Ozarks Environmental and Water Resources Institute (OEWRI) Missouri State University (MSU)

Stream Crossing Inventory and Evaluation, Upper Big Barren Creek Watershed, Southeast Missouri

FINAL REPORT

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SCOPE AND OBJECTIVES

Increased flooding, channel instability, and excessive gravel deposition have recently been observed in headwater streams within the upper Big Barren Creek watershed located in the southeastern Missouri Ozarks. Hydrologic and geomorphic changes in Ozarks watersheds have been attributed to a variety of factors including historical landscape disturbance, land management techniques, and stream corridor management, (Jacobson and Pugh 1992, Panfil and Jacobson 2001, Jacobson 2004, Owen et al. 2011, Shepard et al. 2011). This portion of the Ozarks has a long history of timber production going back to the late19th century. Historical widespread landscape disturbance from timber harvest caused geomorphic instability by altering channel morphology and hydrology, causing headwaters streams to incise into chert-rich quaternary deposits, introducing large volumes of gravel to Ozark streams (Jacobson and Primm 1997). While the implementation of conservation practices has reduced erosion and runoff rates, a significant amount of sediment remains stored in historical channel and floodplain deposits that can be available for remobilization as the watershed adjusts to changing hydrologic conditions (Owen et al. 2011, Pavlowsky et al. 2017). Moreover, questions still remain on what impact contemporary forest management efforts, such as prescribed fire, have on the hydrology of headwater streams in the forested areas of the Ozarks. Furthermore, recent changes in the magnitude and frequency of rainfall events in the Ozarks may also be contributing to current flooding and sedimentation trends that are observed in Big Barren Creek (Pavlowsky et al., 2016).

Understanding that Ozarks streams are responding to a complicated set of historical and modern disturbances, the U.S. Forest Service is interested in evaluating the role of road crossings in stream stability within the Big Barren Creek watershed. It is well known that road networks cause stream channel instability by altering hydrologic pathways, acting as sites for sediment deposition, and supplying sediment to drainage networks through incision (Jones et al., 2000). Jacobson (2004) even suggests that unpaved logging roads generate more runoff and excess sediment than current logging practices due to decreased recovery period of logged areas. Still, little is known about how stream crossings in these areas may influence local stream stability. Therefore, the purpose of this study is to establish a preliminary database of road-stream crossings in the Big Barren Creek watershed and evaluate the potential of these crossings to influence stream stability. Furthermore, Big Barren Creek watershed is of particular interest because the Big Barren Creek Natural Area (BBCNA) is located there and is home to an endangered mussel species that may be sensitive to changes in hydrology and stream stability. The objectives of this study are to (1) develop an inventory of road-stream crossings on the main stem of Barren Creek and surrounding tributaries upstream of the BBCNA; (2) tabulate channel morphology and sediment properties upstream and downstream of each crossing; and (3) describe the effects of road-stream crossings on channel reaches within the Big Barren Creek watershed. The results of this study will be used to identify problematic crossings in the Big Barren Creek drainage network that will be the focus of future study to understand the specific causes of the instability and identify alternatives that may reduce impacts of crossings on stream stability in the watershed.

STUDY AREA

The Big Barren Creek watershed is located within Carter, Ripley, and Oregon counties in southeast Missouri (Figure 1). Big Barren Creek is a tributary of the Current River and drains approximately 190 km^2 (73.3 mi^2) of the Salem Plateau of the Missouri Ozarks. The Big Barren Creek watershed is underlain by chert-rich Paleozoic sedimentary strata that promote the development of karst features such as springs, sinkholes, and caves (Adamski et al., 1995). Soils are highly weathered, contain an abundance of clay and chert, and are capped by a thin layer of glacial loess in the gently sloping uplands (Gott 1975, Adamski et al. 1995). Stream channels are typically dry consisting of sand, gravel, and cobble beds. Vegetation and trees growing within the active channel promotes sediment deposition and increased hydraulic roughness, except where the channels have been modified on private land (McKenney et al. 1995, Thies 2017). Land cover within the watershed is about 92% forested, with around 78% being National Forest lands. The majority of the remainder is pasture and hay, along with small areas of developed open space. The road network within the Big Barren Creek watershed is primarily made up of unpaved dirt roads with the exception of two paved state highways that run north and south through the watershed.

METHODS

Field work was completed on December 19-20, 2016 and the site was visited again on May 4, 2017 after the large flood event. The initial field work consisted of both topographic surveys and a modified rapid geomorphic assessment protocol designed to assess the influence of crossings on channel stability. The follow-up visit in May 2017 was an opportunity to document what happened to these crossings after the extreme flood event.

Topographic Surveys

Topographic surveys consisted of a longitudinal profile and a road profile survey. All surveys were performed with an auto-level, 100 m tape, and a stadia rod recording relative elevations. A longitudinal profile shows the downstream changes in the stream bed elevations measured at the deepest point of the channel along the surveyed reach (Rosgen 1996). Longitudinal profiles are important because they help show changes in bed slope and channel bed forms (riffle, pools, etc.) which are important for hydraulic analysis and habitat assessments (Harrelson et al., 1994). For this study, the longitudinal profile was surveyed roughly 50 m upstream and downstream of the crossing in order to see how the crossing elevation compared to the overall slope of the stream and to analyze changes in bed elevations directly above and below the crossing. The road profile survey was performed by collecting elevations along the crown of the road over the crossing. Each road profile was at least 30 m long and shows the slope of the road approaching the crossing.

Rapid Assessment

This study used a modified rapid assessment specifically designed to quantify the geomorphic influence of stream crossings on local channel conditions (USDA 1998, Heeren et al. 2012, Sarver 2016). The rapid assessment consisted of measurements of channel geometry, pebble counts, and large woody debris (LWD) surveys at three transects upstream and downstream of the crossing. The location of each transect was based on the width of the stream near the crossing. The first transect was located twice the width of the stream from the center of the road. The second and third transects were located an additional half channel width apart (Figure 2A). At each transect, bank height, bankfull width, active channel width, bar width, and bar height were measured using a stadia rod and tape (Figure 2B).

A modified pebble count procedure was performed where a total of 10 pebbles were selected by a blind-touch method at equally spaced intervals along three transects upstream and three transects downstream of the crossing. Each pebble was categorized into Wentworth size classes using a gravelometer (Harrelson et al. 1994). A grain size distribution was then calculated using the 30 pebbles counted upstream and downstream of the crossing to determine the d10, d25, d50, d75, d84, and the d90. Therefore, the grain size distribution identifies the range of bed material sizes that can be found both upstream and downstream of the crossing.

Finally, large woody debris and stranded trees in the channel were also tabulated and the diameter of each piece was measured using a caliper. Stranded trees in the channel provide resistance to erosion and are also an indicator of a stable bed. Large woody debris also helps stabilize streams and affects the flow of water in a stream creating important aquatic habitat (Rosgen, 1996). However, since many of the stream channels in the forested areas have trees growing in the bed, excess loading of wood may be an indicator of stream disturbance in the watershed.

RESULTS

A total of 18 road-stream crossings were identified and evaluated for this project. There were a total of 11 crossings located on the main stem of the upper Big Barren Creek, and 7 were located along tributaries (Figure 3). Each site was classified by crossing type as well as the relative influence of the crossing on the channel. There are two general types of road-stream crossings identified in the Big Barren Creek watershed: low-water crossings (LWCs), where water flows on top of the road surface; and elevated crossings that allow water to flow below the road surface. LWC were further classified into gravel or concrete LWCs. Elevated crossings were classified into box culverts or pipe culverts. Culverts are generally defined as closed structures where pressure flow occurs, and is different from a bridge, which is an open span where pressure flow typically does not occur (Greene County 1999). The generalized impact of road-stream crossings in the Big Barren Creek watershed are described through field observations (Table 1 and 2).

Crossing Types and Visual Evaluation

Box Culvert

A box culvert is relatively large capacity rectangular concrete structure that allows water to pass beneath the road surface without overtopping and flooding the road. These generally are used at major road crossings of small-medium sized streams. Only one box culvert was identified for this study where Highway J crosses Big Barren Creek (Site 17). This crossing has three, 3.0 m (10 ft) wide x 1.8 m (6 ft) tall culverts with a concrete invert. This culvert causes deposition upstream of crossing and there is a scour hole downstream. During larger floods water crosses Highway J to the north where the road is lower compared to the crown of the road at the culvert. Water re-enters the channel via the east road ditch.

Pipe Culvert

A pipe culvert is a round, corrugated metal, concrete, or plastic pipe that allows water to flow beneath the road surface without overtopping and flooding the road but generally has less capacity than a box culvert. Typically this would be installed on moderately used roads crossing of smaller streams. Only one pipe culvert was identified for this study where County Road J-173 crosses an unnamed tributary of Big Barren Creek (Site 16). This crossing has four 0.65 m (26 in) corrugated metal pipes under the road. Most tributary crossings that are near (<1 km) the main stem of Big Barren Creek are being destabilized as head cuts move upstream due to base level lowering of the main channel (Bradley 2017, Thies 2017). The pipe culvert crossing is especially vulnerable to destabilization as the road fill can be eroded away as head cut moves upstream causing the crossing to fail.

Gravel Low-water Crossing

Gravel LWCs are where road surface is built on top of the channel bed, allowing water to flow across the road surface and is made of gravel either found locally in the stream or in some cases quarried limestone or dolomite. These are generally built on roads with low traffic volume. A total of 12 gravel LWCs were identified in this study at Sites 1-3, 5, 8-13, 15, and 18. Generally in dry streams gravel LWC are built at the grade of the stream and create deposition zones due to being over widened. This may be good, since road crews need a place to get aggregate without having to go into the stream and destabilize the channel and banks (Jacobson and Gran 1999). Gravel LWCs along tributaries near the main channel are also being destabilized as head cuts move upstream. In wet areas gravel LWC crossings placed in shallower areas create forced riffles. They may need additional gravel after large floods as smaller gravel is transported away leaving larger cobbles at the crossings that are difficult for vehicles to drive across.

Concrete Low-water Crossing

A concrete LWC is also built on top of the channel bed, but the crossing is made of concrete for stability. A total of four concrete LWCs were identified in this study at Sites 4, 6, 7, and 14. In dry streams, these crossing are built at grade or are slightly elevated above the bed. Elevated concrete LWCs act as grade control creating deposition zone upstream of crossing and transport zone downstream where slope is increased. Concrete LWCs built at the grade of the stream bed have less impact upstream and downstream, but does create deposition zone on top of crossing where it is over widened. One concrete LWC is built in a wet area and is located in a deep section of the creek and is elevated. There is a scour pool on downstream end that is undermining crossing causing the concrete to be tilted downstream that will eventually need to be repaired.

Rapid Assessment Results

For this study, a rapid geomorphic survey was used to quantify changes in channel stability around crossings. Figure 4 shows the downstream changes in active width, bankfull width, bankfull depth, and the d50 grain size for the main channel and tributaries. These data are organized into main channel sites and tributary sites. Main channel sites are displayed from upstream (Site 18) to downstream (Site 1). Tributary sites are displayed moving downstream where the tributary confluence enters the main stem. Geomorphic data collected at each crossing including the longitudinal stream profile, road profile, channel dimensions, and bed particle-size distribution can be found in Appendix A.

Results of the rapid geomorphic assessment suggest road crossings can influence local stream morphology within the Big Barren Creek in three important ways. First, elevated crossings raise bed elevations that can cause upstream deposition that increases channel width and incision/scour downstream with increased slope causing the channel to get deeper (Sites 2, 6, 8, 9, 12, and 17). Second, LWC at or below the grade of the stream promotes excess deposition at the crossing that routinely needs to be maintained. However, crossings that accumulate gravel are also a location were road building material can be easily accessed (Sites 7, 13, 14, and 15). Finally, crossings also can act as grade control structures for tributary streams that are near the main channel. In some instances road crossings stop the advance of headcuts that are moving upstream due to base level changes occurring along the main channel of Big Barren Creek (Sites 10 and 16). However, the headcut at Site 11 has moved upstream of the crossing and will continue to release sediment as it advances upstream.

Crossing Response to Recent Flooding

Many of the stream crossings evaluated for this project were damaged following a record intense rainfall event that caused widespread flooding in southern Missouri rainfall in April 2017. Approximately 10 to 12.5 inches of rain fell on the Missouri Ozarks between April 26 and May 1 (Figure 5). Channel bed incision, road scouring, and sediment aggradation were found along many of the evaluated crossing that became impassable immediately following the flooding (Appendix B). Many of the crossing over the main channel were either filled in with small-medium, unconsolidated gravel or deeply scoured down to large cobbles. Tributary crossings were also deeply scoured as head cuts moved passed many of the crossings located near the main channel liberating large volumes of gravel and cobble. One important observation was that at Site 10 the road actually “pirated” the stream and diverted high flows down the side ditch causing excessive erosion/deposition, scour/aggradation, and gravel/cobble transport downstream creating an expensive road maintenance problem to not only fix the crossing, but to re-grade the roads that approach these crossings.

