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Comparison of AHYMO and HEC-HMS for Runoff Modeling in New Mexico Urban Watersheds

Gerhard Schoener

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Comparison of AHYMO and HEC-HMS for Runoff Modeling in New Mexico Urban Watersheds

by

Gerhard Schoener

Committee

Dr. Julie Coonrod, Chair

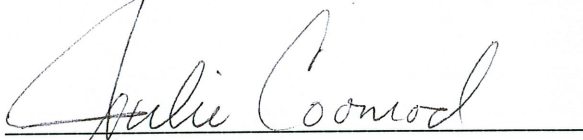
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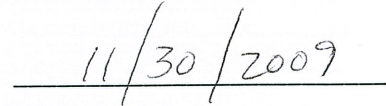
**A Professional Project Report Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Water Resources
Hydroscience Concentration
Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
May, 2010**

Committee Approval

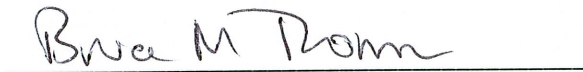
The Master of Water Resources Professional Project Report of Gerhard Schoener, entitled *Arid Lands Hydrologic Model (AHYMO) and Hydrologic Modeling System (HMS): A Case Study Comparing Results from two Rainfall-Runoff Models for a Small Urban Watershed in Central New Mexico*, is approved by the committee:



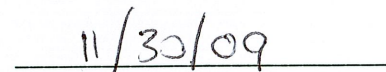
Chair - Dr. Julie Coonrod



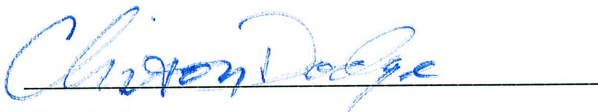
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Dr. Bruce Thomson



Date



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Date

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Abstract

In the Albuquerque/Rio Rancho area in central New Mexico, the Arid-Lands Hydrologic Model (AHYMO) has been used for more than a decade by land developers, municipalities and flood control agencies to simulate the effect of urban development on storm water runoff. An effort is underway to switch from the proprietary AHYMO program to the public domain model HEC-HMS. The majority of watersheds in the greater Albuquerque area are un-gauged, but more than ten years of experience show that AHYMO produces reliable results for the region. New guidelines that exist for the use of HEC-HMS were therefore developed to closely match AHYMO results. This paper presents a case study comparing AHYMO and HEC-HMS results for a small urban watershed in central New Mexico, testing specifically the influence of sub-basin size, impervious surfaces and modeling time steps on differences in model results. The methodologies used in AHYMO and HEC-HMS were based on the above mentioned guidelines.

Out of twelve model scenarios created as part of this study, six resulted in significant differences between AHYMO and HEC-HMS peak flow rates computed for individual sub-basins. Sub-basin size appears to play an important role in explaining those differences. Four out of six model runs with small sub-basins (between five and 30 acres) yielded significantly different results, compared to only two out of six runs with larger sub-basins (between 60 and 75 acres). In addition to sub-basin size, imperviousness appears to influence differences between AHYMO and HEC-HMS. For all sub-basin sizes modeled in this study, HEC-HMS peak flow rates were significantly higher for scenarios with low imperviousness. Scenarios with high imperviousness and small sub-basins resulted in significantly higher AHYMO peak flows. Differences between the two models can be reduced by adjusting the storage coefficient R in HEC-HMS.

1. Introduction

Arroyos are water-carved channels or gullies in arid regions (Morris, 1992); they are by far the most common type of watercourse in central New Mexico. Dry during most of the year, arroyos convey large volumes of water for brief periods after heavy rainfall events. The photographs below show the difference between a typical arroyo in Rio Rancho, New Mexico, during dry conditions (Figure 1) and during a flash flood caused by heavy rainfall (Figure 2).



Figure 1: Dry conditions in the Lomitas Negras Arroyo east of Saratoga Road in Rio Rancho, New Mexico. The Sandia Mountains can be seen in the background.



Figure 2: The Lomitas Negras Arroyo after a storm event in 2006. Picture courtesy of SSCAFCA.

Flash floods and their danger for citizens and infrastructure are a particular concern in rapidly growing urban areas such as Albuquerque and Rio Rancho. It is therefore important for planners, developers, local and regional government entities to understand and quantify the relationship between rainfall and runoff.

2. Background

The methodologies currently used to quantify rainfall-runoff relationships by local New Mexico entities such as the Albuquerque Metropolitan Area Flood Control Authority (AMAFCA), the Cities of Albuquerque and Rio Rancho, and the Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA), are outlined in Section 22.2, Hydrology, of the Development Process Manual (CABQ, 1997 and SSCAFCA, 2009). According to the DPM, a simplified procedure based on the empirical Rational Method can be used for smaller watersheds up to 40 acres in size. For larger watersheds, a unit hydrograph procedure is used to calculate runoff volumes and peak flow rates.

In the Albuquerque/Rio Rancho area, the unit hydrograph procedure has been implemented using the Arid Lands Hydrologic Model AHYMO (Anderson, 1997) for more than a decade. AHYMO is based on HYMO (Hydrologic Model), a program developed by the US Department of Agriculture's Agricultural Research Service (Williams and Hann, 1973). It was expanded and modified for New Mexico conditions by Cliff Anderson and AMAFCA (Anderson, 1997). The software was tested using gauged precipitation and streamflow data; Local engineers and hydrologist who have used AHYMO for more than ten years state that the program has so far produced reliable results (personal communications). AHYMO is proprietary software, and it is unclear if the program will be maintained in the future. It was therefore of interest to explore a transition to the Hydrologic Modeling System HEC-HMS (USACE, 2000), a program

developed and maintained at the Hydrologic Engineering Center of the US Army Corps of Engineers.

HEC-HMS is available to anyone free of charge.

Both AHYMO and HEC-HMS allow the user to choose from a number of methodologies to model rainfall-runoff processes. Both models can therefore be used in a variety of geographic areas with distinct physical conditions. The challenge lies in selecting the appropriate methodologies when modeling a particular watershed in order to obtain usable results. Guidelines for the use of AHYMO in the greater Albuquerque area have been established for more than ten years (CABQ, 1997). Until recently, no such guidelines existed for the use of HEC-HMS.

In 2007, SSCAFCA began a process to adopt HEC-HMS as a new hydrologic model. A consulting firm was tasked to evaluate methodologies and input parameters that, if used with HEC-HMS, would yield results similar to those obtained when using AHYMO. The resulting recommendations were incorporated into SSCAFCA's DPM (SSCAFCA, 2009). Two drainage systems – both located in Southern Sandoval County – were used in the conversion process: the Black Arroyo Watershed, which covers nearly ten square miles (24 square kilometers) and the Montoyas Arroyo Watershed, with a total size of 58 square miles (151 square kilometers). Models of that scale are used for regional watershed management plans. Hydrologic models, however, are also used on a much smaller scale by land developers. Development projects in the City of Rio Rancho, for instance, range in size from less than 40 acres (0.2 square kilometers) to about 1300 acres (5.3 square kilometers). No case studies comparing AHYMO and HEC-HMS for smaller, urban drainage systems in the greater Albuquerque area have been published to date.

3. Related Literature

Several published studies examine the effect of sub-basin size on HEC-HMS model results. Cleveland et al. (2009) found no significant impact on computed runoff hydrographs for watersheds in central Texas ranging from twelve to 166 square miles in size. A study conducted by Al-Hamdan (2009) tested the sensitivity of HEC-HMS results to the number of sub-basins for a watershed in Alabama and found that computed peak discharges changed with sub-basin size, while the discharge volumes were not influenced significantly. Edward and Yen (1994) tested the effects of spatial discretization of a hypothetical watershed on simulation results of HEC-1, the predecessor of the HEC-HMS program. They determined that a coarser discretization – i.e. less and larger sub-basins – decreased the model accuracy. Edward and Yen (1994) also found that the magnitude of the discretization effect is influenced by other model input parameters, such as the duration of the rainfall event.

4. Objective

The objective of this study is to compare AHYMO and HEC-HMS results for a small, urban watershed in central New Mexico, testing specifically the influence of sub-basin size, impervious surfaces and modeling time steps on differences in model results.

Furthermore, this project will assist engineers and hydrologists in the greater Albuquerque area who face the challenge of using a new hydrologic model to be aware of differences between AHYMO and HEC-HMS.

5. Study Area – The Unnamed Arroyo Watershed

The study area is a small urban watershed of approximately 270 acres (1.1 square kilometers), located partially in the City of Rio Rancho and the Town of Bernalillo (Figure 3).

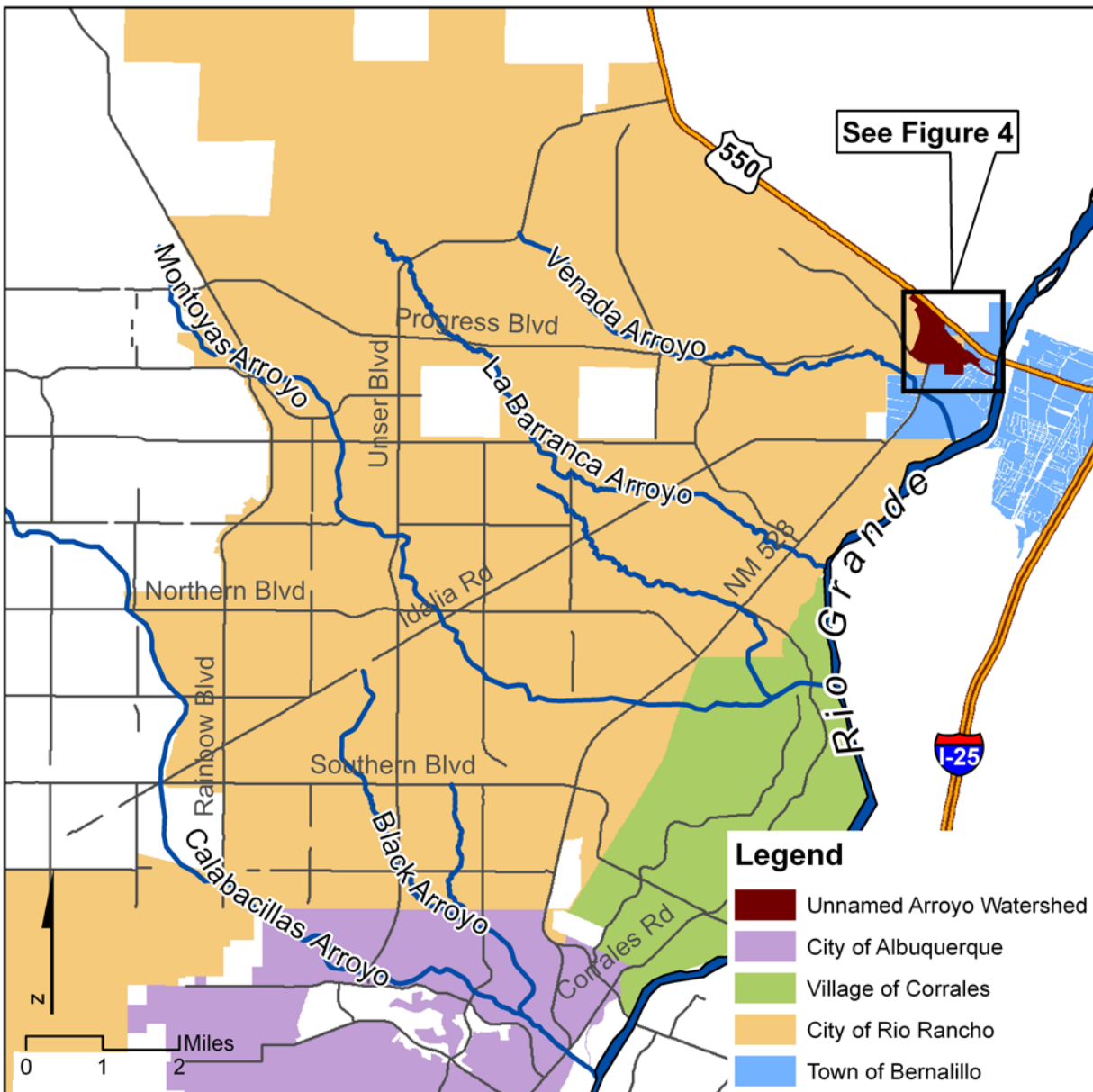


Figure 3: Vicinity map showing major arroyos in the Rio Rancho area. The Unnamed Arroyo Watershed is indicated in red.

Historically, the drainage basin of the Unnamed Arroyo as well as the arroyo itself extended further to the northwest. The Encantado Channel, built in conjunction with the Enchanted Hills Subdivision, now diverts flows to the neighboring Venada Arroyo and thereby acts as an upper boundary for the Unnamed Arroyo Watershed (Figure 4).

