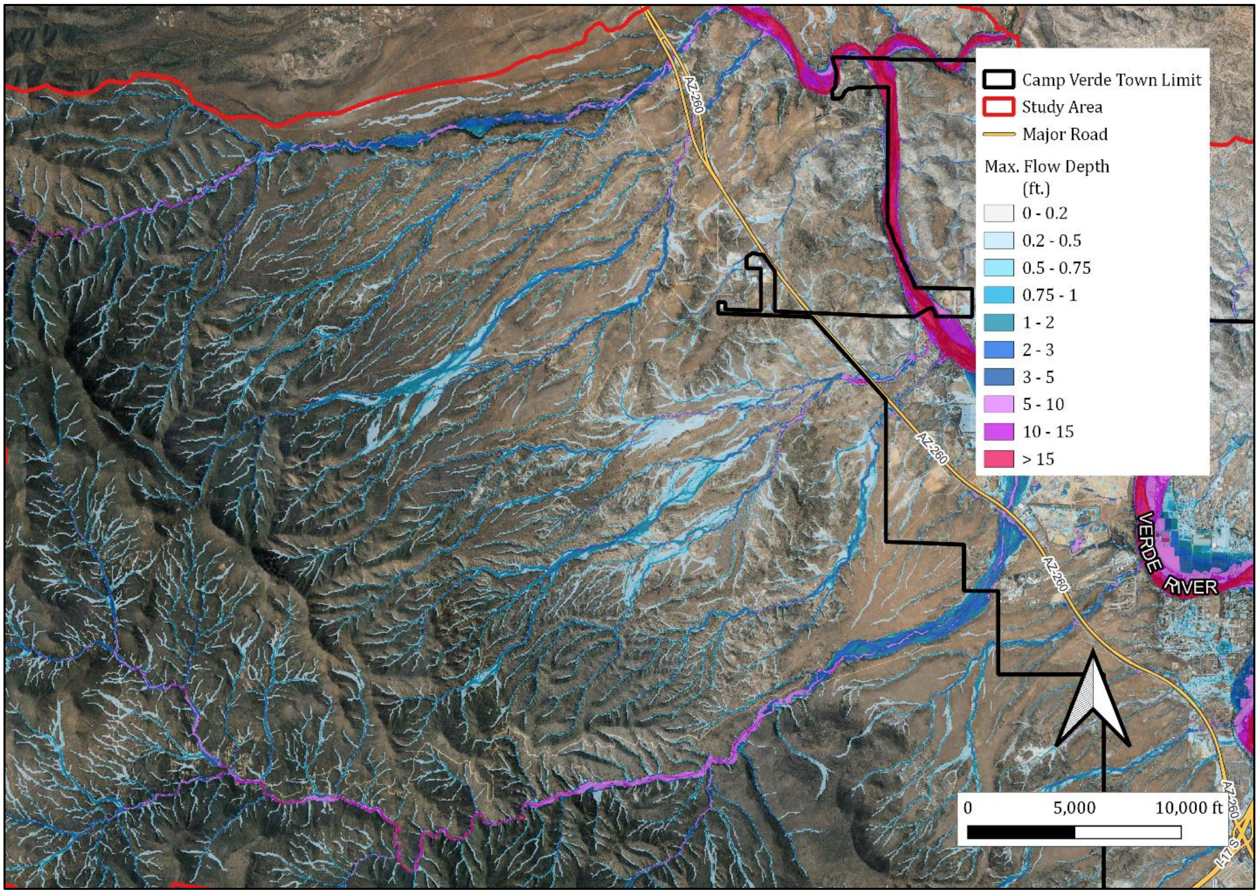


Figure 6-2. Pluvial Flows in the Upper Study Area from the FLO-2D 100-Year, 24-Hour Modeling Results

6.1.2 Riverine Flooding

All rivers and creeks throughout the study area receive flow from various natural washes and overland flow. Where Beaver Creek and West Clear Creek combine with the Verde River, there is significant overland flooding due to backwater effects. This overland flooding primarily affects rural and agricultural areas. See Appendix C for the FLO-2D modeling results in GIS format.