RECOMMENDATIONS

1. In many instances roads and crossings are built in such a way that they pirate stream flow during high water events that tend to destabilize the crossing and road near the approaches (Sites 5, 9, and 18). There are several situations where roads become the stream channel during runoff events where both excessive scour and/or

gravel deposition can occur. After the large flood at the end of April, head cuts were observed along the upstream road ditches that undermined the road making them impassible. Streams in the Big Barren watershed are typically multi-threaded with wide and shallow flood flows making crossing design a challenge. However, strategically placed pipe culverts under the roads at places where water from floods enter the road could help reduce the frequency of washouts. This may ultimately reduce maintenance costs and the time the road is closed.

2. Elevated crossings act as grade control structures that promote sediment deposition upstream and erosion downstream (Sites 2, 6, 8, 9, 12, and 17). However, the problem is localized in and around the crossing. Excess gravel deposition upstream of the crossing offers an opportunity to access road aggregate for construction and maintenance without further destabilization of the bed and bank.

3. Crossings at or below grade create sediment deposition zones where the increased channel width at a crossing decreases velocity (Sites 7, 13, 14, and 15). Again, this situation offers an opportunity to access road aggregate for construction and maintenance without further destabilization of the bed and bank.

4. Wet crossings located above the natural area tend to cross at riffles located between the bluff pools (Sites 1, 3, and 4). For the most part these crossings are stable, but frequently become impassible during even moderate floods. Since this area is hydrologically unique and ecologically sensitive, it may be worth the resources to install box culverts in this area. Here a two-stage design that has a low flow channel for fish passage would be recommended (Ward et al. 2016).

5. Head cuts moving up tributaries from the lowering of base level at the modified main channel causes repeated episodes of crossing failure (Sites 10, 11, and 16). If traffic volume is a concern here, these crossings may be good candidates for box culverts that can pass flow generally as large as the present channel capacity. This could lower maintenance costs over time.

CONCLUSION

The purpose of this study was to create an inventory of road-stream crossings in the Big Barren Creek watershed and to quantify geomorphic effects of the stream crossing using topographic surveys and a rapid geomorphic assessment. Topographic surveys included a longitudinal profile and a road profile. The rapid geomorphic assessment was conducted both upstream and downstream of the crossing consisting of channel geometry measurements, pebble counts, and LWD assessments. There were a total of

18 crossing evaluated for this project. There were two general types of crossings identified, elevated crossings and LWCs. Elevated crossings included box culverts and pipe culverts, and low-water crossings were made of either concrete or gravel. Different geomorphic effects were observed at each type of crossing. Generally, upstream sediment aggradation and scouring were found at elevated LWCs. LWCs constructed at or below grade created sediment deposition zones that may be useful as road construction material access points. Recent flooding severely altered several crossings that were assessed in this report. The most expensive maintenance problems occurred where roads captured flow and diverted down straightened road ditches causing crossings and road instability. Finally, alternative crossings that utilize a two-stage design and allow fish passage are recommended in the hydrologically unique and ecologically sensitive reach above the Natural Area.

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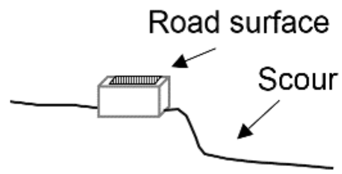
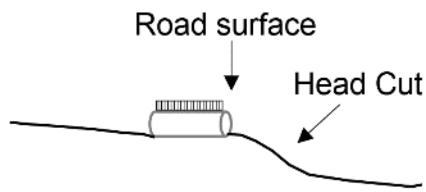
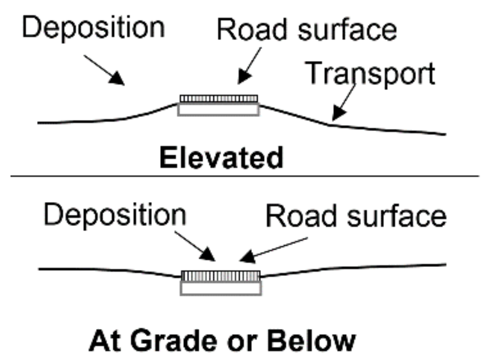
TABLES

Table 1. General types of **DRY** road crossings in the Big Barren Creek watershed.

<table>
<tr><th>Type</th><th>Example</th><th>Impacts</th></tr>
<tr><td>Box
Culvert

(Site 17)</td><td></td><td>
</td></tr>
<tr><td>Pipe
Culvert

(Site 16)</td><td></td><td>
</td></tr>
<tr><td>Concrete
LWC

(Sites 6,7,14)</td><td></td><td>
</td></tr>
<tr><td>Gravel
LWC

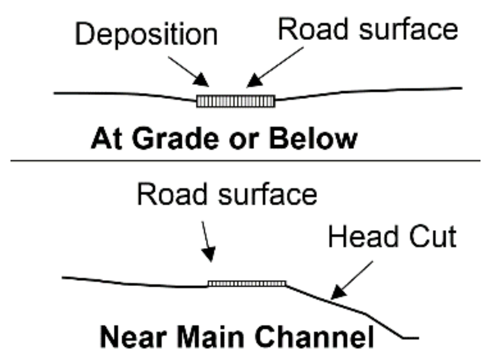
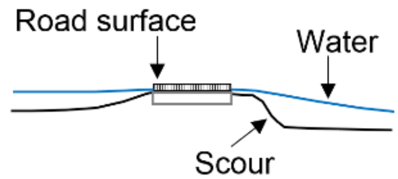
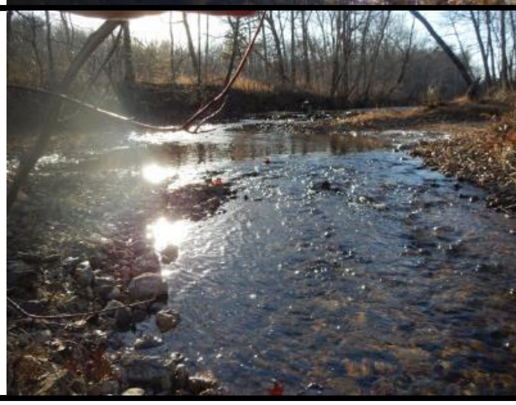
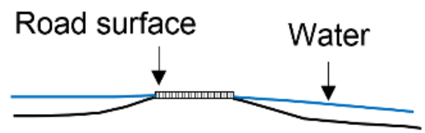
(Sites 5,8,
9,10,11,12,
13,15,18)</td><td></td><td>
</td></tr>
</table>

Table 2. General types of **WET** road crossings in the Big Barren Creek watershed.

Type	Example	Impacts
Concrete LWC (Site 4)		
Gravel LWC (Sites 1,2,3)		

FIGURES

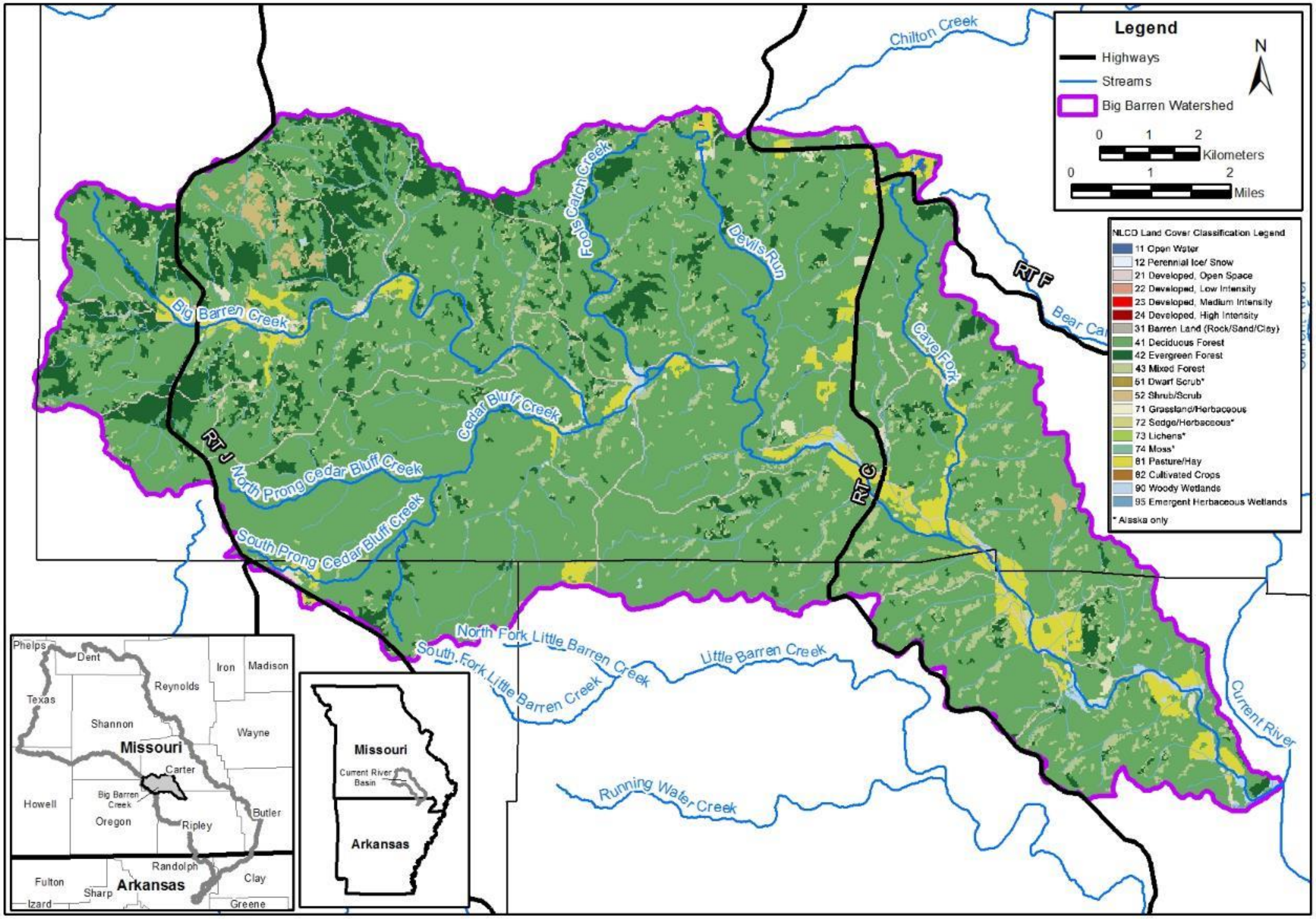


Figure 1. Big Barren Creek watershed land use.

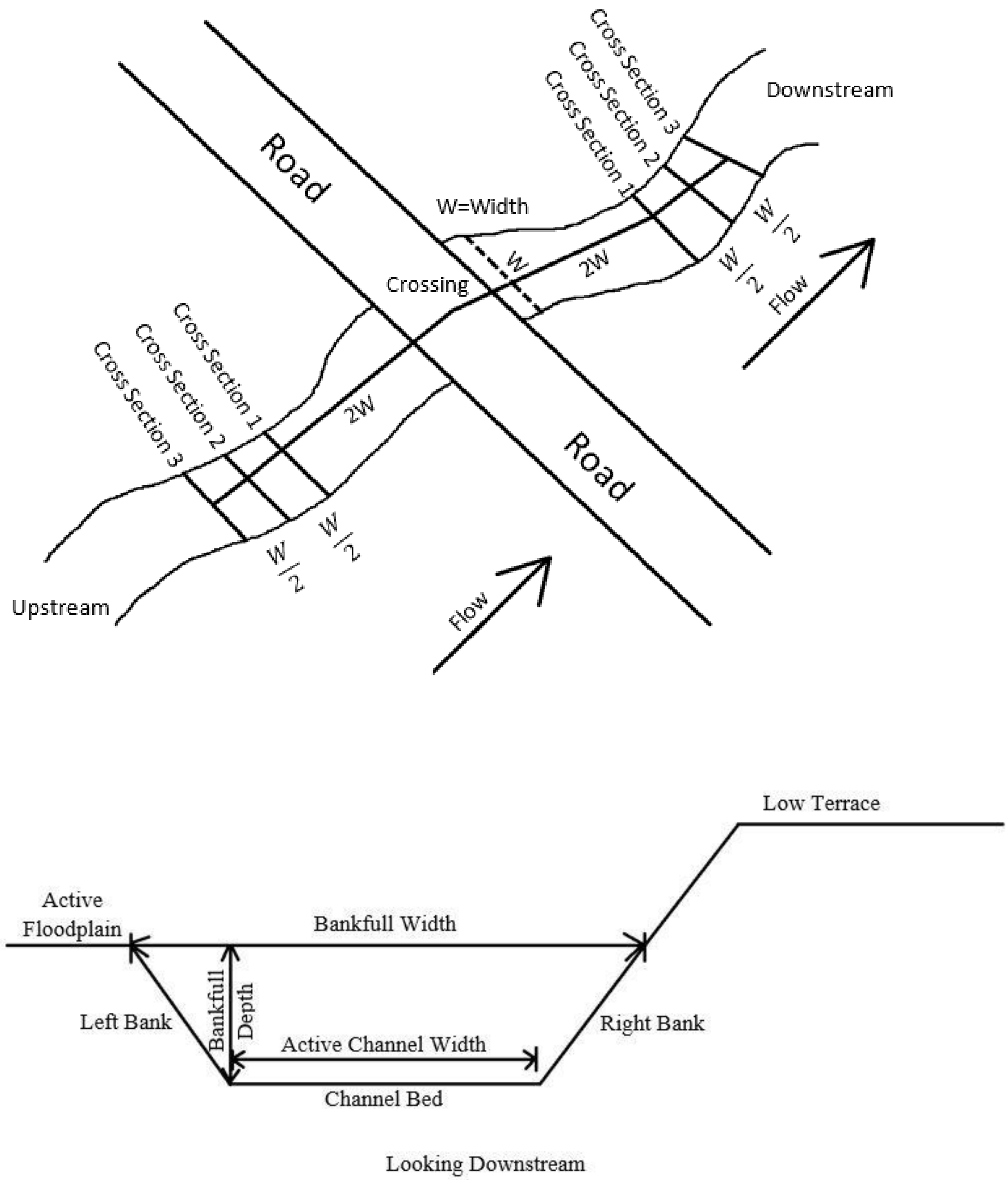


Figure 2. Sampling procedure (A) and channel units (B) measured in rapid assessment.