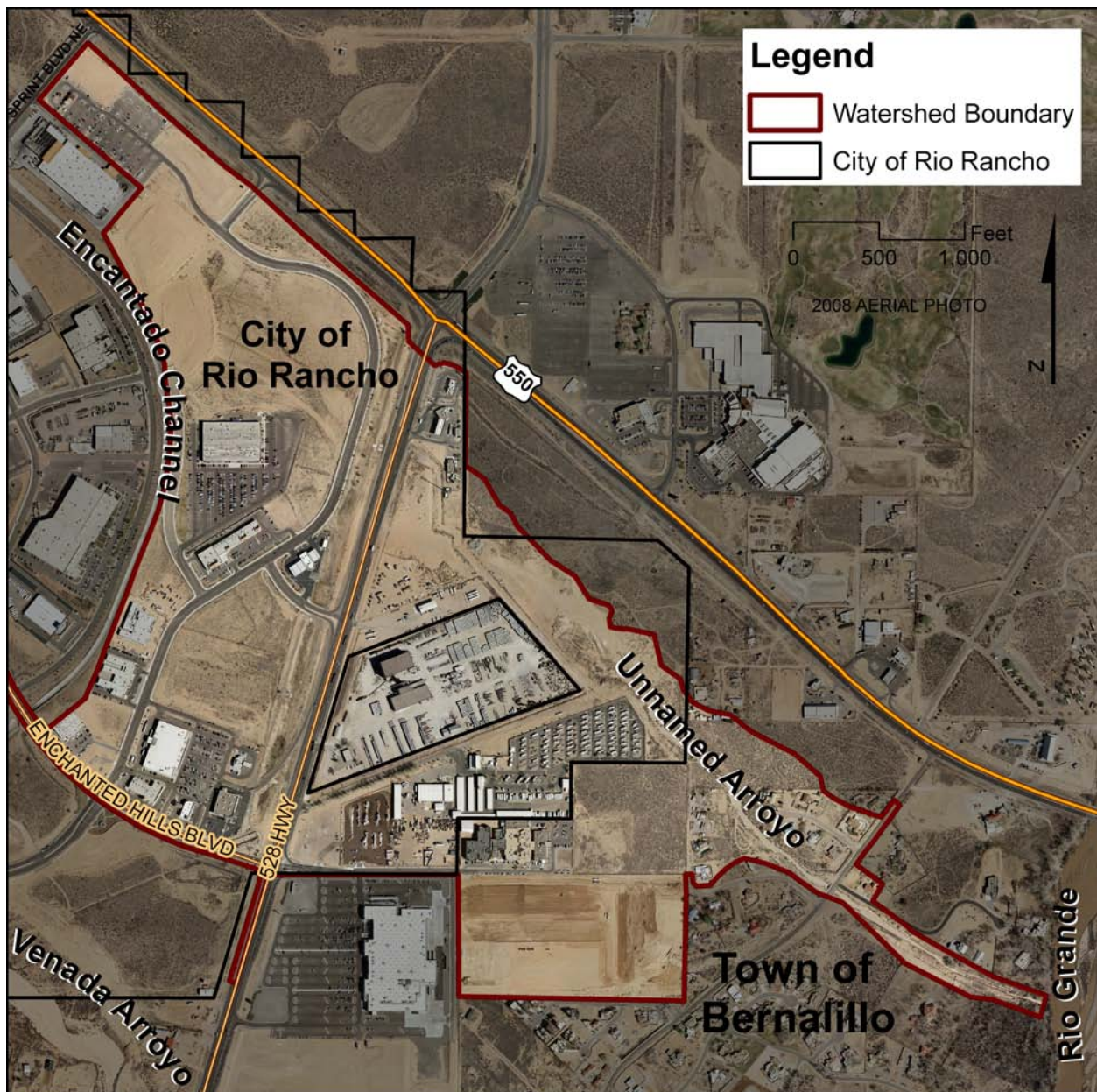


Figure 4: Overview map of the Unnamed Arroyo watershed, located near the intersection of US 550 and NM 528. The upper reach of the watershed is within the City of Rio Rancho, the lower reach in the Town of Bernalillo.

The upper reach of the original Unnamed Arroyo, west of New Mexico State Road 528 (NM 528), was subsequently filled in. Only the lower reach of the arroyo, located east of NM 528, is still visible in the aerial photograph (Figure 4).

The entire watershed area has been platted, and approximately 60 percent of the area is currently developed. The watershed – although small in size – contains a large number of different drainage facilities such as storm drains, retention ponds, crossing structures, as well as natural and constructed channels. Land uses range from commercial, industrial and residential development to undisturbed open space. These small-scale differences lead to complex local drainage pathways.

Several AHYMO models dating from the years 2000 to 2008 exist for developed portions of the watershed (see Appendix A for a list of reports). Prior to this study, no comprehensive model existed for the entire watershed.

6. Methods

6.1 Physical Hydrology

A topographic map of the Unnamed Arroyo watershed (Figure 4) was created using ESRI software (ArcGIS 9.3). Two foot elevation contours and aerial photographs of the area flown in January of 2009 were used as base layers of the map. Other relevant geographic information such as roadways, jurisdictional boundaries and parcel information was obtained from the Sandoval County GIS department (Sandoval County GIS website, 2008) and SSCAFCA. The topographic map served as the basis for delineating watershed and sub-basin boundaries, as well as obtaining slopes and distances used in hydrologic calculations. The extent of development and land use types were estimated from aerial photographs and available zoning information.

Location and physical parameters of existing drainage facilities such as retention ponds and storm drain pipes were obtained from previously completed drainage reports and by field investigation. A list of existing drainage reports is contained in Appendix A.

Unnamed Arroyo Watershed - Hydrology

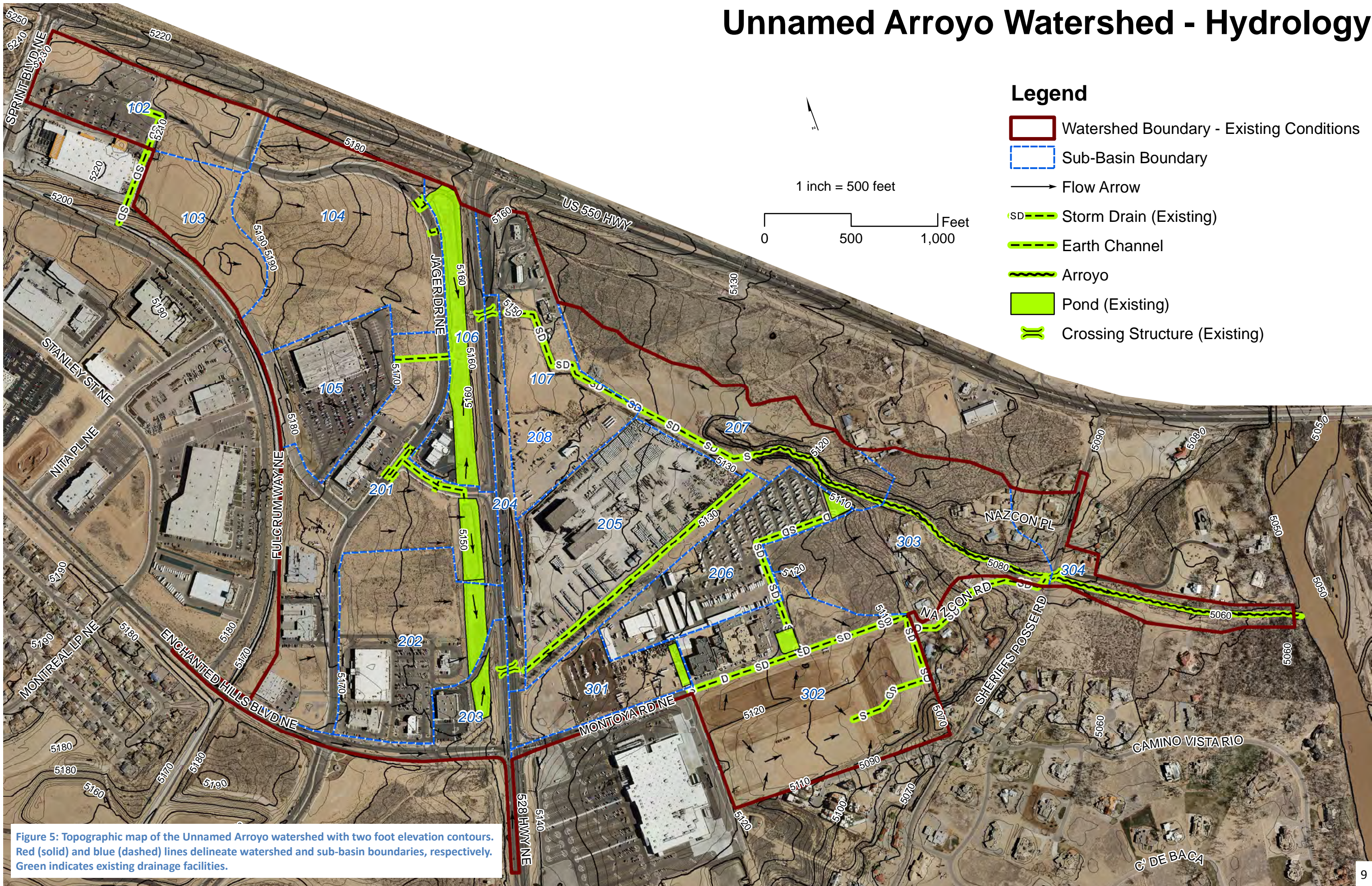


Figure 5: Topographic map of the Unnamed Arroyo watershed with two foot elevation contours. Red (solid) and blue (dashed) lines delineate watershed and sub-basin boundaries, respectively. Green indicates existing drainage facilities.

6.2 Hydrologic Models - Methodologies and Parameters

The first step in creating a hydrologic model is defining rainfall criteria, namely rainfall depth and temporal distribution. Not all of the rain that falls on a given sub-basin, however, results in runoff. Some of the precipitation is retained on the surface, some infiltrates into the soil. The remaining so called *excess precipitation* runs off on the surface. A transform procedure that takes into account the physical characteristics of the sub-basin is used to convert excess precipitation to a runoff hydrograph at the sub-basin outlet. According to the DPM, a unit hydrograph procedure is to be used as transform method. A unit hydrograph is a dimensionless hydrograph that results from one unit (e.g. one inch) of excess precipitation. The shape of a unit hydrograph depends on characteristics of the drainage area and of the rainfall event. When scaled by the excess rainfall depth, the unit hydrograph can be used to calculate a runoff hydrograph (Nix, 1994). A hydrologic or hydraulic routing method is used to simulate the downstream movement of the flood wave (hydrograph) through arroyos, channels and reservoirs. The routing accounts for the time lag of a flow peak due to the travel time and attenuation of the peak as a result of the storage capacity of channels and reservoirs.

Table 1 summarizes the methodologies used in AHYMO and HEC-HMS to simulate rainfall and rainfall loss, as well as the procedures used to transform excess precipitation into a runoff hydrograph and route the hydrograph downstream. Details about each procedure are contained in sections 6.2.1 through 6.2.4 below.

Table 1: Overview of similarities and differences between methodologies used in AHYMO and HEC-HMS.

Methodology	AHYMO	HEC-HMS
Rainfall	100 year, 24 hour design storm	
Rainfall Loss	Initial abstraction, uniform infiltration	Initial & constant method
Transform – Unit Hydrograph	Split hydrograph procedure	Clark unit hydrograph
Routing	Muskingum-Cunge method	

6.2.1 Rainfall

The DPM (SSCAFCA, 2009) defines a design storm with a 100 year recurrence interval and 24 hour duration for use in hydrologic models. Point rainfall depths are based on the NOAA 14 atlas (NOAA Atlas 14, 2009). Since the watershed in question is significantly smaller than five square miles, no reduction factor has to be applied to the point rainfall depths. Figure 6 shows a plot of cumulative rainfall of the hypothetical storm.

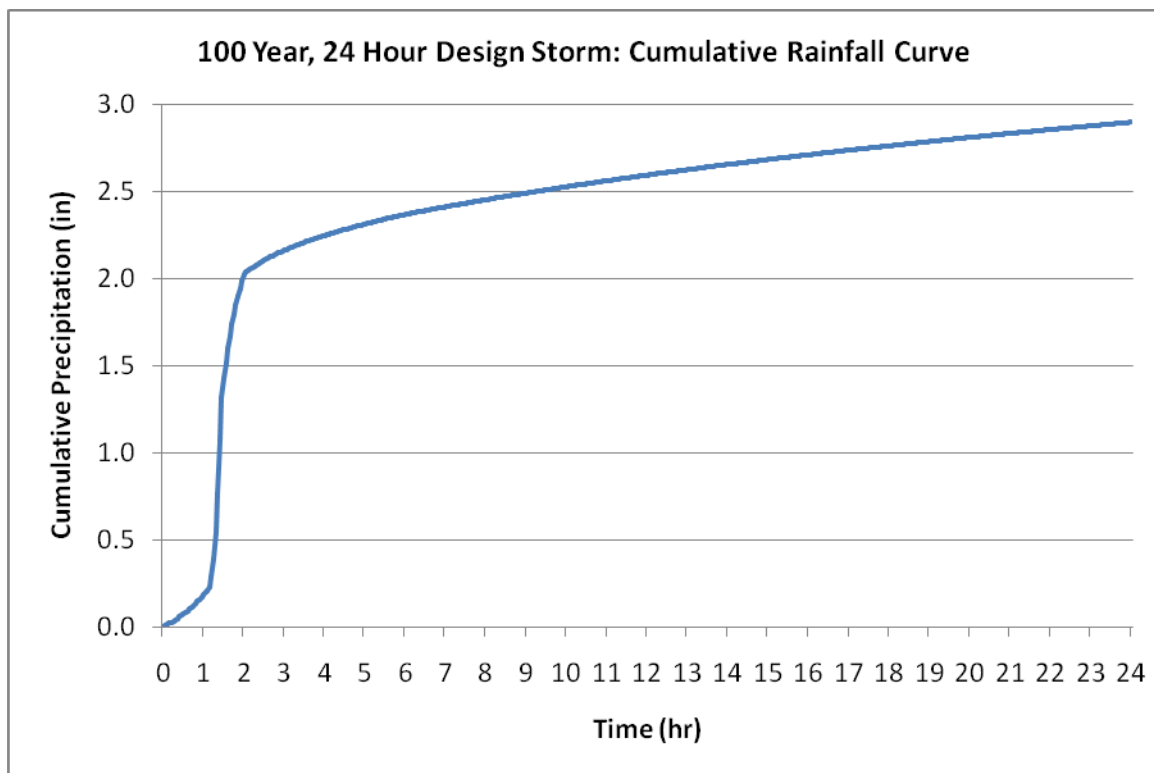


Figure 6: Cumulative rainfall curve for the 100 year, 24 hour design storm. The bulk of the precipitation falls within the first two hours of the event.

