

A Case Study of 2-Dimensional Floodplain Modeling in an Urban Environment

W. Scott Ogden and J. S. O'Brien

*Project Manager, JE Fuller/ Hydrology & Geomorphology, Inc., Tempe, AZ, and
Senior Hydraulic Engineer, Tetra Tech ISG, Nutrioso, AZ.*

Introduction

Floodplain development presents many challenges to the floodplain manager and hydraulic engineer. Historic floodplain maps that were created when little or no development existed are no longer valid representations of the existing floodplain condition. Conveyance of floodwaters in wash corridors and arroyo floodplains that were once predominantly overland sheet flow or flow in rills and gullies, are now redirected by houses, fences, small buildings, streets, and other obstructions to flow. In many of these cases, flood containment within the historic mapped flood plain is questionable due to loss of storage and flow path obstruction, and there is a need to quantify the discharge that has been diverted from the floodplain. Traditional one-dimensional backwater models are inadequate to predict the unconfined flow behavior in such urban environments and if used, require too many assumptions regarding flow diversions and potential confinement. Advances in the computational speed of computers has facilitated the reality of using two-dimensional flood routing programs to efficiently simulate these complex urban flood environments with accuracy and detail.

This paper presents a case study using the FLO-2D model to route flood flows through an unconfined urban environment where significant encroachment and alteration of the historic floodplain have occurred. A description of the FLO-2D model is presented in a companion paper.

Project Description

The focus of the case study is a five-acre property located in the floodplain fringe of a small watershed located in north-central Phoenix, Arizona near the intersection of 7th Street and Thunderbird Road. The property owner wished to develop the site and subsequently discovered that it was in a floodplain. The current jurisdictional floodplain was originally mapped for the 100-year recurrence interval by Federal Emergency Management Agency (FEMA) over 12 years ago using results from the U.S. Army Corps of Engineer's (USACE) HEC-2 model. As a part of the development process, the property owner was required to address the floodplain related impacts that would be caused by the proposed development. Field and aerial photo observation of the project area and review of existing data indicated that the study area floodplain characteristics had changed from the what was historically analyzed and that the presence of development made the use of HEC-2 prohibitive to model the floodplain. Accordingly, the FLO-2D model was selected to analyze the floodplain and the modeling limits were generally set to be approximately 75 acres in size with limits defined by 7th Street on the west, Hearn Road on the north, 11th Street on the east, and Roberts Road on the south. A depiction of the 5-acre property location and current FEMA floodplain is shown on Figure 1.

Hydrology

The overall watershed for the project area is illustrated in Figure 2. The hydrologic characteristics of the watershed include mountain (greater than 10% slopes) and hill-slope (2 – 10% slopes) topography. Land uses include natural Upper Sonoran desert vegetation in the undeveloped areas, a golf course, and several densities of residential development. Flooding is typically caused by short duration, locally centered, and high intensity summertime convective storms or regionally centered, longer duration, and higher volume winter storms.

