Identification of Fish Passage Barriers through Inventory and Assessment of Road-Stream Crossings within the Big River Watershed Missouri

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Abstract

The Big River watershed provides a unique collection of management issues. While rare mussel beds are located in the downstream reaches of the river, extensive lead mining in the upper reaches of the watershed has contaminated stretches of the river. A fish passage barrier inventory was conducted in the watershed to determine the number of road stream crossings which act as barriers to benthic fishes. Structure measurements were also used to determine if any of the existing stream crossings could serve as collection sites for lead tailings accumulation. Field crews visited 484 road crossing sites. Twenty-six percent of these (127) were barriers to movements of benthic fishes at low to normal flows. Eighty-one of these sites were culvert-based crossings which fish biologists would traditionally perceive to be a fish passage barrier. The remaining forty-six crossings were more bridge-like in structure but included aprons or foundations of previous structures which caused barriers to movement of benthic species. One bridge site was found which acted structurally like a small dam and could be considered as a site for lead collection. Recommendations are provided for consideration when conducting further watershed inventories in Missouri.

Introduction

Dams on large rivers have long been known to create barriers to movement of migratory fish species such as salmonids and sturgeon (Jager et al. 2001; Raymond 1979). However, low-head dams on interior warmwater streams also have adverse effects on fish populations. A series of low-head dams on the Fox River in northeast Illinois adversely affected the biotic integrity on local and landscape levels (Santucci et al. 2005). Fragmentation of the river basin restricted movements of fish while the small impoundments created by the low-head dams resulted in degraded habitat, water quality and biotic communities. Gillette et al. (2005) also documented a pattern of upstream and downstream habitat alterations and differences in small bodied fish assemblages caused by a series of small low-head dams on the Neosho River in Kansas. Long term effects of population fragmentation may even result in genetic isolation of population segments as seen in logperch darter populations in the Grand River, Ohio which were separated by the Munroe Falls low-head dam for 188 years (Haponski et al. 2007).

In the last twenty years, focus has also been placed on the impacts of road stream crossings to individual movement of native stream fishes and fragmentation of these fish populations (Winston et al. 1991). Road crossing designs vary from simple low water fords to large bridges. While bridges generally do not appear to be barriers to passage of fish and other aquatic organisms, other crossing types may impact fish movement (Benton et al. 2008; Warren and Pardew 1998).

The degree to which crossings act as barriers is related to flow alterations through the crossings (Warren and Pardew 1998). In small streams of the Ouachita Mountains in west-central Arkansas, culvert and slab crossings reduced fish movement, diversity of movement and fish family movement when compared to natural stream reaches (Warren and Pardew 1998). Culvert crossings had the highest mean velocities (exceeding 40 cm/s) while open-box culverts had the lowest mean velocities and highest fish passage. Culvert crossings were bidirectional passage barriers to sunfishes and minnows despite the presumed ranges of their swimming abilities indicating they should be able to navigate the culvert velocities (Warren and Pardew 1998).

Topeka shiners in northeast Kansas also moved through box culverts and single large corrugated culverts but did not pass through low-water crossings with multiple pipe culverts (Bouska 2008). These low water crossings had greater perching and higher velocities than crossings constructed with box culverts and single large corrugated culverts. In Cape Fear River basin streams in North Carolina stream fish movements were not impacted by structure type if the structures were not perched (Vander Pluym et al. 2008). This indicates it is important to assess not only structure design but its placement relative to the streambed.

Due to the increased awareness of culvert impacts, crossing replacement plans and programs are being developed across the country (Collins et al. 2007; Maine Department of Transportation 2004; Vermont Agency of Natural Resources 2009). The U.S. Fish and Wildlife Service's National Fish Passage Program provides funds to modify or replace barriers to fish passage. This program has funded the replacement of three low-water culvert crossings with free span bridges in Missouri streams to benefit the threatened Niangua darter (*Etheostoma niangua*) and one crossing to benefit the endangered Topeka shiner (*Notropis topeka*). Free span bridges are expensive structures. The U.S. Fish and Wildlife Service (Service) and the Missouri Department of Conservation (MDC) wanted to maximize the cost-benefits of future fish passage funding by prioritizing crossings for replacement to both maximize benefits to the threatened species and costs per stream mile. A collection of fisheries and streams staff members from both agencies developed protocols to inventory and assess crossings within the range of the threatened Niangua darter. Thirty-two low water crossings were identified as barriers to the darter and other benthic fishes (Novinger et al. 2008). This report was provided to partners in numerous agencies with programs and funding for either transportation or habitat restoration. Using similar procedures in other Missouri watersheds will enable natural resource agencies to continue proactive watershed level fish passage planning. The Big River basin was selected as the next focus watershed due to a combination of threatened and endangered mussels in the downstream reaches, lead (Pb) contamination in the upper reaches and partner interests.

Methods

Study Area

The Big River originates in Iron County in east-central Missouri. The watershed drains 955 square miles in portions of six counties. The river flows northward 138 miles to the Meramec River confluence near Eureka, Missouri (Figure 1). The basin contains 129 miles of permanent streams and 220 miles of intermittent streams (Meneau 1997).

The Big River basin is unique in that it contains six sensitive aquatic natural communities including two examples of Ozark creeks and four examples of Ozark springs and spring branches. The diverse mussel community includes the federally endangered pink mucket (*Lampsilis abrupta*) and scale shell mussels (*Leptodea leptodon*) and the candidate spectacle case mussel (*Cumberlandia monodonta*). Eight species of crayfish inhabit the Big River basin including the belted crayfish (*Orconectes harrisoni*); found only in Missouri in the St. Francis and Big River basins (Meneau 1997). The state endangered crystal darter (*Crystallaria asprella*) was found in the lower Big River by William Pflieger (Meneau 1997). The basin is also home to a variety of game fish including smallmouth bass (*Micropterus dolomieu*), rock bass (*Ambloplites rupestris*), channel catfish (*Ictalurus punctatus*), flathead catfish (*Pylodictis*

olivaris), sunfish (*Lepomis* spp), crappie (*Pomoxis* spp) and suckers (*Catostomus* spp) (Meneau 1997). MDC established a Smallmouth Bass Special Management Area on the Lower Big River in 1992 (Meneau 1997). This area extends from the Leadwood Access in St. Francois County to the river's confluence with the Meramec River. It also includes a portion of the Mineral Fork from the Highway F bridge to the Big River confluence (MDC 2009).

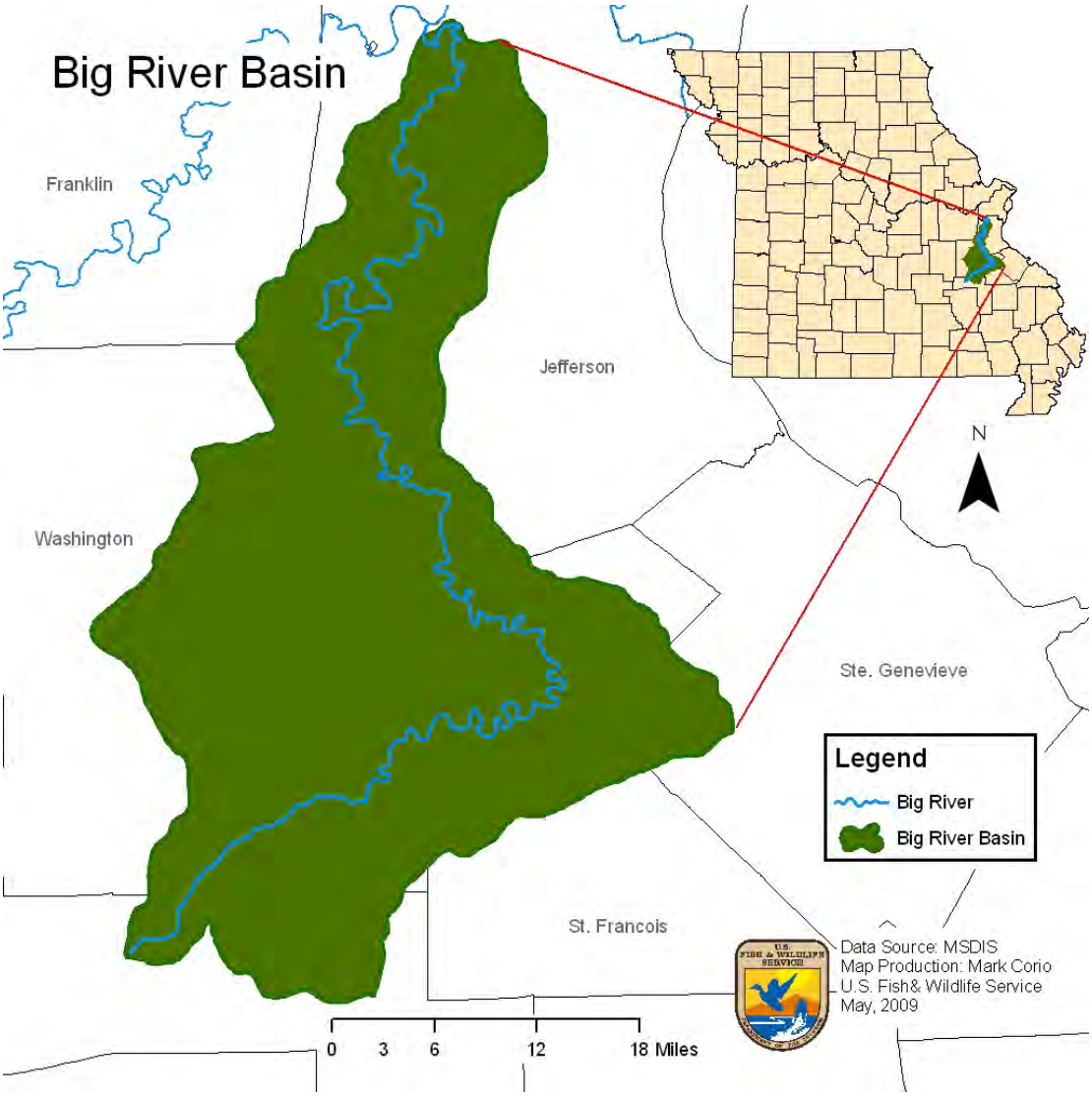


Figure 1. Map of the Big River watershed location

The Missouri Department of Conservation identified five Management Problems and Opportunities for the Big River Basin in their Watershed Inventory and Assessment (Meneau 1997). The first goal is to maintain or improve water quality due in part to lead contamination. Anglers are warned not to consume any size of sunfish, carp (*Cyprinus carpio*), redhorse (*Moxostoma* spp) or suckers from the Big River in St. Francois and Jefferson counties due to lead contamination (MDC 2009).

Lead was discovered and began to be exploited in the early 1700s in the upper Big River Basin. Missouri has been a leading producer of Pb since 1920.While mining efforts in the Old Pb Belt area of St. Francois County largely ceased after 1972, 45 mine dams and numerous piles of mine waste remain. Twenty-seven of the mine dams have been rated as high-hazard or unsafe with potential for failure during a large flood or earthquake (Meneau 1997). The Desloge tailings pile failed in 1977 resulting in an estimated 90,000 cubic yards of heavy metals contaminated tailings entering the Big River. Erosion of tailings into the river continues from this site and others in the region (Czarnezki 1985). Elevated concentrated levels of metals have been documented in in algae, crayfish and minnows (Jennett et al. 1981).

As ore bodies in the Old Pb Belt were exhausted, mining shifted southwest in the 1950s to the New Lead Belt, also known as the Viburnum Trend (Schmitt et al 2007) (Figure 2). The Viburnum Trend primarily produces Pb but also produces smaller quantities of zinc, copper, and silver (Poulton et al. 2009). Environmental impacts from mining in the Viburnum Trend were initially severe and have diminished but not ceased entirely with improvements in mining and milling practices over the last several decades. Recent studies confirm that elevated concentrations of Pb and other metals are still found in fish tissues of the area (Besser et al. 2007).

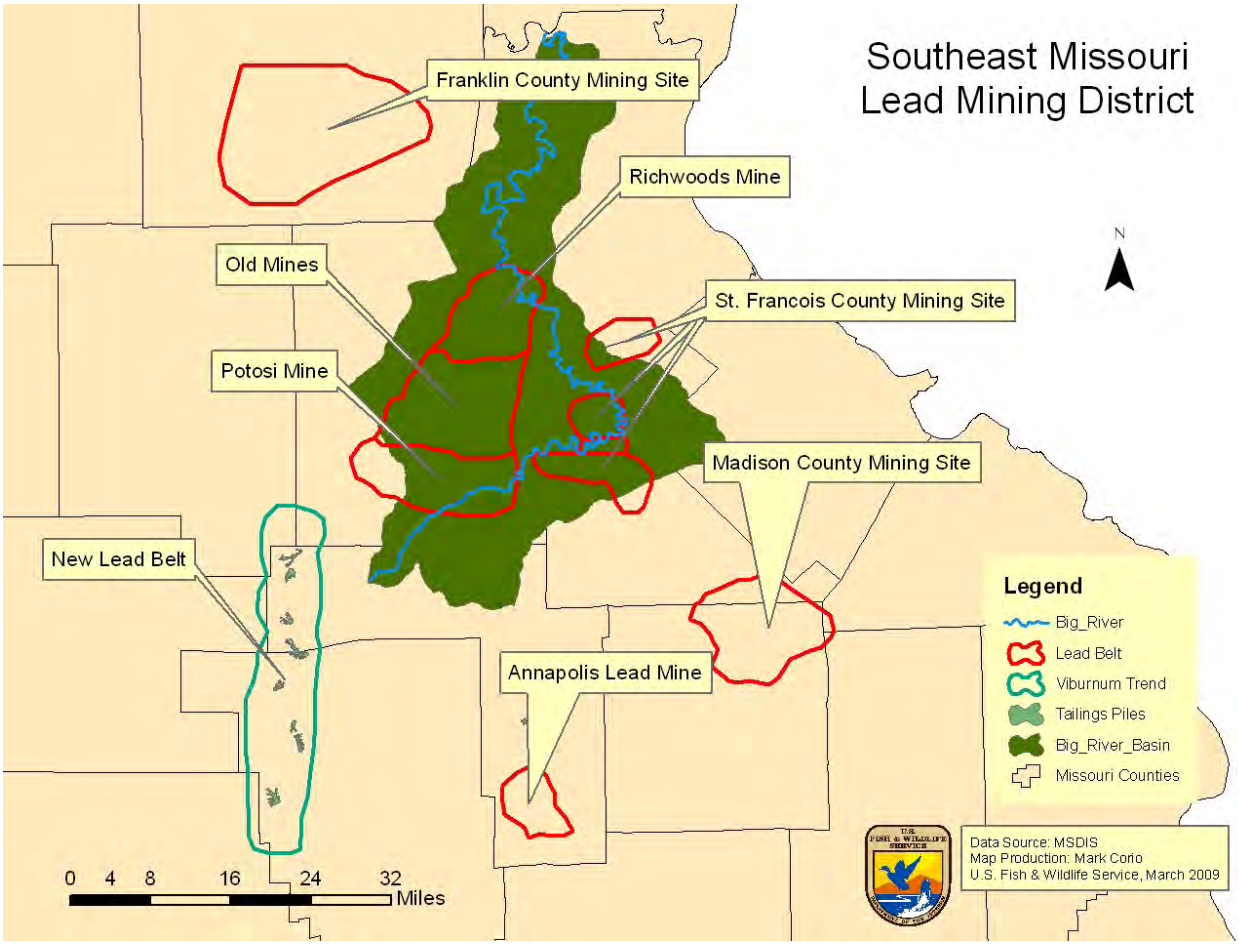


Figure 2. Map of Southeast Missouri lead mining district

In 2008, the Service and the US Geological Survey launched a series of multidisciplinary studies to assess potential adverse effects of mining on the aquatic biota of the Big River. Studies included a mussel population and sediment survey, mussel and macroinvertebrate sediment toxicity testing, a crayfish population and in situ toxicity testing, a riffle fish population survey among others. Collectively, the studies demonstrated widespread heavy metal contamination of sediments from Leadwood to the confluence of the Big River with the Meramec River. The studies document uniformly adverse effects of the sediment metal contamination on the aquatic biota of the Big River (Roberts et al. 2009; Besser et al. 2009; Allert et al. 2009; McKee et al. 2010).

Five low-head dams in the lowermost reaches of the Big River act as containment devices for lead contaminated sediments (Pavlowsky 2010.). They help to reduce the downstream movements of these sediments into the lower Big River and the Meramec River. It is possible that other stream barriers such as low-water crossings may also be serving as catchment areas for migrating lead contaminated sediments. One goal of this fish passage survey is to identify these potential sites.

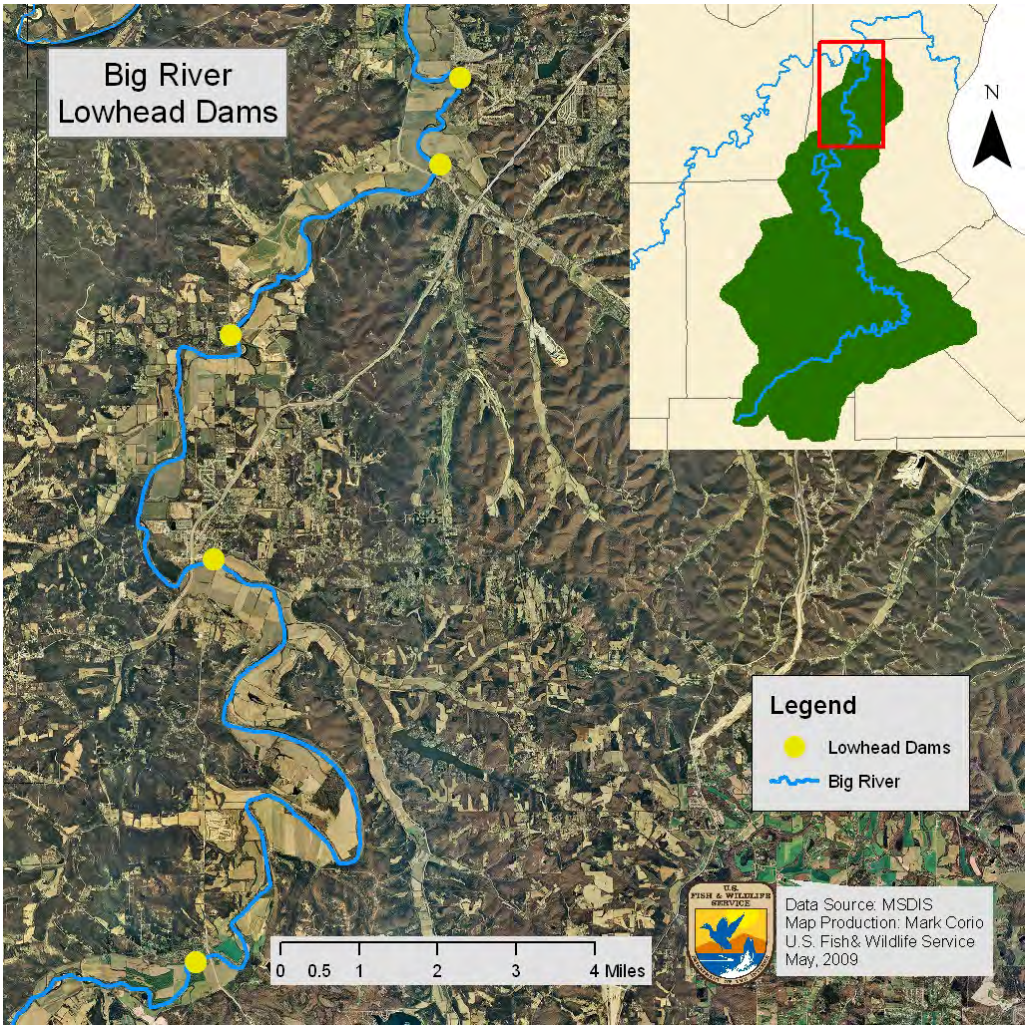


Figure 3. Location of low-head dams in lower Big River.

