IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 2, Issue 7, Jul 2014, 19-32

ASSESSING THE IMPACT OF REZONING AND URBANIZATION ON SURFACE WATERSHED HYDROLOGY

RAVIKUMAR B. CHOODEGOWDA[1], GILBERT MALINGA[2] & KEDARNATH[3]

[1]Associate Professor, Department of Agricultural Engineering, University of Agricultural Sciences, Bangalore, Karnataka, India

[2]Research Scholar, Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, KS, USA

[3]Senior Research Fellow, Department of Agricultural Engineering, University of Agricultural Sciences, Bangalore, Karnataka, India

ABSTRACT

Land development in urbanized watersheds poses a potential of increasing storm runoff rates and therefore increasing the risk of flooding in the downstream areas of a watershed. To investigate the temporal change in land use practices on the watershed hydrology, a hydrological analysis was conducted on Little Kitten Creek watershed located near Manhattan city of Riley county, Kansas, USA. Native land use types in the watershed changed in to commercial development and residential parcels due to rapid development over the period of ten years. Data collected and analyzed included digital elevation model (DEM) of study site, stream network and soil data using Arc GIS and Arc-Hydro Software. Watershed characteristics were also computed. The delineated watershed boundary, stream segments and soil data layers were over laid to produce soil maps. Time of concentration (T_c) was determined for the pre and post development conditions in the watershed using seven different methods. These computed time of concentration values were observed to be shorter for the post-development condition when compared to the pre-development condition of the watershed. The reduced time of concentration in the post development condition is attributed to increase in percentage of impervious areas due to increased residential development in the watershed resulted in increased runoff rates.

KEYWORDS: Rezoning, Time of Concentration, DEM, Arc Hydro, Kinematic Wave, Drainage Density, Circularity Ratio

INTRODUCTION

Little Kitten Creek watershed is located in Riley county, near Manhattan city of Kansas State, USA, and covers an area of 619.50 hectares. A watershed analysis was conducted in 2008 on Little Kitten Creek watershed to investigate the impact of post development land use practices on the watershed hydrology. Prior to development, land cover/ land use types in the watershed included woodland, pasture, fallow land, and partial residential housing. However, rapid rezoning and urbanization has occurred in the watershed in the last ten years. Post development land use practices include commercial development, residential housing, and conservation (woodland and grasslands).

The objectives of this study are:

- Delineate the watershed and compute drainage area.

- Investigate watershed characteristics such as slope, soil types, land use types, and time of concentration (T_c)* during pre development and post development scenarios in the watershed.

  *Time of concentration is the time taken by water to flow from remote point to the outlet of a watershed

  The analysis of Little Kitten Creek watershed is presented as shown below.

MATERIALS

Site Location

Little Kitten creek watershed is located in the southern part of Riley county near Manhattan city in Kansas, USA Figure 1. The predominant hydrologic soil groups of the watershed are C and D and received annual average precipitation of 762.0 mm. Land use types during pre-development and post-development conditions in the watershed are shown in figures 2 and 3.

