TERM PROJECT REPORT

Effects of Land Cover Changes on the Austin-Travis Lakes Watershed

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Abstract

With fast human development, a notable amount of wet areas have been changed into developed land in the Austin-Travis Lakes Watershed. Developed land increases by 1.2% for each five-year period from 2001 to 2011, while forests decrease by 1.6%. This watershed is delineated based on Digital Elevation Model (DEM) to determine gages and corresponding drainage area. Runoff ratio is used to evaluate precipitation-runoff processes by calculating the proportion of surface runoff to precipitation. Despite the fact that more impervious land leads to less infiltration, the runoff ratio tends to decline during these years, that is, 0.1543 in 2001, 0.01452 in 2006 and 0.01092 in 2011. This indicates that more thinking is needed to understand how the runoff ratio is affected in a given hydrological system.

The HEC-HMS model is established to output the peak flow rates by simulating precipitation-runoff processes. The peak flow rate at the Onion Creek Gage increases by 324.9 cfs from 2001 to 2006, and 280.3 cfs from 2006 to 2011. Further analysis shows that the increase of peak flow rates during a storm is proportional to the increase of developed land. Besides, the accuracy of the HEC-HMS model is proved by comparing the results with other studies.

Key Words

Land cover changes; Runoff ratio; HEC-HMS model; Peak flow rates

Contents

1. Introduction

1.1 Austin-Travis Lakes Watershed

The Austin-Travis Lakes Watershed lies at the downstream of the Colorado River which flows southeast from the Llano Estacado to Matagorda Bay on the Gulf of Mexico (Wikipedia). Besides the Colorado River, the watershed contains two important streams: the Barton Creek and the Onion Creek. With an area of 3199.2543 km^2, the watershed overlaps 6 counties in Texas: Llano, Burnet, Blanco, Williamson, Travis and Hays, covering Austin city.

Based on National Flood Interoperability Experiment: NFIE-Geo for the Texas-Gulf Region in Hydroshare, the Austin-Travis Lakes Watershed is delineated, as is shown in Figure 1 (Fagan, C., 2015).

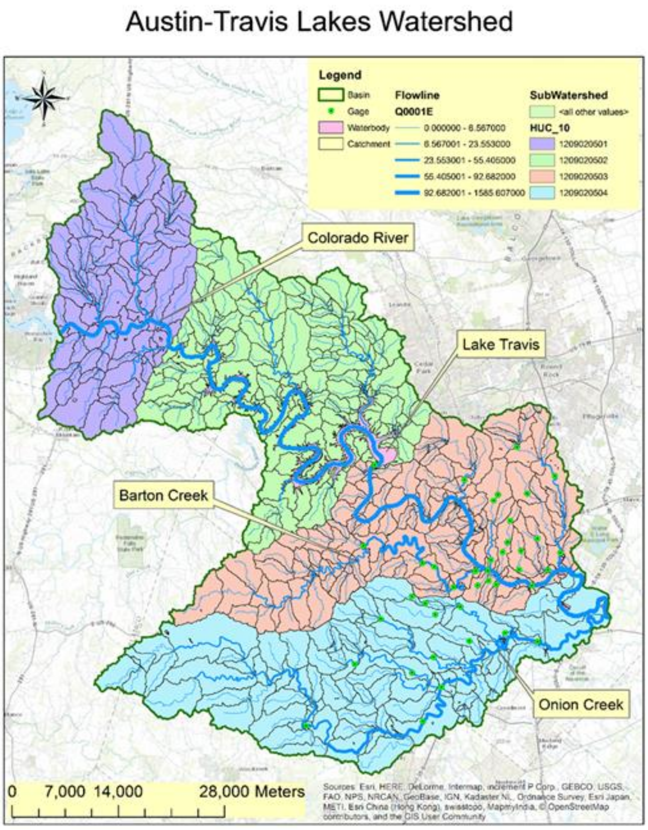


Figure 1 Austin-Travis Lakes Watershed

After summarizing the attributes of Flowline and Catchment feature classes, the properties of flowlines and catchments in the watershed can be determined. See Table 1.

Table 1 Properties of flowlines and catchments in Austin-Travis Lakes Watershed

Flowline		Catchment	
Count	Length (km)	Count	Area (km^2)
593	1834.247	590	3199.2543

During recent years, enormous changes of land use have taken place in the Austin-Travis Lakes Watershed due to fast development. Take Travis County as an example. The total population in Travis County has increased by 26.1% from 2000 to 2010 (U.S. Census Bureau, 2001; U.S. Census Bureau, 20011). Developed land is listed as one of the potential water stressors by EnviroAtlas. Figure 2 shows the percentage of land which was previously wet and has been developed within each subwatershed (12-digit HUC) (EnviroAtlas). It is worth noticing that the area at the bottom of the watershed has over 6.5% of developed land on wet areas. So it is of significant importance to determine the effects of such changes.

Developed Land as One of Potential Water Stressors

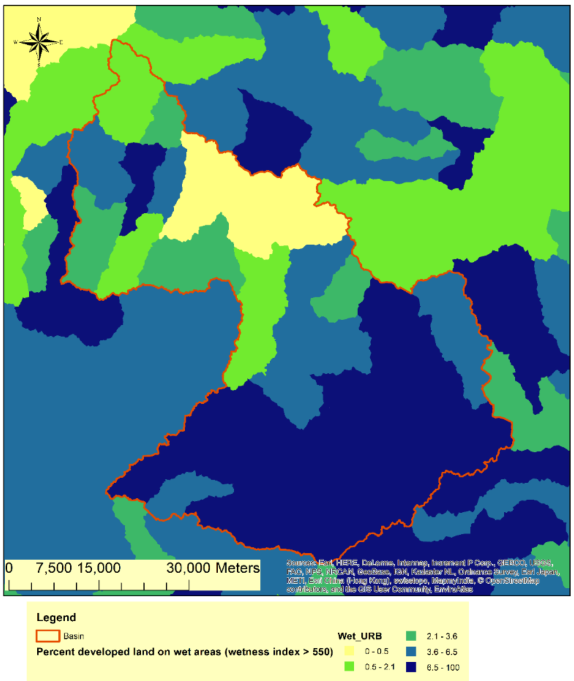


Figure 2 Percent developed land on wet areas in the Austin-Travis Lakes Watershed

1.2 Precipitation-Runoff Process

When there is precipitation over a watershed, surface will first hold a large proportion of the precipitation which is called surface storage; water also enters soil to form soil moisture storage by infiltration. When soil moisture storage begins filling with precipitation, surface runoff and subsurface runoff will occur, some of which turns into streams later (Chow et al., 1988). A simplified hydrologic cycle in Figure 3 illustrates the precipitation-runoff process.