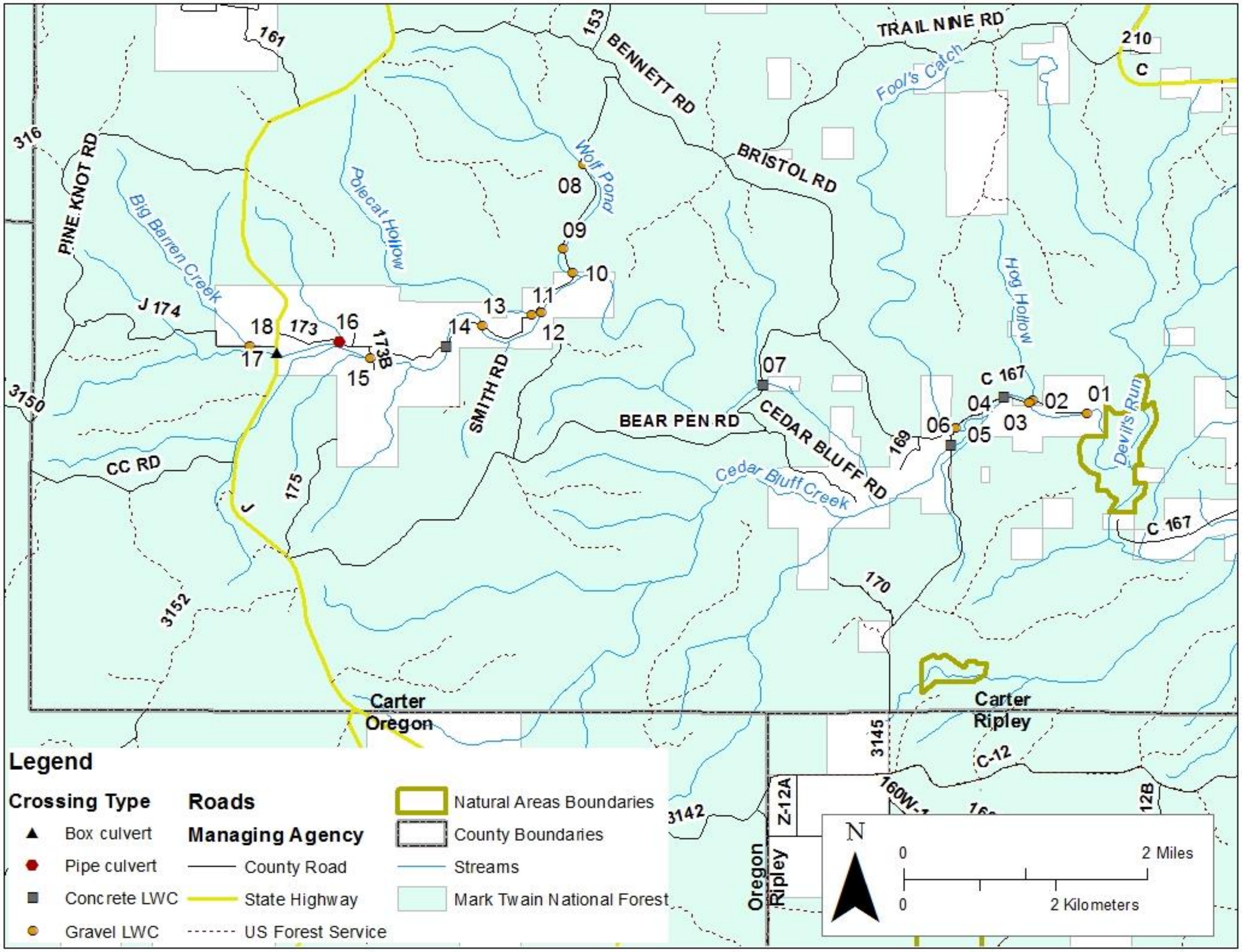


Figure 3. Location of assessed road-stream crossings.

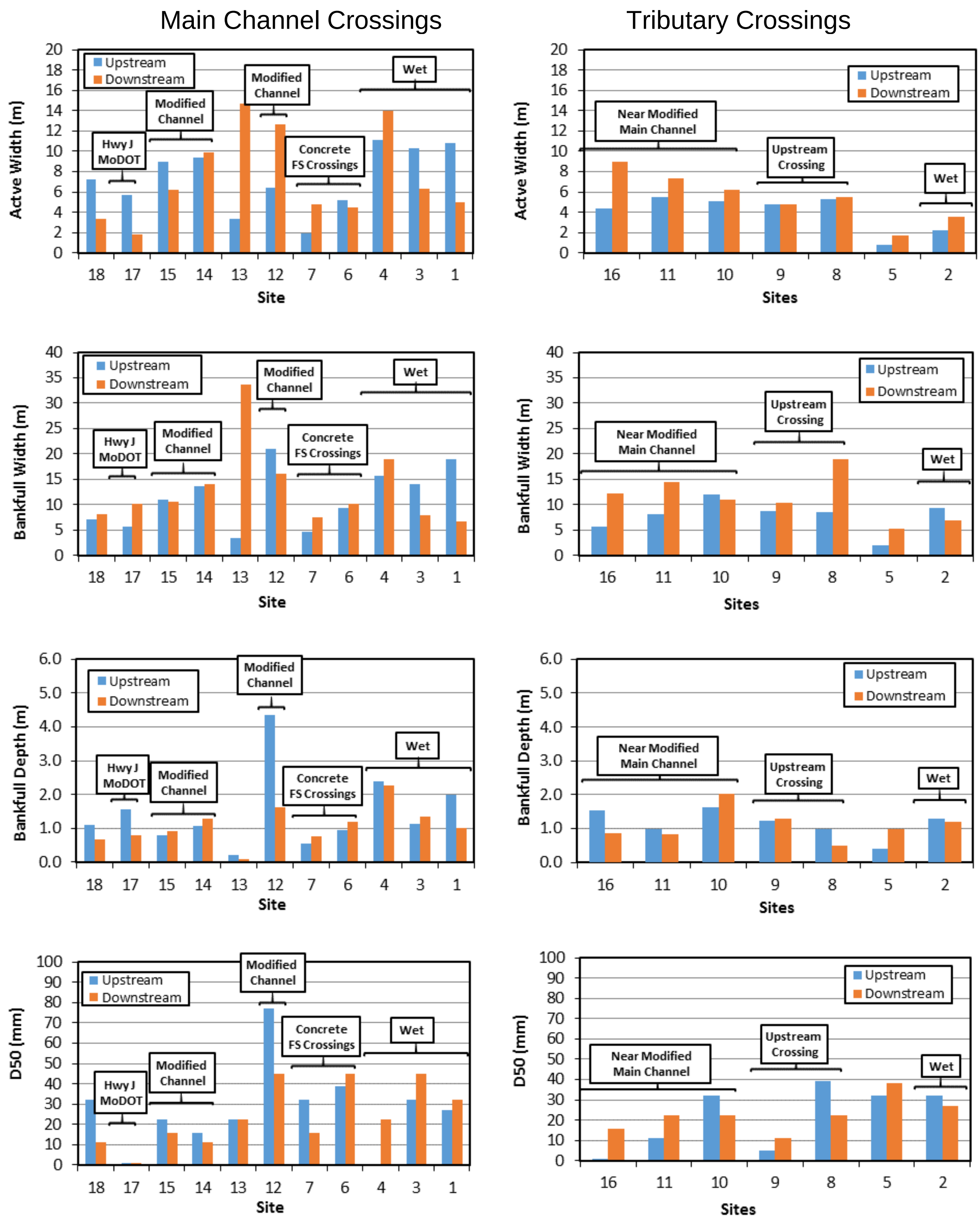


Figure 4. Downstream changes in active channel width, bankfull width, bankfull depth, and D50 grain-size upstream and downstream of main channel and tributary crossings.

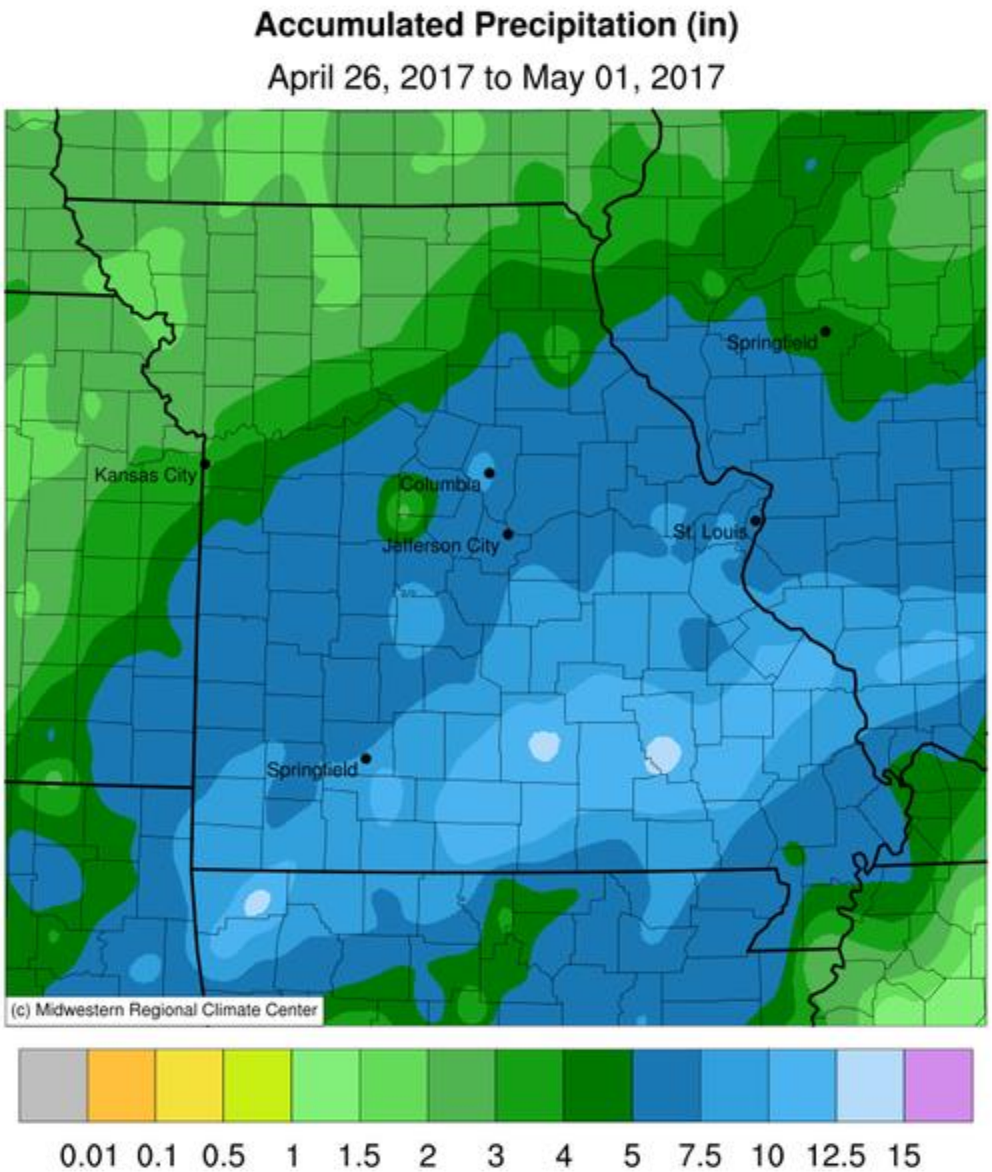
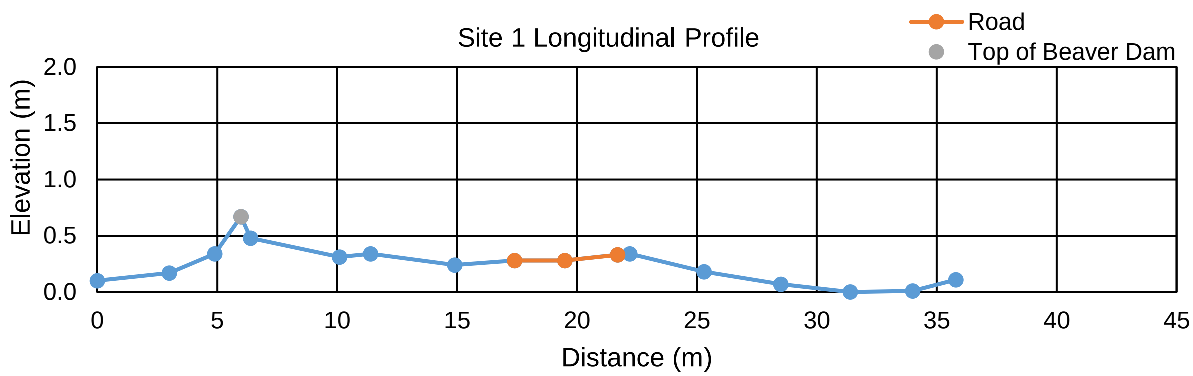
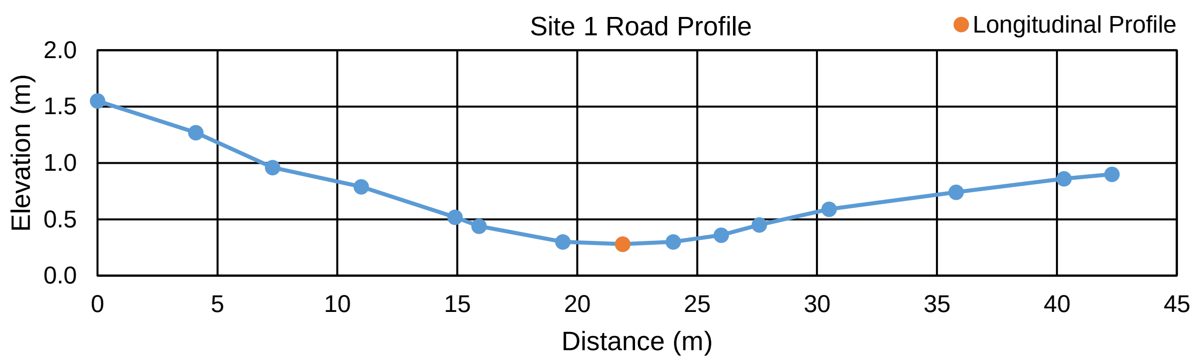


