Hydrologic Modeling of South Mountain under an Extreme Event and Implications for Downstream Urban Growth and Ecological Design Alternatives

Central Arizona-Phoenix Long-Term Ecological Research CAP LTER

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Introduction

With increasing populations in urban centers throughout the world, urban development in residential and commercial areas, as well as in transportation routes, has increased in order to meet growing population demands. An example of a transportation project is the Loop 202 South Mountain Freeway, as seen in **Fig. 1**. This project will connect the East and West Valley through Southwest Phoenix in order to alleviate traffic congestions in other sections of the freeway system.

Assuming a future development of the surrounding area where the new freeway will pass by South Mountain, an investigation was conducted in the region where the Loop 202 will be built using the HEC-HMS software. The investigation consists of a hydrologic simulation from May 1st, 2014 through October 31st, 2014 during which significant rainfall was observed in the South Mountain region, as well as throughout the Phoenix Valley. This time period allows for the model to react to both dry and wet periods in a single continuous simulation. Determining the parameters for such a simulation would improve the robustness of the model to simulate any time period, regardless of the length and rainfall.

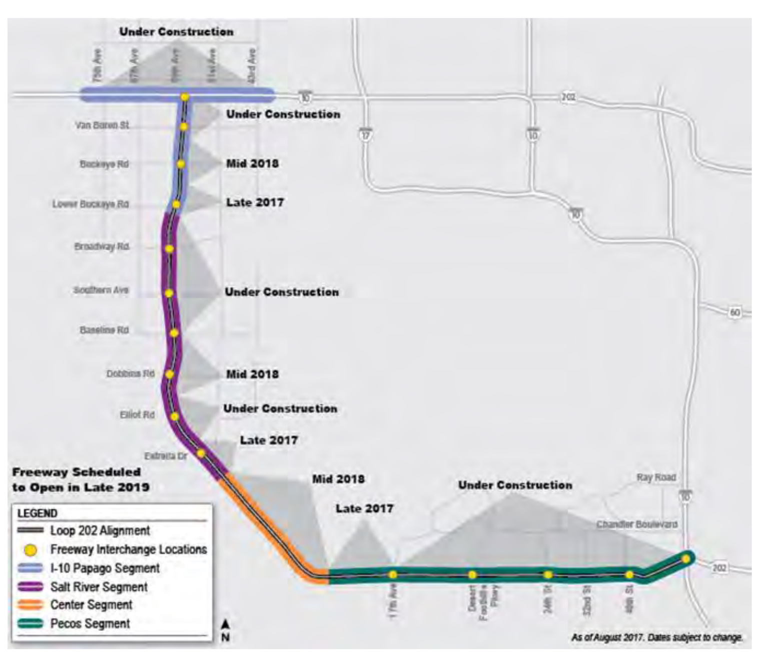

Fig. 1. Loop 202 South Mountain Freeway Map (ADOT).

Study Area

The investigation takes place in the South Mountain region, where a total of 69 basins of different sizes were delineated. Due to limited discharge monitoring stations in the area, the investigation focused on two basins where data was readily available to use. The Pima Canyon Wash and South Mountain Fan basins are located at opposite ends of South Mountain in the north-east and south-west, respectively. **Fig. 2** and **Fig. 3** demonstrate the delineations of the two basins as they were modeled in the HEC-HMS software. The Pima Canyon Wash basin consists of an area of 3.92 km^2, 5 sub-basins, and 2 main reaches. The South Mountain Fan basin consists of an area of 6.29 km^2, 35 sub-basins, and 17 main reaches.

