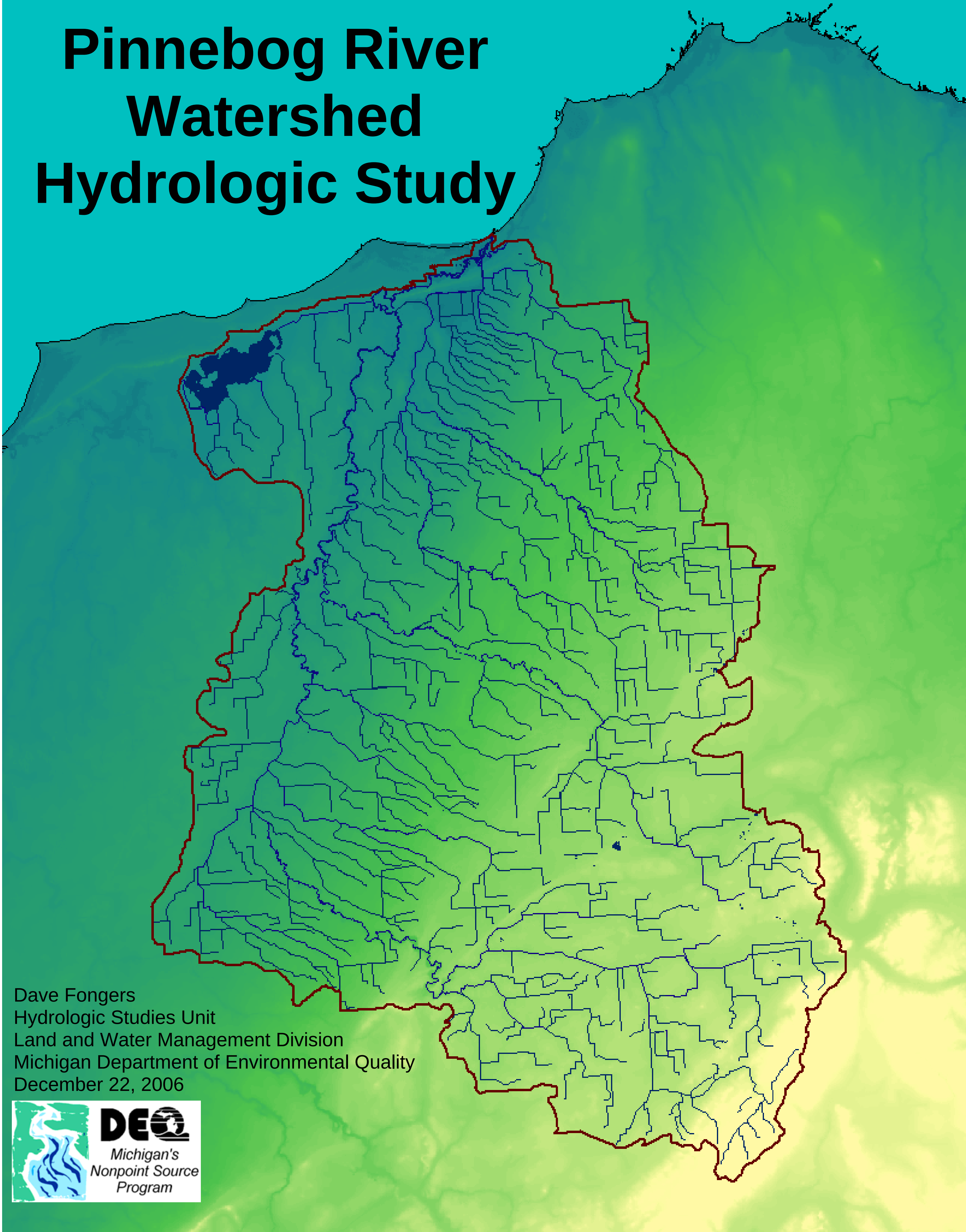
Pinnebog River Watershed Hydrologic Study



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Michigan Department of Environmental Quality
December 22, 2006

DEQ Michigan's Nonpoint Source Program

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This Nonpoint Source Pollution Control project has been funded wholly by the United States Environmental Protection Agency through a Part 319 grant to the Michigan Department of Environmental Quality. 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 drains, streams, lakes, and rivers and ground elevations of the Pinnebog River Watershed. Lighter colors are higher elevations.

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DEQ
Michigan's Nonpoint Source Program

Summary

A hydrologic study of the Pinnebog River watershed was conducted by the Hydrologic Studies Unit (HSU) of the Michigan Department of Environmental Quality (MDEQ) in support of a Pinnebog River Nonpoint Source (NPS) watershed planning project. Using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), a hydrologic model was developed to better understand the watershed's hydrologic characteristics, to provide a basis for stormwater management to protect stream morphology, and to help determine the watershed management plan's critical areas.

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. Local governments within the watershed could also use the information to help develop stormwater ordinances.

The hydrologic study has three land use scenarios corresponding to land cover in 1800, 1978, and 2005. General land use trends are illustrated in Figure 1. Additional land use information is provided in the Watershed Description section and in Appendix A of this report.

The hydrologic modeling quantifies the increases in stormwater runoff volumes and peak flood flow yields, peak flows per square mile, from 1800 to 1978 throughout the watershed. The increases are due to changes in land use and loss of runoff storage. From 1978 to 2005, the hydrologic modeling demonstrates that the land use changes have had no quantifiable effect at the scale of this study, 10 to 20 square mile drainage areas. Detailed discussions of the results are in the Hydrologic Analysis section of this report.

Increases in the runoff volume and peak flow from the 4 percent chance (25-year), 24-hour storm could cause or aggravate flooding problems unless mitigated using effective stormwater management techniques. Increases in the 50 percent chance (2-year), 24-hour storm will increase channel-forming flows. The channel-forming flow in a stable stream usually has a one- to two-year recurrence interval. These relatively modest storm flows, because of their higher frequency, have more effect on channel form than extreme flood flows. Hydrologic changes that increase this flow can cause the stream channel to become unstable. Stream instability is indicated by excessive erosion at many locations throughout a stream reach. Stormwater management techniques used to mitigate flooding can also help mitigate projected channel-forming flow increases. However, channel-forming flow criteria should be specifically considered in the stormwater management plan so that the selected BMPs will be most effective. For example, detention ponds designed to control runoff from the 4 percent chance, 24-hour storm may do little to control the runoff from the 50 percent chance, 24-hour storm, unless the outlet is specifically designed to do so.

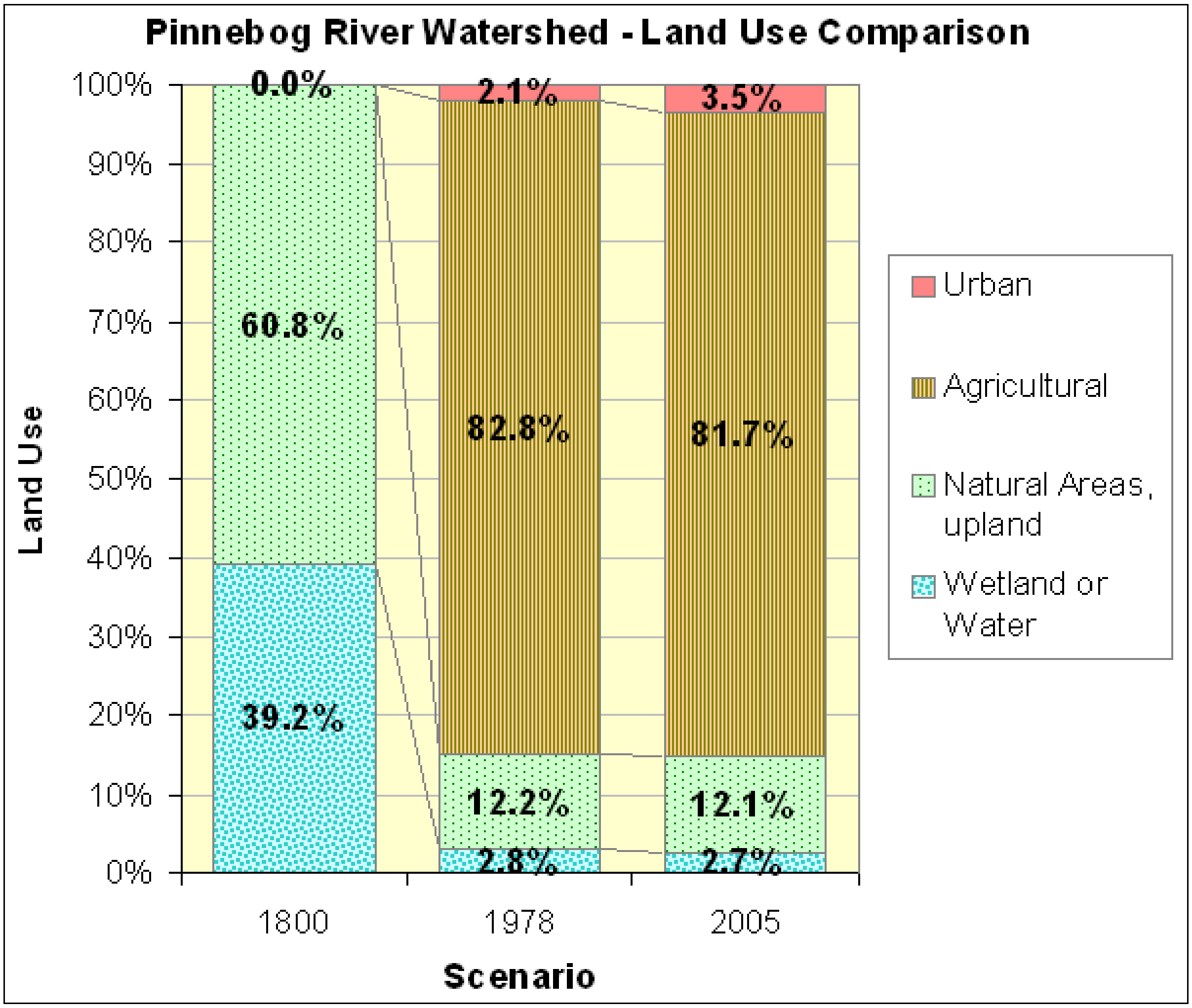


Figure 1: Land Use Comparison, Overall Pinnebog River Watershed

Project Goals

The Pinnebog River hydrologic study was initiated in support of the Huron Conservation District, which is developing a watershed management plan for the Pinnebog River watershed. This Pinnebog River hydrologic study is funded by a United States Environmental Protection Agency (USEPA) Part 319 grant administered by the MDEQ. The goals of this Pinnebog River study are:

- To better understand the watershed's hydrologic characteristics and the impact of land use changes in the Pinnebog River watershed on storm flows
- To provide a basis for stormwater management to protect stream morphology
- To help determine the watershed management plan's critical areas – the geographic portions of the watershed contributing the majority of the pollutants and having significant impacts on the waterbody

One focus of this study compares hydrologic characteristics of Pinnebog River watershed subbasins that are less than approximately 20 square miles. This hydrologic analysis of the subbasins models 1800, 1978, and 2005 land use. 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. Runoff from each subbasin for a standard 24-hour storm is calculated for the three scenarios. This highlights subbasins that generate a higher proportion of runoff due to soils and land use. Peak flood flow yields, which are peak flows divided by drainage areas, are calculated for each subbasin as a measure of hydrologic responsiveness. To ensure that yield values are comparable, subbasins are similarly sized, and a confidence range is provided based on the drainage area ratio equation used by MDEQ's Hydrologic Studies Unit. A higher peak flood flow yield indicates that the subbasin has comparatively more runoff due to the combination of soils, land uses, storage, and drainage efficiency, and is contributing a proportionately higher flow to the receiving streams. Either peak flood flow yields or runoff volume per area can be used to help select critical areas. Lower values can identify sensitive areas to be protected. Higher values can identify areas that need rehabilitation activities.

Percent imperviousness of each subbasin is analyzed based on land use and population density. The results are compared to the Center for Watershed Protection's proposed classification of headwater urban streams as described in "The Importance of Imperviousness, The Practice of Watershed Protection: Article 1," by Thomas R. Schueler and Heather K. Holland, 2000.

To provide a basis for stormwater management practices and ordinances to protect channel morphology, the Center for Watershed Protection's recommendation of 24-hour extended detention of the one-year 24-hour storm event will be considered.

Watershed Description

The 195 square mile Pinnebog River watershed (Figures 2 and 3) outlets to Lake Huron near Port Austin and is located in Huron County.

According to Rosgen, 1996, "generally, channel gradient decreases in a downstream direction with commensurate increases in streamflow and a corresponding decrease in sediment size." The Pinnebog River's profile, Figure 4, steeper in the headwaters and flatter toward the mouth, exemplifies this profile. A streams ability to move sediment, both size and quantity, is directly related the stream's slope and flow. Thus the steeper upstream reaches generally move larger material, such as stones and pebbles, and the flatter downstream portion of the river tends to accumulate sediment.

This study divides the watershed into 13 subbasins, as shown in Figure 5. The watershed was modeled using HEC-HMS 3.0.1 and the runoff curve number technique to calculate surface runoff volumes and flows from subbasins. 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 curve numbers for each subbasin, listed in Appendix A, were calculated using Geographic Information Systems (GIS) technology from the digital land use and soil data shown in Figures 6 through 11. Land use maps based on the MDEQ GIS data for 1800 and 1978 are shown in Figures 6 and 7, respectively. Average residential lot size was assumed to be 1/2 acre. The 1800 land use information is provided at the request of the grantee. The MDEQ Nonpoint Source Program does not expect or recommend that the flow regime calculated from 1800 land use be used as criteria for BMP design or as a goal for watershed managers. The 2005 land use map, Figure 8, is based on HSU's analysis of 2005 aerial photos.

The NRCS soils data for the watershed is shown in Figures 9 through 11. Where the soil is given a dual classification, B/D for example, the soil type was selected based on land use. In these cases, the soil type is specified as D for natural land uses, or the alternate classification (A, B, or C) for developed land uses. The runoff curve numbers calculated from the soil and land use data are listed in Appendix B. The time of concentration for each subbasin, which is the time it takes for water to travel from the hydraulically most distant point in the watershed to the design point, was calculated from the USGS quadrangles. The same time of concentration values were used in all land use scenarios. Storage coefficients were calculated based on GIS-derived ponding adjustment factors.

The design rainfall value used in this study is 2.14 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.

