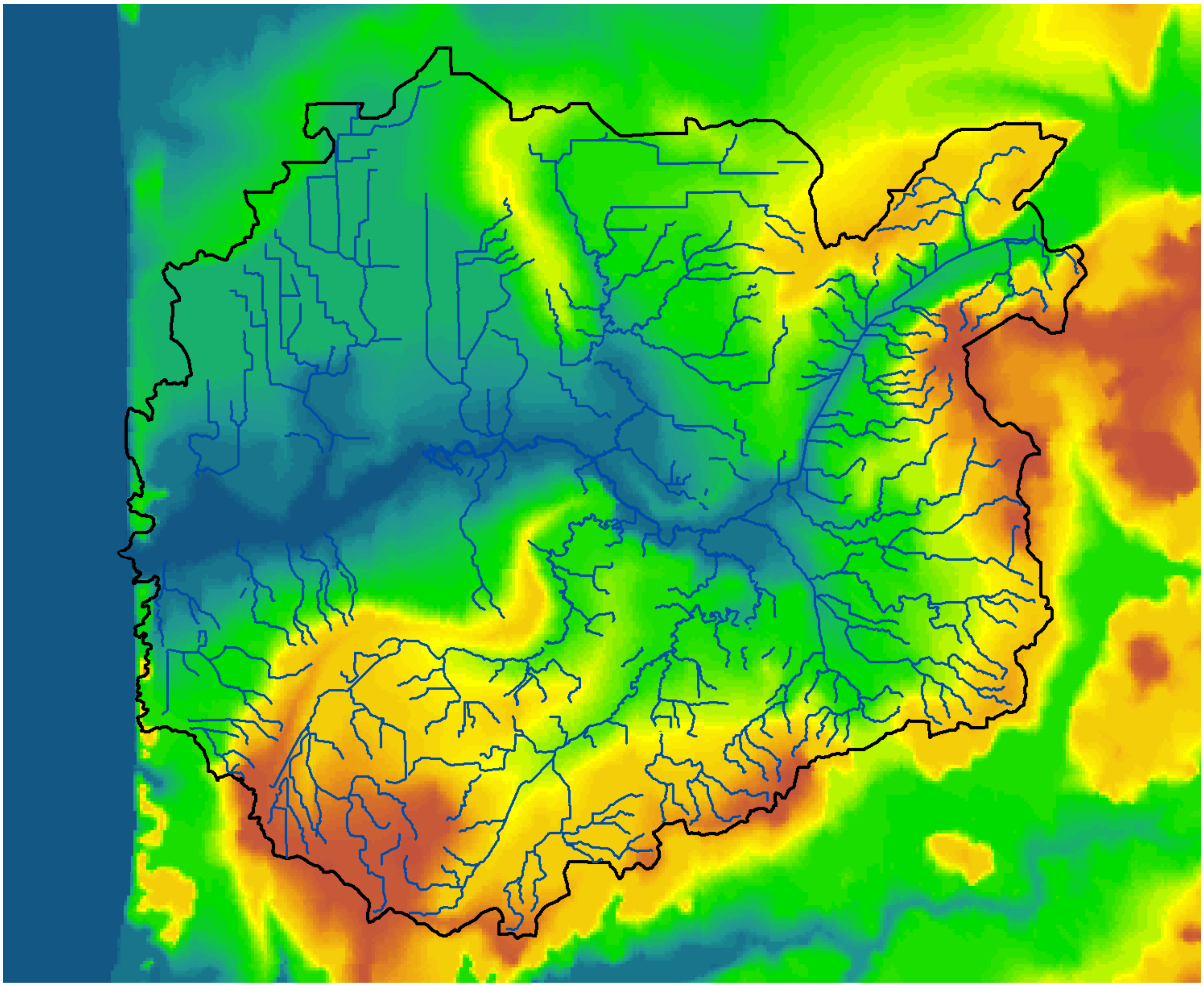
Macatawa Watershed Hydrologic Study



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DEQ
Michigan's Nonpoint Source Program
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This Nonpoint Source (NPS) Pollution Control project has been funded wholly by the United States Environmental Protection Agency (EPA) through a Part 319 grant to the Michigan Department of Environmental Quality. This study is in support of a NPS Macatawa watershed planning grant, 2008-0016. The contents of the document do not necessarily reflect the views and policies of the EPA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use.

The cover depicts the streams, rivers, and ground elevations of the Macatawa Watershed. Lighter colors are higher elevations.

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Summary

This hydrologic study of the Macatawa watershed was conducted by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) to better understand the watershed's hydrologic characteristics. This study supports the Macatawa watershed plan update task in a NPS grant to the Macatawa Area Coordinating Council.

Hydrologic characteristics of the watershed were evaluated to provide a basis for stormwater management to protect streams from increased erosion and flooding and to help determine the watershed management plan's critical areas. Local governments within the watershed could use the information to help develop stormwater ordinances. Watershed stakeholders may combine this information with other determinants, such as open space preservation, to decide which locations are the most appropriate for wetland restoration, stormwater infiltration or detention, in-stream Best Management Practices (BMPs), or upland BMPs.

Hydrologic modeling quantifies changes in stormwater runoff from 1800 through 1978 to 2005 due to land use changes. The loss of wetland and the establishment of agricultural and urban land uses are the most noticeable land use transitions during this period. Agriculture is the dominant land use throughout the watershed, but has declined over the past three decades as urbanization doubled from 15.3 percent to 30.6 percent, with an almost identical loss in agricultural land uses. The cities of Holland and Zeeland are the largest urban areas. Two percent of the watershed is public land or protected by conservation easements.

Although Lake Macatawa is a designated trout lake, no portions of the Macatawa River and its tributaries are designated trout streams. This indicates that the Macatawa system is dominated by surface runoff, with little groundwater-fed baseflow, which helps keep the stream flows and temperatures steady.

The 50 percent chance (2-year) 24-hour storm is used in the hydrologic modeling. Relatively modest, but frequent, storm events, such as the 50 percent chance storm, have more effect over time on channel form than extreme flood flows. Unless properly managed, increases in runoff from 1- to 2-year storms increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows. Increasing flashiness has not been identified at the United States Geological Survey (USGS) gage in the Macatawa River watershed.

Based on high flows for USGS gage 04108800 and weather data, the Macatawa watershed has characteristics of both a snowmelt-driven and storm-driven system. Many of the gaged bankfull flows are associated with snowmelt and frozen ground. This hydrologic modeling however does not attempt to replicate runoff from snowmelt and rainfall on frozen ground. HSU expects that stream flow from snowmelt and rain-on-snow events would be less sensitive to differences in land cover than indicated in this hydrologic model.

Watershed Description

Overview

The 175-square mile Macatawa watershed, Figure 1, includes portions of Ottawa and Allegan Counties. The major subwatersheds for Lake Macatawa and the Macatawa River are shown in Figure 2. For this analysis, Lake Macatawa is considered hydraulically equal to Lake Michigan, meaning the water surface elevation of Lake Macatawa stays the same as the water surface elevation of Lake Michigan. Streams and drains flowing directly to Lake Macatawa are also included in this Macatawa watershed hydrologic study.

A stream's ability to move sediment, both size and quantity, is directly related the stream's slope and flow. Thus, steeper reaches generally move larger material, such as stones and pebbles, and the flatter reaches tend to accumulate sediment. According to Rosgen, 1996, "generally, channel gradient decreases in a downstream direction with commensurate increases in streamflow and a corresponding decrease in sediment size." A typical river profile is steeper in the headwaters and flatter toward the mouth. The profile of Macatawa River and its major tributaries, Figure 3, is typical, although the mainstem is flatter than the tributaries. The mainstem is flatter because the Macatawa River was once the outlet for the Grand River, as suggested by the regional land elevations, Figure 4. Geologists refer to the river of that time, 14,500 to 13,000 years ago, as the Glacial Grand (Van Faasen, 2008).

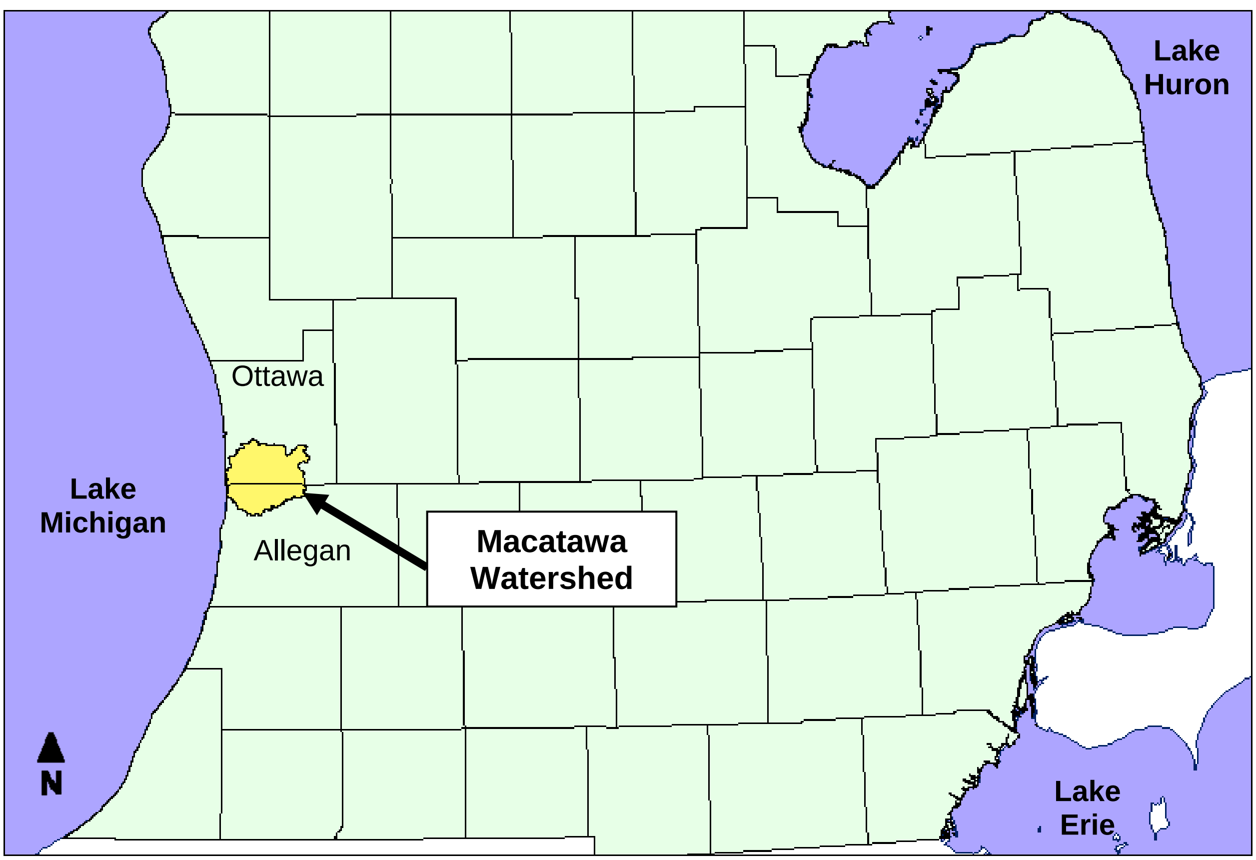


Figure 1 – Lake Macatawa Watershed Location

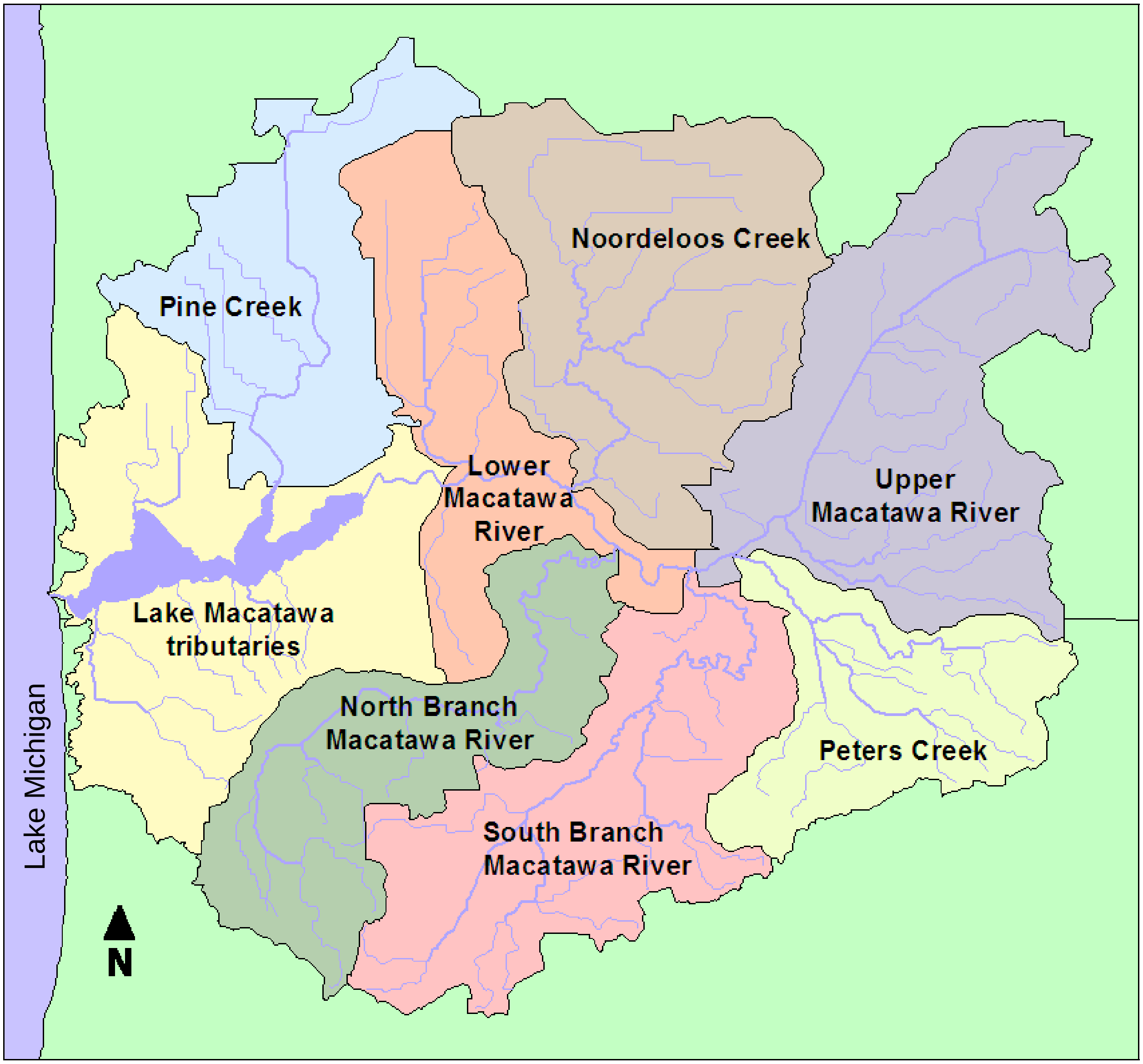


Figure 2 – Major Subwatersheds for Lake Macatawa and the Macatawa River

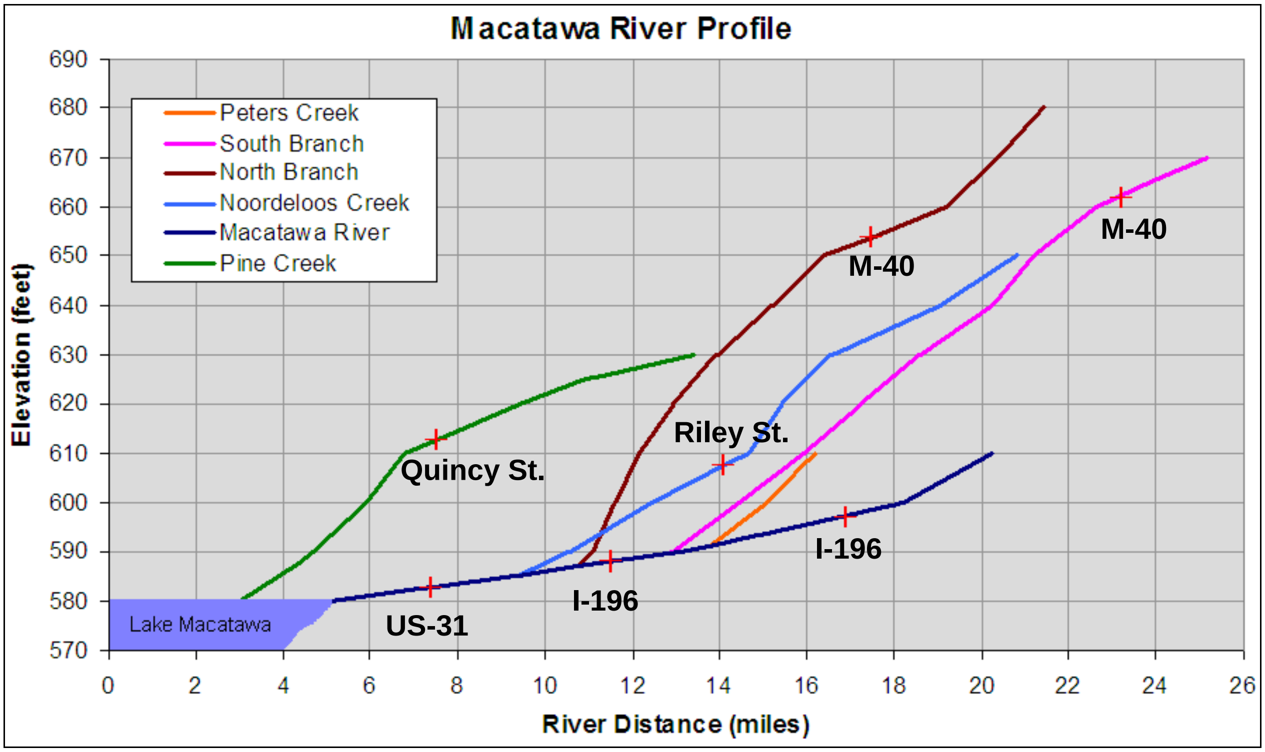


Figure 3 – Profile of Lake Macatawa, the Macatawa River, and their major tributaries

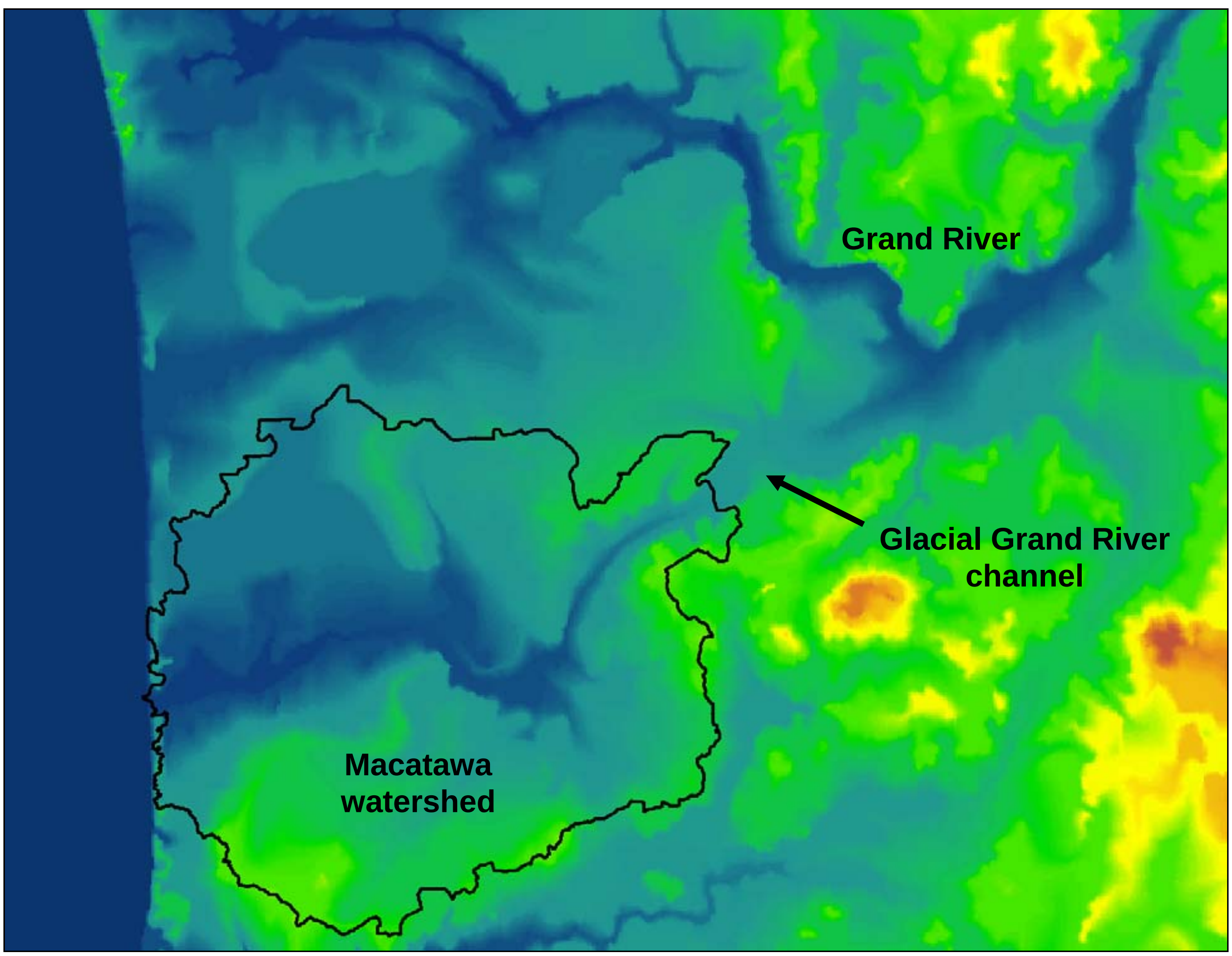


Figure 4 – Topography of the Macatawa watershed and adjoining region

Stream Order

Stream order is a numbering sequence which starts when two first order, or headwater, streams join, forming a second order stream, and so on. Two second order streams converging form a third order. Streams of lower order joining a higher order stream do not change the order of the higher, as shown in Figure 5. Stream order provides a comparison of the size and potential power of streams.

MDNR's Institute for Fisheries Research and the USGS Great Lakes Gap have nearly completed a three-year EPA-funded study that provides Geographic Information Systems (GIS) stream order data for Michigan's streams using the 1:100,000 National Hydrography Dataset (NHD). The Macatawa watershed results are shown in Figure 6.

The stream orders shown are not absolute. If larger scale maps are used or actual channels are found through field reconnaissance, the stream orders designated in Figure 6 may increase, because smaller channels are likely to be included. A more detailed analysis, based on 1:24,000 NHD layer, is being developed.

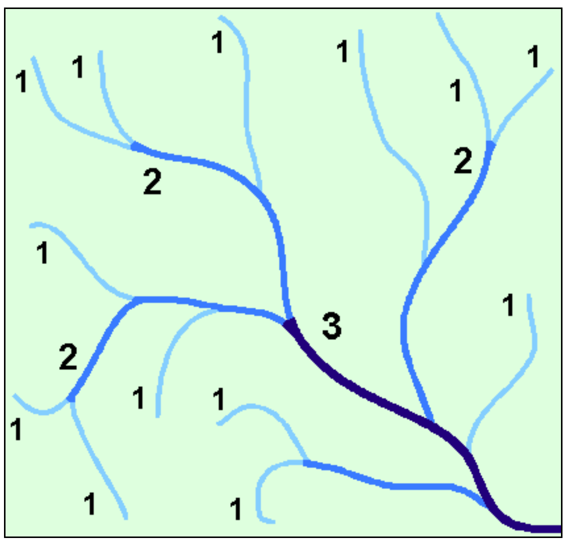


Figure 5 – Stream Ordering Procedure

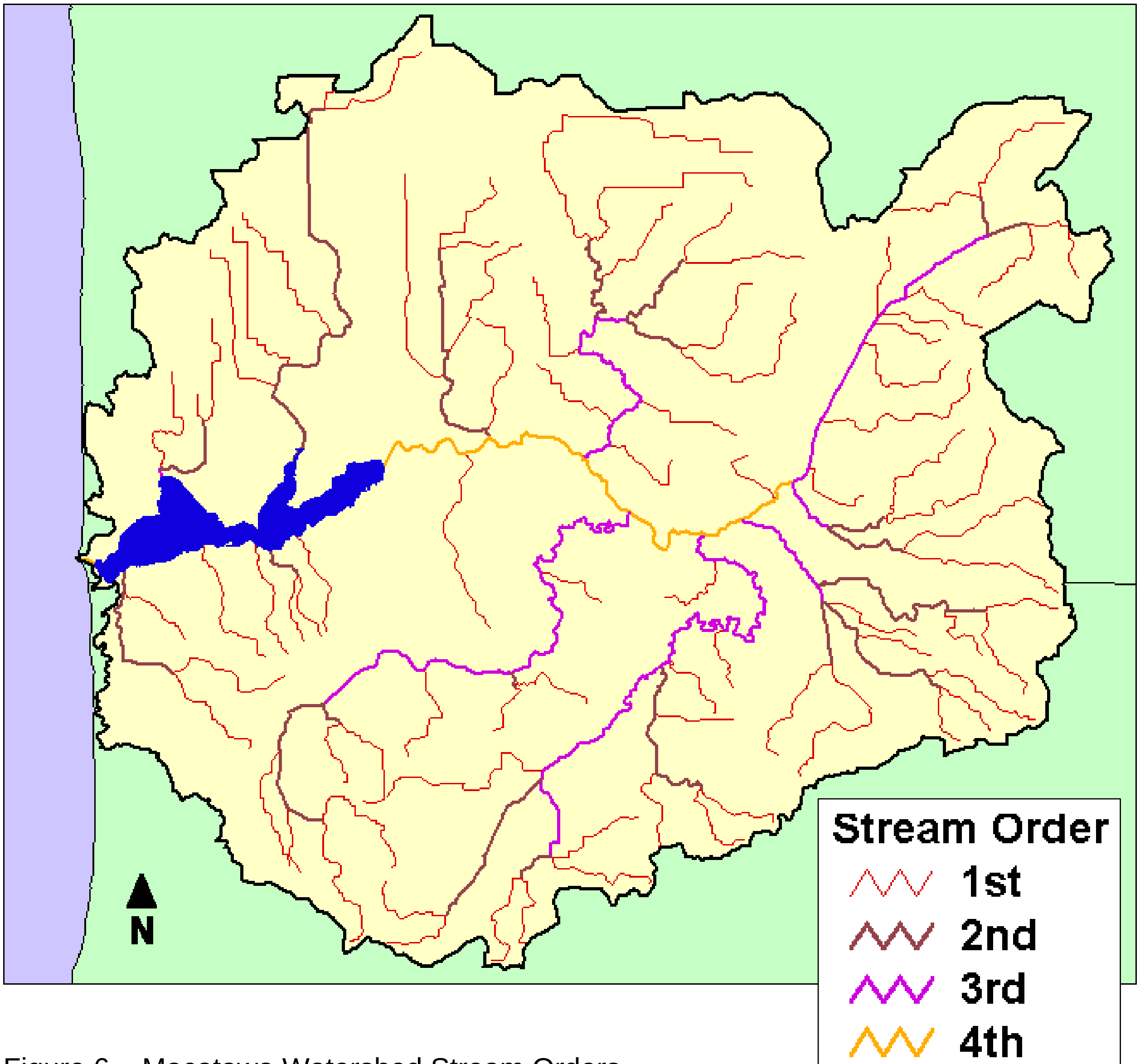


Figure 6 – Macatawa Watershed Stream Orders

Stream Temperature

Summer stream temperature was assessed statewide for the Water Withdrawal Assessment Tool, which is required of all new withdrawals as of July 9, 2009. Streams were classified as Cold, Cold Transitional, Cool, or Warm. The Macatawa has no cold or cold transitional streams. The reaches classified as cool are Kelly Lake Drain and the Upper Macatawa River and tributaries to Peters Creek, except Hunderman Creek, Figure 7. For reference, the summer temperature classifications of the region are shown in Figure 8. Colder summer temperatures are associated with a good supply of groundwater-fed baseflow.

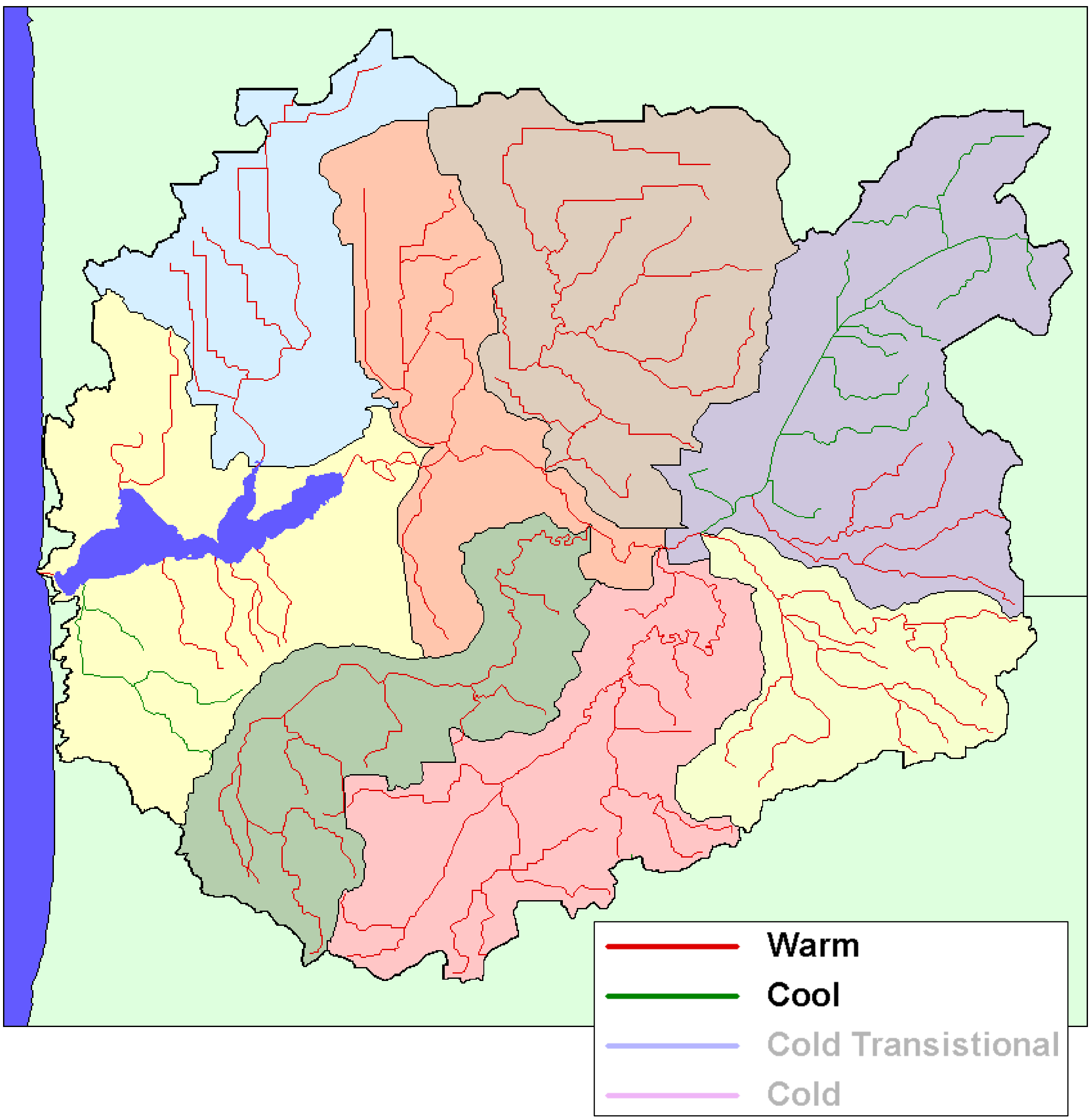


Figure 7 – Macatawa Summer Stream Temperatures

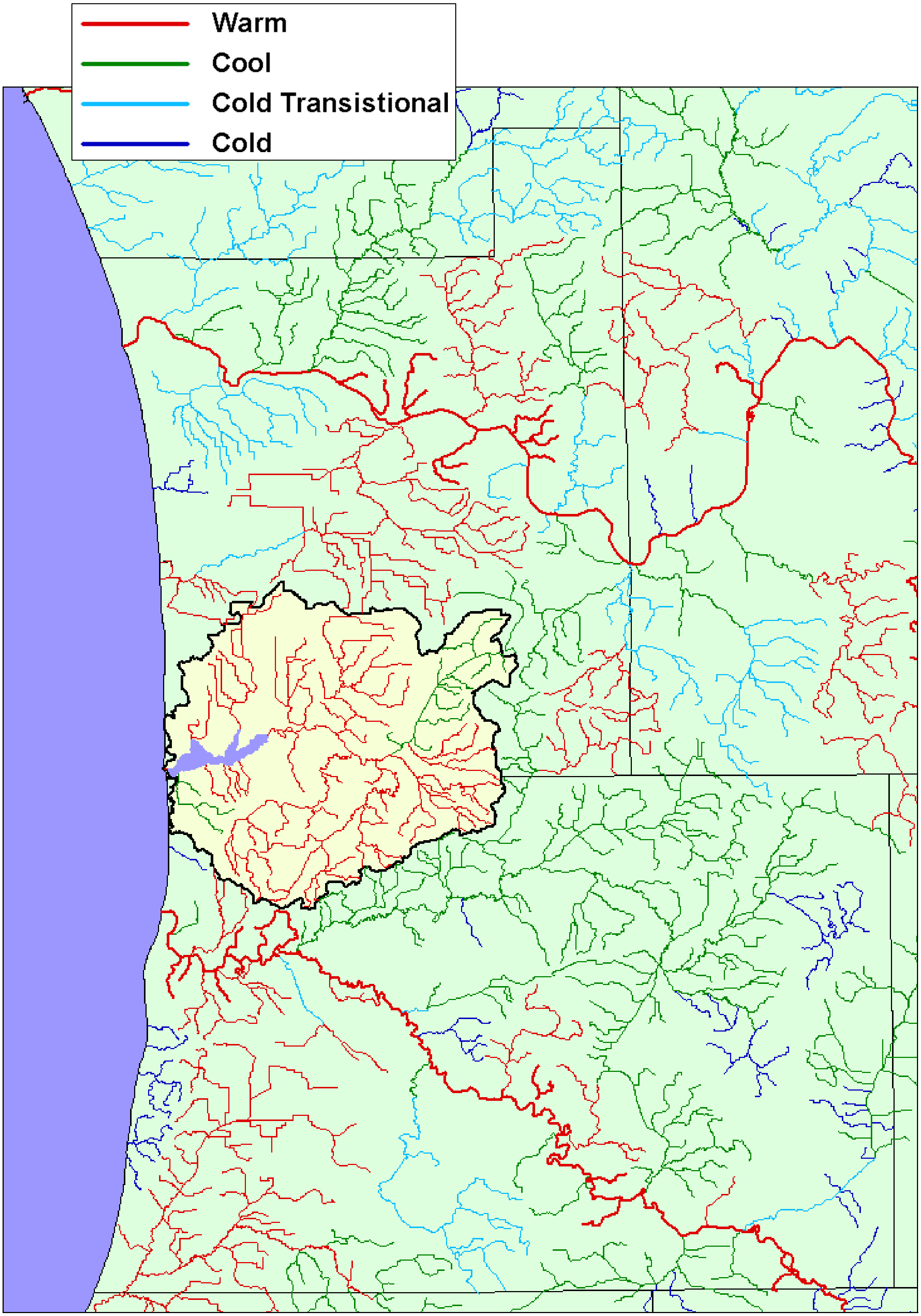


Figure 8 –Summer Stream Temperatures, Allegan and Ottawa Counties

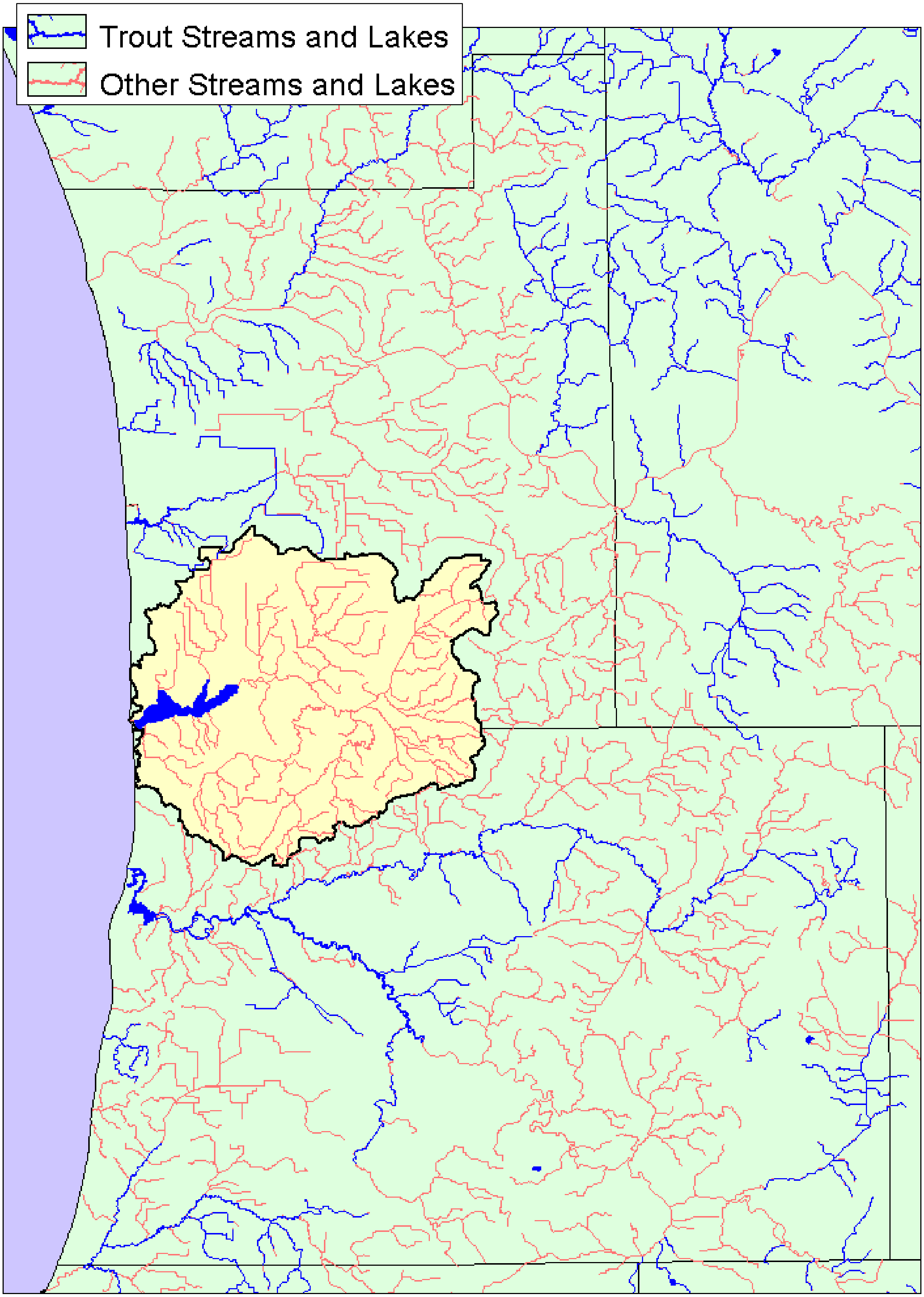


Figure 9 – Trout Streams and Lakes, Allegan and Ottawa Counties

Trout Streams and Lakes

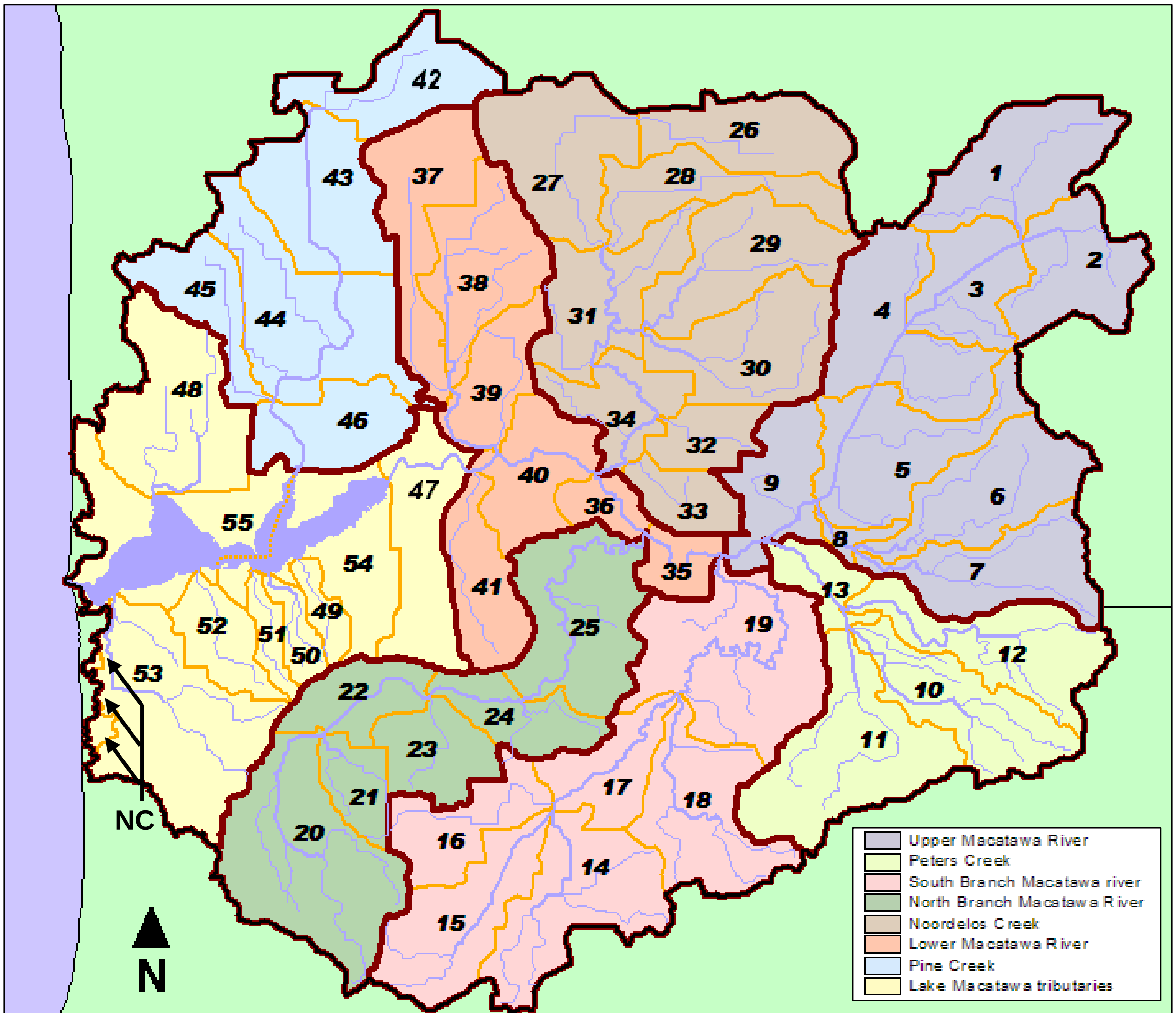
Although Lake Macatawa is a designated trout lake, no portion of the Macatawa River or tributaries are designated trout streams, Figure 9. Trout streams are associated with high quality waters and a good supply of groundwater-fed baseflow, which helps keep the stream flows and temperatures steady. Kregg Smith, Michigan Department of Natural Resources (MDNR) (personal communication, 2009) states that this is because "the Macatawa system is dominated by surface runoff. The area is relatively low relief and the Darcy Maps show low groundwater potential. Combined with the fact that most of the watershed has been drained or tiled because of a large percentage of the land use as agriculture, there is not much opportunity for trout management."

Subbasins

This study divides the watershed into 55 subbasins, Figure 10.

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, all within the Kelly Lake Drain subbasin and totaling 0.27 square miles, do not contribute surface runoff to Kelly Lake Drain or its tributaries. Runoff may pool within the areas, but that runoff has no natural outlet and therefore must either evaporate or infiltrate. If these areas become developed, artificial drainage may be installed, potentially increasing runoff to Kelly Lake Drain. Runoff from the non-contributing areas has not been included in any scenario in the Macatawa hydrologic model.

The subbasin delineations are available on request from MDEQ's Hydrologic Studies Unit. Drainage areas are provided in Table 4 (page 23) or Appendix A.



1	Beaver Dam Drain to Macatawa River	29	Hunters Creek to Brower Drain
2	Macatawa River to Beaver Dam Drain	30	Brower Drain to Hunters Creek
3	Macatawa River at 72nd Avenue	31	Noordeloos Creek to Drain #52
4	Macatawa River at I-196 Overpass	32	Cedar Drain to Noordeloos Creek
5	Macatawa River to Hunderman Creek	33	Drain #4 and 43 to Noordeloos Creek
6	Big Creek to Hunderman Creek	34	Noordeloos Creek to Macatawa River
7	Hunderman Creek to Big Creek	35	Macatawa River to North Branch
8	Hunderman Creek to Macatawa River	36	Macatawa River to Noordeloos Creek
9	Macatawa River to South Branch	37	North Holland Creek to Drain #40
10	Unnamed tributary to Peters Drain	38	Drain #15 and 17 to Drain #40
11	Peters Drain	39	Drain #40 to Macatawa River
12	Unnamed tributary to Peters Creek	40	Macatawa River to Windmill Island
13	Peters Creek to Macatawa River	41	Maplewood Intercounty Drain to Macatawa River
14	Kleinheksel Drain to South Branch	42	Troost and Boven Dam Drains to Pine Creek/Harlem Drain
15	Jaarda Drain to South Branch	43	Pine Creek/Harlem Drain at Quincy St.
16	South Branch Macatawa River to Jaarda Drain	44	Pine Creek/Harlem Drain to Drain #37
17	South Branch Macatawa River to unnamed tributary near 146th	45	Drain #37 to Pine Creek/Harlem Drain
18	East Fillmore Drain (including Eskes Drain)	46	Pine Creek/Harlem Drain to Lake Macatawa
19	South Branch Macatawa River to Macatawa River	47	Macatawa River/Lake Macatawa
20	North Branch Macatawa River to Den Bleyker Drain	48	Winstrom Creek and Drains #20A, 23, 53 to Lake Macatawa
21	Vanderbie Drain and Rotman Drain	49	Old Lela Drain to Lake Macatawa
22	North Branch Macatawa River to Den Bleyker Drain	50	Weller Drain to Lake Macatawa
23	Den Bleyker Drain	51	Arbor Creek to Lake Macatawa
24	North Branch Macatawa River at M-40	52	Ottogan Intercounty Drain to Lake Macatawa
25	North Branch Macatawa River to Macatawa River	53	Kelly Lake Drain to Lake Macatawa
26	Bosch and Hulst Drain at 104th Avenue	54	East Lake Macatawa drainage (does not include lake)
27	Bosch and Hulst Drain to Noordeloos Creek	55	West Lake Macatawa drainage (does not include lake)
28	Tributary to Bosch and Hulst Drain to Noordeloos Creek	NC	Non-contributing

Figure 10 – Macatawa Watershed Subbasin Identification

Land Use

1800, 1978, and 2005 Land Cover

General land use trends for the entire watershed from 1800 through 1978 to 2005 are illustrated in Figure 11 and in Table 1. More detailed information for each subbasin is provided in Appendix A. Land use maps depicting MDEQ GIS data for 1800, 1978, and 2005 are shown in Figures 12 through 14.

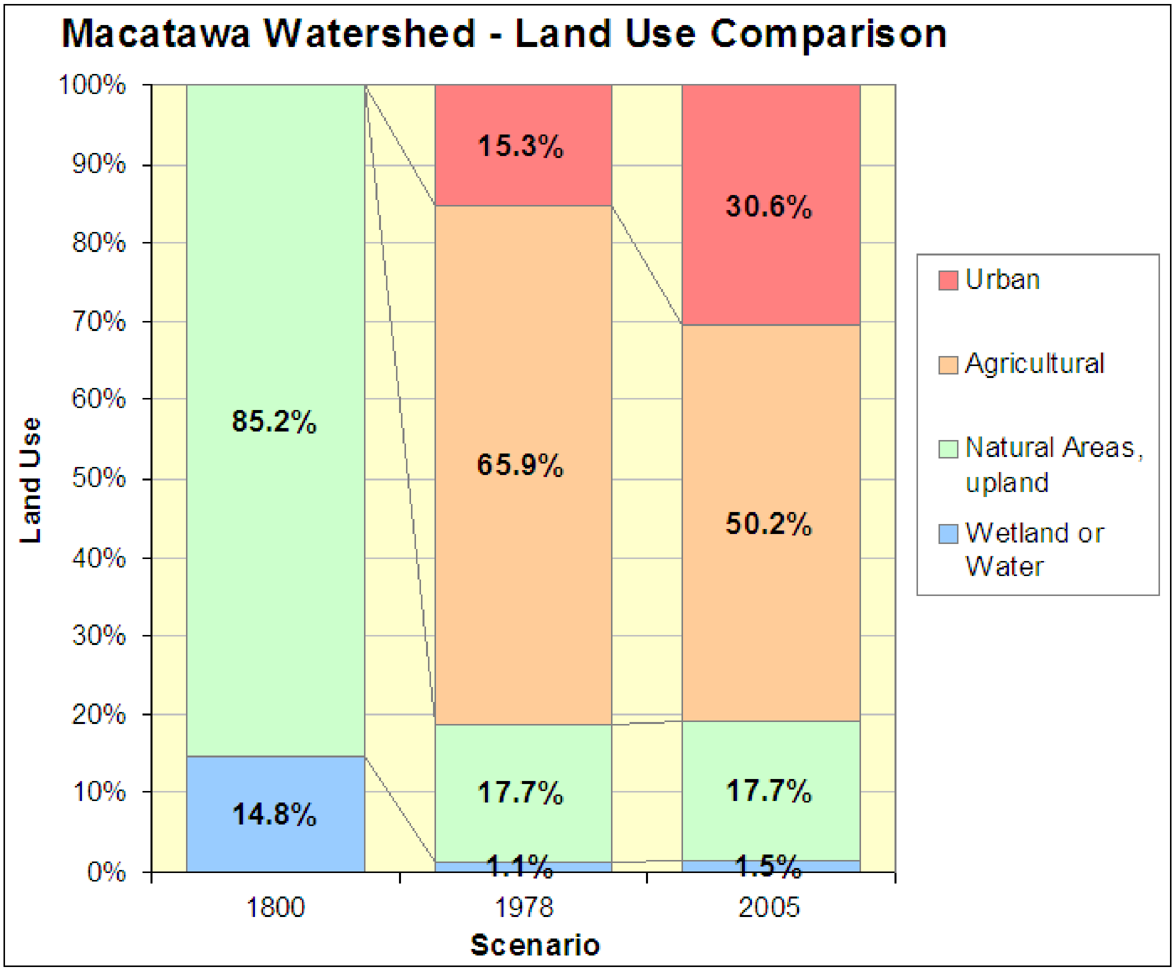


Figure 11 – Land Use Comparison, Macatawa Watershed

Land use circa 1800 is from a statewide database based on original surveyors' tree data and descriptions of the vegetation and land between 1816 and 1856. Michigan was systematically surveyed during that time by the General Land Office, which had been established by the federal government in 1785. The detailed notes taken by the land surveyors have proven to be a useful source of information on Michigan's landscape as it appeared prior to widespread European settlement. The database creators recognize that there are errors in the database due to interpretation and data input.

The 1978 land cover files represent a compilation of data from county and regional planning commissions or their subcontractors. This data set is intended for general planning purposes. It is not intended for site specific use. Data editing, manipulation, and evaluation was completed by the Michigan State University Center for Remote

Sensing and GIS and by the MDNR. Files have been checked by MDNR against original MDNR digital files for errant land cover classification codes.

The Zeeland Township 2005 land cover data was produced for the Macatawa Area Coordinating Council by Grand Valley State University's Robert B. Annis Water Resources Institute (AWRI). The 2005 land cover for the remainder of the watershed is an update of the 1978 data based on HSU's analysis of 2005 aerial photos.

