Comparison of Physical Characteristics for Selected Small Watersheds in Texas as Determined by Automated and Manual Methods

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The University of Houston, Lamar University, Texas Tech University and the U.S. Geological Survey conducted a study in cooperation with the Texas Department of Transportation to compare manually and automatically determined physical watershed characteristics. For this study, 96 Texas watersheds were selected to examine the relationships between manually and automatically determined physical characteristics. These watersheds were derived from USGS streamflow gaging stations and comprise a database (Asquith et. al. 2004) upon which the authors are conducting broader investigations of watershed unit hydrographs, rainfall hyetographs, and timing characteristics.

Six sets of manually and automatically determined physical characteristics were compared. Manual and automated measures of physical watershed characteristics are qualitatively similar; however the differences are statistically significant. Qualitative analysis suggested that a multiplicative correction factor could be applied to each manually determined characteristic. After correction, the differences between automated and "corrected" manual characteristics were not statistically significant. The ability to apply a single multiplicative correction factor to each characteristic suggests that method differences are systematic and scale with watershed size.

An illustrative application using Kirpich's (1940) formula for calculating time of concentration produced estimates well within an order of magnitude of the "correct" automated results. A statistical analysis indicated that the manual and automated time of concentration calculations are comparable when the underlying manual basin characteristics are corrected.

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Introduction

The U.S. Geological Survey, University of Houston, Lamar University and Texas Tech University conducted a study in cooperation with the Texas Department of Transportation of the comparability of manually and automatically determined watershed physical properties. The study was the result of an unusual opportunity when the University of Houston research team had manually determined watershed characteristics and later the U.S. Geological Survey automatically analyzed the same watersheds in support of another research project.

Watershed or "basin" physical characteristics such as drainage area, channel slope, channel length are important parameters in a variety of hydrologic models. In the present work the physical characteristics are used as explanatory variables to construct synthetic unit hydrographs.

For this study, 96 watersheds in Texas were selected to examine the relationships between manually and automatically determined physical characteristics. These watersheds have U.S.G.S. streamflow gaging stations and comprise a data base (Asquith et. al. 2004) upon which the authors have recently conducted or are conducting broader investigations of watershed unit hydrographs, rainfall hyetographs, and timing characteristics of watersheds in Texas (TxDOT Research Projects 0-2104; 0-4193; 0-4194; 0-4405; and 0-4696). The locations of the 96 watersheds are shown on Figure 1.

Physical watershed characteristics such as drainage area, channel slope, and channel length are important parameters in a variety of hydrologic models. When compared with manual derivation, computer technology (Geographic Information System; GIS) enhances the speed at which watershed boundaries and characteristics are generated. A collection of manually and automatically derived watershed characteristics was created in the course of the broader hydrologic studies, and presents an opportunity for comparison. In the remainder of this paper it is assumed that all GIS measures are the default "accurate" results, and specifically the area computed by the GIS for each watershed is the "nominal" area.

Methods

A collection of more than 20 basin characteristics was computed for 96 watersheds using GIS automation processes. These watershed data were compiled in a geo-database (spatial database) to provide a stable base dataset for the computation of several timing parameters. USGS gaging station locations were confirmed using latitude and longitude, addresses, and digital raster graphics of 7.5 minute topographic quadrangles (DRGs). Watersheds were automatically delineated from the 96 USGS gaging stations using 30-meter resolution elevation data obtained from The National Map Digital Elevation Model.

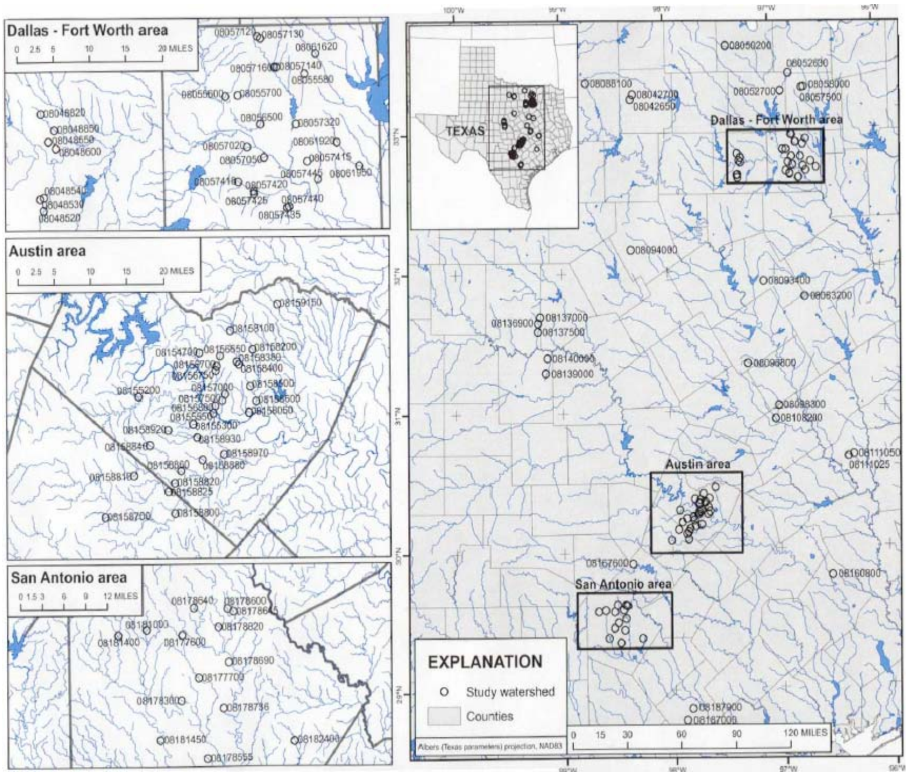

Figure 1. Study Watershed Locations

(Map courtesy of F.T. Heitmuller, Geographer, U.S. Geological Survey, Texas Water Science Center, 8027 Exchange Dr. Austin, TX., used with permission).