Figure 5. Accumulated rainfall in the Missouri Ozarks between April 26 and May 1, 2017, in inches.

APPENDIX A: CROSSING DATABASE

Site 1: Big Barren Creek at Old C-167 above Natural Area





Particle Size Distribution (mm)	Upstream	Downstream
d10	16	10
d25	18	18
d50	27	32
d75	45	45
d84	52	52
d90	64	64
dMax	90	90

Channel Geometry	Upstream	Downstream
Active Width (m)	10.8	5
Bankfull Width (m)	18.9	6.8
Bankfull Depth (m)	0.7	1
Bankfull W/D Ratio	58.7	7
Slope (%)		1.69

Site 1: Pictures (12-20-2016)

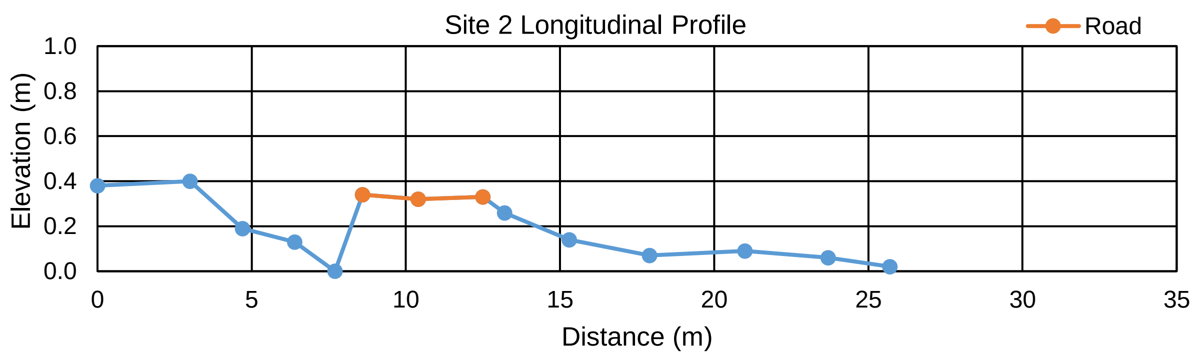
Upstream View

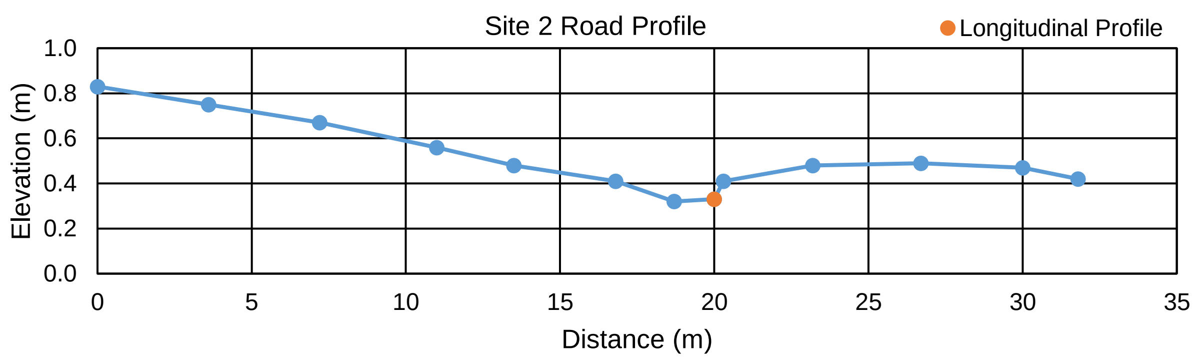
Left Road Edge

Downstream View

Right Road Edge

Site 2: Hog Hollow at Old C-167





Particle Size Distribution (mm)	Upstream	Downstream
d10	11	10
d25	25	14
d50	32	27
d75	45	32
d84	56	39
d90	70	47
dMax	128	64

Channel Geometry	Upstream	Downstream
Active Width (m)	2.2	3.6
Bankfull Width (m)	9.3	7
Bankfull Depth (m)	1.2	0.9
Bankfull W/D ratio	7.8	8.1
Slope (%)		1.92

Site 2: Pictures (12-20-2016)

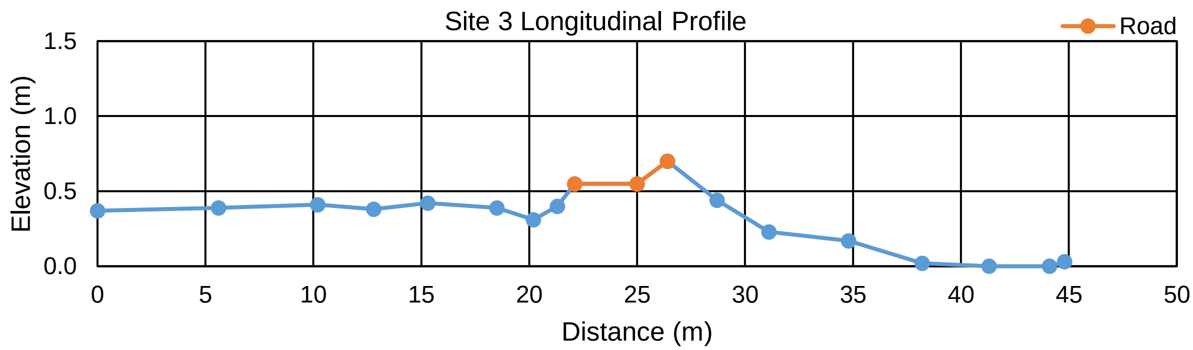
Upstream View

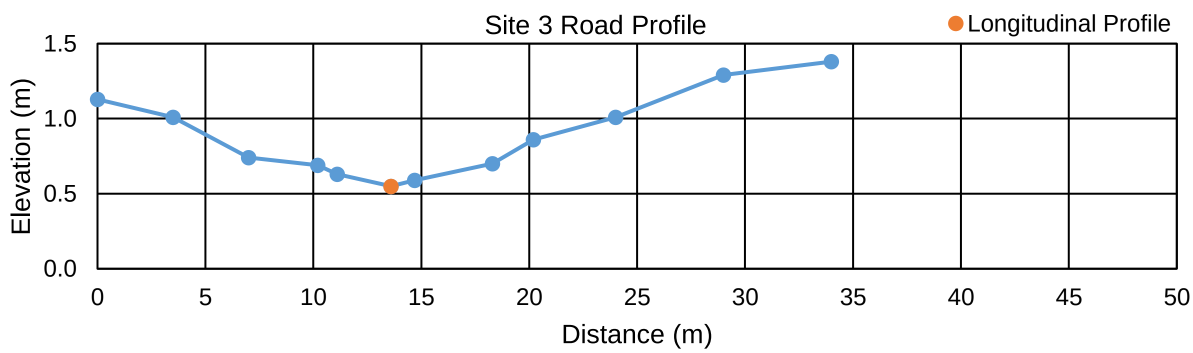
Downstream View

Left Road Edge

Right Road Edge

Site 3: Big Barren Creek at Old C-167 below bluff pool





Particle Size Distribution (mm)	Upstream	Downstream
d10	11	11
d25	22.6	18
d50	32	45
d75	45	64
d84	64	74
d90	64	90
dMax	90	90

Channel Geometry	Upstream	Downstream
Active Width (m)	10.3	6.3
Bankfull Width (m)	14	8
Bankfull Depth (m)	1.1	1
Bankfull W/D Ratio	14	9.3
Slope (%)		2.55

Site 3: Pictures (12-20-2016)

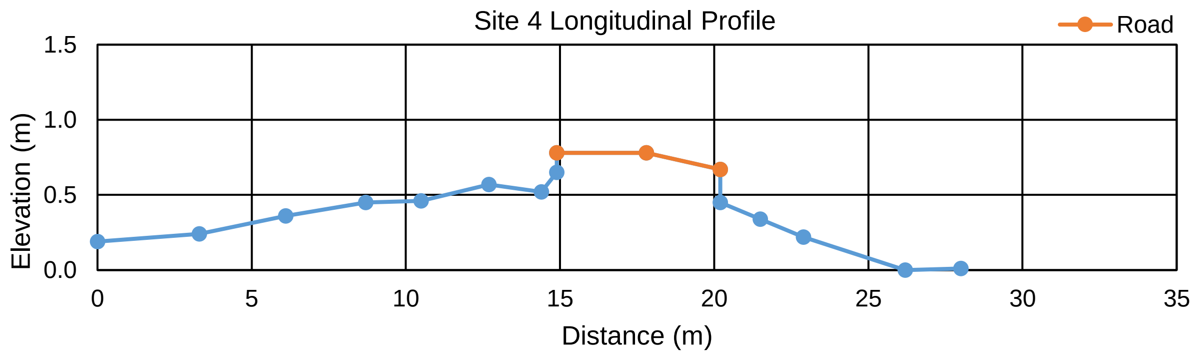
Upstream View

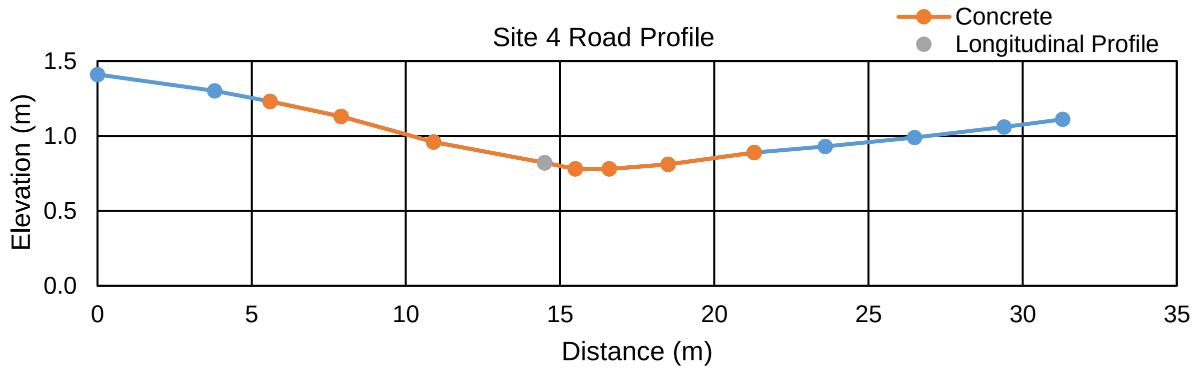
Downstream View

Left Road Edge

Right Road Edge

Site 4: Big Barren Creek at Old C-167 above bluff pool





Particle Size Distribution (mm)	Upstream	Downstream
d10	No Access	1
d25	No Access	12
d50	No Access	22.6
d75	No Access	32
d84	No Access	45
d90	No Access	47
dMax	No Access	64