6.1.2.1 Verde River

The Verde River contributes approximately 109,000 cfs for the 100-year, 24-hour storm event at the northern Town boundary, which includes flows coming from Oak Creek. Oak Creek contributes approximately 44,000 cfs near the upstream boundary of sub-domain 2 for the 100-year, 24-hour storm event. All flows generated inside the Town ultimately outfall to the Verde River, where it exits the Town to the south. Beaver Creek and West Clear Creek contribute their flow to the Verde River as well. See Figure 6-1 for an overview of the modeled portion of the Verde River and its contributing creeks.

Significant flooding occurs near bends in the Verde River where flow inundates the shallow overbank areas. Development that is directly adjacent to the Verde River is susceptible to ponding. Significant breakouts of flow occur at and between the Beaver Creek and West Clear Creek confluences.

6.1.2.2 Beaver Creek

Beaver Creek contributes approximately 60,000 cfs to the Verde River during the 100-year, 24-hour storm event. This creek is well channelized and contains its flow until reaching the confluence with the Verde River (see Figure 6-3). Flows that would enter either Beaver Creek or the Verde River seem to become stagnant at this confluence and begin to pond in the adjacent agricultural areas.

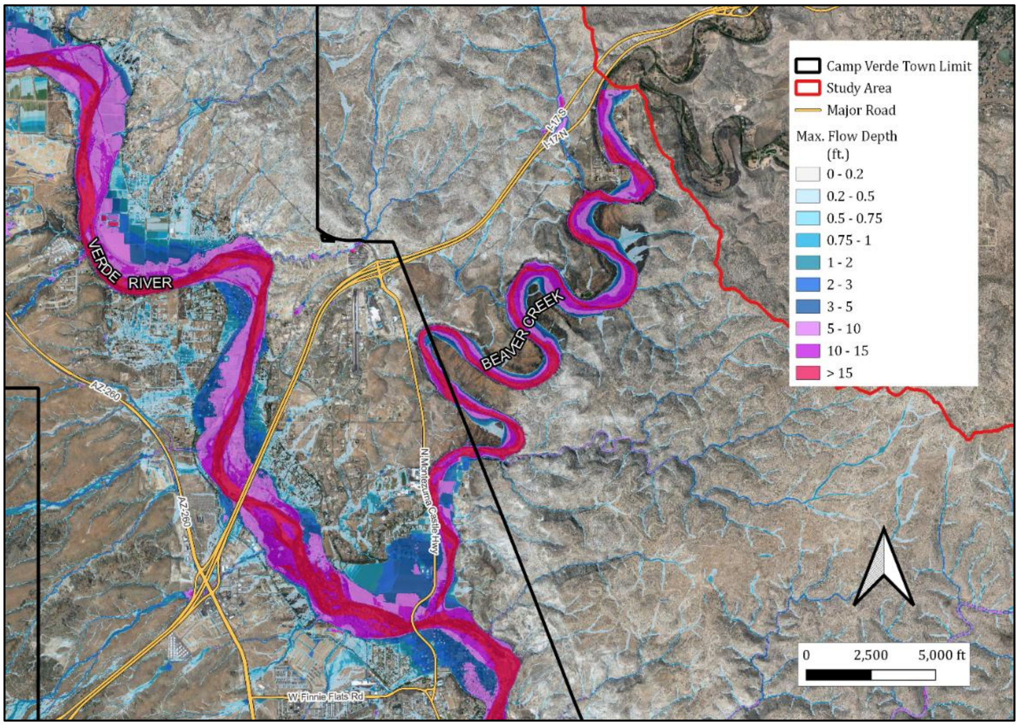


Figure 6-3. Riverine Flows of Beaver Creek from FLO-2D 100-Year, 24-Hour Modeling Results

6.1.2.3 West Clear Creek

West Clear Creek is well channelized before reaching Highway 260 but becomes highly braided from then on until combining with the Verde River (see Figure 6-4). West Clear Creek contributes approximately 32,000 cfs to the Verde River. Flows from West Clear Creek contribute to frequent flooding within the Verde Lakes Community where flow frequently overtops roadways, ponds in residential lots, and contributes to debris.

