A GIS Approach for Delineating Variable-Width Riparian Buffers Based on Hydrological Function

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Background

Delineation of riparian management zones using geographic information system (GIS) analysis is often accomplished by applying a standard-width buffer around previously mapped hydrographic features. Buffering is a simple and straightforward GIS procedure, and a fixed-width riparian setback is easily transferable from GIS to the field or among different geographic regions. In many GIS environments, a fixed-width buffer may be the only choice permitted by time and resource constraints; manually interpreting and digitizing riparian areas for even a township-sized region would be a large undertaking, and for an entire state would be completely outside the scope of most budgets.

Unfortunately, a fixed-width buffer approach for riparian delineation involves generalizations that may result in gross inaccuracies when estimating amount of a land base that might be considered riparian. Fixed-width buffers may leave lands that are riparian out of such a delineation, for instance when wide floodplains or low terraces extend beyond the standard buffer width. Alternatively, lands that are arguably not riparian can be included in a fixed-width buffer, such as lands that are adjacent to small order streams, but are too distant to be influenced by or to influence the stream.

Recognizing the limitations of a fixed-width buffer approach, the U.S. Forest Service North Central Research Station and the Minnesota Department of Natural Resources Forestry Resource Assessment Office, set out to develop a GIS-based methodology for variable width delineation that is functional derived and potentially widely applicable. Our approach is based on a hydrogeomorphic delineation model (Ilhardt et al 2000) that uses topography to predict flood-prone area surrounding a stream or river, as well as shoreline proximity, to delineate the riparian area. In an earlier study, Skally and Sagor (2001) applied a similar methodology to a small stream segment in northern Minnesota. Their variable width buffer was delineated using this hydrogeomorphic approach in the field with a GPS. Our study is an attempt to expand the application to whole watersheds and to model the process in a GIS so that it is widely applicable. With our method, the GIS collects land elevation data surrounding sample points along a stream and creates a riparian boundary relative to each sample point. The result is a variable-width polygon roughly corresponding to the 50-year flood inundation zone.

We developed and tested the procedure on two stream basins in Minnesota – the Prairie River watershed in the immature, generally flat and heavily glaciated northeastern part of the state, and the Root River watershed in the mature, dissected and unglaciated southeast part of the state. In this report, we summarize the methodology and present results from the two watersheds. For each, we compare results on amounts, land use, and ownership of riparian areas as estimated using the variable-width approach, to the same data derived from standard fixed-width buffers.

Data layers

Minnesota is fully covered by hydrographic data layers digitized from 1:24,000 scale source materials: stream and lake data from standard 7.5-minute topographic quadrangles, and wetlands from National Wetland Inventory mapsheets. All data layers are available from the MIS Bureau, Minnesota DNR:

- http://deli.dnr.state.mn.us/metadata/full/dnrlkpy3.html for lakes,
- http://deli.dnr.state.mn.us/metadata/full/nwixxpy3.html for wetlands, and
- http://deli.dnr.state.mn.us/metadata/full/dnrstln3.html for streams.

These data layers were used in ESRI Arc/INFO GIS environment together with USGS 30-meter DEMs (http://deli.dnr.state.mn.us/metadata/full/dem30im3.html) and a watershed boundary layer (http://deli.dnr.state.mn.us/metadata/full/mnwshpy3.html) to create riparian zone data layers. A combined hydrographic layer was first created. All lakes and NWI open-water wetland polygons, i.e., those coded 3, 4 and 5 in U.S. Fish & Wildlife Service Circular 39 (Shaw and Fredine 1956), were clipped to the appropriate watershed boundary and placed into a single polygon coverage. The Arc/INFO `DISSOLVE` command was used to join overlapping or adjacent polygons. All streams were also clipped to the selected watershed boundary, and the Arc/INFO `ERASE` command was used to eliminate all lines in the clipped streams dataset that overlapped with the lakes and wetlands, leaving intermittent, perennial and unclassified streams and drainage ditches as a base layer for the variable-width boundary. (Drainage ditches were included to avoid stream discontinuity.) Next, a stream order attribute was added to the streams layer, and stream order values were calculated manually in ArcEdit. This attribute was later used as a general surrogate to determine flood height.

Defining the riparian boundary

Since our variable-width approach is based on flood elevation, it was not applied to lakes and wetlands. Rather, the lakes and wetlands polygon dataset was buffered by 100 feet as the riparian boundary for those features. This temporary polygon layer was set aside to be combined later with riparian polygons derived from the streams layer.

