Missouri Department of Natural Resources
Water Protection Program

Total Maximum Daily Load (TMDL)

for

Shibboleth Creek

in

Washington County, Missouri

Completed: Dec. 20, 2010
Approved: Dec. 23, 2010

Total Maximum Daily Load (TMDL)
Shibboleth Branch

Pollutant: Inorganic Sediment

Name: Shibboleth Branch (formerly known as Shibboleth Creek)

Location: Washington County

State map showing location of watershed

Hydrologic Unit Code (HUC): 07140104-080002

Water Body Identification (WBID): 2120

Missouri Stream Class: Class C Stream[1]

Beneficial/Designated Uses[2]:
- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B

Size of Impaired Segment: 3.0 miles[3]

Size of Impairment within the Segment: 0.5 miles[3]

Location of Impaired Segment:
- On 1998, 2002 and 2004/2006 303(d) lists – Starting downstream at NE ¼ Section 14, T38N, R3E, upstream to N ½ Section 21, T38N, R3E (Bottom Diggins Dam)
- On 2008 303(d) List –

	Latitude	Longitude
Upstream	38.0075	-90.7079
Downstream	38.0209	-90.6639

Location of Impairment within Segment: From Bottom Diggins Dam downstream 0.5 miles

Impaired Use: Protection of Warm Water Aquatic Life

Pollutant:
- On 1998 303(d) List – Sediment
- On 2002 303(d) List – Nonvolatile Suspended Solids (NVSS)

[1] Class C streams may cease flow in dry periods but maintain permanent pools which support aquatic life. See 10 CSR 20-7.031(1)(F) (MoDNR 2009).
[2] For Beneficial "or Designated" Uses see 10 CSR 20-7.031(1)(C) and Table H (MoDNR 2009).
[3] In the 2004/2006 Missouri 303(d) List, EPA revised the length of the impaired portion of this water body segment from the 0.5 miles originally listed in 1998 and 2002, to the length of the entire WBID 2120 segment, 3.0 miles, as it remained on the 2008 303(d) List.

Pollutant (continued):

- On 2004/2006 and 2008 303(d) lists – Inorganic Sediment
- NOTE: While Shibboleth Branch is not currently 303(d)-listed for cadmium, lead and zinc, it is recognized that these metals in sediment (S) are causing or contributing to toxicity issues in the water body. As a result, TMDLs for cadmium, lead and zinc in sediment and dissolved cadmium, lead and zinc in the water column have been included in this TMDL document.

Pollutant Source:

- On 1998, 2002 and 2004/2006 303(d) lists, source – Barite Tailings Pond
- On 2008 303(d) List, source – Mill tailings (Abandoned)

TMDL Priority Ranking: Low

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

This Shibboleth Creek Total Maximum Daily Load (TMDL) for sediment is being established by the Missouri Department of Natural Resources (department) in accordance with Section 303(d) of the federal Clean Water Act. The department is establishing this TMDL by no later than 2010 to meet the milestones of the 2001 Consent Decree, *American Canoe Association, et al. v. EPA*, No. 98-1195-CV-W in consolidation with No. 98- 4282-CV-W, February 27, 2001.

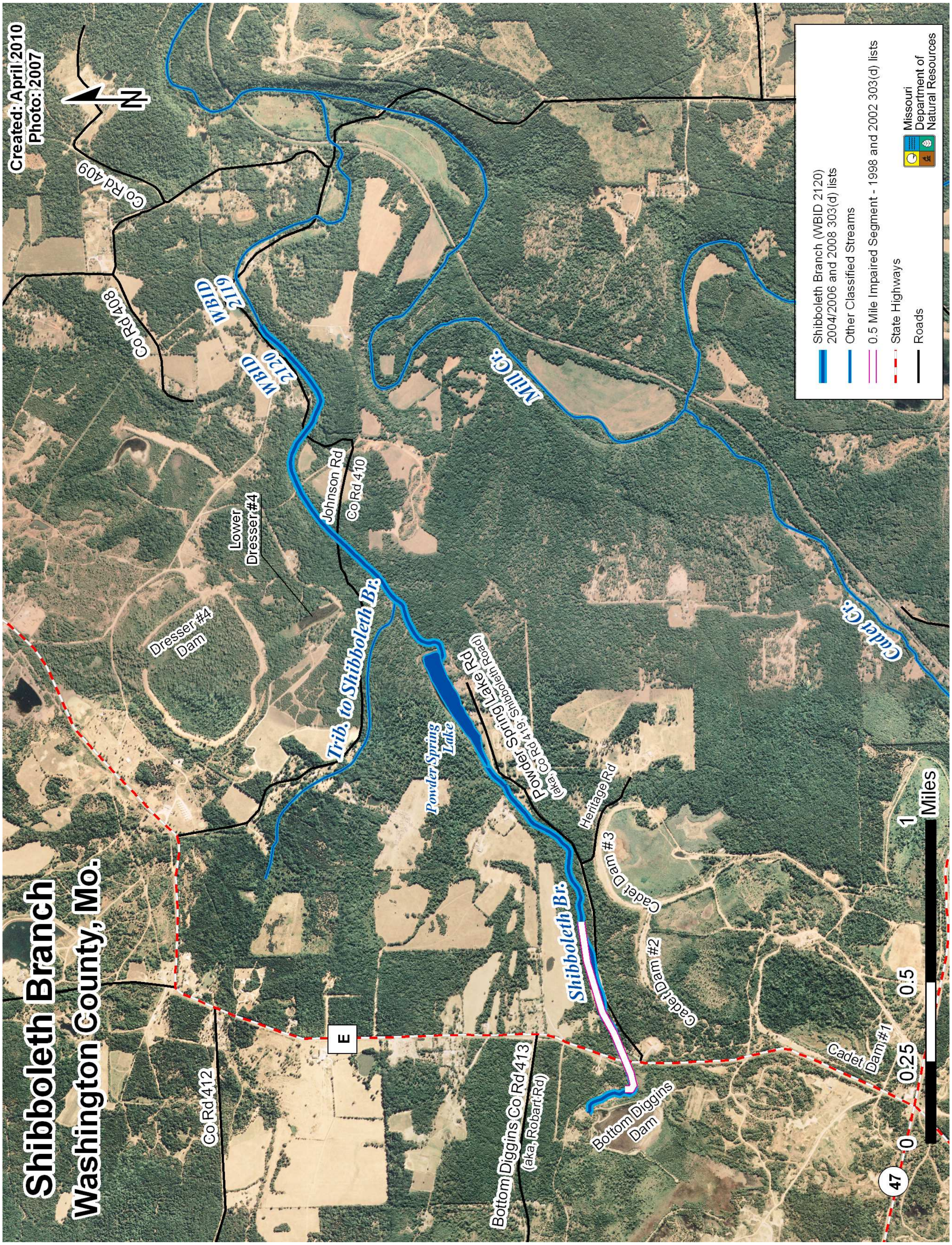
This water quality limited-segment in Washington County has historically been misnamed in Missouri's Water Quality Standards and 303(d) lists as Shibboleth "Creek." Effective Oct. 30, 2009, the name, as listed in 10 CSR 20-7.031, Table H, was changed to Shibboleth "Branch" in order to agree with the stream as identified in the U.S. Geological Survey's Geographic Name Information System (USGS 1990; Appendix A-1). Future Missouri 303(d) lists will reflect this correction. The stream is referenced by the "Branch" name in most of this TMDL.

The upper half mile of Shibboleth "Creek" was included on the U.S. Environmental Protection Agency (EPA)-approved 1998 and 2002 303(d) lists for Missouri for sediment and nonvolatile suspended solids (NVSS), respectively. The change from sediment to NVSS was to specify that the problem was due to mineral solids (e.g., silt, sand and gravel) coming from eroding mine waste materials and stockpiles. On the 2004/2006 and 2008 303(d) lists, the pollutant, NVSS, was replaced with "inorganic sediment." Since NVSS and inorganic sediment have essentially the same meaning, the listing was changed to inorganic sediment to better characterize the impairment. While the two terms may be used interchangably, the data used to identify the listed impairment has not changed.

Another modification from previous 303(d) listings is a change by the EPA on the 2004/2006 and 2008 303(d) lists to include the entire classified segment length of three miles as impaired instead of the previous listing of only the upper 0.5 mile. The formerly-listed half mile was upstream of Powder Spring Lake, but the entire 3-mile segment reaches approximately 1.25 miles downstream of Powder Spring Lake's dam (See Figure 1). In the 2008 303(d) List, the 3-mile upper segment Shibboleth Branch (Water Body Identification (WBID) 2120) is listed as impaired by inorganic sediment eroded from barite mine tailings.

Missouri Water Quality Standards (WQS) include rules associated with designated beneficial uses, water quality criteria and antidegradation. The purpose of a TMDL is to determine the pollutant load a water body can assimilate without exceeding the WQS for the pollutant for which the water body was listed. The TMDL also establishes the pollutant load allocation necessary to meet the criteria established for each water body based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload capacity (WLA), a load allocation (LA) and a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint sources. The MOS is a percentage of the TMDL that accounts for the uncertainty associated with the model assumptions and data inadequacies. These elements are discussed in detail in Section 6.2.

Figure 1. Aerial photo-based map of Shibboleth Branch.



2. BACKGROUND

2.1 Geography

Shibboleth Branch is located in the Big River Basin in Washington County, north of Cadet, Mo., and is located within the Ozark/Meramec Ecological Drainage Unit (EDU No. 25)[4]. The first of two headwater forks begins just south of Highway 47 and proceeds north where it met the second tributary, coming in from the west, in what is now the lake impounded by Bottom Diggins Dam. From the Bottom Diggins dam (See Figure 1), the impaired Class C segment flows east/northeast for 3 miles. Powder Spring Lake dam impounds Shibboleth Branch about in the middle of this upper segment. The lower, Class P[5] segment (WBID 2119) begins about 1.5 miles downstream of Powder Spring Lake Dam and flows for another mile before its confluence with Mill Creek. Approximately 3 miles further downstream, in extreme northwest St. Francois County, Mill Creek converges with the Big River

2.2 Population

The population of the Shibboleth Branch watershed is not directly available. However, the population of the watershed can be roughly estimated based on the population of Washington County. Washington County covers an area of approximately 763 square miles and has an estimated population of 24,548 people (U.S. Census Bureau 2008). The largest urban center in Washington County is Potosi, the county seat, with a population of approximately 2,700 people. The next largest communities are Irondale and Mineral Point, both with populations under 500. Because the Shibboleth Branch watershed does not have an urban population, the rural population estimate for the watershed is also the estimated total watershed population. The rural population for Washington County (total population minus total urban population) is 20,844 people. The Shibboleth Branch watershed area is 8.81 square miles. Therefore, the rural population of the Shibboleth Branch watershed is estimated to be 241 people (derived by dividing 8.81 square miles by 763 square miles, and then multiplying by 20,844 people). The Shibboleth Branch watershed does not have an urban population