A collection of 8 basin characteristics were developed using manual methods. Paper-based 7.5 minute topographic maps were used as the data source for subsequent physical measurements. The characteristics selected reflect the kind of measurements available to civil engineers and convey hydrologic behavior. Traditionally area, distance, and slope are hydrologicaly important, however automated methods were used to compute many more characteristics well beyond the scope of the manual methodology. Of the 20 watershed characteristics that were considered by the USGS (Brown and others, 2000), only the 8 characteristics common to both methods are reported here.

Each characteristic is briefly described first the computed characteristic then its manual equivalent.

Total drainage area (TDA): Computed upon delineation of watershed boundaries. TDA is the area contained within the polygon that defines the watershed boundary.

Manual drainage area (TDA_M): The gaging station is located from the reported latitude and longitude, and the watershed is delineated by trial-and-error. A mechanical planimeter is used to measure the area in an initial enclosed curve. The measured area is compared to the nominal drainage area (Asquith and others, 2004) assigned to the watershed. The boundary is adjusted if the mechanical result and the nominal result differ by more than 10 percent. In most cases adjustments are relatively minor to achieve area differences less than 10 percent. The manual area is recorded in square miles.

Basin perimeter (BP): Computed upon delineation of watershed boundaries. BP is the arc-length of the watershed boundary polygon.

Manual basin perimeter (BP_M): The perimeter of the drainage area is determined by traversing the sketched perimeter with navigation dividers set to span 5 millimeters. The number of 5-millimeter increments required to traverse the perimeter is converted into a distance using the map scale. The value is recorded in units of miles.

Minimum basin elevation (MNELEV): Derived from the DEM.

Manual minimum basin elevation (MNELEV_M): The lowest elevation within the watershed – typically this should be at the outlet. Read from the topographic maps. The value is recorded in units of feet.

Maximum basin elevation (MXELEV): Derived from the DEM.

Manual maximum basin elevation (MXELEV_M): The highest elevation within the watershed. Read from the topographic maps. The value is recorded in units of feet.

Basin relief (BR): MXELEV-OUELEV, which is the difference between the highest cell value in the elevation grid of the basin and the elevation of the grid cell at the outlet.

Manual basin relief (BR_M): (MXELEV_M-MNELEV_M), which is the difference between the highest elevation of the basin and the lowest elevation of the basin. In the manual method the outlet is assumed to be the lowest elevation in the watershed. BR_M is recorded in feet.

Main channel length (MCL): The distance measured along the main channel (longest flow path) from the watershed outlet to the basin divide.

Manual main channel length (MCL_M): The length the main stream is determined by moving upstream from the station location following Horton's rules for navigating bifurcations. Once the stream is marked, navigation dividers are used in the same fashion as for perimeter. The value is recorded in units of miles.

Main channel slope (MCS) (Brown and others, 2000): Computed as the difference in elevation at 10 percent (E10) and 85 percent (E85) of the distance along the main channel from the outlet to the basin divide. MCS = (E85 – E10) / 0.75 (MCL), and alternate method is MCS = (E85-E10)/(L85-L10), where L85 and L10 are channel lengths up to 85 and 10 percent of the total length.

Manual main channel slope (MCS_M) : Computed as the difference in elevation at 10 percent (E10) and 85 percent (E85) of the distance along the main channel from the outlet to the basin divide. MCS_M = (E85 – E10) / 0.75 (MCL_M). MCS_M is conceptually similar to MCS as determined by the automated analysis.

Main channel slope (MCS2): MCS2 = (BDELEV-OUELEV)/MCL, the ratio of the basin divide elevation minus the outlet elevation to the main channel length (Asquith and Slade, 1997).

Manual main channel slope (MCS2_M): MCS2_M = (BR_M)/MCL_M, the ratio of the basin relief and main channel length. MCS2_M is conceptually similar to MCS2 determined by the automated analysis, except the manual method assumes the minimum elevation is the outlet elevation, while the automated method does not make this assumption. MCS2_M is recorded in feet per mile.

Selected Comparative Results

Table 1 is a list of all the study watersheds with the manual and automated physical parameters that are common or comparable.