Various criteria were investigated to fit DEM data to the Ilhardt et al. (2000) definition for the riparian boundary around streams; the 50-year flood inundation zone for streams in each watershed was finally selected. The mapping approach first established sample points at regular intervals along each stream segment, followed by exploration of the DEM outward from those points along transects roughly perpendicular to the segment. For each sample point, a target elevation was calculated by adding a 50-year 'flood height' value to the stream elevation at the sample point. Flood height values were predetermined using stream order as a surrogate for stream width. Along each transect, the coordinates of every 30-meter DEM elevation point less than the target elevation were written to an ASCII text file. The transect was prolonged until a value above the target elevation was reached. Processing then moved to the next sample point along the stream. Processing started at one end of a stream segment, sampled one side of the segment until reaching the far end, then "turned around" and sampled the opposite side of the segment back to the start point. When one stream segment was completed, the program moved to the next segment. After all stream segments in the basin were completed, an Arc/INFO `GENERATE` file was created, containing all transect points that would be inundated if the associated stream flooded to its calculated 50-year height. This generate file was turned into an Arc/INFO point coverage using the `GENERATE` command. Next an Arc/INFO polygon coverage was created from the DEM elevation data via the `GRIDPOLY` command. These polygons contained a `GRID-CODE` attribute whose value represented the elevation of the polygon. All elevation polygons that intersected with the "inundation" points were identified using the ArcPlot `RESELECT` command (with `OVERLAP POINT WITHIN` options). A dummy attribute item in the selected set of "inundated" polygons was calculated to be 1, all other polygons having 0 values. Finally, the Arc/INFO `DISSOLVE` command was run on the elevation polygons, leaving only polygon boundaries showing the approximate 50-year flood inundation area for the entire basin.

The last step was to combine the lake and wetland 100-foot buffer coverage with the stream 50-year flood inundation area coverage, using the Arc/INFO `UNION` command. The `DISSOLVE` command was again used to eliminate boundaries between overlapping and/or adjacent riparian polygons, and create the final variable-width riparian coverage. This coverage was compared against the standard 200-foot buffer mapped in the existing Minnesota DNR 200-Foot Riparian Zone dataset for the two target basins (http://jmaps.dnr.state.mn.us/gis/dp_full_record.jsp?mpid=39000118&ptid=21&fcid=1&dsid=66).

Results

Stream riparian boundaries differ substantially between the two delineation approaches (Figures 1 and 2), as does total riparian area (Table 1). In both the Prairie River and Root River basins, the variable-width riparian buffers often extend 800 to 2500 feet from the stream. Wide buffers are common throughout the Prairie River watershed, as in some portions of the Root River watershed, due to its minimal topographic relief. Consequently, extensive lowland areas, that are within the 50-year flood prone extent, are delineated as riparian using the variable-width approach (Figures 1,2). Total riparian acreage for the Prairie River using the variable-width approach is 75,725 acres, or 26% of total basin area, nearly 2.5 times the estimate using the 200-foot fixed-width buffer In the steeper topography of the Root River basin, variable-width riparian zones tend to conform more closely to the fixed-width buffers, yet total riparian acreage using the variable-width approach (281,051 acres or 27% or total basin area) is still 1.5 times the fixed-width estimate.

Differences in delineation methods affect not only the total area of riparian buffers, but also the proportions of land ownerships and land uses included within riparian zones. We applied the fixed-width and variable-width riparian boundaries to land cover and land stewardship layers as delineated in the Minnesota Gap Analysis Program, using the following data sources:

- http://deli.dnr.state.mn.us/metadata/full/gapstpy2.html
- http://deli.dnr.state.mn.us/metadata/full/gap1ara3.html

Results are summarized in Tables 2 through 4. In general, land cover and ownership acreage grew proportionally with riparian area increases and the percentages of riparian area in different land cover and ownership classes tended to remain similar between definitions. Regardless of delineation approach, land cover in the Prairie River watershed was dominated by aspen-paper birch forest, lowland shrubs, and upland shrubs. Ownership in this watershed was dominated by small private and county ownership regardless of delineation approach. In the Root River watershed, dominant land cover in riparian areas included cropland, grassland, and red oak forest. Ownership was almost exclusively small private parcels regardless of delineation approach. Notably, the amount of cropland within the riparian buffer in the Root River watershed increased from 42.6% to 65.6% of total basin area using the variable-width approach, while red oak forest declined from 12% to 4.5%. This reflects the fact that agriculture, the dominant land use in the watershed, often extends down the stream valleys to within the 50-year flood prone area. Moreover, there is less red oak forest, as a percent of total watershed area, outside of riparian areas than inside of them.

