DEFINING LARGE RIVERS IN MONTANA USING A WADEABILITY INDEX

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EXECUTIVE SUMMARY

A simple, single parameter and physically-based approach for determining river wadeability is proposed by the Montana Department of Environmental Quality (DEQ) to differentiate between wadeable and non-wadeable rivers for the purpose of watershed management. Data from 54 different rivers and 157 sites were compiled to identify key attributes of wadeability including baseflow annual discharge, mean baseflow hydraulic depth and velocity, and the product of the two, herein referred to as the wadeability index. Very consistent relationships between the wadeability index and baseflow annual discharge (r^2=0.91) were found, indicating that hydraulic geometry, and its independent variable discharge, are suitable approximations for assessing wadeability. Data analysis also revealed that a statistically significant changepoint occurs within the wadeability function ($p << 0.001$) around which a wadeable/non-wadeable threshold can be determined at the 90% confidence interval. This threshold correlates to an approximate baseflow annual discharge of 1,500 cfs, depth of 3.15 ft, or wadeability index of 7.24 ft^2/s, and compares well with other wadeability indices proposed in the literature. Using the above criteria, eight rivers in the state were determined to be non-wadeable in at least one portion of their extent. They are: the Bighorn, Clark Fork, Flathead, Kootenai, Madison, Missouri, South Fork of the Flathead, and Yellowstone rivers. As a result, a demarcation upon which future monitoring, modeling, and assessment methodologies for large rivers in Montana is now established.

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INTRODUCTION

The concept of river wadeability is a relatively important component in the field of river management. This is largely due to implications regarding the design and selection of monitoring procedures or equipment, and the importance of how water-quality management endpoints are formulated. Several attempts have been made to define wadeability, of which Wilhelm et al. (2005) and Flotemersch et al. (2006) provide very good reviews. Attributes commonly used to define wadeability include stream order (Strahler, 1957), drainage area, or site specific characteristics such as depth or width. State-level definitions are as follows: in Michigan, a non-wadeable or large river is defined as a reach which cannot be waded across its length or from bank to bank (Wilhelm et al., 2005); in Wisconsin, non-wadeability constitutes a river with more than three kilometers of continuous channel that is too deep to sample by wading during summer baseflow (Lyons et al., 2001); in Ohio, a large river is one that exceeds a drainage area of 1600 km^2 (Ohio EPA, 1989); and, in Idaho, average width at baseflow, average depth at baseflow, average greatest depth, site discharge, mean annual site discharge, and site drainage area have all been considered (Grafe, 2002). Average depth of one meter (Stalnaker et al., 1989), width of 50 meters (Simonson et al. 1994), or a river order of six or greater (Vannote et al., 1980; Sheehan and Rasmussen 1999) have also been suggested.

Clearly, the available literature suggests that a foundation for determining wadeability already exists. However, most of the methods detailed above require that the assessor is physically at the river, or alternatively, are unreliable predictors of wadeability (Flotemersch et al., 2006). Due to these reasons, DEQ wishes to devise a simple, single parameter index that defines wadeability up-front, using readily available data. Therefore we have initiated our own investigation to define appropriate wadeability measures for Montana rivers.

BACKGROUND

The demarcation between wadeable and non-wadeable rivers is ambiguous and indistinct (Wilhelm et al., 2005). As a result, DEQ simply defines a large river as *one that is unwadeable during the summer and early fall baseflow period*. Techniques to distinguish between wadeable/non-wadeable thresholds, as well as what constitutes the baseflow period, are described below.

The Wadeability Index (WI)

In its simplest form, wadeability is dependent on river flow and channel hydraulic geometry. Resultant force is exerted on a person by oncoming flow which must be overcome by the wader to avoid toppling or instability. Abt et al. (1989) conducted tests on human wading subjects in a re-circulating flume, and defined a measure of human stability under different flow conditions as the product number (P.N.). Defined as the multiplicand of the water depth and velocity, P.N. is a direct measure of wadeability, and therefore has been re-coined the wadeability index (WI) for our purposes. WI is calculated as follows (Equation 1) where, d = mean depth (ft) and v = mean velocity (ft/s):

$$WI = d \times v \ \text{ft}^2/\text{s} \qquad \text{(Equation 1)}$$

Results from Abt et al., (1989) indicate that WI values ranging from 7-20 ft^2/s cause instability in human subjects (i.e., the inability to stay upright), and the relative ability of an individual to avoid toppling depends on their height, weight, and compensation skills. A lower limit for stability was suggested at approximately 7 ft^2/s. Consequently, this WI threshold is a logical starting point for partitioning between wadeable and non-wadeable rivers in Montana using safety, and the ability of an assessor to stay upright when wading as the sole measure. Ideally, if the variables described above (i.e. depth and velocity) could be easily ascertained for a site, wadeability could readily be determined.

Existing Measures of Wadeability

For all practical purposes, the only extant measures of river wadeability are made by the U.S. Geological Survey (USGS) as part of their field measurement program. Observations are made for purpose of determining discharge as part of routine gaging activities, and mean depth (*d*), as identified as the cross-sectional area of the measurement divided by the measurement width, and mean velocity (*v*), the quotient of the discharge divided by the cross-sectional area, are all reported. Leopold and Maddock (1953) effectively demonstrate how these observations can be used to approximate the hydraulic geometry of natural river channels using simple power functions (Equations 2 and 3), thereby forming the initial basis of our supposition:

$$d = aQ^b \qquad \text{(Equation 2)}$$

$$v = cQ^d \qquad \text{(Equation 3)}$$

where, Q = discharge (ft^3/s), a, b = experimentally determined coefficient and exponent related to depth, and c, d = experimentally determined coefficient and exponent related to velocity. The utility of these relationships lies in the fact that for any given discharge, the channel hydraulic geometry, and subsequently WI can be determined in a predictable way.