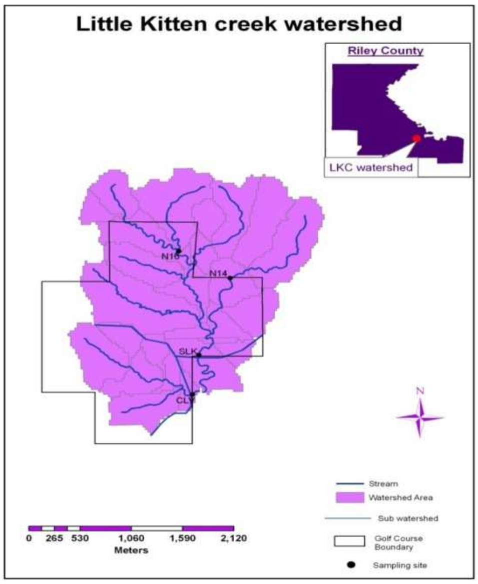


Figure 1: Little Kitten Creek Watershed: A General View

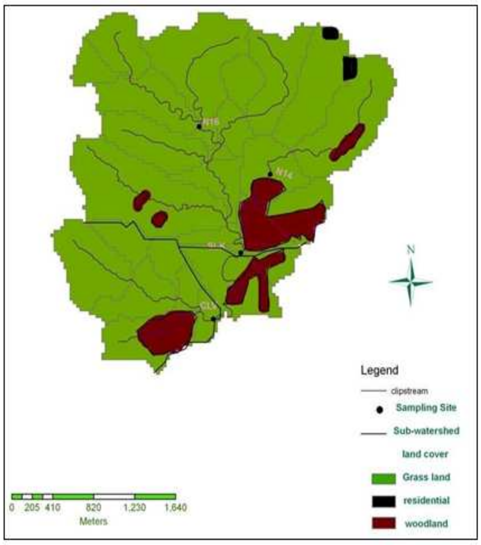


Figure 2: Land Use Types at Little Kitten Creek Watershed: A Pre-Development View

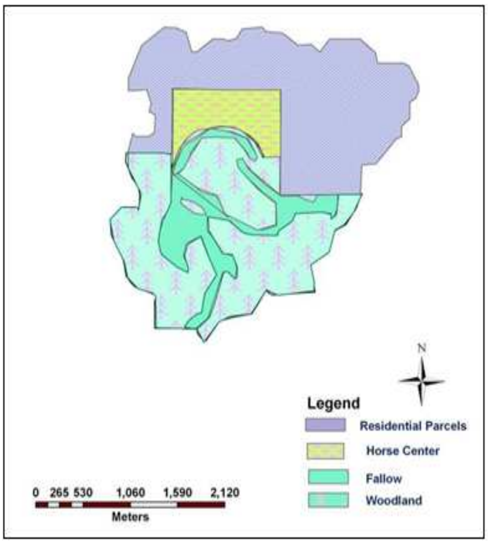
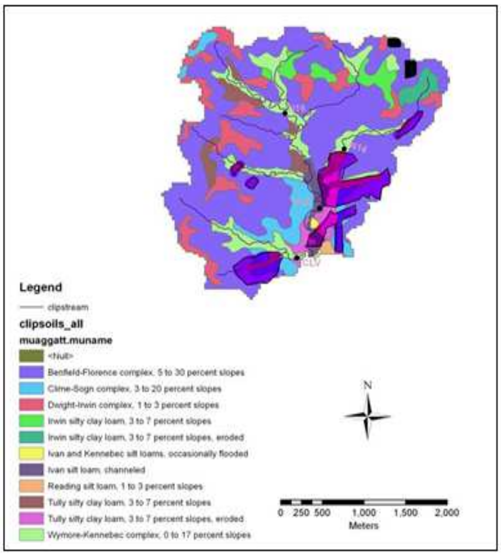


Figure 3: Land Use Types at Little Kitten Creek Watershed: A Post-Development View

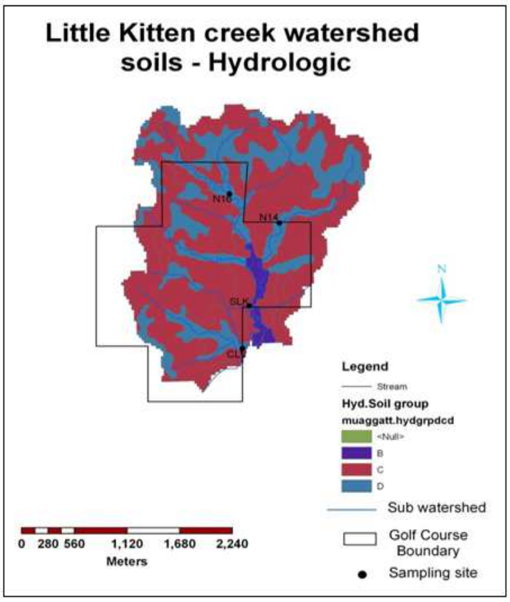
METHODS

In order to conduct a preliminary hydrological analysis of Little Kitten Creek watershed, certain data requirements had to be fulfilled. Data collected and analyzed included digital elevation model (DEM) of study site downloaded from Kansas Geospatial Community Commons database, stream network data from National Hydrologic Database (NHD), and soil data from Soil Survey Geographic Database (SSURGO). The DEM of the watershed and stream net work data were used to delineate the watershed and sub-watershed boundaries Figure 1, and 2 using Arc GIS (ESRI, 2006) and Arc-Hydro Software (Maidment, 2002). The delineated watershed boundary, stream segments and soil data layers were over laid to produce soil maps Figure 4 and Figure 5. In order to determine the size of the watershed drainage area, topographic map (7.5 minutes series, scale 1: 24,000) was used to delineate watershed boundary and a planimeter used to calculate the drainage area. Watershed characteristics such as slopes, channel length, circularity ratios, and drainage density were also computed as shown in the appendix.



