A Hydrologic Study of the Bear Creek Watershed

Michigan's Nonpoint Source Program

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Summary

A hydrologic model of the Bear 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 in the watershed on Bear Creek's flow regime and to provide design flows for streambank stabilization Best Management Practices (BMPs). The Bear Creek Watershed Committee 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. The communities within the watershed could also use the information to help develop stormwater ordinances.

The hydrologic model has four scenarios corresponding to 1800, 1978, 1997, and build-out land use. The build-out scenario is based on zoning. General land use changes illustrated in Figure 1 show that urban uses are projected to continue to increase, with a net loss of natural areas. Because of these land use trends, the model predicts increases in runoff volumes and peak flows from 1800 to 1978/1997 and from 1978/1997 to build-out for all four design storms analyzed, as shown in Figures 2 through 9. More detailed land use information is provided in the Watershed Description and Model Parameters section of this report. Additional flow details are in the Model Results section of this report.

The projected runoff volume and peak flow increases from the 10, 4, and 2 percent chance (10-year, 25-year, and 50-year), 24-hour storms would aggravate flooding problems unless mitigated through the use of effective stormwater management techniques. The projected increases from the 50 percent chance (2-year), 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 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 often do little to control the runoff from the 50 percent chance, 24-hour storm unless the outlet is specifically designed to do so.

The average yield from the 50 percent chance, 24-hour storm for the Bear Creek watershed is 0.01 and 0.02 cubic feet per second per acre (cfs/acre) for current and build-out conditions, respectively. These values have implications for fish habitat and stream stability management. The average yield from the 4 percent chance, 24-hour storm for the Bear Creek watershed is 0.07 and 0.11 cfs/acre for current and build-out conditions, respectively. These values have implications for flood control management. Additional details are shown in Figures 10 through 12 and in the Model Results section of this report.