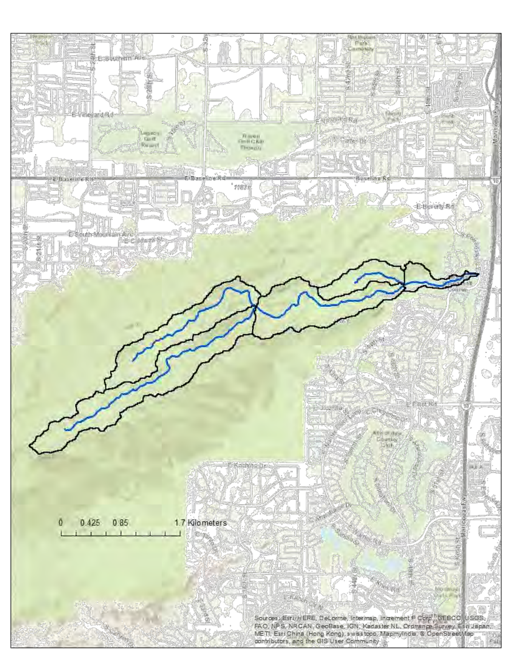

Fig. 2. Study area for the Pima Canyon Wash. The area is located in the north-east portion of South Mountain.

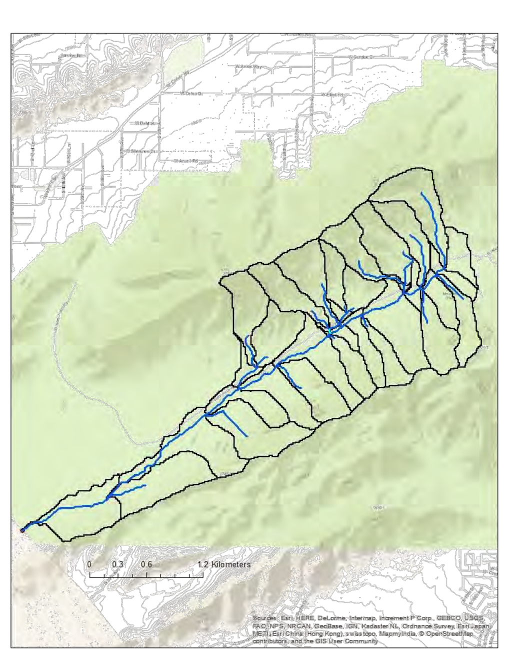

Fig. 3. Study area for the South Mountain Fan. The area is located in the south-west portion of South Mountain.

Data

The data used for both the project boundary delineation and simulation input was gathered from multiple government agencies at different temporal and spatial resolutions. The observed meteorological and hydrological data was gathered at a 1-hour time-step and used as input during the simulation and calibration processes. This data was gathered from the Flood Control District of Maricopa County (FCDMC) and it consists of:

- Four Rainfall Stations
- Two Streamflow Stations
- Two Meteorological Stations

The meteorological stations provided the following data: dewpoint temperature, average windspeed, relative humidity, air temperature, barometric pressure, and incoming solar radiation.

Remote Sensing data was gathered from multiple federal agencies including the U.S. Geological Survey and the U.S. Department of Agriculture. The data, as seen in **Fig. 4** and **Fig. 5**, consists of:

- 10-meter DEM
- 10-meter gSSURGO
- 30-meter Land Use/Land Cover
- 100-meter Impervious Surface