Over a 24 hour period, the hypothetical storm produces 2.9 inches of precipitation. The majority of the rain, approximately two inches, falls within the first two hours of the storm. The design storm data, which can be entered identically in AHYMO and HEC-HMS, was used in all model runs of this project.

6.2.2 Rainfall Loss

In AHYMO, the calculation of rainfall loss has two components: initial abstraction and uniform infiltration. Initial abstraction accounts for losses due to evaporation, interception and depression storage. Depending on the land treatment type, values for initial abstraction range from 0.10 to 0.65 inches for the Rio Rancho area. Infiltration rates range from 0.04 inches per hour for pavement and roof areas to 1.67 inches per hour for undisturbed open space. According to SSCAFCA's DMP, the AHYMO loss method is simulated in HEC-HMS using the *Initial and Constant Loss Method*.

Although the methods are very similar, there is one difference: in AHYMO, impervious areas are assigned an initial abstraction of 0.1 inches. The infiltration rate is 0.04 inches per hour for the first three hours, and then decreases linearly to zero at hour six of the storm. The *Initial and Constant* method in HEC-HMS assumes that impervious areas are absolutely impervious and have no associated initial abstraction or infiltration.

6.2.3 Transform – Unit Hydrograph

AHYMO uses a split hydrograph procedure to transform excess precipitation from a sub-basin to a runoff hydrograph at the basin outlet. A separate hydrograph is computed for pervious and impervious portions of each sub-basin. The two hydrographs are added to compute the sub-basin hydrograph (CABQ, 1997). The split hydrograph procedure is unique to the AHYMO program. No comparable methodology exists in HEC-HMS.

When tasked by SSCAFCA in 2007 to find a solution to this problem, Stantec Consulting Inc. (Gerlach, 2008) found that out of all methods available in HEC-HMS, the Clark unit hydrograph (USACE, 2000 and Sabol, 1988) produces the most similar results when compared to the AHYMO procedure. The shape of both the AHYMO and the Clark unit hydrographs are determined by two input parameters: time of

concentration, and a second parameter that is called recession constant k in AHYMO and storage coefficient R in HEC-HMS.

The time of concentration is defined as “the time it takes for runoff to travel from the hydraulically most distant part of the basin to the basin outlet” (CABQ, 1997). The time of concentration for each sub-basin is calculated in accordance with SSCAFCA’s DPM (SSCAFCA, 2009). Three distinct methods are used depending on the length of the sub-basin flow path. Identical values for the time of concentration are used in AHYMO and HEC-HMS.

The recession constant k in AHYMO depends on the values of initial abstraction, infiltration, impervious surface as well as size of the corresponding sub-basin. Different equations are used for sub-basins that are either smaller than 40 acres or larger than 200 acres. For sub-basins between 40 and 200 acres, a linear interpolation is used to calculate k (CABQ, 1997). Since AHYMO uses a split hydrograph procedure, the recession constant is calculated separately for pervious and impervious areas of each sub-basin. All calculations of k in AHYMO are performed internally by the program, requiring the user to input only the sub-basin area and the percentage for each of four land treatment types. Each land treatment type is assigned specific initial abstraction and infiltration rates.

The storage coefficient R required for the Clark method in HEC-HMS describes the effect that temporary storage in the watershed has on the hydrograph. In his technical paper, Gerlach (2008) developed an empirical relationship between storage coefficient R , time of concentration (T_c), infiltration rate (INF), initial abstraction (IA), and the percentage of impervious area (D) of a sub-basin:

$$R = 1.165 * T_c \left(INF^{0.45} - IA^{1.4} \left(\frac{D}{100} \right)^{0.4} \right)$$
Equation 1

Equation 1 was developed to calibrate the Clark method to runoff hydrographs computed by AHYMO's split hydrograph procedure. According to Gerlach (2008), the form of equation 1 is based on equations used to calculate the recession constant k in AHYMO. The coefficients and exponents were determined by regression analysis using more than nineteen million different combinations of hypothetical basin sizes, slopes, roughness coefficients and land treatment types. Sub-basin sizes used in the analysis ranged from 0.2 to ten square miles, smaller sub-basins were not considered.

6.2.4 Hydrologic Routing

The Muskingum-Cunge method, which was used for channel routing both in AHYMO and HEC-HMS, is a finite difference model that approximates the true movement of a hydrograph through a channel reach. The AHYMO user manual lists as one of the advantages of the Muskingum-Cunge methods that "the solution is independent of the user specified computation interval" (Anderson, 1997). Gerlach (2008), however, found that in AHYMO, results of the Muskingum-Cunge method vary depending on the computation interval or time step. If the AHYMO user "specifies a routing time step that is too long, numerical instabilities may result. AHYMO forces a stable solution that results in artificially long floodwave travel times" (Gerlach, 2008). This problem does not occur in HEC-HMS, and it can be avoided in AHYMO if small time steps (one minute or less) are selected. Gerlach's paper discusses the influence of routing inconsistencies on large watersheds with long routing reaches. The potential influence for small watersheds was tested in this study.

Reservoir routing in both AHYMO and HEC-HMS was accomplished by using stage-storage-discharge tables that define the relationship between inflow and outflow for each detention facility.

6.2.5 Model Scenarios

The following section describes different model scenarios that were developed to test the influence of sub-basin size, extent of impervious surfaces and modeling time steps on differences between AHYMO and HEC-HMS results.

6.2.6 Sub-Basin Scenarios

Based on the topography, the watershed was divided into several smaller sub-basins. Two different scenarios were considered. In the first scenario, the watershed was divided into 17 sub-basins, with an average size of approximately 16 acres (Figure 7).

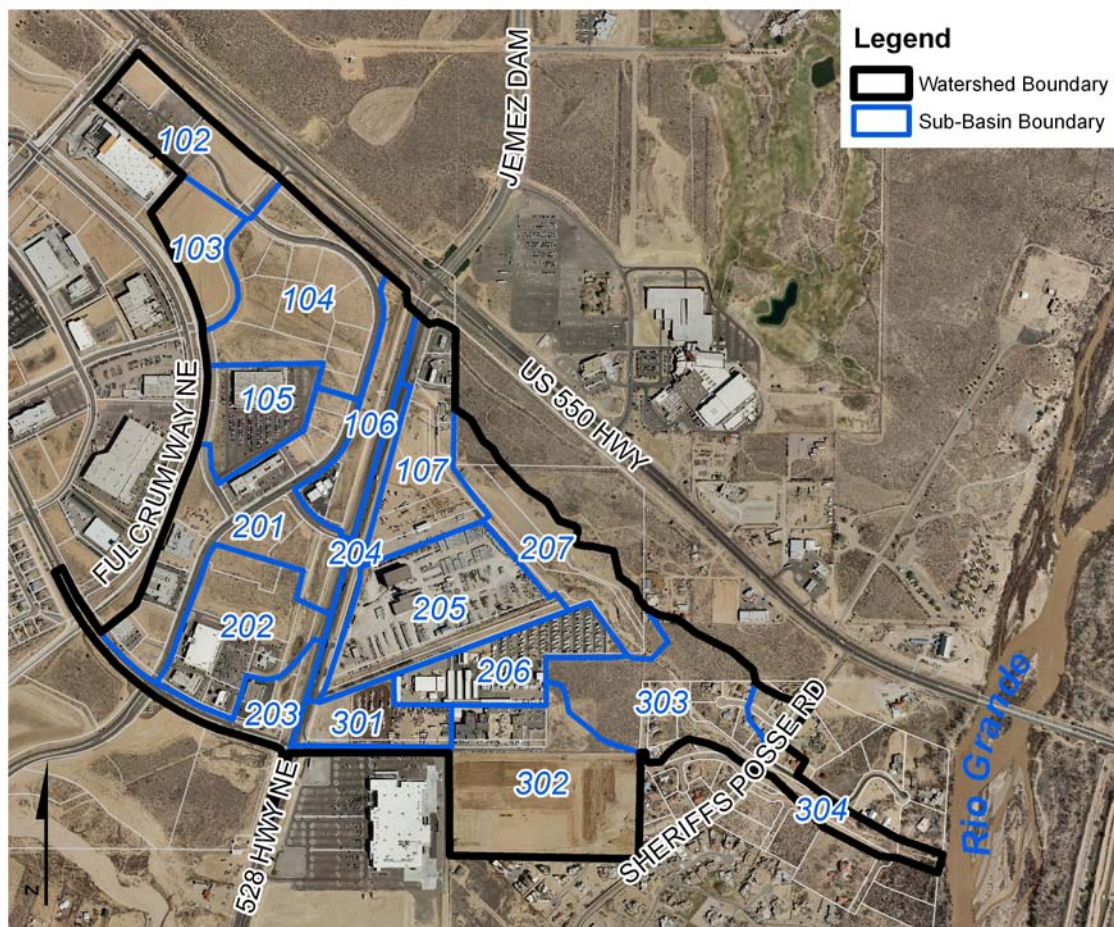


Figure 7: Model scenario with 17 sub-basins.

The second scenario had only four sub-basins, measuring on average 68 acres each (Figure 8).

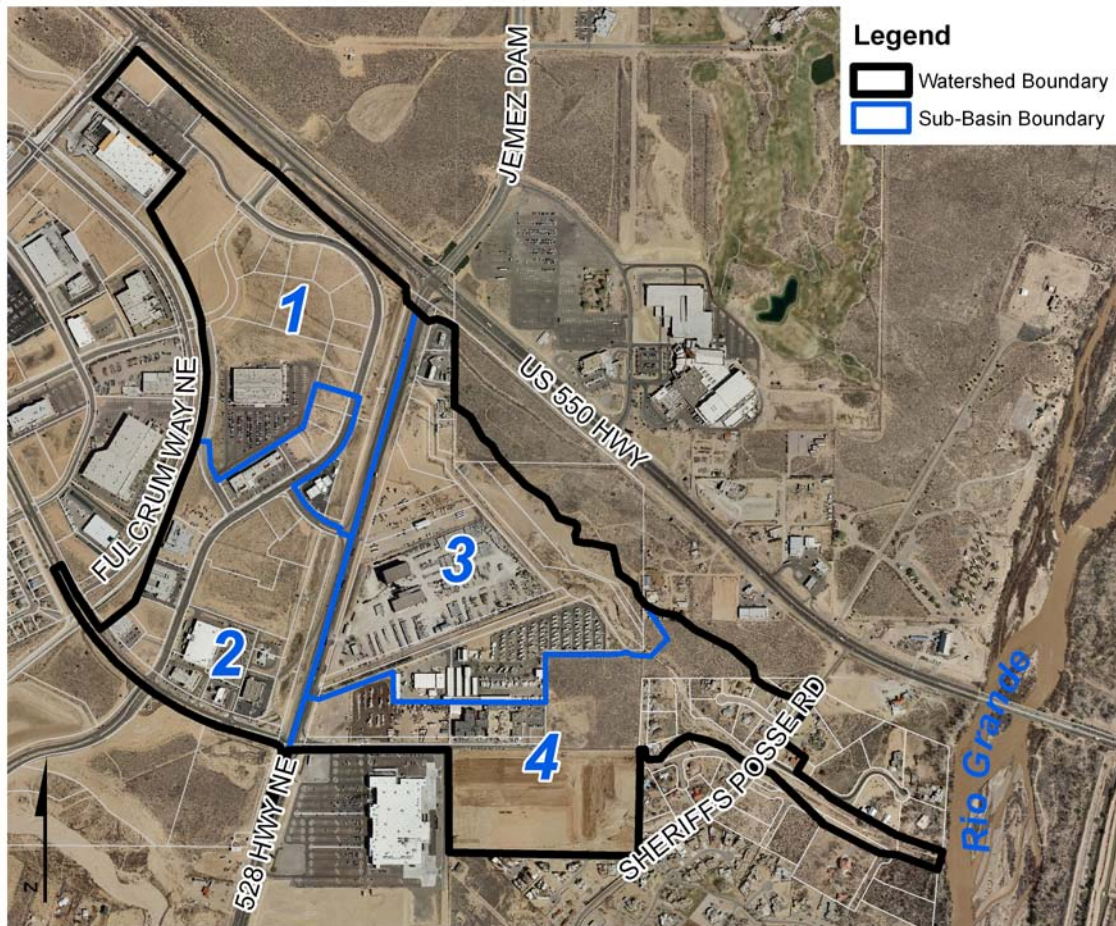


Figure 8: Model scenario with four sub-basins.

6.2.7 Development Scenarios

For each of the two sub-basin models, three development scenarios were created so as to evaluate the effects of impervious surfaces on model results. The EXISTING development conditions scenario (Figure 9) is based on the extent of current urban development.