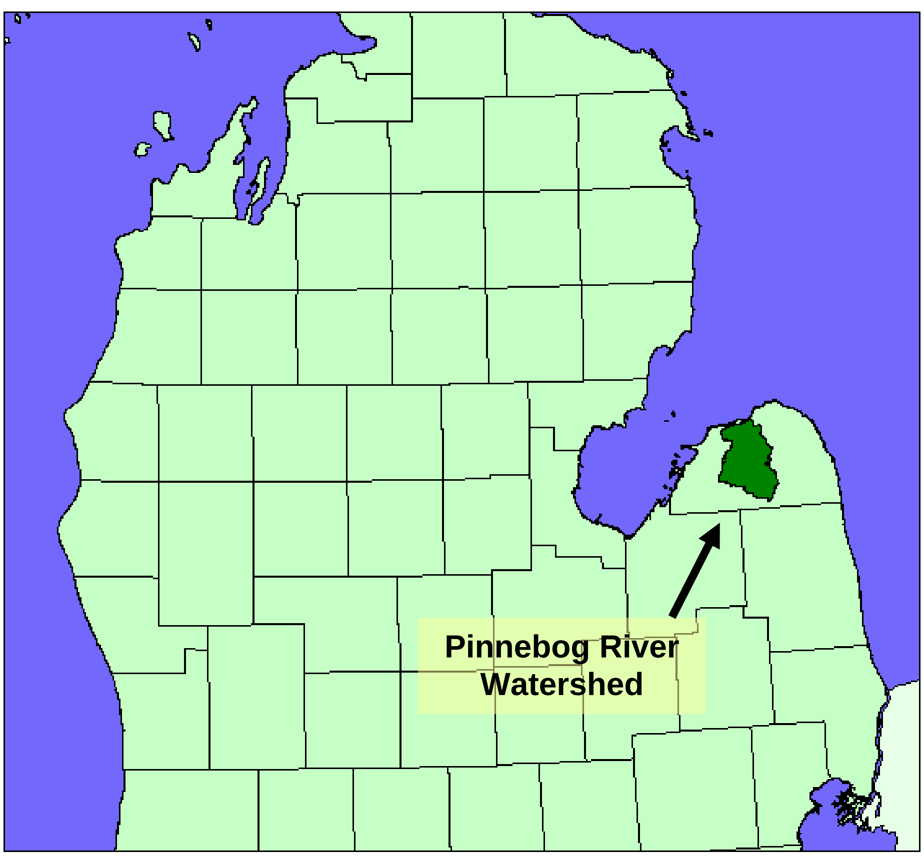


Figure 2: Pinnebog River Watershed Location

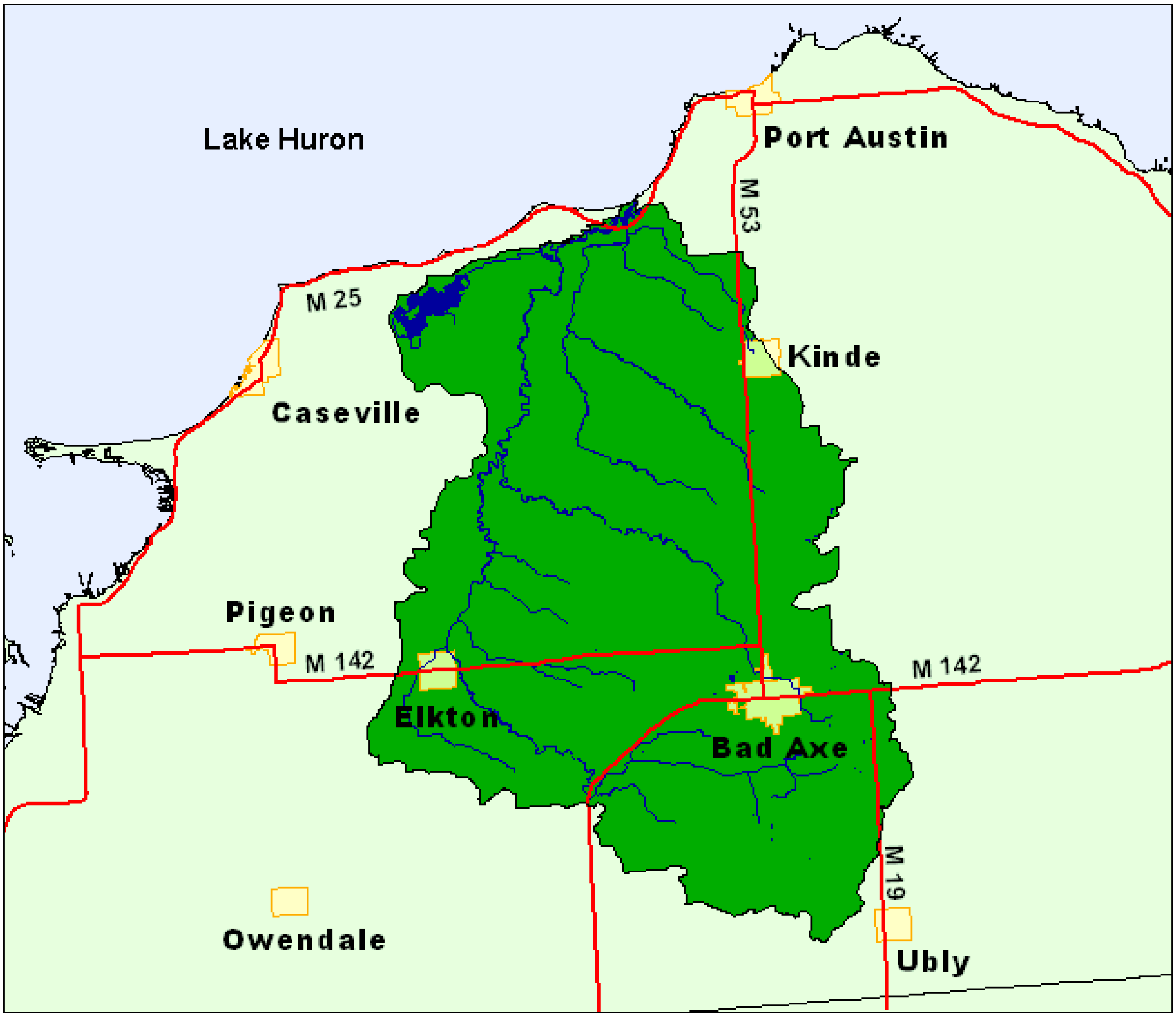


Figure 3: Delineated Pinnebog River Watershed

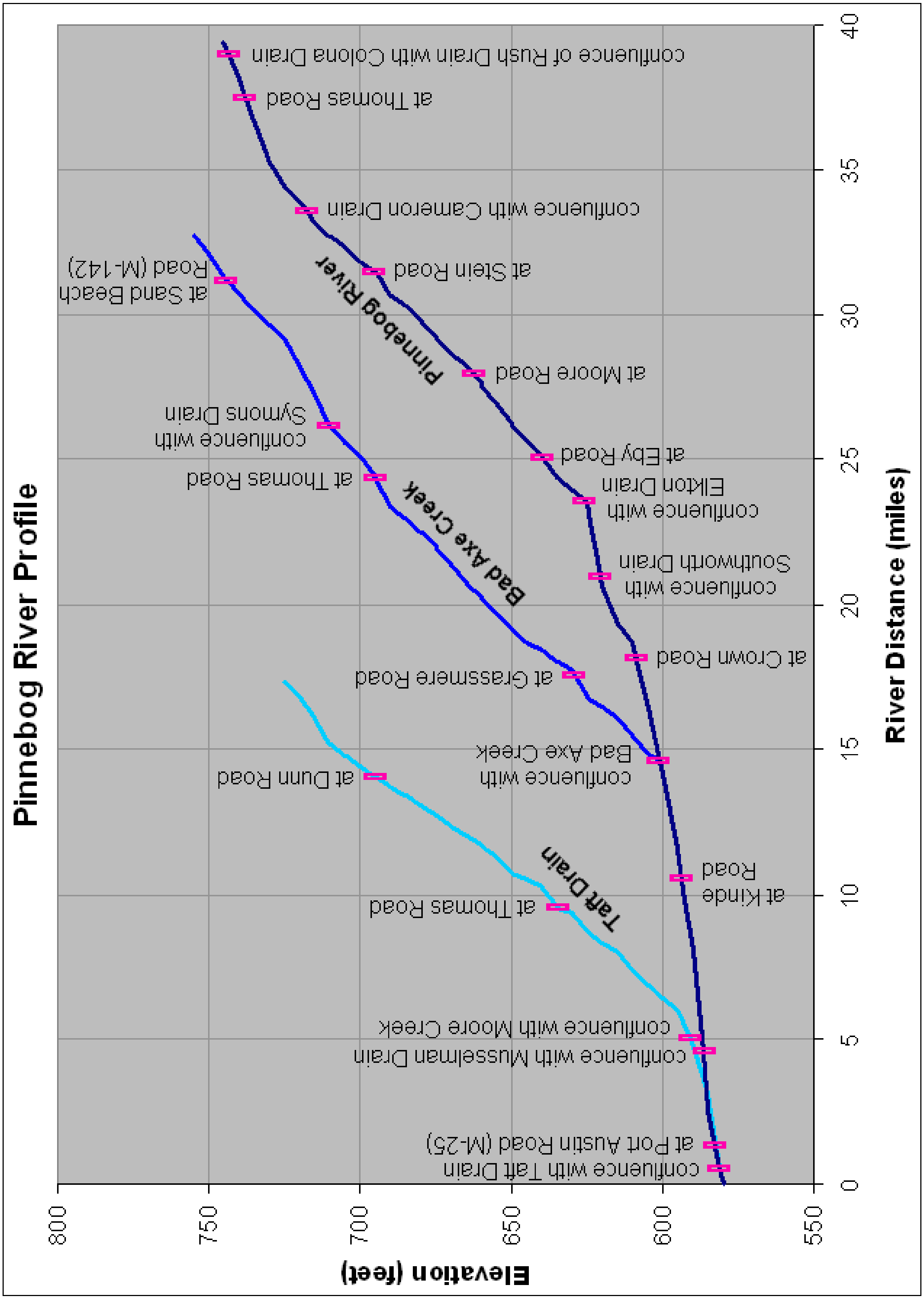


Figure 4: Pinnebog River Profile

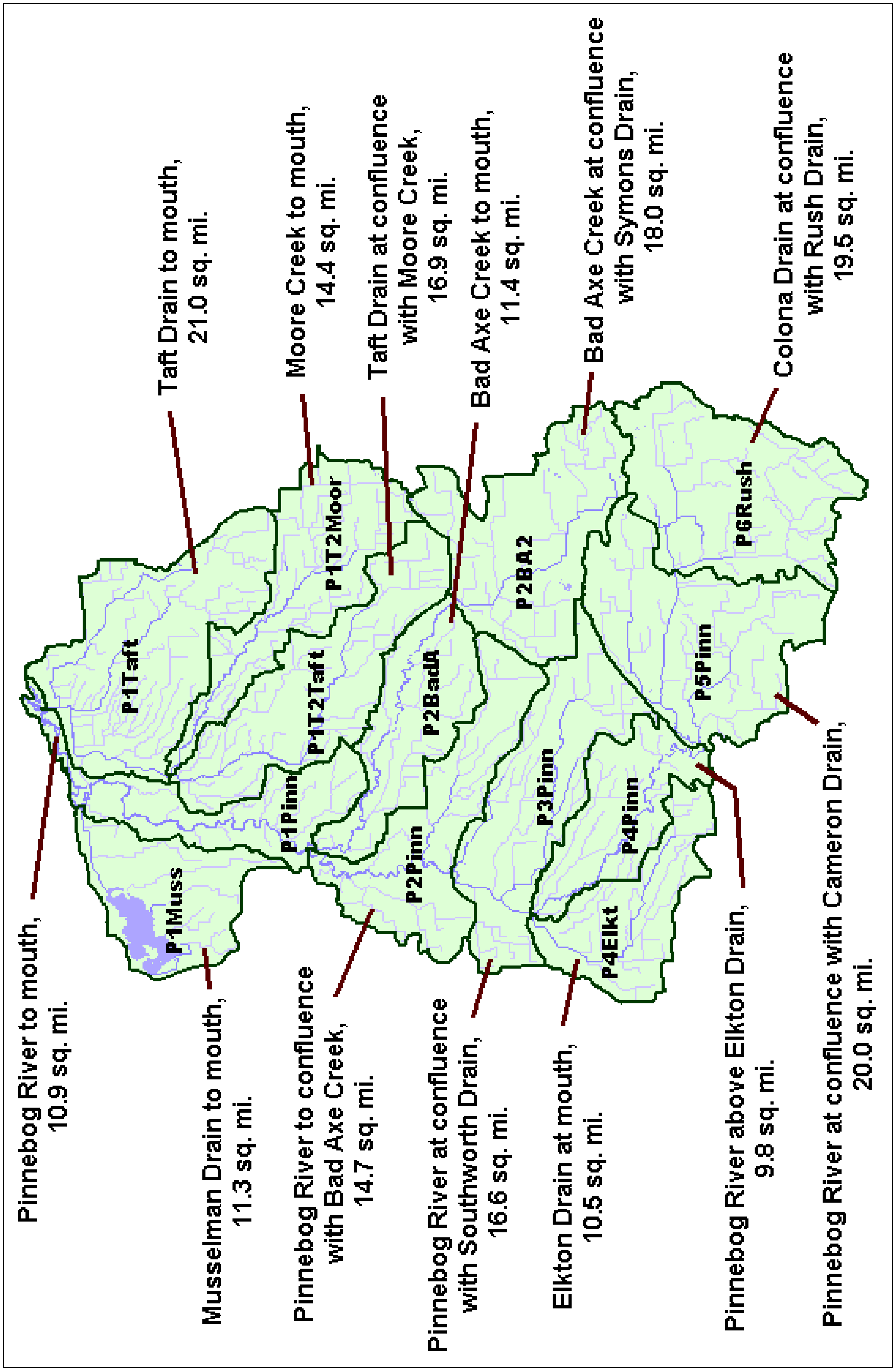


Figure 5: Pinnebog River Subbasin Identification

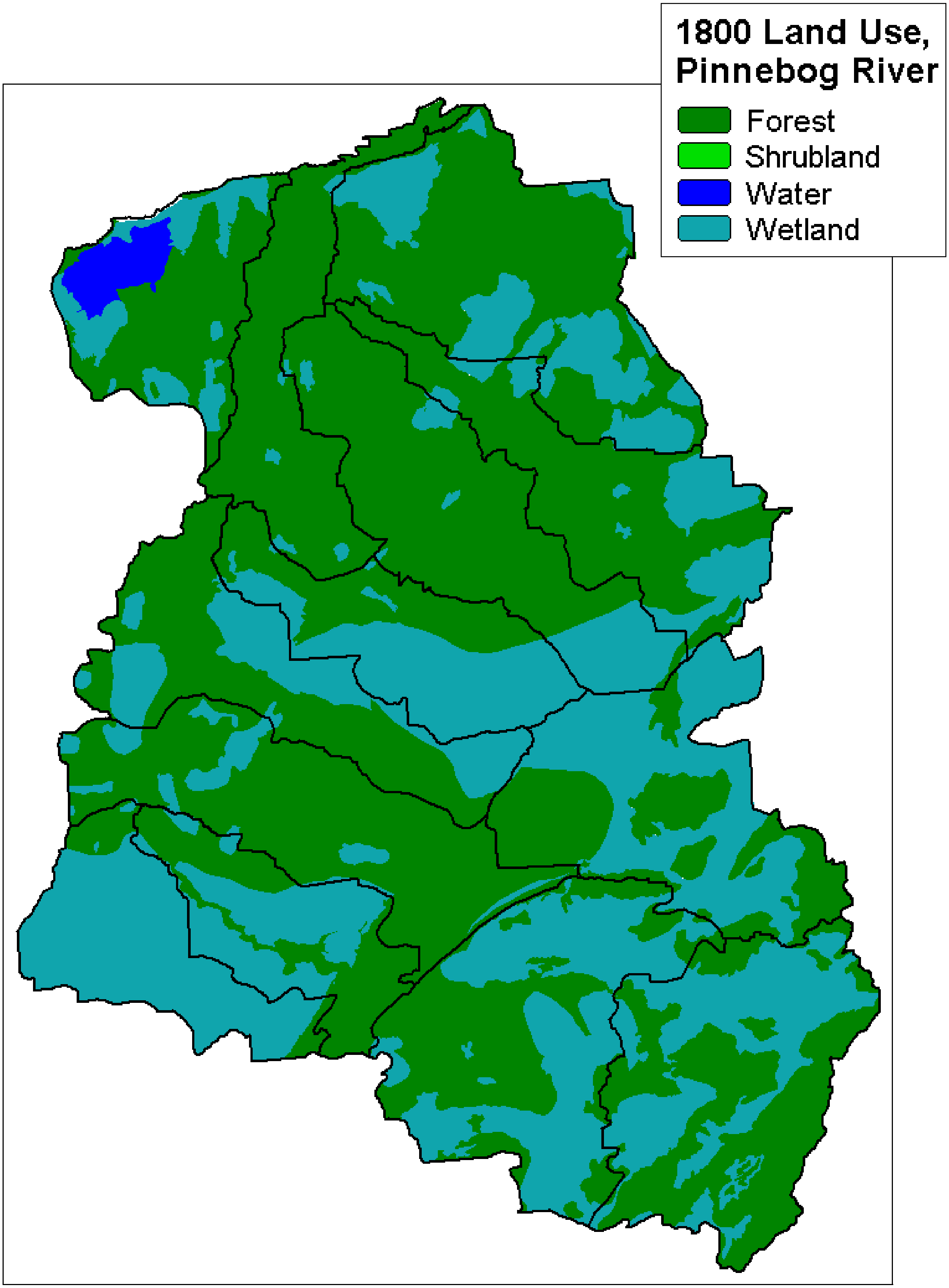


Figure 6: 1800 Land Cover

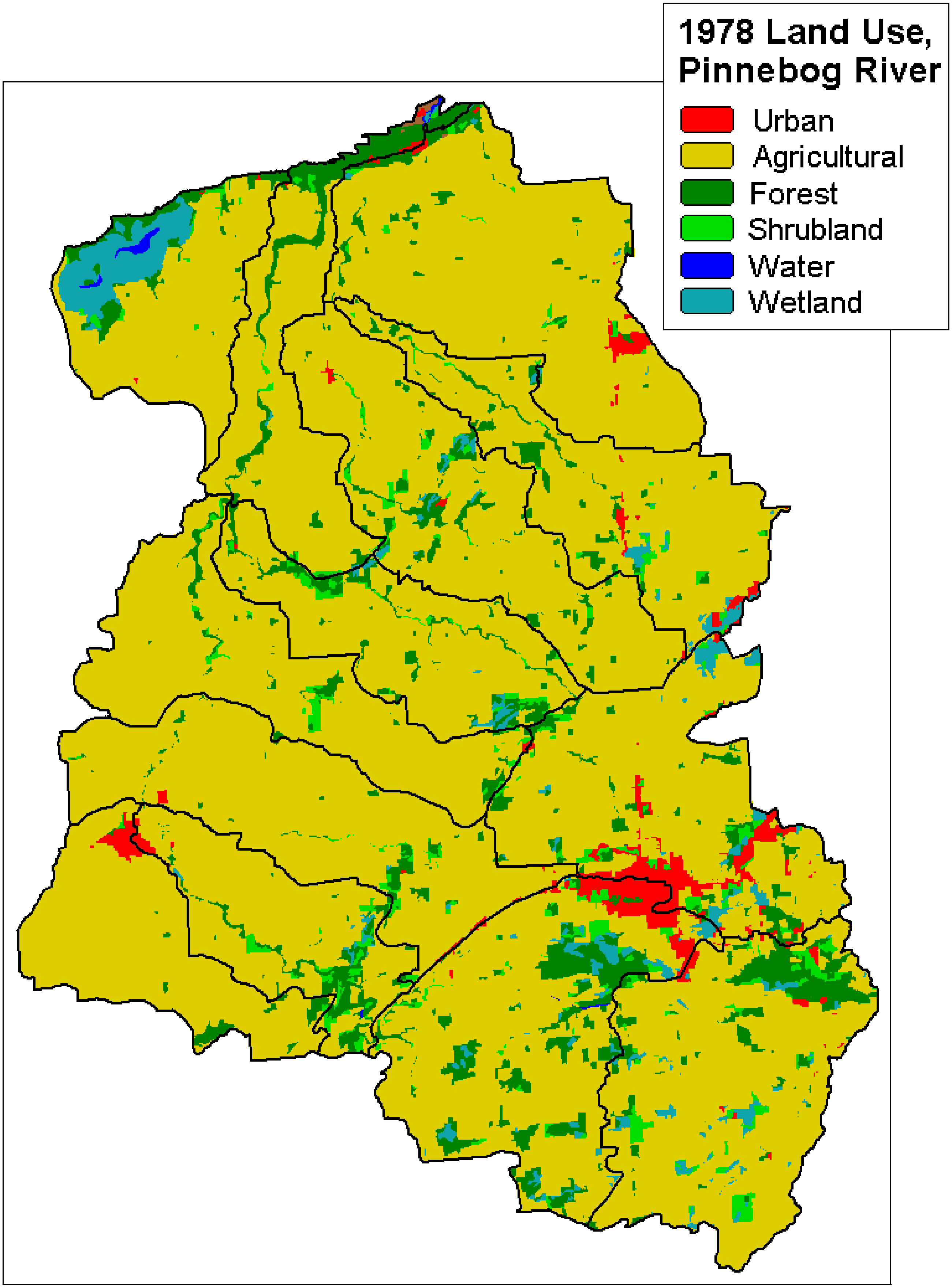


Figure 7: 1978 Land Cover

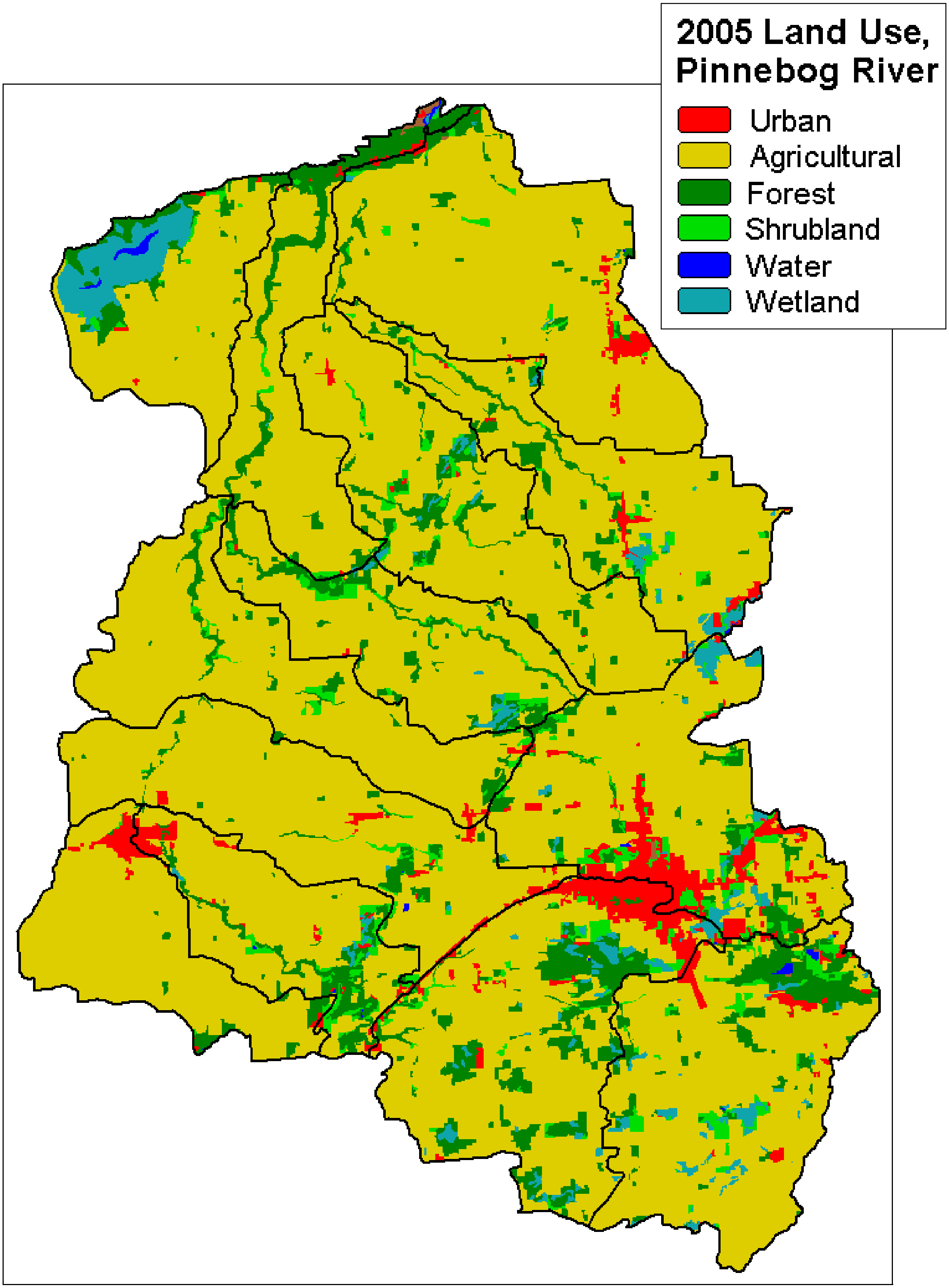


Figure 8: 2005 Land Cover

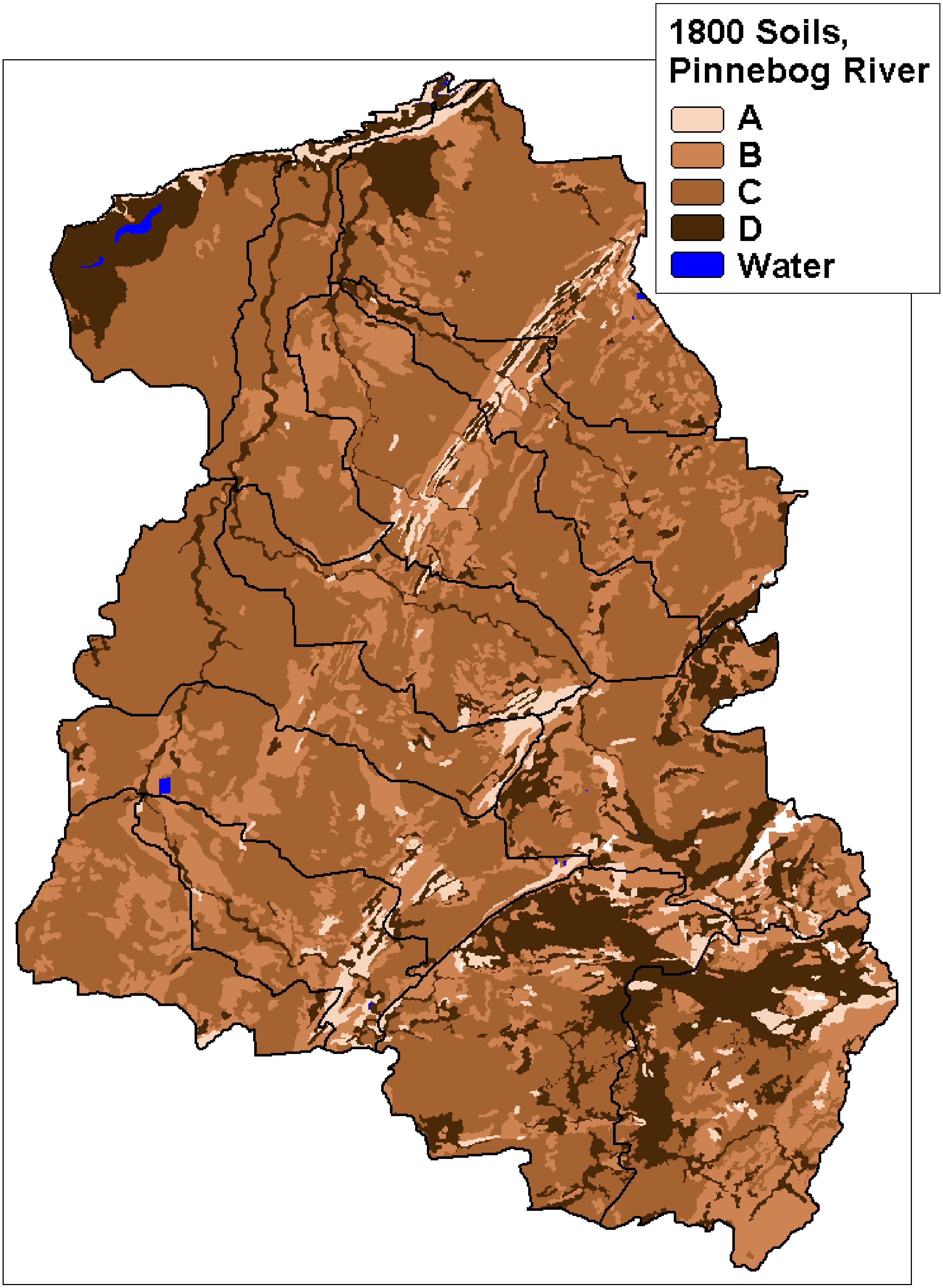


Figure 9: NRCS Soils Data, 1800 Land Cover

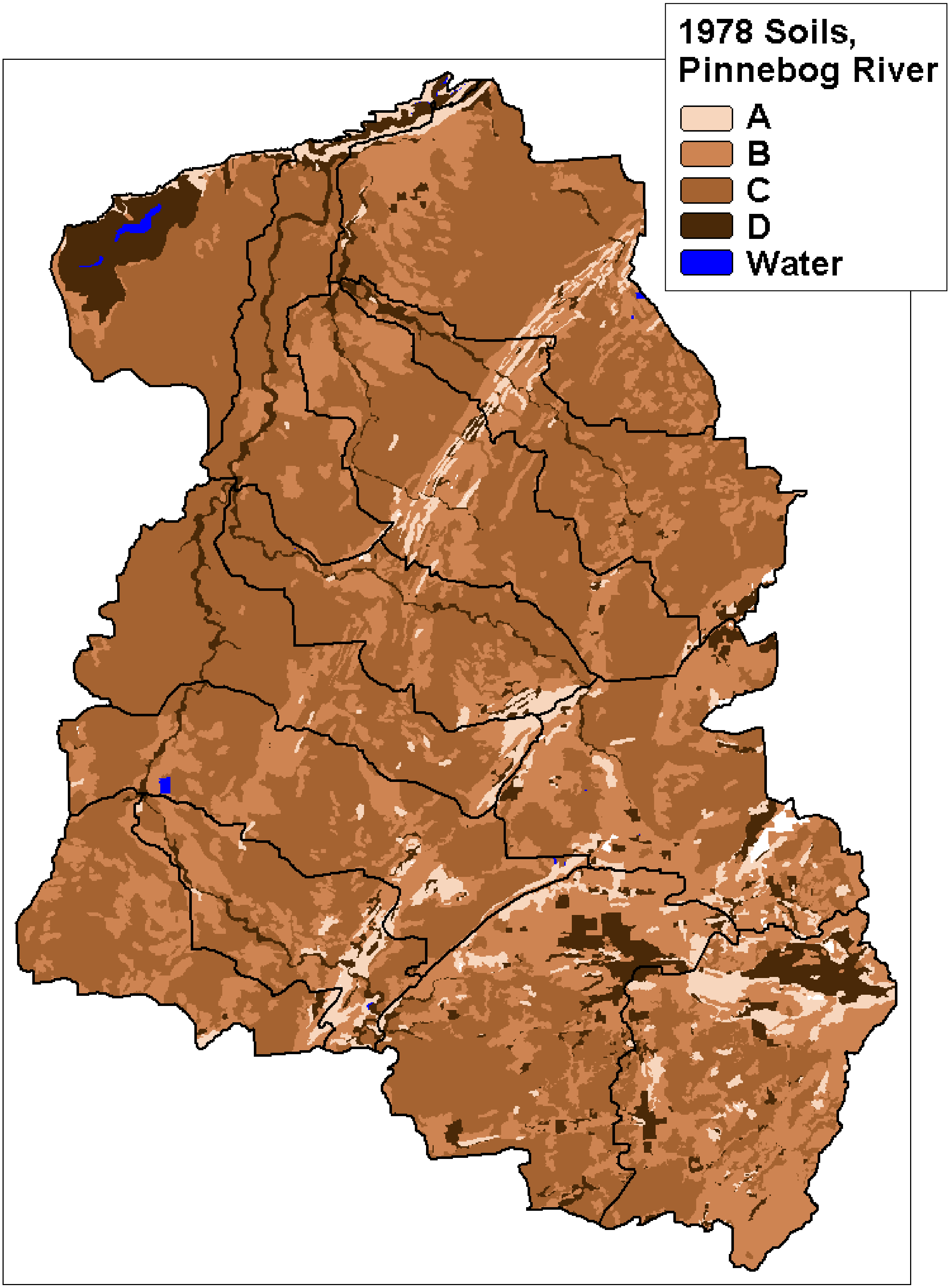