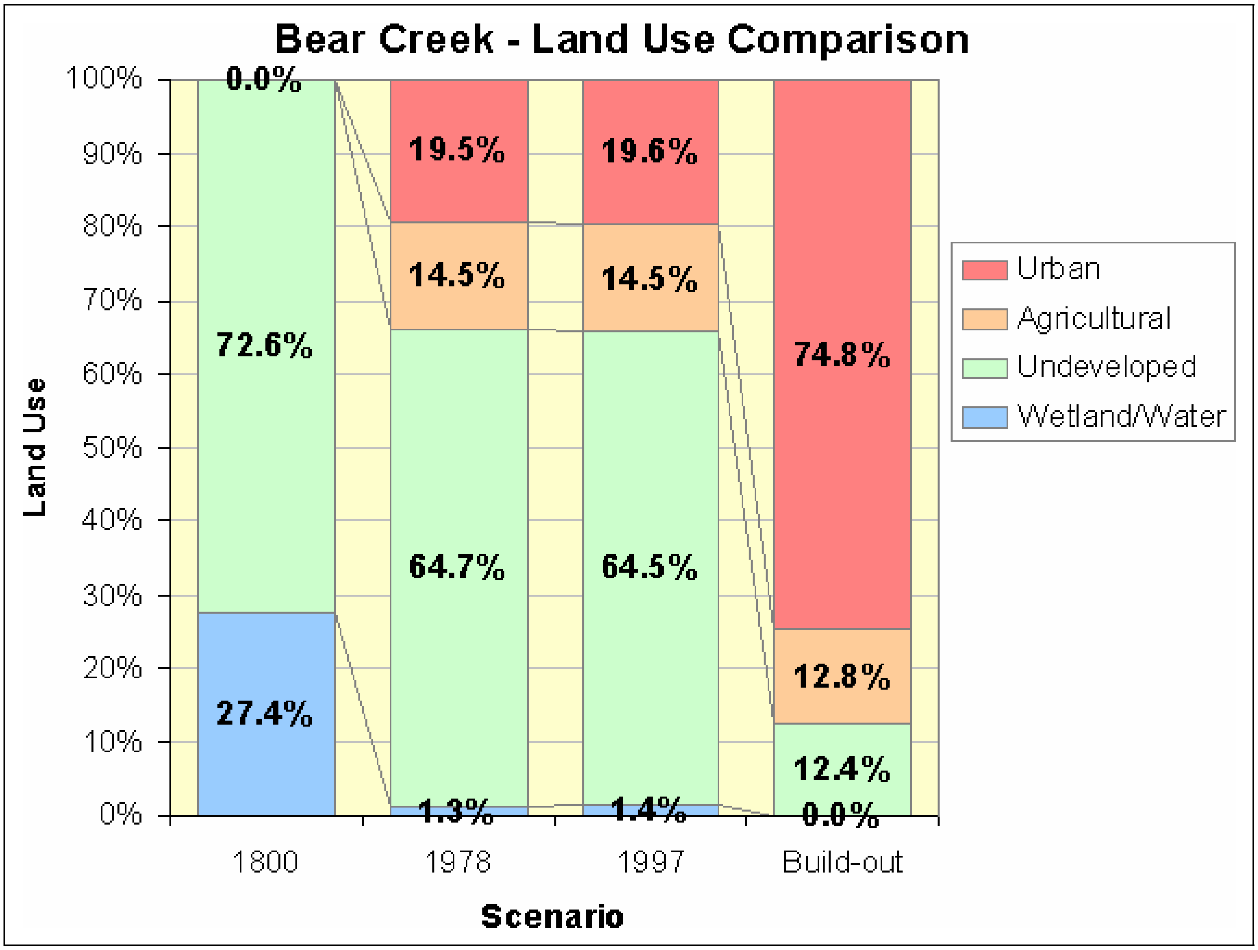

Figure 1: Land Use Comparison

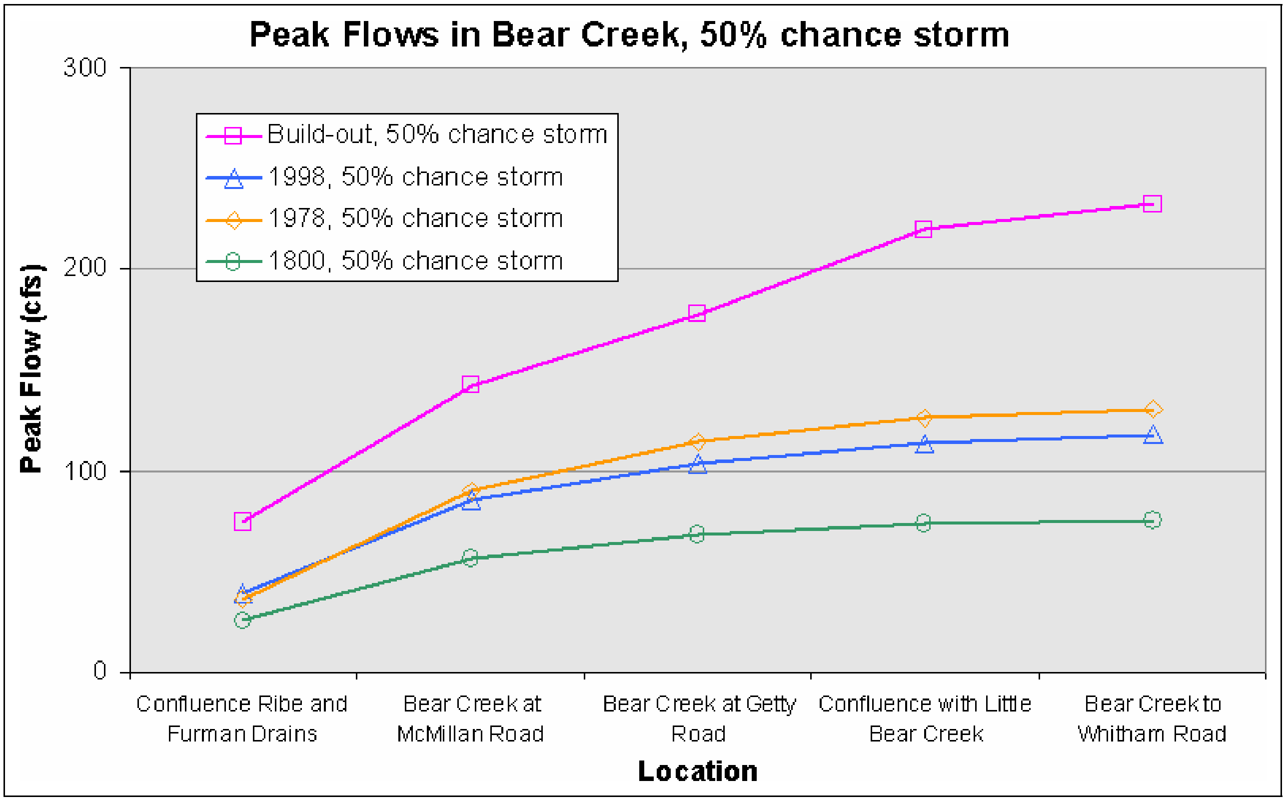

Figure 2: Predicted peak flows for selected locations, 50 percent chance storm

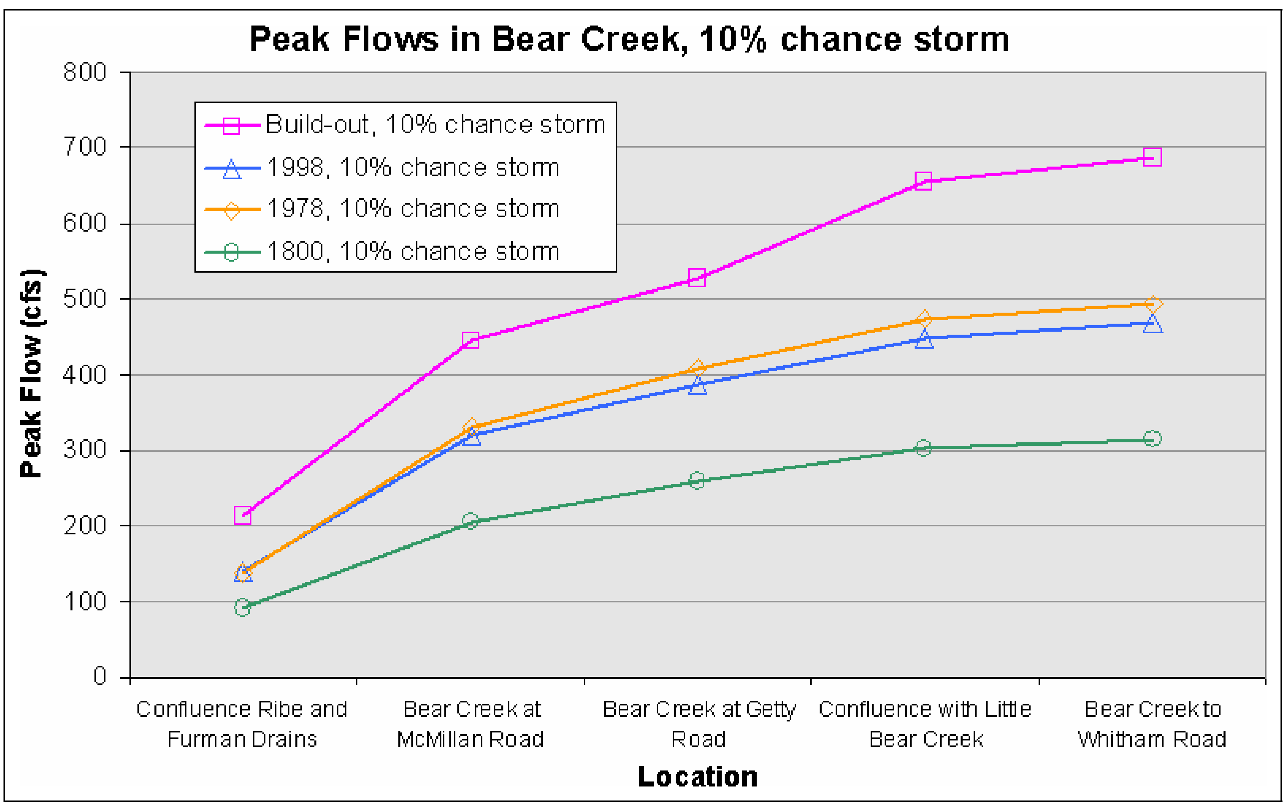

Figure 3: Predicted peak flows for selected locations, 10 percent chance storm

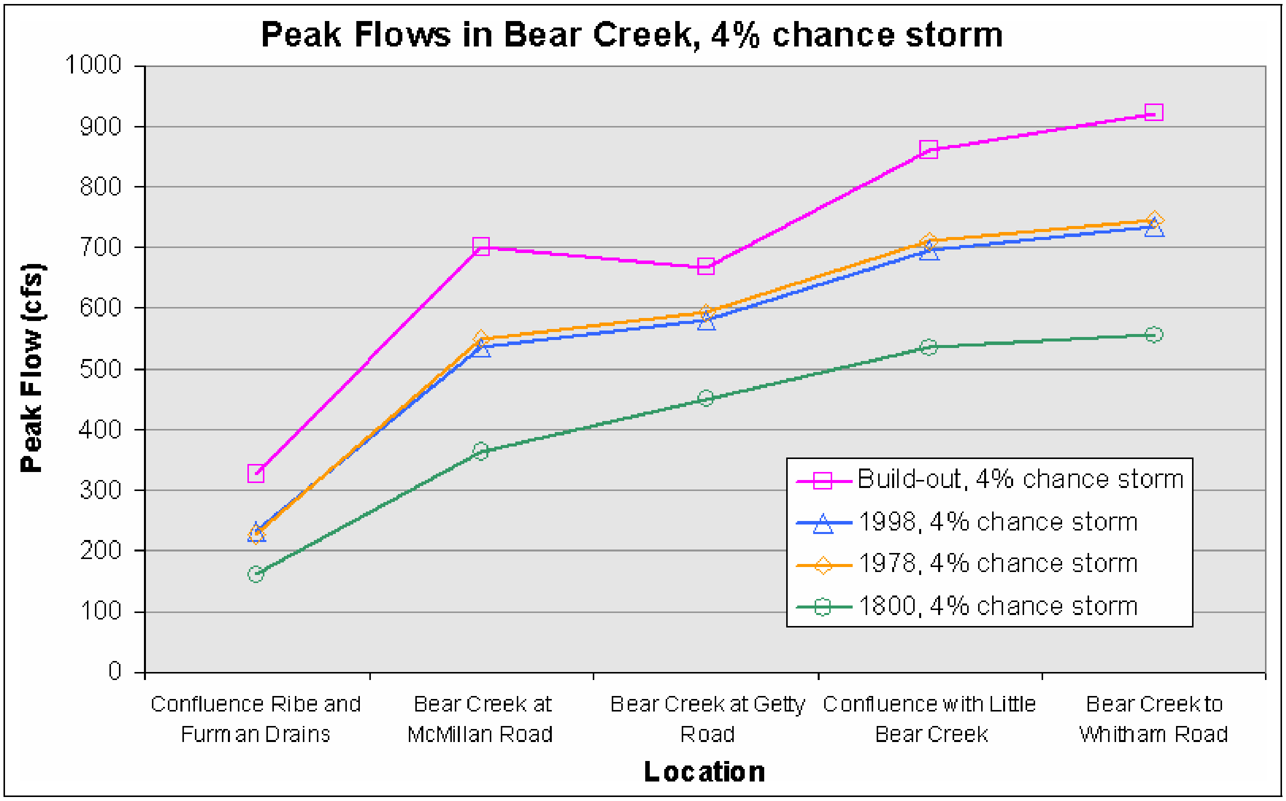

Figure 4: Predicted peak flows for selected locations, 4 percent chance storm

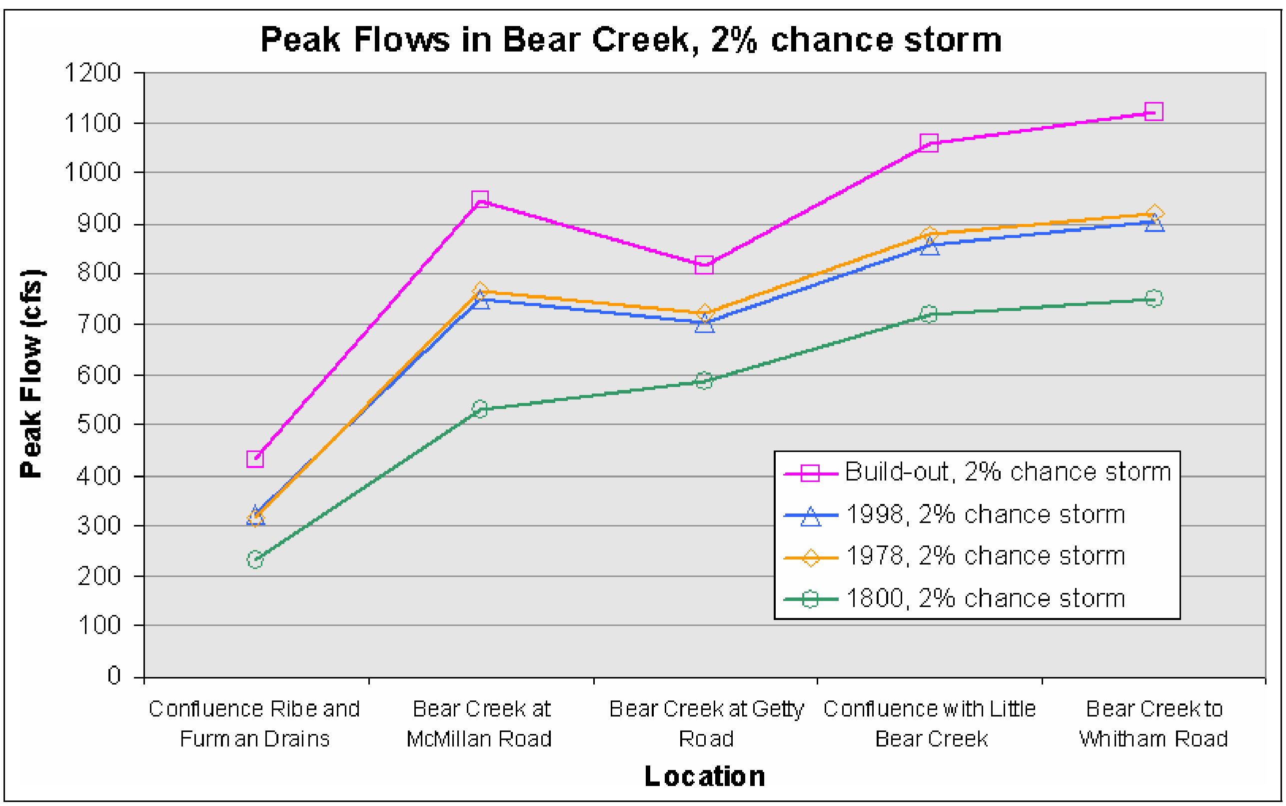

Figure 5: Predicted peak flows for selected locations, 2 percent chance storm

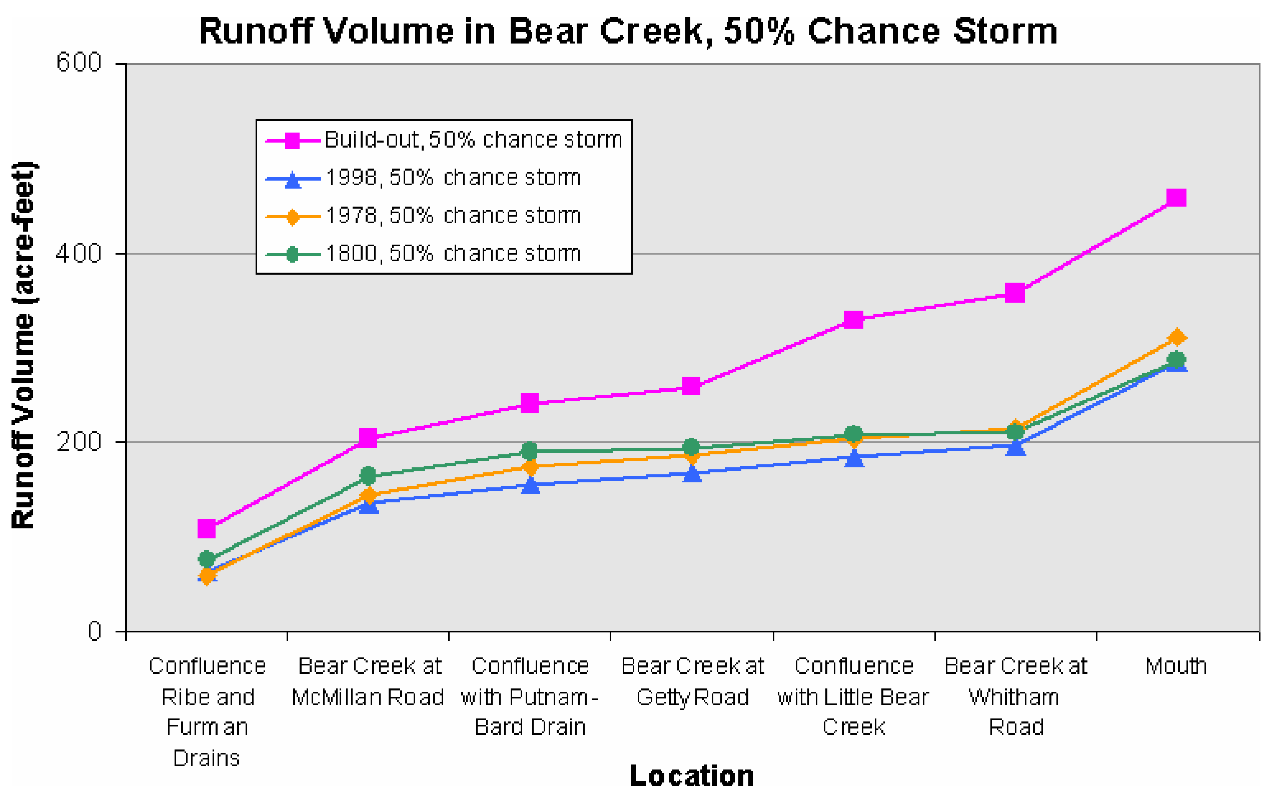

Figure 6: Predicted runoff volumes, 50 percent chance storm

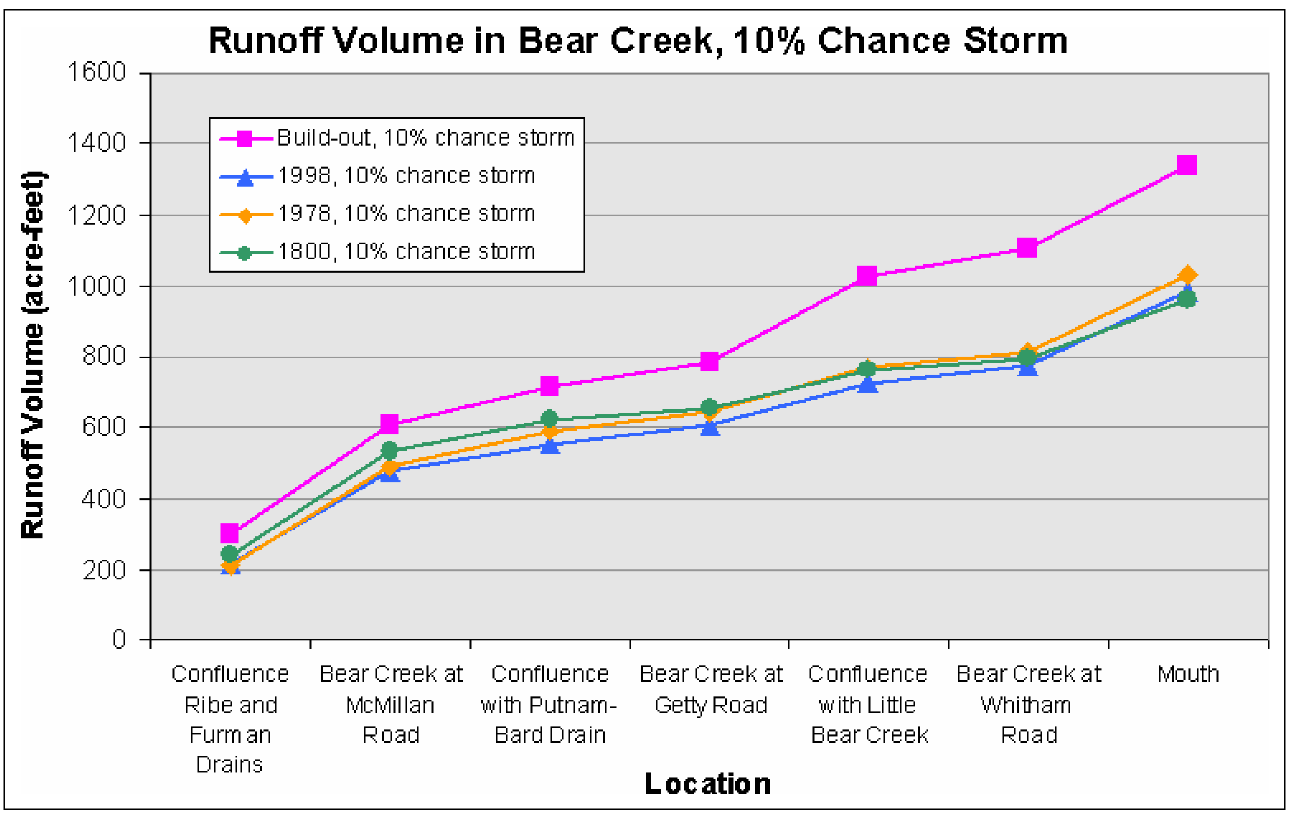

Figure 7: Predicted runoff volumes, 10 percent chance storm

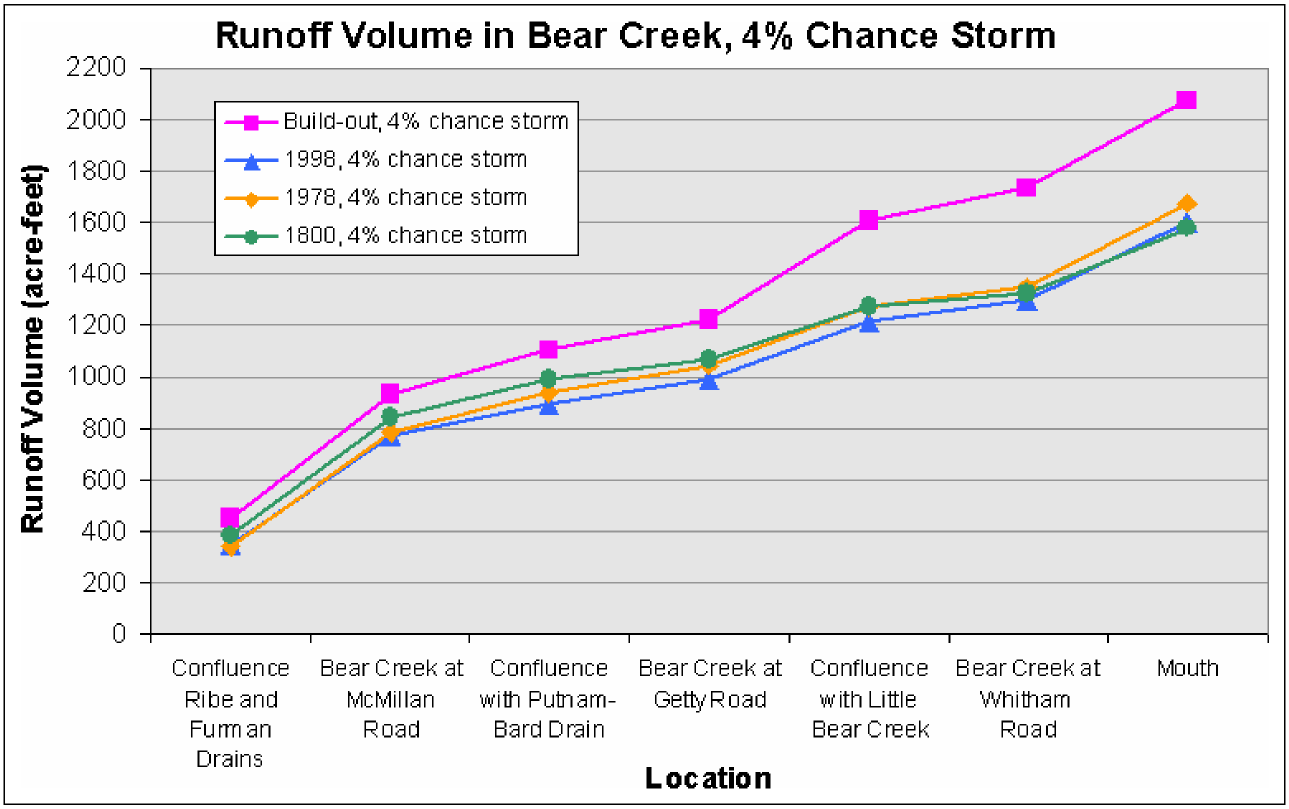

Figure 8: Predicted runoff volumes, 4 percent chance storm

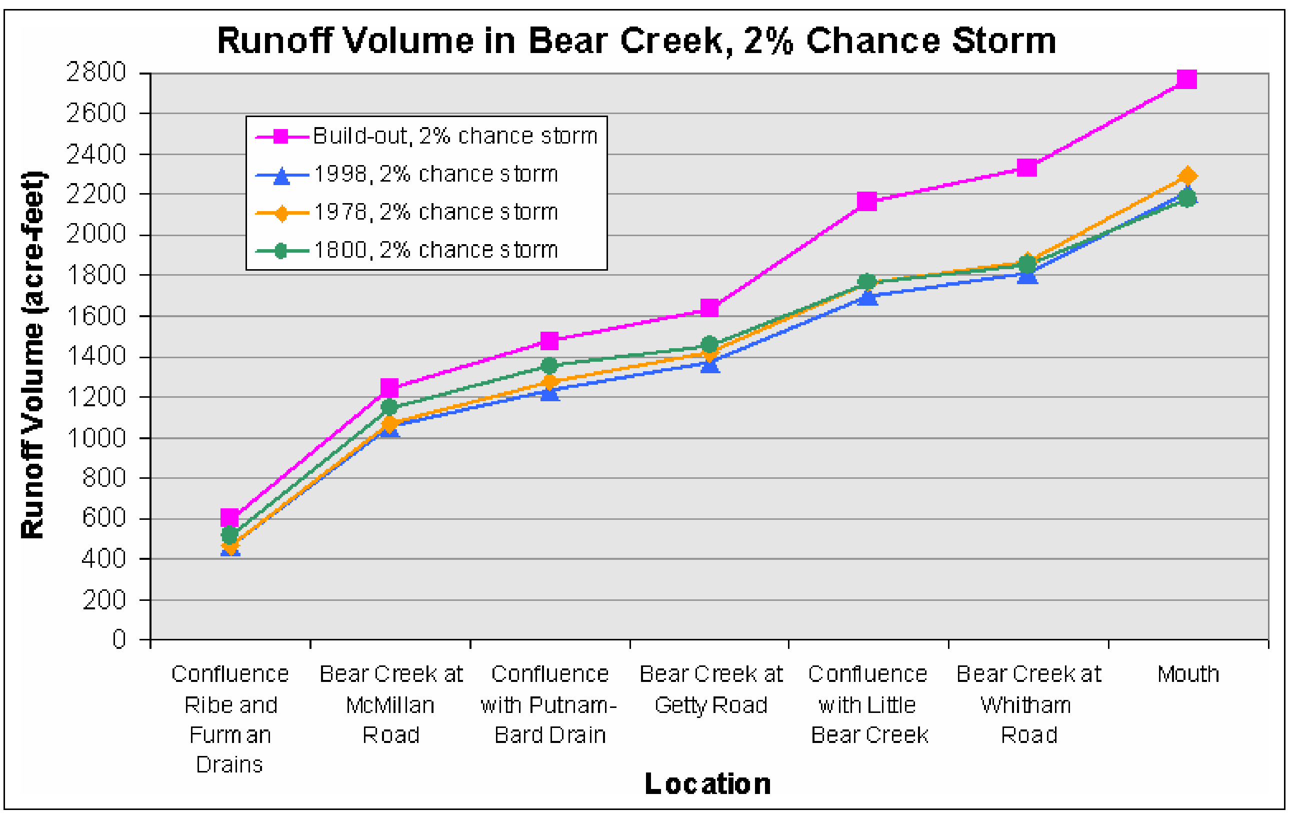

Figure 9: Predicted runoff volumes, 2 percent chance storm

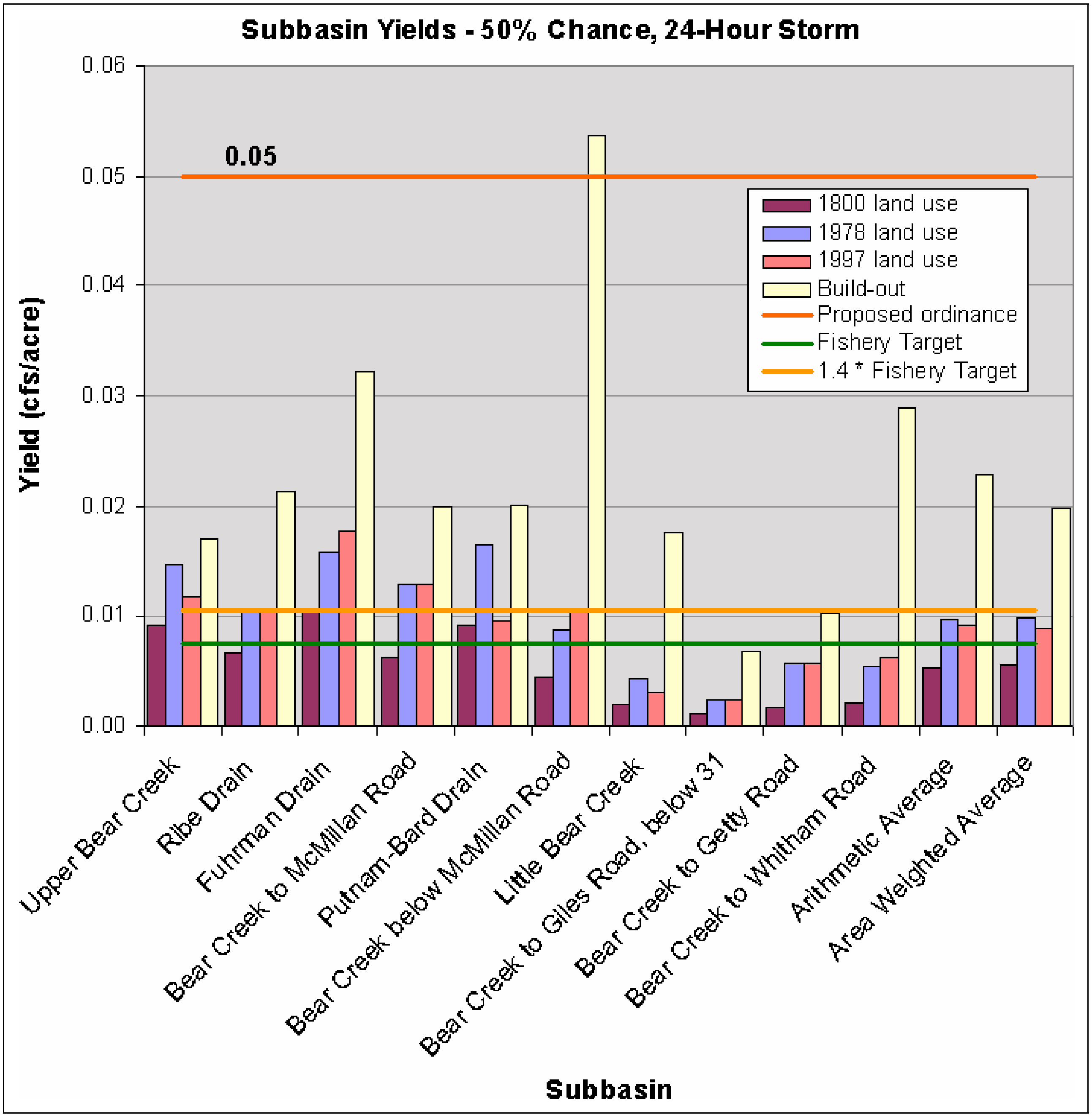

Figure 10: Subbasin Yields, 50 percent chance, 24-hour storm

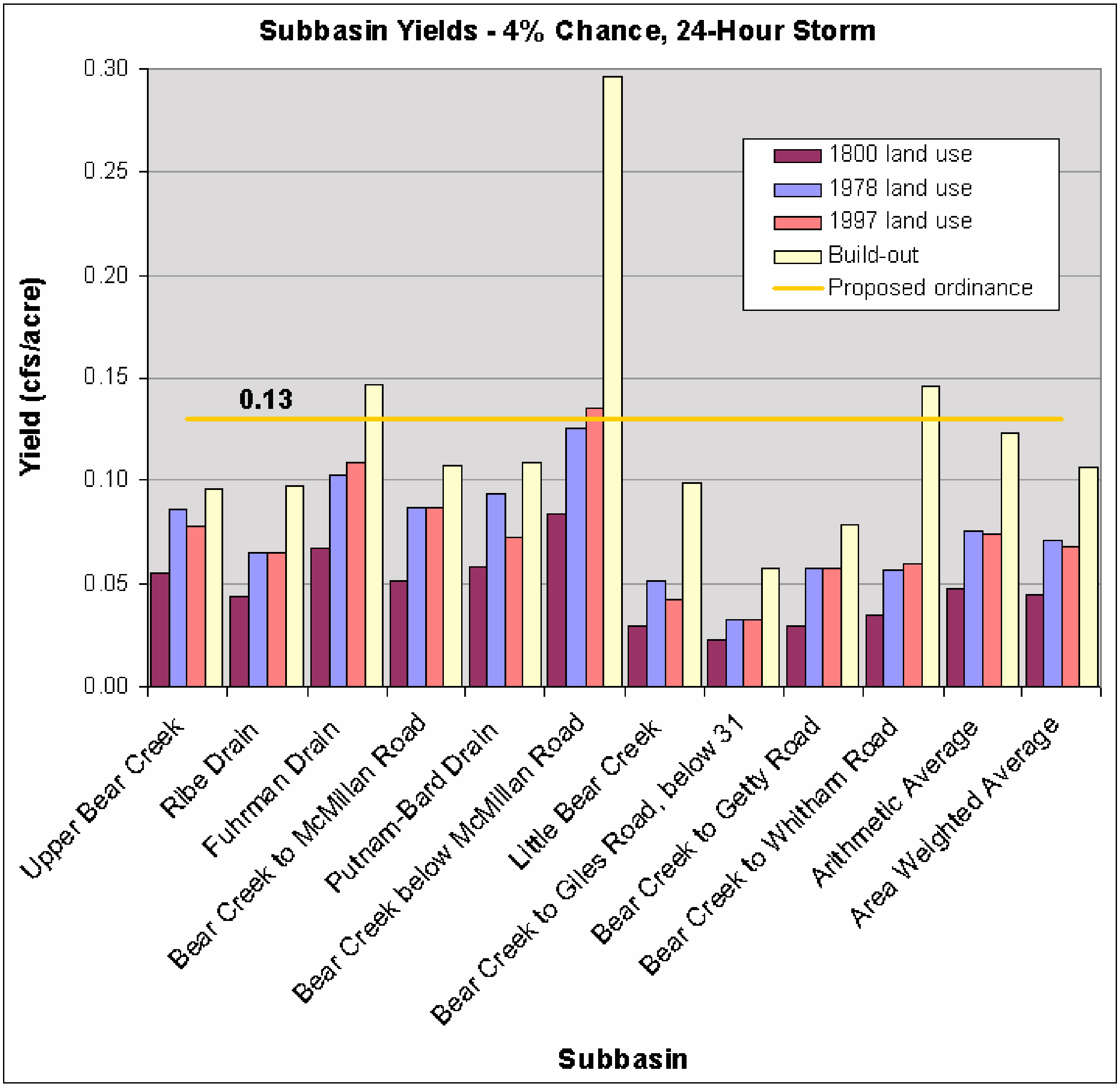

Figure 11: Subbasin Yields, 4 percent chance, 24-hour storm

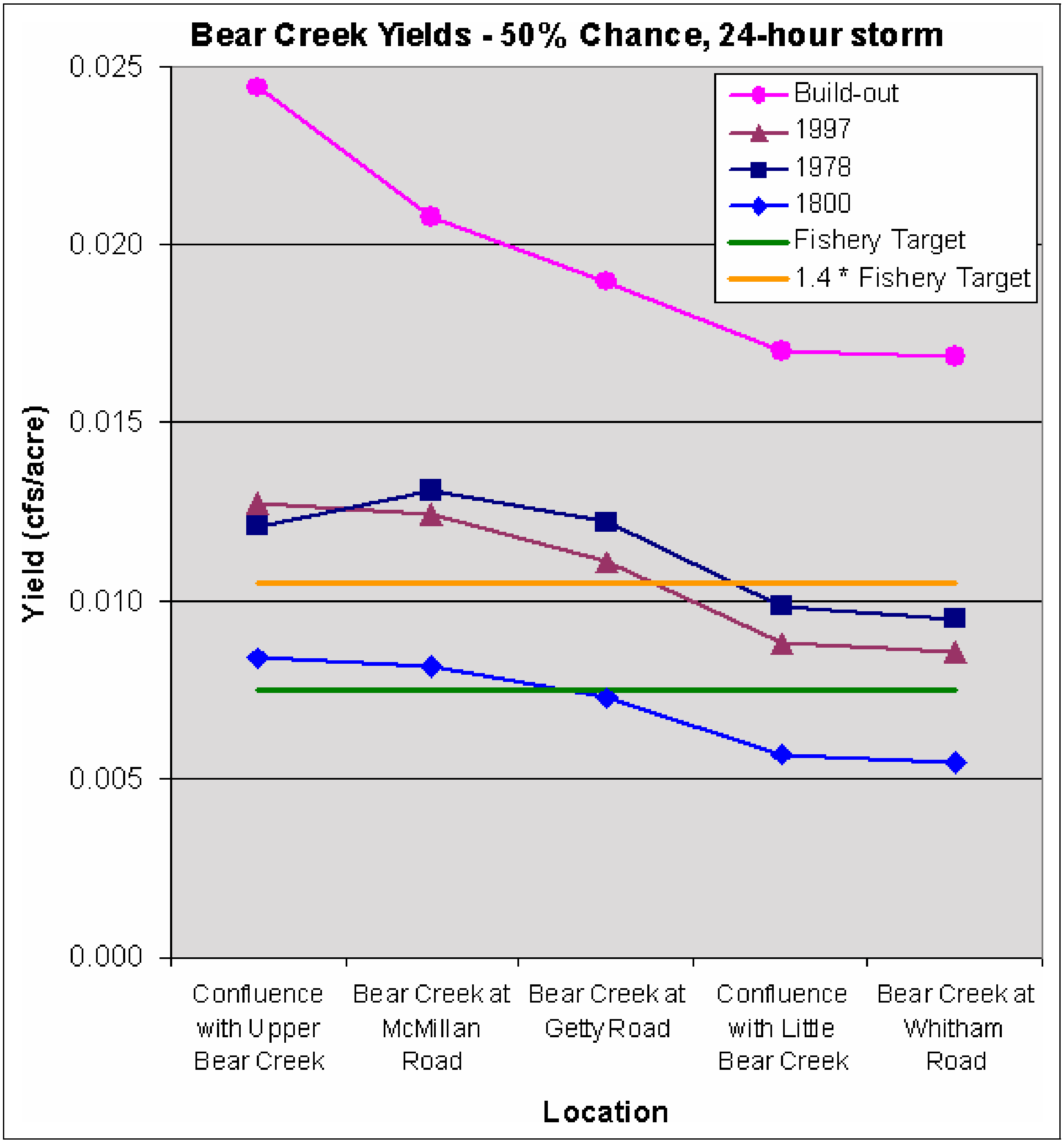

Figure 12: Bear Creek Yields, 50 percent chance, 24-hour storm

Project Goals

The Bear Creek hydrologic study was initiated in support of a Muskegon River watershed project, which is funded in part by a United States Environmental Protection Agency (USEPA) Part 319 grant administered by the MDEQ. The goals of this study are:

- to better understand the watershed's hydrologic characteristics and the impact of hydrologic changes, especially land use changes, in the Bear 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

Watershed Description and Model Parameters

The 29.8 square mile Bear Creek watershed, Figure 13, is located in Muskegon County. Bear Creek outlets to the Muskegon River. The study divides the watershed into sixteen subbasins, as shown in Figure 14. Subbasins 1, 2, 3, and 11a are not included in our hydrologic model. Subbasins 1, 2, and 3 do not have an apparent overland outlet for surface runoff. We have assumed that these subbasins do not contribute surface runoff to Bear Creek or its tributaries. According to the United States Geological Survey (USGS) quadrangle, Subbasin 11a does not have a stream or surface drain. Overland runoff would have to cross a railroad track and a freeway. We do not expect runoff above the freeway from Subbasin 11a to significantly contribute to the peak flow.

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 15 through 19. Land use maps based on the MDEQ GIS data for 1800 and 1978, are shown in Figures 15 and 16, respectively. The 1800 land use information is provided at the request of the Bear 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 1997 land use data were provided by the University of Michigan, but have been modified slightly. The extent of the sand mining land use spanning Subbasins 1 and 11 was enlarged to match the extent visible in the 1992 aerial photos shown in Figure 20. Sand mining is assumed to be a noncontributing area within the subbasins. The aerial photos in Figure 20 were also used to estimate the housing densities. Densities of one house per one-third acre for Subbasin 15 and one house per one-half acre for all other subbasins were used in the runoff curve number calculations. The build-out analysis, Figure 18, assumes land use is developed to the maximum allowed under zoning regulations. Zoning information was compiled and provided by HNTB Michigan, Inc. Zoning classifications and land use classes used for the hydrological analysis are shown in Table 1. The conservation/open space classification was assumed to be 50 percent agricultural and 50 percent forest and is shown as the cross-hatched area in Figure 18. Land use information by subbasin is also detailed in Table 2.