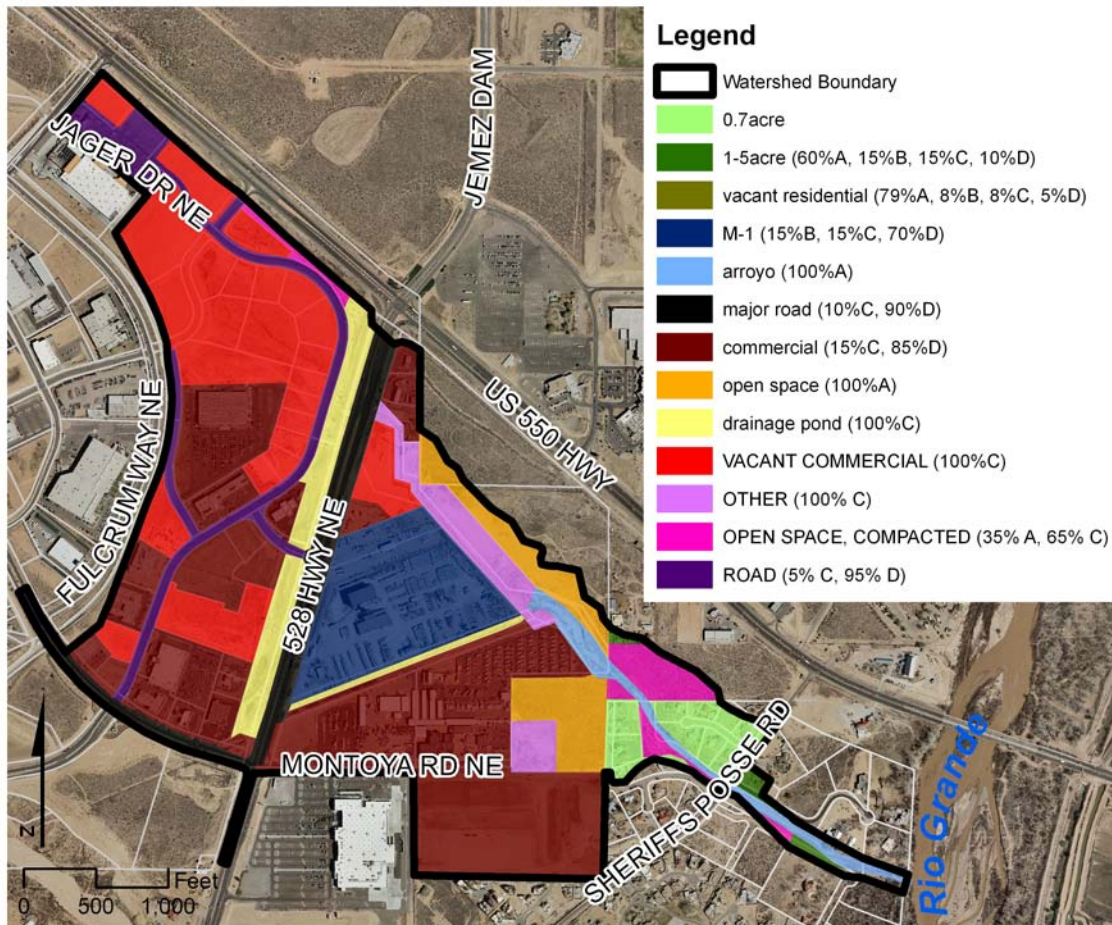


Figure 9: Model scenario for existing development conditions (EXISTING) with approximately 50 percent impervious surface over the entire watershed.

The hypothetical LOW impact development scenario (Figure 10) assumes a platted watershed of vacant lots with five percent impervious surfaces.

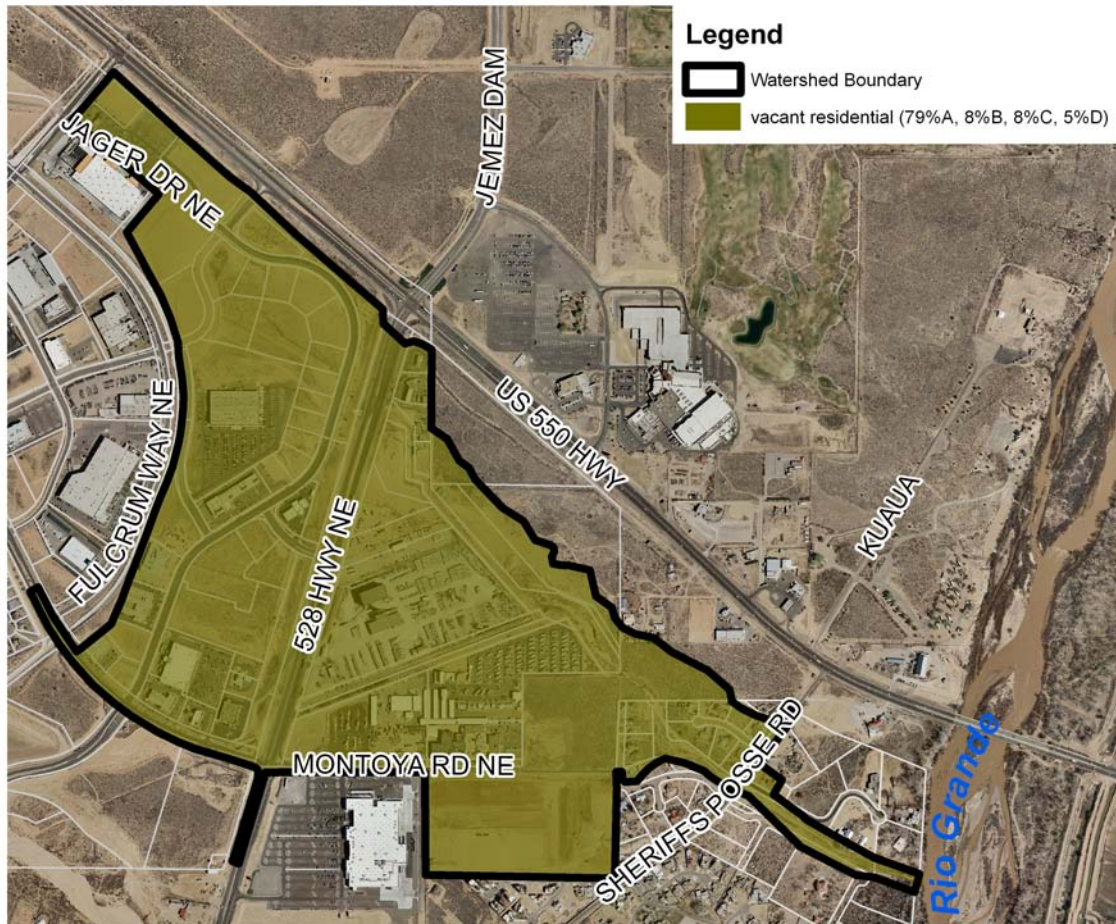


Figure 10: Hypothetical low impact development scenario (LOW), with five percent impervious surface.

The hypothetical HIGH impact development scenario (Figure 11) assumes commercial development everywhere with 85 percent impervious surfaces.

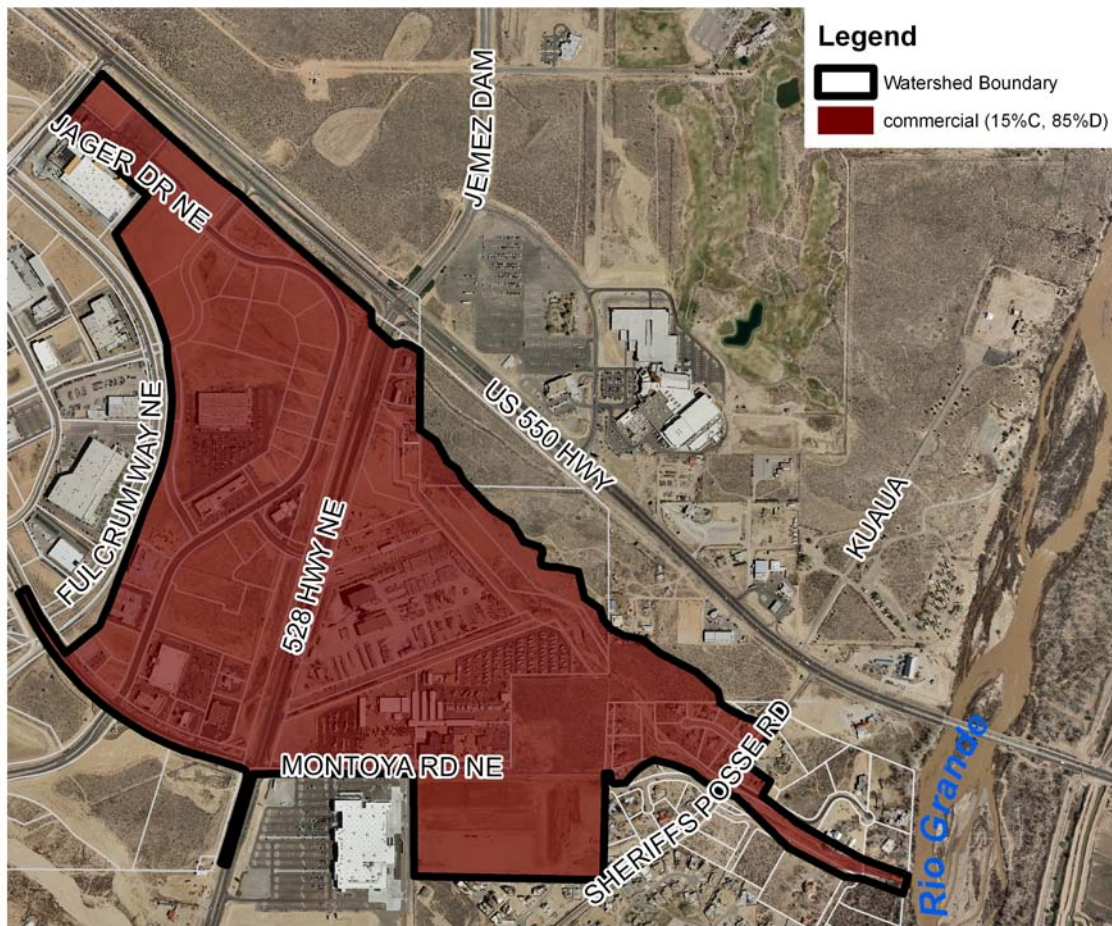


Figure 11: Hypothetical high impact development scenario (HIGH), with 85 percent impervious surface.

6.2.8 Evaluation of Results

Differences between AHYMO and HEC-HMS model runs were evaluated by comparing results at selected analysis points. The comparison of model results was performed on two levels: runoff hydrographs were compared visually to assess differences in hydrograph shape and timing; peak flow rates were analyzed for statistically significant differences.

Sub-basin peak flow rates computed by HEC-HMS in this study are not independent from AHYMO results. The statistical analysis was therefore based on samples of differences between AHYMO and HEC-HMS results. Since some of the samples of differences showed non-normal, skewed distributions, the non-parametric sign test (Samuels and Witmer, 1999) and confidence interval was used to test, on a five percent level, which differences were significant. The sign test uses the population median as the basis for the analysis, in contrast to the standard t-test, which uses the population mean. The median provides a better measure of the center of a skewed population. In a symmetrically distributed population, the population mean and median are identical, and the sign test would yield results identical to the t-test.

All statistical analyses were performed using the statistical package Minitab (version 15).

7. Results

7.1 Comparison of Sub-Basin Peak Flow Rates

Figure 12 compares AHYMO and HEC-HMS peak flow rates for individual sub-basins for all model scenarios with 17 sub-basins.

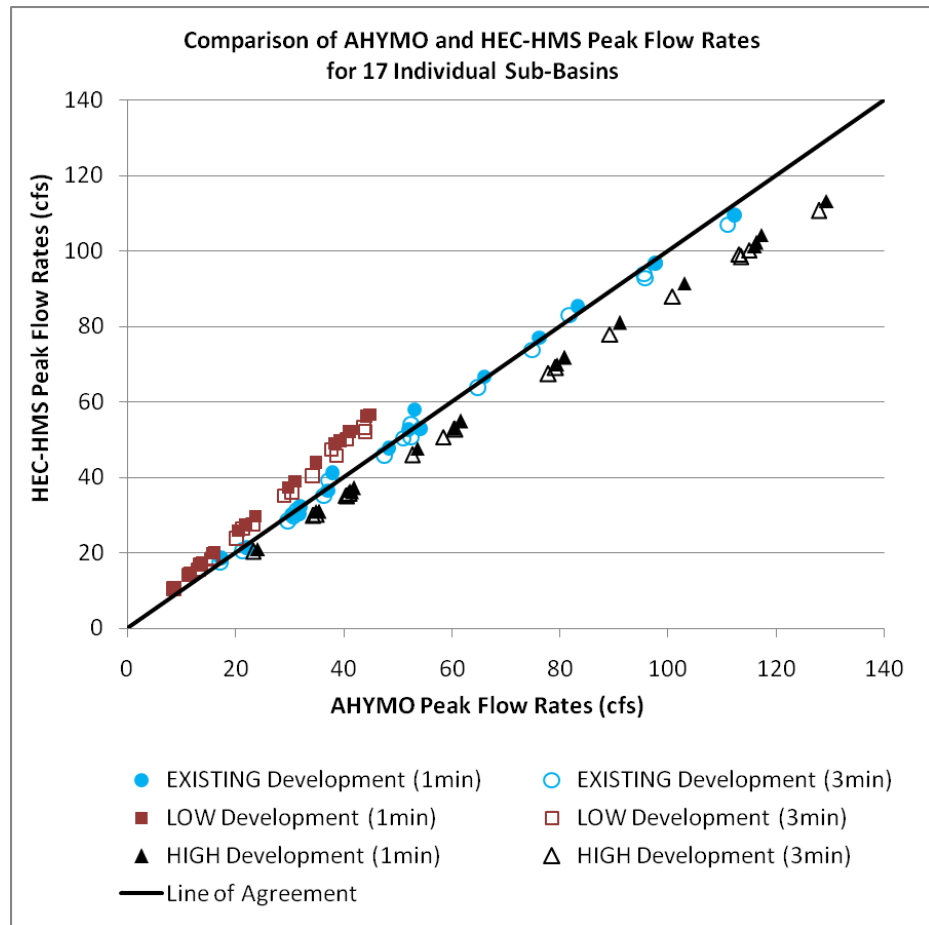


Figure 12: Comparison of AHYMO and HEC-HMS sub-basin peak flow rates for all model scenarios with 17 sub-basins. Data points located above the line of agreement indicate that HEC-HMS yielded higher results for the corresponding sub-basin; AHYMO results were higher for points below the line of agreement.