2.3 Current Land Use

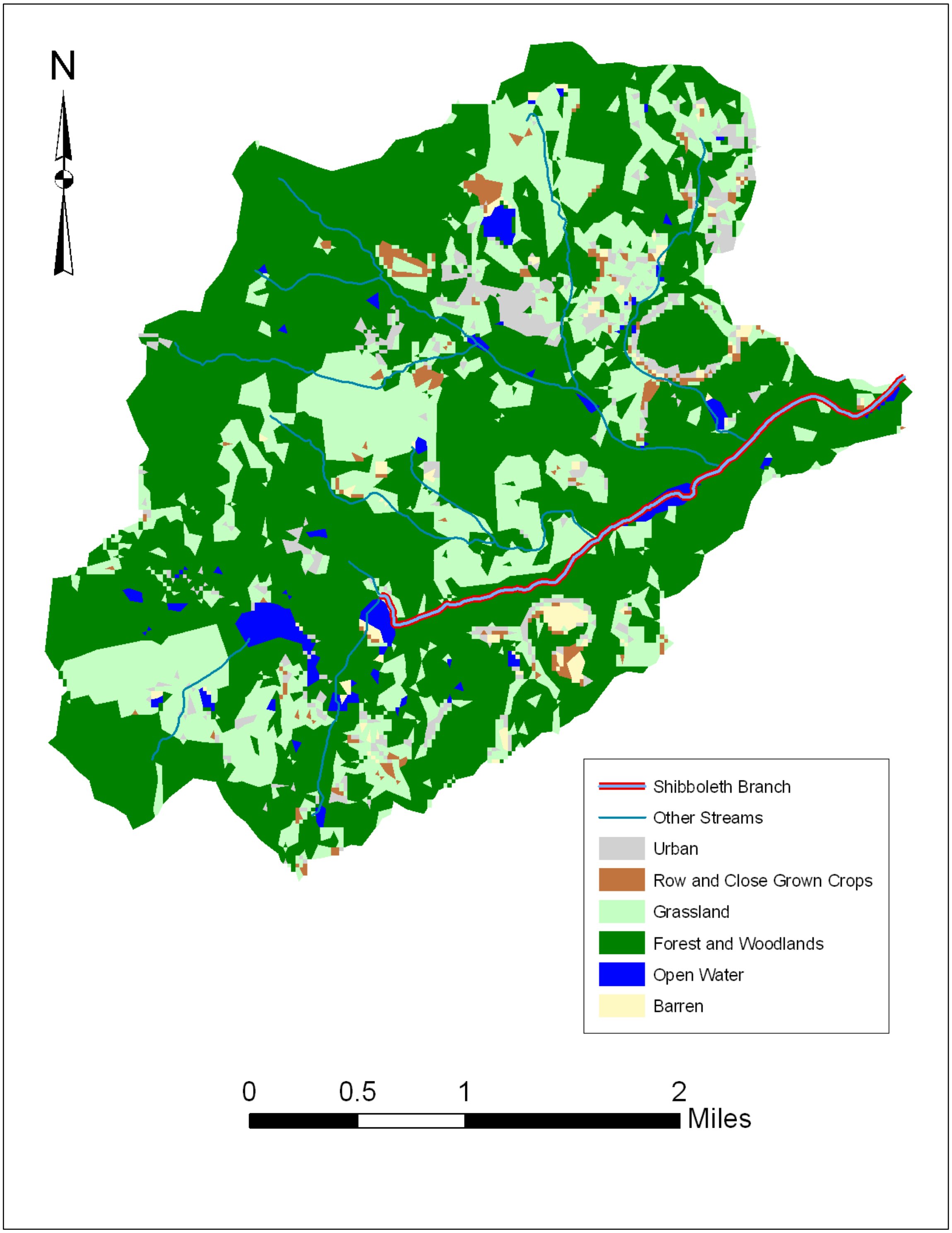
The watershed associated with the impaired segment of Shibboleth Branch is approximately 8.8 square miles. Forest and woodland, and grassland are predominate land uses in the watershed (Table 1 and Figure 2). While there are no urban centers in the Shibboleth Branch watershed, urban land use represents areas of impervious cover such as roads and rooftops of buildings.

Table 1. Land use distribution for the upper Shibboleth Branch (WBID 2120) watershed (MoRAP 2005)**.**

Land Use Type	*Area in Acres*	*Area in Square Miles*	*Percentage*
Urban	226	0.35	4.0
Row and Close-grown Crops	95	0.15	1.7
Grassland	1,373	2.15	24.4
Forest & Woodland	3,749	5.86	66.5
Wetlands and Open Water	132	0.21	2.3
Barren	64	0.10	1.1
Totals:	**5,639**	**8.82**	**100.0**

[4] EDUs are delineated drainage units that are described by physiographic and major riverine components.
[5] Class P streams maintain permanent flow even in drought periods. See 10 CSR 20-7.031(1)(F) (MoDNR 2009).

Figure 2. Map of Land Use in the Upper Shibboleth Branch (WBID 2120) Watershed (MoRAP 2005).



2.4 Soils and Geology

The Washington County Soil Survey describes the area and soils as follows:

> Washington County is part of the Interior Highlands Division, Ozark Plateau Province, Springfield-Salem plateaus section. It has a variety of landforms, surface features, geologic formations, structural complexities, and mineralized trends.

> Streams typically flow to the north, away from the St. Francois Mountains and the Ozark Dome. Tributaries of the Big River drain to the east.
>
> The Potosi Formation, where barite was mined, is located in the southwestern and eastern parts of the county. The major soils are Gravois on the ridges, Goss on the side slopes, and Tiff in mined areas (USDA NRCS 2005).
>
> The Potosi Formation is dominated by massive beds of dolostone with an abundance of quartz druse also called mineral blossom. The Goss, Moko, and Sonsac soils dominate these areas (USDA NRCS 2006).

A map illustrating the soil types in the Shibboleth Branch watershed can be found in Figure 3a (next page) of this TMDL document. The headwaters of Shibboleth Branch (WBID 2120) incise the Tiff soil series (See Figure 3a and Figure 4), which consists of very deep (over 60 inches), well-drained, moderately permeable soils that formed clayey residuum[6] on uplands. These soils are on nearly level to moderately steep areas that have been truncated by mining operations with slopes ranging from 1 to 20 percent. The soil's taxonomic class is clayey-skeletal, kaolinitic, mesic Rhodic Paleudalfs. Typical pedon[7] is tiff gravelly clay - on a convex escarpment of 13 percent slope in a mined area at an elevation of 710 feet (USDA NRCS 2005).

Figure 4. Shibboleth Branch streambank approximately 0.6 miles downstream of Bottom Diggins Dam illustrating "Tiff Soil Series," with wiffle golf ball for scale (photograph taken March 23, 2009)**.**

The relationship of the Tiff soil series (labeled "gravelly-clayey residuum") and the overlying Gravois-Goss complex can be found in Figure 3b. Where exposed, the Tiff soil series and the barite-rich clay materials found in barite tailings areas are similar in appearance and composition. For this reason it is often difficult to distinguish between historic abandoned barite mine areas and more recently disturbed Tiff soils. Therefore, for the purposes of the Shibboleth Creek TMDL the materials classified as "mine tailings" and "tiff gravelly clay" will be considered similar materials.

Barite, or barium sulfate, also known as "tiff," is a mineral used in well-drilling mud, chemical manufacture, fillers and extenders, face powders, chocolate coatings, glass making, golf and

---

[6] Parent material is the unconsolidated mass in which a soil forms. The type of parent material from which the Tiff soil series formed is residuum – material weathered from bedrock.
[7] A pedon is a three-dimensional body of soil large enough to study its horizons. It is about one meter square by 1.5 to 2 meters deep (Kohnke and Franzmeier 1995).

Figure 3a. Map of Soils in the Upper Shibboleth Branch (WBID 2120) Watershed (NRCS 2007).

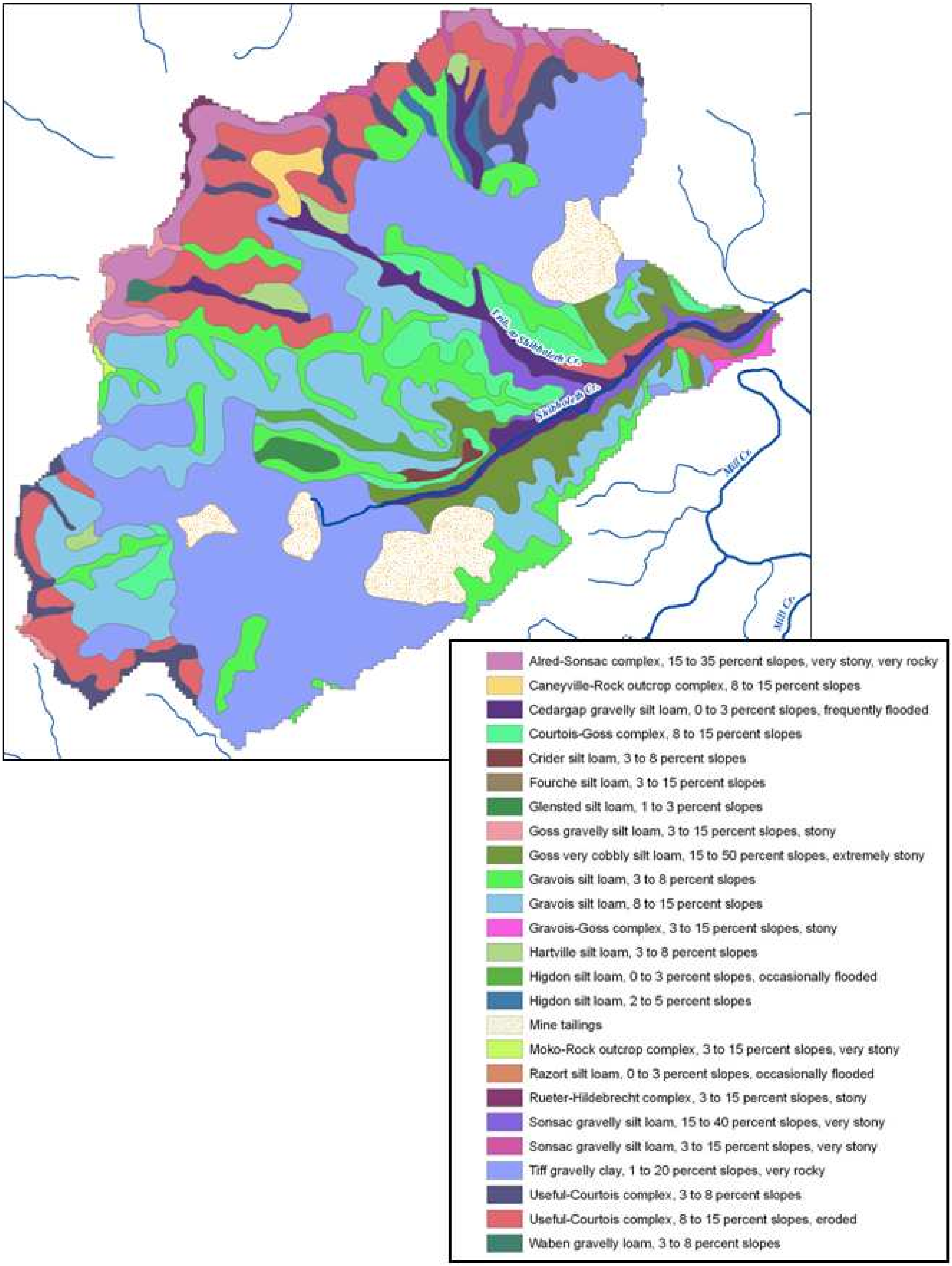
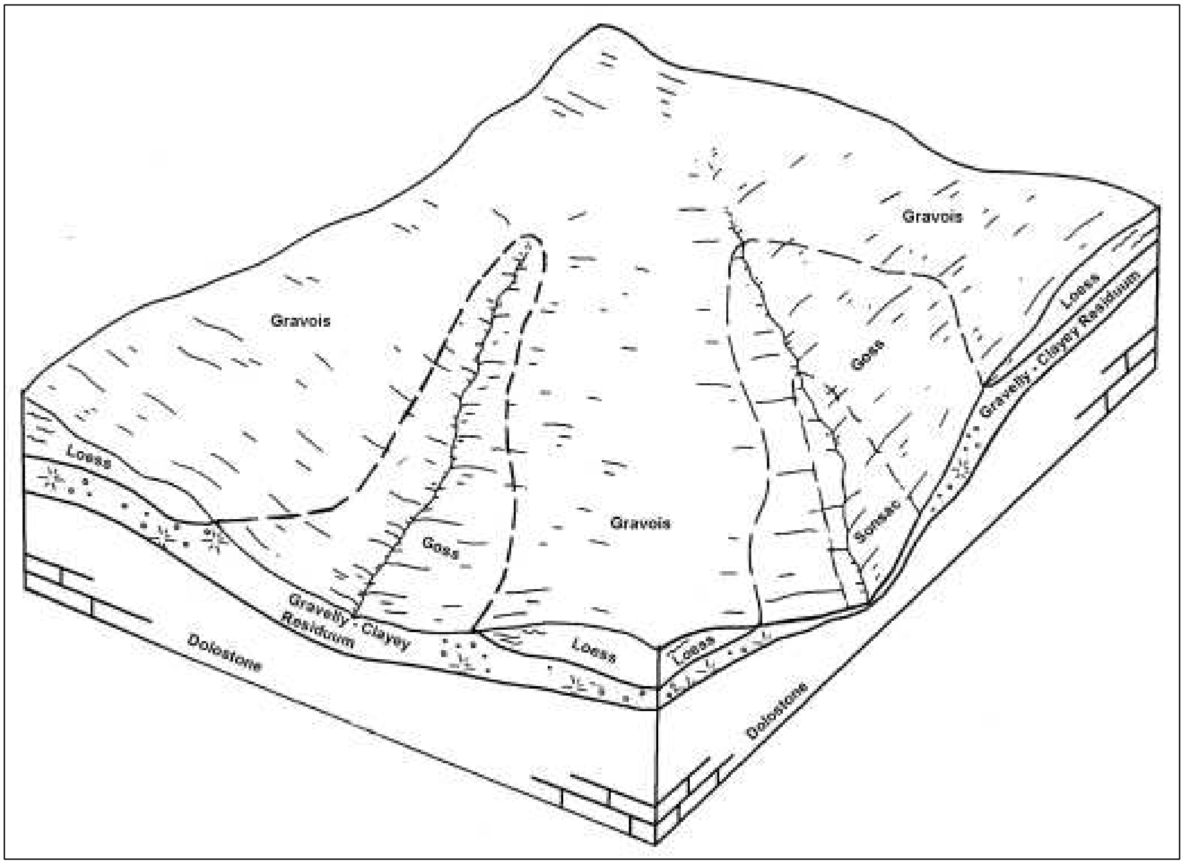