Figure 10: NRCS Soils Data, 1978 Land Cover

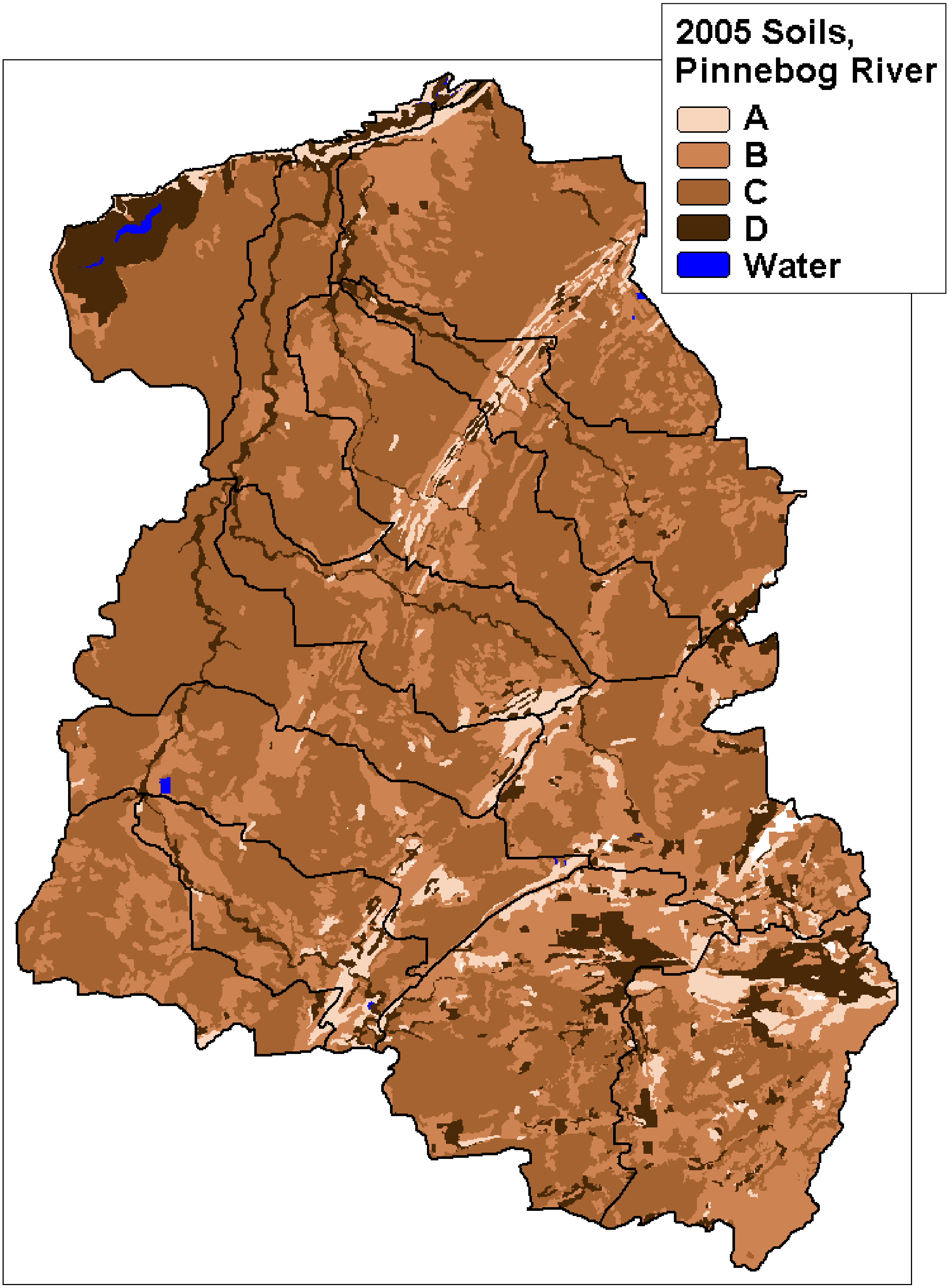


Figure 11: NRCS Soils Data, 2005 Land Cover

Hydrologic Analysis

General Results

Hydrologic modeling shows significant increases in runoff volumes and peak flood flow yields from 1800 to 1978. The increases are due to changes in land use and loss of runoff storage. The increases cause channel erosion and higher flood levels. From 1978 to 2005, the hydrologic modeling demonstrates that the land use changes have had no quantifiable effect on streamflow at the scale of this study, 10 to 20 square mile drainage areas. This report does not evaluate smaller streams within a subbasin.

