Cedar Creek Watershed Hydrologic Study

DEQ

Michigan's Nonpoint Source Program

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DEQ Michigan's Nonpoint Source Program

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Summary

A hydrologic model of the Cedar Creek watershed was developed by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). The hydrologic model was developed to help determine the effect of land use changes on the Cedar Creek's flow regime and to provide design flows for streambank stabilization Best Management Practices (BMPs). Watershed stakeholders may combine this information with other determinants, such as open space preservation, to decide what locations are the most appropriate for wetland restoration, stormwater detention, in-stream BMPs, or upland BMPs. Local governments within the watershed could also use the information to help develop stormwater ordinances.

The hydrologic model has four scenarios corresponding to land uses in 1800, 1978, 1998, and built-out land uses. General land use trends, illustrated in Figure 1, show that the watershed has retained most of its natural areas, and that further development appears to be primarily a transition from agricultural to urban land uses. More detailed land use information is provided in the Watershed Description and Model Parameters section of this report.

Because of these land use trends, the model shows increases in runoff volumes and peak flows from 1800 to 1978/1998 for the 50 percent chance (2-year), 4 percent chance (25-year), and 1 percent chance (100-year) 24-hour design storms, as shown in Figures 10 through 15. The build-out simulation of future land use changes projects further increases in runoff volumes and peak flows. Additional flow details are in the Model Results section of this report. Increases in the runoff volume and peak flow from the 4 percent chance and 1 percent chance, 24-hour storms could cause or aggravate flooding problems unless mitigated through the use of effective stormwater management techniques. Increases in the 50 percent chance, 24-hour storm will increase channel-forming flows. The channel-forming flow in a stable stream usually has a one- to two-year recurrence interval. These relatively modest storm flows, because of their higher frequency, have more effect on channel form than extreme flood flows.

Hydrologic changes that increase this flow can cause the stream channel to become unstable. Stream instability is indicated by excessive erosion at many locations throughout a stream reach. Stormwater management techniques used to mitigate flooding can also help mitigate projected channel-forming flow increases. However, channel-forming flow criteria should be specifically considered in the stormwater management plan so that the selected BMPs will be most effective. For example, detention ponds designed to control runoff from the 4 percent chance, 24-hour storm may do little to control the runoff from the 50 percent chance, 24-hour storm, unless the outlet is specifically designed to do so.

One way to compare runoff from different subbasins is to calculate the yield, which is the peak flow divided by the drainage area. The average yield from the 50 percent

chance (2-year), 24-hour storm for the Cedar Creek watershed is 0.004 cubic feet per second per acre (cfs/acre) for 1978/1998 land use conditions. This value may be used to guide stakeholders' fish habitat and stream stability management decisions. The average yield from the 4 percent chance (25-year), 24-hour storm for the Cedar Creek watershed is 0.03 cfs/acre for 1978/1998 land use conditions. This value may be used to guide stakeholders' flood control management decisions. Additional details are shown in Figures 16 through 18 and in the Model Results section of this report.

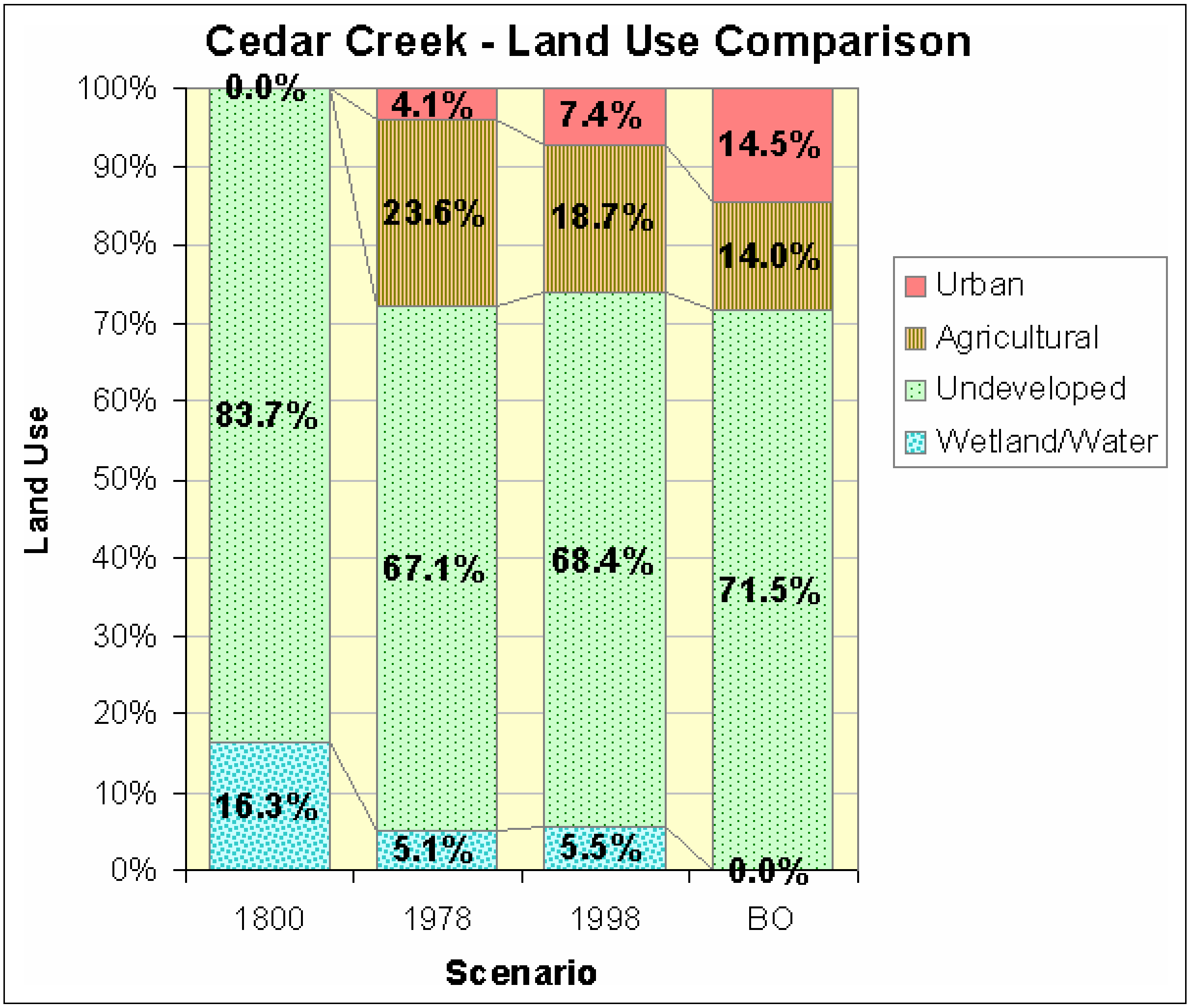

Figure 1: Land Use Comparison

Project Goals

The Cedar Creek hydrologic study was initiated in support of a larger watershed study being conducted by the Muskegon River Watershed Assembly. The goals of this Cedar Creek study are:

- To better understand the watershed's hydrologic characteristics and the impact of hydrologic changes in the Cedar Creek watershed
- To facilitate the selection and design of suitable BMPs
- To provide information that can be used by local units of government to develop or improve stormwater ordinances
- To protect one of the best brook trout streams in the state as determined by the Department of Natural Resources' Fisheries Division

Watershed Description and Model Parameters

The 57.1 square mile Cedar Creek watershed, Figure 2, outlets to the Muskegon River and is located in Muskegon and Newaygo counties. Cedar Creek's profile, Figure 3, is typical - steeper in the headwaters, flattening out toward the mouth.

This Cedar Creek study divides the watershed into 14 subbasins, as shown in Figure 4. Some areas have been identified as non-contributing, meaning that they do not have an apparent overland outlet for surface runoff. We have assumed that these areas, totaling 7.2 square miles, do not contribute surface runoff to the Cedar Creek or its tributaries and are not included in the hydrologic model. Runoff may pool within the area, but that runoff has no natural outlet and therefore must either evaporate or infiltrate. If these areas become developed, artificial drainage may be installed, increasing runoff to Cedar Creek. This possibility has not been included in the model.

Our analysis of the watershed uses the curve number technique to calculate surface runoff volumes and peak flows. This technique, developed by the Natural Resources Conservation Service (NRCS) in 1954, represents the runoff characteristics from the combination of land use and soil data as a runoff curve number. The curve numbers for each subbasin, listed in Appendix A, were calculated from digital soil and land use data using Geographic Information Systems (GIS) technology.

Runoff curve numbers were calculated from the land use and soil data shown in Figures 5 through 9. Land use maps based on the MDEQ GIS data for 1800 and 1978 are shown in Figures 5 and 6, respectively. The 1800 land use information is provided at the request of the Cedar Creek project manager. The MDEQ Nonpoint Source program does not expect or recommend that the flow regime calculated from 1800 land use be used as criteria for BMP design or as a goal for watershed managers. The Muskegon County Conservation District provided the GIS data for the 1998 and build-out land use maps shown in Figures 7 and 8, respectively. The build-out analysis assumes land use is developed to the maximum allowed under current zoning regulations.

The NRCS soils data for the watershed is shown in Figure 9. Where the soil is given a dual classification, B/D for example, the soil type was selected based on land use. In these cases, the soil type is specified as D for natural land uses or the alternate classification (A, B, or C) for developed land uses. The runoff curve numbers calculated from the soil and land use data are listed in Appendix A. The percent impervious field is left at 0.0, because it is already incorporated in the curve numbers. The initial loss field is left blank so that HMS uses the default equation based on the curve number.
The time of concentration for each subbasin, which is the time it takes for water to travel from the hydraulically most distant point in the watershed to the design point, was calculated from the USGS quadrangles. The storage coefficients, which represent storage in the subbasin, were iteratively adjusted to provide a peak flow reduction equal to the ponding adjustment factors described further in Appendix A.

The reach routing method is the lag method. Lag is the travel time of water within each section of the stream. The method translates the flood hydrograph through the reach without attenuation. It is not appropriate for reaches that have ponds, lakes, wetlands, or flow restrictions that provide storage and attenuation of floodwater. Cedar Creek, downstream of Ryerson Road, and Little Cedar Creek, downstream of Tyler Road, has extensive wetlands along the river, according to USGS quadrangles. These areas were modeled using reservoirs for all land use scenarios. Although the build-out land use scenario does not show these areas as wetland, they are shown as predominately undeveloped, and therefore these reservoirs are included in the build-out analysis. Lag and reservoir storage values for each reach were calculated using USGS quadrangles and are listed in Appendix A.

The selected precipitation events were the 50, 4, and 1 percent chance (2-, 25-, and 100-year), 24-hour storms. Design rainfall values for these events are tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129, and summarized for this site in Appendix A. These values have been multiplied by 0.948 to account for the size of the watershed.

These parameters were then incorporated into a HEC-HMS model to compute runoff volume and flow.