METHODS AND MATERIALS

Data Compilation

All USGS gage sites within the state of Montana having the nomenclature “river”, as well as a handful of selected locations outside the state were compiled by DEQ from the USGS National Water Information System (NWIS, 2010). This was done for the purpose of developing site coefficients and exponents for Equation 2 and 3, and included data from 54 different rivers and 157 gaging sites (Figure 1). For each site, the information necessary to determine wadeability index, i.e. mean cross-sectional velocity, discharge, and top width were acquired over the period of record for the gage. Only sites with 10 field observations or more, and at least 10 years of published streamflow statistics (McCarthy, 2004), or provisional streamflow statistic data from NWIS, were considered. Quality control (QC) for each site was completed through review of the constructed depth and velocity rating curves. Errant values were corrected if identifiable typos

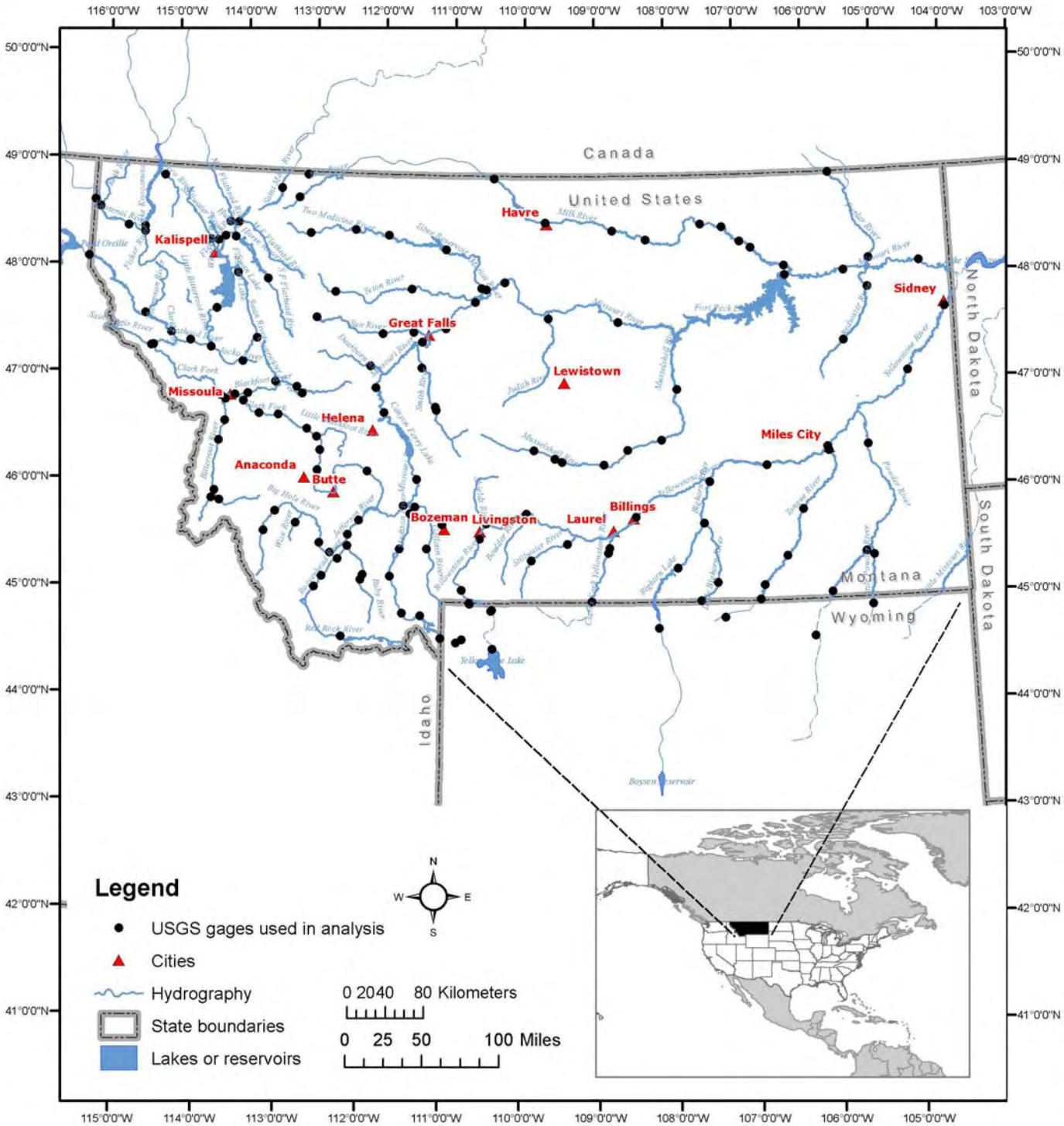

Figure 1. Locations of USGS gage sites used in compilation of Montana's wadeability index.

were found, or were removed in instances where the error or source of the error could not be identified. All field measurements were included in the data compilation regardless of channel control condition or measurement type, and no efforts were made to remove high flow data unless it was clearly apparent that a shift in the rating curve had occurred. While it is possible that some error is introduced into our analysis due to these conditions, the number of sites used in the analysis likely overrides any effects from a handful of anomalous stations.

Relationship between Discharge and Hydraulic Geometry

The relationship between discharge and hydraulic geometry at each gage was determined using the least squares method within Microsoft Excel®. Depth and velocity were evaluated against discharge, and yielded very good site specific regressions with individual coefficients of determination (r^2) ranging from 0.35-0.99 and 0.15-0.99 for depth and velocity, with an average r^2 for all sites of 0.82 and 0.81, respectively. Figure 2 shows an example of the rating curve for USGS 12363000, Flathead River at Columbia Falls MT (top) as well as a combined rating curve for all 157 sites and 54 rivers (bottom). The coefficients and exponents of most sites are very similar to those reported by Leopold and Maddock (1953). The number of observations at each gage site, and r^2 for each rating curve, are shown in Appendix A.

