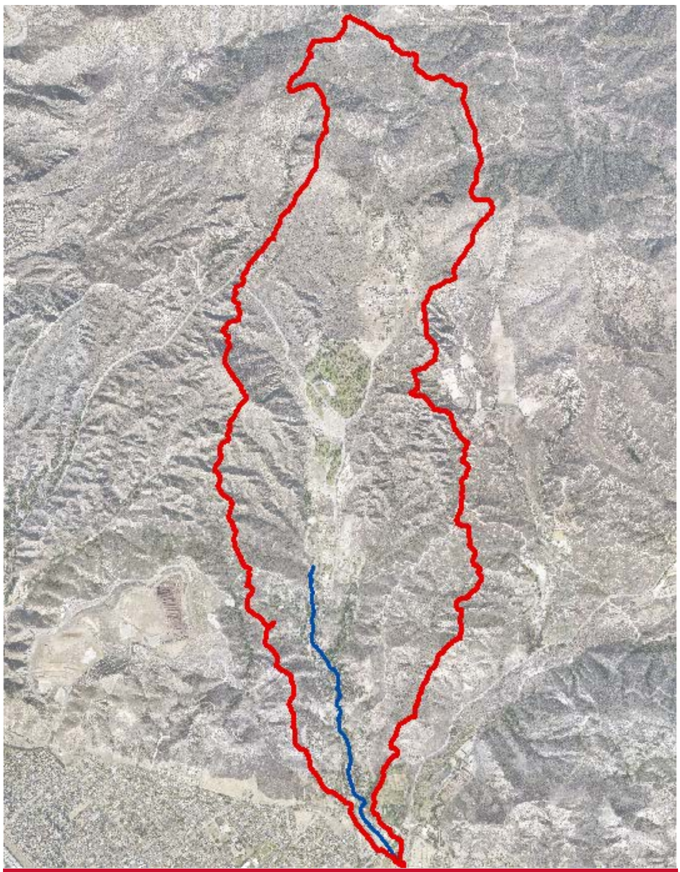

Final Hydraulic Analysis Report

Kagel Canyon Flood Hazard Study

Los Angeles County Department of Public Works

Kagel Canyon, CA

October 8, 2020

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Contents

Tables

Figures

Appendices

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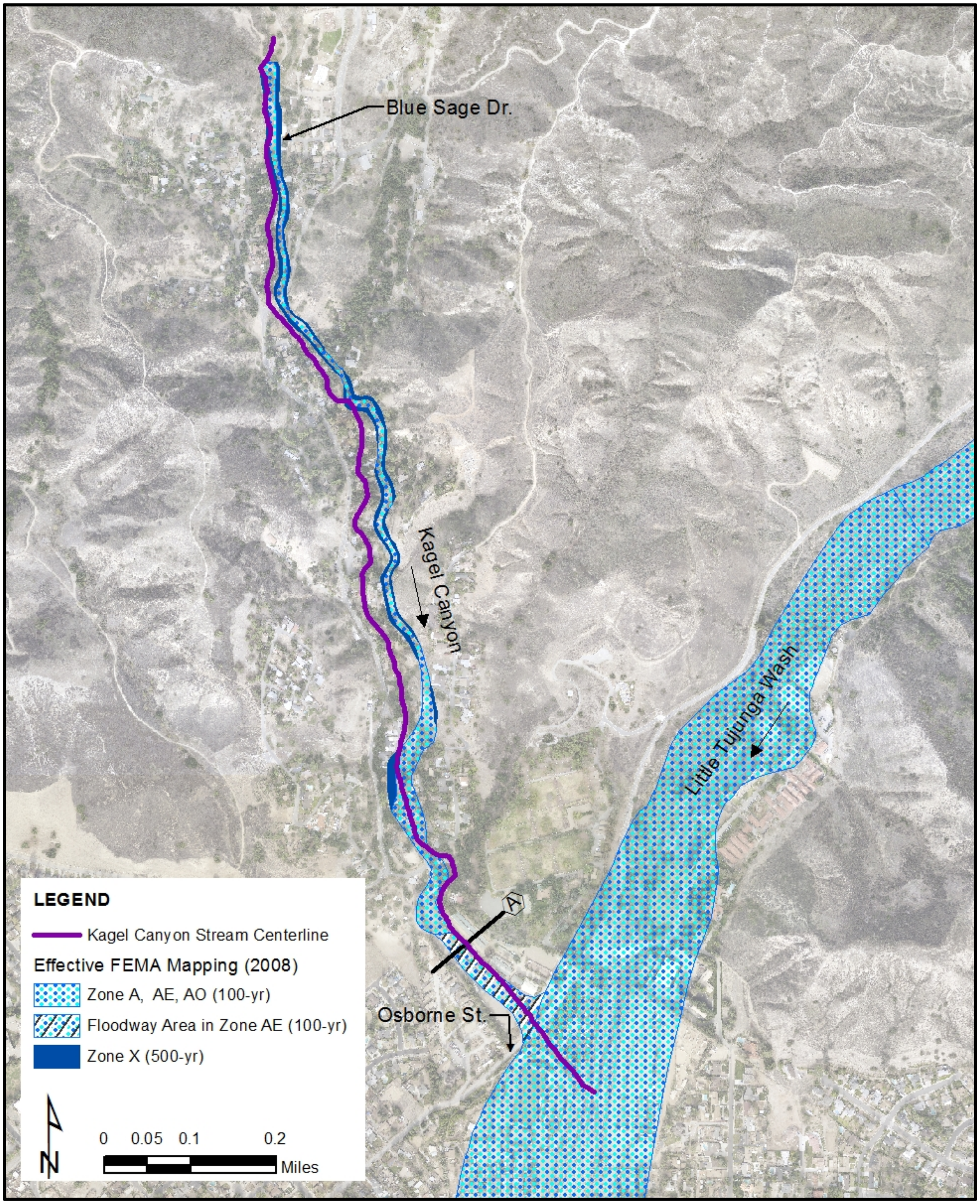
1 Study Introduction and Background

The Kagel Canyon Flood Hazard Study (Study) investigates the Kagel Canyon Watershed, located near San Fernando Valley, California for purposes of updating the regulatory flood hazard mapping of the mainstem stream. The tributaries to the main channel were not evaluated as a part of this Study. The Study was completed for the Los Angeles County Department of Public Works (LACDPW).

1.1 Introduction

The Federal Emergency Management Agency (FEMA) Flood Map Modernization was a multiyear initiative funded by Congress from fiscal year 2003 to 2008, for purposes of updating the nation's flood maps with digital Flood Insurance Rate Maps (FIRMs). The FIRMs for Los Angeles County and incorporated areas were digitized and reissued on 26 September 2008. As a result of the modernization process, it was determined that the flood zone for Kagel Canyon was shifted from the physical stream alignment. Figure 1-1 depicts the effective 100- and 500-year floodplain and floodway boundaries for Kagel Canyon and Little Tujunga Wash, in relation to the actual stream alignment of Kagel Canyon. This error in the mapping needed to be corrected to properly identify the flood hazards in this developing area and establish revised 100- and 500-year floodplain and floodway boundaries using better terrain data and improved modeling tools. Therefore, the basis of this revision includes; indisputable errors in the current mapping, better topographic data, improved hydrologic data and technically superior methods. The history of the previous studies is described in more detail in Section 2.1.

Figure 1-1. Effective FEMA Mapping



1.2 Project Purpose

The purpose of this Study is to correct the existing FIRM panels by performing the following tasks:

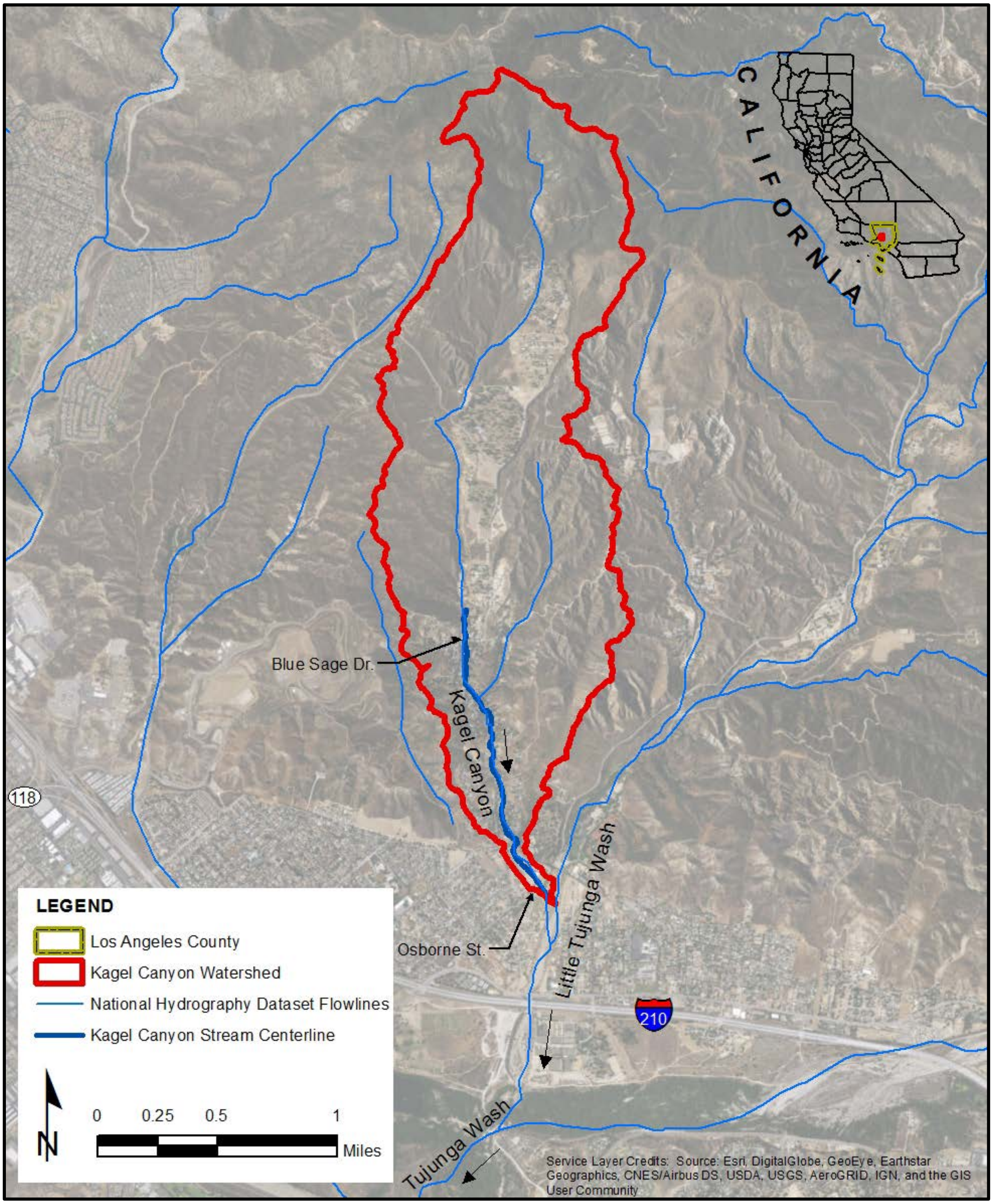
- Review previous Flood Insurance Studies (FIS) performed for the Kagel Canyon Watershed
- Review available topographic data for the channel and floodplain areas
- Conduct necessary field investigations and detailed topographic survey
- Review and utilize the recently completed hydrologic analysis and results developed for Kagel Canyon Watershed (Kagel Canyon Flood Hazard Study Hydrology Analysis Report, prepared by the LACDPW and dated June 2015)
- Develop a new hydraulic model to perform hydraulic analysis of the Kagel Canyon Watershed
- Delineate floodplain boundaries and generate flood hazard mapping for peak flows associated with the 100- and 500-year rainfall events
- Generate updated flood profiles for the 10-, 50-, 100-, and 500-year rainfall events