Inventory and Assessment

GIS (ESRI ArcMap v9.2) analysis was used to develop a list of potential road-stream intersections within the major sub-watersheds of the Big River basin: Belews Creek, Cedar Creek, Dry Creek, Flat River, Heads Creek, Mill Creek, Mineral Fork, and Terre Bleue (see sub-watershed maps Appendix A). Using a detailed road layer (MoDOT) and a stream network layer (MoRAP Valley Segment Type v.2.2), a list of stream/road intersections was created using GIS intersect functions. This initial list included 435 crossings (Figure 4).

Stream crossing inventory and assessment followed the procedures outlined in Novinger et al. (2008). The crossings were surveyed to collect information about the structure type, location, condition and crossing dimensions. A series of measurements were made at each opening (water depth, perch above the stream bottom, bridge height, opening length and width, percent culvert blockage). Crossing measurements were taken primarily from public road crossings. Crossings on private roads were not measured unless a private landowner was present and interested in the project. Digital photos were taken from six determined vantage points at each location (see field data sheet Appendix B). Crossings were surveyed at normal to low flow conditions during the summer of 2008. Each crossing was assigned a unique crossing identification number and entered into an MS Access database for data analysis.

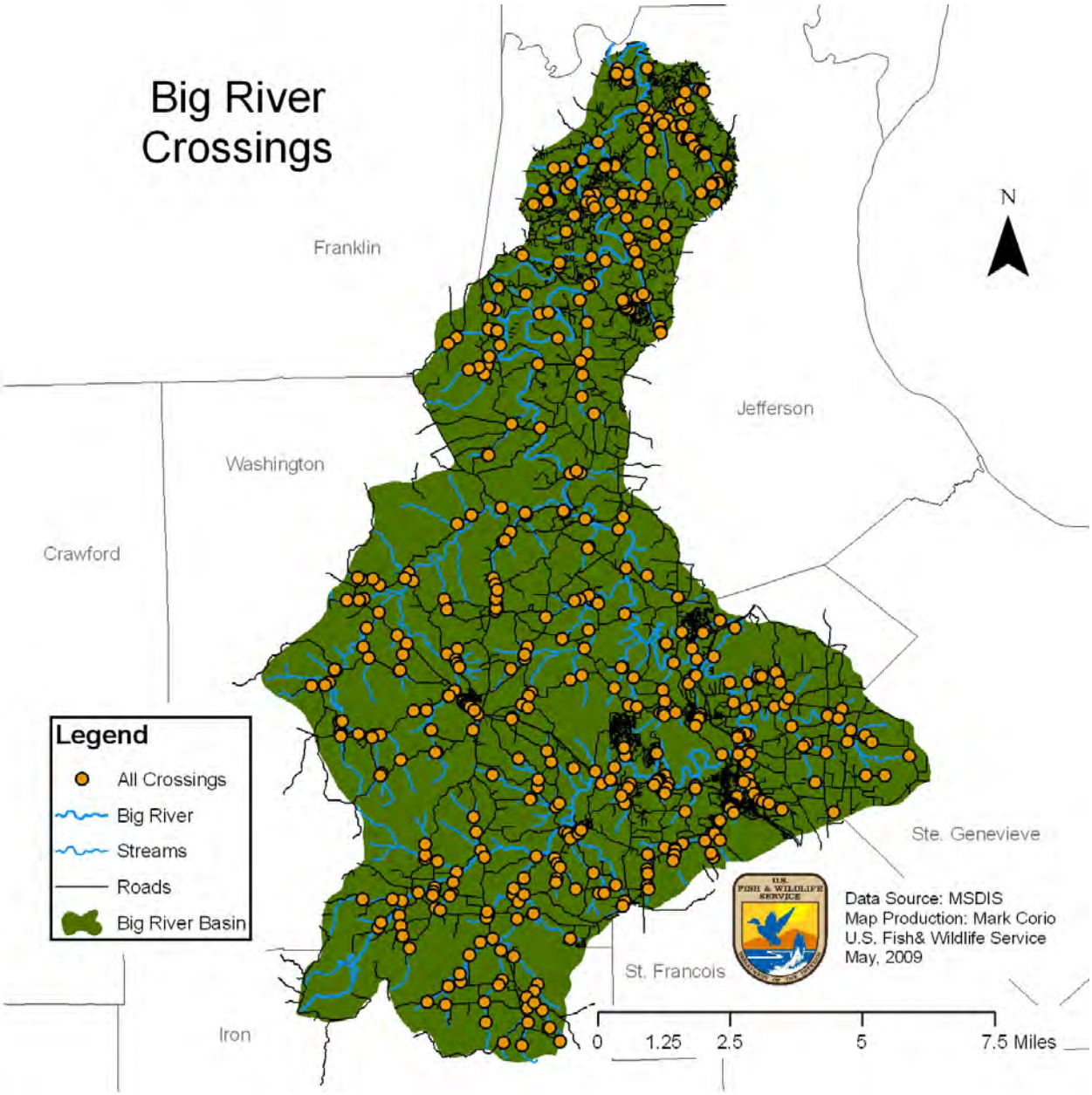


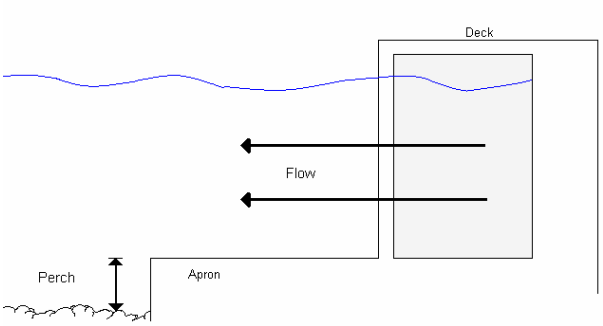
Figure 4. Road stream crossing intersections of the Big River watershed as identified in ArcMap.

Analysis

Microsoft Access database programming written by Julie Fleming of the MDC and modified by Brian Elkington of the Service was used to analyze the crossing data. Similar to the Niangua darter inventory (Novinger et al. 2008), we assumed any structure that did not pass benthic species was a barrier. We calculated the following metrics for each of the 485 crossings to quantify attributes that might negatively affect passage of aquatic species per Novinger et al. 2008:

- Behavioral/Perch barrier - Where an opening bottom was perched above the stream bottom (perch > 0; Figure 5). Movement of benthic fish species may be inhibited by a requirement to swim up and over the edge of a perched opening regardless of water depth. For each crossing, we calculated the proportion of perched openings and the minimum perch, done separately for downstream and upstream openings.

A



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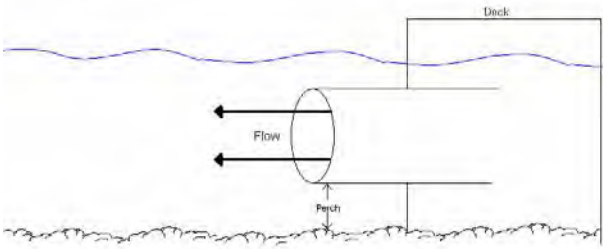

Figure 5. Examples of low water crossings with behavioral passage barriers created by perched box (A) and pipe (B) culvert openings. Pictured in (A) is the Dellwood Road crossing over a tributary to Heads Creek (Crossing_ID 360) and in (B) is the Lick Skillet Road crossing over Goose Creek (Crossing_ID 84) (Novinger et al. 2008).

- Jump barrier - Where an opening bottom was perched above the water surface elevation (perch - depth > 0; Figure 6). Darters and other similar benthic fishes are not known to possess the capability

of jumping into an opening that is elevated above the water's surface. For each crossing, we calculated the proportion of openings with a jump barrier and the minimum height of the jump done separately for downstream and upstream openings.

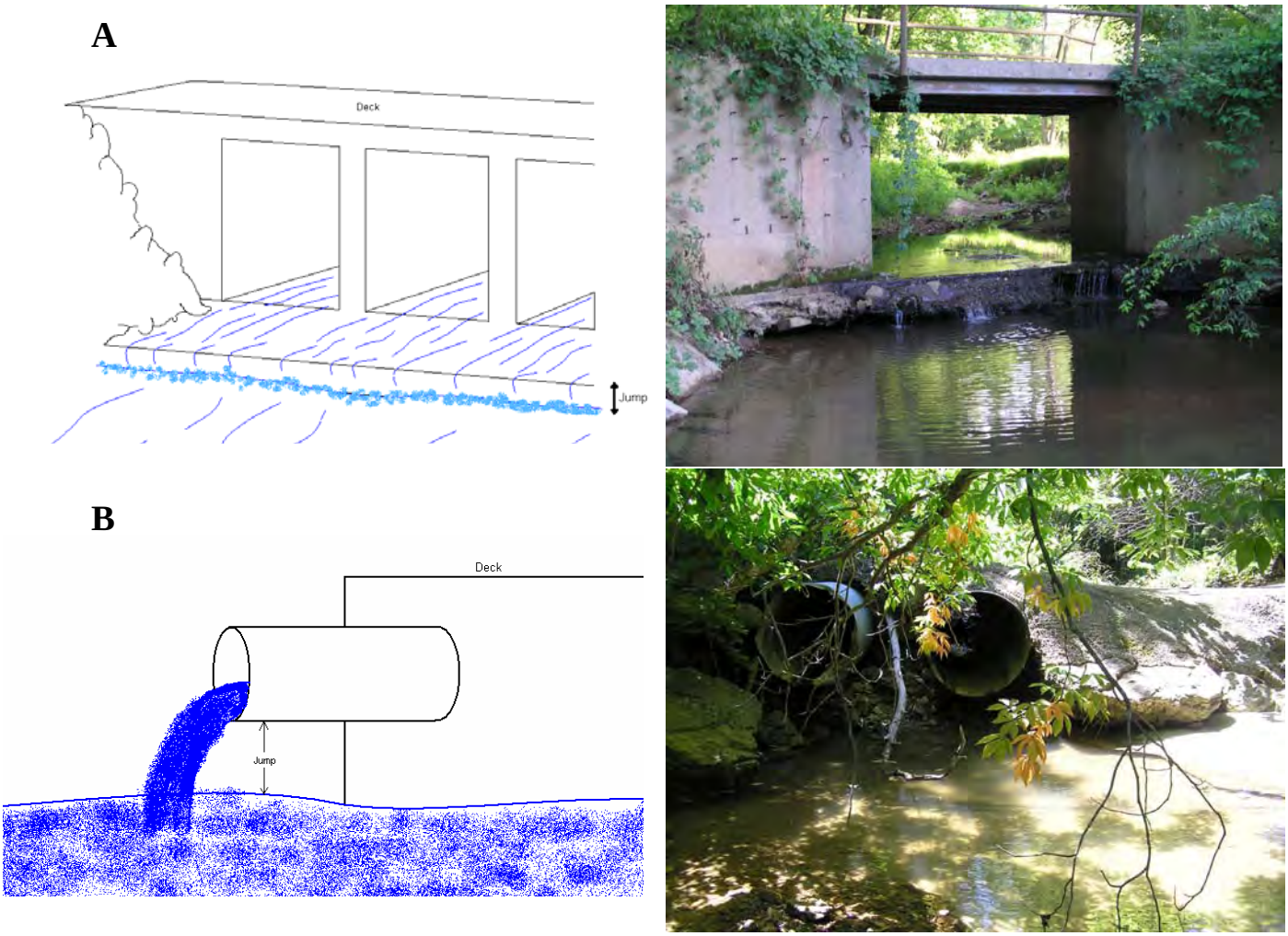

Figure 6. Examples of low water crossings with jump passage barriers created by box (A) and pipe (B) culvert openings that are elevated above the water's surface. Pictured in (A) is Beach Road crossing over Buck Creek in the Belews Creek subwatershed (Crossing_ID 35) and in (B) is the Hillshire Lane crossing over Belews Creek (Crossing_ID 309) (Novinger et al. 2008).

- Stream reconnected - GIS tools were used to measure the stream distance upstream from each crossing that would be reconnected with the downstream reach if the crossing were modified or replaced. The upstream boundaries were usually determined by the presence of another crossing or were based on extension of the reach into headwaters (variable: RECONNECT).

- Percent Passable Face – Where wetted culverts do not present a jump barrier to benthic fishes, the sum of the culvert widths corrected for percent blockage was divided by the length of the crossing. This represents the "passage opportunity" to the fish in a 2D plane as the fish faces the structure. It is theorized that at smaller numbers less opportunity exists for benthic fishes and they will have to work harder to find an opening. For each crossing, widths of wetted culverts were adjusted by the estimated percent blockage. These width openings were summed and the total was divided by the total measured length of the crossing. Calculations were made for both the upstream and downstream sides of the crossing.

- LEAD–Polygons identifying lead concentrations as being low, medium or high were created with input of Dave Mosby, U.S. Fish and Wildlife Service contaminants specialist. After running several weighting scenarios to determine the correct range, these polygons were assigned values of 1 for low, -1 for medium, and -2 for high lead concentrations (Figure 7). Lead contaminated sediments were highest in the upper Big River near tailings mines. These sediments traveled downstream in the main channel Big River, therefore, the actual Big River mainstem is more contaminated than its watershed in the middle portion of the river. The series of low-head dams in the lowermost portion of the river help to contain some of these sediments, reducing the contaminant level in this portion of the watershed (Pavlowsky 2010).

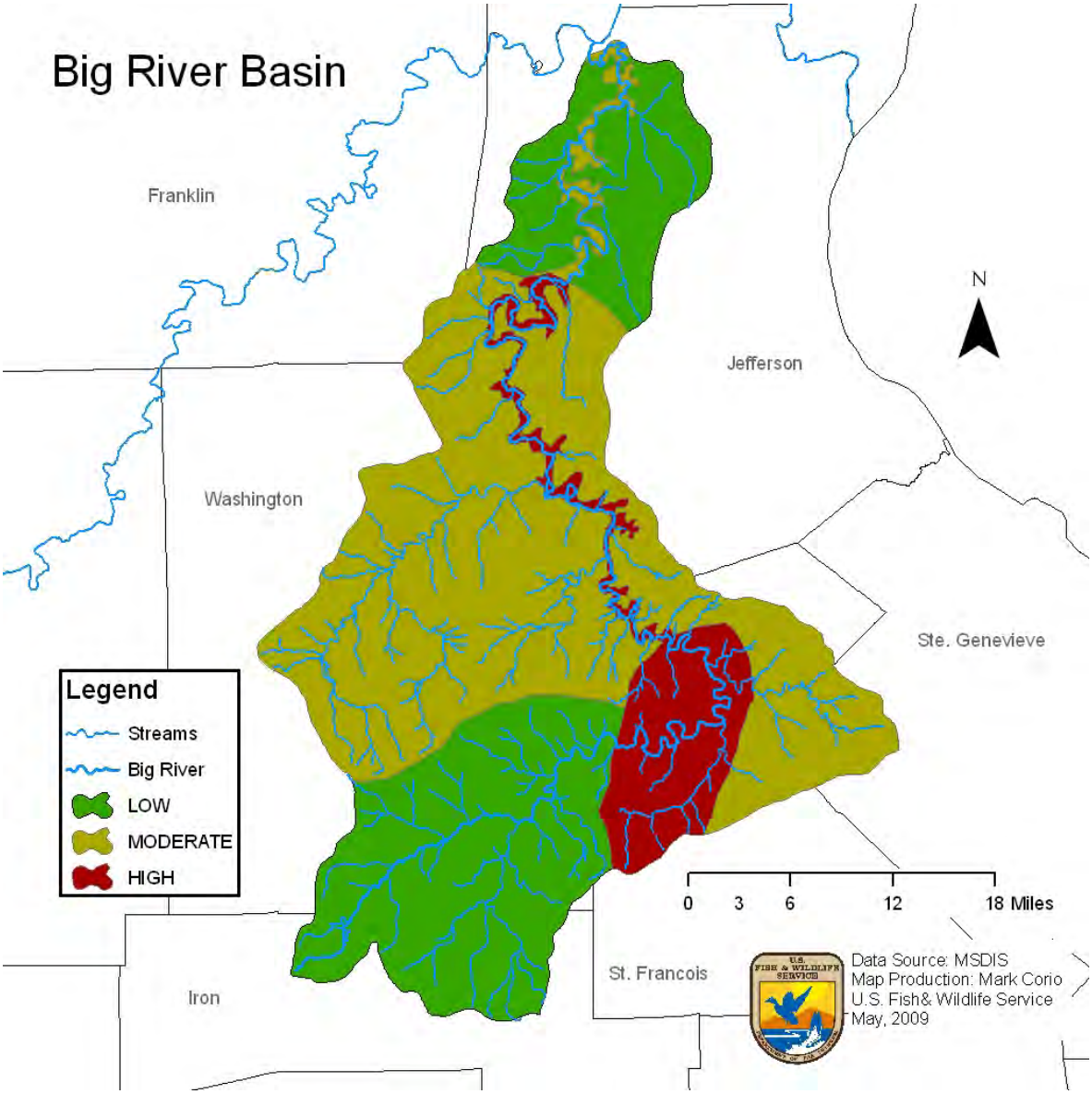

Figure 7. Identification of lead contaminant zones within the Big River Basin (Dave Mosby, USFWS, pers.comm.).

- Scaling and weighting index variables

The values for each index variable were scaled by dividing by the maximum value of that variable. This resulted in a range for each variable of 0 to 1. The values of each variable were weighted because some index metrics were described by multiple variables or otherwise seemed to exert too much influence on the final index score. Perch and jump barrier metrics were each associated with four variables that were all weighted by 0.25. RECONNECT was weighted by 0.5, Lead concentration was weighted at 0.75 and each percent passable face variable was left unmodified. Altogether, the weighting strategy resulted in each variable having a contribution to

the final index score as follows: Perch = 1 (19%), Jump = 1 (19%), Lead Concentration Level = 0.75 (14%), Reconnected stream distance = 0.5 (10%), and Percent Passable Face = 2 (38%) (Novinger et al. 2008).