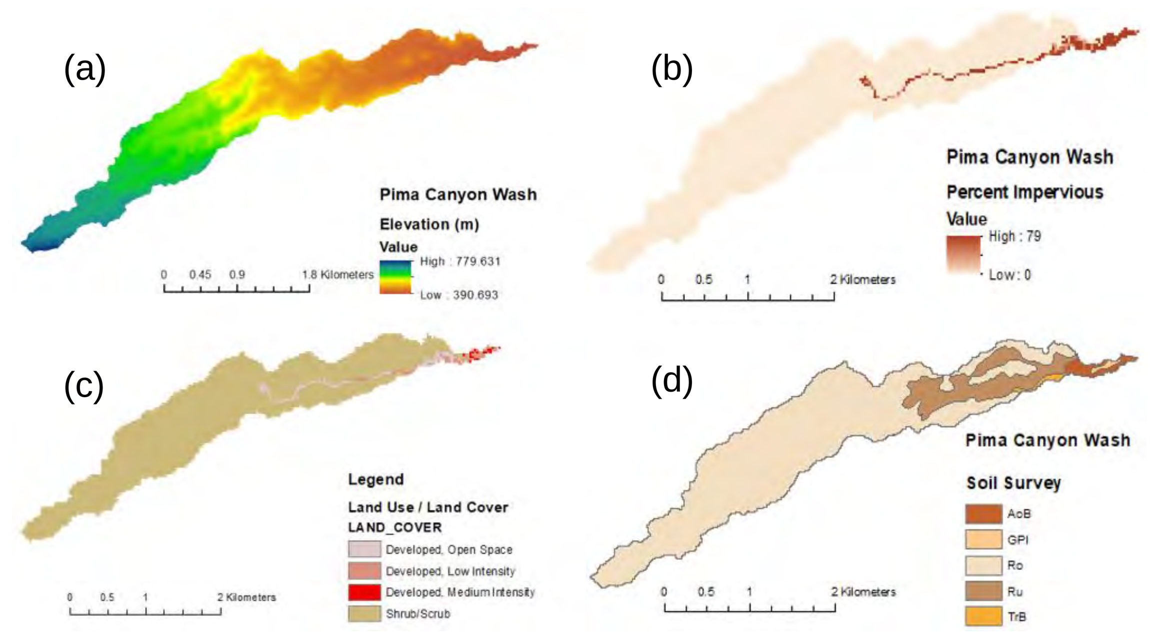

Fig. 4(a-d). Pima Canyon Wash (a) Elevation, (b) Percent Impervious, (c) Land Use/Land Cover, and (d) Soil Survey.

