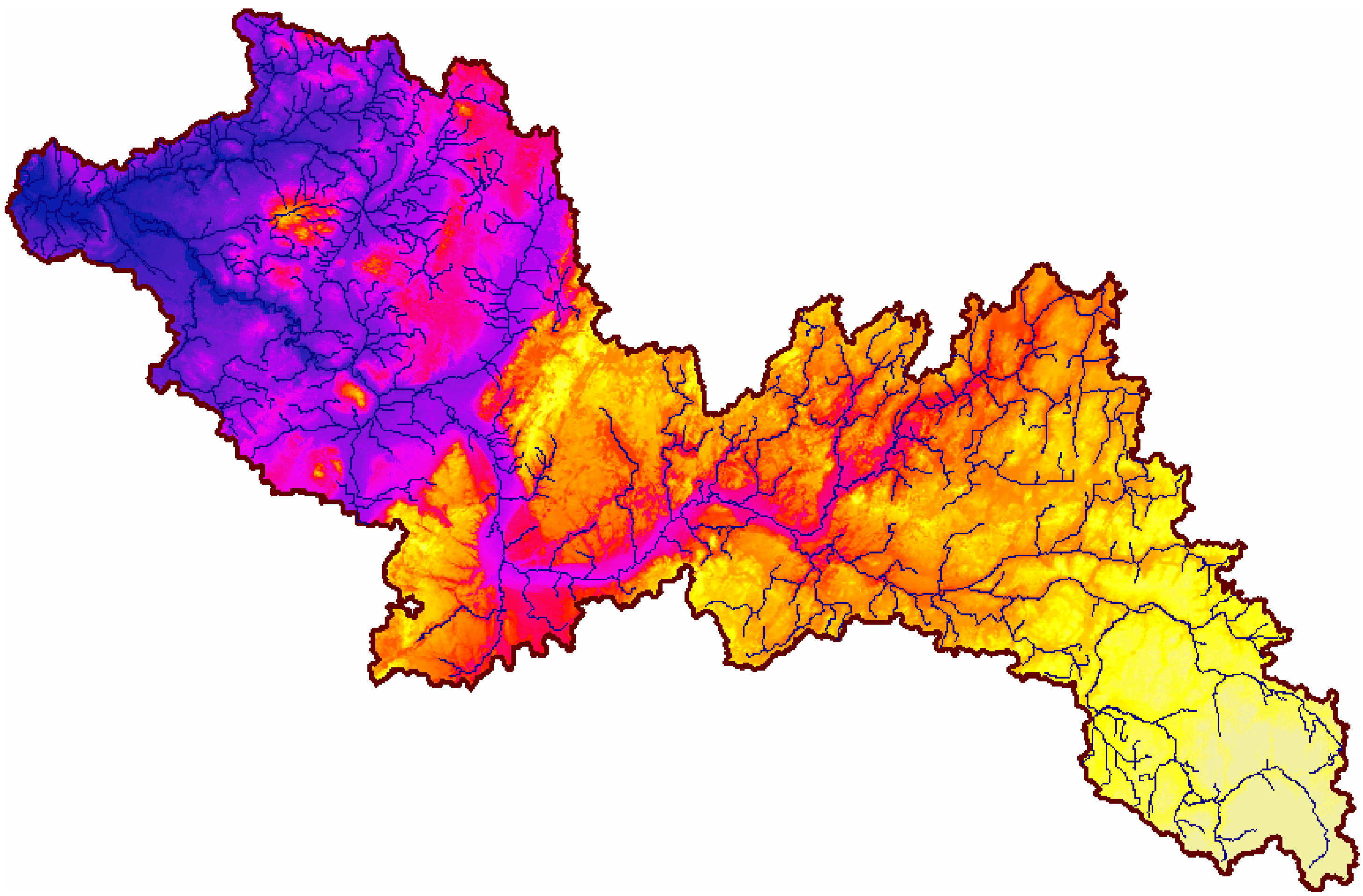
# Kalamazoo River Watershed Hydrologic Study



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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 Kalamazoo River watershed planning grant, 2006-0148. 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. For more information, go to www.michigan.gov/deqnps.


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

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# Summary

This hydrologic study of the Kalamazoo River 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. The project supports the NPS Kalamazoo River watershed planning grant to the Kalamazoo River Watershed 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 to 1978 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 now the dominant land use throughout the watershed. The Kalamazoo and Battle Creek metropolitan areas are the largest urban land use areas. The largest natural land use areas are Allegan State Game area and Fort Custer. Five percent of the watershed is public land or protected by conservation easements. Twenty-one percent of the Kalamazoo River and its tributaries are designated trout streams. Seven lakes in the watershed are designated trout lakes.

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 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. Flashiness increases have been identified at seven USGS gages in the Kalamazoo River watershed.

# Watershed Description

## *Overview*

The 2,030 square mile Kalamazoo River watershed, Figure 1, includes portions of ten Michigan counties.  The river outlets to Lake Michigan near Saugatuck in Allegan County.

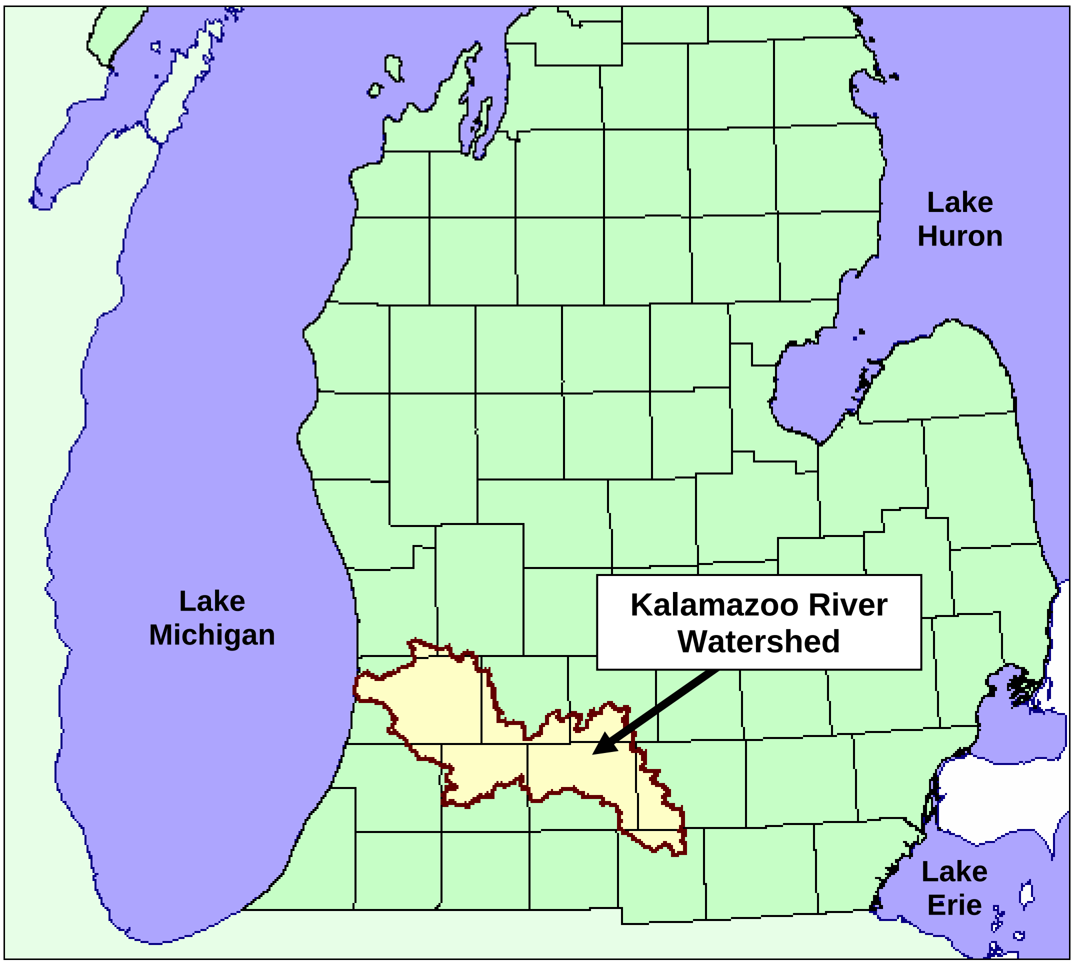



Figure 1 – Kalamazoo River Watershed Location

## *Trout Streams*

Approximately 21 percent of the Kalamazoo River and its tributaries are designated trout streams, as shown in Figure 2. Seven lakes are designated trout lakes. The largest are Gull Lake and Kalamazoo Lake. Trout streams and lakes are associated with high quality waters and a good supply of groundwater-fed baseflow, which helps keep the stream flows and temperatures steady.

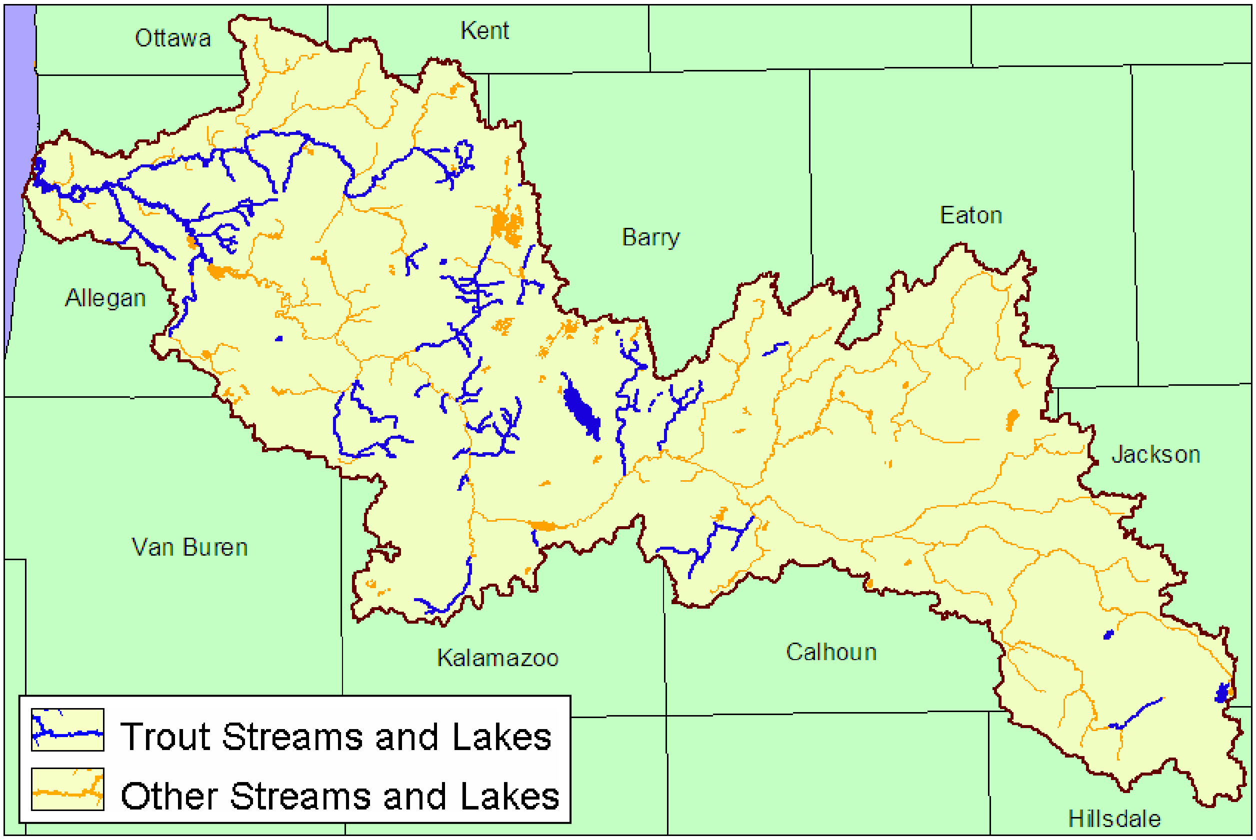



Figure 2 – Kalamazoo River watershed trout streams and lakes

## *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 3. Stream order provides a comparison of the size and potential power of streams.

The Michigan Department of Natural Resources (MDNR) Institute for Fisheries Research and the United States Geological Survey (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 Kalamazoo River watershed results are shown in Figure 4.

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 4 may increase, because smaller channels are likely to be included. A more detailed analysis, based on 1:24,000 NHD layer, is being developed.

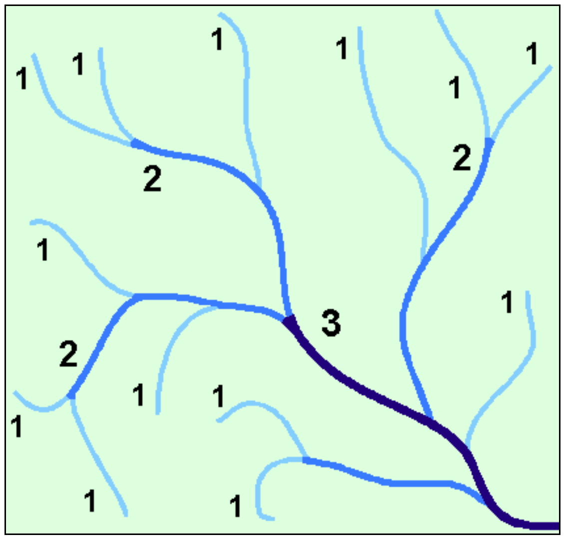


Figure 3 – Stream Ordering Procedure

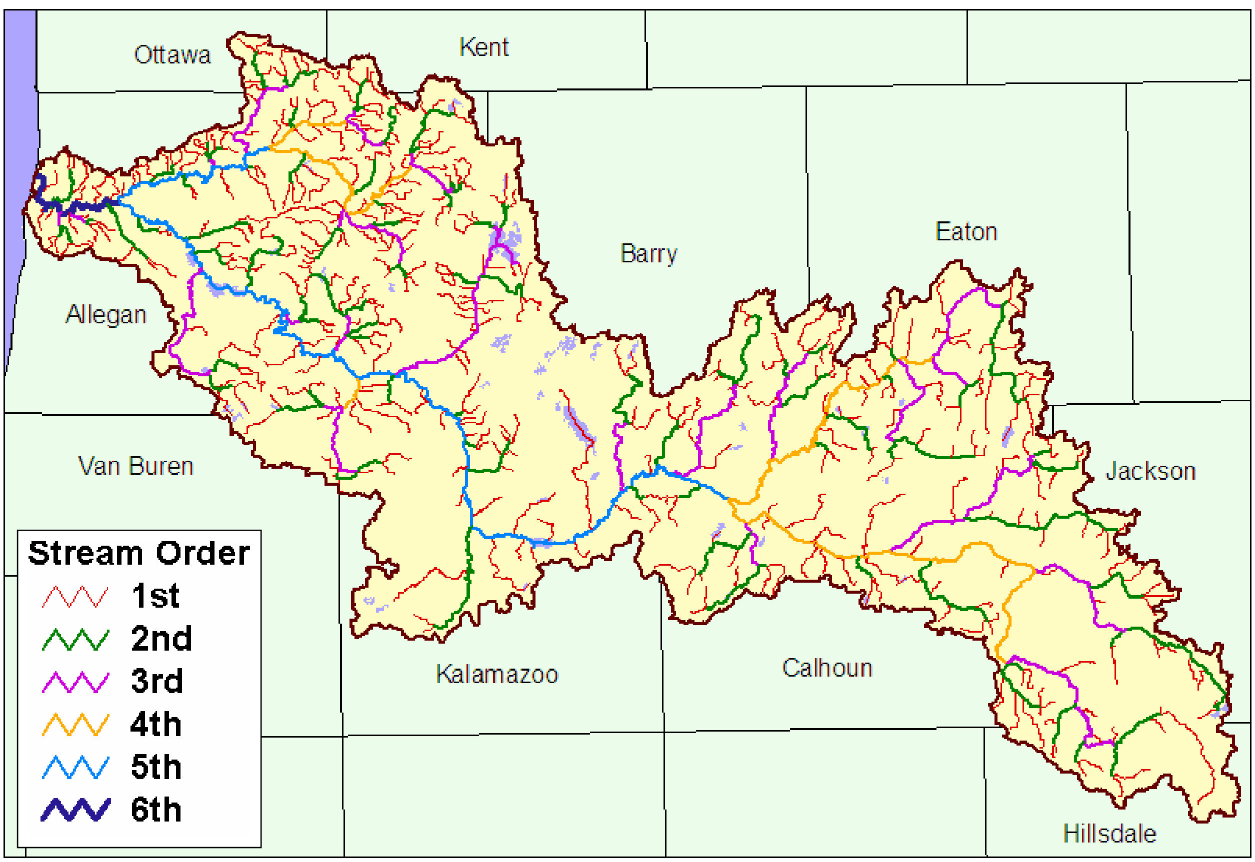


Figure 4 – Kalamazoo River Watershed Stream Orders

## *Subbasins*

This study divides the watershed into 96 subbasins, Table 1 and Figure 5. The subbasin delineations are available from the Michigan Geographic Data Library, www.mcgi.state.mi.us/mgdl/. Drainage areas are provided in Table 5 or Appendix A.

Table 1 – Subbasins

| | |
|---|---|
| 1 | S Br Kalamazoo River at Mosherville Road |
| 2 | S Br Kalamazoo River below tributary |
| 3 | S Br Kalamazoo River below tributary |
| 4 | S Br Kalamazoo River below Beaver Creek |
| 5 | S Br Kalamazoo River below Swains Lake Drain |
| 6 | Lampson Run Drain at Mouth |
| 7 | S Br Kalamazoo River at Gage #04102850 |
| 8 | S Br Kalamazoo River at Mouth |
| 9 | North Kalamazoo River at Cross Lake Outlet |
| 10 | Spring Arbor and Concord at Mouth |
| 11 | N Br Kalamazoo River below Spring Arbor & Concord Drain |
| 12 | Kalamazoo River at Gage #04103010 |
| 13 | Wilder Creek below Huckleberry Drain |
| 14 | Wilder Creek at Mouth |
| 15 | S Br Rice Creek at M-99 |
| 16 | S Br Rice Creek at Mouth |
| 17 | N Br Rice Creek at Gordon Lake Outlet |
| 18 | N Br Rice Creek at Mouth |
| 19 | Rice Creek at Mouth |
| 20 | Kalamazoo River at Gage #04103500 |
| 21 | Kalamazoo River below Squaw Lake Drain |
| 22 | Kalamazoo River below Pigeon Creek |
| 23 | Kalamazoo River below Dickinson Creek |
| 24 | Harper Creek at Mouth |
| 25 | Minges Brook at Mouth |
| 26 | Battle Creek above Hogle and Miller Drain |
| 27 | Hogle and Miller Drain at Mouth |
| 28 | Battle Creek below tributary |
| 29 | Big Creek at Mouth |
| 30 | Battle Creek below Big Creek |
| 31 | Indian Creek below State and Indian Creek |
| 32 | Indian Creek at Mouth |
| 33 | Battle Creek below Indian Creek |
| 34 | Battle Creek at Gage #04104500 |
| 35 | Battle Creek below Ackley Creek |
| 36 | Battle Creek below tributary |
| 37 | Wanadoga Creek below Ellis Creek |
| 38 | Wanadoga Creek at Gage #04104945 |
| 39 | Wanadoga Creek at Mouth |
| 40 | Battle Creek at Gage #04105000 |
| 41 | Battle Creek at Mouth |
| 42 | Kalamazoo River at Gage #04105500 |
| 43 | Wabascon Creek at Luce Road |
| 44 | Wabascon Creek at Mouth |
| 45 | Kalamazoo River below Wabascon Creek |
| 46 | Sevenmile Creek at Mouth |
| 47 | Augusta Creek below tributary |
| 48 | Augusta Creek at Gage #04105700 |
| 49 | Augusta Creek at Mouth |
| 50 | Gull Creek at Gage #04105800 |
| 51 | Gull Creek at Mouth |
| 52 | Kalamazoo River below Gull Creek |
| 53 | Kalamazoo River at Morrow Lake Dam |
| 54 | Comstock Creek at Mouth |
| 55 | Kalamazoo River at Gage #04106000 |
| 56 | Davis Creek at Mouth |
| 57 | Portage Creek at Gage #04106180 |
| 58 | Portage Creek at Gage #04106300 |
| 59 | W Fork Portage Creek at Gage #04106320 |
| 60 | W Fork Portage Creek at Gage #04106400 |
| 61 | Portage Creek at Gage #04106500 |
| 62 | Portage Creek at Mouth |
| 63 | Kalamazoo River below Portage Creek |
| 64 | Spring Brook at Mouth |
| 65 | Kalamazoo River below Spring Brook |
| 66 | Kalamazoo River below Silver Creek |
| 67 | Kalamazoo River at Plainwell Dam |
| 68 | Gun River at Gun Lake Outlet |
| 69 | Gun River below Culver Drain |
| 70 | Gun River at Mouth |
| 71 | Sand Creek at Mouth |
| 72 | Base Line Creek at Mouth |
| 73 | Pine Creek at Mouth |
| 74 | Kalamazoo River at Otsego Dam |
| 75 | Schnable Brook at Mouth |
| 76 | Kalamazoo River at Trowbridge Dam |
| 77 | Kalamazoo River at Unnamed Dam |
| 78 | Kalamazoo River at Unnamed Dam |
| 79 | Swan Creek at Mouth |
| 80 | Kalamazoo River at Gage #04108500 |
| 81 | Little Rabbit River below Dorr & Nichols Drain |
| 82 | Little Rabbit River at Mouth |
| 83 | Bear Creek at Mouth |
| 84 | Green Lake Creek at Mouth |
| 85 | Rabbit River below Green Lake Creek |
| 86 | Rabbit River at Gage #04108600 |
| 87 | Miller Creek at Mouth |
| 88 | Rabbit River below Bear Creek |
| 89 | Rabbit River below Little Rabbit River |
| 90 | Black Creek at Mouth |
| 91 | Rabbit River below Silver Creek |
| 92 | Rabbit River at Mouth |
| 93 | Kalamazoo River below Rabbit River |
| 94 | Mann Creek at Mouth |
| 95 | Kalamazoo River below Peach Orchid Creek |
| 96 | Kalamazoo River at Mouth |

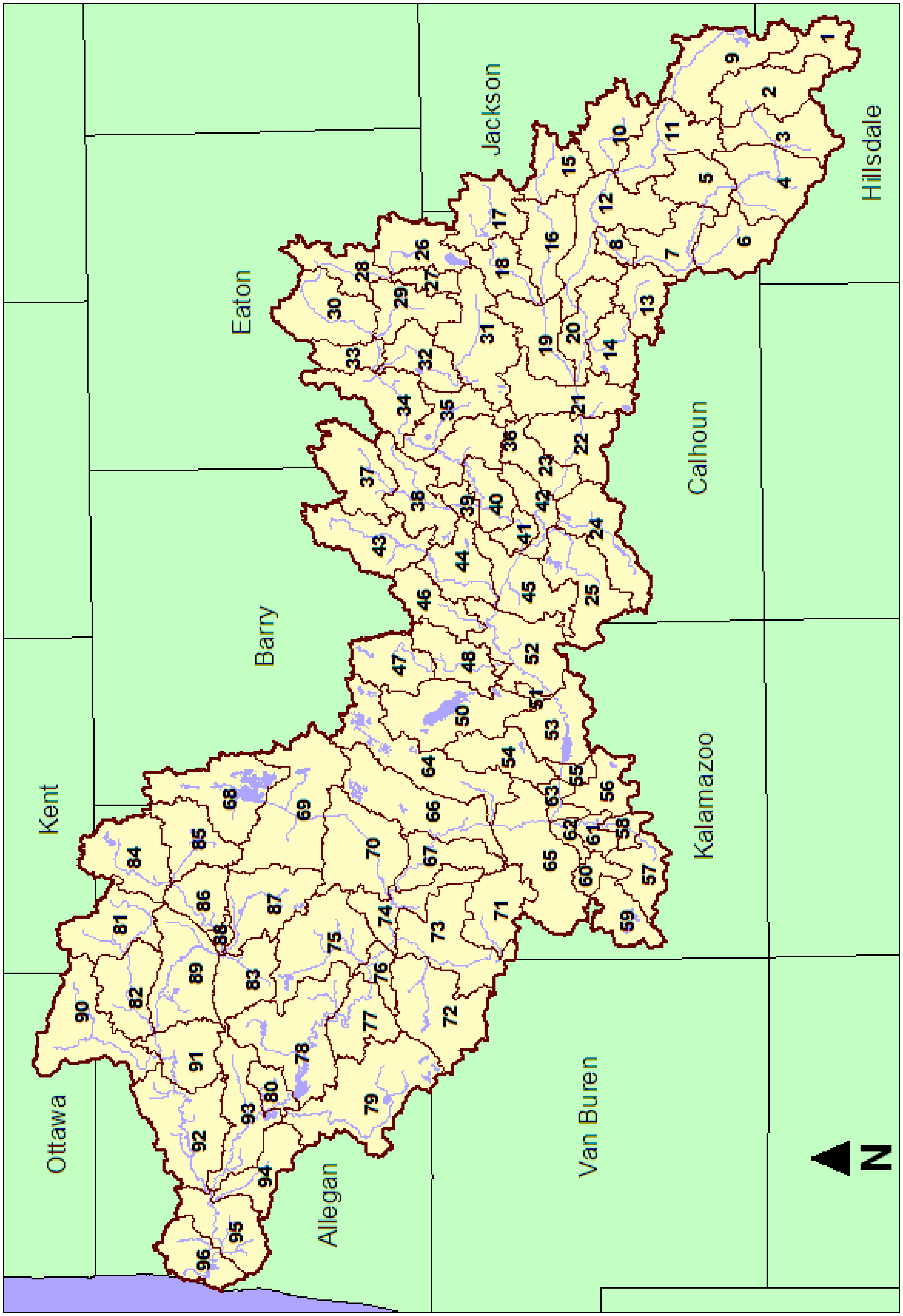


Figure 5 – Kalamazoo River Subbasin Identification

## *Land Use*

### 1800 and 1978 Land Cover

General land use trends for the watershed from 1800 to 1978 are illustrated in Figure 6. More detailed land use information for each subbasin is tabulated in Table 2. Land use maps depicting MDEQ GIS data for 1800 and 1978 are shown in Figures 7 and 8.