Channels are shaped primarily by flows that recur fairly frequently; every one to two years in a stable stream. Bankfull flows are the channel-forming flows in a stable stream. Increases in runoff volumes and peak flows 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. Increases in runoff volumes and peak flows from less frequent storms, the 4 percent chance (25-year) storm, for example, aggravate flooding.

Although most of the modeled land use and storage changes are not recent, the rivers and streams may still be adapting to them. A stream can take 50 years or more to adapt to flow changes (Schueler, 2000, *Dynamics of Urban Stream Channel Enlargement*).

Future hydrologic changes can continue to 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

Runoff Volume

One aspect of this study compares hydrologic characteristics of Pinnebog River watershed subbasins that are less than approximately 20 square miles. Runoff from each subbasin for a standard 50 percent chance 24-hour storm of 2.14 inches is calculated for the 1800, 1978, and 2005 scenarios. This storm was selected because runoff from the 50 percent chance storm can be associated with channel-forming flows. For comparison, the calculated runoff volumes are divided by the drainage areas, as shown in Figures 12 and 13, respectively. The units are acre-inches per acre (volume per area), or simply inches.

Changes in runoff per area from 1800 to 2005 are shown in Figure 14 and tabulated in Table A2 of Appendix A. Changes in runoff per area from 1978 to 2005 are also tabulated in Table A2, but are essentially unchanged. While the results are for a 2.14-inch storm, the trends would be similar for larger storms, although the percentage increases would be less than the 50 percent chance, 24-hour storm.

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

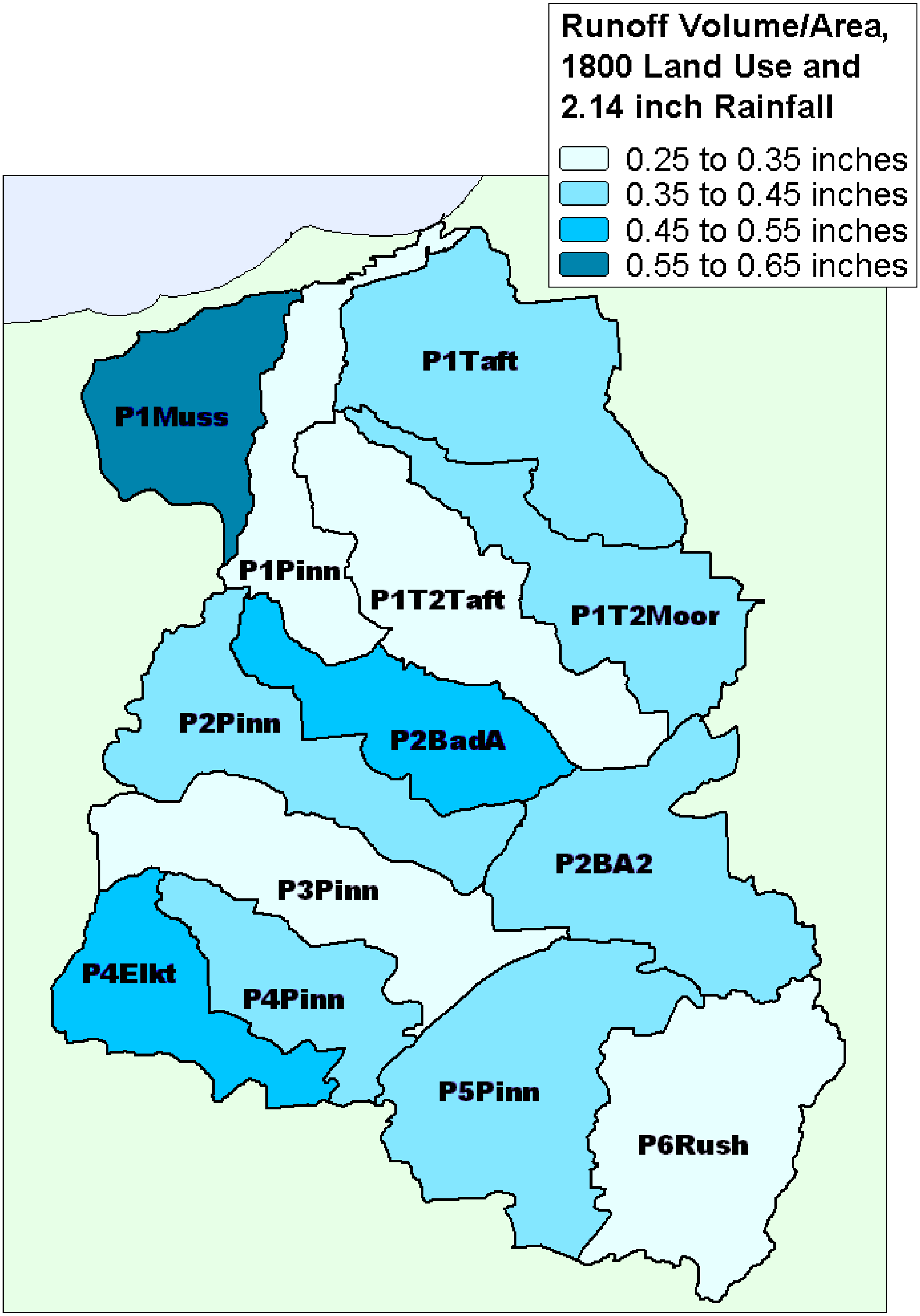


Figure 12: Runoff Volume/Drainage Area, 1800 Land Use

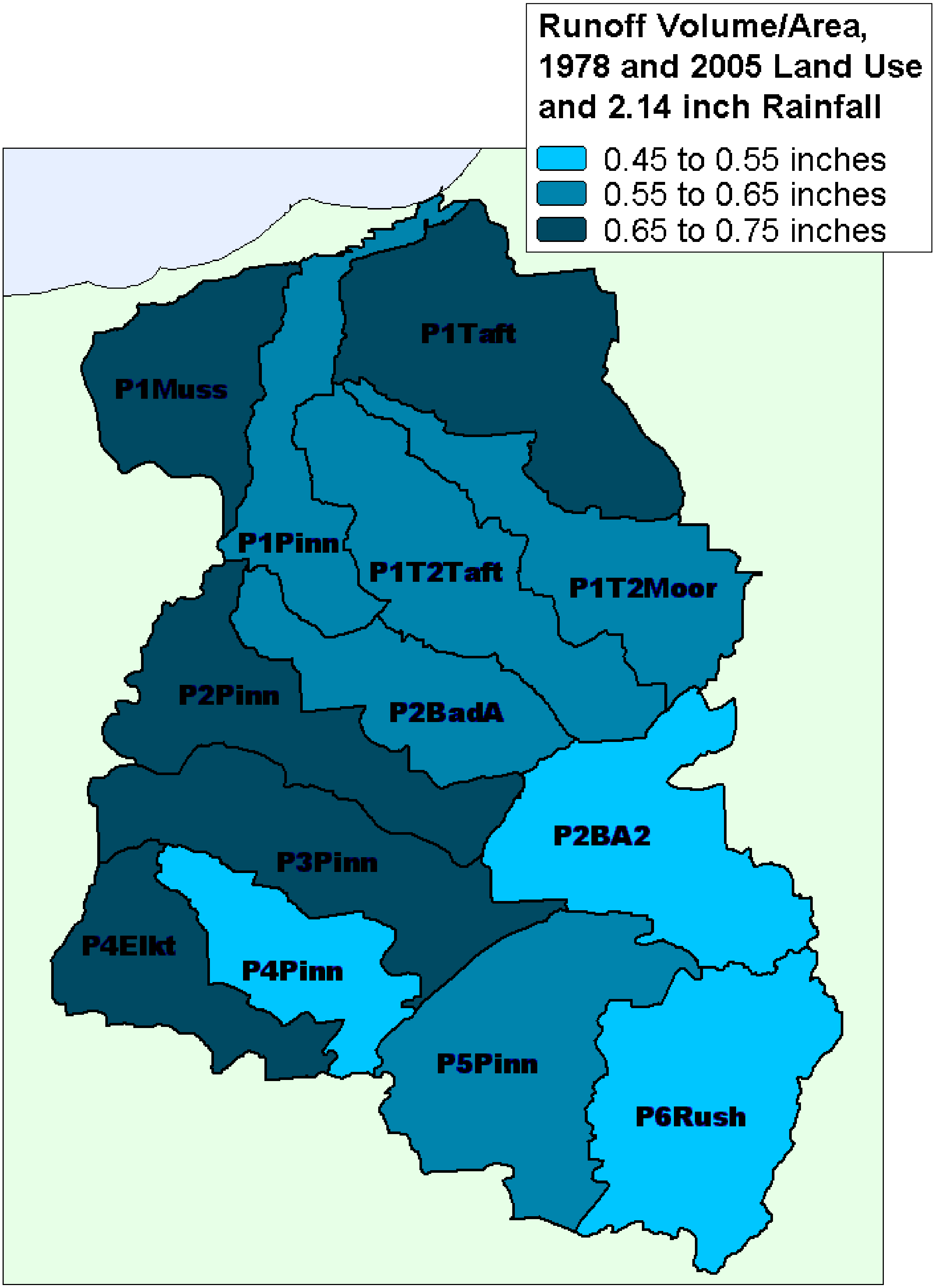


Figure 13: Runoff Volume/Drainage Area, 1978 and 2005 Land Use

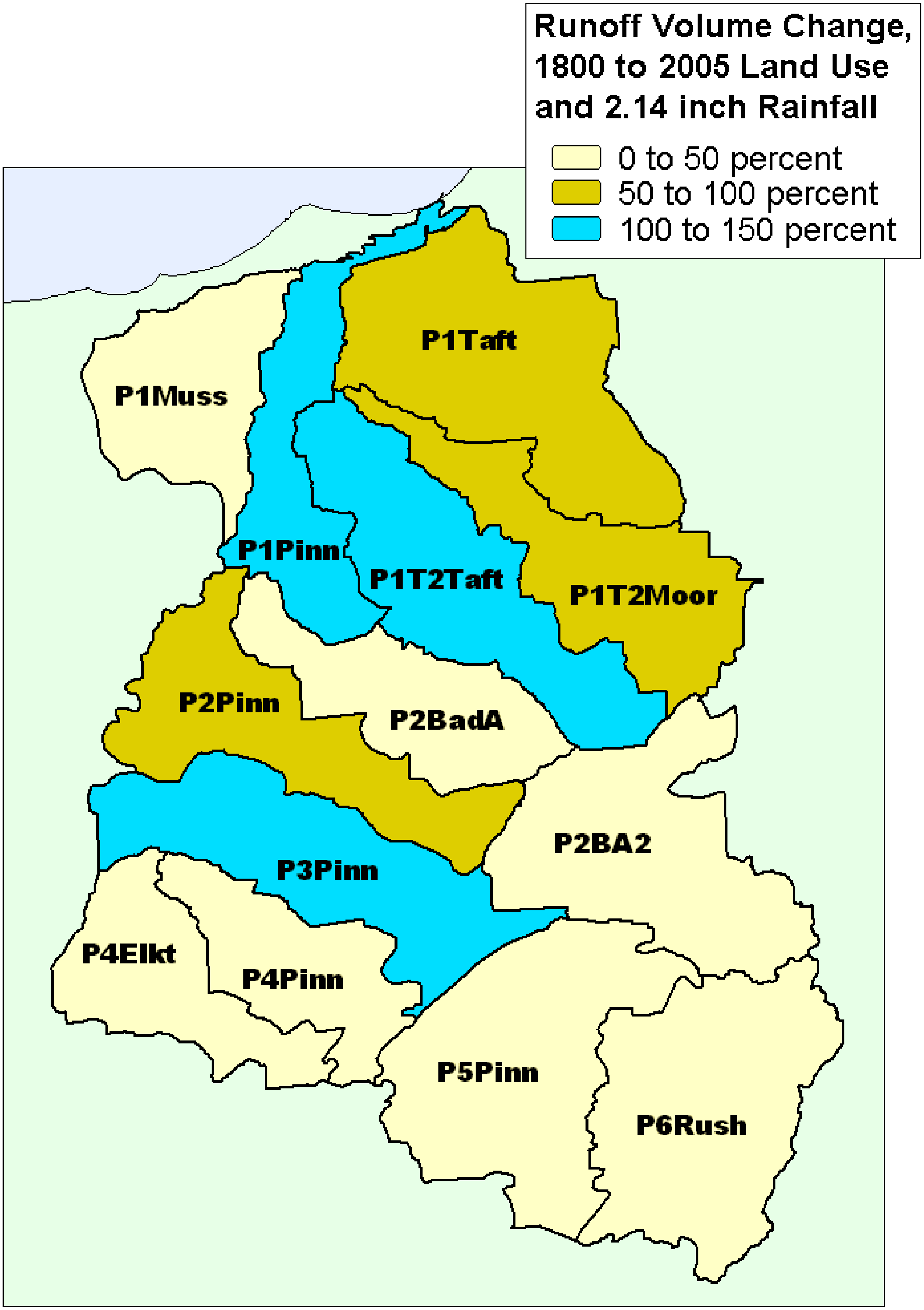


Figure 14: Change in Runoff Volume/Drainage Area, 1800 to 2005 Land Use

Peak Flood Flow Yield Analysis

The preceding runoff analysis accounts only for land use and soils. Peak flood flow yield analysis adds runoff storage, or ponding, and the time it takes for runoff to flow through the subbasin's drainage network. Peak flood flow yield, which is the peak flow divided by the drainage area, is therefore a more complete measure of hydrologic responsiveness. To ensure that yield values are comparable, subbasins are similarly sized, and a confidence range is provided based on the drainage area ratio equation used by MDEQ's Hydrologic Studies Unit. The equation is $Q_2 = Q_1*(A_2/A_1)^{0.89}$. The confidence range adjusts each yield based on the smallest and largest subbasins in the study.

Graphs of the peak flood flow yields and confidence intervals for each subbasin for the 1800, 1978, and 2005 scenarios are shown in Figure 15. Figures 16 and 17 are maps of the same data using a consistent legend, in cfs/acre, to group the data.

A higher peak flood flow yield indicates that the subbasin has comparatively more runoff due to the combination of soils, land uses, storage, and drainage efficiency, and is contributing a proportionately higher flow to the receiving streams.

Peak flood flow yield changes from 1800 to 2005 are shown in Figure 18 and tabulated in Table A3 of Appendix A. Yield changes from 1978 to 2005 are also tabulated in Table A3, but are essentially unchanged. As with the runoff analysis, even though the results are based on one specific storm, the overall trends would be similar for larger storms also. Since all scenarios use the same time of concentration values, changes in peak flood flow yields do not reflect any changes in drainage efficiency that may have occurred.

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

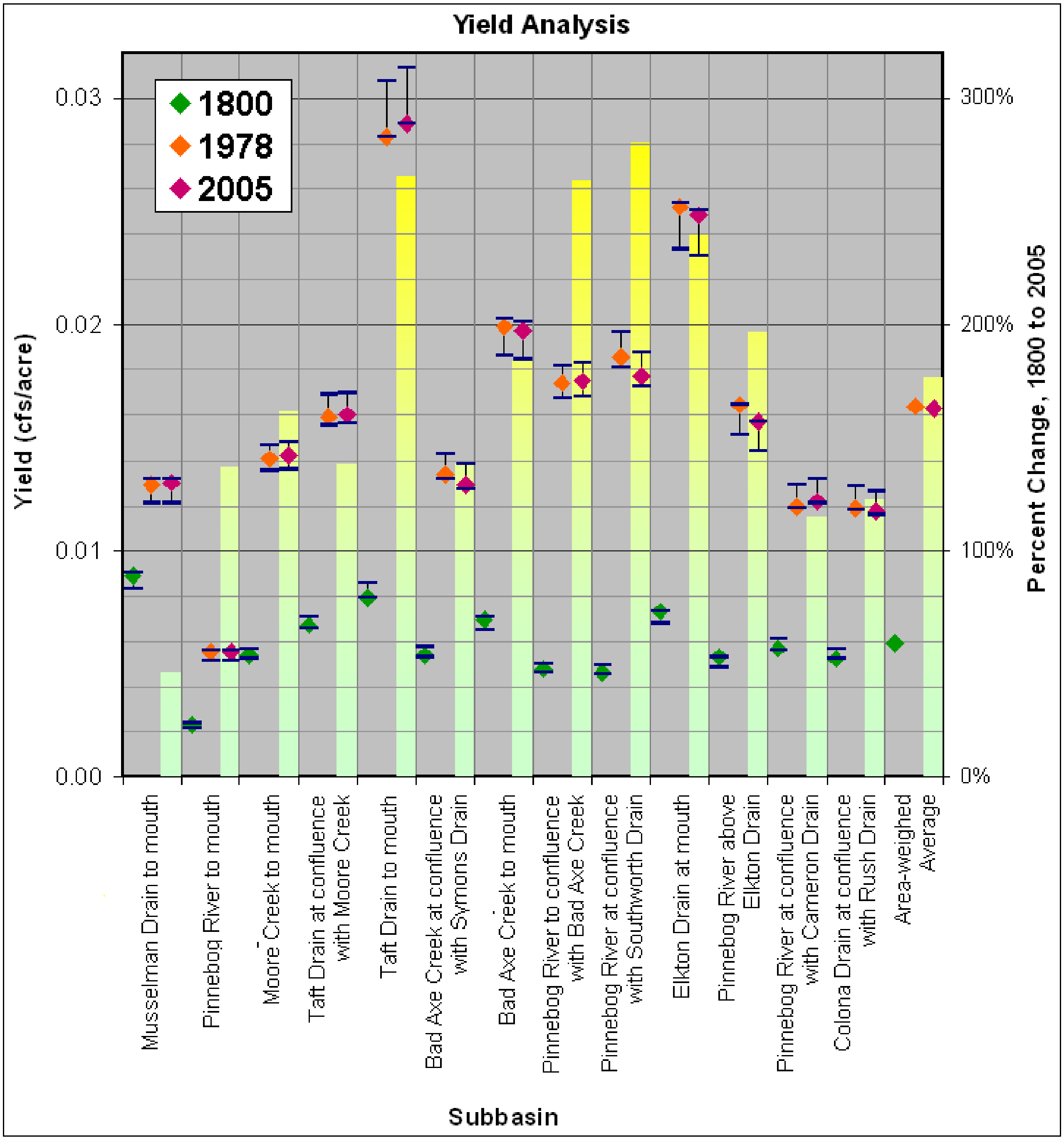


Figure 15: Peak Flood Flow Yield Analysis Chart per subbasin, with percent change from 1800 to 2005