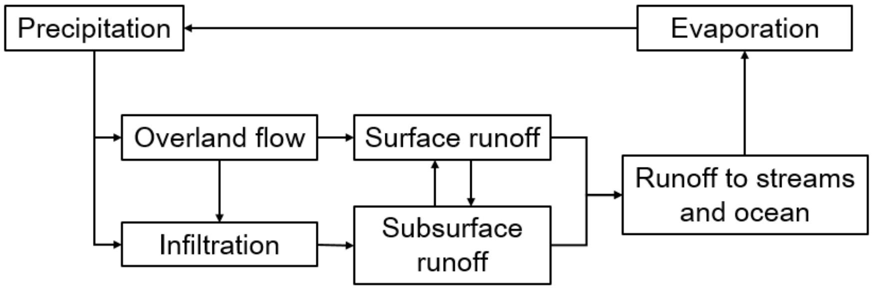


Figure 3 Simplified hydrologic cycle adapted from Chow et al. (1988)

It is well accepted by hydrologists that urbanization, or more developed land, increases total runoff volumes and peak flow rates. On the one hand, more developed land means more impervious land, which will reduce the amount of infiltration, thus increasing the volume of surface runoff. On the other hand, the value of peak flow rates tends to go up due to less residence time of water on land surface and more artificial water paths, such as artificial channels (Chow et al., 1988).

Several studies on the effects of land cover changes on the precipitation-runoff process have been performed with different kinds of models. With the Xinanjiang model, Qu et al. (2012) showed that runoff of Dapoling watershed in the upper Huaihe river basin decreased by 25% from 1976 to 2005 in response to land cover changes due to human development. Note that this conclusion is contrary to the one stated above. The reason may be that the dominant mechanism is different in the precipitation-runoff process. Analysis of the Xinanjiang model parameters indicated that most of the reduction of runoff resulted from increased evapotranspiration, while the statement by Chow et al. (1988) mainly considered infiltration. Besides, the statement by Chow et al. (1988) dealt with land cover changes from other types of land to developed land, not the more complex situations in reality, such as the changes from forests to crop land. The SWAT (Soil and Water Assessment Tool) model was applied to study the impact of land cover changes on water balance for a humid watershed in southeastern Texas (Heo et al., 2015). The results showed that the ratio of surface runoff to precipitation remained almost the same from 1970 to 2009, when there was a 16.3% increase in precipitation and 5.2% increase in developed land. It was suggested that this watershed was controlled by climate and the increase of developed land was not significant enough to change the precipitation-runoff process.

Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a hydrologic model containing many mature hydrologic methods to simulate precipitation-runoff processes in basins (USACE-HEC, 2006). Effects of urbanization on the flow of Cottonwood Creek in California Watershed were analyzed using the HEC-HMS model by increasing the impervious area and imperviousness percentage (USACE-HEC, 2001).It was concluded that urbanization would result in increased flow volumes and peak flow rates in the watershed.

1.3 Objective

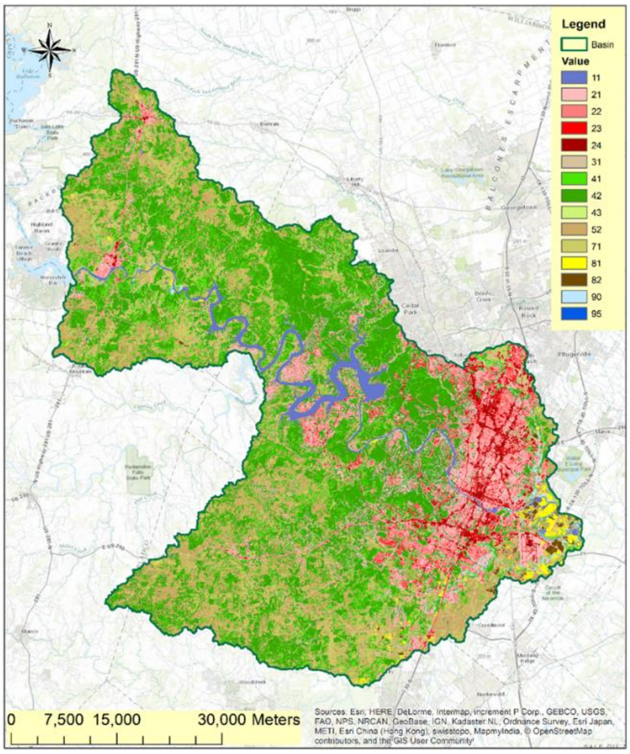
The objective of this study is to quantify the effects of land cover changes on the precipitation-runoff process in the Austin-Travis Lakes Watershed from 2001 to 2011. This objective is divided into four steps:

1) Analyzing land cover changes through the land cover data for 2001, 2006 and 2011;
2) Delineating watershed from DEM;
3) Calculating runoff ratio to illustrate changes of precipitation-runoff processes;
4) Using the HEC-HMS model to simulate peak flow rates for different years' land cover.

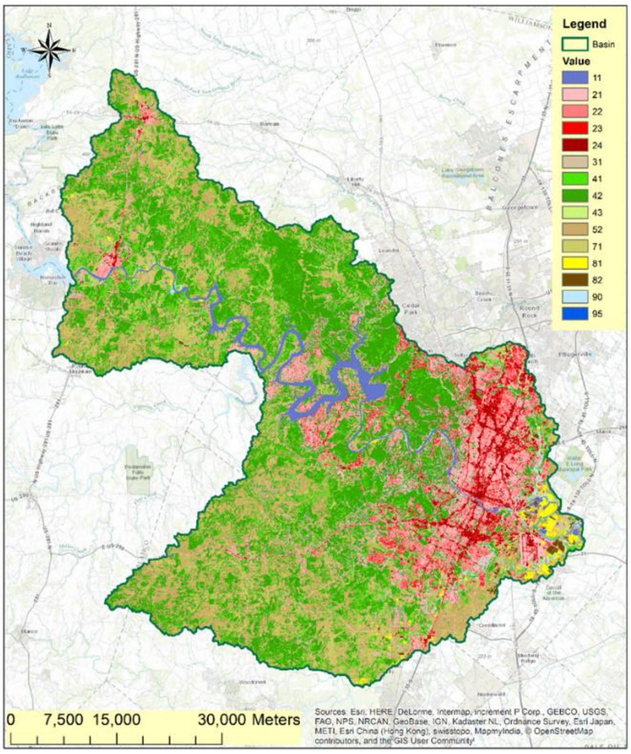
2. Land Cover Changes

Based on National Land Cover Database 2001 (NLCD 2001), 2006 (NLCD 2006) and 2011 (NLCD 2011), maps of land cover in Austin-Travis Lakes Watershed in 2001, 2006 and 2011 are depicted in Figure 4 and data are summarized in Table 2 (Homer et al., 2007; Fry et al., 2011; Homer et al., 2015).