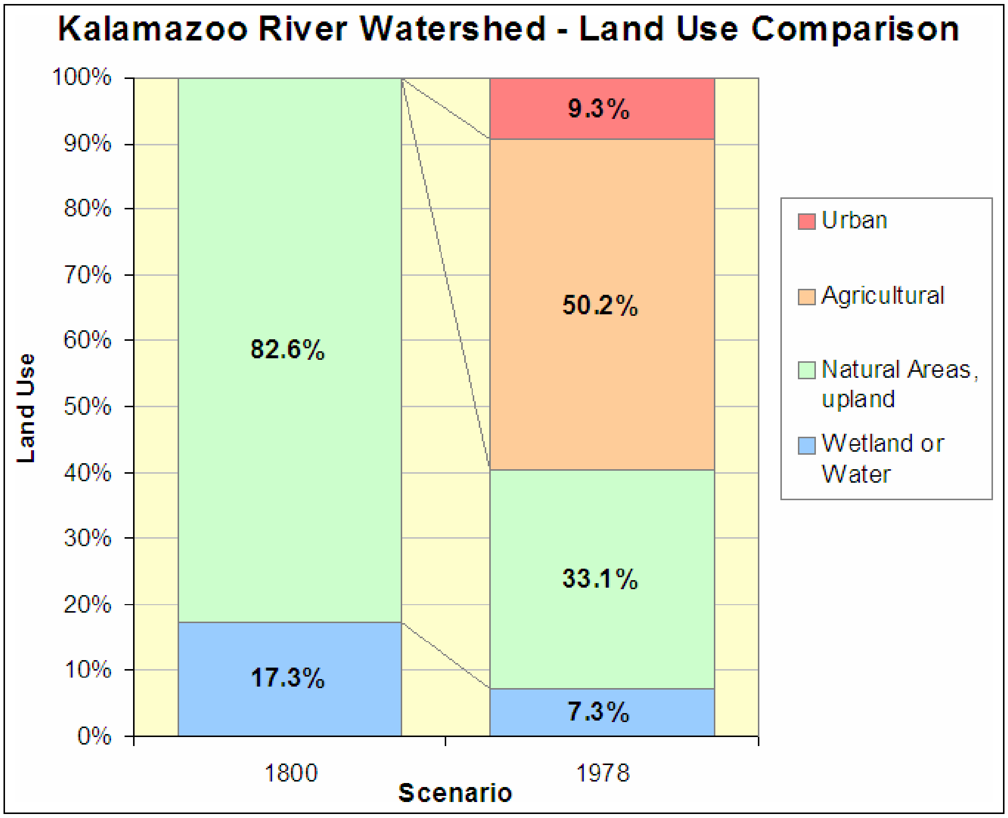


Figure 6 – Land Use Comparison, Kalamazoo River Watershed

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 MDEQ NPS Program does not expect flow regimes calculated from 1800 land use be used as criteria for BMP design or as a goal for watershed managers.

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.

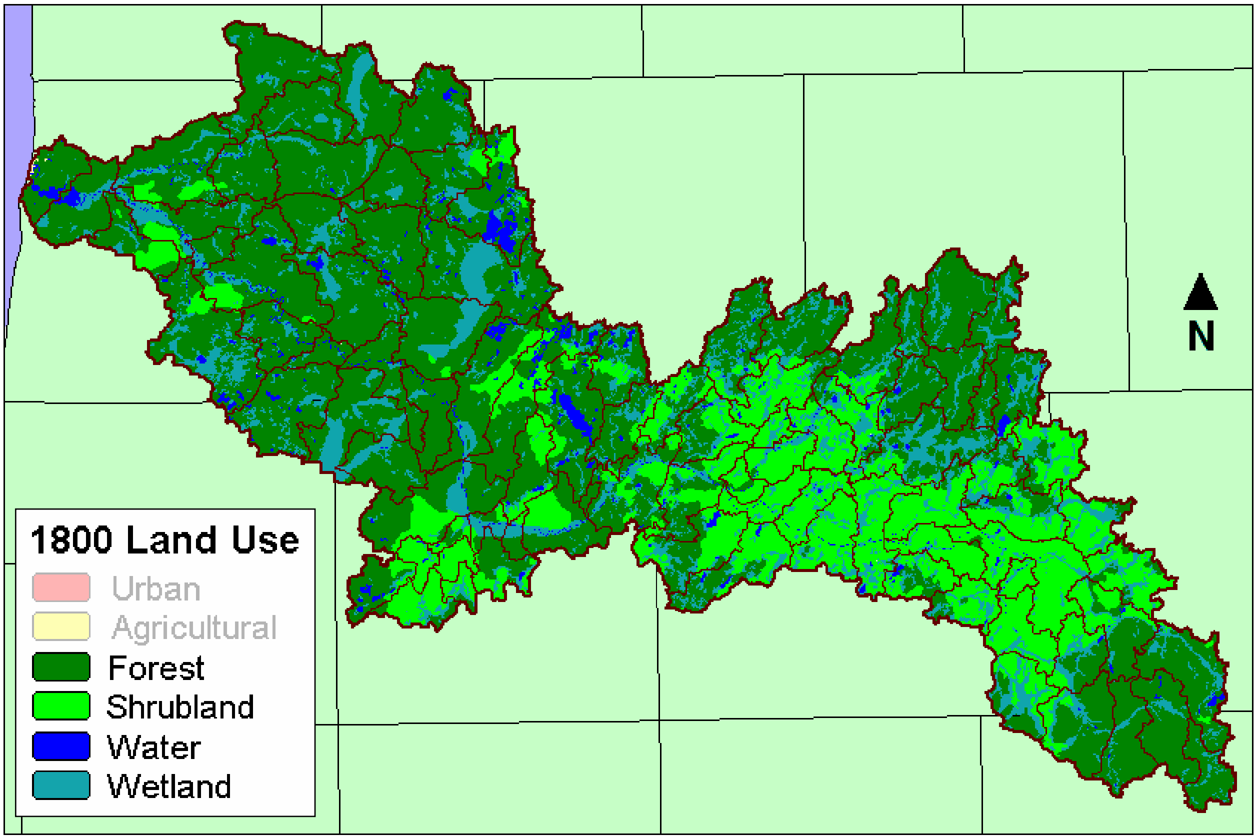


Figure 7 – 1800 Land Cover

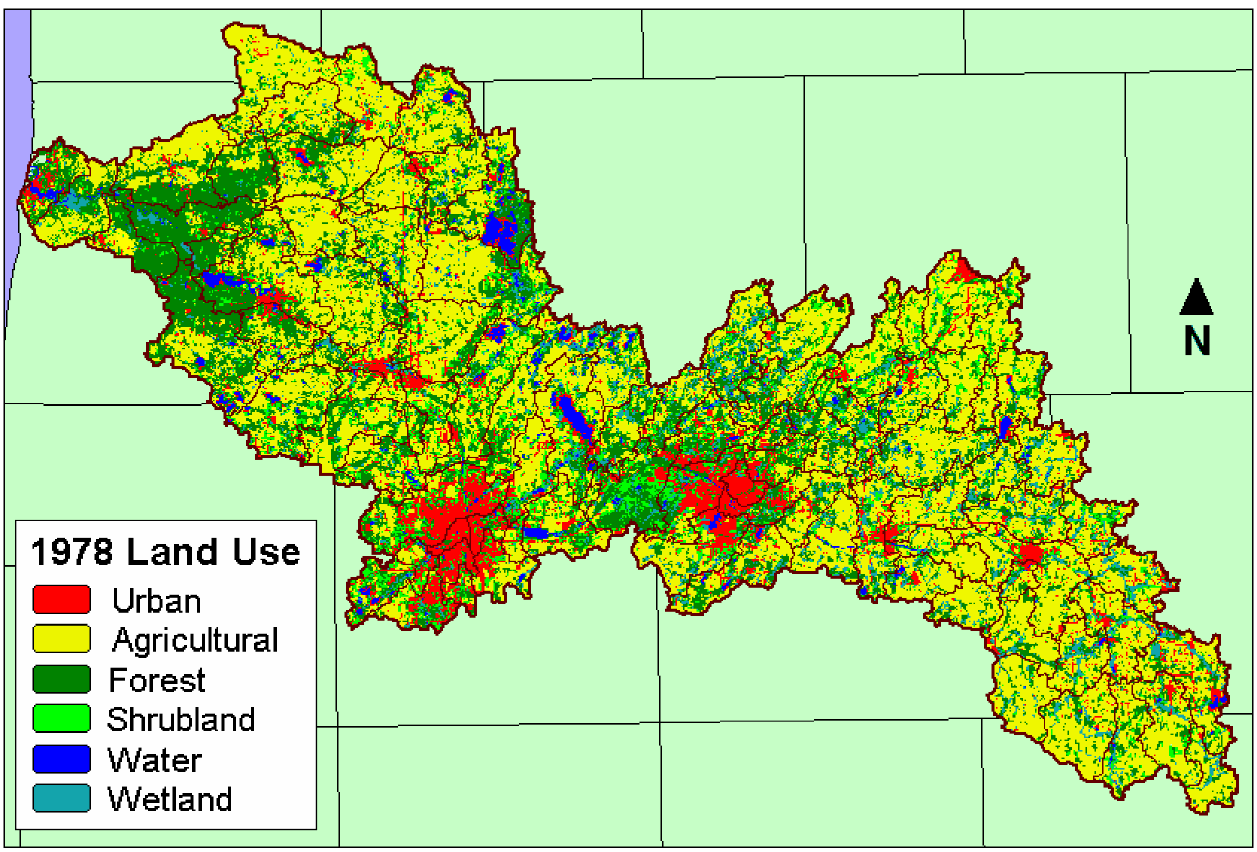


Figure 8 – 1978 Land Cover

Table 2 – Land Use

| Subbasin | Scenario | Urban | Agriculture | Herbaceous Open Land | Forest | Open Water | Wetland | Bare Soil, Dune |
|---|---|---|---|---|---|---|---|---|
| 1 | 1800 | | | | 88.0% | | 12.0% | |
| | 1978 | 1.7% | 70.1% | 3.1% | 16.1% | 0.1% | 8.8% | |
| 2 | 1800 | | | | 91.9% | 0.9% | 7.1% | |
| | 1978 | 5.4% | 64.9% | 6.7% | 16.9% | 0.2% | 5.8% | |
| 3 | 1800 | | | | 91.6% | 0.4% | 8.0% | |
| | 1978 | 2.1% | 64.8% | 8.1% | 19.0% | 0.7% | 5.3% | |
| 4 | 1800 | | | 14.6% | 70.6% | 0.2% | 14.5% | |
| | 1978 | 2.4% | 73.6% | 3.0% | 15.3% | 0.3% | 5.5% | |
| 5 | 1800 | | | 41.0% | 36.7% | 0.9% | 21.4% | |
| | 1978 | 6.6% | 59.0% | 3.7% | 17.7% | 1.0% | 12.0% | |
| 6 | 1800 | | | 39.0% | 28.0% | | 33.0% | |
| | 1978 | 0.8% | 80.2% | 1.4% | 11.7% | | 5.9% | |
| 7 | 1800 | | | 90.1% | | 0.4% | 9.6% | |
| | 1978 | 3.6% | 69.5% | 1.8% | 20.0% | | 5.1% | |
| 8 | 1800 | | | 88.8% | | 1.7% | 9.4% | |
| | 1978 | 13.6% | 50.6% | 7.4% | 19.4% | 1.2% | 7.8% | |
| 9 | 1800 | | | 3.4% | 79.6% | 2.3% | 14.8% | |
| | 1978 | 11.9% | 53.3% | 4.6% | 19.3% | 2.6% | 8.2% | |
| 10 | 1800 | | | 66.6% | 15.5% | | 18.0% | |
| | 1978 | 9.1% | 61.1% | 4.8% | 12.1% | 0.1% | 12.9% | |
| 11 | 1800 | | | 37.3% | 51.7% | 1.1% | 9.8% | |
| | 1978 | 9.8% | 61.0% | 4.1% | 15.7% | 0.6% | 8.8% | |
| 12 | 1800 | | | 91.2% | 1.1% | 1.1% | 6.6% | |
| | 1978 | 11.6% | 65.8% | 4.5% | 13.1% | 0.3% | 4.7% | |
| 13 | 1800 | | | 61.8% | 17.0% | 0.3% | 20.9% | |
| | 1978 | 1.2% | 75.3% | 1.3% | 15.7% | 0.1% | 6.3% | |
| 14 | 1800 | | | 57.0% | 24.1% | 3.1% | 15.7% | |
| | 1978 | 5.6% | 63.7% | 3.8% | 15.7% | 2.1% | 9.2% | |
| 15 | 1800 | | | 63.3% | 11.4% | | 25.4% | |
| | 1978 | 6.6% | 55.8% | 11.4% | 16.2% | | 9.9% | |
| 16 | 1800 | | | 58.8% | 22.4% | 0.9% | 17.9% | |
| | 1978 | 5.8% | 57.8% | 5.0% | 21.7% | 0.3% | 9.3% | |
| 17 | 1800 | | | 59.8% | 19.9% | | 20.2% | |
| | 1978 | 4.1% | 69.1% | 1.5% | 13.3% | 1.2% | 10.7% | |
| 18 | 1800 | | | 41.6% | 25.9% | 1.1% | 31.4% | |
| | 1978 | 2.0% | 53.8% | 5.4% | 26.7% | 1.0% | 11.1% | |
| 19 | 1800 | | | 81.2% | 7.2% | 0.2% | 11.5% | |
| | 1978 | 10.1% | 63.7% | 5.6% | 14.0% | 0.1% | 6.5% | |
| 20 | 1800 | | | 92.4% | 1.8% | 1.5% | 4.3% | |
| | 1978 | 5.6% | 73.1% | 4.1% | 12.1% | 1.6% | 3.6% | |
| 21 | 1800 | | | 77.7% | 0.6% | 1.5% | 20.1% | |
| | 1978 | 12.8% | 49.8% | 8.5% | 15.9% | 1.0% | 11.9% | |
| 22 | 1800 | | | 80.3% | 1.3% | 0.7% | 17.7% | |
| | 1978 | 3.9% | 67.8% | 3.8% | 15.7% | 1.1% | 7.6% | |
| 23 | 1800 | | | 87.1% | | 1.8% | 11.1% | |
| | 1978 | 8.2% | 55.4% | 5.3% | 24.1% | 0.1% | 6.8% | |
| 24 | 1800 | | | 48.4% | 32.2% | 2.4% | 17.0% | |
| | 1978 | 11.0% | 45.5% | 5.4% | 27.7% | 2.2% | 8.1% | |

| Subbasin | Scenario | Urban | Agriculture | Herbaceous Open Land | Forest | Open Water | Wetland | Bare Soil, Dune |
|---|---|---|---|---|---|---|---|---|
| 25 | 1800 | | | 50.9% | 32.5% | 2.6% | 14.0% | |
| | 1978 | 22.9% | 44.6% | 10.3% | 13.2% | 2.1% | 7.0% | |
| 26 | 1800 | | | 4.2% | 69.2% | 6.2% | 20.4% | |
| | 1978 | 3.8% | 62.4% | 6.8% | 18.3% | 5.5% | 3.3% | |
| 27 | 1800 | | | | 84.8% | | 15.2% | |
| | 1978 | 1.2% | 76.0% | 6.0% | 14.6% | 0.1% | 2.1% | |
| 28 | 1800 | | | | 77.9% | | 22.1% | |
| | 1978 | 3.2% | 68.7% | 9.9% | 16.8% | | 1.4% | |
| 29 | 1800 | | | | 86.2% | 0.1% | 13.7% | |
| | 1978 | 1.2% | 69.9% | 11.5% | 14.7% | 0.1% | 2.6% | |
| 30 | 1800 | | | | 90.0% | | 10.0% | |
| | 1978 | 12.4% | 62.3% | 10.7% | 13.3% | | 1.3% | |
| 31 | 1800 | | | 11.6% | 48.3% | 0.7% | 39.5% | |
| | 1978 | 2.3% | 63.2% | 3.8% | 21.8% | 0.4% | 8.6% | |
| 32 | 1800 | | | 5.0% | 75.9% | 2.7% | 16.5% | |
| | 1978 | 8.4% | 54.8% | 7.9% | 20.3% | 1.6% | 7.0% | |
| 33 | 1800 | | | 0.9% | 78.2% | | 20.9% | |
| | 1978 | 2.1% | 67.1% | 14.3% | 14.4% | 0.1% | 2.1% | |
| 34 | 1800 | | | 14.9% | 68.8% | 0.3% | 16.0% | |
| | 1978 | 5.0% | 56.9% | 13.3% | 20.5% | 0.5% | 3.7% | |
| 35 | 1800 | | | 49.6% | 17.2% | 3.1% | 30.1% | |
| | 1978 | 3.6% | 35.8% | 11.2% | 32.7% | 2.4% | 14.2% | |
| 36 | 1800 | | | 75.1% | 1.6% | 1.0% | 22.3% | |
| | 1978 | 3.9% | 43.7% | 7.2% | 36.0% | 0.9% | 8.4% | |
| 37 | 1800 | | | 6.6% | 73.8% | 0.2% | 19.4% | |
| | 1978 | 2.4% | 63.2% | 9.2% | 18.8% | 0.2% | 6.1% | |
| 38 | 1800 | | | 65.0% | 14.1% | 1.1% | 19.8% | |
| | 1978 | 5.6% | 40.5% | 11.8% | 31.9% | 0.7% | 9.6% | |
| 39 | 1800 | | | 79.2% | | 0.7% | 20.1% | |
| | 1978 | 15.3% | 26.7% | 10.4% | 39.7% | 1.1% | 6.8% | |
| 40 | 1800 | | | 82.0% | 2.0% | 1.8% | 14.3% | |
| | 1978 | 21.0% | 24.7% | 14.8% | 35.2% | 0.4% | 4.0% | |
| 41 | 1800 | | | 82.0% | 13.9% | 1.8% | 2.4% | |
| | 1978 | 81.6% | 0.2% | 6.6% | 9.6% | 0.3% | 1.7% | |
| 42 | 1800 | | | 92.2% | 0.7% | 1.4% | 5.8% | |
| | 1978 | 39.8% | 19.2% | 8.8% | 26.1% | 0.8% | 5.3% | |
| 43 | 1800 | | | 12.8% | 61.4% | 0.8% | 25.1% | |
| | 1978 | 2.5% | 44.5% | 6.8% | 29.4% | 1.1% | 15.9% | |
| 44 | 1800 | | | 43.0% | 38.7% | 2.2% | 16.1% | |
| | 1978 | 18.4% | 23.9% | 13.5% | 33.4% | 2.1% | 8.8% | |
| 45 | 1800 | | | 46.9% | 38.9% | 1.2% | 13.1% | |
| | 1978 | 39.1% | 10.7% | 20.5% | 22.8% | 1.7% | 5.3% | |
| 46 | 1800 | | | 50.2% | 32.0% | 0.9% | 16.9% | |
| | 1978 | 5.1% | 40.5% | 9.9% | 32.0% | 0.2% | 12.3% | |
| 47 | 1800 | | | 15.6% | 62.8% | 4.4% | 17.2% | |
| | 1978 | 2.6% | 54.4% | 6.5% | 19.7% | 3.2% | 13.6% | |
| 48 | 1800 | | | 10.7% | 70.4% | 1.4% | 17.6% | |
| | 1978 | 5.1% | 36.8% | 8.9% | 37.4% | 0.9% | 10.8% | |
| 49 | 1800 | | | 26.9% | 58.1% | | 15.0% | |
| | 1978 | 13.6% | 17.6% | 19.0% | 38.7% | | 11.1% | |

| Subbasin | Scenario | Urban | Agriculture | Herbaceous Open Land | Forest | Open Water | Wetland | Bare Soil, Dune |
|---|---|---|---|---|---|---|---|---|
| 50 | 1800 | | | 15.8% | 64.6% | 12.6% | 7.0% | |
| | 1978 | 8.9% | 46.2% | 9.6% | 17.0% | 11.9% | 6.4% | |
| 51 | 1800 | | | | 100.0% | | | |
| | 1978 | 6.4% | 59.3% | 11.1% | 21.7% | 0.9% | 0.5% | |
| 52 | 1800 | | | 26.7% | 54.6% | 2.2% | 16.5% | |
| | 1978 | 9.7% | 10.4% | 23.0% | 49.5% | 1.2% | 6.2% | |
| 53 | 1800 | | | 31.9% | 57.1% | 1.2% | 9.8% | |
| | 1978 | 10.2% | 45.8% | 15.8% | 20.1% | 6.3% | 1.9% | |
| 54 | 1800 | | | 37.4% | 53.7% | 1.8% | 7.0% | |
| | 1978 | 12.9% | 53.7% | 13.8% | 12.1% | 3.0% | 4.5% | |
| 55 | 1800 | | | 14.5% | 54.4% | 1.2% | 29.9% | |
| | 1978 | 19.3% | 51.9% | 16.7% | 9.6% | 1.1% | 1.4% | |
| 56 | 1800 | | | 34.9% | 50.3% | 1.4% | 13.3% | |
| | 1978 | 31.0% | 41.1% | 12.2% | 11.5% | 1.3% | 2.9% | |
| 57 | 1800 | | | 70.6% | 17.7% | | 11.7% | |
| | 1978 | 30.6% | 27.5% | 18.2% | 18.9% | 0.3% | 4.5% | |
| 58 | 1800 | | | 65.6% | 14.8% | | 19.7% | |
| | 1978 | 43.8% | 15.1% | 21.5% | 18.8% | | 0.9% | |
| 59 | 1800 | | | 17.4% | 70.5% | 7.1% | 5.1% | |
| | 1978 | 12.3% | 21.3% | 24.9% | 30.2% | 6.3% | 5.0% | |
| 60 | 1800 | | | 94.7% | | 1.9% | 3.4% | |
| | 1978 | 31.7% | 30.5% | 21.3% | 11.6% | 1.9% | 3.1% | |
| 61 | 1800 | | | 98.6% | 0.6% | 0.8% | | |
| | 1978 | 79.3% | 1.3% | 9.1% | 7.7% | 1.0% | 1.7% | |
| 62 | 1800 | | | 53.0% | 31.9% | 1.2% | 13.9% | |
| | 1978 | 88.3% | | 2.7% | 6.9% | 1.3% | 0.8% | |
| 63 | 1800 | | | 23.3% | 32.5% | 2.9% | 41.3% | |
| | 1978 | 62.5% | 5.0% | 12.1% | 16.5% | 2.8% | 1.1% | |
| 64 | 1800 | | | 25.4% | 60.8% | 8.2% | 5.6% | |
| | 1978 | 6.1% | 47.2% | 10.0% | 23.4% | 5.0% | 8.3% | |
| 65 | 1800 | | | 19.6% | 68.2% | 1.0% | 11.2% | |
| | 1978 | 42.8% | 18.4% | 17.8% | 18.8% | 1.0% | 1.2% | |
| 66 | 1800 | | | 15.9% | 70.6% | 5.0% | 8.5% | |
| | 1978 | 8.0% | 43.5% | 13.8% | 27.6% | 3.9% | 3.3% | |
| 67 | 1800 | | | | 94.5% | 1.8% | 3.7% | |
| | 1978 | 19.1% | 44.1% | 14.3% | 19.8% | 0.3% | 2.4% | |
| 68 | 1800 | | | 11.8% | 58.7% | 16.8% | 12.7% | |
| | 1978 | 7.1% | 31.9% | 5.8% | 34.3% | 16.6% | 4.3% | |
| 69 | 1800 | | | | 71.4% | 2.1% | 26.5% | |
| | 1978 | 4.0% | 56.0% | 7.9% | 23.9% | 2.0% | 6.2% | |
| 70 | 1800 | | | 2.2% | 77.4% | 0.3% | 20.1% | |
| | 1978 | 7.7% | 59.4% | 7.7% | 23.5% | 0.1% | 1.5% | |
| 71 | 1800 | | | | 81.5% | 0.3% | 18.2% | |
| | 1978 | 7.4% | 45.4% | 12.6% | 30.3% | 1.8% | 2.5% | |
| 72 | 1800 | | | | 84.6% | 2.4% | 12.9% | |
| | 1978 | 3.9% | 54.7% | 10.1% | 26.2% | 2.0% | 3.0% | |
| 73 | 1800 | | | 0.2% | 66.5% | 0.2% | 33.1% | |
| | 1978 | 4.6% | 52.4% | 9.4% | 30.8% | 0.5% | 2.3% | |
| 74 | 1800 | | | | 91.6% | 1.8% | 6.6% | |
| | 1978 | 18.4% | 45.4% | 10.5% | 20.8% | 0.8% | 4.0% | |

| Subbasin | Scenario | Urban | Agriculture | Herbaceous Open Land | Forest | Open Water | Wetland | Bare Soil, Dune |
|---|---|---|---|---|---|---|---|---|
| 75 | 1800 | | | | 83.6% | 2.6% | 13.7% | |
| | 1978 | 2.8% | 63.6% | 4.1% | 24.2% | 2.0% | 3.3% | |
| 76 | 1800 | | | | 91.4% | 3.7% | 4.8% | |
| | 1978 | 4.4% | 46.5% | 4.6% | 33.4% | 2.0% | 9.0% | |
| 77 | 1800 | | | 0.7% | 84.4% | 3.7% | 11.2% | |
| | 1978 | 10.0% | 40.1% | 7.0% | 38.7% | 2.1% | 2.0% | |
| 78 | 1800 | | | 10.0% | 78.6% | 2.7% | 8.7% | |
| | 1978 | 9.6% | 39.5% | 6.2% | 36.3% | 7.2% | 1.3% | |
| 79 | 1800 | | | 5.3% | 68.7% | 3.5% | 22.4% | |
| | 1978 | 3.8% | 30.1% | 4.1% | 56.5% | 3.0% | 2.6% | |
| 80 | 1800 | | | | 77.2% | 2.6% | 20.2% | |
| | 1978 | 2.3% | 15.4% | 4.5% | 73.8% | | 3.9% | |
| 81 | 1800 | | | | 76.9% | | 23.1% | |
| | 1978 | 6.0% | 71.3% | 8.8% | 10.7% | 0.1% | 3.0% | 0.2% |
| 82 | 1800 | | | | 89.4% | | 10.6% | |
| | 1978 | 3.5% | 66.3% | 3.0% | 24.1% | 0.1% | 2.8% | 0.2% |
| 83 | 1800 | | | | 82.3% | 0.3% | 17.4% | |
| | 1978 | 2.2% | 78.8% | 2.2% | 13.9% | 0.3% | 2.6% | |
| 84 | 1800 | | | | 88.6% | 2.0% | 9.4% | |
| | 1978 | 4.4% | 65.2% | 4.3% | 21.2% | 2.0% | 2.8% | |
| 85 | 1800 | | | 9.7% | 73.9% | 1.6% | 14.8% | |
| | 1978 | 5.9% | 57.4% | 5.5% | 25.6% | 1.1% | 4.6% | |
| 86 | 1800 | | | | 90.9% | 0.2% | 8.9% | |
| | 1978 | 6.3% | 73.4% | 3.1% | 14.6% | 0.2% | 2.4% | |
| 87 | 1800 | | | | 92.0% | 1.8% | 6.2% | |
| | 1978 | 3.9% | 65.1% | 4.4% | 19.9% | 1.7% | 5.1% | |
| 88 | 1800 | | | | 82.8% | 0.3% | 16.9% | |
| | 1978 | 0.1% | 69.8% | 1.4% | 24.4% | 0.2% | 4.1% | |
| 89 | 1800 | | | | 88.2% | 0.3% | 11.4% | |
| | 1978 | 4.8% | 59.7% | 3.7% | 28.0% | 1.5% | 2.4% | |
| 90 | 1800 | | | | 91.2% | 0.1% | 8.8% | |
| | 1978 | 1.9% | 82.5% | 3.0% | 10.7% | 0.1% | 1.8% | |
| 91 | 1800 | | | 1.9% | 86.4% | 0.8% | 10.8% | |
| | 1978 | 1.8% | 29.3% | 3.3% | 63.5% | 0.1% | 1.8% | 0.1% |
| 92 | 1800 | | | 11.7% | 75.6% | 1.2% | 11.5% | |
| | 1978 | 4.0% | 52.2% | 2.1% | 39.8% | 0.3% | 1.7% | |
| 93 | 1800 | | | 14.2% | 60.0% | 1.7% | 24.1% | |
| | 1978 | 2.8% | 7.7% | 4.9% | 77.6% | 1.5% | 5.6% | |
| 94 | 1800 | | | 31.2% | 59.8% | 0.6% | 8.4% | |
| | 1978 | 7.0% | 13.6% | 6.6% | 70.8% | 0.3% | 1.6% | |
| 95 | 1800 | | | | 79.2% | 6.9% | 13.9% | |
| | 1978 | 2.4% | 50.4% | 4.2% | 32.8% | 2.0% | 8.2% | |
| 96 | 1800 | | | | 86.0% | 9.8% | 1.3% | 3.0% |
| | 1978 | 18.7% | 19.1% | 6.7% | 40.9% | 7.8% | 2.2% | 4.5% |
| All | 1800 | | | 24.7% | 57.9% | 2.2% | 15.2% | |
| | 1978 | 9.3% | 50.2% | 7.9% | 25.2% | 1.9% | 5.4% | |

## Imperviousness

Percent imperviousness can be compared to the Center for Watershed Protection's proposed classification of headwater urban streams, excerpted in Table 3 and detailed in *The Importance of Imperviousness, The Practice of Watershed Protection* (Schueler and Holland, 2000).