Channel Geometry	Upstream	Downstream
Active Width (m)	11.1	14.0
Bankfull Width (m)	15.7	19
Bankfull Depth (m)	1.9	1.6
Bankfull W/D Ratio	11	12.1
Slope (%)		5.64

Site 4: Pictures (12-20-2016)

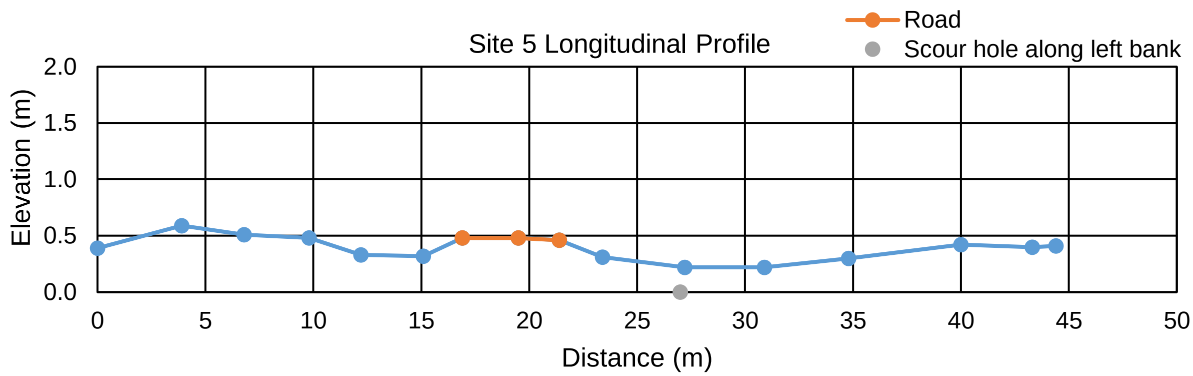
Upstream View

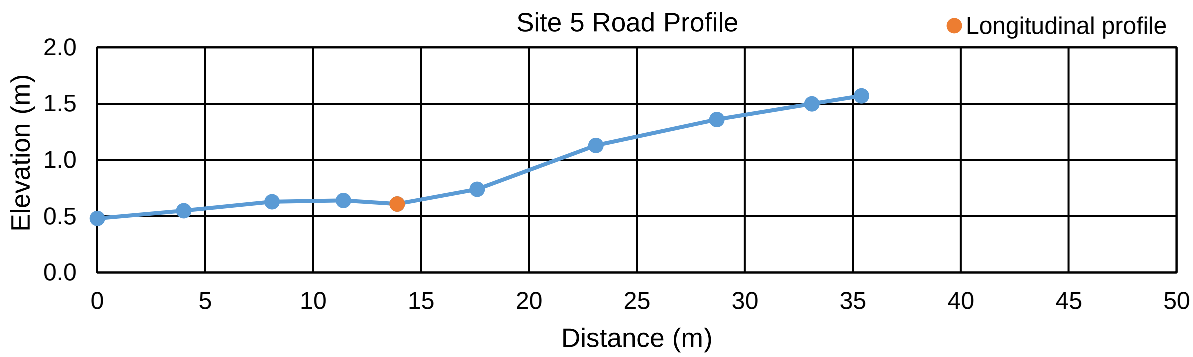
Downstream View

Left Road Edge

Right Road Edge

Site 5: Fools Catch at Old C-167





Particle Size Distribution (mm)	Upstream	Downstream
d10	1	16
d25	17.7	22.6
d50	32	38
d75	45	45
d84	64	45
d90	67	64
dMax	128	90

Channel Geometry	Upstream	Downstream
Active Width (m)	0.8	1.7
Bankfull Width (m)	2.1	5.2
Bankfull Depth (m)	0.4	0.7
Bankfull W/D Ratio	5.2	13.7
Slope (%)		0.27

Site 5: Pictures (12-20-2016)

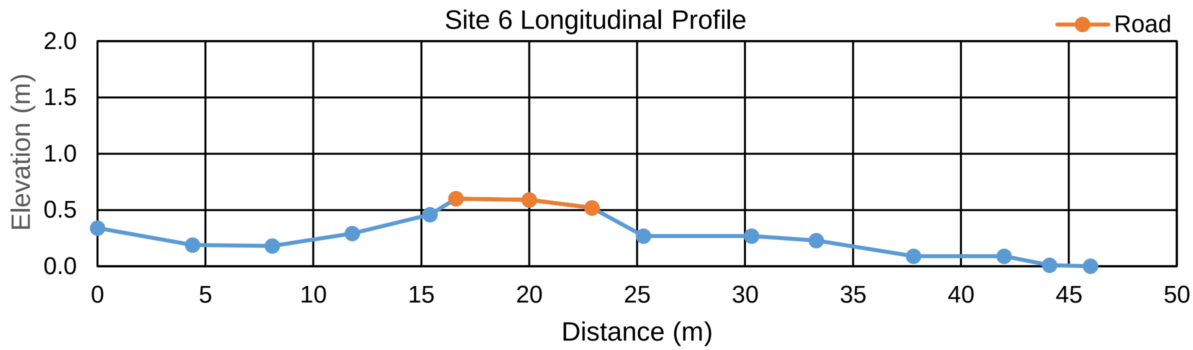
Upstream View

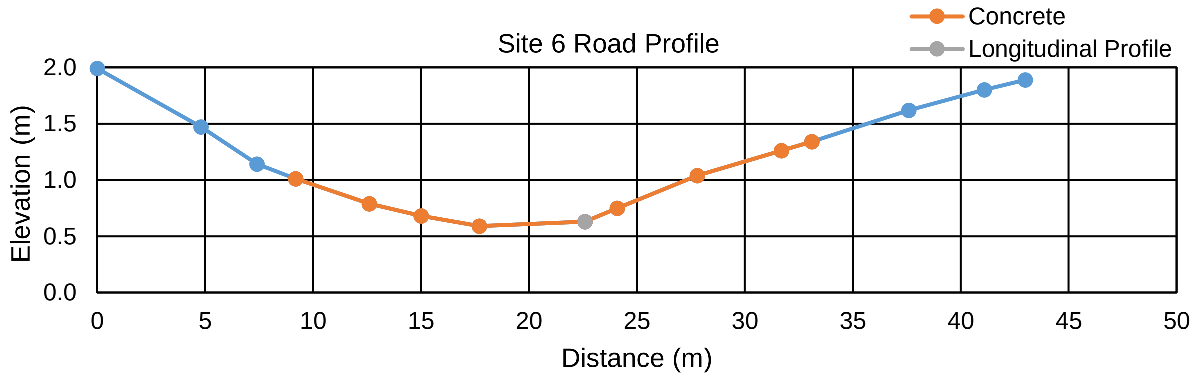
Downstream View

Left Road Edge

Right Road Edge

Site 6: Big Barren Creek at C-167 (from Handy Road)





Particle Size Distribution (mm)	Upstream	Downstream
d10	16	16
d25	25	22.6
d50	39	45
d75	64	64
d84	64	78
d90	64	90
dMax	128	90

Channel Geometry	Upstream	Downstream
Active Width (m)	5.2	4.4
Bankfull Width (m)	9.4	10.2
Bankfull Depth (m)	0.8	0.5
Bankfull W/D Ratio	13.6	19.9
Slope (%)		1.3

Site 6: Pictures (12-20-2016)

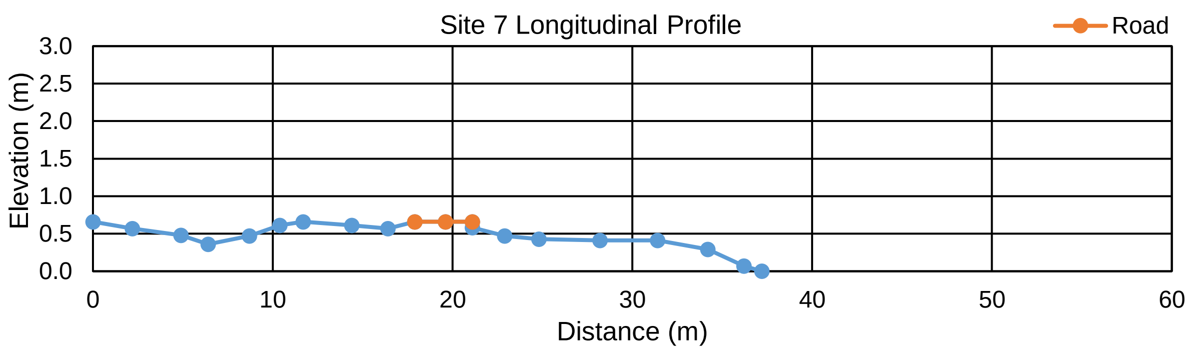
Upstream View

Downstream View

Left Road Edge

Right Road Edge

Site 7: Big Barren Creek at C-167 (Bearpen Road)



Particle Size Distribution (mm)	Upstream	Downstream
d10	16	1
d25	32	6
d50	32	16
d75	45	22.6
d84	64	37
d90	64	47
dMax	90	128

Channel Geometry	Upstream	Downstream
Active Width (m)	2.0	4.7
Bankfull Width (m)	4.6	7.6
Bankfull Depth	0.3	0.5
Bankfull W/D Ratio	14.2	14.8
Slope (%)		3.29

Site 7: Pictures (12-20-2016)

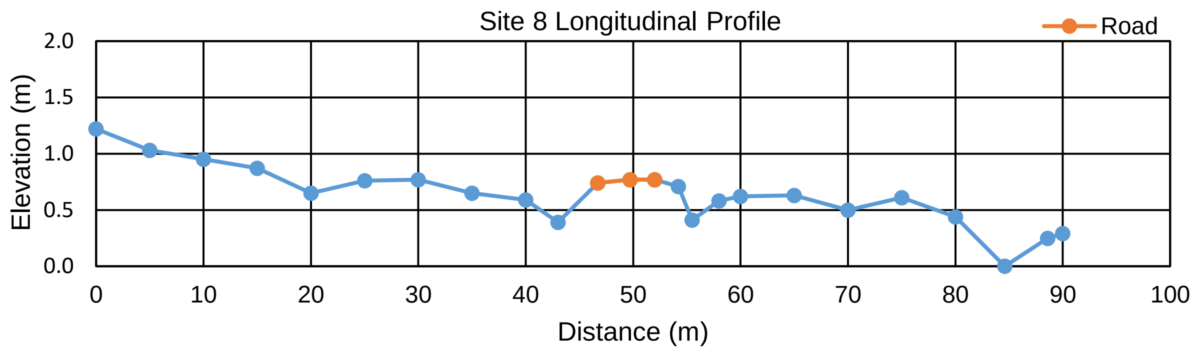
Upstream View

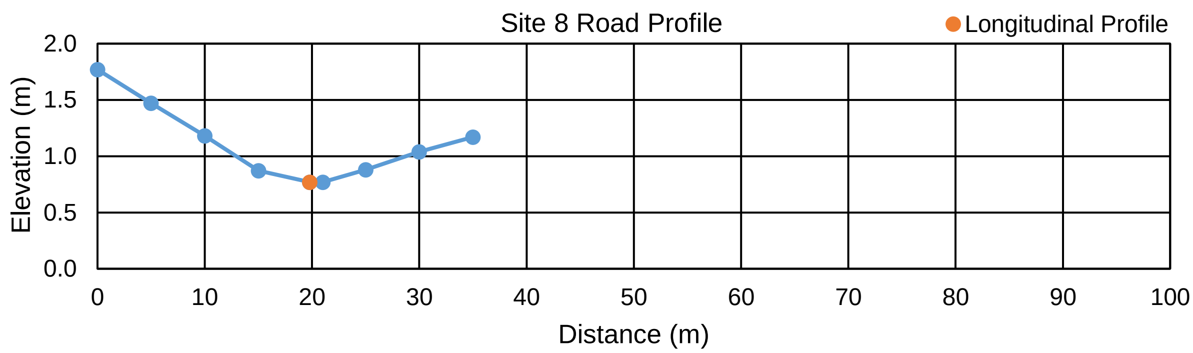
Downstream View

Left Road Edge

Right Road Edge

Site 8: Wolf Pond at J-173 (upstream of Wolf Pond stream gage)





Particle Size Distribution (mm)	**Upstream**	**Downstream**
d10	16	8
d25	22.6	11
d50	39	22.6
d75	45	32
d84	73	45
d90	94	47
dMax	150	90

Channel Geometry	**Upstream**	**Downstream**
Active Width (m)	5.3	5.5
Bankfull Width (m)	8.6	19
Bankfull Depth (m)	0.4	0.4
Bankfull W/D Ratio	24.4	53.7
Slope (%)		1.18

Site 8: Pictures (12-19-2016)