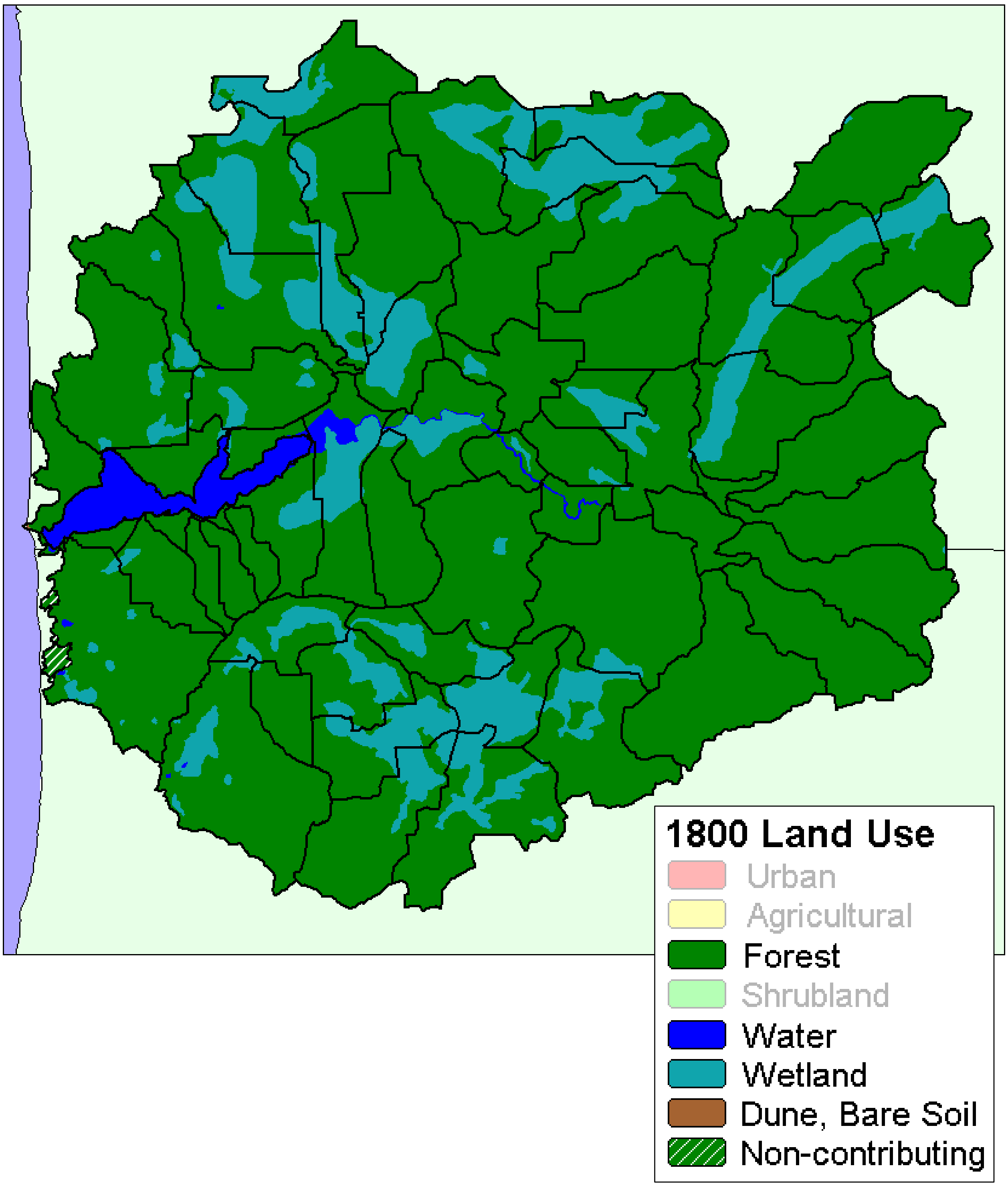


Figure 12 – 1800 Land Cover

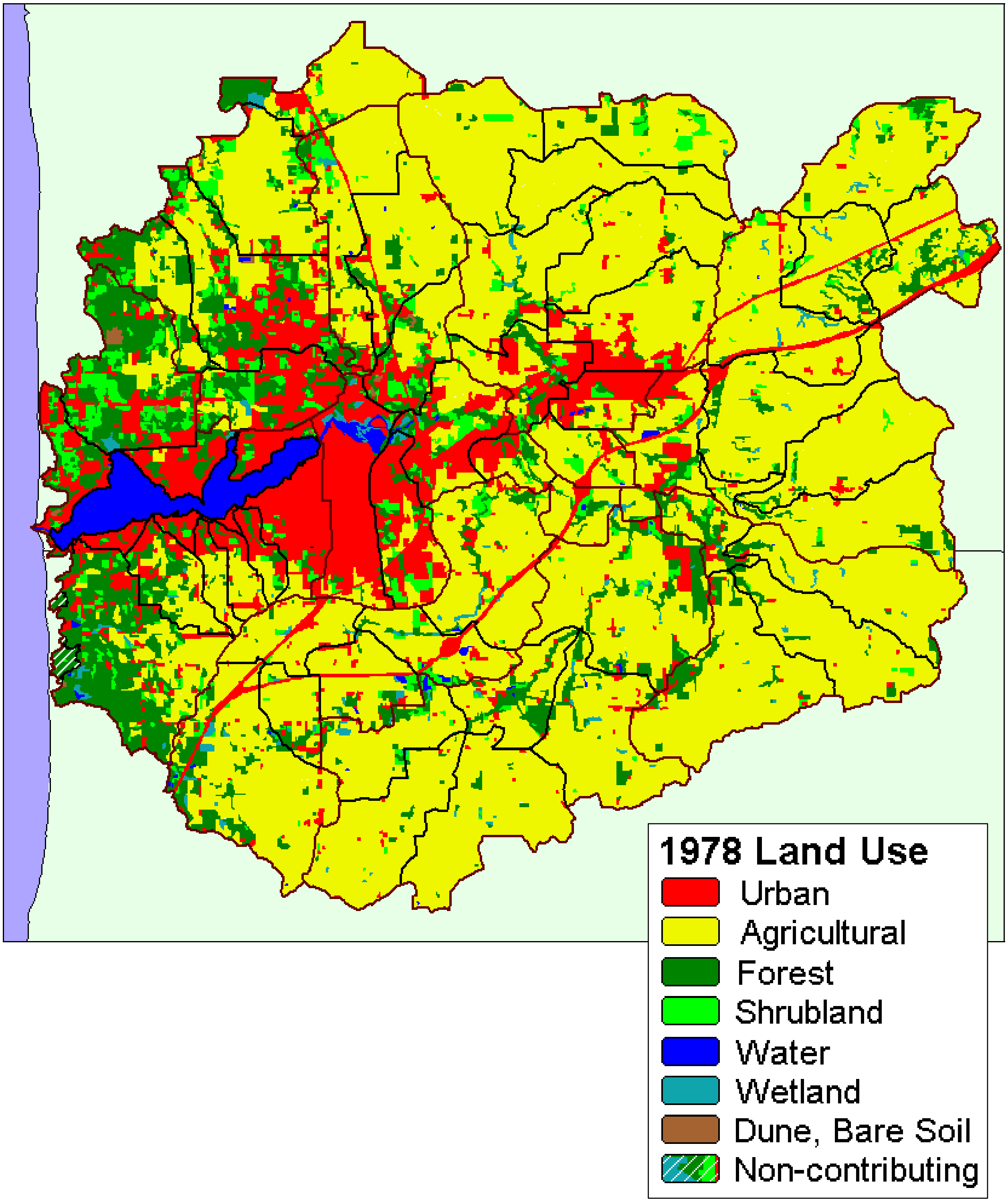


Figure 13 – 1978 Land Cover

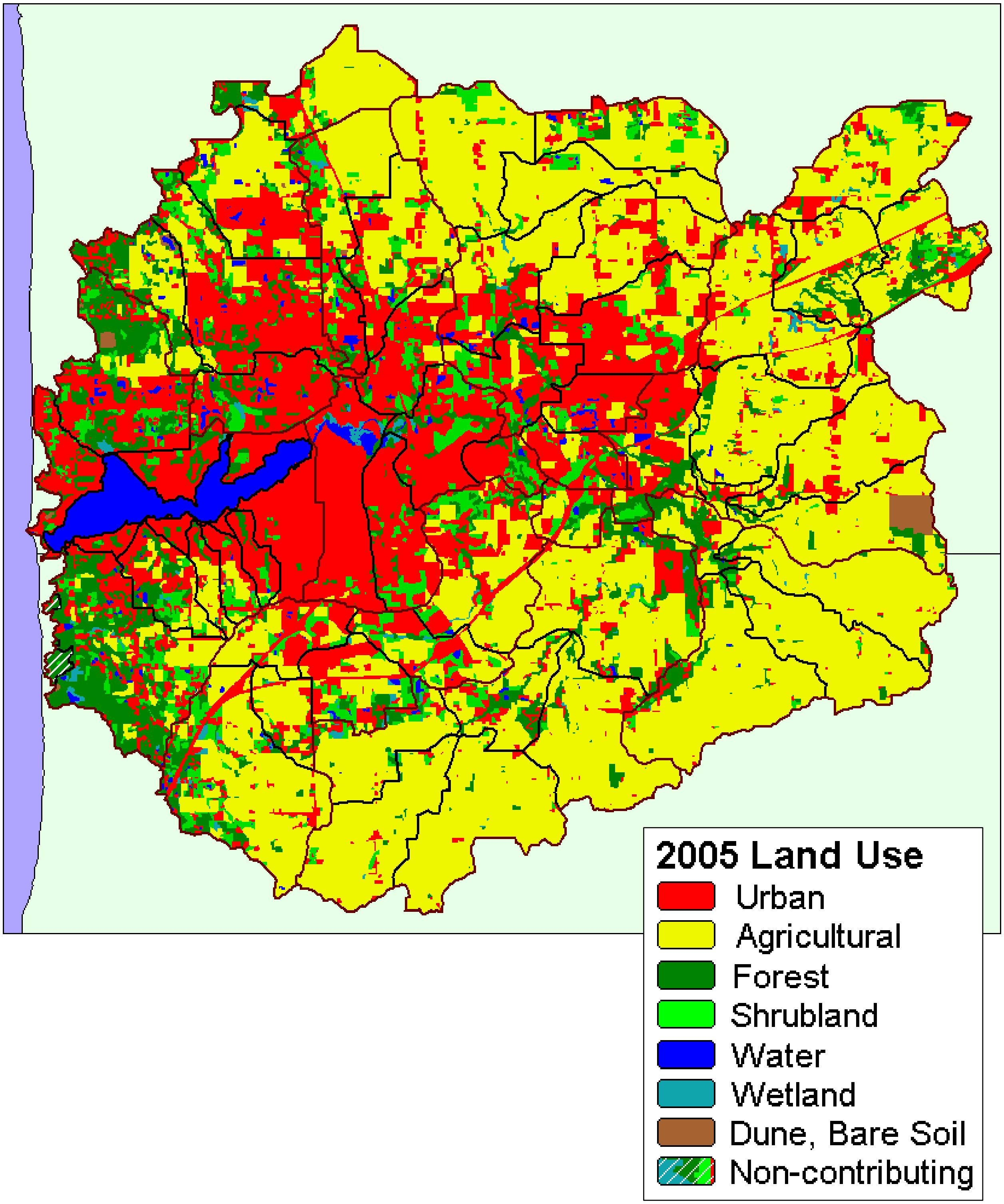


Figure 14 – 2005 Land Cover

Table 1 – Macatawa Watershed Land Use

Subbasin	Urban			Agricultural			Natural Areas, Upland			Water, Wetland		
	1800	1978	2005	1800	1978	2005	1800	1978	2005	1800	1978	2005
1	NA	1.1%	14.0%	NA	87.2%	72.2%	99.4%	10.9%	12.6%	0.6%	0.8%	1.2%
2	NA	11.7%	16.9%	NA	70.5%	58.7%	78.8%	16.8%	23.3%	21.2%	1.0%	1.1%
3	NA	5.9%	15.7%	NA	79.9%	65.4%	67.3%	13.2%	17.9%	32.7%	1.1%	0.9%
4	NA	9.8%	23.7%	NA	84.2%	67.5%	89.7%	3.8%	5.6%	10.3%	2.1%	3.2%
5	NA	4.1%	14.0%	NA	88.9%	75.2%	79.9%	6.4%	9.2%	20.1%	0.6%	1.5%
6	NA	2.0%	16.2%	NA	94.1%	79.2%	100.0%	3.8%	4.6%	0.0%	0.1%	0.0%
7	NA	0.7%	13.2%	NA	90.1%	76.1%	99.8%	8.7%	10.3%	0.2%	0.5%	0.3%
8	NA	4.5%	33.9%	NA	88.1%	49.2%	99.8%	7.4%	16.4%	0.2%	0.0%	0.4%
9	NA	25.1%	50.7%	NA	56.6%	21.1%	90.0%	16.2%	25.0%	10.0%	2.1%	3.2%
10	NA	0.7%	2.2%	NA	93.5%	92.2%	100.0%	5.3%	5.4%	0.0%	0.4%	0.2%
11	NA	2.5%	3.9%	NA	87.4%	84.8%	100.0%	9.9%	11.1%	0.0%	0.2%	0.2%
12	NA	0.8%	2.1%	NA	92.8%	91.9%	100.0%	5.3%	5.2%	0.0%	1.2%	0.9%
13	NA	9.4%	17.2%	NA	55.4%	48.3%	100.0%	34.8%	33.3%	0.0%	0.4%	1.2%
14	NA	0.7%	2.2%	NA	97.1%	95.4%	77.9%	1.7%	2.2%	22.1%	0.5%	0.2%
15	NA	1.2%	4.2%	NA	95.6%	92.0%	82.6%	2.7%	3.6%	17.4%	0.4%	0.2%
16	NA	1.8%	7.7%	NA	81.7%	72.5%	58.4%	13.4%	16.6%	41.6%	3.1%	3.2%
17	NA	5.6%	16.2%	NA	66.6%	54.5%	43.1%	27.1%	28.6%	56.9%	0.7%	0.7%
18	NA	2.6%	6.4%	NA	86.4%	85.1%	81.5%	9.5%	8.0%	18.5%	1.4%	0.5%
19	NA	7.1%	17.4%	NA	73.1%	62.0%	96.9%	18.5%	19.4%	3.1%	1.3%	1.2%
20	NA	6.4%	14.6%	NA	74.3%	60.0%	91.3%	17.0%	23.1%	8.7%	2.3%	2.3%
21	NA	11.3%	23.7%	NA	73.1%	60.0%	98.9%	14.1%	15.2%	1.1%	1.5%	1.1%
22	NA	12.2%	44.1%	NA	83.3%	41.4%	74.8%	3.5%	13.5%	25.2%	1.0%	1.0%
23	NA	10.8%	37.8%	NA	73.9%	35.5%	70.7%	11.9%	22.9%	29.3%	3.4%	3.7%
24	NA	12.9%	39.0%	NA	71.4%	37.2%	73.3%	12.5%	20.9%	26.7%	3.2%	2.8%
25	NA	7.5%	29.2%	NA	80.5%	51.0%	98.8%	10.5%	18.6%	1.2%	1.5%	1.3%
26	NA	0.9%	11.6%	NA	82.3%	66.9%	51.1%	16.7%	20.7%	48.9%	0.1%	0.8%
27	NA	0.4%	3.5%	NA	95.4%	88.2%	75.4%	4.1%	8.2%	24.6%	0.1%	0.1%
28	NA	0.2%	2.7%	NA	98.2%	90.7%	43.9%	1.5%	5.9%	56.1%	0.2%	0.7%
29	NA	3.5%	23.2%	NA	92.9%	72.3%	90.4%	3.6%	4.4%	9.6%	0.0%	0.1%
30	NA	22.8%	60.0%	NA	72.3%	27.7%	100.0%	5.0%	12.1%	0.0%	0.0%	0.2%
31	NA	4.8%	33.2%	NA	85.2%	51.2%	96.4%	8.6%	12.7%	3.6%	1.3%	2.8%
32	NA	59.5%	79.8%	NA	29.5%	9.3%	70.9%	9.9%	7.6%	29.1%	1.2%	3.3%
33	NA	14.5%	61.3%	NA	73.2%	14.3%	95.4%	12.1%	21.6%	4.6%	0.2%	2.8%
34	NA	38.3%	62.9%	NA	39.6%	10.2%	96.3%	21.7%	25.6%	3.7%	0.3%	1.3%
35	NA	10.7%	28.1%	NA	71.7%	43.0%	96.7%	16.2%	27.9%	3.3%	1.4%	0.9%
36	NA	36.7%	64.7%	NA	39.6%	2.3%	93.4%	23.7%	32.4%	6.6%	0.0%	0.6%
37	NA	9.0%	31.4%	NA	75.0%	49.7%	70.8%	15.0%	16.8%	29.2%	1.0%	2.1%
38	NA	8.6%	30.3%	NA	77.7%	54.3%	87.8%	13.5%	14.7%	12.2%	0.1%	0.8%
39	NA	25.8%	66.1%	NA	44.1%	12.1%	54.5%	30.0%	20.6%	45.5%	0.1%	1.2%
40	NA	44.1%	71.9%	NA	31.9%	0.4%	80.3%	22.4%	25.5%	19.7%	1.6%	2.2%
41	NA	58.1%	80.2%	NA	17.7%	2.9%	96.2%	22.5%	15.3%	3.8%	1.6%	1.6%
42	NA	9.7%	15.4%	NA	69.5%	66.9%	69.3%	19.1%	16.5%	30.7%	1.8%	1.2%
43	NA	5.9%	35.7%	NA	75.4%	47.0%	56.2%	18.1%	14.6%	43.8%	0.5%	2.7%
44	NA	31.3%	60.3%	NA	28.1%	16.0%	81.2%	40.0%	22.6%	18.8%	0.6%	1.1%
45	NA	6.3%	14.6%	NA	43.2%	46.2%	92.3%	50.3%	37.0%	7.7%	0.1%	2.1%
46	NA	45.3%	71.4%	NA	11.0%	1.2%	89.6%	42.5%	24.2%	10.4%	1.2%	3.2%
47	NA	76.8%	85.2%	NA	6.3%	0.4%	60.8%	6.2%	4.3%	39.2%	10.7%	10.1%
48	NA	20.6%	40.1%	NA	9.4%	8.8%	93.9%	68.9%	48.5%	6.1%	1.1%	2.6%
49	NA	48.3%	80.4%	NA	28.5%	3.5%	100.0%	22.9%	15.5%	0.0%	0.4%	0.6%
50	NA	36.3%	58.0%	NA	54.6%	24.5%	100.0%	8.4%	16.8%	0.0%	0.7%	0.7%
51	NA	22.3%	39.6%	NA	66.4%	47.9%	100.0%	10.7%	12.5%	0.0%	0.6%	0.1%
52	NA	20.4%	40.1%	NA	45.3%	21.3%	96.7%	33.6%	37.2%	3.3%	0.7%	1.5%
53	NA	12.2%	23.9%	NA	25.3%	14.4%	96.0%	60.4%	59.2%	4.0%	2.1%	2.5%
54	NA	81.9%	94.1%	NA	5.7%	0.6%	85.7%	11.6%	4.5%	14.3%	0.8%	0.8%
55	NA	61.3%	77.3%	NA	2.7%	0.0%	97.8%	34.2%	21.1%	2.1%	1.8%	1.7%
NC	NA	3.5%	6.3%	NA	0.0%	0.0%	100.0%	96.5%	93.7%	0.0%	0.0%	0.0%
Total	NA	15.3%	30.6%	NA	65.9%	50.2%	85.2%	17.7%	17.7%	14.8%	1.1%	1.5%

NC = Non-contributing, NA = Not Applicable

Imperviousness

Percent imperviousness can be compared to the Center for Watershed Protection's Impervious Cover Model (ICM) for headwater urban streams, excerpted in Table 2 and detailed in *The Importance of Imperviousness, The Practice of Watershed Protection* (Schueler and Holland, 2000). In May 2008, three refinements to the ICM were presented by Tom Schueler, Chesapeake Stormwater Network, and Lisa Fraley-McNeal, Center for Watershed Protection, at the 2nd Symposium on Urbanization and Stream Ecology (www.rivercenter.uga.edu/research/urban/urban_meeting3.htm). Figure 15 shows the revised figure, adapted with permission. The three refinements as described by Fraley-McNeal (2008) are:

1. The imperviousness/stream quality relationship is now a cone rather than a line. The cone represents the observed variability in stream quality and also the typical range in expected improvement that could be attributed to subwatershed treatment. The cone illustrates that most regions show a generally continuous but variable gradient of stream degradation as impervious cover increases.

2. The cone width is greatest for impervious cover values less than 10 percent, which reflects the wide variability in stream quality observed for these streams. This prevents the misperception that streams with low impervious cover will automatically possess good or excellent quality. The expected quality of streams in this range of impervious cover is generally influenced more by other watershed characteristics such as forest cover, road density, riparian continuity, and cropping practices.

3. The transition between stream quality classifications is now a band rather than a fixed line. If specific values are used to separate stream categories, the values should be based on actual monitoring data for the ecoregion, the stream indicators of greatest concern, and the predominant predevelopment regional land cover (e.g., crops or forest).

To properly apply and interpret the ICM in a watershed context:

- Watershed scale matters. The use of the ICM should generally be restricted to first to third order alluvial streams.
- The ICM may not work well in subwatersheds with major pollutant point sources, or extensive impoundments or dams within the stream network.
- The ICM is best applied to subwatersheds located within the same physiographic region. In particular, stream slopes, as measured from the top to the bottom of subwatersheds, should be in the same general range.
- The ICM is unreliable when management practices are poor, particularly when impervious cover levels are low (e.g., deforestation, acid mine drainage, intensive row crops, denudation of riparian cover).

When these caveats are applied, the available science generally reinforces the validity of the ICM as a watershed planning tool to forecast the general response of freshwater and tidal streams as a result of future land development.

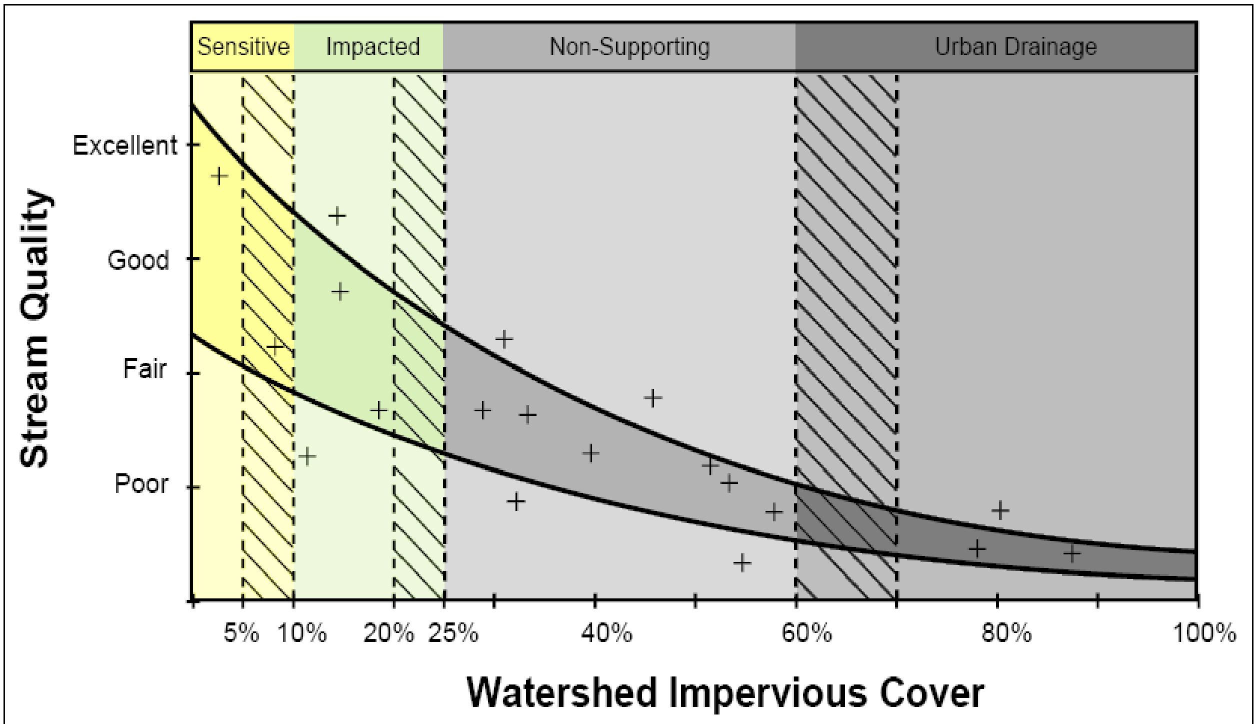


Figure 15 – Impervious Cover Model, adapted with permission (Fraley-McNeal 2008)

Table 2 – Classification of Urban Headwater Streams

Urban Stream Classification	Sensitive	Impacted	Non-supporting
Channel Stability	Stable	Unstable	Highly unstable
Water Quality	Good	Fair	Fair-Poor
Stream Biodiversity	Good-Excellent	Fair-Good	Poor
Resource Objective	Protect biodiversity and channel stability	Maintain critical elements of stream quality	Minimize downstream pollutant loads

Excerpted from “The Practice of Watershed Protection” by Thomas Schueler and Heather Holland, p. 15

The percent imperviousness of each subbasin was analyzed based on the 1978 and 2005 land use GIS data, Figures 13 and 14. The percent imperviousness was computed according to Table 3. The imperviousness values for residential, commercial, and industrial are from the Natural Resources Conservation Service (NRCS, 1986). Average residential lot size was specified as 0.50 acres, except for the Holland and Zeeland Areas. Based on analysis of 2005 aerial photos, average residential lot size was specified as 0.33 acres for subbasins 30, 32, 40, 41, 49, and 54 and 0.25 acres for subbasin 42.

The results, shown in Figures 16 and 17 and tabulated in Table 4, indicate that approximately half of the subbasins, 27 of the 55 subbasins, now exceed ten percent imperviousness. Of these 27, 12 exceed 25 percent imperviousness. For comparison, in 1978, 13 exceeded ten percent imperviousness. Of these 13, three exceeded 25 percent imperviousness.

The highlight colors of the 1978 and 2005 percent imperviousness columns in Table 4 are consistent with Figures 16 and 17. The blue highlighting in the imperviousness change column highlights those subbasins where an additional ten percent or more of the subbasin has become impervious since 1978.

Table 3 – Imperviousness Table for Impervious Area Analysis

GIS Class	Description	Imperviousness (percent)
1	Residential	0.25 acre lots: 38 0.33 acre lots: 30 0.50 acre lots: 25
2	Commercial	85
3	Industrial	72
4	Road, Utilities	85
5	Gravel Pits	0
6	Outdoor Recreation	0
7	Cropland	0
8	Orchard	0
9	Pasture	0
10	Openland	0
11	Forests	0
12	Open Water	0
13	Wetland	0
14	Bare Soil, Dune	0

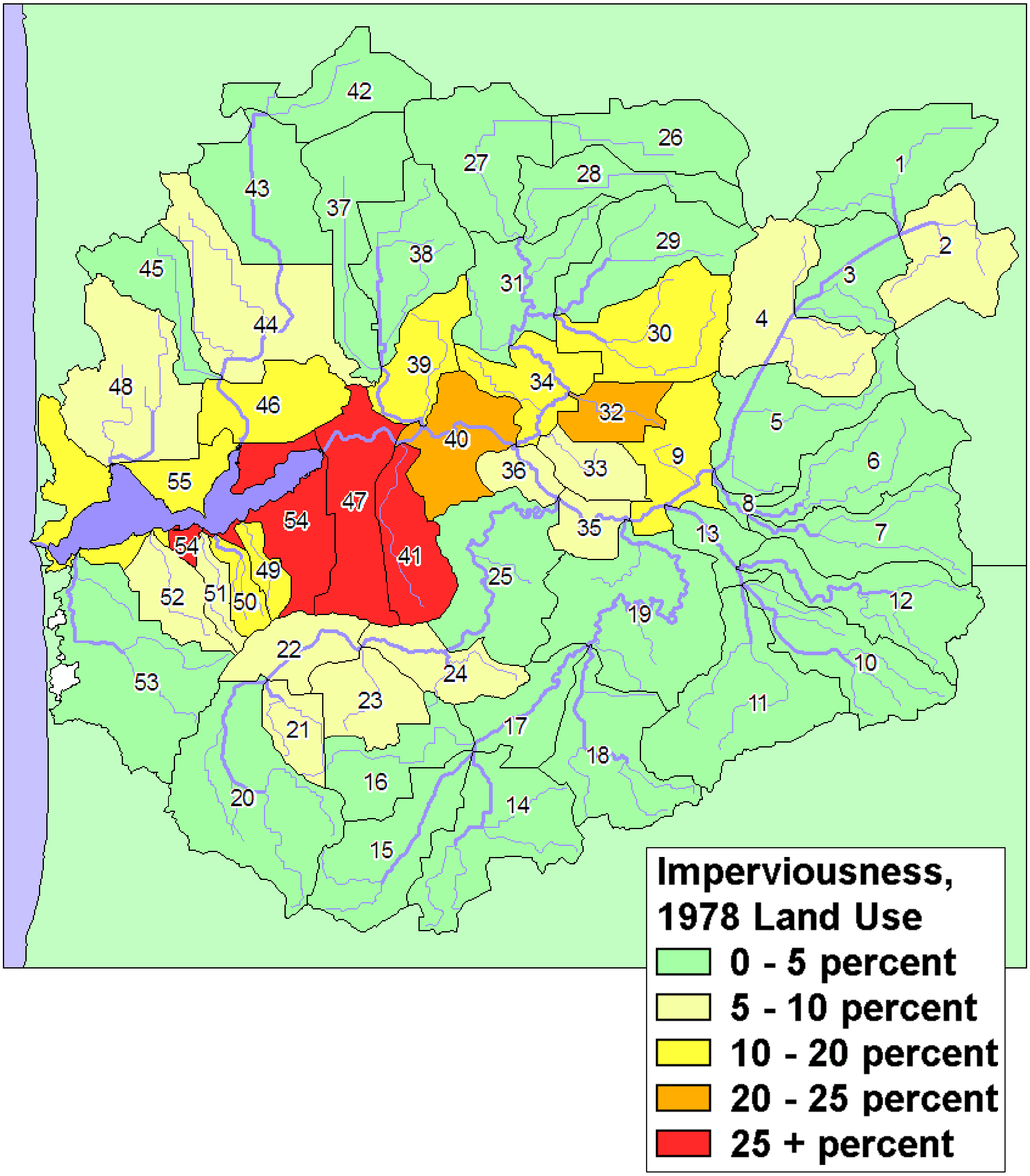


Figure 16 – Percent Imperviousness based on 1978 Land Cover

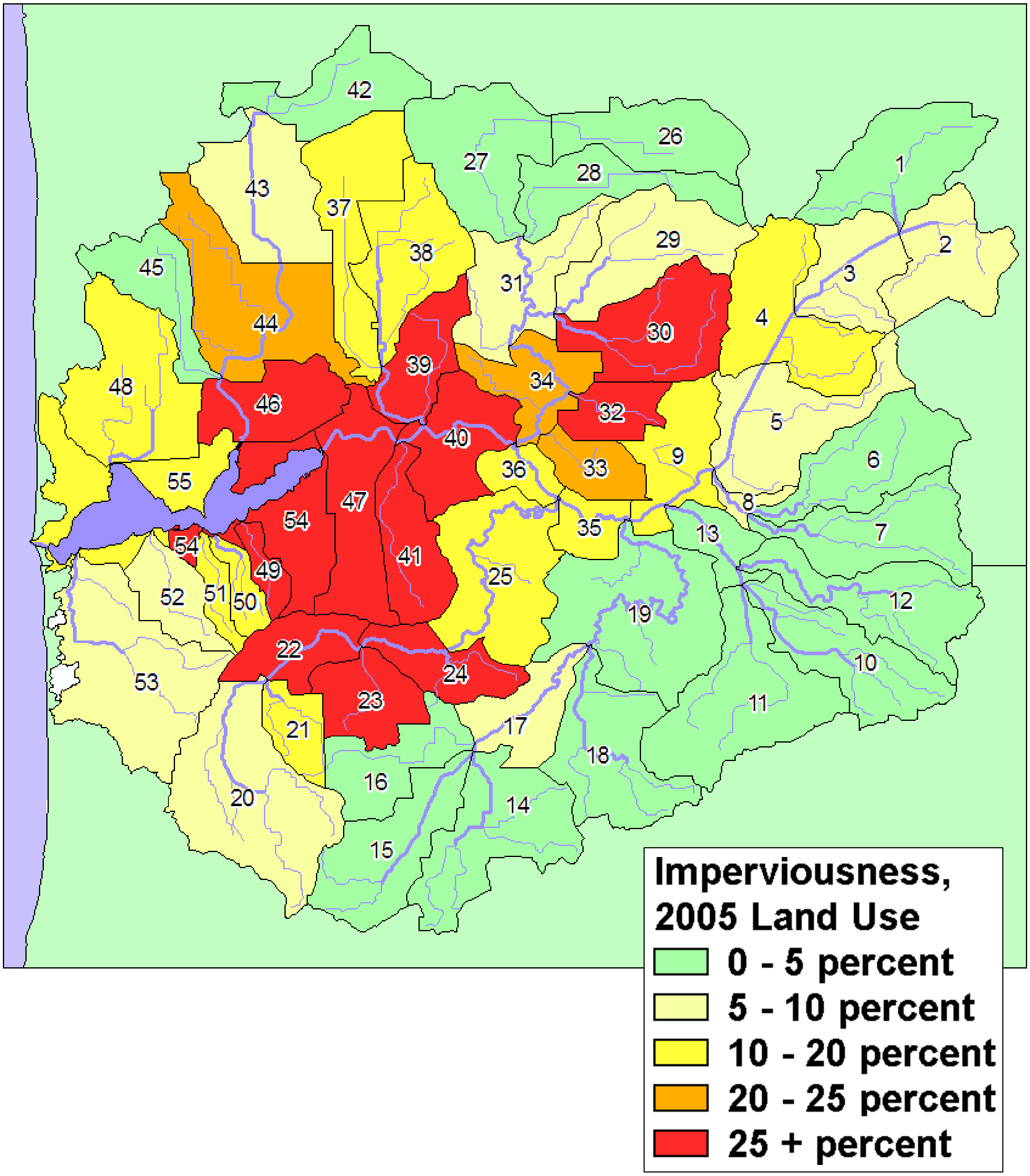


Figure 17 – Percent Imperviousness based on 2005 Land Cover

Table 4 – Percent Imperviousness and Conservation and Recreation Lands

ID	Subbasin	Drainage Area (sq. mi.)	Imperviousness			CARL
			1978	2005	Increase	
1	Beaver Dam Drain to Macatawa River	3.89	0.5%	3.6%	3.1%	0.0%
2	Macatawa River to Beaver Dam Drain	3.20	9.4%	9.9%	0.5%	0.0%
3	Macatawa River at 72nd Avenue	2.68	4.2%	6.2%	2.1%	0.0%
4	Macatawa River at I-196 Overpass	4.53	6.8%	11.1%	4.3%	0.1%
5	Macatawa River to Hunderman Creek	4.22	3.2%	6.0%	2.8%	14.4%
6	Big Creek to Hunderman Creek	3.76	0.6%	4.7%	4.1%	0.0%
7	Hunderman Creek to Big Creek	3.40	0.1%	1.1%	1.0%	0.0%
8	Hunderman Creek to Macatawa River	0.40	1.6%	9.1%	7.4%	0.5%
9	Macatawa River to South Branch	2.68	10.3%	17.0%	6.7%	2.3%
10	Unnamed tributary to Peters Drain	3.63	0.2%	0.6%	0.4%	0.0%
11	Peters Drain	5.35	0.7%	1.2%	0.5%	0.0%
12	Unnamed tributary to Peters Creek	3.91	0.1%	0.4%	0.3%	0.0%
13	Peters Creek to Macatawa River	1.32	1.6%	3.9%	2.3%	0.0%
14	Kleinheksel Drain to South Branch	4.48	0.2%	0.8%	0.5%	0.0%
15	Jaarda Drain to South Branch	3.77	0.4%	1.2%	0.8%	0.0%
16	South Branch Macatawa River to Jaarda Drain	2.58	0.3%	1.8%	1.4%	1.6%
17	South Branch Macatawa River to unnamed tributary near 146th	2.25	1.7%	5.7%	4.1%	0.0%
18	East Fillmore Drain (including Eskes Drain)	4.07	0.8%	1.6%	0.8%	0.0%
19	South Branch Macatawa River to Macatawa River	6.25	1.4%	3.8%	2.4%	5.1%
20	North Branch Macatawa River to Den Bleyker Drain	6.36	4.1%	6.6%	2.5%	0.0%
21	Vanderbie Drain and Rotman Drain	1.32	5.6%	10.9%	5.4%	0.0%
22	North Branch Macatawa River to Den Bleyker Drain	2.02	8.5%	27.4%	18.9%	0.0%
23	Den Bleyker Drain	2.21	7.2%	26.4%	19.2%	0.5%
24	North Branch Macatawa River at M-40	2.05	9.2%	27.2%	18.0%	0.0%
25	North Branch Macatawa River to Macatawa River	4.76	3.9%	15.2%	11.3%	5.2%
26	Bosch and Hulst Drain at 104th Avenue	3.09	0.2%	2.9%	2.7%	1.6%
27	Bosch and Hulst Drain to Noordeloos Creek	4.26	0.2%	1.0%	0.8%	2.6%
28	Tributary to Bosch and Hulst Drain to Noordeloos Creek	2.74	0.0%	0.7%	0.6%	0.0%
29	Hunters Creek to Brower Drain	3.86	1.0%	7.0%	6.0%	0.1%
30	Brower Drain to Hunters Creek	3.90	13.7%	36.9%	23.2%	0.2%
31	Noordeloos Creek to Drain #52	3.48	1.5%	8.7%	7.2%	1.6%
32	Cedar Drain to Noordeloos Creek	1.46	23.1%	32.2%	9.1%	3.0%
33	Drain #4 and 43 to Noordeloos Creek	1.47	8.6%	24.2%	15.7%	0.3%
34	Noordeloos Creek to Macatawa River	2.31	12.8%	23.9%	11.1%	2.5%
35	Macatawa River to North Branch	1.14	8.4%	19.9%	11.5%	0.3%
36	Macatawa River to Noordeloos Creek	1.00	8.0%	18.0%	10.0%	5.2%
37	North Holland Creek to Drain #40	3.87	4.5%	17.1%	12.6%	0.0%
38	Drain #15 and 17 to Drain #40	3.61	4.4%	18.0%	13.7%	0.6%
39	Drain #40 to Macatawa River	2.20	10.9%	35.8%	25.0%	0.1%
40	Macatawa River to Windmill Island	2.82	24.6%	43.0%	18.5%	6.0%
41	Maplewood Intercounty Drain to Macatawa River	2.50	33.1%	46.3%	13.2%	2.3%
42	Troost and Boven Dam Drains to Pine Creek/Harlem Drain	2.93	2.8%	4.9%	2.1%	6.8%
43	Pine Creek/Harlem Drain at Quincy St.	3.96	1.8%	6.7%	4.9%	2.6%
44	Pine Creek/Harlem Drain to Drain #37	5.49	9.8%	21.3%	11.5%	0.5%
45	Drain #37 to Pine Creek/Harlem Drain	2.35	1.7%	3.6%	1.9%	0.0%
46	Pine Creek/Harlem Drain to Lake Macatawa	2.66	16.9%	27.1%	10.2%	1.1%
47	Macatawa River/Lake Macatawa	3.57	34.7%	39.7%	5.0%	4.7%
48	Winstrom Creek and Drains #20A, 23, 53 to Lake Macatawa	4.96	6.8%	12.3%	5.5%	9.3%
49	Old Lela Drain to Lake Macatawa	0.70	19.2%	33.4%	14.1%	3.2%
50	Weller Drain to Lake Macatawa	0.82	10.1%	15.9%	5.8%	0.0%
51	Arbor Creek to Lake Macatawa	0.72	7.2%	11.7%	4.4%	0.0%
52	Ottogan Intercounty Drain to Lake Macatawa	1.77	5.6%	9.6%	4.0%	0.0%
53	Kelly Lake Drain to Lake Macatawa	6.13	2.9%	6.0%	3.1%	0.3%
54	East Lake Macatawa drainage (does not include lake)	3.08	35.6%	41.0%	5.4%	2.0%
55	West Lake Macatawa drainage (does not include lake)	3.21	14.4%	19.9%	5.5%	9.9%

Conservation and Recreation Lands

With United States Fish and Wildlife Service support, Ducks Unlimited and the Nature Conservancy in Michigan (2008) are creating a comprehensive GIS layer of Michigan's Conservation and Recreation Lands (CARL). The CARL GIS layer consists of public lands (federal, state, and local government-owned lands), private lands (The Nature Conservancy, Audubon, and local conservancies), and some conservation easements (with permission). CARL areas by management type are shown in Table 5 for the entire watershed. The CARL layer should be a valuable tool for planning and development of coastal and inland wetland habitat restoration and protection activities. The CARL layer will also assist other land-use planners by formulating informed decisions, including plans for greenways, conservation, and recreational activities. Figure 18 depicts the conservation and recreation lands for the Macatawa watershed as of February 2008. The area of these lands is 3.3 square miles, which is two percent of the watershed. Table 4 shows this information for each subbasin. The information is not final but is expected to be reasonably accurate.

Table 5 – CARL area by management type

Management Description	Area (acres)	Area (percent)
Park	985	46%
Forest Reserve	428	20%
Golf Course	349	16%
Country Club	111	5%
Wildlife Area	101	5%
Fairgrounds	66	3%
Conservation Easement	43	2%
Nature Preserve	40	2%
Education Center	14	1%
Total	2138	

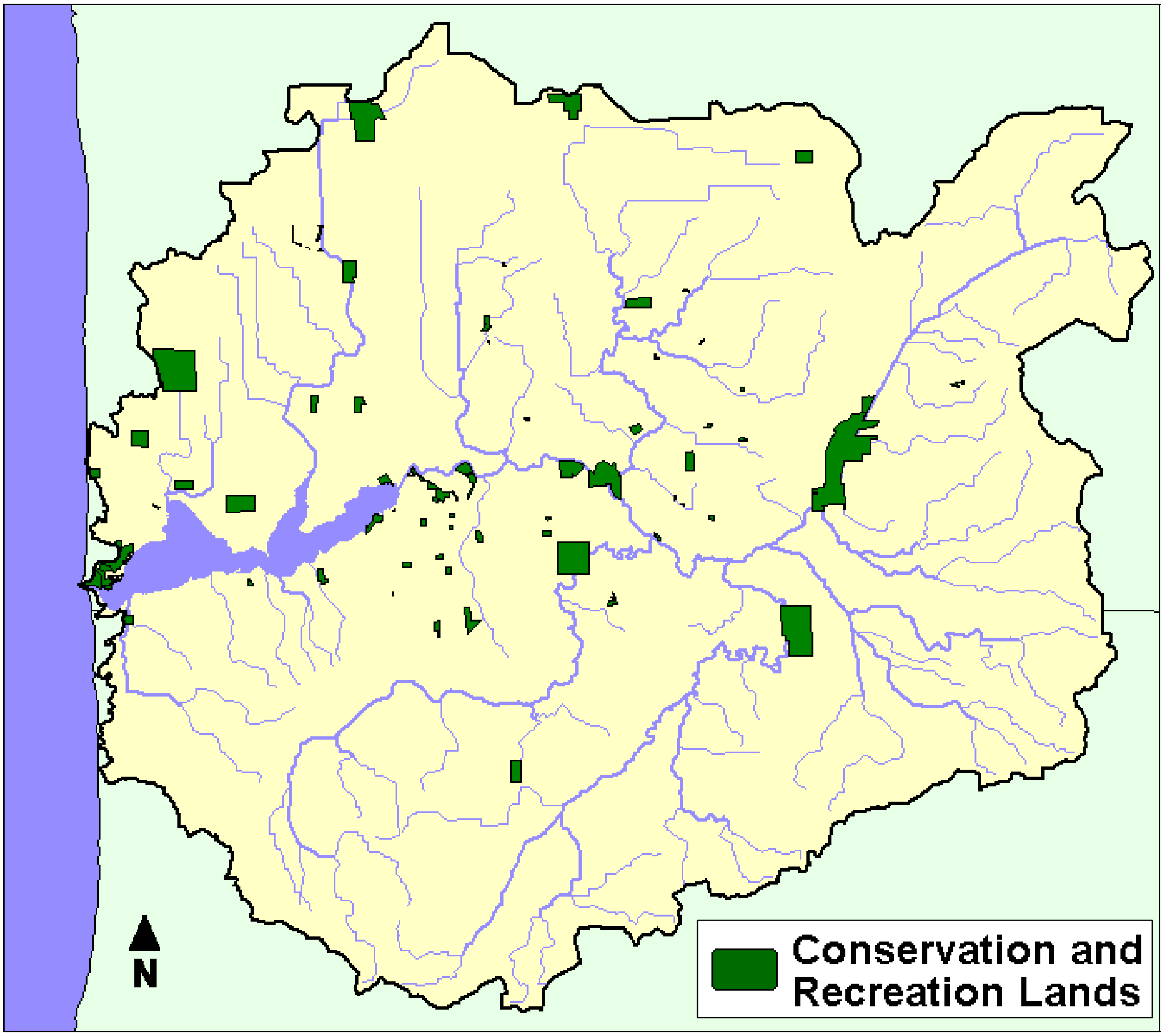


Figure 18 – Conservation and Recreation Lands

Soils

Hydrologic soil groups, or hydrogroups, are grouped according to the infiltration of water when the soils are thoroughly wet and receive precipitation from long-duration storms, as described in Table 6. The soils map for the Macatawa watershed is shown in Figure 19. Where the soil is given a dual hydrogroup classification, A/D for example, the soil type selected for calculating runoff curve numbers is 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 soils maps resolved for 1800, 1978, and 2005 land uses are shown in Figures 20 through 22, respectively. The differences in resolved soil hydrogroups from 1800 to 1978 and 2005, Table 7, are due to agricultural and urban land use transitions and the addition of drains.