The hydraulic analysis and revised flood hazard mapping will be required for a Letter of Map Revision (LOMR) to FEMA indicating the effective FIRMs have been modified. Preparation of the LOMR Application and response to FEMA comments are provided in the project scope as optional tasks.

1.3 Study Location

The Kagel Canyon Watershed is located in Los Angeles County, California and is a tributary of Little Tujunga Wash. Situated on the north (right) bank of Little Tujunga Wash, Kagel Canyon generally flows in a southeasterly direction with a total drainage area of approximately 2.31 square miles. The watershed is located in the southwest part of the Angeles National Forest, east of the City of San Fernando. The Kagel Canyon Watershed consists of primarily rural areas, with some residential development. Many residential buildings are situated in close proximity to the Kagel Canyon channel. The southern portion of the watershed lies within the City of Los Angeles. The total FEMA mapped length of Kagel Canyon is approximately 1.3 miles from just upstream of Blue Sage Drive downstream to Osborne Street. The general location of Kagel Canyon Watershed, as delineated in the 2015 hydrology study, is shown in Figure 1-2.

Figure 1-2. Project Location



2 Data Collection and Review

Available information on Kagel Canyon was reviewed to obtain a broader understanding of the previous studies, analyses, and other data and was utilized to support the development of a hydraulic model for purposes of updating the effective FEMA flood hazard maps. Much of the information was supplied by the LACDPW or was downloaded from the FEMA Flood Map Service Center. For reporting purposes, the data was organized into the following categories:

- FEMA FIRMs and FIS Reports
- Geographic Information System (GIS) Mapping Data
- Kagel Canyon Hydrologic Analysis Report
- Hydraulic Model Development

2.1 FEMA FIRMs and FIS Reports

The following timeline outlines FEMA's history of the Los Angeles County and incorporated areas, which includes the Kagel Canyon Watershed. The FIS reports and FIRMs were downloaded from the FEMA Flood Map Service Center.

24 Oct 1978 FIRM	Kagel Canyon Creek is designated as a Zone A floodplain, where base flood elevations (BFEs) were not determined and a floodway was not defined.
02 Dec 1980 FIS (Revised 06 Jul 1998)	This FIS was prepared for the unincorporated areas of Los Angeles County and Kagel Canyon Creek was restudied as a detailed study reach. Although there were revisions to the FIS in 1985 and 1998, the hydrologic and hydraulic analysis and mapping data for Kagel Canyon was republished without modification from the 1980 study. Peak flood rates were calculated using the Regional Runoff Frequency Equations developed by the Los Angeles County Flood Control District (LACFCD). The 100-year and 500-year peak discharges were computed as 1,380 and 2,159 cfs at cross-section A (see Figure 1-1), with a total drainage area of 2.04 square miles. The hydraulic analysis was performed by the LACFCD and was completed in 1979. Obstructions, such as buildings or walls were considered in the hydraulic analysis. The analysis was based on available topographic maps from 1961. Manning's n values for Kagel Canyon range from 0.03 in the channel to 0.06 in the overbank areas. Per the analysis, Kagel Canyon was found to have relatively high velocities which have historically eroded the main channel. All data was presented in the National Geodetic Vertical Datum of 1929 (NGVD 29).

02 Dec 1980 FIRM	Kagel Canyon Creek was restudied as a detailed study reach. As a result of that restudy, Kagel Canyon Creek was designated as a Zone A3, A5 100-year floodplain where BFEs and flood hazard factors were determined. 500-year flood limits (Zone B) were also defined. Per the FIS, the entire 100-year floodplain should be delineated as a floodway; however a Flood Boundary and Floodway Map was not located for Kagel Canyon.
26 Sept 2008 FIS	The 2008 FIS was prepared to include the unincorporated and incorporated areas of Los Angeles County. Individual FIS reports were also combined into a single county-wide FIS. As such, an additional 800 feet of channel along the downstream end of Kagel Canyon, which falls within the City of Los Angeles, was studied in detail and was included in the FEMA flood hazard mapping. Peak discharges remained unchanged. This FIS was prepared using the North American Vertical Datum of 1988 (NAVD 88), based on a conversion factor of +2.8 feet (NAVD above NGVD). Kagel Canyon was again noted as having relatively high velocities that have historically eroded the main channel, resulting in unpredictable channel meandering and a hazard to structures within the floodplain. For the portion of the channel that flows through the City of Los Angeles, the Federal and City representatives concluded that due to the highly erosive nature of the channel, the entire 100-year floodplain should be delineated as a floodway.
26 Sept 2008 FIRM	In 2008, the floodplain boundaries from the previously effective FIRMs were digitized, resulting in a digital product, known as DFIRM. The current effective FEMA floodplain mapping shows floodplain areas along Kagel Canyon just upstream of Blue Sage Drive to the confluence with Little Tujunga Wash, and a regulated floodway through the City of Los Angeles to the confluence with Little Tujunga Wash for a distance of approximately 800 feet. The floodplain areas are designated as Zone AE and Zone X. Zone AE designates areas within the 100-year flood, where BFEs were determined. Zone X designates areas within the 500-year flood or areas within the 100-year flood with average depths less than one foot. Kagel Canyon discharges into Little Tujunga Wash, mapped as a Zone AO, with flood depths of one to three feet and velocities determined.
06 Jan 2016 FIS	The purpose of the 2016 FIS was to update the information for Los Angeles County from the previous FIS. Peak discharges remained unchanged from the previous FIS at 1,380 and 2,159 cfs for the 100-year and 500-year rainfall events, respectively, at cross-section A (drainage area of 2.04 square miles). The flood profiles appear unchanged from the previous FIS.

The effective FIS and flood hazard mapping is based on hydrologic and hydraulic data that was published in 1980. The purpose of this Study is to generate updated flood hazard mapping for peak flows associated with the 100- and 500-year rainfall events and update the flood profiles for the 10-, 50, 100-, and 500-year rainfall events using recent topographic data and improved hydrologic data. The effective flood profiles for Kagel Canyon from the 2016 FIS report are provided in Appendix A.

2.2 GIS Mapping Data

A summary of the GIS mapping data pertinent to the Study is provided in Table 2-1. The majority of the data was obtained from the LACDPW. Other information was utilized from other mapping services and was downloaded from FEMA.

Table 2-1. GIS Mapping Data Inventory

GIS Data Type	Source	Information Included
Aerial Photography	2014 Los Angeles Regional Imagery Consortium (LAR-IAC) Aerial tiles provided by LACDPW Google Earth; Bing; ESRI Basemaps	Aerial imagery Street Mapping
Topographic Data	Wagner Engineering and Survey, Inc., August 2019 LACDPW, 2015 LACDPW, 22 March 2011. North American Datum of 1983, California, Zone 5	2019 Survey Data (point elevations, breaklines, triangulated irregular network) within channel and overbank areas from the upstream limit of the study to approximately 1000 ft downstream of Blue Sage Dr. 2015 LiDAR Data (point elevations) for the entire watershed - Point spacing between 1.2 to 1.8 feet (point density between 0.31 to 0.69 points/square foot) 2011 Survey Data (point elevations, breaklines, triangulated irregular network) within the channel
Effective (2008) FEMA Mapping	FEMA Flood Map Service Center	100-year and 500-year floodplain, floodway

2.3 Kagel Canyon Hydrologic Analysis Report

The LACDPW recently completed a hydrologic analysis for the Kagel Canyon Watershed, which will serve as the basis for the hydraulic analysis for this Study. The Kagel Canyon Flood Hazard Study Hydrologic Analysis Report, prepared by the LACDPW and dated June 2015, provides peak discharges for the 10-, 50-, 100-, and 500-year rainfall events at various drainage concentration points within the watershed. The 2015 hydrology was adjusted as part of this Study to include additional interpolated values between the concentration points defined in the previous study in order to reduce the change in discharge between points. Refer to Sections 4.1 and 4.2 for additional details regarding the hydrologic analysis, Study updates, and results for the Kagel Canyon Watershed.