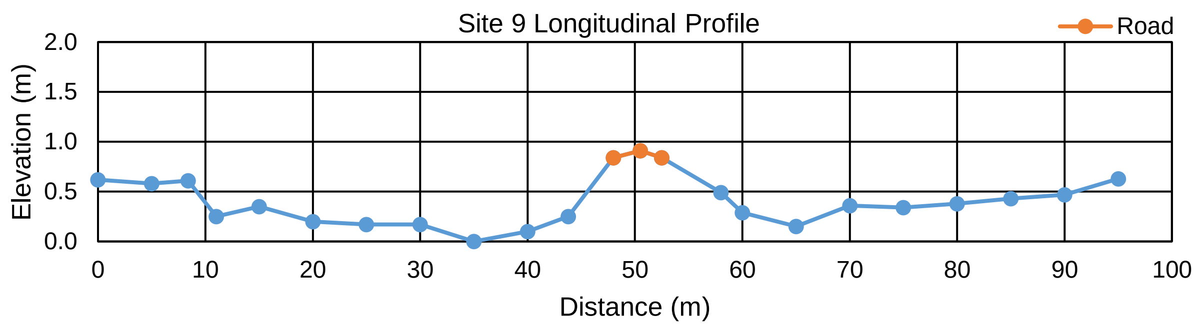
Upstream View

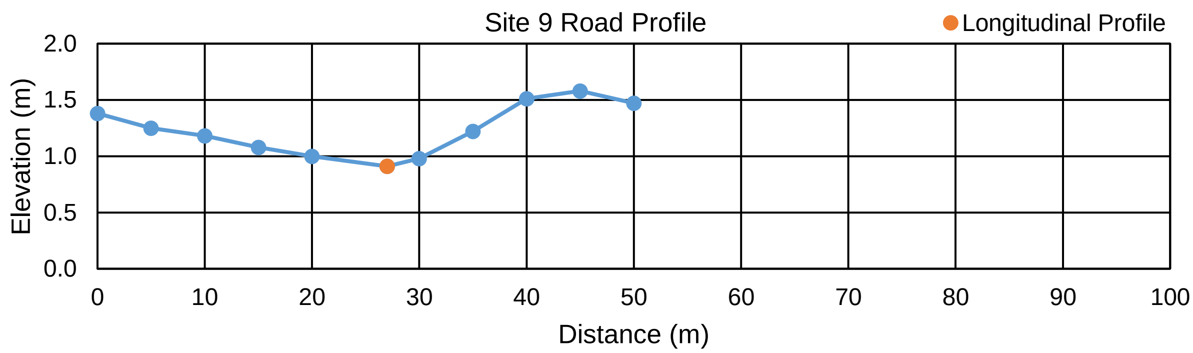
Downstream View

Left Road Edge

Right Road Edge

Site 9: Wolf Pond at J-173 (above lower bend)





Particle Size Distribution (mm)	**Upstream**	**Downstream**
d10	1	1
d25	1	7
d50	5	11
d75	22.6	14
d84	32	17
d90	32	22.6
dMax	64	22.6

Channel Geometry	**Upstream**	**Downstream**
Active Width (m)	4.8	4.8
Bankfull Width (m)	8.7	10.3
Bankfull Depth (m)	1.2	1.1
Bankfull W/D Ratio	7.2	9.6
Slope (%)		0.49

Site 9: Pictures (12-19-2016)

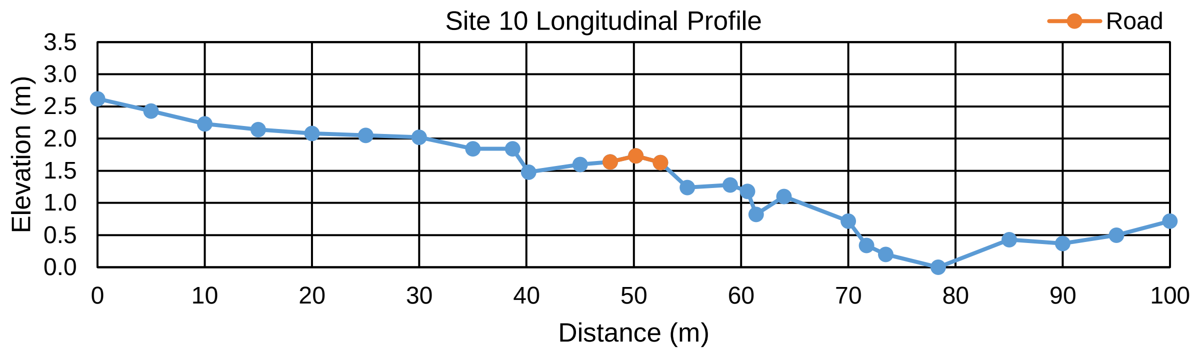
Upstream View

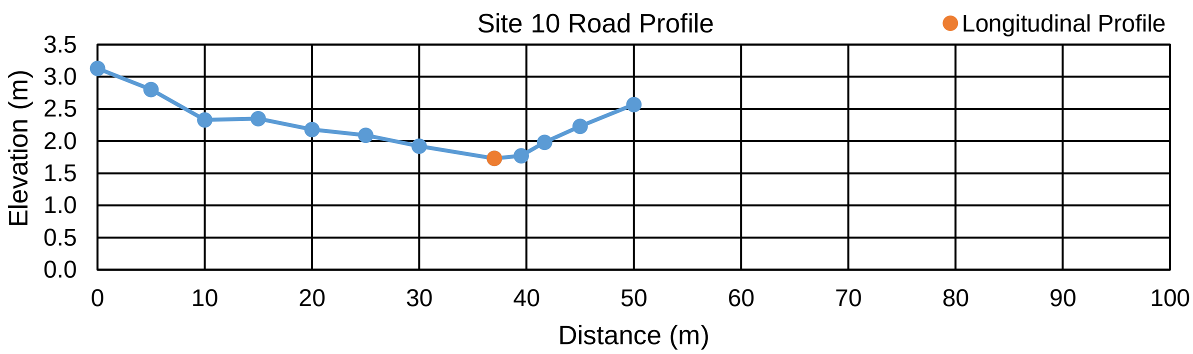
Downstream View

Left Road Edge

Right Road Edge

Site 10: Wolf Pond at J-173 (headcut zone)





Particle Size Distribution (mm)	Upstream	Downstream
d10	22	6
d25	22.6	11
d50	32	22.6
d75	45	32
d84	64	45
d90	64	47
dMax	90	90

Channel Geometry	Upstream	Downstream
Active Width (m)	5.1	6.2
Bankfull Width (m)	12.1	10.9
Bankfull Depth (m)	0.8	1.6
Bankfull W/D Ratio	16.5	6.9
Slope (%)		6.2

Site 10: Pictures (12-19-2016)

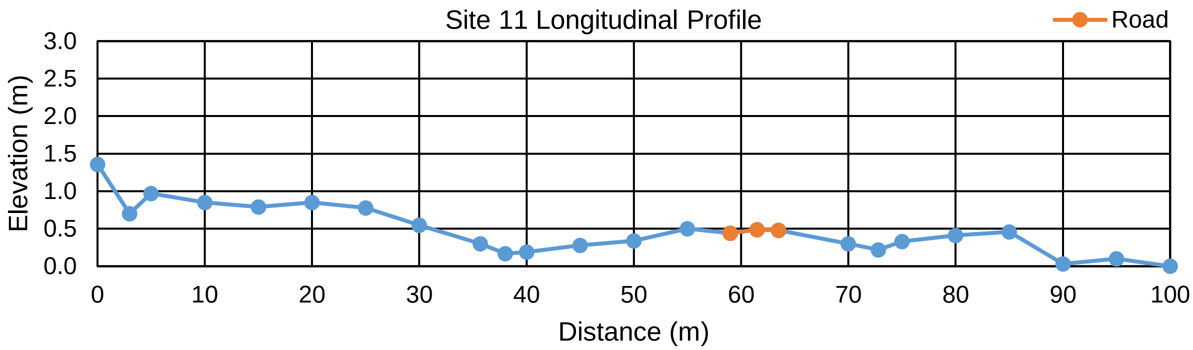
Upstream View

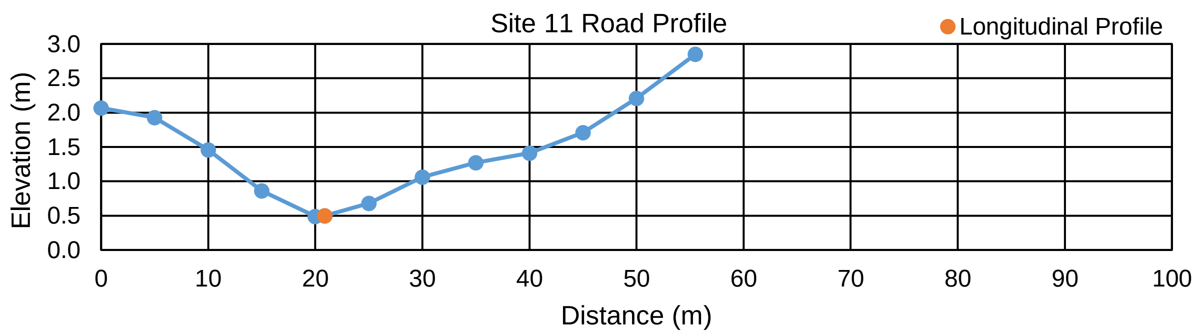
Downstream View

Left Road Edge

Right Road Edge

Site 11: Polecat Hollow at J-173





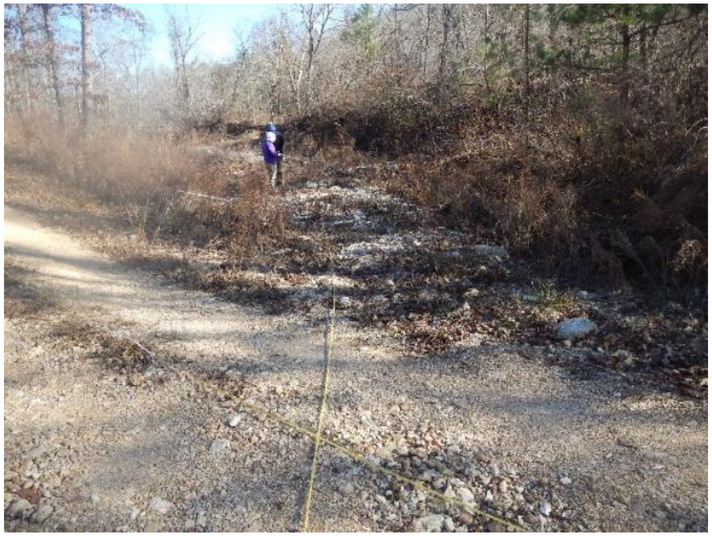
Particle Size Distribution (mm)	Upstream	Downstream
d10	5	8
d25	8	16
d50	11	22.6
d75	22.6	35
d84	29	45
d90	32	45
dMax	32	45

Channel Geometry	Upstream	Downstream
Active Width (m)	5.5	7.3
Bankfull Width (m)	8.2	14.6
Bankfull Depth (m)	0.8	0.8
Bankfull W/D Ratio	12.1	24.8
Slope (%)		1

Site 11: Pictures (12-19-2016)

Upstream View

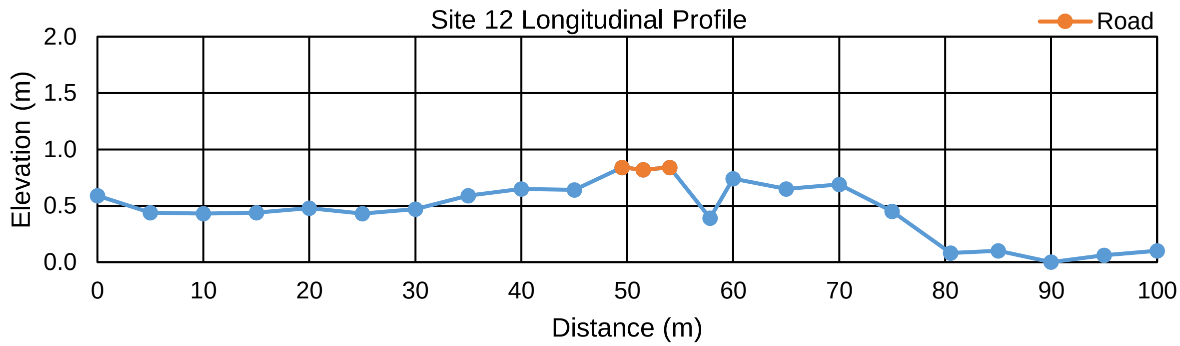
Downstream View

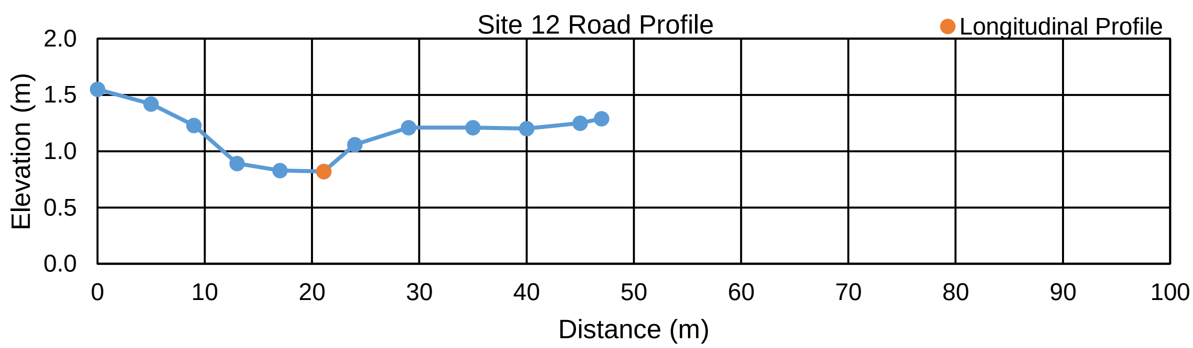


Left Road Edge

Right Road Edge

Site 12: Big Barren Creek at J-173 (private road upstream of Polecat Hollow)