Table 6 – Soil Hydrogroups

Hydrologic Soil Group	Infiltration Rate when thoroughly wet	Description
A	High	• Sand • Gravelly sand
B	Moderate	• Moderately fine textured to moderately coarse textured soils
C	Slow	• Moderately fine textured to fine textured soils • Soils with a soil layer that impedes downward movement of water
D	Very Slow	• Clays • Soils with a clay layer near the surface • Soils with a permanent high water table

Table 7 – Areal Extent of Soil Hydrogroups for Entire Watershed

Hydrologic Soil Group	1800 Land Use	1978 Land Use	2005 Land Use
A	16.7%	24.6%	24.6%
B	19.2%	26.5%	26.0%
C	38.9%	40.4%	40.4%
D	24.6%	7.8%	8.3%
Water	0.6%	0.6%	0.6%

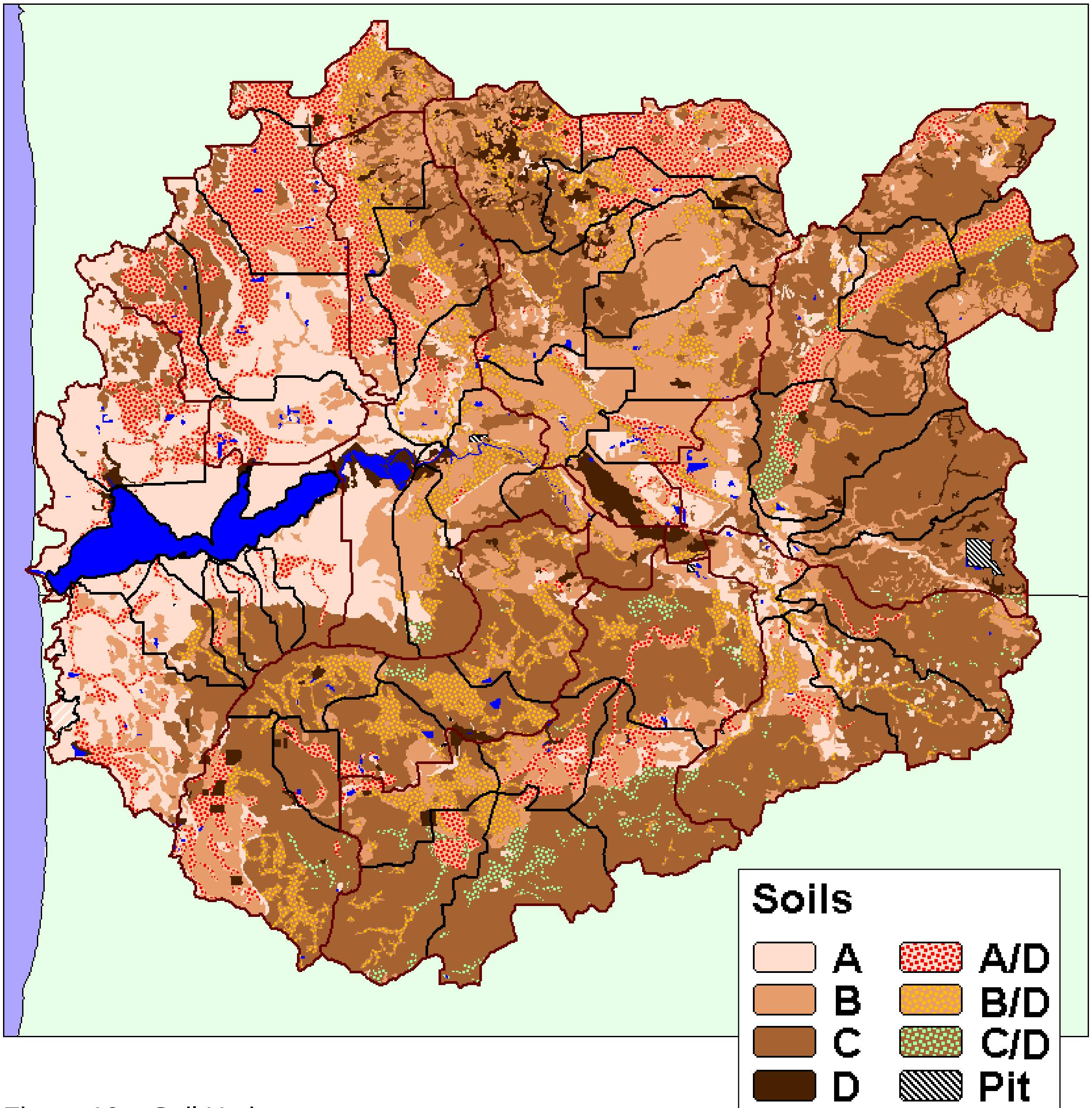


Figure 19 – Soil Hydrogroups

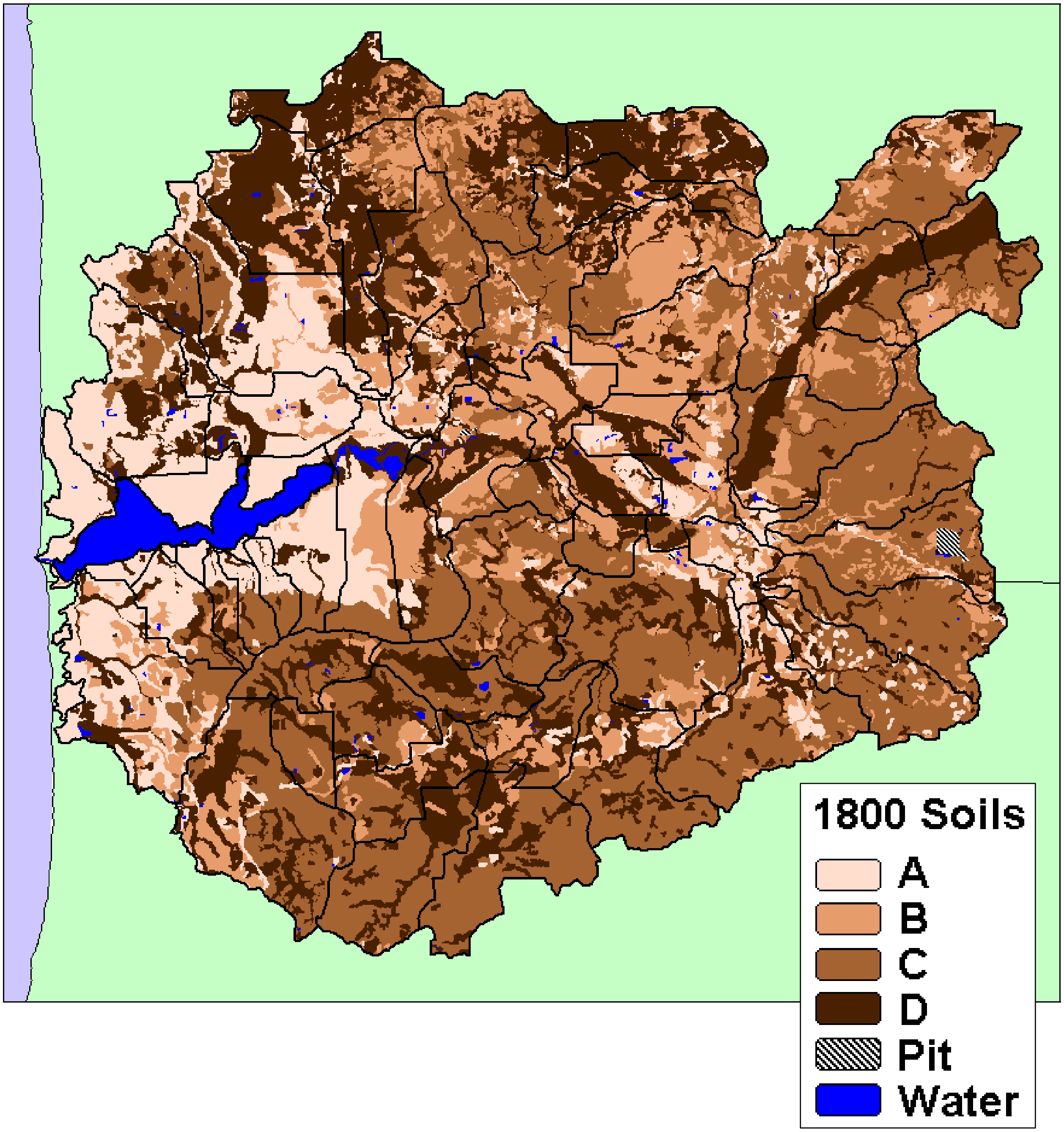


Figure 20 – Soil Hydrogroups, 1800 Land Use

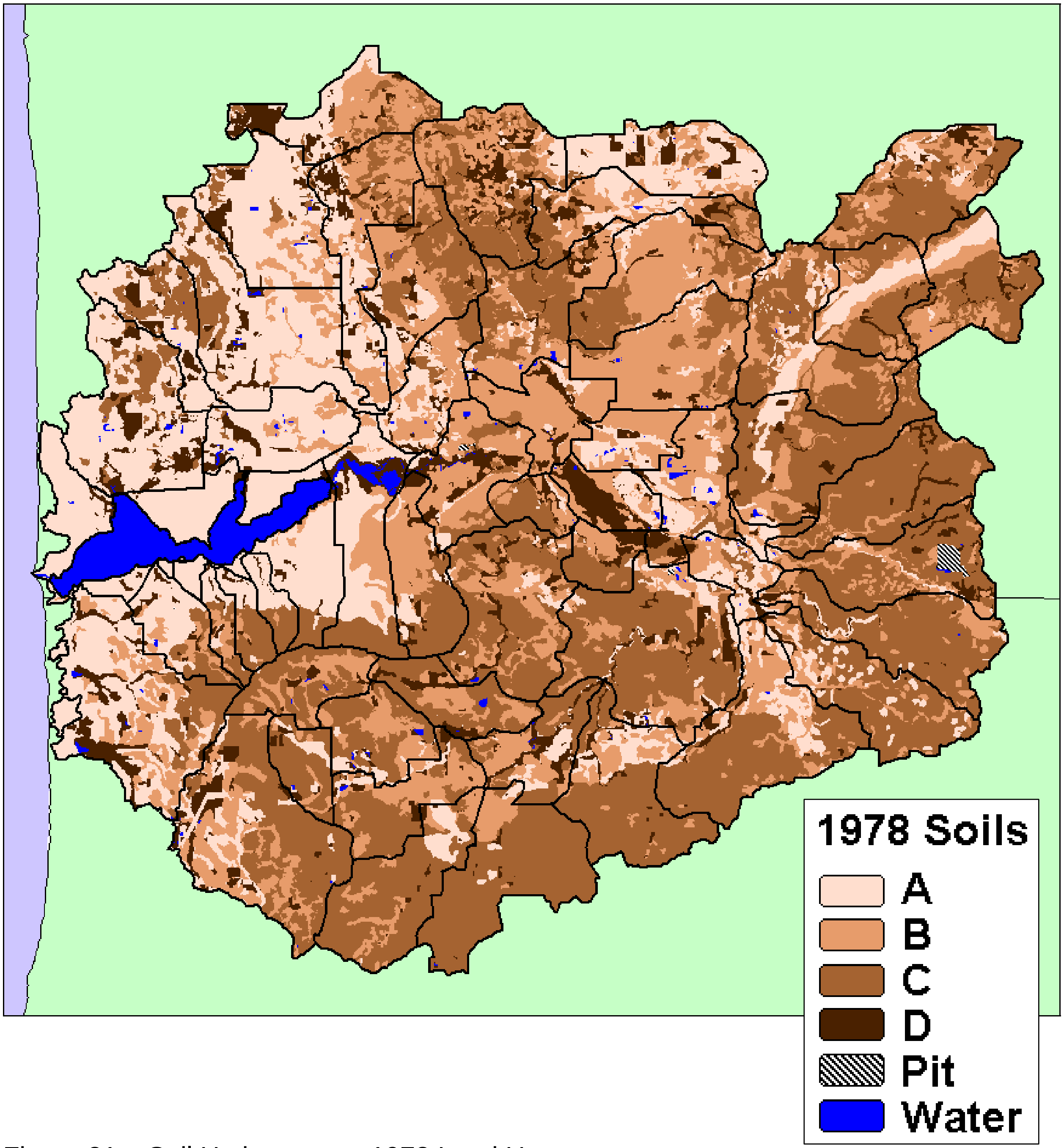


Figure 21 – Soil Hydrogroups, 1978 Land Use

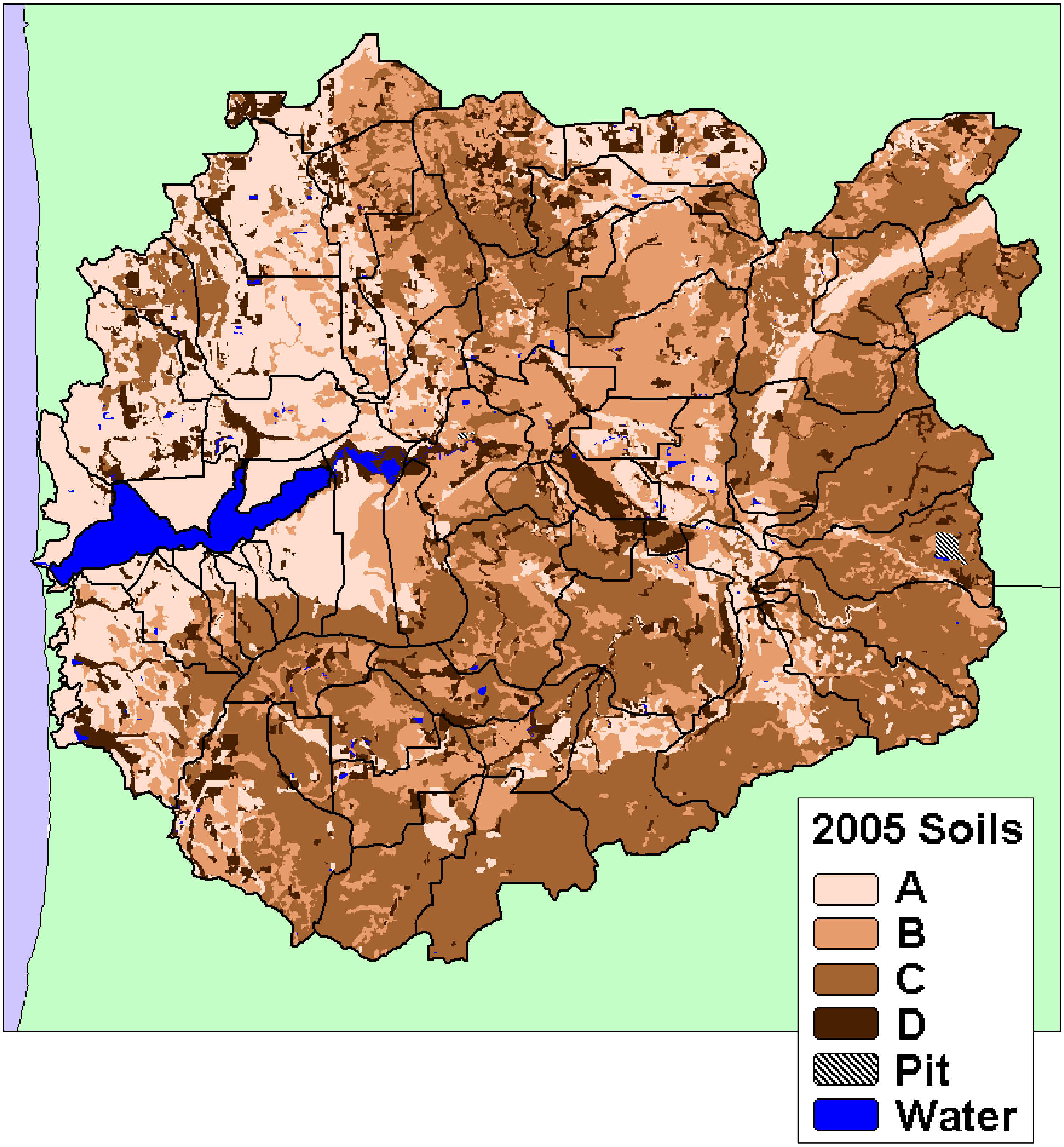
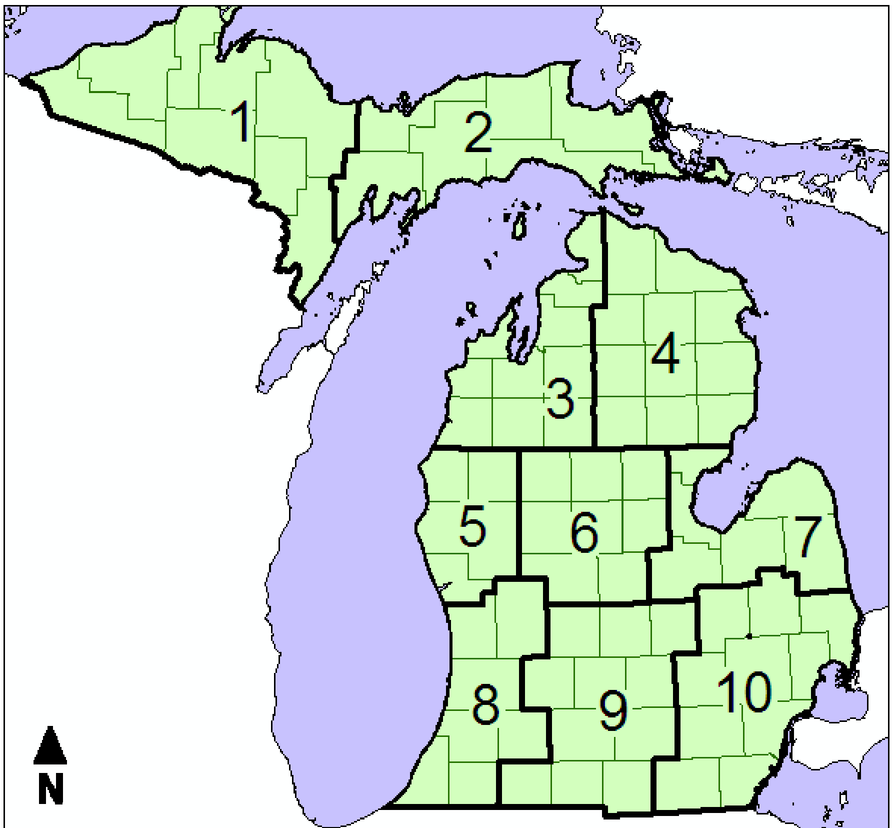


Figure 22 – Soil Hydrogroups, 2005 Land Use

Hydrologic Analysis Parameters

Rainfall

The design rainfall value used in this study is 2.37 inches, corresponding to the 50 percent chance (2-year) 24-hour storm for the watershed, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992. This storm was selected because runoff from the 50 percent chance design storm approximates channel-forming flows assuming the watershed is, and was, a storm-driven system. The Macatawa watershed is in climatic zone 8, Figure 23.



Zone	Rainfall frequencies, 24-hour duration (rainfall in inches)					
	2-year	5-year	10-year	25-year	50-year	100-year
1	2.39	3.00	3.48	4.17	4.73	5.32
2	2.09	2.71	3.19	3.87	4.44	5.03
3	2.09	2.70	3.21	3.89	4.47	5.08
4	2.11	2.62	3.04	3.60	4.06	4.53
5	2.28	3.00	3.60	4.48	5.24	6.07
6	2.27	2.85	3.34	4.15	4.84	5.62
7	2.14	2.65	3.05	3.56	3.97	4.40
8	2.37	3.00	3.52	4.45	5.27	6.15
9	2.42	2.98	3.43	4.09	4.63	5.20
10	2.26	2.75	3.13	3.60	3.98	4.36

Figure 23 – Rainfall Amounts for Michigan's Climatic Zones (Macatawa watershed climatic zones highlighted)

Runoff Curve Numbers

Calculations

Surface runoff volumes were modeled using the runoff curve number technique. 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 technique, as adapted for Michigan, is described in "Computing Flood Discharges For Small Ungaged Watersheds" (Sorrell, 2008).

The runoff curve numbers (CN) were calculated for each land cover and soil complex using GIS technology from the digital land use and soil data shown in Figures 12, 13, 14, 20, 21, and 22. Housing density is a part of the curve number calculations. Average residential lot size was specified as 0.50 acres, except for the Holland and Zeeland Areas. Based on analysis of 2005 aerial photos, average residential lot size was specified as 0.33 acres for subbasins 30, 32, 40, 41, 49, and 54 and 0.25 acres for subbasin 42. Additional details on the GIS method are at www.mi.gov/deqhydrology, GIS category, Calculating Runoff Curve Numbers with GIS.

The runoff volumes were then summed by subbasin. Curve numbers that provide the same runoff volumes were then iteratively calculated for each subbasin in order to calculate peak flows.

Assumptions and Limitations

P/S Test, Weighted Q Method

An assumption of the composite runoff curve number technique is that the entire watershed contributes runoff. The curve number technique documentation is the NRCS's Part 630 Hydrology National Engineering Handbook (NEH). Chapter 10, Section 630-1003 Accuracy, of the NEH states, "The runoff equation generally did reasonably well where the runoff was a substantial fraction of the rainfall, but poorly in cases where the runoff was a small fraction of the rainfall; i.e., the CNs are low or rainfall values are small. Curve numbers were originally developed from annual flood flows from experimental watersheds, and their application to low flows or small flood peak flows is not recommended. (See Hawkins, et al. 1985, for a precise measure of small.)" According to Hawkins, "relative storm size is then proposed to be defined on the ratio P/S, where a "large" storm has P/S>0.46, when 90 percent of all rainstorms will create runoff." P/S is the ratio of precipitation, P, to potential maximum retention, S. When P/S is less than 0.46, runoff volumes and peak flows for smaller events would depend upon the portion of each subbasin contributing runoff, which will vary with the rainfall total and intensity.

For the 50 percent chance storm analyses, nine to fifteen of the Macatawa subbasins do not meet the P/S test, meaning only portions of those subbasins are contributing runoff. Runoff volumes and flows would be underestimated if those subbasins were modeled with composite curve numbers. An improvement is to calculate the runoff from each land cover and soil complex, then sum the runoff volumes. This method is referred to as the weighted Q method in the NEH Chapter 10, which states, “The method of weighted Q always gives the correct result (in terms of the given data), but it requires more work than the weighted-CN method especially when a watershed has many complexes.” The weighted Q method is used to calculate runoff from the 50 percent storm in this study.

Snowmelt or Storms

The modeling assumes that runoff from the 2-year design storm under average watershed conditions approximates bankfull flow. However, if the watershed were a snowmelt-driven system, snowmelt and runoff from frozen ground would most frequently cause bankfull events. Snowmelt-driven systems are usually less flashy than storm-driven systems, because the snow pack supplies a steadier rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, can produce dramatic flow increases. The runoff from the rain and snowmelt also likely occur with saturated or frozen soil conditions, when the ground can absorb or store less water, resulting in more overland flow to surface waters than would occur otherwise. In a storm-driven system, rainfalls during the growing season also generate flood flows.

As detailed in the “Gage Analysis - Snowmelt or Storms” section, the Macatawa watershed has characteristics of both a snowmelt-driven and storm-driven system. Many of the gaged bankfull flows are associated with snowmelt and frozen ground. This hydrologic modeling, however, does not attempt to replicate runoff from snowmelt and rainfall on frozen ground. HSU expects that stream flow from snowmelt and rain-on-snow events would be less sensitive to differences in land cover than indicated in this hydrologic model.

Time of Concentration and Storage Coefficients

Time of concentration, Tc, is the time it takes for water to travel from the hydraulically most distant point in the subbasin to the design point. Times of concentration for each subbasin were calculated using United States Geological Survey (USGS) quadrangles following the methodology described in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008). Times of concentration were not calculated for subbasins 47, 54, and 55, because runoff from these subbasins is collected in storm drains and piped directly to Lake Macatawa. Runoff from subbasin 46 is also conveyed by storm drains and piped to Pine Creek. The Tc for this subbasin is an estimate based on travel time in Pine Creek and estimates of storm drain length and slope.

Storage coefficients, SC, represent temporary storage in ponds, lakes, or swampy areas in each subbasin. Ponding was estimated to be located throughout each subbasin except for subbasins 40, 41, and 48, where it is located near the outlet. Storage Coefficients are initially set equal to the curve numbers then iteratively adjusted to provide a peak flow reduction equal to the ponding adjustment factors shown in Table 8 and detailed in “Computing Flood Discharges For Small Ungaged Watersheds” (Sorrell, 2008).

Table 8 – Ponding Adjustment Factors

ID	Ponding, 1800	Adjustment Factor, 50% Storm	Ponding, 1978	Adjustment Factor, 50% Storm	Ponding, 2005	Adjustment Factor, 50% Storm
1	0.6%	0.870	0.9%	0.840	1.2%	0.820
2	21.2%	0.521	1.0%	0.830	1.1%	0.825
3	32.7%	0.480	1.1%	0.825	1.0%	0.830
4	10.3%	0.579	2.1%	0.770	3.2%	0.695
5	20.1%	0.527	0.6%	0.870	1.5%	0.805
6	0.0%	1.000	0.1%	1.000	0.0%	1.000
7	0.2%	0.940	0.5%	0.880	0.3%	0.920
8	0.2%	0.940	0.0%	1.000	0.4%	0.900
9	10.0%	0.580	2.2%	0.760	3.4%	0.688
10	0.0%	1.000	0.4%	0.900	0.2%	0.940
11	0.0%	1.000	0.2%	0.940	0.2%	0.940
12	0.0%	1.000	1.2%	0.820	0.9%	0.840
13	0.0%	1.000	0.4%	0.900	1.2%	0.820
14	22.1%	0.518	0.5%	0.880	0.2%	0.940
15	17.4%	0.543	0.4%	0.900	0.2%	0.940
16	41.6%	0.458	3.1%	0.700	3.2%	0.695
17	56.9%	0.428	0.7%	0.860	0.7%	0.860
18	18.5%	0.538	1.4%	0.810	0.5%	0.880
19	3.1%	0.700	1.3%	0.815	1.2%	0.820
20	8.7%	0.596	2.3%	0.750	2.3%	0.750
21	1.1%	0.825	1.5%	0.805	1.1%	0.825
22	25.2%	0.505	1.0%	0.830	1.0%	0.830
23	29.3%	0.491	3.4%	0.688	3.7%	0.681
24	26.7%	0.500	3.2%	0.695	2.8%	0.715
25	1.2%	0.820	1.5%	0.805	1.3%	0.815
26	48.9%	0.442	0.1%	1.000	0.8%	0.850
27	24.6%	0.507	0.1%	1.000	0.1%	1.000
28	56.1%	0.429	0.2%	0.940	0.7%	0.860
29	9.6%	0.585	0.0%	1.000	0.1%	1.000
30	0.0%	1.000	0.0%	1.000	0.2%	0.940
31	3.6%	0.683	1.3%	0.815	2.8%	0.715
32	29.1%	0.491	1.3%	0.815	3.3%	0.690
33	4.6%	0.659	0.2%	0.940	2.8%	0.715
34	3.7%	0.681	0.3%	0.920	1.3%	0.815
35	3.3%	0.690	1.4%	0.810	0.9%	0.840
36	6.6%	0.622	0.0%	1.000	0.6%	0.870
37	29.2%	0.491	1.0%	0.830	2.1%	0.770
38	12.2%	0.569	0.1%	1.000	0.8%	0.850
39	45.5%	0.449	0.1%	1.000	1.2%	0.820
40	19.7%	0.482	1.6%	0.764	2.2%	0.720
41	3.8%	0.625	1.6%	0.764	1.6%	0.764
42	30.7%	0.486	1.8%	0.790	1.2%	0.820
43	43.8%	0.453	0.5%	0.880	2.7%	0.720
44	18.8%	0.536	0.6%	0.870	1.1%	0.825
45	7.7%	0.608	0.1%	1.000	2.1%	0.770
46	10.4%	0.578	1.2%	0.820	3.2%	0.695
47	39.2%	NA	10.7%	NA	10.1%	NA
48	6.1%	0.577	1.1%	0.794	2.6%	0.684
49	0.0%	1.000	0.4%	0.900	0.6%	0.870
50	0.0%	1.000	0.7%	0.860	0.7%	0.860
51	0.0%	1.000	0.6%	0.870	0.1%	1.000
52	3.3%	0.690	0.7%	0.860	1.5%	0.805
53	4.0%	0.674	2.1%	0.770	2.5%	0.730
54	14.3%	NA	0.8%	NA	0.8%	NA
55	2.1%	NA	1.8%	NA	1.7%	NA

Routing

Storm flows from each subbasin were routed through the hydrologic model using 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. Initial lag values for each reach were calculated using USGS quadrangles and are listed in Appendix A. Lag values were adjusted for wave celerity, which accounts for the flood wave moving faster than the actual flood water. The celerity value of 0.71 is based on USGS gage data for the storm of June 19 – 20, 2009, Figure 24. Figure 25 illustrates the observed flow compared to the modeled flow with no celerity adjustment. Figure 26 illustrates the observed flow compared to the modeled flow with optimized celerity adjustment. The hourly rainfall data is from Hudsonville's Michigan Celery Cooperative in the Michigan Automated Weather Network (MAWN), Figure 54. The weather station reported 3.03 inches for the June 19 – 20 storm event, a total which is apparently well below what portions of the Macatawa watershed received. Because the reported rainfall was reportedly more intense for portions of the Macatawa watershed and because 15-Minute gage flow data were not available from 6/20/2009 2:00 to 14:45, the model calibration was only for timing, not runoff volume or peak flow.

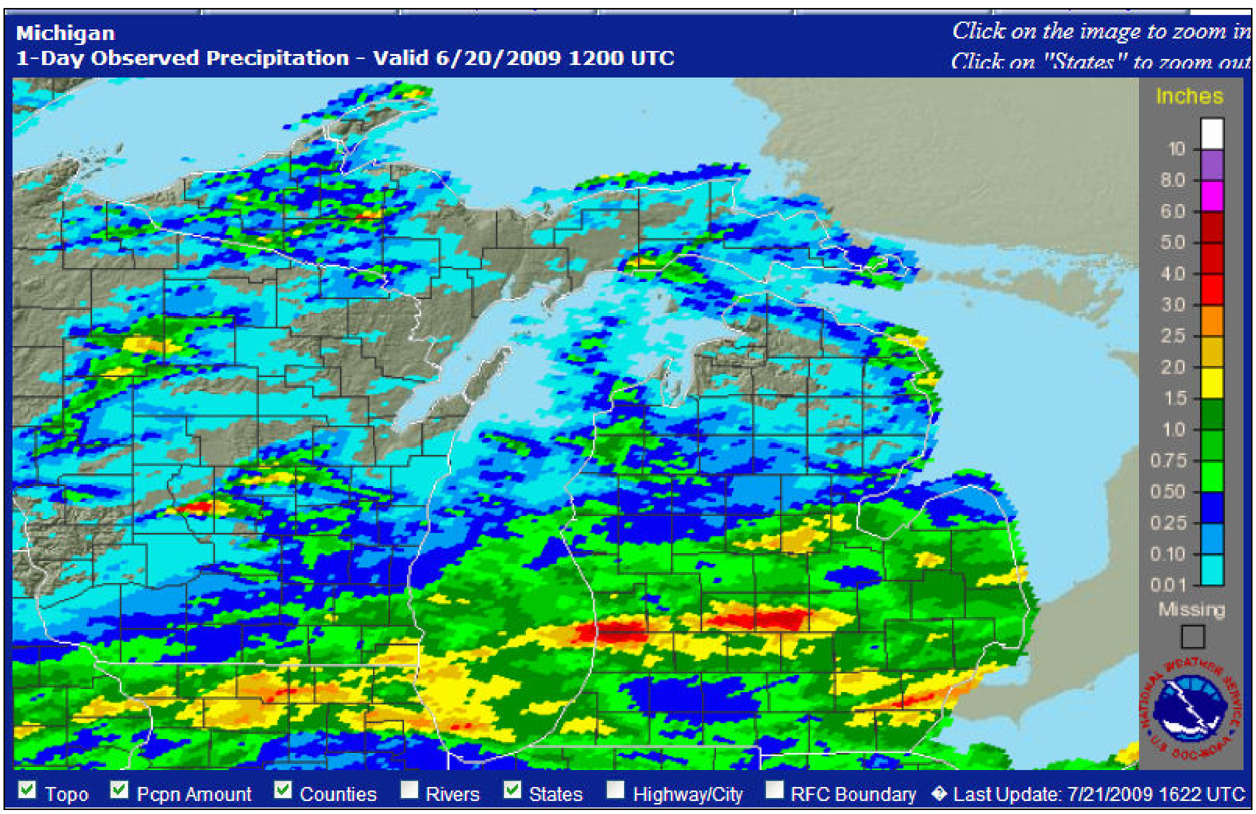


Figure 24 – Radar Image of June 20, 2009, Michigan Rainfall (http://water.weather.gov/)

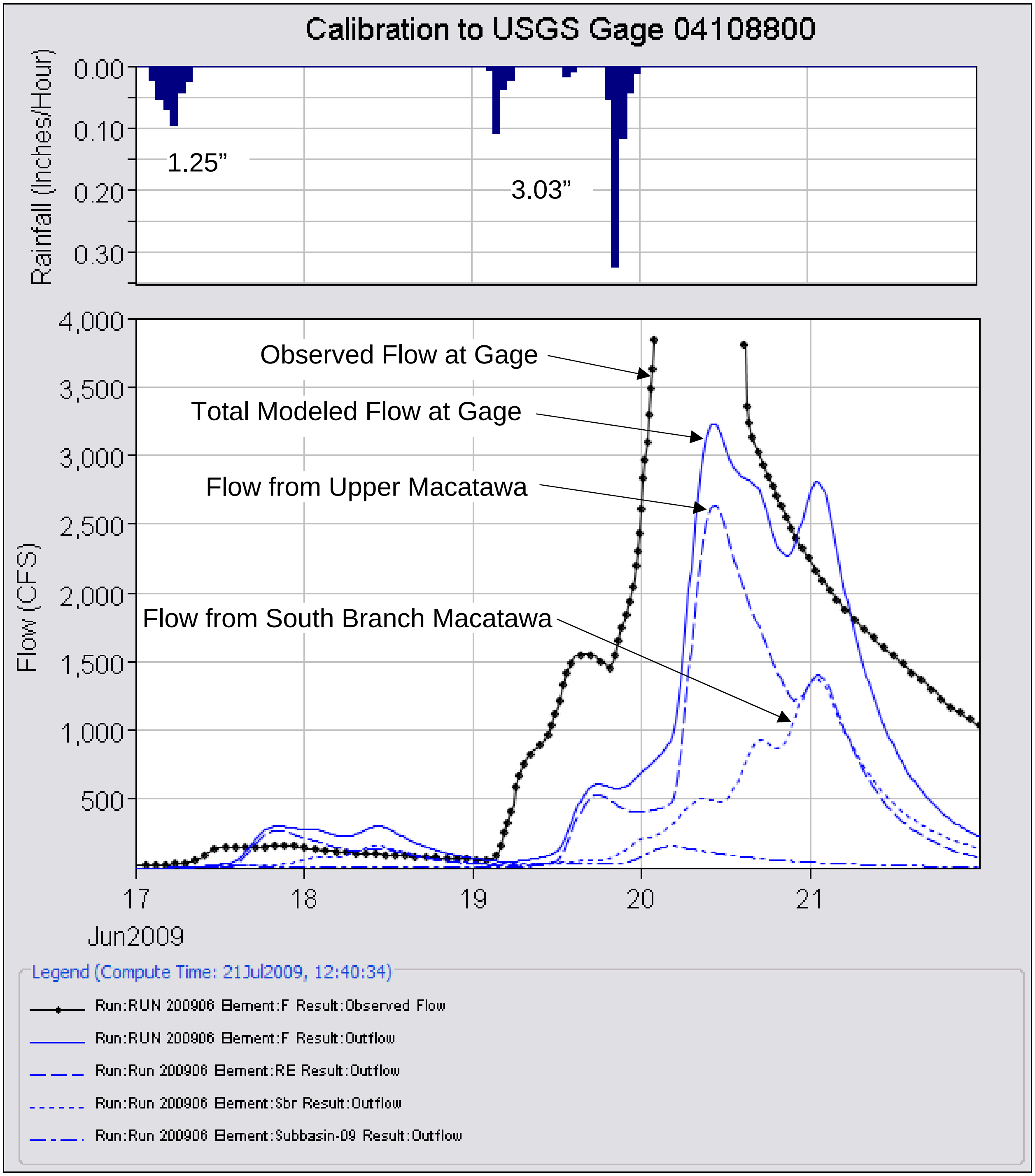


Figure 25 – Pre-calibration Hydrographs

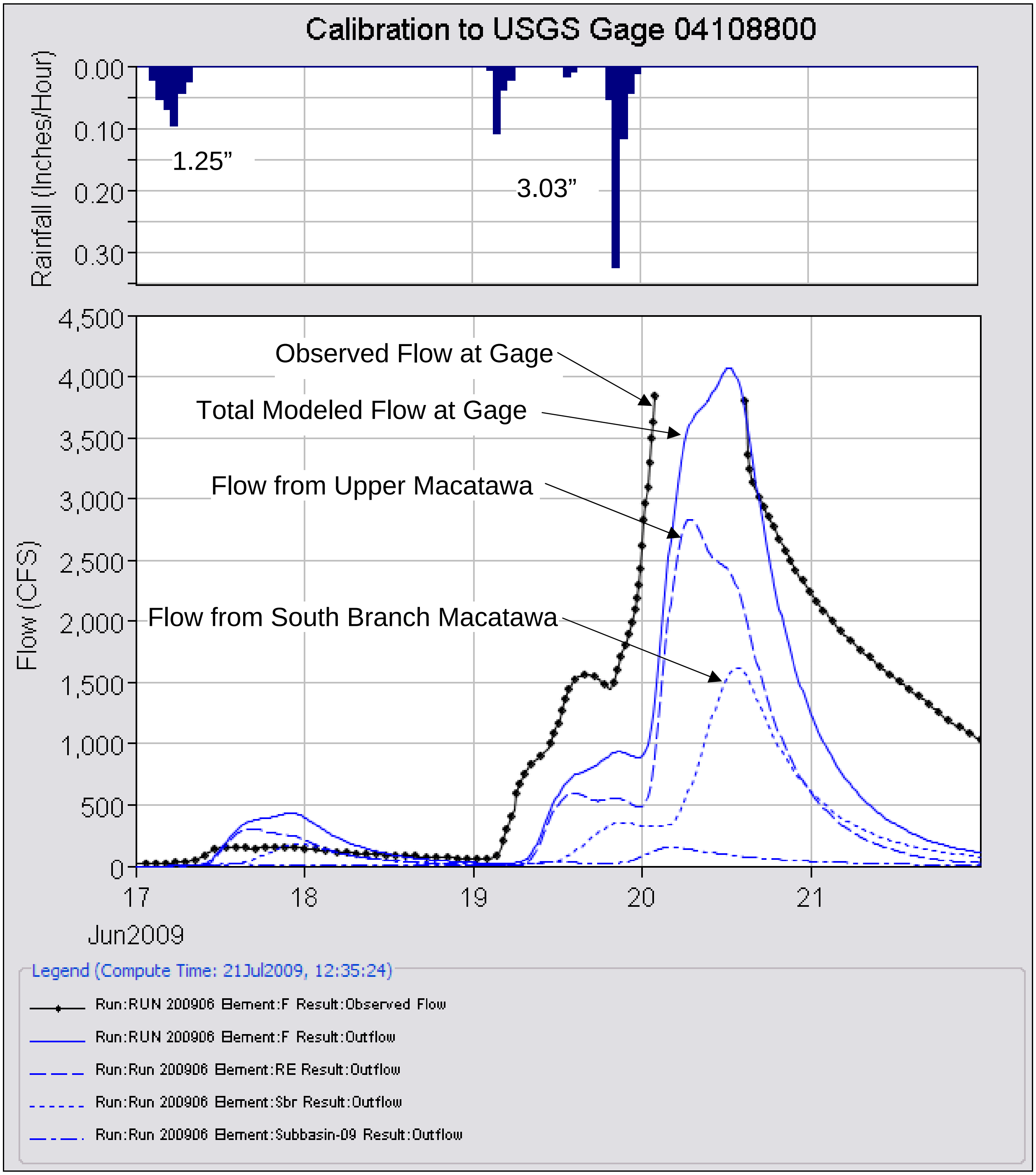


Figure 26 –Calibrated Hydrographs

Results

For this analysis, Lake Macatawa is considered hydraulically equal to Lake Michigan. Further, we assume Lake Macatawa begins where the flood insurance study begins to show an increase in predicted flood elevations, which is 4,000 feet upstream of Butternut Drive/River Avenue. This is approximately equivalent to Windmill Island. Streams and drains flowing directly to Lake Macatawa are also included in this Macatawa watershed hydrologic study.

Subbasins 47, 54, and 55 have no apparent surface drainage, meaning that runoff from these subbasins is collected in storm drains and piped directly to Lake Macatawa. For these subbasins, the discussions of channel protection do not apply. From a NPS perspective, treatment of the runoff to improve water quality would be the primary issue.

Runoff Volume per Area Analysis

Runoff volumes from each subbasin were calculated for 1800, 1978, and 2005 and the 50 percent chance (2-year), 24-hour storm. For comparison, the calculated runoff volumes are divided by the drainage areas. The units are acre-inches per acre (volume per area), or simply inches. Changes in runoff volume per area from 1800 to 1978 and 1978 to 2005 are shown in Figures 30 and 31 and are tabulated in Tables 9 and 10.

The results highlight subbasins that generate a higher proportion of runoff due to soils and land use. Either current runoff volume per area or runoff volume change per area can be used to help select critical areas. Higher values can identify areas that may need rehabilitation activities. Lower values can identify sensitive areas to be protected.

From 1800 to 1978, three subbasins had decreases. Of the 52 subbasins with increases, 39 had increases of over 0.25 inches, with four of those increasing by over 0.50 inches. From 1978 to 2005, fourteen subbasins had decreases. Of the 41 subbasins with increases, three had increases of over 0.25 inches. Refer to Table 10 for additional information.

In terms of total volume, the watershed would have generated 4,070 acre-feet of runoff from a 2.37 inch rainfall in 1800. In 1978, it would have generated 6,710 acre-feet, an increase of 2,640 acre-feet or 65 percent. In 2005, it would have generated 7,280 acre-feet, an increase of 570 acre-feet or 8 percent from 1978. The increased channel-forming flow runoff volume, and likely peak flow, has undoubtedly resulted in channel enlargement as the Macatawa River and its tributaries adapt to the higher flows. Refer to Table 9 for additional information. Table 9 includes runoff from Lake Macatawa itself for comparison.

Future hydrologic changes can further impact stream flows, water quality, channel erosion, and flooding. These changes can be moderated with effective stormwater management techniques such as:

- treatment of the “first flush” runoff
- wetland protection
- retention and infiltration of excess runoff
- low impact development techniques
- 24-hour extended detention of 1-year flows
- properly designed detention of runoff from low probability storms

Refer to the Stream Morphology and Stormwater Management sections for more detail.

Table 9 – Runoff Volume Summary

Description	Scenario	Volume		Increase	
		(acre-feet)	(gallons)	1800 to 1978	1978 to 2005
Macatawa River	1800	3,270	1,066,000,000	69%	6%
	1978	5,530	1,802,000,000		
	2005	5,880	1,917,000,000		
Other Tributaries to Lake Macatawa	1800	627	204,000,000	21%	23%
	1978	756	246,000,000		
	2005	931	303,000,000		
Direct Drainage to Lake Macatawa	1800	175	57,000,000	141%	10%
	1978	422	138,000,000		
	2005	463	151,000,000		
Total to Lake Macatawa	1800	4,070	1,327,000,000	65%	8%
	1978	6,710	2,186,000,000		
	2005	7,280	2,371,000,000		
Lake Macatawa	All	356	116,000,000	NA	NA
Total including Lake Macatawa	1800	4,430	1,443,000,000	60%	8%
	1978	7,060	2,302,000,000		
	2005	7,630	2,487,000,000		

Table 10 – Runoff Volume per Area by Subbasin

ID	Subbasin	Volume/Area (inches)			Change (inches)	
		1800	1978	2005	1800 - 1978	1978 - 2005
1	Beaver Dam Drain to Macatawa River	0.41	0.79	0.79	0.38	0.00
2	Macatawa River to Beaver Dam Drain	0.48	0.81	0.75	0.33	-0.06
3	Macatawa River at 72nd Avenue	0.53	0.72	0.69	0.20	-0.04
4	Macatawa River at I-196 Overpass	0.40	0.85	0.86	0.45	0.01
5	Macatawa River to Hunderman Creek	0.49	0.87	0.87	0.38	0.00
6	Big Creek to Hunderman Creek	0.47	0.96	0.95	0.49	-0.01
7	Hunderman Creek to Big Creek	0.44	0.87	0.87	0.43	0.00
8	Hunderman Creek to Macatawa River	0.19	0.53	0.56	0.34	0.03
9	Macatawa River to South Branch	0.37	0.71	0.73	0.34	0.02
10	Unnamed tributary to Peters Drain	0.45	0.83	0.84	0.39	0.01
11	Peters Drain	0.43	0.79	0.79	0.35	0.00
12	Unnamed tributary to Peters Creek	0.47	0.91	0.91	0.44	0.00
13	Peters Creek to Macatawa River	0.21	0.39	0.40	0.18	0.01
14	Kleinheksel Drain to South Branch	0.55	0.96	0.96	0.41	0.00
15	Jaarda Drain to South Branch	0.56	0.89	0.89	0.33	0.00
16	South Branch Macatawa River to Jaarda Drain	0.58	0.78	0.79	0.20	0.00
17	South Branch Macatawa River to unnamed tributary near 146th	0.64	0.73	0.75	0.09	0.02
18	East Fillmore Drain (including Eskes Drain)	0.51	0.83	0.83	0.32	0.00
19	South Branch Macatawa River to Macatawa River	0.49	0.81	0.80	0.33	-0.01
20	North Branch Macatawa River to Den Bleyker Drain	0.50	0.79	0.79	0.29	0.00
21	Vanderbie Drain and Rotman Drain	0.53	0.87	0.89	0.34	0.02
22	North Branch Macatawa River to Den Bleyker Drain	0.58	0.96	1.12	0.38	0.16
23	Den Bleyker Drain	0.58	0.86	1.03	0.28	0.17
24	North Branch Macatawa River at M-40	0.63	0.97	1.13	0.34	0.16
25	North Branch Macatawa River to Macatawa River	0.48	0.86	0.92	0.38	0.06
26	Bosch and Hulst Drain at 104th Avenue	0.57	0.43	0.48	-0.14	0.05
27	Bosch and Hulst Drain to Noordeloos Creek	0.52	0.83	0.82	0.31	-0.01
28	Tributary to Bosch and Hulst Drain to Noordeloos Creek	0.61	0.68	0.71	0.08	0.03
29	Hunters Creek to Brower Drain	0.35	0.71	0.73	0.36	0.02
30	Brower Drain to Hunters Creek	0.30	0.84	1.09	0.53	0.25
31	Noordeloos Creek to Drain #52	0.42	0.75	0.77	0.32	0.02
32	Cedar Drain to Noordeloos Creek	0.36	0.70	0.89	0.33	0.19
33	Drain #4 and 43 to Noordeloos Creek	0.44	0.86	0.93	0.42	0.06
34	Noordeloos Creek to Macatawa River	0.32	0.67	0.78	0.35	0.11
35	Macatawa River to North Branch	0.51	0.95	1.00	0.44	0.05
36	Macatawa River to Noordeloos Creek	0.48	0.73	0.76	0.26	0.03
37	North Holland Creek to Drain #40	0.52	0.60	0.84	0.08	0.24
38	Drain #15 and 17 to Drain #40	0.51	0.74	0.94	0.23	0.20
39	Drain #40 to Macatawa River	0.51	0.62	1.01	0.11	0.39
40	Macatawa River to Windmill Island	0.45	0.98	1.17	0.52	0.20
41	Maplewood Intercounty Drain to Macatawa River	0.39	1.02	1.19	0.63	0.17
42	Troost and Boven Dam Drains to Pine Creek/Harlem Drain	0.58	0.61	0.63	0.03	0.02
43	Pine Creek/Harlem Drain at Quincy St.	0.60	0.25	0.43	-0.35	0.18
44	Pine Creek/Harlem Drain to Drain #37	0.33	0.42	0.61	0.09	0.20
45	Drain #37 to Pine Creek/Harlem Drain	0.46	0.35	0.41	-0.11	0.06
46	Pine Creek/Harlem Drain to Lake Macatawa	0.24	0.52	0.74	0.29	0.21
47	Macatawa River/Lake Macatawa	0.62	1.11	1.18	0.49	0.06
48	Winstrom Creek and Drains #20A, 23, 53 to Lake Macatawa	0.29	0.38	0.49	0.08	0.11
49	Old Lela Drain to Lake Macatawa	0.28	0.77	0.89	0.49	0.12
50	Weller Drain to Lake Macatawa	0.38	0.80	0.76	0.42	-0.04
51	Arbor Creek to Lake Macatawa	0.41	0.74	0.74	0.34	0.00
52	Ottogan Intercounty Drain to Lake Macatawa	0.28	0.52	0.51	0.24	-0.01
53	Kelly Lake Drain to Lake Macatawa	0.24	0.39	0.41	0.15	0.02
54	East Lake Macatawa drainage (does not include lake)	0.24	0.88	0.95	0.64	0.07
55	West Lake Macatawa drainage (does not include lake)	0.10	0.38	0.49	0.28	0.10
	Average	0.44	0.74	0.80	0.30	0.07
	Minimum	0.10	0.25	0.40	-0.35	-0.06
	Maximum	0.64	1.11	1.19	0.64	0.39