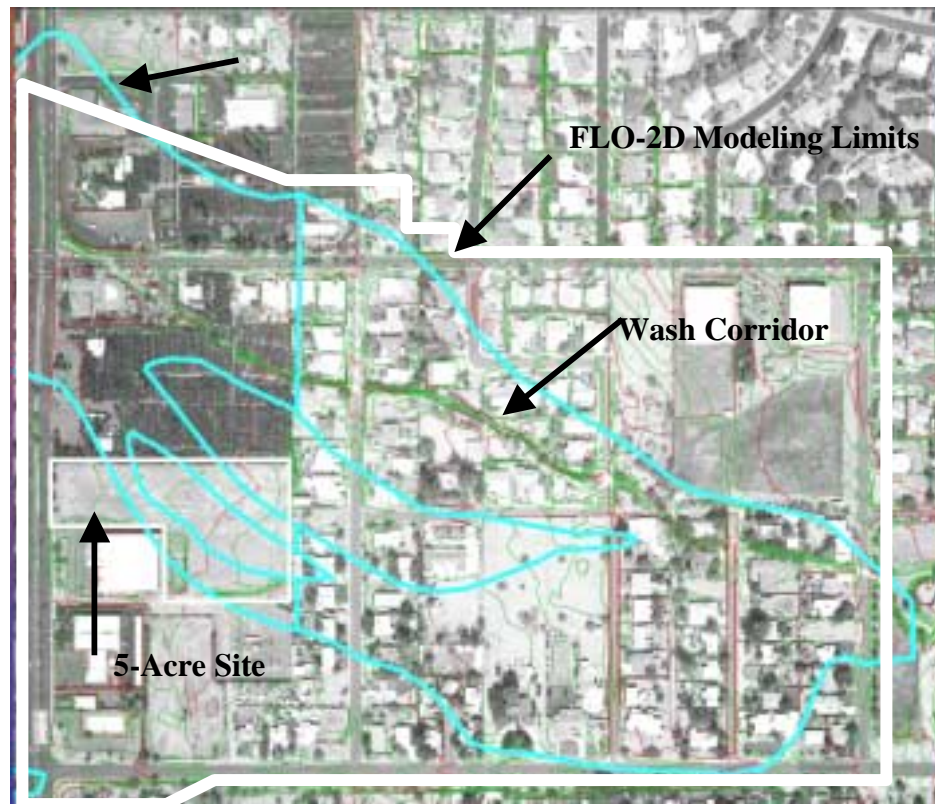


Figure 1. Current FEMA Floodplain Overlay

Since only a portion of the watershed was modeled with FLO-2D, runoff hydrographs at the major points of concentration along the modeling network perimeter had to be developed for input to the FLO-2D model. The model itself will handle the rainfall/runoff process within the network grid area. Four primary inflow points were identified for this project. The location of those points and delineation of each subbasin are indicated in Figure 3. The numbers in the rectangles correspond to a FLO-2D grid into which the runoff is entering.

The USACE's HEC-1 Flood Hydrograph Model was used to develop the runoff hydrographs for this project. Base modeling developed by the Flood Control District of Maricopa County for a regional study was used and modified to generate the hydrographs needed at the specified grids. The original FEMA floodplain analysis used a peak discharge of 970 cfs in the HEC-2 model. The peak discharge estimate for Subbasin S202A (see Figure 3) is approximately 15 percent higher (i.e. 970 cfs compared to 1,123 cfs).

