Quantifying the effect of land use on flood severity

Alicia Sendrowski

Term Project: Flood Forecasting

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Introduction

Travis County, Texas, has seen immense change in the last 30 thirty years, both in its population and development. The county population has more than doubled between 1980 and 2010 (Figure 1). The population of the city of Austin has almost doubled since 1990. With this influx of people comes an increase in commercial buildings, roadways, and homes, among other structures.

From a hydrologic perspective, this construction has a large impact on the movement of water over the landscape. Floodplains are the natural flood control structures of many rivers, but they often times also serve as prime real estate. Channels that naturally migrate across the landscape are restricted by the creation of artificial levees that also reduce the sinuosity of rivers. The connection between water and people then relies on the sophistication of urban drainage systems to move water away from roadways and other impervious cover in the most efficient way possible.

The price of increasing impervious cover is a loss in the infiltration area during storm events. In an area without impervious cover, such as a forest or grassland, surface runoff does not begin until water has infiltrated the soil enough that it becomes saturated. As the land use changes, so do the dynamics of surface runoff. The volume of runoff is increased, and the time for the runoff to reach its outlet is decreased. The purpose of this work to quantify these changes given the change in impervious cover in Travis County between 2001 and 2011.

This work is motivated Travis County's vulnerability to large storm events due to its location in an area termed "flash flood alley" (Figure 2). Flash flood alley is an area in central Texas that is especially prone to large storm events. These events exhaust many of the cities resources and cause millions of dollars in damage, such as the devastation seen in the Onion Creek Flood in Austin, TX, in October 2013. Given the increase in Travis County's development, potentially putting more people and infrastructure at risk of flood occurrences, the characterization of land use and floods is of upmost importance.

The objectives of this project are to model the flows in a catchment that has seen a large increase in impervious cover over the last 10 years. An assessment will be made about the effect of land cover on catchment outflow and on the lag time between rainfall and runoff in the catchment given the change in land cover. Two different storms will be modeled for the two time periods: a 10-year storm and a 100-year storm.

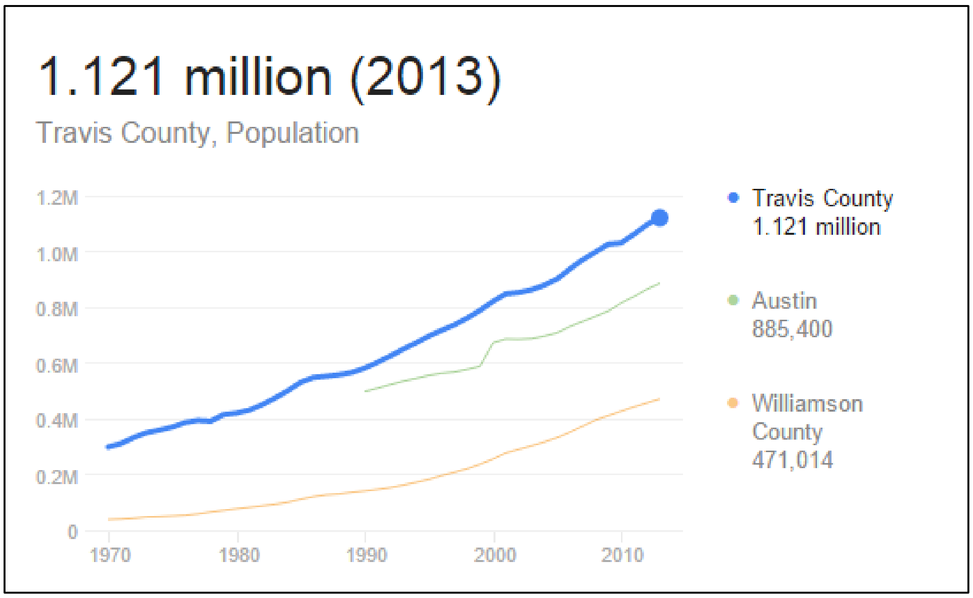

Figure 1: Population trends of Travis and Williamson County, and Austin, Texas from 1970-Present. Data from the U.S. Census Bureau.

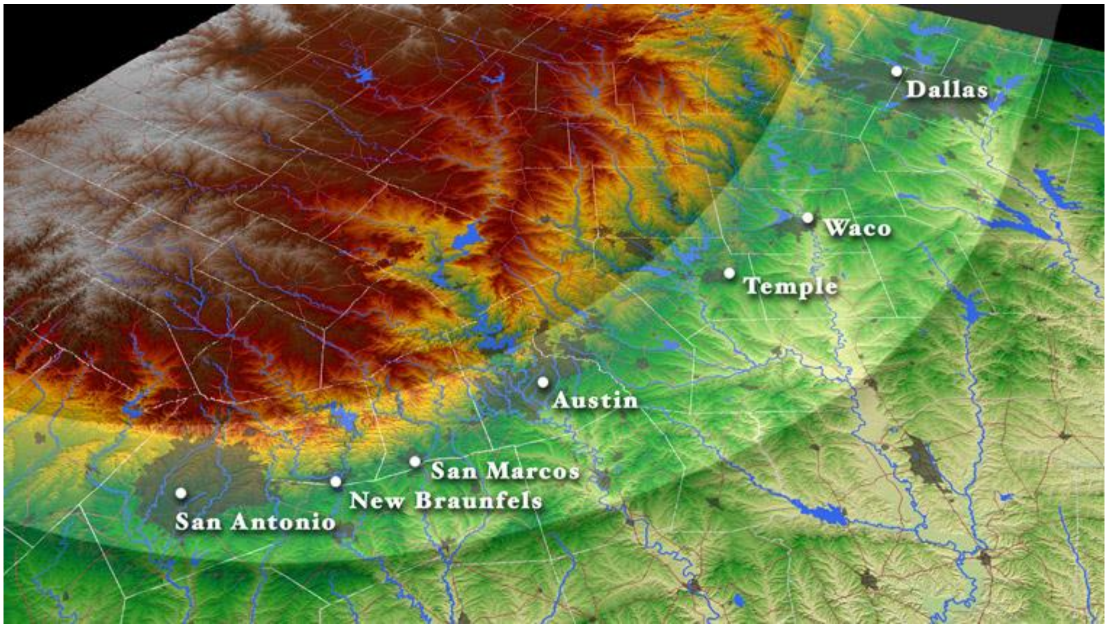

Figure 2: Flash flood alley, map made by the Flood Safety Education Project

Methods

Land use maps were downloaded from the Multi-Resolution Land Characteristics Consortium's (MRLC) National Land Cover Database (NLCD). The NLCD is a 30-meter resolution map detailing the land use of the United States, broken down into 20 different types of use. The NLCD maps of Travis County land use for 2001 and 2011 (Figures 3a and b) give an excellent picture of the development occurring in the county. The red areas correspond to varying degrees of developed surface, from low to high intensity (12% to 85% impervious).

There are several areas that have seen increased development since at least 2001. The area North of Travis County, in Williamson County, shows increased impervious cover (Figure 3b). Areas around water bodies have also been developed, especially near Lake Travis, located in the left area of the map. Additionally, many areas saw an increase in development intensity versus development across space.

The change in land use between 2001 and 2011 was mapped in order to better visualize areas of change (Figure 4). The city of Austin watersheds, used in floodplain modeling, were plotted on top of the land use change in order to select a catchment that has a floodplain model (Figure 5).