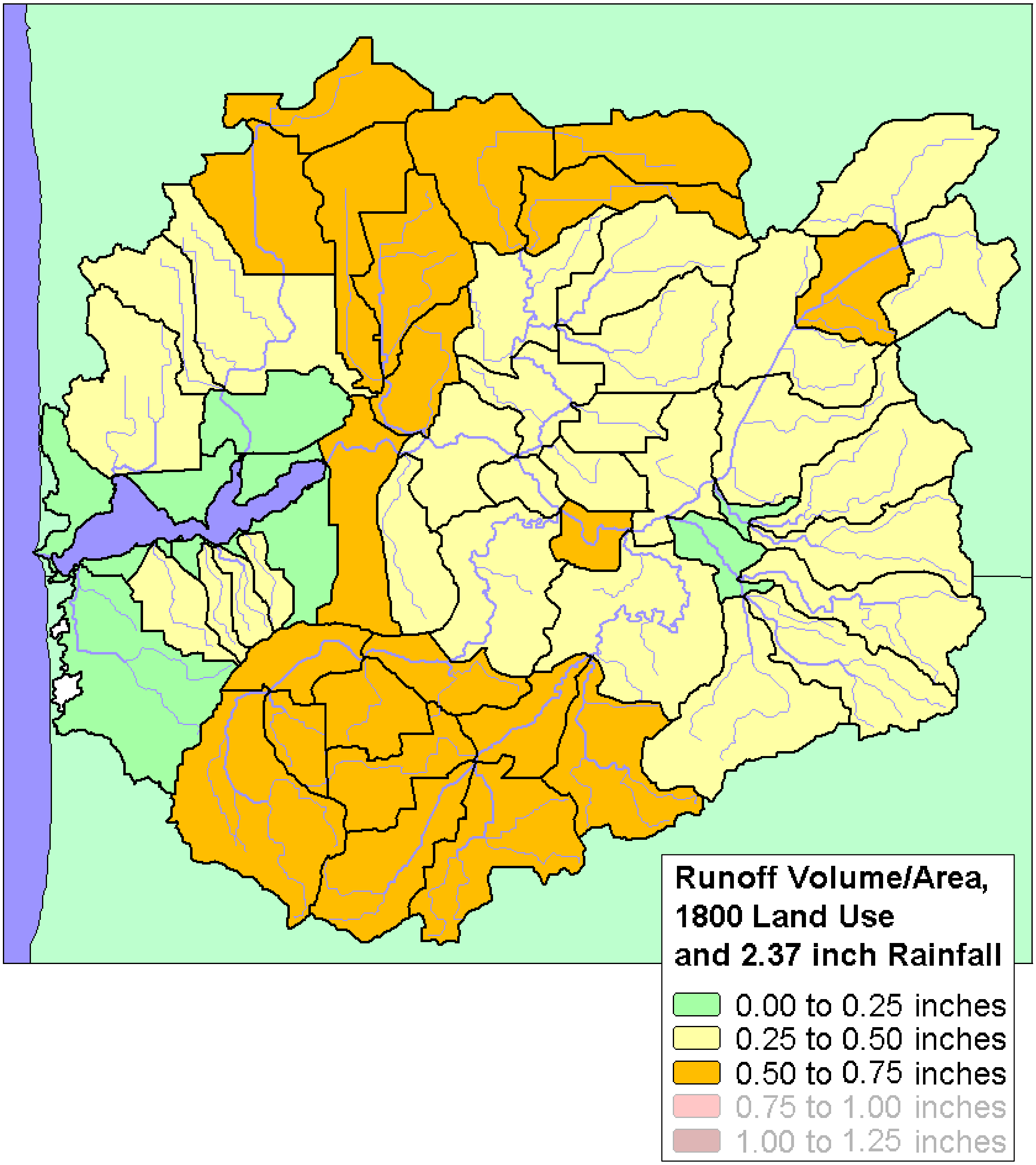


Figure 27 – Runoff Volume/Drainage Area, 1800 Land Use

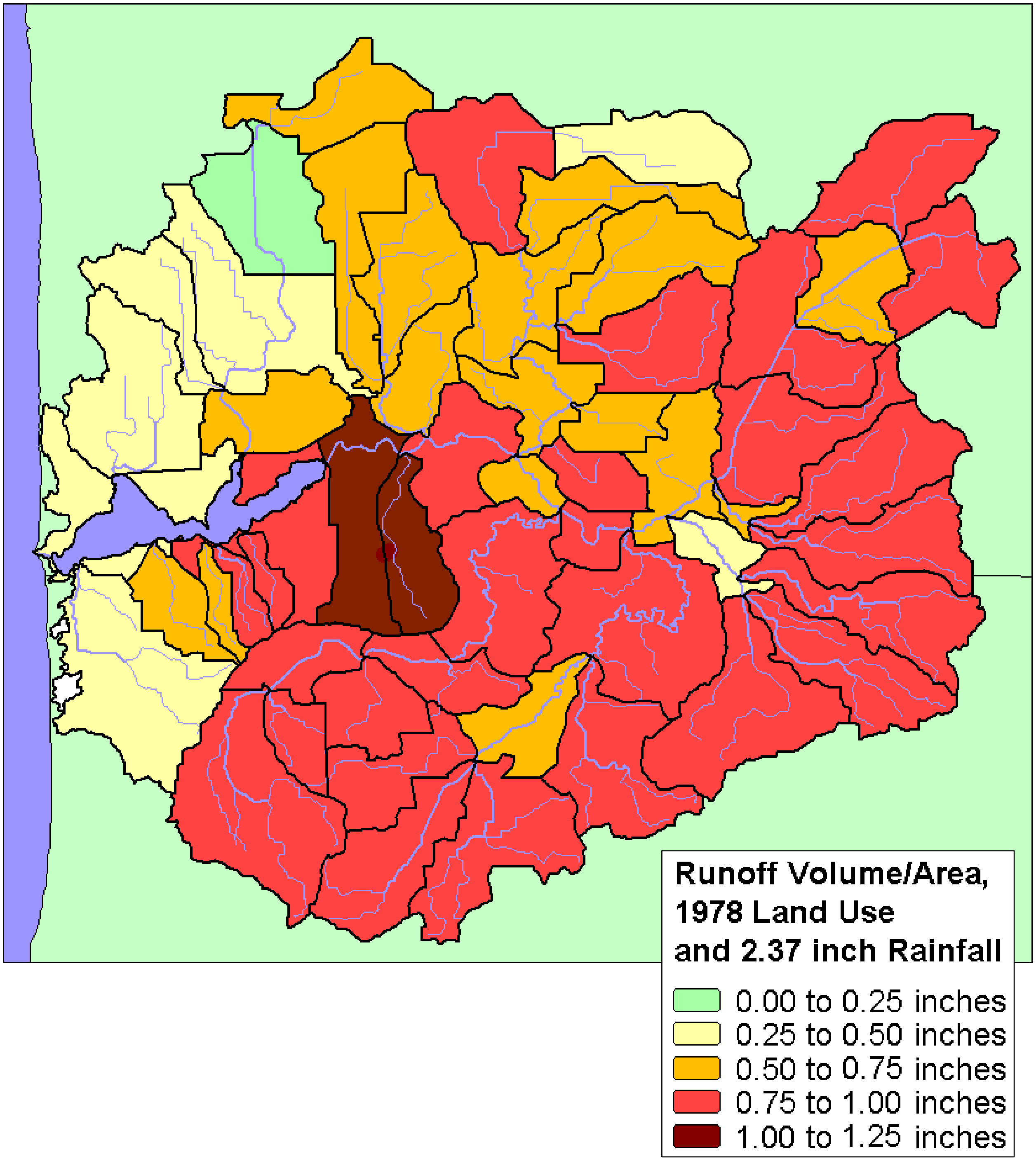


Figure 28 – Runoff Volume/Drainage Area, 1978 Land Use

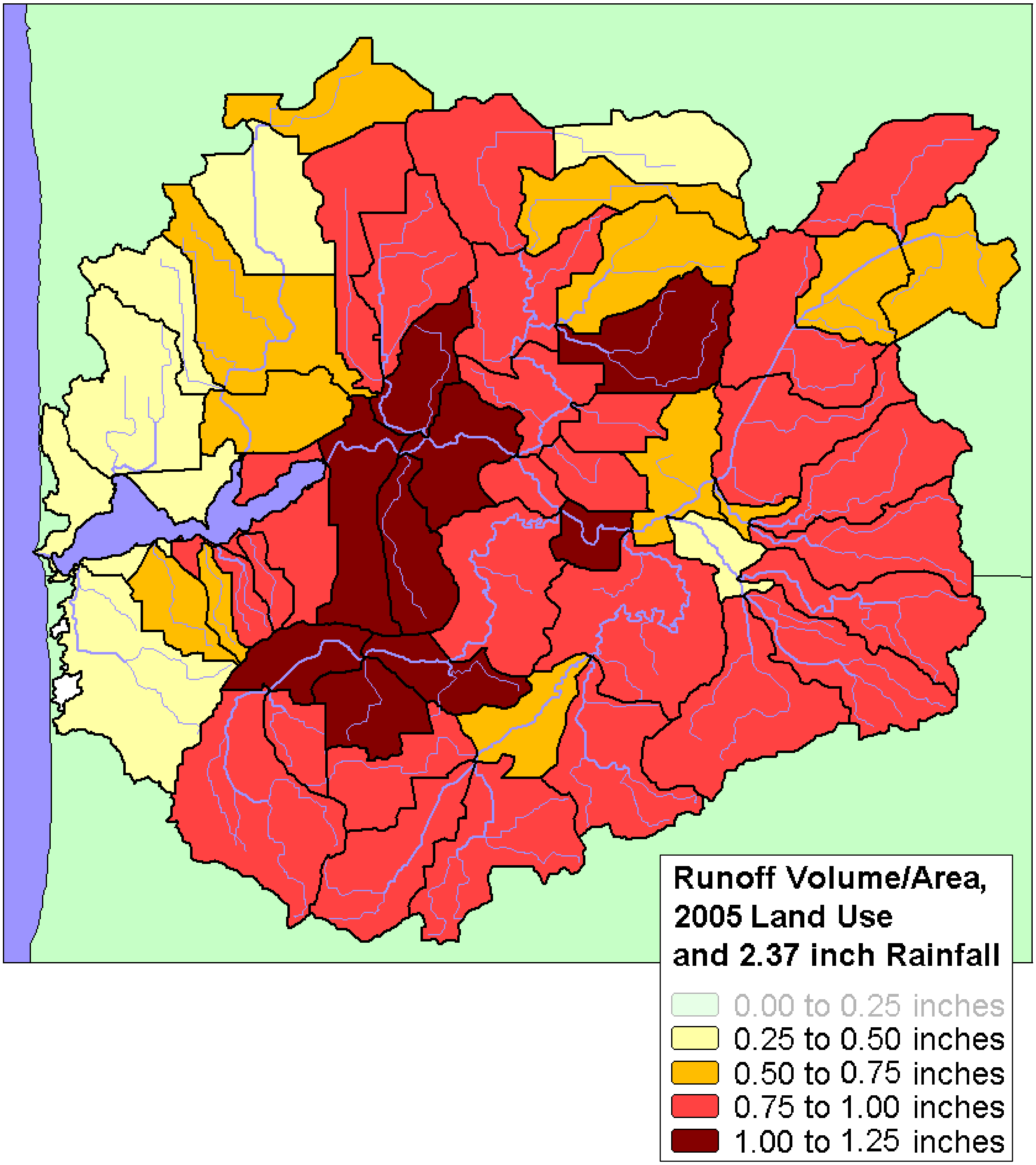


Figure 29 – Runoff Volume/Drainage Area, 2005 Land Use

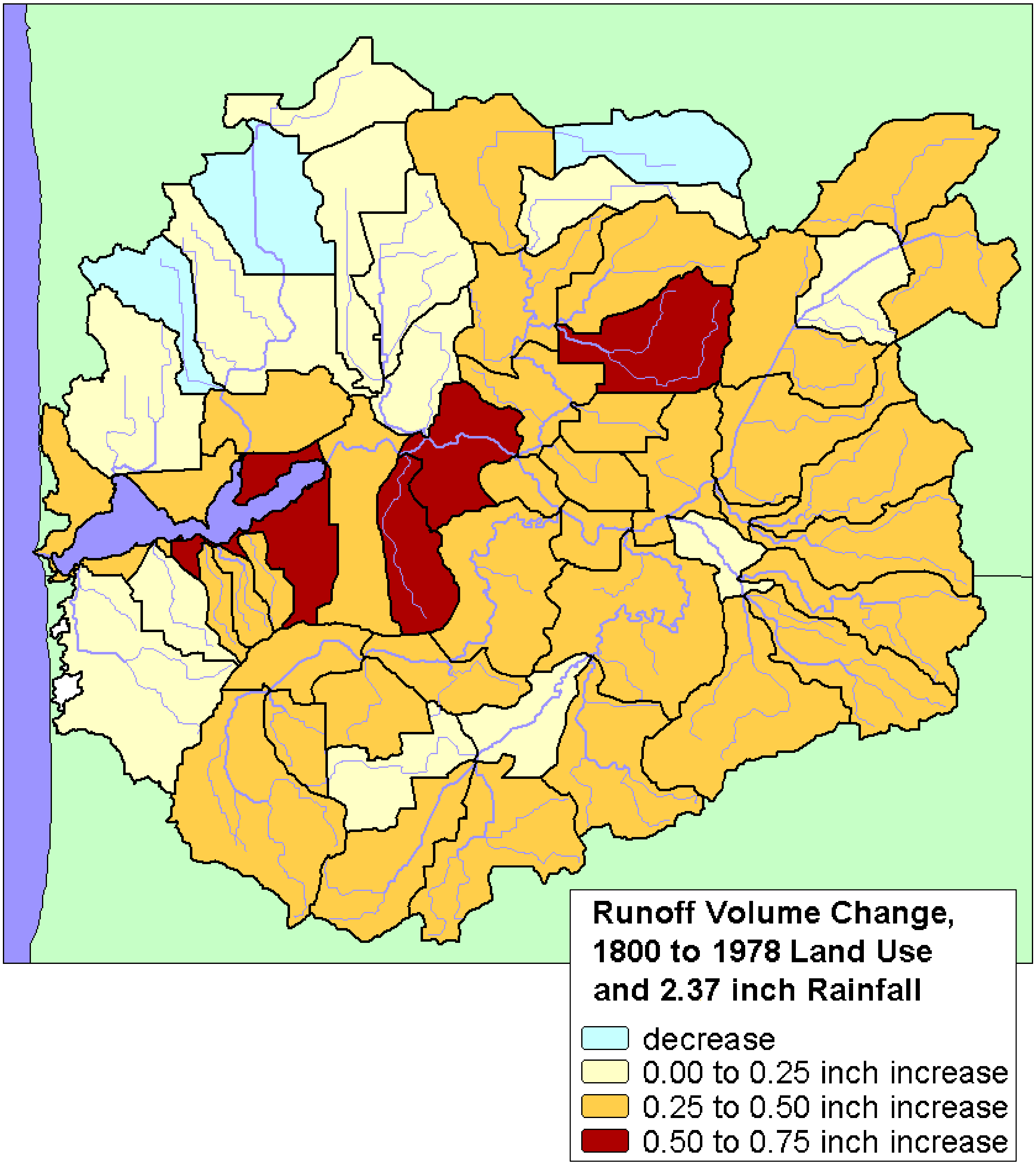


Figure 30 – Change in Runoff Volume/Drainage Area, 1800 to 1978 Land Use

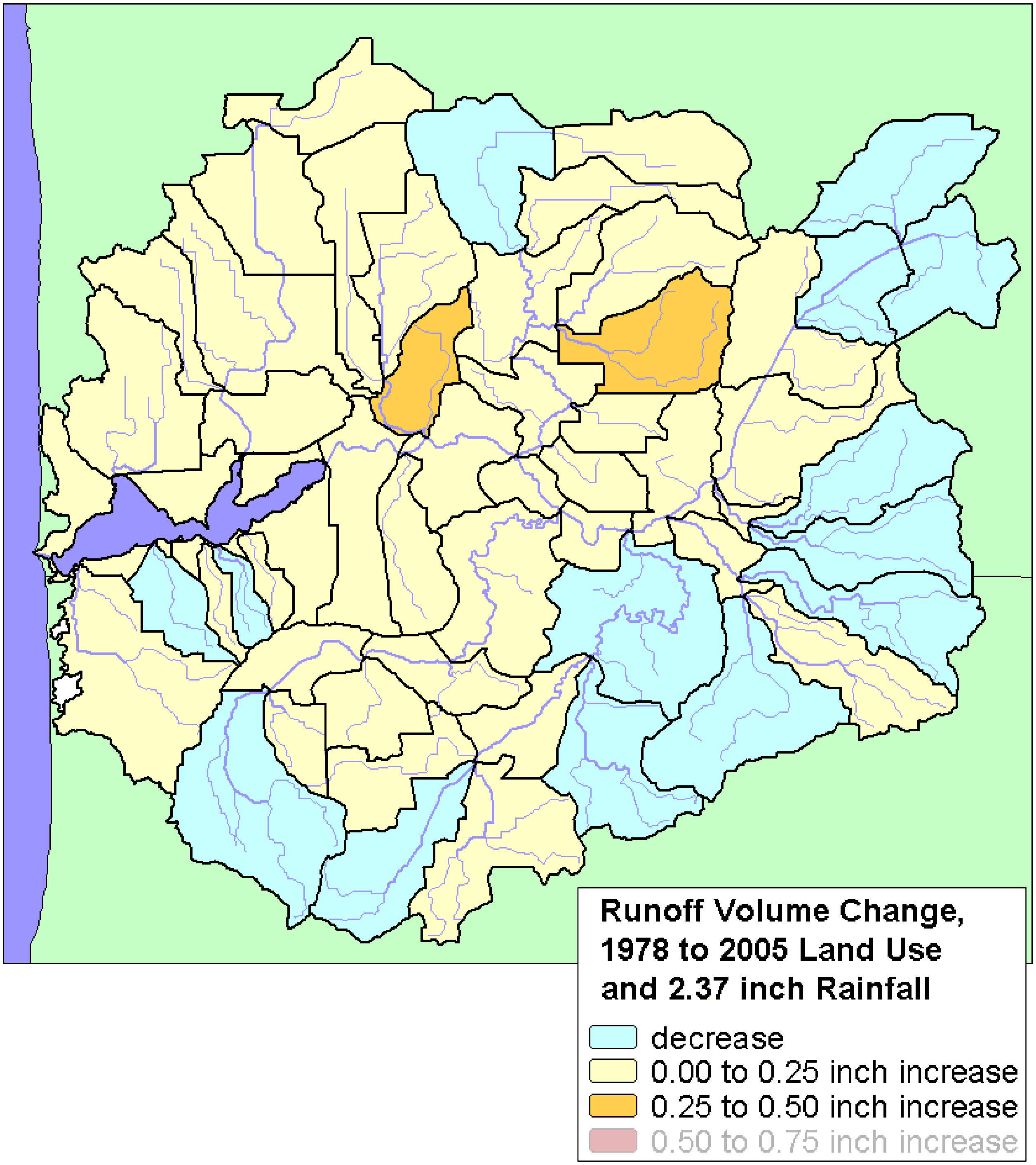


Figure 31 – Change in Runoff Volume/Drainage Area, 1978 to 2005 Land Use

Peak Flood Flow Yield Analysis

The preceding runoff volume analysis accounts only for land use and soils. Peak flood flow yield analysis adds runoff storage, or ponding, and the time it takes for runoff to flow through the subbasin's drainage network. Peak flood flow yield, which is the peak flow divided by the drainage area, is therefore a more complete measure of the hydrologic responsiveness of each subbasin. The hydrologic responsiveness of a subbasin could be thought of as the flashiness of each subbasin. For headwater subbasins, it would be based on measurable peak flow at the subbasin outlet. For other subbasins, it is the subbasin's contribution to stream flow through the subbasin.

Peak flood flow yields are intended to provide a measure of relative subbasin hydrologic responsiveness. They cannot be used to calculate peak flows for any portion of a subbasin.

To ensure that yield values are comparable, subbasins are similarly sized, and a confidence range is provided based on the drainage area ratio equation used by HSU. The equation is $Q_2 = Q_1*(A_2/A_1)^{0.89}$. The confidence range adjusts each yield based on the smallest and largest subbasins in the study.

Graphs of the peak flood flow yields and confidence intervals for each subbasin for the 1800, 1978, and 2005 scenarios are shown in Figure 32. Figures 33 through 35 are maps of the same data using a consistent legend, in cubic feet per second per acre (cfs/acre), to group the data.

Peak flood flow yield changes from 1800 to 1978 and 1978 to 2005 are shown in Figures 36 and 37 and tabulated in Table 11. As with the runoff volume per area analysis, even though the results are based on one specific storm, the overall trends would be similar for larger storms. Since all scenarios use the same time of concentration values, changes in peak flood flow yields do not reflect any changes in drainage efficiency that may have occurred.

Either peak flood flow yields or runoff volume per area can be used to help select critical areas. Lower values can identify sensitive areas to be protected. Higher values can identify areas that need rehabilitation activities.

Table 11 – Peak Flood Flow Yield by Subbasin

ID	Subbasin	Yield (cfs/acre)*			Change (percent)	
		1800	1978	2005	1800 - 1978	1978 - 2005
1	Beaver Dam Drain to Macatawa River	0.027	0.054	0.053	103%	-2%
2	Macatawa River to Beaver Dam Drain	0.022	0.065	0.059	197%	-9%
3	Macatawa River at 72nd Avenue	0.018	0.044	0.042	147%	-5%
4	Macatawa River at I-196 Overpass	0.018	0.056	0.051	212%	-9%
5	Macatawa River to Hunderman Creek	0.026	0.086	0.080	229%	-7%
6	Big Creek to Hunderman Creek	0.032	0.071	0.071	122%	-1%
7	Hunderman Creek to Big Creek	0.031	0.063	0.066	105%	4%
8	Hunderman Creek to Macatawa River	0.019	0.067	0.063	259%	-6%
9	Macatawa River to South Branch	0.013	0.034	0.032	166%	-7%
10	Unnamed tributary to Peters Drain	0.033	0.060	0.063	81%	5%
11	Peters Drain	0.031	0.058	0.058	84%	0%
12	Unnamed tributary to Peters Creek	0.026	0.043	0.044	67%	2%
13	Peters Creek to Macatawa River	0.017	0.029	0.027	75%	-6%
14	Kleinheksel Drain to South Branch	0.018	0.057	0.061	215%	7%
15	Jaarda Drain to South Branch	0.021	0.059	0.062	178%	4%
16	South Branch Macatawa River to Jaarda Drain	0.018	0.038	0.038	114%	0%
17	South Branch Macatawa River to unnamed tributary near 146th	0.020	0.046	0.048	134%	3%
18	East Fillmore Drain (including Eskes Drain)	0.020	0.052	0.056	160%	8%
19	South Branch Macatawa River to Macatawa River	0.012	0.023	0.023	97%	-1%
20	North Branch Macatawa River to Den Bleyker Drain	0.017	0.034	0.034	106%	0%
21	Vanderbie Drain and Rotman Drain	0.044	0.077	0.081	76%	6%
22	North Branch Macatawa River to Den Bleyker Drain	0.022	0.064	0.076	191%	19%
23	Den Bleyker Drain	0.028	0.063	0.077	122%	22%
24	North Branch Macatawa River at M-40	0.027	0.063	0.077	129%	22%
25	North Branch Macatawa River to Macatawa River	0.017	0.030	0.033	80%	9%
26	Bosch and Hulst Drain at 104th Avenue	0.011	0.019	0.018	67%	-5%
27	Bosch and Hulst Drain to Noordeloos Creek	0.013	0.041	0.040	225%	-2%
28	Tributary to Bosch and Hulst Drain to Noordeloos Creek	0.012	0.030	0.029	150%	-5%
29	Hunters Creek to Brower Drain	0.014	0.055	0.057	282%	4%
30	Brower Drain to Hunters Creek	0.018	0.058	0.072	211%	26%
31	Noordeloos Creek to Drain #52	0.019	0.044	0.040	126%	-9%
32	Cedar Drain to Noordeloos Creek	0.020	0.074	0.082	268%	11%
33	Drain #4 and 43 to Noordeloos Creek	0.024	0.071	0.059	202%	-17%
34	Noordeloos Creek to Macatawa River	0.011	0.032	0.034	197%	5%
35	Macatawa River to North Branch	0.018	0.042	0.046	131%	10%
36	Macatawa River to Noordeloos Creek	0.020	0.053	0.048	163%	-10%
37	North Holland Creek to Drain #40	0.012	0.023	0.031	97%	32%
38	Drain #15 and 17 to Drain #40	0.019	0.050	0.055	166%	10%
39	Drain #40 to Macatawa River	0.019	0.052	0.074	176%	42%
40	Macatawa River to Windmill Island	0.012	0.043	0.049	265%	15%
41	Maplewood Intercounty Drain to Macatawa River	0.022	0.081	0.097	277%	19%
42	Troost and Boven Dam Drains to Pine Creek/Harlem Drain	0.014	0.025	0.027	74%	8%
43	Pine Creek/Harlem Drain at Quincy St.	0.013	0.010	0.015	-21%	43%
44	Pine Creek/Harlem Drain to Drain #37	0.008	0.016	0.023	108%	41%
45	Drain #37 to Pine Creek/Harlem Drain	0.013	0.016	0.015	25%	-10%
46	Pine Creek/Harlem Drain to Lake Macatawa	0.010	0.033	0.040	222%	22%
47	Macatawa River/Lake Macatawa	Not Applicable				
48	Winstrom Creek and Drains #20A, 23, 53 to Lake Macatawa	0.008	0.015	0.016	77%	12%
49	Old Lela Drain to Lake Macatawa	0.053	0.155	0.178	191%	15%
50	Weller Drain to Lake Macatawa	0.066	0.135	0.127	104%	-6%
51	Arbor Creek to Lake Macatawa	0.067	0.121	0.139	81%	15%
52	Ottogan Intercounty Drain to Lake Macatawa	0.023	0.056	0.051	143%	-9%
53	Kelly Lake Drain to Lake Macatawa	0.012	0.023	0.023	95%	-1%
54	East Lake Macatawa drainage (does not include lake)	Not Applicable				
55	West Lake Macatawa drainage (does not include lake)	Not Applicable				
	Area-weighted Average	0.019	0.045	0.048	138%	5%
	Minimum	0.008	0.010	0.015	-21%	-17%
	Maximum	0.067	0.155	0.178	282%	43%

*Peak flood flow yields cannot be used to calculate peak flows for any portion of a subbasin.

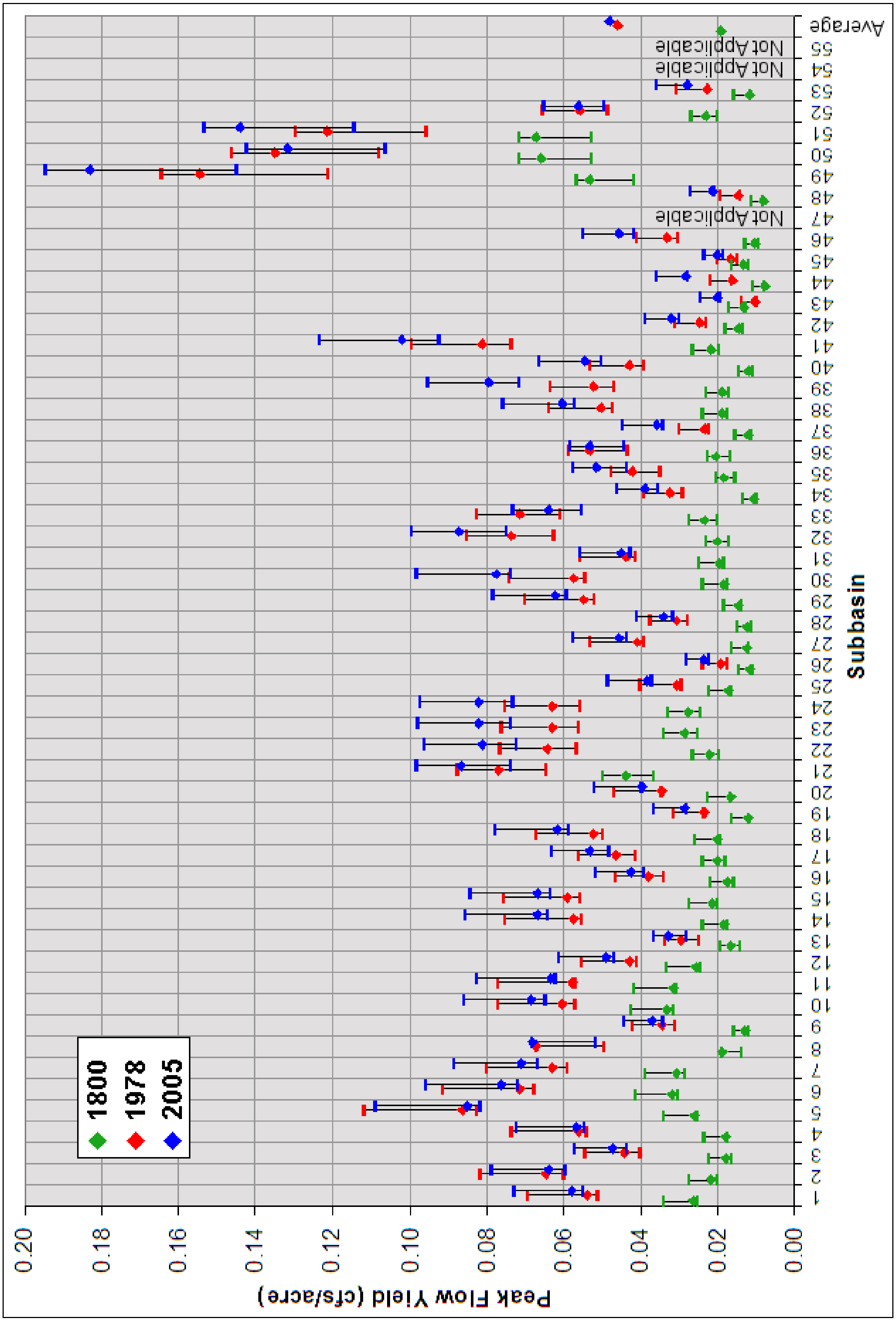


Figure 32 – Peak Flood Flow Yield Analysis Chart per subbasin

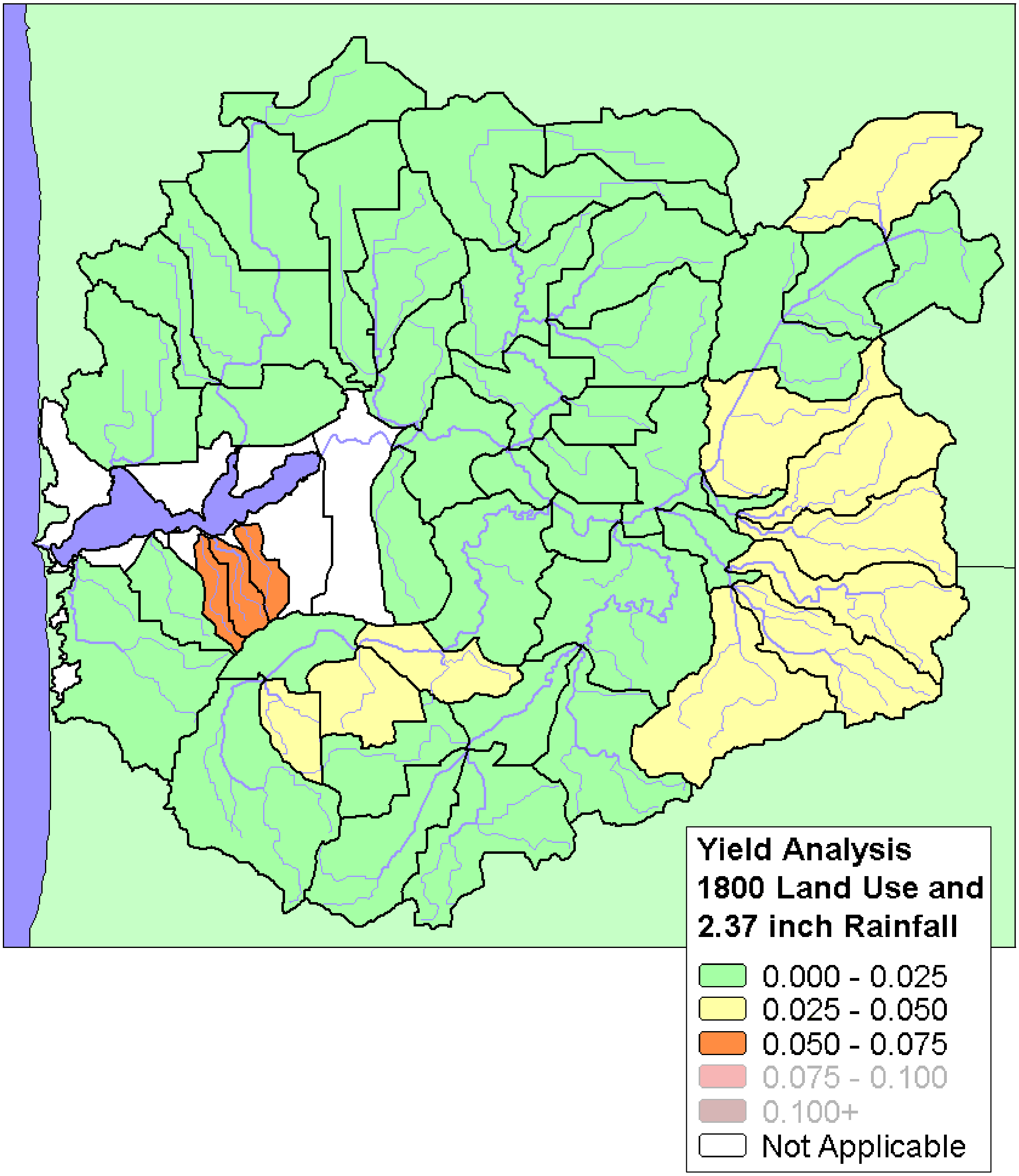


Figure 33 – Peak Flood Flow Yield Analysis Map, 1800 Land Use

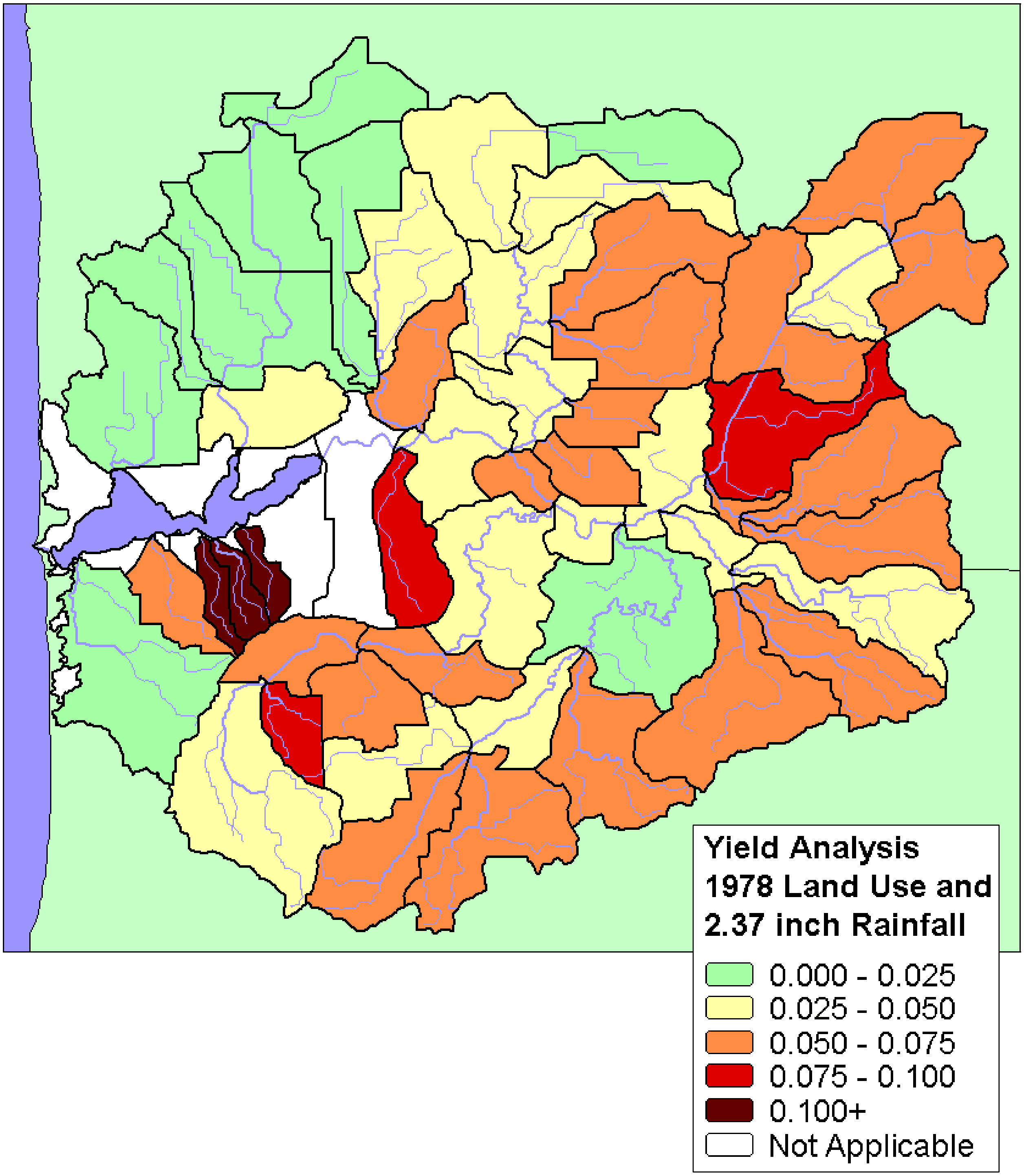


Figure 34 – Peak Flood Flow Yields Analysis Map, 1978 Land Use

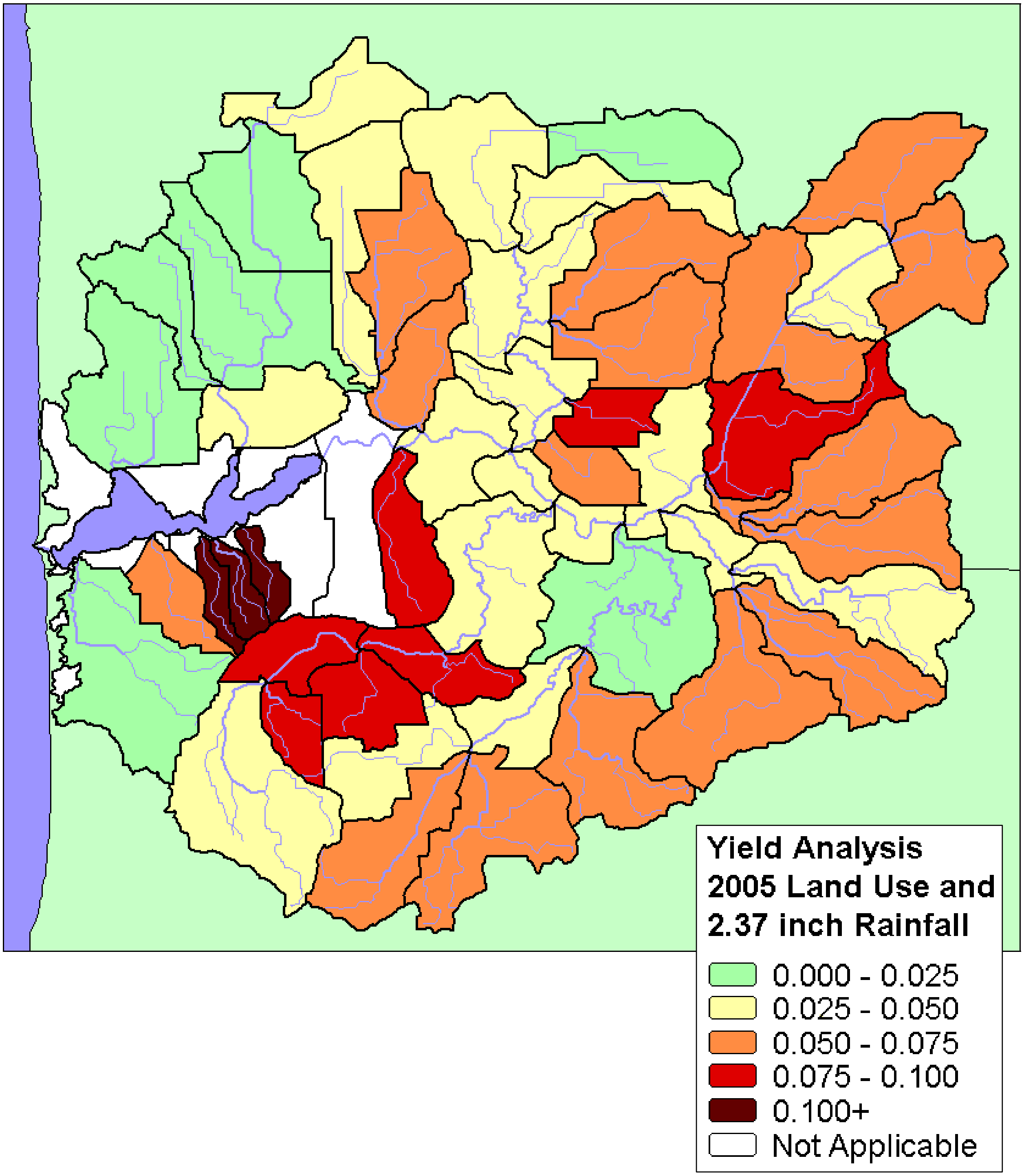


Figure 35 – Peak Flood Flow Yields Analysis Map, 2005 Land Use

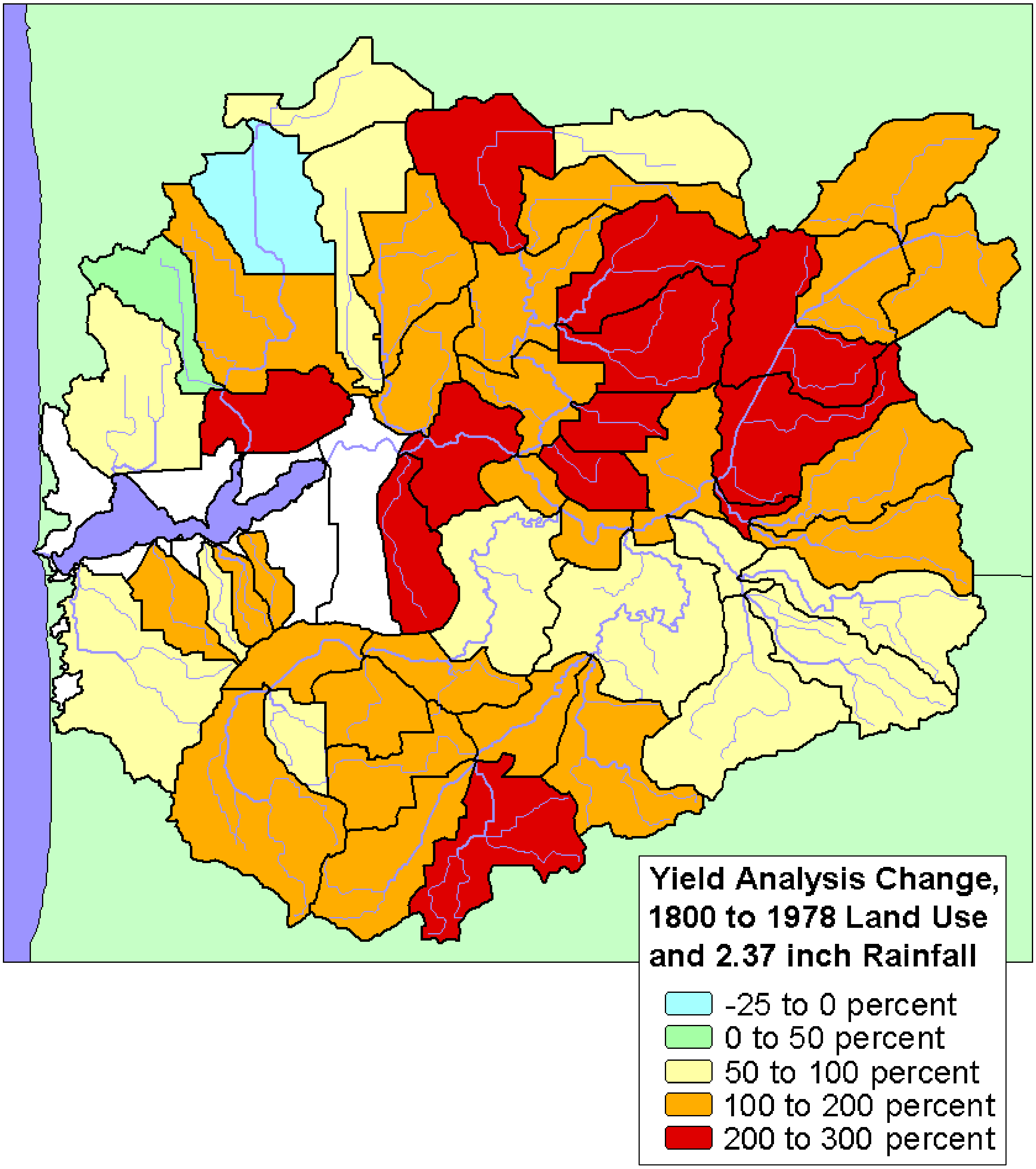


Figure 36 – Peak Flood Flow Yields Analysis Map, 1800 to 1978 Land Use

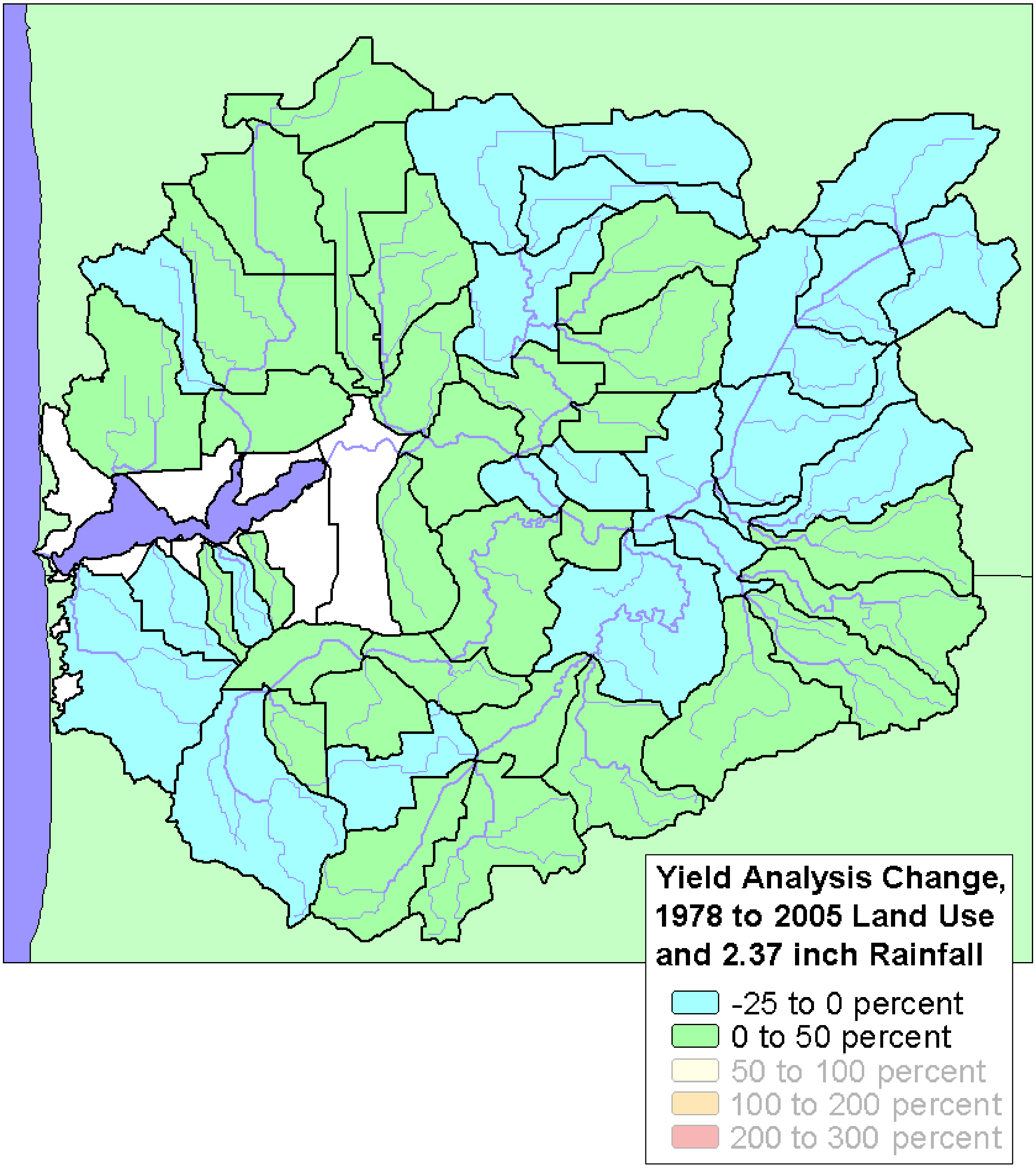


Figure 37 – Peak Flood Flow Yields Analysis Map, 1978 to 2005 Land Use

Results – Stream Flow

The conveyance of the runoff through the drainage system to the stream determines the stream's flows. Peak flows are determined not only by the volume of runoff, but also the drainage system characteristics: slope, length, hydraulic roughness, and ponding. Relatively frequent flows, flows that recur on average every one to two years, are considered channel-forming flows and have more cumulative effect on channel form than extreme flood flows. Increases in runoff from relatively small storms, such as the 50 percent chance (2-year) 24-hour storm correspondingly increase channel-forming flows, which increase streambank and bed erosion as the stream enlarges to accommodate the higher flows.

In-stream flows were calculated for each location shown in Figure 38. Peak flows and cumulative runoff volumes for just the mainstem of the Macatawa River are shown in Figures 39 and 40. The total runoff volume and peak flow results for each scenario are shown in Table 12. In addition, hydrographs for the major subbasins are shown in Figures 41 through 52.

The modeled in-stream flows can also highlight which subwatersheds and subbasins contribute proportionally more or less to runoff volume and peak flow increases. With regard to the Macatawa River, it is evident from Figures 39 and 40 that the flow regime changes from 1800 to 1978 are larger than the changes from 1978 to 2005. However, for planning purposes, the more recent changes should be weighted more heavily because the river system has had little time to adapt to the altered flow regimes caused by those changes. Nevertheless, because a stream can take 50 years or more to adapt to flow changes (Article 19 in Schueler, 2000), the pre-1978 changes should also be considered.

In-stream peak flow and runoff volume changes at the outlet of each major subwatershed, except for the Lake Macatawa tributary subwatershed, are summarized in Tables 13 and 14. Volumes of runoff from each subbasin are additive, unlike peak flows which also depend upon timing of the contributing subbasins.

Tables 13 and 14 do not include the subwatershed termed Lake Macatawa tributaries. These tributaries outlet to Lake Macatawa at numerous locations around the lake. Since the lake is considered hydraulically equivalent to Lake Michigan, there are no channel protection concerns with regard to cumulative flow changes from these tributaries on the lake itself. Channel protection considerations do apply to many of the subbasins within the subwatershed, however.

Six of the seven other subwatersheds comprise the Macatawa River watershed. Because Pine Creek is not connected to the Macatawa River, flow regime changes in Pine Creek have no effect on the Macatawa River flows depicted in Figures 39 and 40. However, the Pine Creek subwatershed is included in Tables 13 and 14 because flow regime changes in that subwatershed system may be deemed as significant as those in the six Macatawa River subwatersheds.

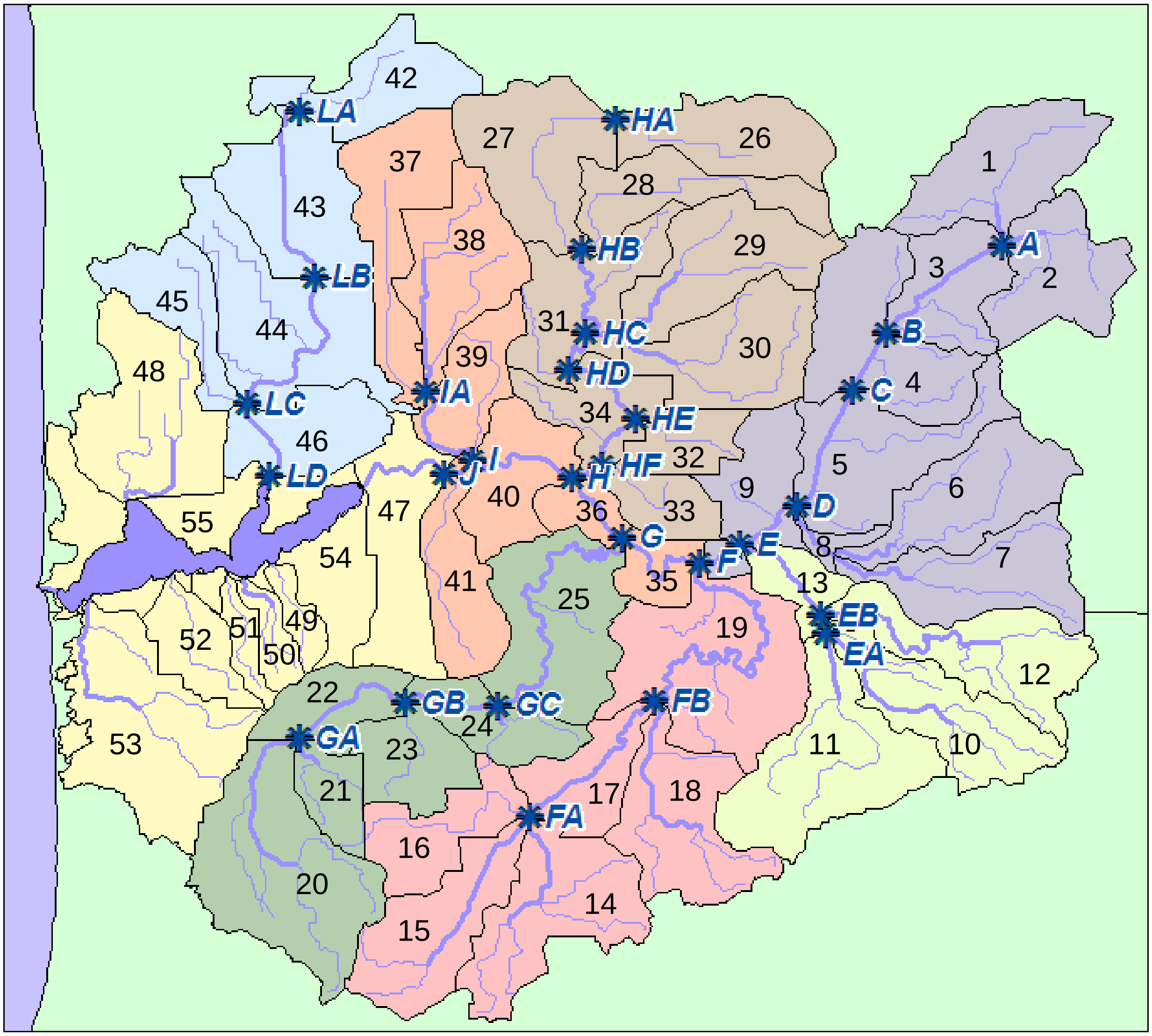


Figure 38 – Locations of Calculated In-Stream Peak Flows

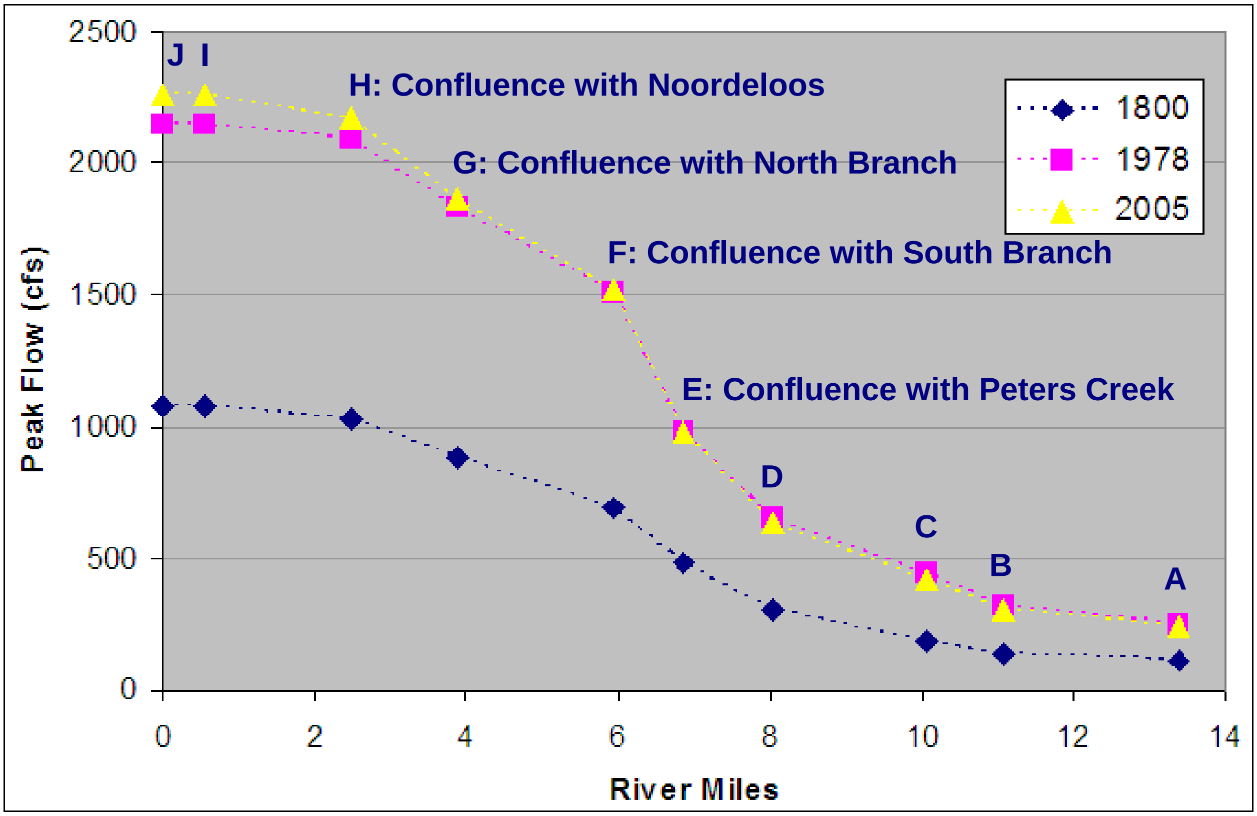


Figure 39 – Macatawa River In-Stream Peak Flows

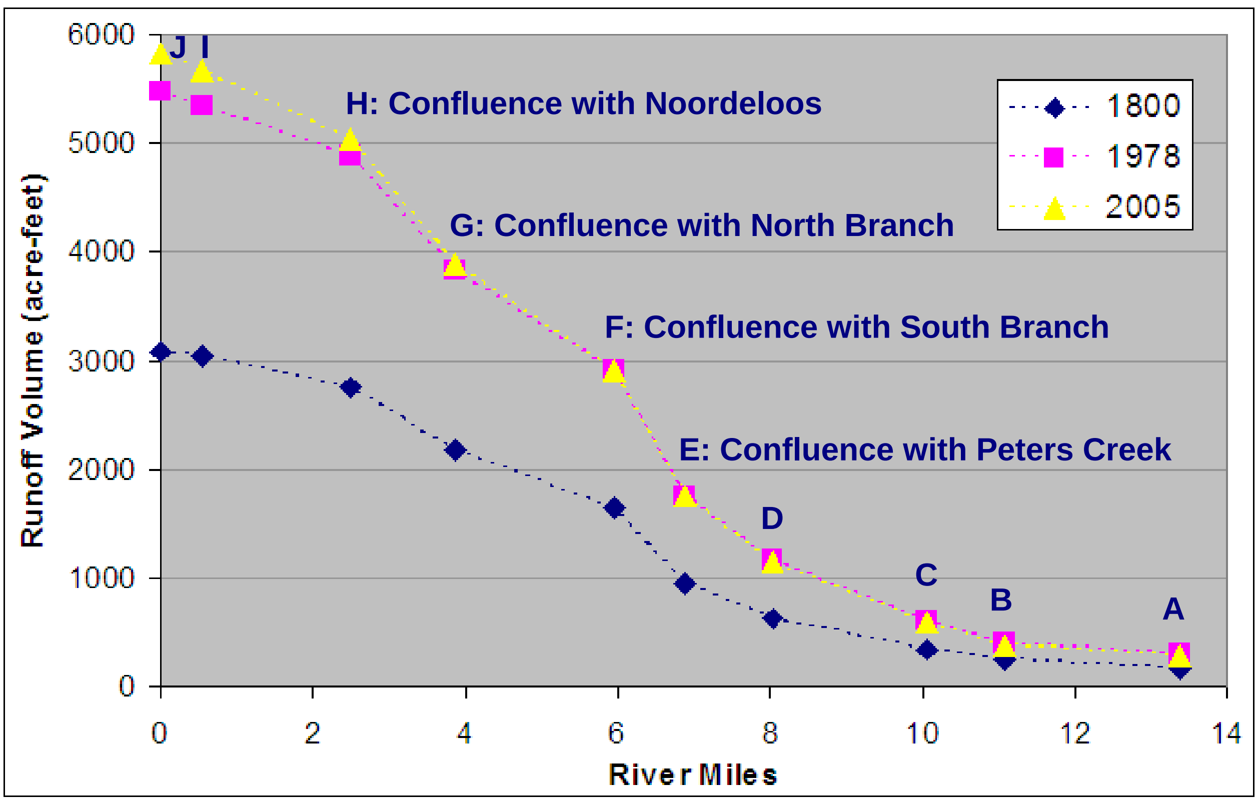


Figure 40 – Macatawa River In-Stream Runoff Volumes

Table 12 –Calculated In-Stream Peak Flows and Runoff Volumes

Stream	Location ID	Distance from Mouth	Peak Flow (cfs)			Volume (acre-feet)		
			1800	1978	2005	1800	1978	2005
Macatawa River	A	13.4	109	253	240	168	303	292
	B	11.1	139	323	305	242	406	390
	C	10.1	187	439	419	339	611	597
	D	8.0	304	650	632	627	1169	1154
	E	6.9	480	980	979	950	1772	1759
	F	6.0	693	1512	1517	1649	2919	2907
	G	3.9	886	1835	1862	2190	3828	3891
	H	2.5	1026	2089	2168	2767	4882	5050
	I	0.6	1076	2146	2256	3048	5355	5683
	J: Mouth	0.0	1078	2146	2259	3086	5486	5836
Peters Creek	EA	2.3	179	328	335	210	386	388
	EB	2.0	233	415	423	309	576	577
	E: Mouth	0.0	243	433	440	323	603	604
South Branch	FA	11.1	131	359	375	320	517	517
	FB	7.6	206	512	532	505	785	787
	F: Mouth	0.0	248	592	612	647	1045	1044
North Branch	GA	10.6	91	181	182	206	331	332
	GB	8.5	154	307	333	337	536	575
	GC	6.7	185	363	400	405	641	698
	G: Mouth	0.0	226	440	486	523	856	928
Noordeloos Creek	HA	11.0	22	37	36	81	71	79
	HB	7.3	75	178	173	265	359	368
	HC	4.9	132	360	389	396	679	745
	HD	4.0	167	437	466	473	818	888
	HE	2.1	176	456	494	498	872	956
	HF	0.7	185	480	524	529	939	1028
	H: Mouth	0.0	198	518	565	566	1021	1124
Drain #40	IA	1.8	71	154	185	196	266	353
	I: Mouth	0.0	95	202	255	254	339	471
Pine Creek	LA	8.3	27	46	50	84	95	99
	LB	4.4	58	68	84	195	147	188
	LC	1.3	99	129	165	335	313	417
	LD: Mouth	0.0	107	147	193	366	386	521
Lake Macatawa			1181*	2256*	2407*	4186**	7000**	7562**

* included only for comparison – The peak flow values are a combination of all streams and drains flowing to Lake Macatawa. Since the actual outlets are located all around the lake, these values are not measurable at a single location.