The aerial photography depicted in Figure 20 has been provided to the Bear Creek project manager in a larger size. The photos were taken in 1992 and 1998. The 1992 photos are the gray-scale aerial photos and cover the upper two-thirds of the watershed. The 1998 photos are the false-color infrared aerial photos and cover the lower third of the watershed. In false-color infrared photos, bright red areas indicate vigorous plant growth. The brightest areas are usually yards and golf courses. Deciduous trees are various shades of dark gray because the photos are generally taken in April for leaf off conditions. Coniferous trees are dark red and often very compact because most are in plantations. Open fields with grasses, forbs, or shrubs are often pink or grayish mixed with pink because there is generally not a lot of vigorous growth when the photos are taken. Because plant coverage is generally minimal in agricultural fields, they are typically gray-green and often mottled looking (light and dark areas). Water is often black or even bluish depending on the sediment content in the water. The reflectivity of impervious areas varies, and often appear either white or dark.

Table 1: Interpretation of Zoning Classifications for Curve Number Calculations

Zoning Classification	**Hydrologic Analysis Classification**
AG – Agriculture	Agricultural
COM – Commercial	Commercial
OF – Office	Commercial
IND – Industrial	Industrial
CON – Conservation/Open Space	Forest/Agriculture
PUB – Public/Quasi-public	Outdoor Recreation
R1 – High Density Residential, minimum lot size 0-43,560 sq. ft.	Residential
R2 – Medium Density Residential, minimum lot size 1-5 acres	Residential
R3 – Low Density Residential, minimum lot size >5 acres	Residential
MF – Multiple Family	Residential
MHP – Manufactured Home park	Residential
MXD – Mixed Uses	Residential

The NRCS soils data for the watershed is shown in Figure 19. 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. Times of concentration and storage coefficients are not listed for Subbasins 14, 15, or 16. Subbasin 16 is Bear Lake. Subbasins 14 and 15 are drainage directly to Bear Lake, split by township boundaries, and are included at the request of the project manager to provide an estimate of the relative runoff contribution from each township. Calculation of peak flow from these subbasins has no significance, because the flows are dispersed and highly attenuated by Bear Lake. Only the runoff volumes from these subbasins are of interest, which is not affected by the time of concentration or storage coefficient values.

The reach routing method is the lag method. Lag is the travel time of water within each section of the river. 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. Lag for each reach is calculated from the USGS quadrangles. These values are listed in Appendix A.

The selected precipitation events were the 50, 10, 4, and 2 percent chance (2-, 10-, 25-, and 50-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 0.964 to account for the size of the watershed.

These parameters were then incorporated into a HEC-HMS model to compute runoff volume and flow. Precipitation and flow monitoring data, Appendix B, were collected with the intent of using it to calibrate the hydrologic model, but the data are not adequate for that purpose.

Although the flow monitoring effort did not result in suitable calibration data, the predicted peak flows were compared to the USGS gage data as described in the “Model Results” section. The preliminary model appeared to substantially overpredict the peak flows from the four and two percent chance storms. Further analysis indicated that significant storage was likely in the wetland above US-31/Putnam Road, as shown in Figure 21. Based on estimates of culvert flows and wetland areas, storage was added to the model in the reach above Getty as specified in Appendix A.