Figure 3b. Typical pattern of soils and parent material in the Goss-Gravois association (Figure 10 from USDA NRCS 2005).



bowling ball cores, in paint and with X-rays. Barite is only sparingly soluble and being a compound formed by a metal and an anion (SO_4^-) of a strong acid (H_2SO_4), it has no effect on pH when it dissolves. The Washington County barite deposits are of the residual type (lumps of barite enclosed in clay). The barite-rich clays accumulated from the solution and weathering of impure carbonate rocks. Such residuum is typically stained red or brown by insoluble iron oxide. Potentially acid-producing sulfide minerals are not associated with these barite ores. Acid-producing hydrolysis of pyritic iron, with its production of orange or red flocculants, is probably not a factor here. Instead, the red color is due to fine red-stained clay (Brian Hicks, R.G., formerly with the department's Land Reclamation Program, e-mail communication, April 2, 2003). Water column samples taken from Shibboleth Branch by department staff in 2008 and 2009 revealed acceptable pH measurements of 7.8 to 8.5, with no indication of acidity (Appendix A-2).

2.5 Barite Mining

Because a barite tailings dam was first identified as the source of Shibboleth Branch's impairment, this section will catalog the history of barite mining and the associated tailings dams in the watershed. Note that more details on specific dams and related permits may be found in Section 5.1.

The first step in processing barite was to wash the mined material to separate the barite ore from the red clay and gravel found with it. Barite was hauled by trucks to barite "washers" where high pressure hoses and jigging tables were used to separate the barite from the red clays and any host rock. The used wash water (slurry) flowed into a pond where the red clays and rock settled out, and water from these ponds was pumped back to be used in the washers. Ideally, returning wash water would be directed along the inside dam face so as to drop it's load of clay particles on the dam, leaving clear water only to cross the areas containing either pumps or spillways (Donald Smith, Cimbar Performance Minerals, personal communication, April 6, 2010).

Old barite mining dams, such as those in the Shibboleth Branch watershed, were built prior to enactment of current safety law administered by the department's Dam and Reservoir Safety Program. These dams are registered with permit numbers beginning with the letter "R" to indicate that status, as opposed to dams registered under current safety laws, which are registered with permit numbers beginning with "S." The old barite dams are handled differently by the Dam and Reservoir Safety Program than a modern dam, and they are given an "industrial registration permit" rather than a regular permit. The barite mining companies were allowed to keep adding coarse rock, which had been separated from the ore, to the top of the dams as a means of building up dam height to increase the size of these settling ponds. The inside slopes of these additions were covered with clay to ensure a water-tight seal (Donald Smith, Cimbar Performance Minerals, personal communication, April 6, 2010). These additions were allowed without the companies being required to have department staff approve the additions on-site every time. Instead, the department would inspect the new additions during their next scheduled inspection. Some of these dams were added to in this manner over a period of 10 or more years.

Due to the nature of the material used to build these dams, the dams themselves always seep water. The seeping water will often appear oily-looking, as it does for all seeping dams due to bacteria metabolism of organics in clay. As long as no sediment is moving through the dam (i.e., the seep water is clear), Dam and Reservoir Safety Program staff are not concerned. If sediment is seen passing through the dam, department staff will require the permittee to construct some sort of filter over the seep. For example, an embankment drain might be required, which is a layer of geo-fabric covered with graded material (e.g., limestone) in layers, ending with a pipe drain for future monitoring of water clarity (Glenn Lloyd, P.E., the department's Dam and Reservoir Safety Program, personal communications, Dec. 5 and 10, 2008).

Although other dams regulated by the Dam and Reservoir Safety Program are required to have both a primary spillway (e.g., a hardened pipe) and a secondary spillway (which does not have to be hardened), barite tailings dams are not required to have both. Program staff members feel that it is acceptable for a barite tailings dam to only have an open channel spillway as long as active erosion is minimal and not jeopardizing the dam's structural integrity. Often, portions or all of the downstream face of these dams remain barren even after decades, not necessarily because they are somehow toxic, but because they lack the soil, nutrients and water retention needed to support plant life in the upper layers (Pat Mulvany, the department's Division of Geology and Land Survey, e-mail communication, Nov. 3, 2009). Some of the lack of vegetation can also be attributed to the requirement to keep all brush and woody growth off the dams to ensure continued structural integrity.

When mining was active, water from a tailings pond was reused at the barite washer. Over time large deposits of red clays and gravels developed behind these dams, often as a deep layer the consistency of thick pudding (Glenn Lloyd, the department's Dam and Reservoir Safety

Program, personal communications, Dec. 5, 2008). If wash water went over the spillway before the suspended clay had time to settle out, overflows could contain suspended clay material that would subsequently be deposited in the bottom of receiving streams. In addition, if the open channels, which often served as the only spillway, experienced erosion, clays and gravels would be deposited downstream from that source as well (John Ford, the department's Water Protection Program, e-mail communication, April 2, 2003). Both phenomena were occurring at Bottom Diggins Dam and are believed to be the source of the problem sediment when the department first added Shibboleth Branch to the 1998 303(d) List.

Mining in the Cadet area occurred for decades before the existence of environmental regulations. Before modern mechanization came to the local mining world, it was common in Washington County for people to hand-mine lead on their family property. Barite was thrown to the side along with other non-lead "waste." Barite mining in the vicinity became a very competitive business starting in the 1920s. At that time, National Paint and Pigment owned and operated barite mining facilities along the Shibboleth Branch headwaters. Mining was done by hand, as was the washing of the barite from its host rock and soil, until the first mechanical washer, made mostly of wood, was installed in 1925 in the area around what is now the current site of Bottom Diggins Lake. Several of the bigger, yet still primitive relative to modern day, operations went out of business when environmental regulations came into existence (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 4, 2009 and April 6, 2010).

A further, albeit not comprehensive, history of barite mining in the Shibboleth Branch watershed follows (much provided by Donald Smith, Cimbar Performance Minerals, during conversations in 2009 and 2010; MoDNR 2010a) and locations mentioned can be found in Figure 1:

1944: Bottom Diggins Dam first completed to support the washing of mined barite.

1956: New Cadet washer constructed just northeast of the intersection of Highways 47 and E.

1957: The "L"-shaped Cadet Dam #1 was completed to support the washing of mined barite at the new Cadet washer, and Bottom Diggins Dam operations were permanently shut down. Note that Cadet #1 Dam's spillway drained to the east, just north of Highway 47, into a small impoundment in an old mining area located southeast of the dam in the Cadet Creek watershed rather than in the Shibboleth Branch watershed. The old wooden washer at Bottoms Diggins was subsequently torn down.

1964: Powder Spring Lake Dam (MO30759) constructed across Shibboleth Branch (WBID 2120) to create a 13-acre lake. The dam is 28 feet in height, and as such, is not regulated by the department's Dam and Reservoir Safety Program, which has jurisdiction over dams greater than 35 feet in height.

1968: Cadet Dam #2 completed to support the washing of mined barite, replacing Cadet #1, which was retired from use.

1972, Dec. 18: The department's Land Reclamation Program issued Permit No. 23 to NL Industries, Inc., Baroid Division, as part of the new industrial mineral mining law that went into effect the previous year. The mining area originally covered

10 acres north of Cadet, Missouri, and included the Bottom Diggins area west of State Route E, as well as along Shibboleth Branch to the east (parts of Sections 20 and 21, T38N, R3W).

1975, Aug. 25: Dresser Minerals Corporation's barite mine tailings dam #4, just northwest of Tiff, Missouri, failed. Dresser Dam #4 was 105 feet in height and impounded approximately 77 acres of water. It is estimated that the dam was built 15-20 years earlier (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 9, 2009). Upon failure, tons of water and mine tailings covered State Route E on the north side of the dam and also traveled south into an unnamed tributary of Shibboleth Branch and into the 7-acre Lower Dresser #4 lake (Dam Identification No. MO31123; See Appendix A-1), which impounded the tributary. The surge of water and tailings then traveled over the Lower Dresser #4 spillway, back into the tributary, and then into Shibboleth Branch itself. From there, the surge traveled down the entire length of Shibboleth Branch into Mill Creek, down its entire length and into Big River where the surge caused increased turbidity down to the mouth of the Big River – a distance of 71.3 miles. The mixture of clay and water caused an extensive fish kill in the upper 11.5 miles of the affected zone. The invertebrate community in Mill Creek remained reduced for at least 38 days after the dam failure, after which recovery continued until 264 days after the dam failure when similar invertebrate communities were found at the control and the affected stations on Mill Creek (Duchrow 1977 and 1982). Dresser Dam #4 was never repaired after the failure and has never been regulated by the department's Dam and Reservoir Safety Program (whose law went into effect in 1977) or the Water Pollution Control Program.

1976: The department issued a State Operating Permit for water protection, MO-0000221, to NL Industries, Inc., Baroid Division for a 40-acre mining area covering three quarter sections north of Highway 47. The farthest west end of the permitted area (NW ¼ N ½ S21, T38N, R3W) covered Bottom Diggins Dam (the only listed outfall).