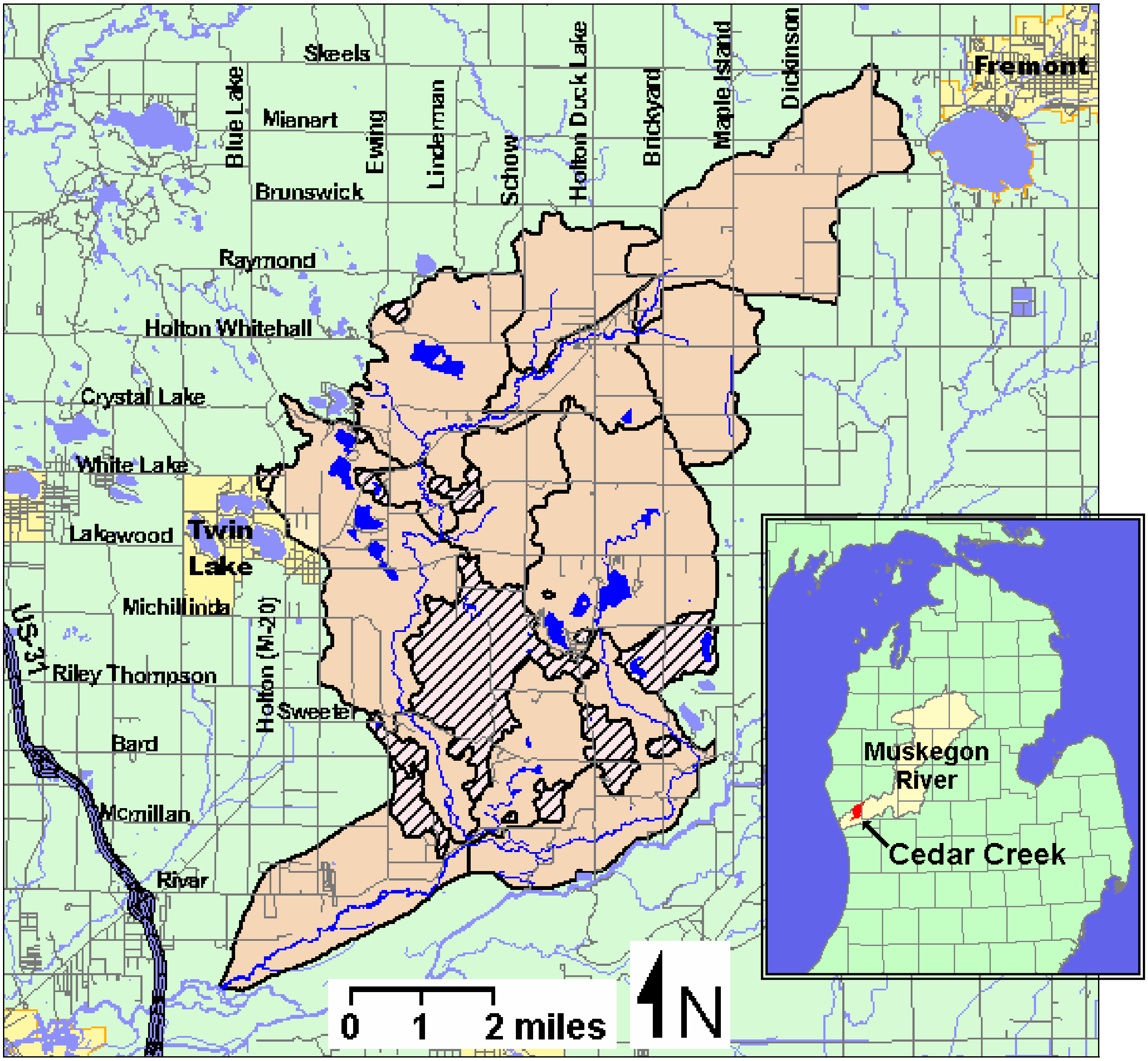

Figure 2: Delineated Cedar Creek Watershed

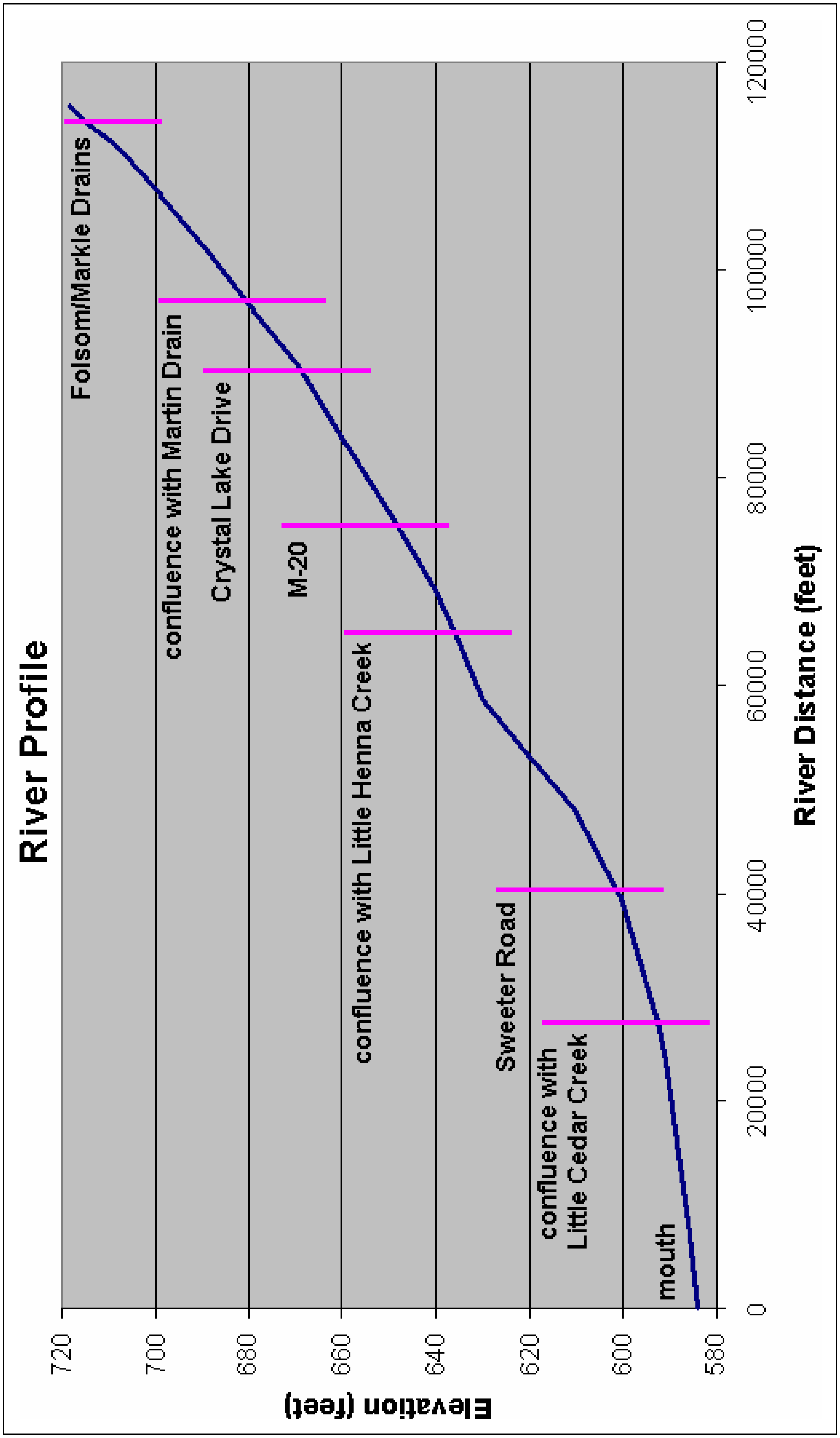

Figure 3: Cedar Creek Profile

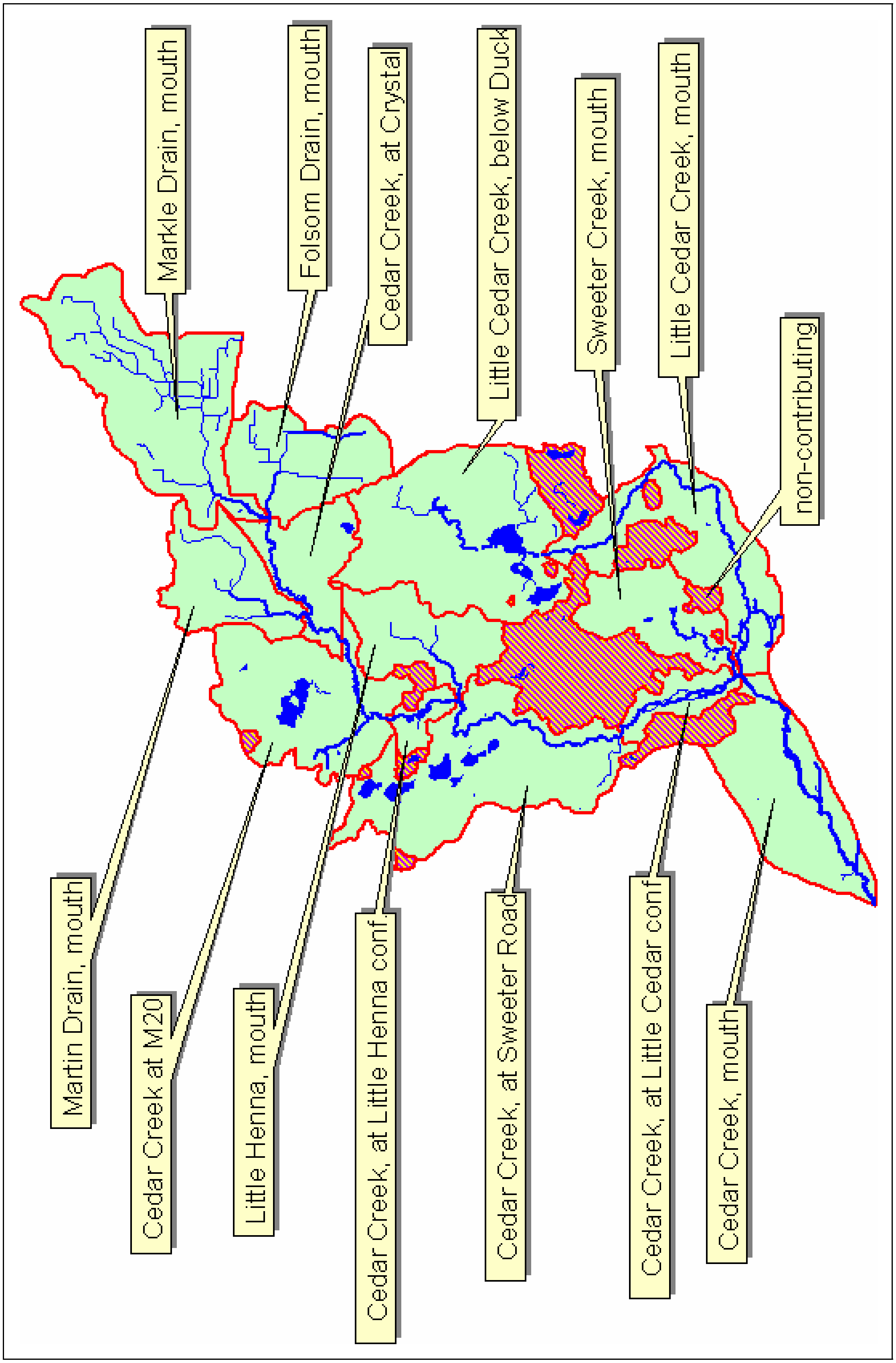

Figure 4: Subbasin Identification

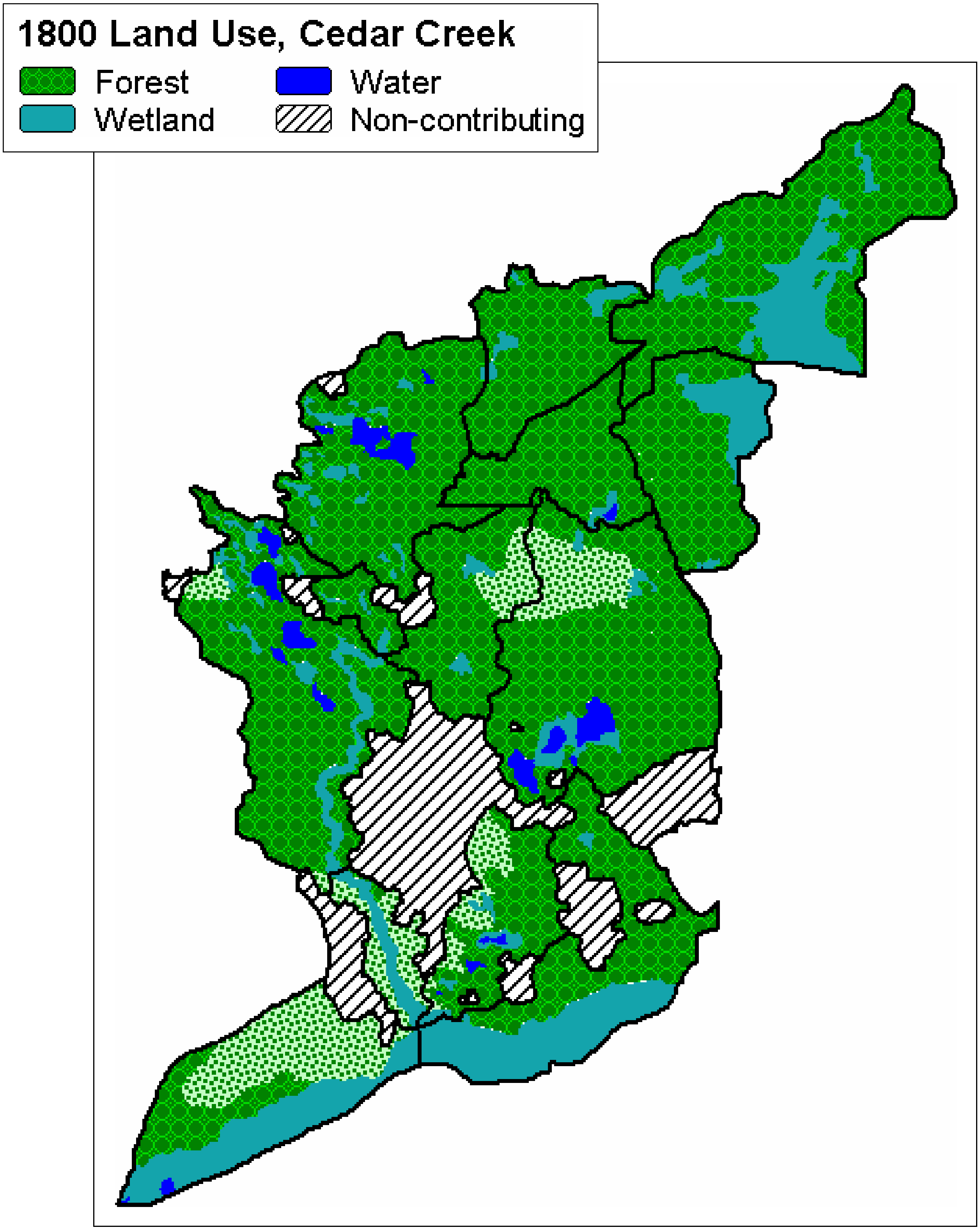

Figure 5: 1800 Land Use Data

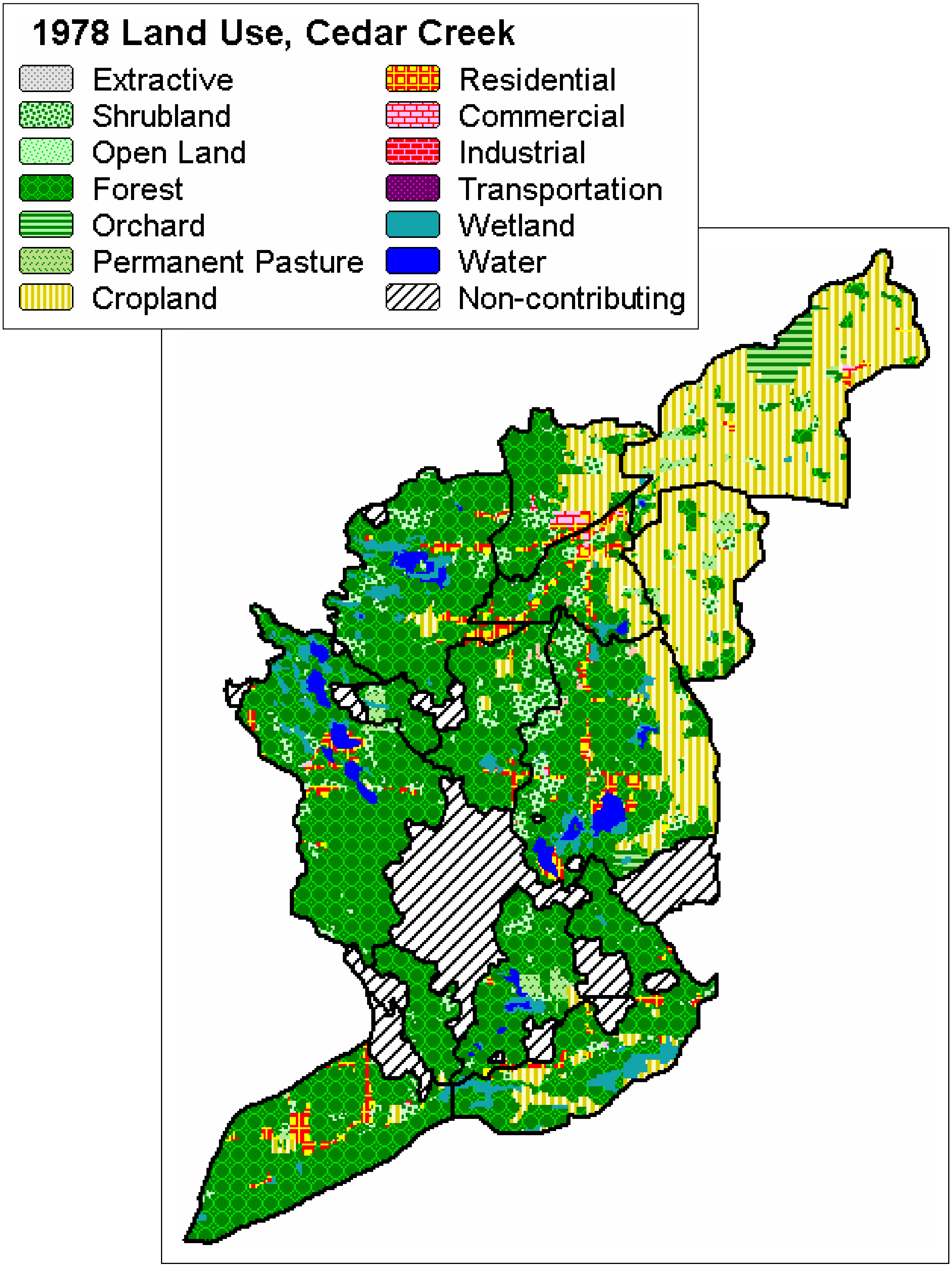

Figure 6: 1978 Land Use Data