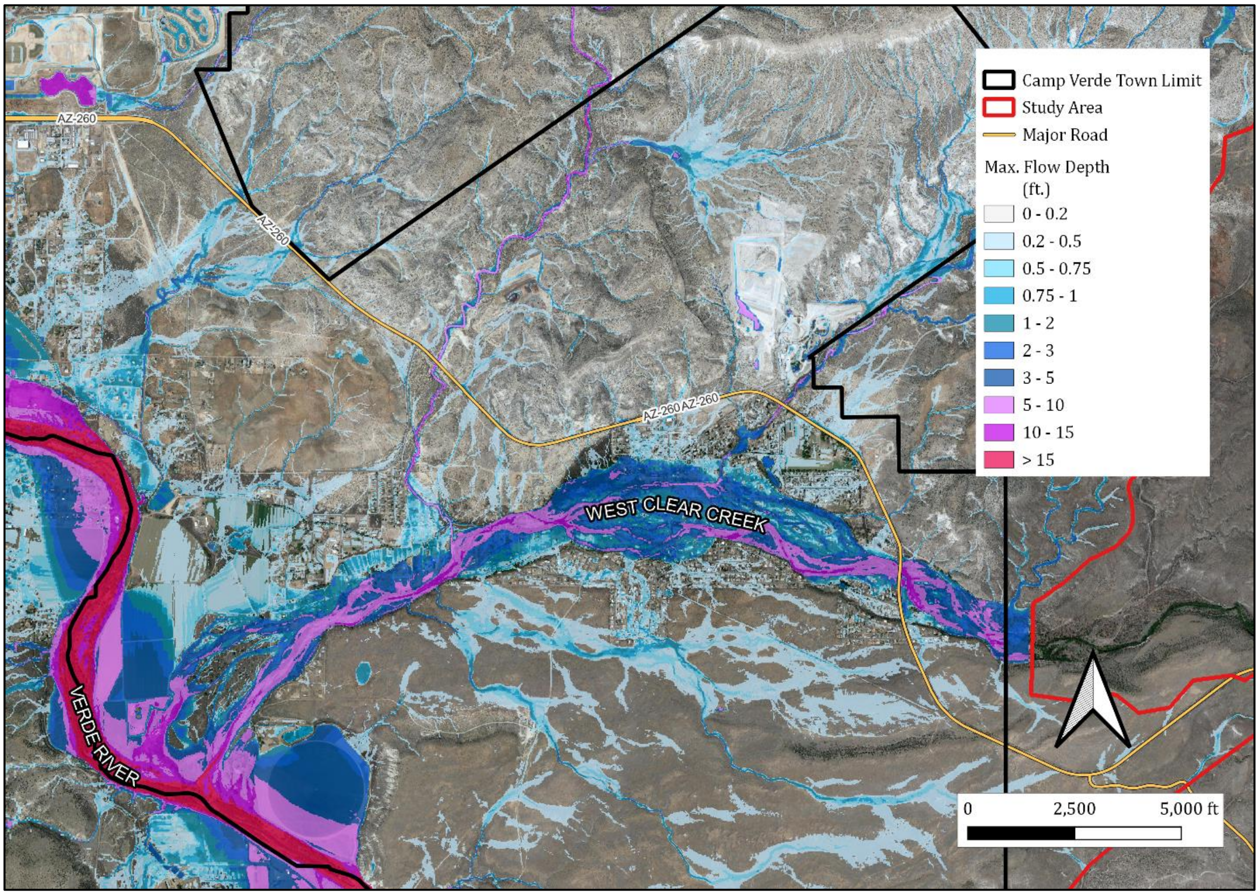


Figure 6-4. Riverine Flows of West Clear Creek from FLO-2D 100-Year, 24-Hour Modeling Results