1992: Cadet Dam #3 completed to support the washing of mined barite at the Cadet washer. For a while, wash water continued to be directed into the Cadet #2 impoundment where it flowed quickly through the impoundment and through the principle spillway on the east side of the dam, discharging into the Cadet #3 impoundment. Later, wash water was sent directly to Cadet #3 and the Cadet #2 impoundment was retired from use.

1994, March 18: Missouri State Operating Permit MO-0000221 issued to Baroid Drilling Fluids, Inc. by the department's Water Pollution Control Program. Expiration date: 1999. By this time, Dresser Minerals Corporation had bought out NL Industries' Baroid Division and owned Baroid Drilling Fluids. The only outfall listed in the permit was an earthen spillway on the east side of Cadet Dam #3. Company staff members collected water quality data just west of Heritage Road, between the dam spillway and Powder Spring Lake Road (aka Co. Rd. 419 and locally known as Shibboleth Road). Samples were taken upstream of the point where the dam's discharge mingled with water leaving the Heritage

Road's road ditch before entering the culverts that run under Powder Spring Lake Road.

1996, Dec. 6: Missouri State Operating Permit MO-0000221 permit was modified only to reflect the shift of the permitted entity from Baroid Drilling Fluids to it subsidiary, Cimbar Performance Minerals, Inc. Around this time period (1996-1998), Halliburton Energy Services purchased Dresser Industries. The resulting company subsequently split their industrial barite operations (like the one around Cadet) away from their barite operations associated with oil- and gas-related drilling. The industrial barite operations were put into a separate branch and named Cimbar Performance Minerals.

1999: Cimbar Performance Minerals, the last barite mining operation in the watershed, ceased mining.

Early 2000s: Missouri no longer had any active barite mines (Bill Zeaman, Land Reclamation Program, personal communication, Nov. 3, 2009).

2000, Aug. 25: Missouri State Operating Permit MO-0000221 issued to Cimbar Performance Minerals. Expiration Aug. 24, 2005.

2002, Oct: Halliburton Energy Services sold 4700 acres of property associated with the barite operation keeping only the dry grinding plant and surrounding 335 acres south of Highway 47 permitted to Cimbar Performance Minerals. (Note that the grinding plant uses no water; and the barite is imported from China.)

2003, Dec. 1: Halliburton Energy Services sold Cimbar Performance Minerals, including the grinding plant and surrounding 335 acres, to United Mineral and Properties of Chatsworth, Georgia.

2004, Jan. 24: The Land Reclamation Program released the last of the performance bonds on industrial mineral mining Permit No. 23 on Jan. 24, 2004, and terminated the mining permit. The release letter included an acknowledgement that the developer who had purchased the land around Bottom Diggins Dam and the Cadet dams was parceling off the property to sell as individual home lots. Note that Missouri's industrial mineral mining law only has jurisdiction over where the actual mining takes place. Since the tailings ponds are associated with the processing of the mineral rather than the actual mining, the Land Reclamation Program had no authority over regulating the barite tailings ponds or their outfalls (MoDNR 2010b and c).

2004, June 4: Missouri State Operating Permit MO-0000221 terminated. Water Protection Program staff were confident at the time that if the Land Reclamation Program had released the mining bonds on the area and terminated the mining permit, that adequate reclamation (i.e., including erosion control) was in place.

2006, Oct. 6: General Missouri State Operating Permit MO-G490947 issued to Cimbar Performance Minerals by the department's Water Protection Program for the remaining 335 acres, including the grinding plant. Expiration Oct. 5, 2011. For details, see Section 5.1.1 of this document.

2006 - present: At the time this TMDL was developed, the properties formerly covered by the Water Protection Program's site specific permit MO-0000221containing the Cadet dams and their drainage areas belonged to individual private landowners and homes had been built. Although Bottom Diggins Dam and part of its watershed's drainage area is owned by a sole landowner, much of the Bottom Diggins watershed formerly owned by Cimbar Performance Minerals has been parceled off. At least eight houses have been built on these properties since Cimbar first sold the property.

3. APPLICABLE WATER QUALITY STANDARDS AND WATER QUALITY TARGETS

The purpose of developing a TMDL is to identify the pollutant loading that a water body can assimilate and still achieve water quality standards. Water quality standards are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S. Code Title 33, Chapter 26, Subchapter III (U.S. Code, 2009)). Water quality standards consist of three components: designated beneficial uses, water quality criteria to protect those uses, and antidegradation rules.

3.1 Designated Beneficial Uses

Shibboleth Branch (WBID 2120) has the following beneficial uses:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation - Category B

Use that is impaired:

- Protection of Warm Water Aquatic Life

Stream classifications and designated uses may be found in the Missouri Water Quality Standards at 10 CSR 20-7.031(1)(C) and (F) and Table H (MoDNR 2009).

3.2 Antidegradation Rules

Missouri's Water Quality Standards include the U. S. Environmental Protection Agency (EPA) "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2).

Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after Nov. 28, 1975, the date of EPA's first Water Quality Standards Regulation.

Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economic and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing uses.

Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges and waters of exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

Waters in which a pollutant is at, near, or exceeds the water quality criteria are considered in Tier 1 status for that pollutant. Because Shibboleth Branch is listed as impaired, it is exceeding the water quality standards for sediment and metals in the sediment. Therefore, the antidegradation goal for Shibboleth Branch is to restore the stream's inorganic sediment and metals levels to the water quality standards.

3.3 Water Quality General Criteria that Apply

3.3.1 Inorganic Sediment

Shibboleth Branch is listed as impaired by inorganic sediment and based upon exceedence of the general, or narrative, criteria contained in Missouri's water quality rules at 10 CSR 20-7.031(3)(A), (C) and (G)(MoDNR 2009):

(A) Waters shall be free from substances in sufficient amounts to cause the formation of putrescent, unsightly, or harmful bottom deposits or prevent full maintenance of beneficial uses.
(C) Waters shall be free from substances in sufficient amounts to cause unsightly color or turbidity, offensive odor, or prevent full maintenance of beneficial uses.
(G) Waters shall be free from physical, chemical, or hydrologic changes that would impair the natural biological community.

And from 10 CSR 20-7.031(4)(H):

(H) Solids. Water contaminants shall not cause or contribute to solids in excess of a level that will interfere with beneficial uses. The stream or lake bottom shall be free of materials which will adversely alter the composition of the benthos, interfere with the spawning of fish or development of their eggs or adversely change the physical or chemical nature of the bottom (MoDNR 2009).

When water quality criteria are expressed as a narrative, a measurable indicator of a pollutant may be selected to express the narrative as a numeric value. There are many quantitative indicators of sediment, such as total suspended solids (TSS), turbidity, and bedload sediment, which are appropriate to describe sediment in rivers and streams (USEPA 2006b). A concentration of total suspended solids was selected to represent the numeric target for this TMDL because it enables the use of the highest quality available data and is included in permit requirements and monitoring data.

3.3.2 Metals

The biological impairment of Shibboleth Branch can also be attributed to elevated metals concentrations associated with fine sediment generated by the barite mining activities within the watershed. At the time this TMDL was developed, Missouri's 2008 303(d) List did not include lead and zinc as impairing Shibboleth Branch, however, the proposed 2010 303(d) List does include both of these metals in sediment. Although impairment due to cadmium has not been specifically proposed, cadmium is included in the analysis because this metal is often associated with lead and zinc and could be contributing to the overall metals toxicity in sediment. Toxic effects of metals on the biological community in Shibboleth Branch are a violation of both general and specific Missouri water quality criteria.

General criteria found at 10 CSR 20-7.031(D) states:

> (D) Waters shall be free from substances or conditions in sufficient amounts to result in toxicity to human, animal, or aquatic life (MoDNR 2009).

Specific criteria for toxic substances found at 10 CSR 20-7.031(4)(B)1 states:

> (B)1. Water contaminants shall not cause the criteria in Tables A and B to be exceeded. Concentrations of these substances in bottom sediments or waters shall not harm benthic organisms and shall not accumulate through the food chain in harmful concentrations, nor shall state and federal maximum fish tissue levels for fish consumption be exceeded (MoDNR 2009).

Current cadmium, lead and zinc criteria for the protection of aquatic life use are expressed in dissolved form in units of micrograms per liter, or µg/L. These criteria are hardness dependent and calculated from the formulas shown below from Table A of 10 CSR 20-7.031:

Dissolved Cadmium

$$\text{Acute} = e^{(1.0166*\ln(\text{Hardness}) - 3.062490)} * (1.136672 - (\ln(\text{Hardness})*0.041838)) = \mu g/L$$

$$\text{Chronic} = e^{(0.7409*\ln(\text{Hardness}) - 4.719948)} * (1.101672 - (\ln(\text{Hardness})*0.041838)) = \mu g/L$$

Dissolved Lead

$$\text{Acute} = e^{(1.273*\ln(\text{Hardness}) - 1.460448)} * (1.46203 - (\ln(\text{Hardness})*0.145712)) = \mu g/L$$

$$\text{Chronic} = e^{(1.273*\ln(\text{Hardness}) - 4.704797)} * (1.46203 - (\ln(\text{Hardness})*0.145712)) = \mu g/L$$

Dissolved Zinc

$$\text{Acute} = e^{(0.8473*\ln(\text{Hardness}) + 0.884211)} * 0.978 = \mu g/L$$

$$\text{Chronic} = e^{(0.8473*\ln(\text{Hardness}) + 0.785271)} * 0.986 = \mu g/L$$

where "e" is the base of the natural logarithm (~2.718) and "ln" is the natural logarithm.

Concentrations of fine sediment, metals in the sediment, and dissolved metals will also be used as TMDL targets for the Shibboleth Branch TMDL.

3.4 Water Quality Targets

For this TMDL, sediment targets were derived using generalized information from the ecological drainage unit (EDU) in which Shibboleth Branch is contained (See Section 2.1 for a definition of an EDU). In this case, the Ozark/Meramec Ecological Drainage Unit (No. 25) was used.

Targets for metals in sediment were developed using the Equilibrium Partitioning Methodology as described in Section 4.3.

The 25th percentile hardness value must be used to calculate hardness dependent dissolved metals criteria as per 10 CSR 20-7.031(1)(Y) that states:

> (Y) Water hardness—The total concentration of calcium and magnesium ions expressed as calcium carbonate. For purposes of this rule, hardness will be determined by the lower quartile (twenty-fifth percentile) value of a representative number of samples from the water body in question or from a similar water body at the appropriate stream flow conditions.

Using available hardness data and this formula results in the 25th percentile of hardness in the Shibboleth Branch watershed being 160 mg/L. Therefore, the corresponding dissolved chronic and acute cadmium targets for Shibboleth Branch are 0.3 and 7.5 µg/L respectively. Likewise, the dissolved chronic and acute lead targets are 4.2 and 107 µg/L respectively, and corresponding zinc chronic and acute targets are 159 and 174 µg/L, respectively. The water quality targets for cadmium, lead and zinc will be based on the chronic criteria to ensure aquatic life will be protected from acute and chronic toxicity. Therefore, targets for Shibboleth Branch are 0.3 µg/L for cadmium, 4.2 µg/L for lead and 159 µg/L for zinc.

4. WATER QUALITY PROBLEM IDENTIFICATION AND CURRENT CONDITIONS

As per Missouri water quality rules, all waters of the state must provide a suitable condition for aquatic life. The conditions include both the physical habitat and the quality of the water. TMDLs are not written to address habitat, but are written to correct water quality conditions. The water quality condition addressed in this TMDL is sedimentation and toxicity derived from metals in sediment.

