MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Technical Report 2008-1
September 2008

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Printed under authority of Michigan Department of Natural Resources
Total number of copies printed 70 — Total cost $146.07 — Cost per copy $2.087

Suggested Citation Format

Mistak, J. L., and D. A. Stille. 2008. Regional hydraulic geometry curve for the Upper Menominee River. Michigan Department of Natural Resources, Fisheries Technical Report 2008-1, Ann Arbor.

Michigan Department of Natural Resources
Fisheries Technical Report 2008-1, 2008

Regional Hydraulic Geometry Curve for the Upper Menominee River

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Abstract.–Regional hydraulic geometry curves provide a better understanding of river morphology and help in the design of stream restoration projects by providing information to estimate bank-full discharge, mean depth, width, and cross-sectional area at ungaged sites within given drainage areas. Although regional curves have been developed for various United States drainage areas, a statewide effort to develop regional curves is only recently underway in Michigan. In July and August 2006, data were collected to develop regional curves for the Upper Menominee River drainage area based on bank-full characteristics of the Sturgeon River, Iron River, Brule River, Pine Creek, and Peshekee River. Data collected on each water body included surveys of longitudinal and cross-sectional profiles and measurement of channel materials. Analysis of the data determined bank-full channel dimensions and allowed for reaches to be classified according to Rosgen valley and stream types. Using the surveyed data, regional curves were developed from regression analyses of the relationship between bank-full channel dimensions and drainage area. Bank-full cross-sectional area and mean depth had the strongest relation to drainage area as evidenced by r^2 values of 0.78 and 0.74, respectively. Although the number of surveyed sites was small, these curves may be used as general guidelines to help ensure proper design and stability of future stream channel modifications and restoration efforts in the Upper Menominee River drainage area.

Introduction

There is growing interest in restoration of stream channels affected by excessive sedimentation, erosion, or otherwise degraded habitat. Accompanying this interest is a trend for managers to design projects that utilize a natural channel approach, with the goal of rebuilding a stable channel with the proper dimension, slope, and pattern that allow for the transfer of water and sediment loads from the drainage area without aggradation or degradation of the stream bed. Projects employing natural channel design are often based on bank-full channel measurements. The bank-full channel is formed by the bank-full discharge, at which channel maintenance is the most effective at moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (see the Glossary for additional definitions of technical terms). Characteristics of the bank-full channel, including bank-full cross-sectional area, width, and mean depth, are strongly correlated with drainage area (Dunne and Leopold 1978).

To facilitate the design of natural channel projects, many states and federal entities have contributed to the development of regional hydraulic geometry curves (hereafter refers to regional curve). Regional curves, which are regressions of the relationships between bank-full channel characteristics taken at a riffle and drainage area, are used to define bank-full characteristics without additional data collection or analysis. Most commonly, a regional curve may be used to estimate bank-full channel dimensions and discharge at ungaged reaches within the same drainage area or within drainage areas having similar characteristics.

The purpose of this project was to produce regional curves for the Upper Menominee River drainage area based on bank-full channel dimensions and drainage area characteristics. The Upper Menominee River regional curves may be used as general guides for restoration designs within the same drainage area by providing information on the correct channel dimensions to accommodate stream flow and sediment load. Information collected from the Upper Menominee River will be included in a larger morphological database of Michigan's regional curves being developed by Michigan's Stream Team for use by federal, state, and local agencies.

Methods

Study Sites

For the purpose of this study, the geographic scope of the Upper Menominee River basin includes the area encompassing the Michigamme River from upstream of Lake Michigamme to the confluence with the Brule River, the Iron and Brule rivers down to the confluence with the Michigamme River, and the Menominee River and its tributaries within Iron and Dickinson counties (Figure 1). The Menominee River, formed by the confluence of the Brule and Michigamme rivers, flows about 114 miles through mostly forested land into Lake Michigan's Green Bay at the cities of Marinette, Wisconsin and Menominee, Michigan. Other than the cities of Iron Mountain and Kingsford and several rural towns and villages, the Upper Menominee River Basin is sparsely populated (Wisconsin Electric Power Company 1999). There are 56 dams within the basin, 19 of which are hydroelectric projects.

We selected study sites at U.S. Geological Survey (USGS) gage stations that met the minimum criteria of having at least 10 years of record, a recoverable benchmark referenced to the gage datum, no influence by dams or artificial control structures, and the ability to be safely waded for a length of 20 bank-full widths or two meander lengths. Station descriptions from the USGS and field reconnaissance were used to determine which study sites met the minimum criteria. Of the 21 potential sites in the Upper Menominee River drainage area that had at least 10 years of gage data, only five sites met all of the selection criteria (Table 1). Many sites were not appropriate because they were either influenced by hydropower dam operations or were too large to be safely waded.

Data Collection

We collected data during July and August 2006 (Table 2) using protocols established by Michigan's Stream Team (2005). Morphological data were used to assign valley and stream types according to the classification system developed by Rosgen (1994).