6.2 Flood Hazard Classifications

The flood hazard classifications presented below were based on research conducted by the University of New South Wales, School of Civil and Environmental Engineering, Water Research Laboratory and published in the *WRL Flood Hazard Technical Report*, September 2014 (WRL Technical Report 2014/07). According to the *WRL Flood Hazard Technical Report:*

> *…in a preliminary assessment of risks or as part of a constraints analysis, there is also an acknowledged need for a combined set of hazard vulnerability curves, which can be used as a general classification of flood hazard on a floodplain.*

Combined flood hazard classifications (curves) prescribed in the *WRL Flood Hazard Technical Report* are based on flow depth (meters) and flow velocity (meters per second). Combined flood hazard classifications address flood risk to people, vehicles, and building structures. The combined flood hazard curves are shown graphically in Figure 6-5 and described in Table 6-1 and Table 6-2.

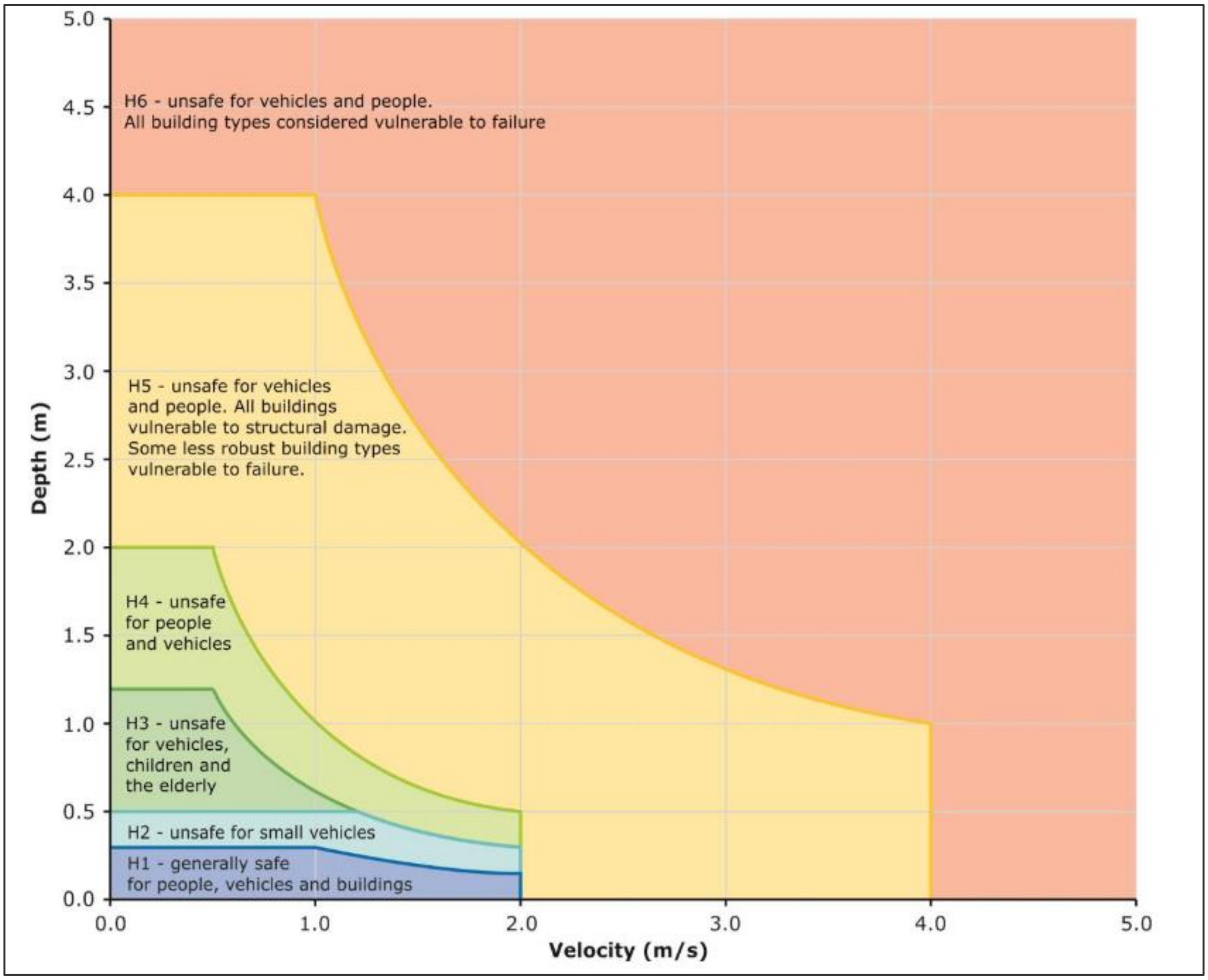


Figure 6-5. Combined flood hazard curves (WRL Flood Hazard Technical Report). For reference: 1 meter = 3.28 feet and 1 meter per second = 3.28 feet per second.

Table 6-1. Combined hazard curves – vulnerability thresholds (WRL Flood Hazard Technical Report).

Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children, and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. All buildings vulnerable to structural damage. Some less robust buildings subject to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Table 6-2. Combined hazard curves – vulnerability thresholds classification limits (WRL Flood Hazard Technical Report).

Hazard Vulnerability Classification	Classification Limit (D and V in combination)	Limiting Still Water Depth (m)	Limiting Velocity (m/s)
H1	D*V ≤ 0.3	0.3 m (0.98 ft)	2.0 m/s (6.56 ft/s)
H2	D*V ≤ 0.6	0.5 m (1.64 ft)	2.0 m/s (6.56 ft/s)
H3	D*V ≤ 0.6	1.2 m (3.94 ft)	2.0 m/s (6.56 ft/s)
H4	D*V ≤ 1.0	2.0 m (6.56 ft)	2.0 m/s (6.56 ft/s)
H5	D*V ≤ 4.0	4.0 m (13.12 ft)	4.0 m/s (13.12 ft/s)
H6	D*V > 4.0	-	-

Combined flood hazard classifications based on the FLO-2D modeling results are shown on the Combined Flood Hazard Classifications exhibits provided in Appendix B. As shown in the Combined Flood Hazard Classifications exhibits, as expected, flood hazards that are unsafe for people, vehicles, and structures are typically limited to areas of deep ponding, high flow velocities, or an unsafe combination of both flow depth and flow velocity – such as flood conditions associated with basins and constructed and natural channels. Figure 6-6 below shows the combined flood hazard rating near the Verde River and AZ-260 crossing for the 100-year, 24-hour storm event. Combined flood hazard classifications for all storm events are provided in raster format on the accompanying external hard drive (Appendix C).