Land Cover of Austin-Travis Lakes Watershed in 2001



Land Cover of Austin-Travis Lakes Watershed in 2006



Land Cover of Austin-Travis Lakes Watershed in 2011

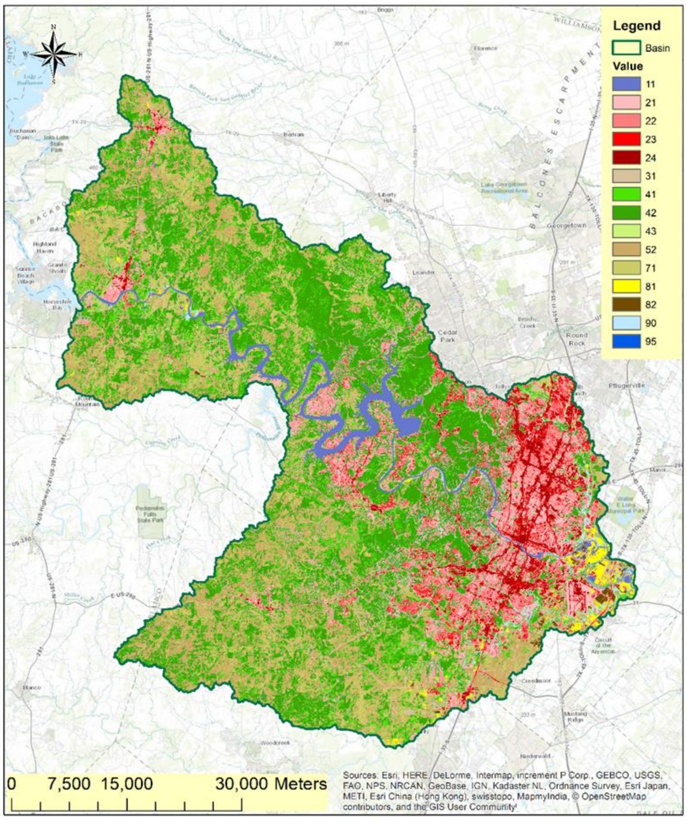


Figure 4 Land cover of the Austin-Travis Lakes Watershed in 2001, 2006 and 2011

Table 2 Comparisons between land cover of the Austin-Travis Lakes Watershed in 2001, 2006 and 2011

Class	Value	2001		2006		2011	
		Count	Percent(%)	Count	Percent(%)	Count	Percent(%)
Water	1	97894	2.741	97688	2.736	97701	2.736
Developed	2	733666	20.545	771027	21.591	816403	22.862
Barren	3	4123	0.115	13315	0.373	13337	0.373
Forest	4	1517356	42.491	1459730	40.877	1400081	39.207
Shrubland	5	705289	19.750	703641	19.704	712193	19.944
Herbaceous	7	433503	12.139	446601	12.506	455471	12.755
Planted/Cultivated	8	42185	1.181	42671	1.195	40092	1.123
Wetlands	9	37005	1.036	36348	1.018	35743	1.001
SUM		3571021	100	3571021	100	3571021	100

As is shown in Table 2, there is an average of 1.2% increase in developed land and 1.6% decrease in forests during each five-year period, while other types of land remains nearly the same. Therefore, it is reasonable to consider the land cover changes as forests turning into developed land, that is, land cover changes can be simplified as the increase of impervious land.

3. Watershed Delineation

The Austin-Travis Lakes Watershed is delineated based on Digital Elevation Model (DEM). A Model Builder geoprocessing program is built up to facilitate this process, as is shown in Figure 5.

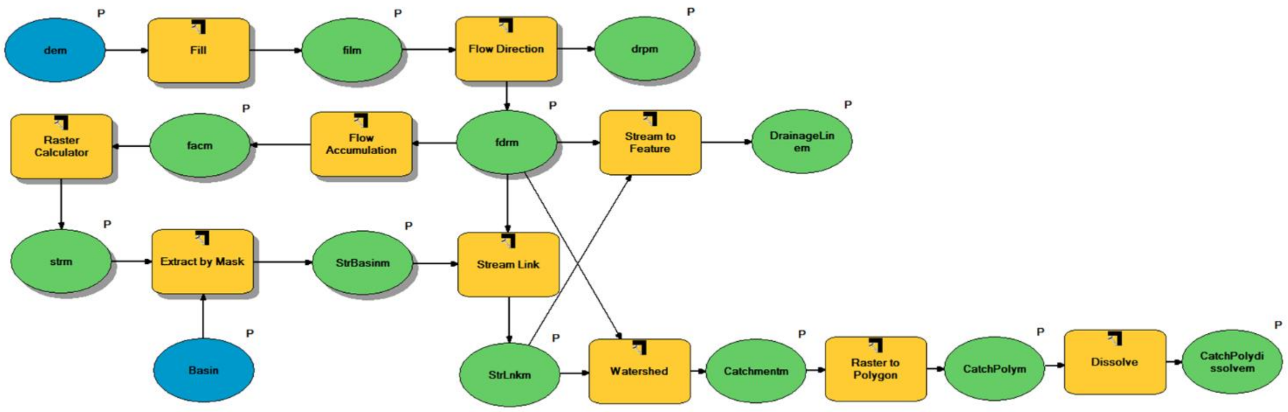


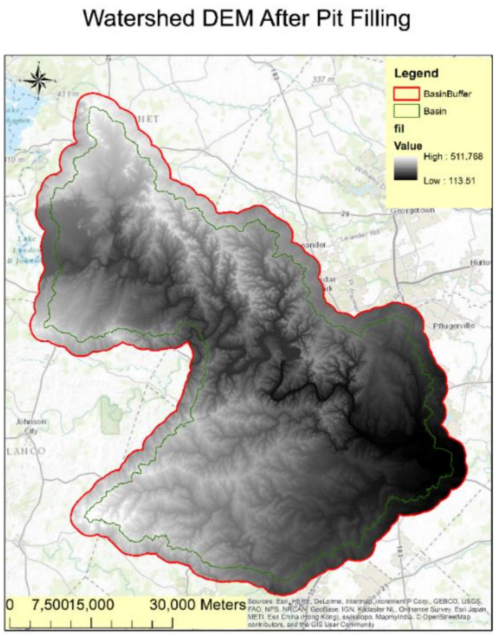
Figure 5 Watershed delineation model based on DEM

3.1 Fill

By using the hydrology tool “Fill”, NED30m from elevation.arcgis.com is modified so that there would be no sinks. Figure 6 shows the result of this step.

3.2 Flow Direction

The D8 model is applied when using the deepest descent of the 8 directions as the flow direction of water. The result is shown in Figure 7.