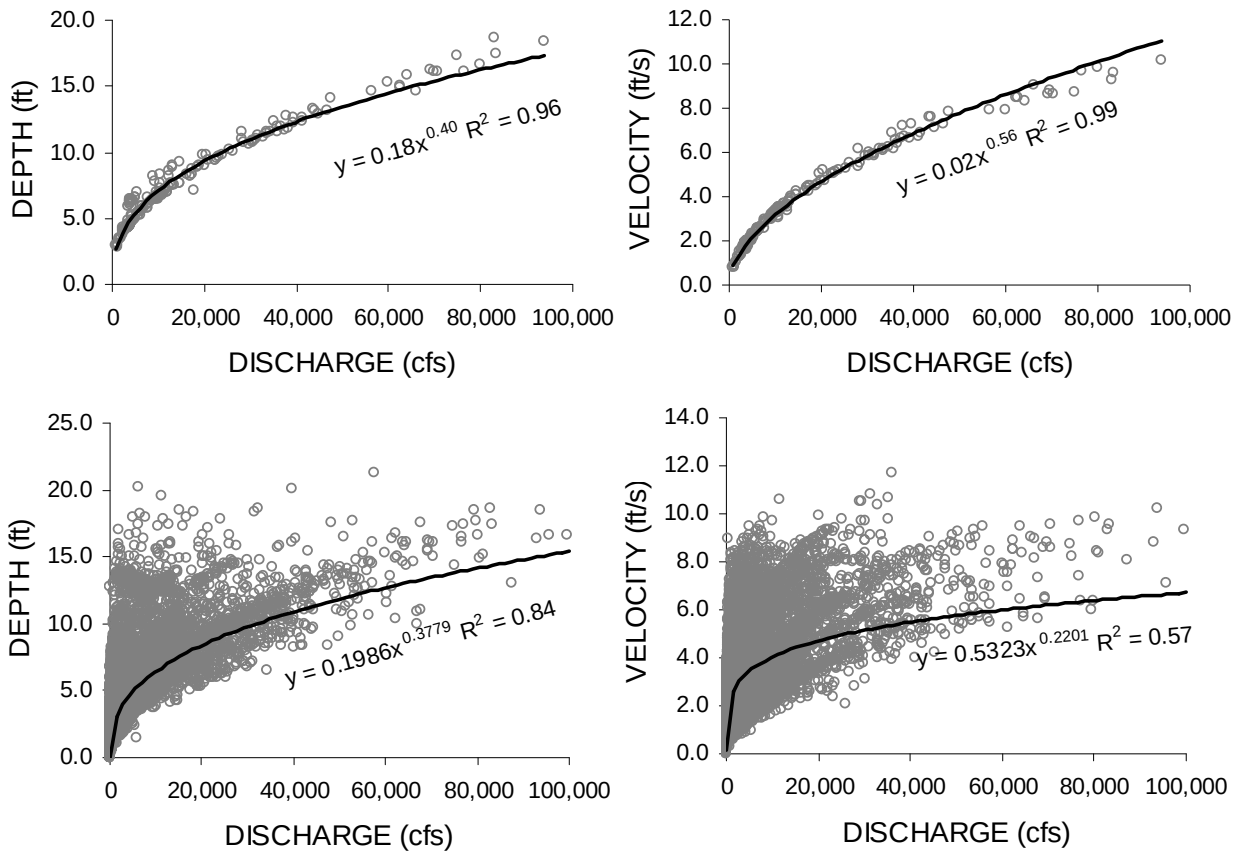

Figure 2. Top. Field observations and site rating curve for USGS station 12363000, Flathead River at Columbia Falls MT, based on 190 observations. Bottom. Field observations and rating curves for all sites.

Computation of the Wadeability Index (WI)

Following development of the site rating curves, the wadeability index was computed for each location using the baseflow annual discharge to provide a Q *vs.* WI dataset. Suplee et al. (2007) defined the onset of baseflow for wadeable streams in Montana as the point of inflection on the recession or falling limb of the mean daily hydrograph. Using this same definition for our analysis, the baseflow period for large rivers in Montana begins on August 1st (Fig. 3) and terminates on October 31st when water temperatures fall below those required for growth of the nuisance algae genus *Cladophora* sp. (Fig. 4). The WI was subsequently computed for this period using the mean of the mean monthly discharges reported by USGS.

Computed WIs ranged from 0.28-36.48 ft^2/s for all rivers examined, and averaged 5.87 ft^2/s (Appendix A). Based solely on the product number and human stability indexes developed by Abt et al. (1989), this in itself suggests that a large proportion of rivers within the state are wadeable during the baseflow period. Further analysis was then completed to determine if there was a statistically-definable change point between wadeable and non-wadeable rivers such that wadeability could be distinguished *a priori*, as detailed in the next section.

Changepoint Analysis of the Wadeable-to-Non-Wadeable Threshold

We carried out changepoint analysis on the baseflow annual discharge Q (x) *vs.* WI index (y) dataset to determine if there was a statistically-definable point where a shift in the wadeability function occurs. Changepoint analysis is a non-parametric statistical method with origins in tree-based modeling used for classification purposes (Breiman et al., 1984). The changepoint method works to minimize deviance within a dataset of paired (x, y) data (Venables and Ripley, 1994; Qian et al., 2003) and systematically bifurcates the dataset at different points along the continuum of x data until the point where the deviance of the resulting two datasets is less than that of the whole dataset. The changepoint statistic can be used to identify shift points or thresholds in x, relative to y, which are not readily identified using other methods (e.g., least squares regression). The defined changepoint was then compared to thresholds defined elsewhere in the literature (e.g., the approach used by Abt et al. [1989], or USGS safety policies).

A statistically significant ($p << 0.001$) changepoint occurred at a baseflow annual discharge of 2,670 ft^3/s, with a 90% confidence interval ranging from 1,320 to 6,540 ft^3/s (Fig. 5). This corresponds to a wadeability index of 10.5 ft^2/s with 90% CI's of 6.5 and 12.1 ft^2/s. Using the lower bound of the 90% confidence interval as a general limit, a baseflow discharge of 1,500 ft^3/s was selected as the wading threshold due to the fact that this falls between the changepoint of 2,670 ft^3/s and its lower bound of 1,320 ft^3/s. Using the lumped depth-discharge regression equation in Fig. 2, this corresponds to a depth of 3.15 ft, and an overall WI of 7.24 ft^2/s.