Table 3 – Classification of Urban Headwater Streams

| **Urban Stream Classification** | **Sensitive (0–10% Impervious)** | **Impacted (11–25% Impervious)** | **Non-supporting (26–100% Impervious)** |
|---|---|---|---|
| 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 land use GIS data, Figure 8. The percent imperviousness was computed according to Table 4. The imperviousness values for residential, commercial, and industrial are from the Natural Resources Conservation Service (NRCS, 1986).

The results, shown in Figure 9 and tabulated in Table 5, indicate that 13 of the 96 subbasins have exceeded the 10 percent impervious threshold, and six of those have exceeded the 25 percent threshold, at this scale of analysis. However, there may also be headwater streams with smaller drainage areas within any subbasin that exceed the thresholds for impacted or non-supporting streams. With proper planning and BMP selection, the negative impacts associated with the increased imperviousness can be mitigated.

Table 4 – Imperviousness Table for Impervious Area Analysis

| GIS Class | Description | Imperviousness (percent) |
|---|---|---|
| 1 | Residential | 38* |
| 2 | Commercial | 85 |
| 3 | Industrial | 72 |
| 4 | Road, Utilities | 95 |
| 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 |

* assumed population density of 250 to 1,000 people per square mile

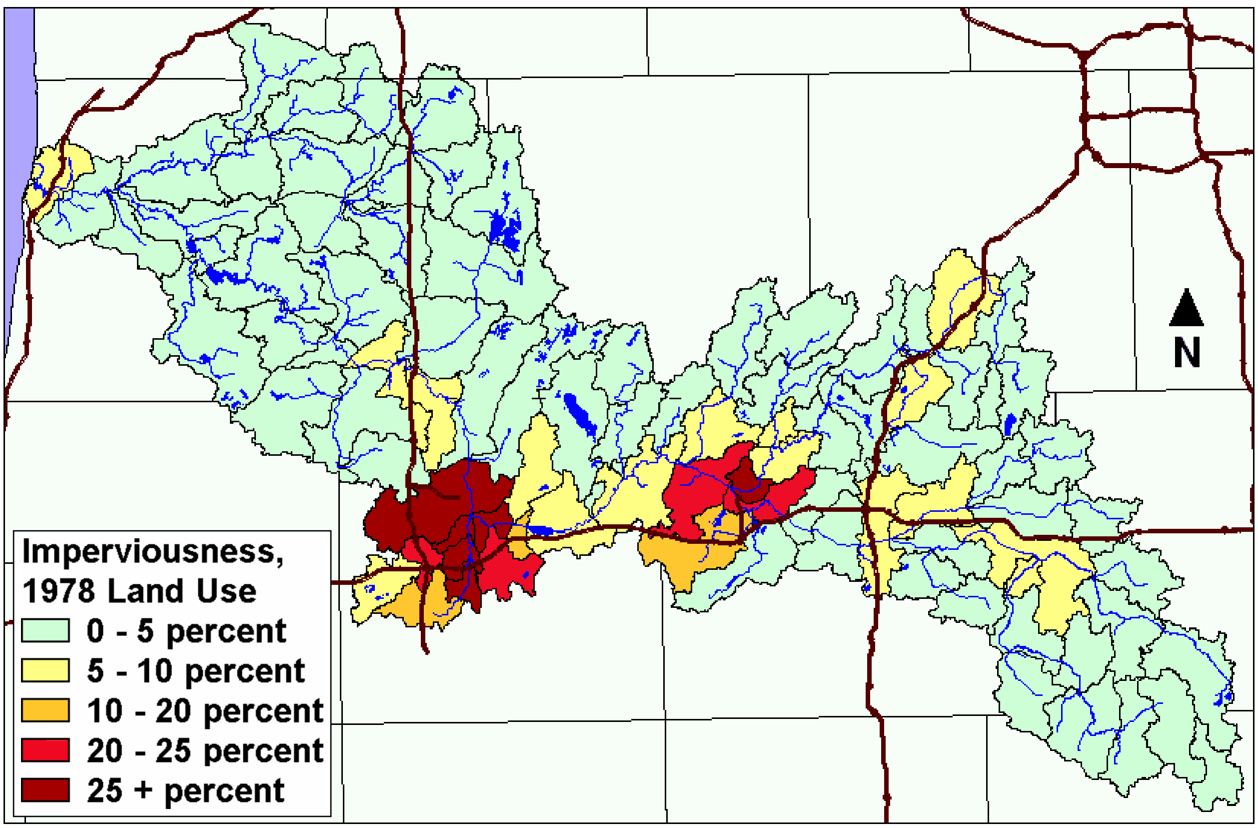



Figure 9 – Percent Imperviousness based on 1978 Land Cover

Table 5 – Percent Imperviousness and Conservation and Recreation Lands

| ID | Subbasin | Drainage Area (sq. mi.) | Percent Impervious | Percent CARL |
|---|---|---|---|---|
| 1 | S Br Kalamazoo River at Mosherville Road | 14.3 | 1.1% | 0.0% |
| 2 | S Br Kalamazoo River below tributary | 24.7 | 2.1% | 0.0% |
| 3 | S Br Kalamazoo River below tributary | 22.0 | 1.1% | 0.0% |
| 4 | S Br Kalamazoo River below Beaver Creek | 29.2 | 1.4% | 0.0% |
| 5 | S Br Kalamazoo River below Swains Lake Drain | 17.3 | 2.2% | 0.5% |
| 6 | Lampson Run Drain at Mouth | 21.6 | 1.0% | 0.3% |
| 7 | S Br Kalamazoo River at Gage #04102850 | 18.4 | 1.6% | 0.0% |
| 8 | S Br Kalamazoo River at Mouth | 5.5 | 6.3% | 1.5% |
| 9 | North Kalamazoo River at Cross Lake Outlet | 33.2 | 3.5% | 0.3% |
| 10 | Spring Arbor and Concord at Mouth | 20.9 | 3.4% | 0.1% |
| 11 | N Br Kalamazoo River below Spring Arbor & Concord Drain | 25.2 | 3.2% | 0.9% |
| 12 | Kalamazoo River at Gage #04103010 | 37.1 | 7.0% | 1.4% |
| 13 | Wilder Creek below Huckleberry Drain | 15.1 | 1.0% | 3.1% |
| 14 | Wilder Creek at Mouth | 14.8 | 3.4% | 1.3% |
| 15 | S Br Rice Creek at M-99 | 17.0 | 3.1% | 0.1% |
| 16 | S Br Rice Creek at Mouth | 22.5 | 3.0% | 0.9% |
| 17 | N Br Rice Creek at Gordon Lake Outlet | 21.6 | 2.2% | 0.0% |
| 18 | N Br Rice Creek at Mouth | 14.5 | 1.1% | 0.0% |
| 19 | Rice Creek at Mouth | 20.9 | 5.6% | 0.4% |
| 20 | Kalamazoo River at Gage #04103500 | 15.4 | 2.5% | 1.4% |
| 21 | Kalamazoo River below Squaw Lake Drain | 24.6 | 8.3% | 0.6% |
| 22 | Kalamazoo River below Pigeon Creek | 21.5 | 2.2% | 0.0% |
| 23 | Kalamazoo River below Dickinson Creek | 14.6 | 4.0% | 2.4% |
| 24 | Harper Creek at Mouth | 26.6 | 4.1% | 4.4% |
| 25 | Minges Brook at Mouth | 27.6 | 14.9% | 1.8% |
| 26 | Battle Creek Above Hogle and Miller Drain | 20.5 | 1.4% | 0.0% |
| 27 | Hogle and Miller Drain at Mouth | 6.6 | 1.0% | 0.0% |
| 28 | Battle Creek below tributary | 15.9 | 1.4% | 0.0% |
| 29 | Big Creek at Mouth | 18.0 | 0.9% | 0.7% |
| 30 | Battle Creek below Big Creek | 27.4 | 7.5% | 2.3% |
| 31 | Indian Creek below State and Indian Creek | 33.0 | 1.7% | 0.6% |
| 32 | Indian Creek at Mouth | 16.7 | 5.3% | 2.4% |
| 33 | Battle Creek below Indian Creek | 9.7 | 1.5% | 0.0% |
| 34 | Battle Creek at Gage #04104500 | 23.9 | 2.4% | 0.5% |
| 35 | Battle Creek below Ackley Creek | 18.4 | 2.0% | 10.2% |
| 36 | Battle Creek below tributary | 16.8 | 1.7% | 0.7% |
| 37 | Wanadoga Creek below Ellis Creek | 26.0 | 1.0% | 0.0% |
| 38 | Wanadoga Creek at Gage #04104945 | 22.3 | 2.3% | 0.0% |
| 39 | Wanadoga Creek at Mouth | 5.9 | 6.3% | 1.2% |
| 40 | Battle Creek at Gage #04105000 | 12.8 | 9.4% | 1.4% |
| 41 | Battle Creek at Mouth | 6.4 | 52.5% | 1.9% |
| 42 | Kalamazoo River at Gage #04105500 | 12.5 | 20.4% | 8.0% |
| 43 | Wabascon Creek at Luce Road | 27.4 | 1.2% | 0.0% |
| 44 | Wabascon Creek at Mouth | 19.5 | 6.7% | 2.3% |
| 45 | Kalamazoo River below Wabascon Creek | 24.5 | 24.9% | 1.8% |
| 46 | Sevenmile Creek at Mouth | 16.3 | 1.7% | 0.7% |
| 47 | Augusta Creek below tributary | 19.1 | 1.1% | 0.7% |
| 48 | Augusta Creek at Gage #04105700 | 17.7 | 1.4% | 16.4% |
| 49 | Augusta Creek at Mouth | 1.0 | 3.6% | 0.0% |

| ID | Subbasin | Drainage Area (sq. mi.) | Percent Impervious | Percent CARL |
|---|---|---|---|---|
| 50 | Gull Creek at Gage #04105800 | 35.7 | 3.0% | 8.3% |
| 51 | Gull Creek at Mouth | 1.8 | 1.3% | 0.0% |
| 52 | Kalamazoo River below Gull Creek | 30.6 | 5.0% | 17.0% |
| 53 | Kalamazoo River at Morrow Lake Dam | 23.8 | 5.8% | 4.2% |
| 54 | Comstock Creek at Mouth | 18.3 | 5.1% | 0.9% |
| 55 | Kalamazoo River at Gage #04106000 | 4.4 | 10.2% | 0.1% |
| 56 | Davis Creek at Mouth | 14.5 | 22.6% | 0.6% |
| 57 | Portage Creek at Gage #04106180 | 14.9 | 16.7% | 14.3% |
| 58 | Portage Creek at Gage #04106300 | 5.4 | 30.1% | 5.5% |
| 59 | W Fork Portage Creek at Gage #04106320 | 14.5 | 6.8% | 0.0% |
| 60 | W Fork Portage Creek at Gage #04106400 | 6.7 | 21.9% | 8.0% |
| 61 | Portage Creek at Gage #04106500 | 6.2 | 51.0% | 8.9% |
| 62 | Portage Creek at Mouth | 4.0 | 62.1% | 5.9% |
| 63 | Kalamazoo River below Portage Creek | 6.0 | 38.5% | 1.8% |
| 64 | Spring Brook at Mouth | 38.6 | 2.2% | 6.1% |
| 65 | Kalamazoo River below Spring Brook | 40.4 | 25.9% | 5.1% |
| 66 | Kalamazoo River below Silver Creek | 36.8 | 2.0% | 6.7% |
| 67 | Kalamazoo River at Plainwell Dam | 17.5 | 9.1% | 1.6% |
| 68 | Gun River at Gun Lake Outlet | 34.2 | 2.0% | 23.0% |
| 69 | Gun River below Culver Drain | 48.9 | 1.5% | 5.6% |
| 70 | Gun River at Mouth | 34.7 | 3.6% | 0.1% |
| 71 | Sand Creek at Mouth | 21.1 | 4.0% | 5.5% |
| 72 | Base Line Creek at Mouth | 36.6 | 1.6% | 0.8% |
| 73 | Pine Creek at Mouth | 33.3 | 2.3% | 2.7% |
| 74 | Kalamazoo River at Otsego Dam | 17.8 | 8.4% | 0.2% |
| 75 | Schnable Brook at Mouth | 35.5 | 1.3% | 0.1% |
| 76 | Kalamazoo River at Trowbridge Dam | 7.3 | 1.3% | 2.7% |
| 77 | Kalamazoo River at Unnamed Dam | 19.5 | 4.5% | 3.4% |
| 78 | Kalamazoo River at Unnamed Dam | 44.8 | 4.5% | 12.1% |
| 79 | Swan Creek at Mouth | 49.1 | 1.0% | 26.1% |
| 80 | Kalamazoo River at Gage #04108500 | 8.1 | 0.9% | 50.8% |
| 81 | Little Rabbit River below Dorr & Nichols Drain | 25.6 | 2.8% | 0.6% |
| 82 | Little Rabbit River at Mouth | 23.4 | 1.6% | 0.0% |
| 83 | Bear Creek at Mouth | 20.1 | 1.6% | 0.1% |
| 84 | Green Lake Creek at Mouth | 28.2 | 2.2% | 0.0% |
| 85 | Rabbit River below Green Lake Creek | 21.4 | 3.6% | 1.6% |
| 86 | Rabbit River at Gage #04108600 | 15.5 | 4.5% | 0.0% |
| 87 | Miller Creek at Mouth | 27.7 | 2.5% | 0.7% |
| 88 | Rabbit River below Bear Creek | 2.7 | 0.7% | 2.1% |
| 89 | Rabbit River below Little Rabbit River | 32.5 | 1.8% | 0.4% |
| 90 | Black Creek at Mouth | 35.1 | 1.5% | 0.0% |
| 91 | Rabbit River below Silver Creek | 20.4 | 0.8% | 25.4% |
| 92 | Rabbit River at Mouth | 37.2 | 1.9% | 14.5% |
| 93 | Kalamazoo River below Rabbit River | 26.9 | 1.3% | 66.6% |
| 94 | Mann Creek at Mouth | 17.4 | 3.2% | 42.8% |
| 95 | Kalamazoo River below Peach Orchid Creek | 23.5 | 1.2% | 0.0% |
| 96 | Kalamazoo River at Mouth | 17.3 | 8.0% | 7.8% |

## Conservation and Recreation Lands

With United States Fish and Wildlife Service support, Ducks Unlimited and the Nature Conservancy in Michigan (2007) 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). 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 10 depicts the conservation and recreation lands for the Kalamazoo River watershed as of May 2007. The area of these lands is 108 square miles, which is five percent of the watershed. Table 5 shows this information for each subbasin. The information is not final but is expected to be reasonably accurate.

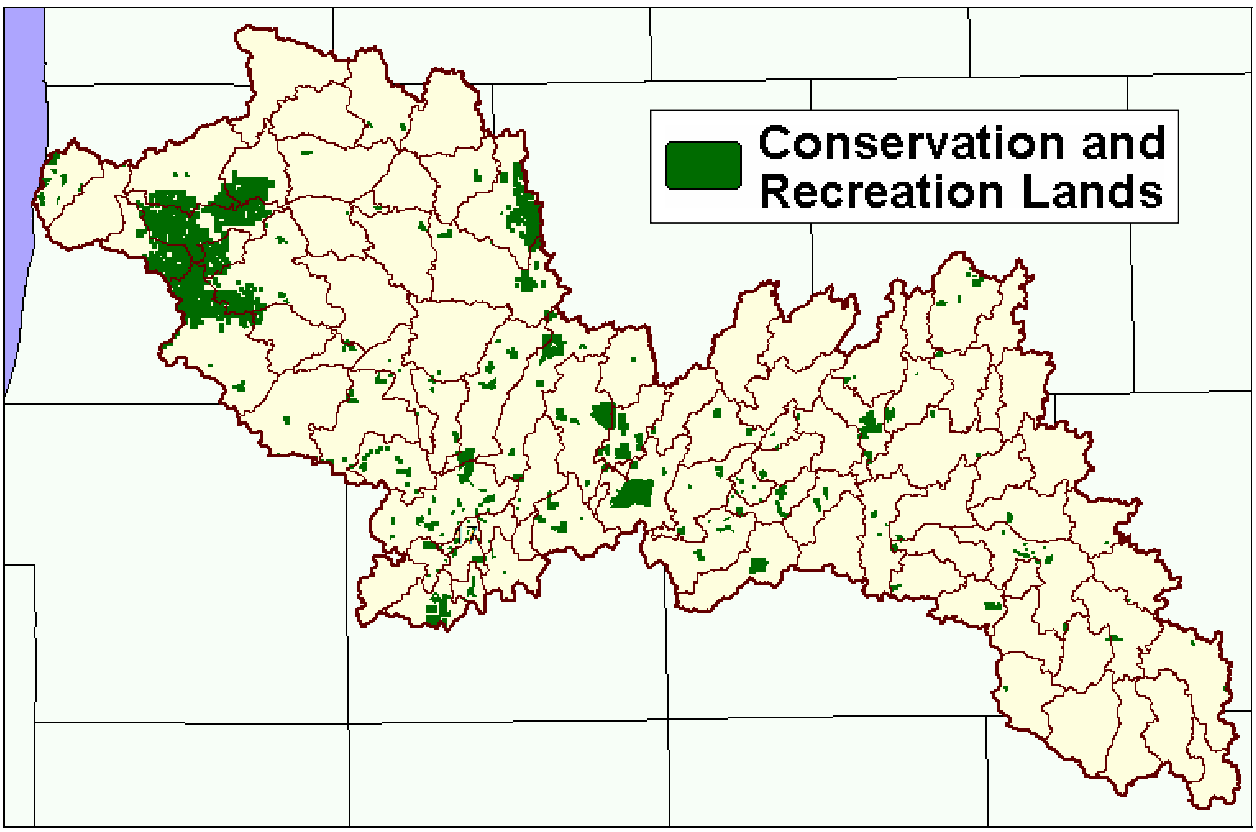



Figure 10 – Conservation and Recreation Lands by Ownership

## *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. Where the soil is given a dual hydrogroup classification, A/D for example, the soil type selected 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 HSU classifies soil designated urban as D soil due to the extensive imperviousness.

The soils maps resolved for 1800 and 1978 land use are shown in Figures 11 and 12 respectively. The differences in resolved soil hydrogroups from 1800 to 1978, 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<br>• Gravelly sand |
| B | Moderate | • Moderately fine textured to moderately coarse textured soils |
| C | Slow | • Moderately fine textured to fine textured soils<br>• Soils with a soil layer that impedes downward movement of water |
| D | Very Slow | • Clays<br>• Soils with a clay layer near the surface<br>• 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 |
|---|---|---|
| A | 20% | 22% |
| B | 49% | 52% |
| C | 8% | 9% |
| D | 20% | 15% |
| Water | 2% | 2% |

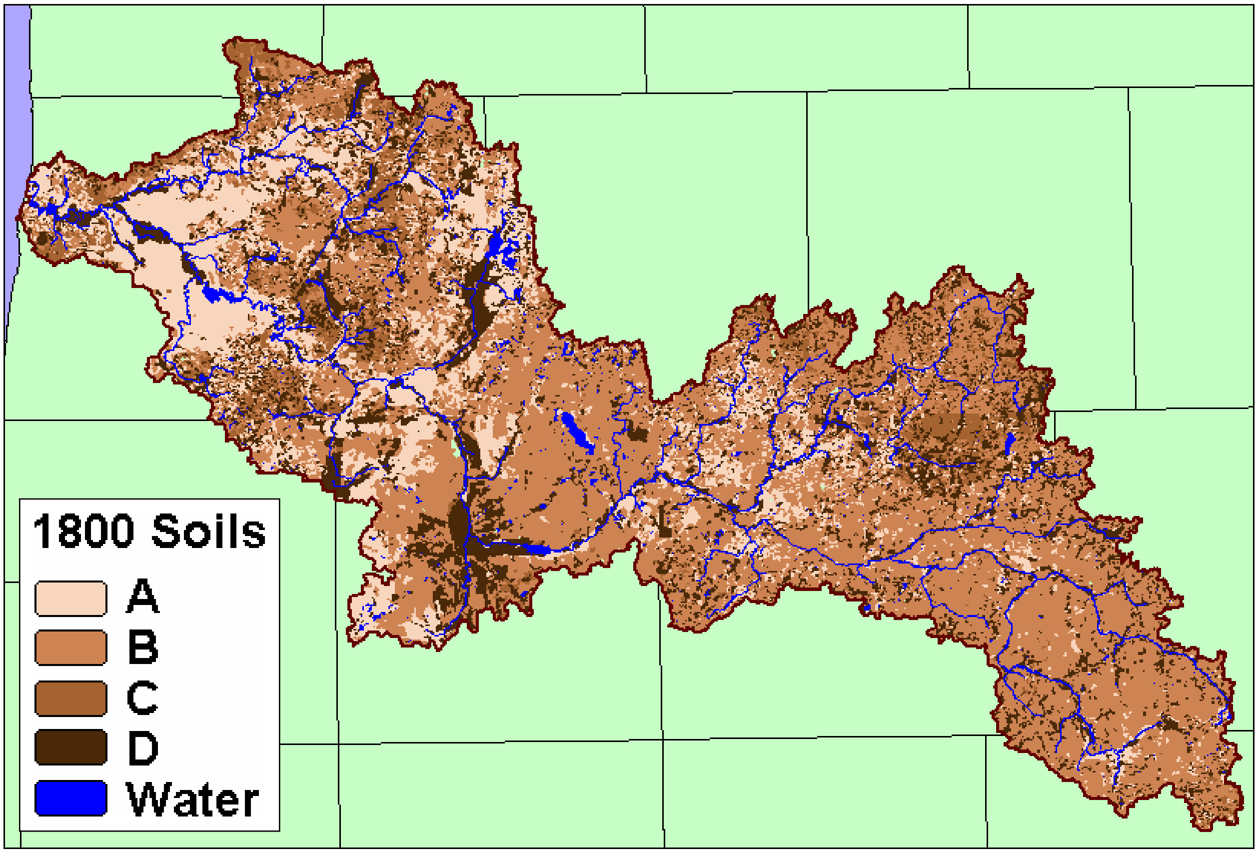


Figure 11 – Soil Hydrogroups, 1800 Land Use

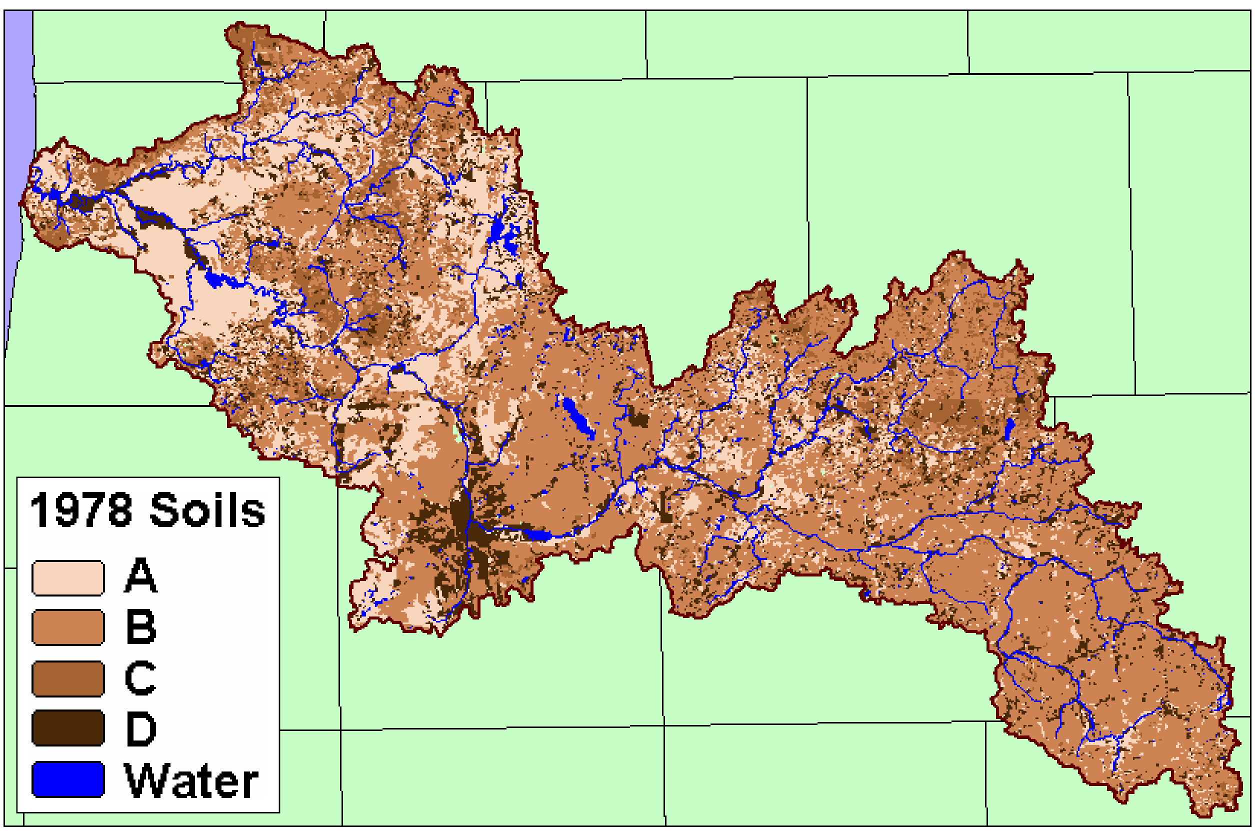


Figure 12 – Soil Hydrogroups, 1978 Land Use

# Hydrologic Analysis Parameters

## *Rainfall*

The design rainfall value used in this study is 2.4 inches, corresponding to the 50 percent chance (2-year) 24-hour storm, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. This storm was selected because runoff from the 50 percent chance storm approximates channel-forming flows assuming the watershed is, and was, a storm-driven system.