Discussion

While the program and methodology were constructed as robustly and generally as possible, the resulting set of riparian polygons is very dependent on the GIS data on which it is based. Streams that exist in the real world but not in the hydrographic GIS data layer generate no riparian polygons. In Minnesota, and many other states, the U.S. Geological Survey 30-meter digital elevation model (DEM) is the only available continuous topographic dataset. While for small-scale applications its resolution is usually adequate, it became clear early in this study that many of the real-world topographic features we hoped to use to define riparian zone boundaries were obscured or absent in the DEM, especially in the case of small first- and second-order streams. After several attempts to extract the needed information from the DEM, ultimately the riparian delineation criteria had to be adjusted to allow for the coarseness of the available data. These adjustments simplified the approach and in the end may have made the model more robust.

Drawbacks to our stream riparian delineation approach include complexity of computing and data processing, preprocessing of datasets, and data resolution issues beyond those raised by the simple fixed-width buffer approach. The most time-consuming additional task is assigning stream order attribute values to the base hydrographic layer. Once data are prepared for processing, the computer does most of the work: as each stream segment had to be processed individually, the procedures were written into an Arc Macro Language (AML) program and the steps automated. Processing took several days for each watershed. As the program evolved many opportunities for streamlining the process were encountered; once these are addressed, processing time should decrease.

An additional and less tractable drawback is that a variable-width buffer is inherently difficult to transfer from the GIS to the field, whereas a fixed-width buffer readily translates into real-world application for logging, resource inventory, or agricultural work. Finally, and most importantly, our stream riparian delineation method relies heavily on the accuracy and precision of the elevation dataset. A complete set of elevation data is often difficult to come by for large areas. And often when such a complete dataset is found, the extent of the dataset limits its resolution. Moreover, 30-meter DEM data often are not finely resolved enough to track landform changes, particularly for first-order and sometimes even second-order stream riparian boundaries. Those developing GIS compatible riparian delineations have the choice of defining their riparian layer as best as available data will allow (thereby altering their riparian definition to fit available data), or developing new higher resolution data layers to support the layer they are trying to create. Truly accurate GIS riparian delineations require highly resolved and continuous data layers, many of which do not yet exist. As remote sensing and computer technology improve and as better data layers become available (e.g. LIDAR elevation data, and high-resolution soils and vegetation data), more precise and accurate riparian GIS layers will evolve. The procedure used here was written as abstractly and generally as possible, and will, it is hoped, continue to be applicable as data and tools improve.