2.4 Hydraulic Model

A data request for any available hydrologic and hydraulic data, including the duplicate effective model was mailed into FEMA on 28 September 2016. FEMA responded to our request on 3 November 2016, indicating that they were unable to locate the requested data after an extensive search. As such, the effective model for Kagel Canyon is unavailable.

In this Study, the entire effective model for Kagel Canyon is being replaced, rather than a portion of the reach, eliminating the need to provide tie-ins at the upstream and downstream ends and therefore, eliminating the need to replicate the effective model. The existing conditions model for Kagel Canyon was developed in Hydrologic Engineering Center River Analysis System (HEC-RAS 5.0.6), using a combination of one-dimensional (1D) and two-dimensional (2D) models. Refer to Section 5 for additional information regarding the development of the hydraulic models.

3 Field Investigations

A field reconnaissance visit was conducted of the lower reaches of the Kagel Canyon Watershed on 4 August 2016 from the confluence with Little Tujunga Wash upstream to Blue Sage Drive. The purpose of the field visit was to obtain structure details, including structure type and size, collect site photographs, note vegetation types, and make other visual observations that would be beneficial for the development of the hydraulic model. Field notes and photographs from the field investigation are provided in Appendix B.

The available topographic data within the upstream reaches of Kagel Canyon showed minor discrepancies and did not accurately represent site conditions as observed during field investigations. As a result, topographic survey was collected within the channel and overbank areas from the upstream limit of the detailed study to approximately 1,000 feet downstream of Blue Sage Drive. Data collection consisted of point elevations and breaklines to represent existing features, channel thalweg, channel toe, top of bank, breaks in terrain, and other notable features on site. Topographic survey was collected on 7 July 2019 and 8 August 2019.

4 Hydrologic Analysis

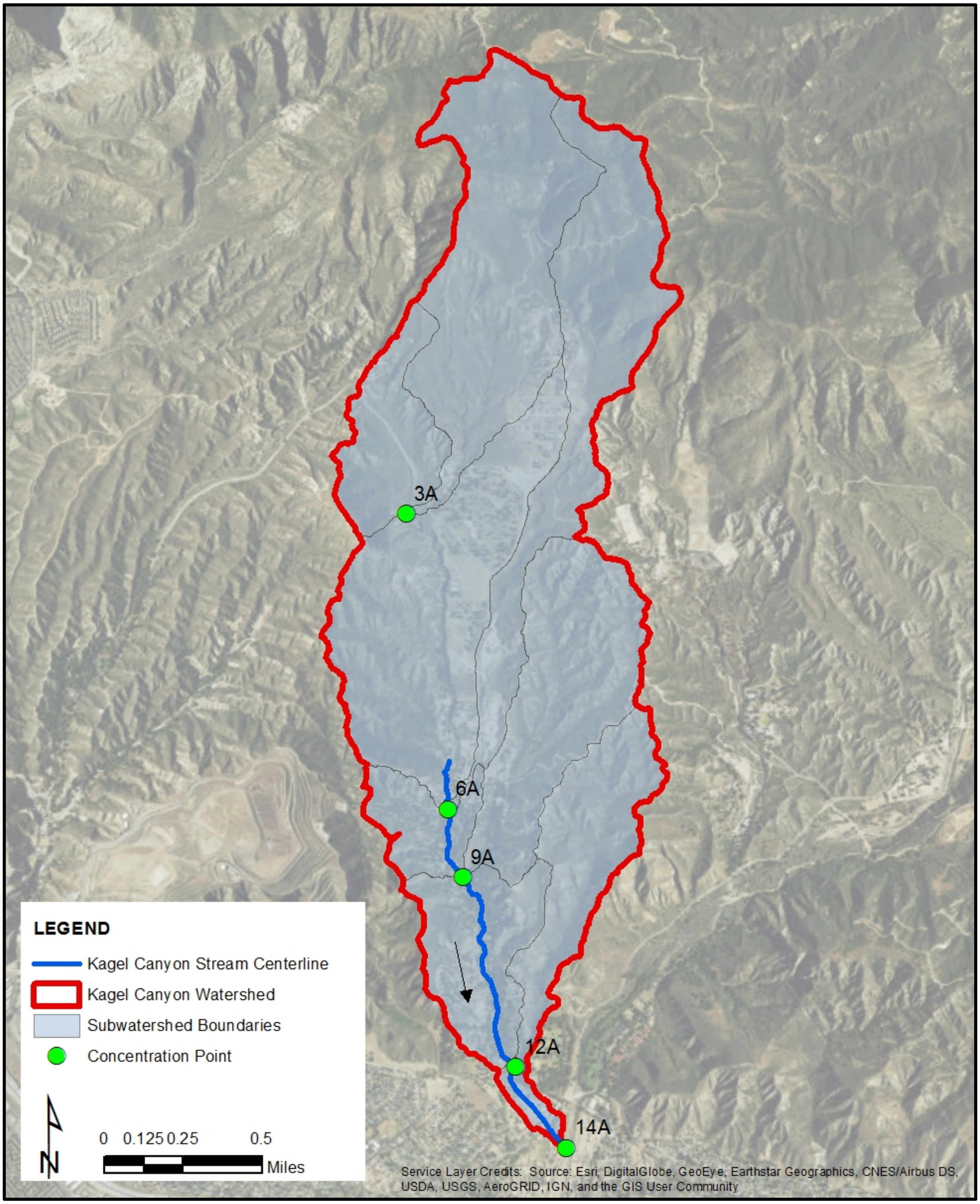
The effective FEMA hydrology is based on a study that was published in 1980 using topographic data from 1961. The hydrologic analysis used as a basis for this Study was previously developed by the LACDPW, and is documented in the Kagel Canyon Flood Hazard Study Hydrologic Analysis Report (June 2015). The Hydrologic Analysis Report is provided for reference in Appendix C. The basis for using more recent hydrologic data includes updated topographic data, land use information and precipitation data, as well as superior modeling methods. Section 4.1 is provided for the convenience of the reader to briefly document the findings of the 2015 study. Refer to the original report (Appendix C) for additional details and specifics regarding the hydrologic analysis. HDR did not prepare or perform a technical review of this hydrologic study; therefore, HDR does not make any assurances or draw any conclusions regarding the accuracy of this Study performed by others. The hydrologic data is being certified by LACDPW and incorporated into this report and the revised hydraulic analysis by reference. HDR has assumed that the third party data is accurate, complete, reliable, and current.

4.1 2015 Hydrology Study

The 2015 hydrologic analysis was completed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) to simulate the 10-, 50-, 100-, and 500-year rainfall events for the Kagel Canyon Watershed.

Figure 4-1 was re-created from the 2015 study to illustrate the Kagel Canyon Watershed boundary, nine subwatershed boundaries, and five concentration points. The extent of the existing FEMA mapped channel is also shown in Figure 4-1.

Figure 4-1. Kagel Canyon Watershed Delineation and Concentration Point Locations



Source: Re-created from Kagel Canyon Flood Hazard Study Hydrologic Analysis Report, June 2015

The 2015 hydrologic study provided peak discharges for five concentration points along the Kagel Canyon channel for the 10-, 50-, 100-, and 500-year rainfall events. The resulting discharges are provided in Table 4-1. Discharge information used in the effective FEMA FIS and FIRMs is also provided in Table 4-1 for comparison purposes.

Cross-section A generally corresponds to a location just downstream from concentration point 12A. The updated flows result in an increase of more than double for the 10-year event, and approximately 45 percent, 29 percent, and 5 percent for the 50-, 100-, and 500-year rainfall events at this location, respectively, above the effective FEMA flows. The increase can likely be attributed to the different hydrologic method, differing precipitation input data, and differences in drainage area at the discharge reporting location.

Table 4-1. Summary of Peak Discharges (2015 LACDPW Study)

Source of Data	HEC-HMS Concentration Point	Drainage Area (sq mi)	10-yr Discharge (cfs)	50-yr Discharge (cfs)	100-yr Discharge (cfs)	500-yr Discharge (cfs)
Table 11, Kagel Canyon Flood Hazard Study Hydrologic Analysis Report, June 2015	3A	0.62	341	485	547	688
	6A	1.48	729	1,052	1,191	1,505
	9A	1.89	924	1,354	1,536	1,941
	12A	2.29	1,069	1,568	1,779	2,265
	14A	2.31	1,067	1,572	1,790	2,270
Table 6, 2016 FEMA FIS	Cross-Section A	2.04	490	1,081	1,380	2,159

4.2 Study Hydrology

The 2015 hydrologic results were used as a basis for this Flood Hazard Study at each of the concentration points (6A, 9A, 12A) defined by the LACDPW study. However, the changes in discharges between the concentration points defined in the HMS model were large enough that interpolated values were deemed necessary between concentration points. The interpolated values were estimated using a ratio of watershed area at intermediate points between model concentration points. The intermediate subwatershed boundaries used for peak flow interpolation were delineated based on the topographic survey (described in Section 5.1) and are depicted in Figure 4-2.

The peak discharges at the intermediate concentration points were estimated using a discharge/area relationship. A ratio of discharge to drainage area (unit discharge per square mile) was determined at the previously identified concentration points upstream and downstream of the new point. The peak discharge for the new concentration point was determined by applying an interpolated value of the ratio at the new concentration point based on the new drainage area. Peak discharges for the original concentration points based on the 2015 study remain unchanged. The resulting discharges are provided in Table 4-2, which were applied in the 1D hydraulic model at the nearest upstream cross-section.