Table 1. (1 of 3) Study Watersheds Characteristics

	Station Location		Drainage Area			Perimeter			Main Channel Length			Basin Relief			Main Channel Slope			Main Channel Slope		
Station_ID	LAT	LON	TDA (sq.mi.)	TDA_M (sq.mi.)	TDA_M-TDA	BP (miles)	BP_M (miles)	RERR (Perimeter)	MCL (miles)	MCL_M (miles)	MCL_M-MCL	BR (feet)	BR_M (feet)	BR_M - MR	MCS (feet/mile)	MCS_M (feet/mile)	MCS_M - MCS	MCS2 (feet/mile)	MCS2_M (feet/mile)	MCS2_M - MCS2
08155200	30()17'46"	97()55'31"	89.64	89.53	-0.11	67.67	97.91	30.24	28.50	29.17	0.67	752.2	723.0	-29.2	19.12	18.59	-0.54	25.58	24.78	-0.79
08155300	30()14'40"	97()48'07"	116.62	116.68	0.06	91.19	113.95	22.76	45.07	45.26	0.19	983.0	953.0	-30.0	15.27	15.79	0.52	21.28	21.05	-0.22
08158810	30()09'19"	97()56'23"	12.30	11.95	-0.34	19.69	17.07	-2.62	6.29	5.67	-0.62	374.1	324.0	-50.1	49.11	42.85	-6.26	58.53	57.13	-1.41
08158820	30()08'25"	97()50'50"	24.50	24.00	-0.06	37.06	28.52	-7.74	14.85	13.66	-0.44	590.6	574.0	-43.6	28.52	31.52	-2.54	39.40	42.03	-2.02
08158825	30()07'31"	97()51'43"	21.02	20.96	-0.50	29.08	21.34	-8.54	12.53	12.09	-1.19	443.6	400.0	-16.6	27.36	24.81	3.00	35.11	33.09	2.63
08158050	30()15'47"	97()40'20"	12.63	13.28	0.65	20.77	15.04	-5.73	7.36	6.92	-0.44	309.8	264.0	-45.8	39.30	28.62	-10.68	41.84	38.17	-3.68
08158880	30()10'50"	97()46'55"	3.57	3.55	-0.02	12.53	10.09	-2.44	4.40	1.79	-2.62	265.7	198.0	-67.7	43.18	83.11	39.93	59.50	110.82	51.32
08154700	30()22'19"	97()47'04"	22.78	21.52	-1.25	31.62	21.79	-9.83	10.04	7.91	-2.13	568.3	490.0	-78.3	36.29	46.46	10.17	56.46	61.94	5.48
08158380	30()21'15"	97()41'52"	5.26	5.38	0.12	13.01	8.71	-4.30	4.01	2.78	-1.23	155.8	140.0	-15.8	32.21	37.74	5.53	36.86	50.32	13.46
08158700	30()04'59"	97()00'29"	123.71	124.14	0.43	78.78	87.70	8.92	33.28	34.74	1.46	794.6	760.0	-34.6	16.27	16.41	0.14	23.83	21.88	-1.95
08158800	30()05'09"	97()50'52"	167.29	167.97	0.68	106.07	80.53	-25.54	48.94	49.92	0.98	1013.7	930.0	-83.7	13.86	13.97	0.11	20.68	18.63	-2.05
08156650	30()21'55"	97()44'11"	2.71	2.84	0.13	10.18	7.35	-2.83	3.00	2.24	-0.76	183.2	190.0	6.8	48.01	63.65	15.64	60.69	84.87	24.17
08156700	30()20'50"	97()44'41"	6.35	6.64	0.29	15.25	11.34	-3.91	4.53	3.73	-0.80	242.0	230.0	-12.0	34.00	46.23	12.23	48.81	61.64	12.82
08156750	30()20'21"	97()44'50"	6.84	7.27	0.43	16.59	12.31	-4.28	5.13	4.25	-0.88	257.9	250.0	-7.9	30.17	44.08	13.91	46.20	58.77	12.57
08156800	30()16'35"	97()45'00"	12.75	12.08	-0.66	29.34	20.15	-9.19	10.58	9.40	-1.18	438.7	410.0	-28.7	30.54	32.70	2.16	39.50	43.60	4.10
08158840	30()12'32"	97()54'11"	8.77	8.55	-0.22	17.86	11.72	-6.14	4.96	4.40	-0.56	313.8	231.0	-82.8	48.71	39.35	-9.37	62.90	52.46	-10.43
08158860	30()09'43"	97()49'55"	23.22	23.27	0.06	34.19	25.83	-8.36	12.79	11.57	-1.23	534.2	531.0	-3.2	31.97	34.43	2.46	41.58	45.91	4.32
08157000	30()17'49"	97()43'36"	2.21	2.29	0.07	10.14	7.84	-2.30	4.12	3.23	-0.89	212.6	200.0	-12.6	47.20	46.39	-0.80	51.71	61.86	10.15
08157500	30()17'08"	97()44'01"	4.17	4.07	-0.10	14.80	9.63	-5.17	5.16	4.02	-1.14	256.9	220.0	-36.9	45.56	41.02	-4.54	49.77	54.69	4.93
08158100	30()24'35"	97()42'41"	12.74	12.88	0.14	23.94	14.96	-4.88	5.67	4.33	-1.24	292.9	240.0	-7.1	47.13	41.59	4.89	48.15	55.45	13.97
08158200	30()22'30"	97()39'37"	26.43	26.47	0.36	32.88	20.97	-5.13	10.92	9.85	-1.67	401.7	330.0	-25.1	30.11	25.12	-2.37	35.00	33.50	6.18
08158400	30()20'57"	97()41'34"	5.71	5.85	0.14	14.17	9.29	-8.98	4.48	3.23	-1.34	167.1	160.0	-52.9	32.22	37.12	-5.54	35.52	49.49	7.29
08158500	30()18'34"	97()40'04"	12.13	12.49	0.04	22.22	17.09	-11.91	8.59	6.92	-1.06	315.1	290.0	-71.7	33.81	31.44	-4.98	35.74	41.92	-1.50
08158600	30()16'59"	97()39'17"	53.58	49.65	-3.94	53.69	35.97	-17.72	19.47	15.57	-3.90	528.9	480.0	-48.9	20.50	23.12	2.61	26.14	30.82	4.68
08155550	30()15'49"	97()45'17"	2.67	3.00	0.33	10.18	7.60	-2.58	3.66	2.61	-1.05	243.2	229.0	-14.2	69.95	65.76	-4.19	66.40	87.67	21.28
08159150	30()27'16"	97()36'02"	4.46	4.58	0.12	12.08	7.61	-4.47	3.74	2.91	-0.83	169.9	180.0	10.1	42.39	46.39	4.00	43.06	61.85	18.78
08158920	30()14'06"	97()51'36"	6.30	6.08	-0.22	14.80	10.45	-4.35	4.97	4.59	-0.39	315.4	276.0	-39.4	51.27	45.11	-6.16	61.92	60.14	-1.78
08158930	30()13'16"	97()47'36"	18.73	18.44	-0.29	30.35	20.38	-9.97	10.40	9.89	-0.51	492.8	426.0	-66.8	37.49	32.31	-5.17	46.73	43.08	-3.64
08158970	30()11'21"	97()43'56"	27.38	27.22	-0.15	42.02	32.27	-9.75	17.61	16.75	-0.85	607.4	600.0	-7.4	27.12	26.86	-0.26	34.08	35.81	1.74