Survey Setup

We reviewed USGS station descriptions, level summaries, and stream rating tables along with aerial photographs and plat maps at each site. Reference marks with known elevations were located from the station description and compared with the most recent level notes. After recording the gage datum water surface elevation, we determined the corresponding discharge using the associated USGS rating table. The recurrence interval or average yearly time interval between occurrences of a hydrological event of a given or greater magnitude for this discharge was calculated with formulae provided by the Michigan Department of Environmental Quality (2006).

The study reaches began and ended on the same type of mesohabitat feature (e.g., top of riffle to top of riffle) and equaled at least two full meander lengths or approximately 20 times the bank-full width. We waded the reaches of the five study sites to lay out the measuring tapes, identify and record distances for each macrohabitat feature (i.e., run, riffle, pool, glide), and mark bank-full elevation. The most representative pool and riffle within the study reach were visually identified for cross-sectional surveys.

Surveys for each study site began at the upstream end of the study reach. To reduce the number of times the laser level needed to be moved, we set up the level in a stable location where the reference marks, bank-full indicators, and the thalweg (the transect location with the deepest water depth) could be surveyed both across the river and for a maximum distance downstream. We took photographs at each of the five study sites to document the conditions upstream and downstream of the reach, and at both banks for each cross-section.

Longitudinal profile.–The longitudinal profile included measurements taken upstream and downstream within a reach to determine water surface slope and shape of the channel bed and floodplain. To obtain a longitudinal profile, we surveyed elevations and positions corresponding to the changing mesohabitat features (run, riffle, pool, and glide). At each pool and riffle cross-section, we installed reinforcement bar (rebar) monuments at least 1 foot beyond bank-full discharge on both sides of the stream and determined the elevation of the rebar using the laser level. To close the longitudinal profile for each site, the survey ended at the same point where it began to ensure the level set closed within acceptable limits (less than 0.02 ft). If measurement accuracy was not within acceptable limits, the longitudinal profile was repeated.

Cross-section.–The cross-section included measurements along a vertical plane perpendicular to the stream to determine channel form. We surveyed at least one riffle cross-section at each of the five study sites to provide cross-section data (bank-full width and mean depth, cross-sectional area, and flood prone width) needed for the regional curve. We also surveyed a pool cross-section at each of the five study sites to provide a range in morphological characteristics for use in future stream restoration project design. All cross-sections were established perpendicular to the direction of the flow and extended laterally beyond the bank-full channel. We used the rebar monuments installed during the longitudinal profile survey to lay a measuring tape across the river, with zero starting on the river left bank. For both the pool and riffle cross-section profile, we surveyed points corresponding to the top of rebar, ground next to rebar, bank-full, edge of bank, water surface, and thalweg. Flood-prone width was estimated at riffle cross-sections by measuring the distance between the two points of elevation on both sides of the river that corresponded to twice the maximum depth of the bank-full channel (Rosgen 1996).

Pebble Count

We conducted pebble counts throughout the reach and at the riffle and pool cross-sections using the method described by Wolman (1954). Pebbles were picked up after averting our gaze, reaching straight down, and selecting the first particle touched by the tip of the index finger. The intermediate axis (neither the longest nor the shortest of the three mutually perpendicular sides) of the particle was measured and recorded by size class. For sand and silt, we determined the size class of particles by tactile and visual comparison with a sand gage.

We used the reach average pebble count to characterize the size of bed materials by measuring 100 samples in ten transects distributed through the entire reach according to the proportion of macrohabitat types. For example, if 30 percent of the reach length was pool habitat, and 70 percent was riffle habitat, the corresponding reach average pebble count would include three transects in pools and seven transects in riffles. The riffle and pool pebble counts were conducted by sampling at least 100 particles along the wetted width of the surveyed cross-sections.

Data Analysis

We entered all data into the RIVERMorph software program (RIVERMorph LLC, Louisville, Kentucky). The RIVERMorph program analyzes geomorphic data and facilitates river assessment, monitoring, and design. The RIVERMorph program also has a tool that develops regional curves, or a series of regression lines on a log-log graph of drainage area versus bank-full channel dimensions.

Results

Characteristics of Assessed Stream Reaches

Iron River at Caspian, Michigan (USGS Gage 04060500).–This site was located in the SE ¼ and SW ¼ of Section 1, Town 42N, Range 35W, in Iron County on County Road 424, in Caspian, Michigan. The longitudinal profile at this site extended for a reach of 950 ft, beginning on the downstream side of the bridge on County Road 424 and ending just above the City of Caspian’s waste water treatment plant discharge. The reach was characterized by low banks with heavy overhanging brush (Figure 2). The bank-full channel was not well defined within the first 200 ft of the reach due to the highway bridge, abandoned railroad track, and altered floodplain. Further downstream, bank-full discharge was defined by a subtle change in bank angle and depositional features.