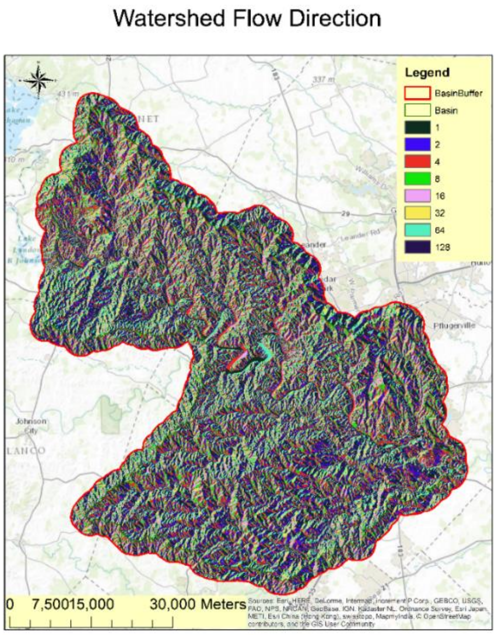


Figure 6 Watershed DEM after Pit Filling

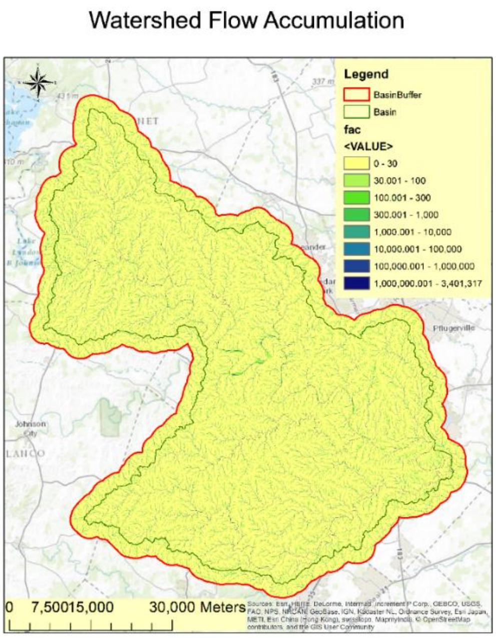
Figure 7 Watershed Flow Direction

3.3 Flow Accumulation

This step calculates the number of cells that flow into one certain grid based on flow direction. Figure 8 shows the flow accumulation grids.

3.4 Stream Definition and Stream Links

Streams are obtained by applying the threshold of 5000 to Flow Accumulation raster. Then through the hydrology tool "Stream Link", each piece of stream gets a unique identification, as shown in Figure 9.



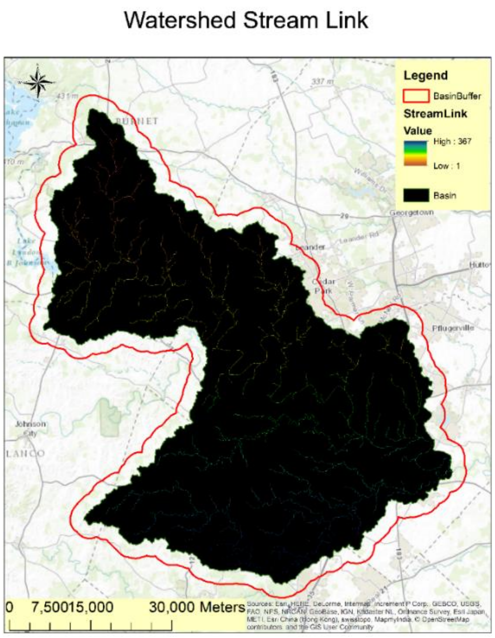


Figure 8 Watershed Flow Accumulation

Figure 9 Watershed Stream Link

3.5 Catchments

Catchments draining to each stream link are identified using the hydrology tool “Watershed”, as shown in Figure 10. The unique value of each catchment is the same as that of the stream link which the catchment directly drains to.

3.6 Conversion to Vector

Stream Links and Catchments are turned into vector forms in this step, as shown in figure 11.

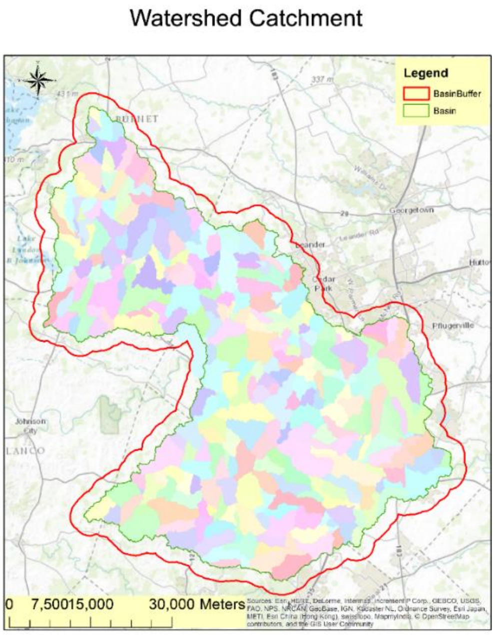


Figure 10 Watershed Catchments

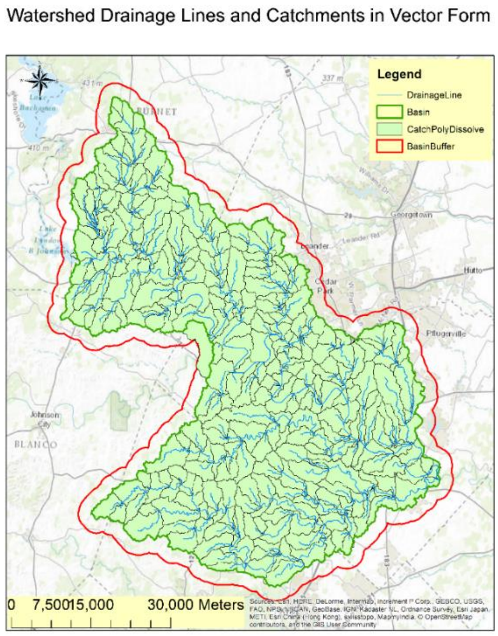


Figure 11 Watershed Drainage Lines and Catchments (vector)

3.7 Gage-Drainage Area

Considering the availability of precipitation data and mean annual flow data of gages, runoff ratio, which is defined as the proportion of surface runoff to precipitation, is adopted as the index to reflect the changes in water resources due to land cover changes. Therefore, it is necessary to find out the USGS gages in this watershed and corresponding drainage areas. There are 42 gages in total, among which several gages are on the Colorado River. Because the Colorado River flows into the watershed directly instead of being formed by small streams in this watershed, the subwatershed draining to the gages on the Colorado River far exceeds the research area. For example, most part of the subwatershed draining to the gage “Colorado Rv at Austin, TX” is out of the current watershed (Figure 12).