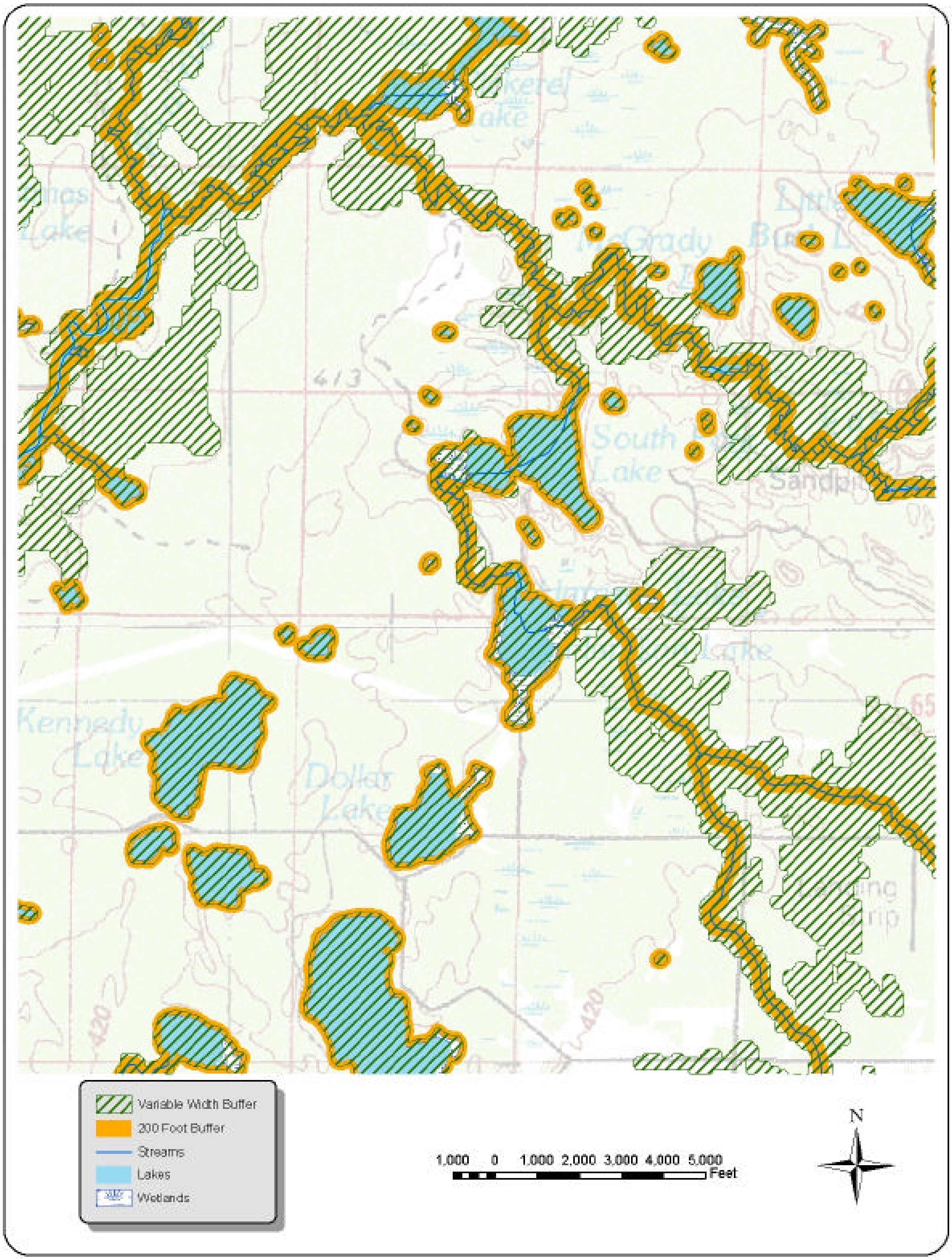

Figure 1. Fixed-width and variable-width riparian buffer representations for a portion of the Prairie River basin.