Source: SSURGO Database

Figure 4: Soil Characteristics of Little Kitten Creek Watershed



Source: SSURGO Database

Figure 5: Hydrologic Classification of Soils on Little Creek Watershed

Time of concentration was calculated using Kirpich, Kerby, Izzard, Bransby-Williams, Federal Aviation Agency, Kinematics wave, and NRCS (SCS) methods for two sampling sites (points B and C) in the watershed. Time of concentration was determined for pre and post development scenarios in the watershed using seven different methods. Results of time of concentration are shown in figures 6 and 7 while detailed calculations are presented in the appendix. In calculating time of concentration, weighted values of land uses constants k and r were calculated for Kerby and Izzard methods respectively.

NRCS runoff curve numbers (CN) were also computed for pre and post-development scenarios of the watershed. The runoff curve numbers could be used to determine amount of runoff from the watershed.

RESULTS

Results and discussion of the watershed analysis is presented below.

The drainage area of the watershed was determined and a summary of the results is shown in Table 1.

Table 1: Drainage Area of Little Kitten Creek Watershed

Watershed Area	Hectares	Sq. m
Topographic Map Method	619.50	6.19×10^6

Other watershed characteristics such as watershed length, channel length, and length to center of area were also determined as shown in table 2

Table 2: Watershed Characteristics

L (m)	Lc (m)	Lc_{10-85} (m)	Lca (m)
4455	4305	3228.50	2148.52

Note: L-watershed length, Lc-channel length, Lc_{10-85}-channel length between 10%-85% of total channel length, Lca-Length to center of area.

Table 3: Watershed and Channel Slope Values

Slope	Percent (%)	m/m
S	1.5	0.015
Sc	1.3	0.013
$Sc_{10\text{-}85}$	1.2	0.012

Note: S-Watershed Slope, Sc-Channel Slope, $Sc10_{\text{-}85}$-Channel Slope between 10% and 85% of channel total length.

Table 4: Parameters of Each Segment of Principal Flow Path

Segment	Elevation Change	Length (L), m	Slope (S), m/m	Slope, %
1	31	1478	0.021	2.10
2	2	385	0.005	0.52
3	7	212	0.033	3.30
4	10	665	0.015	1.50
5	2	212	0.009	0.94
6	3	1347	0.002	0.22
7	41	1142	0.036	3.59
8	43	1429	0.030	3.01
9	52	2383	0.022	2.18
10	25	758	0.033	3.30
11	40	1417	0.028	2.82
12	50	1700	0.029	2.94
13	23	834	0.028	2.76

Table 5: A Summary of Watershed Ratios

Ratio	Ratio Value
Elongation Ratio (Re)	0.88
Circularity Ratio (Fc)	1.26
Circularity Ratio (Rc)	0.63

Curve numbers for pre development and post development scenarios in the watershed were calculated as shown in table 6 and 7 respectively.

Table 6: Curve Numbers for Pre-Development Condition

Cover Description	Soil Group	Curve Number	Area (ha)	Area x Curve Number
		(CN)	(A)	A*(CN)
Residential	C	77	3.34	257.56
Grassland (meadow)	B	58	5.53	320.87
	C	71	437.04	31,029.87
	D	78	110.64	8,630.17
Woodland	B	55	3.14	172.90
	C	70	50.30	3,520.86
	D	77	9.43	726.18
			∑A=619.43	44,658.40
			Weighted CN = ∑A*CN/ ∑A	29.19

Table 7: Curve Numbers for Post-Development Condition

Cover Description	Soil Group	Curve Number (CN)	Area (ha) (A)	Area x Curve Number A*(CN)
Residential				
	C	77	163.00	12,550.69
	D	82	108.66	8,910.45
Golf Course Turf			0.00	0.00
	C	74	102.02	7,549.80
	D	80	25.51	2,040.49
Woodland	B	55	2.61	143.62
	C	70	41.78	2,924.70
	D	77	7.83	603.22
Farmstead (Housing)	C	82	7.29	597.57
Parking	D	98	12.15	1,190.28
Bare Ground (Compacted)	D	91	19.43	1,768.42
Pasture (Good Condition)	C	74	9.72	719.03
Fallow (with residue)	B	83	2.39	198.26
	C	88	95.55	8,408.10
	D	90	21.50	1,934.82
			∑A = 619.43	49,539.43
			Weighted CN =	32.38