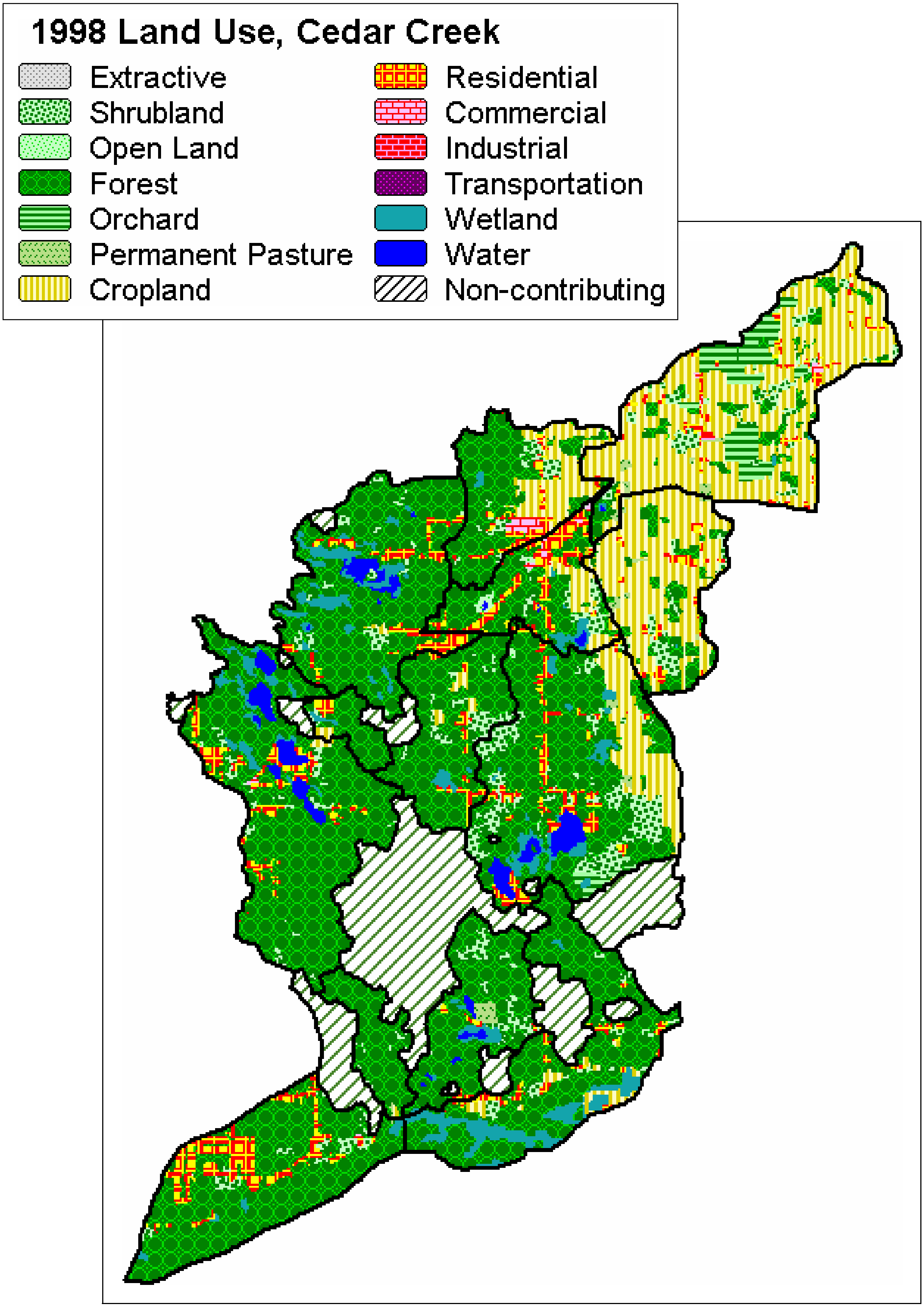

Figure 7: 1998 Land Use Data

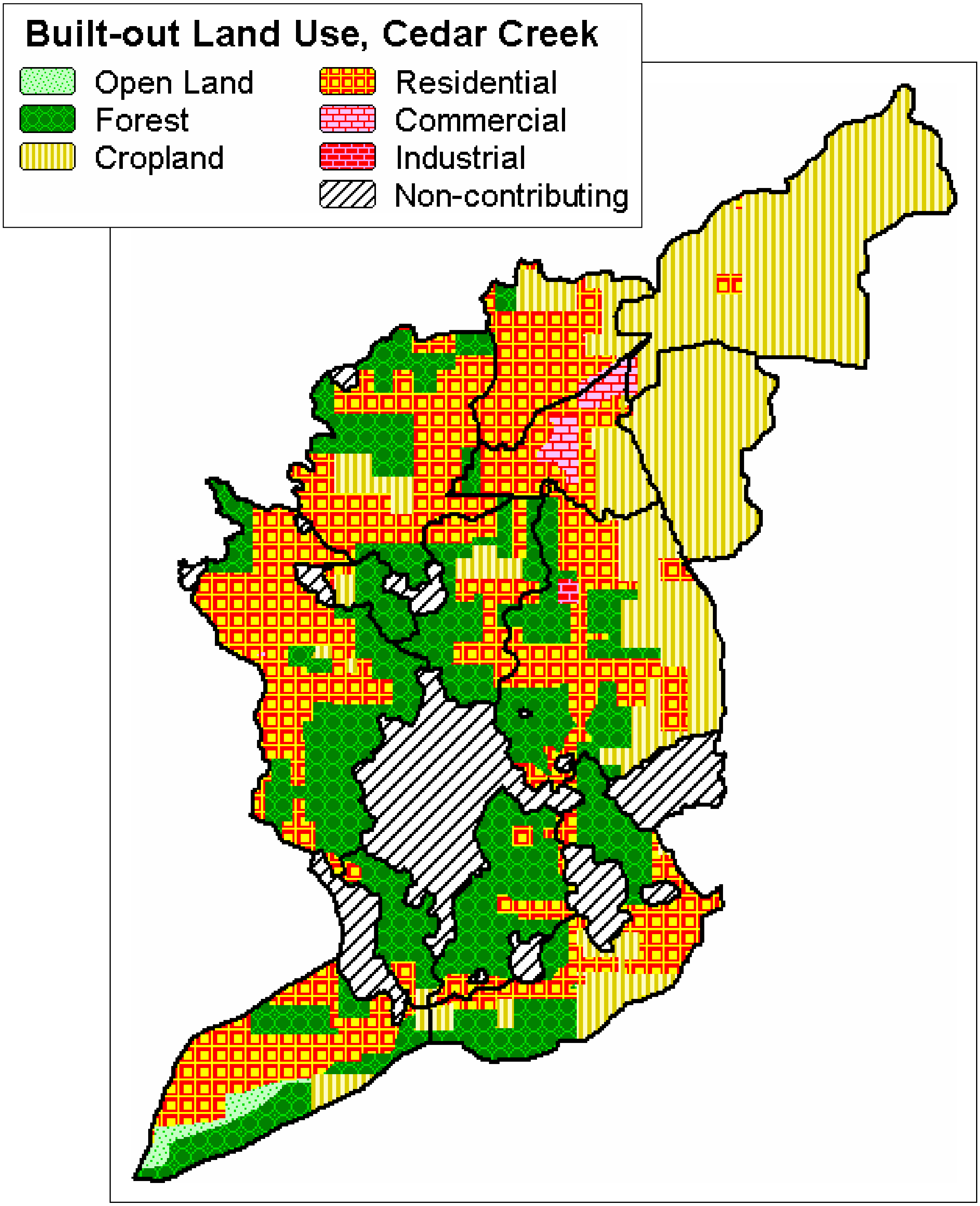

Figure 8: Build-out Land Use Data

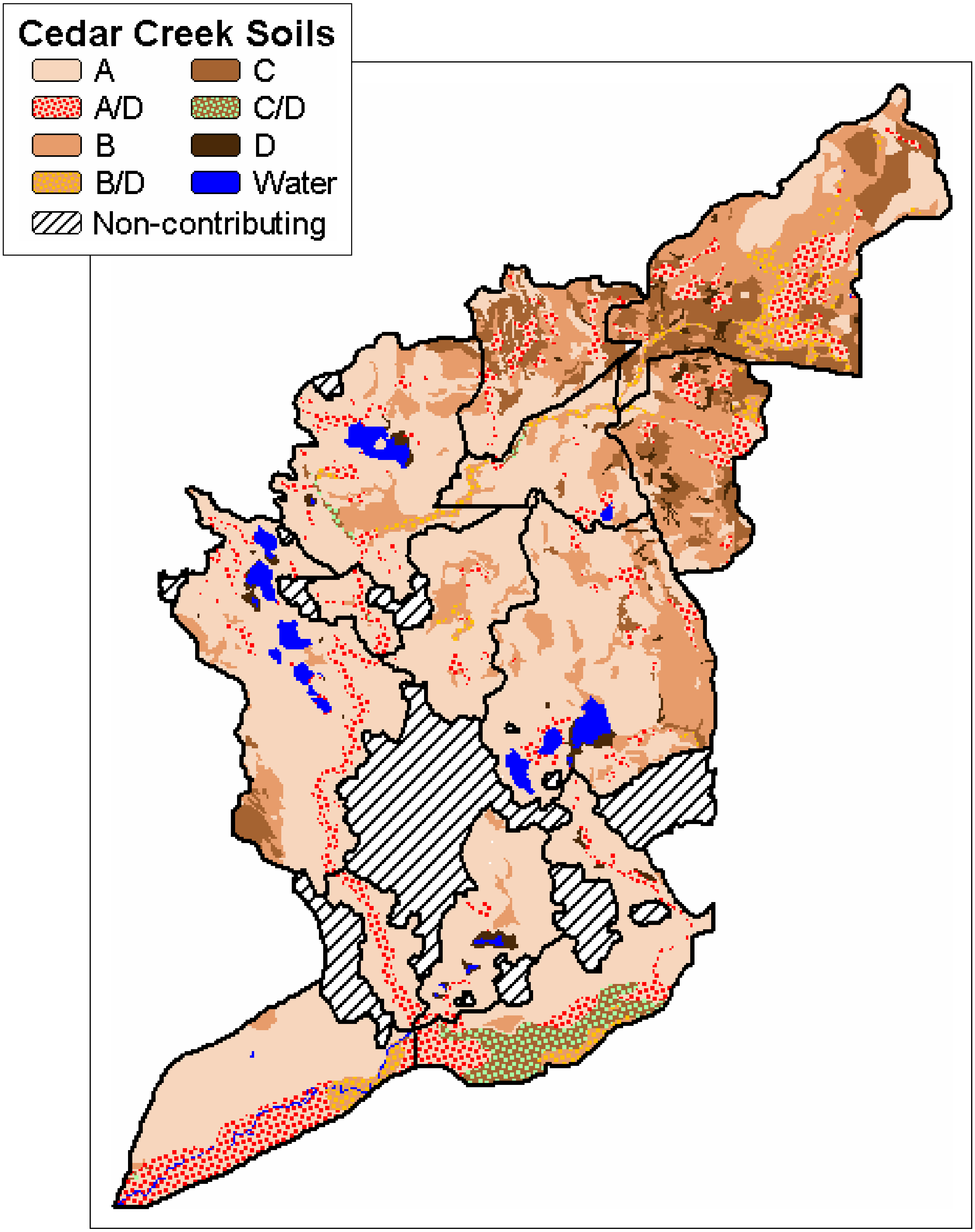

Figure 9: NRCS Soils Data

Table 1: Land Use by Subbasins (Land uses less than 0.5 percent are not listed because all percentages are rounded to the nearest percent)