Brule River near Florence, Wisconsin (USGS Gage 04060933).–This site was located in the NW ¼ SE ¼ of Section 9, Town 41N, Range 32W, in Iron County on U.S. Highway 2, 4 mi northwest of Florence, Wisconsin. The longitudinal profile at this location began upstream of the U.S. Highway 2 Bridge and extended 1,340 ft downstream. The reach was characterized by a fairly straight channel, riffle habitat, and relatively steep banks (Figure 3). The bank-full indicators were more easily identified on the left bank by changes in bank angle and riparian vegetation.

Pine Creek near Iron Mountain, Michigan (USGS Gage 04065600).–This site was located in the SE ¼ SE ¼ of Section 19, Town 41N, Range 29W, Dickinson County on County Road 866, 9 mi northeast of Iron Mountain, Michigan. The longitudinal profile for this study site (Figure 4) consisted of a 555 ft reach beginning upstream of County Road 866. Much of this reach was characterized by a gradually meandering channel with a prevalence of run habitat. Bank-full discharge was characterized by a change in bank angle and riparian vegetation.

Sturgeon River near Foster City, Michigan (USGS Gage 04065500).–This site was located in the NW ¼ of Section 36, Town 41N, Range 28W, Dickinson County on County Highway 569, 4 mi south of Foster City, Michigan. The longitudinal profile at this location began on the downstream side of the bridge on County Road 569 and extended 1,510 ft downstream. This reach was wide and shallow (Figure 5), with a bottom substrate composed primarily of sand. The left bank was fairly high and not suitable for bank-full measurements. Most bank-full measurements on the right bank were characterized by depositional features and a change in bank angle and riparian vegetation.

Peshekee River near Champion, Michigan (USGS Gage 04062200).–This site was located in the NW ¼ of Section 13, Town 48N, Range 30W, Marquette County on County Highway 607, 3.5 mi northwest of Champion, Michigan. To avoid a deep, nonwadeable pool, the longitudinal profile for this 1,800 ft reach (Figure 6) began approximately 100 ft downstream of the gage at the County Road 607 Bridge. There were no tributaries or sources of increased discharge between the gage and the start of the longitudinal profile. Much of this reach was characterized by high banks and coarse gravel and bedrock. Bank-full indicators included change in bank angle and riparian vegetation.

Rosgen Classification

We characterized all five streams as Rosgen (1994, 1996) valley type VIII, with one stream classified as stream type B (Iron River) and the other four streams classified as stream type C (Brule River, Pine Creek, Sturgeon River and Peshekee River, Table 2). Valley type VIII is distinguished by multiple river terraces with low sloping valley relief. Stream type B typifies moderately entrenched streams with moderate gradient that are dominated by riffles and characterized by stable banks, and stream type C typifies low gradient, meandering streams defined by riffle-pool channels and broad, well-defined floodplains (Rosgen 1996). The number accompanying each stream type (e.g., C5) refers to the predominant channel material, while the sub-letter accompanying some stream types (e.g., $B4_c$) indicates that the measured slope is outside of that stream type's normal range. Both Pine Creek and Sturgeon River were classified as having sand-dominated bed material, while the other rivers were classified as gravel-dominated.

Bank-full Stream Flow

Our results show that the recurrence interval for bank-full flow events ranged from every 1 to 1.75 years (Table 2). On average, bank-full flows occurred approximately every 1.2 years in the Upper Menominee River drainage area.

Regional Hydraulic-geometry Relations

After reviewing the data, we determined that the Peshekee River lies in a hydro-physiographic region more similar to the area north of the geographic boundary of the Upper Menominee River drainage area. Compared to the other rivers surveyed in the Upper Menominee River drainage area, the drainage area of the Peshekee River is characterized by higher and more intense surface runoff and snowmelt events. To improve the accuracy of the regional curves for the Upper Menominee River, data from the Peshekee River were not included in our analyses.

The regional curves for the Upper Menominee River drainage areas against bank-full discharges, widths, mean depths and cross-sectional areas are shown in Figures 7–10. The relationship between bank-full discharge and drainage area determined for the Upper Menominee River is $Q_{\mathrm{bkf}} = 12.19\ A^{0.63}$ (r^2 = 0.42), where Q_{bkf} is bank-full discharge in ft^3/s and A is the drainage area in mi^2. The relation between width (W_{bkf}) in ft and drainage area is $W_{\mathrm{bkf}} = 25.35\ A^{0.20}$ (r^2 = 0.65), while the relation between mean depth (D_{bkf}) in ft and drainage area is $D_{\mathrm{bkf}} = 1.45\ A^{0.13}$ (r^2 = 0.74), and the relation between cross-sectional area (A_{bkf}) in ft and drainage area is $A_{\mathrm{bkf}} = 36.73\ A^{0.33}$ (r^2 = 0.78).