In a storm-driven system, rainfalls during the growing season usually generate the flood flows. 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.

## *Runoff Curve Numbers*

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, 2003).

The runoff curve numbers (CN) were calculated using GIS technology from the digital land use and soil data shown in Figures 7, 8, 11, and 12. Housing density is a part of the curve number calculations. In non-urban areas, average residential lot size was specified as 0.50 acre. The lot size was specified as 0.25 acre for urban subbasins 42, 45, 56, 63, 65, 57, and 64. The lot size was specified as 0.13 acre for urban subbasins 41, 61, and 62. Runoff curve numbers for each subbasin are listed in Appendix A.

# Analysis

## *Hydrology*

Runoff volumes were calculated for each subbasin from 1800 to 1978 for the 50 percent chance (2-year), 24-hour storm. For comparison, the calculated runoff volumes are divided by the drainage areas. The analysis indicates that runoff volumes increased substantially from 1800 to 1978. The results are shown in Figures 13 and 14 and tabulated in Table 8. The units are acre-inches per acre (volume per area), or simply inches. Changes in runoff volume per area from 1800 to 1978 are shown in Figure 15 and are also tabulated in Table 8.

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. The 1800 scenario is included to show the impact of land use change, but is not intended as BMP design criteria or as a goal for watershed managers.

In terms of total volume, the watershed would have generated 22,900 acre-feet of runoff from a 2.4 inch rainfall in 1800. In 1978, it would have generated 47,300 acre-feet, an increase of 24,400 acre-feet. The doubling of channel-forming flow runoff volume, and likely peak flow, has undoubtedly resulted in channel enlargement as the streams adapt to the higher flows.

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 8 – Runoff Volume per Area by Subbasin

| ID | Subbasin | Runoff Volume/Area (inch) | | |
|---|---|---|---|---|
| | | 1800 | 1978 | Increase |
| 1 | S Br Kalamazoo River at Mosherville Road | 0.25 | 0.53 | 0.29 |
| 2 | S Br Kalamazoo River below tributary | 0.19 | 0.48 | 0.29 |
| 3 | S Br Kalamazoo River below tributary | 0.16 | 0.42 | 0.25 |
| 4 | S Br Kalamazoo River below Beaver Creek | 0.21 | 0.53 | 0.32 |
| 5 | S Br Kalamazoo River below Swains Lake Drain | 0.23 | 0.54 | 0.31 |
| 6 | Lampson Run Drain at Mouth | 0.30 | 0.59 | 0.29 |
| 7 | S Br Kalamazoo River at Gage #04102850 | 0.17 | 0.54 | 0.37 |
| 8 | S Br Kalamazoo River at Mouth | 0.15 | 0.42 | 0.27 |
| 9 | North Kalamazoo River at Cross Lake Outlet | 0.24 | 0.50 | 0.25 |
| 10 | Spring Arbor and Concord at Mouth | 0.23 | 0.56 | 0.33 |
| 11 | N Br Kalamazoo River below Spring Arbor & Concord Drain | 0.19 | 0.51 | 0.31 |
| 12 | Kalamazoo River at Gage #04103010 | 0.12 | 0.50 | 0.37 |
| 13 | Wilder Creek below Huckleberry Drain | 0.23 | 0.53 | 0.31 |
| 14 | Wilder Creek at Mouth | 0.22 | 0.57 | 0.35 |
| 15 | S Br Rice Creek at M-99 | 0.24 | 0.53 | 0.29 |
| 16 | S Br Rice Creek at Mouth | 0.20 | 0.52 | 0.32 |
| 17 | N Br Rice Creek at Gordon Lake Outlet | 0.26 | 0.59 | 0.33 |
| 18 | N Br Rice Creek at Mouth | 0.30 | 0.54 | 0.24 |
| 19 | Rice Creek at Mouth | 0.16 | 0.54 | 0.38 |
| 20 | Kalamazoo River at Gage #04103500 | 0.14 | 0.54 | 0.40 |
| 21 | Kalamazoo River below Squaw Lake Drain | 0.19 | 0.56 | 0.36 |
| 22 | Kalamazoo River below Pigeon Creek | 0.18 | 0.55 | 0.37 |
| 23 | Kalamazoo River below Dickinson Creek | 0.12 | 0.43 | 0.31 |
| 24 | Harper Creek at Mouth | 0.18 | 0.45 | 0.27 |
| 25 | Minges Brook at Mouth | 0.21 | 0.50 | 0.29 |
| 26 | Battle Creek Above Hogle and Miller Drain | 0.49 | 0.70 | 0.21 |
| 27 | Hogle and Miller Drain at Mouth | 0.42 | 0.70 | 0.29 |
| 28 | Battle Creek below tributary | 0.32 | 0.53 | 0.21 |
| 29 | Big Creek at Mouth | 0.37 | 0.63 | 0.26 |
| 30 | Battle Creek below Big Creek | 0.27 | 0.56 | 0.29 |
| 31 | Indian Creek below State and Indian Creek | 0.45 | 0.61 | 0.15 |
| 32 | Indian Creek at Mouth | 0.32 | 0.56 | 0.24 |
| 33 | Battle Creek below Indian Creek | 0.31 | 0.55 | 0.23 |
| 34 | Battle Creek at Gage #04104500 | 0.25 | 0.46 | 0.21 |
| 35 | Battle Creek below Ackley Creek | 0.28 | 0.48 | 0.20 |
| 36 | Battle Creek below tributary | 0.09 | 0.33 | 0.24 |
| 37 | Wanadoga Creek below Ellis Creek | 0.32 | 0.55 | 0.23 |
| 38 | Wanadoga Creek at Gage #04104945 | 0.13 | 0.34 | 0.21 |
| 39 | Wanadoga Creek at Mouth | 0.07 | 0.25 | 0.18 |
| 40 | Battle Creek at Gage #04105000 | 0.04 | 0.20 | 0.16 |
| 41 | Battle Creek at Mouth | 0.11 | 0.80 | 0.69 |
| 42 | Kalamazoo River at Gage #04105500 | 0.05 | 0.46 | 0.40 |
| 43 | Wabascon Creek at Luce Road | 0.23 | 0.43 | 0.19 |
| 44 | Wabascon Creek at Mouth | 0.12 | 0.25 | 0.12 |
| 45 | Kalamazoo River below Wabascon Creek | 0.11 | 0.35 | 0.24 |
| 46 | Sevenmile Creek at Mouth | 0.17 | 0.36 | 0.20 |
| 47 | Augusta Creek below tributary | 0.26 | 0.52 | 0.26 |

| ID | Subbasin | Runoff Volume/Area (inch) | | |
|---|---|---|---|---|
| | | 1800 | 1978 | Increase |
| 48 | Augusta Creek at Gage #04105700 | 0.23 | 0.39 | 0.16 |
| 49 | Augusta Creek at Mouth | 0.24 | 0.32 | 0.08 |
| 50 | Gull Creek at Gage #04105800 | 0.30 | 0.57 | 0.27 |
| 51 | Gull Creek at Mouth | 0.11 | 0.32 | 0.21 |
| 52 | Kalamazoo River below Gull Creek | 0.17 | 0.22 | 0.05 |
| 53 | Kalamazoo River at Morrow Lake Dam | 0.20 | 0.43 | 0.23 |
| 54 | Comstock Creek at Mouth | 0.19 | 0.47 | 0.29 |
| 55 | Kalamazoo River at Gage #04106000 | 0.31 | 0.50 | 0.18 |
| 56 | Davis Creek at Mouth | 0.40 | 0.81 | 0.41 |
| 57 | Portage Creek at Gage #04106180 | 0.07 | 0.28 | 0.21 |
| 58 | Portage Creek at Gage #04106300 | 0.45 | 0.69 | 0.25 |
| 59 | W Fork Portage Creek at Gage #04106320 | 0.07 | 0.12 | 0.05 |
| 60 | W Fork Portage Creek at Gage #04106400 | 0.18 | 0.55 | 0.37 |
| 61 | Portage Creek at Gage #04106500 | 0.39 | 1.11 | 0.72 |
| 62 | Portage Creek at Mouth | 0.53 | 1.35 | 0.83 |
| 63 | Kalamazoo River below Portage Creek | 0.51 | 0.87 | 0.36 |
| 64 | Spring Brook at Mouth | 0.20 | 0.41 | 0.22 |
| 65 | Kalamazoo River below Spring Brook | 0.27 | 0.58 | 0.31 |
| 66 | Kalamazoo River below Silver Creek | 0.16 | 0.30 | 0.14 |
| 67 | Kalamazoo River at Plainwell Dam | 0.10 | 0.27 | 0.17 |
| 68 | Gun River at Gun Lake Outlet | 0.20 | 0.32 | 0.12 |
| 69 | Gun River below Culver Drain | 0.21 | 0.31 | 0.10 |
| 70 | Gun River at Mouth | 0.14 | 0.27 | 0.14 |
| 71 | Sand Creek at Mouth | 0.12 | 0.24 | 0.13 |
| 72 | Base Line Creek at Mouth | 0.25 | 0.43 | 0.18 |
| 73 | Pine Creek at Mouth | 0.24 | 0.36 | 0.12 |
| 74 | Kalamazoo River at Otsego Dam | 0.10 | 0.24 | 0.14 |
| 75 | Schnable Brook at Mouth | 0.38 | 0.61 | 0.23 |
| 76 | Kalamazoo River at Trowbridge Dam | 0.21 | 0.37 | 0.16 |
| 77 | Kalamazoo River at Unnamed Dam | 0.19 | 0.33 | 0.14 |
| 78 | Kalamazoo River at Unnamed Dam | 0.15 | 0.31 | 0.16 |
| 79 | Swan Creek at Mouth | 0.17 | 0.21 | 0.04 |
| 80 | Kalamazoo River at Gage #04108500 | 0.10 | 0.11 | 0.01 |
| 81 | Little Rabbit River below Dorr & Nichols Drain | 0.30 | 0.49 | 0.19 |
| 82 | Little Rabbit River at Mouth | 0.11 | 0.31 | 0.20 |
| 83 | Bear Creek at Mouth | 0.25 | 0.52 | 0.27 |
| 84 | Green Lake Creek at Mouth | 0.27 | 0.54 | 0.27 |
| 85 | Rabbit River below Green Lake Creek | 0.10 | 0.29 | 0.19 |
| 86 | Rabbit River at Gage #04108600 | 0.29 | 0.59 | 0.30 |
| 87 | Miller Creek at Mouth | 0.28 | 0.58 | 0.29 |
| 88 | Rabbit River below Bear Creek | 0.37 | 0.59 | 0.23 |
| 89 | Rabbit River below Little Rabbit River | 0.15 | 0.32 | 0.17 |
| 90 | Black Creek at Mouth | 0.29 | 0.60 | 0.31 |
| 91 | Rabbit River below Silver Creek | 0.06 | 0.12 | 0.06 |
| 92 | Rabbit River at Mouth | 0.07 | 0.24 | 0.17 |
| 93 | Kalamazoo River below Rabbit River | 0.06 | 0.10 | 0.04 |
| 94 | Mann Creek at Mouth | 0.00 | 0.02 | 0.02 |
| 95 | Kalamazoo River below Peach Orchid Creek | 0.35 | 0.47 | 0.12 |
| 96 | Kalamazoo River at Mouth | 0.15 | 0.23 | 0.08 |

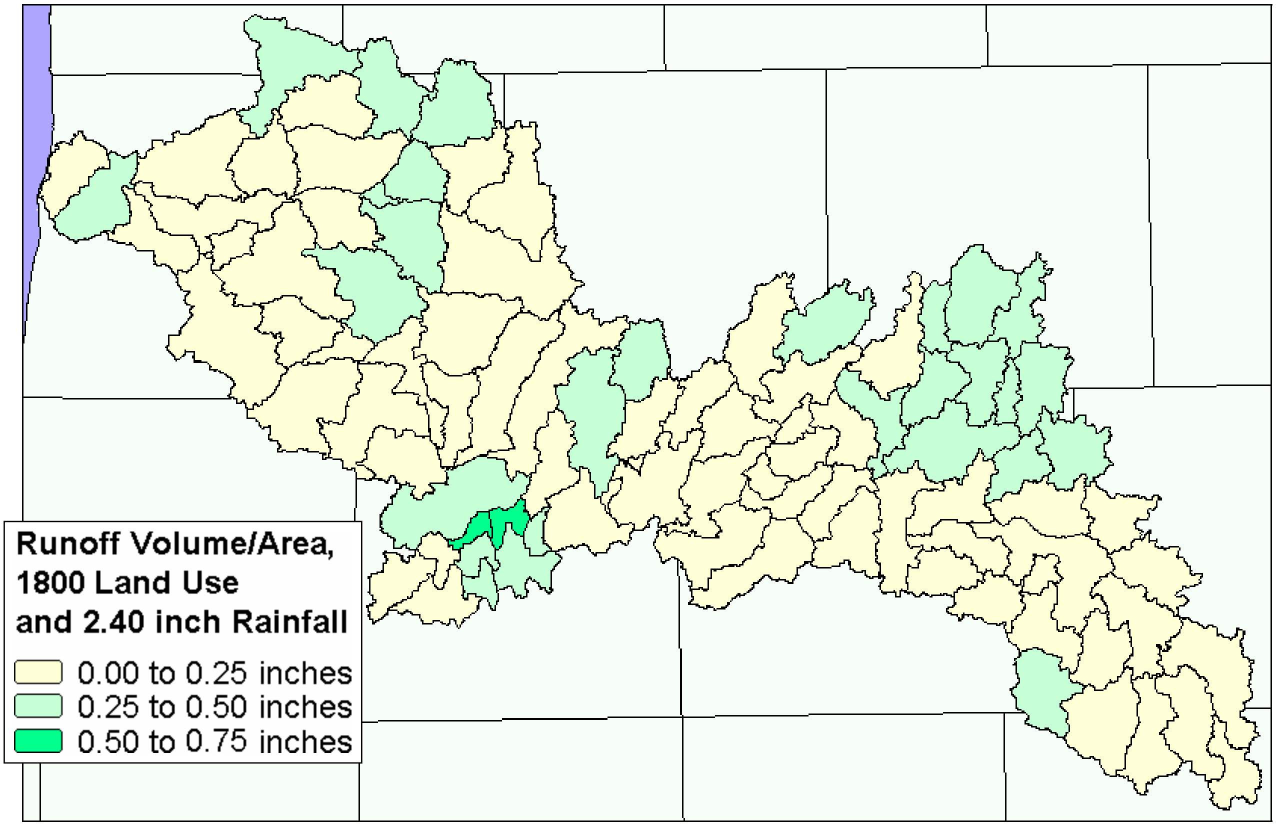



Figure 13 – Runoff Volume/Drainage Area, 1800 Land Use

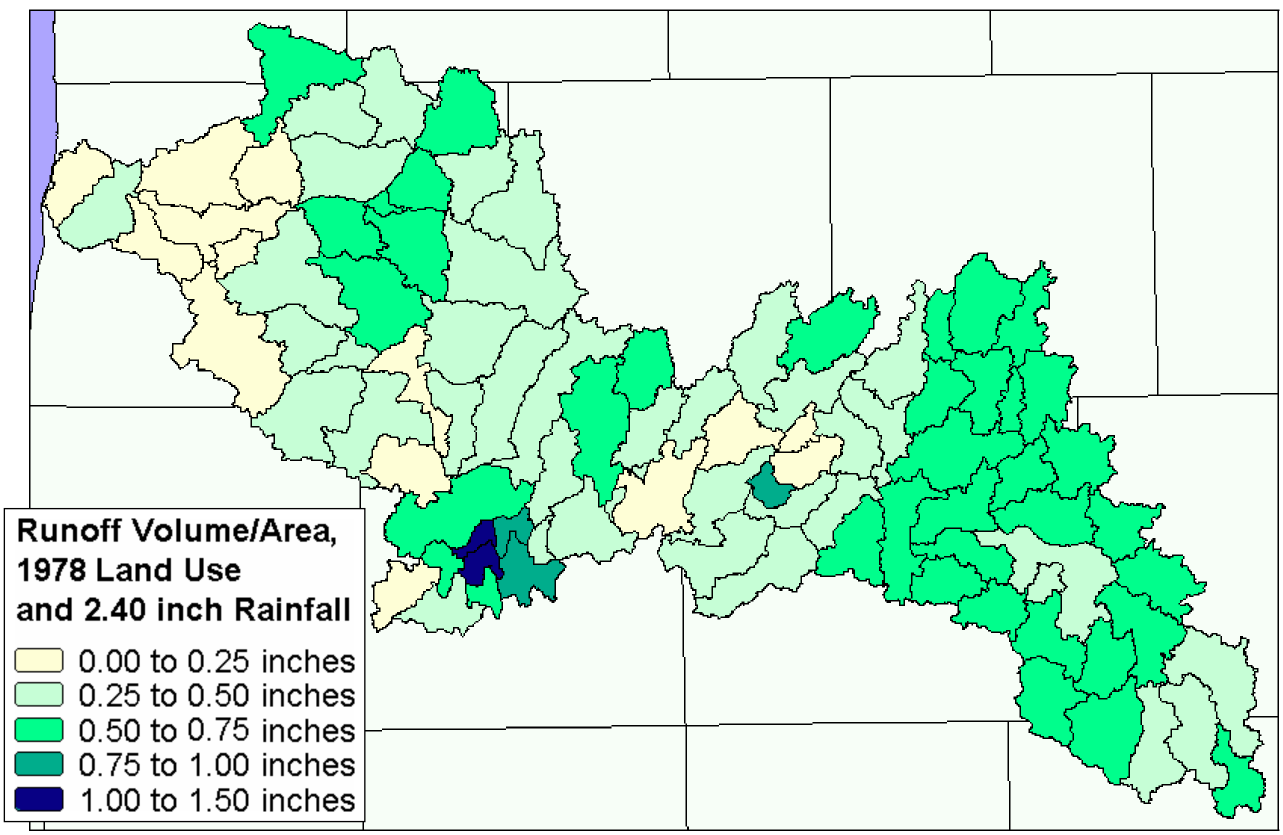



Figure 14 – Runoff Volume/Drainage Area, 1978 Land Use

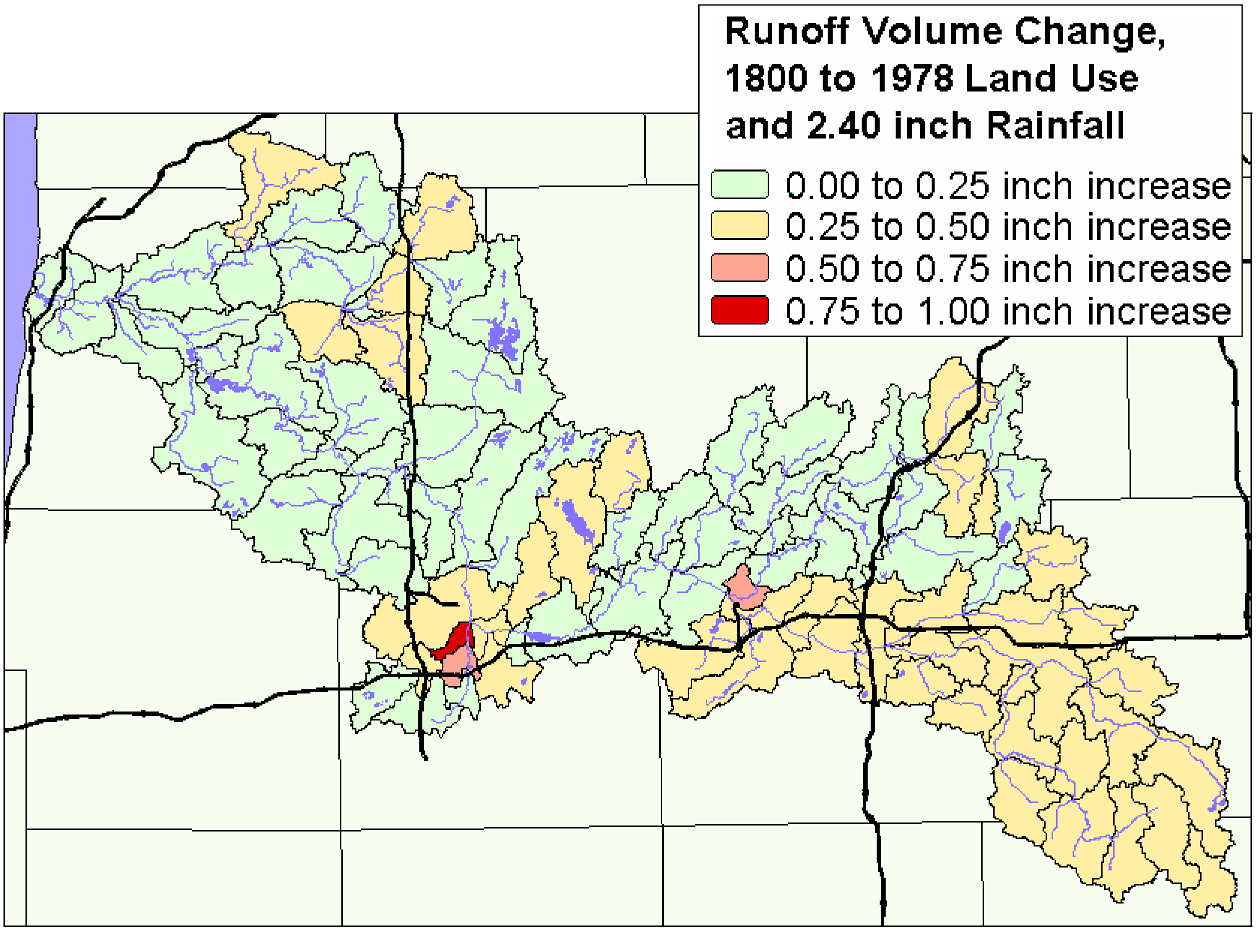


Figure 15 – Change in Runoff Volume/Drainage Area, 1800 to 1978 Land Use

## *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 16, 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.

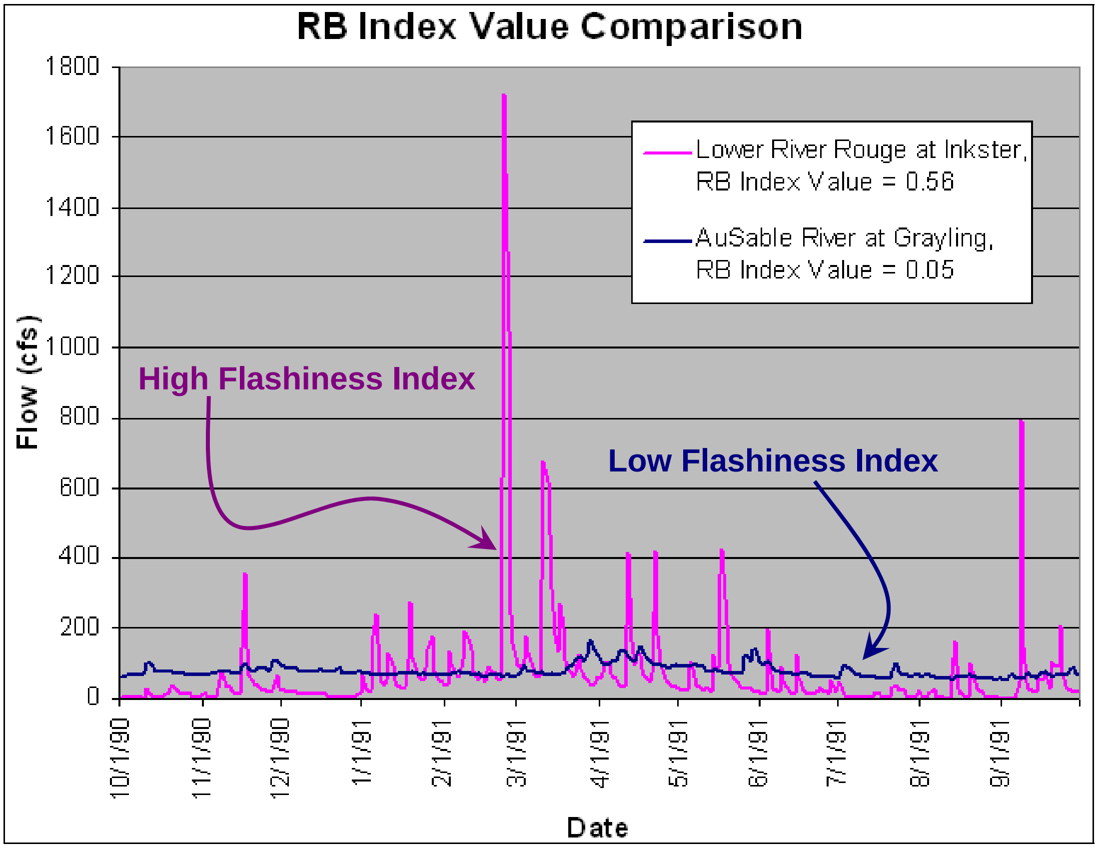



Figure 16 – Hydrographs for Two Michigan Streams

## 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 17. 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.

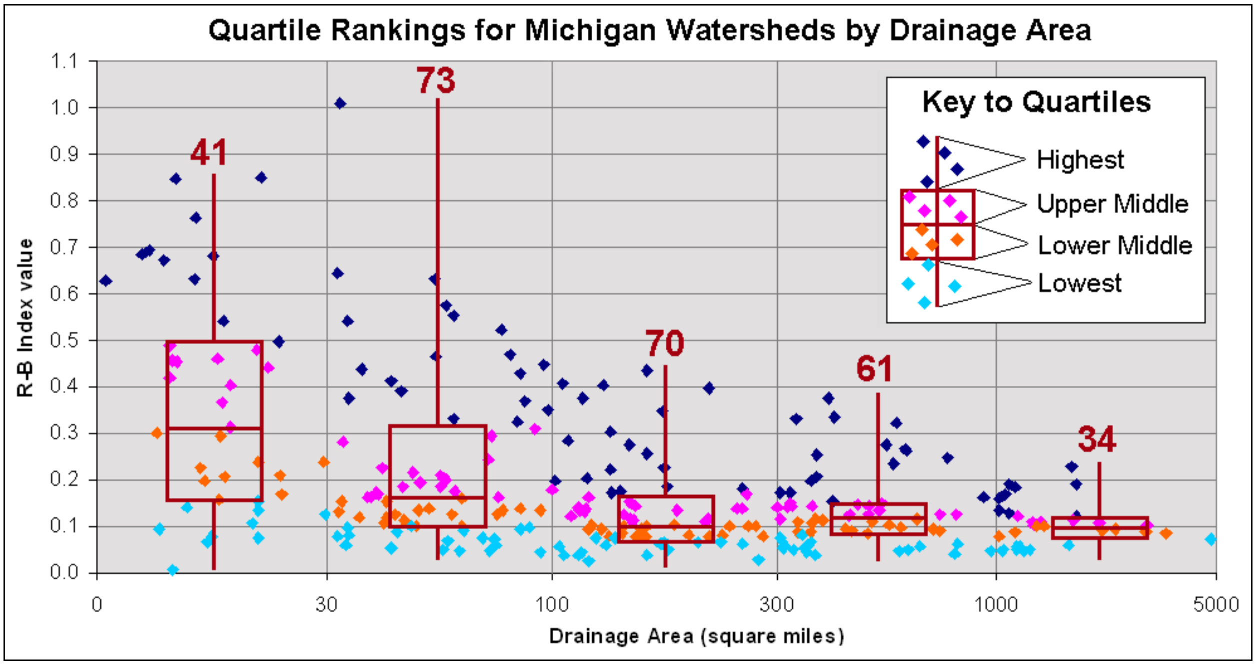



Figure 17 – Summary and Ranking of the R-B Index Values for 279 Michigan Gages

The yearly averaged R-B Index values for the Kalamazoo River watershed range from 0.059 to 0.209, with no gage in the uppermost quartile on a statewide basis. In itself, a high or low ranking is not necessarily good or bad. Rankings for Saginaw Bay area gages tend to be high at least partly because of the soils in that area, for example. The gage rankings in the Kalamazoo River watershed are typical of other gages in southwest lower Michigan, Figure 18, which generally are in the lower half of the rankings. The relative rankings of Kalamazoo River watershed gages, Figure 19 and Table 9, may be used to identify areas where methods to reduce flashiness can be employed, or to identify areas where extra effort is warranted to protect our most sensitive and exceptional streams.