Description	Scenario	Residential	Commercial	Industrial	Cemeteries, Outdoor Rec.	Cropland	Orchard	Pasture	Herbaceous Openland	Forest	Water	Wetland	Bare Soil, Rock, Dune
B1C1	1800								43%	22%	1%	34%	
	1978	8%				2%		1%	4%	84%		1%	
	1998	17%							4%	78%		1%	
	Build-out	52%			8%	6%				34%			
B2C2	1800								65%	4%		31%	
	1978					2%			6%	92%			
	1998					1%		1%	4%	94%			
	Build-out	16%				4%				80%			
B2LC1	1800									60%		40%	
	1978	4%				11%			2%	74%		9%	
	1998	5%				4%			4%	74%		14%	
	Build-out	37%				20%				43%			
B2SC	1800								27%	64%	2%	7%	
	1978	2%				2%		6%	7%	76%	3%	4%	
	1998	2%						3%	9%	79%	3%	4%	
	Build-out	20%								79%			
B3C3	1800								3%	80%	5%	11%	
	1978	4%							6%	80%	5%	5%	
	1998	7%							3%	80%	6%	4%	
	Build-out	56%				1%				43%			
B4C4	1800									89%		11%	
	1978							14%	10%	73%		3%	
	1998	8%				6%			3%	79%		3%	
	Build-out	10%				15%				75%			
B4HC	1800								16%	80%		4%	
	1978	3%				3%			15%	76%		2%	1%
	1998	5%				3%			9%	81%		2%	
	Build-out	38%				10%				52%			
B5C5	1800									89%	5%	6%	
	1978	6%				2%			8%	74%	3%	7%	
	1998	8%							4%	77%	3%	8%	
	Build-out	57%				8%				35%			
B6C6	1800									97%	1%	2%	
	1978	15%	1%			21%		1%	6%	52%	1%	2%	
	1998	21%	2%		2%	12%			8%	50%	1%	4%	
	Build-out	47%	20%			28%				4%			
B7Martin	1800									93%		7%	
	1978	4%	3%			30%			9%	53%			
	1998	8%	3%			26%			6%	57%		1%	
	Build-out	67%	1%			28%				3%			

Description	Scenario	Residential	Commercial	Industrial	Cemeteries, Outdoor Rec.	Cropland	Orchard	Pasture	Herbaceous Openland	Forest	Water	Wetland	Bare Soil, Rock, Dune
B8NMDr	1800									76%		24%	
	1978	1%				79%	9%	2%	2%	6%			
	1998	4%	1%			65%	13%	1%	6%	9%			
	Build-out	1%	1%			98%							
B8SFDr	1800									80%		20%	
	1978					80%		4%	3%	13%			
	1998	5%				68%		2%	7%	18%			
	Build-out	1%				99%							
BTLC2	1800								13%	77%	5%	5%	
	1978	5%				21%	2%		10%	52%	5%	4%	1%
	1998	7%				14%	2%	1%	13%	54%	4%	4%	
	Build-out	35%		1%		33%				30%			
Non-contributing	1800								36%	60%	2%	2%	
	1978	1%				2%	1%		11%	80%	2%	2%	
	1998	2%				2%	1%		11%	80%	2%	2%	
	Build-out	14%				14%				72%			

Model Results

Model results are illustrated in Figures 10 through 20 and detailed in Tables 2 through 5. Table 2 lists the computed peak flows from each subbasin. These values represent the peak flow contribution from the subbasins, not the flow in the river. Table 3 and Figures 10, 12, and 14 show the computed peak flows at locations in the river. Table 4 lists the predicted runoff volumes from each subbasin. Table 5 and Figures 11, 13, and 15 show the predicted runoff volumes at locations in the stream.

The projected increases in stormwater runoff volume and peak flows conditions are due to changes in land use and loss of storage. The hydrologic model computes significant increases in runoff volumes and peak flows for all three design storms. Peak flows and runoff volumes from the 50 percent chance 24-hour storm are predicted to increase more, on a percentage basis, than flows from the 4 percent chance, 24-hour storm. Increases in runoff volumes and peak flows from the 50 percent chance storm increase channel-forming flows, which will increase streambank erosion. Channel-forming flow is the flow that is most effective at shaping the channel. In a stable stream, the channel-forming flow has a one- to two-year recurrence interval and is the bankfull flow. Increases in runoff volumes and peak flows from the 4 percent chance storm will aggravate flooding. These projected increases can be moderated through the use of effective stormwater management techniques.

A model stormwater ordinance adopted by nearby Kent County, which is also being considered for adoption by other local units of government, calls for a maximum release rate of 0.05 cfs/acre for runoff from the 50 percent chance, 24-hour storm for Zone A areas, the most environmentally sensitive of the three management zones. Currently, the average yield from this storm for the Cedar Creek Watershed is 0.004 cfs/acre, with no subbasin greater than 0.03 cfs/acre, as shown in Figure 16. The ordinance also calls for a maximum release rate of 0.13 cfs/acre for runoff from the 4 percent chance, 24-hour storm for Zones A and B. Currently, the average yield from this storm is 0.03 cfs/acre, with only one subbasin at 0.13 cfs/acre, as shown in Figure 17. Additional details are listed in Table 2. If the Muskegon River Watershed Assembly or Cedar Creek watershed stakeholders use the Kent County model ordinance as a basis for a Cedar Creek stormwater ordinance, they should consider whether the Kent County model ordinance standards will adequately protect the Cedar Creek and its tributaries.

According to the Department of Natural Resources Fisheries Division, Cedar Creek is one of the best brook trout streams in the state and also provides relatively good steelhead reproduction and recruitment. Fish diversity and composition below Holton are what would be expected for a coldwater stream. Brook trout biomass at Sweeter Road (65.4 lbs/acre, ranks 5th) and M-20 (50.7 ranks 12th) both are well above the average of 22.2 pounds/acre for 78 sites in Michigan streams. Rainbow trout biomass is about average at Sweeter Road and below average at M-20. This information indicates Cedar Creek is primarily a brook trout stream.

In our Pigeon River watershed study, we compared the flows from the 50 percent chance, 24-hour storm to flows based on a target yield of 0.0075 cfs/acre. This target yield was selected as criteria for a good trout fishery based on Mike Wiley and Paul Seelbach's November 1998 report titled "*An ecological assessment of opportunities for fisheries rehabilitation in the Pigeon River, Ottawa County*." Although clearly not the sole factor determining fish habitat quality, the good quality trout habitat there corresponds to the locations with yields less than the target yield. Impaired habitat corresponds to locations with yields less than about 1.4 times the target yield. Locations with higher yields generally did not have trout. These same thresholds were applied to the Cedar Creek results. For the 1800 scenario, all nine locations would be good. For the 1978/1998 scenarios, Cedar Creek would be impaired above approximately M-20. Markle and Folsom Drains would be poor. For the build-out scenario, Cedar Creek would transition from good at Sweeter to just poor below the confluence with Little Henna Creek. Complete results are shown in Figure 18 and listed in Table 9. Hydrographs, graphs of flow over time, are provided for the key M-20 location in Figures 19 and 20.