- Passage Quality Index prioritized list of crossings

The final step involved combining the scaled and weighted values to create a total that was the Passage Quality Index score. Perch and jump-related variables, RECONNECT, and Lead Concentration Level were all added to the total because higher values for these variables related to higher priority. Percent passable face was subtracted from the total because higher values for this variable related to lower priority. Possible index scores ranged from -2.5 to 2.5. The actual scores ranged from -2.22 to 2.28. The list of crossings and their index scores was then sorted in descending order so that the highest score received a priority rank of 1 (Novinger et al. 2008).

Results

Road-stream intersection analysis in ArcMap identified 431 potential crossing sites. Eight of the potential crossing intersections identified by GIS were not actual stream crossings. This occurred for a variety of reasons related to the accuracy of the roads and streams coverages. Thirty-four of the crossing intersections occurred on private land and were not measured. Field crews found 96 additional low water crossings which weren't identified by GIS analysis when conducting their field work. A total of 484 crossings were visited in the field and entered into the Access database for analysis.

A large proportion (42%) of the crossings (201 of 484) were identified in the field as being a bridge or clear span without a bottom. Our field crews identified crossings with large openings, a total span which appeared to encompass most of the channel width, and an open stream bottom as bridges. These crossings are considered open to passage of aquatic organisms and not measured. They were not considered for further analysis. Crossings with large box openings with artificial stream bottoms perched above the stream bed were classified as "Concrete slabs with multiple box culverts" regardless of the height or width of the openings.

Most of the remaining crossings were concrete slabs with various sizes and numbers of openings. Ninety-two crossings had at least one culvert elevated above water levels on either the upstream or downstream side of the crossing, creating a physical jump barrier for fish. An additional 35 crossings had at least one culvert perched above the stream bottom on either the upstream or downstream side of the crossing, creating a behavioral barrier particularly for benthic species such as darters. A total of 127 crossings were identified as presenting potential barriers to fish passage assuming the target was passage of benthic fishes (Figure 8). A table identifying the number of openings at each crossing which were either perch and jump barriers to benthic fish can be found in Appendix C.

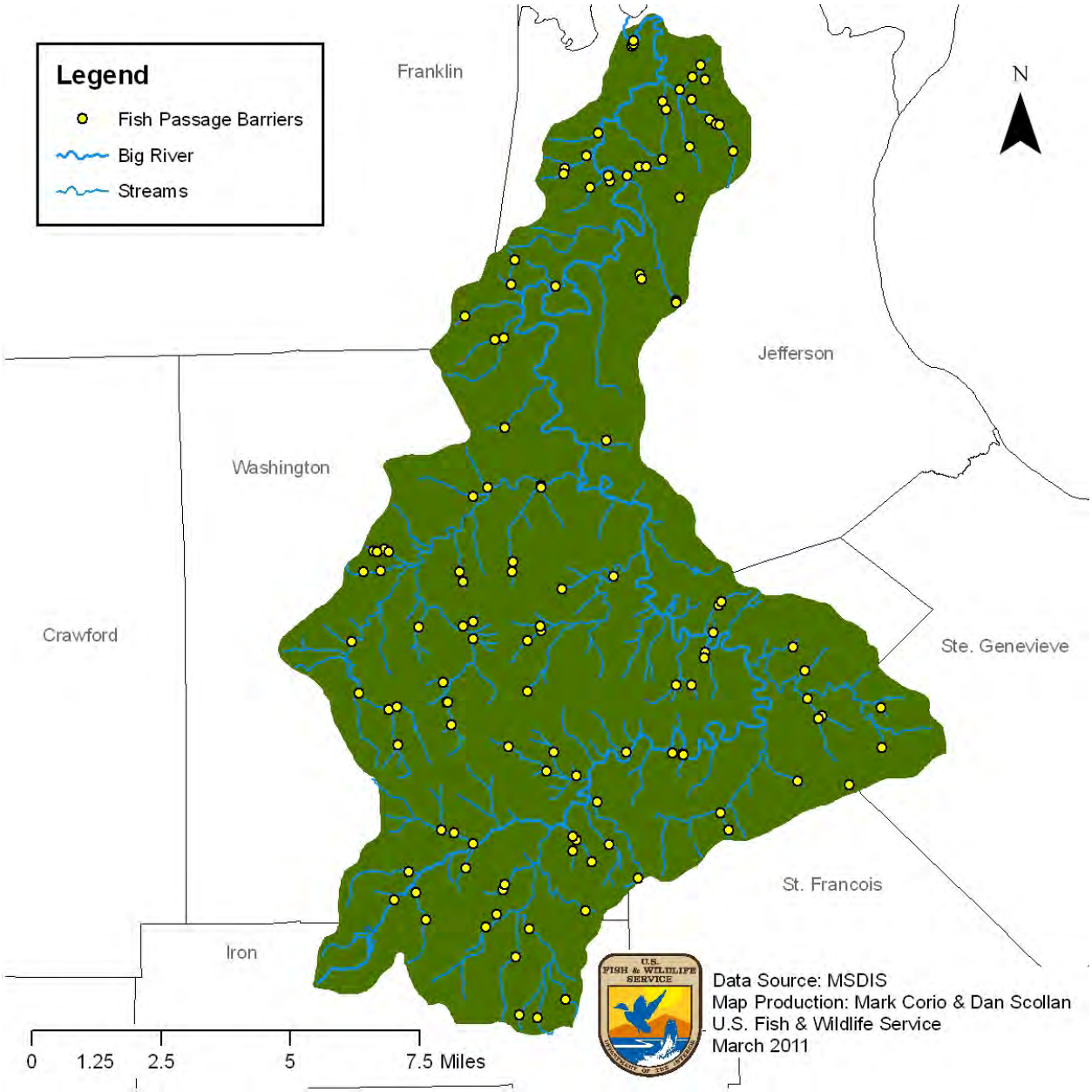

Figure 8. Locations of road stream crossings within the Big River watershed that pose barriers to movements of benthic fishes.

An additional five crossings which were initially identified as barriers in the analysis were eliminated upon further review of the output and photo documentation. These crossings are in the confusing gray area between “box culverts” and “bridges”. All had large values for Percent Passable Face indicating they would appear open to a fish and little to no observable culvert perch or jump.

The crossings were ranked for replacement prioritization based on the structure measurements, the number of stream miles which would be opened to aquatic organism passage and the amount of Pb contamination present in that portion of the watershed. Formulas used to rank crossings were similar to those used for the Niangua darter. During review of the initial

ranking list, several bridges with wide openings which would likely provide passage during higher water elevations, scored very high. Stream crossings with culverts which look like barriers to the casual observer ranked lower than these structures. After our initial review, we changed the primary structure type to “Bridge with bottom” in Access for forty-six crossings to account for these structures. The bridge scoring and ranking analysis was run again with the crossings in two groups. We identified 81 culverted crossings (Table 1) and 46 bridge like structures with aprons as barriers to benthic fishes (Table 2). Photos of the culverted stream crossings which are barriers to fish passage can be found in Appendix D while photos of bridges that may be at least partial barriers to fish passage are found in Appendix E. This technique addressed some, but not all of the potential questions that will arise when individuals review the ranked crossing photos. Some of the crossings with no water scored unusually high, as a depth value of zero was used in the Access equations. The top thirty-five culverted crossings and top twenty bridge crossings were mapped to enable natural resource managers to quickly identify potential project sites with the most benefit to the Big River watershed (Figures 9 and 10).

The top three ranked culverted crossings do not have water visibly present at the crossing site. A water depth of zero automatically creates a 0% Passable Face value, increasing the final score for the crossing. This is an important issue that remains to be corrected with MS ACCESS programming and should be examined for future watershed inventories.

Table 1. Priority rank, Passage Quality Index (PQI) score and additional descriptive information for culverted road crossings including: stream and road names, barrier type, lead contamination level, location and structure type.

Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W	Structure Type
1	1.88	386	Jump	1	Dulin Creek	Dulin Creek	Jefferson	38.39501	90.58457	Concrete slab with one pipe culvert
2	1.86	336	Jump	1	Gallighers Creek	Lexington Drive	Jefferson	38.26079	90.6158	Concrete slab with one pipe culvert
3	1.85	226	Jump	1	Jones Creek Trib	Big River Rd	Washington	37.76106	90.86213	Concrete slab with one pipe culvert
4	1.76	217	Jump	1	Clear Creek	Gildea Rd	Washington	37.79964	90.80266	Concrete slab with multiple box culverts
5	1.54	498	Jump	1	Branch of Flat River	Shut In Rd	Washington	37.79231	90.70008	Concrete slab with multiple pipe culverts
6	1.54	317	Jump	1	Janes Creek	Janes Creek Rd	Washington	37.73893	90.8526	Concrete slab with one box culvert
7	1.48	33	Jump	1	Little Dutch Creek	Little Dutch Creek Rd	Jefferson	38.3589	90.66801	Concrete slab with one box culvert
8	1.47	315	Jump	1	Lost Creek	Carr Rd	Washington	37.74279	90.6885	Concrete slab with multiple pipe culverts
9	1.43	389	Jump	1	Unknown	Eime Rd	Jefferson	38.34948	90.69152	Concrete slab with one pipe culvert
10	1.42	239	Jump	1	Cedar Creek	CR 21	Iron	37.70976	90.08071	Concrete slab with one box culvert
11	1.42	345	Jump	1	Dutch Creek	Little Dutch Creek Rd	Jefferson	38.3589	90.66794	Concrete slab with one box culvert
12	1.27	210	Jump	1	Wallen Creek	CR 516	Washington	37.8783	90.76373	Concrete slab with multiple pipe culverts
13	1.27	528	Jump	1	Belews Creek Trib	Hillsboro House Springs	Jefferson	38.32315	90.57237	Concrete slab with multiple box culverts
14	1.26	53	Jump	1	Heads Creek	Hluzek Valley Rd	Jefferson	38.38638	90.53902	Concrete slab with multiple pipe culverts
15	1.23	54	Jump	1	Heads Creek	Rainbow Ln	Jefferson	38.38203	90.53307	Concrete slab with one box culvert
16	1.22	309	Jump	1	Belews Creek	Hillshire	Jefferson	38.23929	90.57953	Concrete slab with multiple pipe culverts
17	1.22	500	Jump	1	Branch of Flat River	CR-529	Washington	37.80101	90.69626	Concrete slab with multiple pipe culverts
18	1.21	58	Jump	1	Heads Creek	Tower Valley Rd	Jefferson	38.35947	90.51608	Concrete slab with multiple pipe culverts
19	1.21	371	Jump	1	Heads Creek Trib	Manor Crest Drive	Jefferson	38.41853	90.54328	Concrete slab with one pipe culvert
20	1.16	312	Jump	1	Townsen Creek	CR 55	Iron	37.65662	90.74023	Concrete slab with multiple pipe culverts
21	1.16	501	Jump	1	Branch of Flat River	Doc Wallen Rd	Washington	37.7829	90.6804	Concrete slab with multiple pipe culverts
22	1.15	218	Jump	1	Clear Creek	King Rd	Washington	37.8091	90.82231	Concrete slab with one box culvert
23	1.08	291	Jump	1	Dulin Creek	Duckworth Drive	Jefferson	38.35481	90.58952	Concrete slab with one pipe culvert

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Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W	Structure Type
24	1.05	478	Jump	1	Branch of Flat River	Zinc Mine Rd	Washington	37.85336	90.69488	Concrete slab with multiple pipe culverts
25	1.02	246	Jump	1	Reid Creek	CR 40	Iron	37.70682	90.76186	Concrete slab with multiple pipe culverts
26	1.00	393	Perch	1	Skullbone Creek Trib	Paradise Estates	Jefferson	38.33818	90.64426	Concrete slab with one box culvert
27	0.98	311	Jump	1	Belews Creek	Hillshire	Jefferson	38.23836	90.57899	Concrete slab with multiple pipe culverts
28	0.95	333	Jump	1	Gallighers Creek Trib	West Vista Drive	Jefferson	38.25733	90.61424	Concrete slab with multiple pipe culverts
29	0.95	238	Perch	1	Cedar Creek	Buford Rd	Iron	37.73127	90.7913	Concrete slab with multiple pipe culverts
30	0.94	248	Jump	1	Salien Creek	CR 27A	Iron	37.72932	90.74645	Concrete slab with multiple pipe culverts
31	0.91	224	Perch	1	Big River	Big River Rd	Washington	37.7553	90.88453	Concrete slab with multiple pipe culverts
32	0.88	530	Perch	1	Big River Trib	Redbud Ln	Jefferson	38.44761	90.6179	Concrete slab with one pipe culvert
33	0.88	209	Perch	1	Wallen Creek	CR 518	Washington	37.85778	90.72499	Concrete slab with multiple pipe culverts
34	0.83	276	Perch	1	Skull Creek	Ficken	Jefferson	38.3329	90.6649	Concrete slab with multiple pipe culverts
35	0.79	219	Jump	1	North Fork Clear Creek	Dellbridge Rd	Washington	37.81132	90.83504	Concrete slab with one box culvert
36	0.62	157	Jump	-1		Westover Rd	St. Francois	37.89682	90.43987	Concrete slab with one box culvert
37	0.61	497	Perch	1	Branch of Flat River	Shut In Rd	Washington	37.80421	90.69937	Concrete slab with one box culvert
38	0.59	475	Jump	1	Branch of Flat River	Germania Rd	St. Francois	37.87179	90.64284	Concrete slab with multiple box culverts
39	0.53	222	Perch	1	Brock Creek	Sunlight Rd	Washington	37.7781	90.8691	Concrete slab with multiple pipe culverts
40	0.38	319	Jump	-1		Hazel Run	St. Francois	37.9343	90.45691	Concrete slab with multiple pipe culverts
41	0.14	527	Jump	-1	Branch of Terre Bleue	Skyline Rd	St. Francois	37.98982	90.54333	Concrete slab with multiple pipe culverts
42	0.05	360	Perch	1	Heads Creek Trib	Dellwood Rd	Jefferson	38.42101	90.5565	Concrete slab with multiple box culverts
43	-0.04	95	Jump	-1	Fourche Renault Creek	Sumen Lake Rd	Washington	37.92464	90.9167	Concrete slab with multiple pipe culverts
44	0.02	406	Jump	-1	Scott Branch	Floyd Tower Rd	Washington	37.96702	90.92321	Concrete slab with multiple box culverts
45	-0.03	271	Jump	-1	Kruze Creek	Black Hawk Ln	Jefferson	38.25584	90.74901	Concrete slab with multiple pipe culverts
46	-0.05	416	Jump	-1	Fiddle Creek	Arnault Branch	Washington	38.01382	90.80656	Concrete slab with one pipe culvert
47	-0.12	423	Jump	-1	Unknown	Simpson Rd	Washington	37.98133	90.797	Concrete slab with multiple pipe culverts
48	-0.25	123	Jump	-1	Miller Branch	Pleasant Hill	Washington	37.97778	90.85336	Concrete slab with multiple pipe culverts
49	-0.26	402	Jump	-1	Unknown	Kinston	Washington	38.08358	90.79409	Concrete slab with multiple pipe culverts
50	-0.27	307	Jump	-1	Fourche Renault Creek	Harmon Rd	Washington	37.91121	90.88651	Concrete slab with multiple pipe culverts

Table 1. Priority rank, Passage Quality Index (PQI) score and additional descriptive information for culverted road crossings including: stream and road names, barrier type, lead contamination level, location and structure type.

Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W	Structure Type
51	-0.28	520	Jump	-1	Old Mines Creek	Villmer Drive	Washington	38.02146	90.75549	Concrete slab with multiple pipe culverts
52	-0.29	83	Jump	-1	Unknown	CR 320	Washington	38.04181	90.88683	Concrete slab with multiple pipe culverts
53	-0.32	299	Jump	-1	Fourche Renault Creek	Eye Rd	Washington	37.91329	90.87772	Concrete slab with multiple pipe culverts
54	-0.39	415	Jump	-1	Fiddle Creek	Pat Daly Rd	Washington	38.02206	90.80949	Concrete slab with multiple pipe culverts
55	-0.41	154	Jump	-1		Cedar Run	St. Francois	37.91142	90.45471	Concrete slab with multiple pipe culverts
56	-0.44	82	Perch	-1	Unknown	CR 320	Washington	38.03988	90.88203	Concrete slab with multiple pipe culverts
57	-0.44	127	Jump	-1	Fountain Branch	Radio Station Rd	Washington	37.9644	90.74178	Concrete slab with multiple pipe culverts
58	-0.46	523	Jump	-1	Calico Creek	Calico Rd	Washington	38.13906	90.75986	Concrete slab with one box culvert
59	-0.52	329	Jump	-1	Branch of Dry Creek	Jim Wilson Rd	Jefferson	38.2533	90.7032	Concrete slab with multiple box culverts
60	-0.63	532	Jump	-1	Old Mines Creek	Sutton Property	Washington	38.09111	90.72315	Concrete slab with multiple pipe culverts
61	-0.64	158	Perch	-1		Westover Rd	St. Francois	37.89495	90.44377	Concrete slab with multiple pipe culverts
62	-0.64	267	Jump	1	Dry Creek	Gifford Street	St. Francois	37.76825	90.63351	Concrete slab with one pipe culvert
63	-0.65	506	Perch	-1	Branch of Terre Bleue	White Oak	Ste Genevieve	37.86951	90.37929	Concrete slab with one pipe culvert
64	-0.67	177	Perch	-1	Branch of Flat River	Hurryville Rd	St. Francois	37.84392	90.46713	Concrete slab with multiple pipe culverts
65	-0.68	508	Jump	-1	Branch of Terre Bleue	Patt Rd	Ste Genevieve	37.90242	90.37925	Concrete slab with multiple pipe culverts
66	-0.69	85	Perch	-1	Goose Creek	CR 304	Washington	38.04105	90.89796	Concrete slab with one pipe culvert
67	-0.69	2	Perch	-1	Mill Creek	Tiff Rd	Washington	38.01549	90.65071	Concrete slab with multiple pipe culverts
68	-0.70	88	Perch	-1	Ebo Creek	Ebo Rd	Washington	38.02362	90.90918	Concrete slab with multiple pipe culverts
69	-0.73	445	Perch	-1	Branch of Terre Bleue	Primero SE Rd	St. Francois	37.96766	90.55017	Concrete slab with multiple pipe culverts
70	-0.78	510	Jump	-1	Branch of Terre Bleue	Gillespie Rd	St. Francois	37.84027	90.41414	Concrete slab with one pipe culvert
71	-0.79	86	Perch	-1	Ebo Creek	Souls Chapel	Washington	38.02433	90.89146	Concrete slab with multiple pipe culverts
72	-0.85	84	Perch	-1	Goose Creek	Lick Skillet	Washington	38.04002	90.89449	Concrete slab with multiple pipe culverts
73	-0.88	521	Perch	-1	Old Mines Creek	Setlles	Washington	38.02909	90.75426	Concrete slab with multiple pipe culverts
74	-1.07	396	Jump	-1	Branch of Dry Creek	Maupin	Franklin	38.23063	90.79803	Concrete slab with multiple pipe culverts
75	-1.08	201	Jump	-2	Big River	Hunt Rd	St. Francois	37.86893	90.5845	Concrete slab with multiple pipe culverts
76	-1.14	151	Perch	-1		Hillsboro	St. Francois	37.95374	90.46783	Concrete slab with multiple pipe culverts
77	-1.19	298	Perch	-1	Rocky Branch	CR 319	Washington	38.09015	90.77917	Concrete slab with multiple pipe culverts

Table 1. Priority rank, Passage Quality Index (PQI) score and additional descriptive information for culverted road crossings including: stream and road names, barrier type, lead contamination level, location and structure type.

Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W	Structure Type
78	-1.23	272	Perch	-1		Joe Buck Rd	Jefferson	38.2752	90.74472	Concrete slab with one pipe culvert
79	-1.26	300	Jump	-2	Branch of Big River	Turkey Creek	St. Francois	37.951	90.55853	Concrete slab with one box culvert
80	-1.54	411	Jump	-1	Bates Creek	Bates Creek Rd	Washington	37.91602	90.82597	Concrete slab with multiple box culverts
81	-1.62	301	Perch	-2	Branch of Big River	Turkey Creek	St. Francois	37.94717	90.55948	Concrete slab with multiple pipe culverts

Table 2. Priority rank, Passage Quality Index (PQI) score and additional descriptive information for bridge crossings with bottoms or aprons which may be barriers to fish passage.

Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W
1	2.53	55	Jump	1	Heads Creek	Heads Creek Rd	Jefferson	38.38174	90.52912
2	2.38	44	Jump	1	Bear Creek	Hillsboro House Springs	Jefferson	38.41108	90.56931
3	2.29	363	Jump	1	Heads Creek Trib	Carol Park Rd	Jefferson	38.43092	90.5469
4	2.21	314	Jump	1	Bourne Creek	Hillsboro House Springs	Jefferson	38.36441	90.56091
5	2.03	234	Jump	1	Goose Creek	Hwy 21	Washington	37.76153	90.77299
6	1.86	35	Jump	1	Buck Creek	Beach Rd	Jefferson	38.37766	90.6552
7	1.65	260	Jump	1	Mill Creek	CR 528	Washington	37.7962	90.66273
8	1.58	356	Jump	1	Big River Trib	Winnefred Drive	Jefferson	38.44925	90.61605
9	1.54	515	Jump	1	Isum Creek Tirb	Graham Rd	Jefferson	38.34916	90.61357
10	1.36	503	Jump	1	Branch of Flat River	Hwy M	Washington	37.83181	90.67391
11	1.35	480	Jump	1	Branch of Flat River	Hwy U	Washington	37.87336	90.71683
12	1.33	382	Jump	1	Dulin Creek Trib	Scottsdale Rd	Jefferson	38.40211	90.58792
13	1.21	288	Jump	1	Isum Creek	Timberland Drive	Jefferson	38.34878	90.60638
14	1.16	255	Perch	1	Logan Creek	MO Hwy 21	Iron	37.67085	90.71175
15	1.11	391	Jump	1	Dutch Creek Trib	Eime Rd	Jefferson	38.34476	90.69179
16	1.01	491	Jump	1	Big River Trib	Hwy C	Washington	37.78027	90.81058
17	1.03	372	Jump	1	Heads Creek Trib	Hwy MM	Jefferson	38.40299	90.55814
18	0.95	310	Perch	1	Belews Creek	Hwy 21	Jefferson	38.23754	90.57903
19	0.86	231	Perch	1	Goose Creek	Hwy 32	Washington	37.76566	90.77111
20	0.78	505	Jump	1	Unknown	MO-O	Iron	37.65907	90.75919
21	0.70	287	Jump	-1	Isum Creek Tirb	Hwy BB	Jefferson	38.34171	90.62637
22	0.61	355	Perch	1	Big River Trib	Hwy W	Jefferson	38.45198	90.61653
23	0.54	76	Jump	-1	Ditch Creek	North Bridge	Jefferson	38.21225	90.75828
24	0.36	141	Jump	-1	Branch of Big River	Timberline	St. Francois	37.99213	90.54035
25	0.28	126	Jump	-1	Fountain Farm Branch	Rte E	Washington	37.97236	90.72752
26	0.22	426	Jump	-1	Unknown	Hwy F	Washington	37.96695	90.79716
27	0.20	104	Jump	-1	Bates Creek	Bates Creek Rd	Washington	37.91599	90.82564
28	-0.09	518	Perch	1	Cedar Creek	Buford Rd	Washington	37.74192	90.78007
29	0.09	286	Jump	-1	Isum Creek	Hwy BB	Jefferson	38.34227	90.6264
30	0.04	424	Jump	-1	Unknown	Hwy F	Washington	37.97746	90.80743
31	-0.02	13	Jump	-1	Big River Trib	Mammoth Rd	Jefferson	38.12654	90.65471
32	-0.10	139	Jump	-2	Cabanna Course	Airport Rd	St. Francois	37.92499	90.58974
33	-0.18	401	Jump	-1	Old Mines Creek	CR-317	Washington	38.08944	90.72318
34	-0.32	412	Jump	-1	Branch of Bates Creek	Hwy 8	Washington	37.93229	90.82964
35	-0.37	410	Jump	-1	Bates Creek	Hwy P	Washington	37.89733	90.82224
36	-0.39	392	Jump	-1	Skullbone Creek Trib	Cedar Hill Rd	Jefferson	38.34268	90.64595

Table 2. Priority rank, Passage Quality Index (PQI) score and additional descriptive information for bridge crossings with bottoms or aprons which may be barriers to fish passage.

Priority Rank	PQI Score	Crossing ID	Barrier Type	Lead	Stream	Road Name	County	UTM_N	UTM_W
37	-0.42	101	Jump	-1	Branch of Mineral Fork	Hwy P	Washington	37.88163	90.87741
38	-0.82	186	Jump	-2	Branch of Flat River	Rte B	St. Francois	37.80614	90.53934
39	-1.06	436	Jump	-1	Mill Creek Trib	Old Hwy 8	Washington	37.92307	90.74234
40	-1.06	464	Jump	-2	Unknown	MO-A	St. Francois	37.86825	90.58421
41	-1.11	443	Jump	-2	Branch of Flat River	Airport Rd	St. Francois	37.92502	90.57372
42	-1.17	469	Jump	-2	Branch of Flat River	MO 8	St. Francois	37.8698	90.59511
43	-1.21	285	Jump	-1	Shibboleth Branch	Rte E	Washington	38.00582	90.70506
44	-1.54	431	Jump	-1	Mill Creek Trib	Rte E	Washington	37.97593	90.72787
45	-1.85	185	Jump	-2	Branch of Flat River	Old Business Rd	St. Francois	37.81985	90.54692
46	-2.07	399	Perch	-1	Ditch Creek	Sycamore Rd	Jefferson	38.21092	90.76756

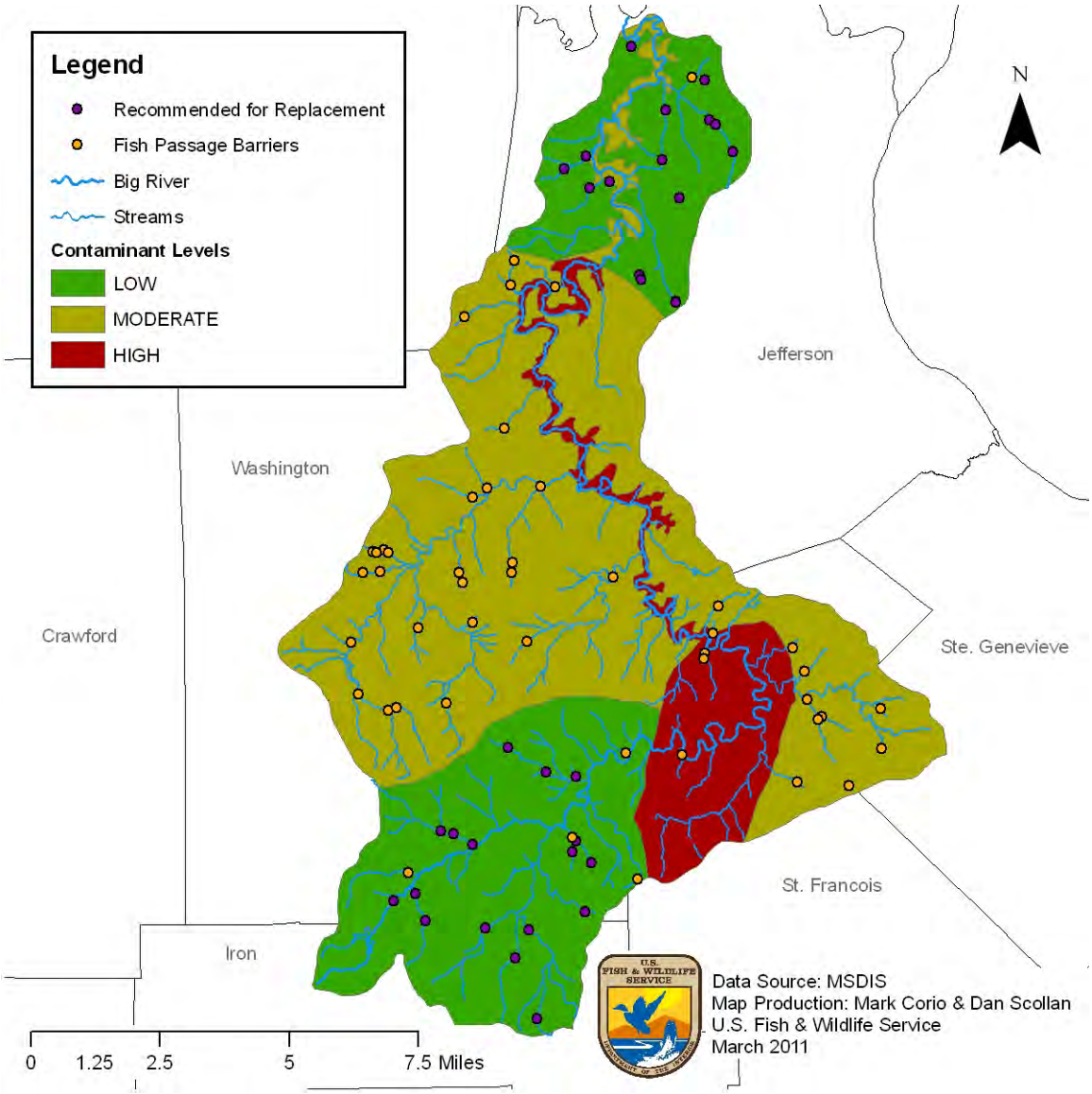

Figure 9. Stream crossings with pipe or box culverts (81) which act as barriers to benthic fish passage. Map identifies the thirty-five structures with the highest PQI score for potential replacement.

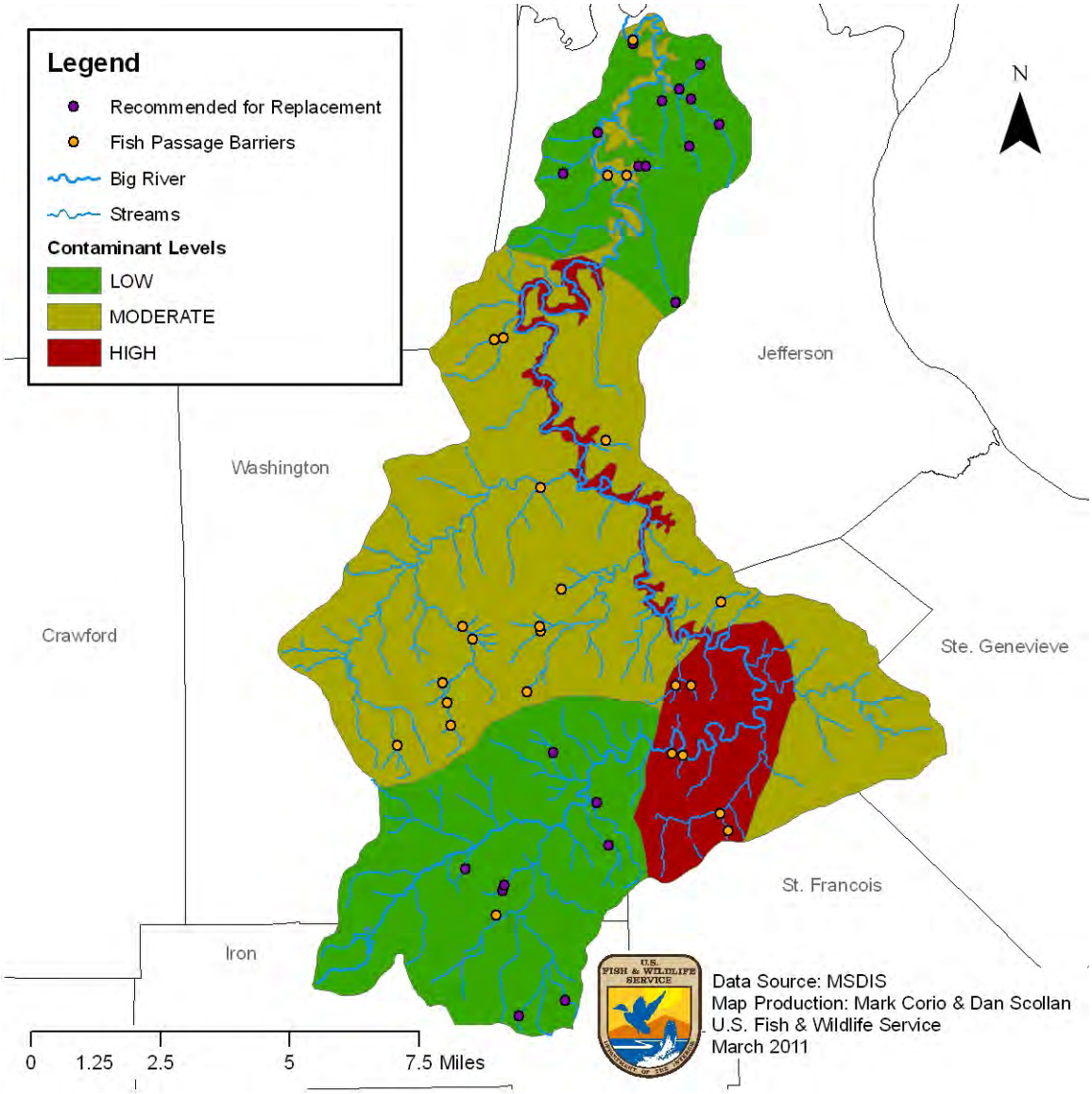

Figure 10. Bridges with concrete stream beds or aprons (47) which may act as barriers to benthic fish passage. Map identifies the twenty structures with the highest PQI score for potential replacement.

A second objective of this survey was to determine for the purposes of ongoing lead remediation efforts those crossings which may serve to contain lead impacted sediments similar to the low-head dams in the lowermost portion of the Big River. Crossings with this potential would have low percent passable face, culverts perched far above the stream bottom on the upstream side of the bridge and occur in the highly contaminated portion of the watershed. The dam like nature of the upstream face would impound stream water, while the elevated culvert would allow the lead contaminated sediments to settle at the base of the structure. The database was queried to find crossings in the contaminated zone with a minimum perch of the upstream culverts of one-foot and a percent passable face less than 10%. Only one low-water crossing (Crossing ID 201) met these requirements (Figures 10 and 11). The Hunt Road crossing over the Big River in St.

Francois County may hold lead contaminated sediments and should be examined for lead remediation efforts.

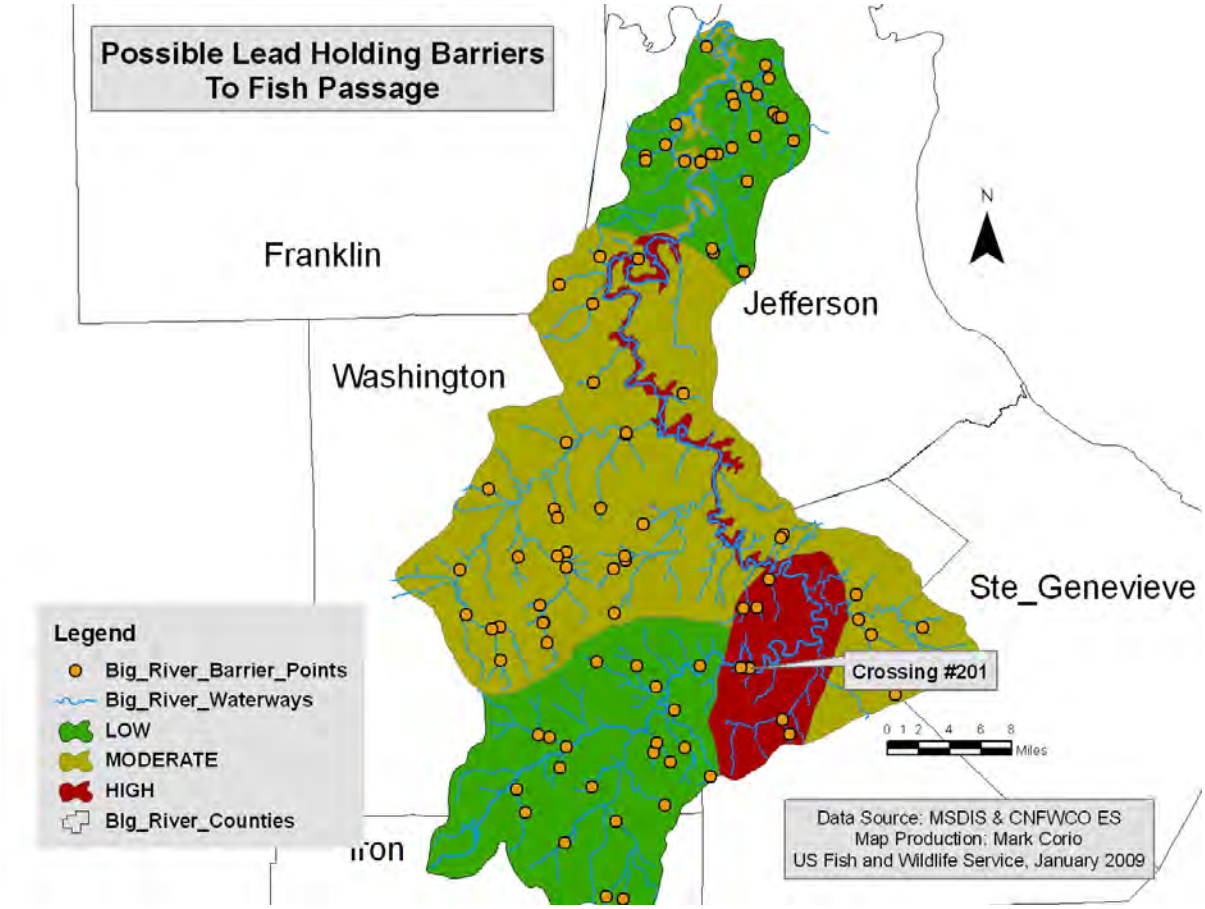

Figure 11. The Hunt Road crossing may be acting as a small dam, stopping downstream movement of lead contaminants.