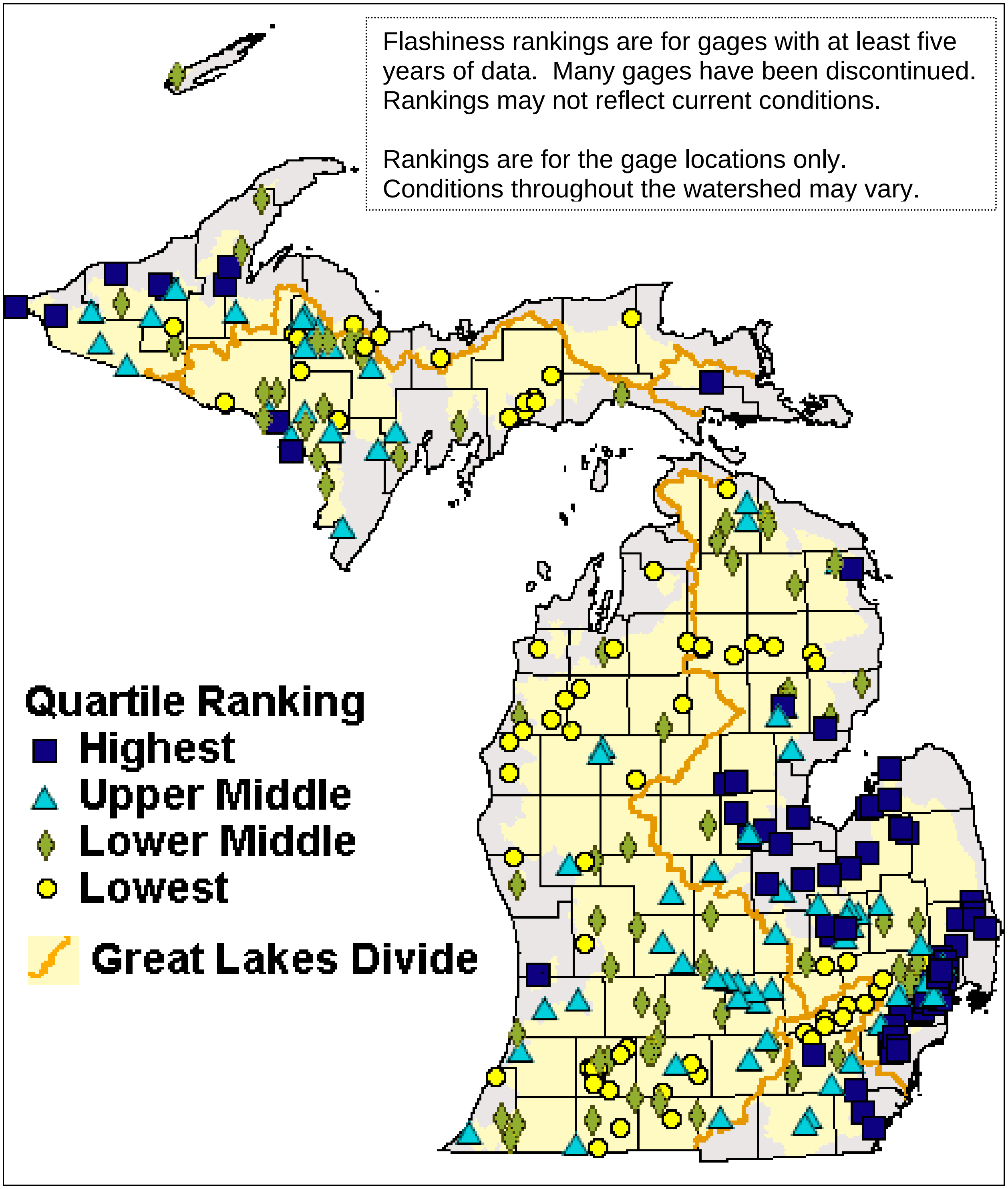



Figure 18 – Quartile Rankings, Michigan Watersheds

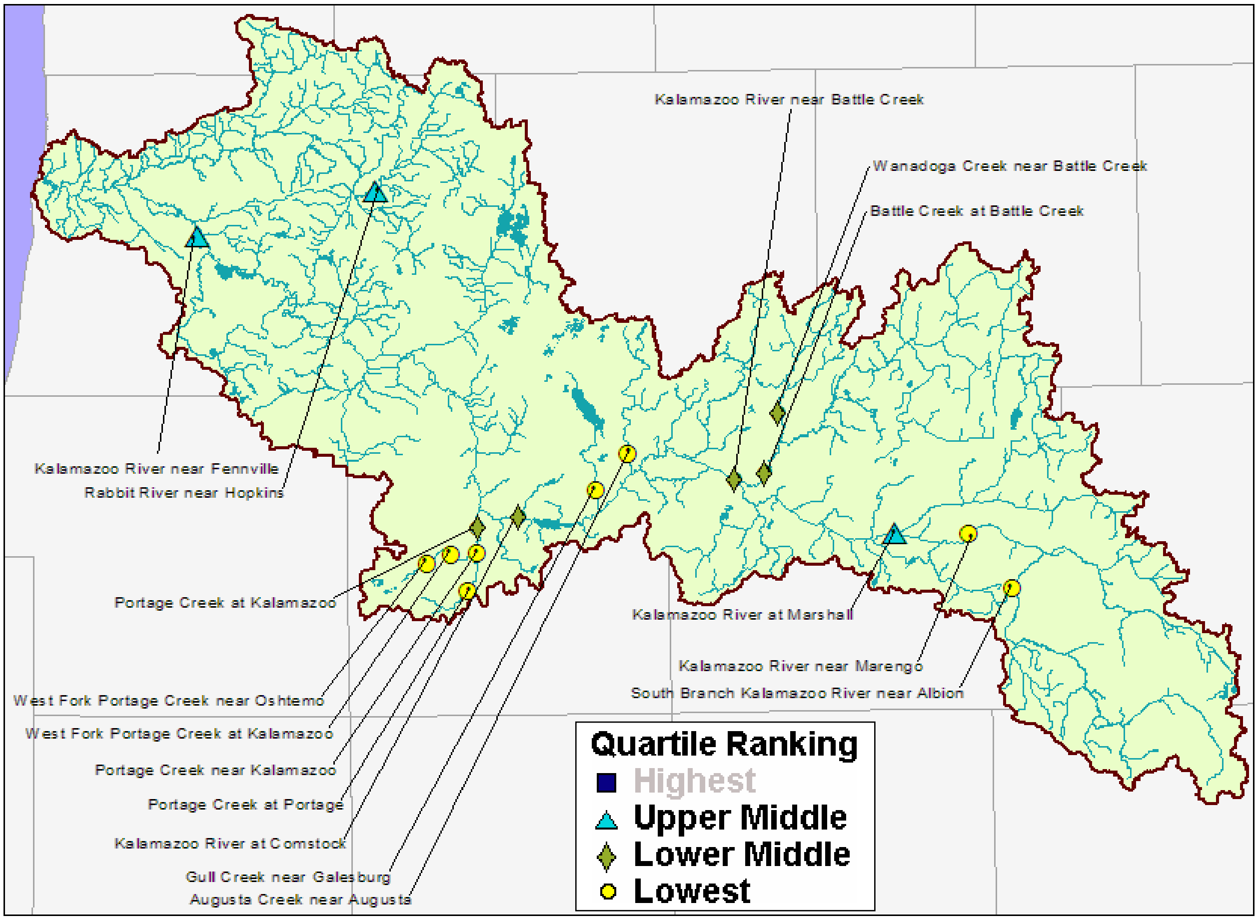


Figure 19 – Quartile Rankings, Kalamazoo River Watershed

Table 9 – Kalamazoo River Watershed Flashiness Results

| Gage Number and Description | Total Drainage Area (sq. mi.) | Quartile Rank | Flashiness Trend |
|---|---|---|---|
| 4102850: South Branch Kalamazoo River near Albion | 148 | lowest | |
| 4103010: Kalamazoo River near Marengo | 270 | lowest | |
| 4103500: Kalamazoo River at Marshall | 411 | upper middle | |
| 4104945: Wanadoga Creek near Battle Creek | 48 | lower middle | |
| 4105000: Battle Creek at Battle Creek | 274 | lower middle | more flashy |
| 4105500: Kalamazoo River near Battle Creek | 819 | lower middle | less flashy |
| 4105700: Augusta Creek near Augusta | 37 | lowest | more flashy |
| 4105800: Gull Creek near Galesburg | 36 | lowest | |
| 4106000: Kalamazoo River at Comstock | 1059 | lower middle | |
| 4106180: Portage Creek at Portage | 15 | lowest | more flashy |
| 4106300: Portage Creek near Kalamazoo | 20 | lowest | |
| 4106320: West Fork Portage Creek near Oshtemo | 15 | lowest | more flashy |
| 4106400: West Fork Portage Creek at Kalamazoo | 21 | lowest | more flashy |
| 4106500: Portage Creek at Kalamazoo | 48 | lower middle | more flashy |
| 4108500: Kalamazoo River near Fennville | 1653 | upper middle | |
| 4108600: Rabbit River near Hopkins | 65 | upper middle | more flashy |

## 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. The linear trend lines shown in Figures 23 though 38 do not guarantee a linear relationship between flashiness and time for those streams, nor can they be used to predict future flashiness trends for those streams. The physical processes causing the changes are undoubtedly more complex. The trends identified are only intended to highlight streams experiencing flow changes that may physically alter the stream's channel morphology.

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 20. Many, but not all, are located near urban areas, Figure 21. 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.

For the Kalamazoo River watershed gages, only one of the 16 gages has a decreasing trend, while seven have increasing trends, Table 9 and Figure 22.

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.

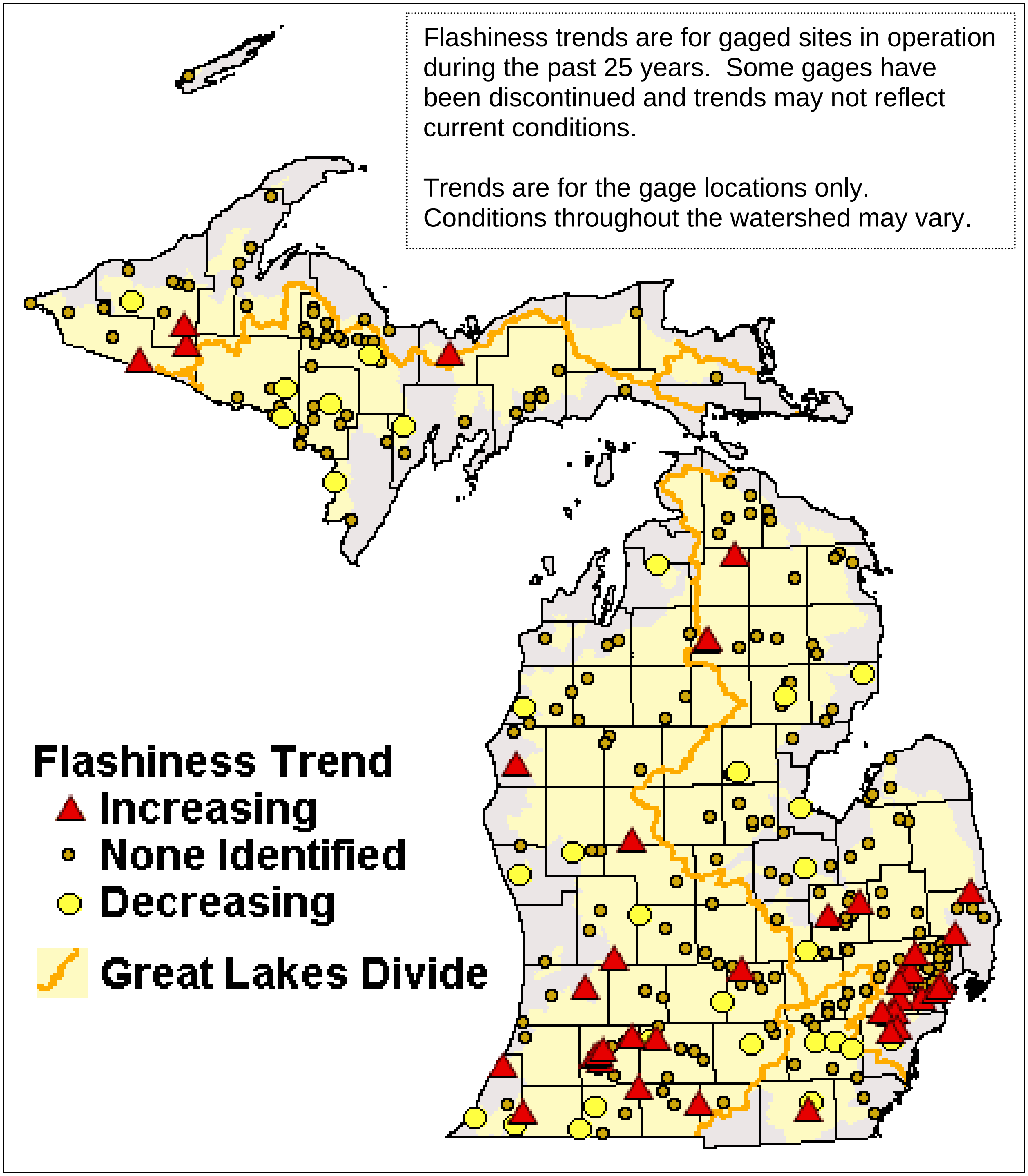



Figure 20 – Flashiness Trend by Gage, Michigan Watersheds

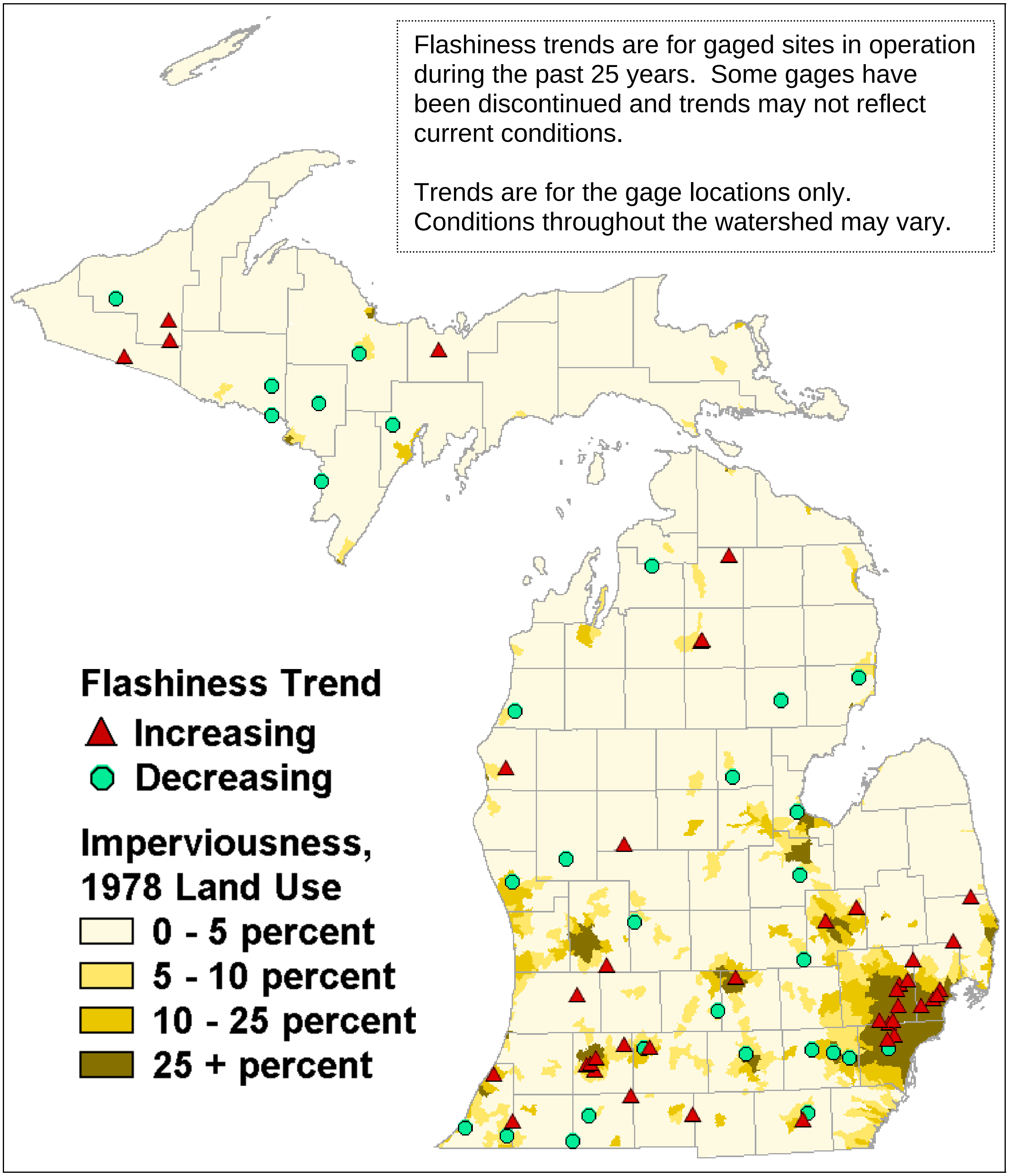



Figure 21 – Statewide Imperviousness with Flashiness Trends, 1978 Land Use

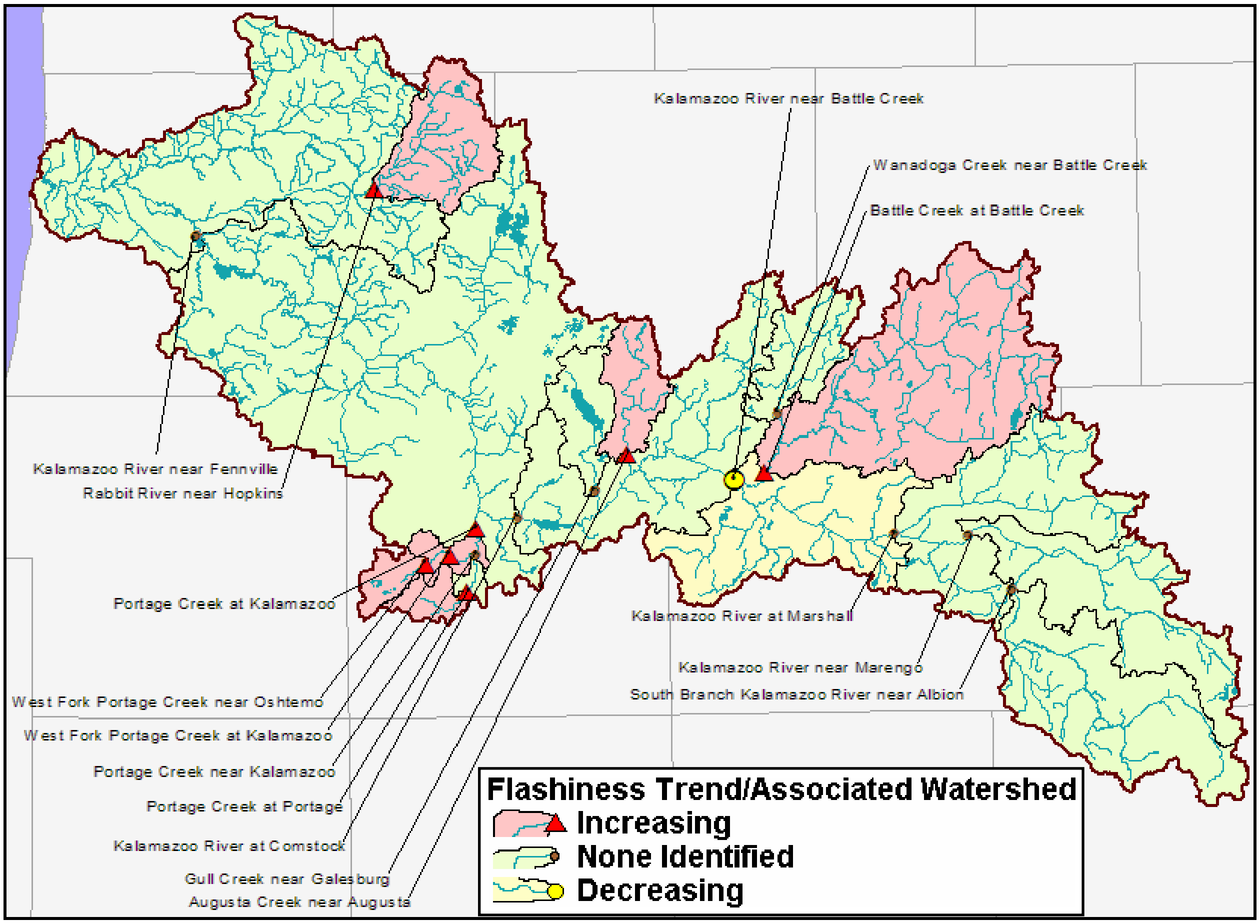


Figure 22 – Flashiness Trend by Gage, Kalamazoo River Watershed

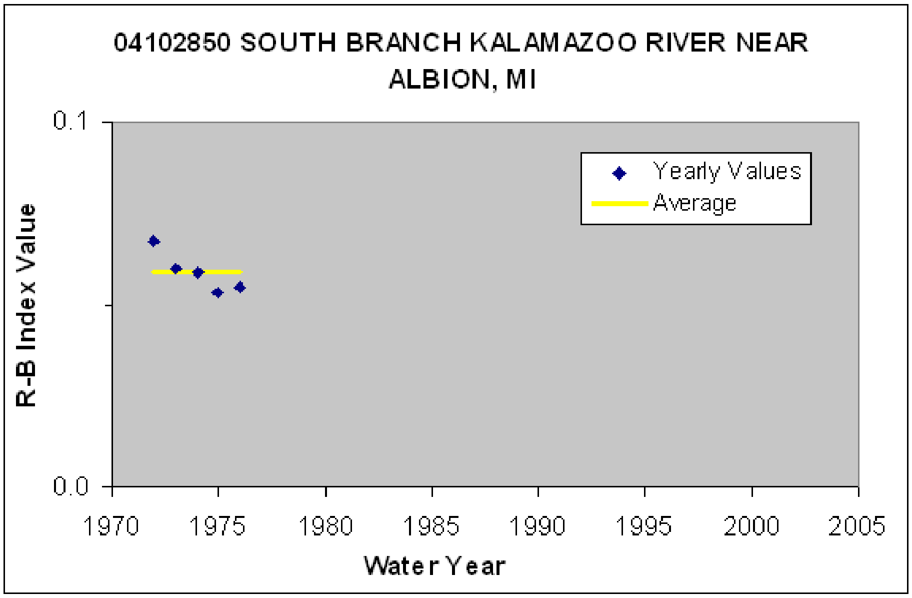
## Gage Information

Graphs of the R-B Index values and trends for each gage are shown in Figures 23 through 39. The graphs are in numerical order. USGS gage stations are numbered in a downstream direction along the main stream. All stations on a tributary entering upstream from a main-stream station are listed before that station. A station on a tributary entering between two mainstream stations is listed between those stations.

The R-B Index value average is shown as a horizontal yellow line spanning the years used to calculate the average. If there is a statistically significant (i.e., $p < 0.10$) trend encompassing at least part of the past 25 years, it is represented by a sloped purple line. If a statistically significant trend change occurred, only the more recent trend is shown, and the R-B Index value average is based only on the years since that change.

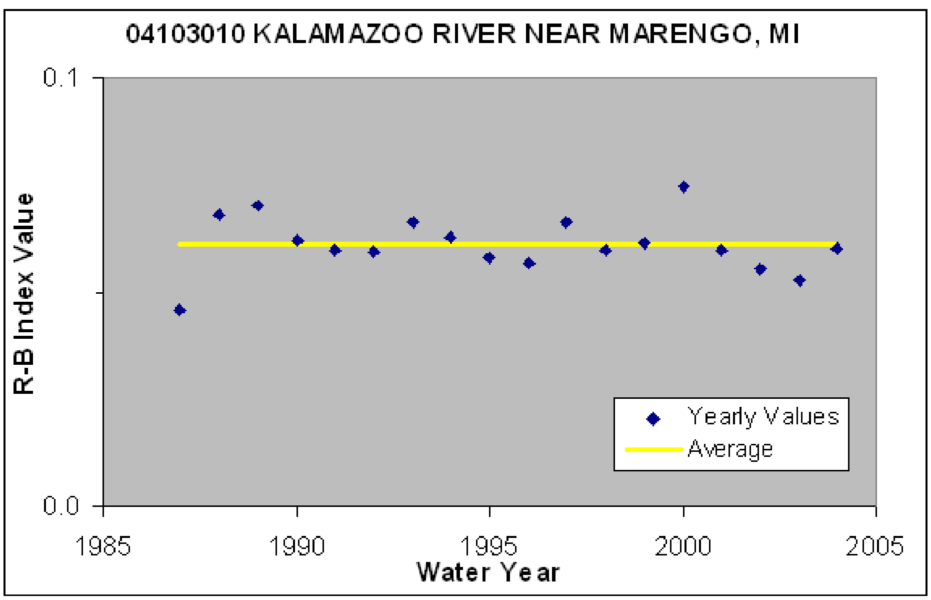
The x-axis always ends at 2005, so that the age of the data is more readily apparent. The y-axis is constrained to show gridlines every for every 0.1 increment, allowing a sense of rank relative to other gages - more gridlines equate to higher values.