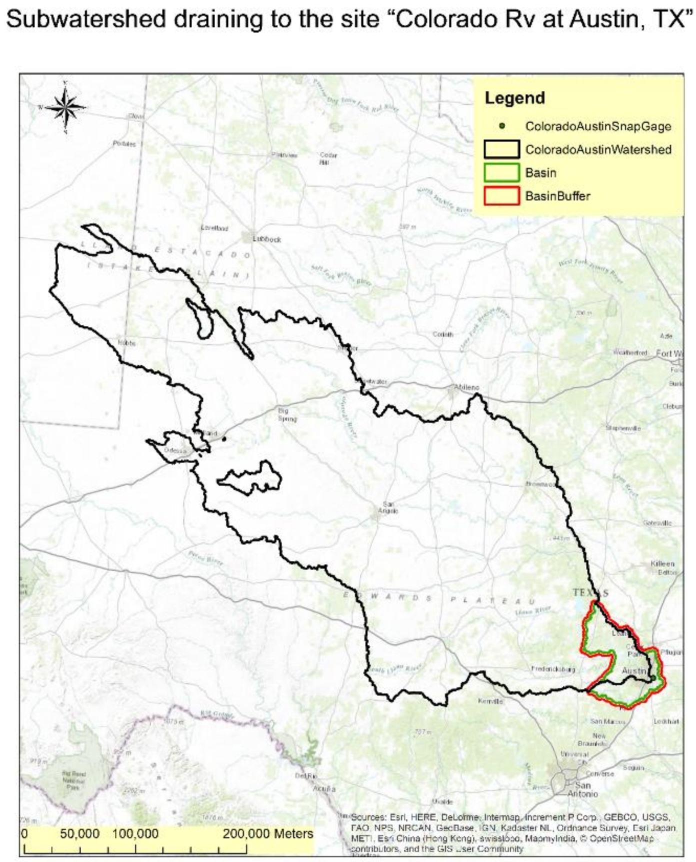


Figure 12 Subwatershed draining to the gage “Colorado Rv at Austin, TX”

To avoid this problem, the subwatershed draining to the gage “Onion Ck at US Hwy 183, Austin, TX” is chosen to represent the whole watershed to some extent, as Figure 13 shows. This subwatershed is referred to as the Onion Creek Watershed to simplify the expression. Note that this subwatershed is different from the Onion Creek Subwatershed in NHDPlus.

Drainage Lines and Catchments in Austin-Travis Lakes Watershed

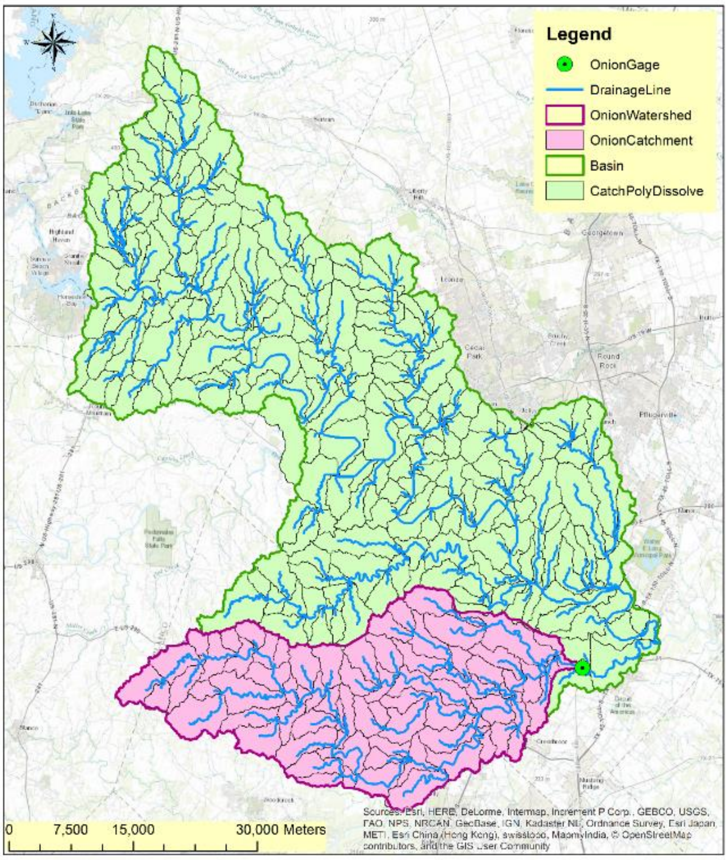


Figure 13 Onion Creek Watershed

4. Runoff Ratio Calculation

4.1 Precipitation

Monthly summaries of precipitation in the counties bordering and overlapping the Onion Creek Watershed in the year 2001, 2006 and 2011 are available from Monthly Summaries of the Global Historical Climatology Network - Daily (NOAA National Climatic Data Center). The following counties are included: Travis, Hays and Blanco. Only stations with 12 months of data in a specific year (2001, 2006 or 2011) are retained. The annual precipitation of each station in each year is calculated based on the monthly average data. Then Thiessen Polygon Method and Tension Spline Method are used to obtain the mean annual precipitation over the Onion Creek Watershed. Figure 14 shows the two methods to estimate precipitation in 2011.

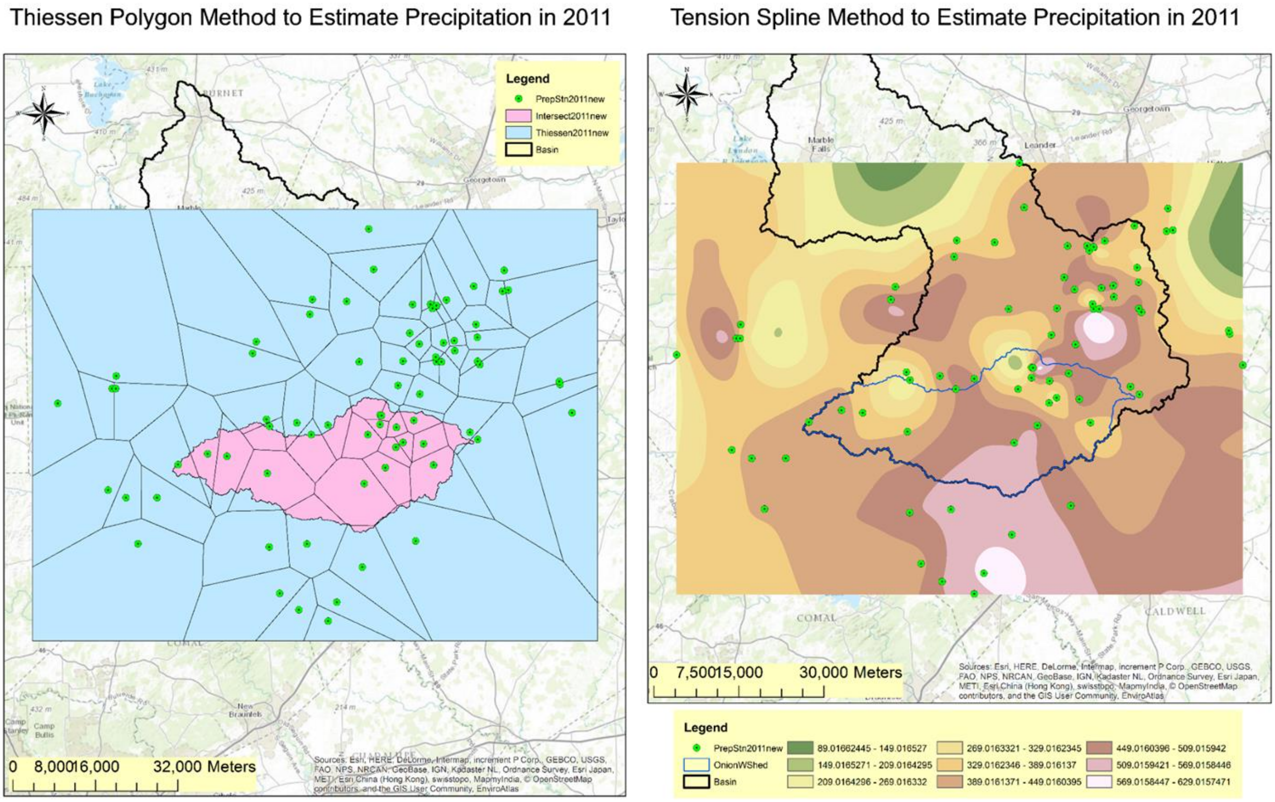


Figure 14 Thiessen Polygon Method and Tension Spline Method to estimate precipitation in 2011