Discussion

The purpose of the Upper Menominee River regional curve is to provide a quantitative understanding of river channel morphology within the drainage area and present the results in a way that is useful for stream restoration projects and assessment of stream health. The data collected for this curve will also contribute to a recently initiated statewide regional curve project.

The Rosgen (1994, 1996) stream classification system represents a method to predict a river's behavior from its appearance, develop specific hydraulic and sediment relationships, extrapolate data to similar reaches, and provide consistent terms of reference. All surveyed streams were Rosgen valley type VIII and either Rosgen stream type B or C. Although this information is useful for the purposes of predictions and reference, the limited number of surveyed streams is insufficient to consider regional relationships by stream type within the Upper Menominee River drainage area. Additional data collection within the Menominee River drainage area, or within the same hydro-physiographic region, is needed to evaluate regional relationships by stream type.

According to the literature, bank-full discharge occurs an average of every 1.5 years on streams in the United States (Emmett 1975; Dunne and Leopold 1978; Leopold et al. 1995). The results from this study show that bank-full discharge in the Upper Menominee drainage area ranged between 1 to 1.75 years and tends to occur relatively frequently, or every 1.2 years on average. The increased frequency may be attributed to the flat terrain and easily distinguishable floodplains of the drainage area (Wolman and Leopold 1957), and the high spring runoff from snowmelt.

Bank-full channel dimensions of cross-sectional area, width, mean depth, and the related streamflow velocities tend to increase linearly with increases in drainage area (Leopold et al. 1995). Since undisturbed, stable rivers are known to have channel configurations that are proportional to the size of the upstream drainage area, discharge, and sediment load; regression analysis can be used to develop regional curves that predict channel response within various drainage areas. To create this predictive tool for the Upper Menominee River, regional curves were developed that regressed drainage area against bank-full discharge, width, depth, and cross-sectional area. Correlation coefficient values (r^2) measured the fit of the regional curve data to the regression line. The r^2 values for the Upper Menominee River regional curves indicate that bank-full discharge had the weakest relation to drainage area, which may be the result of visually estimating bank-full stage. In contrast, measured values of bank-full cross-sectional area and depth had the strongest relation to drainage area as evidenced by r^2 values of 0.78 and 0.74, respectively.

Federal, state, and local agencies are increasingly undertaking channel improvement projects on Michigan's streams and rivers. In most cases, such projects are initiated without knowledge of either the historical morphology of the stream channel or the difference between current and pre-development conditions. The regional curves developed for the Upper Menominee River can be used to facilitate interpretation and design of stream restoration projects and assess stream health. The results of this study should serve as a general guide for identification of bank-full channel dimensions at ungaged reaches. Additionally, the relationships developed in this document provide preliminary design parameters for streams with similar characteristics. However, there are limitations when using this information in designing channel improvement projects. Since the sample size is small and represents a limited range of stream types, these data should be used only for general guidance and design. Finer scale aspects of channel improvement design should come from appropriate reference reaches that closely match the conditions of the desired project reach.

Acknowledgments

We thank Michigan's Stream Team and Kristine Boley-Morse for assistance with data collection and analysis. We also thank Phil Schneeberger, Todd Wills, Chris Freiburger, and Li Wang for thoughtful reviews and editorial assistance. Funding for this project was provided by the Wilderness Shores Settlement Agreement Mitigation and Enhancement Fund.

Glossary

Bank-full channel – The area of the channel formed by bank-full discharge.

Bank-full cross-sectional area – The area of the bank-full channel measured along a vertical plane perpendicular to the stream to determine channel form.

Bank-full discharge – The streamflow at which channel maintenance and movement of bedload sediment are most effective. The bank-full discharge corresponds to bank-full stage.

Bank-full mean depth – The mean depth of the bank-full channel measured perpendicular to the streamflow.

Bank-full width – The width of the bank-full channel measured along a vertical plane perpendicular to the stream.

Drainage area – The area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Flood-prone width – The width of a surface perpendicular to the channel at an elevation that corresponds to twice the maximum depth of the bank-full channel. The flood prone width corresponds to elevations of relatively frequent floods (<50 year recurrence interval).

Regional curves – Regressions of the relation of bank-full channel characteristics to drainage areas. Regional curves are a common tool for defining bank-full characteristics without additional data collection or analysis, and for estimating bank-full channel dimensions and discharge at ungaged reaches within the same drainage area or within drainage areas having similar characteristics.

Stream reach – For this report, a section of stream that met the minimum criteria of having at least 10 years of U.S. Geological Survey gage station record, a recoverable benchmark referenced to gage datum, no influence by dams or artificial control structures, and the ability to be safely waded for a length of 20 bank-full widths or two meanders.

Stream restoration – The adjustment of stream dimension, pattern, and profile to a condition where it effectively accommodates a range of streamflow and sediment and supports diverse habitat. Although this may occur naturally over a long time span (e.g., decades), it is often attempted by people in order to see quicker results.