The stream was placed on the 1998 Missouri 303(d) List primarily based on the department's multiple observations of instream conditions violating narrative water quality criteria in the form of sediments being deposited into the stream. At the time, no sediment data existed to directly document sediment impacts to the stream.

4.1 Water Quality Issues and Mining Activities

Inorganic sediment is composed of mineral particles such as clay, silt, sand, assorted-sized rocks and other non-organic materials. These particles enter the stream via erosion of soils or other materials within the watershed. The deposited red clays constitute the inorganic sediment that impair Shibboleth Branch. When these solids enter into a stream, they settle onto the bottom, smothering natural substrates (and interstitial spaces associated with that habitat), aquatic invertebrates and fish eggs (John Ford, the department's Water Protection Program, e-mail communication, April 2, 2003). Dissolved metals, whether in the water column or in the sediment pores[8], also pose a significant risk to aquatic life (Hansen *et al.* 2005, Besser *et al.* 2009).

The effects of mining on streams in the area was documented in the early 1960s in the Missouri Water Pollution Board's first published report on water quality, *Water Quality of Big, Bourbeuse and Meramec River Basins*, specifically in Part V, "The Benthos of Meramec River Basin as Related to Water Quality." The pools in Mill Creek near Cadet were reported to be "choked with red clay from barite washing" operations upstream (Kuester 1964).

[8] Pore water is the water that exists in the interstitial spaces between particles (Hansen *et al.* 2005).

4.2 Water Quality Data

4.2.1 Biological Data

In October 2002, the department conducted a qualitative examination of the aquatic invertebrate benthic community of Shibboleth Branch (See Appendix A-1, Site A), two other streams with an inactive barite tailings pond, and one without a barite tailings pond, which was used as a control. The results of this survey are summarized in Table 2. Shibboleth Branch supported the next to lowest number of total taxa and the lowest number of EPT taxa[9] of the sampled streams. When evaluation methodology, a stream's biological community is considered healthy if the number of EPT taxa in the stream are equal to or greater than those found in one quarter of the reference

Table 2. Summary of qualitative aquatic invertebrate sampling of four streams in eastern Washington County, Oct. 2002 (MoDNR 2002a).

Stream	*Total Number of Taxa*	*Total Number of EPT* Taxa*
Tributary to Pond Creek – inactive tailings pond	23	7
Tributary to Mineral Fork – inactive tailings pond	20	6
Rubeneau Creek – control	16	6
Shibboleth Branch – inactive tailings pond	17	5

* EPT= Ephemeroptera, Plecoptera and Trichoptera (Mayflies, Stoneflies and Caddisflies)

streams in its area (i.e., high quality streams in the ecological drainage unit, or EDU). Note that although Rubeneau Creek is the "control," it is not a "reference" stream. In this case, the number of EPT taxa in the 25th percentile in the fall in reference streams in the area (the Meramec basin) is eight. However, the reference streams are larger in size than the four streams noted above, and, all other things being equal, would be expected to have more taxa. Regardless, the relatively low number of taxa found in Shibboleth Branch, along with continued violation of the general water quality criteria, was cause enough to consider it impaired and Shibboleth Branch continued to be included on the 2002 303(d) List.

Since the first 303(d) listing of Shibboleth Branch, the department has developed a sediment protocol to determine if sediment is actually the pollutant of concern for listed streams. The first step of this protocol is a biological assessment to determine if the stream's biological community is showing signs of impairment.

The department's Environmental Services Program conducted a biological assessment and fine sediment study on Shibboleth Branch (both WBID 2120 and 2119) in the fall of 2008, spring of 2009, and fall of 2009 (MoDNR 2010d). The study included three sites on Shibboleth Branch and covered both classified segments (See Appendices A-1 and A-2). As illustrated in Table 3, Site E was on the furthest downstream segment, WBID 2119, and Sites D and B were on WBID 2120, the upstream, impaired segment on which this TMDL is written. Site B is the most upstream and is just below Bottom Diggins Dam, east of State Route E. Site D is downstream of Powder Spring Lake.

The department tested five stream sites within the Ozark/Meramec Ecological Drainage Unit (EDU) as reference streams ("EDU" is defined in Section 2.1). The five sampling sites are described in Table 4. Of these five streams, two, Shoal Creek and the West Fork of Huzzah Creek, were found to be fully supporting of aquatic life (i.e., meeting water quality standards), as

[9] "EPT" taxa are those three taxonomic Orders of aquatic insects (See Table 2) most intolerant of poor water quality.

measured by macroinvertebrate counts. As a result, data from these two streams serve as control sites for this TMDL.

Table 3. Department's Environmental Services Program's sampling sites (by Water Body ID) and seasons on Shibboleth Branch (MoDNR 2010d)**.**

	Site B	***Site D***	***Site E***
Season	**WBID 2120** (in the upper 0.5 mi)	**WBID 2120** (below Powder Spring Lake)	**WBID 2119** (lower of the two segments)
Sept. 2008		x	x
Spring 2009	x	x	x
Sept. 2009	x	x	

Table 4. Sampling sites in Shibboleth Branch and control streams.

Stream	***Site***	***Class***	***Lat/Long***	***Description/County***
Shibboleth Branch Site B	2120/2.3	C	38.0072/ -90.6988	NENENE S21, T38N, R3E/ Washington
Shibboleth Branch Site D	2120/0.3	C	38.0191/ -90.6668	SWNE S14, T38N, R3E/ Washington
Shibboleth Branch Site E	2119/0.5	P	38.0188/ -90.657	SWNW S13, T38N, R3E/ Washington
West Fork Huzzah Creek	1923/0.1	C	37.6346/ -91.2592	NWNW S22, T34N, R3W/ Dent
Shoal Creek	1934/6.3	P	37.8202/ -91.1372	NESW S22, T36N, R2W/ Crawford

Dominant macroinvertebrate families were cataloged, and the macroinvertebrate community was examined using Macroinvertebrate Stream Condition Index (MSCI) scores based on individual metric scores for each sampling station for the fall and spring seasons.

A Macroinvertebrate Stream Condition Index (MSCI) is a qualitative rank measurement of a stream's aquatic biological integrity (Rabeni *et al.* 1997). The MSCI was further refined for reference streams within each EDU in *Biological Criteria for Perennial/Wadeable Streams* (BIOREF; MoDNR 2002b), where comparisons are made between test streams and a BIOREF scoring range generated from data collected from wadeable/perennial reference streams. A station's MSCI score ultimately identifies the ability of the stream to support the beneficial use for the protection of warm water aquatic life and human health-fish consumption (AQL).

The MSCI score is a compilation of rank scores that were assigned to individual biological criteria metrics as a measure of biological integrity. Four primary biological criteria metrics were compared to respective BIOREF scoring ranges and were used to calculate the MSCI per station: 1) Taxa Richness (TR); 2) Ephemeroptera/Plecoptera/Trichoptera Taxa (EPTT); 3) Biotic Index (BI); and 4) Shannon Diversity Index (SDI). Metric scores are compared to the BIOREF scoring range (BIOREF Scoring Table) and rank scores (5, 3, 1) are assigned to each metric. Rank scores are compiled and the MSCI was completed for each station. The MSCI scores are interpreted as follows: 20-16 = full support of AQL; 14-10 = partial support of AQL; and 8-4 = non-support of AQL. Further information on this biometric scoring system can be found in Sarver *et al.* 2002.

Because Shibboleth Branch was generally smaller than the typical wadeable/perennial reference stream used to create the BIOREF criteria, the final scores represent metric evaluations generated for each season using only the similar size control streams. Comparing Shibboleth Branch to similar size control streams seemed more appropriate since there were concerns that the impairment assessment of upper Shibboleth Branch could have been due to unfair comparisons to the larger BIOREF streams.

MSCI scores were compared among stations and grouped by season (Tables 5, 6 and 7). Biological Criteria Metric Scores, Biological Support Category, and MSCI Scores are presented in Tables 5-7.

Table 5. Control Criteria Metric scores, Biological Support Category, and Macroinvertebrate Stream Condition Index (MSCI) scores using similar size stream criteria, Fall 2008.

Stream and Station No.	*Sample No.*	*TR*	*EPTT*	*BI*	*SDI*	*MSCI*	*Support*
Shibboleth Br. Site D	0804109	91	25	**5.9**	3.33	18	F
Shibboleth Br. Site E	0804108	90	24	**6.5**	3.08	18	F
Shoal Creek	0804110	82	22	**5.9**	3.11	18	F
W. Fk. Huzzah Cr.	0804116	82	24	5.1	3.56	20	F
Control Score=5	--	>75	>21	≤5.1	>2.97	20-16	**F**ull
Control Score=3	--	75-37	21-11	5.1-7.5	2.97-1.49	14-10	**P**artial
Control Score=1	--	<37	<11	>7.5	<1.49	8-4	**N**on

Control criteria MSCI Scoring Table (in light gray) developed from Control streams (n=6); TR=taxa richness; EPTT=Ephemeroptera, Plecoptera, Trichoptera Taxa; BI=Biotic Index; SDI=Shannon Diversity Index; **Bold**= not attaining optimum Control criteria score

Table 6. Control Criteria Metric scores, Biological Support Category, and Macroinvertebrate Stream Condition Index (MSCI) scores using similar size stream criteria, Spring 2009.

Stream and Station No	*Sample No.*	*TR*	*EPTT*	*BI*	*SDI*	*MSCI*	*Support*
Shibboleth Br. Site B	0930012	**69**	**18**	4.3	3.23	16	F
Shibboleth Br. Site D	0930006	97	30	**5.6**	3.47	18	F
Shibboleth Br. Site E	0930005	112	33	**5.8**	3.78	18	F
Shoal Creek	0930008	99	**23**	**5.6**	3.77	16	F
W. Fk. Huzzah Cr.	0930016	96	29	4.3	3.36	18	F
Control Score=5	--	>81	>26	<4.5	>3.00	20-16	**F**ull
Control Score=3	--	81-41	26-13	4.5-7.3	3.00-1.50	14-10	**P**artial
Control Score=1	--	<41	<13	>7.3	<1.50	8-4	**N**on

Control criteria MSCI Scoring Table (in light gray) developed from Control streams (n=6); TR=taxa richness; EPTT=Ephemeroptera, Plecoptera, Trichoptera Taxa; BI=Biotic Index; SDI=Shannon Diversity Index; **Bold**= not attaining optimum Control criteria score

Table 7. Control Criteria Metric scores, Biological Support Category, and Macroinvertebrate Stream Condition Index (MSCI) scores using similar size stream criteria, Fall 2009.

Stream and Station Number	*Sample No.*	*TR*	*EPTT*	*BI*	*SDI*	*MSCI*	*Support*
Shibboleth Br. Site B	0918402	76	**18**	**5.4**	**2.83**	**14**	P
Shibboleth Br. Site D	0918401	93	22	**6.3**	3.48	18	F
Control Score=5	--	>75	>21	<5.1	>2.97	20-16	**F**ull
Control Score=3	--	75-37	21-11	5.1-7.5	2.97-1.49	14-10	**P**artial
Control Score=1	--	<37	<11	>7.5	<1.49	8-4	**N**on

Control criteria MSCI Scoring Table (in light gray) developed from Control streams (n=6); TR=taxa richness; EPTT=Ephemeroptera, Plecoptera, Trichoptera Taxa; BI=Biotic Index; SDI=Shannon Diversity Index; **Bold**= not attaining optimum Control criteria score

Shibboleth Branch Site E, on the lower of the two segments, was found to meet water quality standards (i.e., "fully support") in both seasons it was sampled (fall 2008 and spring 2009), suggesting that the historic impairment did not extend downstream.