Table 2. (2 of 3) Study Watersheds Characteristics

	Station Location		Drainage Area			Perimeter			Main Channel Length			Basin Relief			Main Channel Slope			Main Channel Slope		
Station_ID	LAT	LON	TDA (sq.mi.)	TDA_M (sq.mi.)	RERR (Area)	BP (miles)	BP_M (miles)	RERR (Perimeter)	MCL (miles)	MCL_M (miles)	RERR (Channel Length)	BR (feet)	BR_M (feet)	RERR(Relief)	MCS (feet/mile)	MCS_M (feet/mile)	RERR(MCS)	MCS2 (feet/mile)	MCS2_M (feet/mile)	RERR(MCS2)
08057320	32()48'18"	96()43'04"	7.17	10.85	3.68	16.63	16.99	0.36	5.42	4.73	-0.68	174.9	160.0	-14.9	34.40	25.34	-9.06	29.54	33.79	4.25
08055700	32()51'26"	96()50'12"	11.04	10.85	-0.19	21.47	16.99	-4.49	7.77	4.73	-3.03	213.2	110.0	-103.2	27.36	17.42	-9.93	26.66	23.23	-3.42
08057050	32()44'50"	96()47'44"	9.48	10.30	0.82	18.42	13.52	-4.89	6.21	5.45	-0.76	258.5	220.0	-38.5	38.34	30.30	-8.04	41.25	40.40	-0.85
08057020	32()46'01"	96()50'07"	4.53	5.11	0.58	15.14	11.25	-3.89	5.09	4.42	-0.67	261.8	220.0	-41.8	49.36	37.34	-12.02	51.26	49.78	-1.47
08057140	32()54'33"	96()45'54"	8.64	8.68	0.04	20.10	14.20	-5.89	7.47	7.02	-0.44	231.0	240.0	9.0	29.96	25.63	-4.33	30.40	34.17	3.77
08061620	32()55'53"	96()39'55"	7.68	9.75	2.07	17.00	12.95	-4.05	5.52	4.50	-1.02	122.7	110.0	-12.7	18.28	18.34	0.07	20.46	24.45	3.99
08057415	32()44'14"	96()41'36"	0.97	1.40	0.43	5.74	4.89	-0.86	1.88	1.18	-0.70	71.8	80.0	8.2	31.42	50.69	19.27	33.44	67.58	34.14
08057418	32()42'19"	96()51'32"	8.06	7.95	-0.11	18.45	17.84	-0.61	5.65	5.05	-0.60	235.8	290.0	54.2	38.01	43.06	5.06	41.60	57.42	15.82
08057420	32()41'15"	96()49'22"	14.39	14.25	-0.13	24.27	27.22	2.95	8.33	7.81	-0.52	285.1	280.0	-5.1	30.63	26.88	-3.75	34.08	35.84	1.76
08057160	32()54'33"	96()45'34"	4.60	4.24	-0.36	15.58	11.14	-4.45	5.34	3.79	-1.56	180.4	140.0	-40.4	32.55	27.72	-4.83	33.69	36.96	3.27
08055580	32()53'43"	96()41'36"	1.90	1.90	0.00	7.87	7.74	-0.13	3.00	3.06	0.06	115.0	103.0	-12.0	38.29	25.24	-13.05	38.04	33.65	-4.39
08055600	32()51'41"	96()52'27"	5.69	6.43	0.74	17.52	10.91	-6.61	6.74	4.97	-1.77	215.1	205.0	-10.1	31.12	30.93	-0.19	31.74	41.23	9.49
08057435	32()39'19"	96()44'41"	5.92	5.97	0.05	13.65	10.11	-3.54	4.12	4.02	-0.10	208.4	190.0	-18.4	45.98	35.41	-10.57	45.85	47.21	1.36
08057445	32()42'17"	96()40'11"	8.93	10.11	1.18	21.92	14.32	-7.60	8.42	8.52	0.11	170.3	180.0	9.7	18.62	15.84	-2.78	19.13	21.12	1.99
08057130	32()57'45"	96()47'44"	1.29	1.22	-0.08	7.31	5.00	-2.31	2.63	2.68	0.05	126.6	120.0	-6.6	41.20	33.54	-7.66	47.93	44.72	-3.20
08061920	32()46'09"	96()37'18"	12.89	13.60	0.71	24.57	17.39	-7.18	7.64	6.71	-0.94	156.5	140.0	-16.5	18.52	15.65	-2.87	20.54	20.87	0.33
08061950	32()43'32"	96()34'12"	23.31	23.30	-0.01	37.02	26.34	-10.68	12.65	12.23	-0.41	205.0	240.0	35.0	13.86	14.72	0.86	16.21	19.62	3.41
08057120	32()57'58"	96()48'11"	6.57	7.21	0.64	15.43	12.81	-2.62	5.19	4.89	-0.29	206.0	220.0	14.0	34.32	33.72	-0.60	39.13	44.97	5.83
08056500	32()48'26"	96()48'08"	6.36	9.06	2.70	17.22	14.66	-2.57	6.37	4.66	-1.71	218.0	190.0	-28.0	31.98	30.61	-1.38	33.46	40.81	7.35
08057440	32()29'26"	96()44'25"	2.62	2.62	0.00	9.69	9.08	-0.61	3.52	3.59	0.08	159.3	151.0	-8.3	45.31	31.52	-13.79	44.07	42.03	-2.05
08057425	32()40'58"	96()49'22"	10.33	10.83	0.50	19.20	16.36	-2.84	6.16	6.00	-0.16	270.2	305.0	34.8	37.37	38.14	0.77	41.59	50.85	9.26
08048550	32()47'19"	97()18'22"	1.11	0.90	-0.21	6.56	3.98	-2.58	2.02	1.58	-0.44	49.6	40.0	-9.6	23.62	19.01	-4.61	23.80	25.35	1.55
08048600	32()47'19"	97()18'22"	2.57	2.67	0.10	11.37	9.52	-1.85	3.85	3.16	-0.69	97.7	70.0	-27.7	23.70	16.63	-7.07	24.97	22.18	-2.79
08048820	32()50'22"	97()19'22"	5.66	5.66	0.00	16.85	11.46	-5.39	6.03	5.52	-0.50	190.9	170.0	-20.9	30.53	23.08	-7.45	31.52	30.77	-0.75
08048850	32()48'33"	97()17'28"	12.86	12.84	-0.02	26.88	18.60	-8.28	9.40	9.23	-0.16	251.4	260.0	8.6	25.45	21.12	-4.33	26.71	28.16	1.45
08048520	32()39'55"	97()19'16"	17.63	17.65	0.01	24.31	16.59	-7.72	7.53	8.05	0.52	219.6	165.0	-54.6	25.61	15.37	-10.24	26.83	20.50	-6.33
08048530	32()41'08"	97()19'44"	0.97	0.98	0.01	4.96	3.57	-1.39	1.70	0.95	-0.75	106.3	110.0	3.7	65.92	87.12	21.20	62.37	116.16	53.79
08048540	32()41'18"	97()19'11"	1.29	1.40	0.11	6.30	4.69	-1.61	2.37	1.66	-0.71	140.5	130.0	-10.5	49.89	58.83	8.94	59.07	78.45	19.37
SSSC*			0.38	0.43	0.05		3.34			1.34			140.0			78.27			104.36	