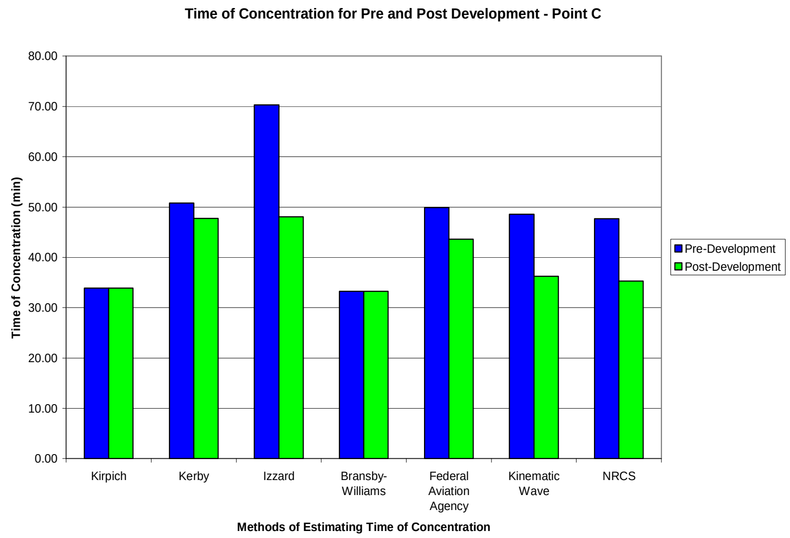


Figure 6: Comparison of Time of Concentration at Sampling Point C, Estimated Using Seven Different Methods

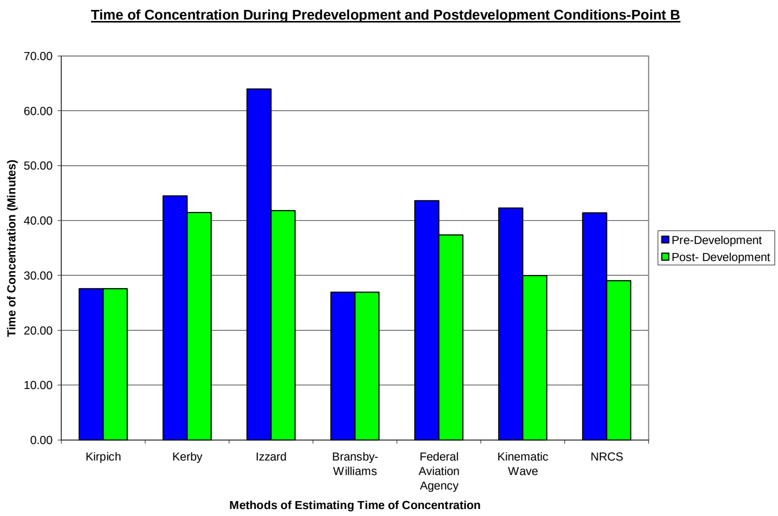


Figure 7: Comparison of Time of Concentration at Sampling Point B, Estimated Using Seven Different Methods

DISCUSSIONS

Among the seven methods used to calculate time of concentration during predevelopment condition of the watershed Figures 6 and 7, it was observed that the Bransby-Williams and Izzard methods showed the lowest and highest time of concentration of 26.95 and 33.22 minutes (point B and C) and 64.00 and 70.26 minutes (point B and C) respectively. Other methods like Kerby, Kirpich, Kinematic wave and NRCS showed moderate values time of concentration in between the lowest and highest values computed using Bransby-Williams and Izzard methods.

Time of concentration during post-development condition was calculated and compared with time of concentration calculated for pre-development condition. As shown in figures 6 and 7, the time of concentration in both scenarios showed a similar trend for the Kerby, Izzard, Federal Aviation Agency, Kinematic and NRCS methods. However estimates of time of concentration for post development condition were much shorter compared to observed estimates of time of concentration during pre-development condition. The reduced time of concentration during the post development condition is attributed to the increase in the percentage of impervious areas in the watershed due to increased residential development. It is also worth noting that, estimates of time of concentration calculated using the Kirpich and Bransby-Williams methods showed similar results in both pre and post development conditions of the watershed. The time of concentration values computed using the Kerby, Federal Aviation Agency, Kinematic Wave and NRCS (SCS) seem more reasonable compared to the other remaining three methods used.