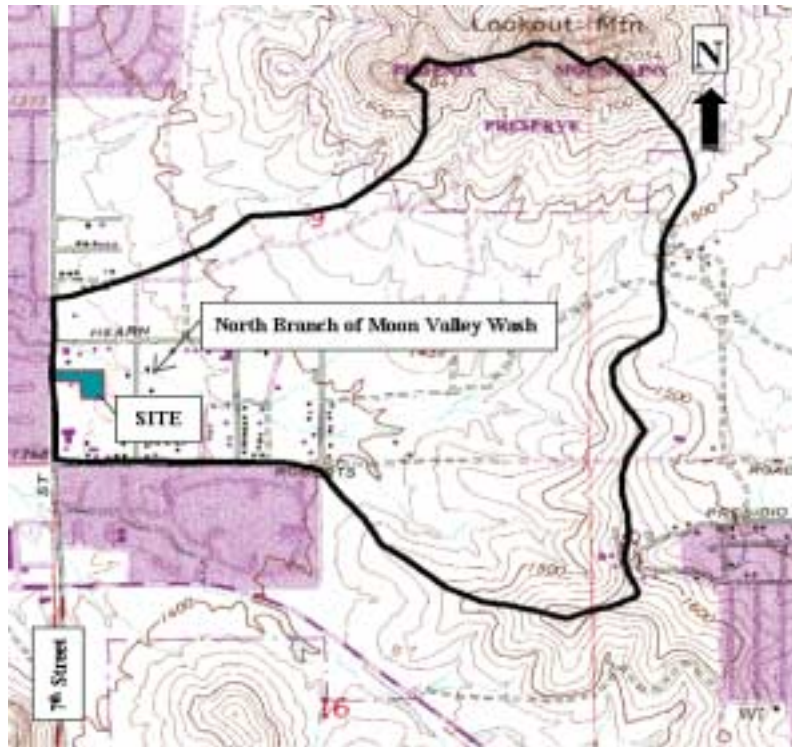


Figure 2. Overall Watershed Map

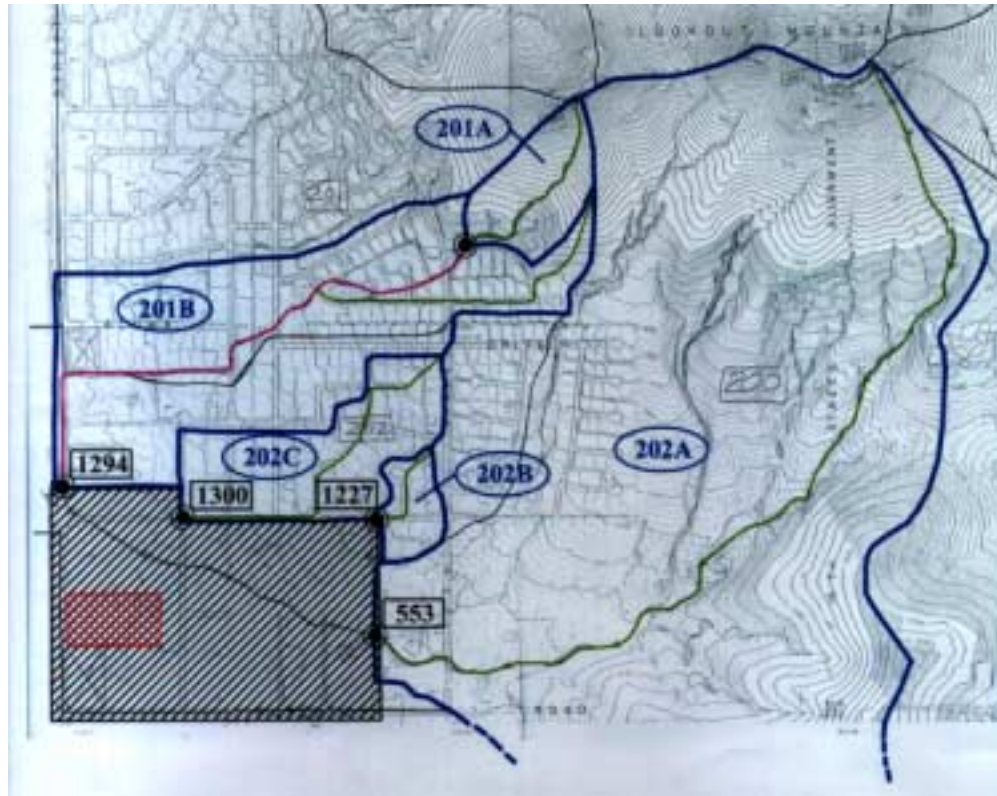


Figure 3. Subbasin Delineation Map

It was desired that the FLO-2D model inflow hydrograph at grid element 553 be comparable to the current FIS peak discharge, therefore, each of the subbasin calculations was multiplied by a ratio of 0.8638, which is the current FIS discharge (970 cfs) divided by the HEC-1 model discharge (1,123 cfs). This was accomplished by use of the JR record in the HEC-1 model. Table 1 provides a summary of the peak 100-year discharges for each of the four inflow locations.

Table 1. Summary of Peak Discharges by Grid Element

FLO-2D Grid Element	HEC-1 Model Operation	Basin Area	HEC-1 Peak Discharge		Time to Peak
			JR=1.00	JR=0.8638	
(1)	(2)	sq. miles (3)	cfs (4)	cfs (5)	hours (6)
553	S202A	0.613	1,123	970	4.25
1227	S202B	0.008	25	22	4.00
1300	S202C	0.044	102	89	4.00
---	S201A	0.021	44	38	4.00
---	S201B	0.134	358	310	4.00
1294	C201	0.155	371	320	4.00

FLO-2D Modeling Parameters

Floodplain Grid Network - The floodplain grid network for this model was developed using the September, 2000 mapping acquired with this project. The grid resolution selected for this project was 50-feet and was based on budgetary constraints and a desire to maintain grid elements large enough to encompass a typical urban street. A digital terrain model (DTM) was developed for the area using standard CAD software and the grid was generated by building a point file from the DTM on a 50-foot spacing and then exporting the point file in the data format required by FLO-2D. The pre-processors within FLO-2D were then used to convert the point file to the *fplain.dat* file. Roughness coefficients were assigned to each elements. A total of 1,307 elements were generated.