Table 3. (3 of 3) Study Watersheds Characteristics

	Station Location		Drainage Area			Perimeter			Main Channel Length			Basin Relief			Main Channel Slope			Main Channel Slope		
Station_ID	LAT	LON	TDA (sq.mi.)	TDA_M (sq.mi.)	RERR (Area)	BP (miles)	BP_M (miles)	RERR (Perimeter)	MCL (miles)	MCL_M (miles)	RERR (Channel Length)	BR (feet)	BR_M (feet)	RERR(Relief)	MCS (feet/mile)	MCS_M (feet/mile)	RERR(MCS)	MCS2 (feet/mile)	MCS2_M (feet/mile)	RERR(MCS2)
08178300	29()27'29"	98()32'59"	3.27	5.73	2.46	10.55	10.61	0.06	3.58	5.29	1.70	316.3	300.0	-16.3	81.14	42.55	-38.59	87.89	56.74	-31.15
08181000	29()35'14"	98()37'40"	5.55	5.73	-0.12	14.47	10.61	-2.91	5.42	5.29	-2.04	463.2	460.0	-33.1	52.32	65.25	-2.89	82.83	87.00	1.37
08181400	29()34'42"	98()41'29"	14.90	15.03	0.18	31.21	22.49	-3.86	9.82	10.10	-0.13	691.4	590.0	-3.2	48.06	43.81	12.93	64.15	58.41	4.17
08181450	29()23'12"	98()36'00"	1.24	1.12	0.13	8.05	5.14	-8.71	3.13	1.09	0.28	53.1	20.0	-101.4	16.62	13.73	-4.25	16.93	18.30	-5.74
08177600	29()34'35"	98()32'45"	0.32	0.33	0.02	3.58	2.59	-0.99	1.30	0.87	-0.44	101.5	110.0	8.5	69.70	95.05	25.35	75.87	126.73	50.86
08177700	29()29'56"	98()30'36"	20.84	20.82	0.53	30.72	25.61	-2.59	10.96	10.13	-1.21	410.3	413.0	3.1	25.39	30.57	1.21	34.77	40.76	6.53
08178555	29()21'05"	98()29'32"	1.91	2.44	-0.02	10.40	7.81	-5.11	4.05	2.84	-0.83	51.9	55.0	2.7	13.31	14.52	5.18	12.83	19.36	6.00
08178600	29()37'31"	98()31'06"	9.61	9.61	-0.11	21.44	15.25	-1.86	7.05	7.58	0.07	489.5	515.0	-24.1	43.19	50.99	-5.38	66.23	67.98	-3.57
08178620	29()35'24"	98()27'47"	4.05	3.95	0.07	11.30	8.41	-0.67	3.61	3.47	-0.72	227.9	230.0	-17.5	51.95	49.68	5.18	63.19	66.24	18.93
08178640	29()37'23"	98()26'29"	2.46	2.54	-0.01	9.28	6.95	-3.06	3.04	2.60	-0.56	328.2	330.0	-25.2	80.60	95.04	11.23	103.48	126.72	6.92
08178645	29()37'04"	98()25'41"	2.46	2.45	0.08	10.59	7.53	-2.33	3.96	3.39	-0.44	340.2	315.0	1.8	58.40	69.62	14.44	85.91	92.83	23.24
08178690	29()31'36"	98()26'25"	0.43	0.31	-0.11	4.32	2.46	-2.89	1.17	1.24	-0.14	46.1	22.0	2.1	18.70	13.33	-2.27	21.33	17.77	3.05
08178736	29()26'37"	98()27'13"	0.69	0.76	0.01	5.22	4.55	-6.19	1.67	0.95	0.53	82.5	65.0	25.5	46.30	51.48	7.79	49.71	68.64	1.75
08096800	31()19'59"	97()16'02"	5.07	5.25	0.18	14.13	10.97	-3.16	4.49	4.03	-0.46	265.2	280.0	14.8	52.45	52.11	-0.34	58.99	69.48	10.49
08094000	32()10'00"	98()20'30"	2.38	3.28	0.90	9.88	15.37	5.49	3.35	3.11	-0.24	158.7	130.0	-28.7	45.81	31.39	-14.42	45.96	41.85	-4.11