The graph shows that results from the LOW and HIGH development scenarios (red squares and black triangles, respectively) diverge from the line of agreement. The LOW scenario resulted in higher HEC-

HMS peak flow rates, the HIGH development scenario on the other hand led to higher AHYMO peak flow rates. Model scenarios with four sub-basins (Figure 13) show similar results for the LOW and EXISTING development scenarios. The HIGH scenario peak flow rates are close to the line of agreement.

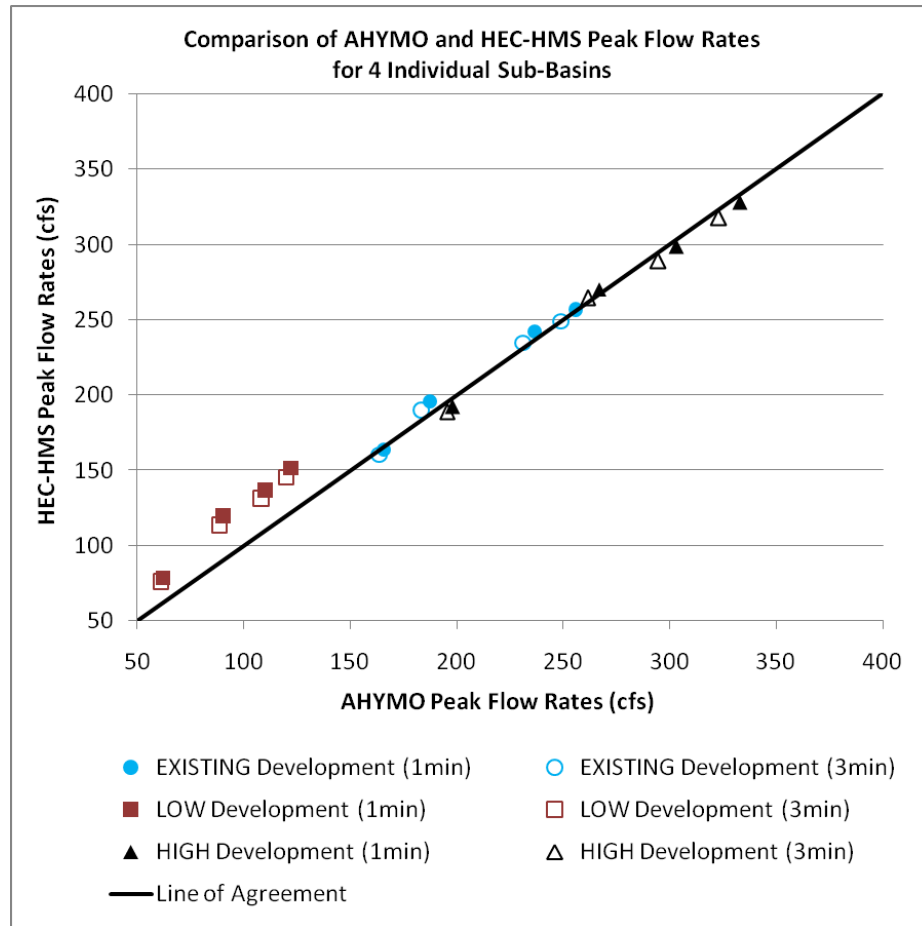


Figure 13: Comparison of AHYMO and HEC-HMS sub-basin peak flow rates for all model scenarios with four sub-basins.

One-sample sign tests (see section 6.2.8) were used to determine which of the observed divergences were statistically significant. The hypothesis that the differences between AHYMO and HEC-HMS sub-basin peak flow rates for each of the twelve scenarios are zero were tested on a five percent level. The non-parametric sign test, which provides inferences about the population median, was used for all analyses.

Analysis results are summarized in Table 2. Model scenarios that yielded significantly different sub-basin peak flow rates are highlighted in color. Orange indicates scenarios with higher HEC-HMS peak flow rates, blue highlights cases with higher AHYMO peak flows. Median differences as well as the 95 percent confidence interval for the median are reported in columns five and six of Table 2. The median is defined as the half-way point between the two middle values of a data set (Samuels and Witmer, 1999). The median is therefore a measure of central location. In this case, the data set consists of the differences between AHYMO and HEC-HMS peak flow rates for each sub-basin. ‘Median Difference’ in column five of Table 2 therefore refers to the median difference between AHYMO and HEC-HMS sub-basin peak flows. Blank cells in columns five and six indicate agreement or insignificant differences between AHYMO and HEC-HMS results.

Table 2: Sign test results for median differences between AHYMO and HEC-HMS sub-basin peak flows for all model scenarios. Model scenarios that resulted in statistically significant differences are highlighted.

Time Step	Sub-Basin Scenario	Development Scenario	Results	Median Difference	95% Confidence Interval
1 Minute	17 Sub-Basins	EXISTING Conditions	HEC-HMS = AHYMO		
		LOW Impact	HEC-HMS > AHYMO	21%	14% to 35%
		HIGH Impact	HEC-HMS < AHYMO	-13%	-21% to -8%
	4 Sub-Basins	EXISTING Conditions	HEC-HMS = AHYMO		
		LOW Impact	HEC-HMS > AHYMO	22%	13% to 23%
		HIGH Impact	HEC-HMS = AHYMO		
3 Minutes	17 Sub-Basins	EXISTING Conditions	HEC-HMS = AHYMO		
		LOW Impact	HEC-HMS > AHYMO	19%	11% to 26%
		HIGH Impact	HEC-HMS < AHYMO	-15%	-24% to -10%
	4 Sub-Basins	EXISTING Conditions	HEC-HMS = AHYMO		
		LOW Impact	HEC-HMS > AHYMO	20%	13% to 21%
		HIGH Impact	HEC-HMS = AHYMO		

Regardless of the time step, HEC-HMS sub-basin peak flows were found to be significantly higher for all LOW impact development scenarios. The HIGH impact scenario yielded significantly lower HEC-HMS results only for the scenario with 17 sub-basins.

7.1.1 Influence of Impervious Surfaces

The results in table 2 show that only scenarios with a low or high percentage of impervious surfaces – five percent for the LOW impact and 85 percent for the HIGH impact scenario – led to significant divergence of HEC-HMS peak flow rates as compared to AHYMO results. Impervious surfaces directly influence rainfall loss calculations and the Clark unit hydrograph in HEC-HMS. The parameters affected are initial abstraction (IA), infiltration rate (INF), and storage coefficient R (see sections 6.2.2 and 6.2.3). A sensitivity analysis was performed to test the sensitivity of HEC-HMS sub-basin peak flow rates to changes in each of the three parameters. The results are displayed in Figure 14.

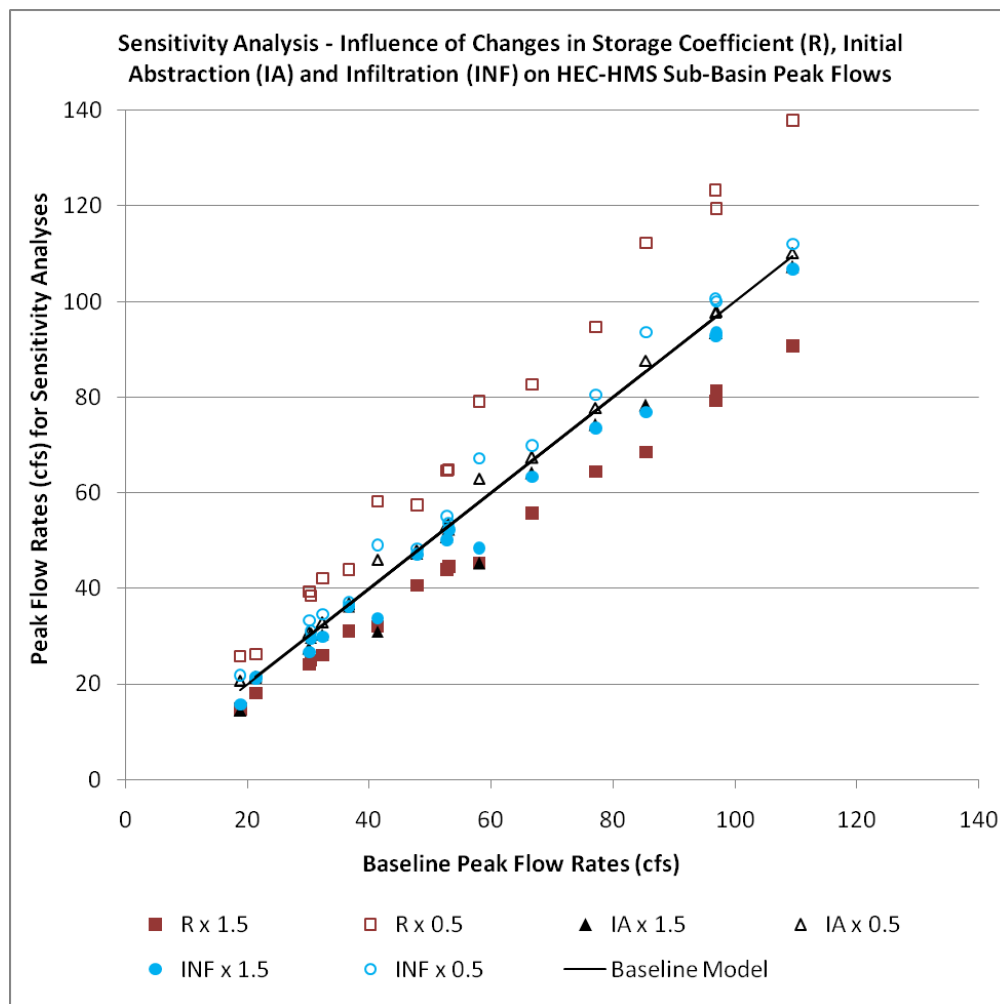


Figure 14: Changes in HEC-HMS sub-basin peak flows resulting from 50 percent increases and decreases of storage coefficient (R), initial abstraction (IA) and infiltration rate (INF).

The EXISTING conditions, 17 sub-basin scenario at a time step of 1 minute was used as the baseline for the analysis (solid black line). Each parameter was increased and decreased by 50 percent, and results were plotted in relationship to the baseline model. The analysis shows that changes in the storage coefficient R (red squares) have a larger impact on sub-basin peak flow rates than comparable changes to the rainfall loss parameters (black triangles and blue circles). In Figure 15, the values of the storage coefficients for all sub-basins were increased by 50 percent for the LOW development scenario and decreased by 40 percent for the HIGH scenario.

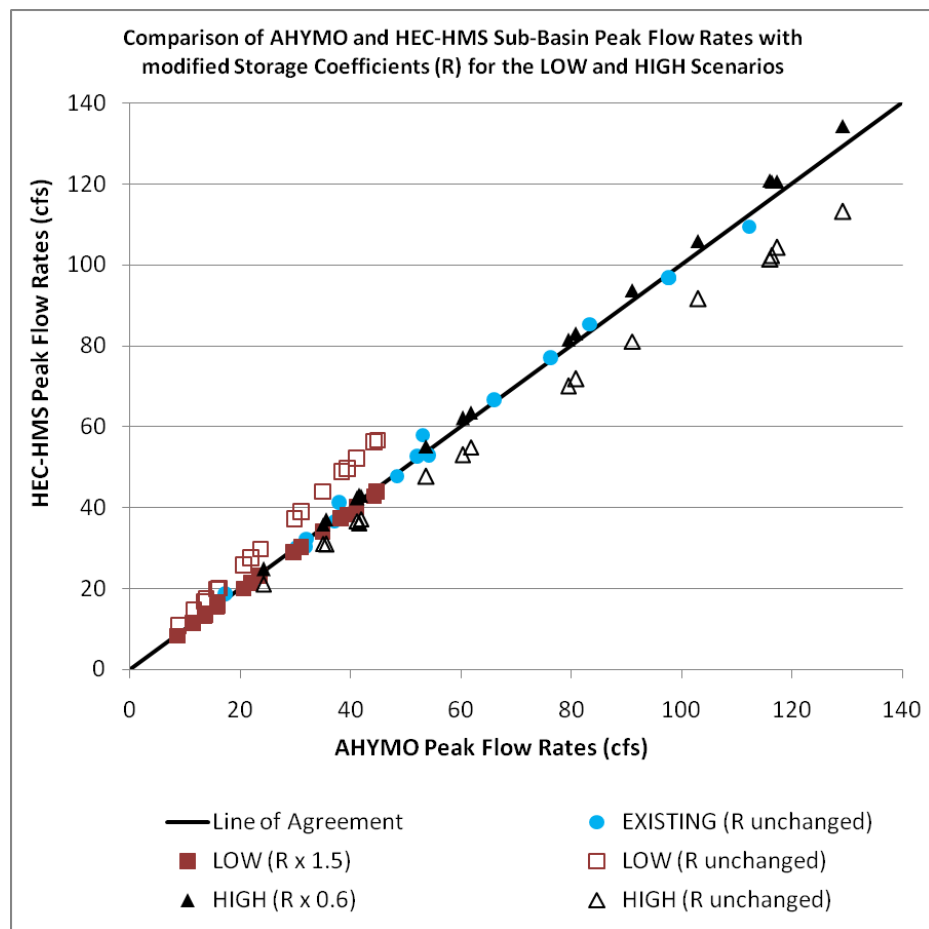


Figure 15: Sub-basin peak flow rates for all development scenarios (EXISTING = blue circles, LOW = red squares, and HIGH = black triangles) with 17 sub-basins at a one minute time step compared to LOW and HIGH scenario results with modified storage coefficient values.

HEC-HMS results from model runs with modified R values are much closer to the line of agreement, and therefore closer to the corresponding AHYMO results.

7.1.2 Influence of Sub-Basin Size

Table 2 reveals that scenarios with larger sub-basins resulted in less significant differences between AHYMO and HEC-HMS results. This suggests that sub-basin size might be an influential model input parameter. To further explore this possibility, differences (in percent) between AHYMO and HEC-HMS sub-basin peak flow rates from three watershed models were plotted against sub-basin size (Figure 16).