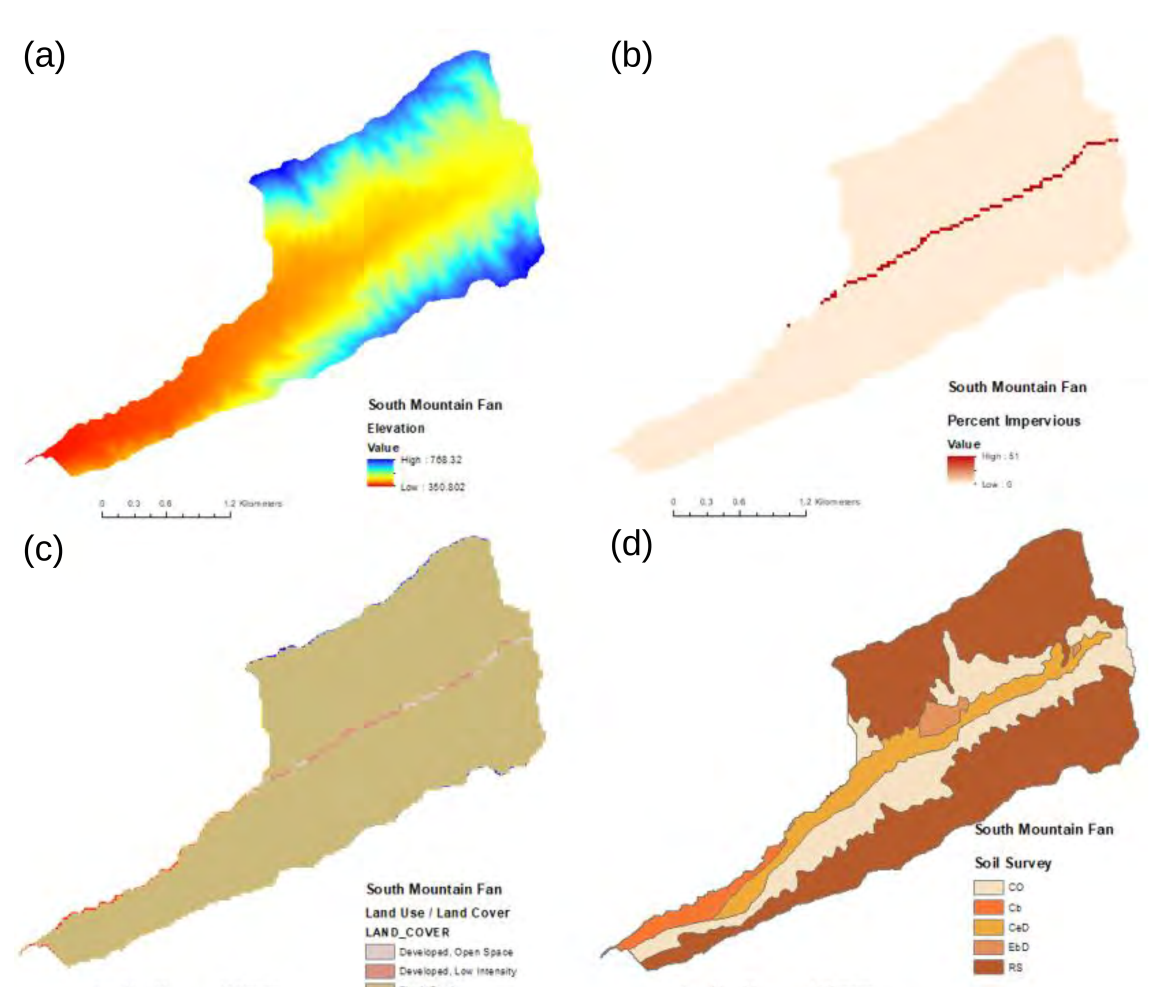

Fig. 5(a-d). South Mountain Fan (a) Elevation, (b) Percent Impervious, (c) Land Use/Land Cover, and (d) Soil Survey.

Hydrologic Processes

In order to perform the simulations in the HEC-HMS software, hydrologic processes were selected. The selected processes were the following:

- Loss Method – Soil Moisture Accounting
- Transform Method – S-Graph
- Channel Routing – Kinematic Wave
- Baseflow Method – None

The Soil Moisture Accounting simulates the movement of water through three soil layers: Soil Storage, Upper Groundwater Storage, and Lower Groundwater Storage. These layers are modeled in conjunction with the Canopy Interception Storage and the Surface Depression Storage.

Parameters & Calibration

The model parameters were determined from literature, remote sensing, and calibration. The model parameters are:

- Vegetation Parameters
    - Maximum Canopy Storage
    - Maximum Surface Storage
- Sub-Basin Parameters
    - Maximum Infiltration Rate
    - Maximum Soil Storage
    - Tension Storage
    - Soil Percolation
- Channel Parameters
    - Manning's n
    - Constant Loss Rate Reduction
    - Constant Loss Fraction

The parameter optimization process was performed using the Nash-Sutcliffe Model Efficiency Index. This methods provides a reliable assessment of the goodness of fit for hydrologic models as their ability to predict the 1:1 relation between observed values and simulated results. For the most part, a model that results with an index of 0.5 or above, is considered to demonstrate good performance.

Parameter	Units	Pima Canyon Wash	South Mountain Fan	Source
Maximum Canopy Storage	(mm)	0.11 – 0.15	0.1 – 0.45	Remote Sensing
Maximum Surface Storage	(mm)	3.81 – 6.35	3.81 – 6.35	Literature
Maximum Infiltration Rate	(mm/hr)	6.35 – 15.87	2.54 – 9.65	Literature

Table 1. Parameters determined through other methods.

Results

Table 1 and **Table 2** provide the parameters that were calibrated, as well as the Nash-Sutcliffe value for each basin.