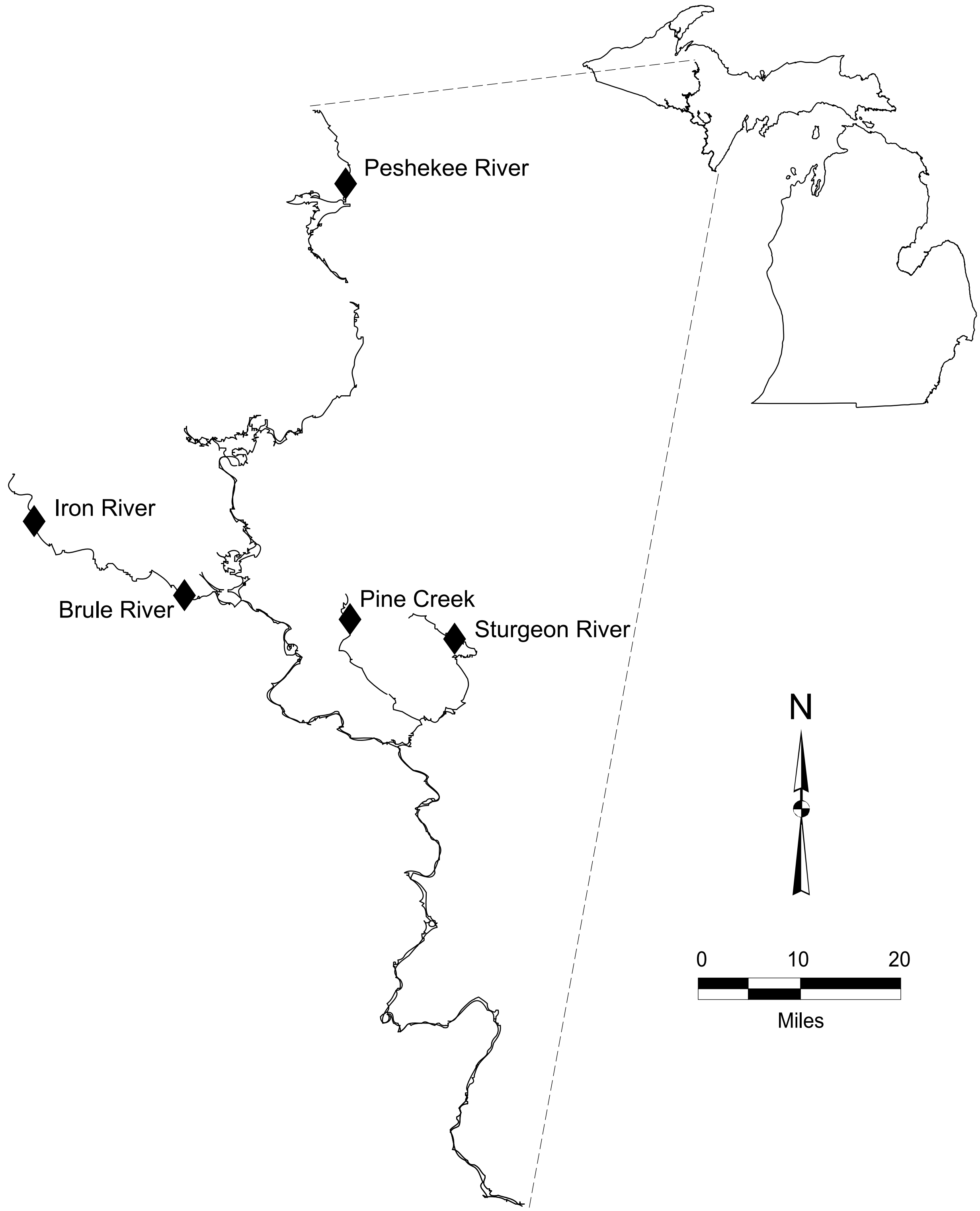

Figure 1.–Map of the Upper Menominee River drainage area, Michigan, showing the locations of the selected study sites used for development of regional curves.

Figure 2.–View looking downstream at reach for Iron River at Caspian, Michigan.

Figure 3.–View looking downstream at reach for Brule River near Florence, Wisconsin.

Figure 4.–View looking upstream at reach for Pine Creek near Iron Mountain, Michigan.

Figure 5.–View looking downstream at reach for Sturgeon River near Foster City, Michigan.

Figure 6.–View looking upstream at reach for Peshekee River near Champion, Michigan.