CONCLUSIONS

Watershed analysis was conducted on Little Kitten Creek watershed. Different watershed characteristics were investigated to aid the watershed analysis. Time of concentration was determined for the pre and post development conditions in the watershed using seven different methods. The time of concentration values computed using Kerby, Federal Aviation Agency, Kinematic Wave and NRCS (SCS) methods seem more reasonable compared to the other remaining three methods used.

The computed time of concentration values (using Kerby, Federal Aviation Agency, Kinematic Wave and NRCS

(SCS) methods), were observed to be shorter for the post-development condition when compared to the pre-development condition of the watershed. The reduced time of concentration in the post development condition is attributed to increase in percentage of impervious areas in the watershed; therefore increased rates of runoff in the watershed are expected.

REFERENCES

1. Gupta, R.S., 2001, Hydrology and Hydraulic Systems, 2nd ed., Waveland Press, Inc, Prospect Heights, Illinois, Kansas Geospatial Community Commons., http://www.kansasgis.org
2. Maidment, D. R. 2002, Archydro. GIS for water resources. Redland: ESRI Press.
3. McCuen, R.H., 2004, Hydrology Analysis and Design, 3rd ed., Pearson Prentice Hall, Inc., Upper Saddle River, NJ, United states Department of Agriculture (USDA) / Natural Resources Conservation Services (NRCS), Riley County Soil Survey Geographic Database (SSURGO), 2006, http://soildatamart.nrcs.usda.gov
4. USGS, National Hydrography Dataset (NHD), 2006. http://nhdgeo.usgs.gov
5. Veissman warren, Jr. *et al*., 1989, Introduction to Hydrology, 3rd ed., Harper Collins Publishers, NY.

APPENDICES

Watershed Slope

Watershed Slope (S) = ΔE/L

Watershed Slope (S) = (410-345) m / 4455m = 0.015 m/ m = 0.015 ft/ft

Watershed Slope (S) = 0.015 x 100 = 1.5 %

Watershed Slope (S) = ((410-345) m / 0.305 m/ft) / (4455 m/ 0.305 m/ft) / 5280 ft/mi) = 77.0 ft/mi

Watershed Slope (Sc10-85) = (ΔE85-ΔE10)/Lc85-10

Watershed Slope (S) = (385-347) m / 3228.5m = 0.012 m/ m = 0.012 ft/ft

Watershed Slope (S) = 0.012 x 100 = 1.2 %

Watershed Slope (S) = ((385-347) m / 0.305 m/ft) / (3228.5 m/ 0.305 m/ft) / 5280 ft/mi) =

= 62.14 ft/mi

Channel Slope (Sc) = ΔE/L

Channel Slope (Sc) = (410-345) m / 4305m = 0.013 m/ m = 0.013 ft/ft

Channel Slope (Sc) = 0.013 x 100 = 1.3 %

Channel Slope (Sc) =((410-345) m / 0.305 m/ft) /(4305 m/ 0.305 m/ft) / 5280 ft/mi) = 67.46ft/mi

Where

ΔE- Change in elevation between two points in the watershed.

L- Watershed length

S- Watershed slope

Sc- Channel slope

Sc_{10-85} - Channel slope

Watershed Ratios

Elongation Ratio (Re)

Table 8

Re =	$2*(A/\pi)^{0.5}/Lm$
Re =	0.88

Circularity Ratio (Fc)

Table 9

Fc =	$P/(4\pi A)^{0.5}$
Fc =	1.26

Circularity Ratio (Rc)

Table 10

Rc =	A/Ao
Rc =	0.63

Where;

A- Area of watershed (ft^2)

Ao- Area of circle that has a perimeter equal to the perimeter of the watershed.

Lm- Maximum length of the watershed parallel to the principal drainage lines.