The lower of the two sites, D, the only site sampled three times, was found to be fully supporting of the standards in both spring and the two fall samples, suggesting no impairment. While the most upstream site, Site B, was found to be fully supporting of water quality standards in the spring of 2009 but only partially supporting in the fall of 2009. When the similar size control criteria were applied to data from the two Shibboleth Branch sample sites on the upper segment (WBID 2120), four out of five samples of macroinvertebrate data were found to be fully supporting water quality standards.

As mentioned previously, this newest data suggests that it is possible that stream size could have potentially affected the BIOREF MSCI scores in past analyses, and ultimately, the categorization of the creek as impaired. The small control streams had fewer TR, lower BI, lower SDI, and seasonally lower EPTT than the larger BIOREF streams used in past comparisons, which confirmed the suspected distinct difference based on size and validated the decision to use only comparisons to similar size streams.

4.2.2 Chemical and Physical Data

As mentioned in 4.2.1, the department's Environmental Services Program (ESP) conducted a biological assessment and fine sediment study on Shibboleth Branch in the fall of 2008, and spring and fall 2009 (MoDNR 2010d). Seasons in which each Shibboleth Branch site was sampled are summarized in Table 3 and site locations and descriptions are found in Appendix A. As mentioned in Section 4.2.1, Shoal Creek and the West Fork of Huzzah Creek were found to be fully supporting of aquatic life, and, as a result, data from these streams serve as control sites for this TMDL.

Estimates of fine sediment cover within the stream beds of Shibboleth Branch and the control streams were made using procedures described in Appendix B. Results are illustrated in Figure 5 and the complete data set is also found in Appendix B.

The report from the study revealed that the two most downstream sampling stations on Shibboleth Branch (below Powder Spring Lake; Appendix A-1, Sites D and E) had significantly ($p<0.05$) more fine sediment than the controls. However, the macroinvertebrates as these two sites were found to be fully supporting of water quality standards during both seasons and not apparently affected by high fine sediment. In the spring of 2009, the sampling site on the upper end of Shibboleth, upstream from Powder Spring Lake (Appendix A-1, Site B), did not have significantly more fine sediment coverage than the grouped control stations. However, fine sediment at the site was patchy, with some low flow areas having a greater than 90 percent cover. The site appeared to have a much higher percentage of sediment coverage in September of 2009, suggesting that sediment deposition may fluctuate seasonally at this station and affect the macroinvertebrate community. It was suggested that fine sediment periodically moves through the station, removed due to the relatively steep gradient. Although Shibboleth Branch just below State Route E is usually only four to six feet wide, it takes on enough runoff that at times its width will swell to over 30 feet (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 9, 2009). This fact may explain the inconsistency in measurable sediment deposition at the uppermost site since periodic high water levels are likely to flush existing depositions further downstream. The fluctuations in the amount of fine, inorganic sediment at

Site A could have altered the macroinvertebrate community and thus affect the stream's ability to support the aquatic life designated use. However, the presence of taxa considered intolerant to fine sediment found at Site A suggests that fine sediment alone may not be the consistent source of the stream's impairment (MoDNR 2010d).

During the study, it was also observed that the tributaries of Mill Creek that had been deemed impaired, including Shibboleth Branch, were the smallest of the streams in the study and usually had lower discharge (i.e., flow) than all other tributaries and controls. The lower observed discharge for these streams is due to the smaller area of these streams' watersheds. In the report, it was concluded that low flow alone, or in combination with other factors (such as concentrations of metals in the pore water or interstitial spaces) may have contributed to the assessment that upper Shibboleth Branch (specifically the sites above Powder Spring Lake), was impaired (MoDNR 2010d).

The department measured barium, cadmium, lead and zinc in both the water column and sediment pore water at the three Shibboleth Branch sampling sites and in the control streams. The level of metals found in the water column did not exceed their associated water quality criteria (See Appendix A-2 and 10 CSR 20-7.030 Table A) at any of the Shibboleth Branch sites. Presence of these dissolved metals is evidence of continuous input of mine-related metals in the tributaries to Mill Creek, however, the study did not find particular metals or outstanding concentrations only in the impaired tributaries, such as Shibboleth Branch, but also in the control streams. Because concentrations of metals in the water column were low and not exclusively found in impaired tributaries, they were not obvious contributors to the impairment.

However, an examination of pore water in the sediment revealed different results. Levels of cadmium, lead and zinc in sediment pore water were compared to Probable Effects Concentrations (PECs) and Threshold Effect Concentrations (TECs) for these metals.

The PEC is the level of a contaminant above which harmful effects are likely to occur and is considered an accurate basis for predicting sediment toxicity (MacDonald *et al.* 2000). The fine sediment at the two sampling sites on upper Shibboleth Branch (Sites D and B) contained high levels of lead and zinc above Probable Effects Concentrations. Although these metals were also found in fine sediment in the unimpaired tributaries of Mill Creek, the controls streams' levels were not above PECs. This suggests that the high levels found in Shibboleth Branch are not naturally occurring or background levels but are instead due to mining activity.

Pore water in the sediment was also analyzed relative to Threshold Effect Concentrations (TECs). The TEC is the concentration of a substance below which adverse effects are not expected to occur. As such, TECs can provide an accurate basis for predicting the absence of sediment toxicity. The results of the TEC comparisons are summarized in Table 8. The results from Shibboleth Branch indicate excursions over existing sediment quality guidelines for lead and zinc at all three sites (i.e., on both WBID 2119 and 2120), and over existing cadmium sediment quality guidelines for the uppermost segment (WBID 2120). This is because, in the absence of promulgated numeric criteria for these metals in sediment, these concentrations exceed the consensus TECs (MacDonald *et al*. 2000).

The collective impact of the metals stressors, along with flow and fine sediment, are likely causing the impairment of Shibboleth Branch.

Figure 5. Boxplots of fine sediment observations in Shibboleth Branch and control streams. (Boxes indicate 25th, 50th and 75th percentiles, lines extend to 0th and 100th percentiles, and "*" indicate outliers.)

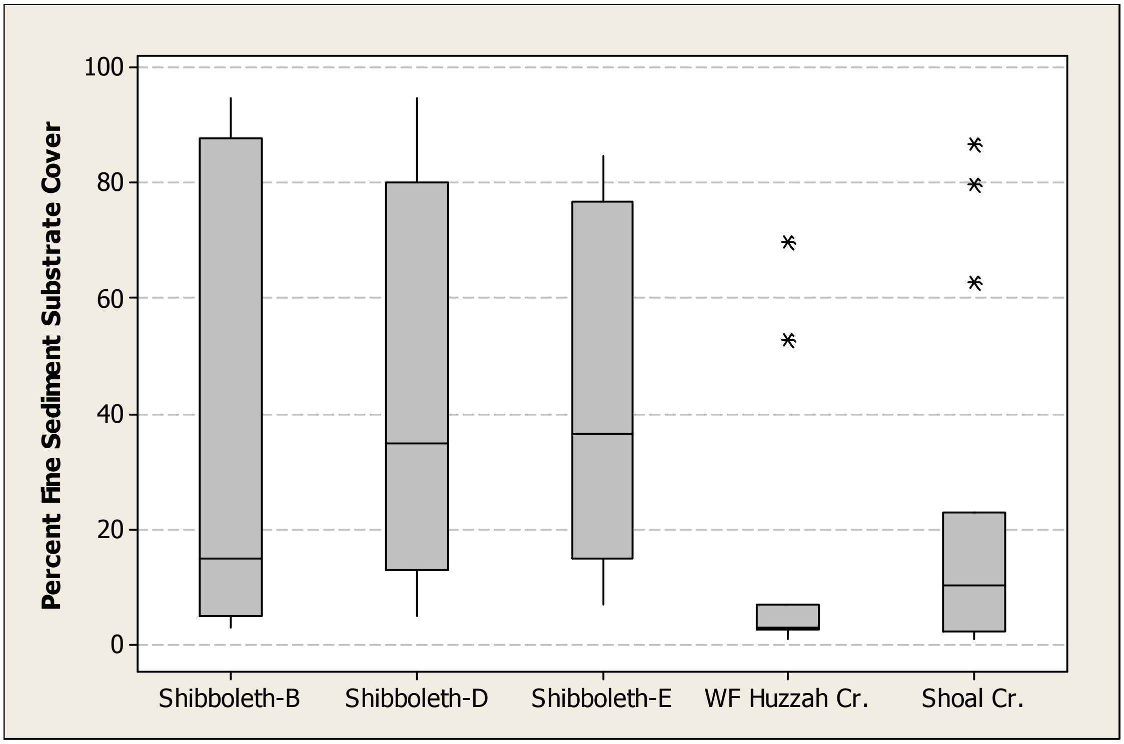


Table 8. Concentration of barium and heavy metals in the sediments of Shibboleth Branch and control streams and threshold effect concentrations for aquatic life (mg/kg).

Sample Location	*Barium*	*Cadmium*	*Lead*	*Zinc*
Shibboleth Branch Site B	2890	0.638	836	697
Shibboleth Branch Site D	2350	0.544	246	845
Shibboleth Branch Site E	428	9.52	607	553
W Fk Huzzah Creek	21.6	0.100	10.8	9.5
Shoal Creek	15.7	0.169	15.9	45.4
Threshold Effect Concentration	--	0.99	35.8	121

4.3 Equilibrium Partitioning Methodology

Department staff prepared the TMDL with regard to potential instream concentrations of cadmium, lead and zinc in water as a surrogate for metals and sediment. This was done by developing a bedded sediment relationship between mass of sediment and mass of these metals in that sediment. Like other states, Missouri has not developed numeric criteria for bedded sediment. In order to understand the extent to which sediment toxicity could be contributing adverse effects to the aquatic environment in the Shibboleth Branch watershed, equilibrium partitioning methodology was applied (USEPA 1999) to assess the levels of contamination from lead and cadmium. This procedure involves a number of simplifying assumptions described below. Because lead and cadmium follow well-defined partitioning behavior between pore water and sediment, measured lead and cadmium in sediment were used to estimate potential exposures in the water column based on equilibrium partitioning principles. These principles generally state that when a metal resides in sediment, it exists in equilibrium with pore water, and when physical-chemical properties are known, the partitioning behavior of the metal between the solid (sediment) and aqueous (pore water) phase can be predicted (Hansen *et al.* 2005). Pore water is important because it is known that the majority of toxicity from dissolved lead and cadmium in an aquatic environment occurs in pore water.

Following this procedure, measured lead and cadmium in sediment data were used to back-calculate pore water concentrations. Estimated pore water concentrations for the purposes of the TMDL development may then be compared to the hardness-dependent criteria promulgated by the department. Pore water concentrations are estimated by applying the following equation:

Equation 1: $[\text{metal}]_{pw,\ \mu g/L} = [\text{metal}]_{sed,\ mg/kg}/(K_{d,mL/g})*(1{,}000\ \mu g/mg)$

where $[\text{metal}]_{pw}$ is the pore water concentration, $[\text{metal}]_{sed}$ is the metal in sediment concentration and K_d is the distribution coefficient.

Based on "Partition Coefficients for Lead" from EPA (USEPA 1999), a polynomial relationship existed between the K_d value and soil pH measurements as follows:

Equation 2: $(K_{d(Pb),\ mL/g}) = 1639 - 902.4(\text{pH}) + 150.4(\text{pH})^2$

In addition, the relationship between the K_d value and equilibrium concentrations of lead at a fixed pH can be expressed as:

Equation 3: $(K_{d(Pb),\ mL/g}) = 9{,}550\ C^{\ -0.335}$

where C is the equilibrium concentration of lead in µg/L.