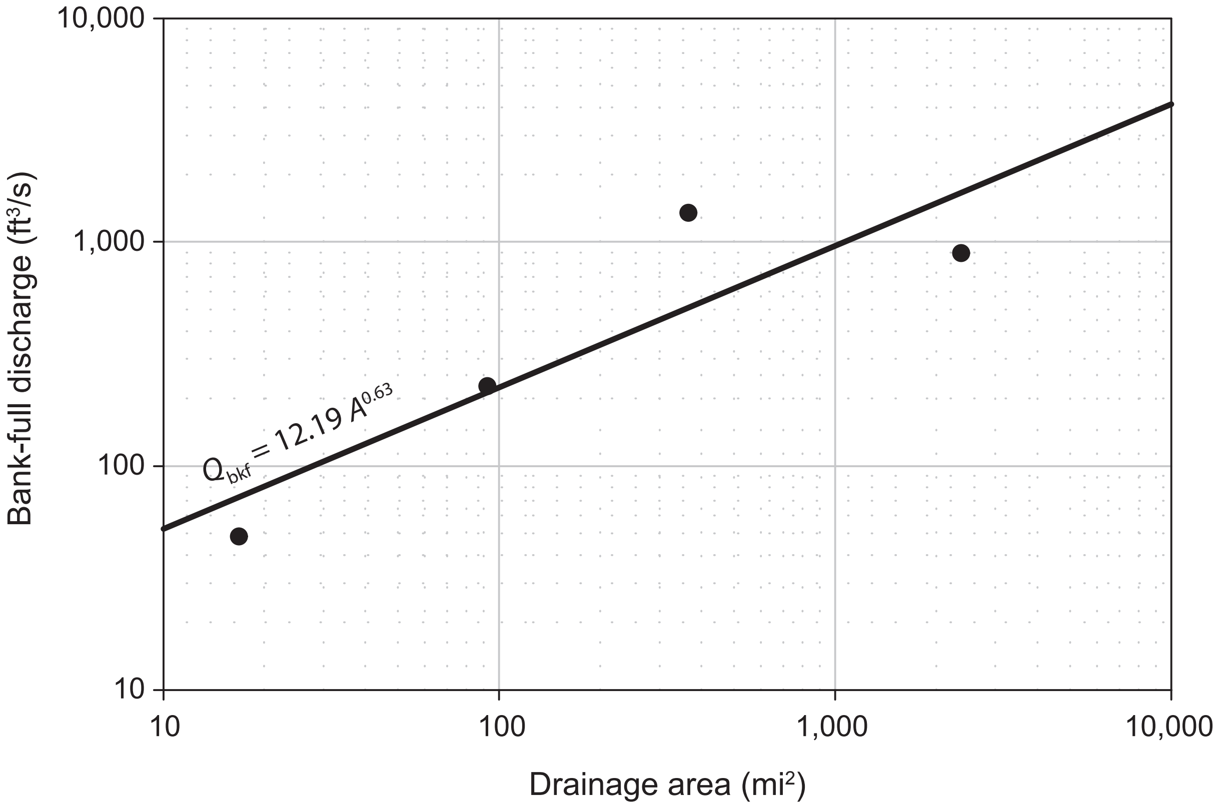

Figure 7.–Regional curve relating bank-full discharge (Qbkf) to drainage area for the Upper Menominee River drainage area in Michigan.