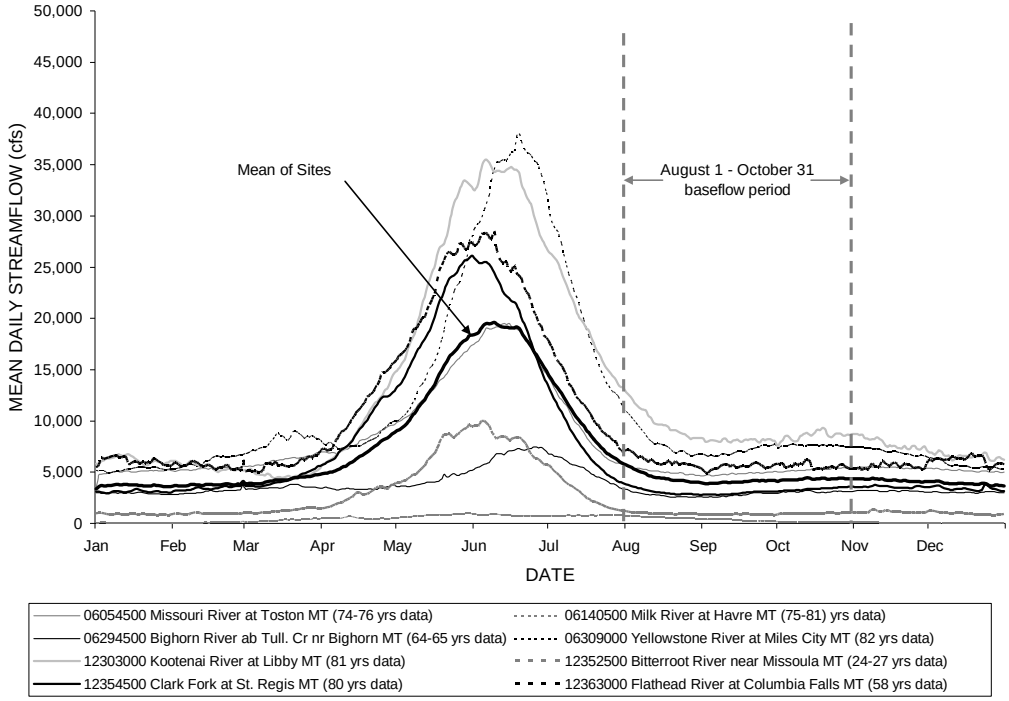

Figure 3. Mean daily hydrographs used to establish the baseflow period.

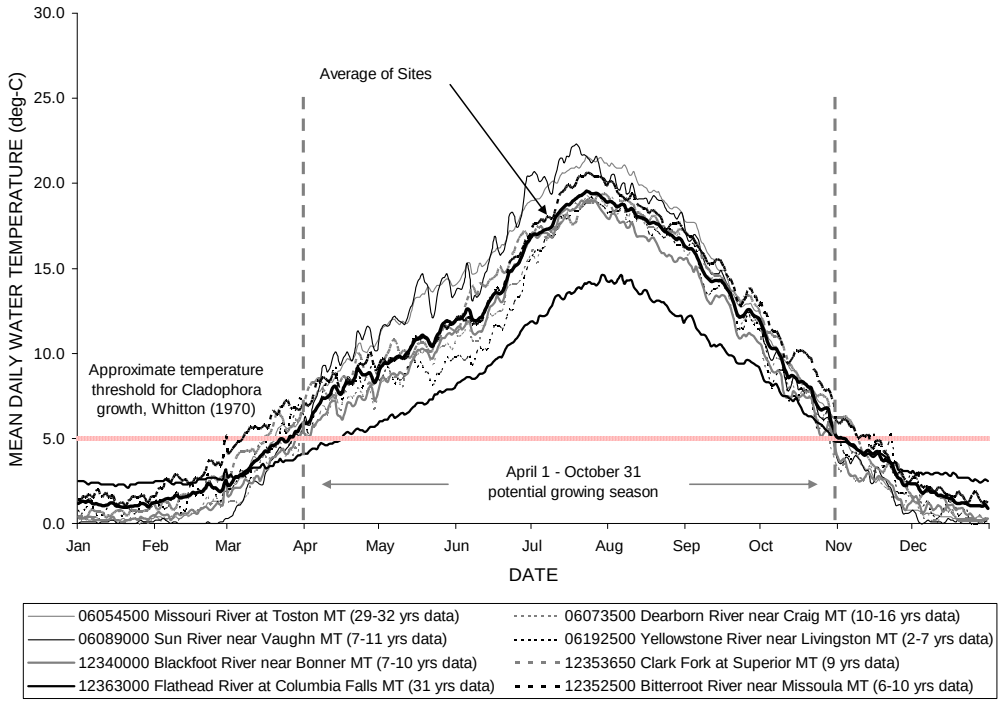

Figure 4. Mean daily water temperatures used to establish the baseflow period.

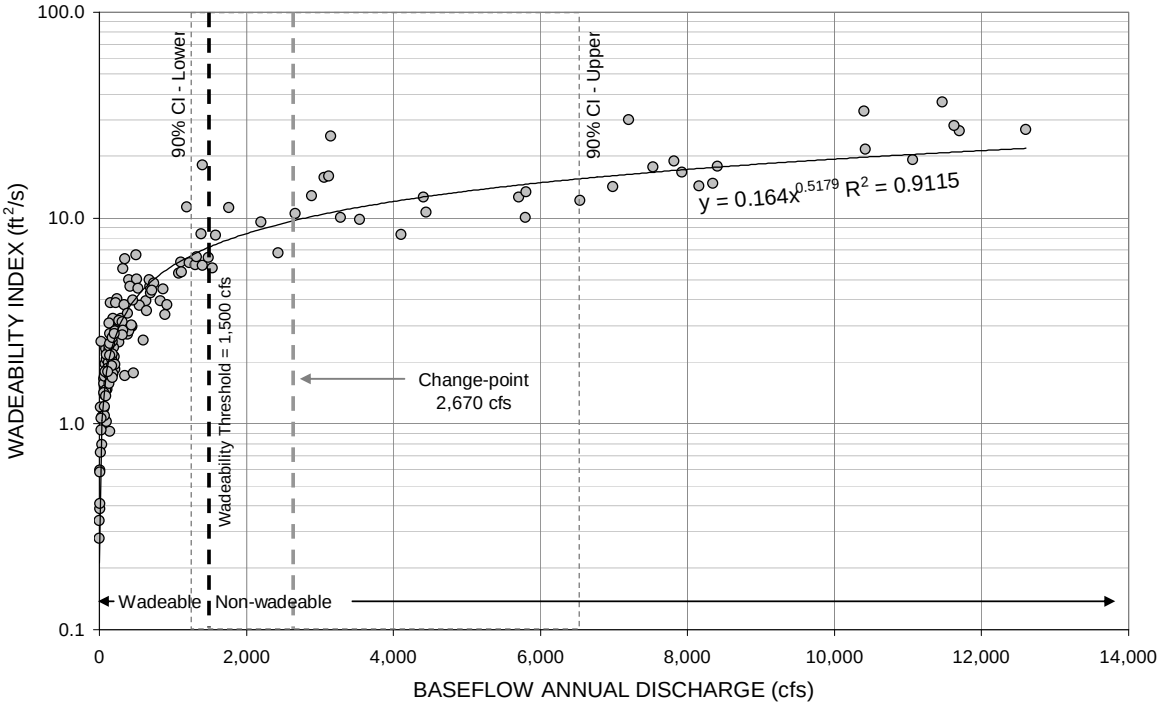

Figure 5. Baseflow annual discharge Q vs. wadeability index (WI) for the 54 sites examined in this study.