The Blunn Creek watershed was chosen for analysis (Figure 6). The population of Blunn Creek in 2000 was ~6000 people. The entire catchment is about 1.258 square miles (Table 1). Blunn Creek is located in South Austin, and drains into the Colorado River. The catchment is divided into eight subbasins. Spatial information on the creek was downloaded through the city of Austin's Floodpro program, a database containing information on the Austin watersheds (austintexas.gov/floodpro).

The impervious cover for each subbasin in the catchment was found by intersecting the spatial information on Blunn Creek and the land use rasters for 2001 and 2011 (Figure 7a and b). The percent impervious area was then calculated by dividing the area for each land use type by the total area (Table 3). The land use characterized as 21: developed, open space, was not used in the impervious number calculation. The composite soil curve number for each subbasin was calculated by taking in the percent of each land use and multiplying by its curve number (Table 1). Soil hydrologic group C was chosen as an average soil group for the Blunn Creek watershed, based on a Wetland Studies report on soil groups across the United States.

The lag time between rainfall and runoff was calculated using the SCS Lag Equation (1973). The equation takes the form:

$$t_c = \frac{100\ L^{0.8}[\left(\frac{1000}{CN}\right) - 9]^{0.7}}{1900\ S^{0.5}}$$

where t_c is the lag time in minutes, L is the longest flow path in feet, CN is the SCS Curve Number, and S is the slope of the subbasin (in %). The lag time was calculated for each subbasin and summed across the subbasins to get the travel time of water from the head of the catchment to the outlet (Table 3).

Table 1: Land use and its associated soil curve number.

LUValue	Land Use	A	B	C	D
11	Open Water (assumed water)	98	98	98	98
21	Developed; assumed 12% Impervious	46	65	77	82
22	Developed; assumed 38% Impervious	61	75	83	87
23	Developed; assumed 65% Impervious	77	85	90	92
24	Developed; assumed 85% Impervious	89	92	94	95
31	Barren Soil, Rock, and Gravel	77	86	91	94
41	Forest (Deciduous)	30	58	71	78
42	Forest (Evergreen)	30	58	71	78
43	Forest (Mixed)	30	58	71	78
52	Shrub and Scrub (assumed Agricultural)	67	77	83	87
71	Grassland (assumed Agricultural)	67	77	83	87
81	Pasture/Hay	49	69	79	84
82	Cultivated Crops	67	77	83	87
90	Woody Wetlands (assumed water)	98	98	98	98
95	Emergent Wetlands (assumed water)	98	98	98	98

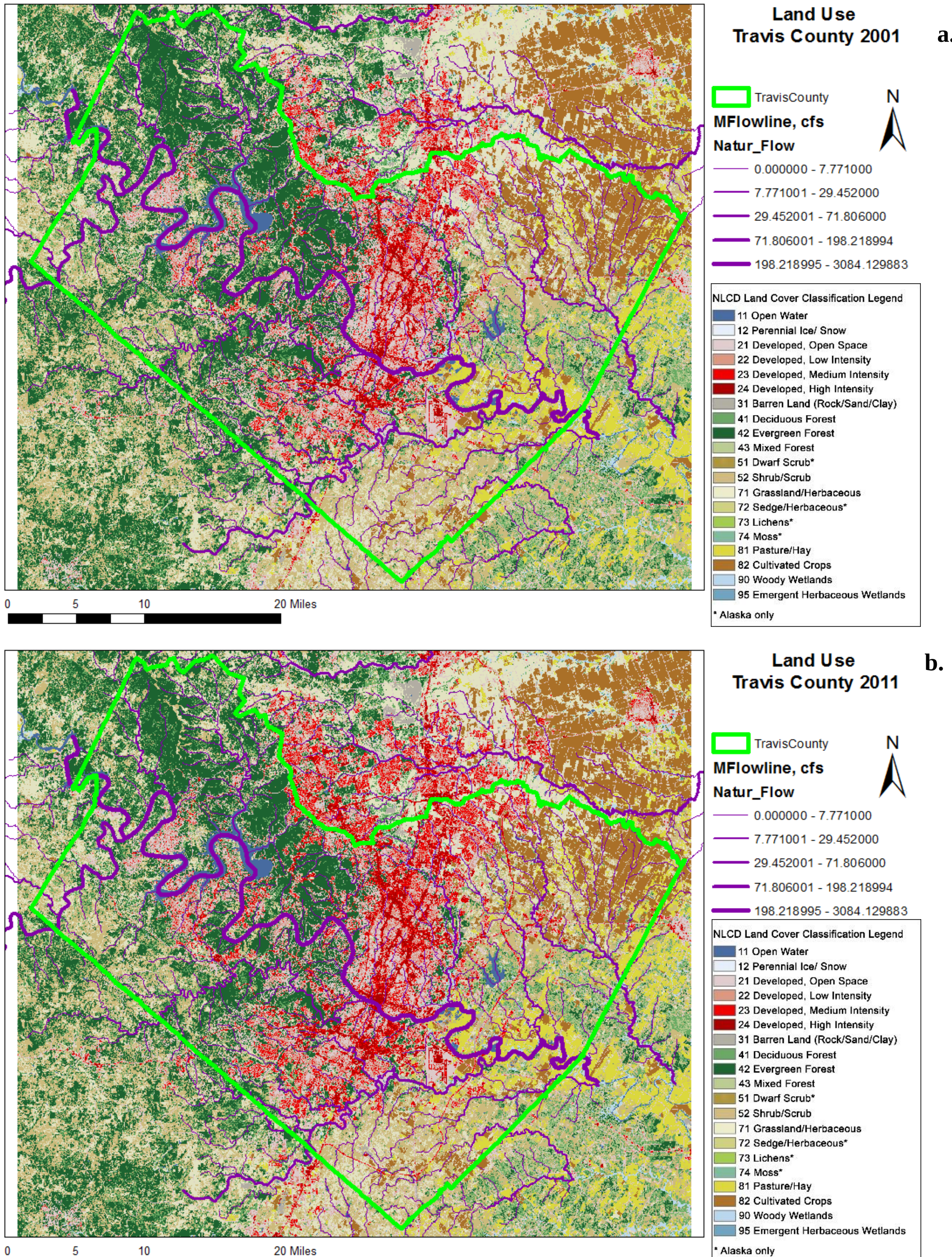

Figure 3a and b: Maps of land use in Travis County in 2001 and 2011. Data is 30 meter resolution from the MRLC NLCD. The county saw increased development north of Travis County and around the Lake Travis area between 2001 and 2011.