Figure 12. The Hunt Road crossing over the Big River in St. Francois County may help contain lead contaminated sediments.

Discussion

Recommendations for the Big River Watershed

While many native species may benefit from removal of fish barriers in this watershed, the potential additional impact of lead mining contaminants is prohibitive throughout much of the watershed. A jointly developed plan for improving aquatic habitat and species access to that habitat is needed. Removal of low water crossings where lead contaminated sediments accumulate would increase the downstream movement of these contaminants. Removal of the Munroe Falls Dam from the Cuyahoga River in Ohio resulted in fining downstream of the former dam; bedload discharge measurements indicated the greatest sediment source was from the former impoundment (Rumschlag and Peck 2007). Until such time as lead remediation work has been completed and the tailings dams are stabilized, fish passage efforts should be limited to the lowermost portion of the basin, downstream of the series of lowhead dams in Jefferson County. This portion of the Big River also contains the remaining known significant mussel beds (Roberts et al. 2009). Fish passage efforts should focus on increasing passage for fish species which are known mussel glochidia hosts. Additional care should be taken when selecting bridge replacement sites to ensure that the resulting change in stream gradient, which could occur post removal of the old structure, does not impact existing mussel beds (Corson et al. 2008).

Recommendations for Future Crossing Inventories

We received bridge data from the Missouri Department of Transportation while working on our data analysis. This coverage could be used in future watershed inventories to identify free span structures which will not require field visits by survey crews. This could decrease the field time required to assess crossings within an individual watershed. Initial comparison of our crossing classification with MODOT's classification system resulted in some level of category mis-match. Further understanding of the engineering classification system as compared to our "fish-eye" view classification system is needed to make this a fully usable screening tool.

This dataset will also aid us in our continuing efforts to define the line between crossings identified as "Bridge or Clear Span" versus "Multiple Box Culverts". Several structures within the Big River watershed would appear at first glance to be open to enough of the stream channel width to fall within the former category. However, on closer inspection concrete bottoms or aprons in each of the openings creating variable levels of potential perch barriers for benthic species would appear to place the crossing in the latter category.

Careful thought should be given to a watershed's species needs and priorities when planning watershed barrier inventories. Thousands of road stream crossings in Missouri may be fish passage barriers. It may not be necessary to assume passage for all benthic species. Where the species of interest lives higher in the water column other assumptions regarding perch or jump heights may be made. This would reduce the number of bridges with bottoms or aprons in the final analysis. Watershed inventories could also be limited to streams providing known preferred habitat for the target species similar to the Niangua darter inventory (Novinger et al. 2008). This would narrow the scope of analysis to more specifically benefit the priority species.

In the Niangua darter inventory field work was limited to third order streams with known darter habitat. There was always water present. One assumption of the current Missouri protocol (and other inventory methods) is that water is present at the crossing site. This is an important assumption which should be understood when planning future watershed inventories. Missouri's karst topography includes disappearing streams. The current Access programming for barrier analysis does not take dry stream beds into account. It may be necessary to modify field work or computer programming to address these sites.

While the intent of the protocol is to inventory the stream crossings at low to normal flows, summer may not be the appropriate time of year for field crews to conduct the survey. Conducting crossing surveys late fall through early spring would minimize the impacts of vegetation. The structure would be more visible in site photos. Sites would be easier to access. It would also increase the survey crew's ability to accurately score structure condition indicators such as bank erosion and rip rap presence/absence.

GIS analyses of factors including stream order and slope have been used by biologists in other regions of the country to locate potential crossing locations. These tools should be examined with a full watershed dataset such as this one to determine their feasibility for reducing unnecessary site visits in future watershed assessments. Additionally, other crossing survey programs include water velocities at and through the culverts to determine if the crossings are acting as velocity barriers. The Missouri protocol was developed specifically to provide a quick and efficient way to identify crossings which act as fish barriers. Some crossings may serve as a barrier through a combination of perch and velocity issues which weren't currently addressed with our protocols.

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Appendix A. Maps of Subwatersheds

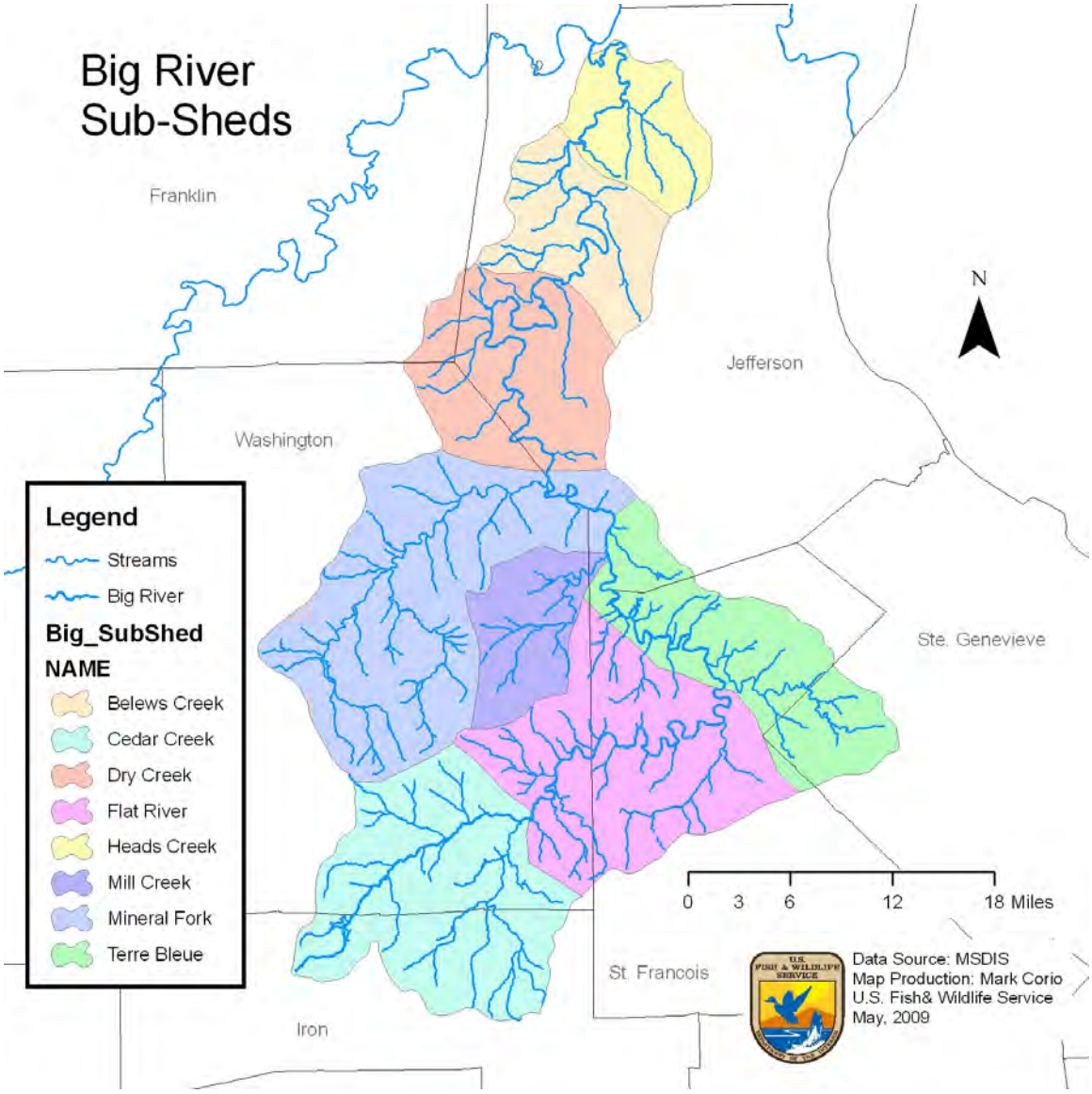


Figure A1. Sub-watersheds of the Big River Basin

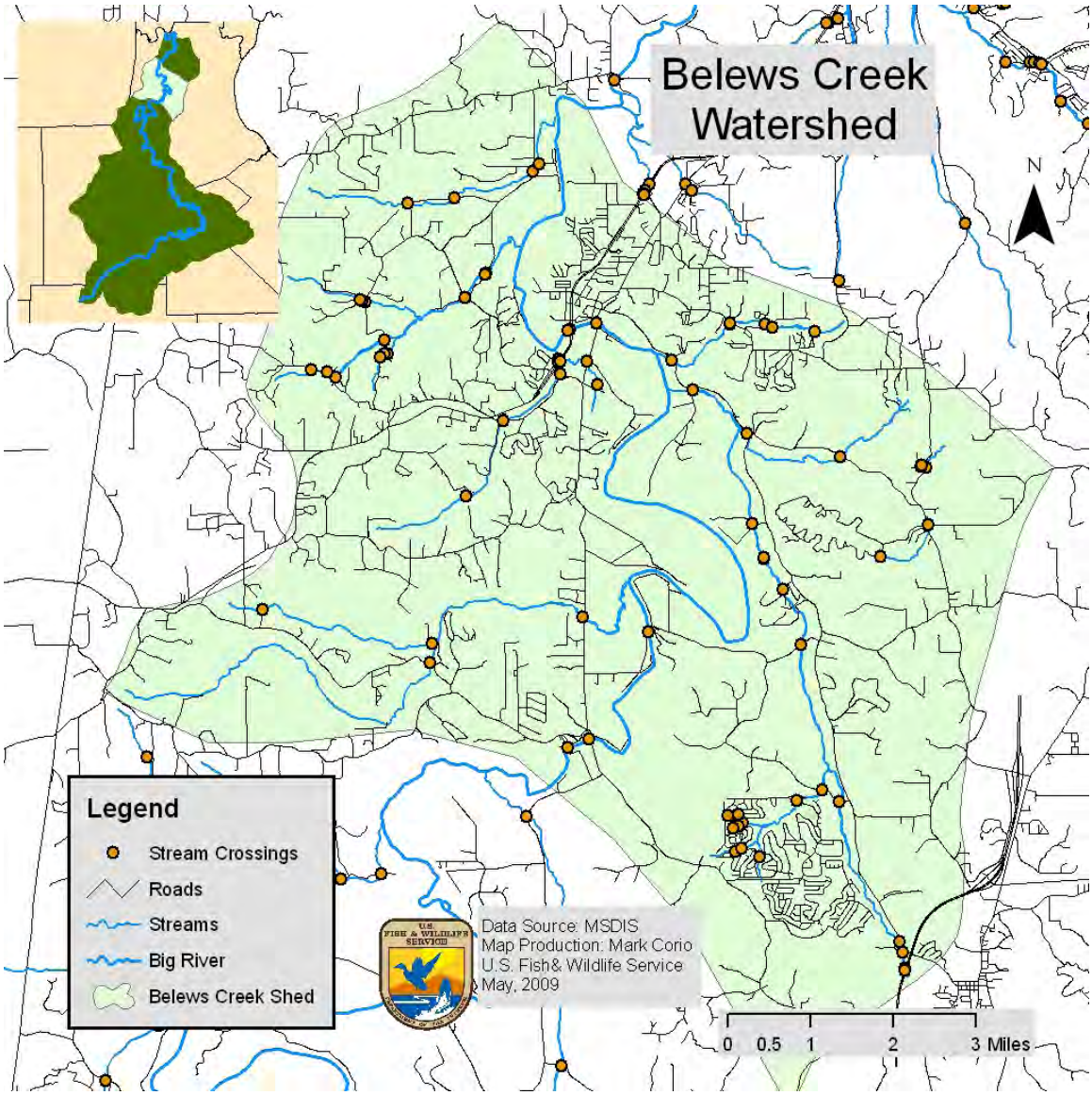


Figure A2. Road crossing locations within the Belews Creek watershed.

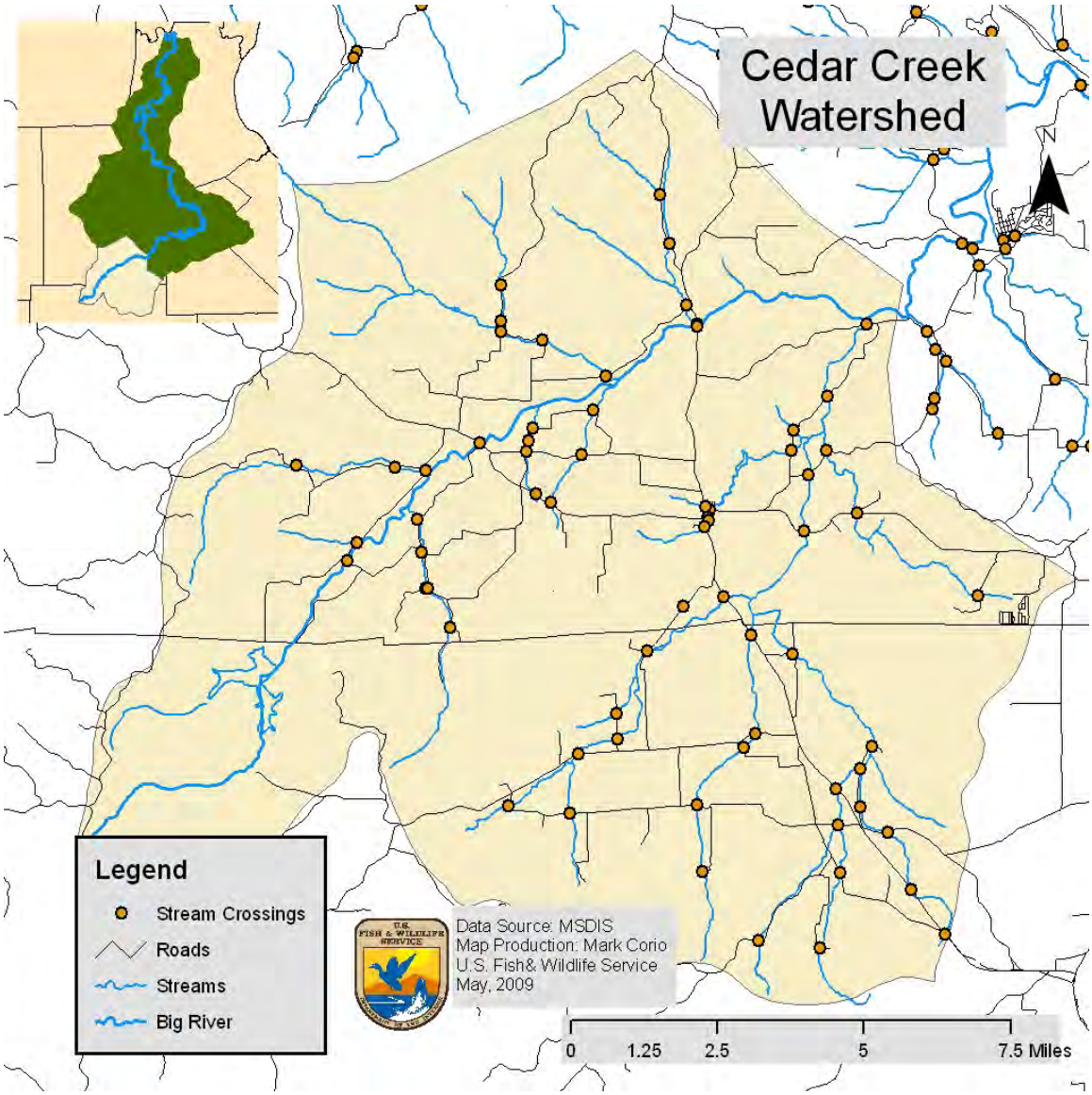


Figure A3. Road crossing locations within the Cedar Creek watershed.

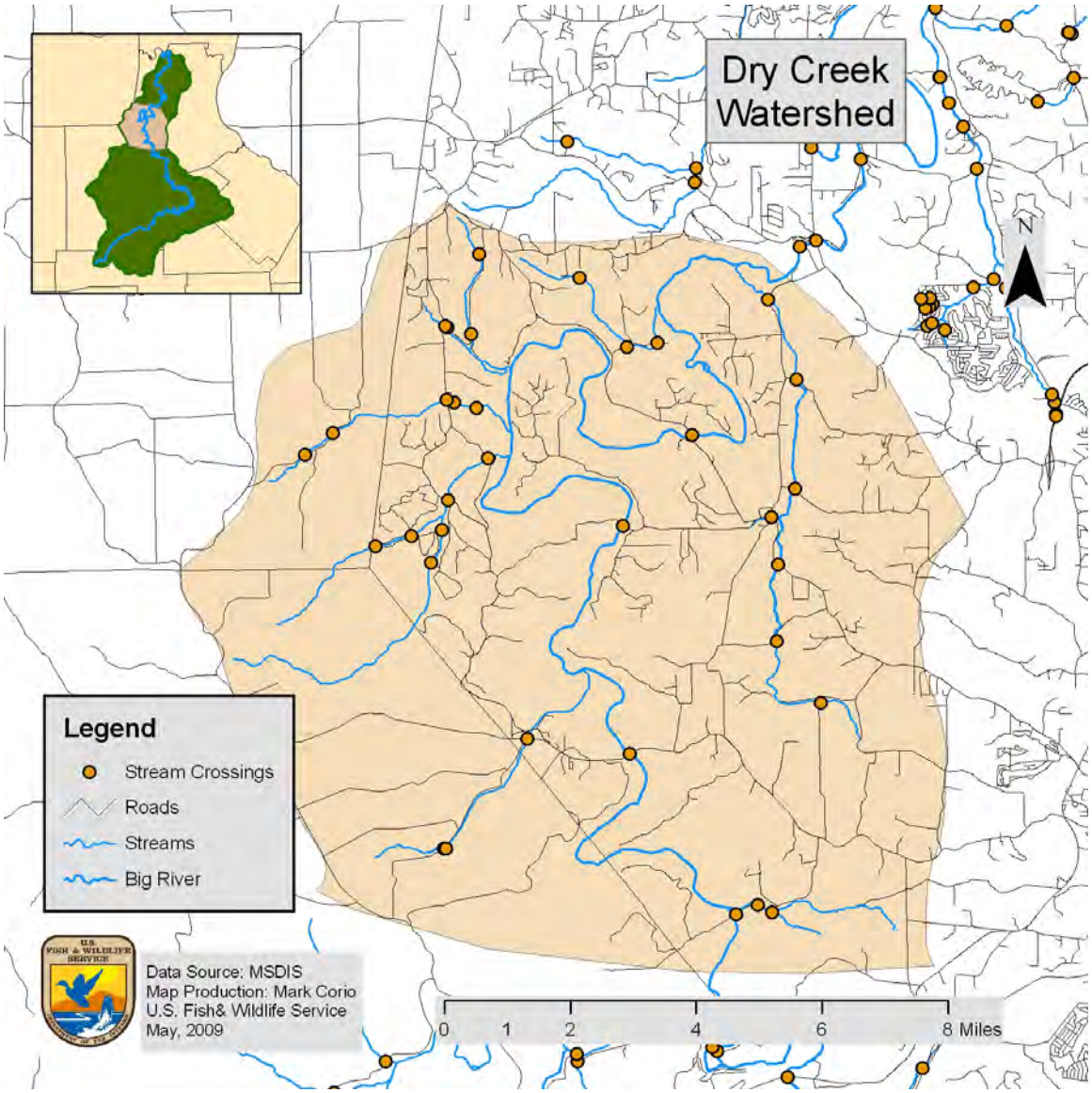


Figure A4. Road crossing locations within the Dry Creek watershed.