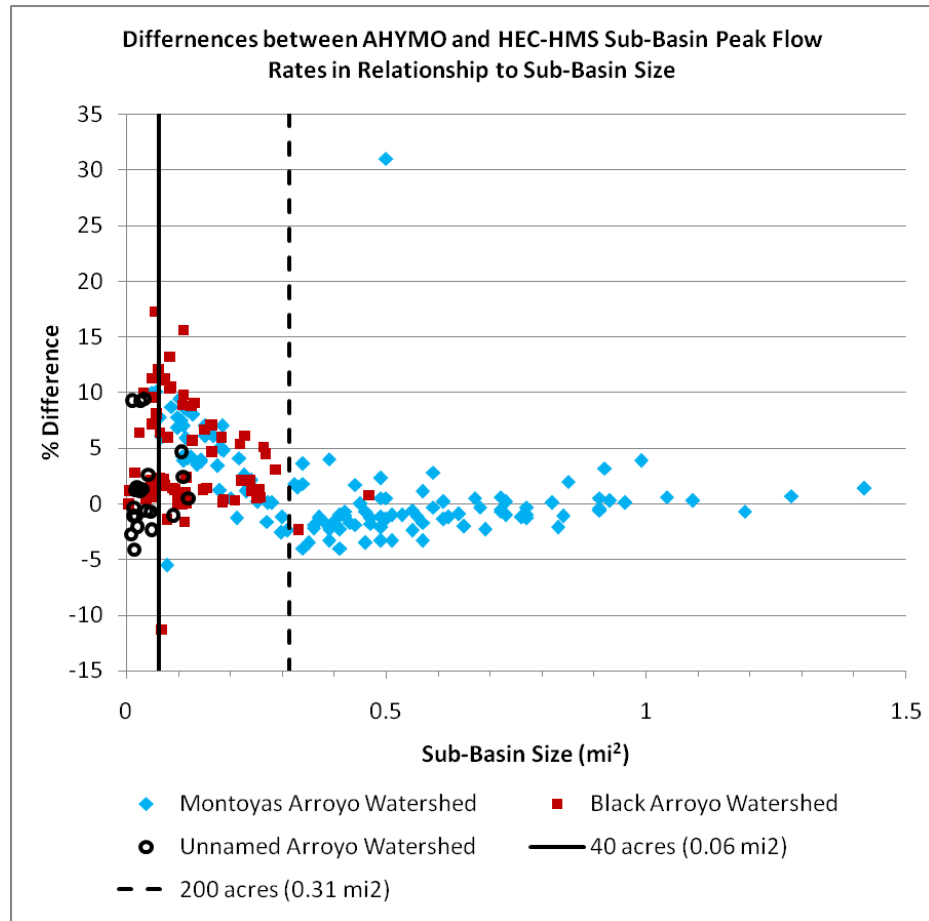


Figure 16: Influence of sub-basin size on differences between AHYMO and HEC-HMS sub-basin peak flow rates for the Montoyas, Black and Unnamed Arroyo watershed models. Only existing conditions results are displayed.

All model results displayed in Figure 16 represent existing drainage and development conditions at the time the models were built. From the Unnamed Arroyo watershed model (black circles), only the EXISTING development conditions results for 4 and 17 sub-basins were used in this comparison. Data for

the Black and Montoyas watersheds (red squares and blue diamonds, respectively) was obtained from the Technical Documentation for the use of HEC-HMS with the DPM (Gerlach 2008). Positive differences indicate higher HEC-HMS peak flows, negative percentages higher AHYMO peak flows.

Figure 16 shows that, on the sub-basin level, the variability of differences (in percent) between AHYMO and HEC-HMS peak flows decreases with increasing sub-basin size. Differences range from zero to slightly more than 15 percent for sub-basins smaller than 200 acres (0.3 square miles). For sub-basins larger than 200 acres (0.3 square miles), differences in peak flow rates range between zero and five percent. The data contains one outlier: one sub-basin in the Montoyas Arroyo watershed model, 320 acres or one half square mile in size, resulted in a HEC- HMS peak flow rate 31 percent higher than the peak flow computed AHYMO.

7.2 Comparison of Peak Flow Rates at Model Junctions

Figure 17 shows a comparison of AHYMO and HEC-HMS peak flows at model junctions for all scenarios with 17 sub-basins. The majority of results show trends similar to those observed for individual sub-basins (Figure 12), with the exception of two groups of outliers.

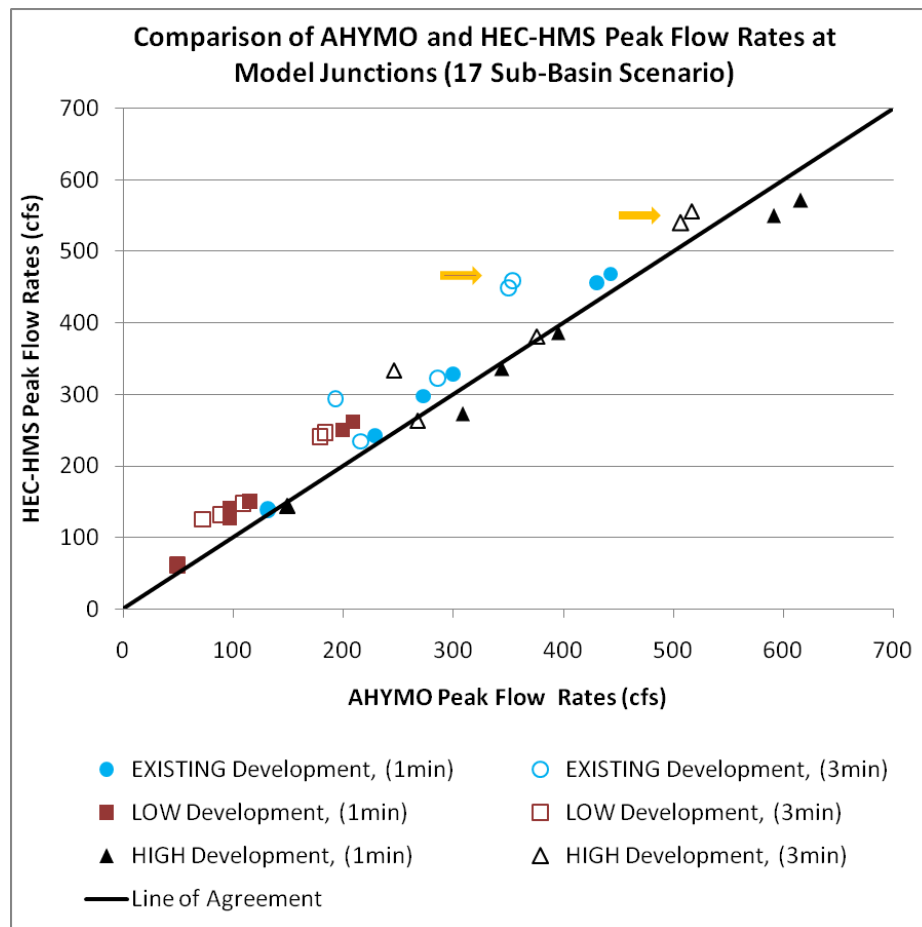


Figure 17: Comparison of AHYMO and HEC-HMS peak flow rates at selected model junctions for all model scenarios with 17 sub-basins.

At a time step of three minutes, two HEC-HMS results in the EXISTING and HIGH development scenarios are disproportionately higher than the corresponding AHYMO results. These flow rates correspond to model junctions D and E (see Figure 19) at the downstream end of the watershed.

A similar observation – if not as pronounced – was made for scenarios with 4 sub-basins (Figure 18). The outliers correspond to the junction at the outlet of the watershed (Junction E).

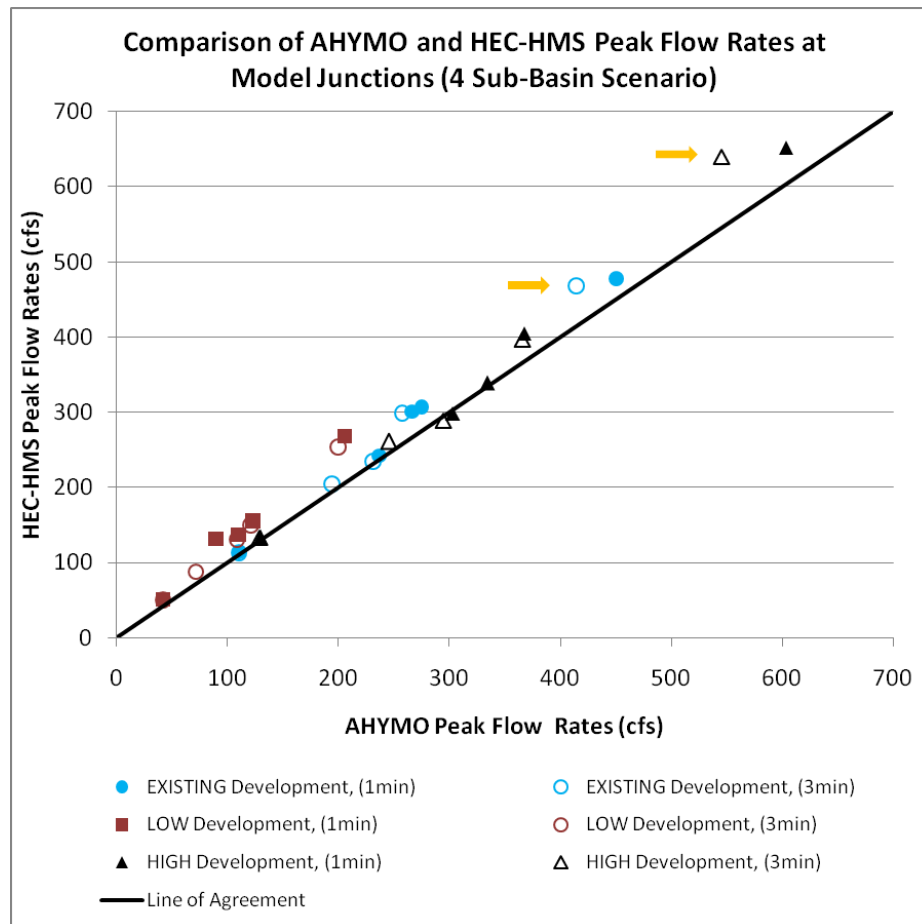


Figure 18: Comparison of AHYMO and HEC-HMS peak flow rates at selected model junctions for all model scenarios with four sub-basins.

Figure 19 highlights the inconsistency of junction peak flows at a modeling time step of three minutes for the 17 sub-basin, HIGH development scenario.

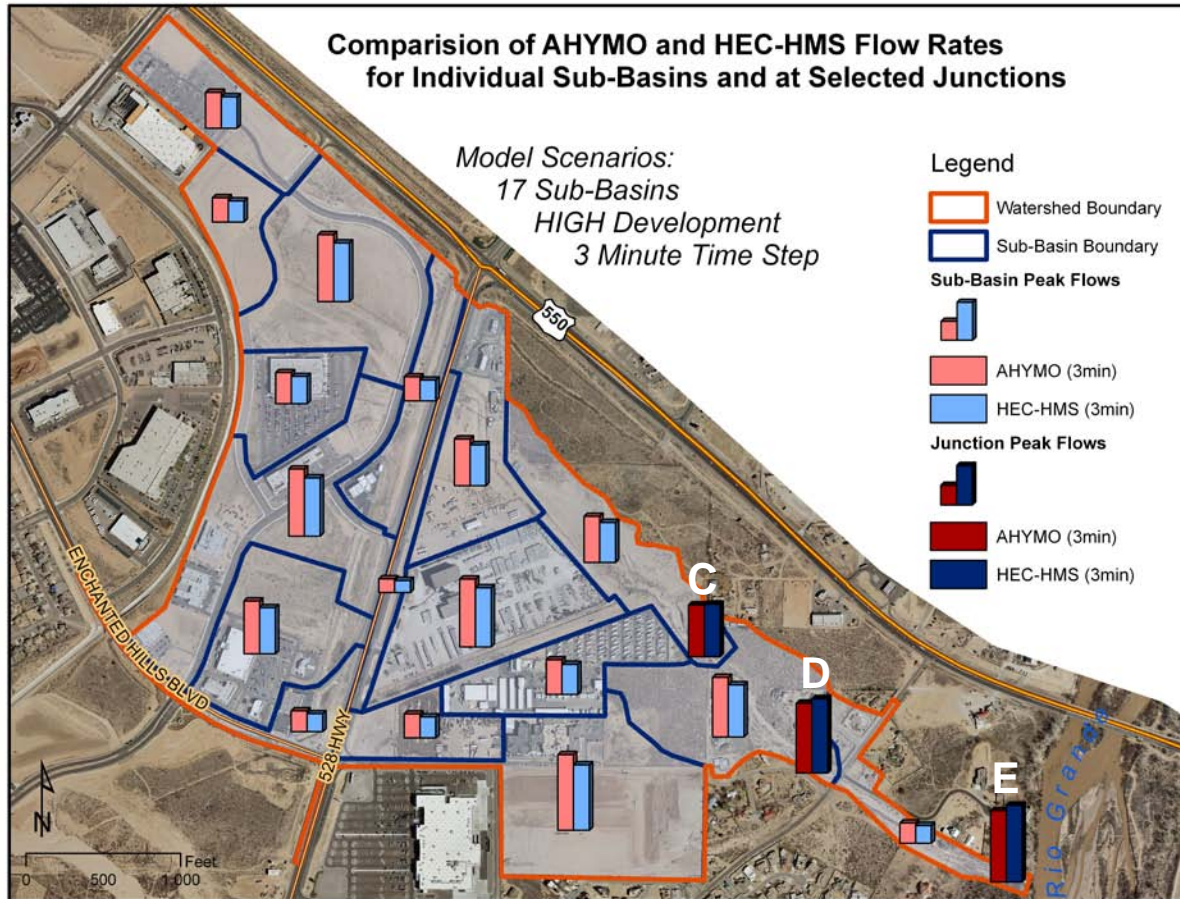


Figure 19: At a time step of three minutes, the 17 sub-basin, HIGH development AHYMO and HEC-HMS scenarios shows inconsistencies between sub-basin and junction peak flow rates: AHYMO peak flows are higher for every sub-basin, but HEC-HMS peak flow rates are higher at model junctions C, D and E.