R-B flashiness statistical details and gage-specific information follow each graph. Statistical significance is based on the flashiness trend regression ‘p’ value. A ‘p’ value of 0.05 or less equates to 95 percent statistical significance. A ‘p’ value of 0.10 or less equates to 90 percent statistical significance. Total water years may be less than the ending water year minus the starting water year because of data gaps. Some gages that may be affected by dam operations are noted, but the listing may be incomplete.



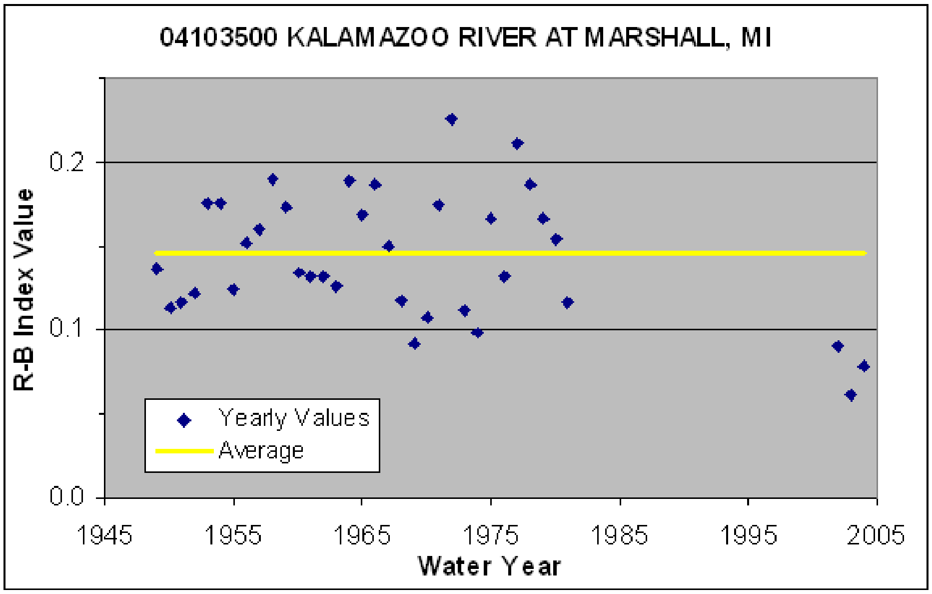

| | |
|---|---|
| Total Drainage Area: 148 square miles<br>Average R-B Index Value: 0.06<br>Rank: lowest<br>Trend: none | First Water Year of Record/Analyzed: 1972<br>Last Water Year: 1976<br>Number of Years Analyzed: 5 |

Figure 23 – USGS Gage 04102850 South Branch Kalamazoo River near Albion



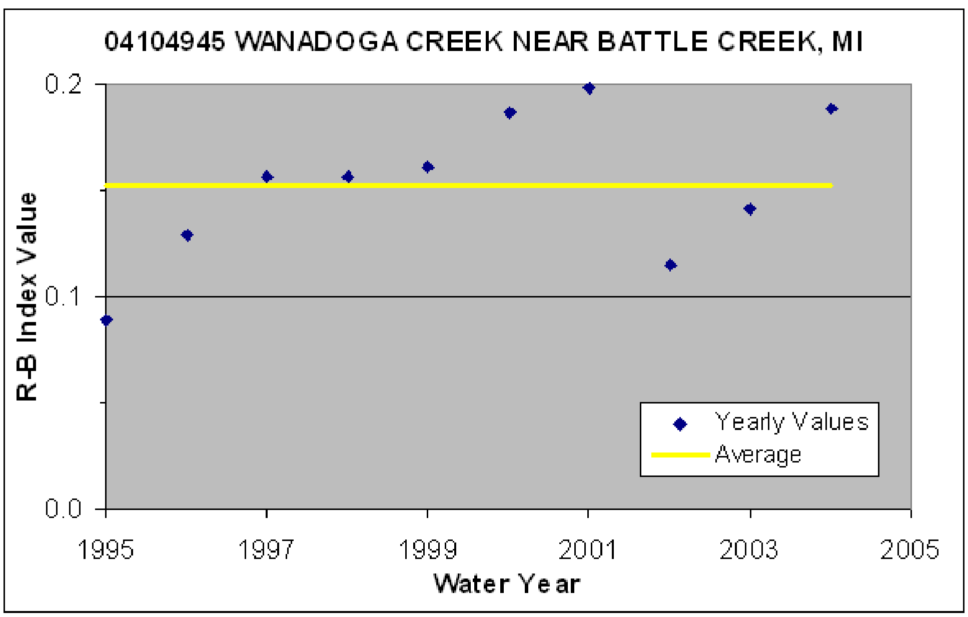

| | |
|---|---|
| Total Drainage Area: 270 square miles<br>Average R-B Index Value: 0.06<br>Rank: lowest<br>Trend: none | First Water Year of Record/Analyzed: 1987<br>Last Water Year: 2004<br>Number of Years Analyzed: 18 |
| Notes: Some diversion by pumping for irrigation. | |

Figure 24 – USGS Gage 04103010 Kalamazoo River near Marengo



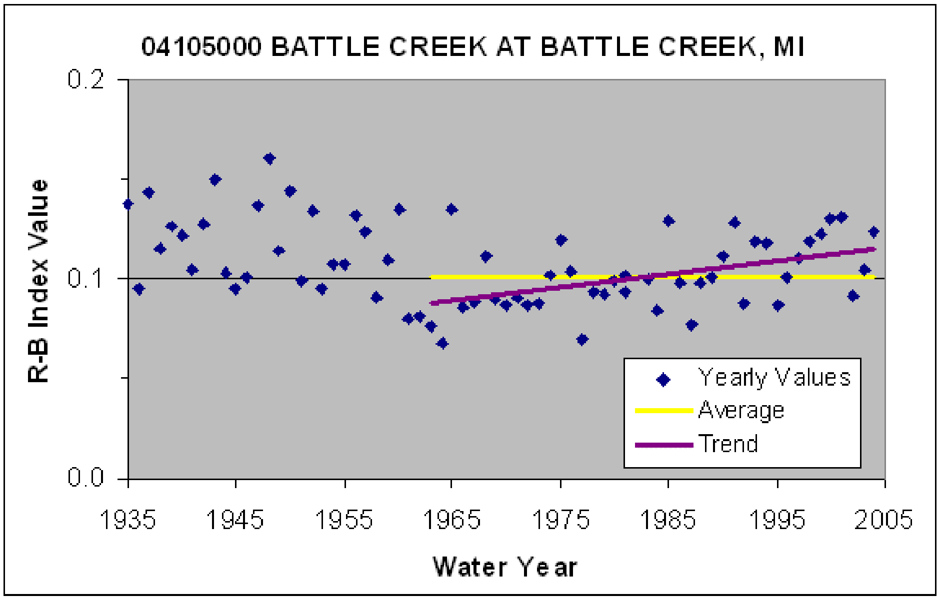

| | |
|---|---|
| Total Drainage Area: 411 square miles<br>Average R-B Index Value: 0.15<br>Rank: upper middle<br>Trend: none | First Water Year of Record/Analyzed: 1949<br>Last Water Year: 2004<br>Number of Years Analyzed: 37 |
| Notes: Flow regulated by power plant upstream from station. | |

Figure 25 – USGS Gage 04103500 Kalamazoo River at Marshall



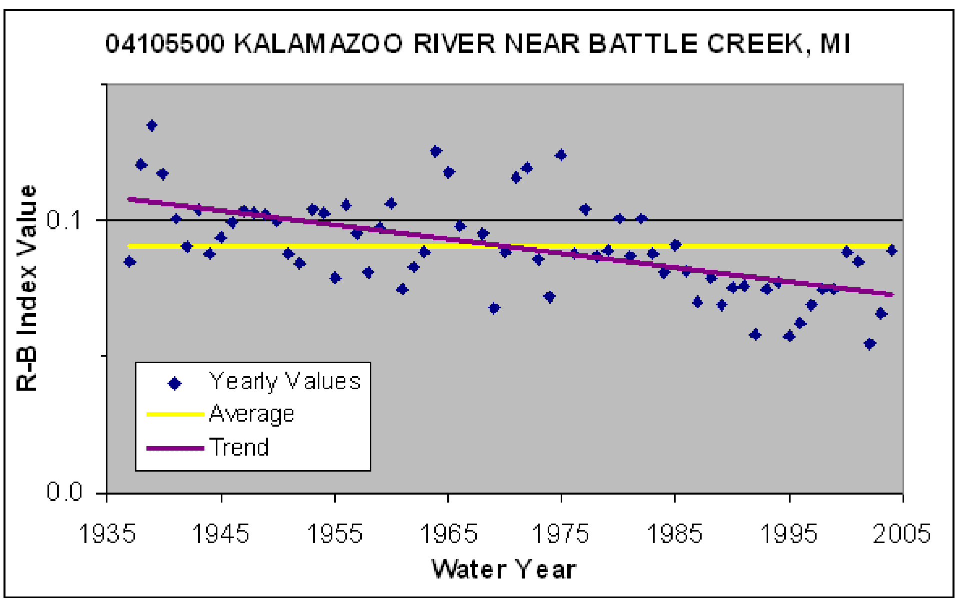

| | |
|---|---|
| Total Drainage Area: 48 square miles<br>Average R-B Index Value: 0.15<br>Rank: lower middle<br>Trend: none | First Water Year of Record/Analyzed: 1995<br>Last Water Year: 2004<br>Number of Years Analyzed: 10 |

Figure 26 – USGS Gage 04104945 Wanadoga Creek near Battle Creek



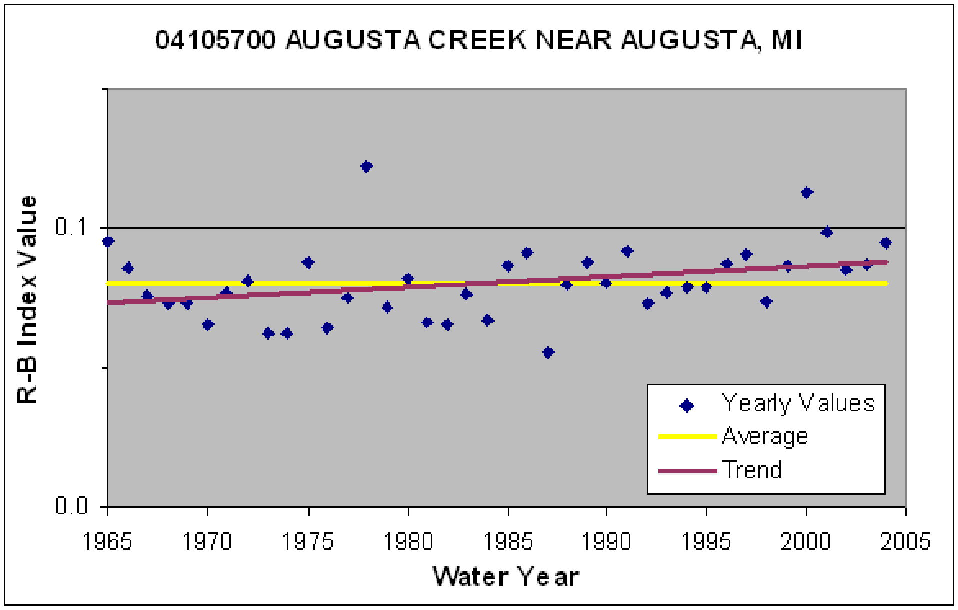

| | |
|---|---|
| Total Drainage Area: 274 square miles<br>Average R-B Index Value: 0.10<br>Rank: lower middle<br>Trend: more flashy | First Water Year of Record: 1935<br>First Water Year Analyzed: 1963<br>Last Water Year: 2004<br>Number of Years Analyzed: 42<br>p Value: <0.005 |
| Notes: Occasional slight regulation prior November 1943. | |

Figure 27 – USGS Gage 04105000 Battle Creek at Battle Creek



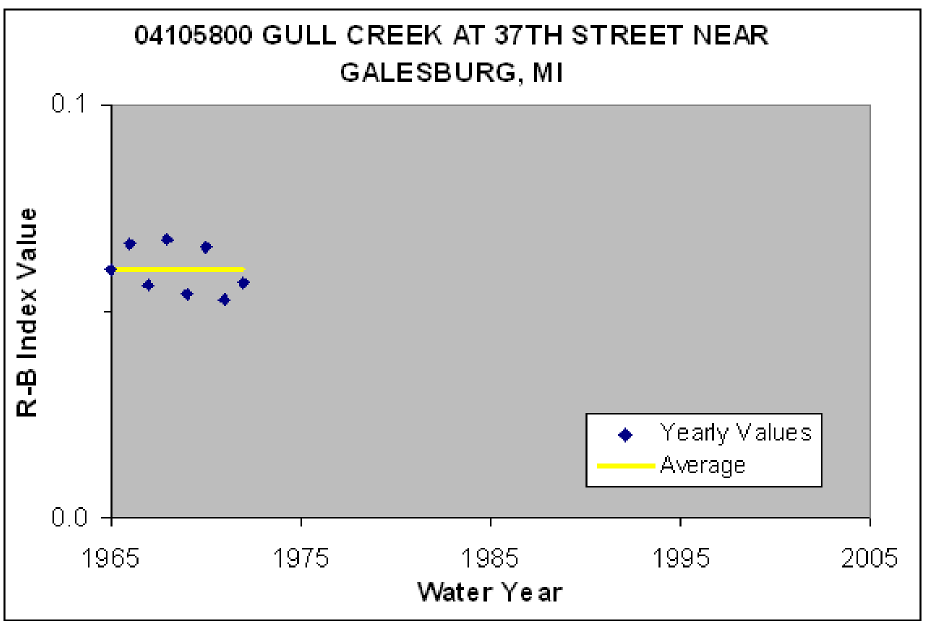

| | |
|---|---|
| Total Drainage Area: 819 square miles<br>Average R-B Index Value: 0.09<br>Rank: lower middle<br>Trend: less flashy | First Water Year of Record/Analyzed: 1938<br>Last Water Year: 2004<br>Number of Years Analyzed: 67<br>p Value: <0.005 |
| Notes: Diurnal fluctuation below 1500 cubic feet per second caused by power plants upstream from station. | |

Figure 28 – USGS Gage 04105500 Kalamazoo River near Battle Creek



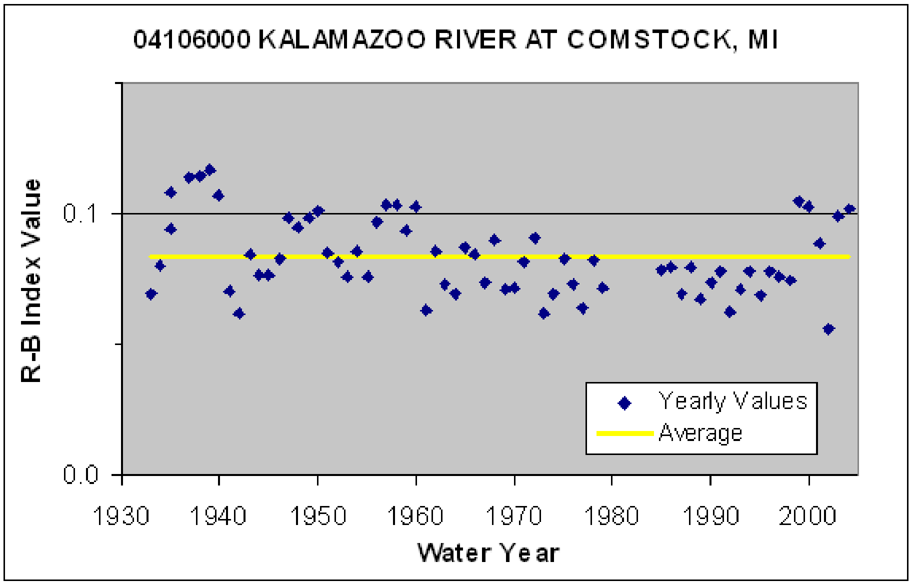

| | |
|---|---|
| Total Drainage Area: 37 square miles<br>Average R-B Index Value: 0.08<br>Rank: lowest<br>Trend: more flashy | First Water Year of Record/Analyzed: 1965<br>Last Water Year: 2004<br>Number of Years Analyzed: 40<br>p Value: 0.04 |

Figure 29 – USGS Gage 04105700 Augusta Creek near Augusta



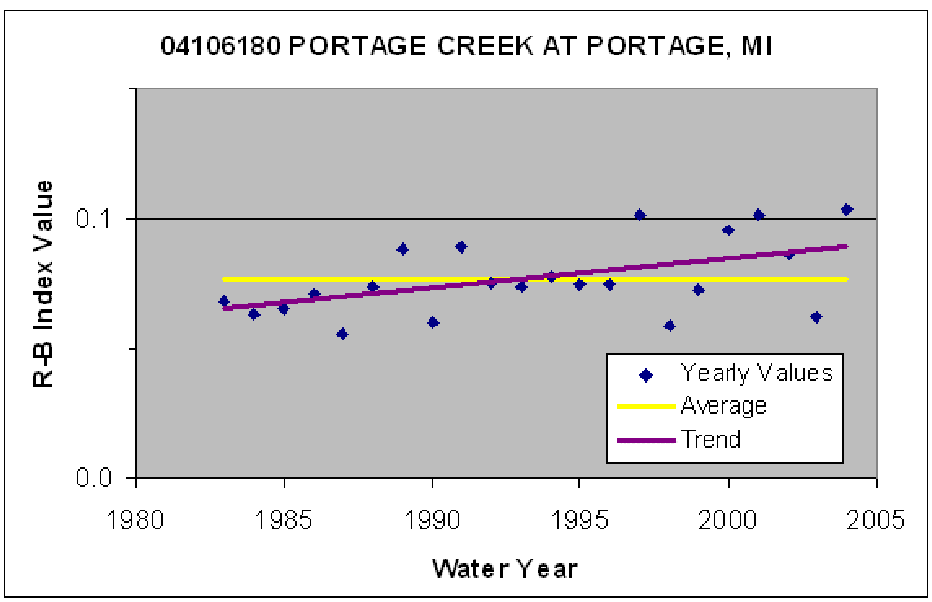

| | |
|---|---|
| Total Drainage Area: 36 square miles<br>Average R-B Index Value: 0.06<br>Rank: lowest<br>Trend: none | First Water Year of Record/Analyzed: 1965<br>Last Water Year: 1972<br>Number of Years Analyzed: 8 |
| Notes: Occasional regulation by many dams upstream. | |

Figure 30 – USGS Gage 04105800 Gull Creek at 37th Street near Galesburg



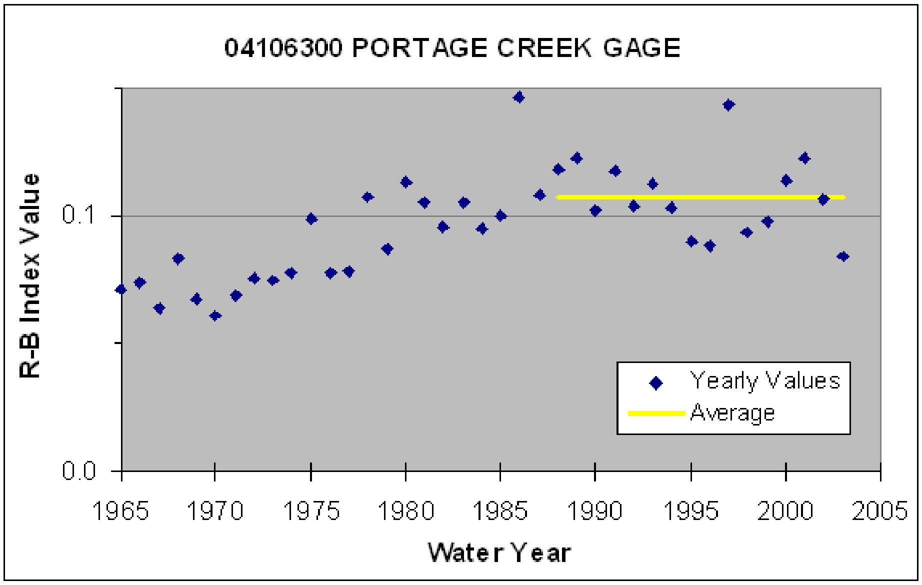

| | |
|---|---|
| Total Drainage Area: 1059 square miles<br>Average R-B Index Value: 0.08<br>Rank: lower middle<br>Trend: none | First Water Year of Record/Analyzed: 1933<br>Last Water Year: 2004<br>Number of Years Analyzed: 67 |
| Notes: Flow regulation by power plant 1.2 miles upstream from station. | |

Figure 31 – USGS Gage 04106000 Kalamazoo River at Comstock



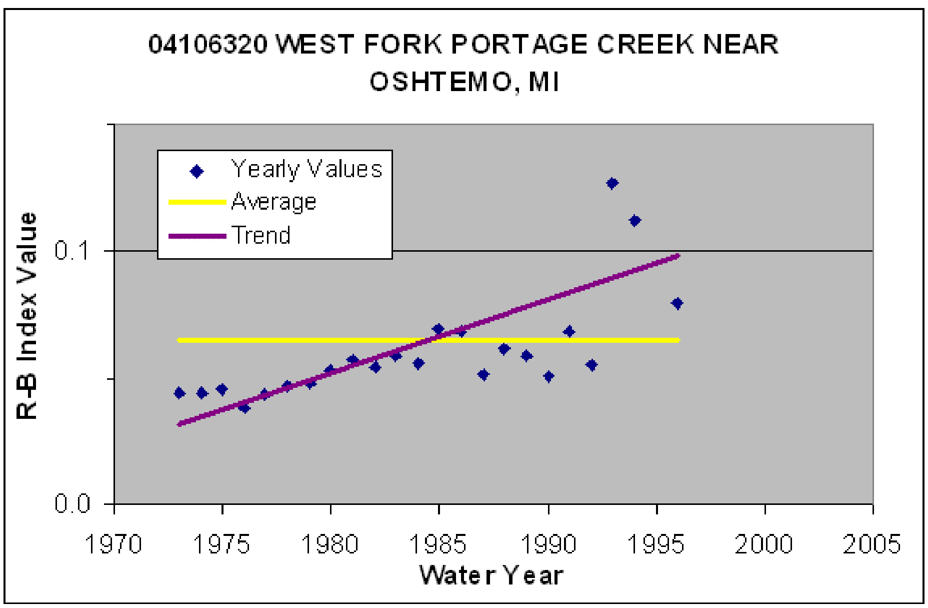

| | |
|---|---|
| Total Drainage Area: 15 square miles<br>Average R-B Index Value: 0.08<br>Rank: lowest<br>Trend: more flashy | First Water Year of Record/Analyzed: 1983<br>Last Water Year: 2004<br>Number of Years Analyzed: 22<br>p Value: 0.02 |

Figure 32 – USGS Gage 04106180 Portage Creek at Portage



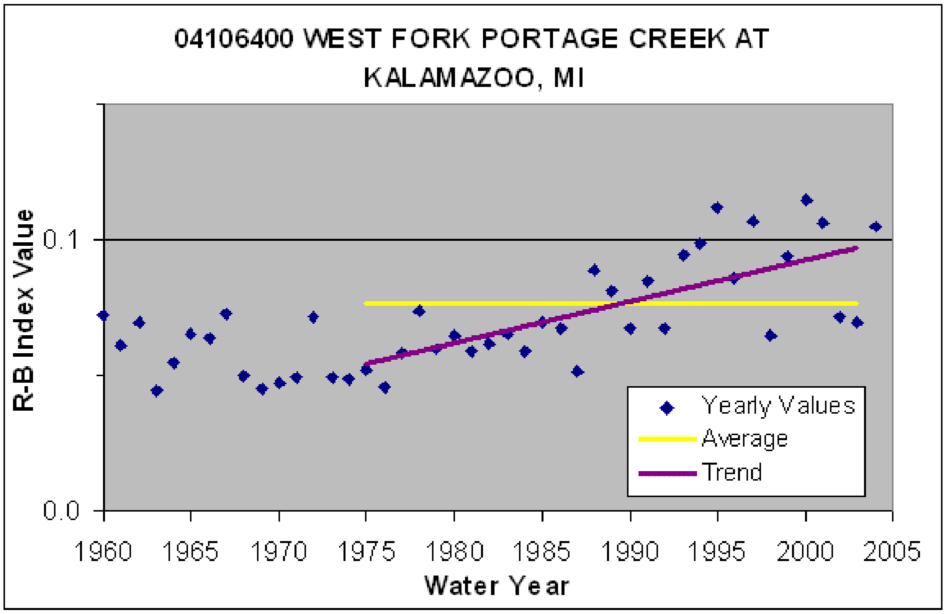

| | |
|---|---|
| Total Drainage Area: 20 square miles<br>Average R-B Index Value: 0.11<br>Rank: lowest<br>Trend: none | First Water Year of Record: 1965<br>First Water Year Analyzed: 1988<br>Last Water Year: 2003<br>Number of Years Analyzed: 16 |
| Notes: No statistically-significant trend since 1988, but an increasing trend is apparent earlier. Flow includes water which is pumped from ground water sources by industry and discharged into stream two miles upstream from station. | |