4.2 Mean Annual Flow

USGS provides annual statistics of discharge of gages. Figure 15 shows the mean annual flow of the gage “Onion Ck at US Hwy 183, Austin, TX” from 1994 to 2014.

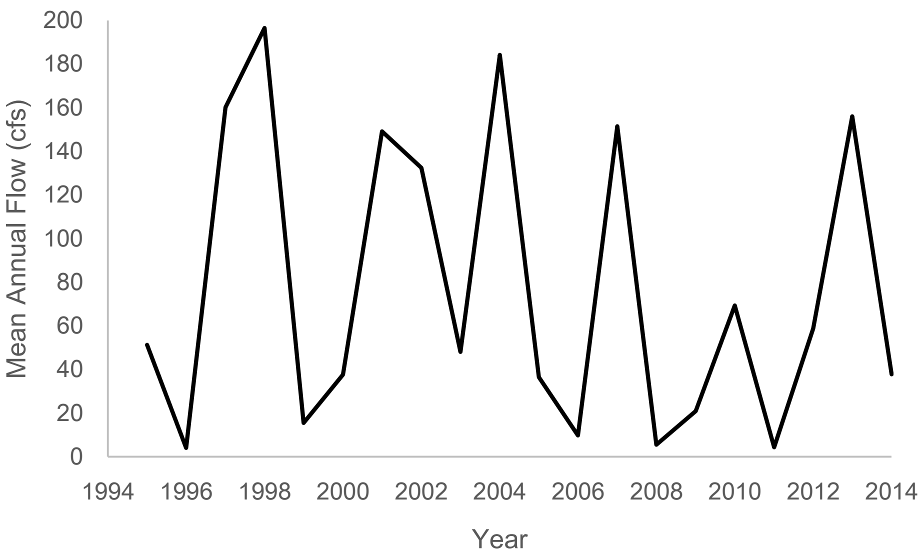


Figure 15 Mean annual flow at “Onion Ck at US Hwy 183, Austin, TX” from 1994 to 2014

4.3 Runoff Ratio

The mean annual precipitation values obtained from two interpolation methods are similar. Thus their geometric mean is used as the final value of precipitation. The intermediate and final results are in Table 3.

Table 3 Calculation results of runoff ratio

	2001	2006	2011
Precipitation by Thiessen Polygon Method(mm)	1029.418	704.672	422.111
Precipitation by Tension Spline Method(mm)	1027.377	733.176	423.564
Mean Precipitation(mm)	1028.397	718.924	422.838
MAFlow(cfs)	149.1	9.81	4.34
Runoff Ratio	0.1543	0.01452	0.01092

It is indicated from Table 3 that the runoff ratio declines from 2001 to 2011. Further analysis shows that the volume of surface runoff decreases by 93.4% from 2001 to 2006 and 55.8% from 2006 to 2011, as the mean precipitation decreases by 30.1% from 2001 to 2006 and 41.2% from 2006 to 2011, which means that the volume of surface runoff decreases more than mean precipitation does. As is well known, increased impervious land leads to decreased infiltration and increased surface runoff, which is in contradiction with the calculation results. A plausible explanation is that the precipitation in 2006 and 2011 is less than the normal level in Texas and similar to some dry areas like Arizona. Taking water balance into consideration, when a hydrological system gets dryer, larger proportion of water to precipitation may evaporate into the atmosphere, causing less proportion of water to run off.

Therefore, it is not operable to quantify the effects of land cover changes on precipitation-runoff process by comparing runoff ratio under such extreme climate conditions.

5. HEC-HMS Model Simulation

In this part, the HEC-HMS model is utilized to output peak flow rates corresponding to a 100-year design storm by simulating the precipitation-runoff process in the Onion Creek Watershed.

5.1 Model Establishment

This model is established by Cyndi Castro. The final model specifications are as follows:

1) Snyder Unit Hydrograph Transform Method:
   Lag Time (HRS), derived using NRCS Watershed Lag Method;
   Peaking Coefficient = 0.075.
2) SCS Curve Number Loss Method:

Curve Number, derived using Land Use and Soils;

Impervious assumed 0%, included in Land Use classifications for development;

Initial Abstraction = 0.5 inch.

3) Reach Routing Method:

Muskingum-Cunge, Trapezoidal Channel;

Manning's n = 0.06;

Side Slope = 8V:1H;

Channel Bottom Width = 35 feet.

These values and methods match the ones used in the FEMA effective model and make sense in looking at the channel cross-sections. Figure 16 shows the model scheme for the Onion Creek Watershed.

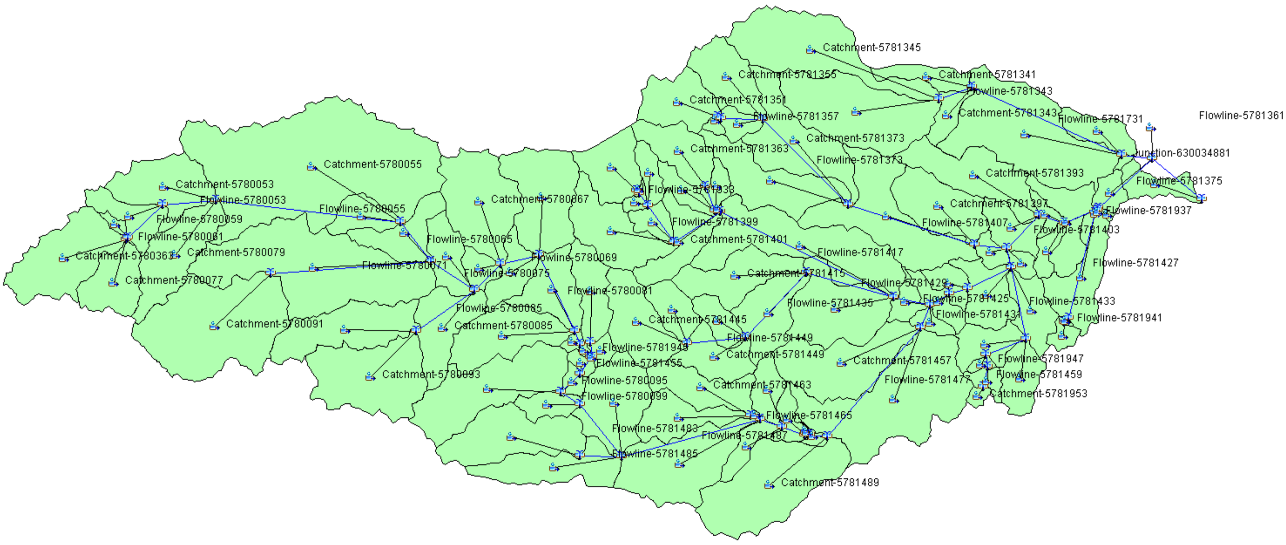


Figure 16 HEC-HMS model for the Onion Creek Watershed

5.2 Model Output

After running the three different storm events in 2001, 2006 and 2011 respectively, hydrographs and peak flow rates for each junction in the model are obtained.