P- Perimeter of watershed (ft)

Drainage Density

Drainage Density = Total Stream Length/ Drainage Area

Drainage Density = 8.92377mi/ 2.39139 = 3.73 mi/ sq.mi

Time of Concentration

Pre-Development Condition at Point C

Table 11

Kirpich			**L=**	**250**	**ft**		
Tc1 =	$0.0078*L^{0.77}/S^{0.385}$						
Tc1 =	2.79	min					
Tc2 =	31.08	min					
Tc =	33.87	min					
Kerby							
Tc =	$0.828*(rL/S^{0.5})^{0.467}$		r = 0.4	L=	250	ft	
			(av. grass)				
Tc1 =	19.69	min					

Table 11: Contd.,

Tc2 =	31.08	min					
Tc=	50.77	min					
Izzard							
Tc1 =	$41.025(0.007i+k)L^{0.33}/S^{0.333}i^{0.667}$			L=	250	ft	
				i=	2	in/hr	5yr-1hr r/f
Tc1 =	39.18	min		k=	0.046		
Tc2 =	31.08	min					
Tc=	70.26	min					
Bransby Williams							
Tc =	$0.00765*L/S^{0.2}*A^{0.1}$		L=	250	ft		
			A=	1530	ac		
Tc1 =	2.14	Min					
Tc2=	31.08	Min					
Tc=	33.22	Min					
Federal Aviation Agency							
Tc1 =	$0.388*(1.1-C)L^{0.5}/S^{0.333}$			C = 0.35			
Tc1 =	18.80	Min					
Tc2=	31.08	Min					
Tc=	49.88						
Kinematic Wave							
			L=14630.54 ft				
Tc1 =	$0.94L^{0.6}n^{0.6}/i^{0.4}S^{0.3}$		S=0.01459			Assume	
			I=	2in/hr		5yr 1hr storm	
Tc1 =	17.47	Min	n=0.1				
Tc2 =	31.07851	Min					
Tc=	48.55	Min					
NRCS							
Tc1 =	$0.42(nL)^{0.8}/(P_2)^{0.5}S^{0.4}$						
Tc_1 =	16.60	Min	V=	7.58	ft/s		
Tc_2 =	31.08	Min					
Tc Total =	**47.68**	**Min**					

Post - Development Condition at Point C

Table 12

Kirpich							
Tc1	$0.0078*L^{0.77}/S^{0.385}$						
Tc1	2.79	min					
Tc2 =	31.08	min					
Tc =	33.87	min					
Kerby							
Tc =	$0.828*(rL/S^{0.5})^{0.467}$						
			L=	250	ft		
Tc =	16.69	min	r=	0.3	poor grass		
Tc =	31.08	min					
Tc=	47.77	min					
Izzard							
Tc1 =	$41.025(0.007i+k)L^{0.33}/S^{0.333}i^{0.667}$						
	Weighted K = 0.012(316.4)+0.017(48)+0.06(870.6)+0.046(295)/1530						
Tc1 =	16.98	min					
Tc2 =	31.08	min	k=	0.01			
Tc =	48.06	min	I =	2.0 in/hr			

Table 12: Contd.,

Bransby Williams							
Tc =	$0.00765*L/ S^{0.2}*A^{0.1}$		L=	250	ft		
			A=	1530	ac		
Tc1 =	2.14	Min					
Tc2=	31.08	Min					
Tc=	33.22	Min					
Federal Aviation Agency							
Tc1 =	$0.388*(1.1-C)L^{0.5}/S^{0.333}$						
			C=	0.6			
Tc1 =	12.53539	Min	L=	250	ft		
Tc2 =	31.08	Min					
Tc=	43.61	Min					
Kinematic Wave			**L=300 ft**				
			L2=14630.54 ft				
Tc =	$0.94L^{0.6}n^{0.6}/ i^{0.4}S^{0.3}$		S=0.01459		Assume		
			I=	2	5yr 1hr storm		
Tc1 =	5.141411	Min	n=0.018				
Tc2 =	31.07851	Min					
Tc Total =	36.22	Min					
NRCS				n=	0.018		
Tc1 =	$0.42(nL)^{0.8}/(P_2)^{0.5}S^{0.4}$						
Tc_1 =	4.209702	Min					
Tc_2 =	31.07851	Min		V =	$1.486*(R^{2/3}*S^{1/2})/n$		
Tc Total=	35.29	Min		A =	h(b+hz)		
				P=	$b+ 2h(1+z^2)^{1/2}$		
				h =	1.8		
				b =	8		
				z =	4		
				A =	27.36		
				P =	22.84318		
				n=	0.025		
				Rh =	1.20		
				V =	7.58	ft/s	