DISCUSSION

The wadeability index and wadeable/non-wadeable threshold for rivers in Montana identified through the changepoint analysis (7.24 ft^2/s) correspond well with WI values suggested in the literature. Abt et al. (1989) show that a person of fairly small stature (125 lbs, 68 inches tall), can no longer sustain themselves when WIs are as low as 7.56 ft^2/s. The USGS (safety Memo WRD99.92) uses a WI value of 10 ft^2/s as a safe wading limit. Therefore, our selected depth and WI thresholds are reasonable, and lean somewhat to the protective (i.e., safety-oriented) side. Based on the baseflow annual discharge threshold of 1,500 ft^3/s (which corresponds to a WI of 7.24 ft^2/s, or depth of 3.15 ft, as identified above), the rivers and associated segments determined to be non-wadeable for the purpose of water quality monitoring or watershed management in Montana are shown in Table 1.

Table 1. Non-wadeable river segments within the state of Montana.

River Name	***Segment Description***
Big Horn River	Yellowtail Dam to mouth
Clark Fork River	Bitterroot River to state-line
Flathead River	Origin to mouth
Kootenai River	Libby Dam to state-line
Madison River	Ennis Lake to mouth
Missouri River	Origin to state-line
South Fork Flathead River	Hungry Horse Dam to mouth
Yellowstone River	State-line to state-line

A final caveat that should not go unmentioned regarding this wadeability determination is that in some instances the mean depth, velocity, or wadeability of a specific river segment will inevitably differ from this analysis. This can be readily discerned in review of the residuals from the best-fit equation in Fig. 5 (data not shown). Discrepancies will occur due to the idealized mathematical descriptions of channel hydraulic geometry and wadeability, natural site variability, or the dynamic behavior of rivers. While the relationships presented herein are approximations only, they do provide useful information about river wadeability in general.

CONCLUSION

This document outlines an approach for defining wadeability based solely on baseflow annual discharge, a parameter that is easily estimated regardless of location, drainage area, or hydrologic considerations. In order to develop the appropriate dependencies, the following was completed: (1) hydraulic geometry relationships for 157 sites were evaluated from USGS field observations, (2) the wadeability index was calculated for each site using the mean baseflow annual discharge (i.e. product of the mean hydraulic depth and velocity), and (3) the data were then examined statistically and partitioned into a wadeable and non-wadeable population with the assistance of non-parametric changepoint methods. As a result, a baseflow annual discharge of 1,500 cfs, depth of 3.15 ft, and wadeability index of 7.24 ft^2/s were found to be a suitable threshold for wadeability, and compare well with the literature.

The process described above proved to be a useful tool in distinguishing between wadeable and non-wadeable river segments in Montana. Eight rivers within the regulatory constraints of the state were determined to be non-wadeable using this approach. These included the Bighorn, Clark Fork, Flathead, Kootenai, Madison, Missouri, South Fork of the Flathead, and Yellowstone rivers. As a result, a framework upon which future monitoring, modeling, and assessment methodologies for large rivers in Montana has now been established.

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REFERENCES

Abt, S.R., Wittler, R.J., Taylor, A. and D.J. Love. 1989. Human stability in a high flood hazard zone. Water Resources Bulletin 25 (4): 881-890.

Breiman, L., J.H. Friedman, R. Olshen, and C.J. Stone, 1984. Classification and regression trees. Wadsworth International Group, Belmont, CA.

Flotemersch, J.E., Stribling, J.B., and M.J. Paul. 2006. Concepts and approaches for the bioassessment of non-wadeable streams and rivers. EPA/600/R-06/127. U.S. Environmental Protection Agency Office of Research and Development. Washington, D.C.

Grafe, C. S. 2002. Idaho river ecological assessment framework: an integrated approach. Idaho Department of Environmental Quality. Boise, Idaho.

Leopold, L.B. and T. Maddock. 1953. The hydraulic geometry of stream channels and some physiographic implications. Geological Survey Professional Paper 252.

Lyons, J., R. R. Piette, and K. W. Niermeyer. 2001. Development, validation, and application of a fish-based index of biotic integrity for Wisconsin's large warmwater rivers. Transactions of the American Fisheries Society 130:1077–1094.

McCarthy, P.M. 2004. Statistical summaries of streamflow in Montana and adjacent areas, water years 1900 through 2002. USGS Scientific Investigations Report 2004-5266

NWIS (National Water Information System). 2010. Accessed multiple times May-June 2010. http://waterdata.usgs.gov/nwis

Ohio EPA (Ohio Environmental Protection Agency). 1989. Biological criteria for the protection of aquatic life. Vol. III. Standardized field sampling and laboratory methods for assessing fish sampling and macroinvertebrate communities. Ohio EPA, Division of Water Quality Monitoring and Assessment. Columbus, Ohio.

Qian, S.S., R.S. King, and C.J. Richardson, 2003. Two statistical methods for the detection of environmental thresholds. Ecological Modeling 166: 87-97.

Sheehan, R. J., and J. L. Rasmussen. 1999. Large rivers. Pages 529–559 in C. Kohler, W. A. Hubert (editors.). Inland fisheries management in North America. 2nd edition American Fisheries Society. Bethesda, Maryland.

Simonson, T. D., J. Lyons, and P. D. Kanehl. 1994. Quantifying fish habitat in streams-transect spacing, sample size, and a proposed framework. North American Journal of Fisheries Management 14:607-615.

Stalnaker, C. B., R. T. Milhous, and K. D. Bovee. 1989. Hydrology and hydraulics applied to fishery management in large rivers. Page 13 in D. P. Dodge (editor). Proceedings of the

International Eastern Rivers and Mountains Network – Phase I: Large River Symposium Canadian Special Publication of Fisheries and Aquatic Sciences 106.

Strahler, A.N., 1964. Quantitative geomorphology of drainage basins and channel networks. In: Handbook of Applied Hydrology, V.T. Chow (Editor). McGraw-Hill, New York.