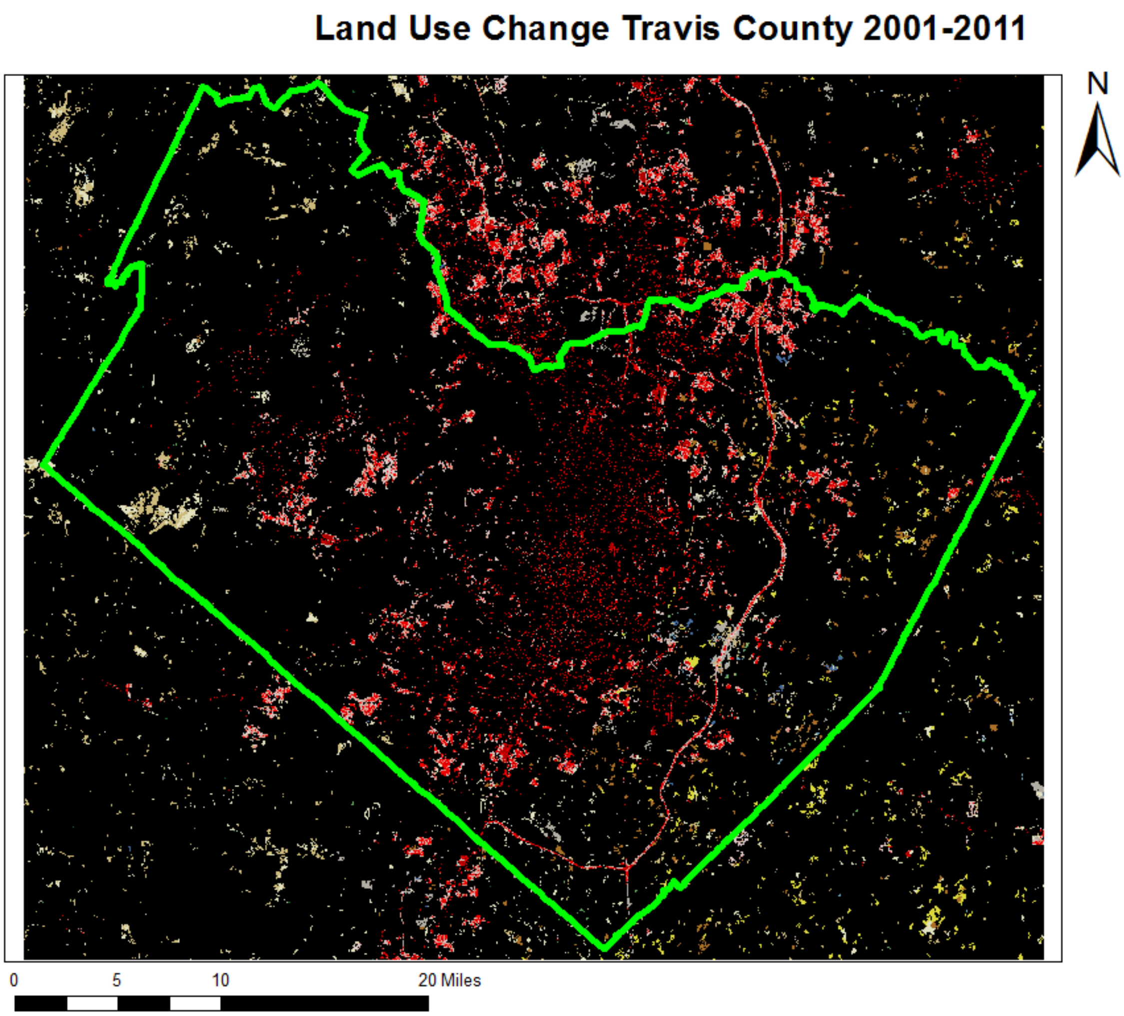

Figure 4: Map of the land use change in Travis County from 2001 to 2011. Data from the MRLC NLCD.

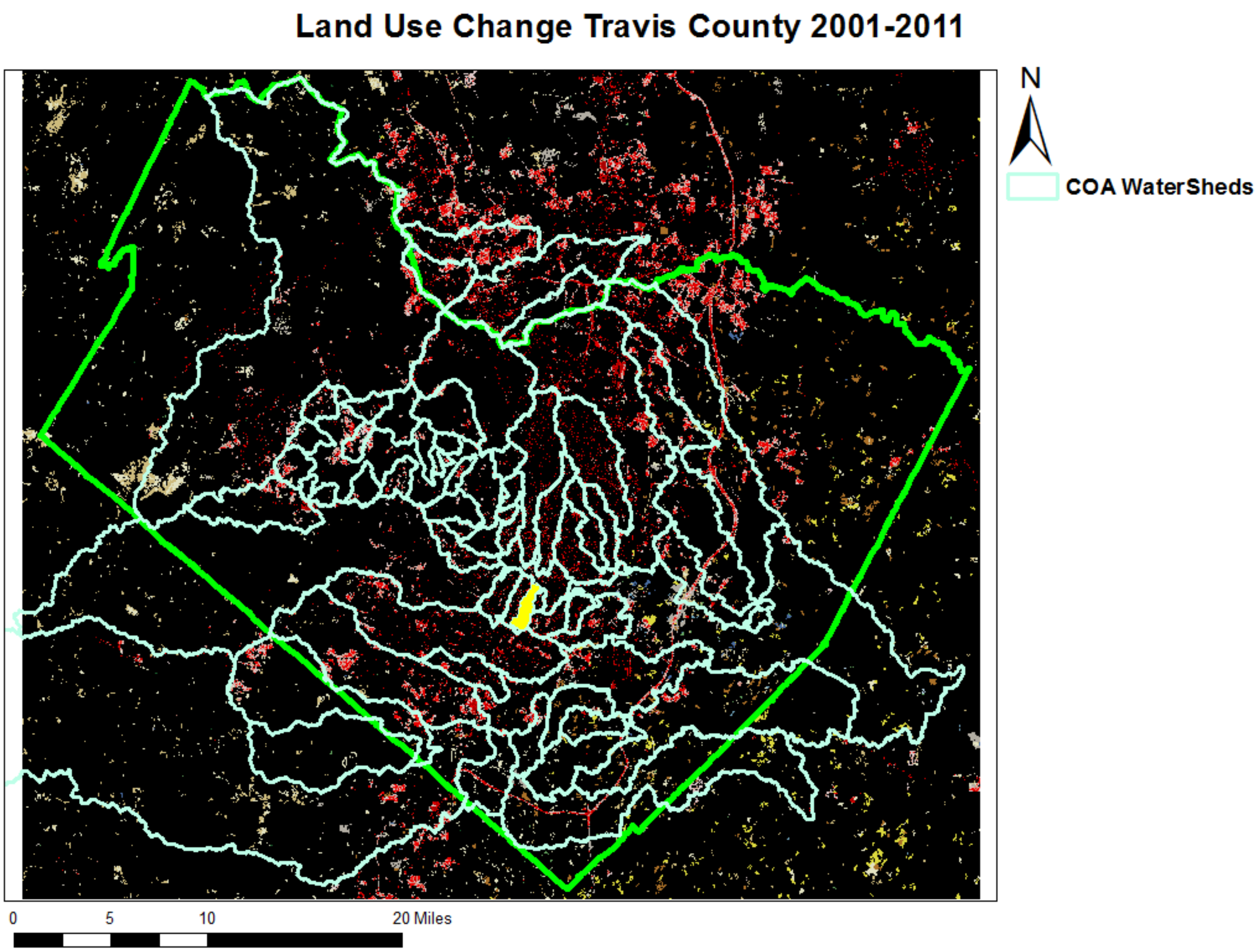

Figure 5: Map of the land use change in Travis County with the city of Austin watershed boundaries on top. This map was used to select a catchment for the study. The catchment highlighted in yellow is the Blunn Creek watershed, the catchment chosen for analysis.