Pre - Development at Point B

Table 13

Kirpich			**L=**	**250**	**ft**		
Tc1 =	$0.0078*L^{0.77}/S^{0.385}$						
Tc1 =	2.79	min					
Tc2 =	24.81	min					
Tc =	27.60	min					
Kerby							
Tc =	$0.828*(rL/S^{0.5})^{0.467}$		r = 0.4	L=	250	ft	
			(av.grass)				
Tc1 =	19.69	min					
Tc2 =	24.81	min					
Tc=	44.50	min					
Izzard							
Tc1 =	$41.025(0.007i+k)L^{0.33}/S^{0.333}i^{0.667}$			L=	250	ft	
				i=	2	in/hr	5yr-1hr r/f
Tc1 =	39.18	min		k=	0.046		

Table 13: Contd.,

Tc2 =	24.81	min					
Tc=	64.00	min					
Bransby Williams							
Tc =	$0.00765*L/ S^{0.2}*A^{0.1}$		L=	250	ft		
			A=	1530	ac		
Tc1 =	2.14	Min					
Tc2=	24.81	Min					
Tc=	26.95	Min					
Federal Aviation Agency							
Tc1 =	$0.388*(1.1\text{-}C)L^{0.5}/S^{0.333}$			C = 0.35			
Tc1 =	18.80	Min					
Tc2=	24.81	Min					
Tc=	43.62	Min					
Kinematic Wave							
			L=14630.54 ft				
Tc1 =	$0.94L^{0.6}n^{0.6}/ i^{0.4}S^{0.3}$		S=0.01459			Assume	
			I=	2	in/hr	5yr 1hr storm	
Tc1 =	17.47	Min	n=0.1				
Tc2 =	24.81244	Min					
Tc=	42.28	Min					
NRCS							
Tc1 =	$0.42(nL)^{0.8}/(P_2)^{0.5}S^{0.4}$						
Tc_1 =	16.60	Min	V=	7.58	ft/s		
Tc_2 =	24.81	Min					
Tc Total =	41.41	Min					

Post- Development at Point B

Table 14

Kirpich					
Tc1	$0.0078*L^{0.77}/S^{0.385}$				
Tc1	2.79	min			
Tc2 =	24.81	min			
Tc =	27.60	min			
Kerby					
Tc =	$0.828*(rL/S^{0.5})^{0.467}$				
			L=	250	ft
Tc =	16.69	min	r=	0.3	poor grass
Tc =	24.81	min			
Tc=	41.50	min			
Izzard					
Tc1 =	$41.025(0.007i+k)L^{0.33}/S^{0.333}i^{0.667}$				
Tc1 =	16.98	min			
Tc2 =	24.81	min		k=	0.012
Tc =	41.79	min		I =	2.0 in/hr
Bransby Williams					
Tc =	$0.00765*L/ S^{0.2}*A^{0.1}$		L=	250	ft
			A=	1530	ac

Table 14: Contd.,

Tc1 =	2.14	Min			
Tc2=	24.81	Min			
Tc=	26.95	Min			
Federal Aviation Agency					
Tc1 =	$0.388*(1.1-C)L^{0.5}/S^{0.333}$			C=	0.6
				L=	250
Tc1 =	12.53539	Min			
Tc2 =	24.81	Min			
Tc=	37.35	Min			
Kinematic Wave			**L=300 ft**		
			L2=14630.54 ft		
Tc =	$0.94L^{0.6}n^{0.6}/ i^{0.4}S^{0.3}$		S=0.01459		Assume
			I=	2	5yr 1hr storm
Tc1 =	5.141411	Min	n=0.018		
Tc2 =	24.81244	Min			
Tc Total =	29.95	Min			
NRCS			**n=**	**0.018**	
Tc1 =	$0.42(nL)^{0.8}/(P_2)^{0.5}S^{0.4}$				
Tc_1 =	4.209702	Min			
Tc_2 =	24.81244	Min	V =	$1.486*(R^{2/3}*S^{1/2})/n$	
Tc Total =	29.02	Min	A =	h(b+hz)	
			P=	$b+ 2h(1+z^2)^{1/2}$	
			h =	1.8	
			b =	8	
			z =	4	
			A =	27.36	
			P =	22.84	
			n=	0.025	
			Rh =	1.20	
			V =	7.58	ft/s