Figure 4-2. Modified Watershed Delineation and Concentration Point Locations

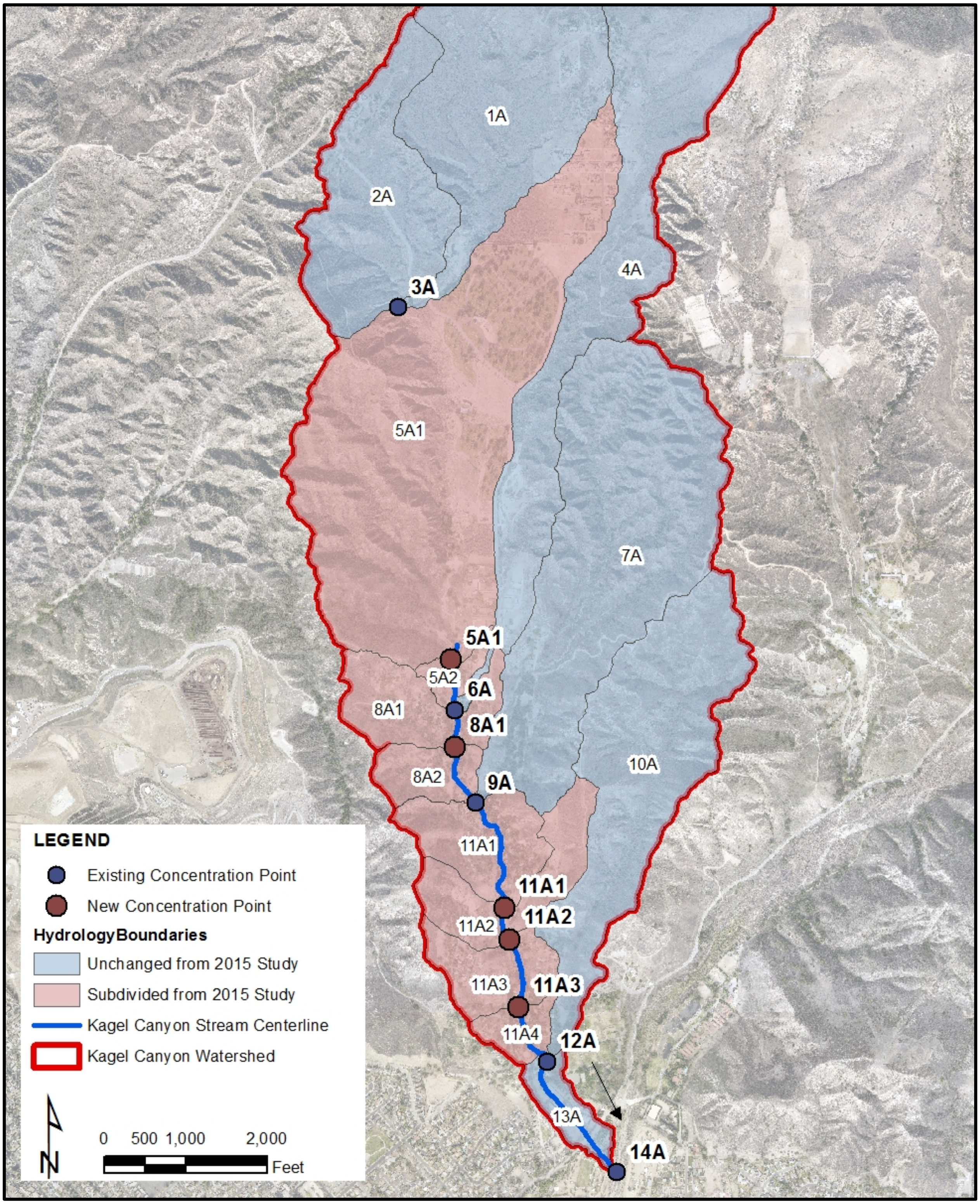


Table 4-2. Summary of Peak Discharges (Used in Hydraulic Analysis)

Concentration Point	Source	10-yr Discharge (cfs)	50-yr Discharge (cfs)	100-yr Discharge (cfs)	500-yr Discharge (cfs)
5A1	New	561	804	908	1,145
6A	2015 study	729	1,052	1,191	1,505
8A1	New	758	1,096	1,241	1,568
9A	2015 study	924	1,354	1,536	1,941
11A1	New	947	1,388	1,574	1,992
11A2	New	969	1,421	1,612	2,041
11A3	New	988	1,448	1,643	2,082
12A	2015 study	1,069	1,568	1,779	2,265

5 Hydraulic Analysis

Hydraulic analyses for the Kagel Canyon channel were performed using HEC-RAS version 5.0.6. The project analysis and results files are georeferenced to the California State Plane coordinate system, Zone V and the North American Datum of 1983. Vertical data is referenced to NAVD 88.

5.1 Steady-State 1D Hydraulic Model Development

HEC-GeoRAS was utilized as a graphical interface allowing for the development of the geometric information in GIS to be imported directly into the 1D HEC-RAS model.

A topographic surface was developed for the Kagel Canyon channel and floodplain areas from the 2015 LiDAR information and 2011 and 2019 topographic survey using 3D Analyst tools in ArcGIS. The 2015 LiDAR provided points for the floodplain areas. The 2011 detailed survey provided point elevations and breaklines within the existing channel identifying the top and toe of the existing channel banks and additional detail within the channel. The 2019 detailed survey provided point elevations, breaklines, and a triangulated irregular network within the existing channel and overbank areas from the upstream limit of the study to approximately 1,000 feet downstream of Blue Sage Drive. In areas where 2019 survey data was collected, the 2019 survey took precedence over the 2011 survey. The Kagel Canyon floodplain contains obstructions, such as buildings, residences, and walls located within the overbank areas. These areas were digitized based on the 2014 aerial imagery and were included in the model as obstructions.

The channel centerline alignment was digitized from 1-foot contour information provided as part of the 2011 and 2019 survey. Cross-section lines were placed in locations along the channel centerline that best represented the channel and floodplain. Cross section spacing ranged from a minimum of 2 feet (at existing drop structures) to a maximum of 120 feet, with an average spacing of approximately 50 feet along the stream centerline due to the relatively steep slope of the stream. Refer to Appendix D for the workmap depicting the cross-section locations. A HEC-RAS 2D model was developed for purposes of informing the 1D hydraulic model with regard to cross-section orientation in the overbank areas and to capture shallow sheet flow conditions in the overbank that the 1D model is unable to properly track once it gets out into the overbank. The 2D model is described in more detail in Section 5.2. The Kagel Canyon channel contains numerous drop structures, varying from a few inches to a foot and a half in vertical drop. Drop structures with a vertical drop of one foot or more were included in the model with additional cross-sections at the top and bottom of the feature. Cross-sections near structures were placed in accordance with the HEC-RAS Reference Manual. HEC-GeoRAS and RAS Mapper used the cross-section coverage file and topographic surface to cut and generate cross-section data.

A typical cross-section within the Kagel Canyon channel consists of nearly vertical channel banks armored with wooden fencing, wire fencing, concrete, or grouted rock. Channel bank stations were aligned with the corresponding breakline from the 2011 and 2019 survey and were manually edited in the graphical geometry editor in HEC-RAS to the point where the ground transitioned from the nearly vertical channel bank to a gentler side slope.

Existing land uses were identified within the channel and overbank areas using recent 2014 LAR-IAC aerial imagery (Figure 5-1). The Manning's roughness coefficient within the channel was selected based on a clean channel with some stones and weeds (without pools). Manning's roughness coefficients were assigned to each vegetative cover type as shown in Table 5-1 per the HEC-RAS user's manual. Manning's roughness coefficients used in this Study provide more variation for cover type and are reasonably comparable to those used in the effective model (0.03 in channel and 0.06 in the overbank areas).

Table 5-1. Land Use and Manning's Roughness Coefficients

Land Use	Manning's Roughness Coefficient
Roadways	0.015
Channel and barren areas	0.035
Areas with minor vegetation	0.05
Residential areas with good vegetative cover	0.055
Dense vegetation, heavy tree cover	0.06

A total of 16 structure locations were identified on-site. Six of the structure locations are roadway crossings; two of which were identified as low water crossings. The remaining structures, located in the downstream portion of the channel, function as foot bridges or horse facility bridges for local residents and the California Polo Club. The structure locations and descriptions are depicted in Figure 5-2. Structure information was manually entered into the HEC-RAS model based on the measurements from the field investigations and 2011 survey data. As-built information on the bridges was not readily available. The pressure and/or weir option was used on all bridges for the high flow method. Bridge handrails and guard rails were modeled as obstructed flow to account for potential debris obstruction.