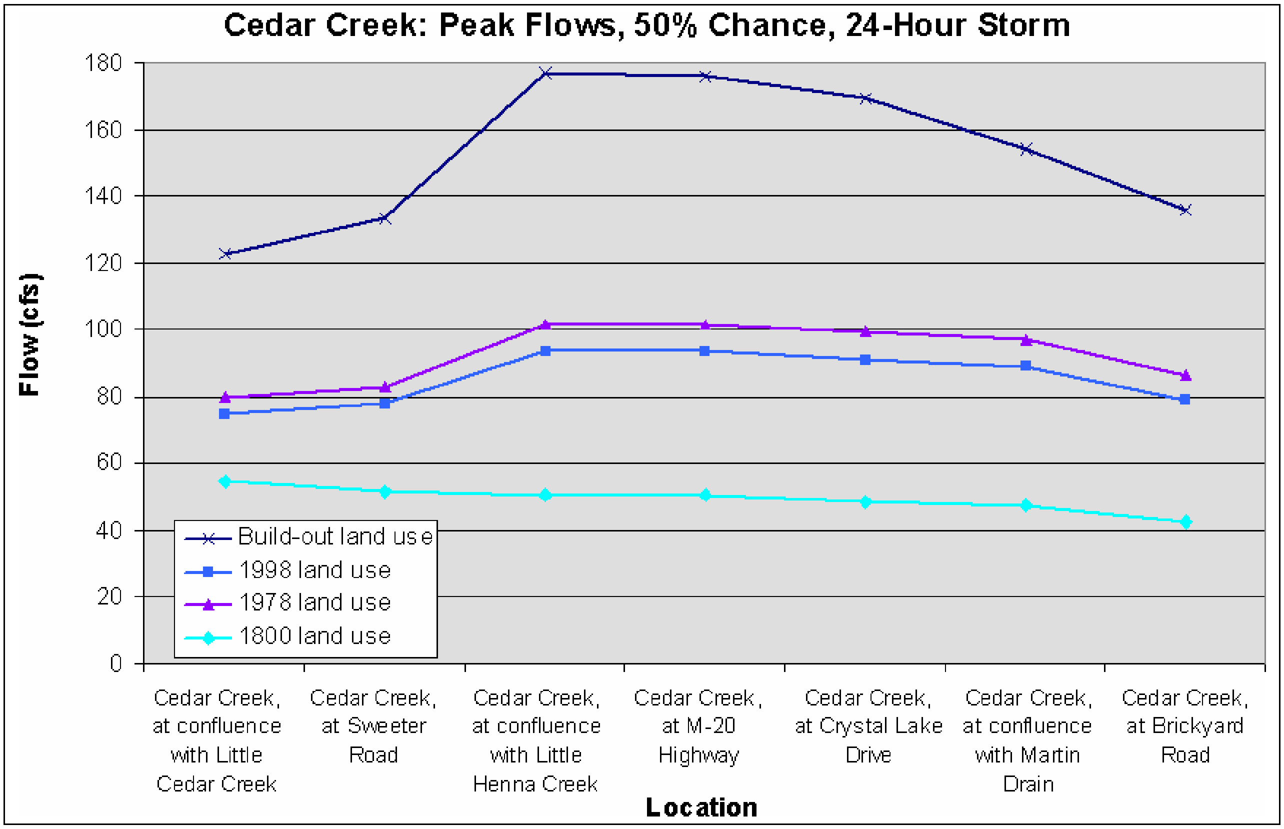

Figure 10: Predicted peak flows for river locations, 50 percent chance storm

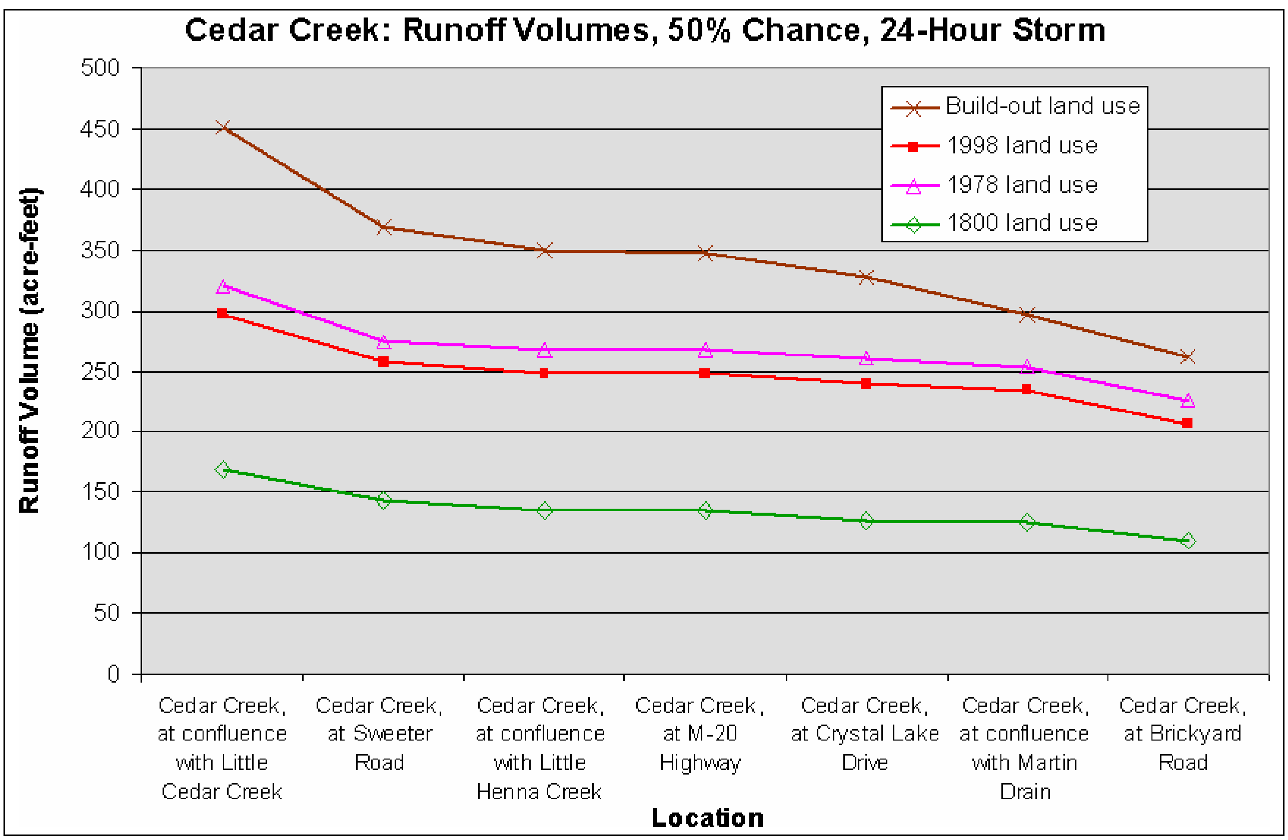

Figure 11: Predicted runoff volumes, 50 percent chance storm

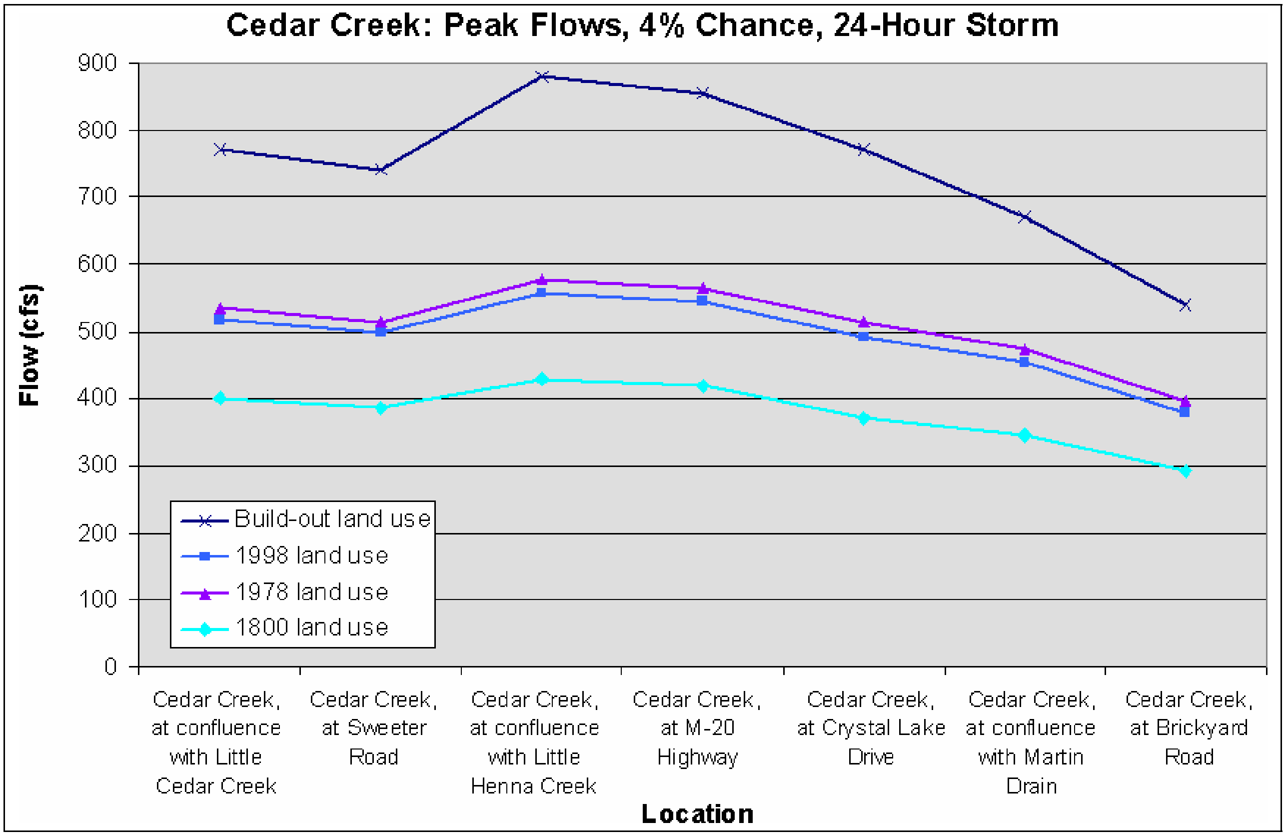

Figure 12: Predicted peak flows for river locations, 4 percent chance storm

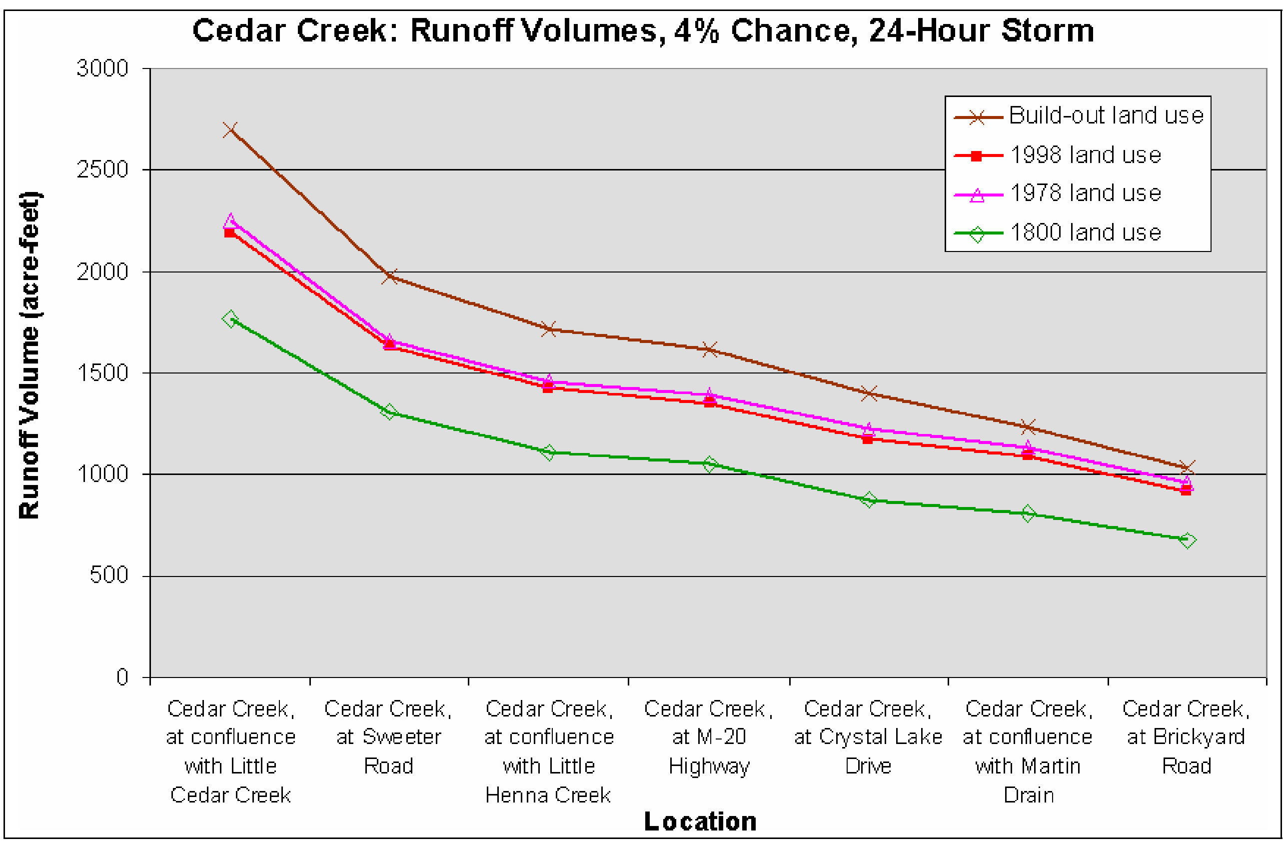

Figure 13: Predicted runoff volumes, 4 percent chance storm

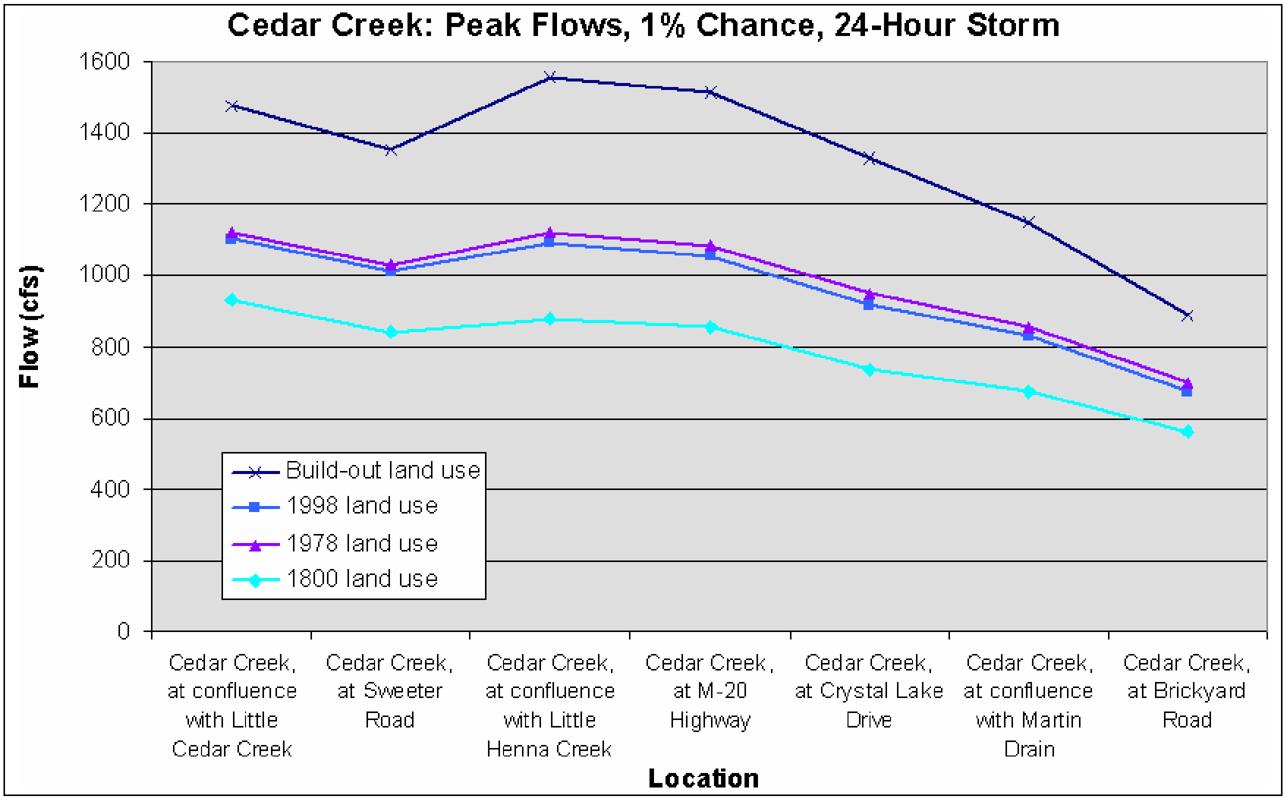

Figure 14: Predicted peak flows for river locations, 1 percent chance storm

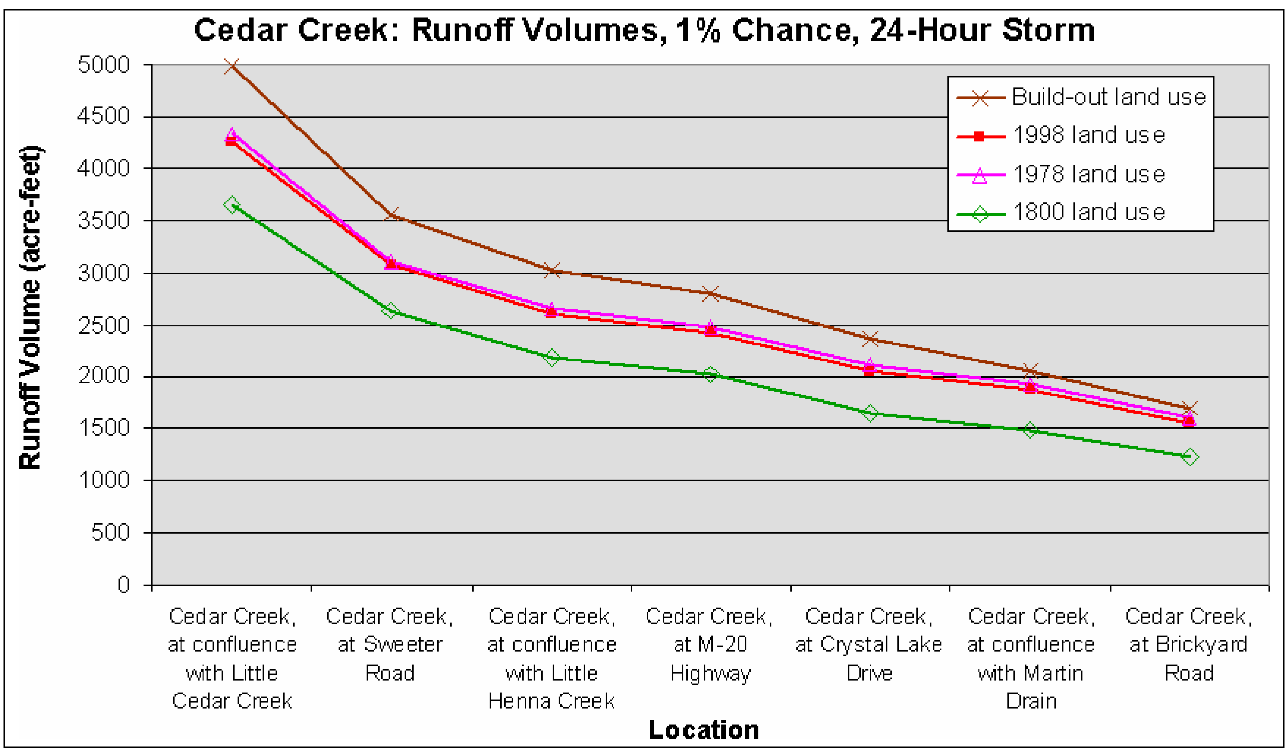

Figure 15: Predicted runoff volumes, 1 percent chance storm

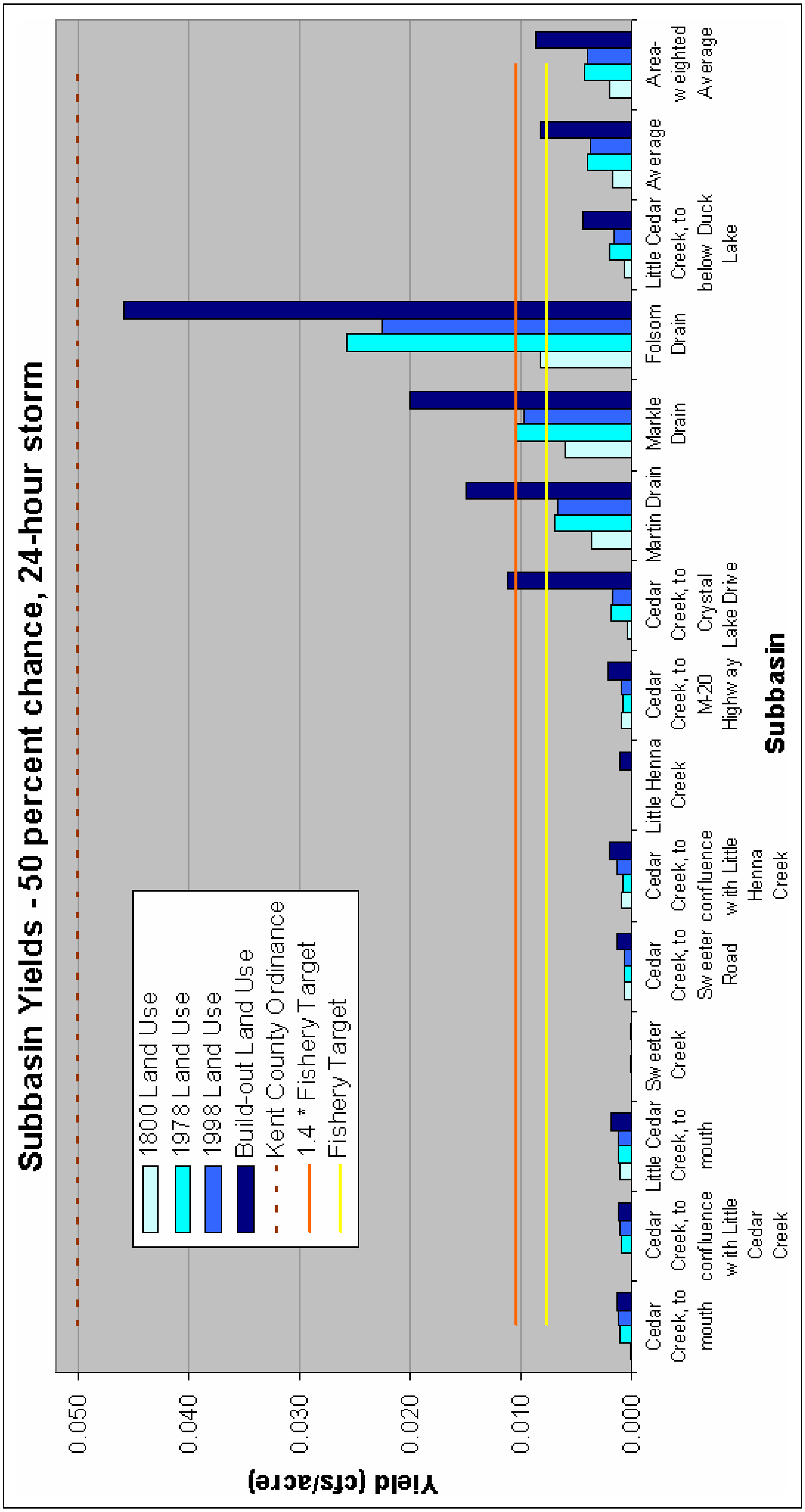

Figure 16: Subbasin Yields, 50 percent chance, 24-hour storm

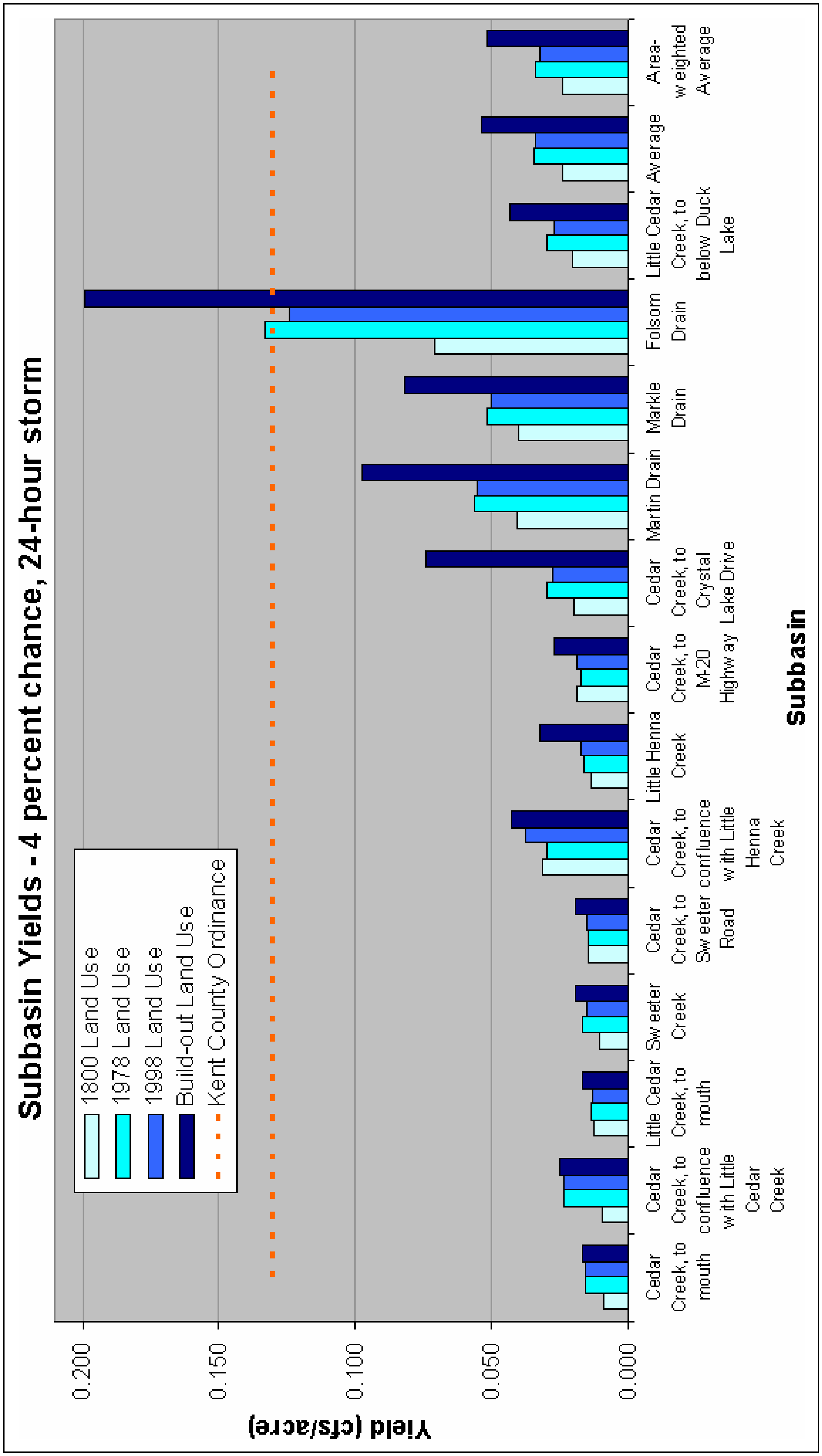

Figure 17: Subbasin Yields, 4 percent chance, 24-hour storm

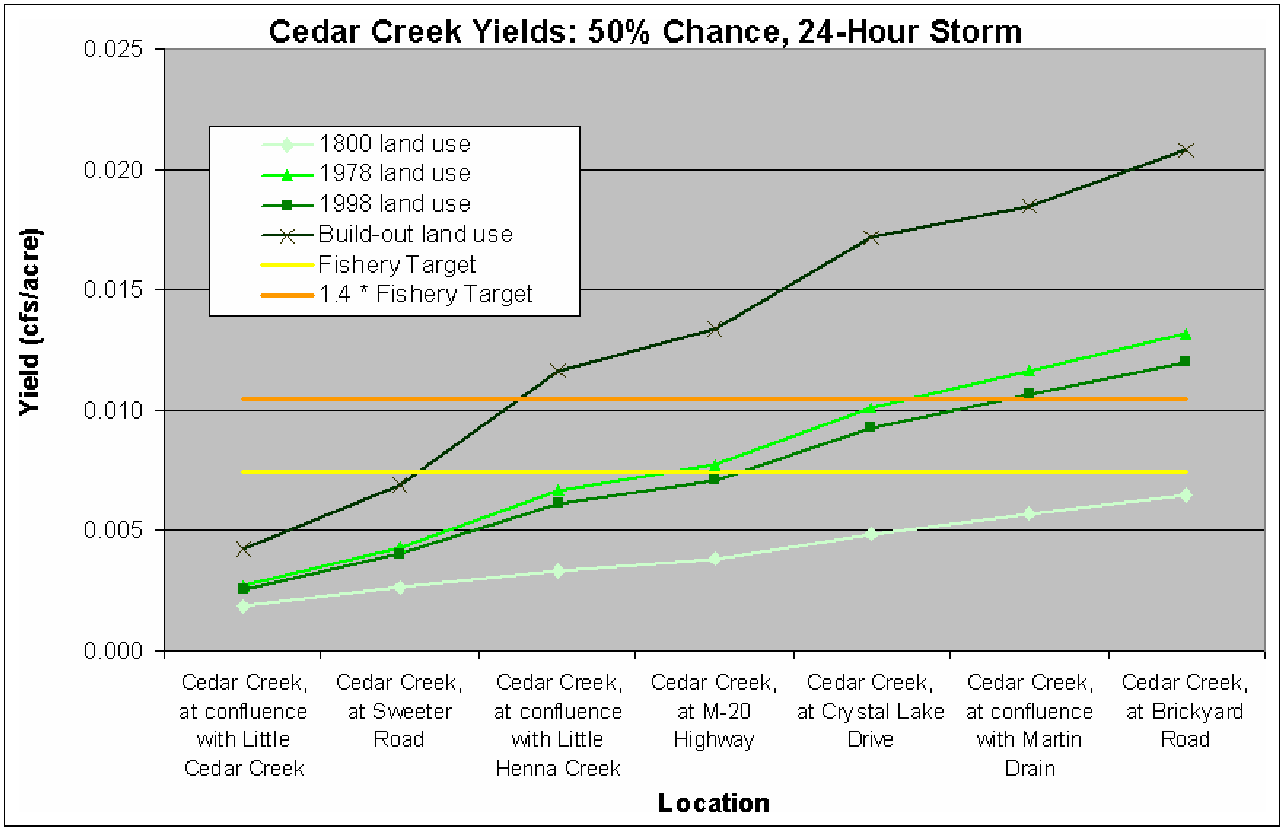

Figure 18: Cedar Creek Yields, 50 percent chance, 24-hour storm

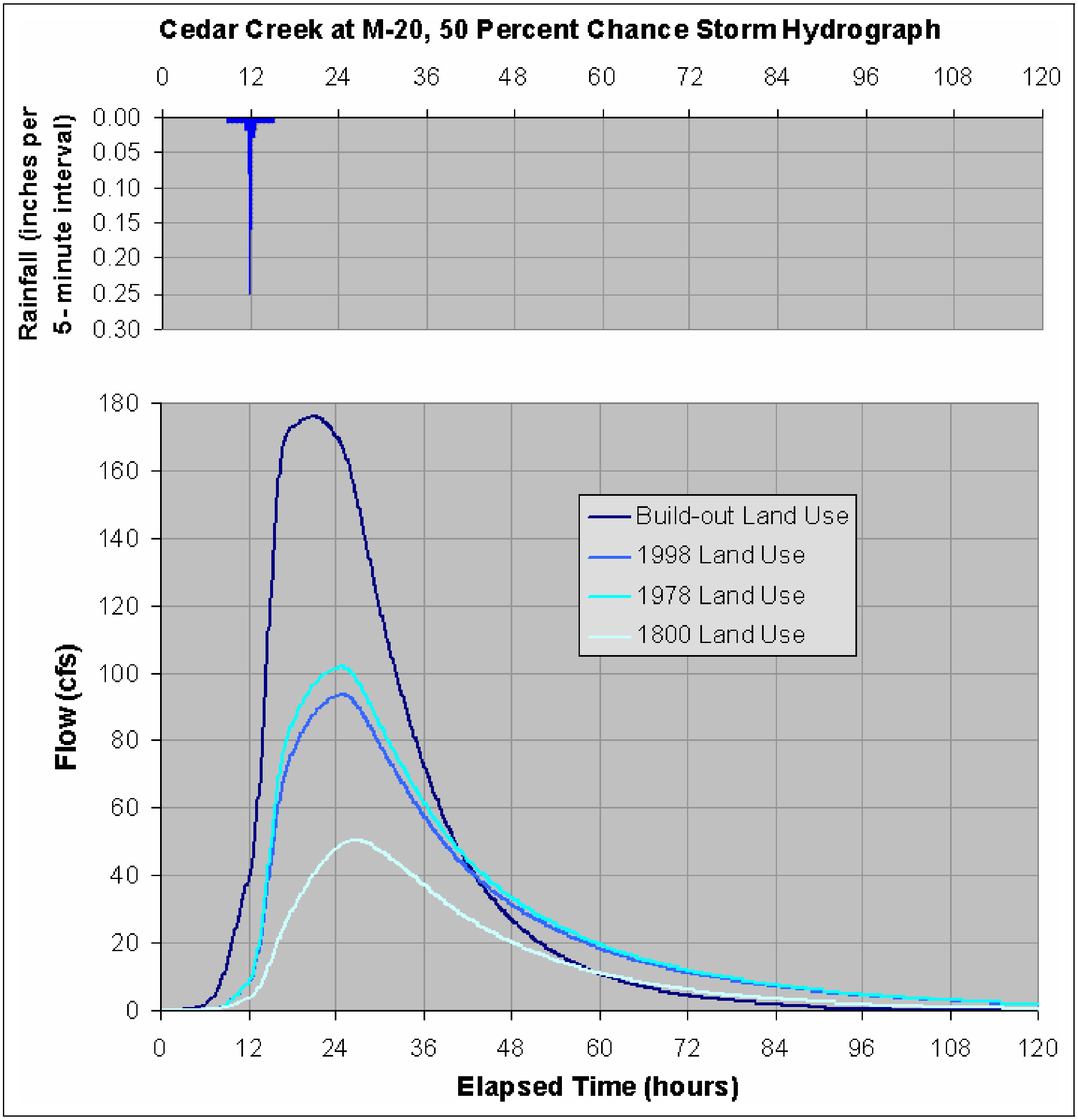

Figure 19: 50 percent chance, 24-hour storm hydrograph for Cedar Creek at M-20

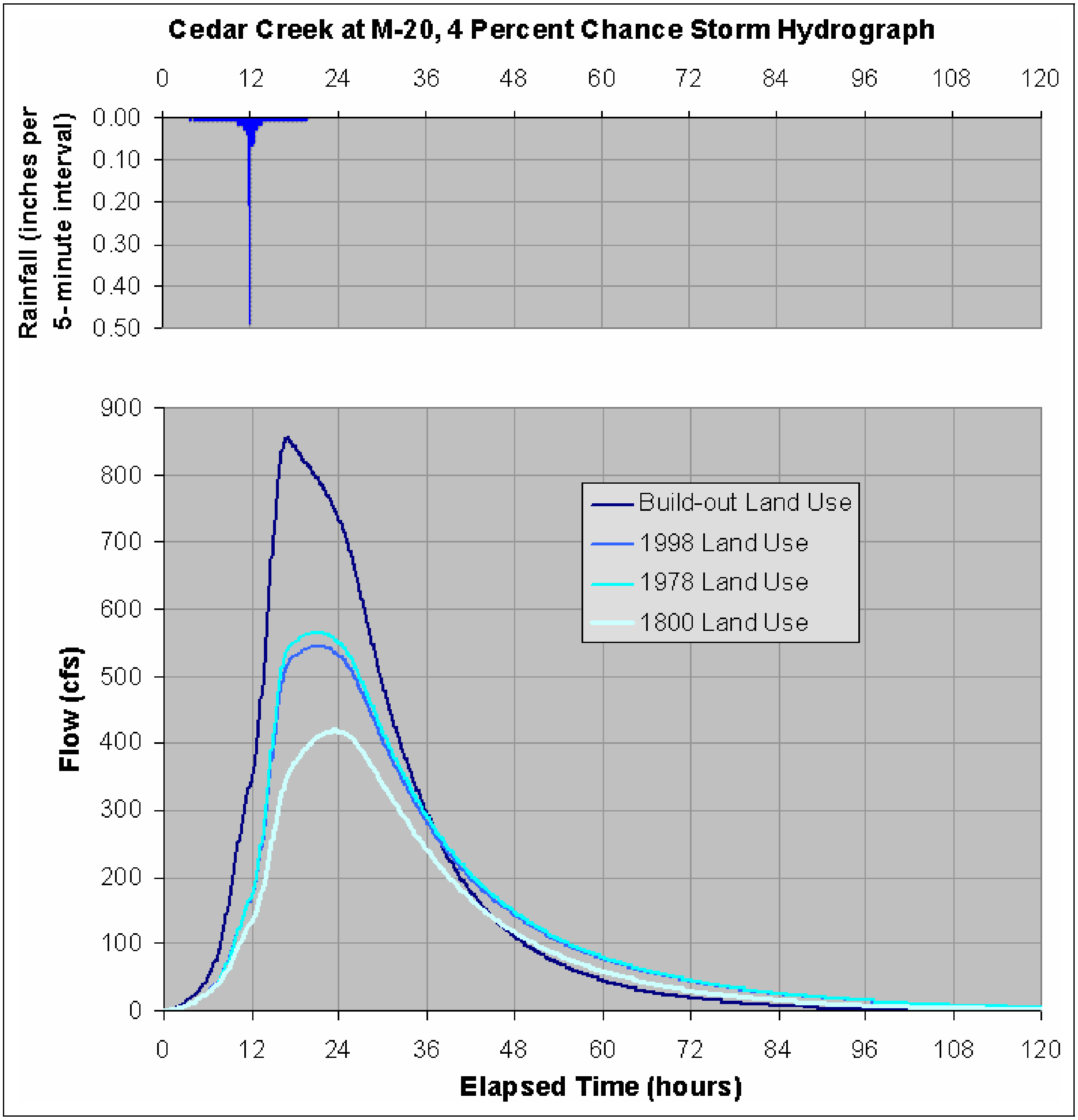

Figure 20: 4 percent chance, 24-hour storm hydrograph for Cedar Creek at M-20

Table 2: Peak flows per subbasin

Subbasin			Land Use Scenario	Peak Flow (cfs)			Yield (cfs/acre)		
ID	Description	Drainage Area (sq. mi.)		50%	4%	1%	50%	4%	1%
B1C1	Cedar Creek, to mouth	4.5	1800	0	26	73	0.000	0.01	0.02
			1978	3	45	108	0.001	0.02	0.04
			1998	3	46	109	0.001	0.02	0.04
			Build-out	4	49	115	0.001	0.02	0.04
B2C2	Cedar Creek, to confluence with Little Cedar Creek	1.1	1800	0	7	23	0.000	0.01	0.03
			1978	1	16	42	0.001	0.02	0.06
			1998	1	16	43	0.001	0.02	0.06
			Build-out	1	17	45	0.001	0.03	0.07
B2LC1	Little Cedar Creek, to mouth	4.5	1800	3	36	88	0.001	0.01	0.03
			1978	4	40	95	0.001	0.01	0.03
			1998	3	39	93	0.001	0.01	0.03
			Build-out	5	49	109	0.002	0.02	0.04
B2SC	Sweeter Creek	2.5	1800	0	16	54	0.000	0.01	0.03
			1978	0	26	76	0.000	0.02	0.05
			1998	0	24	70	0.000	0.02	0.04