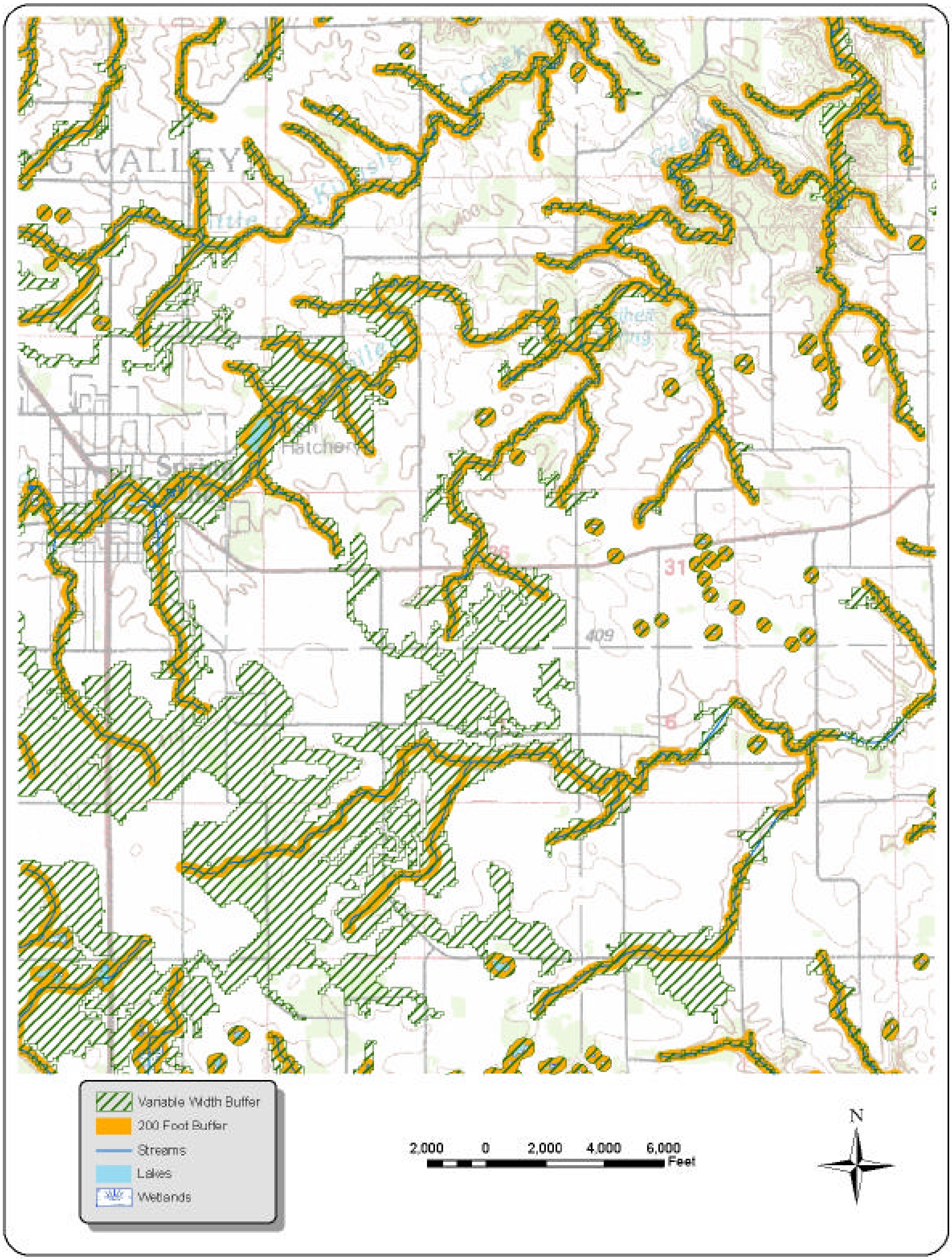

Figure 2. Fixed-width and variable-width riparian buffer representations for a portion of the Root River Basin.

Table 1. Differences between total acreage of riparian area in two Minnesota watersheds using 200 foot fixed-width and variable-width stream riparian delineation approaches.

	Prairie River Basin		Root River Basin	
Riparian characteristic	**200 foot Buffer**	**Variable-width Riparian Zone**	**200 foot Buffer**	**Variable-width Riparian Zone**
Total riparian acres	31,097	75,725	182,797	281,051
Percent of Basin Riparian	10.7%	26.0%	17.3%	26.6%
Total Basin Size (acres)	291,657		1,057,151	

Table 2. GAP land cover distribution for riparian areas in the Prairie River basin using fixed-width and variable-width buffers.

	Gap Level 4	Total acres, 200 foot buffer	% Riparian Area	Total Acres, Variable-width Definition	% Riparian Area
Prairie River Basin	?	9.72	0.03%	96.06	0.13%
	Aspen/White Birch	9,097.50	29.26%	17,159.81	22.66%
	Balsam Fir mix	986.82	3.17%	2,623.41	3.46%
	Black Ash	1,193.44	3.84%	3,523.62	4.65%
	Broadleaf Sedge/Cattail	96.27	0.31%	181.54	0.24%
	Bur/White Oak	1.95	0.01%	1.95	0.00%
	Cropland	331.23	1.07%	853.95	1.13%
	Floating Aquatic	1,336.60	4.30%	1,608.76	2.12%
	Grassland	848.91	2.73%	2,443.96	3.23%
	High intensity urban	16.24	0.05%	31.87	0.04%
	Jack Pine	450.95	1.45%	1,729.71	2.28%
	Low intensity urban	13.46	0.04%	24.46	0.03%
	Lowland Black Spruce	616.88	1.98%	4,407.82	5.82%
	Lowland Deciduous	0.82	0.00%	0.82	0.00%
	Lowland Deciduous Shrub	7,281.75	23.42%	19,354.42	25.56%
	Lowland Northern White-Cedar	229.49	0.74%	1,440.36	1.90%
	Maple/Basswood	275.52	0.89%	318.00	0.42%
	Mixed Developed	515.46	1.66%	859.01	1.13%
	Red Oak	64.03	0.21%	65.15	0.09%
	Red Pine	325.18	1.05%	496.38	0.66%
	Red/White Pine	0.00	0.00%	0.02	0.00%
	Sedge Meadow	62.16	0.20%	120.43	0.16%
	Stagnant Black Spruce	111.48	0.36%	789.70	1.04%
	Stagnant Conifer	65.64	0.21%	77.35	0.10%
	Stagnant Northern White-Cedar	8.91	0.03%	157.33	0.21%
	Stagnant Tamarack	42.80	0.14%	625.13	0.83%
	Tamarack	549.49	1.77%	3,713.91	4.90%
	Transportation	0.00	0.00%	0.87	0.00%
	Upland Deciduous	0.96	0.00%	0.95	0.00%
	Upland Shrub	4,542.21	14.61%	10,566.35	13.95%
	Water	1,978.61	6.36%	2,346.11	3.10%
	White Pine mix	7.93	0.03%	17.14	0.02%
	White Spruce	34.76	0.11%	88.30	0.12%
	TOTAL	**31,097.16**	**100.00%**	75,724.65	100.00%