Figure 5-1. Kagel Canyon Land Use

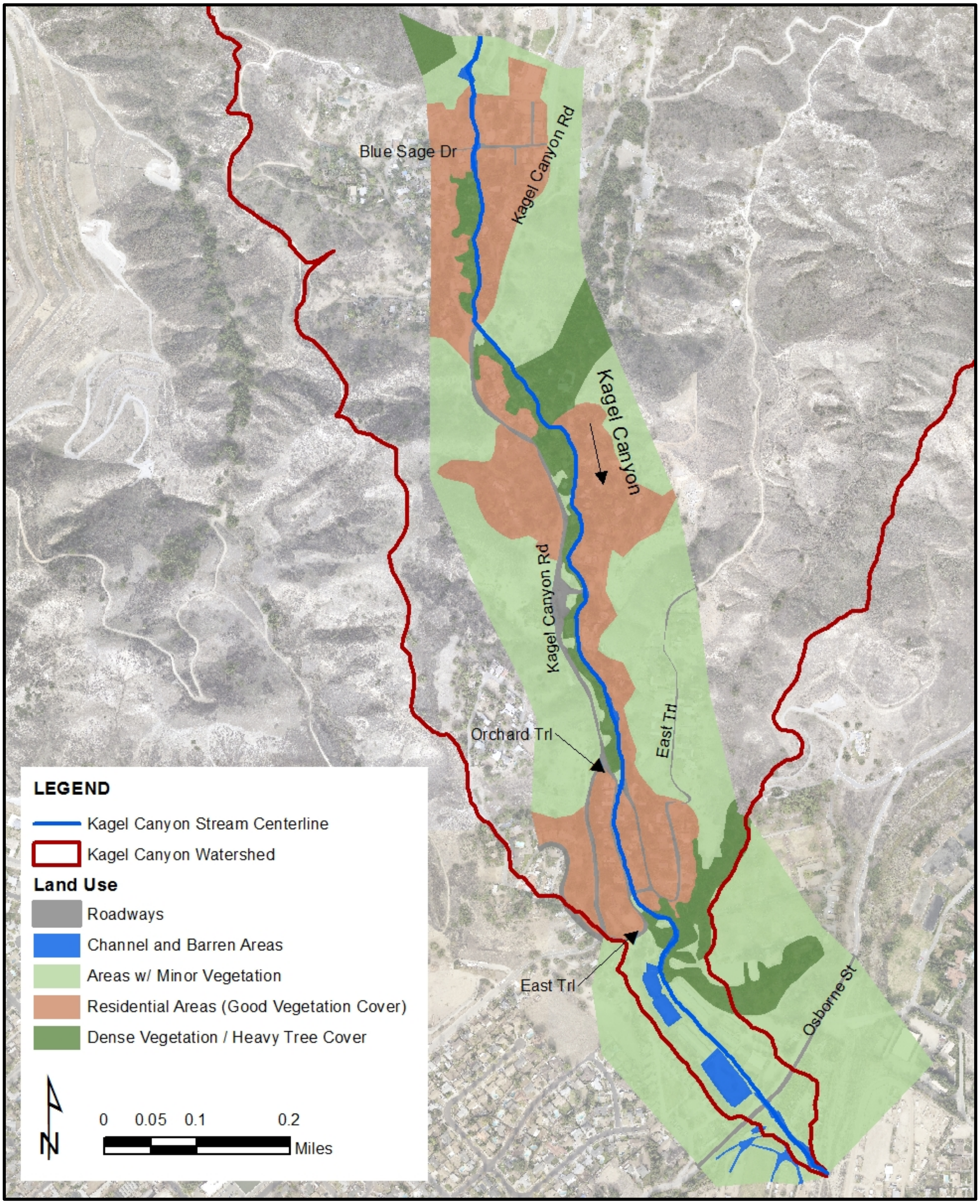
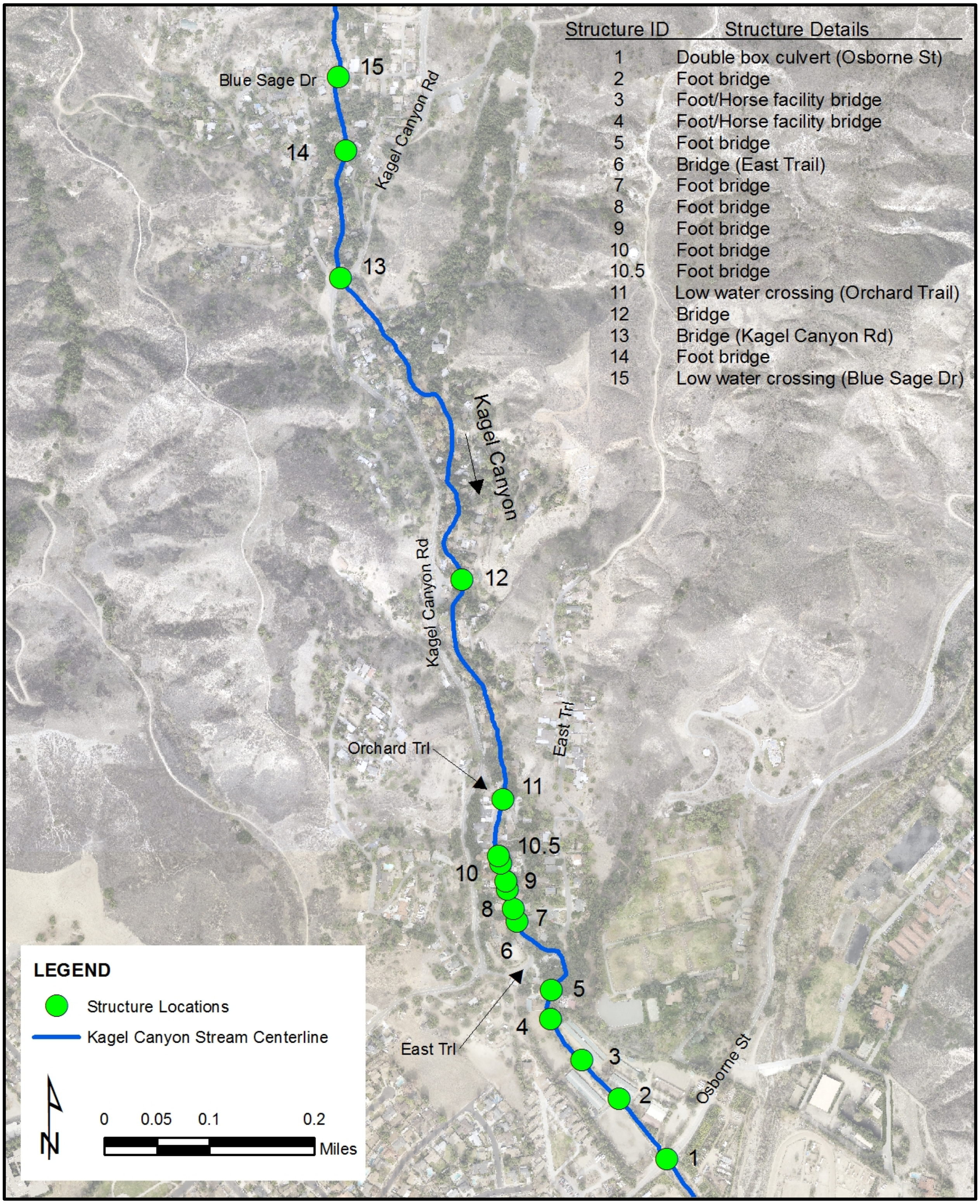


Figure 5-2. Kagel Canyon Structure Locations



The default values for expansion and contraction coefficients (0.1 and 0.3, respectively) were used for all sections that were not in the proximity of structures. For cross-sections near structures, which resulted in a constricting effect, coefficients of 0.3 and 0.5 were assumed, as recommended by the HEC-RAS manual. Coefficients near structures, such as low water crossings and bridges that had little constricting effect, were left as the default values of 0.1 and 0.3. The model was evaluated for sensitivity to contraction and expansion losses, and results indicate that the model is not overly sensitive to contraction and expansion losses and only small localized changes were evident from a change in the coefficients.

Ineffective flow areas in the overbank areas and in the vicinity of structures were placed using engineering judgment and based on the recommended contraction and expansion ratios from the HEC-RAS Reference Manual.

Peak discharges for the 10-, 50, 100-, and 500-year rainfall events were based on results from the hydrology study developed by the LACDPW and documented in the Kagel Canyon Flood Hazard Study Hydrologic Analysis Report (June 2015) and were further refined as described in Section 4.2. The peak discharges utilized in the steady-state model are provided in Table 4-2.

The hydraulic analysis was performed using subcritical computation assumptions since this channel is partially natural with a very inconsistent slope and geometry. Some cross-sections default to critical depth as a result, but use of mixed flow would result in water surfaces that are below critical depth. A solution below critical depth (i.e. supercritical velocities) is not likely to be sustained in natural conditions due to sediment entrainment. A solution below critical depth is not likely to be sustained in natural conditions; therefore, maximum depths are more likely to remain at or above critical depth and have been estimated based on that assumption.

Boundary conditions at the downstream end of the study reach were assumed to be normal depth. Per FEMA guidelines, the starting conditions on tributaries shall use normal depth unless a coincident peak situation is assumed. Based on the guidelines, the drainage area ratio should fall between 0.6 and 1.4 to assume coincidental peaks. In this case, the drainage area ratio between Kagel Canyon and Little Tujunga Wash is approximately eight; therefore coincidental peak analysis is not required. The downstream slope used for the normal depth boundary condition was based on an approximate slope of Little Tujunga Wash in the vicinity of the confluence, and was approximated as 1.7%. The model extends downstream into the mapped area of Little Tujunga Wash, simulating non-coincidental peak conditions, in order to better establish hydraulic conditions at the mapped boundary between the two systems.

The Kagel Canyon channel is a complex hydraulic system. The stream represents a high gradient stream with complex flow conditions in the overbank areas. In a few locations, results from the 1D model indicate flow is present in the overbank areas that would likely continue to flow in the overbanks; however due to the nature of the 1D model, the next downstream section shows that the flow can be contained within the main channel; therefore there is no continuation of flow in the overbank areas where flow will remain until it is able to rejoin the channel downstream. In order to have a better understanding of the flow patterns, particularly in the channel overbanks, a 2D hydraulic model was developed. Additional information regarding the 2D model development and results are provided in the subsequent sections.