At a time step of three minutes, AHYMO peak flows for each sub-basin (light red) were higher than HEC-HMS flows (light blue); the average difference was fifteen percent. This is consistent with the data represented in Figure 12. At several junctions in the model, however, the relationship was reversed: AHYMO flows (dark red) were lower than HEC-HMS flows (dark blue). This inconsistency increased going

downstream: at junction C, AHYMO results were one percent lower than HEC-HMS flows. At junctions D and E, the difference increased to six and seven percent, respectively. The inconsistency was not observed when the same scenario was modeled at a time step of one minute (Figure 20).

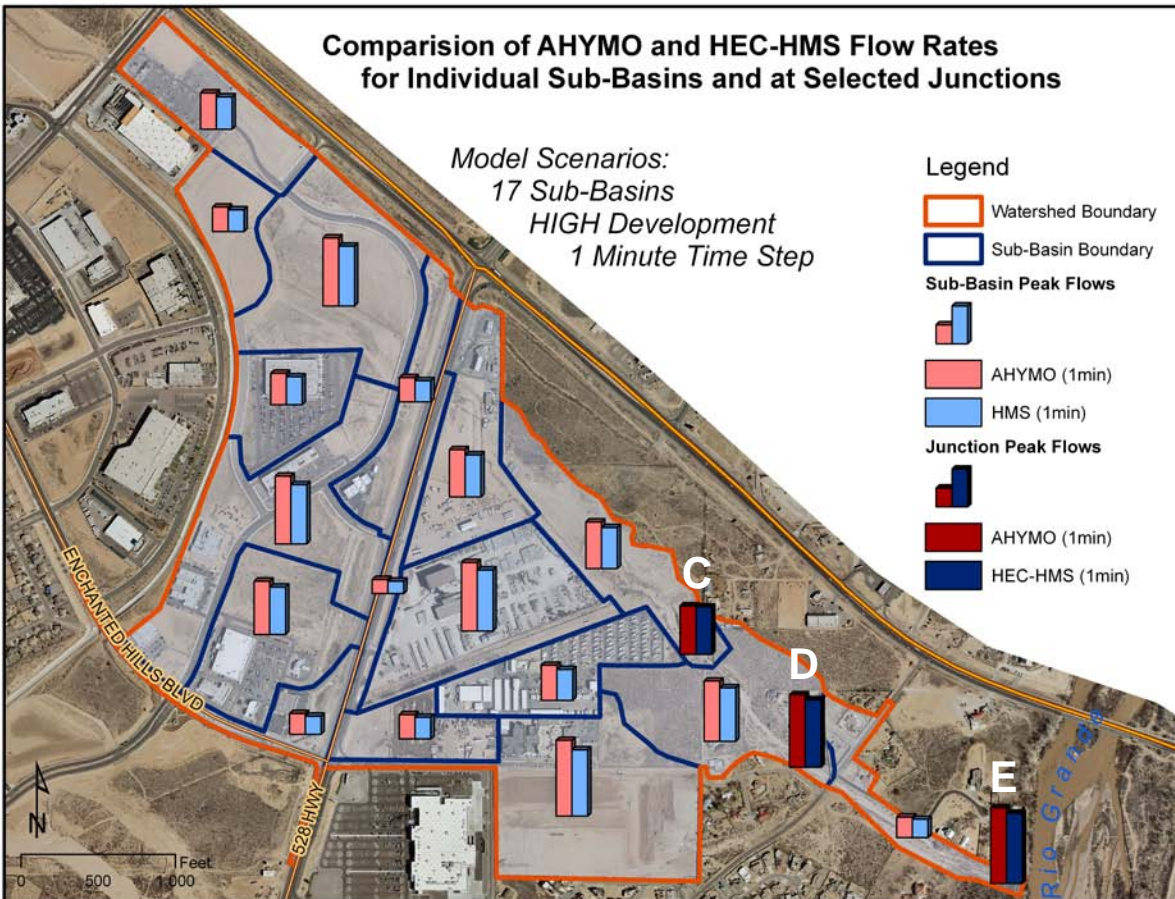


Figure 20: At a time step of one minute, the inconsistencies between sub-basin and junction peak flows observed in Figure 18 are not present.

With the shorter time step, AHYMO peak flow rates were higher for all seventeen sub-basins compared to the corresponding HEC-HMS results. The resulting flows at junctions C, D and E were also higher for AHYMO.

Figure 21 provides a closer look at the outflow hydrograph at junction D (blue) and all contributing inflow hydrographs (red, green and black) for a three minute time step. AHYMO hydrographs are represented with solid lines; HEC-HMS hydrographs are dashed.

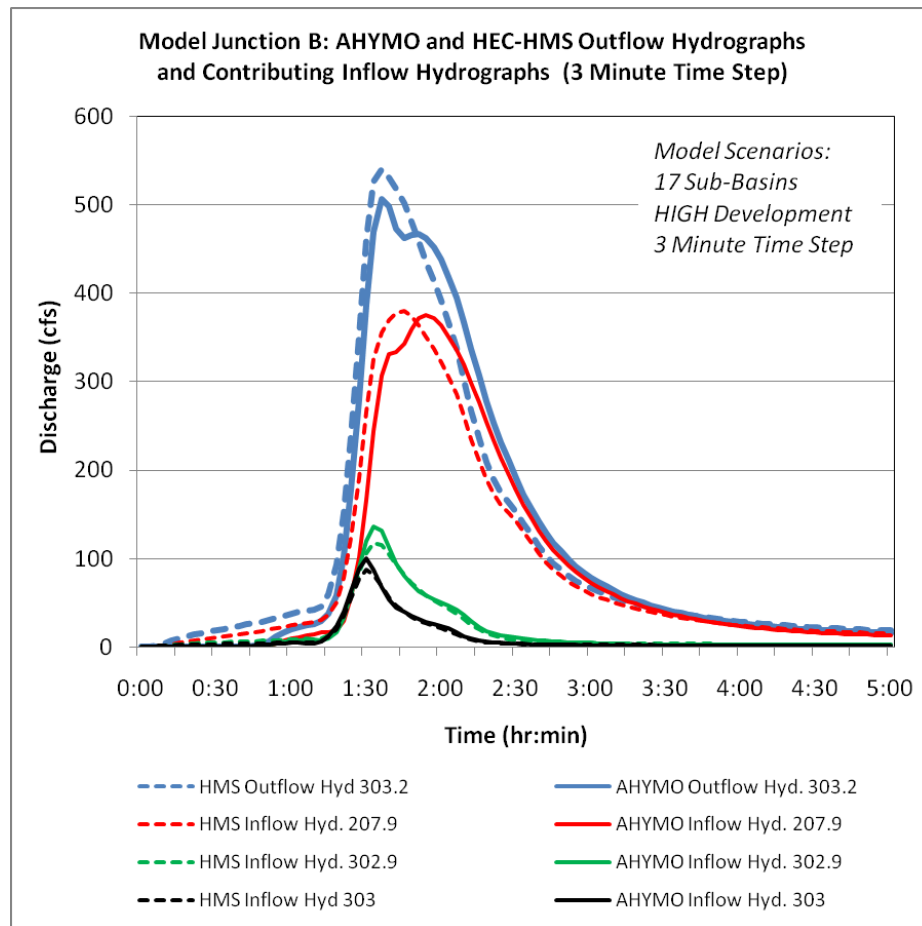


Figure 21: Inflow hydrographs (red, green and black) and resulting outflow hydrographs (red) at model junction B for the 17 sub-basin, HIGH development scenario at a time step of three minutes. HEC-HMS hydrographs are represented with solid lines, AHYMO hydrographs are dashed.

Figure 21 reveals that the AHYMO inflow hydrograph 207.9, which contains routed flows from thirteen upstream sub-basins, peaks approximately ten minutes later than the corresponding HEC-HMS

hydrograph. This difference in timing causes the peak of the AHYMO outflow hydrograph to be 34 cubic feet per second or six percent lower than the HEC-HMS peak flow.

Results for the same scenario, only with a time step of one minute, are plotted in Figure 22.

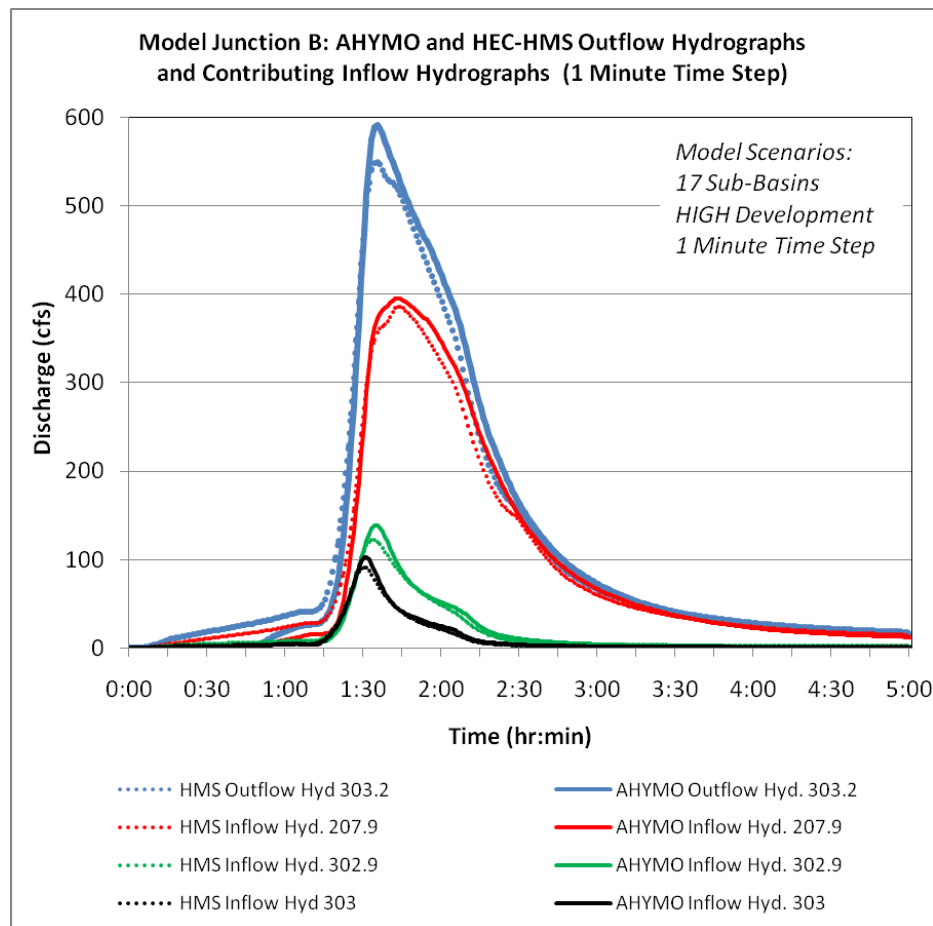


Figure 22: Inflow hydrographs (red, green and black) and resulting outflow hydrographs (red) at model junction B for the 17 sub-basin, HIGH development scenario at a time step of one minute.

In this case, the AHYMO and HEC-HMS inflow hydrographs 207.9 peak at the same time, resulting in AHYMO peak flow rates that exceed the HEC-HMS peak by 42 cubic feet per second or eight percent.

7.3 Effect of the Modeling Time Step on Hydrologic Routing

The results of Figures 21 and 22 suggest that the choice of modeling time step can cause differences in the timing of hydrograph peaks. Figures 23 and 24 show that the differences are caused by inconsistencies in the AHYMO routing procedure. Figure 23 shows how a hydrograph is routed through one exemplary routing reach in AHYMO.

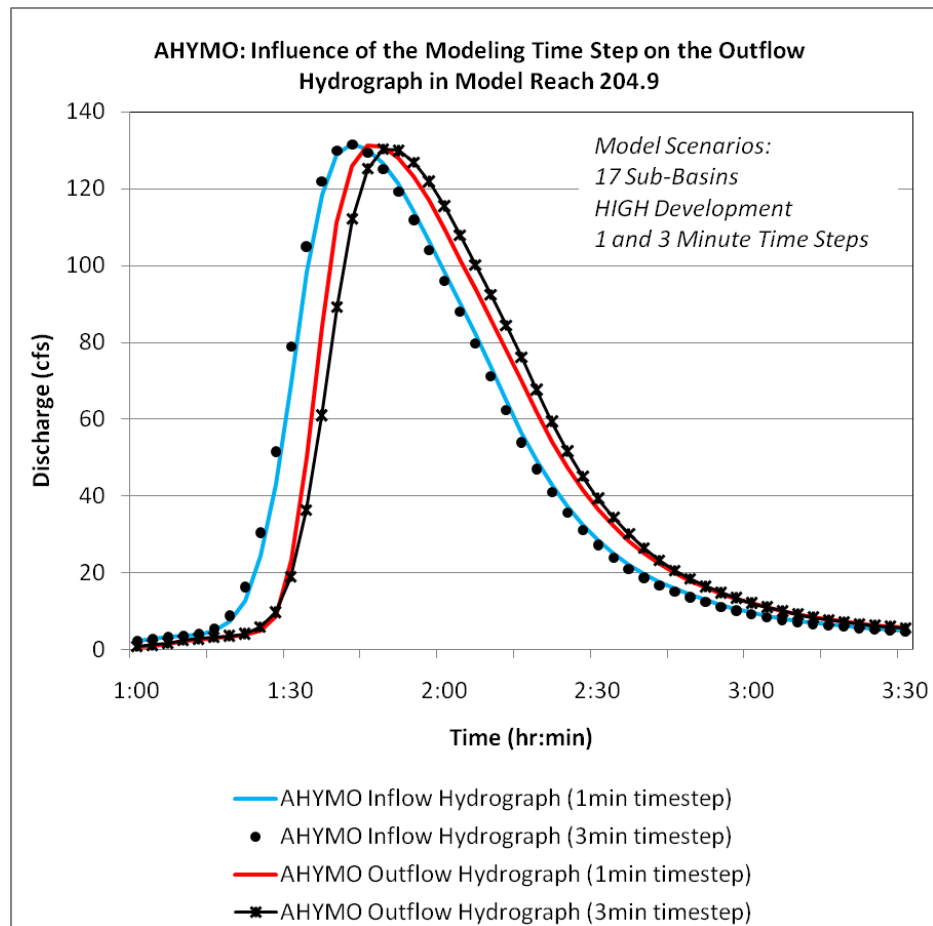


Figure 23: AHYMO inflow and outflow hydrographs for routing reach 204.9, modeled at time steps of one and three minutes: while inflow hydrographs are identical, the outflow hydrograph peaks later when modeled at a three minute time step.