Table 3. GAP land cover distribution for riparian areas in the Root River basin using fixed-width and variable-width buffers.

	Gap Level 4	Total acres, 60 meter buffer	% Riparian Area	Total Acres, Variable-width Definition	% Riparian Area
Root River Basin	?	6.96	0.00%	111.22	0.04%
	Aspen/White Birch	9.70	0.01%	5.07	0.00%
	Barren	7.30	0.00%	12.01	0.00%
	Broadleaf Sedge/Cattail	402.40	0.22%	675.88	0.24%
	Bur/White Oak	2,270.38	1.24%	1,818.34	0.65%
	Cropland	77,861.62	42.59%	184,495.08	65.64%
	Floating Aquatic	20.99	0.01%	38.27	0.01%
	Grassland	50,764.02	27.77%	55,007.61	19.57%
	High intensity urban	355.28	0.19%	1,081.63	0.38%
	Low intensity urban	323.59	0.18%	856.55	0.30%
	Lowland Deciduous	9,497.14	5.20%	8,447.26	3.01%
	Lowland Deciduous Shrub	774.22	0.42%	1,307.04	0.47%
	Maple/Basswood	1,384.45	0.76%	1,034.36	0.37%
	Red Oak	22,131.66	12.11%	12,645.56	4.50%
	Red Pine	44.18	0.02%	31.30	0.01%
	Red/White Pine	14.24	0.01%	12.27	0.00%
	Red/White Pine-Deciduous mix	58.83	0.03%	31.68	0.01%
	Redcedar	150.32	0.08%	74.09	0.03%
	Redcedar-Deciduous mix	457.09	0.25%	173.37	0.06%
	Sedge Meadow	139.52	0.08%	232.69	0.08%
	Silver Maple	920.13	0.50%	1,589.44	0.57%
	Transportation	1,399.23	0.77%	2,278.04	0.81%
	Upland Deciduous	954.57	0.52%	643.18	0.23%
	Upland Shrub	1,586.48	0.87%	1,105.32	0.39%
	Water	562.07	0.31%	1,637.21	0.58%
	White Pine mix	18.96	0.01%	12.03	0.00%
	White/Red Oak	10,681.17	5.84%	5,694.85	2.03%
	TOTAL	**182,796.50**	100.00%	**281,051.37**	100.00%

Table 4. Stewardship categories for the Prairie River and Root River watersheds based on fixed-width and variable width riparian delineation approaches

	Steward	Total Acres 200 foot buffer	% of Total Riparian Area	Total Acres Variable-width	% of Total Riparian Area
Prairie River	Water or None	0	0.0%	450	0.6%
	Federal	1,907	6.1%	2,227	2.9%
	State	3,757	12.1%	12,207	16.1%
	County	7,160	23.0%	20,296	26.8%
	Large Private	4,102	13.2%	13,161	17.4%
	Small Private, Tribal and Misc.	14,170	45.6%	27,385	36.2%
	TOTAL	**31,097**	**100%**	**75,725**	**100.0%**
Root River	Water or None	0	0.0%	1,656	0.6%
	Federal	106	0.1%	260	0.1%
	State	5,605	3.1%	5,585	2.0%
	County	18	0.0%	13	0.0%
	Large Private	1,087	0.6%	3,363	1.2%
	Small Private, Tribal and Misc.	175,981	96.3%	270,175	96.1%
	TOTAL	**182,796**	**100.0%**	**281,051**	**100.0%**

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