Parameter	Units	Pima Canyon Wash	South Mountain Fan	Source
Maximum Soil Storage	(mm)	50 – 150	150	Calibration
Soil Tension Storage	(mm)	10 – 35	20 – 45	Calibration
Maximum Percolation Rate	(mm/hr)	3 - 5	4 – 5	Calibration
Manning's n	(-)	0.010 – 0.075	0.05 – 0.12	Calibration
Constant Flow Rate	(m^3/s)	1 – 1.10	0.1 – 1.125	Calibration
Constant Loss Fraction	(-)	0.48 – 0.52	0.05 – 0.75	Calibration

Table 2. Calibrated parameters for each basin.

	Pima Canyon Wash	South Mountain Fan
Nash-Sutcliffe	0.890	0.757
Peak Discharge (m^3/s)	7.9	9.1
Volume (mm)	13.62	10.74

Table 3. Nash-Sutcliffe Index for each sub-basin after calibration.

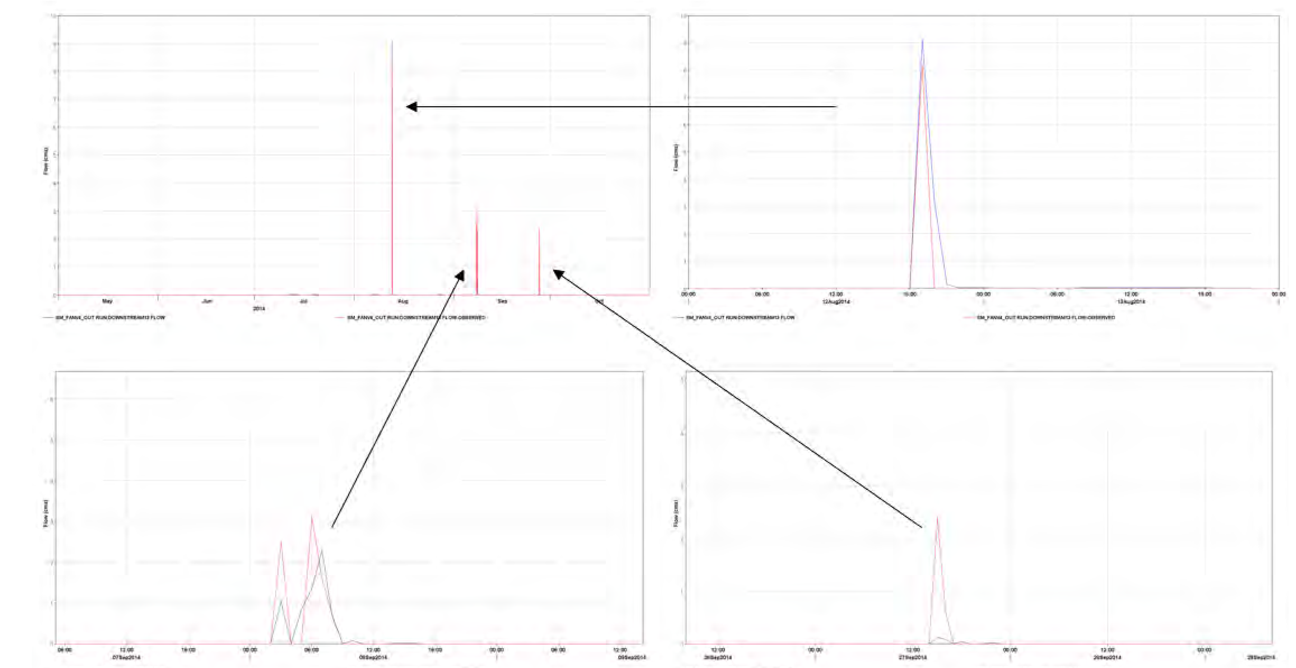

Fig. 6 South Mountain Fan hydrograph after model calibration.