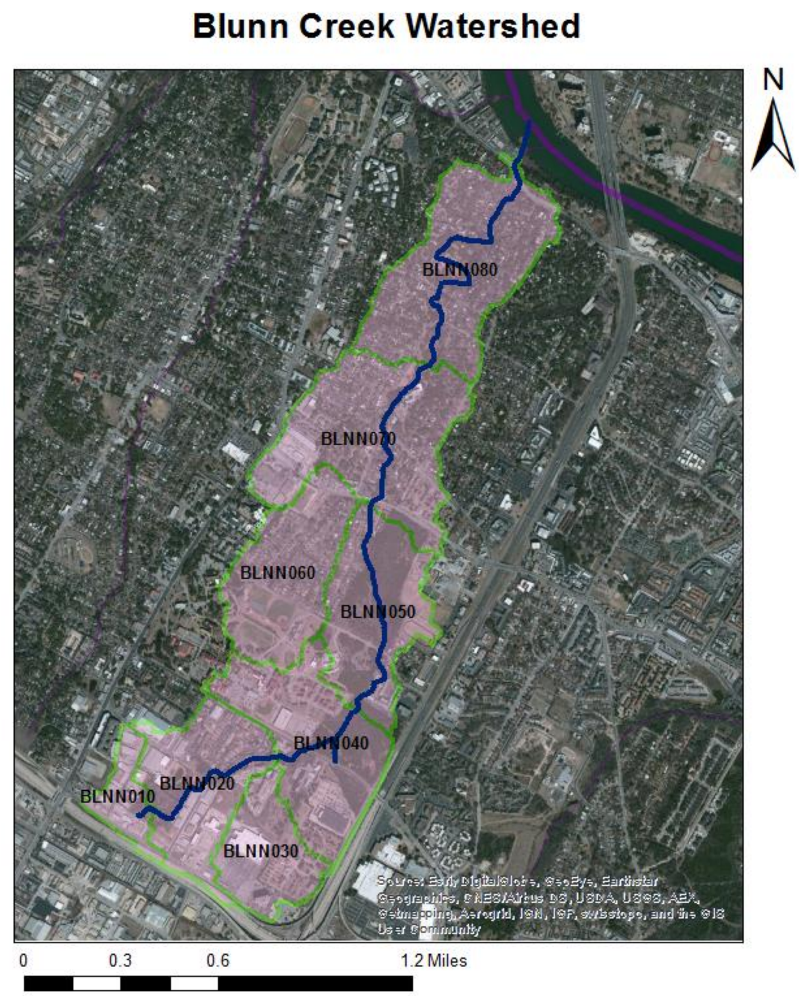

Figure 6: Map of the Blunn Creek watershed. The subbasins are denoted in green. The creek drains into the Colorado River.

Table 2: Spatial information about the Blunn Creek watershed. The total area is 1.258 square miles with an average slope of ~0.93%.

Subbasin	Area, Square Miles	Longest Flow Path, feet	Slope, %
80	0.23	6673	0.90
70	0.238	4412	1.66
60	0.156	4201	0.65
50	0.158	4460	0.30
40	0.186	3285	0.90
30	0.095	2910	1.32
20	0.152	3647	0.78
10	0.043	2862	0.93
Total	1.258		

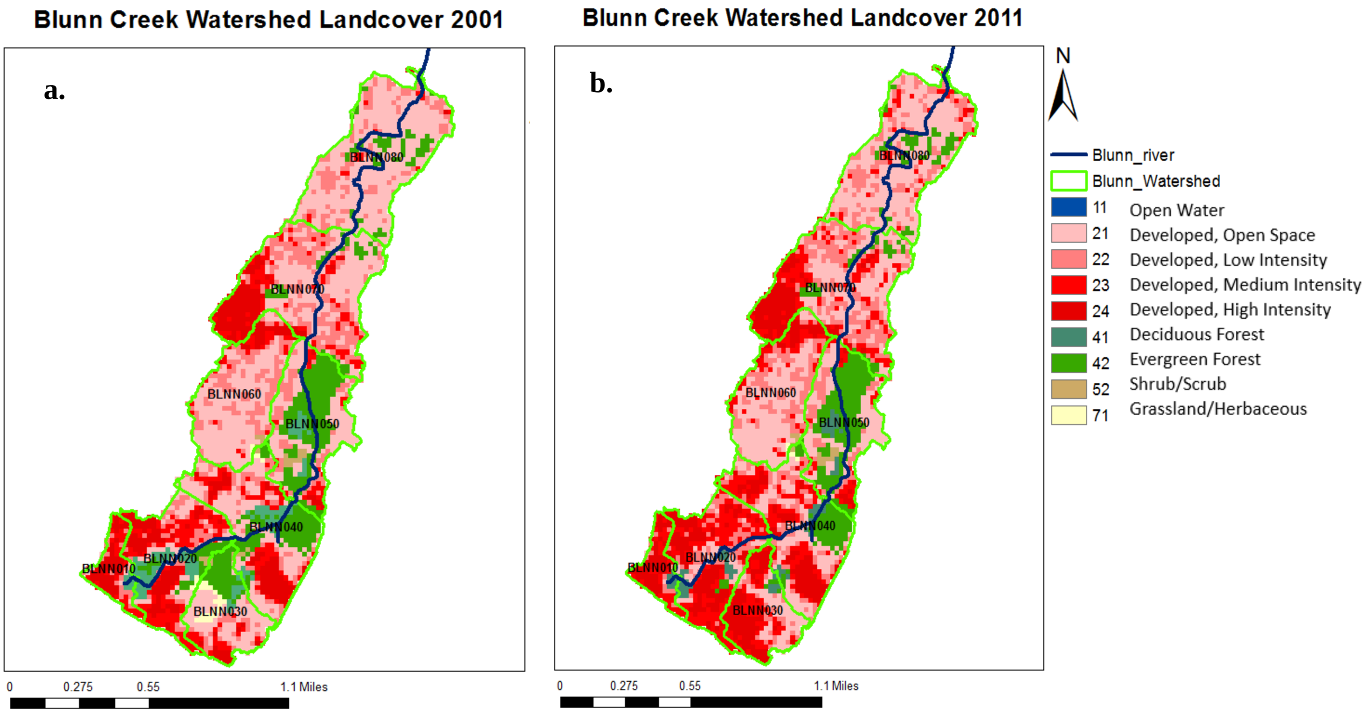

Figure 7a and b: Maps showing the land cover in Blunn Creek in 2001 and 2011. These maps were used to find the percent change in impervious cover, and the soil curve number in the two time periods.

Table 3: The % impervious, soil curve number, and lag time for the subbasins in Blunn Creek Watershed in 2001 and 2011. The lag time show in the time for water to exit the entire catchment.

	2001			**2011**		
Subbasin	**%Impervious**	**CN**	**Lag time (min)**	**%Impervious**	**CN**	**Lag time (min)**
80	21%	78	163	30%	79	159
70	55%	82	238	62%	83	231
60	41%	81	360	47%	82	349
50	21%	76	455	23%	76	446
40	39%	80	541	56%	83	526
30	27%	79	608	72%	87	578
20	62%	84	698	82%	87	657
10	88%	88	756	91%	90	712
Total	**41%**			**56%**		

Modeling

A HEC-HMS (Hydrologic Engineering Center Hydrologic Modeling System) model was downloaded from the city of Austin Floodpro modeling database for the Blunn Creek watershed (austintexas.gov/floodpro). HEC-HMS is a model created by the Army Corps of Engineers that can calculate rainfall-runoff flows in a catchment. In the model, the catchment is divided into subbasins, reaches, an outlet, and junctions (Figure 8).

The model components consist of basin models, meteorological models, and control specifications. The basin model contains the information about the catchment, such as area, and the parameters of interest in this study: % impervious cover, SCS Curve Number (CN) and the lag time. In order to compute surface runoff, loss and transform methods are chosen to calculate rainfall into runoff. The SCS Curve Number and SCS Unit Hydrograph methods were chosen for this analysis. The SCS Curve Number method computes incremental runoff based on the infiltration properties of the soil. The SCS Unit Hydrograph method uses a time lag to relate the centroid of precipitation to the peak flow in the hydrograph.