** included only for comparison – The volumes represent all inflows to Lake Macatawa, except for rain falling on the lake, which would be an additional 356 acre-feet for the design rainfall of 2.37 inches.

Table 13 – Calculated In-Stream Subwatershed Peak Flows and Associated Changes

Description	Peak Flows (cfs) 1800	1978	2005	Percent change 1800 to 1978	1978 to 2005	Comment
Subwatersheds						
Peters Creek	243	433	440	78%	2%	
Upper Macatawa (does not include Peters Creek)	320	679	661	112%	-3%	These are not discrete flows.
South Branch	248	592	612	139%	3%	
North Branch	226	440	486	95%	10%	
Noordeloos Creek	198	518	565	161%	9%	
Lower Macatawa River (does not include the five upstream subwatersheds)	155	376	449	143%	19%	These are not discrete flows.
Pine Creek	107	147	193	37%	32%	Outlets to Lake Macatawa
Combined Macatawa River Peak Flows						
Macatawa River with Peters Creek	480	980	979	104%	0%	E
Macatawa River before South Branch (Upper Macatawa Subwatershed outflow)	500	1029	1024	106%	0%	F*
Macatawa River with South Branch	693	1512	1517	118%	0%	F**
Macatawa River with North Branch	886	1835	1862	107%	1%	G
Macatawa River with Noordeloos	1026	2089	2168	104%	4%	H
Lower Macatawa River	1078	2146	2259	99%	5%	J

* before confluence with South Branch

** after confluence with South Branch

Table 14 – Calculated Subwatershed Runoff Volumes and Associated Changes

	Runoff Volume (acre-feet)			Percent		Comment
Description	1800	1978	2005	1800 to 1978	1978 to 2005	
Subwatersheds						
Peters Creek	323	603	604	86%	0%	
Upper Macatawa (does not include Peters Creek)	679	1271	1258	87%	-1%	
South Branch	647	1045	1044	61%	0%	
North Branch	523	856	928	64%	8%	
Noordeloos Creek	566	1021	1124	80%	10%	
Lower Macatawa River (does not include the five upstream subwatersheds)	348	690	878	98%	27%	
Pine Creek	366	386	521	6%	35%	Outlets to Lake Macatawa
Combined Macatawa River Runoff Volumes						
Macatawa River with Peters Creek	950	1772	1759	87%	-1%	E
Macatawa River before South Branch (Upper Macatawa Subwatershed outflow)	1002	1874	1862	87%	-1%	F*
Macatawa River with South Branch	1649	2919	2907	77%	0%	F**
Macatawa River with North Branch	2190	3828	3891	75%	2%	G
Macatawa River with Noordeloos	2767	4882	5050	76%	3%	H
Lower Macatawa River	3086	5486	5836	78%	6%	J

* before confluence with South Branch

** after confluence with South Branch

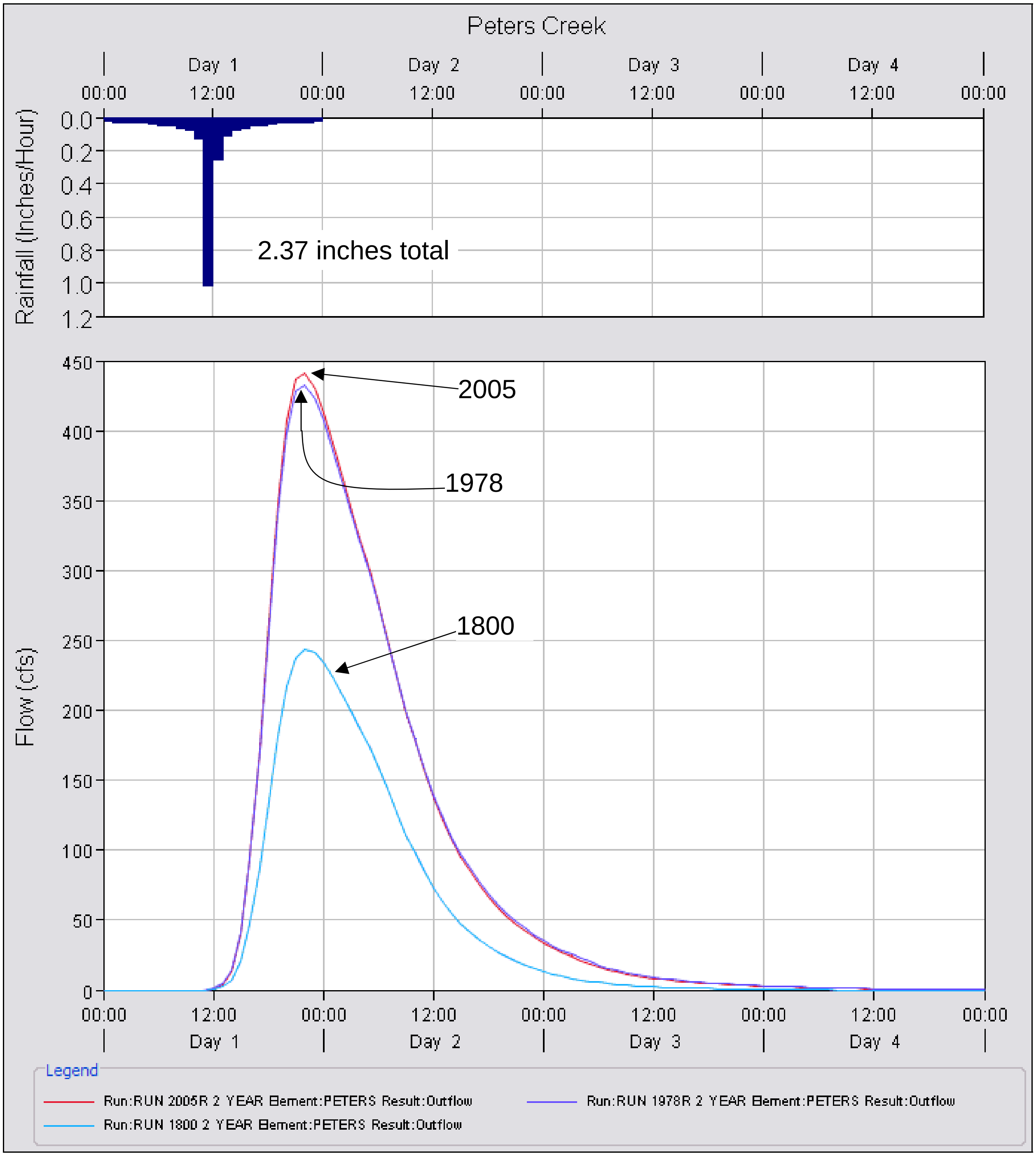


Figure 41 – Peters Creek

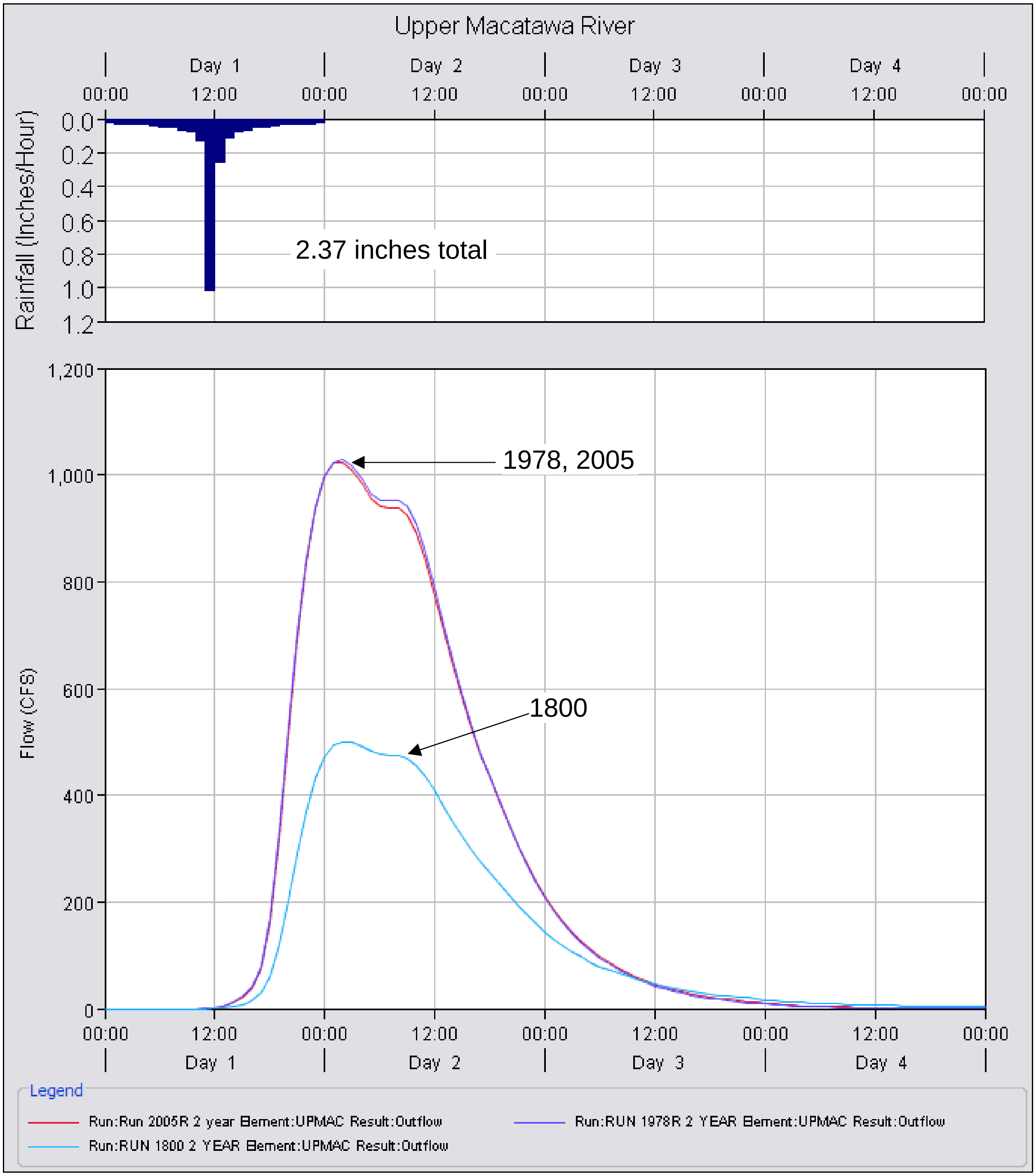


Figure 42 – Upper Macatawa River, includes Peters Creek but before confluence with the South Branch

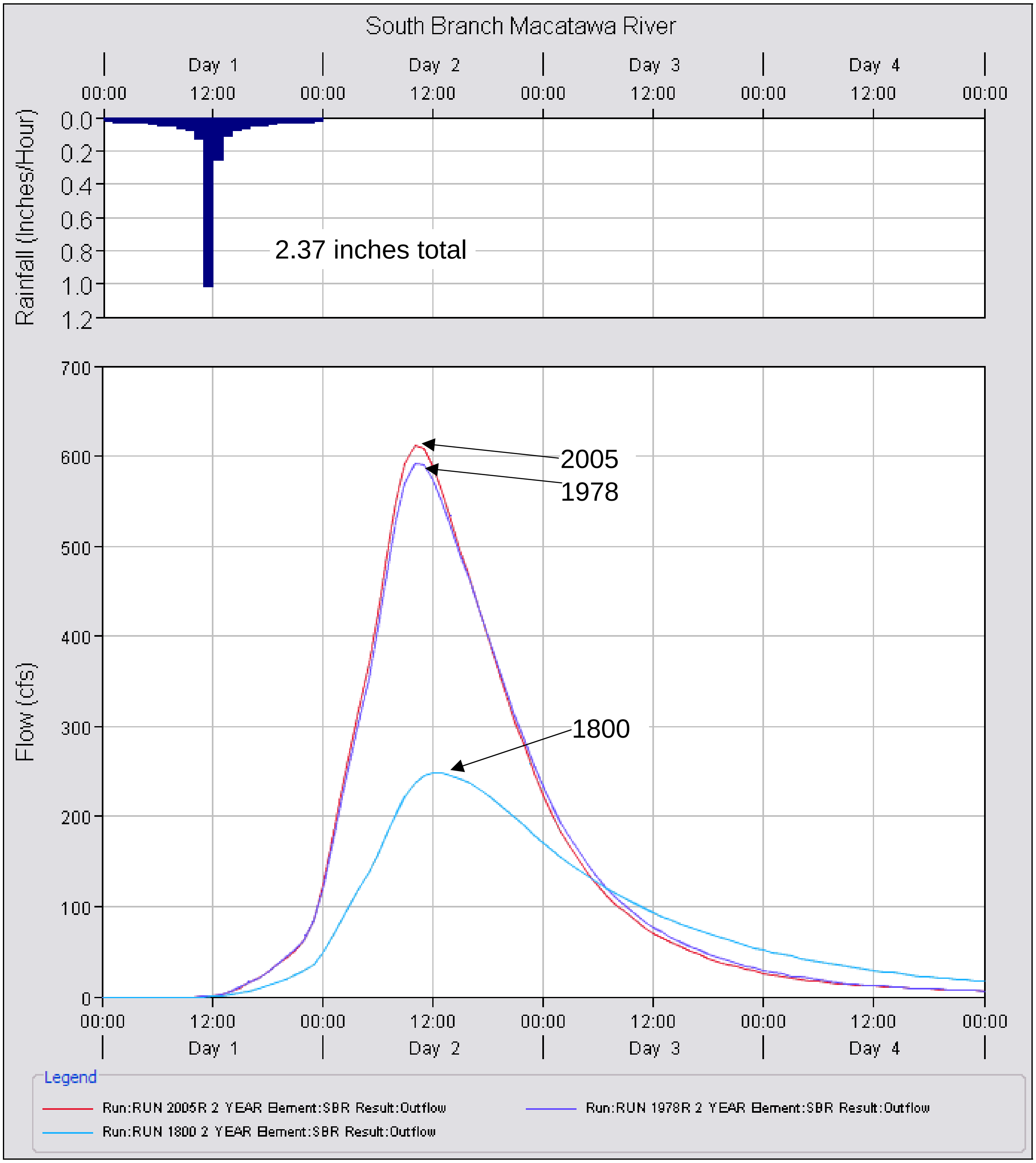


Figure 43 – South Branch Macatawa River

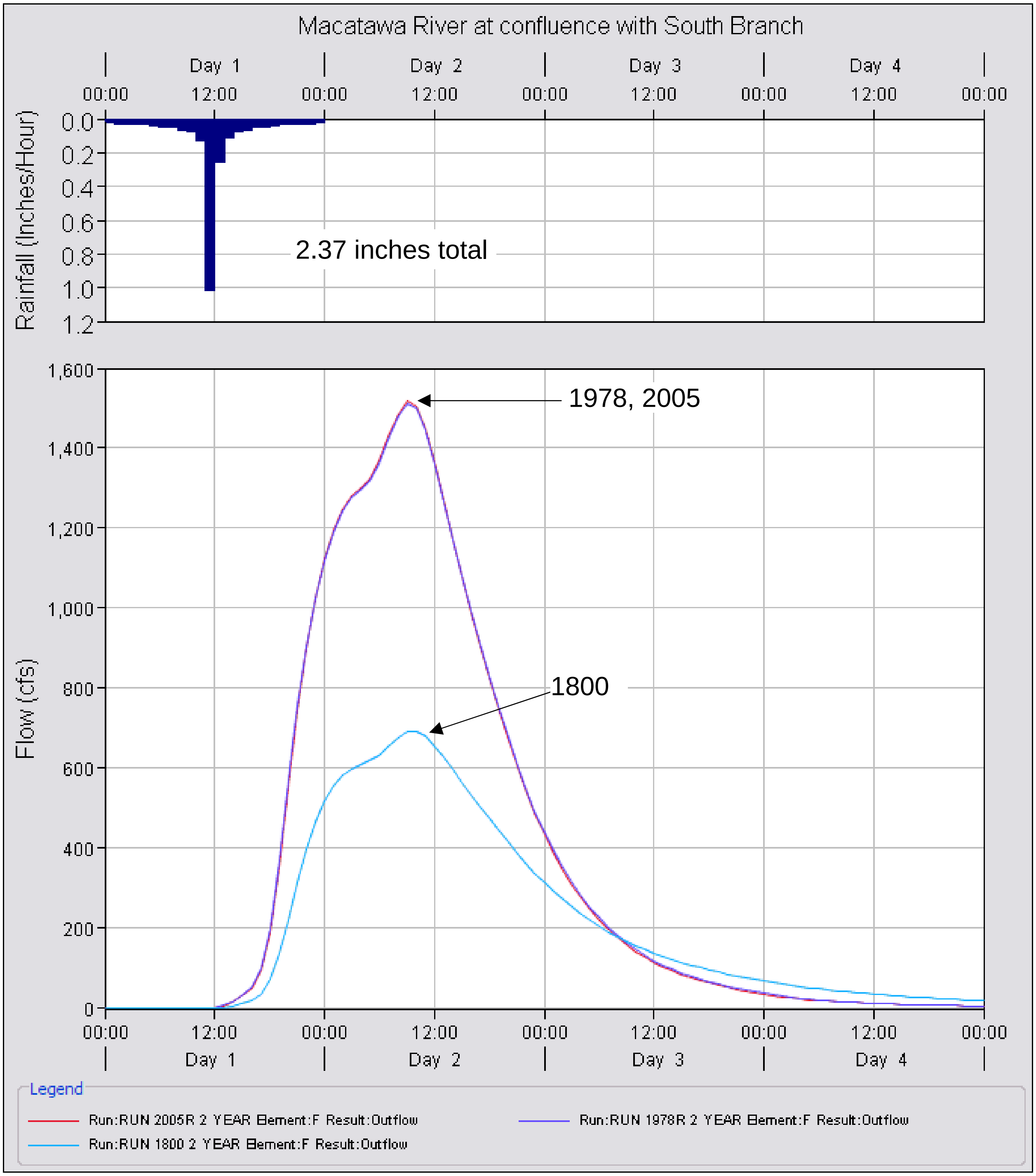


Figure 44 – Macatawa River at confluence with South Branch

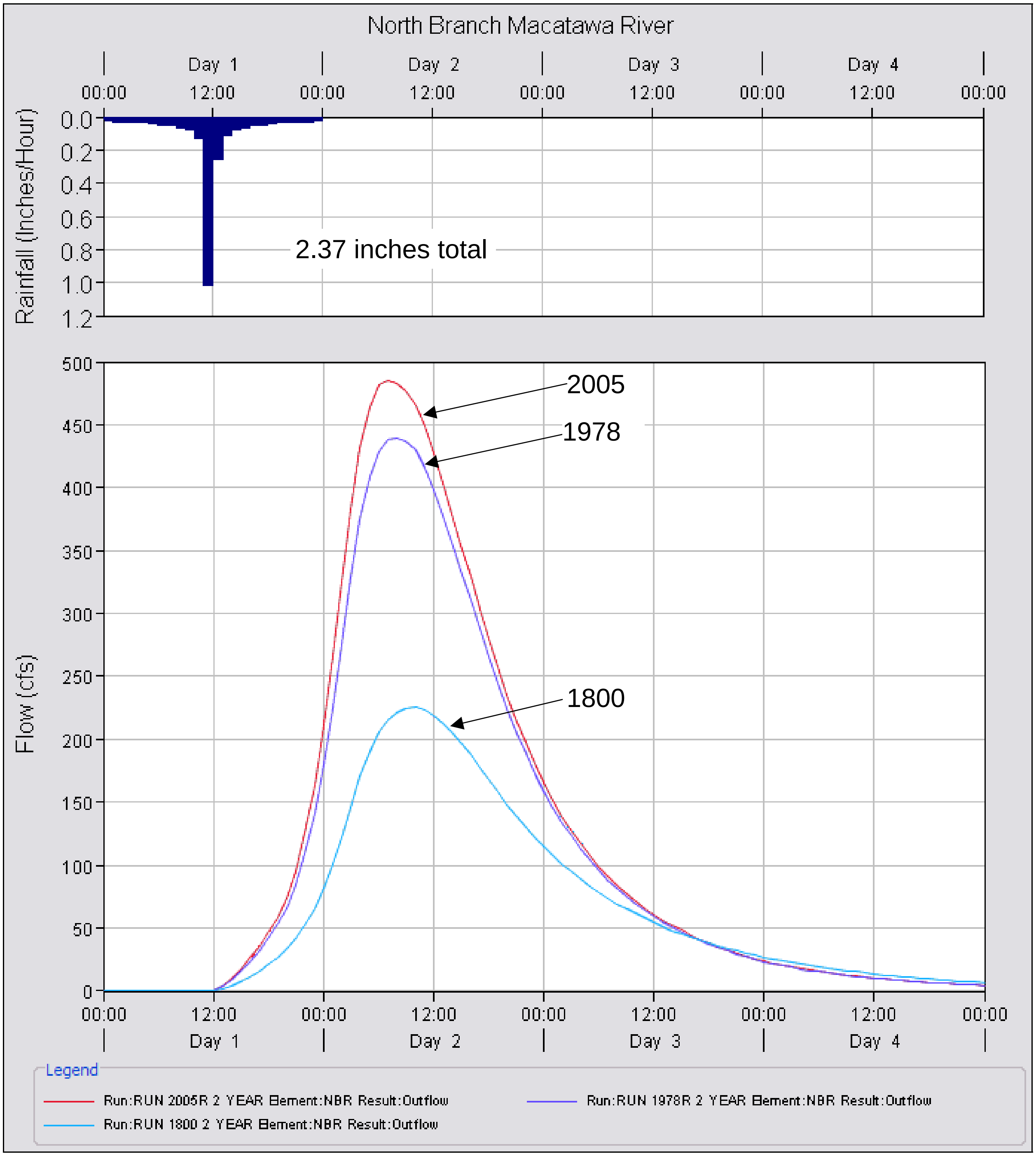


Figure 45 – North Branch Macatawa River

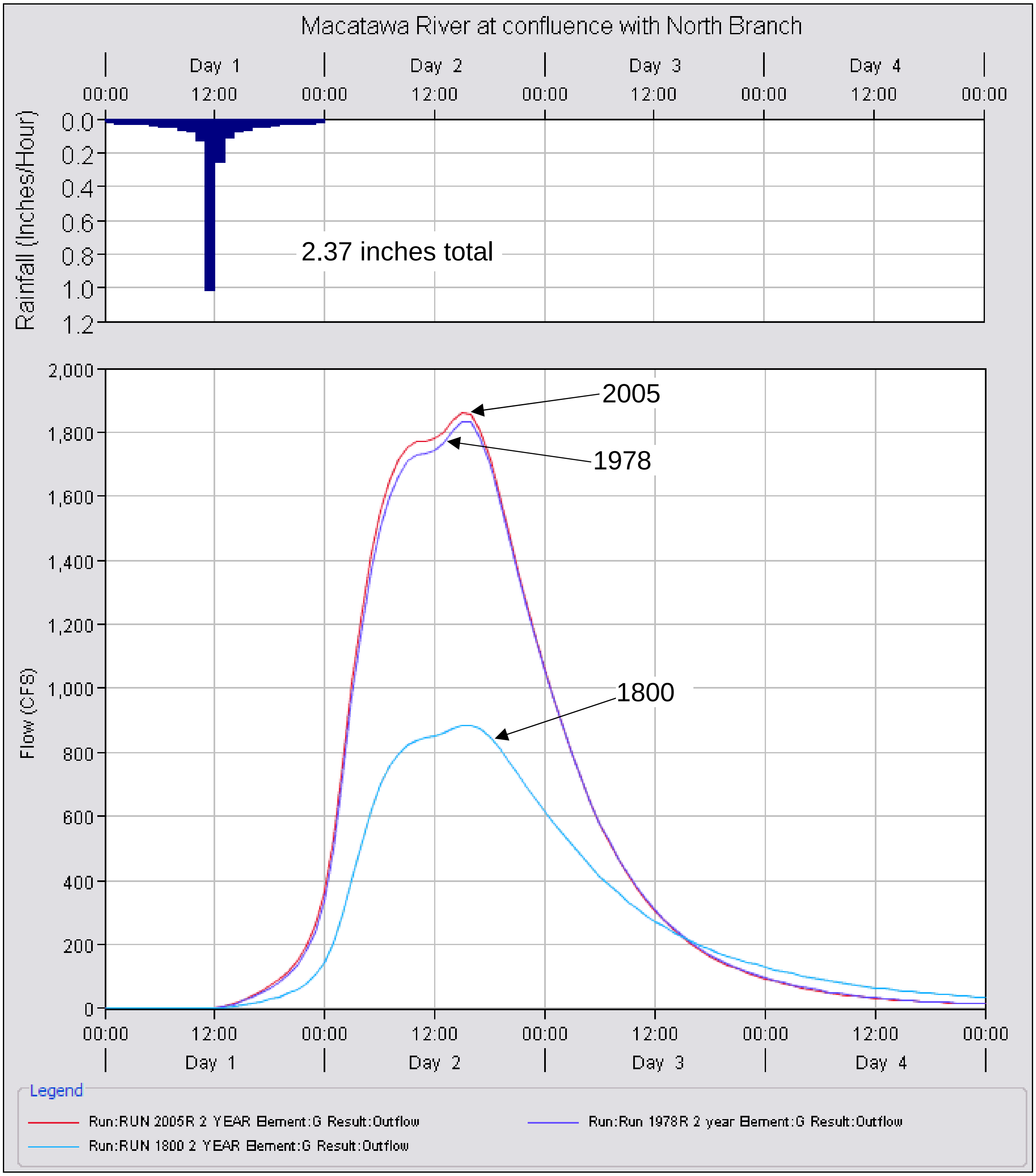


Figure 46 – Macatawa River at confluence with North Branch

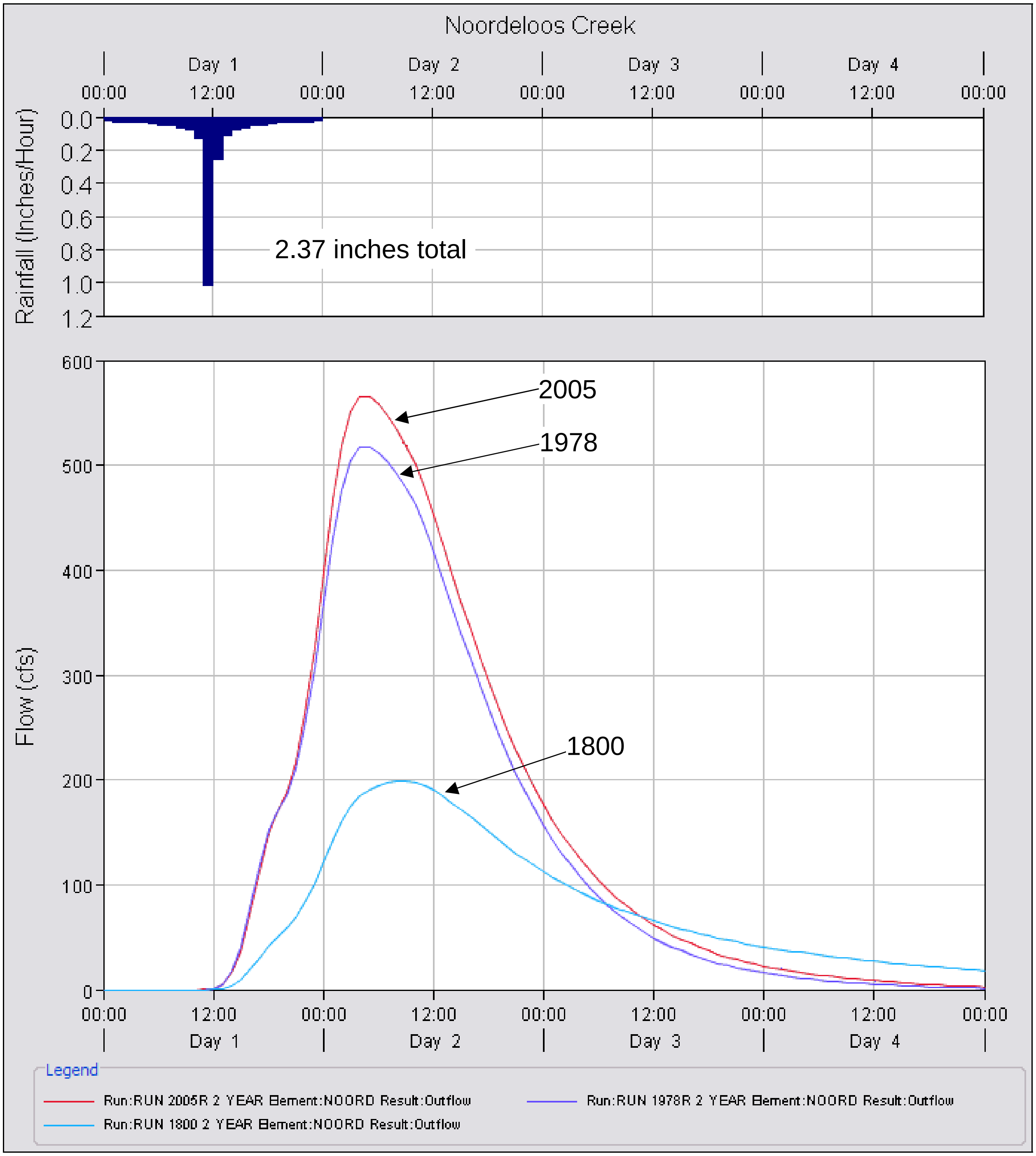


Figure 47 – Noordeloos Creek

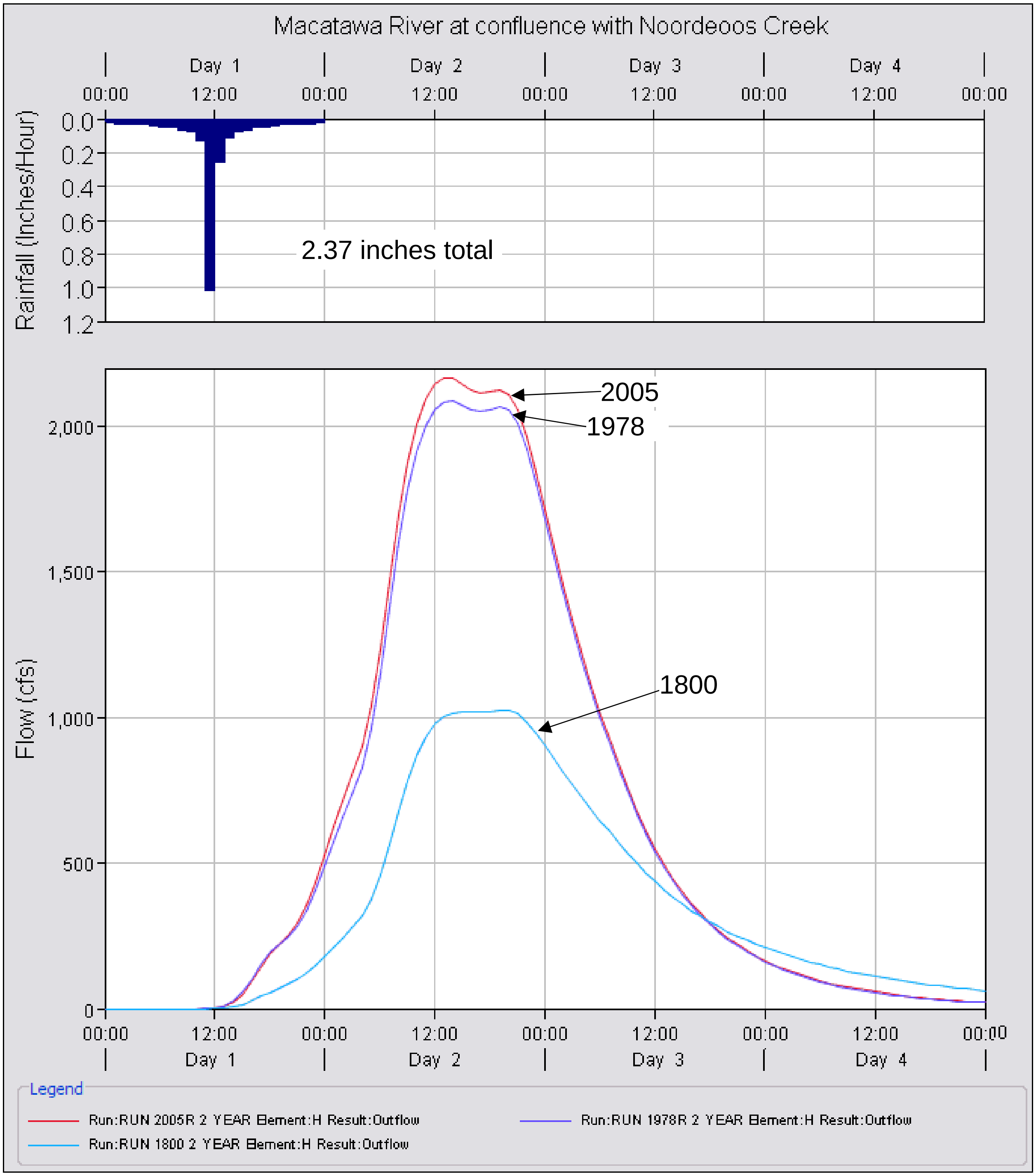


Figure 48 – Macatawa River at confluence with Noordeloos Creek

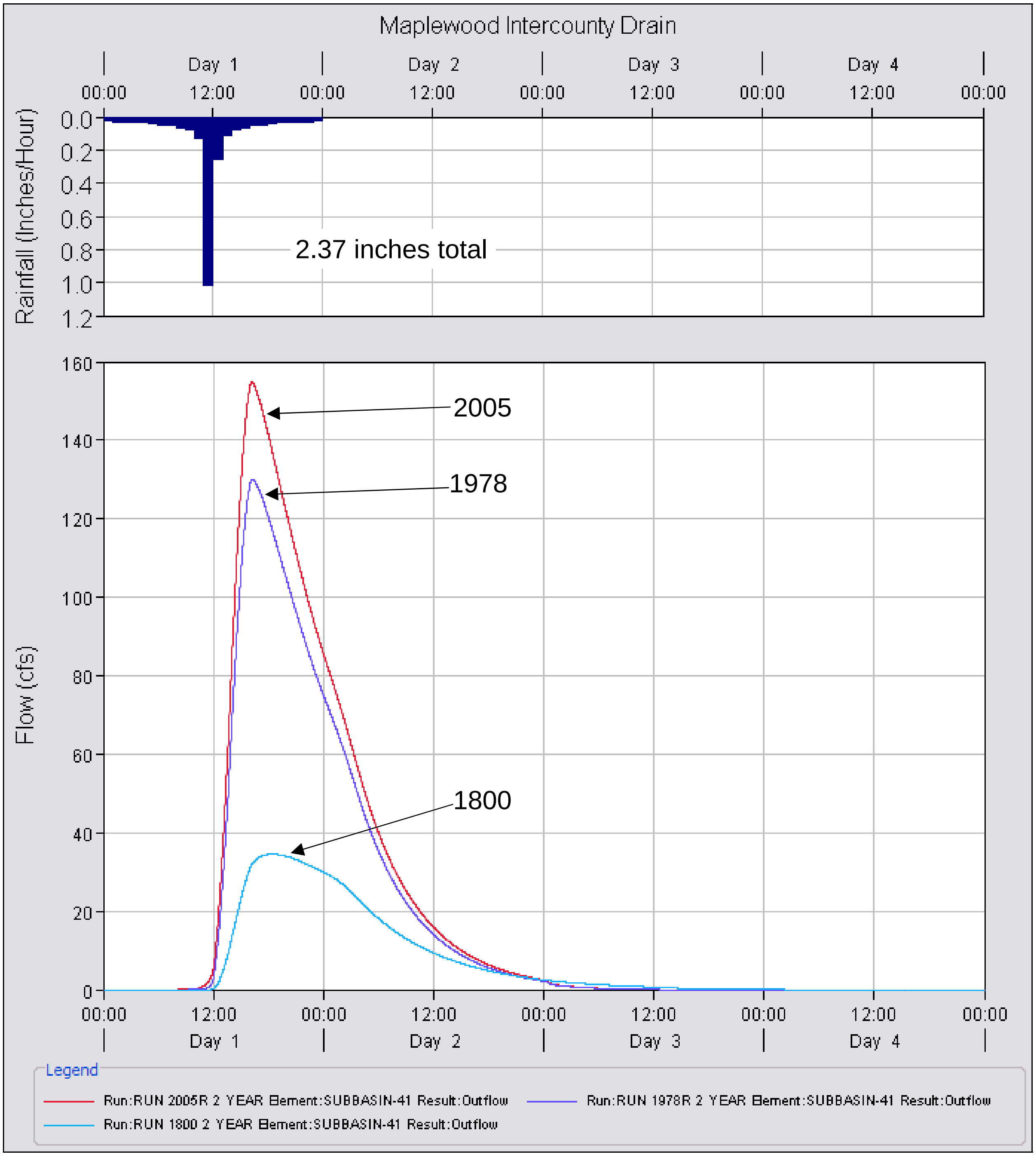


Figure 49 – Maplewood Intercounty Drain

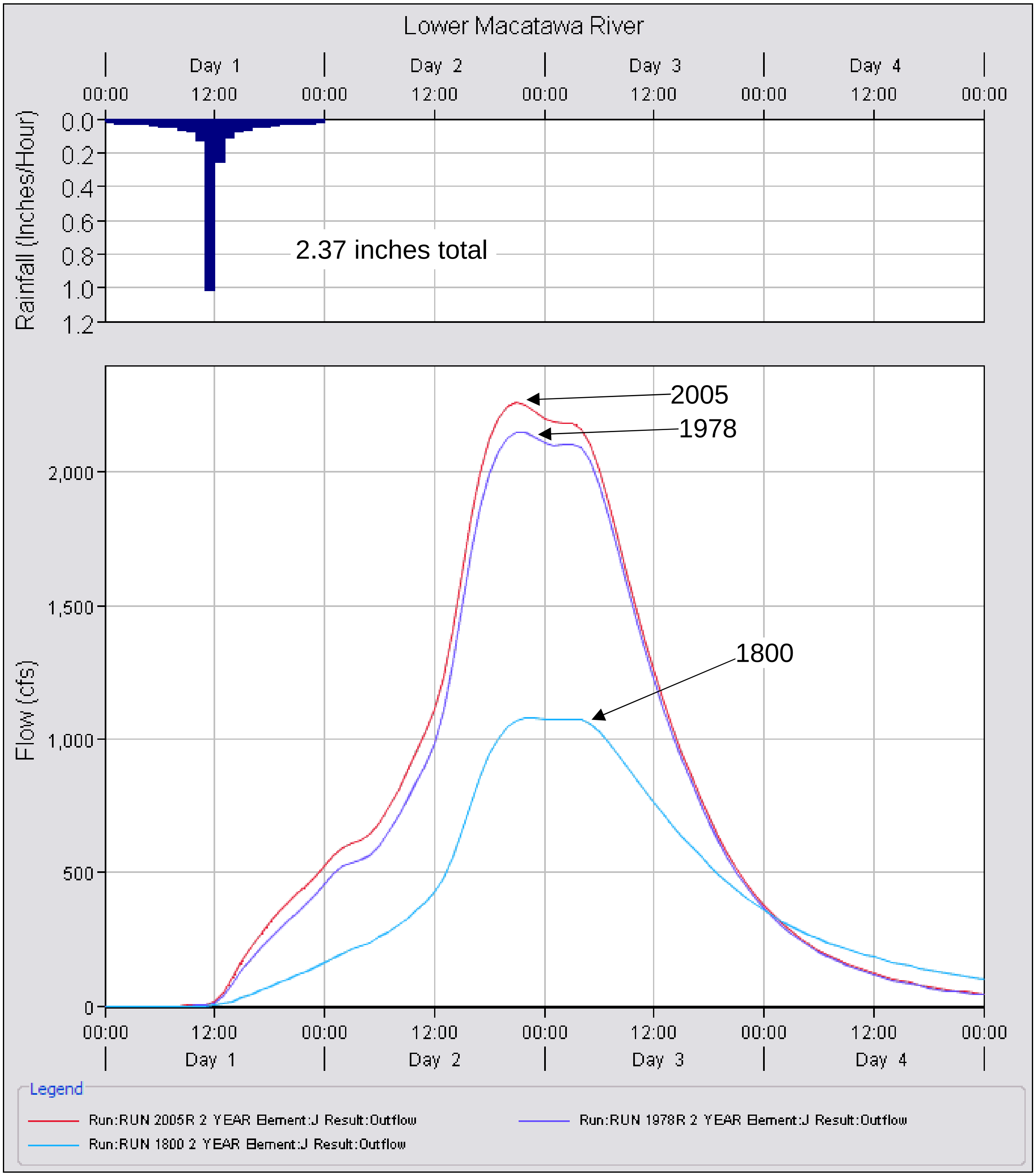


Figure 50 – Lower Macatawa River, includes Upper Macatawa River, Peters Creek, South Branch Macatawa River, North Branch Macatawa River, Noordeloos Creek, and Maplewood Intercounty Drain

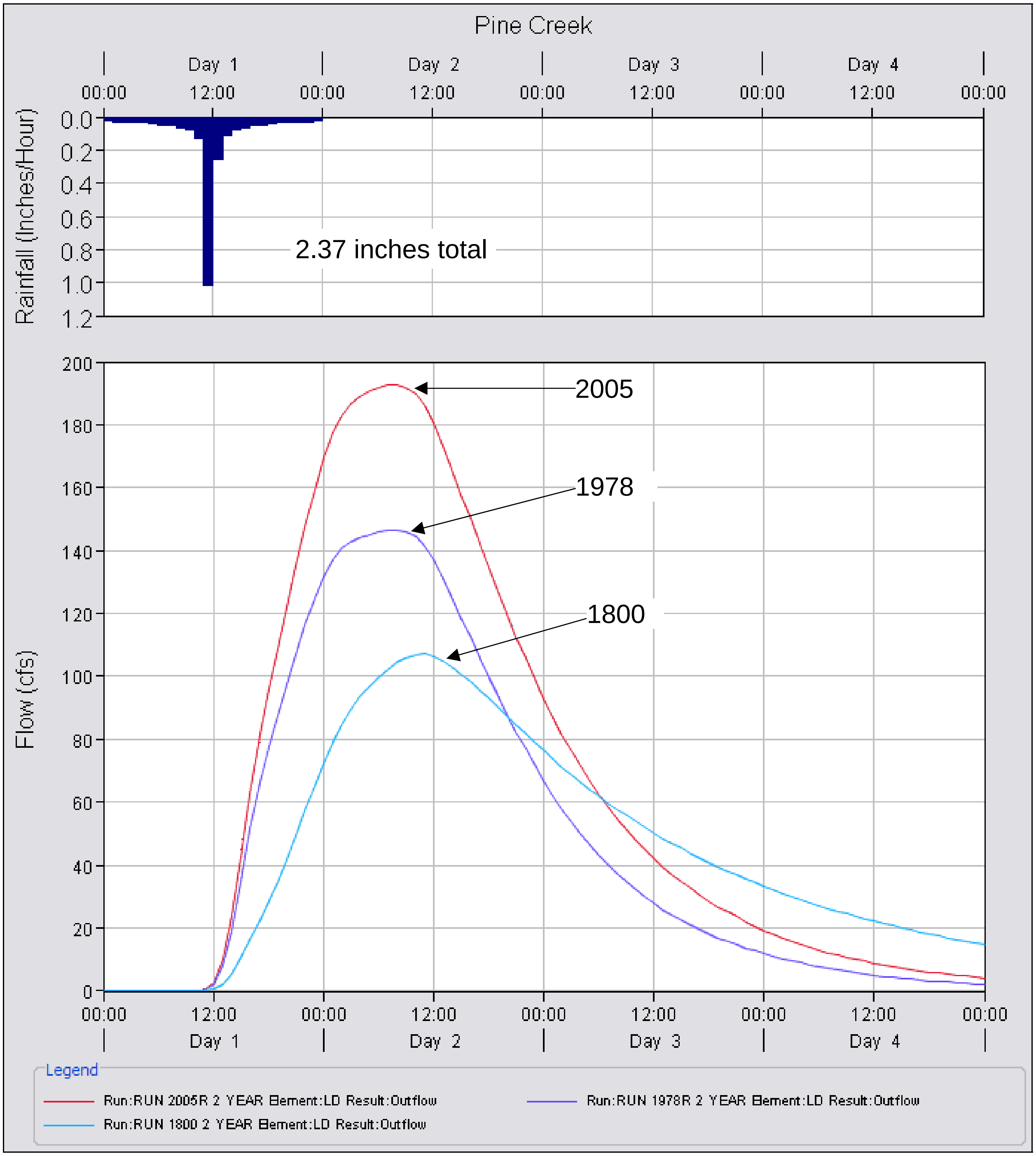


Figure 51 – Pine Creek

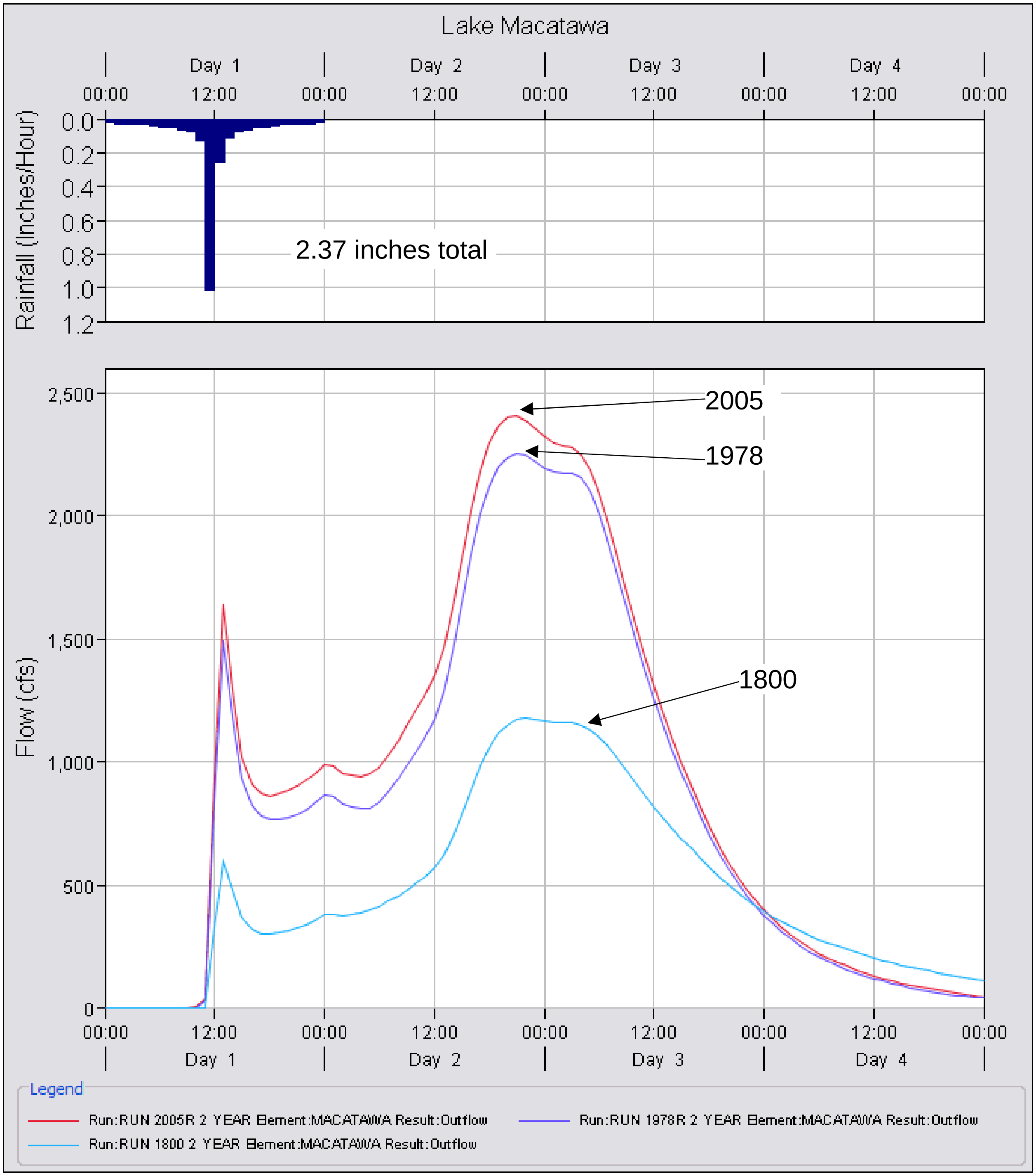


Figure 52 – Lake Macatawa (This hydrograph represents all inflows to Lake Macatawa. Since the inflows are located all around the lake, it is not a measurable hydrograph. It is provided only to illustrate the combined flow changes to Lake Macatawa. It does not include rainfall falling directly on the lake.)