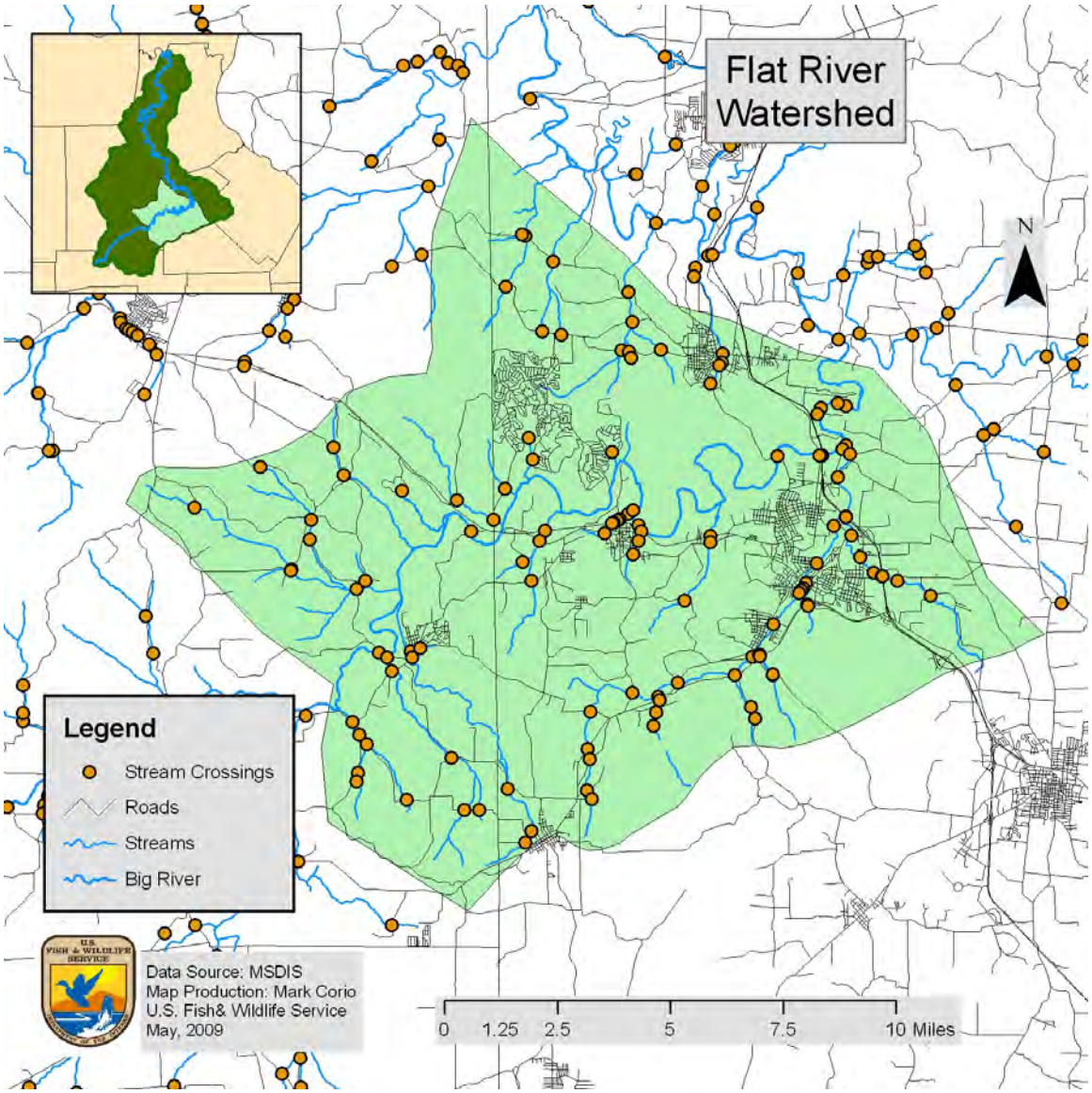


Figure A5. Road crossing locations within the Flat River watershed.

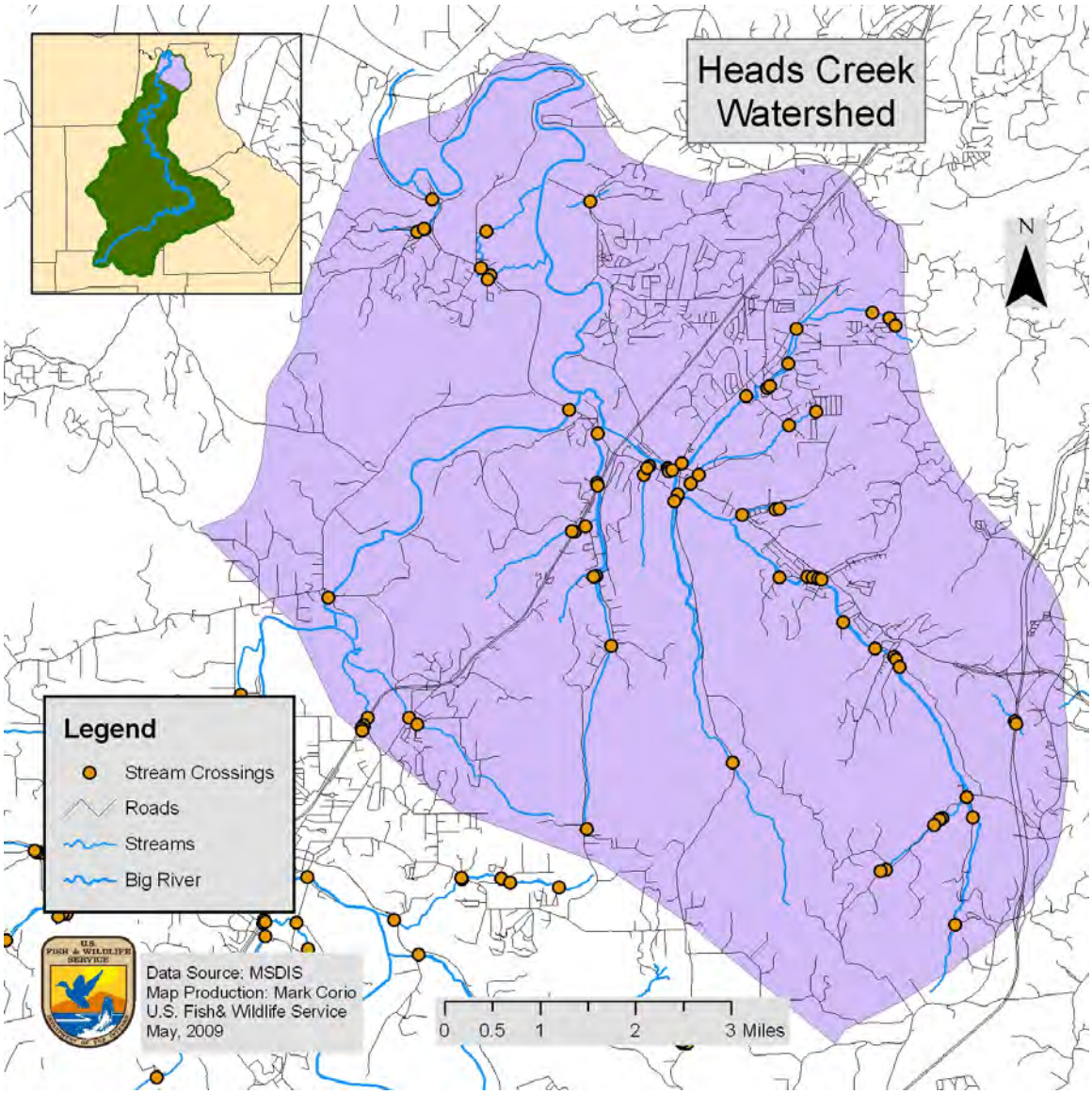


Figure A6. Road crossing locations within the Heads Creek watershed.

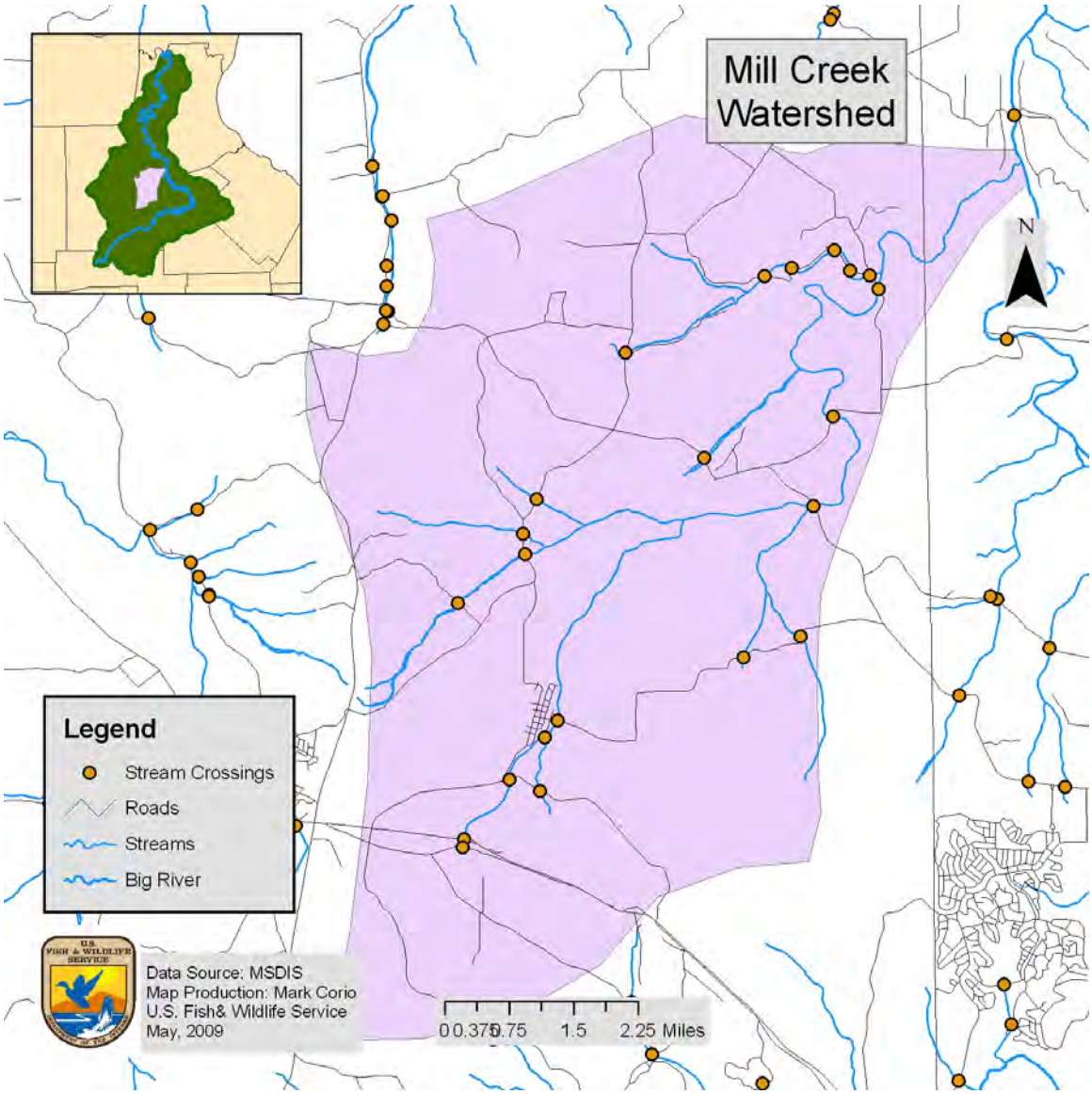


Figure A7. Road crossing locations within the Mill Creek watershed.

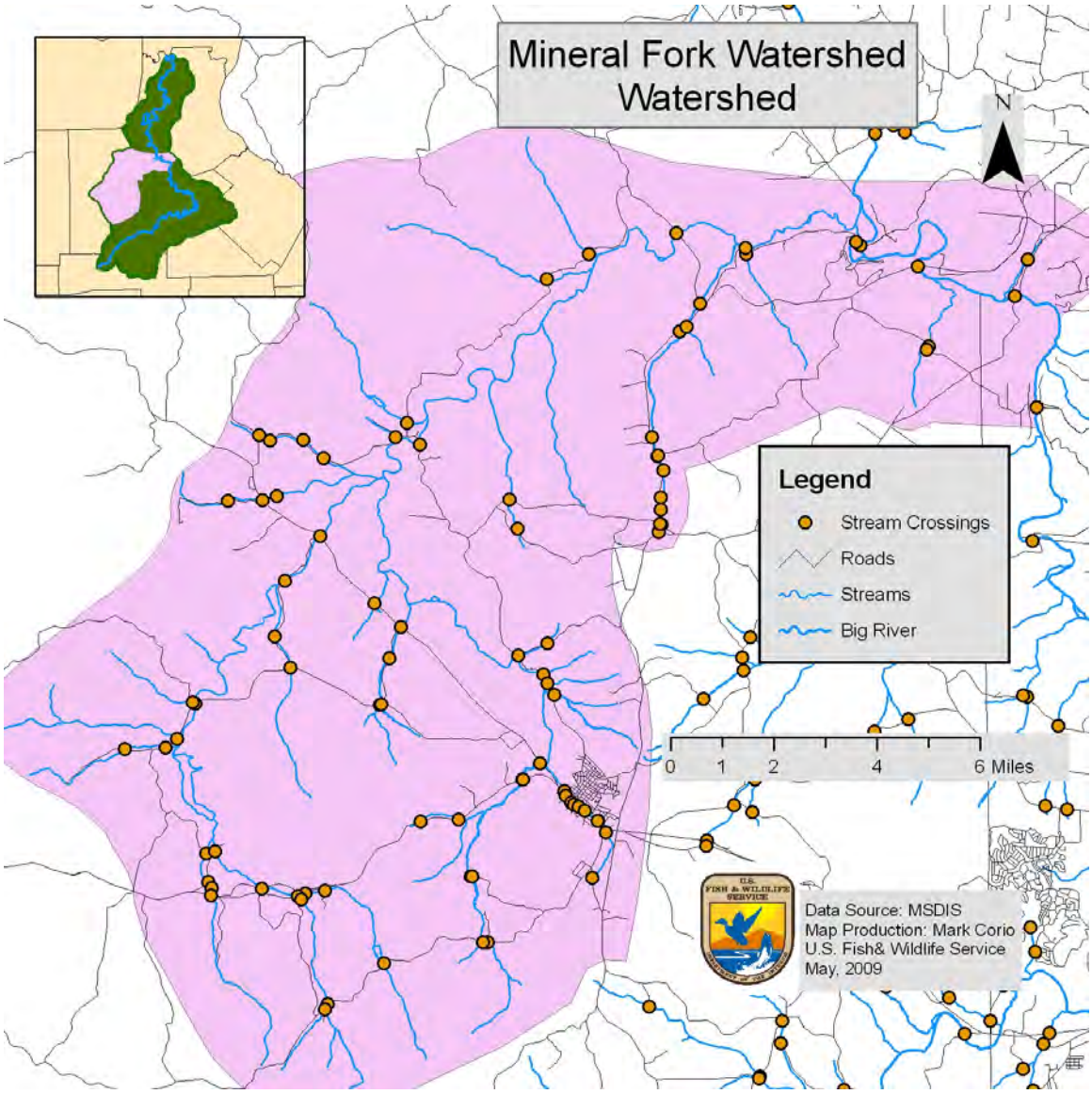


Figure A8. Road crossing locations within the Mineral Fork watershed.

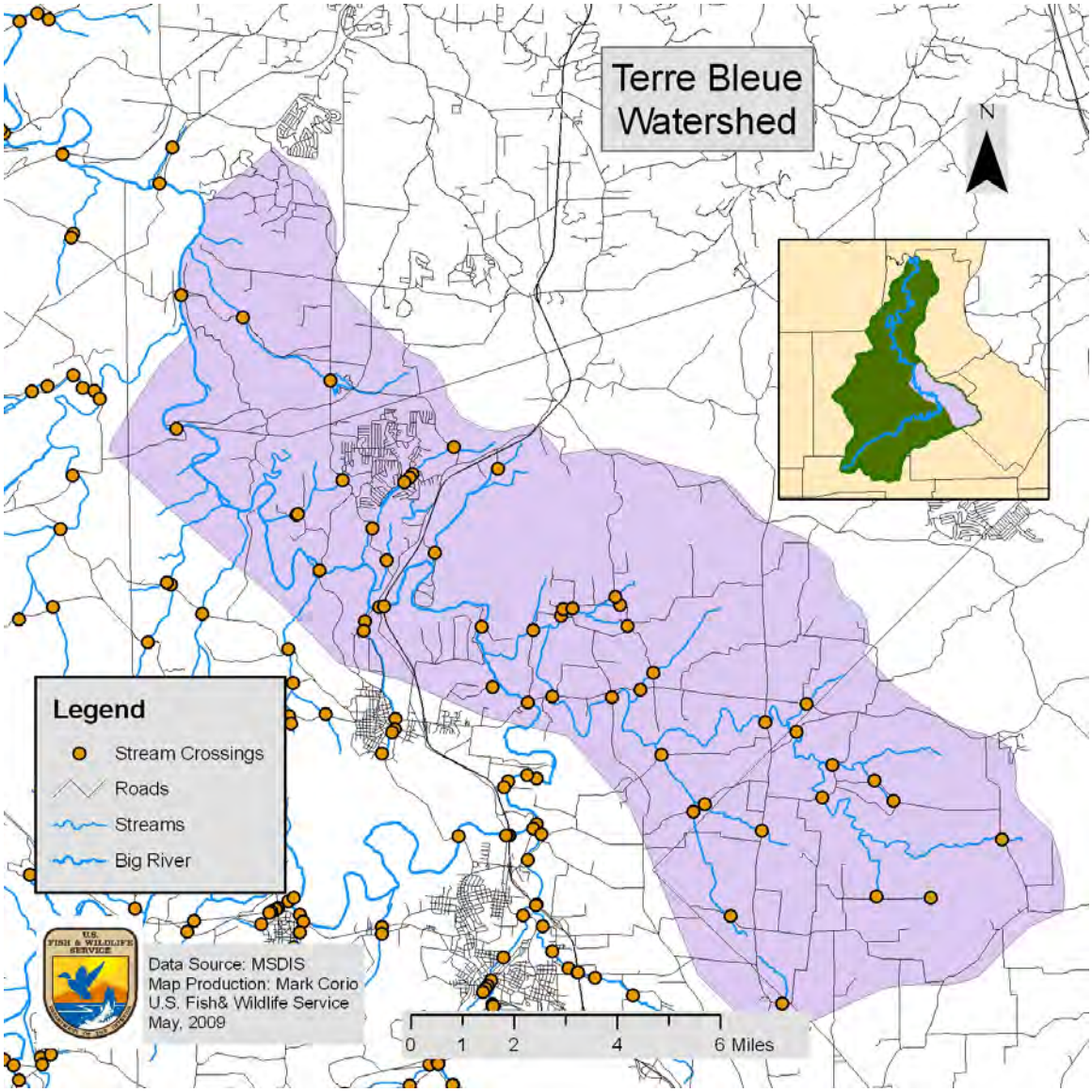


Figure A9. Road crossing locations within the Terre Bleue watershed.