The meteorological model specifies the type of storm event desired in the simulation. The SCS method for storm design was used. This method uses a cumulative distribution to temporally distribute rainfall over the surface in a 24 hour period (Figure 9). The 10-year storm event occurs over 24 hours and results in 6.1 inches of precipitation. The 100-year storm event also occurs over 24 hours and results in 10.2 inches of precipitation over the watershed. The control specifications designate the run time of the simulation and the time step. The runoff is calculated for a 4 day period, at 10 minute timesteps.

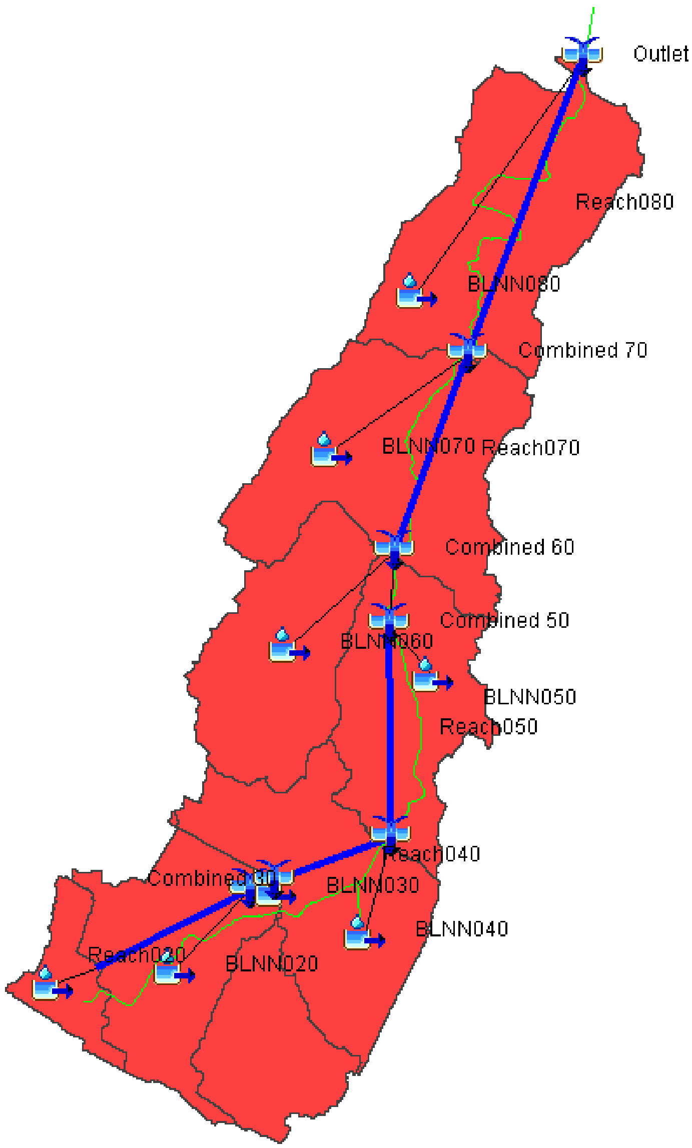

Figure 8: Basin model of the HEC-HMS model created for the simulation of Blunn Creek flows.

Results

The Blunn Creek watershed saw a 15% change in impervious cover between 2001 and 2011 (Table 3). The greatest change was in subbasin 30, which changed from 27% to 72% impervious. Subbasin 30 has a large area that went from an Evergreen forest to a developed surface of medium and high intensity. All areas saw an increase in % impervious cover. All subbasins also saw an increase in SCS Curve Number except for subbasin 50. The lag time for all subbasins decreased with a total time change for the catchment of 44 minutes. The biggest change in lag time was in subbasin 30, with 15 minute decrease in lag, followed by subbasin 20, with a 10 minute decrease in lag.

In the 10 year storm, the peak discharge increased by 10 percent between 2001 and 2011 (Tables 4 and 5, Figures 9a and b). The peak discharge in 2001 was 779 cfs and was 863 cfs in 2011. All subbasins and reach saw an increase in the flow between 2001 and 2011. While the outlet hydrograph does not show the change in time (Figure 9), the peak of the hydrograph would likely appear earlier than in 2001, about 44 minutes earlier. The subbasin with the greatest change in impervious cover, subbasin 30, had a 40% increase in discharge (Figure 10) and appeared 15 minutes earlier is 2011. The peak discharge increased from 80.4 cfs in 2001 to 113.3 cfs in 2011. Subbasins 20 and 40 saw the greatest change after subbasin 30, with 14.4% and 13.7% increase in outflow (Table 8).

Table 4: Summary of the 2001 Blunn Creek 10 year storm simulation outflows.

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Outlet	1.258000	779.0	01Jan2001, 14:00	4.74
BLNN080	0.230000	103.0	01Jan2001, 15:00	4.18
Combined 70	1.028000	693.7	01Jan2001, 13:40	4.87
BLNN070	0.238000	213.7	01Jan2001, 13:20	5.19
Combined 40	0.476000	390.7	01Jan2001, 13:30	4.99
BLNN010	0.043000	50.3	01Jan2001, 13:00	5.93
BLNN040	0.186000	141.3	01Jan2001, 13:30	4.74
Combined 20	0.195000	171.2	01Jan2001, 13:20	5.53
BLNN030	0.095000	80.4	01Jan2001, 13:10	4.40
Combined 50	0.634000	415.4	01Jan2001, 13:40	4.75
BLNN060	0.156000	97.3	01Jan2001, 14:10	4.85
BLNN050	0.158000	55.5	01Jan2001, 16:00	4.02
BLNN020	0.152000	125.5	01Jan2001, 13:30	5.41
Reach080	1.028000	692.4	01Jan2001, 14:00	4.87
Reach070	0.790000	508.9	01Jan2001, 13:50	4.77
Reach050	0.476000	389.0	01Jan2001, 13:40	4.99
Reach040	0.290000	249.5	01Jan2001, 13:30	5.16
Reach020	0.043000	49.7	01Jan2001, 13:10	5.93
Combined 30	0.290000	250.4	01Jan2001, 13:20	5.16
Combined 60	0.790000	509.0	01Jan2001, 13:50	4.77

Table 5: Summary of the 2011 Blunn Creek 10 year storm simulation outflows.