08098300	31()01'35"	96()59'17"	22.98	24.58	1.60	40.79	25.49	-15.30	13.73	12.39	-1.34	191.6	190.0	-1.6	10.35	11.50	1.16	13.91	15.34	1.43
08108200	30()55'52"	97()01'13"	46.38	46.86	0.48	60.66	40.00	-20.66	19.96	20.15	0.19	274.1	260.0	-14.1	11.01	9.68	-1.33	13.33	12.90	-0.42
08139000	31()17'25"	99()08'13"	3.13	2.71	-0.42	11.04	7.46	-3.58	3.36	2.91	-0.45	269.3	240.0	-29.3	83.64	61.85	-21.79	80.14	82.46	2.32
08140000	31()24'09"	99()08'13"	7.32	4.78	-2.55	18.79	8.77	-10.02	5.91	4.03	-1.88	319.7	270.0	-49.7	31.42	50.25	18.83	48.92	67.00	18.08
08136900	31()39'01"	99()13'30"	21.74	21.69	0.01	37.54	24.78	-3.49	12.42	11.49	-0.67	502.7	419.0	-21.7	22.44	27.34	1.83	40.43	36.46	1.82
08137000	31()41'40"	99()12'18"	4.09	4.10	-0.05	13.79	10.30	-12.76	4.40	3.73	-0.92	121.7	100.0	-83.7	18.28	20.10	4.90	24.98	26.80	-3.97
08137500	31()35'24"	99()13'36"	69.23	69.17	-0.06	60.99	36.27	-24.72	19.38	15.30	-4.09	568.5	490.0	-78.5	15.69	24.02	8.34	29.30	32.03	2.73
08182400	29()22'49"	98()17'33"	7.15	6.87	-0.28	17.04	12.33	-4.71	4.87	3.86	-1.00	146.5	160.0	13.5	33.45	31.06	-2.39	30.21	41.41	11.21
08187000	28()46'41"	97()53'41"	3.06	3.20	0.14	9.92	7.54	-2.38	2.78	2.54	-0.24	143.9	165.0	21.1	48.07	48.77	0.70	51.44	65.03	13.59
08187900	28()53'39"	97()53'41"	8.78	8.29	-0.49	16.52	12.69	-3.83	4.87	4.03	-0.84	145.2	140.0	-5.2	21.71	26.06	4.35	27.73	34.74	7.01
08050200	33()37'13"	97()24'15"	0.87	2.09	1.21	6.90	6.64	-0.26	2.64	1.73	-0.91	149.0	140.0	-9.0	58.95	60.72	1.77	56.37	80.95	24.59
08057500	33()18'12"	96()41'22"	2.09	2.09	0.00	8.28	6.64	-1.37	2.07	1.73	-0.28	120.6	112.0	-3.3	54.66	48.57	-6.99	56.03	64.76	6.82
08058000	33()18'20"	96()40'12"	1.21	1.20	0.00	6.11	4.74	-1.64	2.09	1.80	-0.34	113.3	110.0	-8.6	52.71	45.72	-6.09	54.14	60.96	8.74
08052630	33()24'33"	96()48'41"	2.05	2.06	0.01	9.28	6.87	-2.41	3.30	2.91	-0.39	114.0	110.0	-4.0	34.75	28.35	-6.40	34.26	37.80	3.53
08052700	33()17'00"	96()53'33"	73.10	73.12	0.01	66.92	44.10	-22.82	23.23	23.43	0.20	297.5	301.0	3.5	8.67	9.63	0.97	11.62	12.85	1.22
08042650	33()14'52"	98()19'19"	6.56	6.65	0.09	14.99	4.25	-10.74	4.63	4.51	-0.12	338.3	320.0	-18.3	48.24	53.20	4.96	72.75	70.93	-1.82
08042700	33()16'57"	98()17'53"	23.99	23.70	-0.29	36.31	20.15	-16.16	11.57	10.08	-1.49	416.6	350.0	-66.6	26.52	26.05	-0.46	31.81	34.74	2.93
08063200	31()48'01"	96()43'02"	18.18	17.12	-1.06	27.29	19.07	-8.22	8.73	8.21	-0.52	192.6	190.0	-2.6	15.79	17.36	1.57	21.19	23.15	1.95