Suplee, M.W., Varghese, A., and J. Cleland. 2007. Developing nutrient criteria for streams: an evaluation of the frequency distribution method. Journal of the American Water Resources Association 43(2):453-472

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Venables, W.N., and B.D. Ripley, 1994. Modern applied statistics with S-Plus. Springer, New York.

Wilhelm, J.G.O., Allan, J.D., Wessell, K.J., Merritt, R.W., and K.W. Cummins. 2005. Habitat assessment of non-wadeable rivers in Michigan. Environmental Management 36(4): 592-609.

Appendix A. Channel data used in the development of wadeability index determinations. Data represent approximations to average channel conditions, and vary depending on site specifics, and location where field measurements are made.

Site ID	*Gage Location*	*Number of Field Measure-ments*	*Depth (r^2)*	*Velocity (r^2)*	*Baseflow Annual Discharge (cfs)*	*Baseflow Annual Depth (ft)*	*Baseflow Annual Velocity (ft/s)*	*Wade-ability Index (ft^2/s)*
05017500	St. Mary River near Babb MT	293	0.90	0.93	688	2.03	2.28	4.6
06012500	Red Rock R bl Lima Reservoir nr Monida MT	104	0.82	0.65	150	2.05	1.88	3.9
06016000	Beaverhead River at Barretts MT	261	0.88	0.90	497	1.90	3.47	6.6
06017000	Beaverhead River at Dillon MT	77	0.70	0.83	349	2.04	3.11	6.3
06018500	Beaverhead River near Twin Bridges MT	320	0.56	0.69	402	1.81	2.77	5.0
06019500	Ruby River above reservoir near Alder MT	328	0.80	0.78	119	1.18	1.93	2.3
06020600	Ruby River below reservoir near Alder MT	322	0.83	0.81	243	1.58	2.56	4.0
06023000	Ruby River near Twin Bridges MT	23	0.35	0.50	184	1.35	2.40	3.2
06024450	Big Hole River bl Big Lake Cr at Wisdom MT	208	0.75	0.64	54	0.90	1.32	1.2
06024540	Big Hole River below Mudd Creek nr Wisdom MT	140	0.79	0.77	139	0.91	1.01	0.9
06024590	Wise River near Wise River MT	23	0.91	0.99	82	1.42	1.38	2.0
06025500	Big Hole River near Melrose MT	312	0.84	0.84	444	1.57	1.90	3.0
06026210	Big Hole River near Glen MT	83	0.98	0.99	350	1.27	1.35	1.7
06026500	Jefferson River nr Twin Bridges MT	156	0.89	0.73	1,107	2.45	2.49	6.1
06027600	Jefferson River at Parsons Bdg nr Silver Star MT	27	0.75	0.92	831	1.92	2.06	3.9
06033000	Boulder River near Boulder MT	254	0.86	0.81	32	0.85	0.93	0.8
06036650	Jefferson River near Three Forks MT	339	0.71	0.73	1,230	3.06	1.98	6.0
06036905	Firehole River near West Yellowstone MT	140	0.42	0.43	278	1.87	1.57	2.9
06037000	Gibbon River near West Yellowstone MT	104	0.77	0.49	96	1.11	1.99	2.2
06037500	Madison River near West Yellowstone MT	179	0.63	0.78	432	1.21	2.45	3.0
06038500	Madison River bl Hebgen Lake nr Grayling MT	195	0.87	0.76	1,193	3.58	3.16	11.3
06038800	Madison River at Kirby Ranch nr Cameron MT	155	0.83	0.95	1,310	1.62	3.66	5.9
06040000	Madison River near Cameron MT	10	0.89	0.91	1,580	2.20	3.73	8.2
06041000	Madison River bl Ennis Lake nr McAllister MT	242	0.45	0.68	1,760	3.34	3.35	11.2
06042600	Madison River at Three Forks MT	46	0.79	0.89	1,390	2.94	2.84	8.4
06043500	Gallatin River near Gallatin Gateway MT	248	0.97	0.99	511	1.97	2.55	5.0
06048700	East Gallatin R bl Bridger C nr Bozeman MT	140	0.86	0.86	59	1.04	1.59	1.7
06052500	Gallatin River at Logan MT	348	0.86	0.80	637	1.59	2.49	4.0
06054500	Missouri River at Toston MT	226	0.99	0.99	3,543	3.77	2.61	9.8
06065500	Missouri River below Hauser Dam nr Helena MT	86	0.85	0.91	2,887	4.65	2.75	12.8
06066500	Missouri River bl Holter Dam nr Wolf Cr MT	417	0.86	0.93	4,413	4.99	2.53	12.6
06073500	Dearborn River near Craig MT	190	0.80	0.87	67	1.00	1.19	1.2
06076690	Smith River near Ft Logan MT	267	0.84	0.62	103	1.09	1.89	2.1
06077200	Smith River bl Eagle Cr nr Fort Logan MT	137	0.86	0.84	112	1.03	1.43	1.5
06077500	Smith River near Eden MT	47	0.92	0.89	160	1.14	1.63	1.9
06078200	Missouri River near Ulm MT	139	0.71	0.72	4,107	5.39	1.54	8.3
06078500	N F Sun River nr Augusta MT	51	0.79	0.89	142	1.11	1.72	1.9
06085800	Sun River at Simms MT	150	0.82	0.65	177	1.14	1.55	1.8
06089000	Sun River near Vaughn MT	475	0.92	0.76	464	1.19	1.48	1.8
06090300	Missouri River near Great Falls MT	269	0.95	0.97	5,797	3.67	2.74	10.1
06090800	Missouri River at Fort Benton MT	236	0.93	0.96	5,707	5.60	2.25	12.6
06091700	Two Medicine River bl S F nr Browning MT	342	0.72	0.90	121	1.15	1.61	1.9
06093600	Two Medicine River near Cut Bank MT	49	0.70	0.68	266	1.22	2.05	2.5
06099500	Marias River near Shelby MT	436	0.85	0.70	384	1.65	1.64	2.7
06101500	Marias River near Chester MT	260	0.67	0.56	872	2.26	2.00	4.5
06102050	Marias River near Loma MT	55	0.53	0.76	1,084	2.27	2.37	5.4
06102500	Teton River bl South Fork nr Choteau MT	117	0.64	0.83	88	1.04	2.24	2.3
06108000	Teton River near Dutton MT	372	0.80	0.60	70	1.08	1.42	1.5
06108800	Teton River at Loma MT	118	0.76	0.74	9	0.50	0.77	0.4
06109500	Missouri River at Virgelle MT	151	0.99	0.99	6,540	4.92	2.46	12.1
06114700	Judith River nr mouth, nr Winifred MT	81	0.70	0.83	236	1.52	1.90	2.9
06115200	Missouri River near Landusky MT	228	0.86	0.81	6,983	6.06	2.35	14.2
06120500	Musselshell River at Harlowton MT	246	0.76	0.77	71	0.97	1.42	1.4
06122800	Musselshell River nr Shawmut MT	115	0.90	0.77	62	1.16	1.35	1.6
06123030	Musselshell River ab Mud Cr nr Shawmut MT	91	0.85	0.80	35	0.83	1.30	1.1
06126050	Musselshell River near Lavina MT	134	0.89	0.78	122	1.11	1.79	2.0
06126500	Musselshell River near Roundup MT	236	0.83	0.65	132	1.25	1.85	2.3
06127500	Musselshell River at Musselshell MT	183	0.91	0.54	108	1.26	1.36	1.7
06130500	Musselshell River at Mosby MT	246	0.89	0.78	101	0.96	1.76	1.7
06132000	Missouri River below Fort Peck Dam MT	30	0.94	0.98	11,467	9.15	3.99	36.5
06132200	S F Milk River near Babb MT	253	0.73	0.60	16	0.71	1.02	0.7
06133500	N F Milk River ab canal nr Browning MT	269	0.45	0.15	17	0.87	1.37	1.2