For cadmium, an estimation of pore water concentration is derived using a similar approach:

Based on "Partition Coefficients for Cadmium" from the same publication (USEPA 1999), the relation between the K_d for cadmium and pH is best described in a linear fashion:

Equation 4: $\log_{10} [K_{d(Cd)}] = -0.54 + 0.45(\text{pH})$

EPA (USEPA 1999) provides look-up tables for the estimated range (i.e., maximum and minimum) of K_d values for lead as a function of soil pH and equilibrium concentrations, and for cadmium as a function of pH using the above equations. Equivalent relationships for zinc have not been calculated at this time.

Tables 9 and 10 present K_d values for lead and cadmium. Values for sediment pore water pH are not known. However, the Tiff soil, from which the stream sediment substantially originates, tends to range from neutral to acidic. Values for pH range from 4.5 to 7.3 (USDA NRCS 2005). Potential pore water concentrations for lead in Shibboleth Branch range from 49.5 to 5,573 µg/L. In the control streams, potential pore water concentrations range from 2.2 to106 µg/L.

Water column samples that were analyzed for dissolved lead all yielded concentrations of less than 1 µg/L (See Appendix A-2), which indicates a probability of low interaction between pore water and surface water. However, elevated pore water concentrations of heavy metals represent significant risks for benthic organisms (Hansen *et al.* 2005, Besser *et al.* 2009).

Table 11 lists final chronic values (FCV) for water quality criteria for the development of interstitial water benchmarks (Hansen *et al.* 2005). It should be noted that potential toxicity from metals in pore water is dependent not only on hardness and pH, but also on the mixture of sediment metals and bio-availability of these metals as affected by the amount of organic matter within the sediment. Benchmarks for individual metals cannot be conclusively determined without consideration of the other metals present (Hansen *et al.* 2005).

Table 9a. Estimated pore water concentrations (C_{pw}) for lead at pH 4.0-6.3.

Site	Sediment Concentration (mg/Kg)	Assumed Equilibrium Conc. (µg/L)	Max Kd Value (mL/g)	Min Kd Value (mL/g)	Estimated C_{pw} based on Max Kd (µg/L)	Estimated C_{pw} based on Min Kd (µg/L)
Shibboleth Branch Site B	836†	10-99.9	1,850	190	451.9	4,400
		100-200	860	150	972.1	5,573
Shibboleth Branch Site D	246†	10-99.9	1,850	190	133.0	1,295
		100-200	860	150	286.0	1,640
Shibboleth Branch Site E	607†	10-99.9	1,850	190	328.1	3,195
		100-200	860	150	705.8	4,047
W Fk Huzzah Cr	10.8	10-99.9	1,850	190	5.8	56.8
		100-200	860	150	12.6	72.0
Shoal Cr	15.9	10-99.9	1,850	190	8.6	83.7
		100-200	860	150	18.5	106.0

Note: C_{pw} = pore water concentration
† exceeds the freshwater Threshold Effect Concentration for lead of 35.8 mg/Kg

Table 9b. Estimated pore water concentrations (C_{pw}) for lead at pH 6.4-8.7.

Site	Sediment Concentration (mg/Kg)	Assumed Equilibrium Conc. (µg/L)	Max Kd Value (mL/g)	Min Kd Value (mL/g)	Estimated C_{pw} based on Max Kd (µg/L)	Estimated C_{pw} based on Min Kd (µg/L)
Shibboleth Branch Site B	836†	10-99.9	4,970	900	168.2	928.9
		100-200	2,300	710	363.5	1,177
Shibboleth Branch Site D	246†	10-99.9	4,970	900	49.5	273.3
		100-200	2,300	710	107.0	346.5
Shibboleth Branch Site E	607†	10-99.9	4,970	900	122.1	674.4
		100-200	2,300	710	263.9	854.9
W Fk Huzzah Cr	10.8	10-99.9	4,970	900	2.2	12.0
		100-200	2,300	710	4.7	15.2
Shoal Cr	15.9	10-99.9	4,970	900	3.2	17.7
		100-200	2,300	710	6.9	22.4

Note: C_{pw} = pore water concentration
† exceeds the freshwater Threshold Effect Concentration for lead of 35.8 mg/Kg

Table 10. Estimated pore water concentrations for cadmium.

Site	Sediment Concentration (mg/Kg)	Kd (mg/g)		Estimated Pore Water Concentration (µg/L)	
		pH 4.5	pH 7.3	pH 4.5	pH 7.3
Shibboleth Br. B	0.638	30.549	555.904	20.9	1.1
Shibboleth Br. D	0.544			17.8	1.0
Shibboleth Br. E	9.52†			311.6	17.1
W Fk Huzzah Cr	0.1			3.3	0.2
Shoal Cr	0.169			5.5	0.3

† exceeds the freshwater Threshold Effect Concentration for cadmium of 0.99 mg/Kg

Table 11. Water quality criteria final chronic value (FCV) for deriving equilibrium sediment benchmarks based on dissolved metal concentrations in interstitial water (µg/L).

Metal	Formulae	Hardness (mg $CaCO_3$/L)		
		50	100	200
Cadmium	$[e^{(0.7409*\ln(Hardness) - 4.719948)}] * (1.101672 - (\ln(Hardness)*0.041838))$	0.15	0.25	0.40
Lead	$[e^{(1.273*\ln(Hardness) - 4.704797)}] * (1.46203 - (\ln(Hardness)*0.145712))$	1.2	2.5	5.3
Zinc	$[e^{(0.8473*\ln(Hardness) + 0.785271)}] * 0.986$	59.5	107.0	192.6

5. SOURCE INVENTORY AND ASSESSMENT

TMDL source assessment characterizes known, suspected and potential sources of pollutant loading to the impaired water body. Pollutant sources identified within the watershed are categorized and quantified to the extent that information is available. Sources of inorganic sediment may be point (regulated) or nonpoint (unregulated) in nature.

5.1 Point Sources

The term, point source, refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the federal National Pollutant Discharge Elimination System (NPDES). Both the federal and Missouri clean water law prohibit the discharge of pollutants into waterways of the United States without a NPDES-type permit. In Missouri, the department's Water Protection Program Water Pollution Control Branch issues Missouri State Operating Permits to regulate discharges from point sources. In addition, the department's Water Resources Center Dam and Reservoir Safety Program holds permit registrations on dams within their jurisdiction, including some in the Shibboleth Branch watershed.

5.1.1 Permits-Water Program

There are currently no Water Protection Program-permitted dischargers (facilities, stormwater outfalls or CAFOs[10]) within the Shibboleth Branch watershed that cause or contribute inorganic sediment to the impaired segment. However, active and abandoned mine areas can be classified as point sources due to the nature of mining and milling activities, regardless if they are currently covered by a discharge permit (USEPA 1993a). The Cimbar Performance Materials, Dresser Industries, and other abandoned mine land areas in the watershed may therefore collectively be considered a point source even though there is no longer a State Operating Permit issued in the watershed. On past 303(d) lists, the source of Shibboleth Branch's impairment was identified as "barite tailings pond" (i.e., Bottom Diggins Lake and Dam). However, as discussed in Section 5.1.2.1, improvements to the Bottoms Diggins Dam led to a change on the 2008 303(d) List's identified source of Shibboleth Branch's impairment to a more general source, "mill tailings (abandoned)." As a result, this TMDL includes an assessment of each dam in the watershed as to its past and current department-permitted status, as well as its condition and stability.

As detailed in Section 2.5, a barite mining company held a site specific State Operating Permit (MO-0000221) with the department for this area (just northwest of Cadet, Missouri) from 1976 until June 4, 2004, when the permit was terminated. There were four main barite mine tailings dams in the Cadet area associated with the permitted operation: Bottom Diggins Dam, which

[10] CAFOs are concentrated animal feeding operations.

was constructed across the headwaters of Shibboleth Branch itself, and Cadet Dams #1, #2 and #3 (See Figure 1). Department records note several complaints regarding the suspended clay in the discharge water entering Shibboleth Branch in the late 1970s and early 1980s. Only Bottom Diggins, Cadet #1 and #2 dams existed above Powder Spring Lake during that time period.

Although Bottom Diggins had not been used to facilitate barite mining since 1957, trespassers, especially those on all-terrain vehicles (ATVs), continued to enter the property, regardless of chains and signs. Unsanctioned vehicle traffic across the dam and spillway resulted in substantial erosion on the spillway itself and resulting continuous contributions of sediment to Shibboleth Branch (Donald Smith, Cimbar Performance Minerals, personal communication, April 6, 2010). As detailed in Section 5.1.2.1 later in this document, the 1996 relocation of the spillway solved that problem.

Until 1992, when Cadet #3 was built, Cadet #2 discharged into a ditch which found its way to Shibboleth Branch. And, although the Cadet Dam #1 itself was mainly within the Shibboleth Branch watershed, it discharged into the Cadet Creek watershed rather than to Shibboleth Branch (Donald Smith, Cimbar Performance Minerals, personal communication, April 6, 2010), leaving only Bottom Diggins and Cadet #2 dams as the only point sources that could have been possibly linked to the various complaints. However, nonpoint sources, such as local roads (See Section 5.2) may well have contributed to, or exacerbated, the problem if incidents were associated with heavy rainfall.

A general permit, MO-G490947, was issued to Cimbar Performance Minerals on Oct. 6, 2006, for their area in NE¼, NE¼, S32, T38N, R3E, Washington County. The intention of the Water Pollution Control Program was to allow Cimbar, who had ceased mining this area in 1999, to change their site specific permit to a general permit. The four dams in the Shibboleth Branch watershed, which were formerly covered by MO-0000221, no longer serviced active mining and were not included in the new general permit. The permit was issued to cover activities at Cimbar's local headquarters located approximately 1.5 miles south of the Cadet dams and expires Oct. 5, 2011. The facility is a dry grinding plant using no water. Barite processed at this facility is imported from outside Missouri rather than mined locally (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 9, 2009). The receiving stream listed in the general permit is an unnamed, unclassified tributary to Fountain Farm Branch, a Class C stream (WBID 3657), which is a tributary to Mill Creek upstream (south) of the Shibboleth Branch/Mill Creek confluence. Because the area covered under this permit is not within the Shibboleth Branch watershed, it is not considered a contributor to the stream's impairment.

In summary, the four dams (See Figure 1) formerly associated with the barite mining activities are no longer permitted through the department's Water Protection Program's State Operating Permit system. While barite mining activities have ceased and the area is no longer permitted by the department, the entire barite mining area is considered a point source of the pollutants of concern. However, inclusion the point source and wasteload allocation section of the Shibboleth Branch TMDL does not permit the area to discharge.

5.1.2 Permits - Dam and Reservoir Safety Program

5.1.2.1 Bottom Diggins Dam

Bottom Diggins Dam (Dam Safety ID No. MO 30750; Registration Permit No. R-431) is 41 feet in height, approximately 1,500 feet long, and currently impounds a 33-acre lake in the headwaters of Shibboleth Branch. The dam is located less than two miles northwest of the town of Cadet, Missouri. The dam embankment was built in 1944 to impound water to be used for wash water and a settling basin to support the local barite mining operation. The records are not clear as to who owned the property at the time the dam was built, but it was likely National Lead Company, NL Industries, or NL Baroid. The property was part of the 4,700 acres owned and sold by Halliburton Energy Services to a private developer in 2002.