			Build-out	0	30	84	0.000	0.02	0.05
B3C3	Cedar Creek, to Sweeter Road	6.4	1800	2	59	150	0.001	0.01	0.04
			1978	2	59	151	0.001	0.01	0.04
			1998	3	62	156	0.001	0.02	0.04
			Build-out	5	79	185	0.001	0.02	0.05
B4C4	Cedar Creek, to confluence with Little Henna Creek	0.6	1800	0	12	35	0.001	0.03	0.09
			1978	0	12	34	0.001	0.03	0.09
			1998	1	15	40	0.001	0.04	0.10
			Build-out	1	17	44	0.002	0.04	0.11
B4HC	Little Henna Creek	2.7	1800	0	24	76	0.000	0.01	0.04
			1978	0	28	86	0.000	0.02	0.05
			1998	0	30	91	0.000	0.02	0.05
			Build-out	2	56	143	0.001	0.03	0.08
B5C5	Cedar Creek, to M-20 Highway	5.1	1800	3	59	150	0.001	0.02	0.05
			1978	2	57	144	0.001	0.02	0.04
			1998	3	60	150	0.001	0.02	0.05
			Build-out	7	87	196	0.002	0.03	0.06
B6C6	Cedar Creek, to Crystal Lake Drive	2.4	1800	1	30	80	0.001	0.02	0.05
			1978	3	45	107	0.002	0.03	0.07
			1998	2	42	102	0.002	0.03	0.07
			Build-out	17	112	216	0.011	0.07	0.14
B7Martin	Martin Drain	2.8	1800	6	73	167	0.003	0.04	0.09
			1978	12	101	211	0.007	0.06	0.12
			1998	12	99	208	0.007	0.06	0.12
			Build-out	26	174	323	0.015	0.10	0.18

Subbasin			Land Use Scenario	Peak Flow (cfs)			Yield (cfs/acre)		
ID	Description	Drainage Area (sq. mi.)		50%	4%	1%	50%	4%	1%
B8NMdr	Markle Drain	6.9	1800	27	179	351	0.006	0.04	0.08
			1978	47	229	423	0.011	0.05	0.10
			1998	43	220	410	0.010	0.05	0.09
			Build-out	89	364	605	0.020	0.08	0.14
B8SFdr	Folsom Drain	3.3	1800	18	149	323	0.008	0.07	0.15
			1978	54	281	524	0.026	0.13	0.25
			1998	47	262	499	0.022	0.12	0.24
			Build-out	97	421	705	0.046	0.20	0.33
BTLC2	Little Cedar Creek, to below Duck Lake	7.2	1800	3	94	247	0.001	0.02	0.05
			1978	9	134	320	0.002	0.03	0.07
			1998	7	123	299	0.002	0.03	0.07
			Build-out	21	199	429	0.005	0.04	0.09
Average			1800				0.002	0.02	0.06
			1978				0.004	0.03	0.08
			1998				0.004	0.03	0.08
			Build-out				0.008	0.05	0.11
Area-weighted Average			1800				0.002	0.02	0.06
			1978				0.004	0.03	0.07
			1998				0.004	0.03	0.07
			Build-out				0.009	0.05	0.10

Table 3: Peak flows in Cedar Creek