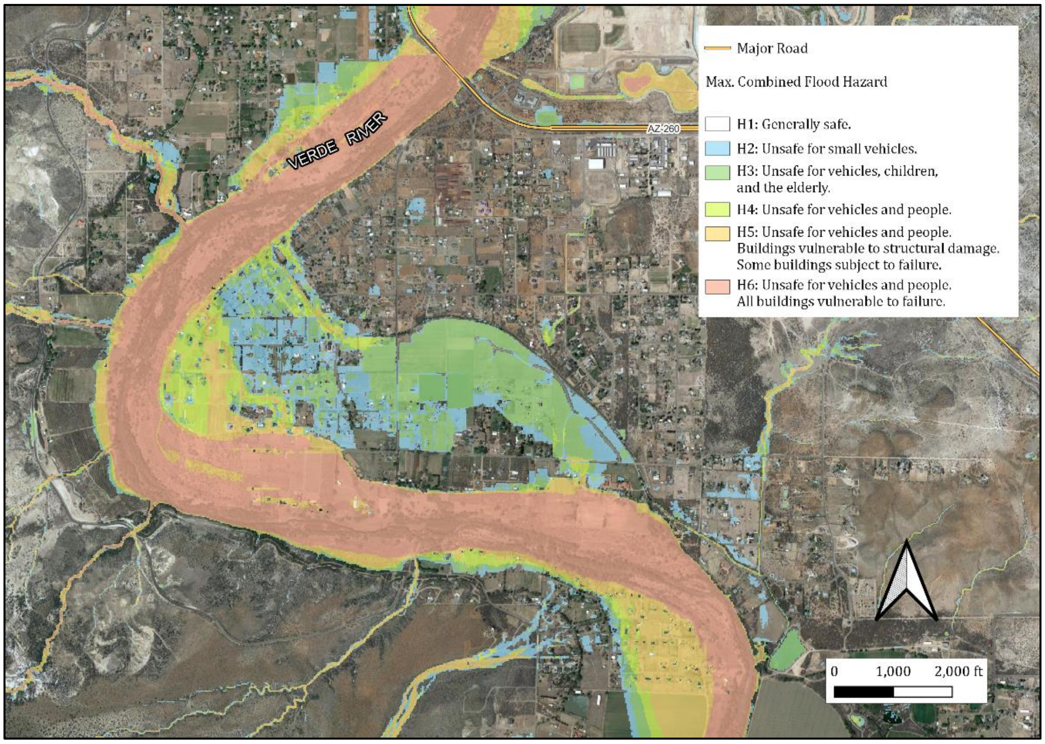


Figure 6-6. Combined flood hazard ratings for the 100-year, 24-hour event near the Verde River and AZ-260 crossing.

6.3 Modeling Results at Areas of Interest

6.3.1 General Areas of Interest

General areas of interest were identified based on input from residents, input from Town staff, and FLO-2D modeling results. A GIS database was created in collaboration with the Town to document known problem areas and improvement status. Information included in the database at the time of this report consists of the following:

- Area of interest identifier
- Drainage issue description
- Drainage issue type(s)
- Potential drainage issue resolution(s)
- Current phase of drainage issue remediation

6.3.2 Select Areas of Interest

Areas of interest commonly discussed during the duration of the Camp Verde ADMS are discussed below.

6.3.2.1 Middle Verde Community

The Middle Verde Community to the north of the Town and is generally bounded by Middle Verde Road to the north, the Verde River to the south, Calico Drive to the west, and Grandpa Wash to the east. The community receives flow from upstream mountainous washes, which cross Middle Verde Road. Flows from the channelized washes become overland sheetflow after reaching Middle Verde Road and are conveyed through the neighborhood. There is a general lack of drainage infrastructure in this area to adequately capture and convey flow through the development. Much of the community becomes inundated during the major storm events.

6.3.2.2 Main Street Area

Flooding occurs on Main Street between Hollamon Street and General Cook Trail. Flows on Main Street originate in the neighborhoods immediately upstream. The existing storm drainage systems in the area are undersized and do not adequately convey these flows out of the roadway and residential areas.

6.3.2.3 Verde Lakes Community

The Verde Lakes Community is located towards the southeast, where the AZ-260 meets West Clear Creek and has historically been a problem area for the Town. The primary entrance point to this community is Verde Lakes Drive, which experiences frequent and significant flooding. During the 100-year, 24-hour storm event, the roadway is completely inundated from Cactus Blossom Lane to Mocking Bird Lane. See Photograph 2-3 for an aerial overview of flooding conditions at the Verde Lakes Drive and Ripple Road intersection from the March 2023 flooding event.

Appendix A

General Project Area Overview Exhibits

Appendix B

FLO-2D Modeling Results Exhibits

(10- and 100-Year, 6- and 24-Hour)

10-Year, 6-Hour

10-Year, 24-Hour

100-Year, 6-Hour

100-Year, 24-Hour

Appendix C
Electronic Data
(Accompanying External Hard Drive)