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Outlet	1.258000	863.6	01Jan2001, 13:50	5.08
BLNN080	0.230000	111.0	01Jan2001, 14:50	4.47
Combined 70	1.028000	774.5	01Jan2001, 13:30	5.22
BLNN070	0.238000	222.5	01Jan2001, 13:20	5.37
Combined 40	0.476000	455.0	01Jan2001, 13:20	5.59
BLNN040	0.186000	161.7	01Jan2001, 13:20	5.26
Combined 20	0.195000	192.6	01Jan2001, 13:20	5.87
BLNN030	0.095000	113.3	01Jan2001, 12:50	5.68
Combined 50	0.634000	478.2	01Jan2001, 13:30	5.21
BLNN060	0.156000	101.9	01Jan2001, 14:00	5.03
BLNN050	0.158000	56.7	01Jan2001, 15:50	4.07
BLNN020	0.152000	142.7	01Jan2001, 13:20	5.83
BLNN010	0.043000	52.0	01Jan2001, 13:00	6.00
Reach080	1.028000	774.1	01Jan2001, 13:50	5.22
Reach070	0.790000	570.9	01Jan2001, 13:40	5.18
Reach050	0.476000	453.8	01Jan2001, 13:30	5.59
Reach040	0.290000	293.3	01Jan2001, 13:20	5.81
Reach020	0.043000	51.7	01Jan2001, 13:10	6.00
Combined 30	0.290000	295.7	01Jan2001, 13:10	5.81
Combined 60	0.790000	569.3	01Jan2001, 13:30	5.18

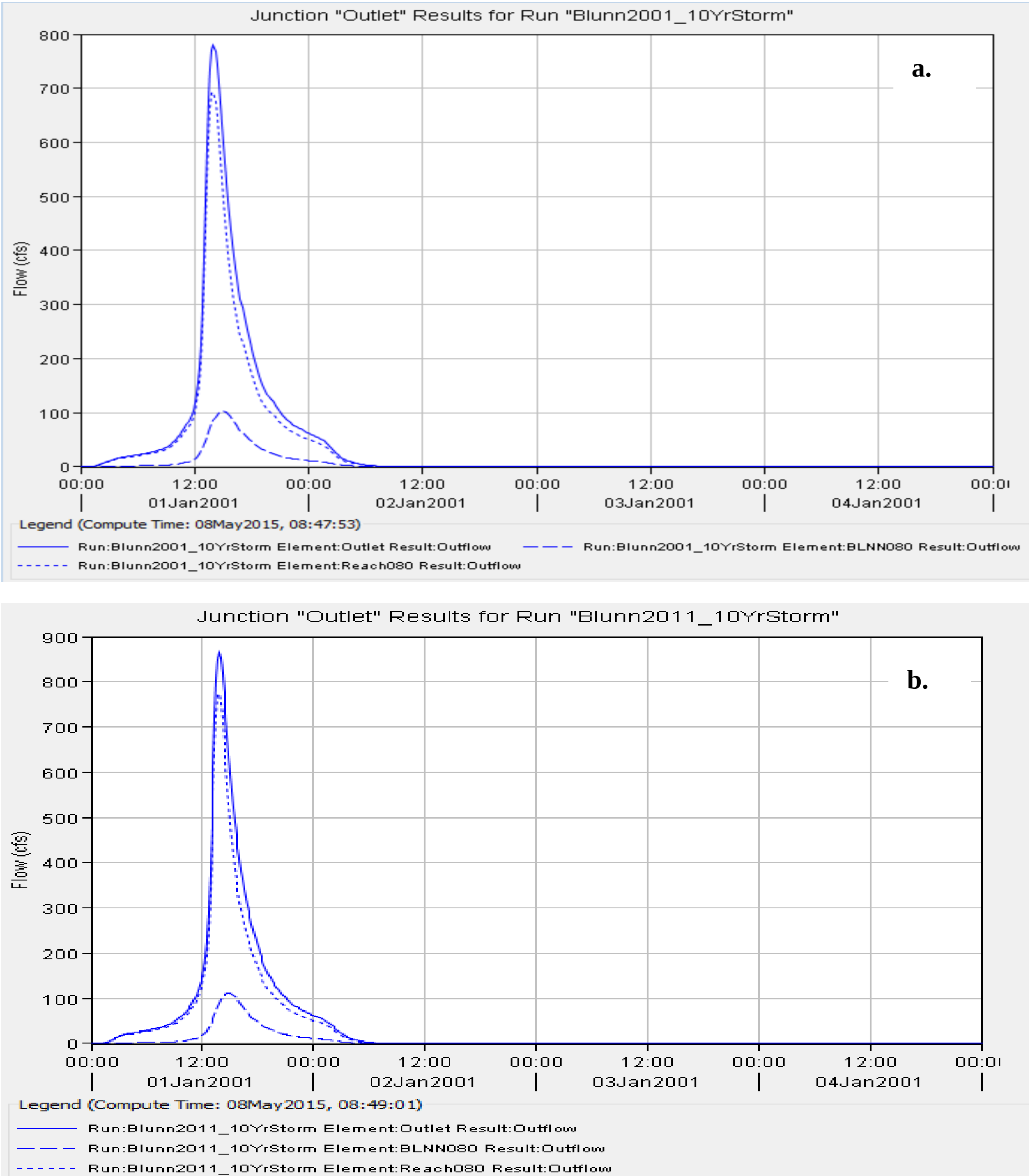

Figure 9a and b: Graph of the outlet hydrograph for the 2001 (a) and 2011 (b) 10 year storm event.

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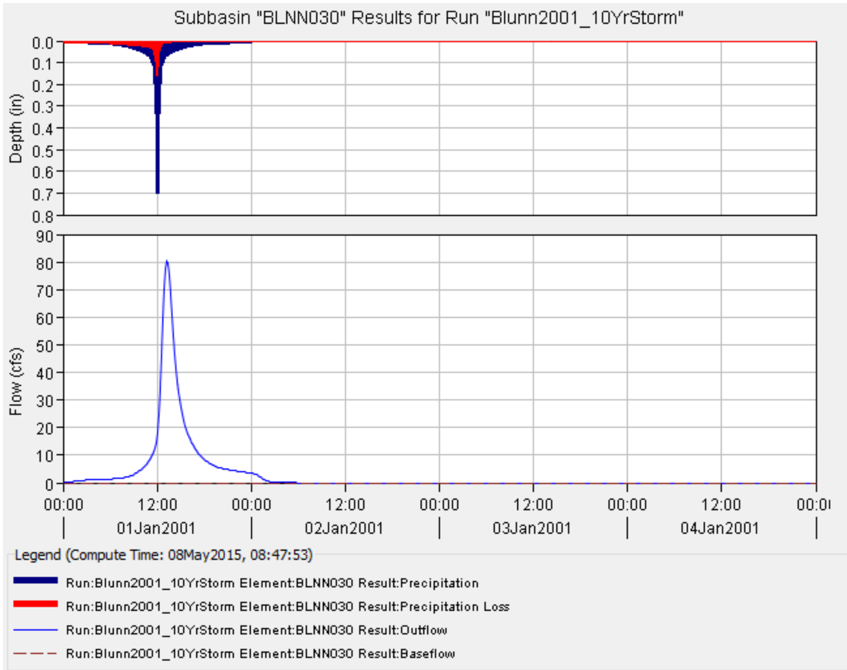

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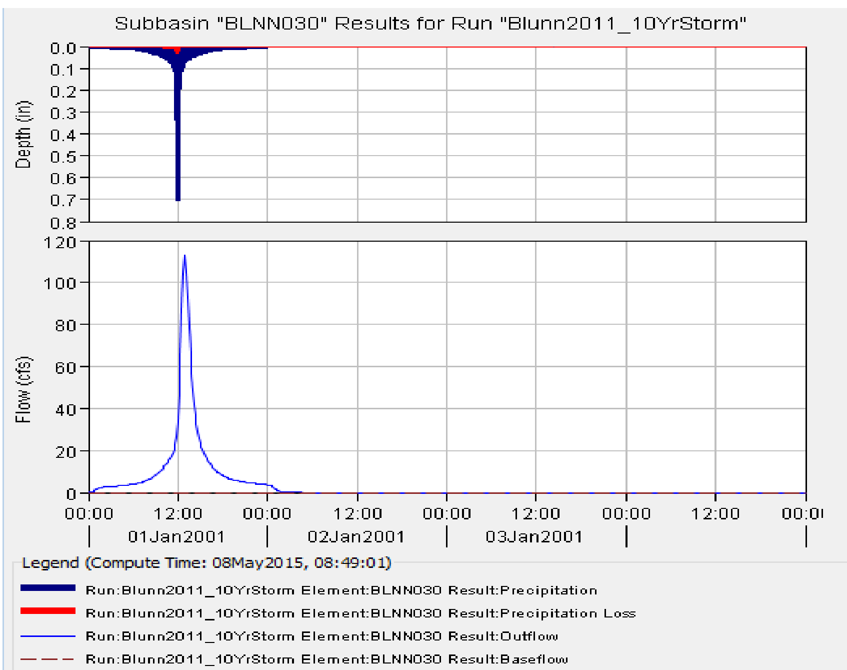


Figure 10a and b: Subbasin 30 hydrograph and precipitation hyetograph for the 2001 (a) and 2011 (b) 10 year storm event.