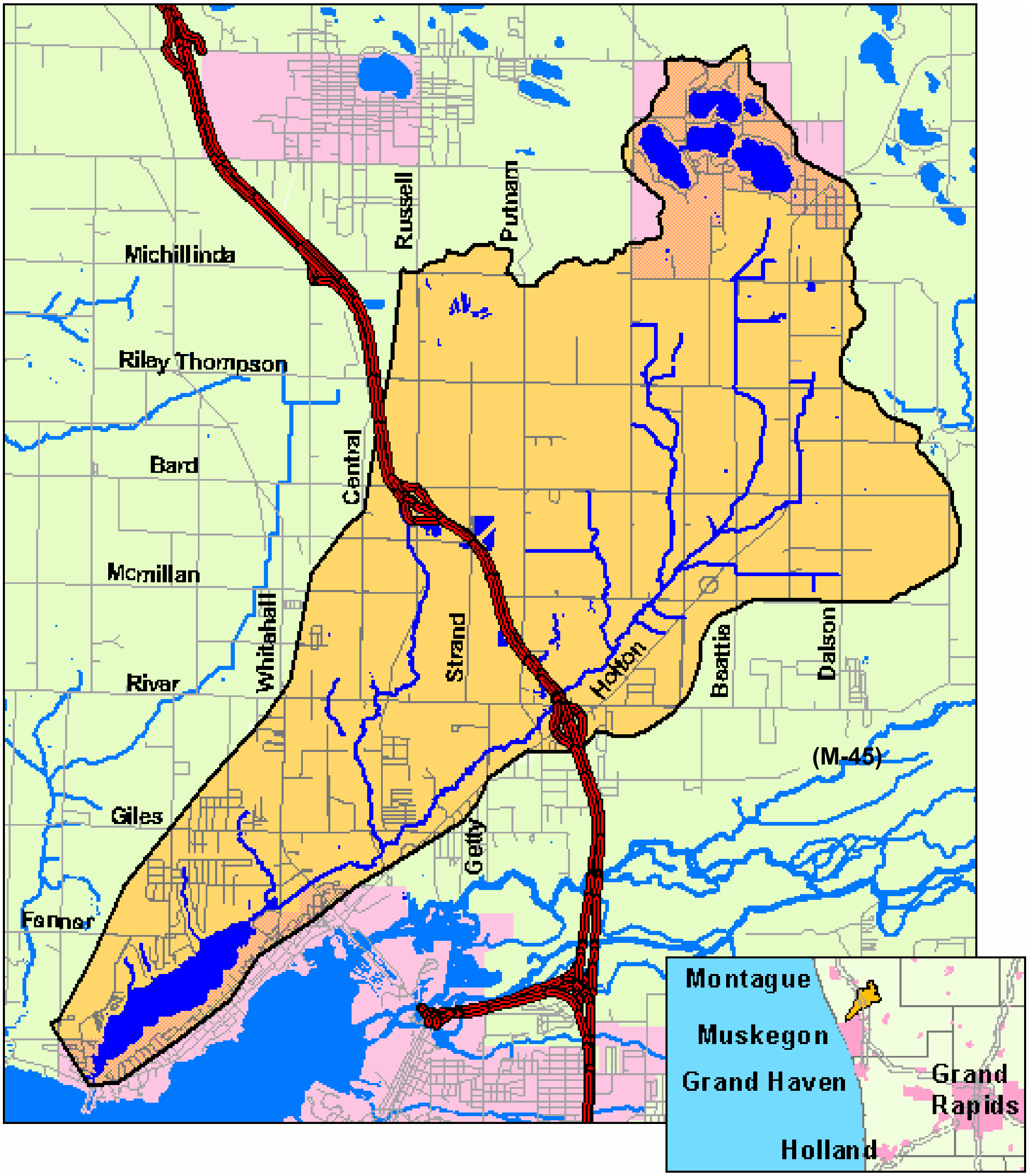

Figure 13: Delineated Bear Creek Watershed

Subbasin	Area (sq. mi.)	Description
1	0.49	Non-contributing area, west
2	0.28	Non-contributing area, central
3	1.77	Non-contributing area, east
4	3.76	Upper Bear Creek
5	2.69	Ribe Drain
6	2.07	Fuhrman Drain
7	2.21	Bear Creek to McMillan Road
8	1.57	Putnam-Bard Drain
9	0.47	Bear Creek below McMillan
10	3.69	Little Bear Creek
11a	1.80	Bear Creek to Giles Road, above 31
11b	1.97	Bear Creek to Giles Road, below 31
12	1.87	Bear Creek to Getty Road
13	1.39	Bear Creek to Whitham Road
14	2.58	Bear Creek, Laketon Twp.
15	0.55	Bear Creek, North Muskegon Twp.
16	0.62	Bear Lake