Channels – FLO-2D’s channel/floodplain interface subroutine allows the simulation channel flow with overflow to and from the overbank areas as the hydrograph rises and falls. Channel cross-sections for the watercourse were obtained using the DTM and contour mapping, as well as field measurements. One cross-section was derived for each grid element that the watercourse passed through. Where reasonable, cross sections were approximated by a trapezoid and power functions were developed for all others using the FLO-2D POWER pre-processor.

Streets – All of the streets were coded with 32-foot widths, 0.33-foot curbs, and a Manning’s n-value of 0.018. Seventh Street was coded as two streets, with one each for the northbound and southbound lanes.

Culverts and Bridges – There are three structures within the project area that were modeled using the bridge routines of FLO-2D. Two are masonry wall openings along a property boundary where the wall spans the wash using a lintel-plate. The third is a 5 barrel, 50-inch by 31-inch

corrugated metal pipe-arch culvert crossing under 7th Street. Rating curves for the two wall openings were developed by analyzing the openings as open channel flow and as orifice flow to capture the hydraulic characteristics for the entire range of potential discharges. The rating curve for the 7th Street culverts were developed using standard design procedures for culverts.

Rainfall and Precipitation Losses – A rainfall and precipitation losses were simulated for the FLO-2D modeling area using the same parameters as those used in the HEC-1 model.

Area Reduction and Width Reduction Factors (ARF and WRF) – The greatest amount of time spent developing data for the FLO-2D model was in developing the ARF and WRF parameters due to the numerous buildings, fences, retaining walls, and other barriers to flow that required modeling. The use of these variables proved invaluable in estimating the affects of the development in the overland flow areas.

FLO-2D Modeling Results

The FLO2D modeling results predicted main watercourse flooding depths that are 0.5 to 1.5 feet deeper than the currently mapped base flood elevations by FEMA. Additionally, areas mapped as dry islands in the overbank floodplain, are now predicted to be points of significant breakouts with flow depths up to 2 feet. Conversely, other overbank areas currently indicated to be in the floodplain are predicted to be non-flood hazard areas. This is particularly evident in the downstream end of the study reach, where FLO-2D indicates that most of the flooding that was once in the right overbank has shifted to the left overbank due to encroachment. Figure 4 is a graphical output presenting the maximum flooding depths predicted for the area modeled. Figure 5 presents the maximum predicted velocities. Another result noted during a review of the model output was that a significant volume of runoff was not reentering the wash downstream of the 7th Street culvert, but rather concentrating in two roadways and proceeding westward. The current floodplain delineation assumes that all runoff is in the wash downstream of 7th Street. This may be under-predicting the flood hazard potential downstream along the two roadways. Other results obtained from the model included a prediction of the offsite flows impacting the property. According to the FLO-2D results, 200 cfs enters the site from the east with most of the flows concentrated to a single grid element. This type of data is critical for designing the onsite drainage facilities and ensuring that the development does not negatively impact the surrounding properties. Prediction of this discharge by conventional methods for this project would be difficult if not impossible.

Summary

The floodplain mapped for the study area over 12-years ago does not adequately depict the current flood hazards. Encroachment of the main-stem wash, obstruction of overbank flow paths, and an overall loss of storage has caused the base flood elevations to increase in several areas and completely shift in others. Analyzing these conditions with any accuracy or detail using a one-dimensional hydraulic model would be extremely difficult. Use of two-dimensional programs like FLO-2D, enhance a modeler's ability to effectively and efficiently predict the flooding hazards in urbanized floodplain areas.