Figure 33 – USGS Gage 04106300 Portage Creek near Kalamazoo



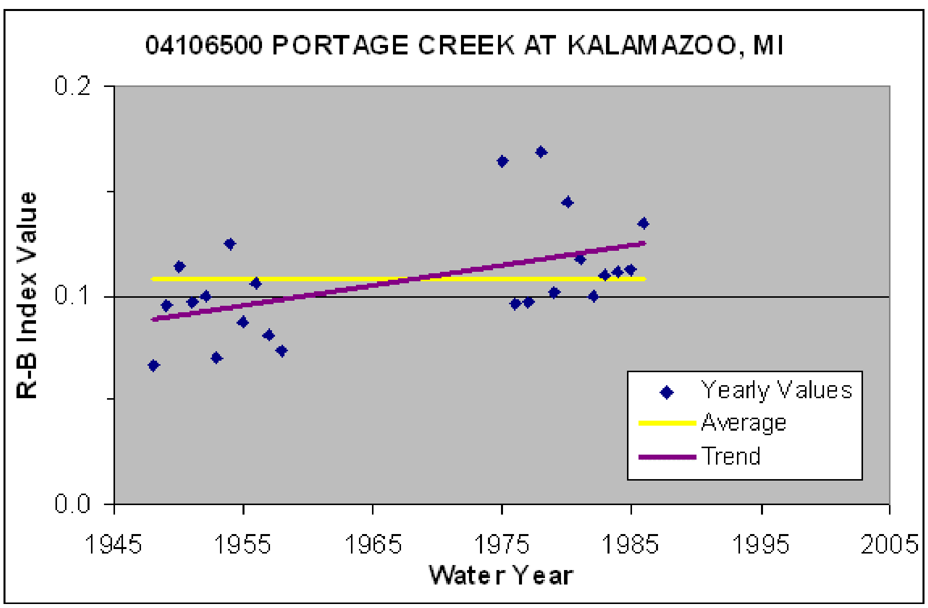

| | |
|---|---|
| Total Drainage Area: 15 square miles<br>Average R-B Index Value: 0.06<br>Rank: lowest<br>Trend: more flashy | First Water Year of Record/Analyzed: 1973<br>Last Water Year: 1996<br>Number of Years Analyzed: 24<br>p Value: $<0.005$ |
| Notes: At times flow is affected by ground water withdrawals. | |

Figure 34 – USGS Gage 04106320 West Fork Portage Creek near Oshtemo



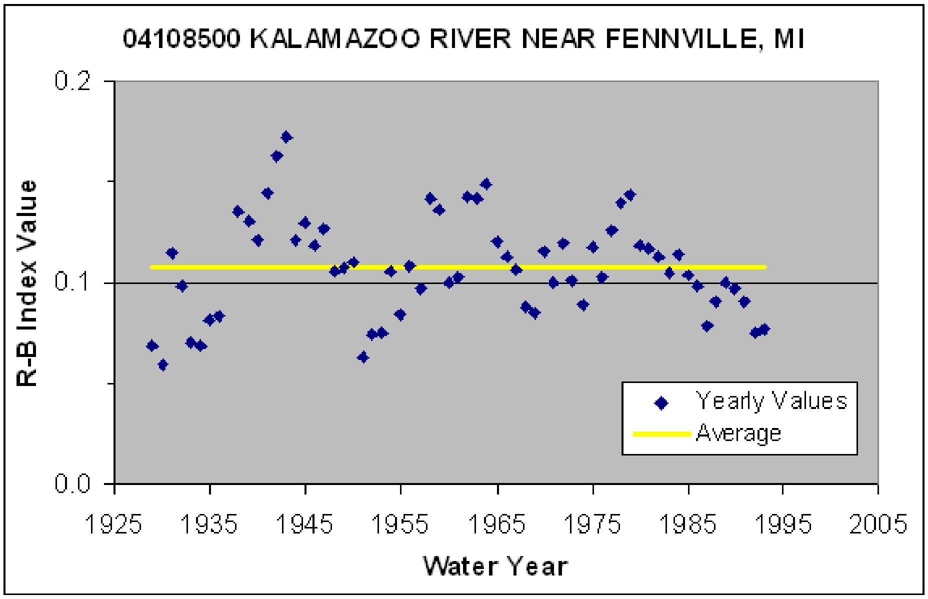

| | |
|---|---|
| Total Drainage Area: 21 square miles<br>Average R-B Index Value: 0.08<br>Rank: lowest<br>Trend: more flashy | First Water Year of Record: 1960<br>First Water Year Analyzed: 1975<br>Last Water Year: 2004<br>Number of Years Analyzed: 30<br>p Value: <0.005 |
| Notes: At times water is affected by water withdrawals. | |

Figure 35 – USGS Gage 04106400 West Fork Portage Creek at Kalamazoo



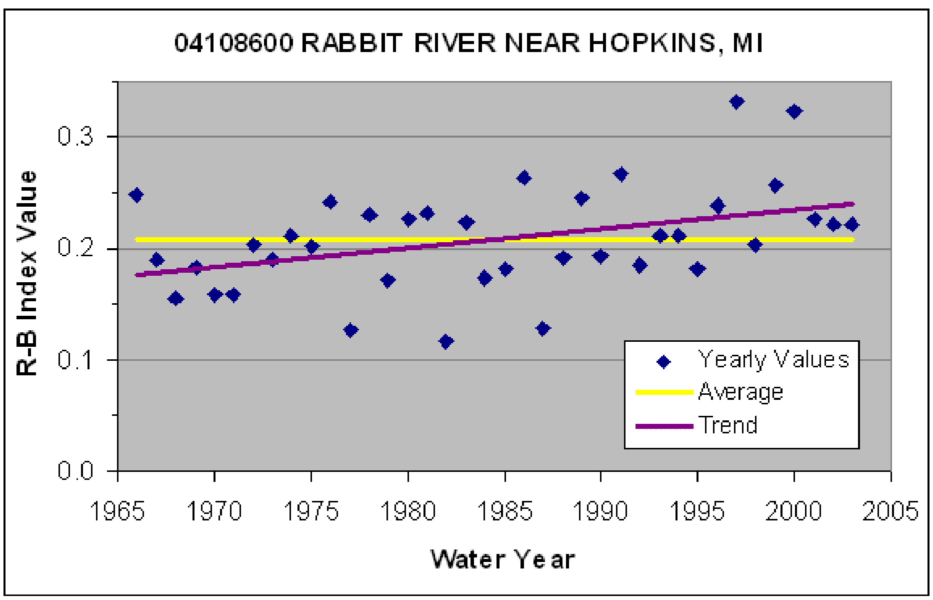

| | |
|---|---|
| Total Drainage Area: 48 square miles<br>Average R-B Index Value: 0.11<br>Rank: lower middle<br>Trend: more flashy | First Water Year of Record/Analyzed: 1948<br>Last Water Year: 1986<br>Number of Years Analyzed: 23<br>p Value: 0.01 |
| Notes: Some regulation by mill ponds upstream from station. Flow includes water which is pumped from groundwater sources by industry and discharged into stream five miles upstream from station. | |

Figure 36 – USGS Gage 04106500 Portage Creek at Kalamazoo




| | |
|---|---|
| Total Drainage Area: 1653 square miles<br>Average R-B Index Value: 0.11<br>Rank: upper middle<br>Trend: none | First Water Year of Record/Analyzed: 1929<br>Last Water Year: 1993<br>Number of Years Analyzed: 64 |
| Notes: Flow regulated at low and medium flow stages by power plant upstream from station and since June 1936 by Calkins Dam and power plant four miles upstream. | |

Figure 37 – USGS Gage 04108500 Kalamazoo River near Fennville




| | |
|---|---|
| Total Drainage Area: 65 square miles<br>Average R-B Index Value: 0.21<br>Rank: upper middle<br>Trend: more flashy | First Water Year of Record/Analyzed: 1966<br>Last Water Year: 2003<br>Number of Years Analyzed: 38<br>p Value: 0.01 |

Figure 38 – USGS Gage 04108600 Rabbit River near Hopkins

## *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) or 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 39. The stream morphology will adapt so that the left side of the equation in Figure 39 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 10. 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 10 – 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 from 1800 to 1978 and the increased flashiness at seven locations in the watershed indicate that the morphology of the Kalamazoo River and its tributaries have had to adapt, and in some cases continue 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 Kalamazoo 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.

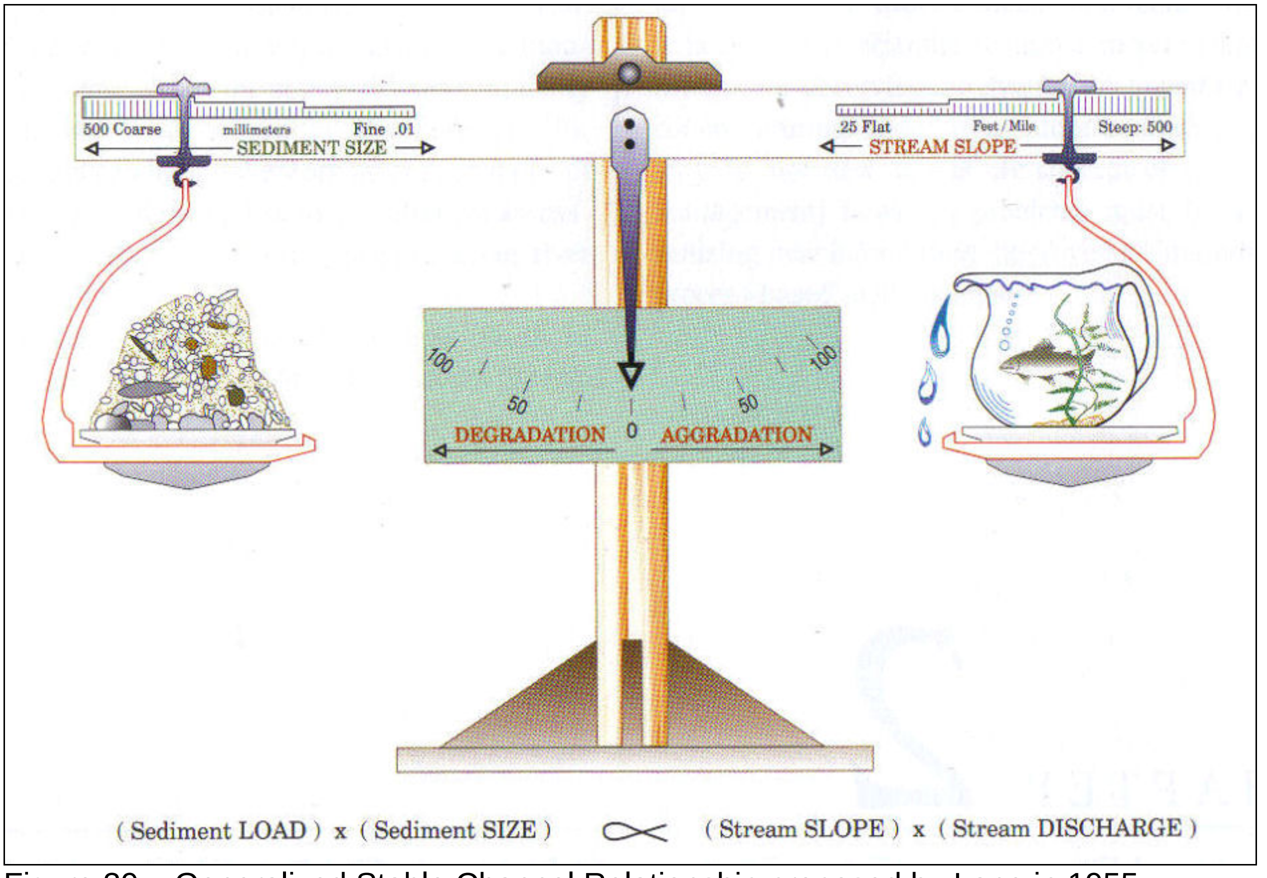



Figure 39 – Generalized Stable Channel Relationship proposed by Lane in 1955 (illustration from Rosgen 1996)

## *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 Kalamazoo River Watershed Council will likely modify these selection criteria.

The selection criteria used for this report are shown in Table 11. The maximum score is 100. Runoff volume per area, calculated from 1978 land use, highlights those subbasins currently contributing the most runoff. Runoff volume increase per area, calculated from 1800 and 1978 land use, highlights those subbasins that have experienced the most hydrologic change. Percent imperviousness highlights subbasins that contribute the most urban runoff. Gage flashiness highlights subbasins that may be contributing to an identified increasing flashiness trend. Trout streams were not explicitly used in the selection criteria because the health of a trout stream generally depends more on the watershed-scale hydrologic characteristics. The results are shown in Table 12 and Figure 40.

Table 11 – Critical Area Scoring

| Condition | Standard | Score |
|---|---|---|
| Runoff Volume per area, 1978 Land Use | 0 – 0.25 inches | 0 |
| | 0.26 – 0.50 inches | 3 |
| | 0.51 – 0.75 inches | 7 |
| | 0.76 – 1.00 inches | 12 |
| | over 1 inch | 20 |
| Runoff Volume Increase per area, 1800 to 1978 Land Use | 0.01 – 0.25 inches | 3 |
| | 0.26 – 0.50 inches | 7 |
| | 0.51 – 0.75 inches | 12 |
| | 0.76 – 1.00 inches | 20 |
| Imperviousness | 0 – 5 Percent | 0 |
| | 6 – 10 Percent | 5 |
| | 11 – 20 Percent | 10 |
| | 21 – 25 Percent | 20 |
| | over 25 Percent | 35 |
| Gage Flashiness | No change or decreasing | 0 |
| | Increasing | 10 |
| | Increasing, directly downstream | 15 |

Table 12 – Subbasin Critical Area Scores, higher total scores highlighted

| ID | Subbasin | Runoff Score | Runoff Increase Score | Impervious Score | Flashiness Score | Total Score |
|---|---|---|---|---|---|---|
| 1 | S Br Kalamazoo River at Mosherville Road | 7 | 7 | 0 | 0 | 14 |
| 2 | S Br Kalamazoo River below tributary | 3 | 7 | 0 | 0 | 10 |
| 3 | S Br Kalamazoo River below tributary | 3 | 7 | 0 | 0 | 10 |
| 4 | S Br Kalamazoo River below Beaver Creek | 7 | 7 | 0 | 0 | 14 |
| 5 | S Br Kalamazoo River below Swains Lake Drain | 7 | 7 | 0 | 0 | 14 |
| 6 | Lampson Run Drain at Mouth | 7 | 7 | 0 | 0 | 14 |
| 7 | S Br Kalamazoo River at Gage #04102850 | 7 | 7 | 0 | 0 | 14 |
| 8 | S Br Kalamazoo River at Mouth | 3 | 7 | 5 | 0 | 15 |
| 9 | North Kalamazoo River at Cross Lake Outlet | 7 | 7 | 0 | 0 | 14 |
| 10 | Spring Arbor and Concord at Mouth | 7 | 7 | 0 | 0 | 14 |
| 11 | N Br Kalamazoo River below Spring Arbor & Concord Drain | 7 | 7 | 0 | 0 | 14 |
| 12 | Kalamazoo River at Gage #04103010 | 7 | 7 | 5 | 0 | 19 |
| 13 | Wilder Creek below Huckleberry Drain | 7 | 7 | 0 | 0 | 14 |
| 14 | Wilder Creek at Mouth | 7 | 7 | 0 | 0 | 14 |

| ID | Subbasin | Runoff Score | Runoff Increase Score | Impervious Score | Flashiness Score | Total Score |
|---|---|---|---|---|---|---|
| 15 | S Br Rice Creek at M-99 | 7 | 7 | 0 | 0 | 14 |
| 16 | S Br Rice Creek at Mouth | 7 | 7 | 0 | 0 | 14 |
| 17 | N Br Rice Creek at Gordon Lake Outlet | 7 | 7 | 0 | 0 | 14 |
| 18 | N Br Rice Creek at Mouth | 7 | 3 | 0 | 0 | 10 |
| 19 | Rice Creek at Mouth | 7 | 7 | 5 | 0 | 19 |
| 20 | Kalamazoo River at Gage #04103500 | 7 | 7 | 0 | 0 | 14 |
| 21 | Kalamazoo River below Squaw Lake Drain | 7 | 7 | 5 | 0 | 19 |
| 22 | Kalamazoo River below Pigeon Creek | 7 | 7 | 0 | 0 | 14 |
| 23 | Kalamazoo River below Dickinson Creek | 3 | 7 | 0 | 0 | 10 |
| 24 | Harper Creek at Mouth | 3 | 7 | 0 | 0 | 10 |
| 25 | Minges Brook at Mouth | 7 | 7 | 10 | 0 | 24 |
| 26 | Battle Creek Above Hogle and Miller Drain | 7 | 3 | 0 | 10 | 20 |
| 27 | Hogle and Miller Drain at Mouth | 7 | 7 | 0 | 10 | 24 |
| 28 | Battle Creek below tributary | 7 | 3 | 0 | 10 | 20 |
| 29 | Big Creek at Mouth | 7 | 7 | 0 | 10 | 24 |
| 30 | Battle Creek below Big Creek | 7 | 7 | 5 | 10 | 29 |
| 31 | Indian Creek below State and Indian Creek | 7 | 3 | 0 | 10 | 20 |
| 32 | Indian Creek at Mouth | 7 | 3 | 5 | 10 | 25 |
| 33 | Battle Creek below Indian Creek | 7 | 3 | 0 | 10 | 20 |
| 34 | Battle Creek at Gage #04104500 | 3 | 3 | 0 | 10 | 16 |
| 35 | Battle Creek below Ackley Creek | 3 | 3 | 0 | 10 | 16 |
| 36 | Battle Creek below tributary | 3 | 3 | 0 | 10 | 16 |
| 37 | Wanadoga Creek below Ellis Creek | 7 | 3 | 0 | 0 | 10 |
| 38 | Wanadoga Creek at Gage #04104945 | 3 | 3 | 0 | 0 | 6 |
| 39 | Wanadoga Creek at Mouth | 3 | 3 | 5 | 10 | 21 |
| 40 | Battle Creek at Gage #04105000 | 0 | 3 | 5 | 15 | 23 |
| 41 | Battle Creek at Mouth | 12 | 12 | 35 | 0 | 59 |
| 42 | Kalamazoo River at Gage #04105500 | 3 | 7 | 20 | 0 | 30 |
| 43 | Wabascon Creek at Luce Road | 3 | 3 | 0 | 0 | 6 |
| 44 | Wabascon Creek at Mouth | 3 | 3 | 5 | 0 | 11 |
| 45 | Kalamazoo River below Wabascon Creek | 3 | 3 | 20 | 0 | 26 |
| 46 | Sevenmile Creek at Mouth | 3 | 3 | 0 | 0 | 6 |
| 47 | Augusta Creek below tributary | 7 | 7 | 0 | 10 | 24 |
| 48 | Augusta Creek at Gage #04105700 | 3 | 3 | 0 | 15 | 21 |
| 49 | Augusta Creek at Mouth | 3 | 0 | 0 | 0 | 3 |
| 50 | Gull Creek at Gage #04105800 | 7 | 7 | 0 | 0 | 14 |
| 51 | Gull Creek at Mouth | 3 | 3 | 0 | 0 | 6 |
| 52 | Kalamazoo River below Gull Creek | 0 | 0 | 5 | 0 | 5 |
| 53 | Kalamazoo River at Morrow Lake Dam | 3 | 3 | 5 | 0 | 11 |
| 54 | Comstock Creek at Mouth | 3 | 7 | 5 | 0 | 15 |
| 55 | Kalamazoo River at Gage #04106000 | 7 | 3 | 10 | 0 | 20 |
| 56 | Davis Creek at Mouth | 12 | 7 | 20 | 0 | 39 |
| 57 | Portage Creek at Gage #04106180 | 3 | 3 | 10 | 15 | 31 |
| 58 | Portage Creek at Gage #04106300 | 7 | 7 | 35 | 0 | 49 |

| ID | Subbasin | Runoff Score | Runoff Increase Score | Impervious Score | Flashiness Score | Total Score |
|---|---|---|---|---|---|---|
| 59 | W Fork Portage Creek at Gage #04106320 | 0 | 0 | 5 | 15 | 20 |
| 60 | W Fork Portage Creek at Gage #04106400 | 7 | 7 | 20 | 15 | 49 |
| 61 | Portage Creek at Gage #04106500 | 20 | 12 | 35 | 15 | 82 |
| 62 | Portage Creek at Mouth | 20 | 20 | 35 | 0 | 75 |
| 63 | Kalamazoo River below Portage Creek | 12 | 7 | 35 | 0 | 54 |
| 64 | Spring Brook at Mouth | 3 | 3 | 0 | 0 | 6 |
| 65 | Kalamazoo River below Spring Brook | 7 | 7 | 35 | 0 | 49 |
| 66 | Kalamazoo River below Silver Creek | 3 | 3 | 0 | 0 | 6 |
| 67 | Kalamazoo River at Plainwell Dam | 3 | 3 | 5 | 0 | 11 |
| 68 | Gun River at Gun Lake Outlet | 3 | 3 | 0 | 0 | 6 |
| 69 | Gun River below Culver Drain | 3 | 0 | 0 | 0 | 3 |
| 70 | Gun River at Mouth | 3 | 3 | 0 | 0 | 6 |
| 71 | Sand Creek at Mouth | 0 | 3 | 0 | 0 | 3 |
| 72 | Base Line Creek at Mouth | 3 | 3 | 0 | 0 | 6 |
| 73 | Pine Creek at Mouth | 3 | 3 | 0 | 0 | 6 |
| 74 | Kalamazoo River at Otsego Dam | 0 | 3 | 5 | 0 | 8 |
| 75 | Schnable Brook at Mouth | 7 | 3 | 0 | 0 | 10 |
| 76 | Kalamazoo River at Trowbridge Dam | 3 | 3 | 0 | 0 | 6 |
| 77 | Kalamazoo River at Unnamed Dam | 3 | 3 | 0 | 0 | 6 |
| 78 | Kalamazoo River at Unnamed Dam | 3 | 3 | 0 | 0 | 6 |
| 79 | Swan Creek at Mouth | 0 | 0 | 0 | 0 | 0 |
| 80 | Kalamazoo River at Gage #04108500 | 0 | 0 | 0 | 0 | 0 |
| 81 | Little Rabbit River below Dorr & Nichols Drain | 3 | 3 | 0 | 0 | 6 |
| 82 | Little Rabbit River at Mouth | 3 | 3 | 0 | 0 | 6 |
| 83 | Bear Creek at Mouth | 7 | 7 | 0 | 0 | 14 |
| 84 | Green Lake Creek at Mouth | 7 | 7 | 0 | 10 | 24 |
| 85 | Rabbit River below Green Lake Creek | 3 | 3 | 0 | 10 | 16 |
| 86 | Rabbit River at Gage #04108600 | 7 | 7 | 0 | 15 | 29 |
| 87 | Miller Creek at Mouth | 7 | 7 | 0 | 0 | 14 |
| 88 | Rabbit River below Bear Creek | 7 | 3 | 0 | 0 | 10 |
| 89 | Rabbit River below Little Rabbit River | 3 | 3 | 0 | 0 | 6 |
| 90 | Black Creek at Mouth | 7 | 7 | 0 | 0 | 14 |
| 91 | Rabbit River below Silver Creek | 0 | 0 | 0 | 0 | 0 |
| 92 | Rabbit River at Mouth | 0 | 3 | 0 | 0 | 3 |
| 93 | Kalamazoo River below Rabbit River | 0 | 0 | 0 | 0 | 0 |
| 94 | Mann Creek at Mouth | 0 | 0 | 0 | 0 | 0 |
| 95 | Kalamazoo River below Peach Orchid Creek | 3 | 3 | 0 | 0 | 6 |
| 96 | Kalamazoo River at Mouth | 0 | 0 | 5 | 0 | 5 |

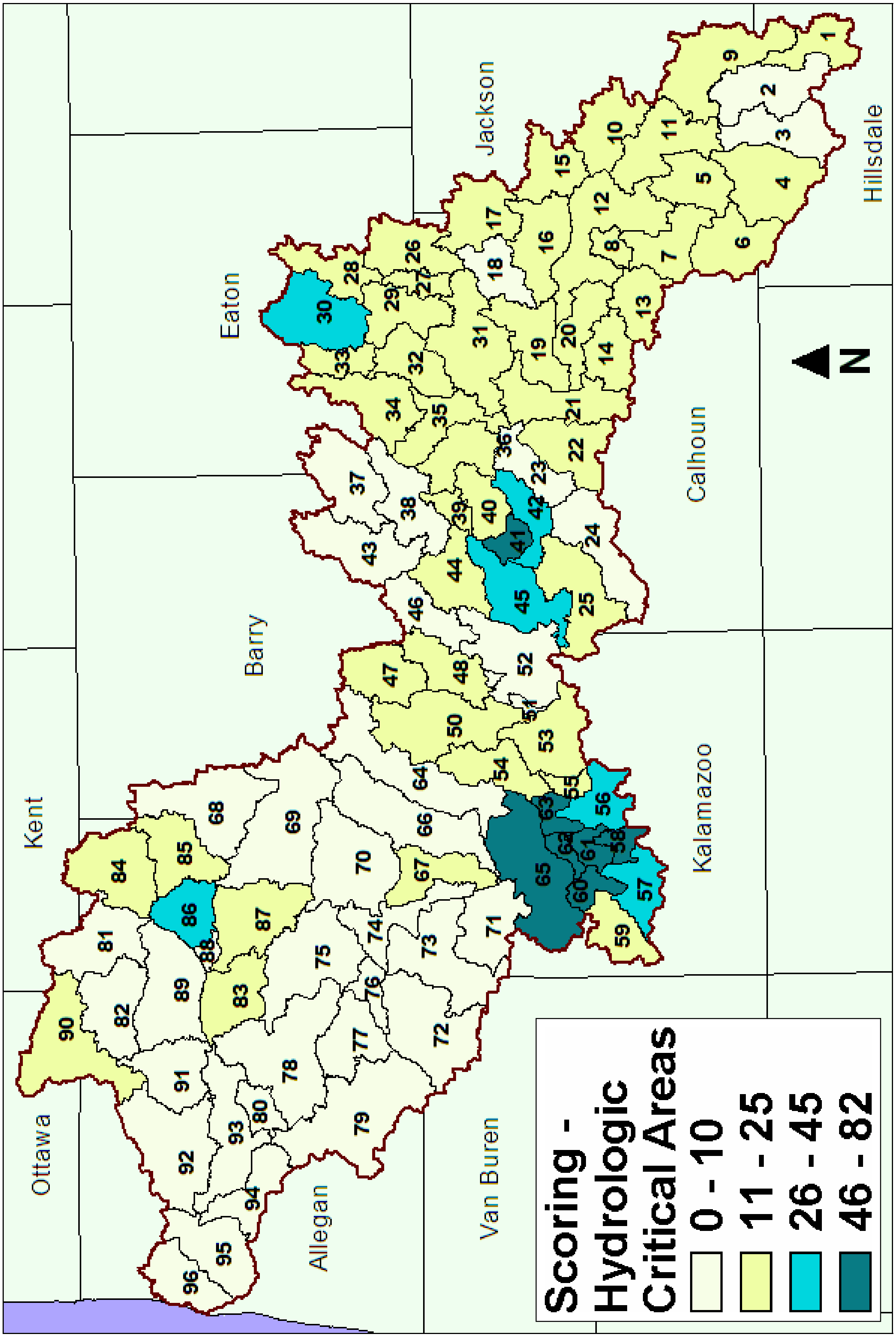



Figure 40 – Hydrologic Critical Areas

## 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 41.

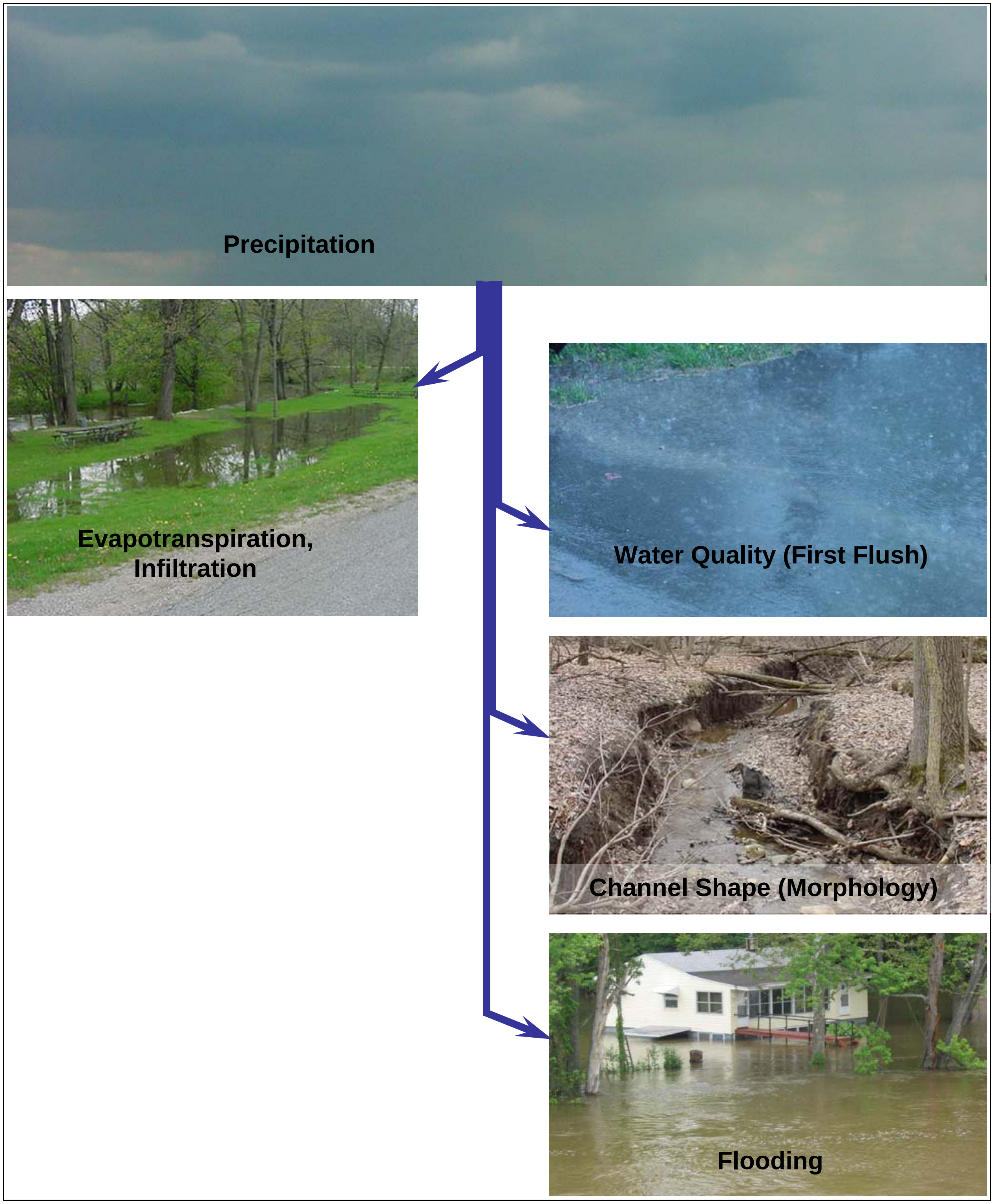



Figure 41 – Runoff Impacts

Land use changes that reduce evapotranspiration and infiltration increase runoff. One reason low impact development has become more popular is that it avoids creating more runoff; intercepting and infiltrating the excess runoff instead.