Figure 2 is a plot of the characteristics and a 1:1 reference line. The plot of TDA_M versus TDA has about six watersheds relatively far from the 1:1 line, the remainder all close to the 1:1 line. The general trend of the markers for this characteristic is parallel to the 1:1 line and nearly coincident with the 1:1 line. The plot of MCL_M versus MCL exhibits similar behavior as drainage area, except at the smaller values of MCL where the manual method produces considerably smaller values. About eight watersheds are relatively far from the 1:1 line and all these watersheds have MCL less than 10 miles; the larger watersheds exhibit good agreement. The plot of BP_M versus BP marker cloud lies about one-fifth of a log cycle below the 1:1 line but with about the same slope. The plot of BR_M versus BR has three watersheds far from the 1:1 line, the remainder all close to the 1:1 line. The plot of MCS_M versus MCS follows the general trend of the 1:1 line with four watersheds far from the line. The plot of MCS2_M versus MCS also follows the 1:1 line.

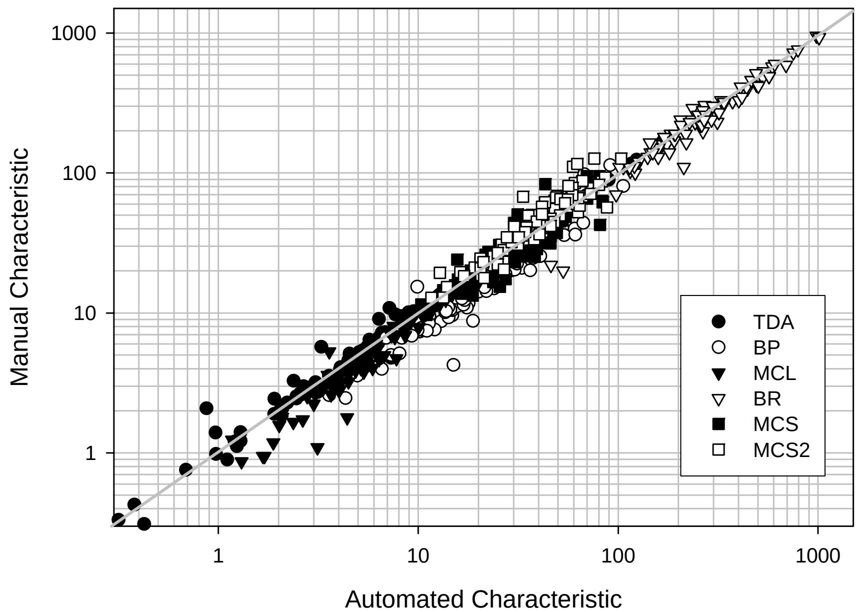

Figure 2. Log-log plot of automatic and manually determined characteristics.

This visual comparison suggests that both approaches produce qualitatively equivalent basin characteristic values, with the exception of BP_M which is considerably smaller than its companion characteristic BP, and the exception of MCL which is considerably smaller in the manual method than its equivalent automated result for watersheds smaller than 10 square miles.

Quantitative Comparative Results

The determination of a characteristic by the two different methods creates a natural pairing for each watershed. Quantitative comparisons were made by computing differences between the automated and manual characteristic for each watershed and applying a paired two-sample *t*-test to the mean value of the differences (Mendenhall and others, 1986). The hypothesis tested is that the mean of the differences is zero (i.e. no difference). All the tests in this paper were tested employing a two-tailed test at level of significance of 0.05. The hypothesis testing of the differences indicated that all the differences between the automated and manual characteristics were statistically significant except for drainage area and main channel slope.

The qualitative analysis shows the marker clouds appear parallel to the 1:1 line suggesting that a multiplicative factor could be applied to "correct" for the differences between the automated and manual characteristics. These corrections were determined by computing the relative differences (divide each difference by its automated characteristic value) and computing the median relative difference. The median relative difference is then used in a multiplicative correction factor on the manual values.

Table 2 is a summary of the median relative errors for each characteristic and the multiplicative correction factor. In all cases after correction the differences between the "corrected" manual characteristics and automated characteristics were not statistically significant.