River Location		Drainage Area (sq. mi.)	Land Use Scenario	Peak Flow (cfs)			Yield (cfs/acre)		
ID	Description			50%	4%	1%	50%	4%	1%
J1	Cedar Creek, at mouth	49.9	1800	51	203	541	0.002	0.01	0.02
			1978	62	285	660	0.002	0.01	0.02
			1998	60	275	646	0.002	0.01	0.02
			Build-out	79	399	842	0.002	0.01	0.03
J2	Cedar Creek, at confluence with Little Cedar Creek	45.3	1800	55	401	929	0.002	0.01	0.03
			1978	80	535	1120	0.003	0.02	0.04
			1998	75	517	1100	0.003	0.02	0.04
			Build-out	123	772	1476	0.004	0.03	0.05
J3	Cedar Creek, at Sweeter Road	30.2	1800	51	386	842	0.003	0.02	0.04
			1978	83	514	1030	0.004	0.03	0.05
			1998	78	500	1011	0.004	0.03	0.05
			Build-out	133	741	1354	0.007	0.04	0.07
J4	Cedar Creek, at confluence with Little Henna Creek	23.7	1800	51	428	878	0.003	0.03	0.06
			1978	102	578	1122	0.007	0.04	0.07
			1998	94	558	1094	0.006	0.04	0.07
			Build-out	177	881	1559	0.012	0.06	0.10
J5	Cedar Creek, at M-20 Highway	20.4	1800	51	418	854	0.004	0.03	0.07
			1978	102	564	1083	0.008	0.04	0.08
			1998	94	544	1053	0.007	0.04	0.08
			Build-out	176	856	1513	0.013	0.07	0.12
J6	Cedar Creek, at Crystal Lake Drive	15.4	1800	48	371	738	0.005	0.04	0.07
			1978	100	515	951	0.010	0.05	0.10
			1998	91	492	918	0.009	0.05	0.09
			Build-out	169	772	1332	0.017	0.08	0.14
J7	Cedar Creek, at confluence with Martin Drain	13.0	1800	48	346	675	0.006	0.04	0.08
			1978	97	475	857	0.012	0.06	0.10
			1998	89	454	829	0.011	0.05	0.10
			Build-out	154	672	1148	0.019	0.08	0.14
J8	Cedar Creek, at Brickyard Road	10.2	1800	42	292	562	0.006	0.04	0.09
			1978	86	396	699	0.013	0.06	0.11
			1998	79	377	675	0.012	0.06	0.10
			Build-out	136	539	889	0.021	0.08	0.14
JT	Little Cedar Creek, below Duck Lake	7.2	1800	3	94	247	0.001	0.02	0.05
			1978	9	134	320	0.002	0.03	0.07
			1998	7	123	299	0.002	0.03	0.07
			Build-out	21	199	429	0.005	0.04	0.09
Average			1800				0.003	0.03	0.06
			1978				0.007	0.04	0.07
			1998				0.006	0.04	0.07
			Build-out				0.011	0.05	0.10
Area-weighted Average			1800				0.003	0.02	0.05
			1978				0.005	0.03	0.06
			1998				0.005	0.03	0.06
			Build-out				0.008	0.04	0.08