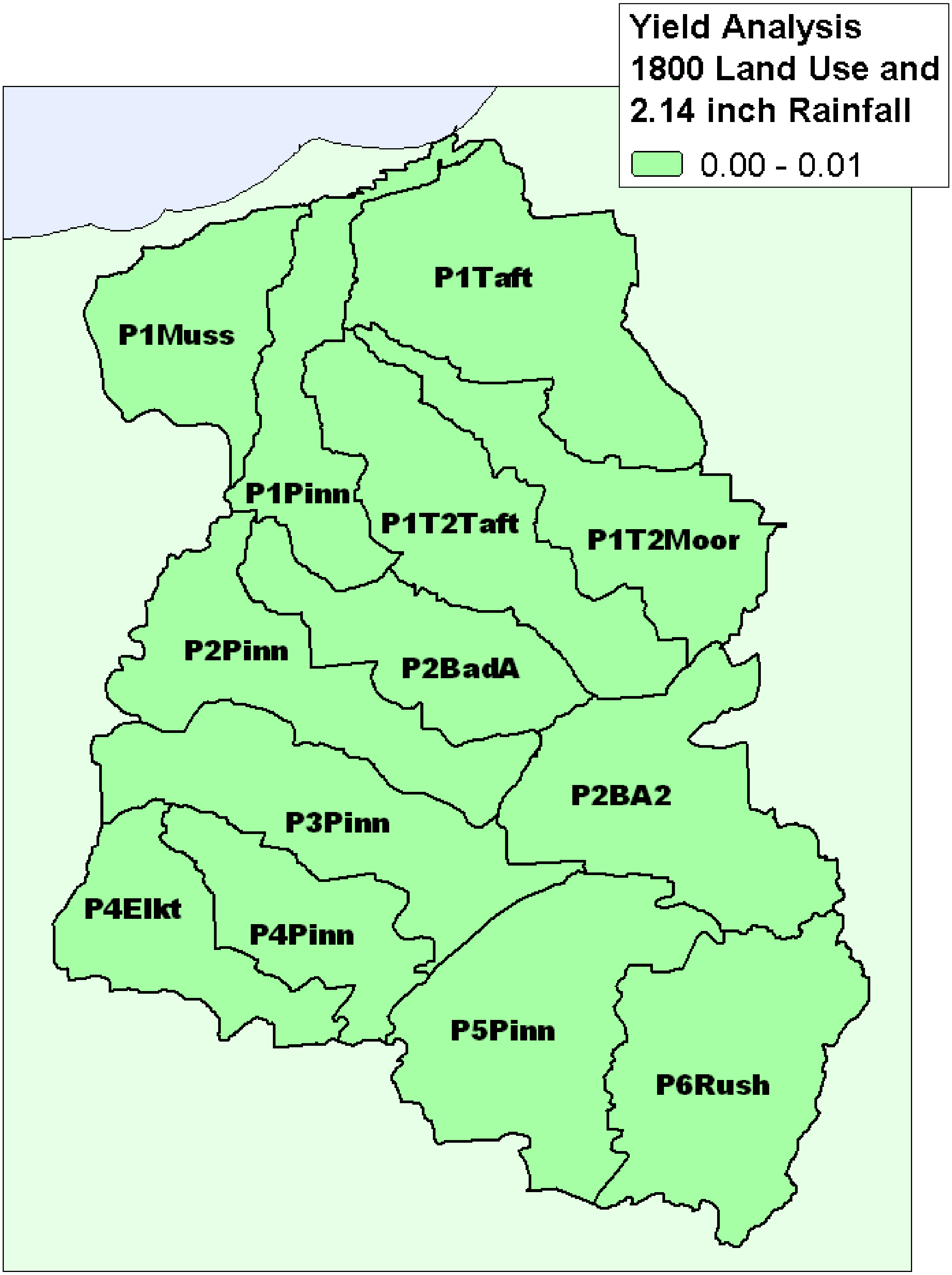


Figure 16: Peak Flood Flow Yield Analysis Map, 1800 Land Use

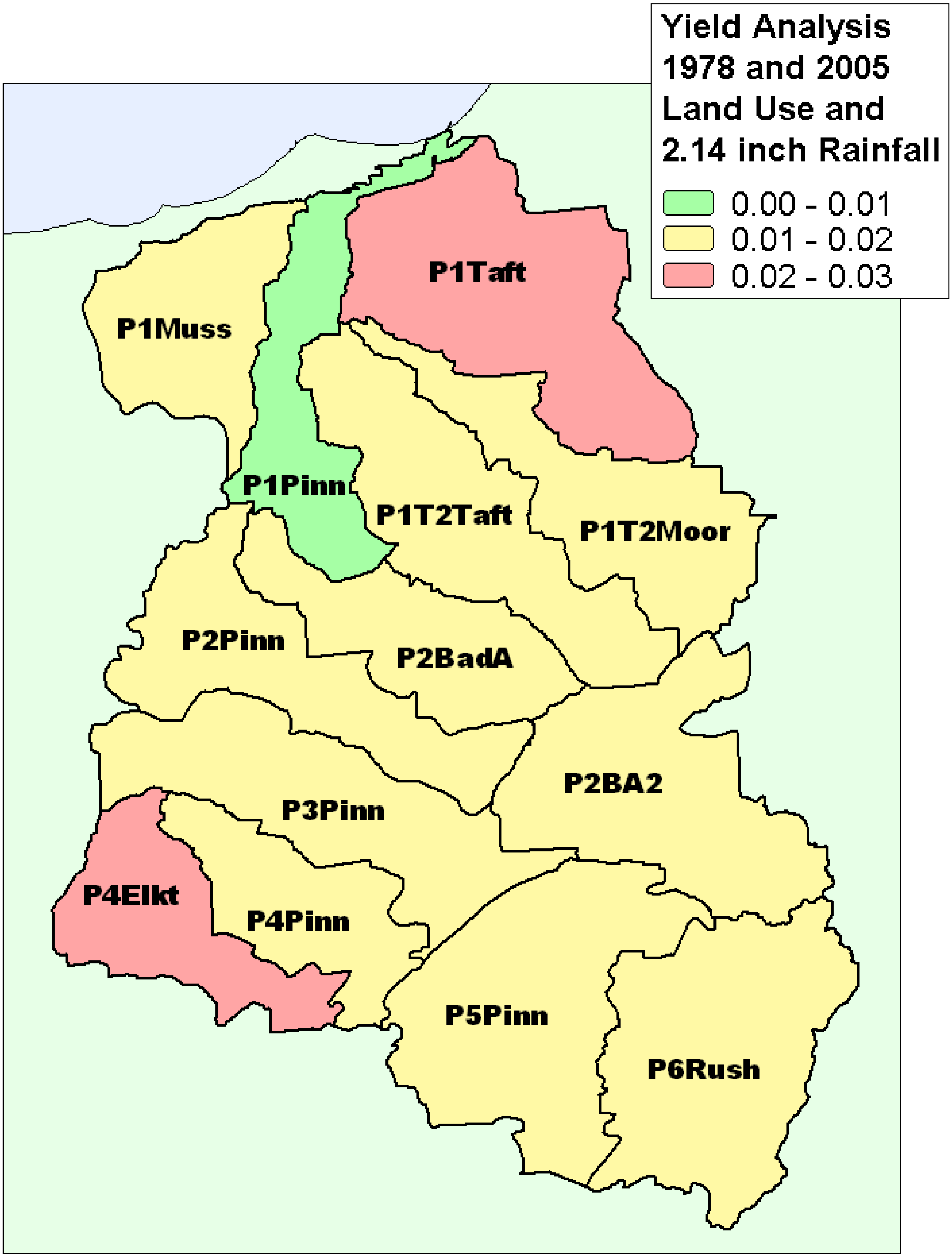


Figure 17: Peak Flood Flow Yields Analysis Map, 1978 and 2005 Land Use

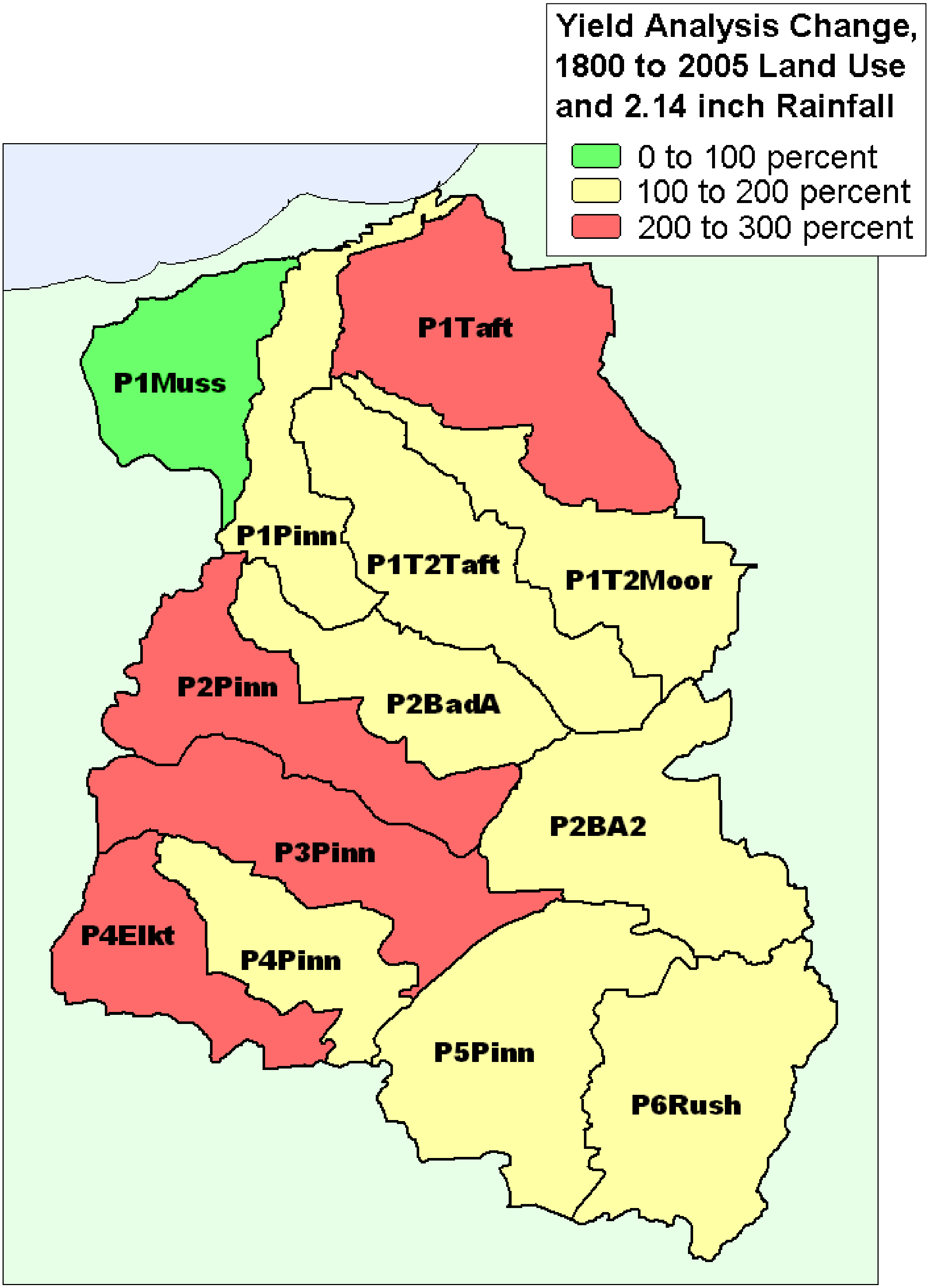


Figure 18: Peak Flood Flow Yields Analysis Map, 1800 to 2005 Land Use

Percent Imperviousness Analysis

Percent imperviousness can be compared to the Center for Watershed Protection's proposed classification of headwater urban streams, excerpted in Table 1 and detailed in *The Importance of Imperviousness, The Practice of Watershed Protection* (Schueler and Holland, 2000).

Table 1: 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 2005 land use GIS data, Figure 8, 1995 Topologically Integrated Geographic Encoding and Referencing (TIGER) population density data, Figure 19, and the Impervious Surface Analysis Tool (ISAT) extension. The population data is from the Michigan Geographic Data Library, www.mcgi.state.mi.us/mgdl/?action=thm, located under Political Features. The population data was converted to 50 meter grids. ISAT was provided by the National Oceanic and Atmospheric Administration (NOAA), www.csc.noaa.gov/crs/cwq/isat.html. ISAT computed the percent imperviousness according to Table 2. The imperviousness values for residential, commercial, and industrial are from the NRCS (NRCS, 1986).

The results, shown in Figure 20 and tabulated in Table A4 of Appendix A, indicate that all subbasins are at less than the 10 percent impervious threshold, at this scale of analysis. Within a subbasin, however, there may be streams with smaller drainage areas that exceed the 10 or 25 percent impervious thresholds for impacted or non-supporting streams. Two examples are Bad Axe and Colfax Drains, Figures 21 through 24, each of which receives runoff from urbanized areas in and near Bad Axe. From 1978 to 2005, urban and natural area land uses increased in both watersheds, while agricultural and wetland land uses decreased, as shown in Table 3. At Pigeon Road, the Bad Axe Drain receives runoff from a 7.9 square mile area and has a calculated imperviousness of 11 percent. At Bad Axe Road, Colfax Drain receives runoff from a 0.08 square mile area and has a calculated imperviousness of 29 percent. With proper planning and BMP selection, the negative impacts associated with the increased imperviousness can be mitigated.

Table 2: Imperviousness Table for ISAT Analysis

Class	Description	Assigned Imperviousness (percent) by Population Density (people per square mile)		
		Less than 250	250-1000	Over 1000
1	Residential	25	38	65
2	Commercial	85	85	85
3	Industrial	72	72	72
4	Road, Utilities	95	95	95
5	Gravel Pits	0	0	0
6	Outdoor Recreation	0	0	0
7	Cropland	1	1	1
8	Orchard	1	1	1
9	Pasture	1	1	1
10	Openland	0	0	0
11	Forests	0	0	0
12	Open Water	0	0	0
13	Wetland	0	0	0
14	Bare Soil	0	0	0
15	Exposed Rock	0	0	0

Table 3: Land Use Table for Example Urban Headwater Streams

	Land Use Area (acres)		Land Use Change	
	1978	2005	Acres	Percent
Colfax Drain to Bad Axe Road				
Urban	150	213	63	42%
Agricultural	163	100	-63	-39%
Natural Areas	30	44	13	43%
Wetland/Water	67	54	-13	-19%
Bad Axe Drain to Pigeon Road				
Urban	929	1244	315	34%
Agricultural	3209	2666	-543	-17%
Natural Areas	718	976	259	36%
Wetland/Water	220	190	-30	-14%