The 100-year storm event saw peak flows change at the outlet of the catchment from 1426.3 cfs in 2001 to 1529.1 cfs in 2011 (Tables 6 and 7, Figure 11). This is a 7% increase from 2001. All basin elements saw an increase in flow from the 10 year to the 100 year storm but the change in flow between 2001 and 2011 was not as great. Subbasin 30 outflow changed from 151.4 cfs to 193.7 cfs resulting in a 28% increase between 2001 and 2011..

Table 6: Summary of the 2001 Blunn Creek 100 year storm simulation outflows.

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Outlet	1.258000	1426.3	01Jan2001, 14:00	8.68
BLNN080	0.230000	198.8	01Jan2001, 14:50	8.03
Combined 70	1.028000	1263.0	01Jan2001, 13:40	8.82
BLNN070	0.238000	378.0	01Jan2001, 13:20	9.20
Combined 40	0.476000	700.9	01Jan2001, 13:30	8.97
BLNN010	0.043000	84.8	01Jan2001, 13:00	10.02
BLNN040	0.186000	259.0	01Jan2001, 13:30	8.68
Combined 20	0.195000	296.0	01Jan2001, 13:20	9.58
BLNN030	0.095000	151.4	01Jan2001, 13:10	8.29
Combined 50	0.634000	756.9	01Jan2001, 13:40	8.68
BLNN060	0.156000	176.7	01Jan2001, 14:10	8.81
BLNN050	0.158000	109.0	01Jan2001, 15:50	7.83
BLNN020	0.152000	218.8	01Jan2001, 13:30	9.45
Reach080	1.028000	1255.3	01Jan2001, 14:00	8.82
Reach070	0.790000	921.4	01Jan2001, 13:50	8.71
Reach050	0.476000	701.5	01Jan2001, 13:40	8.97
Reach040	0.290000	441.9	01Jan2001, 13:30	9.15
Reach020	0.043000	83.9	01Jan2001, 13:10	10.02
Combined 30	0.290000	444.5	01Jan2001, 13:20	9.15
Combined 60	0.790000	923.4	01Jan2001, 13:40	8.71

Table 7: Summary of the 2011 Blunn Creek 100 year storm simulation outflows

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
Outlet	1.258000	1529.1	01Jan2001, 13:50	9.07
BLNN080	0.230000	208.7	01Jan2001, 14:50	8.37
Combined 70	1.028000	1358.7	01Jan2001, 13:30	9.22
BLNN070	0.238000	388.5	01Jan2001, 13:20	9.40
Combined 40	0.476000	782.1	01Jan2001, 13:20	9.65
BLNN040	0.186000	284.9	01Jan2001, 13:20	9.27
Combined 20	0.195000	325.9	01Jan2001, 13:20	9.95
BLNN030	0.095000	193.7	01Jan2001, 12:50	9.75
Combined 50	0.634000	831.8	01Jan2001, 13:30	9.21
BLNN060	0.156000	182.7	01Jan2001, 14:00	9.02
BLNN050	0.158000	110.7	01Jan2001, 15:50	7.89
BLNN020	0.152000	242.1	01Jan2001, 13:20	9.91
BLNN010	0.043000	87.3	01Jan2001, 13:00	10.09
Reach080	1.028000	1357.2	01Jan2001, 13:50	9.22
Reach070	0.790000	997.4	01Jan2001, 13:40	9.17
Reach050	0.476000	780.6	01Jan2001, 13:30	9.65
Reach040	0.290000	498.4	01Jan2001, 13:10	9.89
Reach020	0.043000	86.9	01Jan2001, 13:10	10.09
Combined 30	0.290000	502.0	01Jan2001, 13:10	9.89
Combined 60	0.790000	996.6	01Jan2001, 13:30	9.17