First, the junction at the gage "Onion Ck at US Hwy 183, Austin, TX" is analyzed. The hydrographs for the three years are quite similar in shape. Figure 17 shows the hydrograph for 2011. The peak flow rates for the three years are summarized in Table 4. There is a steady increase in the peak flow rates from 2001 to 2011.

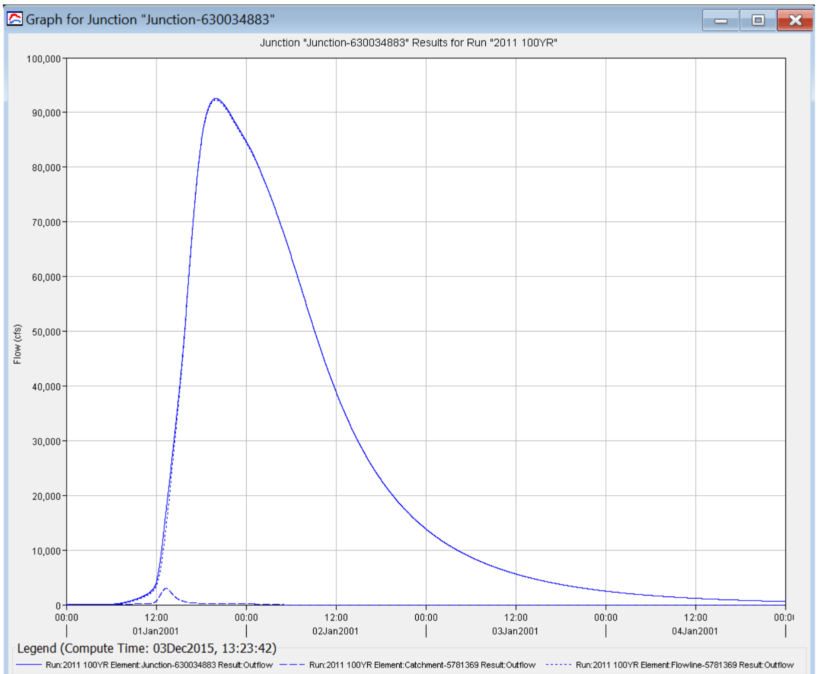


Figure 17 Hydrograph at the gage “Onion Ck at US Hwy 183, Austin, TX” for 2011

Table 4 Peak flow rates at the gage “Onion Ck at US Hwy 183, Austin, TX”

Year	Peak flow rates (cfs)	Change of peak flow rates (cfs)
2001	91941.7	—
2006	92266.6	324.9
2011	92546.9	280.3

Considering the Onion Creek Watershed is chosen to represent the Austin-Travis Lakes Watershed, analysis of land cover in this chosen watershed is redone in the same way as before in order to attain more accurate relationship between changes of land cover and peak flow rates (Table 5).

Table 5 Percentage of each type of land cover in the Onion Creek Watershed

Class	2001(%)	2006(%)	2011 (%)
Water	0.183	0.187	0.195
Developed	17.253	18.703	20.445
Barren	0.167	0.410	0.385
Forest	37.423	35.732	34.473
Shrubland	28.163	27.871	27.580
Herbacious	15.282	15.549	15.442
Planted/Cultivated	0.678	0.716	0.657
Wetlands	0.852	0.832	0.823
SUM	100	100	100

Table 5 reveals a similar trend of land cover changes from 2001 to 2011 in the Onion Creek Watershed to that in the Austin-Travis Lakes Watershed, that is, steady increase in developed land and decrease in forests with other types of land nearly unchanged. This helps to support the idea of choosing the Onion Creek Watershed to represent the Austin-Travis Lakes Watershed.

A linear relationship between the percentage of developed land and the peak flow rate is assumed to fit the current hydrological system, as is shown in Figure 18. Though it is not strictly accurate to determine a linear relationship with three points, reasonable deduction can be made from this relationship. An increase of 1% in the developed land is likely to bring about an increase of 189 cfs in the peak flow rate at the outlet during a 100-year designed storm for the Onion Creek Watershed. A more general guess for the Austin-Travis Lakes Watershed is that the increase of peak flow rates during a storm is proportional to the increase of developed land.

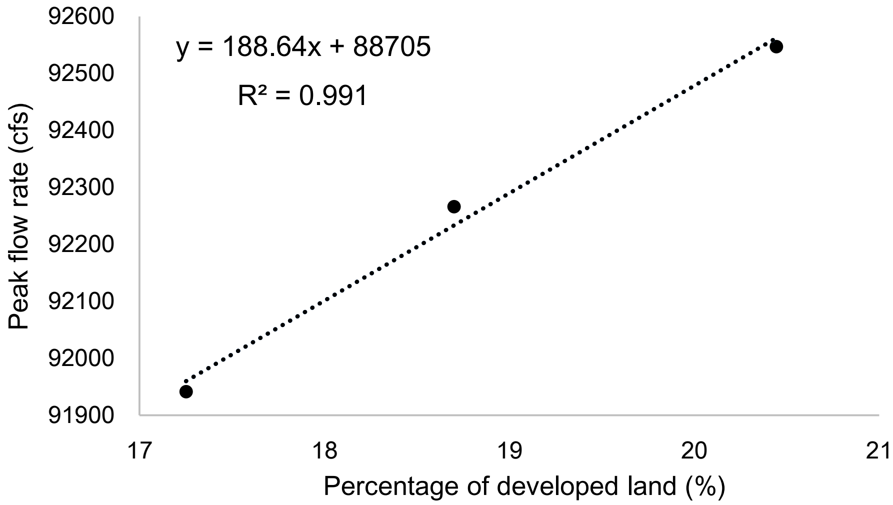


Figure 18 Linear fitting of the relationship between percentage of developed land and peak flow rate

Second, changes of peak flow rates inside the Onion Creek Watershed are studied by looking into two specific junctions. One junction (630034785) is at the upstream, and the other one (630034881) is at the downstream and formed by a tributary instead of the Onion Creek main stream (Figure 19). Their peak flow rates are in Table 6.