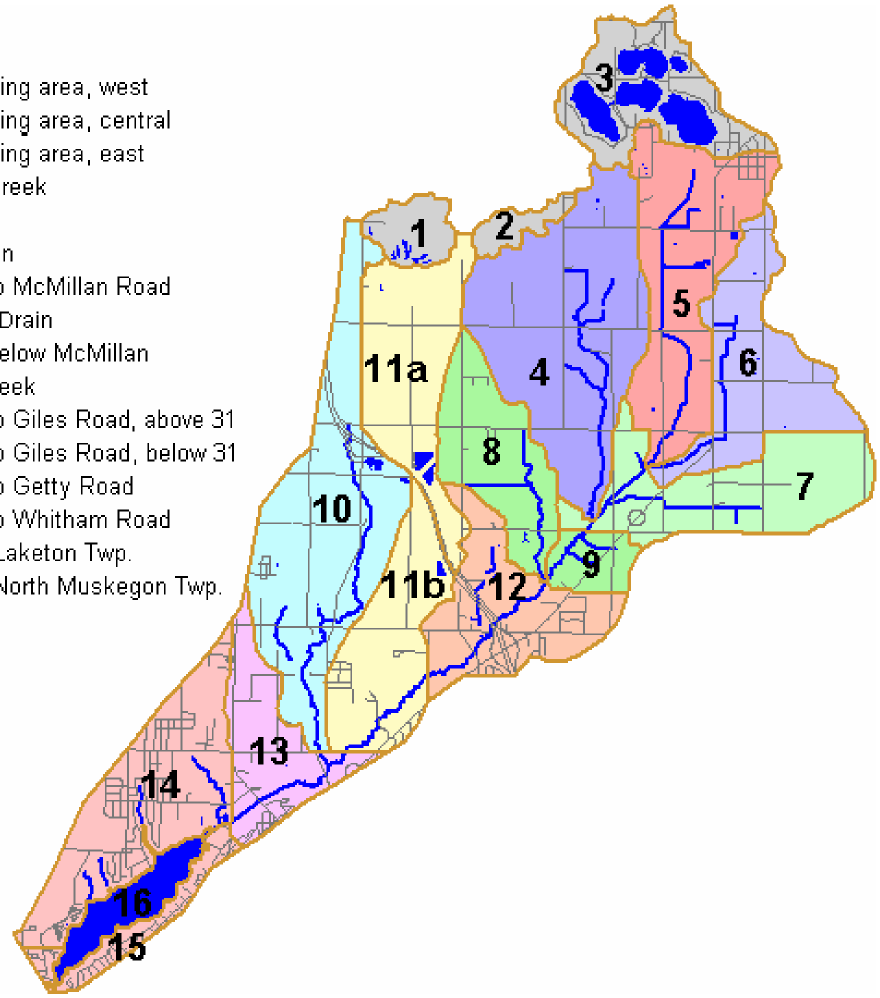

Figure 14: Subbasin Identification

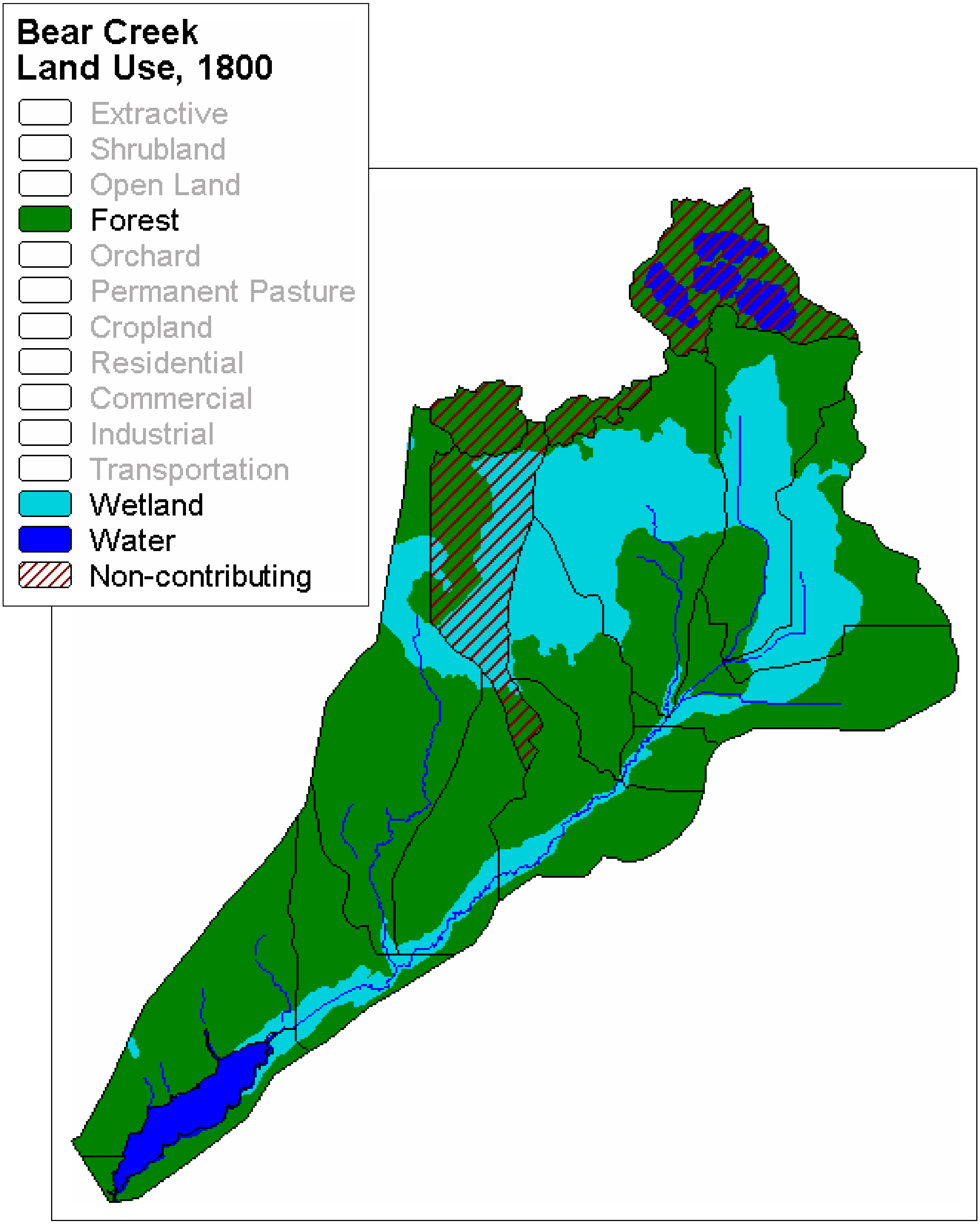

Figure 15: 1800 Land Use Data

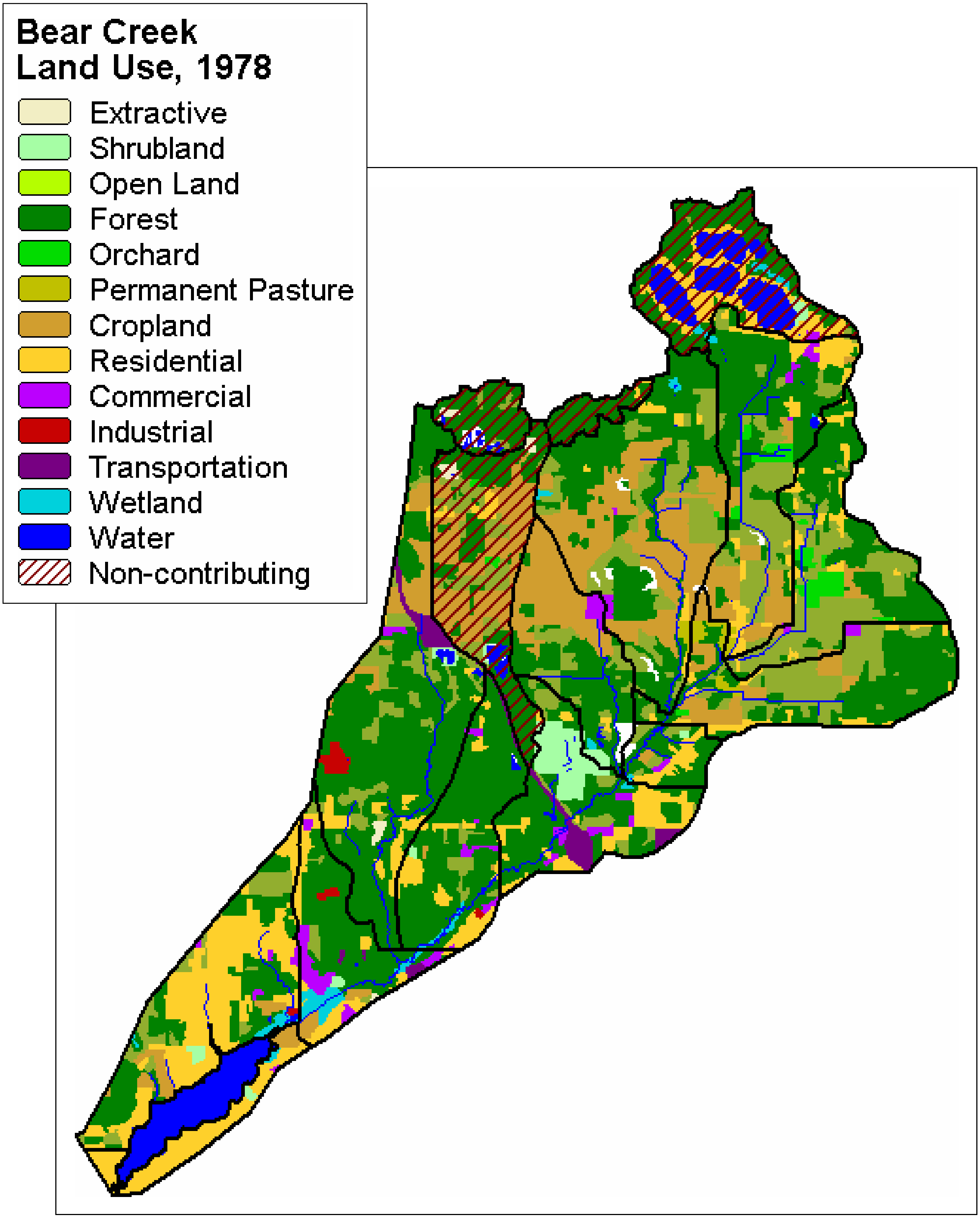

Figure 16: 1978 Land Use Data

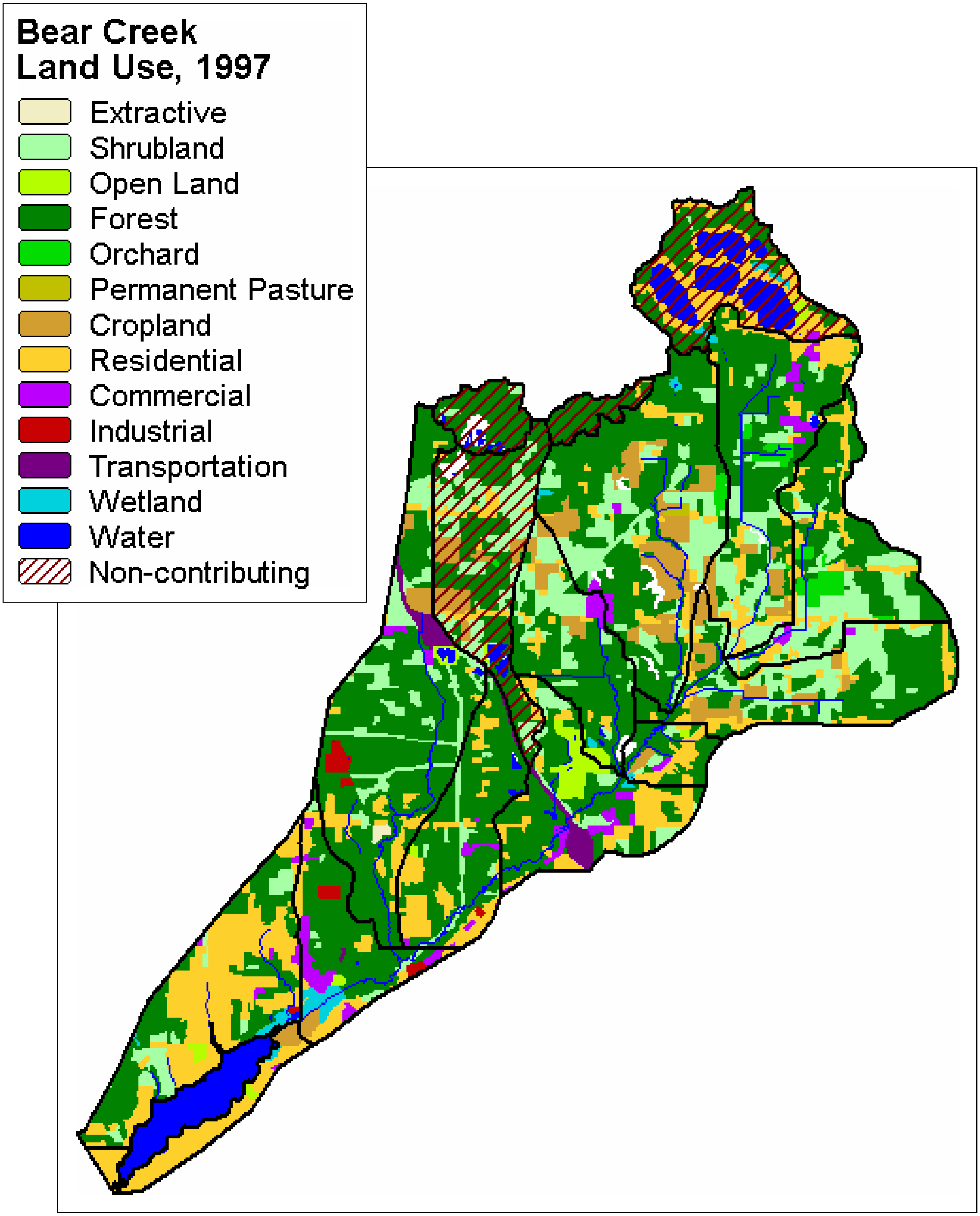

Figure 17: 1997 Land Use Data

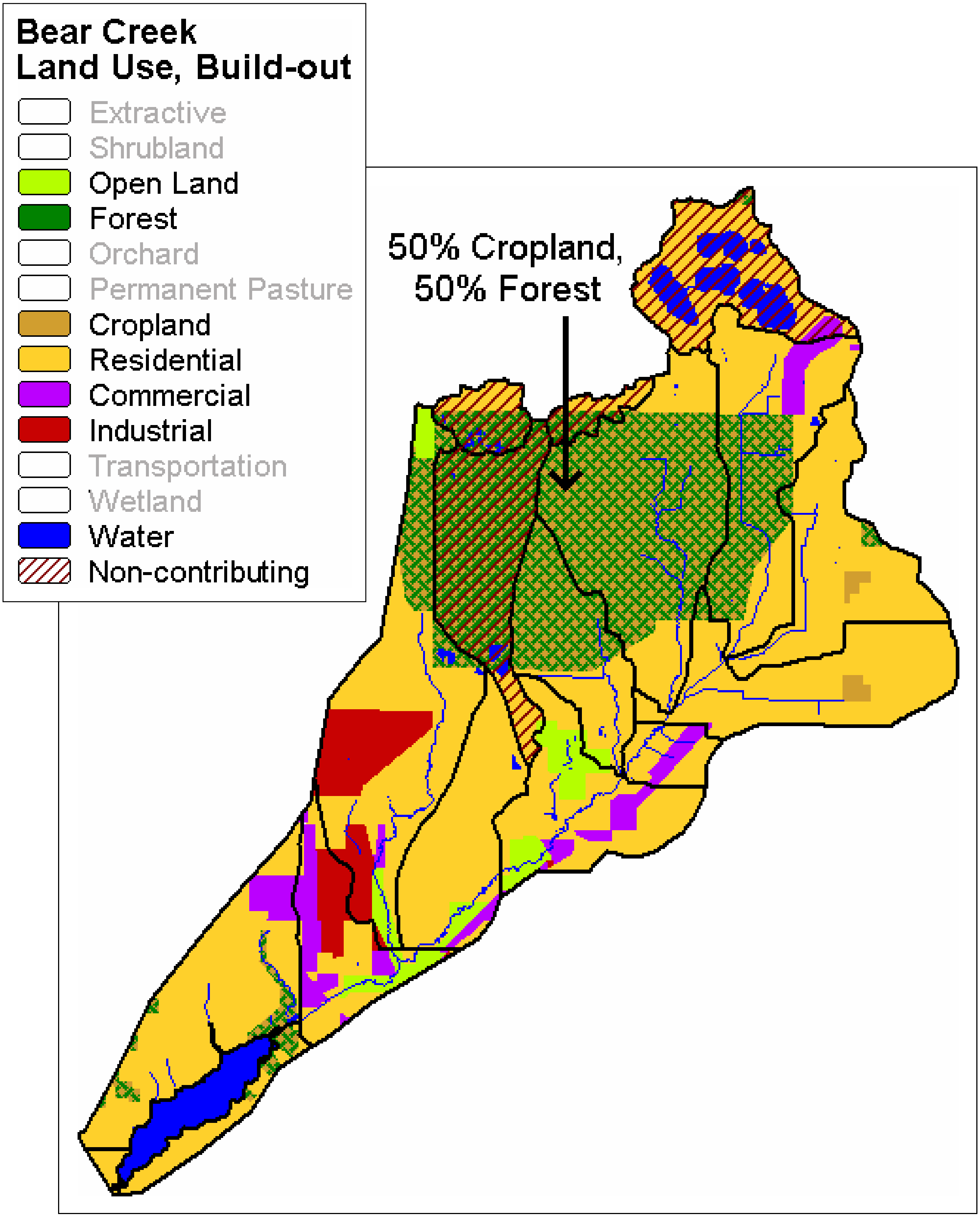

Figure 18: Zoned, or Build-Out, Land Use Data

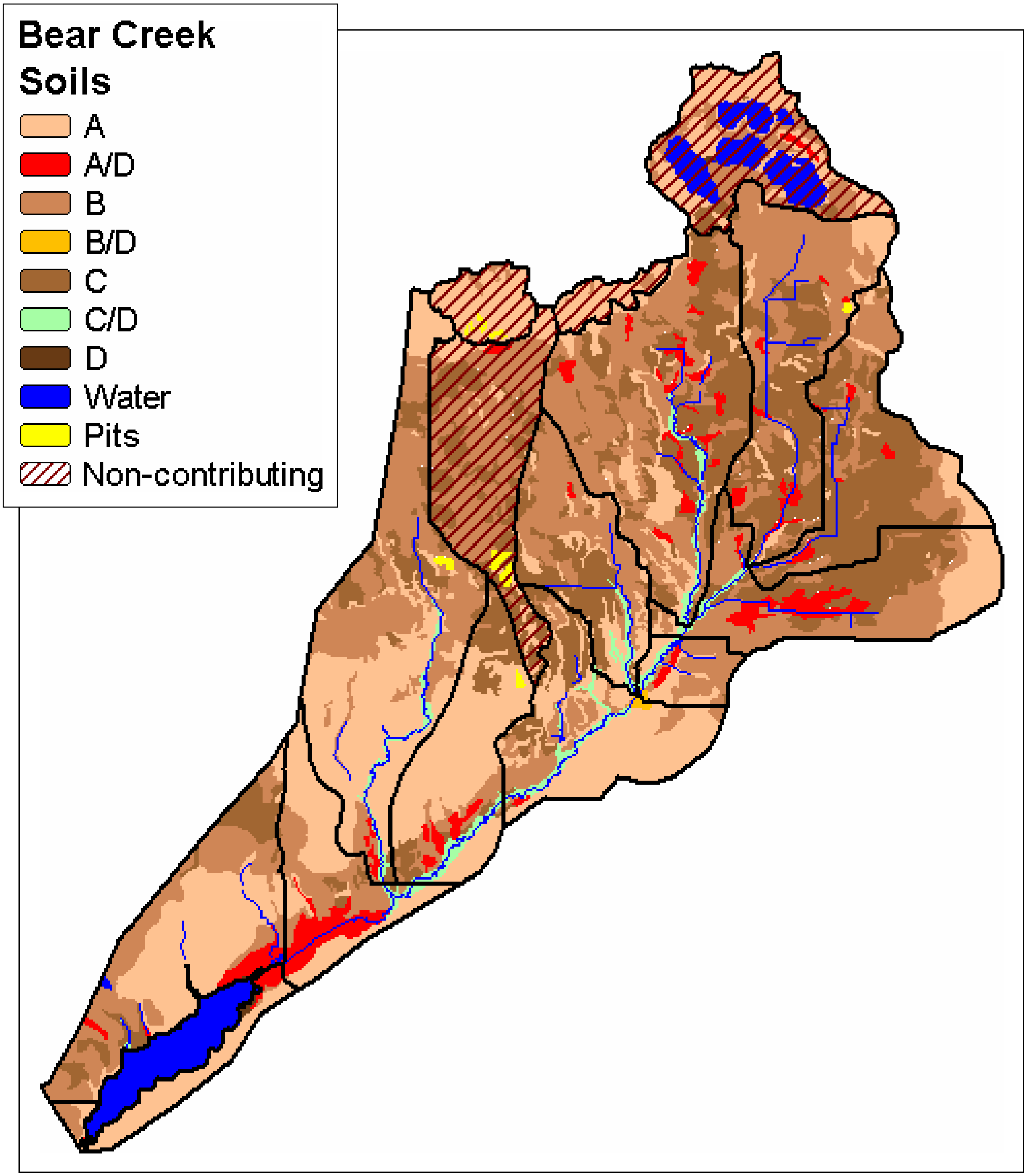

Figure 19: NRCS Soils Data

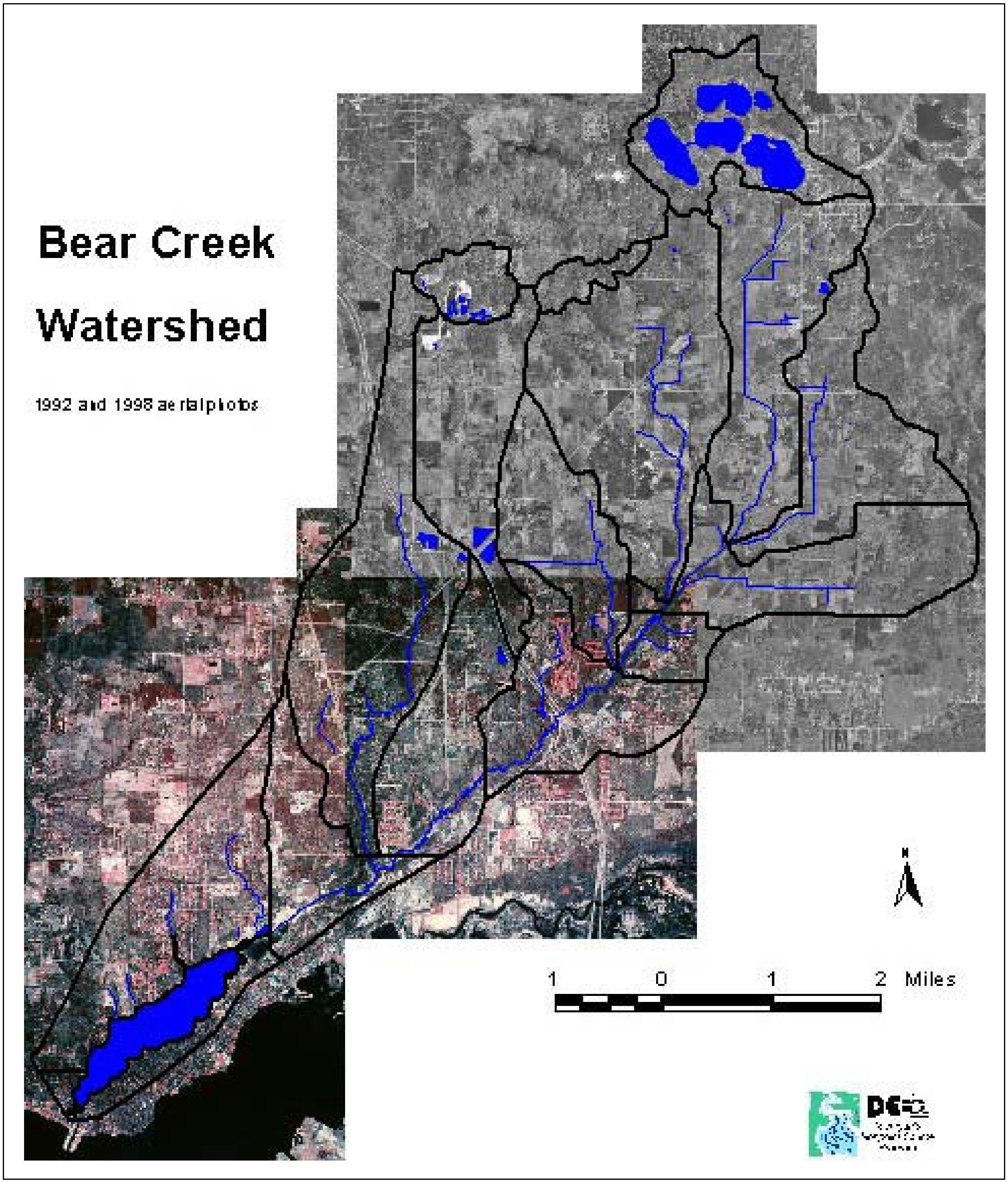

Figure 20: 1992 and 1998 Aerial Photography

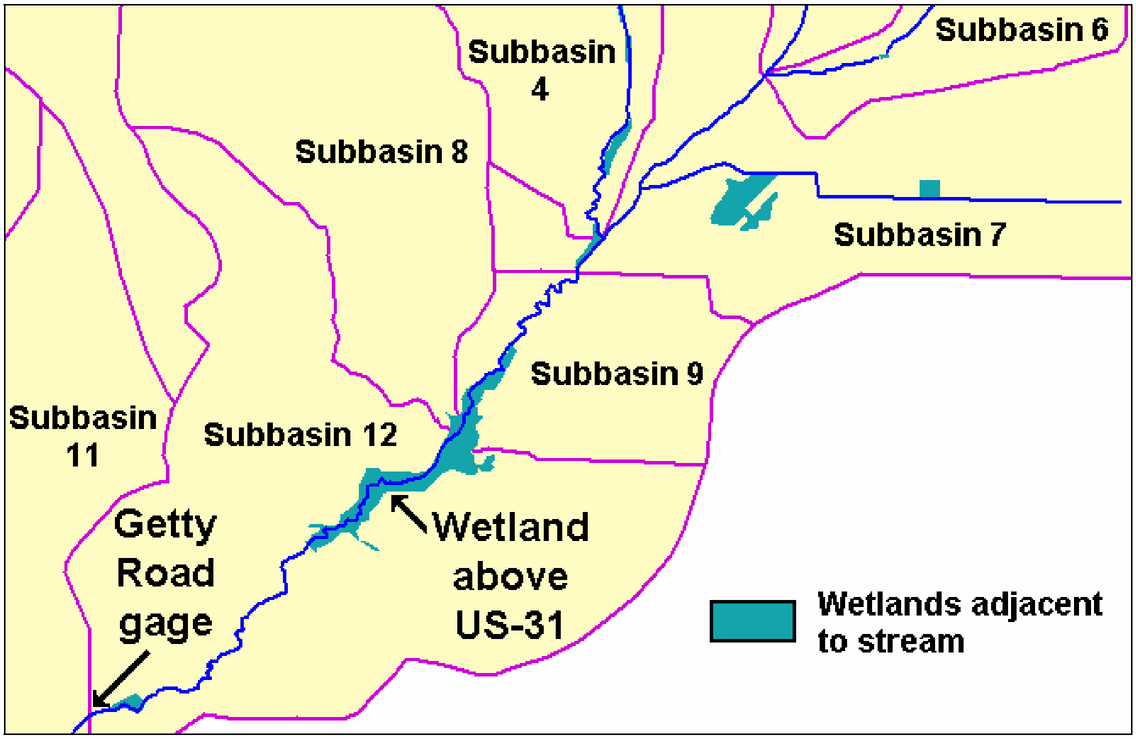

Figure 21: Wetlands adjacent to the creek as shown on USGS quadrangles

Table 2: 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	Road	Pit	Cemeteries, Outdoor Rec.	Cropland	Orchard	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune
Upper Bear Creek	1800											46%		54%	
	1978	2%	1%					34%		1%	19%	41%		1%	1%
	1997	2%	1%					35%		1%	20%	42%		1%	
	Build-out	20%						40%				40%			
Ribe Drain	1800											57%		43%	
	1978	11%	2%					14%	3%	1%	26%	42%			
	1997	11%	2%					14%	3%	1%	26%	42%			
	Build-out	52%	7%					20%				20%			
Fuhrman Drain	1800											52%		48%	
	1978	8%						3%	8%		38%	42%			
	1997	8%						3%	8%		39%	42%			
	Build-out	94%						4%				2%			
Bear Creek to McMillan Road	1800											84%		16%	
	1978	7%	1%					14%		3%	28%	46%			
	1997	7%	1%					14%		3%	28%	46%			
	Build-out	95%						4%				1%			

Description	Scenario	Residential	Commercial	Industrial	Road	Pit	Cemeteries, Outdoor Rec.	Cropland	Orchard	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune
Putnam-Bard Drain	1800											54%		46%	
	1978	1%	3%				2%	37%			12%	41%			2%
	1997	1%	3%				2%	37%			12%	41%			2%
	Build-out	35%					3%	31%				31%			
Bear Creek below McMillan Road	1800											89%		11%	
	1978	23%	2%				1%	3%			12%	54%		1%	3%
	1997	23%	2%				1%	3%			12%	54%		1%	3%
	Build-out	77%	23%												
Little Bear Creek	1800											86%		14%	
	1978	5%		2%	3%	1%	1%	8%			11%	68%			1%
	1997	5%		2%	3%	1%	1%	8%			11%	68%	1%		
	Build-out	54%	1%	24%			5%	8%				8%			
Bear Creek to Giles Road, below 31	1800											88%		12%	
	1978	13%	3%		1%		1%				5%	75%	1%	2%	
	1997	13%	3%		1%		1%				5%	75%	1%	2%	
	Build-out	92%	3%				5%								
Bear Creek to Getty Road	1800											88%		12%	
	1978	17%	4%		8%		16%				9%	46%			
	1997	17%	4%		8%		16%				9%	46%			
	Build-out	68%	11%				21%								
Bear Creek to Whitham Road	1800											79%		21%	
	1978	15%	10%	1%	2%		1%	4%			4%	53%		8%	
	1997	15%	10%	1%	2%		1%	4%			4%	53%		8%	
	Build-out	38%	28%	21%			13%								
Bear Creek, Laketon Twp.	1800											97%		3%	
	1978	49%	1%				1%	5%			11%	31%		2%	
	1997	49%	1%				1%	5%			11%	31%		2%	
	Build-out	84%	7%					4%				4%			
Bear Creek, North Muskegon Twp.	1800											85%	2%	13%	
	1978	85%	1%				2%	10%						2%	
	1997	85%	1%				2%	10%						2%	
	Build-out	84%						8%				8%			
Overall Watershed	1800											73%		27%	
	1978	14%	2%		1%		2%	13%	1%		17%	47%		1%	1%
	1997	14%	2%		1%		2%	13%	1%		17%	48%		1%	
	Build-out	62%	5%	5%			4%	13%				12%			

Model Results

The model results for the 50, 10, 4, and 2 percent chance, 24-hour storms and the 1800, 1978, 1997, and build-out land use scenarios are illustrated in Figures 2 through 9 and detailed in Tables 4 through 7. Table 4 lists the predicted peak flows from each subbasin. These values represent the peak flow contribution from the subbasins, not the flow in the creek. Table 5 lists the predicted peak flows at locations in the creek. Flows for the Bear Creek confluence with Putnam-Bard Drain location are not reported because the actual wetland storage extends through that location, but the modeled storage does not. Actual flows for the Whitham Road location may be lower than reported because that flow could be attenuated by the wetlands in that area, which is not included in the model. The amount of attenuation may also vary with the level of Bear Lake, which fluctuates with the level of Lake Michigan. Table 6 lists the predicted runoff volumes from each subbasin. Table 7 lists the predicted runoff volumes at locations in the creek.