Site ID	Gage Location	Number of Field Measure-ments	Depth (r^2)	Velocity (r^2)	Baseflow Annual Discharge (cfs)	Baseflow Annual Depth (ft)	Baseflow Annual Velocity (ft/s)	Wade-ability Index (ft^2/s)
06135000	Milk River at Eastern Crossing of Int Bndry	491	0.84	0.86	335	1.59	1.84	2.9
06140500	Milk River at Havre MT	351	0.81	0.27	424	3.03	1.54	4.7
06154100	Milk River nr Harlem MT	248	0.87	0.58	321	4.68	1.21	5.7
06155030	Milk River near Dodson MT	197	0.94	0.48	135	2.19	1.41	3.1
06155900	Milk River at Cree Crossing nr Saco MT	74	0.84	0.64	75	1.03	1.65	1.7
06164510	Milk River at Juneburg Bridge near Saco MT	232	0.92	0.48	259	1.60	1.79	2.9
06172000	Milk River near Vandalia MT	26	0.94	0.61	226	3.42	1.13	3.9
06172310	Milk River at Tampico MT	183	0.93	0.56	163	1.51	1.45	2.2
06174500	Milk River at Nashua MT	270	0.95	0.66	298	1.48	2.19	3.2
06177000	Missouri River near Wolf Point MT	220	0.88	0.77	11,700	9.34	2.84	26.5
06177500	Redwater River at Circle MT	135	0.80	0.43	2	0.44	0.77	0.3
06177825	Redwater River near Vida MT	10	0.79	0.80	6	0.49	0.83	0.4
06178000	Poplar River at International boundary	233	0.75	0.57	3	0.41	0.67	0.3
06181000	Poplar River near Poplar MT	262	0.77	0.73	27	0.91	1.03	0.9
06185500	Missouri River near Culbertson MT	123	0.85	0.87	11,067	7.59	2.52	19.1
06186500	Yellowstone River at Yellowstone Lk Outlet YNP	249	0.91	0.90	1,407	2.43	2.43	5.9
06187550	Yellowstone River at Tower Junction YNP	14	0.58	0.99	1,407	5.59	3.23	18.1
06188000	Lamar River nr Tower Ranger Station YNP	210	0.90	0.74	265	1.62	1.97	3.2
06190540	Boiling River at Mammoth YNP	166	0.65	0.91	27	1.41	1.79	2.5
06191000	Gardner River near Mammoth YNP	243	0.87	0.95	142	1.25	2.19	2.7
06191500	Yellowstone River at Corwin Springs MT	278	0.80	0.89	2,197	3.59	2.66	9.6
06192500	Yellowstone River near Livingston MT	322	0.77	0.93	2,670	3.85	2.73	10.5
06195600	Shields River near Livingston MT	323	0.91	0.92	139	1.11	1.96	2.2
06200000	Boulder River at Big Timber MT	231	0.87	0.93	219	1.47	1.93	2.8
06202510	Stillwater River above Nye Creek nr Nye MT	74	0.88	0.91	197	1.54	1.52	2.4
06205000	Stillwater River near Absorakee MT	256	0.85	0.92	677	1.77	2.83	5.0
06207500	Clarks Fork Yellowstone River nr Belfry MT	276	0.95	0.95	403	1.70	1.65	2.8
06208500	Clarks Fork of the Yellowstone at Edgar MT	201	0.85	0.89	542	1.77	2.12	3.8
06208800	Clarks Fork Yellowstone River nr Silesia MT	103	0.93	0.90	698	1.74	2.48	4.3
06214500	Yellowstone River at Billings MT	322	0.88	0.88	4,447	3.44	3.10	10.6
06279500	Bighorn River at Kane WY	257	0.90	0.91	1,537	2.48	2.30	5.7
06287000	Bighorn River near St. Xavier MT	420	0.79	0.91	3,060	5.40	2.91	15.7
06289000	Little Bighorn River at State Line nr Wyola MT	250	0.74	0.97	103	1.33	1.63	2.2
06290500	Little Bighorn R bl Pass Cr nr Wyola MT	202	0.87	0.90	114	1.16	1.60	1.9
06294000	Little Bighorn River near Hardin MT	249	0.64	0.52	134	1.23	1.94	2.4
06294500	Bighorn River above Tullock Cr, nr Bighorn MT	169	0.49	0.57	3,123	6.74	2.36	15.9
06295000	Yellowstone River at Forsyth MT	154	0.41	0.75	7,533	7.75	2.27	17.6
06298000	Tongue River near Dayton WY	479	0.93	0.98	91	1.24	1.18	1.5
06306300	Tongue River at State Line nr Decker MT	284	0.81	0.81	214	1.21	1.52	1.8
06307500	Tongue River at Tongue R Dam nr Decker MT	257	0.91	0.92	314	1.65	1.90	3.1
06307616	Tongue R at Birney Day School Br nr Birney MT	224	0.94	0.77	322	1.67	1.71	2.8
06307830	Tongue River below B. Bridge, nr Ashland MT	75	0.82	0.52	337	1.60	2.37	3.8
06308500	Tongue River at Miles City MT	282	0.83	0.70	210	1.29	1.63	2.1
06309000	Yellowstone River at Miles City MT	251	0.93	0.91	8,350	4.89	3.01	14.7
06317000	Powder River at Arvada WY	422	0.73	0.84	99	0.70	1.46	1.0
06324500	Powder River at Moorhead MT	356	0.80	0.84	183	1.14	1.52	1.7
06324710	Powder River at Broadus MT	102	0.92	0.90	172	1.37	1.50	2.1
06324970	Little Powder River ab Dry Cr near Weston WY	361	0.84	0.54	7	0.53	1.13	0.6
06325500	Little Powder River near Broadus MT	74	0.67	0.53	9	0.52	1.12	0.6
06326500	Powder River nr Locate MT	241	0.91	0.86	214	1.10	1.76	1.9
06327500	Yellowstone River at Glendive MT	43	0.77	0.98	7,923	6.60	2.53	16.7
06329500	Yellowstone River near Sidney MT	299	0.76	0.89	8,157	6.40	2.23	14.3
12301300	Tobacco River near Eureka MT	269	0.89	0.95	116	1.12	1.57	1.7
12301933	Kootenai River bl Libby Dam nr Libby MT	122	0.98	0.99	11,633	11.74	2.39	28.0
12303000	Kootenai River at Libby MT	368	0.85	0.94	12,600	4.71	5.69	26.8
12302055	Fisher River near Libby MT	51	0.85	0.86	132	1.17	1.34	1.6
12304500	Yaak River near Troy MT	364	0.95	0.96	187	1.46	1.20	1.7
12305000	Kootenai River at Leonia ID	236	0.93	0.95	7,820	4.94	3.84	19.0
12323800	Clark Fork near Galen MT	210	0.75	0.89	79	1.22	1.47	1.8
12324200	Clark Fork at Deer Lodge MT	317	0.83	0.95	175	1.37	1.59	2.2
12324590	Little Blackfoot near Garrison MT	371	0.74	0.87	64	0.94	1.50	1.4
12324680	Clark Fork at Goldcreek MT	333	0.83	0.93	314	1.47	1.85	2.7
12331800	Clark Fork near Drummond MT	214	0.88	0.83	453	1.65	2.42	4.0
12331900	Clark Fork near Clinton MT	156	0.75	0.76	526	1.93	2.35	4.5
12334550	Clark Fork at Turah Bridge near Bonner MT	244	0.78	0.74	739	1.88	2.57	4.8