Particle Size Distribution (mm)	Upstream	Downstream
d10	16	1
d25	25	16
d50	77	45
d75	119	64
d84	128	64
d90	130	64
dMax	200	128

Channel Geometry	Upstream	Downstream
Active Width (m)	6.5	12.6
Bankfull Width (m)	21	16
Bankfull Depth (m)	2.2	1.6
Bankfull W/D Ratio	9.8	10.6
Slope (%)		1.6

Site 12: Pictures (12-19-2016)

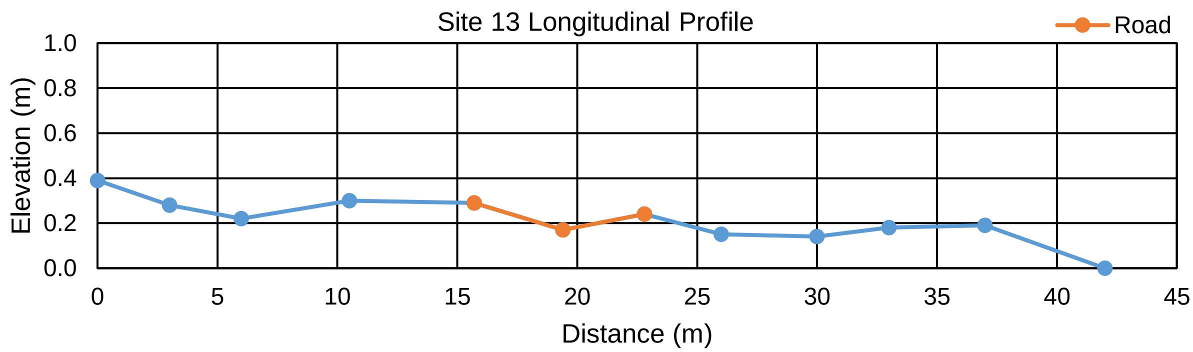
Upstream View

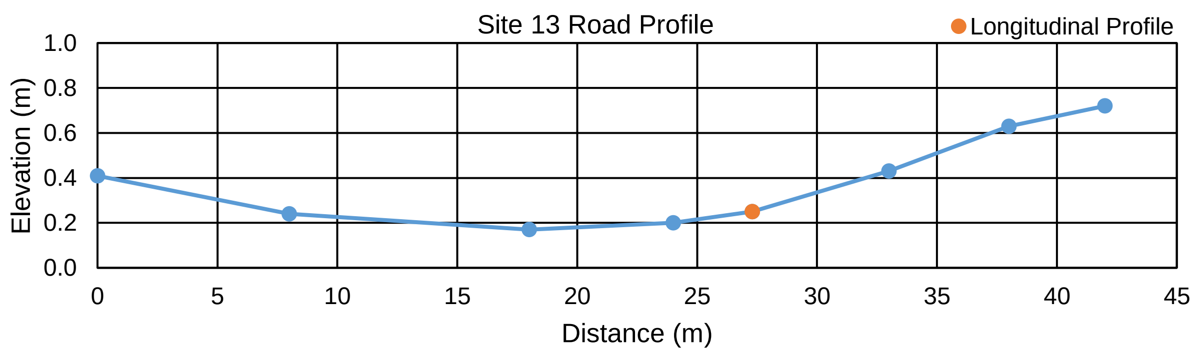
Downstream View

Left Road Edge

Right Road Edge

Site 13: Big Barren Creek at J-173 (below North bend)





Particle Size Distribution (mm)	Upstream	Downstream
d10	1	10
d25	9	16
d50	22.6	22.6
d75	64	32
d84	168	41
d90	255	45
dMax	300	90

Channel Geometry	Upstream	Downstream
Active Width (m)	3.4	14.7
Bankfull Width (m)	3.4	33.6
Bankfull Depth (m)	0.2	0.1
Bankfull W/D Ratio	17	336
Slope (%)		1.25

Site 13: Pictures (12-19-2016)

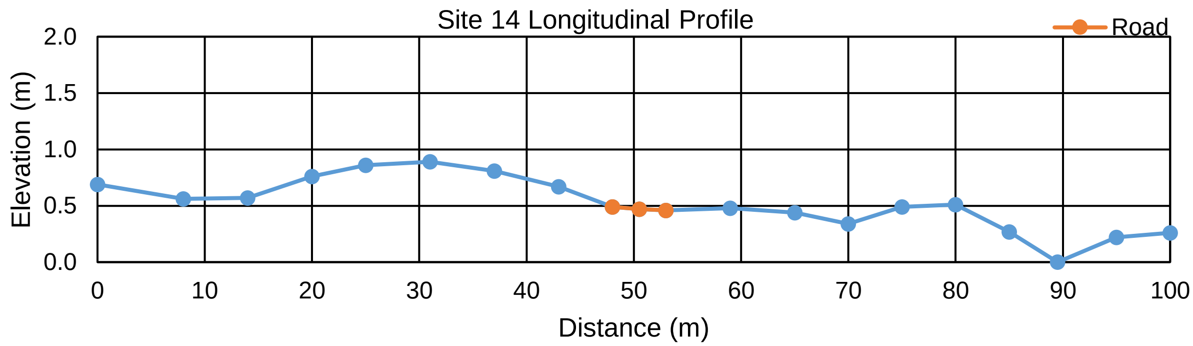
Upstream View

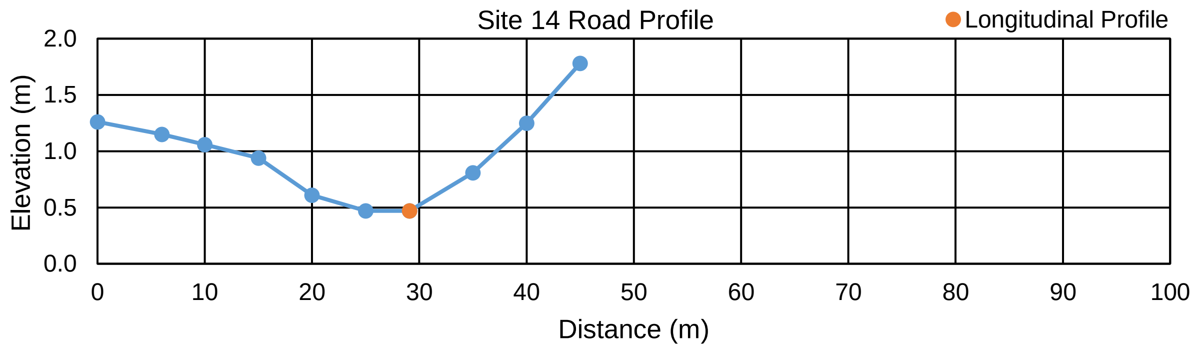
Downstream View

Left Road Edge

Right Road Edge

Site 14: Big Barren Creek at J-173 (above North bend)





Particle Size Distribution (mm)	Upstream	Downstream
d10	1	5.6
d25	11	10
d50	16	11
d75	32	16
d84	37	22.6
d90	47	22.6
dMax	100	45

Channel Geometry	Upstream	Downstream
Active Width (m)	9.4	9.9
Bankfull Width (m)	13.6	14.1
Bankfull Depth (m)	0.4	1.1
Bankfull W/D Ratio	52.7	12.8
Slope (%)		0.54

Site 14: Pictures (12-19-2016)

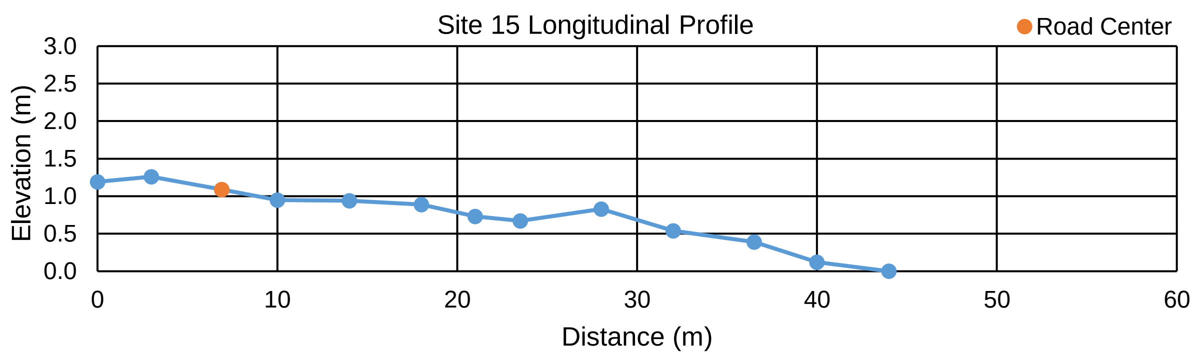
Upstream View

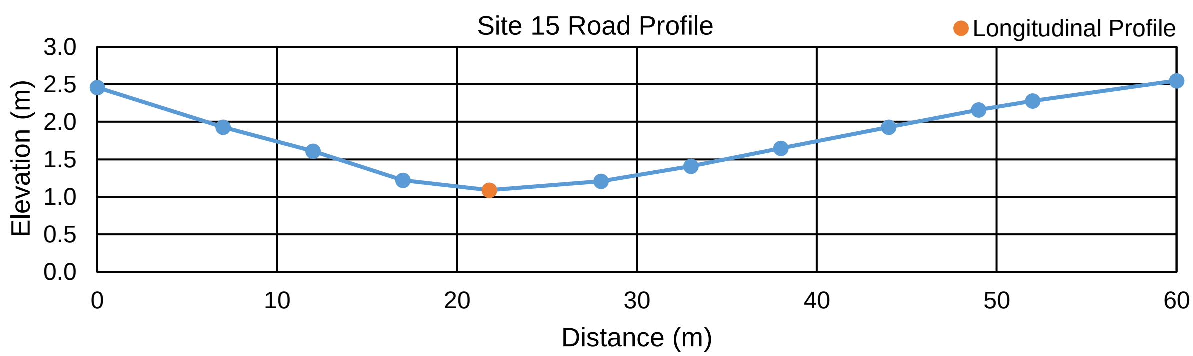
Downstream View

Left Road Edge

Right Road Edge

Site 15: Big Barren Creek at J-173 B (by old schoolhouse)





Particle Size Distribution (mm)	Upstream	Downstream
d10	15	1
d25	22.6	5.6
d50	22.6	16
d75	32	64
d84	32	64
d90	32	69
dMax	225	128

Channel Geometry	Upstream	Downstream
Active Width (m)	9	6.2
Bankfull Width (m)	11	10.5
Bankfull Depth (m)	0.7	0.6
Bankfull W/D Ratio	15.7	21.2
Slope (%)		2.11

Site 15: Pictures (12-19-2016)

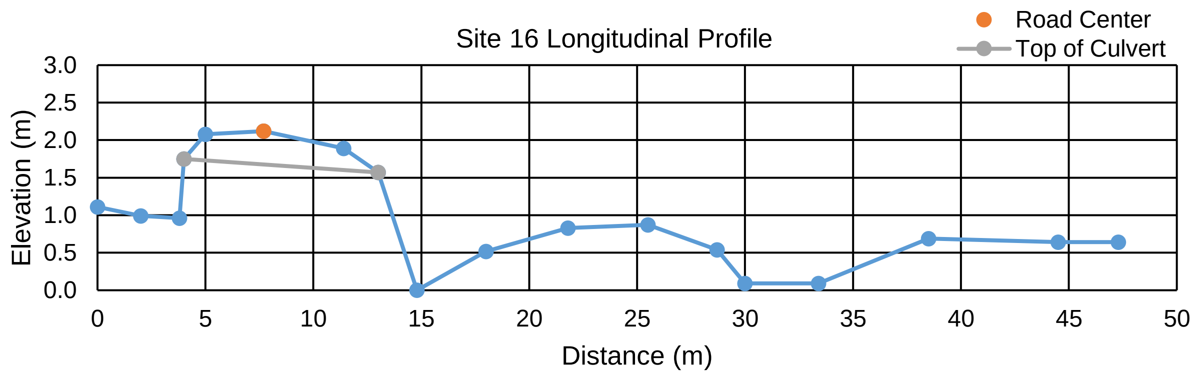
Upstream View

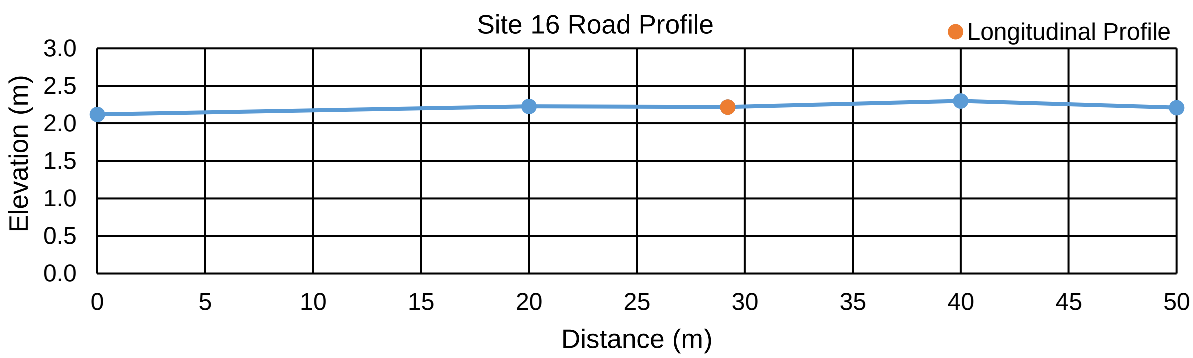
Downstream View

Left Road Edge

Right Road Edge

Site 16: Unnamed tributary at J-173





Particle Size Distribution (mm)	Upstream	Downstream
d10	No access	7
d25	No access	11
d50	No access	16
d75	No access	30
d84	No access	32
d90	No access	33
dMax	No access	45