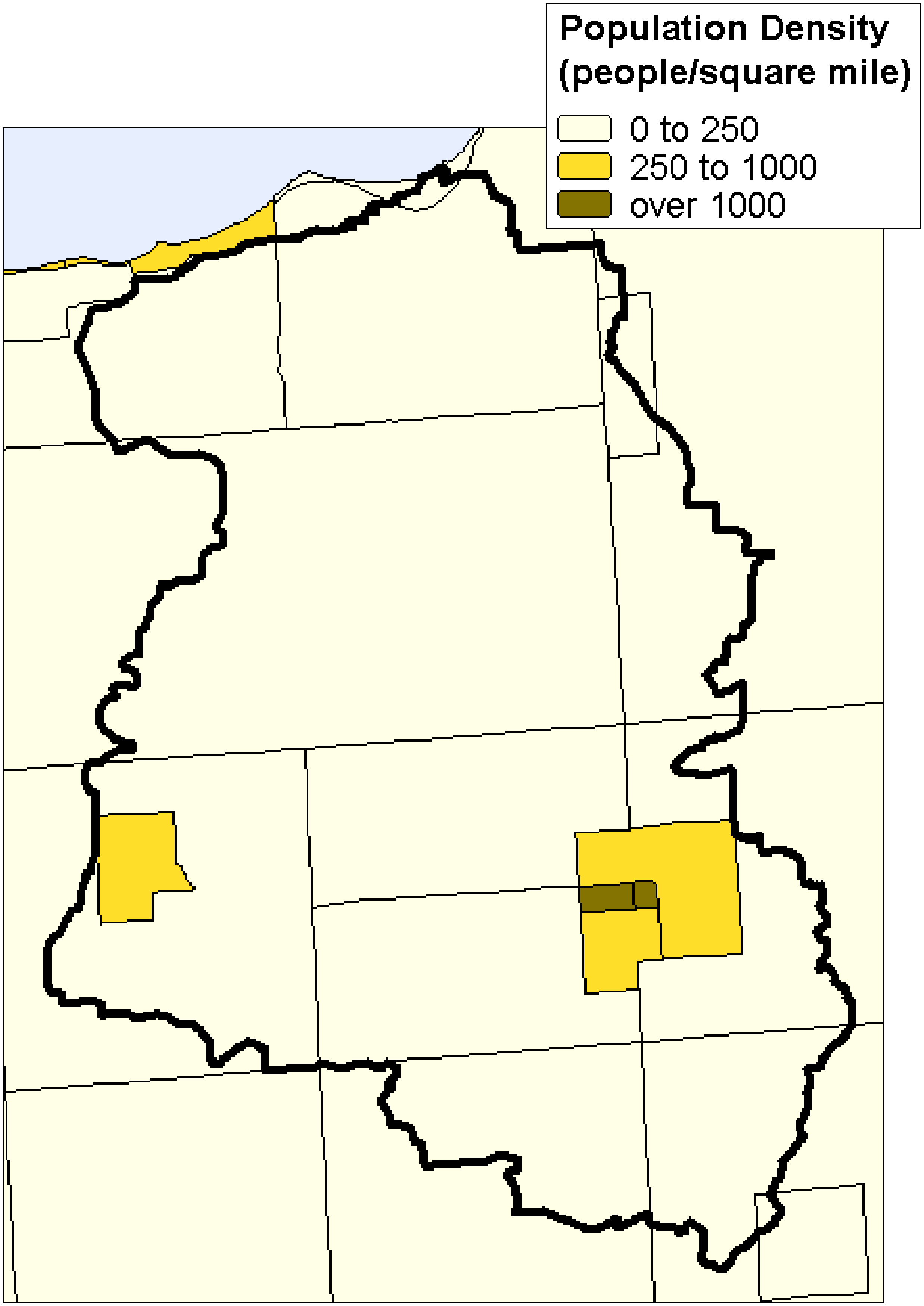


Figure 19: Population Density, 1995 TIGER Census Data

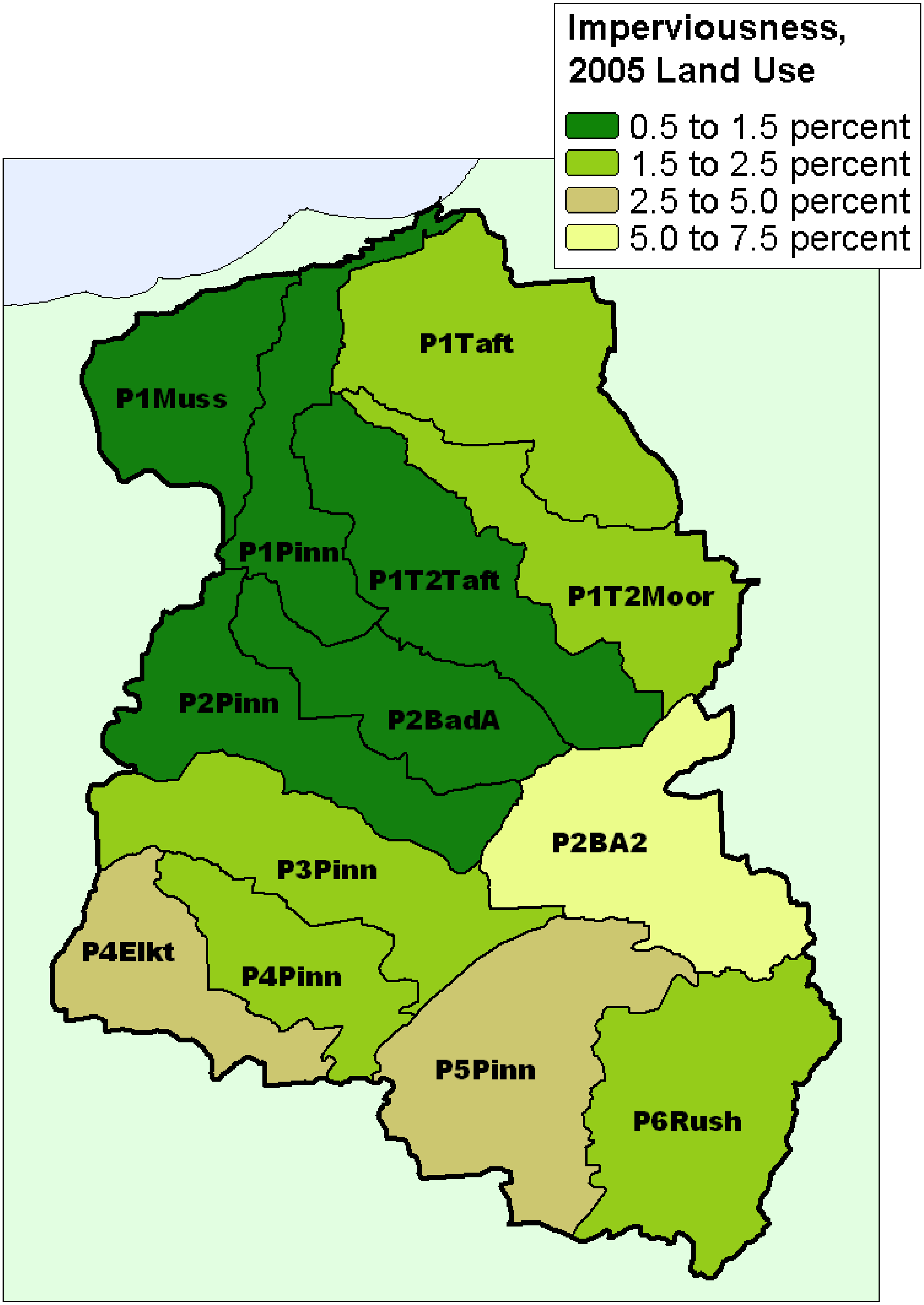


Figure 20: Percent Imperviousness, 2005 Land Use

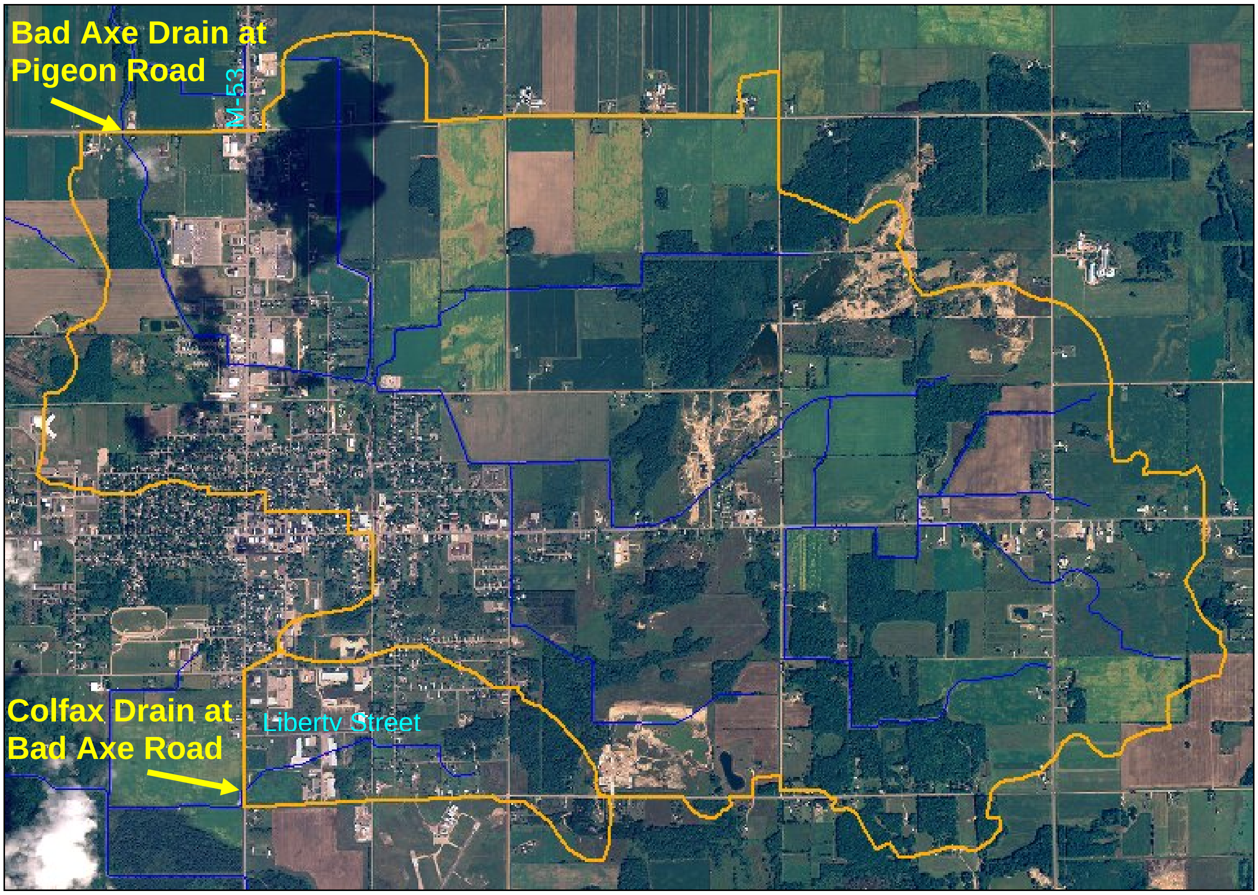


Figure 21: Examples of urban headwater streams, 2005 aerial photo


Figure 22: Bad Axe Drain at M-53 (Van Dyke Road)

Figure 23: An urbanized area of the Bad Axe Drain watershed

Figure 24: Colfax Drain along Liberty Street

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 25. Stream order provides a comparison of the size and potential power of streams.

The Michigan Department of Natural Resources Institute for Fisheries Research and the USGS Great Lakes Gap have nearly completed a three-year EPA-funded study that provides GIS stream order data for Michigan's streams using the 1:100,000 National Hydrography Dataset (NHD). The Pinnebog River results are shown in Figure 26.

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

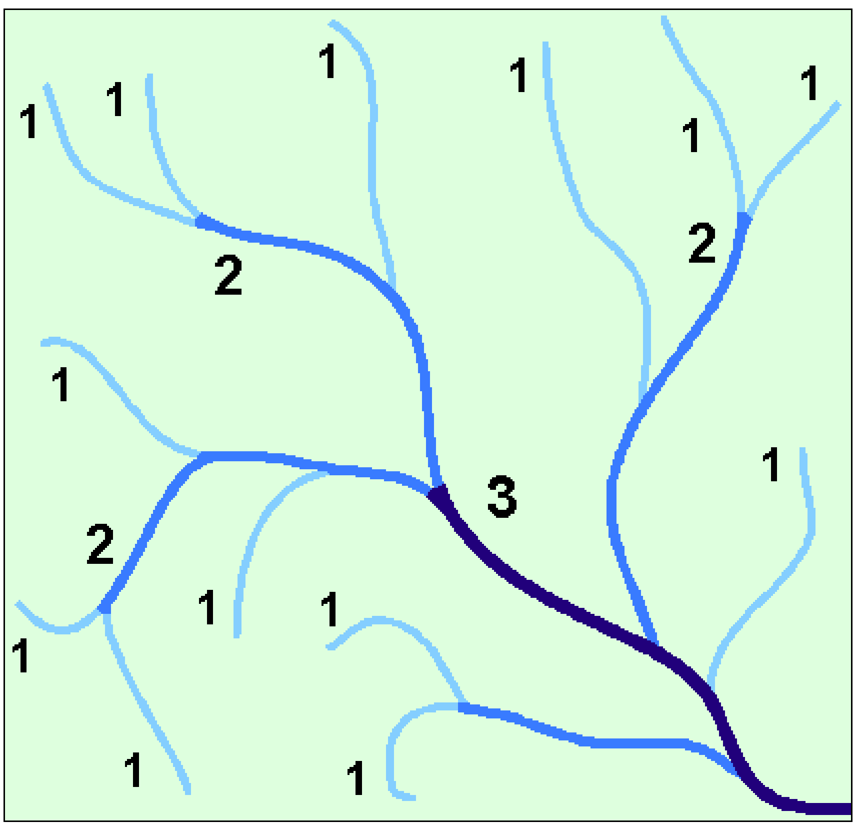


Figure 25: Stream Ordering Procedure

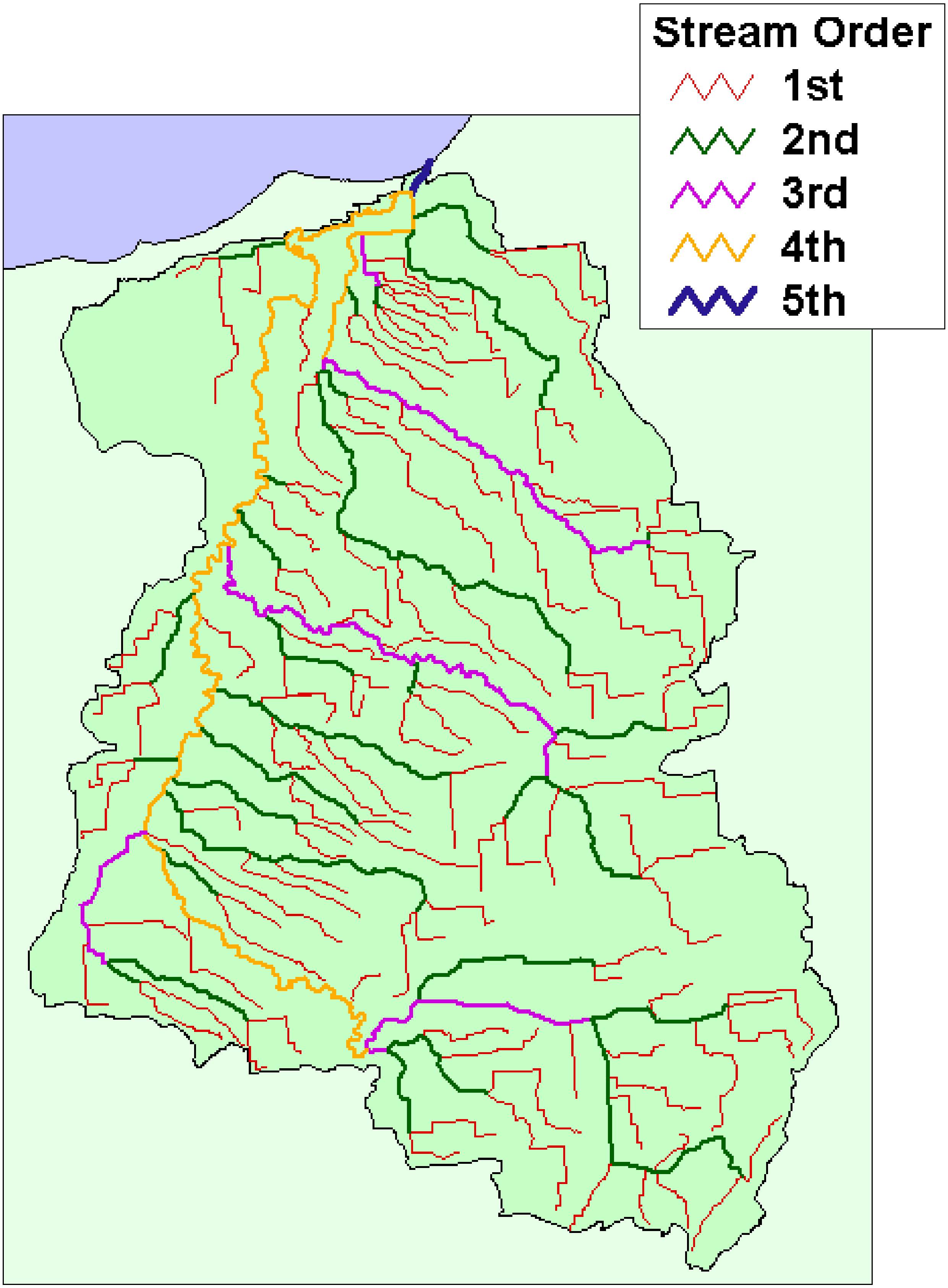


Figure 26: Pinnebog River Watershed Stream Orders

Recommendations

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 27.