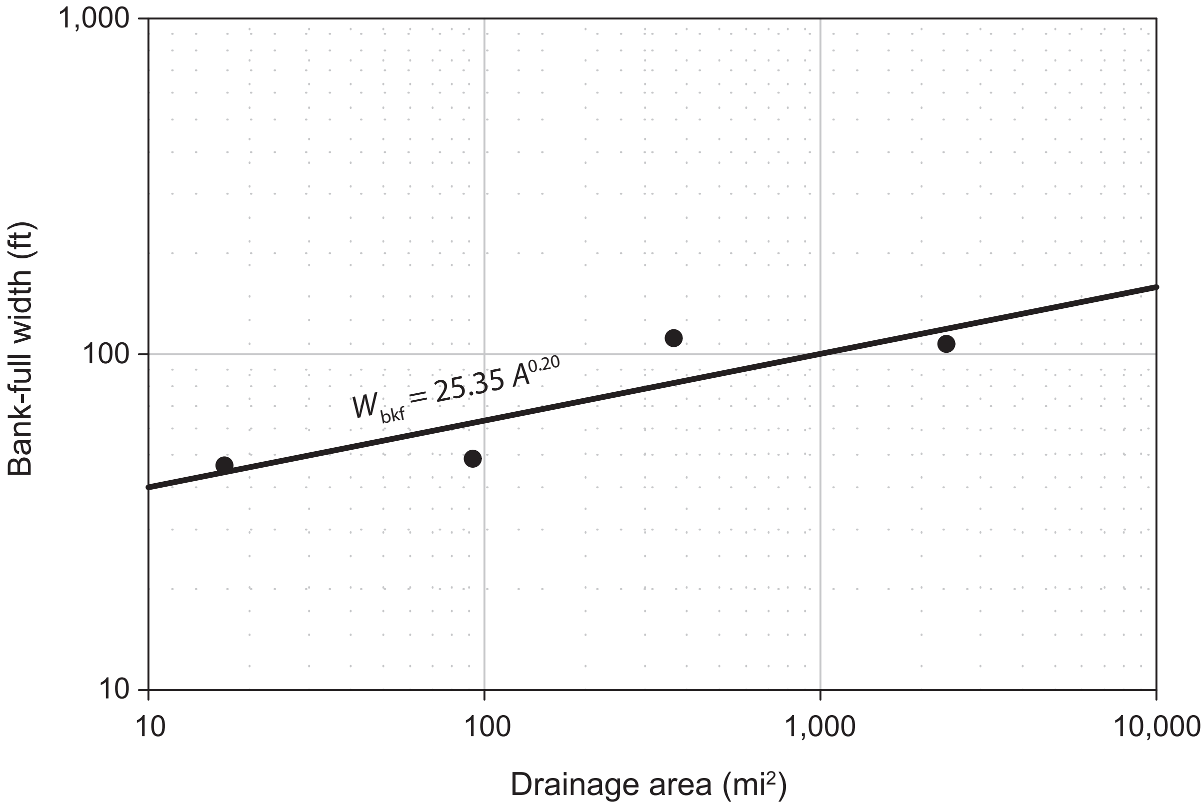

Figure 8.–Regional curve relating bank-full mean width (Wbkf) to drainage area for the Upper Menominee River drainage area in Michigan.

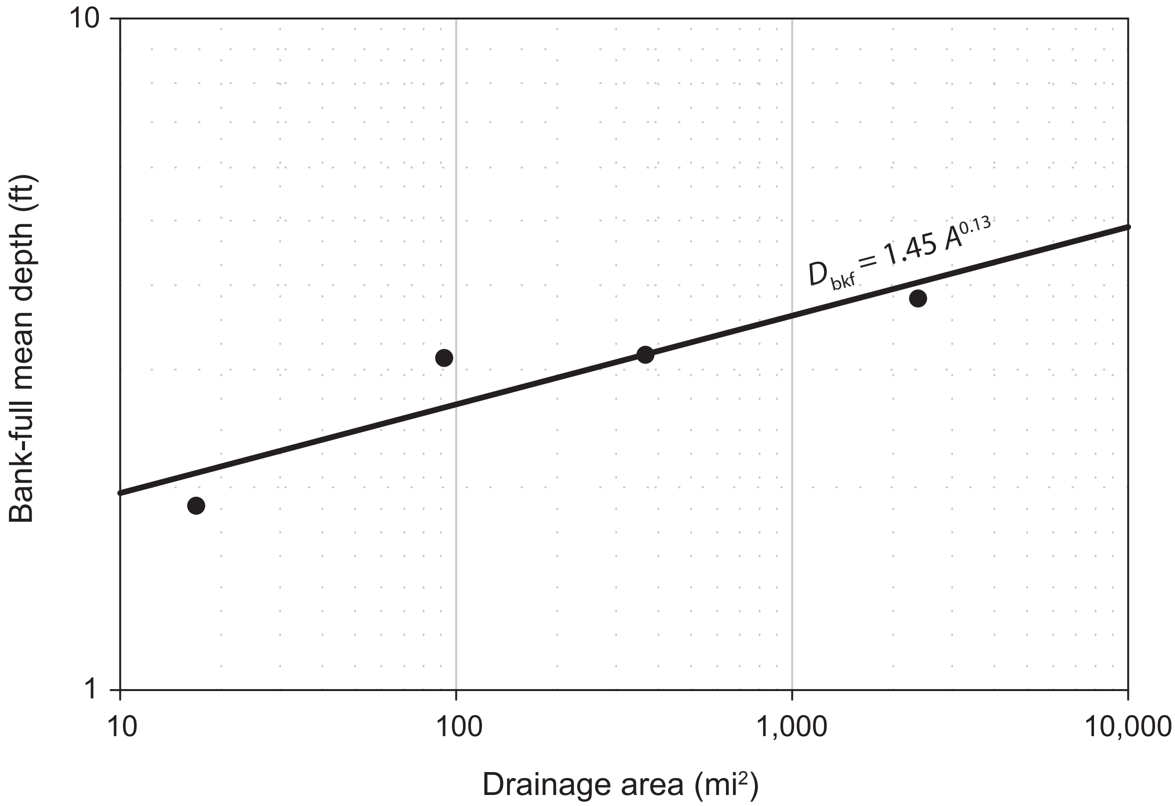

Figure 9.–Regional curve relating bank-full mean depth (Dbkf) to drainage area for the Upper Menominee River drainage area in Michigan.