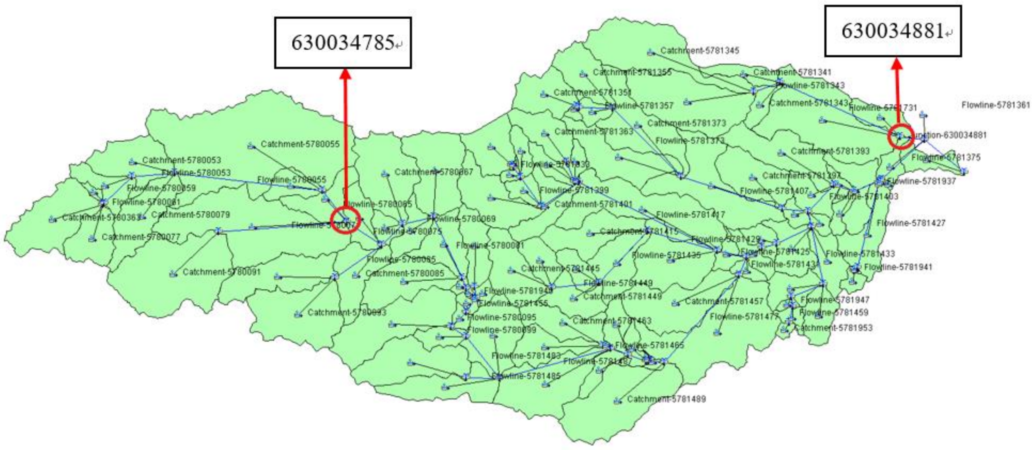


Figure 19 Locations of the two junctions chosen

Table 6 Peak flow rates at two junctions

Year	Junction upstream (630034785) (cfs)	Junction downstream (630034881) (cfs)
2001	49807.5	21979.4
2006	49822.9	22242.0
2011	49838.3	22415.9

The peak flow rate of junction downstream rises by 2.0% from 2001 to 2011 while that of junction upstream rises by merely 0.06%. It can be seen from Figure 4 that land cover changes mainly take place at the downstream catchments inside the Onion Creek Watershed. Except the land cover, all conditions of the two junctions are assumed to be similar. So it is fair to say that increase of developed land plays a significant role in the growth of the peak flow rate.

5.3 Comparisons of Model Results

Federal Emergency Management Agency (FEMA) (2008) conducted a study on the Onion Creek Watershed by using the FEMA effective model. The study showed that the output flow for a 2001 rain event was 101,929 cfs. Note that the Onion Creek Watershed in the FEMA study is derived from NHDPlus, instead of the one draining to the gage “Onion Ck at US Hwy 183, Austin, TX” used in this study. However, output results from the two studies are still comparable because the differences between the Onion Creek Watershed defined in two ways are small. And comparisons show that the output flow in the FEMA study is quite similar to the HEC-HMS results (91941.7 cfs in 2001, 92266.6 cfs in 2006 and 92546.9 cfs in 2011). This suggests that the automated GIS data is able to produce similar HMS flows as an effective FEMA study.

For the 2015 Halloween flood in the Onion Creek Watershed, the maximum discharge at the gage “Onion Ck at US Hwy 183, Austin, TX” was measured as 123000 cfs (USGS), as is shown in Figure 20. This also proves that the peak flow rates from the HEC-HMS model are quite reasonable.

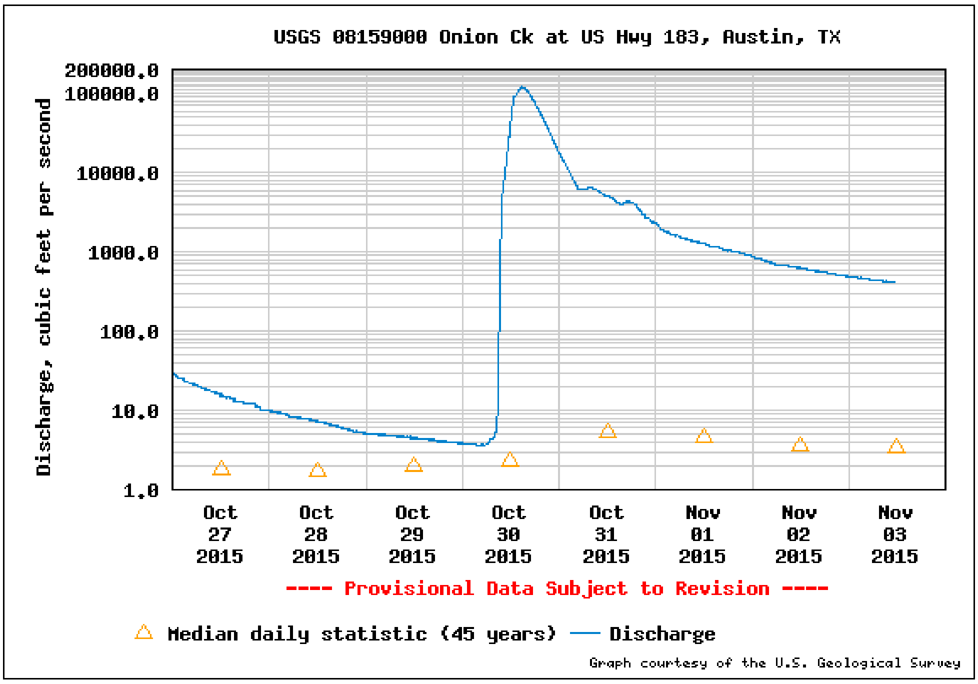


Figure 20 Peak outflow of the Onion Creek gage during the 2015 Halloween flood

6. Conclusion

In the Austin-Travis Lakes Watershed, the most significant change in land cover from 2001 to 2011 is that developed land increases by 1.2% while forests decreases by 1.6% every five years. Though runoff ratio can reflect the actual precipitation-runoff process in a hydrological system, it is not suitable for analyzing the watershed change caused by land cover changes in this study because the watershed has abnormally dry conditions in 2006 and 2011. Such extreme conditions make other mechanisms other than infiltration, such as evaporation, dominate the proportion of surface runoff to precipitation.

The HEC-HMS model provides a way to simulate precipitation-runoff processes and output hydrograph and peak flow rates. Results of the model reveal that the increase of peak flow rates during a storm is proportional to the increase of developed land. For the Onion Creek Watershed, an increase of 1% in the developed land is likely to cause an increase of 189 cfs in the peak flow rate at the outlet during a 100-year storm. Besides, results from the HEC-HMS model are similar to those from the effective FEMA study and USGS gage discharge for the Onion Creek Watershed, proving the accuracy of the HEC-HMS model.

Acknowledgement

This study is completed under the instruction of Dr. David R. Maidment and Dr. David G. Tarboton. The HEC-HMS model is established with the help of Cyndi Castro.

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