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 42 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "first flush." Some of the pollutants can settle out before discharging to a stream if this first flush runoff is detained for a period of time. Filtering systems are also used at some sites to treat the first flush stormwater.

Nationally, the amount of runoff recommended for capture and treatment varies from 0.5 inch per impervious acre to the runoff from a 50 percent chance storm. Michigan BMP guidelines recommend capture and treatment of 0.5 inches of runoff from a single site (Guidebook of Best Management Practices for Michigan Watersheds, 1998). The runoff is then released over 24 to 48 hours or is allowed to infiltrate into the ground within 72 hours. Dry detention ponds are less effective than retention or wet detention ponds, because the accumulated sediment in a dry detention pond may be easily resuspended by the next storm (Schueler, 2000).

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. For multiple sites or watershed wide design, it is best to design to capture and treat 90 percent of runoff-producing storms. This "90 percent rule" effectively treats storm runoff that could be reaching the treatment at different times during the storm event. It was designed to provide the greatest amount of treatment that is economically feasible. In Michigan, values calculated for these storms range from 0.77 to 1.00 inches. For the Kalamazoo River watershed climatic regions, the calculated value is 0.90 to 1.00 inches. Additional information is available at www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf.

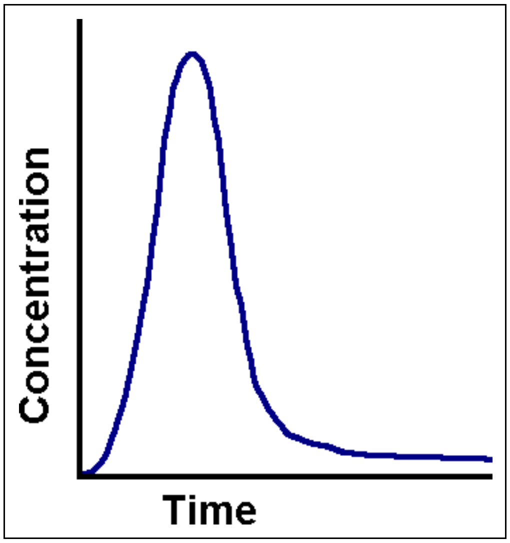



Figure 42 – Plot of Pollutant Concentration versus Time

## *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 steam 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 43, 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 44 (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 it 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 45. A few watershed plans funded through the MDEQ Nonpoint Source Program have recommended requirements based on this criterion. One such example is from the Anchor Bay Technical Report and is shown in Figure 46. This analysis, which is for climatic region 10, is for 2.06 inches of rainfall. The Kalamazoo River watershed is mostly in climatic region 8, which has a 50 percent chance (2-year) 24-hour storm design rainfall value of 2.37 inches, as tabulated in *Rainfall Frequency Atlas of the Midwest*, Bulletin 71, Midwestern Climate Center, 1992, pp. 126-129. The MDEQ Nonpoint Source Program is funding this analysis for western Michigan through the Lower Grand Initiatives grant, 2007-0137, to the Grand Valley Metropolitan Council.

Detention designed to control channel-forming flows and prevent streambank erosion may not be needed for runoff routed from a city through storm sewers to a large river, such as the Kalamazoo River at Saugatuck, simply because the runoff routed through the storm sewers enters the river well ahead of the peak flow in the river. 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.

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. Kalamazoo River watershed stakeholders may elect to recommend some conditions when detention or retention for channel protection is not necessary. For example, the watershed stakeholders may adopt a watershed plan that calls for channel protection measures, unless runoff discharges from a storm drain directly to a specific order or higher stream, as shown in Figure 4.

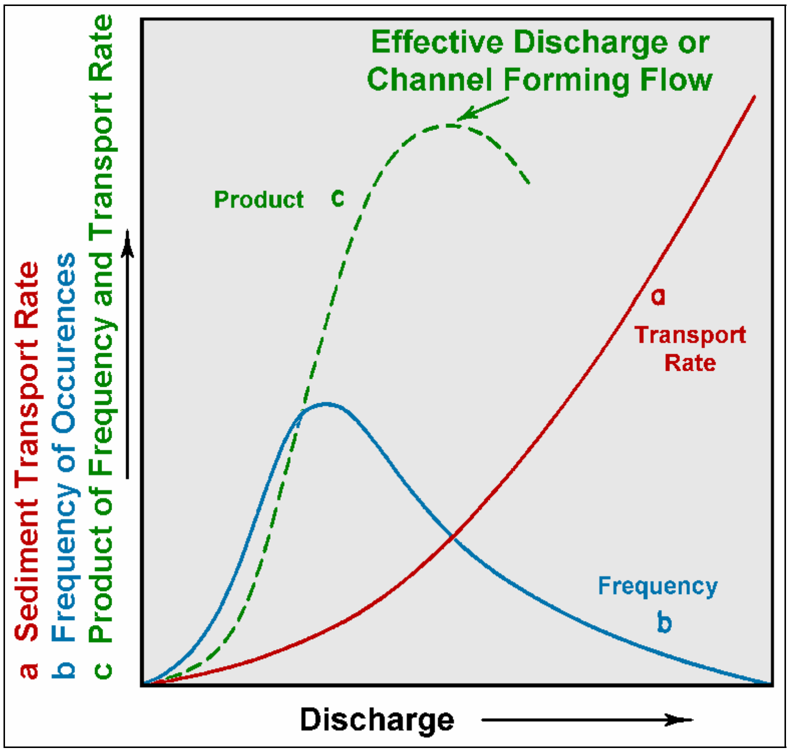



Figure 43 – Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

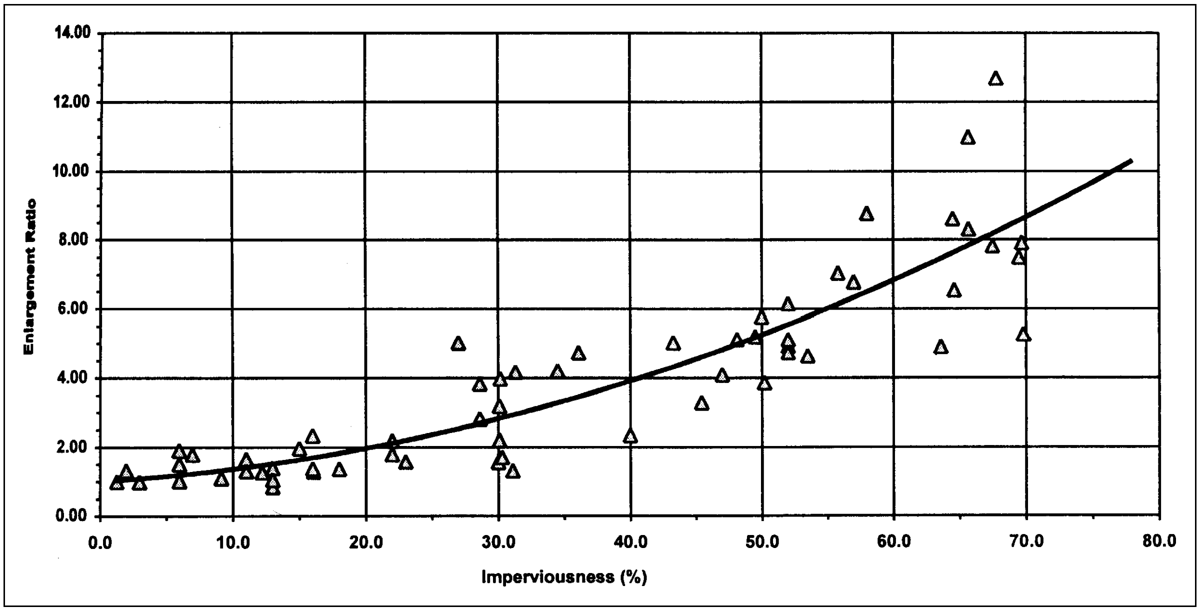



Figure 44 – “Ultimate” Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

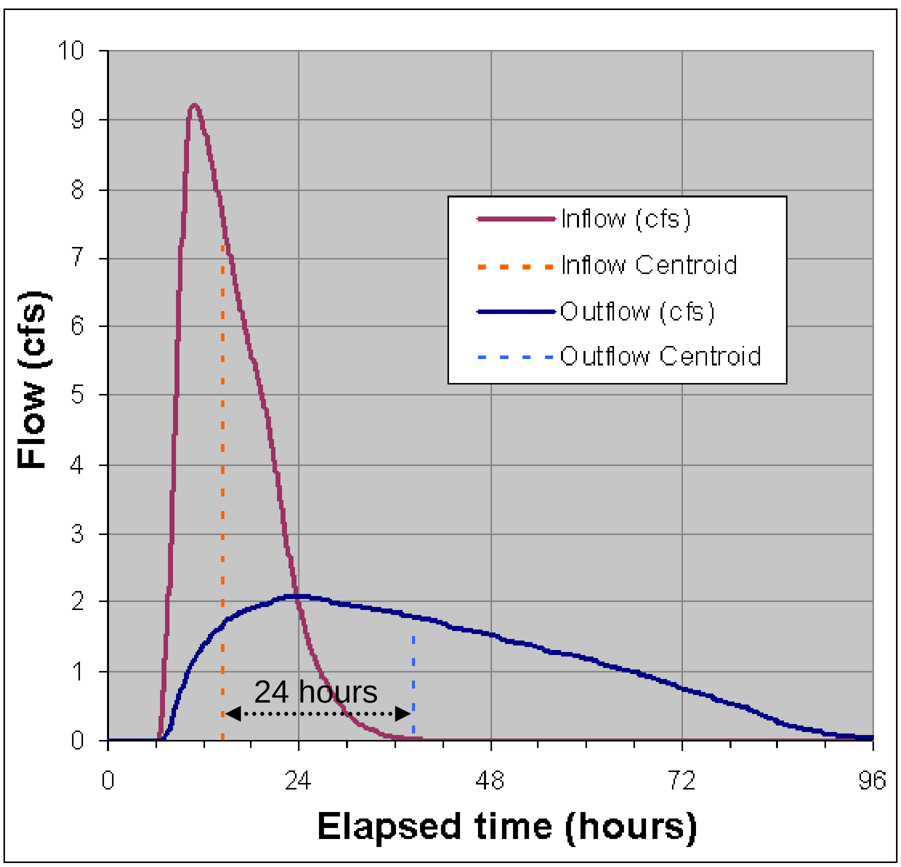



Figure 45 – Example of 24-hour extended detention criterion applied to detention pond design

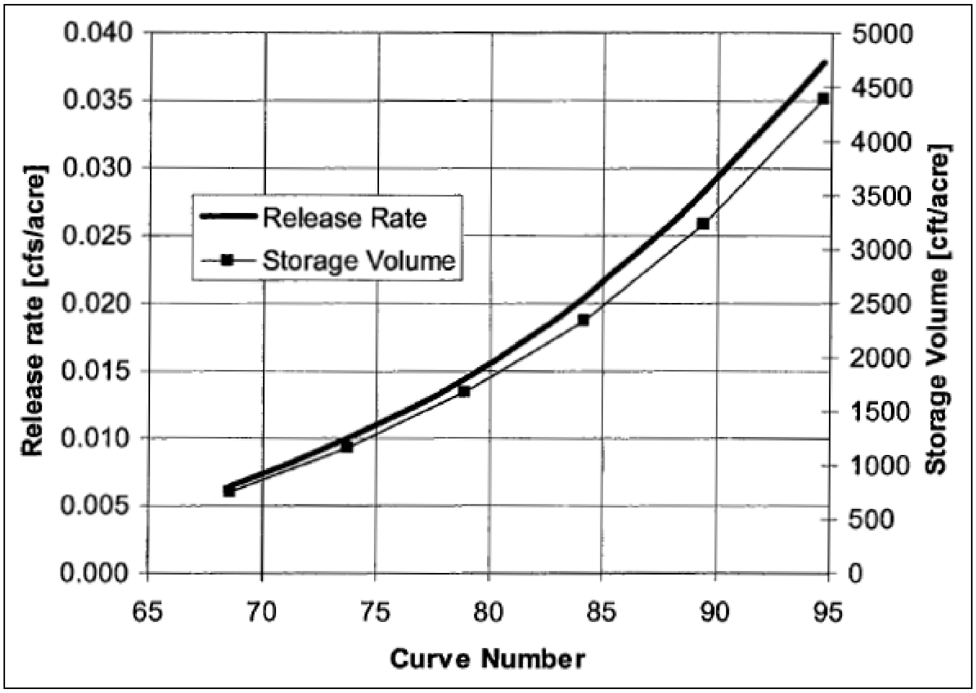


Figure 46 – Example of detention pond requirements derived from the 24-hour extended detention criterion

## *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. 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.

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# Appendix A: Kalamazoo River Hydrologic Parameters

Table A1 provides the hydrologic parameters specified for each of the subbasin elements in the hydrologic analysis.

Table A1 – Subbasin Parameters – Drainage Area and Curve Number

| ID | Subbasin | Drainage Area (sq. mi.) | CN 1800 | CN 1978 |
|---|---|---|---|---|
| 1 | S Br Kalamazoo River at Mosherville Road | 14.3 | 64.6 | 73.5 |
| 2 | S Br Kalamazoo River below tributary | 24.7 | 62.1 | 72.0 |
| 3 | S Br Kalamazoo River below tributary | 22.0 | 60.8 | 70.3 |
| 4 | S Br Kalamazoo River below Beaver Creek | 29.2 | 62.9 | 73.5 |
| 5 | S Br Kalamazoo River below Swains Lake Drain | 17.3 | 63.6 | 73.7 |
| 6 | Lampson Run Drain at Mouth | 21.6 | 66.5 | 74.9 |
| 7 | S Br Kalamazoo River at Gage #04102850 | 18.4 | 61.0 | 73.7 |
| 8 | S Br Kalamazoo River at Mouth | 5.5 | 60.3 | 70.4 |
| 9 | North Kalamazoo River at Cross Lake Outlet | 33.2 | 64.3 | 72.5 |
| 10 | Spring Arbor and Concord at Mouth | 20.9 | 63.6 | 74.1 |
| 11 | N Br Kalamazoo River below Spring Arbor & Concord Drain | 25.2 | 62.1 | 72.8 |
| 12 | Kalamazoo River at Gage #04103010 | 37.1 | 58.7 | 72.5 |
| 13 | Wilder Creek below Huckleberry Drain | 15.1 | 63.7 | 73.5 |
| 14 | Wilder Creek at Mouth | 14.8 | 63.5 | 74.4 |
| 15 | S Br Rice Creek at M-99 | 17.0 | 64.2 | 73.3 |
| 16 | S Br Rice Creek at Mouth | 22.5 | 62.4 | 73.2 |
| 17 | N Br Rice Creek at Gordon Lake Outlet | 21.6 | 65.0 | 75.0 |
| 18 | N Br Rice Creek at Mouth | 14.5 | 66.4 | 73.7 |
| 19 | Rice Creek at Mouth | 20.9 | 60.8 | 73.7 |
| 20 | Kalamazoo River at Gage #04103500 | 15.4 | 59.7 | 73.6 |
| 21 | Kalamazoo River below Squaw Lake Drain | 24.6 | 62.2 | 74.1 |
| 22 | Kalamazoo River below Pigeon Creek | 21.5 | 61.5 | 74.0 |
| 23 | Kalamazoo River below Dickinson Creek | 14.6 | 58.6 | 70.5 |
| 24 | Harper Creek at Mouth | 26.6 | 61.6 | 71.2 |
| 25 | Minges Brook at Mouth | 27.6 | 62.7 | 72.6 |
| 26 | Battle Creek Above Hogle and Miller Drain | 20.5 | 72.3 | 77.5 |
| 27 | Hogle and Miller Drain at Mouth | 6.6 | 70.2 | 77.5 |
| 28 | Battle Creek below tributary | 15.9 | 67.1 | 73.4 |
| 29 | Big Creek at Mouth | 18.0 | 68.7 | 75.9 |
| 30 | Battle Creek below Big Creek | 27.4 | 65.4 | 74.2 |
| 31 | Indian Creek below State and Indian Creek | 33.0 | 71.3 | 75.3 |
| 32 | Indian Creek at Mouth | 16.7 | 67.0 | 74.1 |
| 33 | Battle Creek below Indian Creek | 9.7 | 66.8 | 73.8 |
| 34 | Battle Creek at Gage #04104500 | 23.9 | 64.5 | 71.6 |
| 35 | Battle Creek below Ackley Creek | 18.4 | 65.7 | 72.0 |
| 36 | Battle Creek below tributary | 16.8 | 56.7 | 67.4 |
| 37 | Wanadoga Creek below Ellis Creek | 26.0 | 67.1 | 74.0 |
| 38 | Wanadoga Creek at Gage #04104945 | 22.3 | 59.2 | 68.0 |
| 39 | Wanadoga Creek at Mouth | 5.9 | 55.2 | 64.4 |
| 40 | Battle Creek at Gage #04105000 | 12.8 | 52.6 | 62.4 |
| 41 | Battle Creek at Mouth | 6.4 | 58.0 | 79.5 |
| 42 | Kalamazoo River at Gage #04105500 | 12.5 | 54.1 | 71.5 |
| 43 | Wabascon Creek at Luce Road | 27.4 | 63.9 | 70.5 |
| 44 | Wabascon Creek at Mouth | 19.5 | 58.8 | 64.4 |

| ID | Subbasin | Drainage Area (sq. mi.) | CN 1800 | CN 1978 |
|---|---|---|---|---|
| 45 | Kalamazoo River below Wabascon Creek | 24.5 | 57.7 | 68.0 |
| 46 | Sevenmile Creek at Mouth | 16.3 | 60.9 | 68.6 |
| 47 | Augusta Creek below tributary | 19.1 | 65.0 | 73.1 |
| 48 | Augusta Creek at Gage #04105700 | 17.7 | 63.8 | 69.3 |
| 49 | Augusta Creek at Mouth | 1.0 | 64.1 | 67.0 |
| 50 | Gull Creek at Gage #04105800 | 35.7 | 66.4 | 74.4 |
| 51 | Gull Creek at Mouth | 1.8 | 58.0 | 67.2 |
| 52 | Kalamazoo River below Gull Creek | 30.6 | 61.2 | 63.5 |
| 53 | Kalamazoo River at Morrow Lake Dam | 23.8 | 62.3 | 70.6 |
| 54 | Comstock Creek at Mouth | 18.3 | 61.9 | 71.9 |
| 55 | Kalamazoo River at Gage #04106000 | 4.4 | 67.0 | 72.5 |
| 56 | Davis Creek at Mouth | 14.5 | 69.8 | 79.8 |
| 57 | Portage Creek at Gage #04106180 | 14.9 | 55.7 | 65.9 |
| 58 | Portage Creek at Gage #04106300 | 5.4 | 71.1 | 77.3 |
| 59 | W Fork Portage Creek at Gage #04106320 | 14.5 | 55.4 | 58.3 |
| 60 | W Fork Portage Creek at Gage #04106400 | 6.7 | 61.7 | 73.9 |
| 61 | Portage Creek at Gage #04106500 | 6.2 | 69.5 | 85.2 |
| 62 | Portage Creek at Mouth | 4.0 | 73.3 | 88.8 |
| 63 | Kalamazoo River below Portage Creek | 6.0 | 72.8 | 80.9 |
| 64 | Spring Brook at Mouth | 38.6 | 62.3 | 70.1 |
| 65 | Kalamazoo River below Spring Brook | 40.4 | 65.4 | 74.6 |
| 66 | Kalamazoo River below Silver Creek | 36.8 | 60.6 | 66.6 |
| 67 | Kalamazoo River at Plainwell Dam | 17.5 | 57.2 | 65.4 |
| 68 | Gun River at Gun Lake Outlet | 34.2 | 62.4 | 67.1 |
| 69 | Gun River below Culver Drain | 48.9 | 63.1 | 66.8 |
| 70 | Gun River at Mouth | 34.7 | 59.4 | 65.4 |
| 71 | Sand Creek at Mouth | 21.1 | 58.3 | 64.3 |
| 72 | Base Line Creek at Mouth | 36.6 | 64.6 | 70.7 |
| 73 | Pine Creek at Mouth | 33.3 | 64.1 | 68.4 |
| 74 | Kalamazoo River at Otsego Dam | 17.8 | 57.3 | 64.3 |
| 75 | Schnable Brook at Mouth | 35.5 | 69.1 | 75.5 |
| 76 | Kalamazoo River at Trowbridge Dam | 7.3 | 63.0 | 68.9 |
| 77 | Kalamazoo River at Unnamed Dam | 19.5 | 62.0 | 67.4 |
| 78 | Kalamazoo River at Unnamed Dam | 44.8 | 60.3 | 66.9 |
| 79 | Swan Creek at Mouth | 49.1 | 61.0 | 62.8 |
| 80 | Kalamazoo River at Gage #04108500 | 8.1 | 57.1 | 57.8 |
| 81 | Little Rabbit River below Dorr & Nichols Drain | 25.6 | 66.4 | 72.3 |
| 82 | Little Rabbit River at Mouth | 23.4 | 58.2 | 66.9 |
| 83 | Bear Creek at Mouth | 20.1 | 64.4 | 73.1 |
| 84 | Green Lake Creek at Mouth | 28.2 | 65.3 | 73.7 |
| 85 | Rabbit River below Green Lake Creek | 21.4 | 57.5 | 66.3 |
| 86 | Rabbit River at Gage #04108600 | 15.5 | 66.2 | 75.0 |
| 87 | Miller Creek at Mouth | 27.7 | 65.9 | 74.6 |
| 88 | Rabbit River below Bear Creek | 2.7 | 68.7 | 75.0 |
| 89 | Rabbit River below Little Rabbit River | 32.5 | 60.1 | 67.2 |
| 90 | Black Creek at Mouth | 35.1 | 66.1 | 75.2 |
| 91 | Rabbit River below Silver Creek | 20.4 | 54.5 | 58.3 |
| 92 | Rabbit River at Mouth | 37.2 | 55.6 | 64.1 |
| 93 | Kalamazoo River below Rabbit River | 26.9 | 54.8 | 57.5 |
| 94 | Mann Creek at Mouth | 17.4 | 45.7 | 50.9 |
| 95 | Kalamazoo River below Peach Orchid Creek | 23.5 | 68.2 | 71.8 |
| 96 | Kalamazoo River at Mouth | 17.3 | 60.1 | 63.7 |

## 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 2 years or less. 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.

**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.

**Critical Depth** - depth of water for which specific energy is a minimum.

**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 subbasin areas 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.

**Flood Hazard Zone** - area that will flood with a given probability.

**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.

**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.

**Overland Flow** - see Runoff.

**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** - time at which outflow from a basin is equal to inflow or time of equilibrium.

**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.

**Vadose Zone** - see Unsaturated Zone.

**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

| | |
|---|---|
| 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 |
| LID | Low Impact Development |
| LWMD | MDEQ's Land and Water Management Division |
| MDEQ | Michigan Department of Environmental Quality |
| NPS | Nonpoint Source |
| NRCS | Natural Resources Conservation Service |