The inflow hydrographs for the one minute (blue line) and three minute time steps (black circles) are practically identical. The outflow hydrograph for the one minute time step (red line) peaks earlier than when modeled with a time step of three minutes (black line and stars).

This discrepancy does not occur in HEC-HMS (Figure 24). Outflow hydrographs for both one and tree minute time steps are not shifted in time.

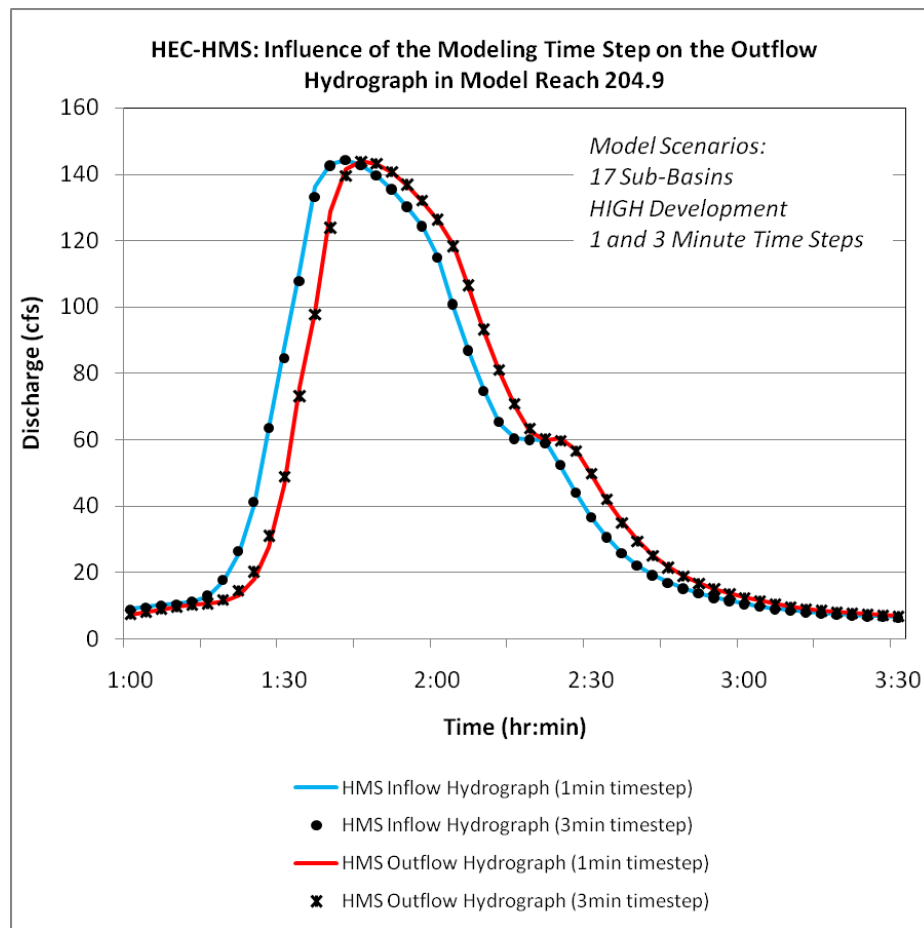


Figure 24: HEC-HMS inflow and outflow hydrographs for routing reach 204.9 modeled at time steps of one and three minutes: inflow and outflow hydrographs are identical.

8. Discussion

The inconsistencies in routing results when using the Muskingum-Cunge method in conjunction with long (e.g. three minute) computational time steps in AHYMO have been known to engineers and hydrologist in the greater Albuquerque area for some time, and have been documented in at least one publication: Gerlach (2008) found that long computational time steps in AHYMO resulted in artificially long floodwave travel times when Muskingum-Cunge routing was used. The problem did not occur with short time steps (one minute or less). Gerlach studied two regional drainage systems, the watersheds of the Black and Montoyas Arroyos, ten and nearly 60 square miles in size, respectively. In the case of the Montoyas Arroyo, HEC-HMS peak flows were in some cases more than 100 percent higher than AHYMO peaks, due to the temporal shift of the AHYMO hydrograph. The present study shows similar – if not as pronounced – effects for a small watershed with short routing reaches. Hence, regardless of the size of the drainage system, the AHYMO program should be used with a computational time step of one minute (or less) to determine peak flow rates.

This study furthermore shows that the extent of impervious surfaces can cause significant differences between sub-basin peak flow rates computed by AHYMO and HEC-HMS. Impervious surfaces influence two components of the hydrologic models: the rainfall loss calculation, and the transform method. Although the rainfall loss methods used in AHYMO and HEC-HMS are very similar, impervious surfaces are treated somewhat differently in each of the models. In AHYMO, impervious surfaces are assigned a small initial abstraction and infiltration rate. In HEC-HMS, impervious surfaces are assumed to be absolutely impervious (see Section 6.2.2 above). All else equal, this should result in higher HEC-HMS peak flows for basins with a large percentage of impervious surfaces. Figure 12 shows that the opposite is the case: AHYMO peak flows are higher for HIGH impact scenarios with 85 percent impervious surfaces in all sub-basins. This suggests that the influence of impervious surfaces on rainfall loss

calculations must be small compared to the impact on the transform method, a suspicion confirmed by the sensitivity analysis (Figure 14).

The results of this study indicate that, in addition to impervious surfaces, sub-basin size has an effect on differences between AHYMO and HEC-HMS peak flow rates. Figure 16 shows that the largest differences occurred for small sub-basins. In the size range between zero and approximately 40 acres, sub-basin peak flow rates differed up to fifteen percent. The variability decreased with increasing sub-basin size, and remained relatively small (up to five percent) for sub-basins larger than 200 acres. Sub-basin size does not affect rainfall, rainfall loss or routing calculations in AHYMO or HEC-HMS. It does, however, have a direct impact on the unit hydrograph. Both in AHYMO and HEC-HMS, the shape of the unit hydrograph for each sub-basin is determined by two parameters: the time of concentration, and a second parameter called recession constant k in AHYMO and storage coefficient R in HEC-HMS. Since the times of concentration used in both models were identical for corresponding sub-basins, the second parameter (k in AHYMO and R in HEC-HMS) must be responsible for the observed differences. In AHYMO, the value of the recession constant depends, among other things, on the size of the corresponding sub-basin. Different equations are used for sub-basins smaller than 40 acres and larger than 200 acres. For sub-basins between 40 and 200 acres, a linear interpolation is used to calculate k . Only one equation is used to compute the value of the storage coefficient R in HEC-HMS (see Section 6.2.3). R does not depend on sub-basin size.

Using equation 1 to calibrate the HEC-HMS unit hydrograph to AHYMO results appears to work well for sub-basins larger than 200 acres in size. The method also yields similar results for smaller sub-basins that neither have a very high nor a very low percentage of impervious surfaces. If equation 1 is used for small sub-basins (five to 30 acres) with a high percentage of impervious surfaces, AHYMO peak flow rates may be significantly higher than HEC-HMS results. If equation 1 is used for small sub-basins (five to 30 acres)

with no or very little impervious surfaces, HEC-HMS may yield significantly higher peak flow rates than AHYMO. For most practical applications, these differences are probably of no consequence. If the distribution of impervious surfaces is not skewed in one direction, AHYMO and HEC-HMS peak flow rates will probably not be significantly different, as the EXISTING development scenarios in this study demonstrate. There are, however, realistic scenarios where caution should be used. Here is one hypothetical example:

A future development plans to convert open space (zero percent imperviousness) into a commercial center with retail stores (approximately 85 percent impervious surfaces). HEC-HMS is used to model the historic and developed conditions hydrology in order to quantify the impact of the development on storm water runoff. Since the area of interest is relatively small, all model sub-basins are smaller than 40 acres in size. Storage coefficients R for each sub-basin are calculated using equation 1.

For the historic conditions in the example above, HEC-HMS can be expected to yield higher peak flow rates than if AHYMO had been used. The opposite is the case for the developed conditions: since the percentage of impervious surface is uniformly high, HEC-HMS will likely yield lower peak flow rates than AHYMO. Overall, HEC-HMS will likely provide a significantly lower estimate for the increase in storm water runoff as compared with AHYMO.

At this point, it has to be emphasized that this study only provides a comparison between AHYMO and HEC-HMS model results using the methodologies described in section 6.2 above. Hydrologic models simulate complex physical processes. Many simplifying assumptions are made, which can affect the accuracy of model results. One example is the unit hydrograph procedure used in this study. A unit hydrograph is the hydrograph that results from one unit of excess rainfall. To obtain a runoff hydrograph, the unit hydrograph is scaled by the excess rainfall depth. The underlying assumption is

that the relationship between rainfall and runoff is linear. In addition to this inherent simplification, there are practical problems when the unit hydrograph procedure is implemented. Ideally, a unique unit hydrograph is developed for each sub-basin in a watershed. The unit hydrograph parameters, time of concentration (T_c) and storage coefficient (R) in the case of the Clark unit hydrograph, are calibrated using gauged precipitation and streamflow data. In reality, gauged data is rare. Some watersheds in the Albuquerque/Rio Rancho area have stream gauges in strategic locations, others are entirely ungauged. The number of rain gauges is often insufficient to capture the spatial distribution of a rain event. It is therefore practically impossible to obtain gauged rainfall and streamflow data for each sub-basin of a watershed. Instead, physical based and/or empirical methods are used to estimate the unit hydrograph parameters.

The accuracy of results from hydrologic models depends on the underlying assumptions and the availability of measured data. No measured data was available to calibrate the models used in this study. Given the inherent uncertainty, one might argue that the differences between AHYMO and HEC-HMS results observed above are not significant. The sole purpose of this study, however, was to determine how selected input parameters affect differences between AHYMO and HEC-HMS results. The results show that in certain cases peak flow estimates from one model were consistently higher or lower. No conclusions can be drawn from this study as to whether AHYMO or HEC-HMS provides a better representation of the real drainage characteristics of the watershed. Ultimately, gauged data should be used to calibrate any hydrologic model, regardless of which software is used.

9. Conclusions

Twelve distinct hydrologic model scenarios for a small urban watershed (approximately 270 acres) in central New Mexico were run in AHYMO and HEC-HMS to test the influence of sub-basin size, impervious surfaces and modeling time steps on differences in model results. The methodologies used in AHYMO and HEC-HMS were based on published guidelines.

Based on the comparison of AHYMO and HEC-HMS simulation results, the following conclusions can be drawn. The AHYMO program should be used with a computational time step of one minute or less to determine peak flow rates, regardless of the size of the drainage system. A longer time step may lead to significant computational discrepancies within the AHYMO program. AHYMO and HEC-HMS appear to yield similar results for models with sub-basins larger than 200 acres, as well as for models with smaller sub-basins that neither have a very high nor a very low percentage of impervious surfaces. This study demonstrates that a drainage system with sub-basins between five and 30 acres and a high percentage of impervious surfaces may result in significantly higher AHYMO peak flow rates as compared to HEC-HMS results. If very little or no impervious surfaces exist in the same system, HEC-HMS may yield significantly higher peak flow rates than AHYMO. In a scenario where a relatively small, previously undeveloped area is to be converted into a high density urban development, HEC-HMS may therefore provide a significantly lower estimate for the increase in storm water runoff compared to AHYMO. Sub-basin size and the percentage of impervious surface appear to be responsible for the observed differences in sub-basin peak flow rates. This study shows that by adjusting the storage coefficient R in HEC-HMS, differences between the two models can be reduced. Future work might investigate a modified procedure for estimating the storage coefficient R that accounts for sub-basin size. Ultimately, gauged precipitation and streamflow data should be used to calibrate any hydrologic model.

10. References

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Appendix A

List of existing hydrologic models for the Unnamed Arroyo Watershed area:

- Drainage Report for Venada Plaza Industrial Center. Prepared by: Tierra West, LLC, July 2008.
(SSCAFCA archive)
- Final Drainage Study for Unnamed Arroyo, Southeast Corner of US 550 and NM 528. Unit 20 Industrial Park, Parcel 'A', Rio Rancho, NM. For Joiner Construction Co., Inc. Prepared by: Huit-Zollars, Inc., October 9, 2003 (SSCAFCA archive).
- Enchanted Hills Subdivision Master Drainage Plan, Enchanted Hills Subdivision (Unit 20), Rio Rancho, New Mexico. For AMREP Southwest, Inc. Prepared by Huit-Zollars, Inc., November 17, 2000 (SSCAFCA archive).