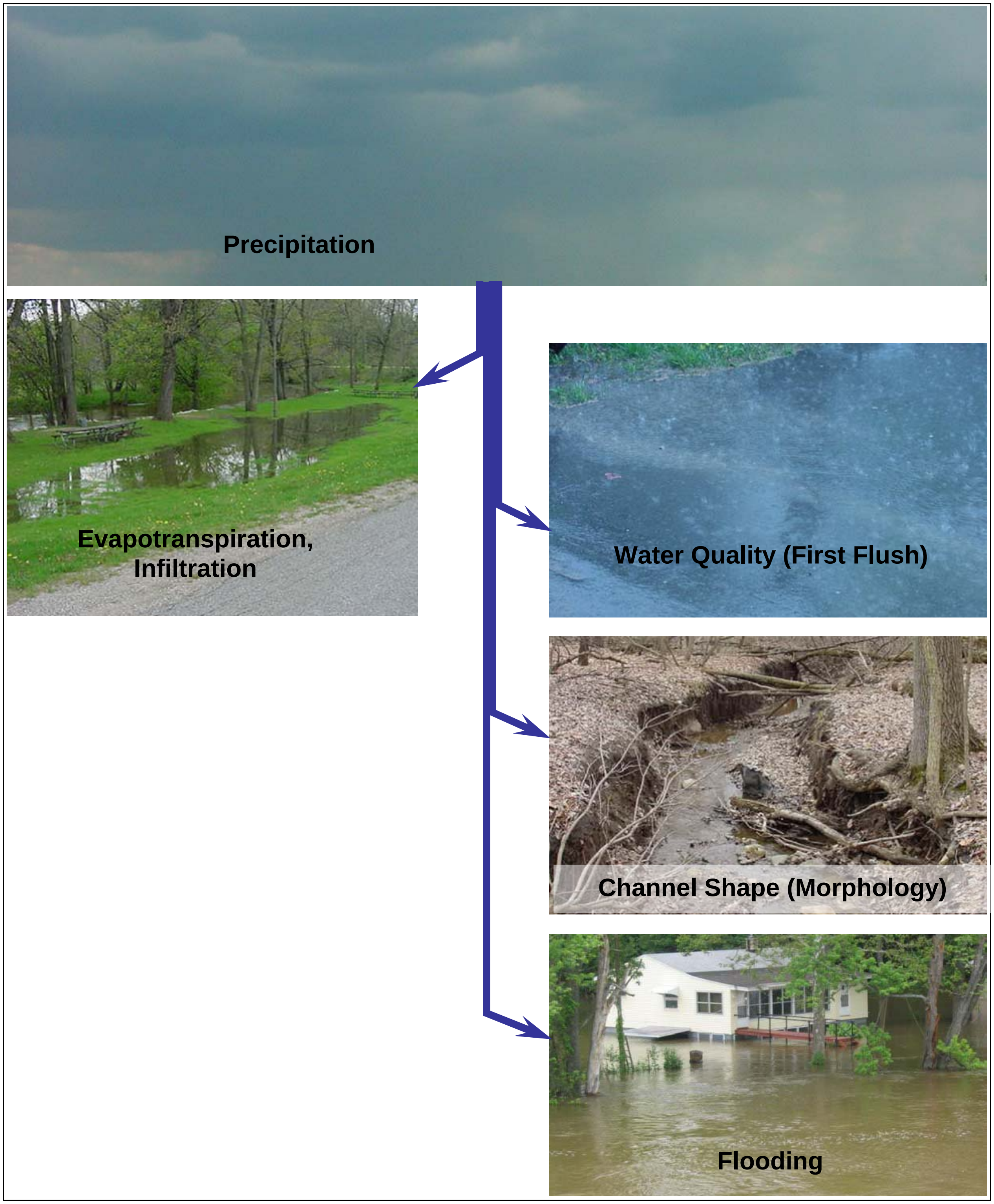


Figure 27: Runoff Impacts

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 28 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 inch 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 Pinnebog River watershed climatic region, the calculated values are 0.87 and 0.92 inches. Additional information is available at http://www.deq.state.mi.us/documents/deq-lwm-hsu-nps-ninety-percent.pdf.

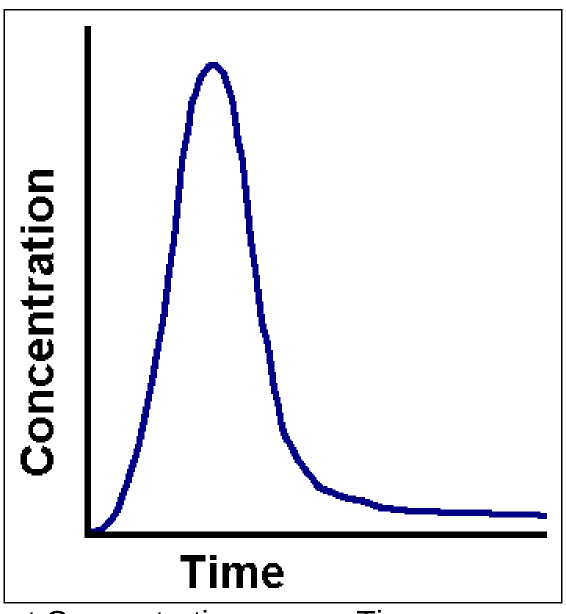


Figure 28: Plot of Pollutant Concentration versus Time

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:

- Knickpoint migration 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 29, 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 causes 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 30 (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 2-year peak discharge control doesn't work, 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 worsen conditions, since it increases the duration of these erosive, channel-forming flows. The Center for Watershed Protection suggests requiring 24-hour extended detention for runoff from 1-year storms as one option for protecting channel morphology. The intent is to limit detention pond outflows from these storms to non-erosive velocities, as shown in Figure 31. 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 32. This analysis, which is for a climatic region, is for 2.06 inches of rainfall. The Pinnebog River is in climatic region 7, which has a 50 percent chance (2-year) 24-hour storm design rainfall value of 2.14 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 exploring funding this analysis for all of Michigan. The results would be provided to the Pinnebog River stakeholders when available.

Control of channel-forming flows is not essential for some drainage areas. For example, detention designed to prevent streambank erosion may not be needed for runoff routed from a city through storm sewers to a large river, 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 city's 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. Pinnebog River 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 sewer directly to a fourth order or higher stream, as shown in Figure 26.

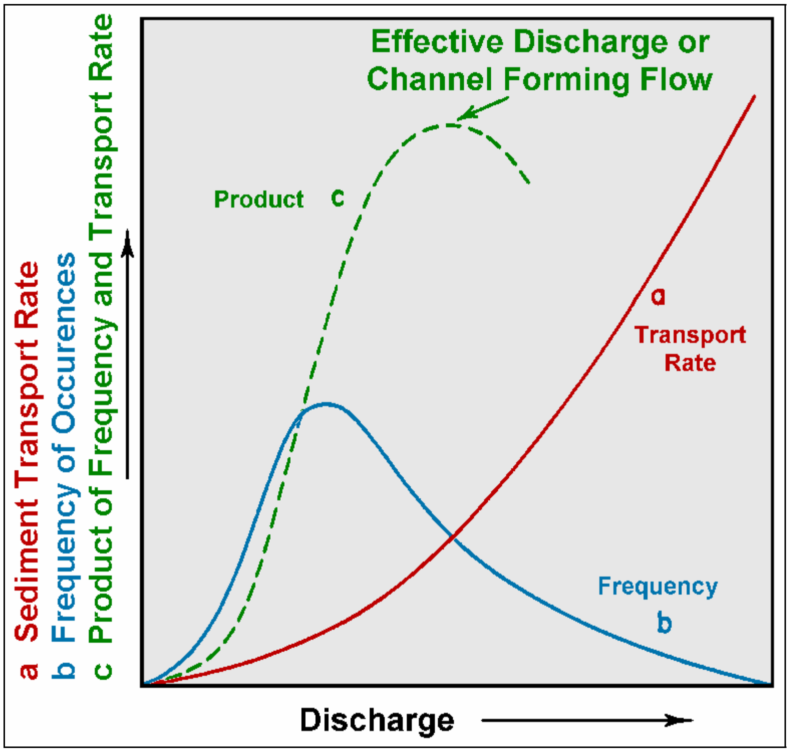


Figure 31: Effective Discharge (from *Applied River Morphology*. 1996. Dave Rosgen)

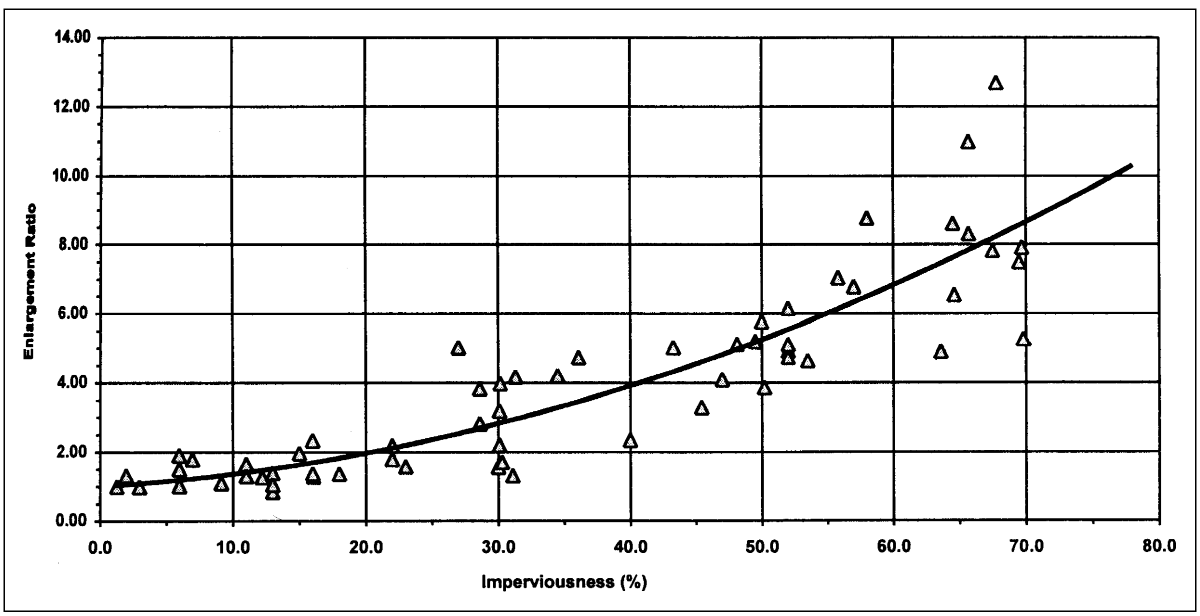


Figure 32: "Ultimate" Channel Enlargement as a Function of Impervious Cover in Alluvial Streams in Maryland, Vermont, and Texas (MacRae and DeAndrea, 1999; and Brown and Claytor, 2000) (From *The Practice of Watershed Protection*, Thomas R. Schueler and Heather K. Holland, 2000)

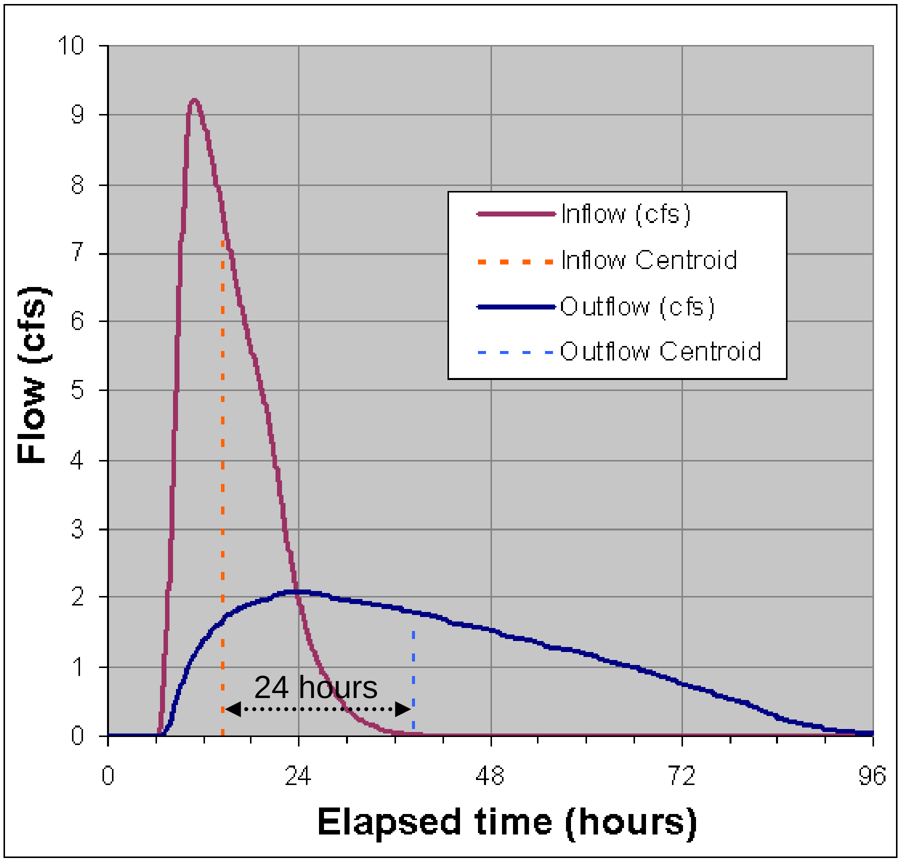


Figure 33: Example of 24-hour extended detention criterion applied to detention pond design

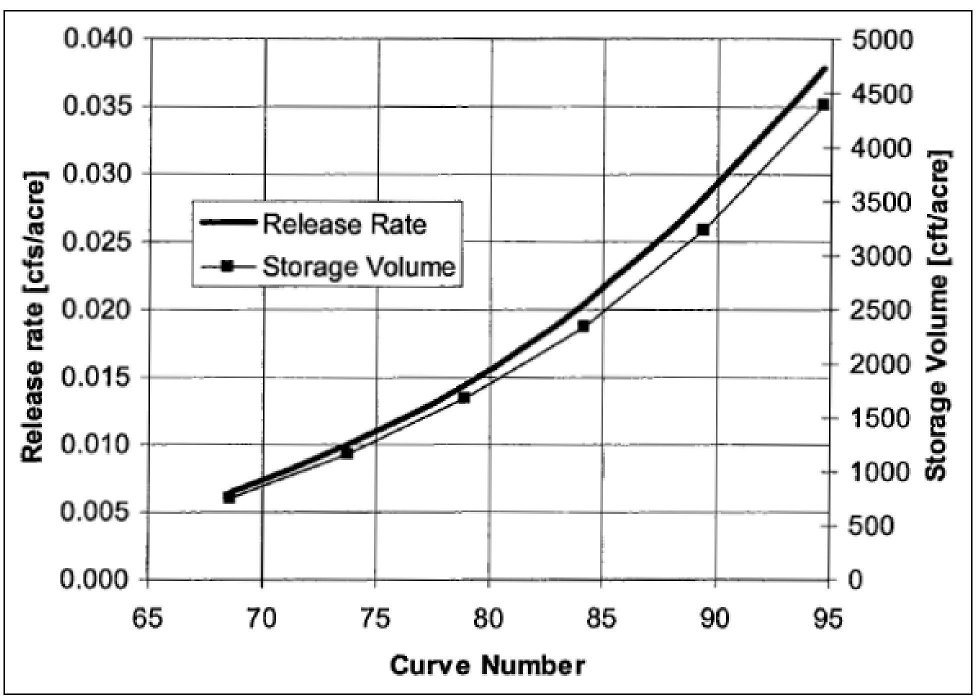


Figure 34: Example of detention pond requirements derived from the 24-hour extended detention criterion

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.

References

Anchor Bay Watershed Transition/Implementation Project, Technical Report for Watershed Management Plan, Fishbeck, Thompson, Carr and Huber, April 2006. www.deq.state.mi.us/documents/deq-ess-nps-wmp-anchor-bay-technical-report.pdf

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (15 Federal agencies of the US government). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3. www.nrcs.usda.gov/technical/stream_restoration/

Guidebook of Best Management Practices for Michigan Watersheds. Michigan Department of Water Quality, Surface Water Quality Division, 1993 (Reprinted October 1998). www.deq.state.mi.us/documents/deq-swq-nps-WholeGuidebook.pdf

Menerey, Bruce, *Stormwater Management Guidebook.* Michigan Department of Natural Resources, Land and Water Management Division, March 1992 (Revised August 1999 and distributed by Michigan Department of Environmental Quality, Land and Water Management Division). www.deq.state.mi.us/documents/deq-lwm-hyd-SMGmastr.pdf

Rosgen, Dave, Applied River Morphology. Printed Media Companies, Minneapolis, Minnesota, 1996.

Schueler, Thomas R. and Holland, Heather K., editors. The Practice of Watershed Protection, Center for Watershed Protection. Elliot City, Maryland, 2000.

Sorrell, Richard C., Computing Flood Discharges for Small Ungaged Watersheds, Michigan DEQ, revised July 2003. www.deq.state.mi.us/documents/deq-glm-water-scs2003.pdf

United States Department of Agriculture, Natural Resources Conservation Service. *Urban Hydrology for Small Watersheds TR-55*, June 1986

Appendix A: Pinnebog River Hydrologic Analysis Data

The following tables summarize the results of the hydrologic analysis by subbasin. These tables are likely to be most useful during the process for defining critical areas for the Pinnebog River Watershed Management Plan. Table A1 presents land use information. Table A2 provides runoff volumes per area. Table A3 lists peak flood flow yields per subbasin. Table A4 lists the imperviousness per subbasin.