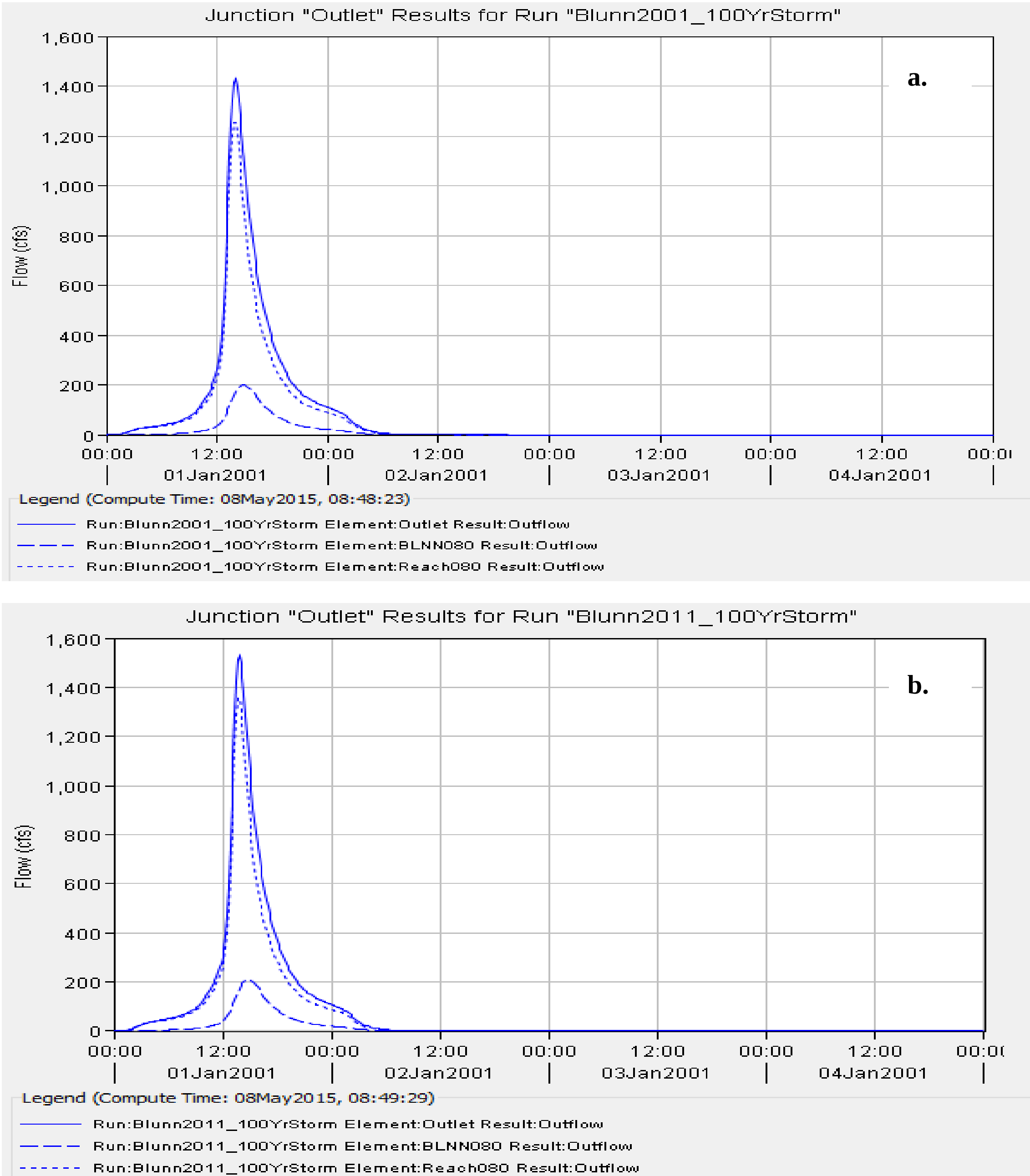
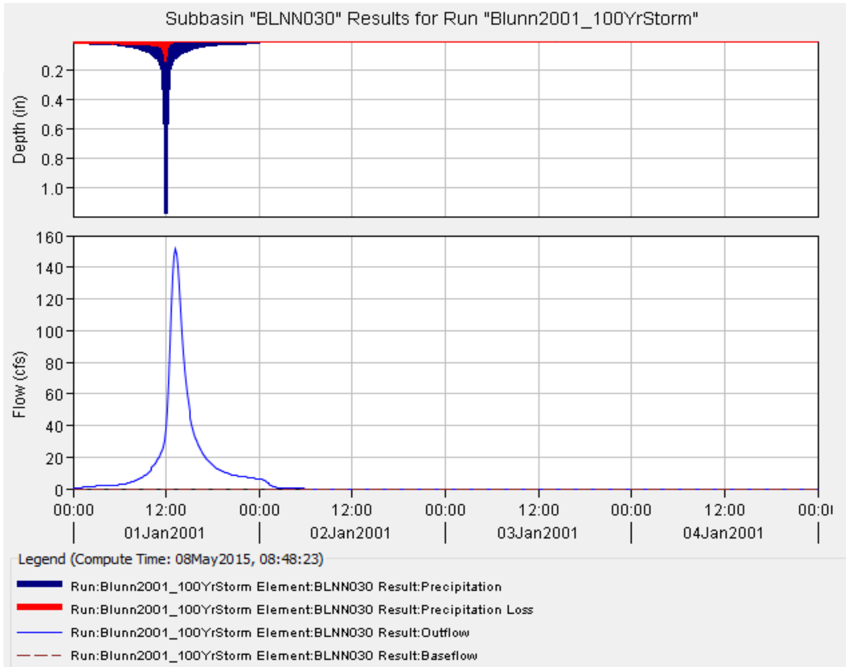


Figure 11a and b: Graph of the outlet hydrograph for the 2001 (a) and 2011 (b) 100 year storm event.

a.



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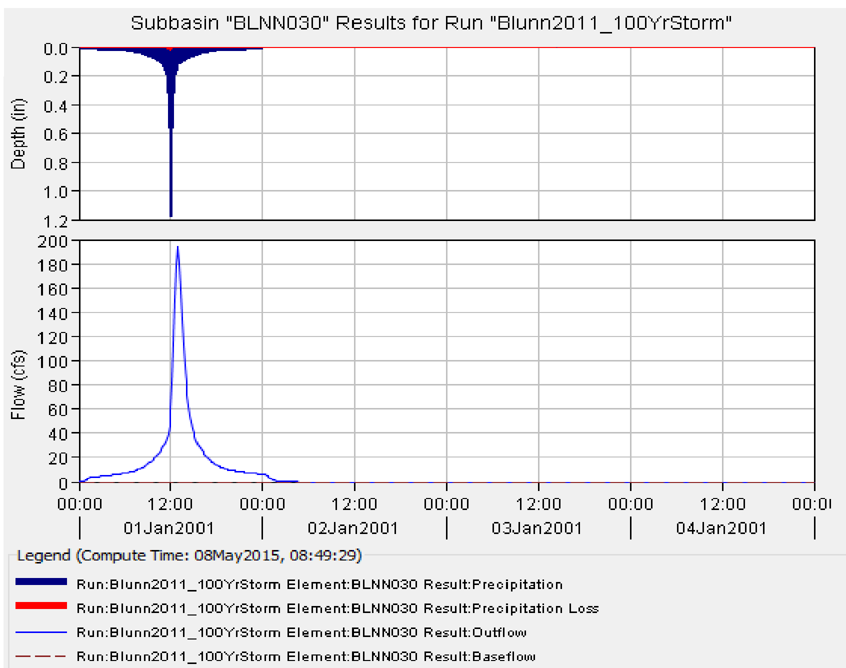

Figure 12a and b: Subbasin 30 hydrograph and precipitation hyetograph for the 2001 (a) and 2011 (b) 100 year storm event.

Table 8: Summary of the outflow and percent change for the outlet and subbasins between 2001 and 2011 for the 10-year and 100-year storm.

Subbasin	2001, 10yr cfs	2011, 10yr	%Change	2001, 100yr cfs	2011, 100yr cfs	%Change
Outlet	779	863.6	10.9%	1426.3	1529.1	7.2%
80	103	111	7.8%	198.8	208.7	5.0%
70	213.7	222.5	4.1%	378	388.5	2.8%
60	97.3	101.9	4.7%	176.7	182.7	3.4%
50	55.5	56.7	2.2%	109	110.7	1.6%
40	141.3	161.7	14.4%	259	284.9	10.0%
30	80.4	113.3	40.9%	151.4	193.7	27.9%
20	125.5	142.7	13.7%	218.8	242.1	10.6%
10	50.3	52	3.4%	84.8	87.3	2.9%

Conclusions

This analysis was able to quantify the relationship between land use and water flow over the land surface. The study considered two different time periods on the Blunn Creek watershed, 2001 and 2011, that saw a 15% increase in impervious cover. The change in SCS Curve Number and lag time were also computed in order to simulate a runoff hydrograph for the catchment in a 10-year and 100-year storm event.

The outlet of the catchment received ~11% more flow in a 10-year storm when the impervious cover increased and received ~7% more flow in a 100-year storm. At the subbasin scale, flow increased from 3.4% to 40.9% in a 10-year storm event and increased from 2.8% to 27.9% in a 100-year storm. The outlet also received the bulk of the water ~45 minutes earlier than in 2001.

Taken over a larger area, this change in outflow could have serious implications for flooding of major developed areas. Water is reaching the outlet in greater volume and more quickly. Combine this for all catchments that drain into the Colorado River, and the increase in water being channeled is significant. Future urban planning and design should take into account that increasing impervious surface will put more pressure on drainage systems and increase the area of flood zones. Design flows for new development will have to reflect this change.

Future work will extend this analysis to all of the watersheds in Travis County, in order to get an estimate of city-wide and county-wide changes to urban hydrology. A goal would be to optimize the land use in an area to be able to handle development but also provide space for infiltration to occur. In this way, flood zones would impact less area. Soil moisture and baseflow will also have to be taken into consideration for future simulations, in order to get a more robust estimate of the hydrograph.

References

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