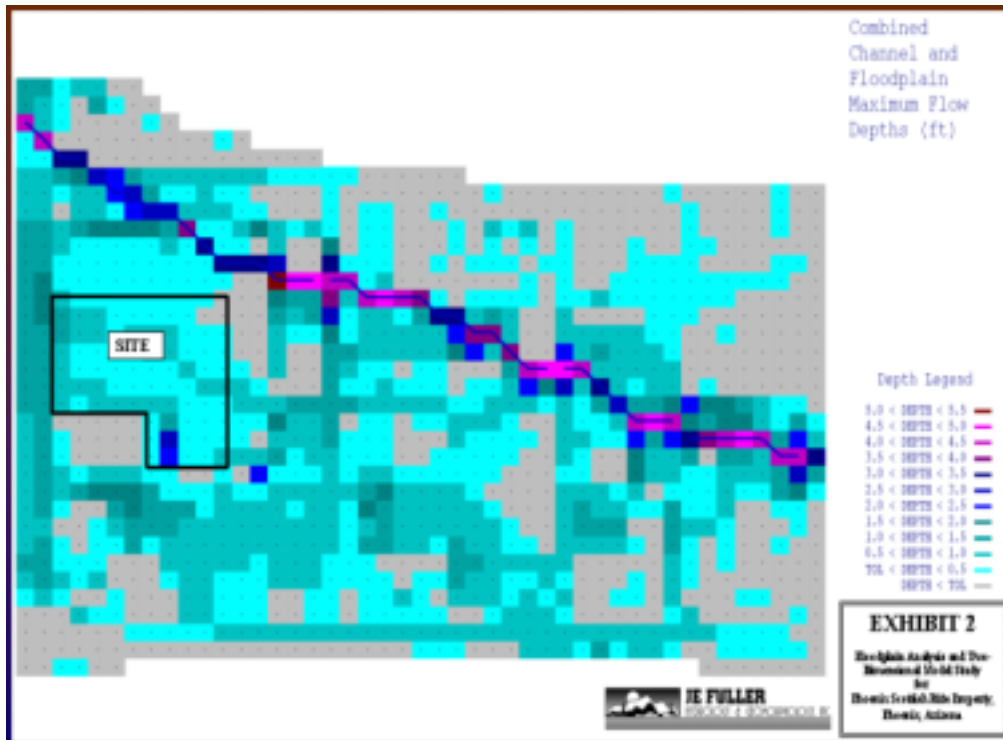


Figure 4. Maximum Predicted Channel and Floodplain Depths

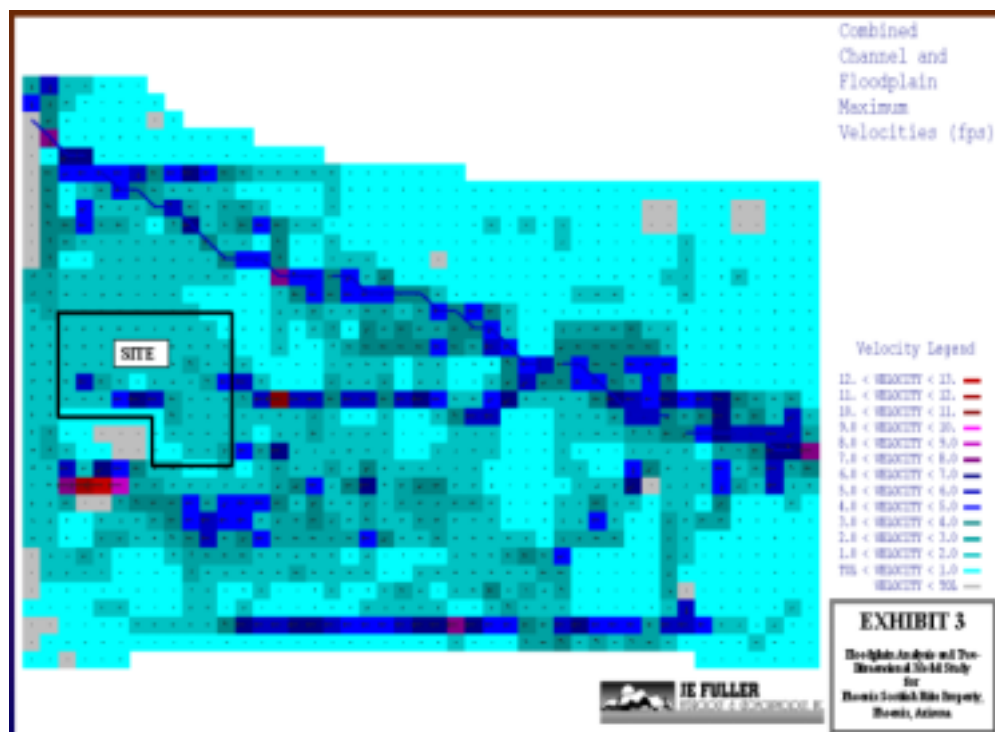


Figure 5. Maximum Predicted Channel and Floodplain Velocities