The flow monitoring effort did not result in suitable calibration data, but the predicted peak flows can be compared to the USGS gage data shown in Table 3. As shown in Figure 22, the preliminary model appeared to substantially overpredict the peak flows from the four and two percent chance storms. Further analysis indicated that significant storage was likely in the wetland above US-31/Putnam Road, as shown in Figure 21. The eight-foot diameter culverts under US-31 and Putnam Road are estimated to have 2 ½ to 3 three feet of sediment, so that at 570 to 750 cfs, the culverts are flowing full. The area of the wetland shown on the USGS quadrangle is estimated to be 36.5 acres. The total area of wetlands adjacent to the stream above Getty Road is estimated to be 68.6 acres. Based on this information, storage was added to the final model in the reach above Getty as specified in Appendix A.

The projected increases in stormwater runoff volume and peak flows from 1978/1997 to build-out conditions are of primary interest to Bear Creek watershed's stormwater managers. Model predictions based on this land use change show significant increases in runoff volumes and peak flows for all four 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 10, 4, or 2 percent chance, 24-hour storms. The projected increases in runoff volumes and peak flows from the 50 percent chance storm would increase the channel-forming flow, 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. The projected increases in runoff volumes and peak flows from the 10, 4, and 2 percent chance storms will aggravate flooding. These projected increases can be moderated through the use of effective stormwater management techniques.

The Bear Creek watershed is in Muskegon County. A model stormwater ordinance adopted, or being considered for adoption, by neighboring counties 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 zones. Currently, the average yield from this storm for the Bear Creek Watershed is 0.01 cfs/acre, with no subbasins higher than 0.05 cfs/acre, as shown in Figure 10. The yield from one of the ten subbasins may exceed 0.05 cfs/acre with continued development. 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 0.07 cfs/acre, with one subbasin higher than 0.13 cfs/acre, as shown in Figure 11. The yield from three of the ten subbasins may exceed 0.13 cfs/acre with continued development. Additional details are listed in Table 8.

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 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 Bear Creek results. For the 1800 scenario, three Bear Creek locations would be classified as good and two would be impaired. For the 1997 scenario, no Bear Creek locations would be classified as good, two would be impaired, and three would be poor. For the build-out scenario, all Bear Creek locations would be classified as poor. Complete results are shown in Figures 10 and 12 and listed in Tables 8 and 9.

Table 3: USGS Gage 04122100 Analysis, Bear Creek near Muskegon

Frequency Flow	Flow (cfs)
99 percent (~1-year)	70
80 percent (1.25-year)	130
50 percent (2-year)	210
20 percent (5-year)	320
10 percent (10-year)	410
5 percent (20-year)	500
2 percent (50-year)	650
1 percent (100-year)	750
0.5 percent (200-year)	900
0.2 percent (500-year)	1100

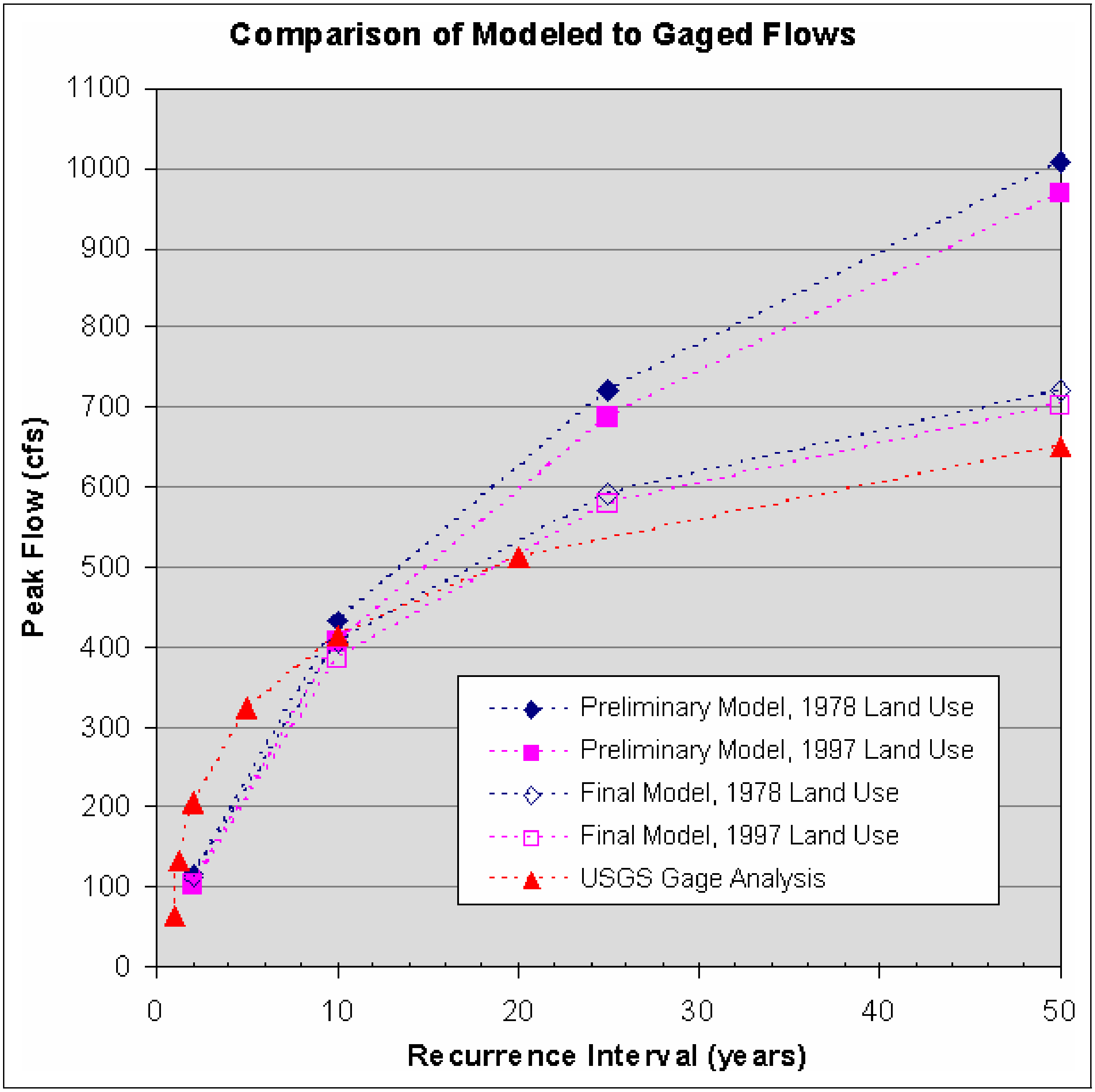

Figure 22: Comparison of Modeled Peak Flows to USGS Gage 04122100

Table 4: Peak flows per subbasin

Subbasin	Land Use Scenario	Peak Flow (cfs)			
		50% chance, 24-hour storm	10% chance, 24-hour storm	4% chance, 24-hour storm	2% chance, 24-hour storm
Upper Bear Creek	1800	22	75	132	192
	1978	35	126	208	289
	1997	29	110	187	264
	Build-out	41	142	231	316
Ribe Drain	1800	12	42	74	109
	1978	18	67	112	157
	1997	18	67	112	157
	Build-out	37	108	167	222
Fuhrman Drain	1800	14	50	89	129
	1978	21	81	137	190
	1997	23	87	144	199
	Build-out	43	126	194	257
Bear Creek to McMillan Road	1800	9	39	72	107
	1978	18	73	123	173
	1997	18	73	123	173
	Build-out	28	95	152	207
Putnam-Bard Drain	1800	9	33	58	86
	1978	17	58	95	131
	1997	10	41	73	104
	Build-out	20	68	110	149
Bear Creek below McMillan Road	1800	1	11	25	41
	1978	3	19	38	58
	1997	3	21	41	62
	Build-out	16	56	89	121
Little Bear Creek	1800	5	33	70	112
	1978	10	62	120	180
	1997	7	50	100	155
	Build-out	41	143	233	319
Bear Creek to Giles Road, below 31	1800	1	12	26	43
	1978	3	19	37	58
	1997	3	19	37	58
	Build-out	8	37	66	95
Bear Creek to Getty Road	1800	2	16	35	57
	1978	7	37	68	102
	1997	7	37	68	102
	Build-out	12	54	93	133
Bear Creek to Whitham Road	1800	2	14	31	50
	1978	5	26	50	76
	1997	6	28	53	80
	Build-out	26	82	129	173

Table 5: Peak flows in Bear Creek

Location	Drainage Area (square miles)	Land Use Scenario	Peak Flow (cfs)			
			50% chance 24-hour storm	10% chance 24-hour storm	4% chance 24-hour storm	2% chance 24-hour storm
Confluence of Ribe and Fuhrman Drains	4.8	1800	26	91	159	232
		1978	37	137	226	315
		1997	39	141	232	322
		Build out	74	213	327	432
Bear Creek at McMillan Road	10.7	1800	56	204	363	528
		1978	90	331	550	766
		1997	85	320	536	750
		Build out	142	444	701	945
Confluence of Bear Creek with Putnam-Bard Drain	12.8	1800	66	244	432	629
		1978	108	397	658	915
		1997	97	371	624	875
		Build out	167	524	828	1115
Bear Creek at Getty Road	14.6	1800	68	259	450	589
		1978	115	408	591	720
		1997	104	386	580	702
		Build out	177	526	667	817
Confluence of Bear Creek with Little Bear Creek	20.1	1800	73	302	535	718
		1978	126	474	711	877
		1997	113	447	695	855
		Build out	219	655	862	1059
Bear Creek at Whitham Road	21.5	1800	75	314	556	752
		1978	131	494	748	921
		1997	118	468	733	901
		Build out	232	686	922	1121

Table 6: Runoff volumes per subbasin

Subbasin	Land Use Scenario	Runoff Volume (acre-feet)			
		50% chance, 24-hour storm	10% chance, 24-hour storm	4% chance, 24-hour storm	2% chance, 24-hour storm
Upper Bear Creek	1800	66	203	270	369
	1978	59	188	297	400
	1997	48	167	297	400
	Build-out	59	188	320	429
Ribe Drain	1800	38	126	192	263
	1978	34	119	192	263
	1997	34	119	204	279
	Build-out	59	166	252	332
Fuhrman Drain	1800	38	115	149	203
	1978	27	92	156	211
	1997	29	98	178	238
	Build-out	49	135	203	265
Bear Creek to McMillan Road	1800	22	86	144	199
	1978	26	92	151	208
	1997	26	92	151	208
	Build-out	38	117	182	244
Putnam-Bard Drain	1800	26	82	102	141
	1978	27	83	129	173
	1997	16	62	130	174
	Build-out	27	83	130	174
Bear Creek below McMillan Road	1800	2	12	22	32
	1978	3	14	25	35
	1997	3	15	26	37
	Build-out	10	28	42	56
Little Bear Creek	1800	11	78	149	221
	1978	14	86	149	221
	1997	11	79	159	234
	Build-out	57	183	289	389
Bear Creek to Giles Road, below 31	1800	3	31	63	95
	1978	6	39	73	108
	1997	6	39	73	108
	Build-out	13	57	99	140
Bear Creek to Getty Road	1800	5	37	71	106
	1978	12	56	98	140
	1997	12	56	98	140
	Build-out	17	69	115	161
Bear Creek to Whitham Road	1800	4	30	56	83
	1978	10	44	76	108
	1997	11	47	81	113
	Build-out	28	81	124	165
Bear Creek, Laketon Twp.	1800	6	51	98	146
	1978	24	95	142	201
	1997	18	82	159	221
	Build-out	30	107	176	241
Bear Creek, North Muskegon Twp.	1800	1	8	17	26
	1978	2	13	24	35
	1997	2	13	24	35
	Build-out	2	13	24	35
Bear Lake	All	69	111	139	163

Table 7: Runoff volumes in Bear Creek

Location	Drainage Area (square miles)	Land Use Scenario	Runoff Volume (acre-feet)			
			50% chance 24-hour storm	10% chance 24-hour storm	4% chance 24-hour storm	2% chance 24-hour storm
Confluence of Ribe and Fuhrman Drains	4.8	1800	76	241	383	517
		1978	61	211	341	466
		1997	64	217	348	474
		Build out	108	300	454	597
Bear Creek at McMillan Road	10.7	1800	164	530	846	1144
		1978	145	491	789	1073
		1997	137	476	769	1050
		Build out	205	605	933	1241
Confluence of Bear Creek with Putnam-Bard Drain	12.8	1800	191	623	996	1349
		1978	175	588	943	1282
		1997	157	553	898	1229
		Build out	241	715	1105	1471
Bear Creek at Getty Road	14.6	1800	195	658	1065	1454
		1978	186	644	1041	1421
		1997	169	609	995	1368
		Build out	258	784	1221	1632
Confluence of Bear Creek with Little Bear Creek	20.1	1800	209	766	1275	1768
		1978	206	769	1273	1763
		1997	185	726	1217	1697
		Build out	328	1024	1609	2161
Bear Creek at Whitham Road	21.5	1800	212	793	1329	1850
		1978	215	813	1349	1871
		1997	197	774	1298	1810
		Build out	356	1105	1733	2326
Mouth	25.2	1800	287	961	1580	2184
		1978	310	1031	1671	2290
		1997	286	980	1603	2210
		Build out	457	1336	2071	2765

Table 8: Subbasin yields

Subbasin	Yield (cfs/acre) from 50% chance 24-hour storm				Yield (cfs/acre) from 4% chance 24-hour storm			
	1800 Land use	1978 Land use	1997 Land use	Build-out	1800 Land use	1978 Land use	1997 Land use	Build-out
Upper Bear Creek	0.009	0.015	0.012	0.017	0.055	0.086	0.078	0.096
Ribe Drain	0.007	0.010	0.010	0.021	0.043	0.065	0.065	0.097
Fuhrman Drain	0.011	0.016	0.018	0.032	0.067	0.103	0.109	0.146
Bear Creek to McMillan Road	0.006	0.013	0.013	0.020	0.051	0.087	0.087	0.107
Putnam-Bard Drain	0.009	0.016	0.010	0.020	0.058	0.095	0.072	0.109
Bear Creek below McMillan Road	0.004	0.009	0.010	0.054	0.084	0.126	0.135	0.296
Little Bear Creek	0.002	0.004	0.003	0.018	0.030	0.051	0.043	0.100
Bear Creek to Giles Road, below 31	0.001	0.002	0.002	0.007	0.023	0.033	0.033	0.057
Bear Creek to Getty Road	0.002	0.006	0.006	0.010	0.029	0.057	0.057	0.078
Bear Creek to Whitham Road	0.002	0.005	0.006	0.029	0.035	0.056	0.060	0.146
Arithmetic Average	0.005	0.010	0.009	0.023	0.048	0.076	0.074	0.123
Area weighted Average	0.006	0.010	0.009	0.020	0.045	0.072	0.068	0.106

Table 9: Bear Creek yields

Location	Yield (cfs/acre) from 50% chance 24-hour storm			
	1800 Land use	1978 Land use	1997 Land use	Build-out
J1, Confluence of Ribe and Fuhrman Drains	0.0084	0.0121	0.0127	0.0244
J2, Bear Creek at McMillan Road	0.0082	0.0131	0.0124	0.0208
J4, Bear Creek at Getty Road	0.0073	0.0122	0.0111	0.0190
J5, Confluence of Bear Creek with Little Bear Creek	0.0057	0.0098	0.0088	0.0170
J6, Bear Creek at Whitham Road	0.0055	0.0095	0.0086	0.0169
Average	0.0070	0.0113	0.0107	0.0196

Appendices

Appendix A: Bear Creek Hydrologic Model Parameters

This appendix is provided so that the model may be recreated by an engineering consultant, or others, if desired. Table A1 provides the 24-hour Type II SCS design rainfall values specific to the region of the state where Bear 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. The curve number for Subbasin 16, Bear Lake, should be 100, but is entered as 99 because that is the maximum allowed by HEC-HMS. The arbitrary value selected for Subbasins 14, 15, and 16 was one hour. These parameters only affect peak flows, not runoff volumes, calculated from these subbasins. Runoff volumes are the only results of interest for these subbasins.