Table 4: Runoff volumes per subbasin

Subbasin ID	Subbasin Description	Land Use Scenario	Runoff Volume (acre-feet) 50% chance storm	4% chance storm	1% chance storm
B1C1	Cedar Creek, to mouth	1800	2	112	269
		1978	16	192	395
		1998	17	194	399
		Build-out	19	203	411
B2C2	Cedar Creek, to confluence with Little Cedar Creek	1800	0	16	45
		1978	2	36	78
		1998	2	36	79
		Build-out	2	38	81
B2LC1	Little Cedar Creek, to mouth	1800	19	196	407
		1978	22	211	429
		1998	21	205	420
		Build-out	29	236	461
B2SC	Sweeter Creek	1800	0	34	99
		1978	0	53	133
		1998	0	48	124
		Build-out	1	57	138
B3C3	Cedar Creek, to Sweeter Road	1800	8	203	450
		1978	8	203	450
		1998	10	213	465
		Build-out	20	258	535
B4C4	Cedar Creek, to confluence with Little Henna Creek	1800	1	18	41
		1978	0	17	39
		1998	1	21	45
		Build-out	1	23	48
B4HC	Little Henna Creek	1800	0	43	119
		1978	0	49	129
		1998	0	53	135
		Build-out	2	78	177
B5C5	Cedar Creek, to M-20 Highway	1800	8	170	371
		1978	7	162	357
		1998	8	170	371
		Build-out	19	219	444
B6C6	Cedar Creek, to Crystal Lake Drive	1800	2	66	153
		1978	7	95	198
		1998	6	90	190
		Build-out	30	169	303
B7Martin	Martin Drain	1800	15	136	268
		1978	28	176	324
		1998	27	174	321
		Build-out	34	195	350

Subbasin		Land Use Scenario	Runoff Volume (acre-feet)		
ID	Description		50% chance storm	4% chance storm	1% chance storm
B8NMdr	Markle Drain	1800	74	455	831
		1978	150	642	1079
		1998	140	618	1048
		Build-out	175	694	1145
B8SFdr	Folsom Drain	1800	36	218	397
		1978	75	314	524
		1998	67	296	501
		Build-out	88	340	557
BTLC2	Little Cedar Creek, to below Duck Lake	1800	7	210	476
		1978	22	289	597
		1998	17	266	563
		Build-out	50	390	746

Table 5: Runoff volumes in Cedar Creek

River Location		Land Use Scenario	Runoff Volume (acre-feet)		
ID	Description		50% chance storm	4% chance storm	1% chance storm
J1	Cedar Creek, at mouth	1800	171	1878	3925
		1978	339	2439	4733
		1998	315	2384	4660
		Build-out	470	2899	5396
J2	Cedar Creek, at confluence with Little Cedar Creek	1800	169	1766	3656
		1978	321	2246	4338
		1998	297	2188	4261
		Build-out	451	2697	4985
J3	Cedar Creek, at Sweeter Road	1800	144	1311	2630
		1978	275	1658	3100
		1998	258	1634	3076
		Build-out	370	1976	3559
J4	Cedar Creek, at confluence with Little Henna Creek	1800	136	1108	2179
		1978	267	1455	2650
		1998	249	1422	2611
		Build-out	350	1718	3024
J5	Cedar Creek, at M-20 Highway	1800	135	1047	2019
		1978	267	1389	2482
		1998	248	1348	2430
		Build-out	346	1618	2800
J6	Cedar Creek, at Crystal Lake Drive	1800	127	876	1649
		1978	260	1228	2125
		1998	239	1178	2060
		Build-out	327	1399	2355
J7	Cedar Creek, at confluence with Martin Drain	1800	125	810	1496
		1978	253	1132	1927
		1998	233	1088	1870
		Build-out	297	1229	2052
J8	Cedar Creek, at Brickyard Road	1800	110	673	1228
		1978	226	956	1603
		1998	207	914	1549
		Build-out	262	1035	1702
JT	Little Cedar Creek, below Duck Lake	1800	7	210	476
		1978	22	289	597
		1998	17	266	563
		Build-out	50	390	746

Appendix

Appendix A: Cedar Creek Hydrologic Model Parameters

This appendix is provided so that the model may be recreated. Table A1 provides the design rainfall values specific to the region of the state where the Cedar Creek is located. Figure A1 summarizes the hydrologic elements in the HEC-HMS model. Tables A2 and A3 provide the parameters that were specified for each of these hydrologic elements. The initial loss field in HEC-HMS is left blank so that the default equation based on the curve number is used. Table A4 provides the reach parameters for the lag routing method. Tables A5 and A6 provide the storage-discharge relationships for the Cedar River and Little Cedar Rivers respectively. HEC-HMS was run for a twelve-day duration using a five-minute computation interval.

Table A1: Design Rainfall Values

SCS Type II Precipitation Event	Precipitation	Area-adjusted Precipitation*
50% chance (2-year), 24-hour storm	2.28 inches	2.16 inches
4% chance (25-year), 24-hour storm	4.48 inches	4.25 inches
1% chance (100-year), 24-hour storm	6.07 inches	5.75 inches

*standard values were multiplied by 0.948 to account for the watershed size

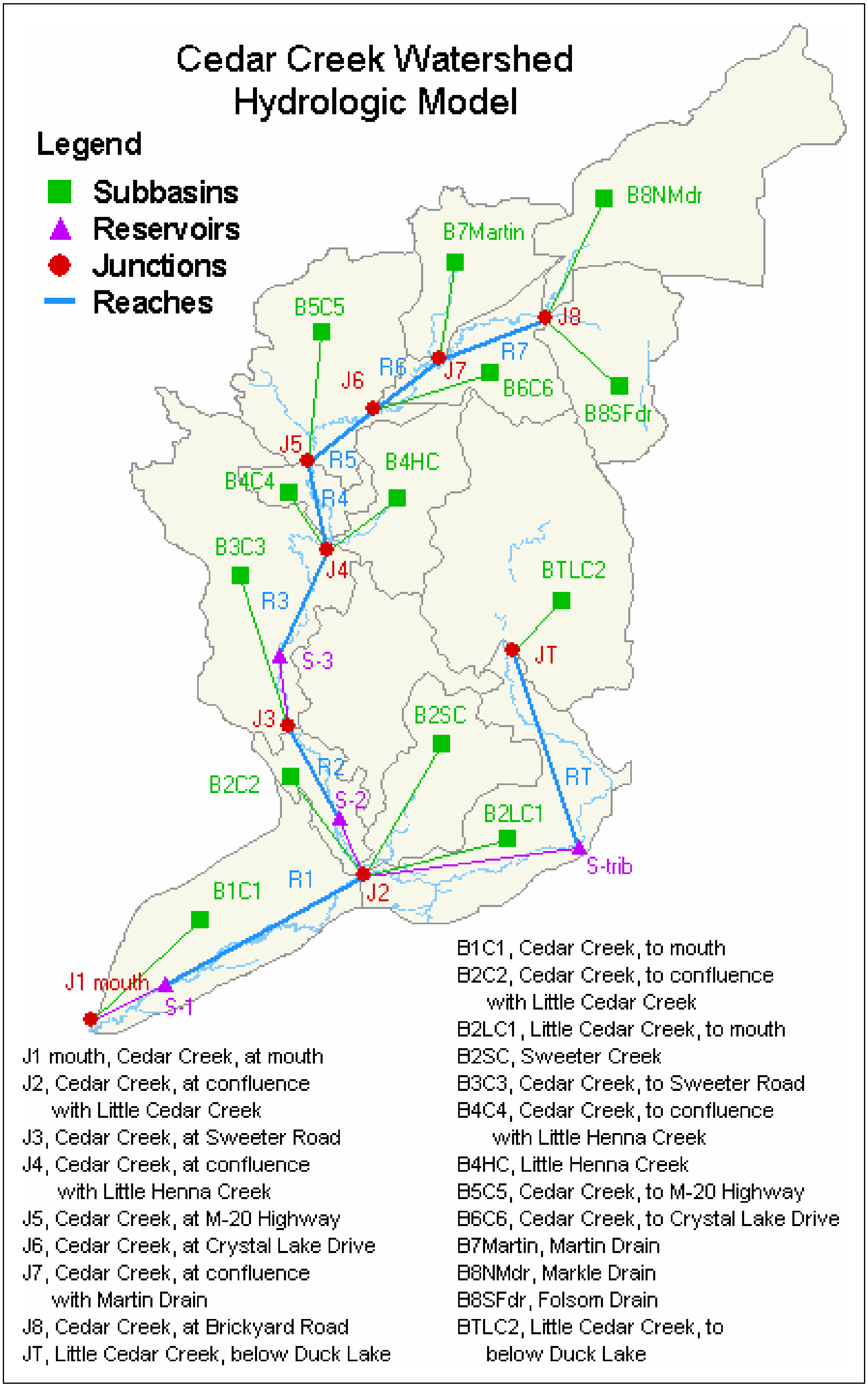

Figure A1: Hydrologic Elements defined for HEC-HMS model

Table A2: Subbasin Parameters – Area, Curve Number, Initial Loss

Subbasins		Drainage Area (sq. mi.)	Runoff Curve Number				Initial Loss
ID	Description		1800	1978	1998	Build-out	
NC	Non-contributing	7.2					
B1C1	Cedar Creek, to mouth	4.5	51	59	59	59	Default
B2C2	Cedar Creek, to confluence with Little Cedar Creek	1.1	46	55	55	56	Default
B2LC1	Little Cedar Creek, to mouth	4.5	60	61	61	62	Default
B2SC	Sweeter Creek	2.5	46	50	49	51	Default
B3C3	Cedar Creek, to Sweeter Road	6.4	54	54	55	58	Default
B4C4	Cedar Creek, to confluence with Little Henna Creek	0.6	53	53	55	56	Default
B4HC	Little Henna Creek	2.7	47	48	49	53	Default
B5C5	Cedar Creek, to M-20 Highway	5.1	55	54	55	59	Default
B6C6	Cedar Creek, to Crystal Lake Drive	2.4	53	57	57	68	Default
B7Martin	Martin Drain	2.8	61	65	65	67	Default
B8NMDr	Markle Drain	6.9	66	73	73	75	Default
B8SFDr	Folsom Drain	3.3	66	74	73	76	Default
BTLC2	Little Cedar Creek, to below Duck Lake	7.2	53	58	56	62	Default
	Total, without NC	49.9					
	Total, with NC	57.1					

Table A3: Subbasin Parameters – Times of Concentration and Storage Coefficients

Subbasin ID	Land Use Scenario	Time of Concentration (hours)	Storage Coefficient		
			50% chance, 24-hour storm	4% chance, 24-hour storm	1% chance, 24-hour storm
B1C1	1800	16.66	47.71	39.38	32.11
	1978		48.90	51.85	31.84
	1998		48.91	38.80	31.83
	Build-out		46.32	37.15	30.81
B2C2	1800	6.54	6.54	19.09	13.51
	1978		23.35	18.52	12.62
	1998		23.40	16.49	12.62
	Build-out		22.37	15.57	12.17
B2LC1	1800	20.16	72.91	56.15	43.21
	1978		69.34	45.11	42.04
	1998		69.36	53.99	42.03
	Build-out		55.63	46.03	37.85
B2SC	1800	6.66	6.66	15.34	11.82
	1978		15.41	31.34	11.31
	1998		14.84	14.35	11.38
	Build-out		14.28	12.51	10.31
B3C3	1800	13.74	35.24	29.33	24.38
	1978		34.48	69.18	24.21
	1998		34.60	29.09	24.19
	Build-out		32.76	27.21	23.32

Subbasin ID	Land Use Scenario	Time of Concentration (hours)	Storage Coefficient		
			50% chance, 24-hour storm	4% chance, 24-hour storm	1% chance, 24-hour storm
B4C4	1800	3.54	15.76	8.44	6.49
	1978		14.73	13.67	6.44
	1998		16.74	8.11	6.38
	Build-out		15.94	7.79	6.25
B4HC	1800	5.53	11.21	11.87	9.18
	1978		11.10	33.49	8.72
	1998		11.47	10.87	8.68
	Build-out		9.26	7.48	6.81
B5C5	1800	10.69	28.01	23.30	19.00
	1978		27.55	65.82	18.94
	1998		27.73	23.08	18.89
	Build-out		23.95	19.44	16.81
B6C6	1800	7.51	19.33	16.08	12.99
	1978		20.79	51.34	12.77
	1998		20.63	15.37	12.79
	Build-out		10.99	9.64	9.09
B7Martin	1800	6.27	19.43	12.83	10.75
	1978		16.82	113.39	10.43
	1998		16.93	11.94	10.43
	Build-out		6.27	6.27	6.27
B8NMDr	1800	13.06	22.03	19.61	17.95
	1978		27.07	252.54	20.29
	1998		27.16	22.79	20.29
	Build-out		13.06	13.06	13.06
B8SFDr	1800	4.39	14.28	9.41	7.87
	1978		8.10	309.90	6.24
	1998		8.19	7.01	6.23
	Build-out		4.39	4.39	4.39
BTLC2	1800	7.63	19.96	16.33	13.22
	1978		20.85	154.60	12.92
	1998		20.61	15.55	12.96
	Build-out		18.94	13.74	12.00

Table A4: Channel Reach Parameters

ID	Reach	Lag (minutes)
R1	Cedar Creek, to mouth	1269
R2	Cedar Creek, to confluence with Little Cedar Creek	395
R3	Cedar Creek, to Sweeter Road	545
R4	Cedar Creek, to confluence with Little Henna Creek	245
R5	Cedar Creek, to M-20 Highway	316
R6	Cedar Creek, to Crystal Lake Drive	126
R7	Cedar Creek, to confluence with Martin Drain	311
RT	Little Cedar Creek, to confluence with Cedar Creek	1211

Table A5: Cedar River Storage-Discharge Relationships

Discharge (cfs)	S1 Storage (acre-feet)	S2 Storage (acre-feet)	S3 Storage (acre-feet)
0	0	0	0
50	0	0	0
100	229	51	47
200	702	156	144
300	948	211	194
400	1197	266	245
500	1431	318	293
600	1655	368	339
700	1872	417	383
800	2084	464	426
1000	2489	554	509
1200	2877	640	589
1500	3444	766	705

Table A5: Little Cedar River Storage-Discharge Relationship

Discharge (cfs)	Strib Storage (acre-feet)
0	0
1	0
150	184
340	285