Site ID	*Gage Location*	*Number of Field Measure-ments*	*Depth (r^2)*	*Velocity (r^2)*	*Baseflow Annual Discharge (cfs)*	*Baseflow Annual Depth (ft)*	*Baseflow Annual Velocity (ft/s)*	*Wade-ability Index (ft^2/s)*
12338300	N F Blackfoot R ab Dry Gulch nr Ovando MT	127	0.88	0.98	183	1.18	1.42	1.7
12335100	Blackfoot R ab Nevada Cr nr Helmville MT	104	0.72	0.67	171	1.18	1.62	1.9
12339450	Clearwater River near Clearwater MT	164	0.85	0.95	74	1.14	0.96	1.1
12340000	Blackfoot River nr Bonner MT	265	0.88	0.93	712	2.18	2.04	4.4
12340500	Clark Fork above Missoula MT	246	0.92	0.95	1,483	3.17	2.02	6.4
12342500	W F Bitterroot River nr Conner MT	298	0.90	0.98	178	1.36	1.85	2.5
12343400	E F Bitterroot River nr Conner MT	41	0.71	0.88	120	1.28	1.40	1.8
12344000	Bitterroot River near Darby MT	351	0.83	0.97	383	1.61	2.15	3.4
12350250	Bitterroot River at Bell Crossing nr Victor MT	137	0.83	0.50	441	1.89	1.60	3.0
12351200	Bitterroot River near Florence MT	76	0.94	0.88	891	2.00	1.69	3.4
12352500	Bitterroot River near Missoula MT	161	0.84	0.75	919	2.42	1.56	3.8
12353000	Clark Fork below Missoula MT	246	0.98	0.99	2,437	4.40	1.54	6.8
12354000	St. Regis River near St. Regis, MT	72	0.92	0.84	147	1.09	1.97	2.2
12354500	Clark Fork at St. Regis MT	248	0.97	0.98	3,283	4.46	2.25	10.0
12355500	N F of Flathead nr Columbia Falls MT	421	0.97	0.97	1,320	2.32	2.79	6.5
12358500	M F Flathead River nr West Glacier MT	269	0.98	0.98	1,119	2.17	2.52	5.5
12359800	S F Flathead R ab Twin C nr Hungry Horse MT	274	0.96	0.95	647	2.09	1.70	3.6
12362500	S F of Flathead River nr Columbia Falls MT	136	0.84	0.66	3,147	8.24	3.03	24.9
12363000	Flathead River at Columbia Falls MT	190	0.96	0.99	5,810	5.70	2.35	13.4
12365000	Stillwater River near Whitefish MT	162	0.95	0.71	139	2.78	0.88	2.5
12366000	Whitefish River near Kalispell MT	428	0.71	0.87	87	1.11	1.23	1.4
12369200	Swan River near Condon MT	157	0.87	0.95	76	1.12	1.09	1.2
12370000	Swan River nr Bigfork MT	323	0.94	0.97	595	1.64	1.55	2.6
12372000	Flathead River near Polson MT	412	0.42	0.99	7,203	13.12	2.29	30.1
12381400	S F Jocko River near Arlee MT	187	0.76	0.87	29	0.94	1.13	1.1
12388200	Jocko River at Dixon MT	159	0.87	0.97	180	1.34	1.96	2.6
12388700	Flathead River at Perma MT	118	0.89	0.96	8,407	8.80	2.02	17.8
12389000	Clark Fork near Plains MT	195	0.94	0.98	10,420	11.44	1.89	21.6
12389500	Thompson River near Thompson Falls MT	296	0.81	0.87	207	1.25	2.18	2.7
12391950	Clark Fork River below Cabinet Gorge Dam ID	56	0.84	0.99	10,400	21.25	1.56	33.1