Table A4 provides the reach parameters for the routing method. Table A5 provides the storage-discharge relationship for the reservoir added to reach 3. Because this reservoir accounts for storage that extends into Reach 2, the computed peak flows Junction 3 are expected to be too high and were not listed in this report. The control specified in HEC-HMS was for a four day duration using a five-minute time interval.

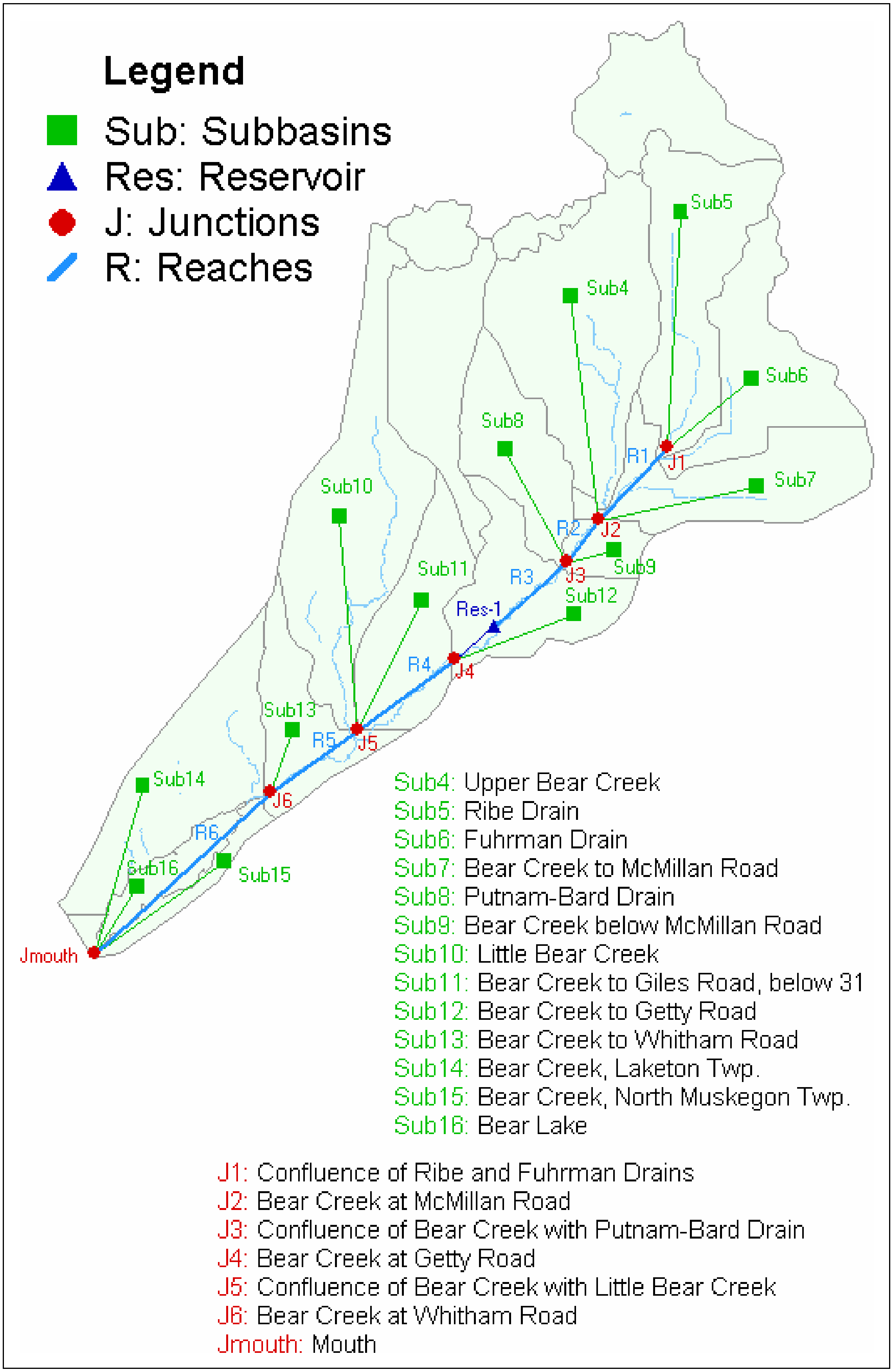

Figure A1: Hydrologic Elements defined for HEC-HMS model

Table A1: Design Rainfall Values for Muskegon County (Region 5)

SCS Type II Precipitation Event	Precipitation*
50% chance (2-year), 24-hour storm	2.20
10% chance (10-year), 24-hour storm	3.47
4% chance (25-year), 24-hour storm	4.32
2% chance (50-year), 24-hour storm	5.05

*standard values were multiplied by 0.964 to account for the watershed size

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

Subbasin		Drainage Area (sq. mi.)				Runoff Curve Number				Initial Loss
		1800	1978	1997	Build-out	1800	1978	1997	Build-out	
4	Upper Bear Creek	3.76	3.76	3.76	3.76	71	69	67	69	Default
5	Ribe Drain	2.69	2.68	2.68	2.68	69	67	67	73	Default
6	Fuhrman Drain	2.07	2.07	2.07	2.07	71	67	68	74	Default
7	Bear Creek to McMillan Road	2.21	2.21	2.21	2.21	65	66	66	70	Default
8	Putnam-Bard Drain	1.57	1.57	1.57	1.57	70	70	65	70	Default
9	Bear Creek below McMillan Road	0.47	0.47	0.47	0.47	59	61	62	72	Default
10	Little Bear Creek	3.67	3.66	3.66	3.66	57	58	57	69	Default
11b	Bear Creek to Giles Road, below 31	1.80	1.79	1.79	1.79	55	57	57	62	Default
12	Bear Creek to Getty Road	1.87	1.87	1.87	1.87	56	61	61	64	Default
13	Bear Creek to Whitham Road	1.38	1.38	1.38	1.38	57	62	63	72	Default
14	Bear Creek, Laketon Twp.	2.57	2.57	2.57	2.57	56	64	62	66	Default
15	Bear Creek, North Muskegon Twp.	0.55	0.55	0.55	0.55	53	58	58	58	Default
16	Bear Lake	0.62	0.62	0.62	0.62	100	100	100	100	Default
	Total	25.23	25.20	25.20	25.20					

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

Subbasin	Scenario	Time of Concentration (hours)	Storage Coefficient			
			50% chance, 24-hour storm	10% chance, 24-hour storm	4% chance, 24-hour storm	2% chance, 24-hour storm
Upper Bear Creek	1800	7.63	28	23	19.5	17.5
	1978		10	9.2	9	8.8
	1997		10.1	9.3	9	8.8
	Build-out		7.63	7.63	7.63	7.63
Ribe Drain	1800	9.61	32.5	27.3	23.5	21
	1978		12.6	11.6	11.4	11.1
	1997		12.7	11.7	11.4	11.1
	Build-out		9.61	9.61	9.61	9.61
Fuhrman Drain	1800	6.04	22	17.5	15	13.5
	1978		6.04	6.04	6.04	6.04
	1997		6.04	6.04	6.04	6.04
	Build-out		6.04	6.04	6.04	6.04
Bear Creek to McMillan Road	1800	7.03	20.5	16.4	14.2	13.2
	1978		7.03	7.03	7.03	7.03
	1997		7.03	7.03	7.03	7.03
	Build-out		7.03	7.03	7.03	7.03
Putnam-Bard Drain	1800	6.89	24.7	20	17	15.2
	1978		9.7	8.9	8.6	8.4
	1997		10	9	8.6	8.4
	Build-out		6.89	6.89	6.89	6.89
Bear Creek below McMillan Road	1800	2.16	10.2	4.9	4.15	3.85
	1978		4	3	2.85	2.75
	1997		3.8	2.95	2.85	2.75
	Build-out		2.16	2.16	2.16	2.16
Little Bear Creek	1800	7.28	20.5	18	15.1	13.7
	1978		7.28	7.28	7.28	7.28
	1997		10.1	9.1	8.7	8.4
	Build-out		7.28	7.28	7.28	7.28
Bear Creek to Giles Road, below 31	1800	9.04	22	21	18.2	16.5
	1978		15.5	14.5	13.2	12.5
	1997		15.5	14.5	13.2	12.5
	Build-out		9.04	9.04	9.04	9.04
Bear Creek to Getty Road	1800	6.97	18.7	16.7	14	12.6
	1978		10.2	8.8	8.5	8.2
	1997		10.2	8.8	8.5	8.2
	Build-out		6.97	6.97	6.97	6.97
Bear Creek to Whitham Road	1800	5.37	19.5	15	12	10.7
	1978		14.7	11	9.7	9
	1997		14.4	10.8	9.6	9
	Build-out		5.37	5.37	5.37	5.37
Bear Creek, Laketon Twp.		See text				
Bear Creek, North Muskegon Twp.		See text				
Bear Lake		See text				

Table A4: Channel Reach Parameters

Reach	Length (meters)	Average Slope	Lag (minutes)
1	1440	0.17	54
2	1440	0.24	47
3	3140	0.17	123
4	2960	0.14	125
5	2090	0.10	103
6	4060	(Lake)	See text

Table A5: Reach Storage-Discharge Relationship

Storage (acre-feet)	Discharge (cfs)	Comments
0	0	
20	300	Minimal storage and flow restriction until stream is out of bank
60	500	
206	640	Values based on culvert capacity and wetland area with an average storage depth of three feet
320	750	Values linearly extrapolated for build-out scenario

Appendix B: Bear Creek Monitoring

STATE OF MICHIGAN
DEPARTMENT OF ENVIRONMENTAL QUALITY
LANSING

JOHN ENGLER
GOVERNOR

RUSSELL J. HARDING
DIRECTOR

November 25, 2002

To: Kathy Evans
Muskegon County Conservation District

From: Dave Fongers
Geological and Land Management Division, MDEQ

Subject: Bear Creek Monitoring

As requested, the Hydrologic Studies Unit (HSU) of the Geological and Land Management Division (GLMD) has completed its hydrologic monitoring of Bear Creek. This monitoring was requested in support of a Section 319 grant.

Precipitation, temperature, and river stage data were collected from August 21 to November 14, 2002. The monitoring locations are shown in Figure 1. The river stage data were adjusted so that a water surface elevation of zero would correspond to our estimate of the hydraulic control of zero flow. Figure 2 is a graph of the temperature data. Figure 3 is a graph of all of the precipitation and river stage monitoring data.

The monitoring study was intended to provide calibration data for a hydrologic model. Figure 4 highlights the monitoring data from the largest storm event that initially appears to be most useful for this purpose. However, although the rain gages in the north end of the watershed recorded 3.29 and 3.33 inches of rainfall, the Muskegon Airport only recorded 1.40 inches of rainfall, as shown in Figures 5 and 6. The precipitation may not have been sufficiently uniform over the watershed to use this storm to calibrate the hydrologic model.

Our ability to convert the stage data to flows is also limited. We were able to obtain only one unique flow measurement at each site. The Quality Assurance Project Plan (QAPP) for this study calls for a minimum of two flow measurements at each location. Without at least two measurements, calculating flows from the stage data involves an unacceptable level of uncertainty. We have to assume that we will be unable to obtain the second measurement within the deadlines of this project and will therefore be unable to provide data suitable calibration data from this monitoring study.

If you have any questions or comments regarding our analysis, please contact me at 517-373-0210.