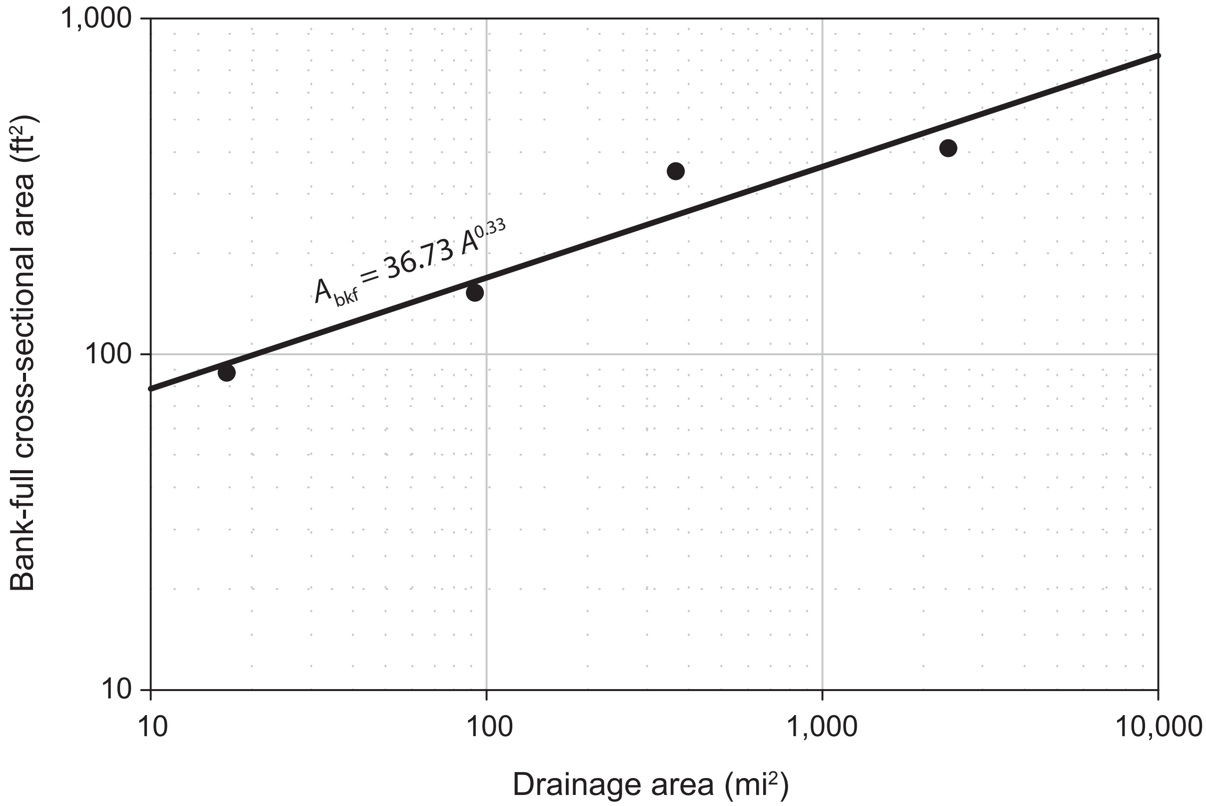

Figure 10.–Regional curve relating bank-full cross-sectional area (Abkf) to drainage area for the Upper Menominee River drainage area in Michigan.

Table 1.–Streamflow gaging stations used for development of regional curves for the Upper Menominee River drainage area, Michigan (dms = degree, minutes, and seconds) (USGS = U.S. Geological Survey).

USGS	Station name	Latitude (dms)	Longitude (dms)	Drainage area (mi^2)	Period of record used for analysis
04060500	Iron River at Caspian, MI	46 03 31	88 37 38	92.10	1948–83, 2004–06
04060933	Brule River near Florence, WI	45 57 39	88 18 57	347.42	1993–2006
04065600	Pine Creek near Iron Mountain, MI	45 55 51	87 58 18	16.80	1971–81
04065500	Sturgeon River near Foster City, MI	45 54 30	87 45 15	237.00	1954–80
04062200	Peshekee River near Champion, MI	45 33 25	88 00 09	133.00	1961–78, 2000–06

Table 2.–Bank-full stream channel characteristics of study sites in the Upper Menominee River drainage area, Michigan (D_{50} = median particle size of streambed material, D_{84}= particle size larger than 84% of streambed material).

Study reach	Iron River	Brule River	Pine Creek	Sturgeon River	Peshekee River
Cross-sectional area (ft^2)	152.2	349.9	87.7	409.6	747.3
Width (ft)	48.8	111.2	46.6	107.1	134.1
Mean depth (ft)	3.1	3.2	1.9	3.8	5.6
Discharge (ft^3/s)	227	1,350	48	890	1,599
Recurrence interval (years)	1.08	1.75	1.00	1.22	1.04
D_{50} (mm)	7.9	33.9	0.1	0.8	37.1
D_{84} (mm)	56	362	0.9	14	77
Width:Depth Ratio	15.6	35.3	24.8	28	24.1
Entrenchment Ratio	1.9	3.2	6.9	5.5	3.8
Slope (ft/1,000 ft)	2.8	0.9	1.2	0.2	1.8
Rosgen stream type	$B4_c$	$C4_{c-}$	C5	$C5_{c-}$	C4

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Approved by Paul W. Seelbach