Table 2. Median relative errors, correction factors, and hypothesis testing results.

Characteristic	Median Relative Error	Correction Factor[1]	*t*-statistic	*p*-value
Area (TDA)	0.002	0.998	-1.09	0.27
Basin Perimeter (BP)	-0.27	1.27	-8.8E-4	0.99
Main Channel Length (MCL)	-0.11	1.11	-0.73	0.46
Basin Relief (BR)	-0.06	1.06	1.48	0.14
Main Channel Slope (MCS)	-0.02	1.02	-0.57	0.57
Alternate Main Channel Slope (MCS2)	0.1	0.90	-1.15	0.25

Hypothesis tested: H_o: $\bar{d} = 0$

[1] The manual characteristic multiplied by the correction factor is the "corrected" manual characteristic

Illustrative Application

Time of concentration (T_c) is an important hydrologic parameter that is typically estimated from basin characteristics such as those in this paper. To illustrate the impact of analysis method the time of concentration is calculated from basin characteristics determined by the manual and automated analysis. Kirpich (1940) developed a formula to estimate time of concentration (T_c) by analyzing data from seven rural watersheds in Tennessee. The formula is expressed as

$$T_c = 0.0078\, L_c^{0.77}\, S_c^{-0.385} \qquad [1]$$

where T_c is the time of concentration in minutes, L_c and S_c are the channel length in feet and the channel slope in ft/ft, respectively. McCuen and others (1984) studied several empirical equations to estimate T_c for 48 urban watersheds and concluded that the Kirpich method had the smallest bias for watersheds with significant channel flow. For the purposes of this paper, this formula is selected as a realistic calculation that might be warranted in a hydrologic study.

Using the watershed parameters (MCL and MCS), travel time for channel flow was calculated by the Kirpich formula for the study watersheds. Thirty minutes were added to the travel time to account for overland and shallow concentrated flow and the results converted to hours.

Figure 3 is a plot of the time of concentration using manual versus automated basin characteristics. Both uncorrected and corrected characteristics were used. A two-sample *t*-test indicates that the differences using the uncorrected values are statistically significant, while using the corrected values the differences are not statistically significant.

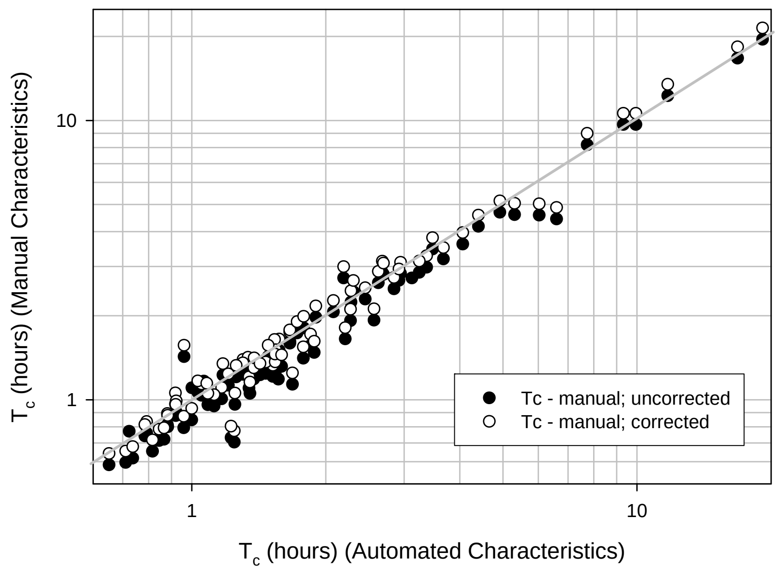

Figure 3. Plot of time of concentration using Kirpich equation using manually determined versus automatically determined characteristics.

Summary

Manual and automated measures of selected physical watershed characteristics are qualitatively similar in the watersheds studied, but the differences in the characteristics are statistically significant.

The qualitative analysis suggested that a multiplicative correction factor could be applied to each manually determined characteristic. After application of the correction factor to each characteristic, the differences between automated and "corrected" manual characteristics were not statistically significant. The ability to apply a single multiplicative correction factor to each characteristic suggests that analysis differences are some systematic bias that scales with watershed size. The largest magnitude corrections were needed for basin perimeter (BP) and main channel length (MCL).

An illustrative application using Kirpich's (1940) formula for calculating time of concentration produced estimates well within an order of magnitude of the "correct" automated results. A two-sample *t*-test indicated that the manual and automated time of concentration calculations are comparable when the underlying manual basin characteristics are corrected.

As compared to automated methods, the manual methods exhibit a watershed area dependent bias; multiplicative corrections can produce results whose differences are not statistically significant. The corrections in this paper are multiplicative indicating that the magnitude of the correction will increase with watershed size (area). This result supports intuition that as multiple map sheets are required in manual analysis analyst fatigue can introduce statistically significant error. The values of correction factors presented in this paper are valid only for the particular watersheds studied and should not be extrapolated to any other geographic areas. There was no intent in this study to regionalize correction factors.

For small watersheds it is concluded that method choice is a matter of analyst preference and the number of watersheds being studied. For large and multiple watershed studies the speed of the automated method, even considering the time required to assemble the digital elevation maps and schedule a GIS analyst, greatly reduces overall effort required to generate these and other physical characteristics.

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