Appendix B. Big River Road Crossing Inventory Datasheet

BIG RIVER WATERSHED LOW WATER CROSSING INVENTORY & ASSESSMENT

SITE: HC BC DC MF MC TB FR CC Data Recorder_____ Crossing I.D. Number:_____

County:_____Road Name:_____Stream Name:_____

Legal Description: T_____N; R_____W; Sec_____ Date:____/____/_____

UTM Coordinates: N_____ W_____(UTM NAD83, Zone 15N)

Water Level: Intermittent_____ Low_____ Normal_____ High__

CROSSING STRUCTURE:

TYPE OF STRUCTURE:

- ☐ Gravel ford with no structure
- ☐ Bridge or clear span without bottom
- ☐ Concrete slab with NO culvert
- ☐ Concrete slab with one pipe culvert
- ☐ Concrete slab with multiple pipe culverts
- ☐ Concrete slab with one box culvert
- ☐ Concrete slab with multiple box culverts
- ☐ Concrete slab with pipe AND box culverts combo
- ☐ Concrete slab with wide box opening(s)
- ☐ Other:_____

CONDITION INDICATORS: (circle all that apply; Note: LDB=Left Descending Bank, RDB=Right Descending Bank, up=Upstream, down=Downstream)

Eroding Banks: upLDB upRDB downLDB downRDB

Rip Rap: upLDB upRDB downLDB downRDB

Grouted Rip Rap: upLDB upRDB downLDB downRDB

Condition of Bridge: cracked deck undermined footings downstream scour hole upstream impounded

other_____

Are the road approaches constricting the floodplain: YES NO

STRUCTURE DIMENSIONS/POSITION: (English units, to the nearest 1/10 foot)

Width:_____ Length:_____ Skew Description:

(Driving Deck) (High Bank to High Bank)

(Sketch Area)

- ☐ Perpendicular
- ☐ Angled
- ☐ Curved upstream
- ☐ Curved downstream
- ☐ Right approach upstream
- ☐ Right approach downstream
- ☐ Other_____

At Each <u>UPSTREAM</u> Opening Measure: (Fill out chart from **<u>LDB to RDB</u>**; to the nearest 1/10 foot)
(Note: if no openings, only measure #'s 1 and 3 up and downstream)

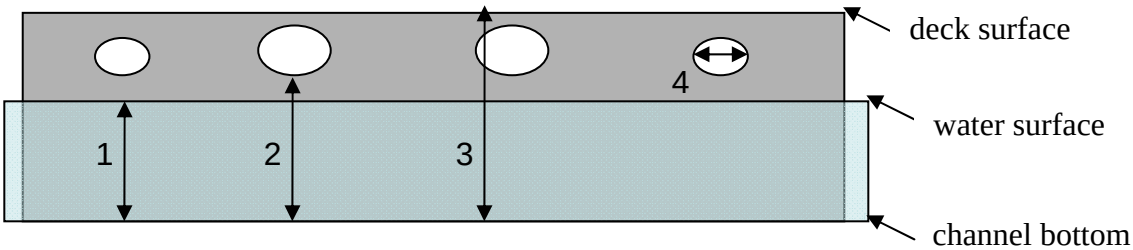
	1st	2nd	3rd	4th	5th	6th
1.Water Depth (channel bottom to water surface)						
2.Opening Perch (channel bottom to bottom of opening)						
3.Height of Bridge (channel bottom to top of deck)						
4.Size of Opening (round-diameter, other-L and W)						
Opening blockage (% plugged by sediment: 0, 25, 50, 75, 100)						

(See numbered graphic for reference)

At Each <u>DOWNSTREAM</u> Opening Measure: (Fill out chart from **<u>LDB to RDB</u>**; to the nearest 1/10 foot)

	1st	2nd	3rd	4th	5th	6th
1.Water Depth (channel bottom to water surface)						
2.Opening Perch (channel bottom to bottom of opening)						
3.Height of Bridge (channel bottom to top of deck)						
4.Size of Opening (round-diameter, other-L and W)						
Opening blockage (% plugged by sediment: 0, 25, 50, 75, 100)						

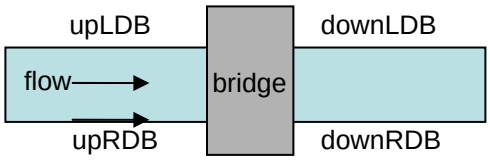
(Take all four measurements at each opening, and at both upstream and downstream side of crossing)



<u>PICTURE POINTS:</u> **<u>Picture I.D. Number</u>**

From:

1. Center of bridge deck upstream _____
2. Center of bridge deck downstream _____
3. Upstream bank to upstream face of bridge _____
4. Downstream bank to downstream face of bridge _____
5. Deck approach along upstream side of deck _____
6. Deck approach along downstream side of deck _____



<u>OTHER COMMENTS:</u>

_____

_____

_____ Data entry_____ Data proofed_____

BIG RIVER WATERSHED LOW WATER CROSSING INVENTORY & ASSESSMENT

Supplemental Data Sheet Date:____/____/_____ Crossing I.D. Number:_____

UPSTREAM LDB to RDB	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
1.Water Depth										
2.Opening Perch										
3.Height of Bridge										
4.Size of Opening										
Opening blockage (0, 25, 50, 75, 100%)										

DOWNSTREAM LDB to RDB	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
1.Water Depth										
2.Opening Perch										
3.Height of Bridge										
4.Size of Opening										
Opening blockage (0, 25, 50, 75, 100%)										

UPSTREAM LDB to RDB	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th
1.Water Depth										
2.Opening Perch										
3.Height of Bridge										
4.Size of Opening										
Opening blockage										

DOWNSTREAM LDB to RDB	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th
1.Water Depth										
2.Opening Perch										
3.Height of Bridge										
4.Size of Opening										
Opening blockage										

Appendix C. Number of openings presenting a barrier to fish movements at the 127 identified fish passage barriers.

Table C1. Number of openings presenting a behavioral barrier (perched) or jump barrier on both the downstream and upstream sides of the 127 crossings which constitute fish passage barriers.

Crossing ID	Number of Downstream Openings	Number of Downstream Perched Openings	Number of Downstream Jump Openings	Number of Upstream Openings	Number of Upstream Perched Openings	Number of Upstream Jump Openings
2	3	1	0	3	3	0
13	1	1	1	1	1	0
33	1	1	1	1	1	0
35	1	0	1	1	1	0
44	3	3	3	3	3	3
53	4	0	4	4	4	0
54	1	1	1	1	1	0
55	1	1	1	1	1	1
58	4	0	3	4	3	0
76	2	1	2	2	2	1
82	2	2	0	2	2	0
83	2	1	0	2	2	1
84	2	0	0	2	2	0
85	1	0	0	1	1	0
86	2	1	0	2	0	0
88	2	0	0	2	1	0
95	6	5	6	6	6	2
101	3	0	2	3	2	0
104	3	2	3	3	3	0
123	3	0	3	3	3	0
126	1	1	1	1	1	0
127	2	0	1	2	2	0
139	2	2	2	2	2	2
141	1	1	1	1	1	0
151	4	0	0	4	2	0
154	10	1	8	10	8	1
157	1	1	1	1	1	1
158	3	1	0	3	2	0
177	3	2	0	3	2	0
185	1	1	0	1	0	1
186	1	1	1	1	1	0
201	6	0	6	6	6	0
209	2	1	0	2	2	0
210	2	0	2	2	2	0
217	3	3	3	3	3	0
218	1	0	1	1	1	0
219	1	1	1	1	1	0
222	5	0	0	5	5	0
224	2	1	0	2	2	0
226	1	1	1	1	1	1
231	2	1	0	2	0	0
234	1	1	1	1	1	1
238	2	0	0	2	2	0
239	1	1	1	1	1	0
246	2	0	1	2	2	0

Table C1. Number of openings presenting a behavioral barrier (perched) or jump barrier on both the downstream and upstream sides of the 127 crossings which constitute fish passage barriers.

Crossing ID	Number of Downstream Openings	Number of Downstream Perched Openings	Number of Downstream Jump Openings	Number of Upstream Openings	Number of Upstream Perched Openings	Number of Upstream Jump Openings
248	4	0	2	4	2	0
255	1	0	0	1	1	0
260	7	3	7	7	7	2
267	3	1	1	3	1	0
271	3	3	3	3	3	0
272	1	0	0	1	1	0
276	3	1	0	3	3	0
285	3	1	1	3	1	0
286	2	2	2	2	2	0
287	1	1	1	1	1	1
288	1	0	1	1	1	0
291	1	0	1	1	1	0
298	3	2	0	3	0	0
299	3	0	3	3	3	0
300	1	0	1	1	1	0
301	2	0	0	2	2	0
307	3	0	3	3	3	0
309	2	1	2	2	2	0
310	2	1	0	2	1	0
311	5	0	5	5	5	0
312	3	0	3	3	3	0
314	1	1	1	1	1	1
315	2	2	2	2	2	0
317	1	1	1	1	1	0
319	2	2	2	2	2	2
329	2	0	2	2	2	0
333	3	0	3	3	3	0
336	1	1	1	1	1	1
345	1	1	1	1	1	0
355	2	1	0	2	0	0
356	2	2	2	2	2	0
360	2	0	0	2	2	0
363	2	2	2	2	2	2
371	1	0	1	1	1	0
372	2	2	2	2	2	0
382	1	1	1	1	1	0
386	1	1	1	1	1	1
389	0	0	1	1	1	0
391	1	0	1	1	1	0
392	1	1	1	1	1	0
393	0	0	0	1	1	0
396	2	0	1	2	2	0
399	2	1	0	2	1	0
401	2	2	2	2	2	0
402	3	0	3	3	3	0
406	2	1	2	2	2	1

Table C1. Number of openings presenting a behavioral barrier (perched) or jump barrier on both the downstream and upstream sides of the 127 crossings which constitute fish passage barriers.

Crossing ID	Number of Downstream Openings	Number of Downstream Perched Openings	Number of Downstream Jump Openings	Number of Upstream Openings	Number of Upstream Perched Openings	Number of Upstream Jump Openings
410	1	0	1	1	1	0
411	3	3	1	3	3	0
412	2	1	2	2	2	0
415	2	1	1	2	2	0
416	1	1	1	1	1	0
423	6	4	4	6	4	4
424	2	2	2	2	2	1
426	2	1	2	2	2	1
431	6	0	1	6	1	0
436	3	0	1	3	1	0
443	1	0	1	1	1	0
445	2	0	0	2	2	0
464	3	1	2	3	2	1
469	2	0	2	2	2	0
475	5	1	5	5	5	0
478	1	0	1	2	2	0
480	2	0	2	2	2	0
491	3	3	3	3	3	0
497	1	0	0	1	1	0
498	2	1	2	2	2	1
500	2	0	2	2	2	0
501	2	0	2	2	2	0
503	1	1	1	1	1	0
505	1	0	1	1	1	0
506	1	0	0	1	1	0
508	2	0	1	2	1	0
510	1	0	1	1	1	0
515	1	1	1	1	1	0
518	2	0	0	2	1	0
520	5	5	3	5	5	0
521	3	1	0	3	0	0
523	1	0	1	1	1	0
527	3	0	3	3	3	0
528	3	0	3	3	3	0
530	1	0	0	1	1	0
532	11	9	0	11	7	1

Appendix D. Photo identification of culvert crossings which may be candidates for replacement

Crossing ID: 386

Rank: 1 **Score:1.88**

Lead Zone: Low

Reconnect: 2.92

Stream: Dulin Creek

Road: Dulin Creek Rd.

Crossing ID: 336

Rank: 2 **Score:1.86**

Lead Zone: Low

Reconnect: 0.06

Stream: Gallighers Creek

Road: Lexington Dr.

Crossing ID: 226

Rank: 3 **Score:1.85**

Lead Zone: Low

Reconnect: 1.77

Stream: Jones Creek Trib

Road: Big River Rd.

Crossing ID: 217

Rank: 4 Score:1.77

Lead Zone: Low

Reconnect: 1.31

Stream: Clear Creek

Road: Gildea Rd.

Crossing ID: 498

Rank: 5 Score:1.54

Lead Zone: Low

Reconnect: 1.16

Stream: Branch of Flat River

Road: Shut In Rd.

Crossing ID: 317

Rank: 6 Score:1.54

Lead Zone: Low

Reconnect: 3.0

Stream: Janes Creek

Road: Janes Creek Rd.

Crossing ID: 33

Rank: 7 Score:1.48

Lead Zone: Low

Reconnect: 5.42

Stream: Little Dutch Creek

Road: Little Dutch Cr. Rd.

Crossing ID: 315

Rank: 8 **Score:1.47**

Lead Zone: Low

Reconnect: 0.61

Stream: Lost Creek

Road: Carr Rd.

Crossing ID: 389

Rank: 9 Score:1.43

Lead Zone: Low

Reconnect: 0.05

Stream: Unknown

Road: Eime Road

Crossing ID: 239

Rank: 10 Score:1.42

Lead Zone: Low

Reconnect: 5.33

Stream: Cedar Creek

Road: County Road 21

Crossing ID: 345

Rank: 11 Score:1.42

Lead Zone: Low

Reconnect: 0.01

Stream: Dutch Creek

Road: Little Dutch Cr. Rd.

Crossing ID: 210

Rank: 12 Score:1.27

Lead Zone: Low

Reconnect: 1.28

Stream: Wallen Creek

Road: County Road 516

Crossing ID: 528

Rank: 13 Score:1.27

Lead Zone: Low

Reconnect: 2.66

Stream: Trib to Belews Cr.

Road: Hillsboro House Springs Rd.

Crossing ID: 53

Rank: 14 Score:1.26

Lead Zone: Low

Reconnect: 0.45

Stream: Heads Creek

Road: Hluzek Valley Road

Crossing ID: 54

Rank: 15 Score:1.22

Lead Zone: Low

Reconnect: 0.18

Stream: Heads Creek

Road: Rainbow Lane

Crossing ID: 309

Rank: 16 Score:1.22

Lead Zone: Low

Reconnect: 0.08

Stream: Belews Creek

Road: Hillshire Ln.

Crossing ID: 500

Rank:17 Score:1.22

Lead Zone: Low

Reconnect: 1.62

Stream: Branch of Flat River

Road: County Road 529

Crossing ID: 58

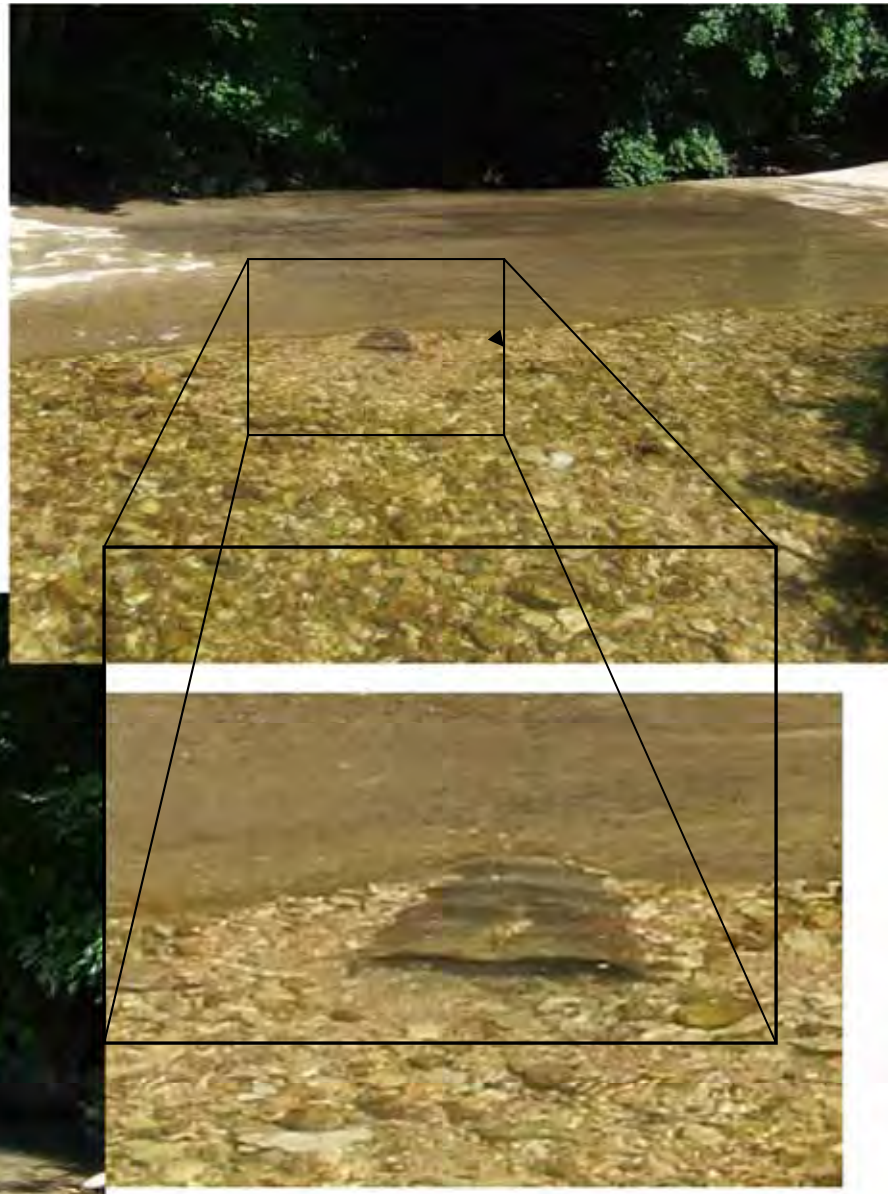
Rank: 18 Score:1.21

Lead Zone: Low

Reconnect: 3.33

Stream: Heads Creek

Road: Tower Valley Rd.