For purposes of this study, the hydraulic analysis was accomplished using a combination of separate 1D and 2D hydraulic models. This approach was perceived as a better approach over conducting a 2D only model or a combination 1D/2D model. Utilizing a 2D only model does not provide a straightforward approach to conducting an encroached floodway analysis required within the City jurisdiction at the downstream end of the reach. Utilizing a combination 1D/2D model (1D in the channel connected with 2D overbank areas defined with lateral structures) requires operating the model entirely under unsteady conditions. Due to the high gradient of the channel and discontinuous overbank flows, model instabilities are very likely within a 1D/2D unsteady model, which are challenging to resolve.

5.2 Unsteady 2D Hydraulic Model Development

A 2D hydraulic model was developed to more accurately capture disperse, shallow overbank flooding not adequately captured with 1D hydraulic modeling. The 100- and 500-year flood events were evaluated in the 2D hydraulic model for purposes of updating flood hazard mapping in the overbank areas of Kagel Canyon.

5.2.1 Inflow Boundary Conditions

HEC-RAS 2D utilizes unsteady-state hydrograph inputs for hydraulic simulation. The simulation requires input hydrographs to be routed into and through a gridded computational 2D flow area. HEC-RAS 2D uses a finite volume approach to flow routing, meaning the volume introduced into the model is completely accounted for until it exits the system.

Unlike the 1D analysis where flow changes can be applied from one cross-section to the next, HEC-RAS 2D requires a flow hydrograph input at the boundary of the computational mesh. As such, flow changes are typically applied where there is a significant tributary area joining the channel in the form of a confluence of two systems.

The 2D model was developed using inflow hydrographs at the upstream end of the reach and additional flow hydrographs were added at concentration points 6A, 9A and 12A (see Figure 4-2). The hydrographs at each of these locations were based on hydrographs from the HEC-HMS models developed as part of the 2015 Hydrology Study. The additional flow change locations (5A1, 8A1, 11A1, 11A2, 11A3) that were applied in the 1D hydraulic model and described in Section 4.2 were not included in the 2D model due to challenges of the topography and being able to contain the additional flow at the boundary of the computational flow area.

Figure 5-3 and Figure 5-4 provide a graphical illustration of the input flow hydrographs for the 100- and 500-year rainfall simulations, respectively.

Figure 5-3. 100-year 2D Input Hydrographs

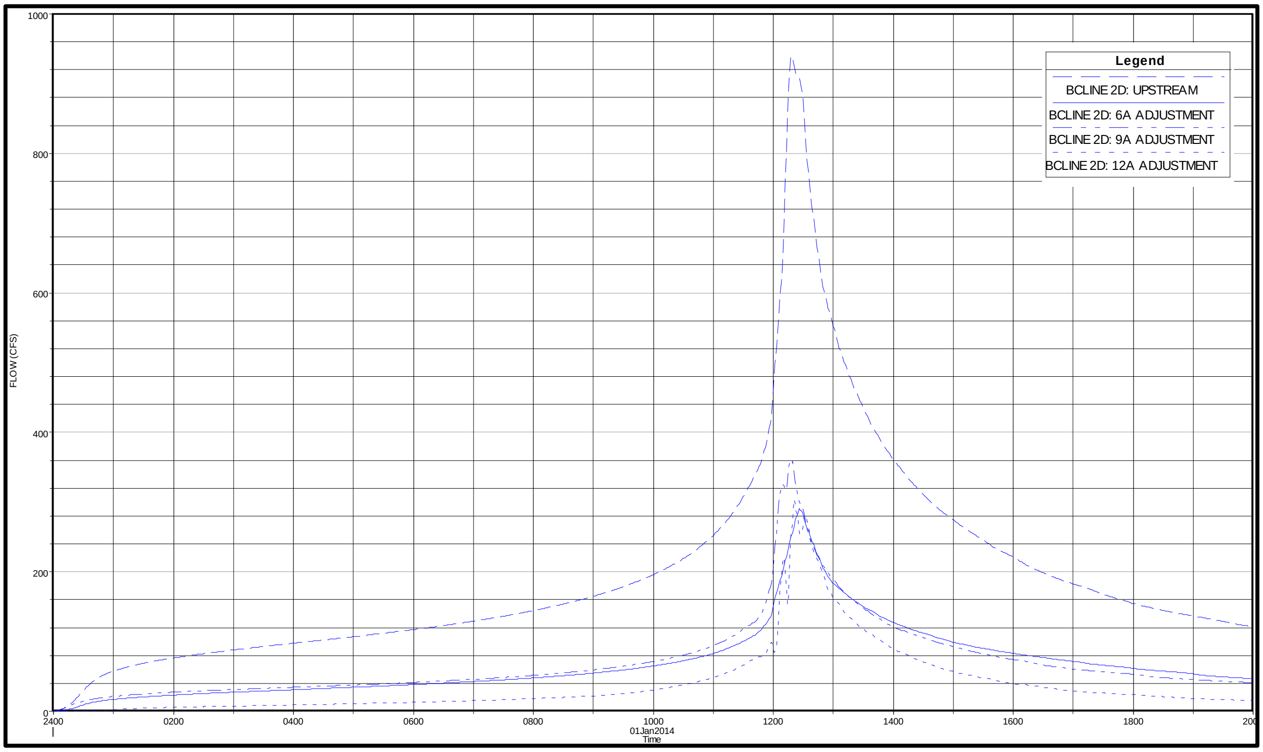
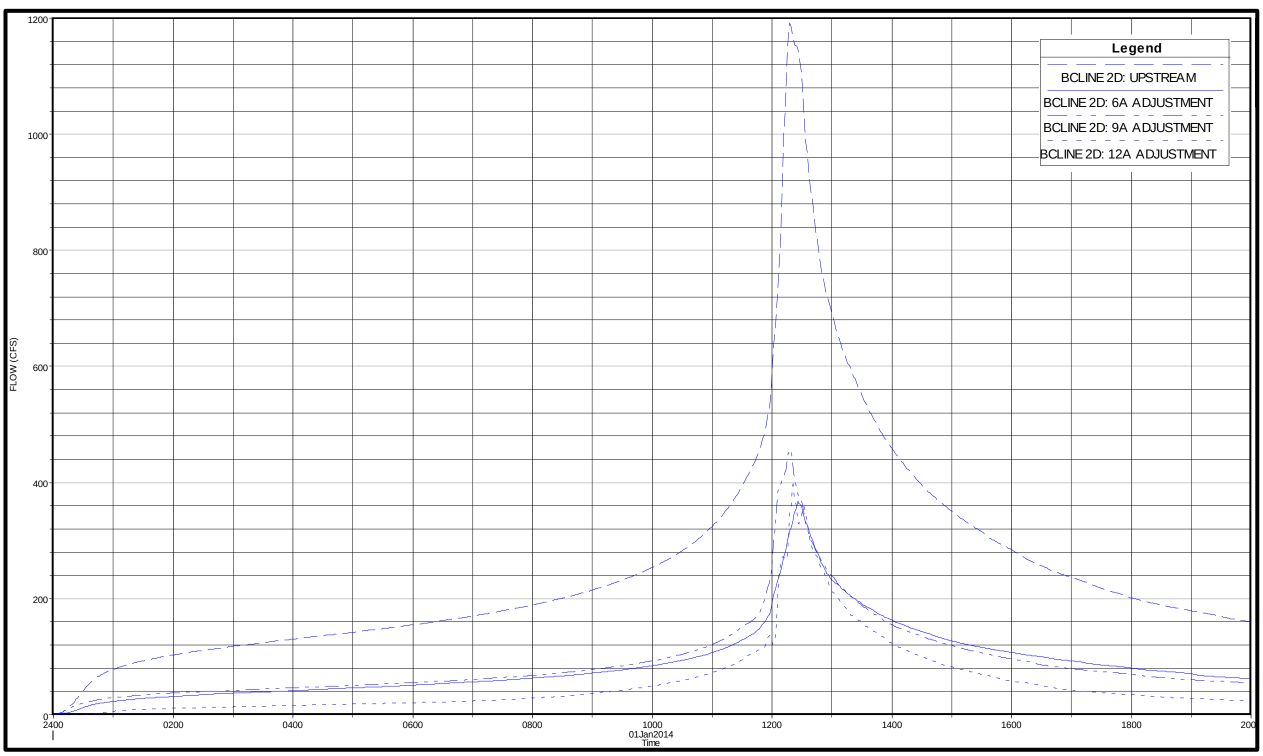


Figure 5-4. 500-year 2D Input Hydrographs



5.2.2 Hydraulic Model Development

The 2D gridded flow area developed in HEC-RAS uses a series of regular and irregular grid cells and the shallow water St. Venant equations to route flow through the project area. During pre-processing of the model, hydraulic tables or rating curves are developed for each grid cell face. These hydraulic properties are then used as "lookup" tables for a particular flow rate through the cell. Each of these grid cell faces derives its cross sectional geometry from the underlying associated terrain dataset.

The terrain is processed in HEC-RAS as a floating point file, which creates a gridded representation of a surface. The resolution of the gridded point file determines the definition of features in the terrain data set. The topographic TIN developed for use with HEC-GeoRAS and the 1D hydraulic model was rasterized and used to develop a HEC-RAS terrain file. Similarly, the obstruction polygon layer used in HEC-GeoRAS to depict buildings in the 1D model was rasterized, converted to a float (.flt) file and used as part of the HEC-RAS 2D terrain file. This resulted in a terrain that included buildings precisely as the 1D model represented them, providing for a more realistic representation of obstructions within the floodplain due to the manmade structures.

The terrain in a 2D HEC-RAS model is the foundation for the entire model; therefore the quality and accuracy of the terrain is critical. The prismatic features within the model terrain proved problematic in HEC-RAS and the model was having a difficult time resolving the hydraulics and reaching a stable solution. As a result, the terrain required modification within the channel banks, and was updated to include an interpolated surface based on the 1D HEC-RAS cross-sections. This provided for a more uniform channel geometry and resulted in a more stable model.