Channel Geometry	Upstream	Downstream
Active Width (m)	4.4	8.9
Bankfull Width (m)	5.7	12.3
Bankfull Depth (m)	1.1	0.8
Bankfull W/D Ratio	5.1	19.9
Slope (%)		0.75

Site 16: Pictures (12-19-2016)

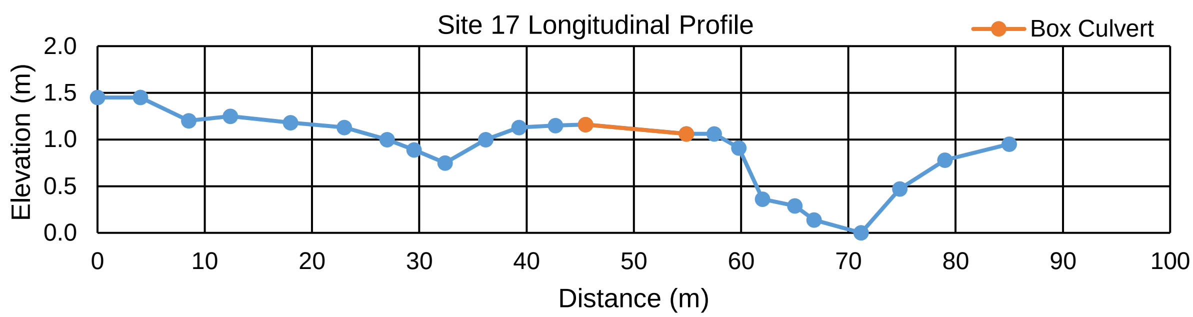
Upstream View

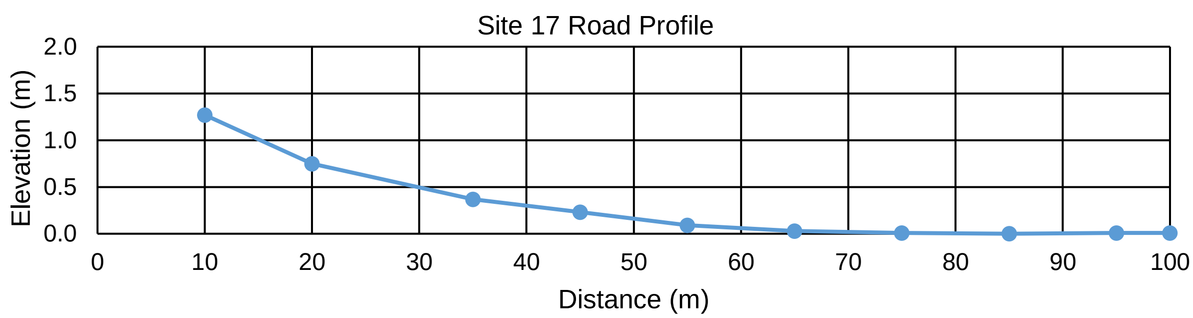
Downstream View

Left Road Edge

Right Road Edge

Site 17: Big Barren Creek at State Highway J





Particle Size Distribution (mm)	Upstream	Downstream
d10	1	1
d25	1	1
d50	1	1
d75	8	2.8
d84	11	5.6
d90	22.6	5.6
dMax	32	16

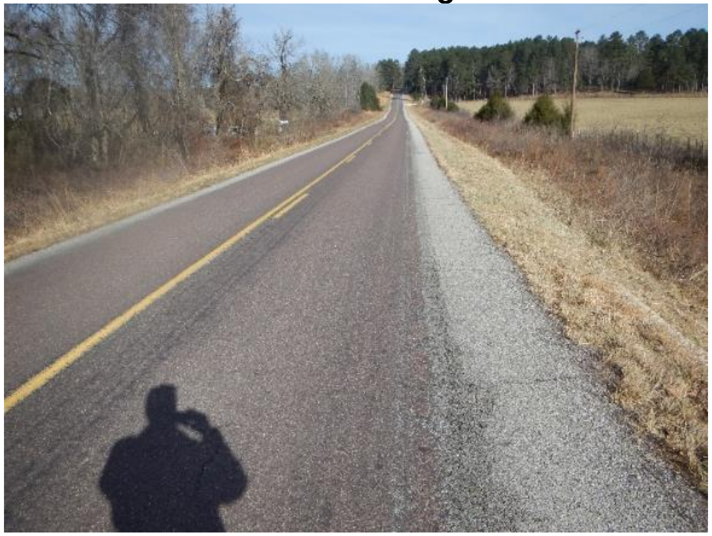
Channel Geometry	Upstream	Downstream
Active Width (m)	5.7	1.8
Bankfull Width (m)	5.7	10.2
Bankfull Depth (m)	0.6	0.5
Bankfull W/D Ratio (m)	12.5	28.2
Slope (%)		0.68

Site 17: Pictures (12-19-2016)

Upstream View

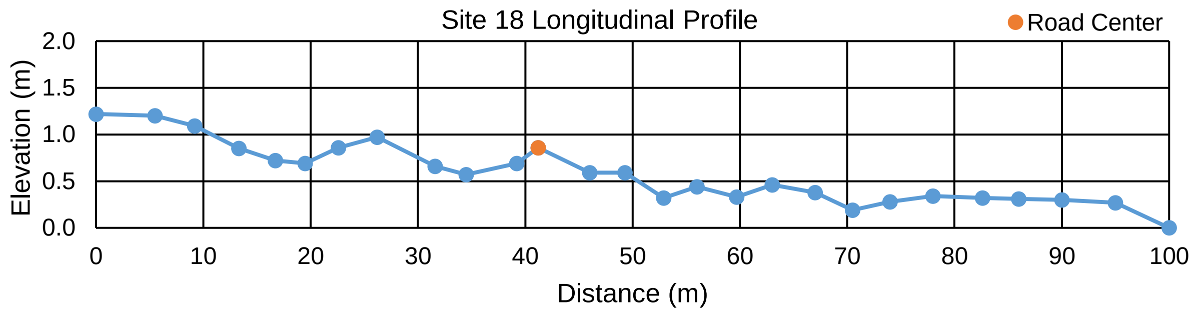
Downstream View

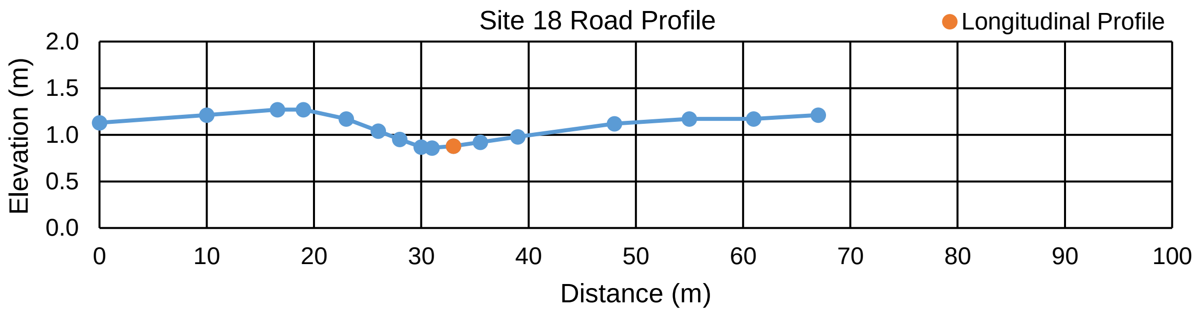
Left Road Edge



Right Road Edge

Site 18: Big Barren Creek at J-174 (road to Freeman Cemetery)





Particle Size Distribution (mm)	**Upstream**	**Downstream**
d10	11	3.1
d25	22.6	5.6
d50	32	11
d75	45	22.6
d84	45	22.6
d90	64	22.6
dMax	64	32

Channel Geometry	**Upstream**	**Downstream**
Active Width (m)	7.2	3.3
Bankfull Width (m)	7.2	8.1
Bankfull Depth (m)	0.5	0.6
Bankfull W/D Ratio	18.1	25.6
Slope (%)		0.65

Site 18: Pictures (12-19-2016)

Upstream View

Downstream View

Left Road Edge

Right Road Edge

APPENDIX B: MAY 2017 FLOOD IMPACTS ON CROSSINGS

Site 10: Wolf Pond at J-173 (headcut zone)

Before Flood: Left Road Edge (12-19-2016)

After Flood: Left Road Edge (5-4-2017)

Site 10: Wolf Pond at J-173 (headcut zone)

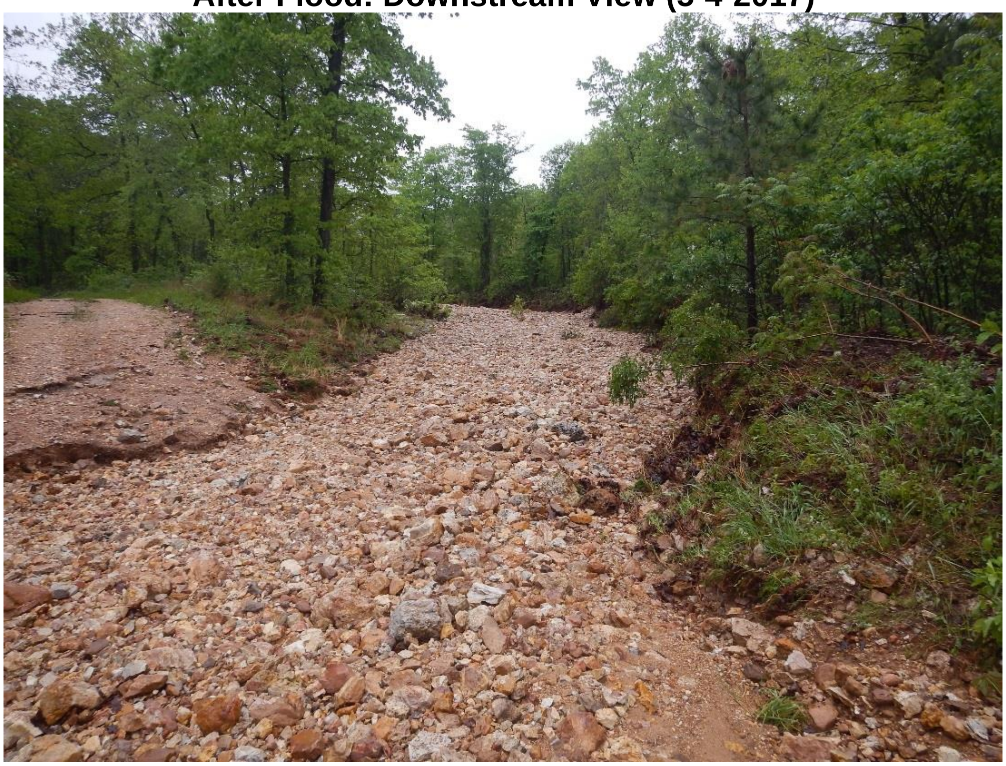
Before Flood: Downstream View (12-19-2016)

After Flood: Downstream View (5-4-2017)

Site 11: Polecat Hollow at J-173

Before Flood: Downstream View (12-19-2016)

After Flood: Downstream View (5-4-2017)



Site 14: Big Barren Creek at J-173 (above North bend)

Before Flood: Upstream View (12-19-2016)

After Flood: Upstream View (5-4-2017)

Site 16: Unnamed tributary at J-173

Before Flood: Upstream View (12-19-2016)

After Flood: Upstream View (5-4-2017)

Site 16: Unnamed tributary at J-173

Before Flood: Downstream View (12-19-2016)

After Flood: Downstream View (5-4-2017)