Crossing ID: 371

Rank: 19 Score:1.21

Lead Zone: Low

Reconnect: 0.01

Stream: Trib to Heads Cr.

Road: Manor Crest Dr.

Crossing ID: 312

Rank: 20 Score:1.16

Lead Zone: Low

Reconnect: 1.59

Stream: Townsen Creek

Road: County Road 55

Crossing ID: 501

Rank:21 Score:1.16

Lead Zone: Low

Reconnect: 0.29

Stream: Branch of Flat River

Road: Doc Wallen Rd.

Crossing ID: 218

Rank: 22 Score:1.15

Lead Zone: Low

Reconnect: 0.76

Stream: Clear Creek

Road: King Rd.

Crossing ID: 291

Rank: 23 Score:1.08

Lead Zone: Low

Reconnect: 0.01

Stream: Dunlin Creek

Road: Duckworth Drive

Crossing ID: 478

Rank: 24 Score:1.05

Lead Zone: Low

Reconnect: 0.68

Stream: Branch of Flat River

Road: Zinc Mine Rd.

Crossing ID: 246

Rank: 25 Score:1.02

Lead Zone: Low

Reconnect: 1.27

Stream: Reid Creek

Road: County Road 40.

Crossing ID: 393

Rank: 26 Score:1.00

Lead Zone: Low

Reconnect: 0.58

Stream: Skullbone Creek Trib.

Road: Paradise Estates

Crossing ID: 311

Rank: 27 Score:0.98

Lead Zone: Low

Reconnect: 0.79

Stream: Belews Creek

Road: Hillshire

Crossing ID: 333

Rank: 28 Score:0.95

Lead Zone: Low

Reconnect: 0.44
Stream: Trib. to Gallighers Creek

Road: West Vista Dr.

Crossing ID: 238

Rank: 29 Score:0.95

Lead Zone: Low

Reconnect: 7.39

Stream: Cedar Creek

Road: Buford Rd.

Crossing ID: 248

Rank: 30 Score:0.94

Lead Zone: Low

Reconnect: 5.99

Stream: Salien Creek

Road: County Road 27A

Crossing ID: 224

Rank: 31 Score:0.91

Lead Zone: Low

Reconnect: 8.92

Stream: Big River

Road: Big River Rd.

Crossing ID: 530

Rank: 32 Score:0.88

Lead Zone: Low

Reconnect: 2.68

Stream: Big River Trib.

Road: Redbud Lane

Crossing ID: 209

Rank: 33 Score:0.88

Lead Zone: Low

Reconnect: 7.34

Stream: Wallen Creek

Road: County Road 518

Crossing ID: 276

Rank: 34 Score:0.83

Lead Zone: Low

Reconnect: 4.93

Stream: Skull Creek

Road: Ficken

Crossing ID: 219

Rank: 35 Score:0.79

Lead Zone: Low

Reconnect: 17.53

Stream: North Fork Clear Creek

Road: Dellbridge Rd.

Crossing ID: 157

Rank: 36 Score:0.62

Lead Zone: Medium

Reconnect: 2.02

Stream:

Road: Westover Rd.

Crossing ID: 497

Rank: 37 Score:0.61

Lead Zone: Low

Reconnect: 0.98

Stream: Branch of Big River

Road: Shut In Rd.

Crossing ID: 475

Rank: 38 Score:0.59

Lead Zone: Low

Reconnect: 3.42

Stream: Branch of Flat River

Road: Germania Rd.

Crossing ID: 222

Rank: 39 Score:0.53

Lead Zone: Low

Reconnect: 8.76

Stream: Brock Creek

Road: Sunlight Road

Crossing ID: 319

Rank: 40 Score:0.38

Lead Zone: Medium

Reconnect: 1.98

Stream:

Road: Hazel Run

Crossing ID: 527

Rank: 41 Score:0.14

Lead Zone: Medium

Reconnect: 0.23

Stream: Branch of Terre Bleue

Road: Skyline Road

Crossing ID: 360

Rank: 42 Score:0.05

Lead Zone: Low

Reconnect: 1.31

Stream: Heads CreekTrib.

Road: Dellwood Rd

Crossing ID: 95

Rank: 43 **Score:0.04**

Lead Zone: Medium

Reconnect: 2.78

Stream: Fourche Renault Creek

Road: Sumen Lake Road

Crossing ID: 406

Rank: 44 Score:0.02

Lead Zone: Medium

Reconnect: 1.97

Stream: Scott Branch

Road: Floyd Tower Road

Crossing ID: 271

Rank: 45 Score:-0.03

Lead Zone: Medium

Reconnect: 2.24

Stream: Kruze Cr.

Road: Black Hawk Ln.

Crossing ID: 416

Rank: 46 Score:-0.05

Lead Zone: Medium

Reconnect: 0.44

Stream: Fiddle Creek

Road: Arnault Branch

Crossing ID: 423

Rank: 47 **Score:-0.12**

Lead Zone: Medium

Reconnect: 0.49

Stream: Unknown

Road: Simpson Rd

Crossing ID: 123

Rank: 48 Score:-0.25

Lead Zone: Medium

Reconnect: 3.69

Stream: Miller Branch

Road: Pleasant Hill

Crossing ID: 402

Rank: 49 **Score:-0.26**

Lead Zone: Medium

Reconnect: 3.52

Stream: Unknown

Road: Kinston

Crossing ID: 307

Rank: 50 Score:-0.27

Lead Zone: Medium

Reconnect: 2.26

Stream: Fourche Renault Creek

Road: Harmon Rd

Crossing ID: 520

Rank: 51 Score:-0.28

Lead Zone: Medium

Reconnect: 0.96

Stream: Old Mines Creek

Road: Villmer Drive

Crossing ID: 83

Rank: 52 Score:-0.29

Lead Zone: Medium

Reconnect: 1.98

Stream: Branch of Dry Creek

Road: CR 320

Crossing ID: 299

Rank: 53 Score:-0.32

Lead Zone: Medium

Reconnect: 1.76

Stream: Fourche Renault Creek

Road: Eye Road

Crossing ID: 415

Rank: 54 **Score:-0.39**

Lead Zone: Medium

Reconnect: 0.62

Stream: Fiddle Creek

Road: Pat Daly Road

Crossing ID: 154

Rank: 55 Score:-0.41

Lead Zone: Medium

Reconnect: 4.55

Stream:

Road: Cedar Run

Crossing ID: 82

Rank: 56 Score:-0.44

Lead Zone: Medium

Reconnect: 1.84

Stream: Unknown

Road: CR 320

Crossing ID: 127

Rank: 57 Score:-0.44

Lead Zone: Medium

Reconnect: 2.35

Stream: Fountain Branch

Road: Radio Station Road

Crossing ID: 523

Rank: 58 Score:-0.46

Lead Zone: Medium

Reconnect: 1.29

Stream: Calico Creek

Road: Calico Road

Crossing ID: 329

Rank: 59 Score:-0.52

Lead Zone: Medium

Reconnect: 2.53

Stream: Branch of Dry Creek

Road: Jim Wilson Road

Crossing ID: 532

Rank: 60 Score:-0.63

Lead Zone: Medium

Reconnect: 84.78

Stream: Old Mines Creek

Road: Sutton Property

Crossing ID: 158

Rank: 61 **Score:-0.64**

Lead Zone: Medium

Reconnect: 4.54

Stream:

Road: Westover Road

Crossing ID: 267

Rank: 62 Score:-0.64

Lead Zone: Low

Reconnect: 1.06

Stream: Dry Creek

Road: Gifford Street

Crossing ID: 506

Rank: 63 Score:-0.65

Lead Zone: Medium

Reconnect: 1.39

Stream: Branch of Terre Bleue

Road: White Oak

Crossing ID: 177

Rank: 64 **Score:-0.67**

Lead Zone: Medium

Reconnect: 9.83

Stream: Branch of Flat River

Road: Hurryville Road

Crossing ID: 508

Rank: 65 Score:-0.68

Lead Zone: Medium

Reconnect: 0.62

Stream: Branch of Terre Bleue

Road: Patt Road

Crossing ID: 85

Rank: 66 Score:-0.69

Lead Zone: Medium

Reconnect: 1.36

Stream: Goose Creek

Road: CR 304

Crossing ID: 2

Rank: 67 **Score:-0.69**

Lead Zone: Medium

Reconnect: 7.33

Stream: Mill Creek

Road: Tiff Road

Crossing ID: 88

Rank: 68 **Score:-0.70**

Lead Zone: Medium

Reconnect: 2.5

Stream: Ebo Creek

Road: Ebo Road

Crossing ID: 445

Rank: 69 Score:-0.73

Lead Zone: Medium

Reconnect: 0.95

Stream: Branch of Terre Bleue

Road: Primero SE Road

Crossing ID: 510

Rank: 70 Score:-0.78

Lead Zone: Medium

Reconnect: 0.14

Stream: Branch of Terre Bleue

Road: Gillespie Road

Crossing ID: 86

Rank: 71 Score:-0.79

Lead Zone: Medium

Reconnect: 0.29

Stream: Ebo Creek

Road: Souls Chapel

Crossing ID: 84

Rank: 72 Score:-0.85

Lead Zone: Medium

Reconnect: 0.22

Stream: Goose Creek

Road: Lick Skillet

Crossing ID: 521

Rank: 73 Score:-0.88

Lead Zone: Medium

Reconnect: 1.11

Stream: Old Mines Creek

Road: Settles

Crossing ID: 396

Rank: 74 Score:-1.06

Lead Zone: Medium

Reconnect: 0.79

Stream: Brach of Dry Creek

Road: Maupin

Crossing ID: 201

Rank: 75 Score:-1.08

Lead Zone: High

Reconnect: 0.55

Stream: Big River

Road: Hunt Road

Crossing ID: 151

Rank: 76 **Score:-1.14**

Lead Zone: Medium

Reconnect: 5.99

Stream:

Road: Hillsboro

Crossing ID: 298

Rank: 77 **Score:-1.20**

Lead Zone: Medium

Reconnect: 6.05

Stream: Rocky Branch

Road: CR 319

Crossing ID: 272

Rank: 78 Score:-1.23

Lead Zone: Medium

Reconnect: 0.73

Stream:

Road: Joe Buck Road

Crossing ID: 300

Rank: 79 **Score:-1.26**

Lead Zone: Medium

Reconnect: 2.93

Stream: Branch of Big River

Road: Turkey Creek

Crossing ID: 411

Rank: 80 **Score:-1.54**

Lead Zone: Medium

Reconnect: 4.13

Stream: Bates Creek

Road: Bates Creek Road

Crossing ID: 301

Rank: 81 Score:-1.62

Lead Zone: High

Reconnect: 1.93

Stream: Branch of Big River

Road: Turkey Creek

Appendix E. Photo identification of “bridge with bottom” crossings which may be candidates for replacement

Crossing ID: 55

Rank: 1 **Score: 2.53**

Lead Zone: Low

Reconnect: 1.73

Stream: Heads Creek

Road: Heads Creek Rd

Crossing ID: 44

Rank: 2 **Score:2.38**

Lead Zone: Low

Reconnect: 2.04

Stream: Bear Creek

Road: Hillsboro House Springs Rd

Crossing ID: 363

Rank: 3 Score:2.30

Lead Zone: Low

Reconnect: 1.48

Stream: Trib. to Heads Cr.

Road: Carol Park Road

Crossing ID: 314

Rank: 4 Score:2.21

Lead Zone: Low

Reconnect: 1.73

Stream: Bourne Creek

Road: Hillsboro House Springs Rd.

Crossing ID: 234

Rank: 5 Score:2.03

Lead Zone: Low

Reconnect: 1.32

Stream: Goose Creek

Road: Hwy. 21

Crossing ID: 35

Rank: 6 **Score:1.86**

Lead Zone: Low

Reconnect: 3.81

Stream: Buck Creek

Road: Beach Rd

Crossing ID: 260

Rank: 7 Score:1.65

Lead Zone: Low

Reconnect: 4.71

Stream: Mill Creek

Road: CR 528

Crossing ID: 356

Rank: 8 **Score:1.58**

Lead Zone: Low

Reconnect: 0.72

Stream: Big River Trib

Road: Winnefred Drive

Crossing ID: 515

Rank: 9 Score:1.54

Lead Zone: Low

Reconnect: 0.4

Stream: Trib. to Isum Cr.

Road: Graham Rd.

Crossing ID: 503

Rank: 10 Score:1.36

Lead Zone: Low

Reconnect: 0.35

Stream: Branch of Flat River

Road: Hwy M

Crossing ID: 480

Rank: 11 Score:1.35

Lead Zone: Low

Reconnect: 3.07

Stream: Branch of Flat River

Road: Hwy U

Crossing ID: 382

Rank: 12 Score:1.33

Lead Zone: Low

Reconnect: 1.51

Stream: Dulin CreekTrib.

Road: Scottsdale Road

Crossing ID: 288

Rank: 13 Score:1.21

Lead Zone: Low

Reconnect: 1.05

Stream: Isum Creek

Road: Timberland Drive

Crossing ID: 255

Rank: 14 Score:1.16

Lead Zone: Low

Reconnect: 1.28

Stream: Logan Creek

Road: Hwy 21

Crossing ID: 391

Rank: 15 Score:1.11

Lead Zone: Low

Reconnect: 0.45

Stream: Trib. to Dutch Cr.

Road: Eime Road

Crossing ID: 491

Rank: 16 **Score:1.01**

Lead Zone: Low

Reconnect: 1.53

Stream: Big River Trib.

Road: Hwy C

Crossing ID: 372

Rank: 17 **Score:1.03**

Lead Zone: Low

Reconnect: 0.72

Stream: Tributary to Heads Creek

Road: Hwy MM

Crossing ID: 310

Rank: 18 **Score:0.95**

Lead Zone: Low

Reconnect: 0.03

Stream: Belews Creek

Road: Hwy 21

Crossing ID: 231

Rank: 19 Score:0.86

Lead Zone: Low

Reconnect: 1.31

Stream: Goose Creek

Road: Hwy 32

Crossing ID: 505

Rank: 20 **Score:0.78**

Lead Zone: Low

Reconnect: 1.04

Stream: Unknown

Road: MO-O

Crossing ID: 287

Rank: 21 Score:0.70

Lead Zone: Medium

Reconnect: 0.53

Stream: Trib to Isum Cr.

Road: Graham Rd.

Crossing ID: 355

Rank: 22 Score:0.61

Lead Zone: Low

Reconnect: 0.36

Stream: Big River Trib.

Road: Hwy W

Crossing ID: 76

Rank: 23 Score:0.54

Lead Zone: Medium

Reconnect: 5.2

Stream: Ditch Creek

Road: North Bridge

Crossing ID: 141

Rank: 24 **Score:0.36**

Lead Zone: Medium

Reconnect: 2.5

Stream: Branch of Big River

Road: Timberline

^ upstream

<- downstream

Crossing ID: 126

Rank: 25 Score:0.28

Lead Zone: Medium

Reconnect: 0.96

Stream: Fountain Farm Branch

Road: Rte E

Crossing ID: 426

Rank: 26 **Score:0.22**

Lead Zone: Medium

Reconnect: 3.24

Stream: Unknown

Road: Hwy F

Crossing ID: 104

Rank: 24 Score:0.20

Lead Zone: Medium

Reconnect: 4.17

Stream: Bates Creek

Road: Bates Creek Rd

Crossing ID: 518

Rank: 28 Score:0.09

Lead Zone: Low

Reconnect: 1.28

Stream: Cedar Creek

Road: Buford Road

Crossing ID: 286

Rank: 29 Score:0.09

Lead Zone: Medium

Reconnect: 0.99

Stream: Isum Creek

Road: Hwy BB

Crossing ID: 424

Rank: 30 Score:0.04

Lead Zone: Medium

Reconnect: 0.61

Stream: Unknown

Road: Hwy F

Crossing ID: 13

Rank: 31 Score:-0.02

Lead Zone: Medium

Reconnect: 0.81

Stream: Trib. to Big River

Road: Mammoth Rd.

Crossing ID: 139

Rank: 32 Score:-0.10

Lead Zone: Medium

Reconnect: 3.22

Stream: Cabanna Course

Road: Airport Rd

Crossing ID: 401

Rank: 33 **Score:-0.18**

Lead Zone: Medium

Reconnect: 2.72

Stream: Old Mines Creek

Road: CR-317

Crossing ID: 412

Rank: 34 **Score:-0.32**

Lead Zone: Medium

Reconnect: 1.09

Stream: Branch of Bates Creek

Road: Hwy 8

Crossing ID: 410

Rank: 35 **Score:-0.37**

Lead Zone: Medium

Reconnect: 0.64

Stream: Bates Creek

Road: Hwy P

Crossing ID: 392

Rank: 36 Score:-0.39

Lead Zone: Medium

Reconnect: 0.68
Stream: Trib. to
Skullbone Cr.

Road: Cedar Hill Rd.

Crossing ID: 101

Rank: 37 Score:-0.42

Lead Zone: Medium

Reconnect: 0.64

Stream: Branch of Mineral Fork

Road: Hwy P

Crossing ID: 186

Rank: 38 Score:-0.82

Lead Zone: High

Reconnect: 0.85

Stream: Branch of Flat River

Road: Airport Road

Crossing ID: 436

Rank: 39 **Score:-1.06**

Lead Zone: Medium

Reconnect: 0.64

Stream: Mill Creek Trib

Road: Old Hwy 8

Crossing ID: 464

Rank: 40 **Score:-1.06**

Lead Zone: High

Reconnect: 0.01

Stream: Unknown

Road: MO-A

Crossing ID: 443

Rank: 41 Score:-1.11

Lead Zone: High

Reconnect: 0.82

Stream: Branch of Flat River

Road: Airport Road

Crossing ID: 469

Rank: 42 **Score:-1.17**

Lead Zone: High

Reconnect: 0.87

Stream: Branch of Flat River

Road: MO 8

Crossing ID: 285

Rank: 43 **Score:-1.21**

Lead Zone: Medium

Reconnect: 0.25

Stream: Shibboleth Branch

Road: Rte E

Crossing ID: 431

Rank: 44 **Score:-1.54**

Lead Zone: Medium

Reconnect: 1.78

Stream: Mill Creek Trib

Road: Rte E

Crossing ID: 185

Rank: 45 Score:-1.85

Lead Zone: High

Reconnect: 1.11

Stream: Branch of Flat River

Road: Old Business Rd

Crossing ID: 399

Rank: 46 Score:-2.07

Lead Zone: Medium

Reconnect: 0.60

Stream: Ditch Creek

Road: Sycamore Road