Flows were introduced into the model by establishing a boundary element along the edges of the computational flow area. As described in Section 5.2.1, four boundary elements were utilized in the 2D model to introduce flow into the system; one boundary element at the upstream end of the model and one element at each of the concentration points (6A, 9A, and 12A). These boundary elements are oriented perpendicular to flow, are extracted from the model terrain, and act in the same manner as a 1D cross section. An energy grade slope is associated with boundary elements and the model determines normal depth hydraulics as a starting point for flow introduction. The Energy Grade Line (EGL) slope was input into the HEC-RAS model for the upstream boundary condition to estimate the inflowing water surface elevations based on the EGL profile from the 1D model at those locations. The upstream EGL slopes range from 0.029 to 0.041. Refer to Figure 5-5 for an illustration of the 2D model layout and inflow locations.

Similarly, a downstream boundary element must be established to allow flows to exit the computational flow area to avoid artificial ponding within the modeling area. The downstream boundary element is based on normal depth hydraulics. The downstream EGL slope was entered as 0.03 based on the EGL profile from the 1D model results. Additional boundary elements were required at the downstream end where the flow opens up into Little Tujunga Wash. Normal depth hydraulics were also used for these downstream boundary conditions.

Numerical hydraulic modeling requires careful consideration of a wide range of modeling parameters. It is important to understand the purpose of the hydraulic model and the use of the output to properly define the input parameters. Sensitivity analysis of modeling input variables is also critical to understanding influence on results and can focus the need for future modeling refinement. Model setup parameters were continually refined as model runs were completed and understanding of the hydraulic system progressed.

The 2D computational flow area used a base cell size of 20 feet. The grid cells were reduced to a cell size of approximately four to five feet on a side within the channel to provide an increased level of detail. The model simulations were performed at a computational time step of 0.3 seconds.

Figure 5-5. 2D Model Layout and Inflow Locations

HEC-RAS 5.0.6 allows the user to select the set of equations for hydraulic computation, the Diffusion Wave equation or the Full Momentum Saint Venant Equation. The Diffusion Wave equation is typically adequate for most large, low velocity floodplain applications without contractions or expansions of flow and is more stable and computationally faster than the Full Momentum equation. However, in locations of rapidly varied flow (expansion and contraction) through rapid flow direction changes or around structures, the Full Momentum equation provides more accurate results in support of hydraulic design as it utilizes inertial terms (excluded with the Diffusion Wave solution) to solve correctly. While the Full Momentum solution is less stable than the Diffusion Wave solution, the 2D hydraulic model was run using the Full Momentum equation as it yield a more accurate solution for the study reach due to the high flow velocities, flashy hydrographs, and significant contractions/expansions. Using this approach yielded a volume continuity error of approximately 0.34% for the 100-year simulation and 0.14% for the 500-year simulation. Efforts were made to further reduce this error in the model with lowered time steps and grid cell modifications. Reducing this percentage further however, became computationally challenging given the scope and budget of the project.

The computational mesh was refined with the inclusion of breaklines along key terrain features. Due to the nature of the HEC-RAS 2D computational methodology, which calculates hydraulics based upon the grid cell faces, it is important that flow confining features are properly accounted for in the computation mesh. Breaklines force revisions in the mesh, allowing for grid cell faces to align along the drawn breakline. This aids considerably in reducing incorrect flow conveyance over hydraulic features such as roads and channel berms.

It is important for hydraulic modeling to accurately represent major roadway crossings and account for impacts to flow paths and inundation limits. HEC-RAS 2D models bridges and culverts in the same manner by using a culvert routine to explicitly compute the hydraulics from an upstream grid cell to a downstream grid cell. This approach is ideal for detailed hydraulic analysis of culverts that pressurize and can cause significant upstream ponding and flow redirection. Bridges that become pressurized cannot be modeled in HEC-RAS 2D; therefore the bridges were represented in the model geometry using the culvert feature with a 2D area connection. Structures 1, 2, 3, 4, 5, 6, 12, 13, and 14 (Figure 5-2 and Figure 5-5) were incorporated into the model geometry. The smaller foot bridges were not included in the analysis as they do not have a substantial effect on flow direction and 100- and 500-year water surface elevations. The box culvert size for each bridge was approximated based on the open flow area of the bridge geometry. The assumptions used for modeling purposes for each structure are shown in Table 5-2.

Table 5-2. 2D Bridge Approximation Summary

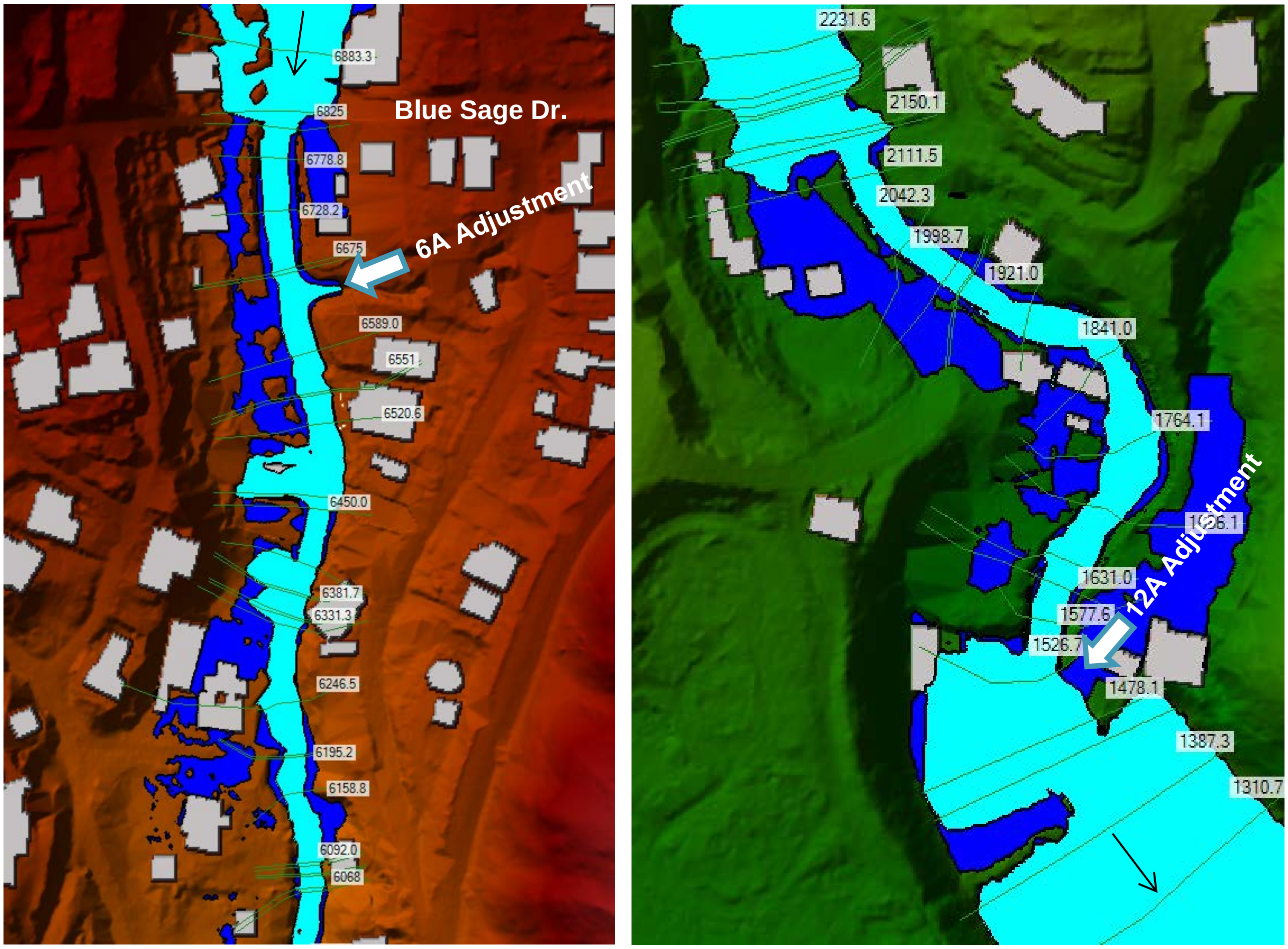
Structure ID	Bridge Open Area (sq ft)	Box Culvert Approximation			
		# Barrels	Span (ft)	Rise (ft)	Open Area (sq ft)
1	382	2	19	10	380
2	36	1	10.3	3.5	36
3	41	1	11	3.7	41
4	49	1	12.5	3.8	48
5	205	1	22.5	9	203
6	112	1	18.5	6	111
12	166	1	17	10	170
13	222	1	17.25	13	224
14	106	1	11	9.5	105

The existing land use file developed for use with HEC-GeoRAS and the 1D hydraulic model was rasterized, converted to a float file and used for the 2D model. Manning's roughness coefficients were increased in the 2D model to represent a more subcritical flow regime in support of FEMA requirements.

5.3 Results and Discussion

The 2D model results provide more uniform flow patterns within the overbank areas as compared to the 1D model results. Results from the 2D model were used to inform the 1D input parameters regarding ineffective flow within the overbank areas. Through the iterative process of updating the 1D and 2D models, the model results began to converge and the differences in flooding extent were minimized. A few inundation areas were identified in the 2D model that do not appear in the 1D model simulations, which represent areas of discontinuous overbank flow in the 1D model. Refer to Figure 5-6 for example locations of overbank flow captured in the 2D model that is not reflected in the 1D model.

Figure 5-6. Comparison of 1D and 2D 100-year Inundation Limits



1D Inundation Limits
2D Inundation Limits

There is uncertainty in the model results due to the high gradient nature of the stream, discontinuous flows in the overbank areas, coarse overbank topographic mapping, and unpredictable sediment and debris movement in the stream. As a result, it is recommended that the floodplain be conservatively defined with a combination of results from the separate 1D and 2D hydraulic models.