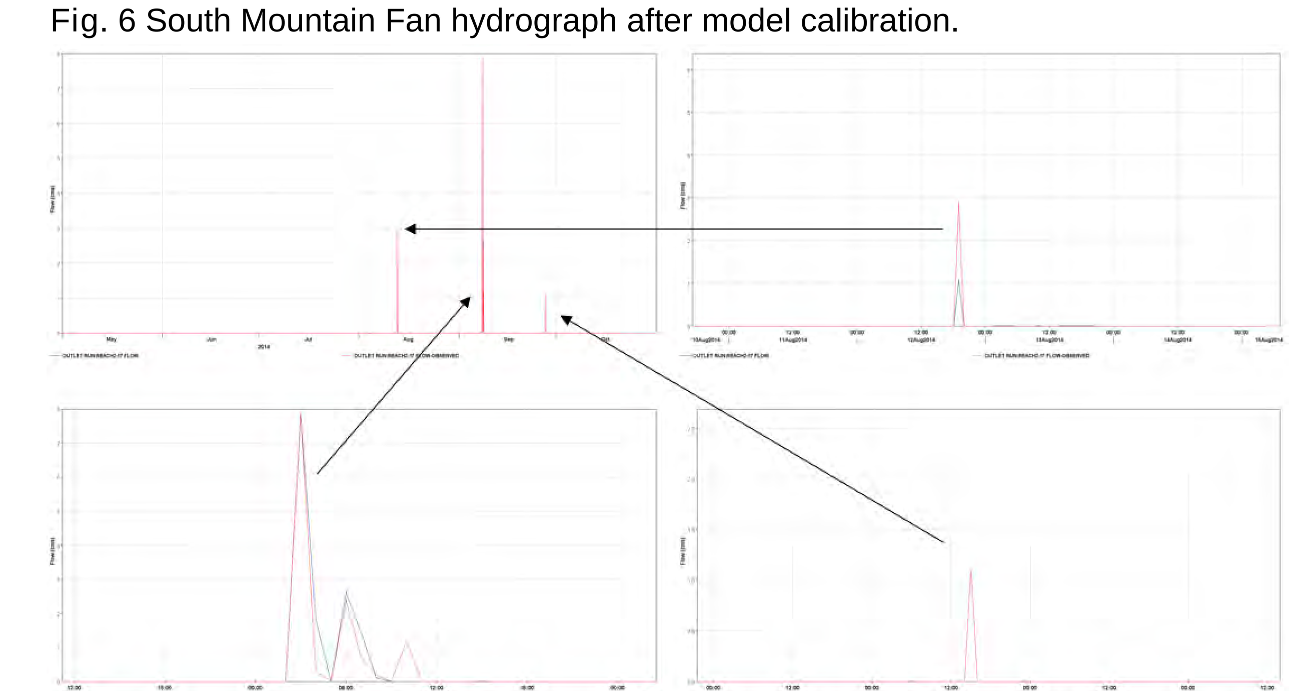

Fig. 7 Pima Canyon Wash hydrograph after model calibration.

Discussion

- With the calibrated parameters for the two basins in which observed data is available, the same parameters can be applied to the remaining basins throughout South Mountain.
- Parameter calibration established that although basin parameters contribute to the generated runoff, the channel losses are the main contributor to the observed simulation results.
- The Nash-Sutcliffe method emphasizes model performance at large peaks at the expense of smaller peaks. This can be observed in **Fig. 6** and **Fig. 7** for all three rainfall events.
- Additional analyses such as averaging parameters, switching parameters, and a higher temporal resolution, were performed to test the calibrated parameters. Results indicate that an average basin parameter can be applied throughout South Mountain, but channel losses will need to be further investigated to do so.
- A higher 15-minute temporal resolution was used to test the robustness of the calibrated parameters. Results didn't demonstrate any improvement in model performance when compared to the original 1-hour time period.

Future Work

- Apply calibrated parameters to the remaining delineated basins throughout the South Mountain region.
- Apply urban development scenario to the parameters.
- Expand on ecological applications for mitigating stormflow through the basin channels and apply to the basin channels in the simulations. This can be emphasized in basins that pose a greater threat to downstream urban growth.

Acknowledgement

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