cc: Ric Sorrell, GLMD
Tim Hall, WD – Grand Rapids
Ralph Reznick, WD

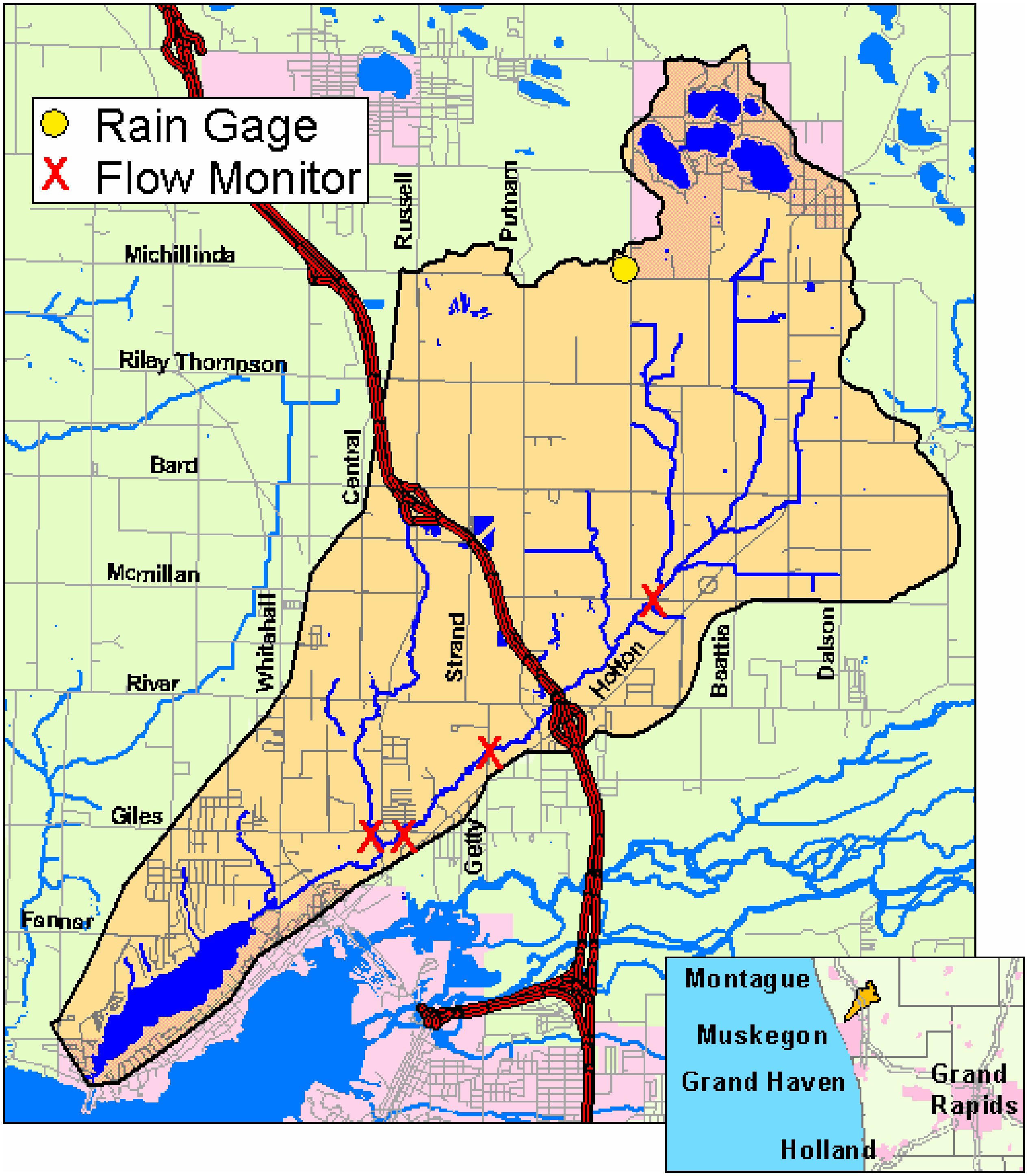

Figure 1: Gage Locations

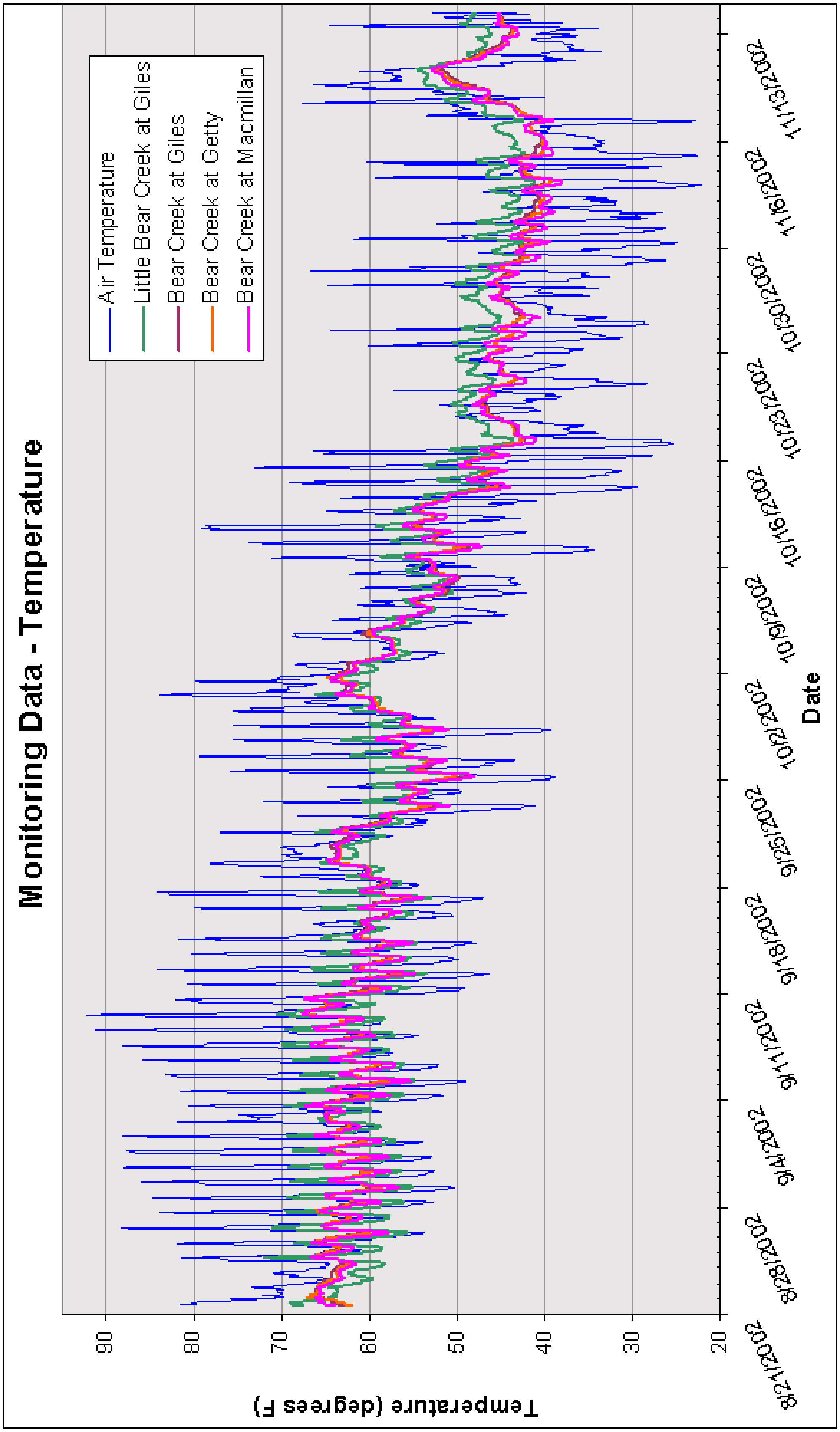

Figure 2: Temperature Data

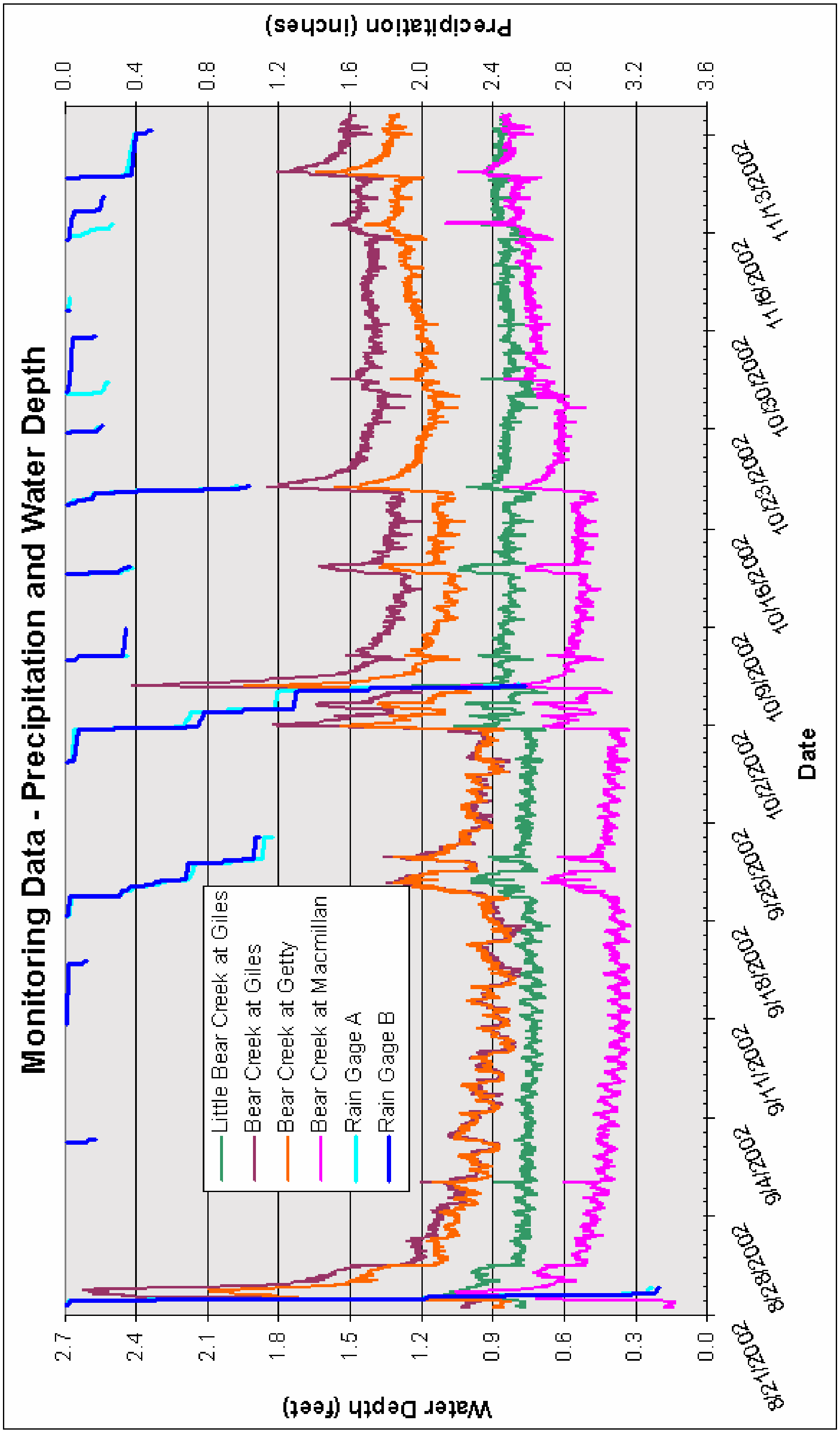

Figure 3: Precipitation and River Stage Data

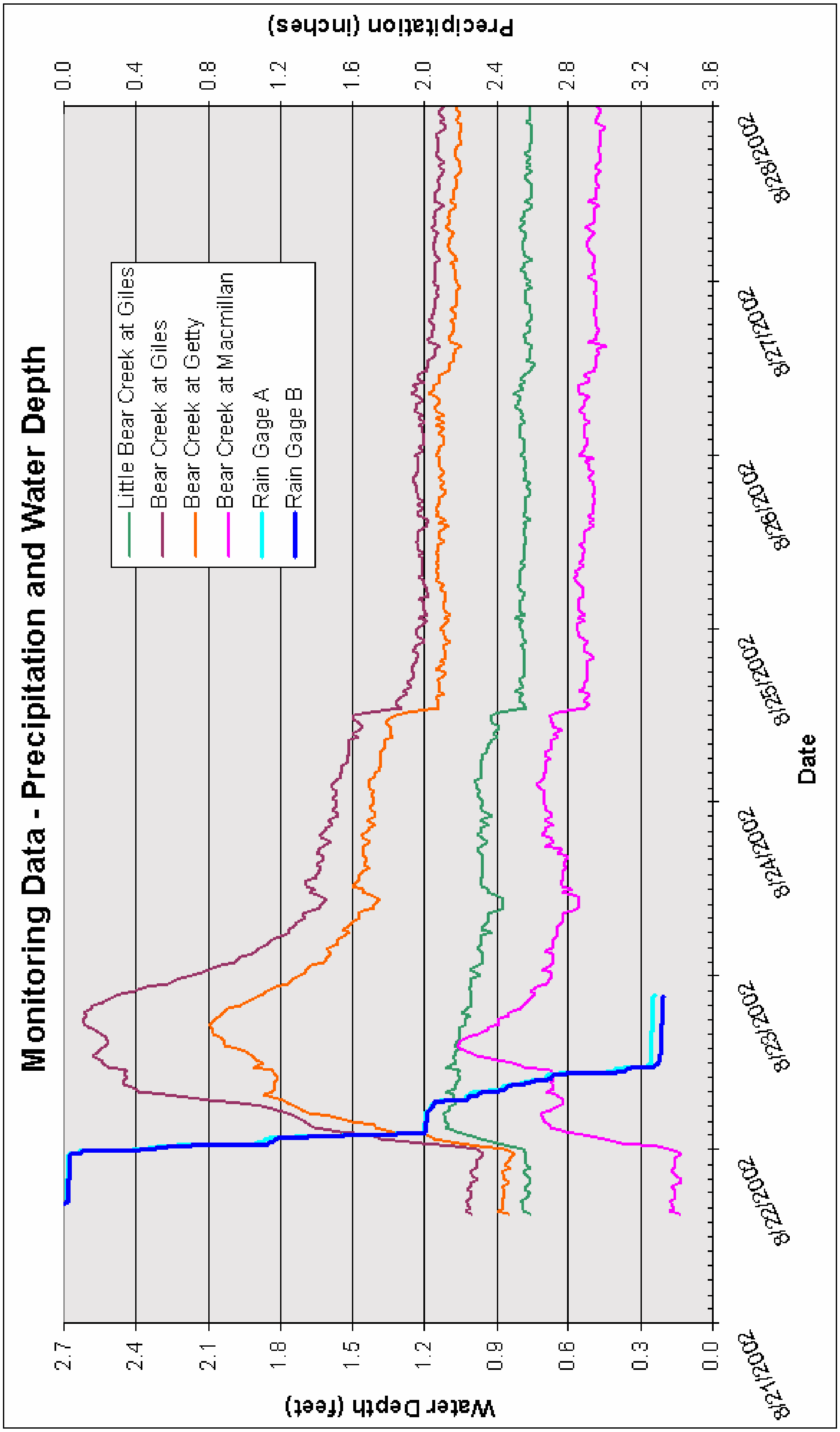

Figure 4: Monitoring Data from the Largest Storm Event

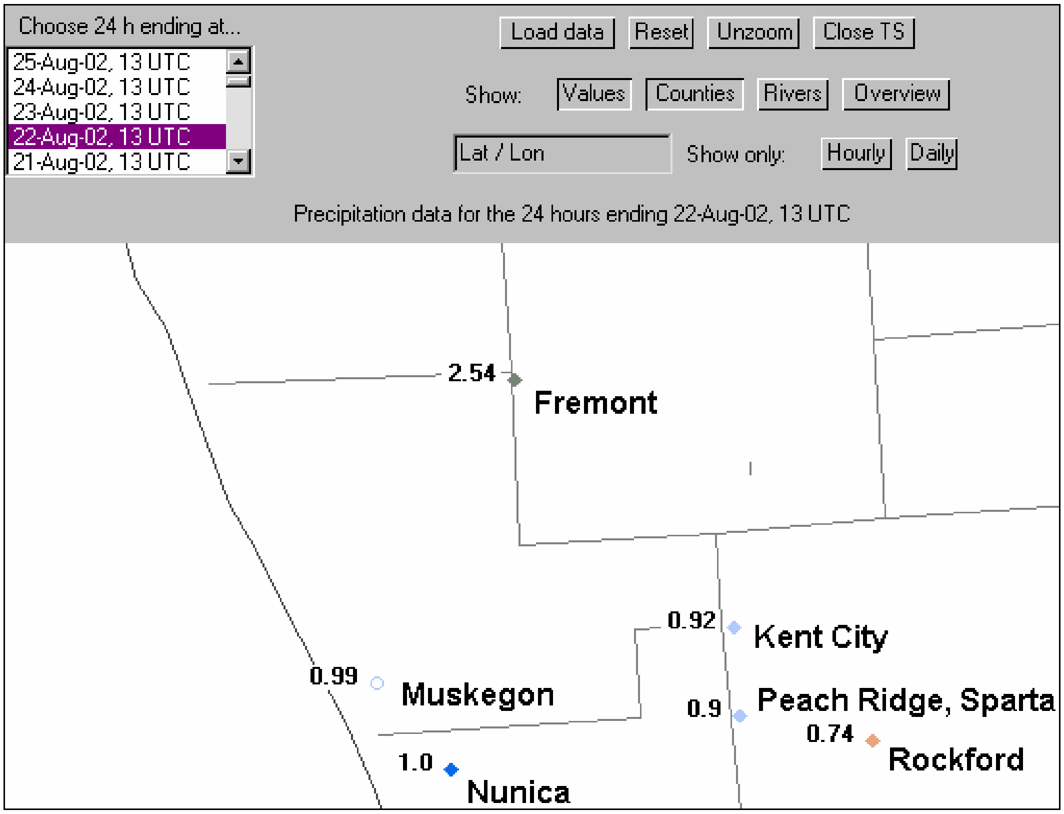

Figure 5: August 22, 2002 Rainfall Totals

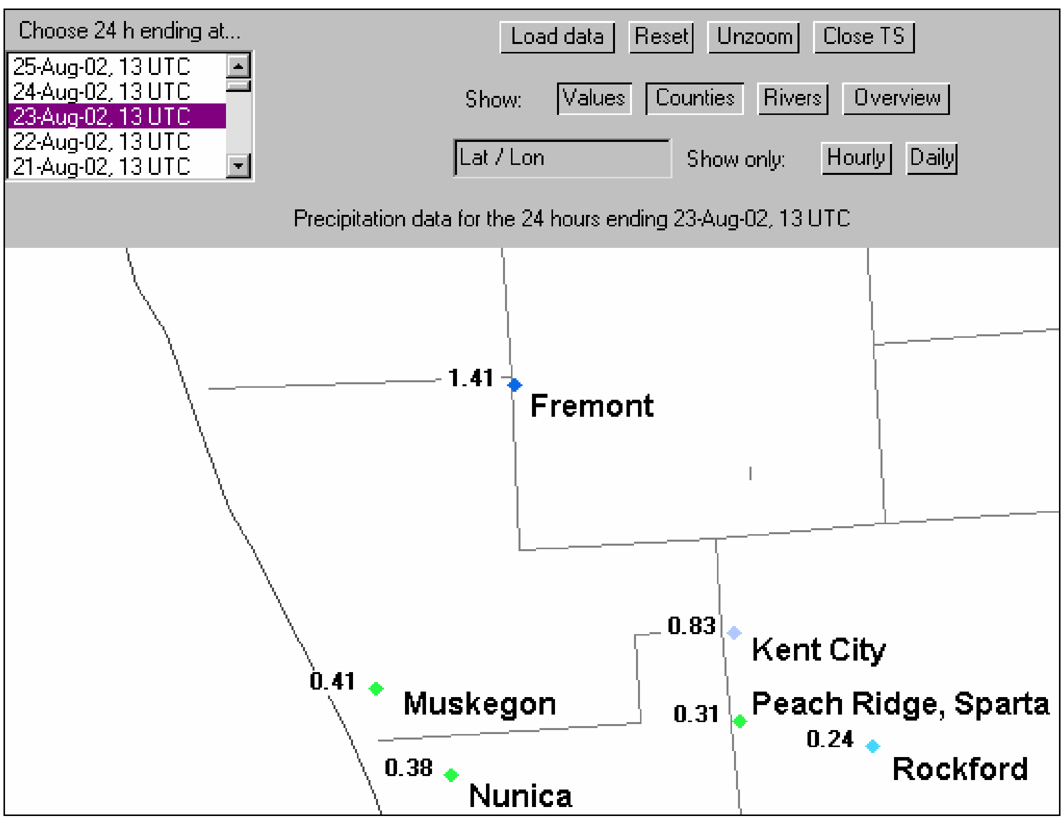

Figure 6: August 23, 2002 Rainfall Totals