The 100- and 500-year floodplain boundaries were delineated using a combination of the 1D and 2D model results. The 1D model results were used to map the channel, connected overbank inundation areas, and floodway boundaries. The 2D model results were used to supplement the 1D floodplain boundaries in the overbank areas to provide continuous overbank flow conditions not captured in the 1D model.

The 100-year floodplain within the main channel and connected overbank areas (1D results) were mapped as Zone AE with BFEs determined. Mapping in the overbank areas as determined from the 2D model results were mapped as Zone AE with BFEs determined if the water depth is equal to or greater than one foot. Inundation areas within the mapped 2D overbank areas that are less than one foot of depth (100-year) or within the 500-year inundation boundary, were mapped as Zone X.

The post-processing inundation extents from the 100-year and 500-year simulations (1D and 2D) are illustrated in the workmap, provided in Appendix D.

The 10-, 50-, 100-, and 500-year flood profiles generated from the 1D HEC-RAS model are provided in Appendix E.

5.4 Encroachment Analysis

A designated floodway is effective in the downstream reaches of Kagel Canyon through the City of Los Angeles. Per the 2016 FIS, the floodway extends the entire width of the 100-year floodplain due to the highly erosive nature of the channel. Similar to the conclusions of the City of Los Angeles in the FIS, where the City reach of the channel was mapped as a bank to bank floodway, the combination of uncertainty and risk warrants consideration of a designated floodway through the entire study reach. However, the floodway analysis completed as part of this Study is limited to the reach within City of Los Angeles jurisdiction.

An encroachment analysis was performed on the 1D steady-state hydraulic model to support development of a mapped floodway. Per definition of a FEMA floodway, cross-section encroachment to the limits of the floodplain will cause a maximum rise of one vertical foot of water surface elevation during the 100-year event. This allows communities to better manage development over the course of time and space more efficiently. HEC-RAS provides multiple methods for determining/specifying encroachment limits for encroached model runs. Method 4 was used as the first step in the analysis, which allows the user to specify a target water surface increase. The Method 4 run provided estimated encroachment stations, but further refinement was required in order to avoid negative surcharges (changes to water surface elevation) at some stations and to smooth transitions in floodway width. These refinements were completed using Method 1, in which the user refines the right and left encroachment station in order to achieve the allowable increase in water surface elevation. An equal conveyance reduction method was used to establish the floodway encroachment stations.

The encroachment analysis was performed in the downstream reaches of Kagel Canyon that lie within the City's jurisdiction. This portion of the reach exhibits a wider 100-year floodplain, with areas of shallow overbank flooding with lower velocities and some ineffective flow areas. Encroachments were achievable, and the floodway is narrower than the floodplain.

Results of the encroachment analysis are provided in the workmap in Appendix D, the encroachment table in Appendix E, and revised annotated mapping in Appendix F.

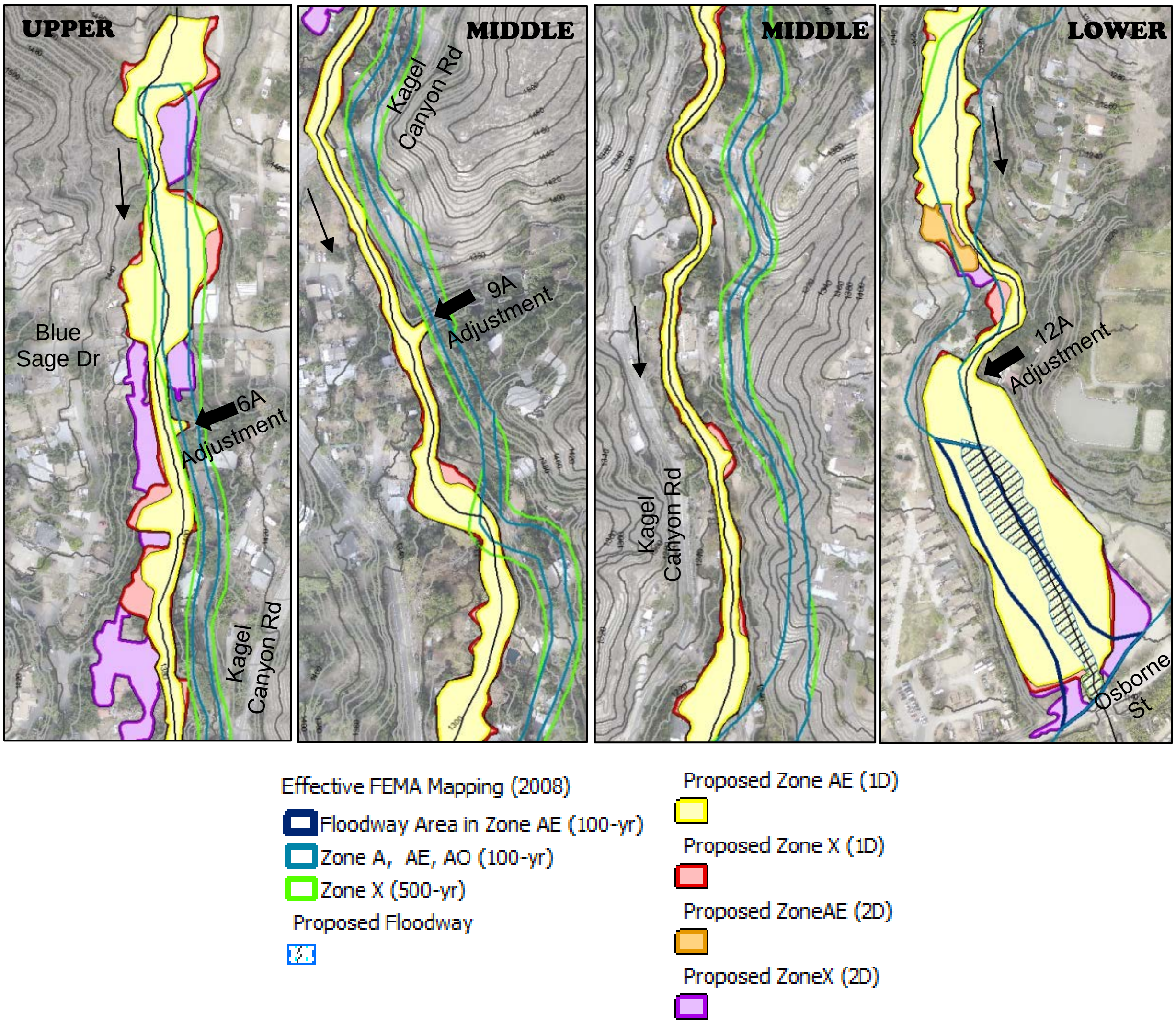
6 Flood Hazard Mapping

The updated flood hazard mapping for Kagel Canyon was developed in accordance with FEMA Policy Standards for Flood Risk Analysis and Mapping.

The raw post-processing inundation extents from the 100-year and 500-year 1D and 2D simulations were further refined to provide smooth transitions and smoothed edges, which define the extents of the proposed flood hazard area. Refer to Appendix D for an illustration of the smoothed flood hazard areas. The limit of the 100-year and 500-year floodplain boundaries at the downstream end of the project tie into the effective floodplain boundary of Little Tujunga Wash. The limit of the floodway extends through to the downstream end of the model. The updated annotated mapping is provided in Appendix F.

While the effective flood hazard mapping for Kagel Canyon is shifted from the actual channel flowpath; on average, the proposed mapping within the upstream and downstream portions of Kagel Canyon is wider than the effective mapping. The downstream reach of the channel, through the City of Los Angeles, is currently mapped as a floodway which spans the entire 100-year floodplain. The proposed flood hazard mapping for this area includes an encroached floodway, with a wider 100-year floodplain. The increased floodplain width could be a result of increased peak discharge (Table 4-1), better topographic data, and/or improved modeling methods and tools. The effective flood hazard mapping is based on hydrologic and hydraulic data that was published in 1980. The effective and proposed floodplain widths throughout the middle portion of Kagel Canyon is comparable. Refer to Figure 6-1 for a comparison of effective and proposed flood hazard mapping for the upper, middle and lower reaches of Kagel Canyon. As previously discussed, the proposed flood hazard mapping was derived from a combination of both the 1D and 2D hydraulic modeling results.

Figure 6-1. Comparison of Effective and Proposed Flood Hazard Mapping



The 100-year BFEs were developed using 3D Analyst Tools in ArcGIS based on the post-processing water surface elevation raster from the 1D HEC-RAS model for the channel and from the 2D HEC-RAS model, for the disconnected overbank areas. The BFEs generated in the overbank area (2D model results near cross-section 1998.7) are slightly higher in elevation than the channel as they are not directly connected to the main channel. The BFEs are provided in the workmap in five foot intervals for clarity. Per FEMA Standards, Kagel Canyon meets the criteria for a steep gradient channel, with greater than five feet of rise or more per one inch of map distance. As such, the BFEs shown in the annotated maps were plotted at 0.5-inch intervals of map distance, since that interval resulted in a wider spacing than BFEs plotted at five-foot intervals.

7 Summary and Next Steps

This Study included the review of previous studies and available information, a field investigation, and development of hydraulic modeling for purposes of updating the regulatory flood hazard mapping for Kagel Canyon for the LACDPW. This information will be required for a LOMR to FEMA, indicating the currently effective FIRMs have been modified.

Next steps to be considered include the following:

- Obtain sealed letter from topographic survey documenting the source and accuracy of the data
- Coordinate with City of Los Angeles for review and concurrence
- Prepare LOMR Application for submittal to FEMA
- Provide property owner and public notification
- Coordinate with FEMA to address comments to their satisfaction
- Update the model, reports and mapping as needed

8 References

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