Gage Analysis - Snowmelt or Storms

One USGS gage has been in operation since October 1, 1960 in the watershed. The gage has been relocated twice, as shown in Figure 54. The gage records are considered equivalent. Data for both gages are provided when requesting information for gage 04108800 (http://waterdata.usgs.gov/mi/nwis/dv/?site_no=04108800).

A Log Pearson Type II Flood Frequency Analysis of the gage data results in the recurrence flows provided in Table 15.

Table 15 – Estimated Flow Recurrences Excerpted from Peak Flow Analysis of Michigan USGS Gages (Fongers, 2006)

Annual Exceedance Probability	Peak Flow Estimate (cfs)* 4108800, Macatawa River near Zeeland (Drainage Area: 69 square miles)
0.9950 (1.005 years)	550
0.9900 (1.01 years)	600
0.950 (1.05 years)	900
0.9000 (1.11 years)	1,100
0.800 (1.25 years)	1,400
0.667 (1.50 years)	1,800
0.500 (2 years)	2,200
0.4292 (2.33 years)	2,500
0.200 (5 years)	3,600
0.100 (10 years)	4,700
0.040 (25 years)	6,100
0.020 (50 years)	7,300
0.010 (100 years)	8,500
0.005 (200 years)	9,900
0.002 (500 years)	12,000

*HSU's flow analyses are updated regularly. Flows should be verified by HSU, www.michigan.com/deqhydrology, if used for an MDEQ permit application.

The approximate 1-year recurrence flows for USGS gage 04108801, Table 15, is 550 cfs (Fongers, 2006). Stream flow is most likely to exceed these values in the spring, Figure 53.

Rainfall and soil temperature data for August 21, 2001 through the present are available from Hudsonville's Michigan Celery Cooperative in the Michigan Automated Weather Network (MAWN), Figure 54, and is shown, along with the USGS gage data in Figures 55 through 63. Recurrences noted on the figures are from Table 15. The data generally show that many of the highest peaks generally occur from relatively minor amounts of rain on frozen, but thawing ground. On the other hand, larger summer rainfalls as often elicit very little change in stream flow. Flows on 3/9/2002, 1/13/2005, 3/13/2007, 12/28/2008, and 2/27/2009 are in excess of the 1¼ year recurrence flow of 1,400 cfs and are at least partially caused by melting snow, as indicated by soil temperatures increasing from 32°F. One of the two highest flows in 2003 occurred on

3/17/2003 after four days of no rain, but is associated with a sharp increase in soil temperature from 31.7 to 61.5°F from 3/15 to 3/17. A 4.62-inch rainfall in early November of that same year had less effect on stream flow than the mid-March snowmelt.

The Macatawa watershed has characteristics of both a snowmelt-driven and storm-driven system. Snowmelt-driven systems are usually less flashy than storm-driven systems, because the snow pack supplies a steadier rate of flow. However, a rain-on-snow event, where rain and snowmelt simultaneously contribute to runoff, can produce dramatic flow increases. The runoff from the rain and snowmelt also likely occur with saturated or frozen soil conditions, when the ground can absorb or store less water, resulting in more overland flow to surface waters than would occur otherwise. In a storm-driven system, rainfall causes flood flows.

This hydrologic modeling does not attempt to replicate runoff from snowmelt and rainfall on frozen ground. HSU expects that stream flow from snowmelt and rain-on-snow events would be less sensitive to differences in land cover than indicated in this hydrologic model.

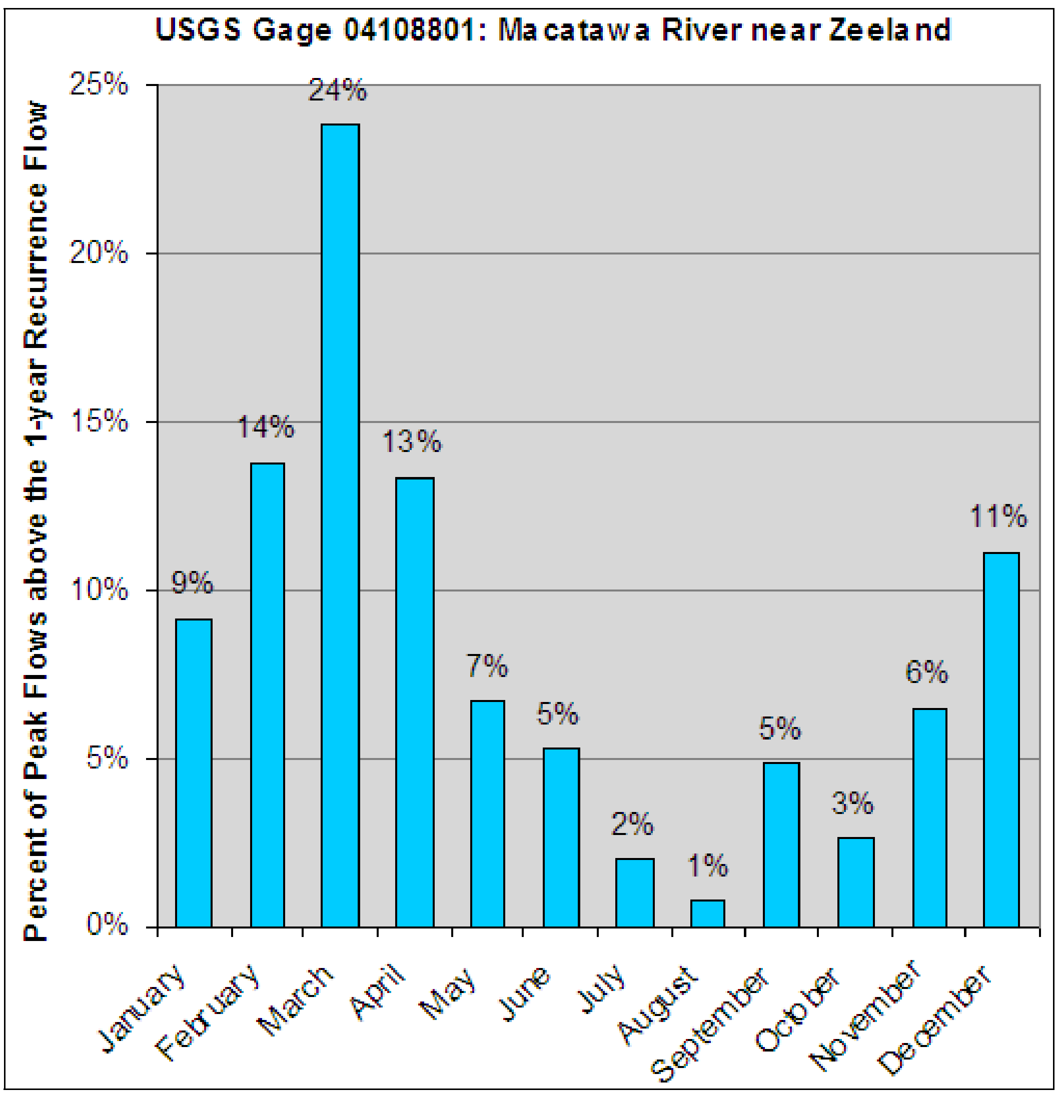


Figure 53 – Percent of Peak Flows above the 1-year recurrence flow by month

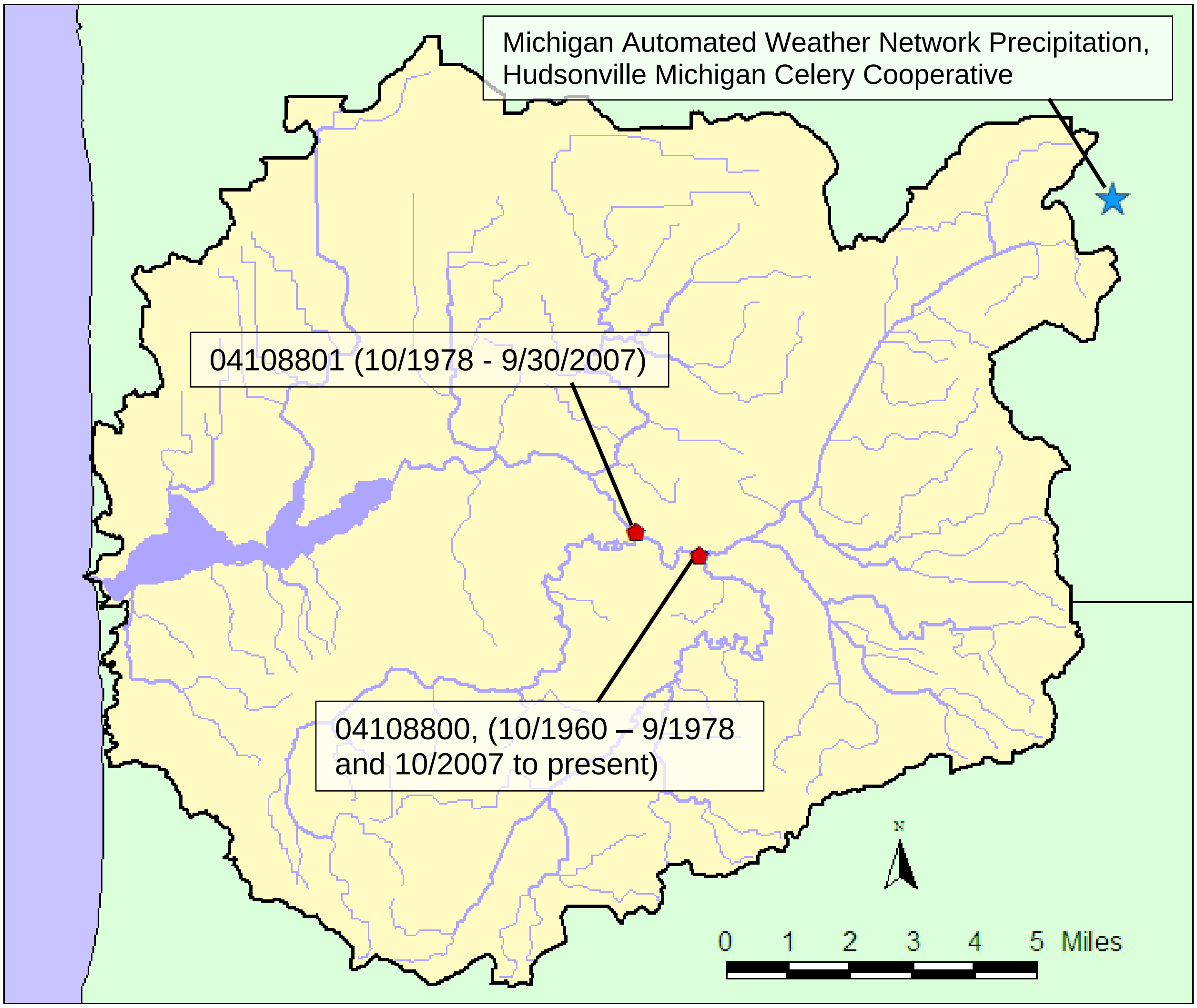


Figure 54 – Location of USGS Flow Gages and MAWN Precipitation Gage

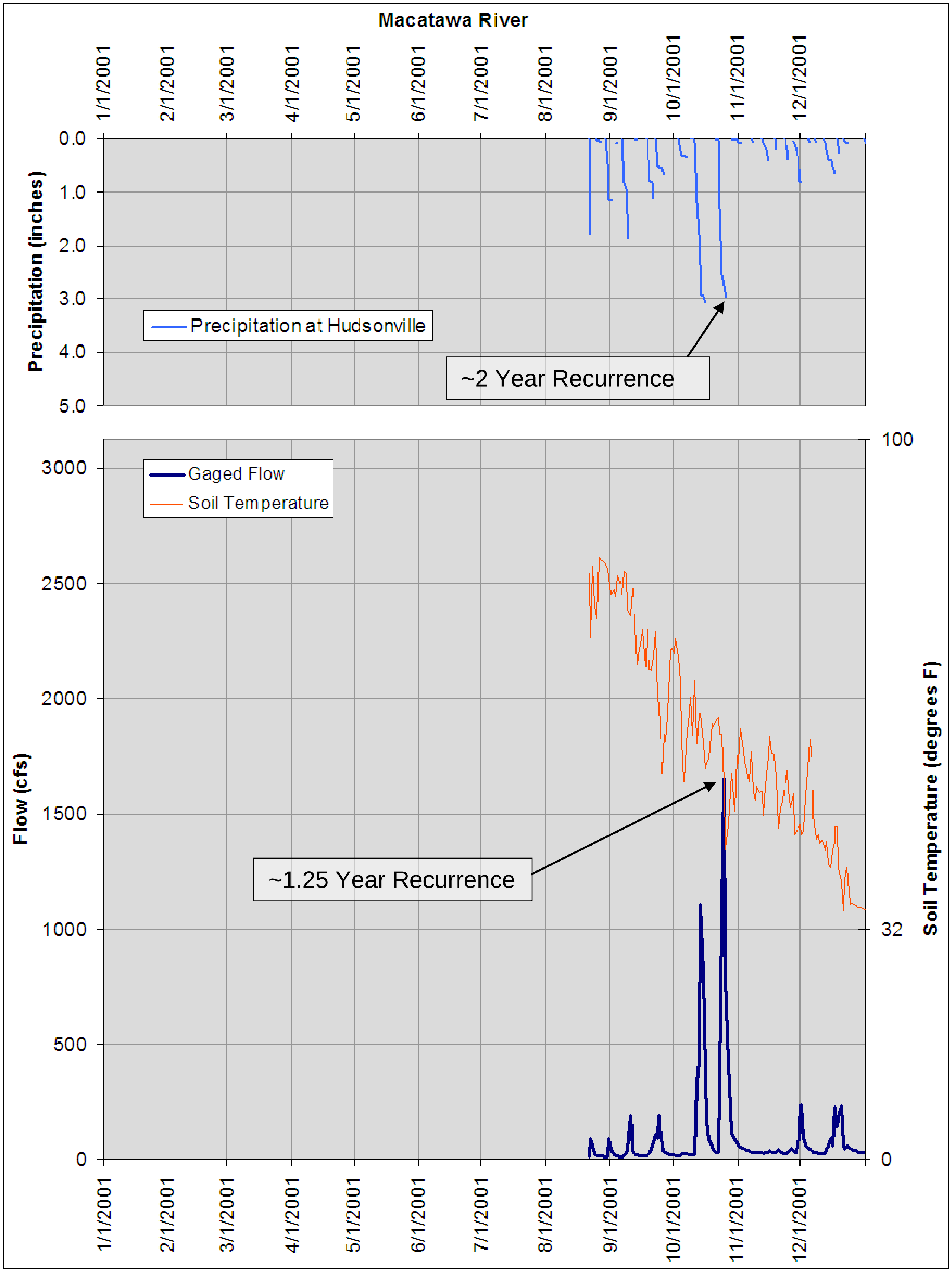


Figure 55 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2001

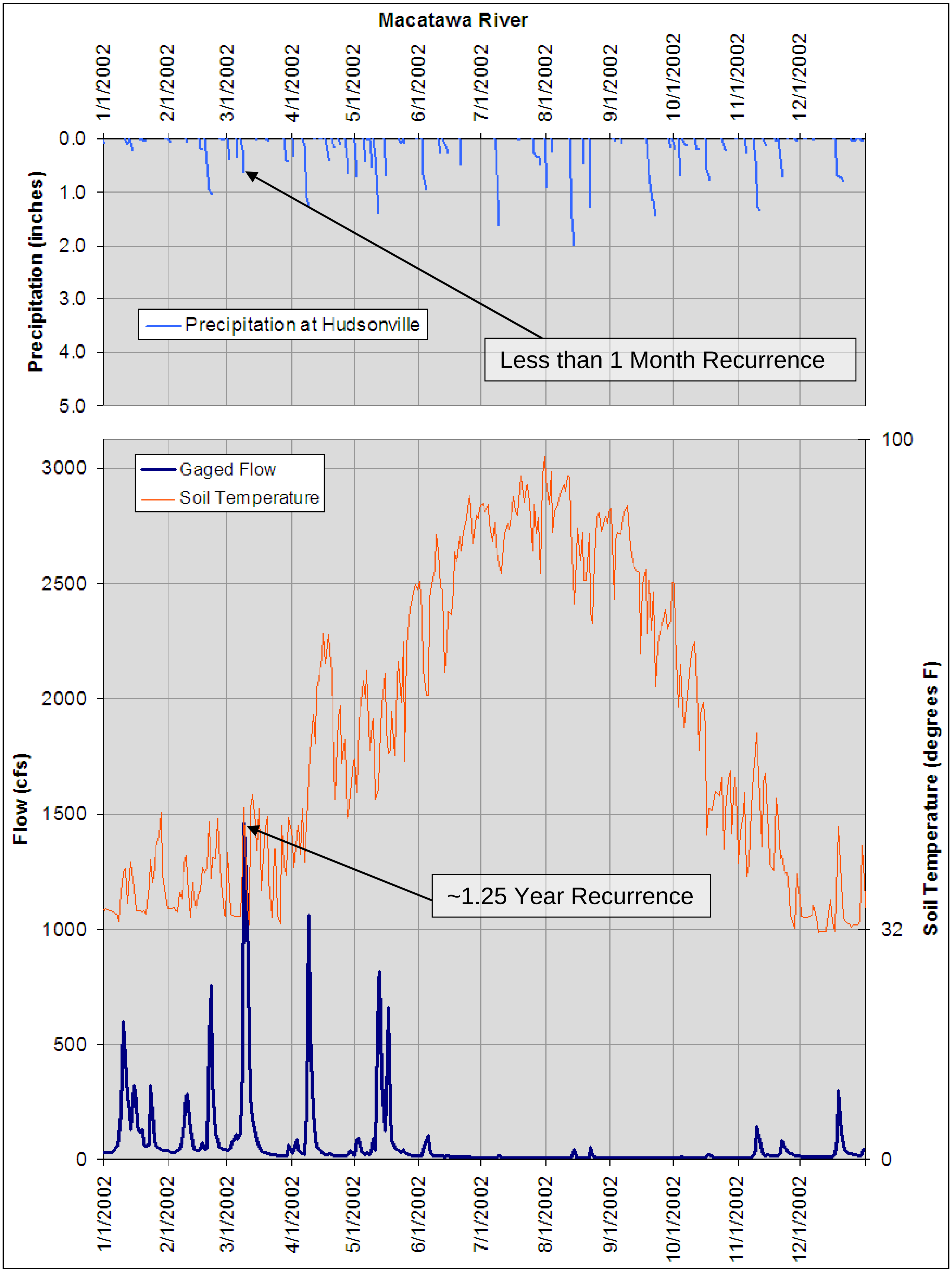


Figure 56 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2002

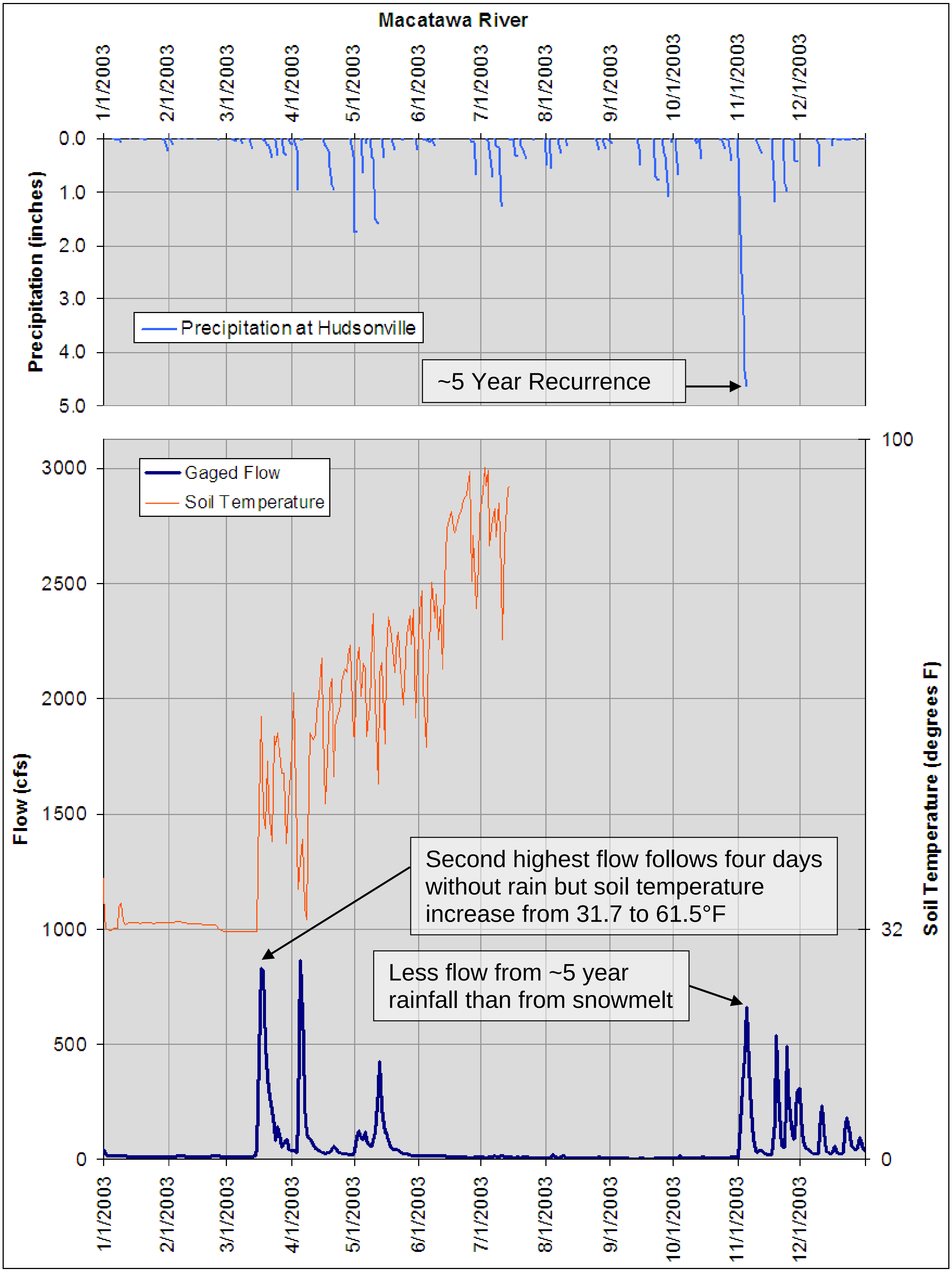


Figure 57 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2003
Soil temperature is not available for 7/15/2003 through 5/4/2004.

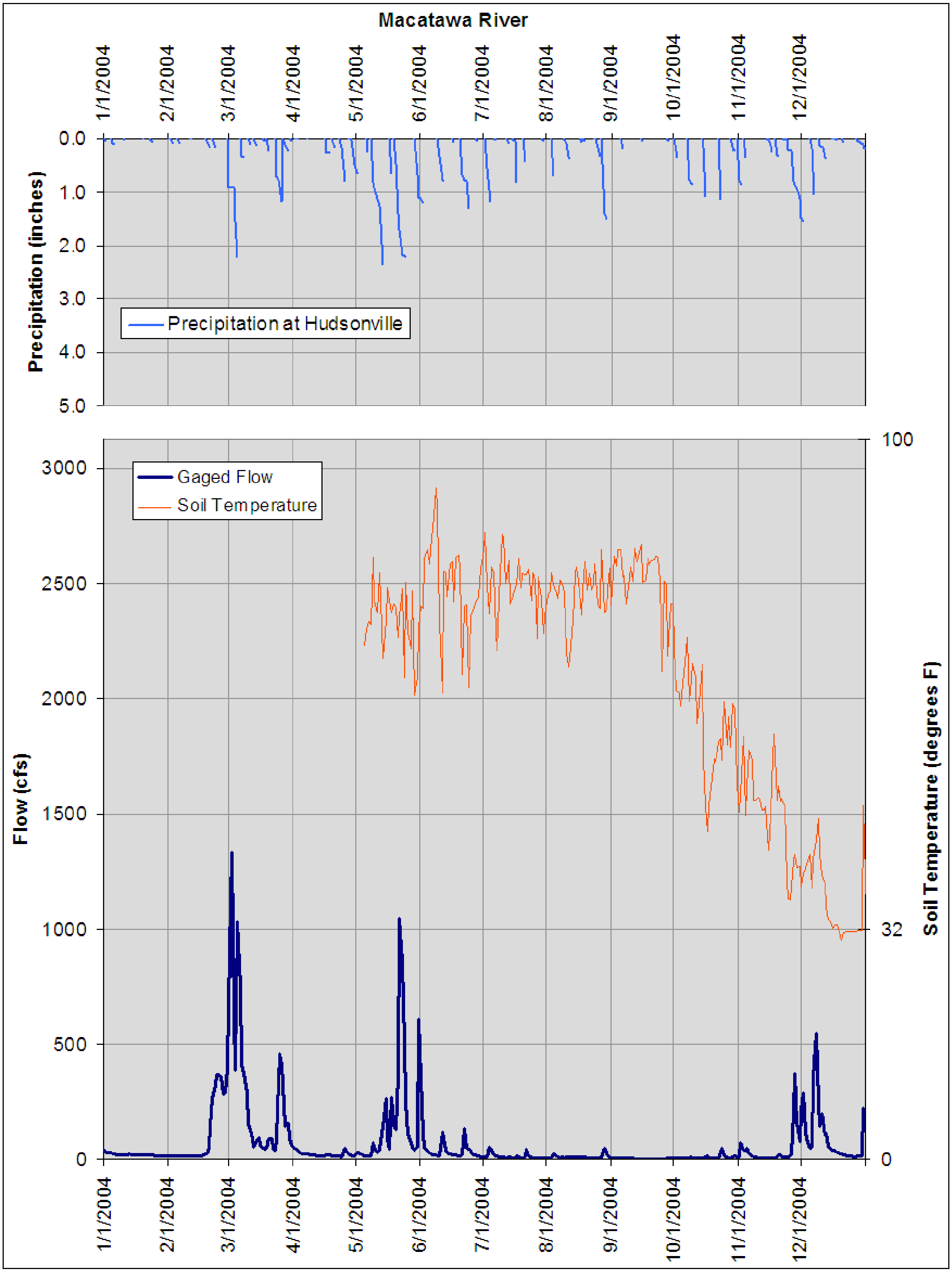


Figure 58 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2004
Soil temperature is not available for 7/15/2003 through 5/4/2004.

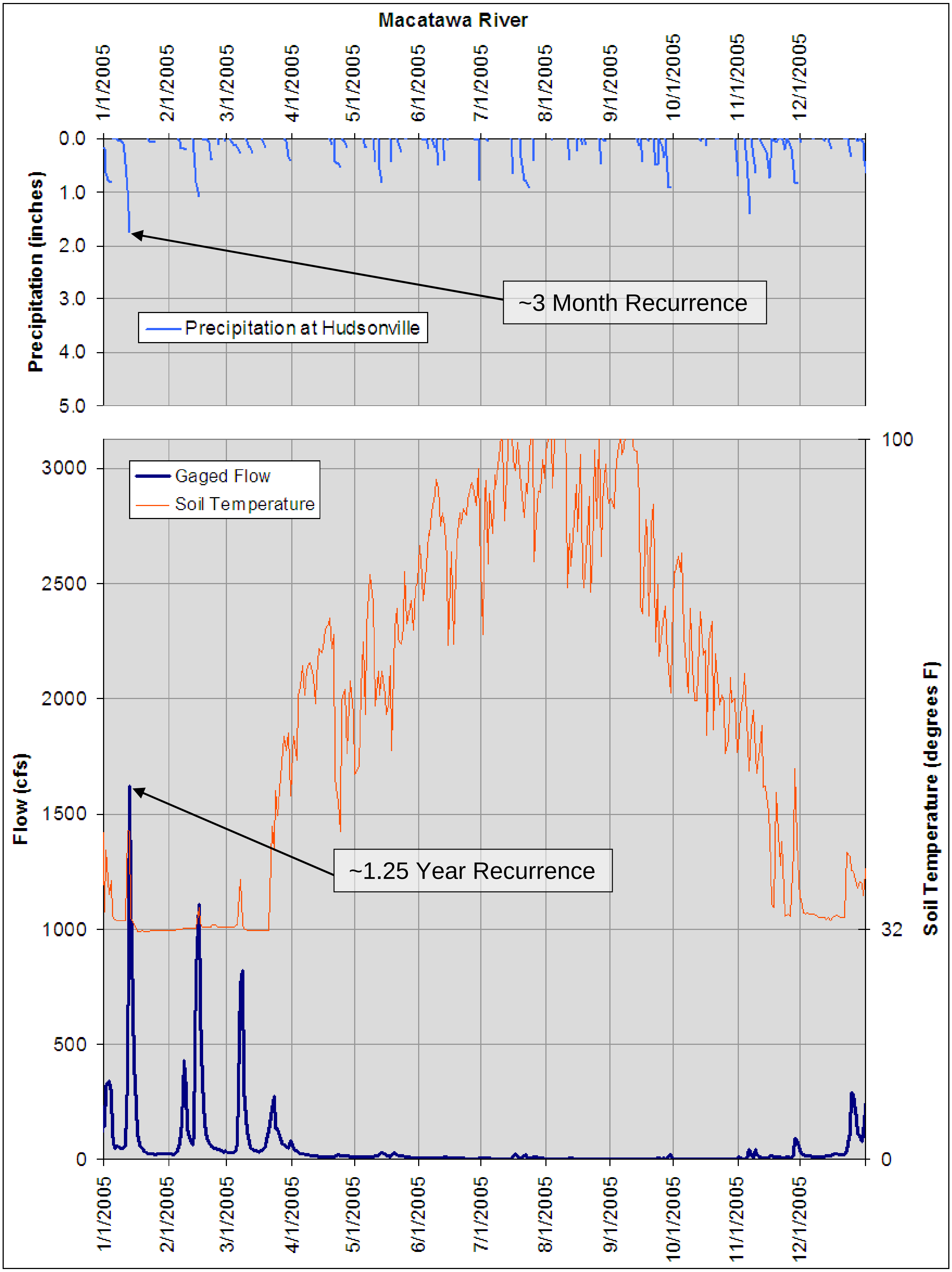


Figure 59 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2005

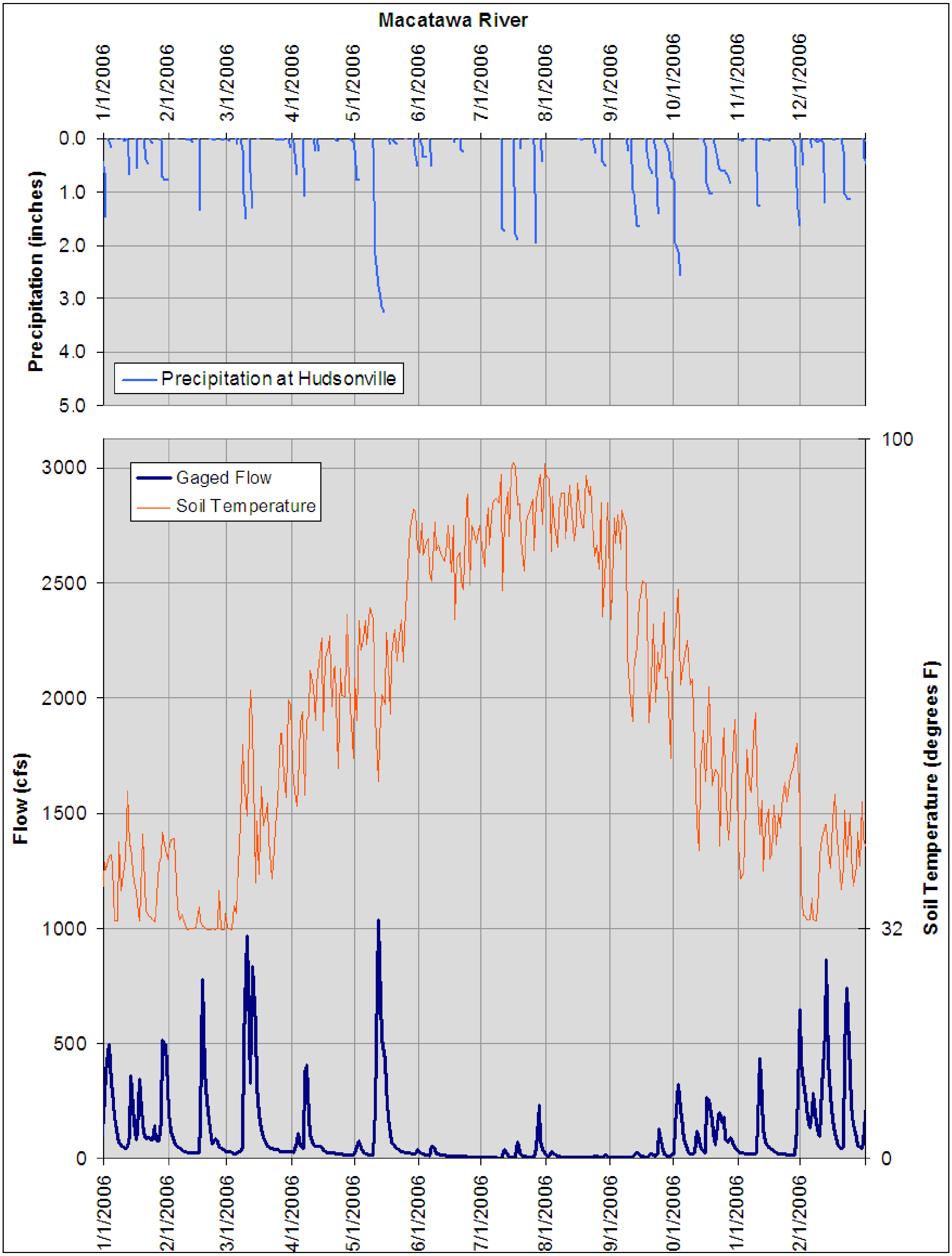


Figure 60 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2006

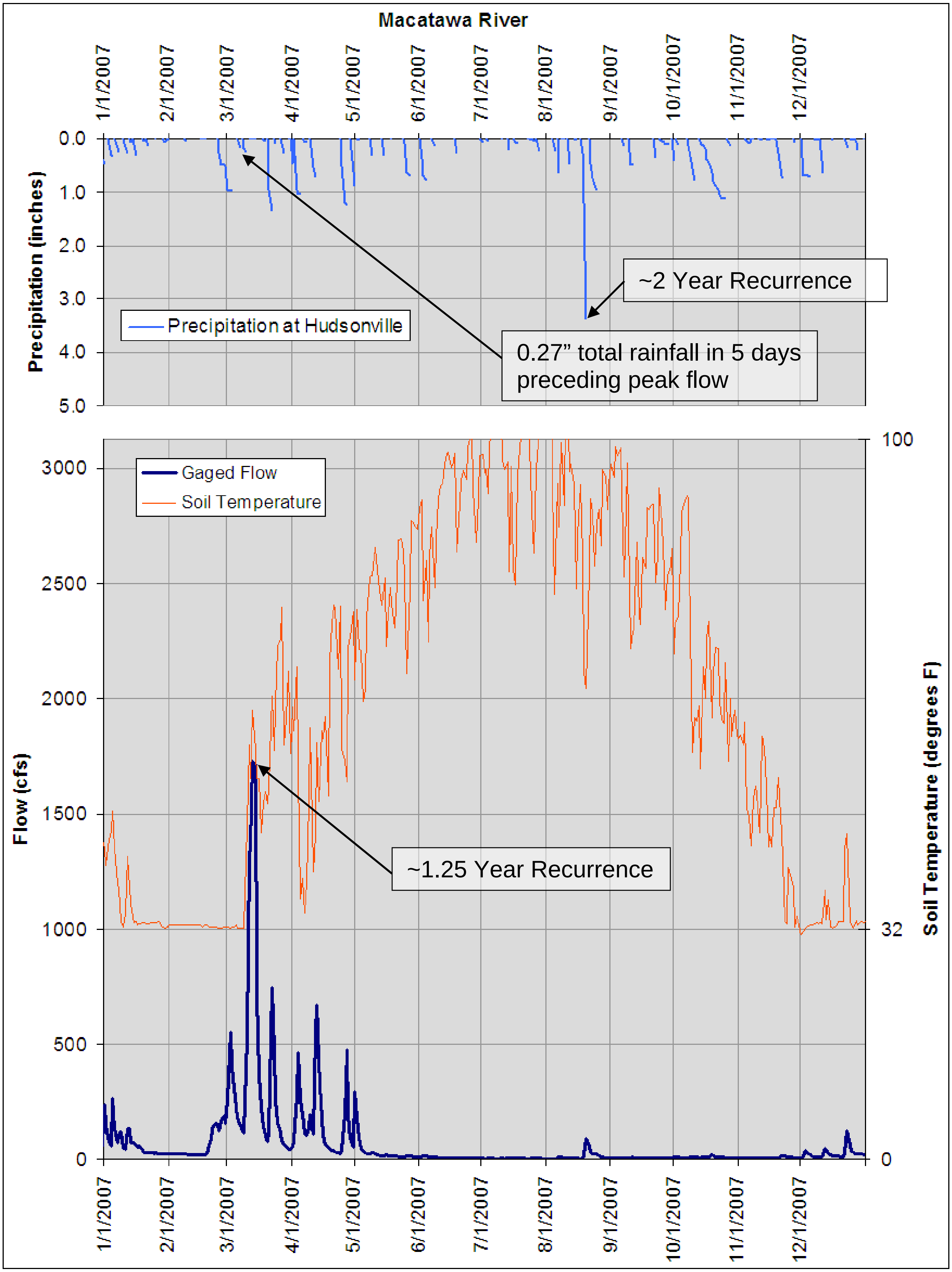


Figure 61 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2007

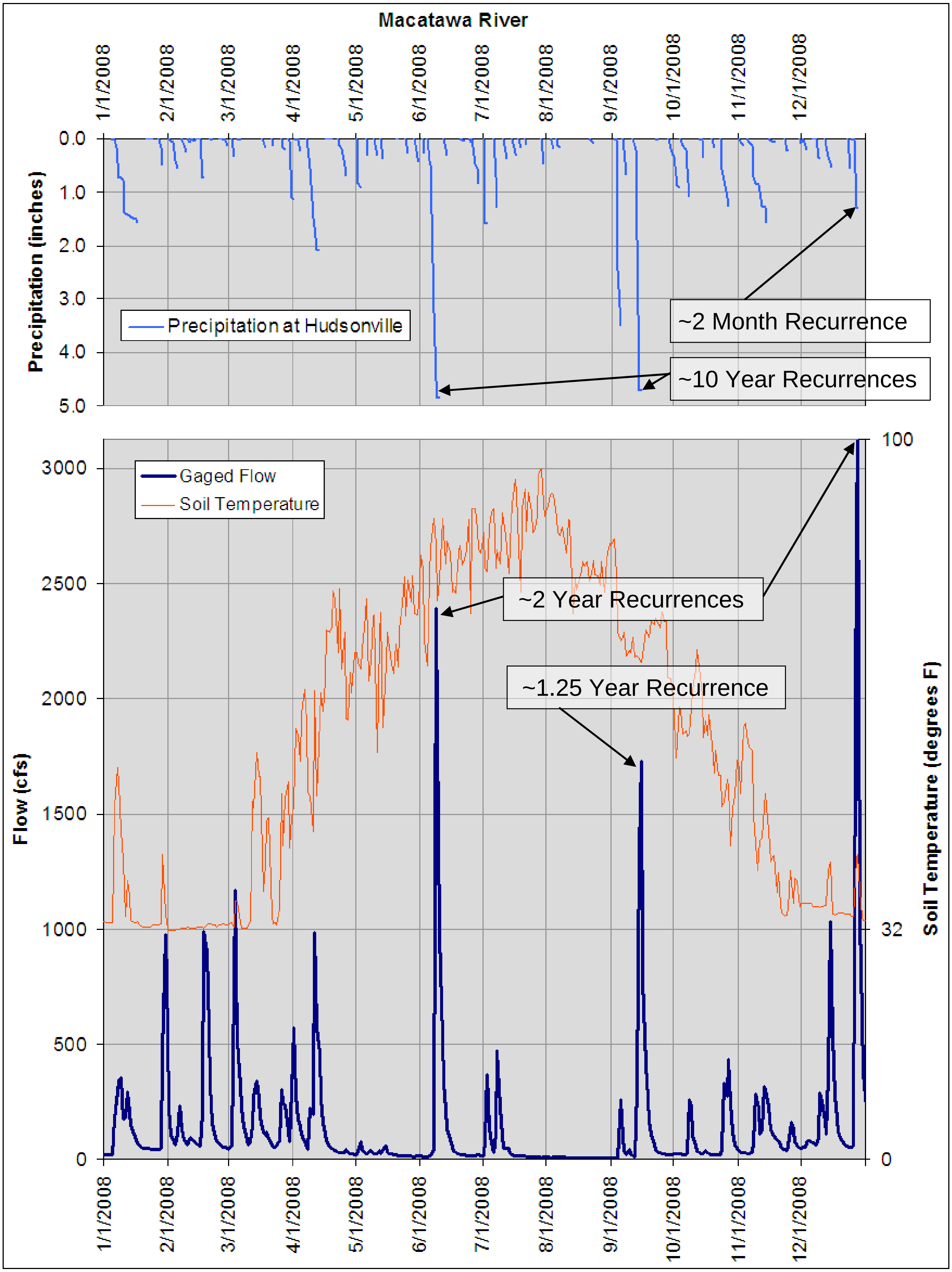


Figure 62 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2008

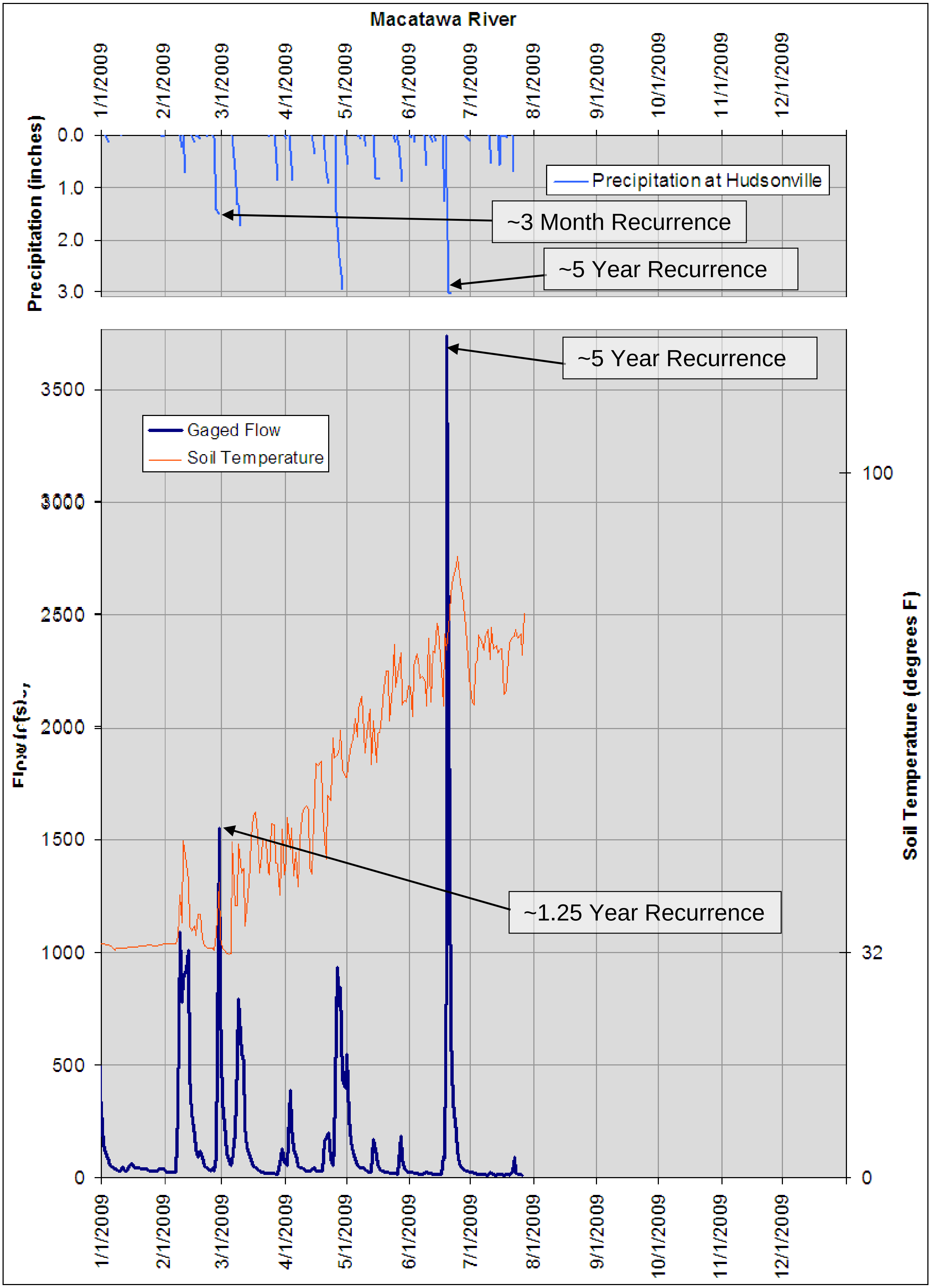


Figure 63 – Macatawa River Hydrographs, Precipitation, and Soil Temperature for 2009

Gage Analysis - Flashiness

The term flashiness reflects the frequency and rapidity of short term changes in stream flow (Baker et al, 2004). A stream described as flashy responds to rainfall by rising and falling quickly. Conversely, a stream that is not flashy would rise and fall less for an equivalent rainfall and would typically derive more of its overall flow from groundwater. An increase in flashiness is a common cause of stream channel instability. In general, flashiness changes result from hydrologic alterations. Some factors that can alter flashiness include:

- In-Stream Changes
  - Removal or change in operation of a dam
  - Expansion or straightening of the drainage network
- Watershed Land Use Changes
  - Urbanization
  - Forest regrowth
  - Soil compaction
  - Change in paved or other impervious areas
  - Use of low impact development (LID) techniques
  - Change in forestry practices
  - Change in agricultural practices
  - Change in runoff storage capacity

One approach to quantifying flashiness was proposed by Baker et al (2004). The method measures the path length of flow oscillations for data from gaged streams. Longer paths correlate with flashier streams, while more constant flows have shorter path lengths. Values for the R-B Index could theoretically range from zero to two. It would have a value of zero if the stream flow were absolutely constant. Its value increases as the path length, and therefore flashiness, increases. The Lower Rouge River hydrograph, Figure 64, illustrates the longer flow path associated with a flashy stream. The Au Sable River hydrograph illustrates the shorter flow path associated with more constant flows.

The R-B Index is one tool for diagnosing the scale of a particular stream channel problem. If the R-B Index values are steady over time, channel erosion problems in the vicinity of the USGS gage may have local, small-scale causes (e.g., cattle access) that can be addressed with a local BMP (e.g., fencing). Conversely, if the R-B Index trend indicates that flashiness is increasing over time, channel erosion problems in the vicinity of the gage station may have large scale causes (e.g., a watershed-wide increase in impervious area) and will require a large scale solution (e.g., regional stormwater management practices). Note that “in the vicinity of the gage” is not well defined. Streams that are increasingly flashy at one location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage. Similarly, flashy flows in a stream above the gage may be masked by the combined flows of other streams at the gage.

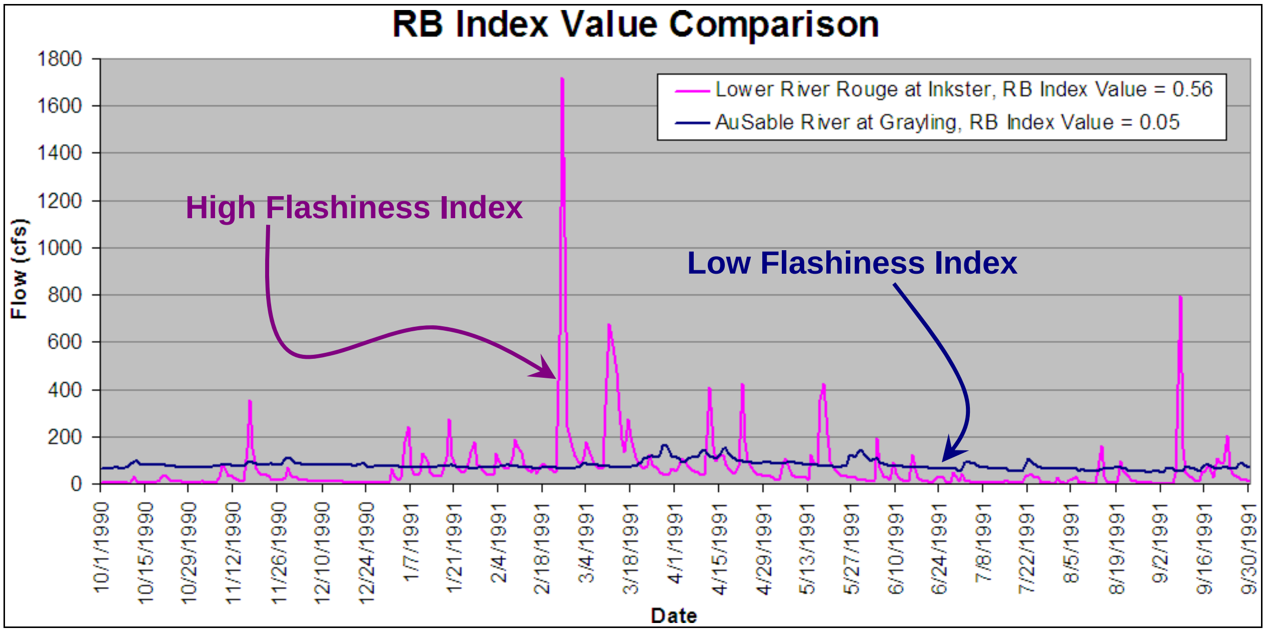


Figure 64 – Hydrographs for Two Michigan Streams

Quartile Ranking

MDEQ's NPS staff calculated yearly averaged R-B Index values and assessed trends for 279 USGS gages in Michigan that had at least five years of data through the end of water year 2004 (Fongers, 2007). The R-B Index values for Michigan ranged from 0.006 to 1.009, Figure 65. Quartile rankings are grouped by watershed size because of the natural tendency for flashiness to decrease as the drainage area increases. As watershed size increases, the varied timing of tributary flows help attenuate main channel peak flow and soils and land uses tend to diversify.