Table A1: Land Use by Subbasins (Land use percentages that round to 0 are not listed)

Description	Scenario	Residential	Institutional	Industrial	Utilities	Gravel Pit	Cemeteries, Outdoor Rec.	Cropland	Orchard	Pasture	Herbaceous Openland	Forest	Water	Wetland	Bare Soil, Sand Dune
P1Muss	1800										1%	59%	16%	24%	
	1978							70%			1%	10%	1%	18%	
	2005							69%			1%	10%	1%	18%	
P1Pinn	1800											98%		2%	
	1978							78%			2%	18%			1%
	2005	1%						77%			1%	19%			1%
P1T2Moor	1800											74%		26%	
	1978	1%				1%		84%			2%	9%		3%	
	2005	1%						83%			3%	9%		3%	
P1T2Taft	1800											83%		17%	
	1978							87%			2%	9%		1%	
	2005							87%			2%	9%		1%	
P1Taft	1800											69%		31%	
	1978	1%						91%		1%	1%	5%			
	2005	2%						91%			1%	5%			
P2BA2	1800											42%		58%	
	1978	4%	1%	1%		3%		74%		2%	3%	8%		4%	
	2005	6%	3%	1%		1%		70%		1%	5%	8%		4%	
P2BadA	1800											41%		59%	
	1978							82%			4%	12%		2%	
	2005							82%			4%	12%		2%	
P2Pinn	1800											63%		37%	
	1978							92%			3%	6%			
	2005	1%						92%			2%	6%			
P3Pinn	1800											89%		11%	
	1978							93%			2%	4%			
	2005	2%						92%			2%	4%			
P4Elkt	1800											10%		90%	
	1978	2%						93%				4%			
	2005	3%	1%					92%				4%			
P4Pinn	1800											50%		50%	
	1978			1%				79%			5%	13%		1%	
	2005	2%		1%			1%	75%			5%	13%		1%	
P5Pinn	1800											45%		55%	
	1978	3%	1%	1%	1%		1%	69%			3%	17%		4%	
	2005	5%	1%	1%	1%		1%	67%			3%	17%		4%	
P6Rush	1800											55%		45%	
	1978					1%		77%		2%	5%	12%		4%	
	2005	1%			1%	1%		78%		1%	4%	11%		3%	
Entire Watershed	1800											61%	1%	38%	
	1978	1%						82%			3%	10%		3%	
	2005	2%						81%			3%	9%		3%	

Table A2: Runoff volumes per area per subbasin Runoff Volume/Area

Subbasin			Scenario	Runoff Volume per Area		
ID	Description	Area (sq. mi.)		Total Amount (inches)	Change, 1800 to 2005	Change, 1978 to 2005
P1Muss	Musselman Drain to mouth	11.3	1800	0.56		
			1978	0.70		
			2005	0.70	26%	0%
P1Pinn	Pinnebog River to mouth	10.9	1800	0.27		
			1978	0.58		
			2005	0.58	117%	0%
P1T2Moor	Moore Creek to mouth	14.4	1800	0.35		
			1978	0.65		
			2005	0.65	84%	0%
P1T2Taft	Taft Drain at confluence with Moore Creek	16.9	1800	0.30		
			1978	0.63		
			2005	0.63	112%	1%
P1Taft	Taft Drain to mouth	21.0	1800	0.37		
			1978	0.67		
			2005	0.67	82%	0%
P2BA2	Bad Axe Creek at confluence with Symons Drain	18.0	1800	0.40		
			1978	0.53		
			2005	0.51	27%	-4%
P2BadA	Bad Axe Creek to mouth	11.4	1800	0.45		
			1978	0.63		
			2005	0.62	38%	-1%
P2Pinn	Pinnebog River to confluence with Bad Axe Creek	14.7	1800	0.40		
			1978	0.71		
			2005	0.71	78%	1%
P3Pinn	Pinnebog River at confluence with Southworth Drain	16.6	1800	0.29		
			1978	0.67		
			2005	0.66	126%	-1%
P4Elkt	Elkton Drain at mouth	10.5	1800	0.51		
			1978	0.69		
			2005	0.68	32%	-1%
P4Pinn	Pinnebog River above Elkton Drain	9.8	1800	0.35		
			1978	0.54		
			2005	0.52	47%	-4%
P5Pinn	Pinnebog River at confluence with Cameron Drain	20.0	1800	0.41		
			1978	0.56		
			2005	0.56	38%	-1%
P6Rush	Colona Drain at confluence with Rush Drain	19.5	1800	0.34		
			1978	0.51		
			2005	0.50	46%	-2%
Area-Weighted Average			1800	0.38		
			1978	0.62		
			2005	0.61	62%	-1%
Minimum			1800	0.27		
			1978	0.51		
			2005	0.50		
Maximum			1800	0.56		
			1978	0.71		
			2005	0.71		

Table A3: Peak Flood Flow Yields per subbasin

Subbasin	Area (sq. mi.)	Scenario	Peak Flood Flow Yield			Calculated Yield Change	
			Calculated	Maximum	Minimum	1800 to 2005	1978 to 2005
P1Muss	11.3	1800	0.009	0.009	0.008		
		1978	0.013	0.013	0.012		
		2005	0.013	0.013	0.012	46%	0%
P1Pinn	10.9	1800	0.002	0.002	0.002		
		1978	0.006	0.006	0.005		
		2005	0.006	0.006	0.005	137%	0%
P1T2Moor	14.4	1800	0.005	0.006	0.005		
		1978	0.014	0.015	0.014		
		2005	0.014	0.015	0.014	162%	1%
P1T2Taft	16.9	1800	0.007	0.007	0.007		
		1978	0.016	0.017	0.016		
		2005	0.016	0.017	0.016	138%	1%
P1Taft	21	1800	0.008	0.009	0.008		
		1978	0.028	0.031	0.028		
		2005	0.029	0.031	0.029	265%	2%
P2BA2	18	1800	0.005	0.006	0.005		
		1978	0.013	0.014	0.013		
		2005	0.013	0.014	0.013	138%	-3%
P2BadA	11.4	1800	0.007	0.007	0.007		
		1978	0.020	0.020	0.019		
		2005	0.020	0.020	0.018	184%	-1%
P2Pinn	14.7	1800	0.005	0.005	0.005		
		1978	0.017	0.018	0.017		
		2005	0.018	0.018	0.017	263%	1%
P3Pinn	16.6	1800	0.005	0.005	0.005		
		1978	0.019	0.020	0.018		
		2005	0.018	0.019	0.017	280%	-5%
P4Elkt	10.5	1800	0.007	0.007	0.007		
		1978	0.025	0.025	0.023		
		2005	0.025	0.025	0.023	240%	-1%
P4Pinn	9.8	1800	0.005	0.005	0.005		
		1978	0.016	0.016	0.015		
		2005	0.016	0.016	0.014	196%	-4%
P5Pinn	20	1800	0.006	0.006	0.006		
		1978	0.012	0.013	0.012		
		2005	0.012	0.013	0.012	115%	2%
P6Rush	19.5	1800	0.005	0.006	0.005		
		1978	0.012	0.013	0.012		
		2005	0.012	0.013	0.012	123%	-2%
Area-Weighted Average		1800	0.006	0.004	0.008		
		1978	0.016	0.011	0.022		
		2005	0.016	0.011	0.022	176%	0%
Minimum	9.8	1800	0.002	0.002	0.002		
		1978	0.006	0.006	0.005		
		2005	0.006	0.006	0.005		
Maximum	21.0	1800	0.009	0.009	0.008		
		1978	0.028	0.031	0.028		
		2005	0.029	0.031	0.029		

Table A4: Imperviousness per subbasin

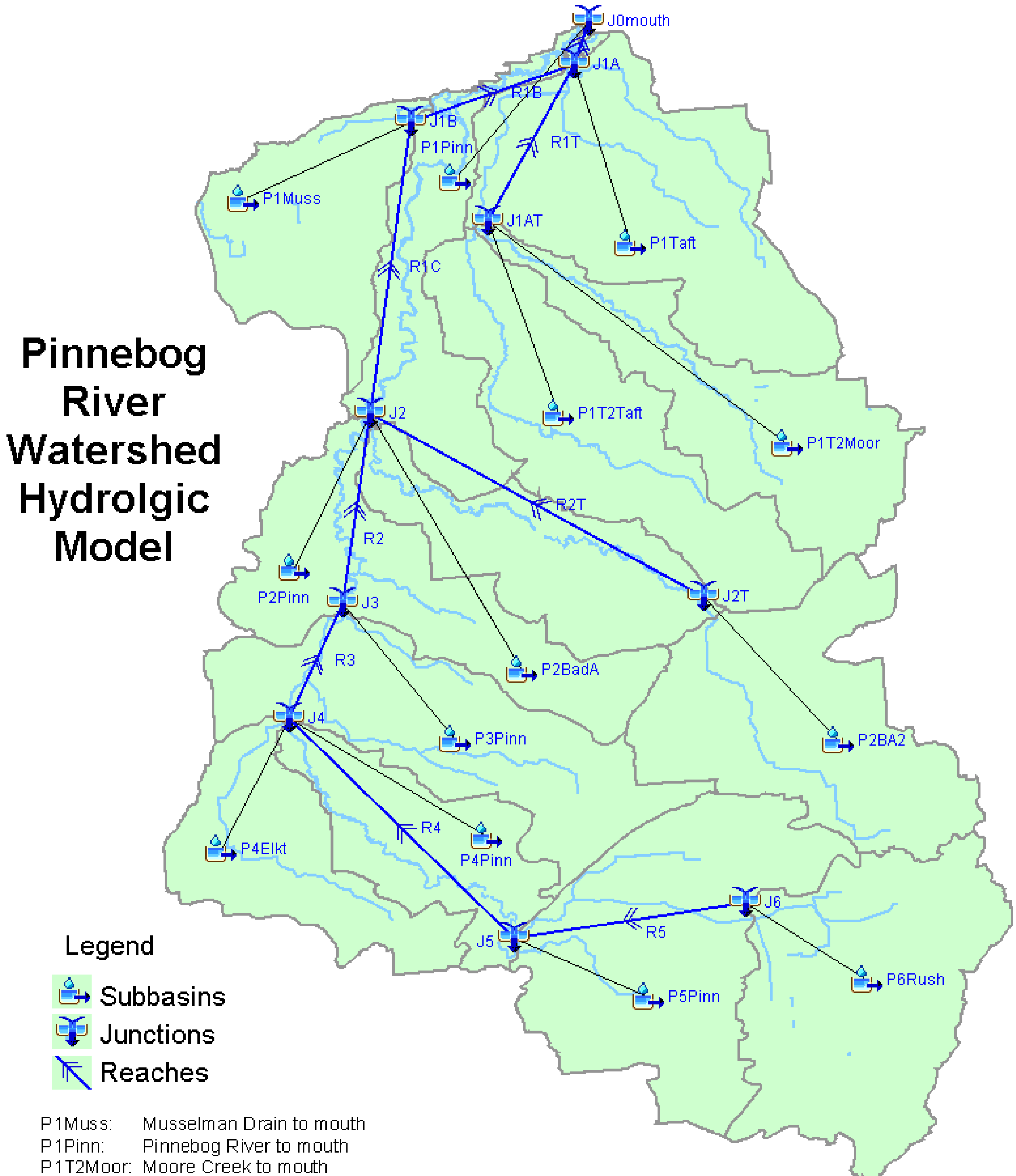
Subbasin ID	Description	Area (sq. mi.)	Imperviousness (percent)
P1Muss	Musselman Drain to mouth	11.3	0.8
P1Pinn	Pinnebog River to mouth	10.9	1.0
P1T2Moor	Moore Creek to mouth	14.4	1.5
P1T2Taft	Taft Drain at confluence with Moore Creek	16.9	1.0
P1Taft	Taft Drain to mouth	21	1.9
P2BA2	Bad Axe Creek at confluence with Symons Drain	18	6.1
P2BadA	Bad Axe Creek to mouth	11.4	0.9
P2Pinn	Pinnebog River to confluence with Bad Axe Creek	14.7	1.1
P3Pinn	Pinnebog River at confluence with Southworth Drain	16.6	1.8
P4Elkt	Elkton Drain at mouth	10.5	2.6
P4Pinn	Pinnebog River above Elkton Drain	9.8	2.3
P5Pinn	Pinnebog River at confluence with Cameron Drain	20	5.0
P6Rush	Colona Drain at confluence with Rush Drain	19.5	1.8

Appendix B: Pinnebog River Hydrologic Parameters

The watershed was modeled using HEC-HMS 3.0.1 to calculate surface runoff volumes and peak flows from individual subbasins. This appendix is provided so that the model may be recreated. Table B1 provides the drainage area and runoff curve number parameters that were specified for each of the hydrologic elements in the HEC-HMS model, Figure B-1. In the HEC-HMS model, the percent impervious fields were left at the default 0.0, because imperviousness is already incorporated in the curve numbers. The initial loss field fields were left blank so that HEC-HMS uses the standard equation based on the curve number. The storage coefficient for each subbasin was initially set equal to the associated time of concentration, Table B3. Peak flows, calculated with HEC-HMS using these parameters, were multiplied by the ponding adjustment factors listed in Table B2 to incorporate flow attenuation by storage in the subbasin. Revised values for the storage coefficients, Table B3, were iteratively calculated to provide the ponding-adjusted peak flows. HEC-HMS was run for a ten-day duration using a five-minute computation interval.

Table B1: Subbasin Parameters – Drainage Area and Curve Number

Subbasins		**Drainage Area (sq. mi.)**	**Runoff Curve Number**		
ID	**Description**		**1800**	**1978**	**2005**
P1Muss	Musselman Drain to mouth	11.3	77.9	81.1	81.1
P1Pinn	Pinnebog River to mouth	10.9	70.5	79.6	79.6
P1T2Mo or	Moore Creek to mouth	14.4	72.1	80.0	80.0
P1T2Taft	Taft Drain at confluence with Moore Creek	16.9	70.1	79.5	79.6
P1Taft	Taft Drain to mouth	21.0	72.5	80.5	80.5
P2BA2	Bad Axe Creek at confluence with Symons Drain	18.0	73.8	77.1	76.6
P2BadA	Bad Axe Creek to mouth	11.4	75.2	79.5	79.4
P2Pinn	Pinnebog River to confluence with Bad Axe Creek	14.7	74.1	81.3	81.4
P3Pinn	Pinnebog River at confluence with Southworth Drain	16.6	70.0	80.4	80.3
P4Elkt	Elkton Drain at mouth	10.5	76.9	80.8	80.6
P4Pinn	Pinnebog River above Elkton Drain	9.8	72.1	77.4	76.8
P5Pinn	Pinnebog River at confluence with Cameron Drain	20.0	73.9	78.0	77.9
P6Rush	Colona Drain at confluence with Rush Drain	19.5	71.7	76.6	76.3
	Total	195.0			
	Minimum	9.8			
	Maximum	21.0			



P1Muss:	Musselman Drain to mouth
P1Pinn:	Pinnebog River to mouth
P1T2Moor:	Moore Creek to mouth
P1T2Taft:	Taft Drain at confluence with Moore Creek
P1Taft:	Taft Drain to mouth
P2BA2:	Bad Axe Creek at confluence with Symons Drain
P2BadA:	Bad Axe Creek to mouth
P2Pinn:	Pinnebog River to confluence with Bad Axe Creek
P3Pinn:	Pinnebog River at confluence with Southworth Drain
P4Elkt:	Elkton Drain at mouth
P4Pinn:	Pinnebog River above Elkton Drain
P5Pinn:	Pinnebog River at confluence with Cameron Drain
P6Rush:	Colona Drain at confluence with Rush Drain

Figure B1: Hydrologic Elements defined for HEC-HMS model

Table B2: Ponding Adjustment

Subbasin ID	Percent Ponding within Subbasin			50% Storm, Adjustment Factor		
	1800	1978	2005	1800	1978	2005
P1Muss	40.0%	18.9%	18.5%	0.46	0.54	0.54
P1Pinn	2.2%	0.5%	0.5%	0.76	0.88	0.88
P1T2Moor	26.4%	3.0%	2.9%	0.50	0.71	0.71
P1T2Taft	17.2%	1.0%	1.0%	0.75	0.83	0.83
P1Taft	31.5%	0.3%	0.2%	0.48	0.92	0.94
P2BA2	57.4%	4.0%	3.7%	0.43	0.81	0.82
P2BadA	58.8%	1.7%	1.7%	0.42	0.88	0.88
P2Pinn	36.6%	0.0%	0.0%	0.47	1.00	1.00
P3Pinn	11.4%	0.1%	0.2%	0.57	1.00	0.96
P4Elkt	89.3%	0.0%	0.0%	0.39	1.00	1.00
P4Pinn	50.3%	1.4%	1.4%	0.44	0.89	0.89
P5Pinn	54.8%	4.4%	3.7%	0.43	0.66	0.68
P6Rush	44.9%	3.7%	3.5%	0.45	0.68	0.69

Table B3: Subbasin Parameters – Time of Concentration and Storage Coefficient

Subbasin ID	Time of Concentration	50% Storm, Storage Coefficient		
		1800	1978	2005
P1Muss	17.26	49.93	41.18	40.98
P1Pinn	64.75	97.20	78.85	78.85
P1T2Moor	19.77	51.60	32.84	32.52
P1T2Taft	19.93	30.68	26.39	26.40
P1Taft	12.07	35.06	13.75	13.31
P2BA2	19.42	61.60	26.54	26.39
P2BadA	16.30	52.84	19.86	19.86
P2Pinn	25.50	70.88	25.50	25.50
P3Pinn	22.19	48.58	22.19	23.67
P4Elkt	16.01	58.35	16.01	16.01
P4Pinn	17.32	53.86	20.79	20.79
P5Pinn	18.83	59.15	33.94	32.85
P6Rush	17.23	52.08	30.18	29.91

Appendix C: 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.

Condensation - phase change of water vapor into liquid droplets.

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.

Evaporation - phase change of liquid water to water vapor.

Evapotranspiration - the combined process of evaporation and transpiration.

Field Capacity - the amount of water held in soil after gravitational water is drained.

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.

Flux - the volume of fluid crossing a unit cross-sectional surface area per unit time.

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.

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.

Stochastic - model that contains a random component.

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 - peak flow divided by drainage area