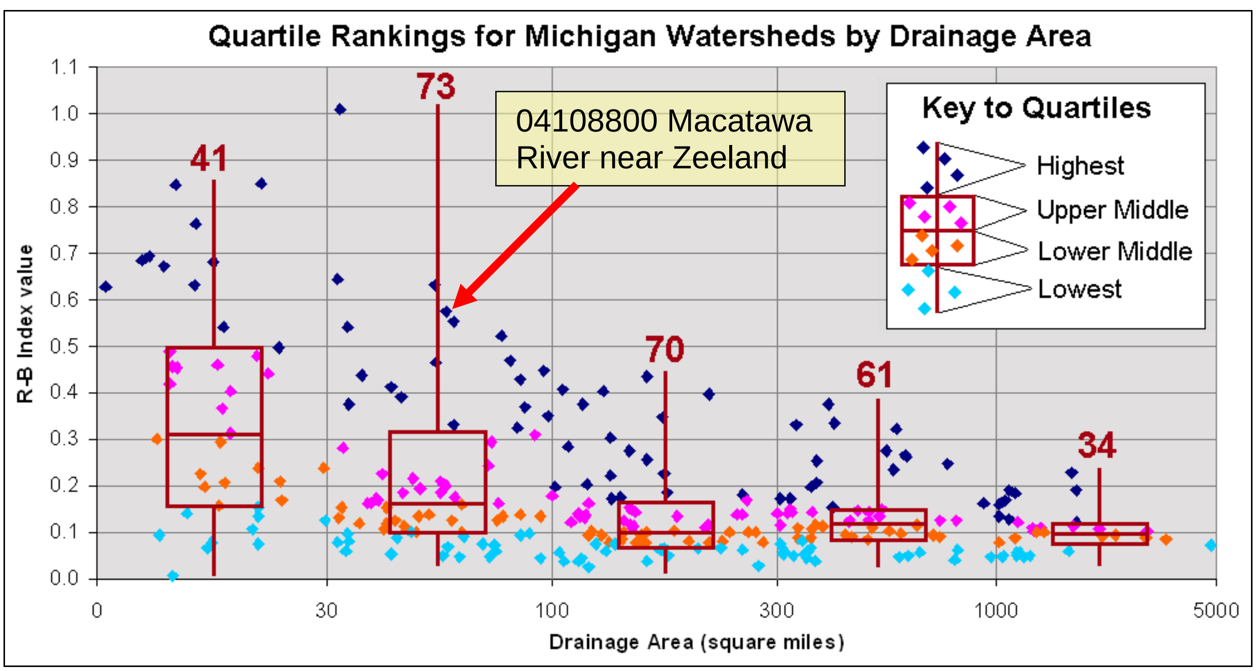


Figure 65 – Summary and Ranking of the R-B Index Values for 279 Michigan Gages

The yearly averaged R-B Index value for the Macatawa River watershed gage is 0.573, Figure 65, which is in the uppermost quartile statewide. In itself, a high or low ranking is not good or bad. For example, Saginaw Bay area gage rankings tend to be high at least partly because of the soils in that area. However, the Macatawa River gage ranking is not typical of other gages in western Michigan, Figure 66.

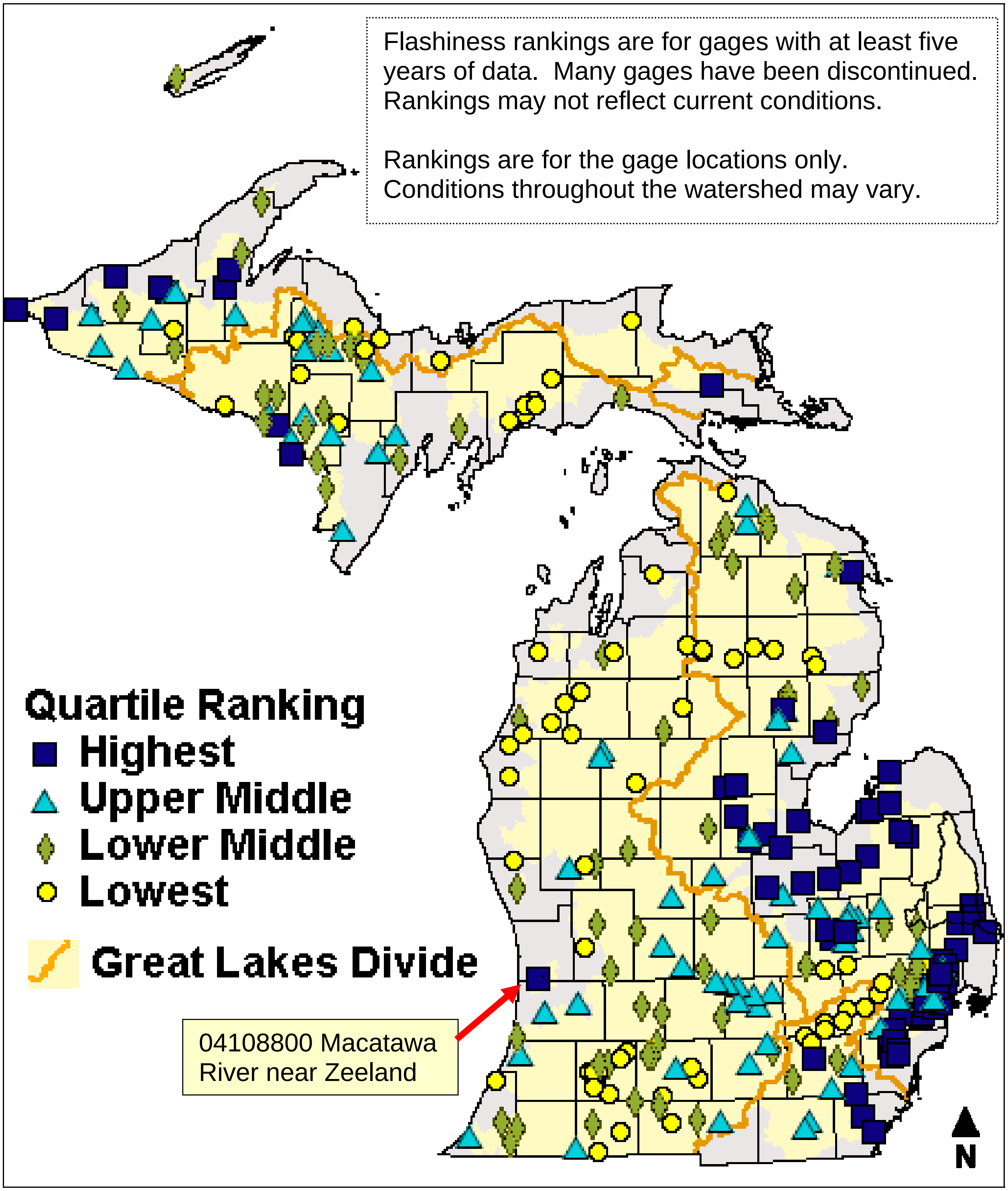


Figure 66 – Quartile Rankings, Michigan Watersheds

Trends

Fluctuations over time are apparent in a stream's R-B Index values. Some fluctuations in the R-B Index values are expected from year to year simply because of natural weather variations. Longer term trends result from hydrologic alterations within the watershed. Increasing flashiness stemming from higher peak flows or more frequent bankfull flows can result in changes to the channel shape: width, depth, sinuosity, and slope. These changes occur by erosion. This is especially true for stream channels that are steep and composed of noncohesive materials (Rhoads et al, 1991). Changes in stream channel shape, in turn, can have significant impacts on aquatic organism populations (Richards et al, 1997; Van Steeter et al, 1998). Because a stream can take 50 years or more to adapt to flow changes (Article 19 in Schueler, 2000), we restricted the trend analysis to gages in operation during the past 25 years. Consequently, any identified trends should be influencing the streams' morphology today.

The trends were based in part on visual examination of each gage's data, with linear regression used to objectively verify statistical significance. Statewide, 30 of the 210 gages in operation during the past 25 years have statistically significant decreasing trends and 41 of the gages have increasing trends, Figure 67. Many, but not all, are located near urban areas, Figure 68. This is expected because stream flow is the stream's response to many factors in a complex system – the watershed. Conversion of forest to cropland, reforestation of cropland, or a change in logging practices can have as much impact on streamflow as the transition from cropland to urban land uses. Nevertheless, urbanization, or more specifically imperviousness, has been undeniably linked with increased flashiness. When wise stormwater management is employed, adverse stream impacts can be minimized.

The Macatawa River gage does not show a statistically significant trend. The R-B Index values and trends apply only to the stream in the vicinity of the gage. Conditions at other locations in the watershed may vary. For example, flashy flows in a stream above a gage may be masked by the combined flows of other streams at the gage. Similarly, streams that are increasingly flashy at one gaged location may become stable downstream due to attenuation of flashy flows by tributary flows downstream of the gage.

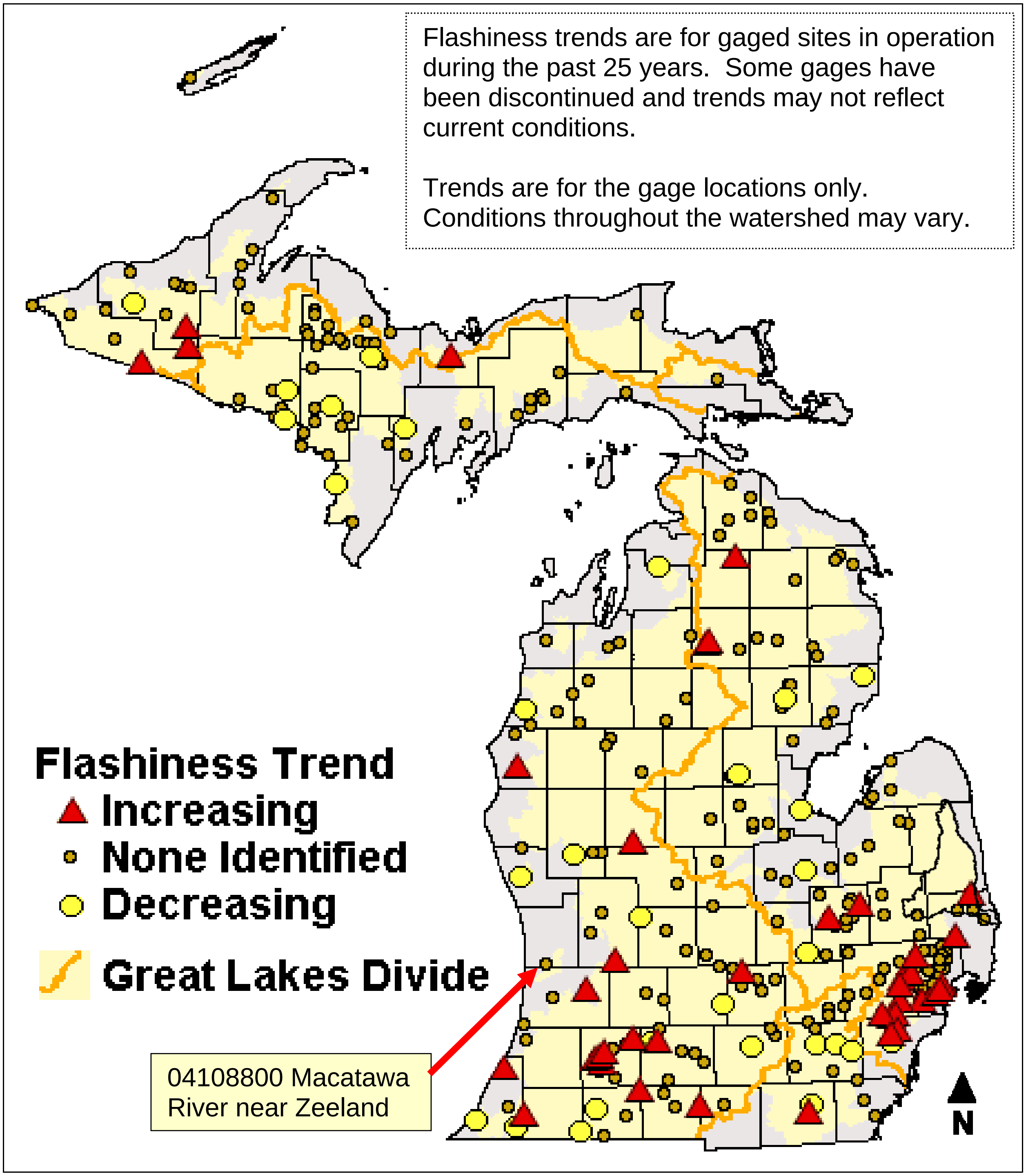


Figure 67 – Flashiness Trend by Gage, Michigan Watersheds

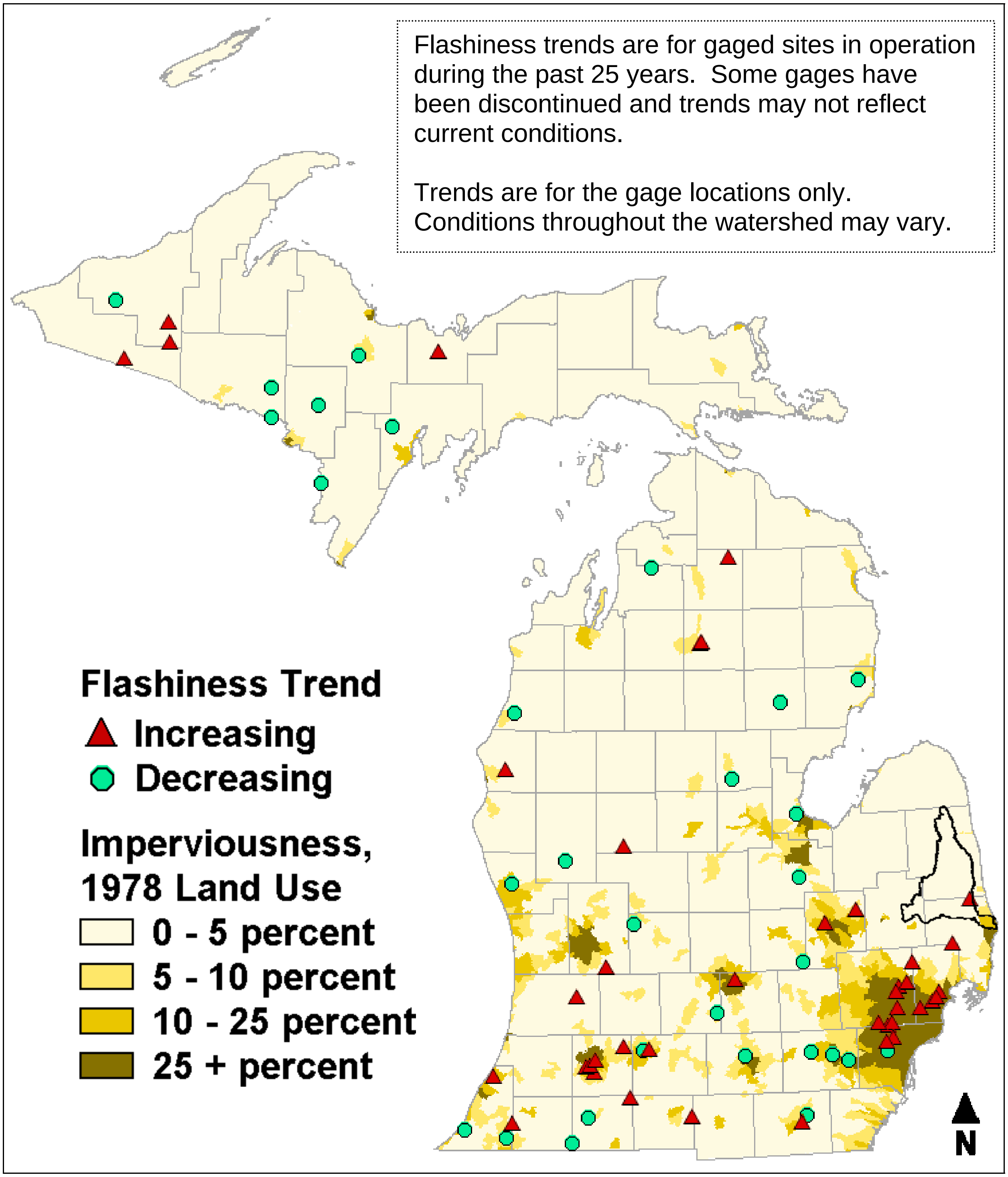
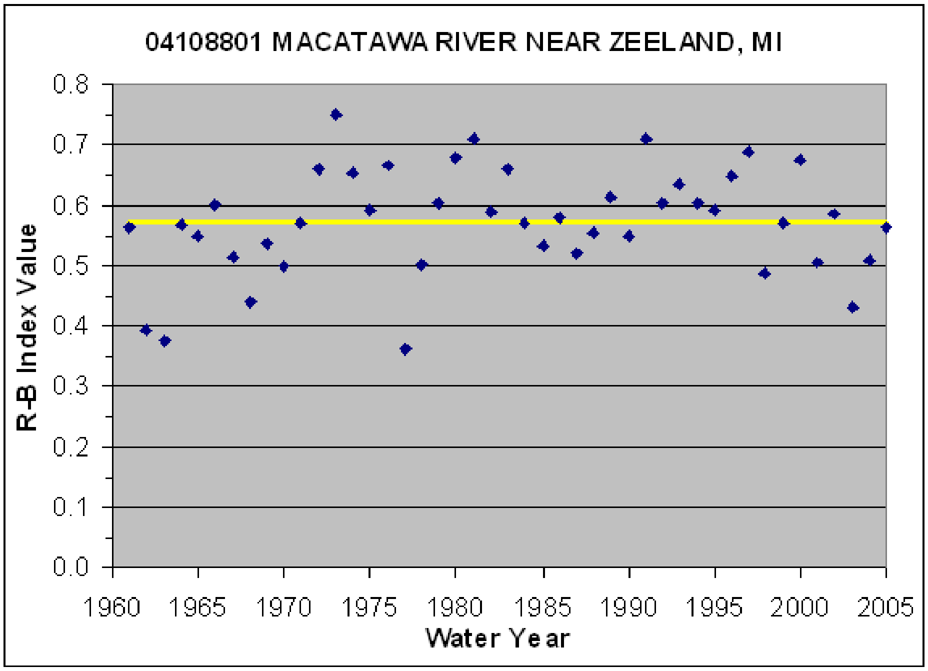


Figure 68 – Statewide Imperviousness with Flashiness Trends, 1978 Land Use

Gage Information

The graph of R-B Index values for the Macatawa River gage is shown in Figure 69. The R-B Index value average is shown as a horizontal yellow line spanning the years used to calculate the average. R-B flashiness statistical details and gage-specific information follow the graph.



Total Drainage Area: 69 square miles Average R-B Index Value: 0.573 Rank: highest Trend: none	First Water Year of Record/Analyzed: 1961 Last Water Year: 2005 Number of Years Analyzed: 45
Notes: Prior to October 1978 published as Black River near Zeeland.	

Figure 69 – USGS Gage 04108801, Macatawa River near Zeeland

Stream Morphology

Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades (fills in) nor degrades (erodes). A stable stream is in dynamic equilibrium, defined as "an open system in a steady state in which there is a continuous inflow and output of materials, in which the form or character of the system remains unchanged." (Rosgen, 2006).

Stream stability is often depicted as a balance between sediment load, sediment size, stream slope, and stream discharge, Figure 70. The stream morphology will adapt so that the left side of the equation in Figure 70 balances the right side. An increase in discharge, especially channel-forming flows, increases the stream's ability to move larger stone and soil particles, and promotes increased channel meandering and lateral bank erosion as the channel attempts to decrease its slope and enlarge its channel to restore balance.

Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural. An unstable stream is characterized by excessive, extensive erosion, with surplus sediment accumulating downstream, typically near the stream's mouth or in a lake.

Simon (1989) defined six stages of channel evolution, Table 16. The stages describe a stream's erosive evolution, starting with a stable channel (stage I) and ending with a refilled channel (stage VI). In between, the stream is disturbed by urbanization, forest clearing, dam construction, etc.

Table 16 – Stages of Channel Evolution

Stage	Stream Condition
I	Stream is stable.
II	Watershed's hydrologic characteristics change – forest clearing, urbanization, dam construction, channel dredging, etc.
III	Channel instability sets in with scouring of the bed.
IV	Bank erosion and channel widening occur.
V	Banks continue to cave into the stream, widening the channel. The stream also accumulates sediment from upstream erosion.
VI	Re-equilibrium occurs and bank erosion ceases. Riparian vegetation becomes established.

The increases in stormwater runoff indicate that the morphology of the Macatawa River and its tributaries have had to adapt, and may be continuing to adapt, to higher flows through channel evolution processes. It is beyond this study's scope to identify the evolutionary stage of a specific reach of the Macatawa River or its tributaries.

Future hydrologic changes can further impact stream morphology, as well as water quality. These changes can be moderated with effective stormwater management techniques, such as treatment of the "first flush" runoff, wetland protection, retention and infiltration of excess runoff, low impact development techniques, 24-hour extended detention of 1-year flows, and properly designed detention of runoff from low probability storms. Refer to the Stormwater Management section for more detail.

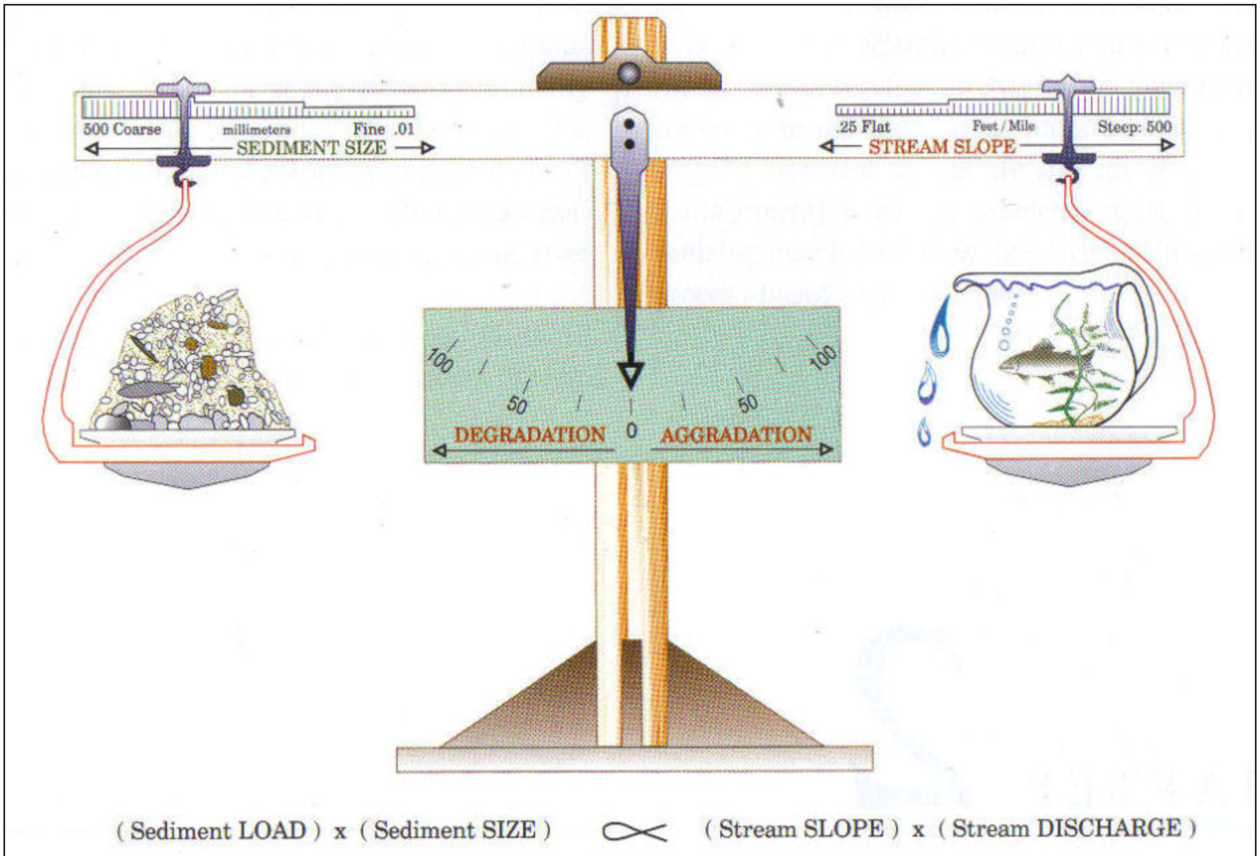


Figure 70 – Generalized Stable Channel Relationship proposed by Lane in 1955 (illustration from Rosgen 1996)

Critical Areas/Recommendations

A river or stream is affected by everything in its watershed. Watershed plans, however, identify critical areas to focus limited technical and financial resources on the parts of the watershed contributing a disproportionate share of the pollutants. For this report, critical areas are based solely on hydrologic criteria. For the watershed management plan, the Macatawa Area Coordinating Council will likely modify these selection criteria.

The selection criteria used for this report are shown in Table 17. Runoff volume per area and peak flow yield, calculated from 2005 land use, highlights those subbasins currently contributing the most runoff or are the most hydrologically responsive. Changes in runoff volume per area and peak flow yield, calculated from 1800 to 1978 and 1978 to 2005 land use, highlights those subbasins that have experienced the most hydrologic change. Percent imperviousness highlights subbasins that contribute the most urban runoff. The results are shown in Table 18 and Figure 71.

If the Macatawa Area Coordinating Council chooses to focus one or more major subwatersheds and then select critical area subbasins within those subwatersheds, these ranking criteria could be selectively applied to the subbasins with just the selected subwatershed(s).

Table 17 – Critical Area Scoring

Condition	Standard	Score
Runoff Volume per Area, 2005 Land Use	0 – 0.25 inches	0
	0.25 – 0.50 inches	2
	0.50 – 0.75 inches	5
	0.75 – 1.00 inches	10
	over 1.00 inch	15
Runoff Volume Increase per Area, 1800 to 1978 Land Use	Decrease	0
	0.00 – 0.25 inches	3
	0.25 – 0.50 inches	5
	Over 0.50 inches	10
Runoff Volume Increase per Area, 1978 to 2005 Land Use	Decrease	0
	0.00 – 0.25 inches	5
	Over 0.25 inches	10
Peak Flood Flow Yield, 2005 Land Use	Not Applicable	0
	0 – 0.025	0
	0.025 – 0.050	2
	0.050 – 0.075	5
	0.075 – 1.000	10
	Over 0.100	15
Peak Flood Flow Yield Change, 1800 to 1978 Land Use	Not Applicable	0
	Decrease	0
	0 – 50 percent	1
	50 – 100 percent	3
	100 – 200 percent	5
	Over 200 percent	10
Peak Flood Flow Yield Change, 1800 to 1978 Land Use	Not Applicable	0
	Decrease	0
	0 – 50 percent	10
Imperviousness, 2005	0 – 5 Percent	0
	6 – 10 Percent	5
	11 – 20 Percent	10
	21 – 25 Percent	20
	over 25 Percent	30

Table 18 – Subbasin Critical Area Scores, higher total scores highlighted with colors similar to Figure 71.

ID	Subbasin	Runoff Volume, 2005	Runoff Volume Change, 1800 to 1978	Runoff Volume Change, 1978 to 2005	Peak Flow Yield, 2005	Peak Flow Yield Change, 1800 to 1978	Peak Flow Yield Change, 1978 to 2005	Imperviousness, 2005	Total Score
	Upper Macatawa								
1	Beaver Dam Drain to Macatawa River	10	5	0	5	5	0	0	25
2	Macatawa River to Beaver Dam Drain	10	5	0	5	5	0	5	30
3	Macatawa River at 72nd Avenue	5	3	0	2	5	0	5	20
4	Macatawa River at I-196 Overpass	10	5	5	5	10	0	10	45
5	Macatawa River to Hunderman Creek	10	5	5	10	10	0	5	45
6	Big Creek to Hunderman Creek	10	5	0	5	5	0	0	25
7	Hunderman Creek to Big Creek	10	5	0	5	5	10	0	35
8	Hunderman Creek to Macatawa River	5	5	10	5	10	0	5	40
9	Macatawa River to South Branch	5	5	5	2	5	0	10	32
	Peters Creek								
10	Unnamed tributary to Peters Drain	10	5	5	5	3	10	0	38
11	Peters Drain	10	5	5	5	3	10	0	38
12	Unnamed tributary to Peters Creek	10	5	0	2	3	10	0	30
13	Peters Creek to Macatawa River	2	3	5	2	3	0	0	15
	South Branch Macatawa River								
14	Kleinheksel Drain to South Branch	10	5	5	5	10	10	0	45
15	Jaarda Drain to South Branch	10	5	0	5	5	10	0	35
16	South Branch Macatawa River to Jaarda Drain	10	3	5	2	5	0	0	25
17	South Branch Macatawa River to tributary near 146th	5	3	5	2	5	10	5	35
18	East Fillmore Drain (including Eskes Drain)	10	5	0	5	5	10	0	35
19	South Branch Macatawa River to Macatawa River	10	5	0	0	3	0	0	18
	North Branch Macatawa River								
20	North Branch Macatawa River to Den Bleyker Drain	10	5	0	2	5	10	5	37
21	Vanderbie Drain and Rotman Drain	10	5	5	10	3	10	10	53
22	North Branch Macatawa River to Den Bleyker Drain	15	5	10	10	5	10	30	85
23	Den Bleyker Drain	15	5	10	10	5	10	30	85
24	North Branch Macatawa River at M-40	15	5	10	10	5	10	30	85
25	North Branch Macatawa River to Macatawa River	10	5	10	2	3	10	10	50
	Noordeloos Creek								
26	Bosch and Hulst Drain at 104th Avenue	2	0	10	0	3	0	0	15
27	Bosch and Hulst Drain to Noordeloos Creek	10	5	0	2	10	0	0	27
28	Tributary to Bosch and Hulst Drain to Noordeloos Creek	5	3	10	2	5	0	0	25
29	Hunters Creek to Brower Drain	5	5	5	5	10	10	5	45
30	Brower Drain to Hunters Creek	15	10	10	5	10	10	30	90
31	Noordeloos Creek to Drain #52	10	5	5	2	5	0	5	32
32	Cedar Drain to Noordeloos Creek	10	5	10	10	10	10	30	85
33	Drain #4 and 43 to Noordeloos Creek	10	5	10	5	10	0	20	60
34	Noordeloos Creek to Macatawa River	10	5	10	2	5	10	20	62
	Lower Macatawa River								
35	Macatawa River to North Branch	15	5	10	2	5	10	10	57
36	Macatawa River to Noordeloos Creek	10	5	10	2	5	0	10	42
37	North Holland Creek to Drain #40	10	3	10	2	3	10	10	48
38	Drain #15 and 17 to Drain #40	10	3	10	5	5	10	10	53

ID	Subbasin	Runoff Volume, 2005	Runoff Volume Change, 1800 to 1978	Runoff Volume Change, 1978 to 2005	Peak Flow Yield, 2005	Peak Flow Yield Change, 1800 to 1978	Peak Flow Yield Change, 1978 to 2005	Imperviousness, 2005	Total Score
39	Drain #40 to Macatawa River	15	3	10	5	5	10	30	78
40	Macatawa River to Windmill Island	15	10	10	2	10	10	30	87
41	Maplewood Intercounty Drain to Macatawa River	15	10	10	10	10	10	30	95
Pine Creek									
42	Troost & Boven Dam Drains to Pine Creek/Harlem Drain	5	3	5	2	3	10	0	28
43	Pine Creek/Harlem Drain at Quincy St.	2	0	10	0	0	10	5	27
44	Pine Creek/Harlem Drain to Drain #37	5	3	10	0	5	10	20	53
45	Drain #37 to Pine Creek/Harlem Drain	2	0	10	0	1	0	0	13
46	Pine Creek/Harlem Drain to Lake Macatawa	5	5	10	2	10	10	30	72
Direct Drainage to Lake Macatawa									
47	Macatawa River/Lake Macatawa	15	5	10	0	0	0	30	60
48	Winstrom Cr. and Drains #20A, 23, 53 to Lake Macatawa	2	3	10	0	3	10	10	38
49	Old Lela Drain to Lake Macatawa	10	5	10	15	5	10	30	85
50	Weller Drain to Lake Macatawa	10	5	0	15	5	0	10	45
51	Arbor Creek to Lake Macatawa	5	5	5	15	3	10	10	53
52	Ottogan Intercounty Drain to Lake Macatawa	5	3	0	5	5	0	5	23
53	Kelly Lake Drain to Lake Macatawa	2	3	5	0	3	0	5	18
54	East Lake Macatawa drainage (does not include lake)	10	10	10	0	0	0	30	60
55	West Lake Macatawa drainage (does not include lake)	2	5	10	0	0	0	10	27

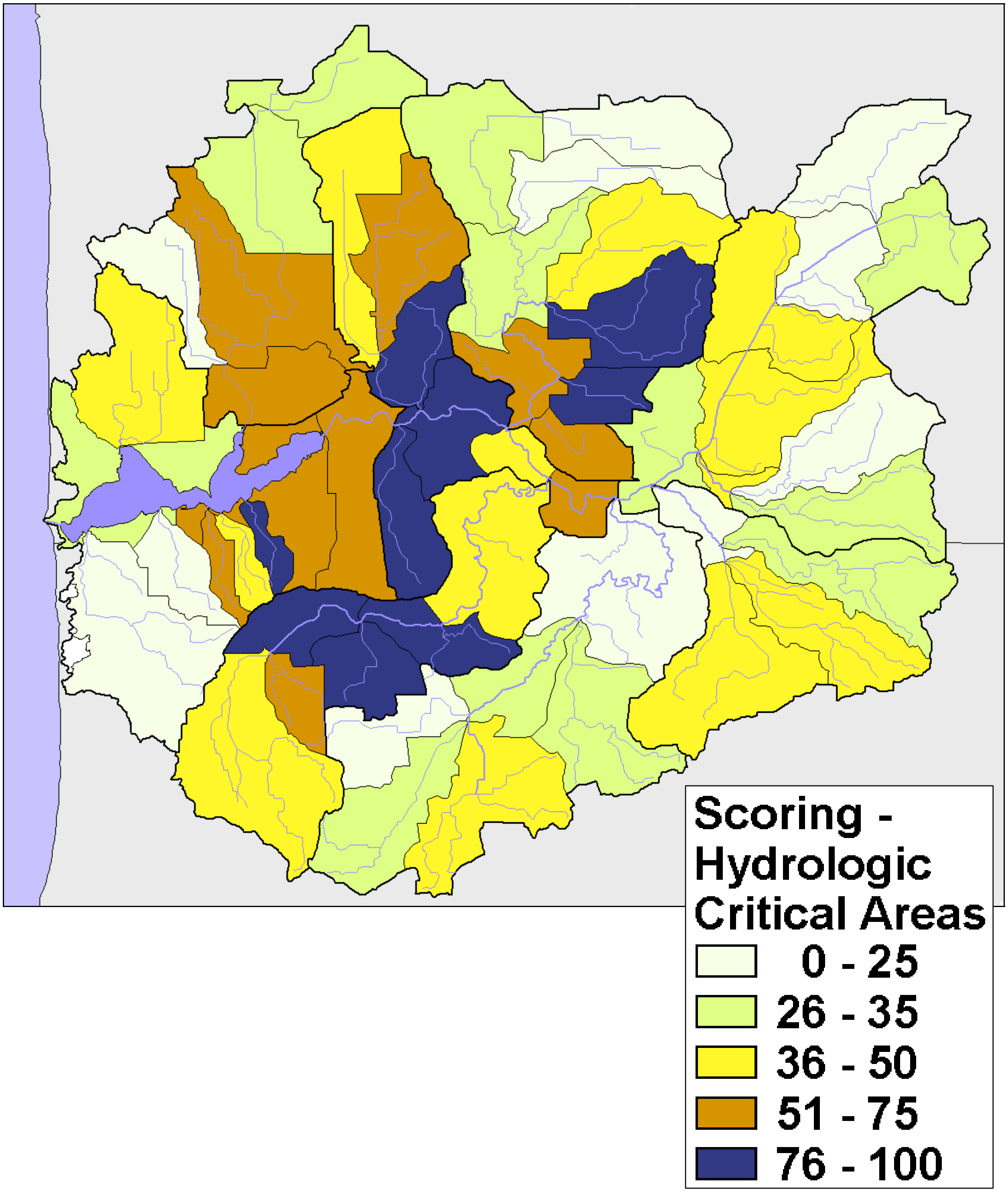


Figure 71 – Hydrologic Critical Areas

Stormwater Management

When precipitation falls, it can infiltrate into the ground, evapotranspirate back into the air, or run off the ground surface to a water body. It is helpful to consider three principal runoff effects: water quality, channel shape, and flood levels, as shown in Figure 72.

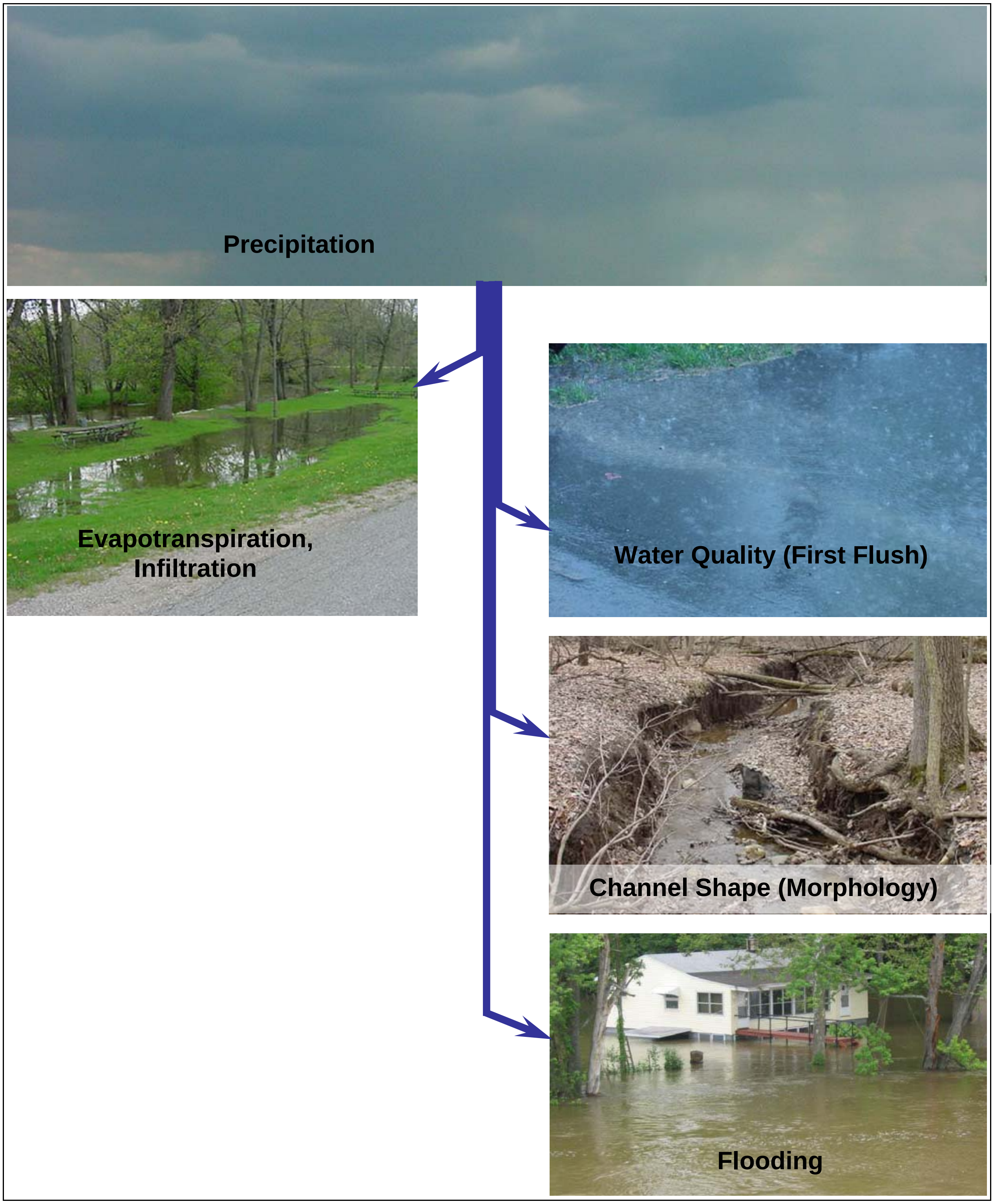


Figure 72 – Runoff Impacts

Land use changes that reduce evapotranspiration and infiltration increase runoff. One reason low impact development (LID) has become increasingly popular is that it avoids creating more runoff; intercepting and infiltrating the excess runoff instead. For more information, refer to the Low Impact Development Manual for Michigan at http://library.semcog.org/InmagicGenie/DocumentFolder/LIDManualWeb.pdf.

Runoff from small rainfall events and the first portion of the runoff from larger events is termed the “first flush”, because it carries the majority of the pollutants. For more information, refer to the Water Quality section.

Larger, but frequent, storms or snowmelts produce the flows that shape the channel. 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. 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. For more information, refer to the Stream Channel Protection section.

Increases in the runoff volume and peak flow from large storms, such as the 4 percent chance (25-year), 24-hour storm, could cause or aggravate flooding problems unless mitigated using effective stormwater management techniques. For more information, refer to the Flood Protection section.

Water Quality

Small runoff events and the first portion of the runoff from larger events typically pick up and deliver the majority of the pollutants to a watercourse in an urban area (Menerey, 1999 and Schueler, 2000). As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 73 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first flush." Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet. The volume of runoff recommended for treatment is calculated as follows:

- **0.5 inch of runoff** from a single impervious area. This criteria was one of the first to define the “first flush” phenomenon by studying runoff from parking lots. It has been widely used as the design water quality volume. Additional research has found that this criterion for water quality volume only applies to the runoff from a single impervious area, such as the parking lot to a single development. It is the minimum value that could be expected to capture the runoff containing the most pollutants. It is not appropriate to use for a mixture of impervious areas and pervious areas. It is also not appropriate to use for multiple impervious areas treated by a single BMP or multiple BMPs. Although it may have applications in some limited circumstances, it is not recommended that this method be used to calculate water quality volume.

- **1 inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas.** This method provides reasonable certainty that the runoff containing the majority of pollutants from impervious areas is captured and treated by applying a simple calculation. It assumes that disturbed pervious areas contribute less runoff and therefore less pollutant to the BMPs selected. This method is recommended when the percentage of impervious area on a site is small and both pervious and impervious areas are treated by the same BMP.
- **1 inch of runoff from disturbed pervious and impervious areas.** The most conservative water quality volume calculated with a simple formula. It virtually assures that all of the first flush from any site will be captured and treated. However, when calculated this way, the water quality volume may exceed the channel protection volume. This volume determined using this method should always be compared to the channel protection volume to determine if additional water quality treatment is necessary. This method is recommended when the amount of pervious area is small or when it is desired to obtain the most conservative estimate of volume needing treatment.
- **90% of runoff producing storms.** This method determines the water quality volume by calculating the runoff generated from the 10 percent exceedance rain event for the entire site. In Michigan, that event varies from 0.77 to 1.00 inches. For the Macatawa watershed climatic regions, the calculated value is 0.87 to 0.92 inches. This method provides a more rigorous analysis based on the site's hydrologic response. To accurately represent the pervious portion of runoff needing treatment, the runoff calculation for this method must use the small storm hydrology method described in www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf. The water quality volume calculated in this way produces a lower volume than using 1 inch of runoff but still assures treatment of the first flush. This method is recommended when a precise estimate of water quality volume is desired or for multiple, distributed sites treated by one BMP.

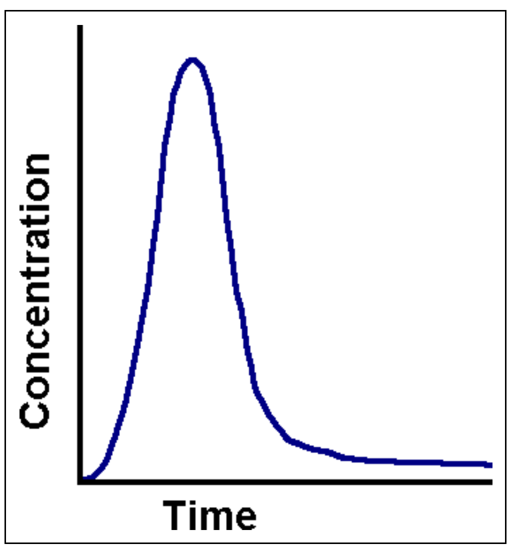


Figure 73 – Plot of Pollutant Concentration versus Time

Stream Channel Protection

A stable stream is one that, over time, maintains a stable morphology: a constant pattern (sinuosity), slope, and cross-section, and neither aggrades or degrades. Stream stability is not the absence of erosion; some sediment movement and streambank erosion are natural.

Possible causes of erosion are:

- Natural river dynamics
- Sparse vegetative cover due to too much animal or human traffic
- Concentrated runoff adjacent to the streambank, i.e. gullies, seepage
- In-stream flow obstructions, i.e. log jams, failed bridge supports
- An infrequent event, such as an ice jam or low probability flood
- Unusually large or frequent wave action
- A significant change in the hydrologic characteristics (typically land use) of the watershed
- A change in the stream form impacting adjacent portions of the stream, i.e. dredging, channelization

An assessment of the cause(s) of erosion is necessary so that proposed solutions will be permanent and do not simply move the erosion problem to another location. The first six listed causes can produce localized erosion. Either of the last two causes, however, could produce a morphologically unstable stream. Symptoms of active channel enlargement in an unstable stream include:

- Down-cutting of the channel bottom
- Extensive and excessive erosion of the stream banks
- Erosion on the inside bank of channel bends
- Evidence in the streambanks of bed erosion down through an armor layer
- Exposed sanitary or storm sewers that were initially installed under the stream bed

Erosion in a morphologically unstable stream is caused by increases in the relatively frequent channel-forming flows that, because of their higher frequency, have more effect on channel form than extreme flood flows. As shown in Figure 74, multiplying the sediment transport rate curve (a) by the storm frequency of occurrence curve (b) yields a curve (c) that, at its peak, indicates the flow that moves most of the sediment in a stream. This flow is termed the effective discharge. The effective discharge usually has a one- to two-year recurrence interval and is the dominant channel-forming flow in a stable stream.

Increases in the frequency, duration, and magnitude of these flows cause stream bank and bed erosion as the stream adapts. According to the *Stream Corridor Restoration* manual, stream channels can often enlarge their cross-sectional area by a factor of 2 to 5 (FISRWG, 10/1998). In *Dynamics of Urban Stream Channel Enlargement, The Practice of Watershed Protection*, ultimate channel enlargement ratios of up to approximately 10 are reported, as shown in Figure 75 (Schueler and Holland, 2000). To prevent or minimize this erosion, watershed stakeholders should specifically consider stormwater management to protect channel morphology. Low impact development and infiltration BMPs can be incorporated to offset flow increases. Stormwater management ordinances can specifically address channel protection. However, where ordinances have included channel protection criteria, it has typically been focused on controlling peak flows from the 2-year storm.

The nationally recognized Center for Watershed Protection asserts that 24-hour extended detention for runoff from 1-year storms better protects channel morphology than 2-year peak discharge control because 2-year peak discharge control does not reduce the frequency of erosive bankfull and sub-bankfull flows that often increase as development occurs within the watershed. Indeed, it may actually increase the duration of these erosive, channel-forming flows. The intent of 24-hour extended detention for runoff from 1-year storms is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 76. As part of a Lower Grand River watershed NPS grant, an analysis of extended detention volume and release rates by runoff curve number has been performed for each of Michigan's ten climatic regions (FTCH, 2009). The Macatawa watershed is in climatic region 8. The detention design parameter curves are shown in Figure 77.

Channel-forming flow controls may not be needed for runoff routed from a city through storm sewers to a large river or lake, such as Lake Macatawa, simply because the runoff routed through the storm sewers enters the lake or river well ahead of the peak flood flow. In this case, the management plan for stormwater routed through storm sewers should focus on treating the runoff to maintain water quality and providing sufficient drainage capacity to minimize flooding. Detention/retention might also be encouraged or required for other reasons, such as water quality improvement, groundwater replenishment, or if watershed planning indicates continued regional development would alter the river's flow regime or increase flood levels.

Further hydrologic and hydraulic modeling may be justified to determine if runoff from a drainage area should be limited, either by detention or infiltration, to prevent flow or flood level increases or to verify that flood peaks are not increased due to the timing of the peak flows from detention ponds and in the stream.

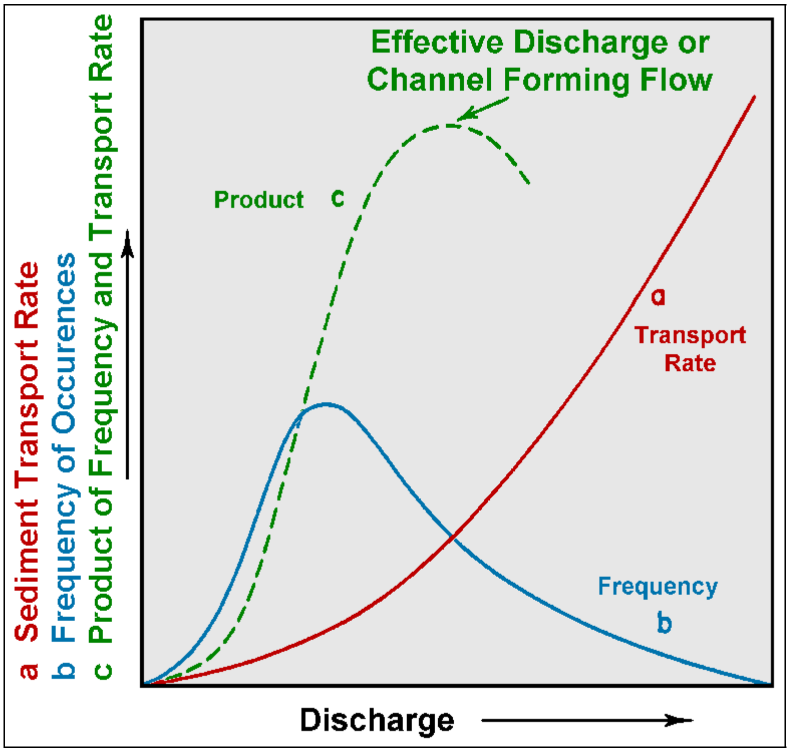


Figure 74 – Effective Discharge (from *Applied River Morphology*, Dave Rosgen, 1996)

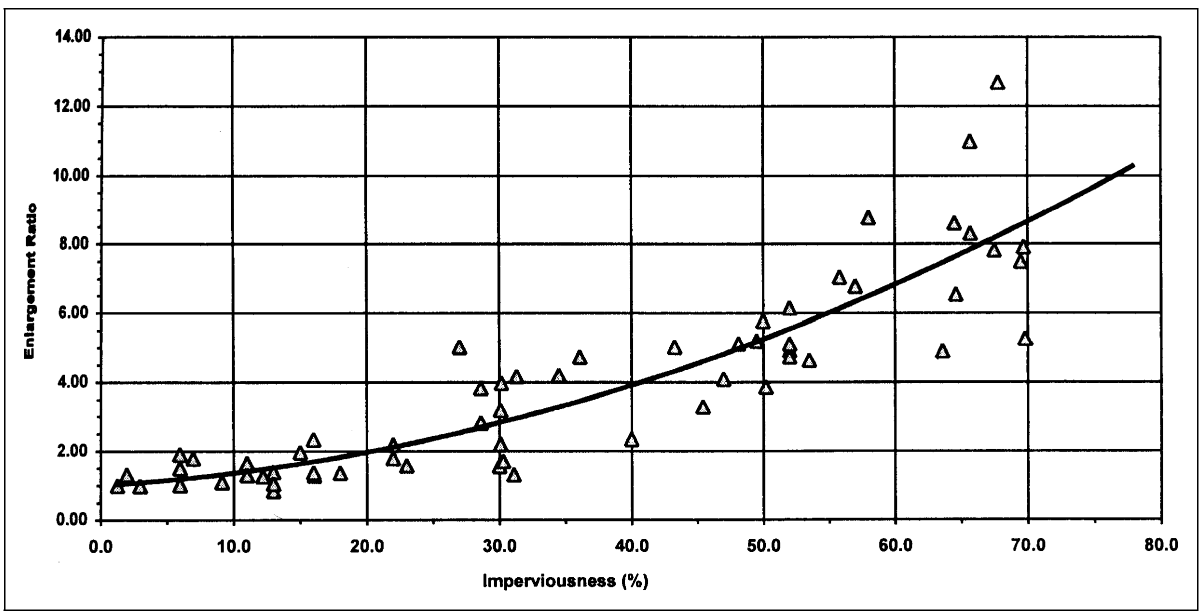


Figure 75 – "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

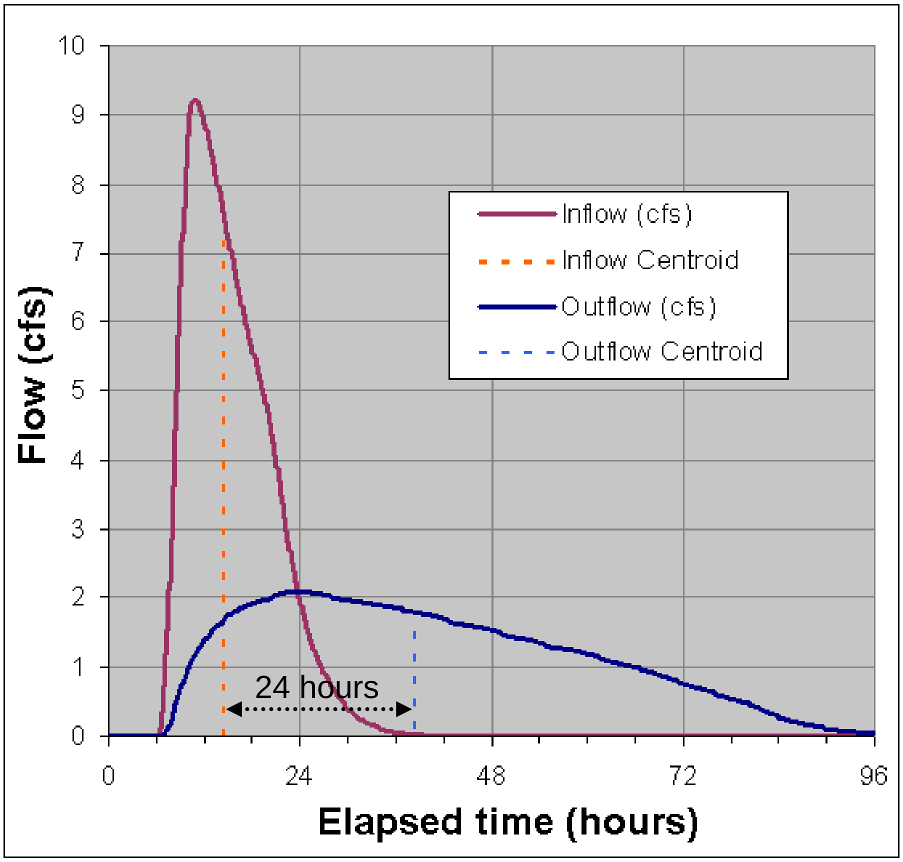


Figure 76 – Example of 24-hour extended detention criterion applied to detention pond design

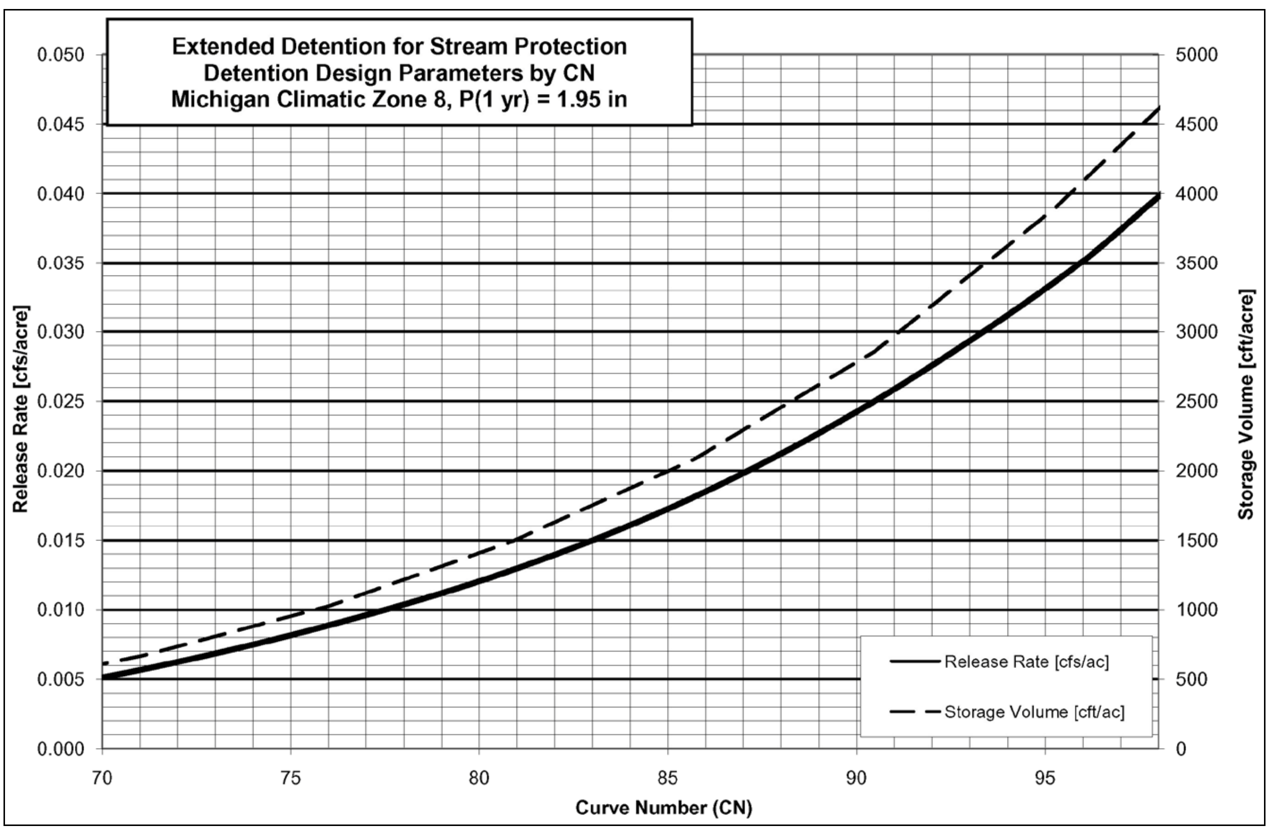


Figure 77 – 24-hour extended detention for the Macatawa watershed (from FTCH 2009)

Flood Protection

A river, stream, lake, or drain may occasionally overflow its banks and inundate adjacent land. This land is the floodplain. The floodplain refers to the land inundated by the 1 percent chance flood, commonly called the 100-year flood. Typically, a stable stream will recover naturally from these infrequent events. Developments should always include stormwater controls that prevent flood flows from exceeding pre-development conditions and putting people, homes, and other structures at risk, Figure 78. Many localities require new development to control the 4 percent chance flood, commonly called the 25-year flood, with some adding requirements to control the 1 percent chance flood.

Figure 78 – Mason County Flooding, June 2008, photo courtesy of Raymond Holt, Michigan State Police

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Appendix A: Macatawa Hydrologic Parameters

This appendix is provided so that the model may be recreated, although the curve numbers listed were calculated to replicate runoff volumes calculated using the weighted Q method and as such are only applicable to the design rainfall in this study.

Table A1 details the land use percentages for each subbasin and model scenario as used to calculate runoff. Non-contributing areas and pits are not included. Figure A1 illustrates the hydrologic elements in the HEC-HMS model. Table A2 provides the hydrologic parameters specified for each of the subbasin elements in the hydrologic analysis. 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 HEC-HMS uses the default equation based on the curve number. The storage coefficients, which represent storage in the subbasin, were iteratively adjusted to provide peak flow reductions equal to the ponding adjustment factors detailed in Sorrell, 2008. Figure A3 illustrates only the hydrologic reach elements in the HEC-HMS model. Table A3 provides the reach element parameters for the lag routing method.

Table A1 – Land Use as used to calculate runoff curve numbers (non-contributing areas and pits are not included)

Subbasin	Scenario	Residential	Commercial	Industrial	Roads, Utilities	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune, Bare Soil
	1800										99.4%	0.0%	0.6%	0.0%
1	1978	0.7%	0.3%	0.0%	0.0%	0.0%	81.1%	0.1%	6.1%	4.2%	6.7%	0.0%	0.9%	0.0%
	2005	11.1%	1.0%	0.0%	0.0%	1.9%	69.9%	0.2%	2.2%	4.7%	7.8%	0.1%	1.1%	0.0%
	1800										78.8%	0.0%	21.2%	0.0%
2	1978	1.0%	0.0%	0.0%	10.8%	0.0%	67.2%	0.0%	3.3%	1.8%	15.0%	0.0%	1.0%	0.0%
	2005	7.0%	0.4%	0.0%	9.2%	0.0%	51.1%	3.2%	4.6%	6.6%	16.8%	0.3%	0.8%	0.0%
	1800										67.3%	0.0%	32.7%	0.0%
3	1978	1.2%	0.0%	0.0%	4.5%	0.1%	77.1%	0.0%	2.8%	2.6%	10.6%	0.0%	1.1%	0.0%
	2005	11.3%	0.2%	0.0%	3.8%	0.1%	62.0%	0.8%	2.9%	0.8%	17.2%	0.0%	1.0%	0.0%
	1800										89.7%	0.0%	10.3%	0.0%
4	1978	2.6%	0.6%	0.0%	6.6%	0.1%	79.4%	0.0%	4.9%	2.5%	1.3%	0.1%	2.0%	0.0%
	2005	13.9%	1.3%	4.2%	4.1%	0.2%	64.9%	0.0%	2.6%	1.7%	3.9%	0.2%	3.0%	0.0%
	1800										79.9%	0.0%	20.1%	0.0%
5	1978	0.5%	0.0%	0.0%	3.6%	0.0%	85.2%	0.0%	3.7%	1.0%	5.4%	0.0%	0.6%	0.0%
	2005	9.7%	0.3%	0.1%	3.9%	0.2%	72.9%	0.0%	2.3%	1.6%	7.7%	0.8%	0.7%	0.0%
	1800										100.0%	0.0%	0.0%	0.0%
6	1978	1.8%	0.2%	0.0%	0.0%	0.0%	91.7%	0.0%	2.4%	1.3%	2.5%	0.0%	0.1%	0.0%
	2005	15.1%	1.1%	0.0%	0.0%	0.0%	75.4%	1.4%	2.4%	0.1%	4.5%	0.0%	0.0%	0.0%
	1800										99.8%	0.0%	0.2%	0.0%
7	1978	0.3%	0.0%	0.0%	0.0%	0.4%	87.4%	0.8%	1.9%	0.9%	7.9%	0.1%	0.4%	0.0%
	2005	3.5%	0.3%	0.0%	0.0%	0.5%	72.7%	1.0%	2.4%	0.7%	9.6%	0.1%	0.2%	8.9%

Subbasin	Scenario	Residential	Commercial	Industrial	Roads, Utilities	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune, Bare Soil
8	1800										99.8%	0.0%	0.2%	0.0%
	1978	2.5%	1.2%	0.0%	0.0%	0.8%	71.4%	14.0%	2.8%	2.6%	4.9%	0.0%	0.0%	0.0%
	2005	31.9%	1.3%	0.0%	0.0%	0.8%	37.3%	11.9%	0.0%	1.7%	14.8%	0.4%	0.0%	0.0%
9	1800										90.0%	0.0%	10.0%	0.0%
	1978	12.3%	0.0%	1.3%	7.4%	0.3%	57.2%	2.2%	0.1%	4.9%	12.1%	1.2%	1.0%	0.0%
	2005	38.1%	3.0%	2.0%	4.2%	0.3%	19.7%	0.0%	2.8%	5.8%	20.7%	3.2%	0.2%	0.0%
10	1800										100.0%	0.0%	0.0%	0.0%
	1978	0.4%	0.1%	0.0%	0.0%	0.3%	93.2%	0.0%	0.3%	1.1%	4.2%	0.0%	0.4%	0.0%
	2005	1.9%	0.1%	0.0%	0.0%	0.2%	91.7%	0.0%	0.5%	1.0%	4.4%	0.1%	0.2%	0.0%
11	1800										100.0%	0.0%	0.0%	0.0%
	1978	2.0%	0.2%	0.0%	0.0%	0.1%	87.6%	0.0%	0.0%	0.4%	9.6%	0.0%	0.2%	0.0%
	2005	3.4%	0.3%	0.1%	0.0%	0.1%	84.8%	0.0%	0.0%	1.7%	9.4%	0.0%	0.1%	0.0%
12	1800										100.0%	0.0%	0.0%	0.0%
	1978	0.5%	0.0%	0.0%	0.0%	0.0%	92.7%	0.3%	0.1%	0.6%	4.7%	0.0%	1.1%	0.0%
	2005	1.7%	0.0%	0.0%	0.0%	0.0%	91.1%	0.9%	0.1%	0.7%	4.5%	0.0%	0.8%	0.1%
13	1800										100.0%	0.0%	0.0%	0.0%
	1978	6.6%	0.0%	0.0%	0.0%	0.0%	43.9%	13.1%	0.2%	4.1%	31.8%	0.0%	0.4%	0.0%
	2005	15.9%	0.0%	0.0%	0.0%	0.2%	30.7%	18.0%	0.2%	2.4%	31.3%	0.8%	0.4%	0.1%
14	1800										77.9%	0.0%	22.1%	0.0%
	1978	0.5%	0.0%	0.2%	0.0%	0.0%	96.6%	0.1%	0.4%	0.2%	1.5%	0.1%	0.5%	0.0%
	2005	1.7%	0.0%	0.5%	0.0%	0.0%	94.8%	0.1%	0.5%	0.6%	1.5%	0.0%	0.2%	0.0%
15	1800										82.6%	0.0%	17.4%	0.0%
	1978	1.1%	0.2%	0.0%	0.0%	0.0%	95.6%	0.0%	0.0%	0.6%	2.0%	0.0%	0.4%	0.0%
	2005	3.9%	0.3%	0.0%	0.0%	0.0%	91.8%	0.0%	0.2%	1.7%	2.0%	0.0%	0.2%	0.0%
16	1800										58.4%	0.0%	41.6%	0.0%
	1978	1.3%	0.0%	0.0%	0.0%	0.5%	81.0%	0.7%	0.0%	4.2%	9.1%	1.1%	2.0%	0.0%
	2005	6.7%	0.1%	0.0%	0.0%	0.9%	71.5%	1.0%	0.0%	8.3%	8.3%	1.3%	2.0%	0.0%
17	1800										43.1%	0.0%	56.9%	0.0%
	1978	4.5%	0.0%	0.3%	0.4%	0.0%	63.8%	1.9%	1.2%	2.6%	24.6%	0.4%	0.3%	0.0%
	2005	11.4%	1.5%	2.1%	0.1%	1.1%	51.2%	2.1%	1.1%	7.4%	21.2%	0.7%	0.0%	0.0%
18	1800										81.5%	0.0%	18.5%	0.0%
	1978	2.2%	0.3%	0.0%	0.0%	0.1%	85.8%	0.1%	0.6%	0.4%	9.2%	0.1%	1.3%	0.0%
	2005	5.0%	0.3%	0.1%	0.0%	1.0%	81.9%	0.1%	3.1%	0.5%	7.5%	0.2%	0.3%	0.0%
19	1800										96.9%	0.0%	3.1%	0.0%
	1978	2.9%	0.1%	0.0%	0.7%	3.4%	72.8%	0.0%	0.4%	2.5%	16.0%	0.2%	1.0%	0.0%
	2005	11.7%	0.3%	0.0%	0.7%	4.7%	61.2%	0.0%	0.8%	3.2%	16.2%	0.5%	0.7%	0.0%
20	1800										91.3%	0.1%	8.6%	0.0%
	1978	2.1%	0.5%	0.0%	3.8%	0.0%	72.9%	1.4%	0.0%	1.7%	15.2%	0.3%	2.0%	0.0%
	2005	8.9%	1.2%	0.3%	3.8%	0.5%	57.6%	1.6%	0.7%	9.5%	13.6%	0.6%	1.7%	0.0%
21	1800										98.9%	0.0%	1.1%	0.0%
	1978	6.3%	0.7%	0.0%	4.3%	0.0%	73.1%	0.0%	0.0%	3.6%	10.5%	0.0%	1.5%	0.0%
	2005	11.5%	1.5%	4.7%	4.3%	1.7%	58.6%	0.0%	1.5%	5.6%	9.6%	0.0%	1.1%	0.0%
22	1800										74.8%	0.0%	25.2%	0.0%
	1978	2.8%	0.6%	0.2%	8.6%	0.0%	83.3%	0.0%	0.0%	1.7%	1.8%	0.0%	1.0%	0.0%
	2005	8.5%	2.6%	18.8%	11.4%	2.9%	41.4%	0.0%	0.0%	11.6%	2.0%	0.5%	0.5%	0.0%

Subbasin	Scenario	Residential	Commercial	Industrial	Roads, Utilities	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune, Bare Soil
23	1800										70.7%	0.0%	29.3%	0.0%
	1978	3.1%	0.5%	0.3%	6.9%	0.0%	70.5%	3.4%	0.0%	2.4%	9.5%	0.9%	2.6%	0.0%
	2005	5.0%	4.0%	7.0%	19.7%	2.2%	32.1%	3.4%	0.0%	13.9%	9.1%	1.3%	2.4%	0.0%
24	1800										73.3%	0.0%	26.7%	0.0%
	1978	2.2%	1.2%	2.2%	7.1%	0.0%	71.3%	0.0%	0.3%	7.2%	5.3%	1.9%	1.4%	0.0%
	2005	4.8%	2.1%	23.7%	8.5%	0.0%	36.9%	0.0%	0.3%	17.2%	3.7%	1.5%	1.4%	0.0%
25	1800										98.8%	0.0%	1.2%	0.0%
	1978	4.1%	0.4%	0.1%	2.8%	0.1%	79.4%	0.0%	1.1%	3.6%	6.8%	0.2%	1.4%	0.0%
	2005	14.0%	6.4%	5.4%	2.8%	0.6%	50.8%	0.0%	0.1%	11.9%	6.7%	0.3%	0.9%	0.0%
26	1800										51.1%	0.0%	48.9%	0.0%
	1978	0.7%	0.0%	0.0%	0.0%	0.2%	79.7%	0.0%	2.5%	8.6%	8.1%	0.0%	0.1%	0.0%
	2005	11.5%	0.0%	0.0%	0.0%	0.0%	66.2%	0.0%	0.7%	12.7%	8.0%	0.7%	0.1%	0.0%
27	1800										75.4%	0.0%	24.6%	0.0%
	1978	0.3%	0.1%	0.0%	0.0%	0.0%	90.6%	0.0%	4.8%	1.8%	2.3%	0.0%	0.1%	0.0%
	2005	3.3%	0.2%	0.0%	0.0%	0.0%	87.2%	0.0%	0.9%	6.1%	2.2%	0.0%	0.1%	0.0%
28	1800										43.9%	0.0%	56.1%	0.0%
	1978	0.2%	0.0%	0.0%	0.0%	0.0%	91.4%	0.0%	6.8%	0.1%	1.3%	0.0%	0.2%	0.0%
	2005	2.7%	0.0%	0.0%	0.0%	0.0%	90.0%	0.0%	0.6%	4.6%	1.3%	0.5%	0.2%	0.0%
29	1800										90.4%	0.0%	9.6%	0.0%
	1978	3.2%	0.0%	0.2%	0.0%	0.0%	89.4%	0.0%	3.4%	1.3%	2.3%	0.0%	0.0%	0.0%
	2005	21.2%	1.7%	0.3%	0.0%	0.0%	70.7%	0.2%	1.3%	1.0%	3.4%	0.1%	0.0%	0.0%
30	1800										100.0%	0.0%	0.0%	0.0%
	1978	7.7%	3.2%	10.1%	1.7%	0.0%	70.1%	0.0%	2.2%	2.0%	2.9%	0.0%	0.0%	0.0%
	2005	19.1%	12.2%	27.1%	1.6%	0.0%	27.1%	0.0%	0.6%	9.1%	3.0%	0.2%	0.0%	0.0%
31	1800										96.4%	0.0%	3.6%	0.0%
	1978	4.2%	0.4%	0.1%	0.0%	0.1%	78.8%	2.9%	3.5%	3.1%	5.5%	0.0%	1.3%	0.0%
	2005	30.3%	1.3%	0.0%	0.0%	1.6%	50.4%	0.0%	0.9%	6.1%	6.6%	1.6%	1.3%	0.0%
32	1800										70.9%	0.0%	29.1%	0.0%
	1978	38.4%	6.8%	0.7%	6.4%	2.9%	26.0%	6.6%	0.0%	5.0%	5.9%	1.3%	0.0%	0.0%
	2005	54.3%	10.5%	4.1%	4.9%	5.1%	4.4%	4.8%	0.0%	5.4%	2.2%	3.3%	0.0%	0.8%
33	1800										95.4%	0.0%	4.6%	0.0%
	1978	6.2%	0.9%	0.0%	7.4%	0.0%	73.3%	0.0%	0.0%	7.4%	4.7%	0.2%	0.0%	0.0%
	2005	44.9%	2.2%	7.3%	7.0%	0.0%	14.0%	0.3%	0.0%	16.4%	5.2%	2.8%	0.0%	0.0%
34	1800										96.3%	0.0%	3.7%	0.0%
	1978	29.5%	2.9%	3.7%	0.3%	1.8%	35.4%	0.7%	3.5%	6.3%	15.4%	0.1%	0.2%	0.0%
	2005	42.6%	11.1%	5.1%	0.3%	3.9%	9.6%	0.0%	0.6%	13.6%	12.0%	1.3%	0.0%	0.0%
35	1800										96.7%	3.3%	0.0%	0.0%
	1978	1.1%	0.0%	0.0%	9.6%	0.0%	68.3%	0.0%	3.4%	5.7%	10.5%	0.7%	0.8%	0.0%
	2005	4.8%	5.1%	8.6%	9.6%	0.0%	41.1%	0.0%	1.9%	15.5%	12.4%	0.8%	0.1%	0.0%
36	1800										93.4%	2.6%	4.0%	0.0%
	1978	31.5%	0.2%	0.0%	0.0%	5.0%	39.6%	0.0%	0.0%	5.6%	18.1%	0.0%	0.0%	0.0%
	2005	54.5%	4.2%	1.3%	0.0%	4.7%	2.3%	0.0%	0.0%	16.5%	16.0%	0.6%	0.0%	0.0%
37	1800										70.8%	0.0%	29.2%	0.0%
	1978	4.8%	1.3%	0.8%	1.9%	0.0%	68.1%	6.1%	0.7%	7.0%	8.0%	0.1%	0.9%	0.1%
	2005	12.5%	3.0%	13.6%	1.9%	0.0%	47.9%	1.1%	0.7%	12.0%	4.8%	1.3%	0.8%	0.3%

Subbasin	Scenario	Residential	Commercial	Industrial	Roads, Utilities	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune, Bare Soil
38	1800										87.8%	0.0%	12.2%	0.0%
	1978	4.6%	1.1%	0.5%	2.3%	0.0%	67.6%	9.2%	0.9%	2.7%	10.8%	0.1%	0.0%	0.2%
	2005	9.1%	7.5%	10.3%	2.3%	0.4%	48.6%	5.7%	0.0%	8.5%	6.2%	0.8%	0.0%	0.6%
39	1800										54.5%	0.0%	45.5%	0.0%
	1978	15.0%	3.8%	2.5%	2.4%	0.0%	43.6%	0.0%	0.5%	14.1%	16.0%	0.1%	0.0%	2.0%
	2005	32.2%	27.6%	3.3%	2.4%	0.0%	12.1%	0.0%	0.0%	13.6%	7.0%	1.2%	0.0%	0.7%
40	1800										80.3%	2.0%	17.8%	0.0%
	1978	15.9%	14.5%	4.2%	5.5%	4.0%	30.9%	0.0%	1.1%	11.0%	11.4%	0.7%	1.0%	0.0%
	2005	23.2%	27.7%	10.1%	6.4%	4.4%	0.4%	0.0%	0.0%	15.9%	9.7%	1.2%	1.0%	0.0%
41	1800										96.2%	0.0%	3.8%	0.0%
	1978	16.1%	14.3%	20.0%	2.0%	5.7%	17.7%	0.0%	0.0%	12.6%	9.9%	0.5%	1.2%	0.0%
	2005	19.1%	17.4%	32.3%	2.9%	8.5%	2.9%	0.0%	0.0%	9.6%	5.6%	0.5%	1.2%	0.0%
42	1800										69.3%	0.0%	30.7%	0.0%
	1978	1.7%	0.3%	0.7%	1.6%	5.4%	67.9%	0.0%	1.6%	4.9%	14.2%	0.0%	1.8%	0.0%
	2005	3.4%	1.1%	1.7%	1.6%	7.5%	65.7%	0.0%	1.1%	4.6%	11.9%	0.1%	1.1%	0.0%
43	1800										56.2%	0.0%	43.8%	0.0%
	1978	4.0%	0.1%	1.0%	0.0%	0.7%	23.2%	50.3%	2.0%	9.4%	8.7%	0.1%	0.4%	0.1%
	2005	9.8%	0.8%	5.0%	0.0%	19.8%	43.0%	3.3%	0.7%	8.9%	5.7%	2.3%	0.4%	0.3%
44	1800										81.2%	0.1%	18.8%	0.0%
	1978	27.0%	3.3%	0.4%	0.0%	0.1%	15.6%	12.0%	0.6%	14.0%	26.0%	0.6%	0.0%	0.4%
	2005	48.0%	10.5%	0.6%	0.0%	0.8%	5.4%	10.1%	0.5%	9.0%	13.6%	1.1%	0.0%	0.4%
45	1800										92.3%	0.0%	7.7%	0.0%
	1978	5.8%	0.3%	0.0%	0.0%	0.0%	15.5%	26.7%	1.0%	5.9%	44.4%	0.1%	0.0%	0.2%
	2005	13.5%	0.3%	0.0%	0.0%	0.0%	12.6%	32.6%	1.0%	4.7%	32.4%	2.1%	0.0%	0.8%
46	1800										89.6%	0.0%	10.4%	0.0%
	1978	35.0%	5.6%	4.7%	0.0%	0.0%	10.7%	0.0%	0.3%	14.5%	28.0%	0.0%	1.2%	0.0%
	2005	55.1%	12.9%	3.4%	0.0%	0.0%	0.9%	0.0%	0.3%	8.1%	16.1%	2.1%	1.2%	0.0%
47	1800										60.8%	10.4%	28.7%	0.0%
	1978	43.6%	15.2%	12.4%	2.5%	3.1%	6.3%	0.0%	0.0%	1.8%	4.4%	7.2%	3.5%	0.0%
	2005	46.4%	19.2%	13.6%	2.6%	3.5%	0.4%	0.0%	0.0%	1.7%	2.6%	7.3%	2.7%	0.0%
48	1800										93.9%	0.0%	6.1%	0.0%
	1978	14.9%	1.0%	0.0%	2.7%	0.1%	7.4%	2.1%	0.0%	23.2%	45.7%	0.0%	1.1%	1.9%
	2005	33.0%	2.0%	0.0%	2.8%	0.8%	4.9%	3.9%	0.0%	11.8%	36.7%	1.6%	1.0%	1.5%
49	1800										100.0%	0.0%	0.0%	0.0%
	1978	32.9%	11.0%	0.0%	0.0%	4.4%	28.5%	0.0%	0.0%	6.9%	16.0%	0.0%	0.4%	0.0%
	2005	51.3%	21.1%	0.0%	0.0%	8.0%	3.5%	0.0%	0.0%	7.1%	8.4%	0.2%	0.4%	0.0%
50	1800										100.0%	0.0%	0.0%	0.0%
	1978	34.3%	0.7%	1.2%	0.0%	0.0%	53.9%	0.8%	0.0%	3.1%	5.3%	0.0%	0.7%	0.0%
	2005	54.3%	1.9%	0.9%	0.0%	0.4%	24.5%	0.0%	0.0%	14.8%	2.0%	0.2%	0.5%	0.4%
51	1800										100.0%	0.0%	0.0%	0.0%
	1978	18.8%	2.8%	0.1%	0.0%	0.0%	65.6%	0.9%	0.0%	1.7%	8.9%	0.0%	0.6%	0.0%
	2005	36.6%	2.8%	0.1%	0.0%	0.0%	47.9%	0.0%	0.0%	3.5%	8.9%	0.1%	0.0%	0.0%
52	1800										96.7%	0.0%	3.3%	0.0%
	1978	19.5%	0.9%	0.0%	0.0%	0.0%	45.2%	0.1%	0.0%	3.6%	30.0%	0.0%	0.7%	0.0%
	2005	34.7%	1.1%	0.0%	0.0%	4.3%	21.1%	0.2%	0.0%	11.1%	26.1%	0.7%	0.7%	0.0%

Subbasin	Scenario	Residential	Commercial	Industrial	Roads, Utilities	Cemeteries, Outdoor Rec.	Cropland	Orchards	Pasture	Herbaceous Openland	Forest	Water	Wetland	Sand Dune, Bare Soil
53	1800										96.0%	0.3%	3.7%	0.0%
	1978	11.0%	0.2%	0.0%	0.0%	0.8%	24.2%	1.0%	0.0%	7.0%	53.4%	0.6%	1.6%	0.1%
	2005	23.4%	0.2%	0.0%	0.0%	0.2%	13.4%	0.6%	0.5%	11.2%	48.0%	1.0%	1.5%	0.1%
54	1800										85.7%	2.5%	11.8%	0.0%
	1978	57.3%	14.3%	7.8%	0.9%	1.4%	5.6%	0.2%	0.0%	4.8%	6.7%	0.7%	0.1%	0.1%
	2005	64.4%	17.1%	9.2%	0.8%	2.5%	0.6%	0.0%	0.0%	1.5%	3.1%	0.7%	0.1%	0.0%
55	1800										97.8%	1.3%	0.9%	0.1%
	1978	52.2%	0.9%	0.0%	0.8%	6.8%	2.7%	0.0%	0.0%	9.5%	24.7%	1.1%	0.7%	0.7%
	2005	66.6%	3.1%	0.0%	0.8%	6.0%	0.0%	0.0%	0.0%	4.2%	16.8%	1.1%	0.6%	0.7%
Watershed	1800										85.1%	0.4%	14.5%	0.0%
	1978	9.2%	1.8%	1.3%	1.9%	0.8%	61.8%	2.8%	1.4%	4.8%	13.0%	0.4%	0.9%	0.1%
	2005	18.7%	4.0%	3.7%	1.9%	1.7%	47.8%	1.6%	0.9%	6.5%	11.3%	0.9%	0.7%	0.3%

Figure A1 – HEC-HMS Model Hydrologic Elements

Table A2 – Subbasin Parameters

Subbasin	Scenario	Total Area (sq. mi.)	Contributing Drainage Area (sq. mi.)	Effective Curve Number	Tc (hours)	SC
1	1800	3.89	3.72	71.2	5.68	7.13
	1978		3.86	80.0		7.42
	2005		3.85	80.0		7.68
2	1800	3.20	3.19	72.5	4.58	12.42
	1978		3.20	80.2		6.09
	2005		3.17	79.1		6.15
3	1800	2.68	2.61	74.0	6.31	18.98
	1978		2.65	78.5		8.47
	2005		2.65	77.7		8.39
4	1800	4.53	4.16	71.3	5.33	12.58
	1978		4.49	81.1		7.89
	2005		4.48	81.3		9.11

Subbasin	Scenario	Total Area (sq. mi.)	Contributing Drainage Area (sq. mi.)	Effective Curve Number	Tc (hours)	SC
5	1800	4.22	4.14	73.0	3.74	9.86
	1978		4.21	81.4		4.64
	2005		4.20	81.5		5.21
6	1800	3.76	3.74	72.4	6.54	6.54
	1978		3.76	83.0		6.54
	2005		3.76	82.9		6.54
7	1800	3.40	3.22	72.0	5.69	6.29
	1978		3.36	81.6		6.94
	2005		3.35	81.6		6.49
8	1800	0.40	0.25	67.0	2.99	3.33
	1978		0.34	76.2		2.99
	2005		0.33	77.1		3.53
9	1800	2.68	2.15	72.0	7.80	18.21
	1978		2.46	79.4		11.78
	2005		2.43	80.0		13.56
10	1800	3.63	3.20	73.2	5.81	5.81
	1978		3.60	80.8		6.85
	2005		3.60	80.9		6.41
11	1800	5.35	4.79	72.6	5.94	5.94
	1978		5.24	80.1		6.55
	2005		5.25	80.0		6.55
12	1800	3.91	3.82	72.6	9.09	9.09
	1978		3.88	82.2		12.29
	2005		3.87	82.2		11.87
13	1800	1.32	0.75	69.2	4.86	4.86
	1978		1.03	72.9		5.75
	2005		1.04	73.1		6.64
14	1800	4.48	4.46	74.5	7.37	19.78
	1978		4.48	83.1		8.99
	2005		4.48	83.1		8.13
15	1800	3.77	3.77	74.7	6.54	16.36
	1978		3.77	81.7		7.71
	2005		3.77	81.7		7.21
16	1800	2.58	2.54	75.3	7.06	22.37
	1978		2.51	80.1		11.97
	2005		2.51	80.1		12.09
17	1800	2.25	2.23	76.6	6.29	21.60
	1978		2.22	78.7		7.94
	2005		2.23	79.1		7.94
18	1800	4.07	3.91	74.0	6.11	15.6
	1978		4.04	80.8		8.41
	2005		4.04	80.7		7.45
19	1800	6.25	5.81	73.7	16.89	28.53
	1978		6.03	80.8		22.97
	2005		6.01	80.7		22.77
20	1800	6.36	6.01	73.9	8.95	19.69
	1978		6.13	80.5		13.76
	2005		6.13	80.5		13.76

Subbasin	Scenario	Total Area (sq. mi.)	Contributing Drainage Area (sq. mi.)	Effective Curve Number	Tc (hours)	SC
21	1800	1.32	1.32	73.9	3.89	5.25
	1978		1.32	81.4		5.42
	2005		1.32	81.9		5.22
22	1800	2.02	2.01	75.2	5.96	16.44
	1978		2.02	83.0		7.93
	2005		2.02	85.7		7.94
23	1800	2.21	2.17	75.5	4.08	11.60
	1978		2.15	81.7		7.07
	2005		2.13	84.9		7.18
24	1800	2.05	2.04	76.3	4.88	13.47
	1978		2.05	83.2		8.34
	2005		2.05	85.8		8.03
25	1800	4.76	4.65	72.8	12.79	17.46
	1978		4.75	81.2		17.75
	2005		4.74	82.3		17.43
26	1800	3.09	2.85	76.0	12.07	38.39
	1978		3.03	71.3		12.07
	2005		3.03	72.7		15.63
27	1800	4.26	4.23	73.6	11.02	30.03
	1978		4.26	80.6		11.02
	2005		4.26	80.3		11.02
28	1800	2.74	2.70	76.0	11.47	38.17
	1978		2.74	77.6		12.65
	2005		2.74	78.1		14.48
29	1800	3.86	3.74	69.0	5.93	14.25
	1978		3.83	78.2		5.93
	2005		3.84	78.7		5.93
30	1800	3.90	3.79	67.3	7.11	7.11
	1978		3.88	80.8		7.11
	2005		3.87	85.3		7.84
31	1800	3.48	3.33	71.4	6.59	12.08
	1978		3.45	79.1		9.00
	2005		3.45	79.5		10.85
32	1800	1.46	1.24	71.0	3.08	9.26
	1978		1.25	80.2		4.21
	2005		1.37	82.7		5.33
33	1800	1.47	1.22	73.9	5.21	9.85
	1978		1.46	81.4		5.75
	2005		1.44	82.8		8.56
34	1800	2.31	2.17	68.2	9.97	18.71
	1978		2.26	77.5		11.37
	2005		2.28	79.8		13.61
35	1800	1.14	1.12	73.5	9.65	17.17
	1978		1.14	82.9		13.27
	2005		1.14	83.8		12.60
36	1800	1.00	0.95	73.0	6.55	13.63
	1978		0.98	79.0		6.55
	2005		0.98	79.5		8.12

Subbasin	Scenario	Total Area (sq. mi.)	Contributing Drainage Area (sq. mi.)	Effective Curve Number	Tc (hours)	SC
37	1800	3.87	3.64	74.5	11.65	32.73
	1978		3.58	76.8		15.54
	2005		3.74	81.4		17.24
38	1800	3.61	3.52	73.7	7.21	17.01
	1978		3.43	79.6		7.21
	2005		3.46	83.4		9.26
39	1800	2.20	1.88	75.5	5.22	16.94
	1978		1.97	77.7		5.22
	2005		2.06	85.0		7.07
40	1800	2.82	2.62	72.7	9.17	27.53
	1978		2.78	83.6		13.71
	2005		2.79	86.8		14.89
41	1800	2.50	2.27	71.0	4.32	9.06
	1978		2.47	84.3		6.49
	2005		2.47	87.1		6.50
42	1800	2.93	2.78	75.8	10.16	29.15
	1978		2.67	77.2		14.57
	2005		2.66	77.8		13.77
43	1800	3.96	3.53	77.2	10.82	33.58
	1978		2.02	72.5		13.30
	2005		3.03	74.5		17.95
44	1800	5.49	2.88	76.1	12.13	29.98
	1978		3.75	75.8		15.08
	2005		4.51	78.9		16.27
45	1800	2.35	1.66	76.8	11.44	23.87
	1978		1.47	74.7		11.44
	2005		1.54	76.2		17.08
46	1800	2.66	0.99	76.3	5.96	13.44
	1978		1.97	78.0		8.07
	2005		2.33	80.8		10.19
47	1800	3.57	2.50	81.7	NA	
	1978		3.48	86.1		
	2005		3.50	86.9		
48	1800	4.96	2.13	77.6	10.98	24.59
	1978		2.77	77.4		15.63
	2005		3.40	78.2		19.36
49	1800	0.70	0.36	73.9	1.57	1.57
	1978		0.59	82.0		1.86
	2005		0.62	83.8		1.96
50	1800	0.82	0.59	73.8	1.81	1.81
	1978		0.78	80.8		2.30
	2005		0.81	79.5		2.29
51	1800	0.72	0.55	73.6	1.90	1.90
	1978		0.69	79.5		2.36
	2005		0.70	79.2		1.90
52	1800	1.77	0.94	73.7	3.05	5.35
	1978		1.45	76.4		3.85
	2005		1.44	76.2		4.25

Subbasin	Scenario	Total Area (sq. mi.)	Contributing Drainage Area (sq. mi.)	Effective Curve Number	Tc (hours)	SC
53	1800	6.13	3.17	72.0	5.91	11.00
	1978		3.97	75.6		8.82
	2005		4.20	75.5		9.55
54	1800	3.08	1.00	79.1	NA	
	1978		2.80	83.2		
	2005		2.92	83.7		
55	1800	3.21	0.29	85.2	NA	
	1978		1.99	76.0		
	2005		2.39	76.8		

NA: does not apply, subbasin drained with storm sewers to Lake Macatawa

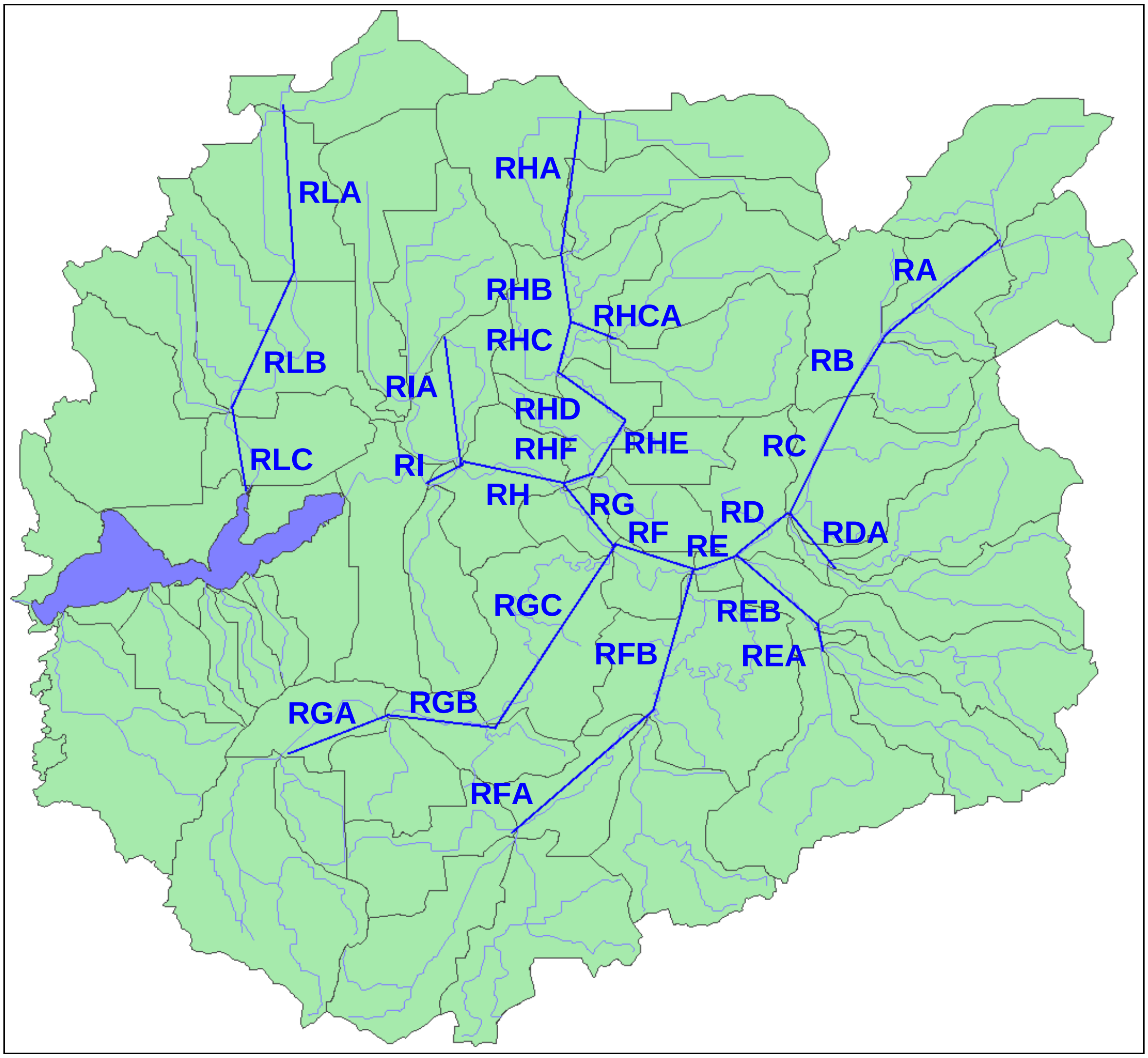

Figure A2 – Reach Elements for HEC-HMS model

Table A3 –Reach Element Parameters

Reach Element	Lag (minutes)	Reach Element	Lag (minutes)
RA	239	RGC	505
RB	157	RH	373
RC	314	RHA	380
RD	178	RHB	181
RDA	76	RHC	93
RE	153	RHCA	46
REA	23	RHD	181
REB	158	RHE	141
RF	404	RHF	76
RFA	313	RI	108
RFB	630	RIA	143
RG	266	RLA	458
RGA	153	RLB	254
RGB	194	RLC	116

Appendix B: Glossary

Aggrade - to fill and raise the level of a stream bed by deposition of sediment.

Alluvium - sediment deposited by flowing rivers and consisting of sands and gravels.

Bankfull discharge - that discharge of stream water that just begins to overflow in the active floodplain. The active floodplain is defined as a flat area adjacent to the channel constructed by the river and overflowed by the river at recurrence interval of about 1 to 2 years in a stable stream. Erosion, sediment transport, and bar building by deposition are most active at discharges near bankfull. The effectiveness of higher flows, called over bank or flood flows, does not increase proportionally to their volume above bankfull in a stable stream, because overflow into the floodplain distributes the energy of the stream over a greater area. See also channel-forming and effective discharge.

Base Flow - the part of stream flow that is attributable to long-term discharge of groundwater to the stream. This part of stream flow is not attributable to short-term surface runoff, precipitation, or snow melt events.

Best Management Practice (BMP) - structural, vegetative, or managerial practices used to protect and improve our surface waters and groundwaters.

Celerity - The velocity of propagation of a wave through a liquid, relative to the rate of movement of the liquid through which the disturbance is propagated.

Channel-forming Discharge - a theoretical discharge which would result in a channel morphology close to the existing channel. See also effective and bankfull discharge.

Critical Areas - the geographic portions of the watershed contributing the majority of the pollutants and having significant impacts on the waterbody.

Curve Number - see Runoff Curve Number.

Design Flow - projected flow through a watercourse which will recur with a stated frequency. The projected flow for a given frequency is calculated using statistical analysis of peak flow data or using hydrologic analysis techniques.

Detention - practices which store stormwater for some period of time before releasing it to a surface waterbody. See also retention.

Dimensionless Hydrograph - a general hydrograph developed from many unit hydrographs, used in the Soil Conservation Service method.

Direct Runoff Hydrograph - graph of direct runoff (rainfall minus losses) versus time.

Discharge - volume of water moving down a channel per unit time. See also channel-forming, effective, and bankfull discharge.

Drainage Divide - boundary that separates subbasins according to direction of runoff.

Effective Discharge - the calculated measure of channel forming discharge. This calculation requires long-term water and sediment measurements, although modeling results are sometimes substituted. See also channel-forming and bankfull discharge.

Ephemeral Stream - a stream that flows only during or immediately after periods of precipitation. See also intermittent and perennial streams.

Evapotranspiration - the combined process of evaporation and transpiration.

First Flush - the first part of a rainstorm that washes off the majority of pollutants from a site. The concept of first flush treatment applies only to a single site, even if just a few acres, because of timing of the runoff. Runoff from multiple or large sites may exhibit elevated pollutant concentrations longer because the first flush runoff from some portions of the drainage area will take longer to reach the outlet.

Flashiness - has no set definition but is associated with the rate of change of flow. Flashy streams have more rapid flow changes.

Groundwater - that part of the subsurface water that is in the saturated zone.

Headwater Stream - the system of wetlands, swales, and small channels that mark the beginnings of most watersheds.

Hydraulic Analysis - an evaluation of water elevation for a given flow based on channel attributes such as slope, cross-section, and vegetation.

Hydrograph - graph of discharge versus time.

Hydrogroups - Soil groups used to estimate runoff from precipitation according to the infiltration of water when the soils receive precipitation from long-duration storms.

Hydrologic Analysis - an evaluation of the relationship between stream flow and the various components of the hydrologic cycle. The study can be as simple as determining the watershed size and average stream flow, or as complicated as developing a computer model to determine the relationship between peak flows and watershed characteristics, such as land use, soil type, slope, rainfall amounts, detention areas, and watershed size.

Hydrologic Cycle - When precipitation falls to the earth, it may:

- be intercepted by vegetation, never reaching the ground.
- infiltrate into the ground, be taken up by vegetation, and evapotranspirated back to the atmosphere.
- enter the groundwater system and eventually flow back to a surface water body.
- runoff over the ground surface, filling in depressions.
- enter directly into a surface waterbody, such as a lake, stream, or ocean.

When water evaporates from lakes, streams, and oceans and is re-introduced to the atmosphere, the hydrologic cycle starts over again.

Hydrology - the occurrence, distribution, and movement of water both on and under the earth's surface. It can be described as the study of the hydrologic cycle.

Hyetograph - graph of rainfall intensity versus time.

Impervious - a surface through which little or no water will move. Impervious areas include paved parking lots and roof tops.

Infiltration Capacity - rate at which water can enter soil with excess water on the surface.

Interflow - flow of water through the upper soil layers to a ditch, stream, etc.

Intermittent Stream - a stream that flows only during certain times of the year. Seasonal flow in an intermittent stream usually lasts longer than 30 days per year. See also ephemeral and perennial streams.

Invert - bottom of a channel or pipe.

Knickpoint - a point of abrupt change in bed slope. If the streambed is made of erodible material, the knickpoint, or downcut, may migrate upstream along the channel and have undesirable effects, such as undermining bridge piers and other manmade structures.

Lag Time - time from the center of mass of the rainfall to the peak of the hydrograph.

Low Impact Development (LID) - a comprehensive design and development technique that strives to mimic pre-development hydrologic characteristics and water quality with a series of small-scale distributed structural and non-structural controls.

Losses - rainfall that does not runoff, i.e. rainfall that infiltrates into the ground or is held in ponds or on leaves, etc.

Low Flow - minimum flow through a watercourse which will recur with a stated frequency. The minimum flow for a given frequency may be based on measured data, calculated using statistical analysis of low flow data, or calculated using hydrologic analysis techniques. Projected low flows are used to evaluate the impact of discharges on water quality. They are, for example, used in the calculation of industrial discharge permit requirements.

Morphology, Fluvial - the study of the form and structure of a river, stream, or drain.

Nonpoint Source Pollution - pollutants carried in runoff characterized by multiple discharge points. Point sources emanate from a single point, generally a pipe.

Peak Flow - maximum flow through a watercourse which will recur with a stated frequency. The maximum flow for a given frequency may be based on measured data, calculated using statistical analysis of peak flow data, or calculated using hydrologic analysis techniques. Projected peak flows are used in the design of culverts, bridges, and dam spillways.

Perched Ground Water - unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

Perennial Stream - a stream that flows continuously during both wet and dry times. See also ephemeral and intermittent streams.

Precipitation - water that falls to earth in the form of rain, snow, hail, or sleet.

Rating Curve - relationship between depth and amount of flow in a channel.

Recession Curve - portion of the hydrograph where runoff is from base flow.

Retention - practices which capture stormwater and release it slowly though infiltration into the ground. See also detention.

Riparian - pertaining to the bank of a river, pond, or small lake.

Runoff - flow of water across the land surface as surface runoff or interflow. The volume is equal to the total rainfall minus losses.

Runoff Coefficient - ratio of runoff to precipitation.

Runoff Curve Number - parameter developed by the Natural Resources Conservation Service (NRCS) that accounts for soil type and land use.

Saturated Zone - (1) those parts of the earth's crust in which all voids are filled with water under pressure greater than atmospheric; (2) that part of the earth's crust beneath the regional water table in which all voids, large and small, are filled with water under pressure greater than atmospheric; (3) that part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

Scarp - the sloped bank of a stream channel.

Sediment - soil fragmental material that originates from weathering of rocks and is transported or deposited by air, water, or ice.

Sinuosity - the ratio of stream length between two points divided by the valley length between the same two points.

Simulation Model - model describing the reaction of a watershed to a storm using numerous equations.

Soil - unconsolidated earthy materials which are capable of supporting plants. The lower limit is normally the lower limit of biological activity, which generally coincides with the common rooting of native perennial plants.

Soil Moisture Storage - volume of water held in the soil.

Storage Delay Constant - parameter that accounts for lagging of the peak flow through a channel segment.

Storage-Discharge Relation - values that relate storage in the system to outflow from the system.

Stream Corridor - generally consists of the stream channel, floodplain, and transitional upland fringe.

Subbasins - hydrologic divisions of a watershed that are relatively homogenous.

Synthetic Design Storm - rainfall hyetograph obtained through statistical means.

Synthetic Unit Hydrograph - unit hydrograph for ungaged basins based on theoretical or empirical methods

Thalweg - the "channel within the channel" that carries water during low-flow conditions.

Time of Concentration - the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the design point.

Transpiration - conversion of liquid water to water vapor through plant tissue.

Tributary - a river or stream that flows into a larger river or stream.

Unit Hydrograph - graph of runoff versus time produced by a unit rainfall over a given duration.

Unsaturated Zone - the zone between the land surface and the water table which may include the capillary fringe. Water in this zone is generally under less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric.

Watershed - area of land that drains to a single outlet and is separated from other watersheds by a divide.

Watershed Delineation - determination of watershed boundaries. These boundaries are determined by reviewing USGS quadrangle maps. Surface runoff from precipitation falling anywhere within these boundaries will flow to the waterbody.

Water Surface Profile - plot of the depth of water in a channel along the length of the channel.

Water Table - the surface of a groundwater body at which the water pressure equals atmospheric pressure. Earth material below the groundwater table is saturated with water.

Yield (Flood Flow) - peak flow divided by drainage area

Appendix C: Abbreviations

BMP	Best Management Practices
CARL	Conservation and Recreation Lands
CN	Runoff Curve Number
cfs	cubic feet per second
EPA	United States Environmental Protection Agency
GIS	Geographic Information Systems
HSU	MDEQ's Hydrologic Studies Unit
ICM	Impervious Cover Model
LID	Low Impact Development
LWMD	MDEQ's Land and Water Management Division
MAWN	Michigan Automated Weather Network
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
NEH	National Engineering Handbook
NHD	National Hydrography Dataset
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
USGS	United States Geological Survey