As mentioned in Section 5.1.1, historically, the spillway was constantly being driven over by ATVs and other vehicles, and was eroding. In addition, the spillway's location in relation to wash water discharge into the lake created a water circulation pattern that allowed suspended tailings fines to go over the spillway with overflowing water. The eroding spillway gave concern to the department's Dam and Reservoir Safety Program, and, as per the department's direction, the mining company filled in the old spillway channel at the left (north) end of the dam and constructed a new open channel spillway on the right (south) abutment[11] in late 1996. The new spillway was located in an area that was not a "through traffic" area, as it had been before, so no longer supported constant vehicle traffic (Glenn Lloyd, the department's Dam and Reservoir Safety Program, personal communication, Nov. 6, 2009). During a January 1997 inspection, department staff found that the channel had been relocated in accordance with the approved plans and specifications and a small riprap-lined channel was inset into the main channel to pass the base flow without eroding the channel. As a result of successfully passing inspection, Cimbar received confirmation in a letter dated Jan. 29, 1997, that the registration permit had been issued and was valid through Jan. 29, 2000 (Alexander and Clay 1997).

The dam remained registered through time and was recertified and registered by Dam and Reservoir Safety Program engineers in January 2008 after needed repairs, identified during their April 2006 inspection, were addressed. The April 2006 inspection summary read as follows:

> The Bottom Diggins Dam is a barite tailings embankment with a principal spillway. The embankment was constructed by dumping coarse waste material produced in the barite mining process on the embankment. This material consists of fine- to medium-sized gravel, with occasional coarse gravel and boulders. The lake stores fine tailings produced in the washing process. The fine tailings typically consist of very soft, high plasticity clays. The embankment is approximately 1500 feet long and 41 feet high. The spillway is an open channel on the right abutment of the dam (Clay 2006).

As a result of successful recertification, the dam was reregistered and permitted (Registration Permit No. R-431) through January 25, 2011 (Alexander 2008). Photos taken during the last two inspections revealed that the downstream face of the dam was well vegetated and unlikely to be a major source of erodible fine clays. The department believes Bottom Diggins Dam, identified on the 1998 303(d) List as the source of Shibboleth Creek's impairment, is no longer a contributing source of the impairment based on the following facts:

- Mining and the associated tailings washing stopped in 1957.
- The original earthen spillway on the north side of the dam was redesigned and relocated to the south side, and has been deemed stable.

---

[11] The USGS's National Hyrdrography Data Set (NHD), on which the department's Water Quality Standards are based, does not yet reflect the relocation of the spillway. As a result, lines in the 1:24,000 NHD layer reflect the spillway and stream below the dam as it was prior to spillway relocation (See Figure 1). However, notification of this change has been included on the list of such corrections the department is assembling for USGS.

- Photographs taken during recent inspections by the Dam and Reservoir Safety Program revealed a fairly well-vegetated (non-woody vegetation) downstream dam face and inspection noted clear water seepage.

As a result, on Missouri's 2008 303(d) List, the source of the inorganic sediment impairment for Shibboleth Branch has been changed from "Barite Tailings Pond" to "Mill tailings (Abandoned)."

5.1.2.2 Cadet Dam #1

Cadet Dam #1 (Dam Safety ID No. MO 30704; Registration Permit No. R-444; expiration date: Oct. 30, 2012) is approximately 53 feet in height and 3500 feet long, and has approximately 13 surface acres of water storage. This dam can be easily seen to the east of State Route E, north of Highway 47 and south of Powder Spring Lake Road (County Road 419; See Figure 1). This dam passed inspection by Dam and Reservoir Safety Program staff on July 28, 2009. The inspection report notes no observed defects, and the "embankment and appurtenant structures appeared to be in good overall condition at the time of the inspection, with no indications of slope instability or excessive seepage."

5.1.2.3 Cadet Dam #2

Cadet Dam #2 (Dam Safety ID No. MO 31830; Registration Permit No. R-326, currently expired) is approximately 77 feet in height and 3500 feet long, and has approximately 20 surface acres of water storage. The embankment has both a principal and an auxiliary spillway, the former being a hardened pipe within a box. The auxiliary (i.e., emergency) spillway is on the west side of the dam and Donald Smith with Cimbar Performance Minerals, reports that he has never seen water top it. Instead, water flows through the principal spillway on the east side of the dam, and as mentioned previously in this document, discharges into the area impounded by Cadet Dam #3. The current owner's home is on the southeast corner of the intersection of State Route E and Powder Spring Lake Road, below the dam. The dam curves east from there and butts up against Cadet Dam #3. In a June 26, 2009 e-mail, Robert Clay, Chief Engineer for the department's Dam and Reservoir Safety Program, conveyed the status of Cadet Dam #2 recertification as follows:

> We are not sure if the dam currently meets our spillway capacity criteria. We will have to do some additional surveying and engineering analysis to resolve this. I have put this on the back burner for the last few months because we were short staffed and had more urgent situations to deal with. I don't believe the dam poses an imminent risk to anyone, even if it were to overtop. Our staff needs to do some additional surveying, but I believe the spillway capacity problem will be relatively easy to fix. [We will get back to] Cadet #2 in the future.

As of late March 2010, the registration status of Cadet Dam #2 remained unchanged (Robert Clay, the department's Dam and Reservoir Safety Program, e-mail communication, March 26, 2010).

5.1.2.4 Cadet Dam #3

Cadet Dam #3 (Dam Safety ID No. MO 30707; Registration Permit No. R-372 – expiration date, Oct. 30, 2012) is 74 feet in height and 2600 feet long, and has approximately 27 surface acres of water storage. It passed an inspection by Dam and Reservoir Safety Program staff on July 28, 2009. The inspection report notes no observed defects, and the "embankment and appurtenant structures appeared to be in good overall condition at the time of the inspection, with no indications of slope instability or excessive seepage." Brush and woody vegetation had been cleared off the downstream dam face as directed during the previous inspection. Based on 2009 site visits, department staff believe that the seep water coming through these dams is not contributing to the continued impairment of Shibboleth Branch.

5.1.3 Additional Pollutant Sources Associated with Abandoned Mine Areas

In addition to the point sources of inorganic sediment described above, pollutant sources associated with present and historic abandoned mine areas could be causing or contributing to the impairment of Shibboleth Branch. These areas include stormwater runoff from public and private roads and driveways, home construction sites, and any areas where local soils are barren of vegetation.

The most likely possible pollutant sources of inorganic sediment entering Shibboleth Branch include:

- Local "Tiff" soil series
- Washington County roads
- Home building south of Bottom Diggins Lake

Local Tiff soil series
As discussed in Section 2.4, the headwaters of Shibboleth Branch incise the Tiff soil series, which consists of very deep (over 60 inches), well-drained, moderately permeable soils that formed clayey residuum on uplands (See Figure 3a). These deep, red soils are ubiquitous in the area, and regardless of past mining activity, provide a continuous source of erodible material. A certain amount of sediment enters the stream naturally due to normal fluvial processes and accounts for a natural background level of inorganic sediments. The nature of this soil, and its availability for deposition into Shibboleth Branch, is evident in the streambanks, as illustrated in Figure 4, a photograph of the streambank upstream of Powder Spring Lake. Because these soils have a composition similar to that of the barite mine tailings found within the watershed, and could be historic mine tailings in and of themselves, the local Tiff soil series and mine tailings are treated the same with respect to pollutant loading under the wasteload allocation.

Washington County roads
Many of the local roads in the watershed, whose associated ditches eventually drain into Shibboleth Branch, remain unpaved. These roads are built of local soils and materials, much of which is vulnerable to erosion, which are potentially sourced from abandoned mine tailings and Tiff soils. Powder Spring Lake Road, which runs along the south side of Shibboleth Branch upstream from Powder Spring Lake (See Figure 1), was blacktopped five or six years ago (Donald Smith, Cimbar Performance Minerals, personal communication, Nov. 9, 2009). The road ditches can carry locally eroded soil material from the roads themselves, as well as from any local land disturbance activities (e.g., home construction), directly to Shibboleth Branch. Regardless of whether or not the roads are surfaced, periodic county road maintenance includes opening up the ditches that run along both sides of the roads. The county does this by cutting deep into the ditch and turning the collected red clays up onto the outside top edge of the ditch (Todd Moyers, Washington County Commissioner, personal communication, March 17, 2009). This practice succeeds in temporarily opening up the ditches to facilitate handling stormwater off road surfaces and is a necessary and unavoidable road maintenance practice. Although the majority of the removed material is trucked away, it exposes freshly turned over deposits of clay soils to stormwater erosion and may serve as another source of this material. In addition, historically, either private or public entities were known to sometimes "mine" the downstream

faces of some of the old barite dams in the county for use on private or public roads (Robert Clay, the department's Dam and Reservoir Safety Program, personal communication, June 26, 2009). Aside from the obvious possibility of destabilizing the dam, this practice may expose deeper layers of materials in the dam that may contain clay fines vulnerable to erosion by precipitation.

Residential home building south of Bottom Diggins Lake
As noted in Sections 2.5 and 5.2.2, since the land in this mining area was sold to private concerns starting in 2004, at least eight new homes are reported to have been built in the Shibboleth Branch headwaters, many of which were built south of Bottom Diggins Lake. Construction is evident in the 2009 aerial photo used as a base for Figure 1. If appropriate best management practices (BMPs) were not, or are not, used to control soil erosion at building sites, these activities could contribute to the impairment of Shibboleth Branch. Activities at these building sites are considered nonpoint sources as they were, or are, assumed to be less than one acre in size and therefore not covered by the department's general land disturbance permit. However, because these areas disturb or redisturb areas covered by abandoned mine areas or the Tiff soil series, these areas are included in the point source wasteload allocation portion of the TMDL.

Regardless of current home building and road maintenance practices, the fundamental source of the Shibboleth Branch inorganic sediment impairment seems to be the existing, ubiquitous soil type that is similar in composition to barite mine tailings that is prone to erosion and transport.

5.1.4 Point Sources Summary

The primary cause of the inorganic sediment impairment to Shibboleth Branch was originally identified on Missouri's 303(d) lists as the eroding spillway on the left embankment of Bottom Diggins Dam. However, since the problem spillway was relocated to the right embankment and redesigned in 1996, and mining and the associated barite washing ceased in the watershed by 1999, abandoned mine lands are currently thought to be the primary contributors to the continued impairment.

Although often without extensive vegetative cover, the barite tailings dams themselves are not necessarily, in their entirety, a source of the sediment that impairs downstream water bodies. Mining ceased in this area 10 years ago and the undisturbed coarse material on the dams' surfaces has long had the fine clays weathered from its matrix (See Figure 6). However, the downstream dam faces are steep enough to make them constantly vulnerable to erosion, especially when the coarse surface material is in any way penetrated exposing the finer material beneath.

As described in the preceding sections, abandoned barite mine areas and the ubiquitous Tiff soil series are considered the primary source of inorganic sediment loading resulting in the impairment of Shibboleth Branch. Because historic distributions of abandoned mine areas and the Tiff soil series cannot be definitively determined, these areas are collectively lumped into the point source wasteload allocation portion of the TMDL. In addition, any activities within the watershed that may disturb, redisturb, redistribute or reuse either the barite mine tailings or Tiff soils will be considered to be part of the point source wasteload allocation for TMDL purposes.

5.2 Nonpoint Sources

Nonpoint source pollution refers to pollution coming from diffuse, non-permitted sources that typically cannot be identified as entering a water body at a single location. They include all other categories of pollution not classified as being from a point source, and are exempt from department regulation as per State rules at 10 CSR 20-6.010(1)(B)2.

Nonpoint sources of pollution that have the potential to influence water quality in streams typically include onsite wastewater treatment systems, various sources associated with runoff from urban and agricultural areas, and riparian corridor conditions. However, as described in the following sections, each of these sources is expected to have little impact on pollutant loading to the impaired segment since the inorganic sediment in question is the result of historic mining (point source) activities within the watershed.

5.2.1 Onsite Wastewater Treatment Systems

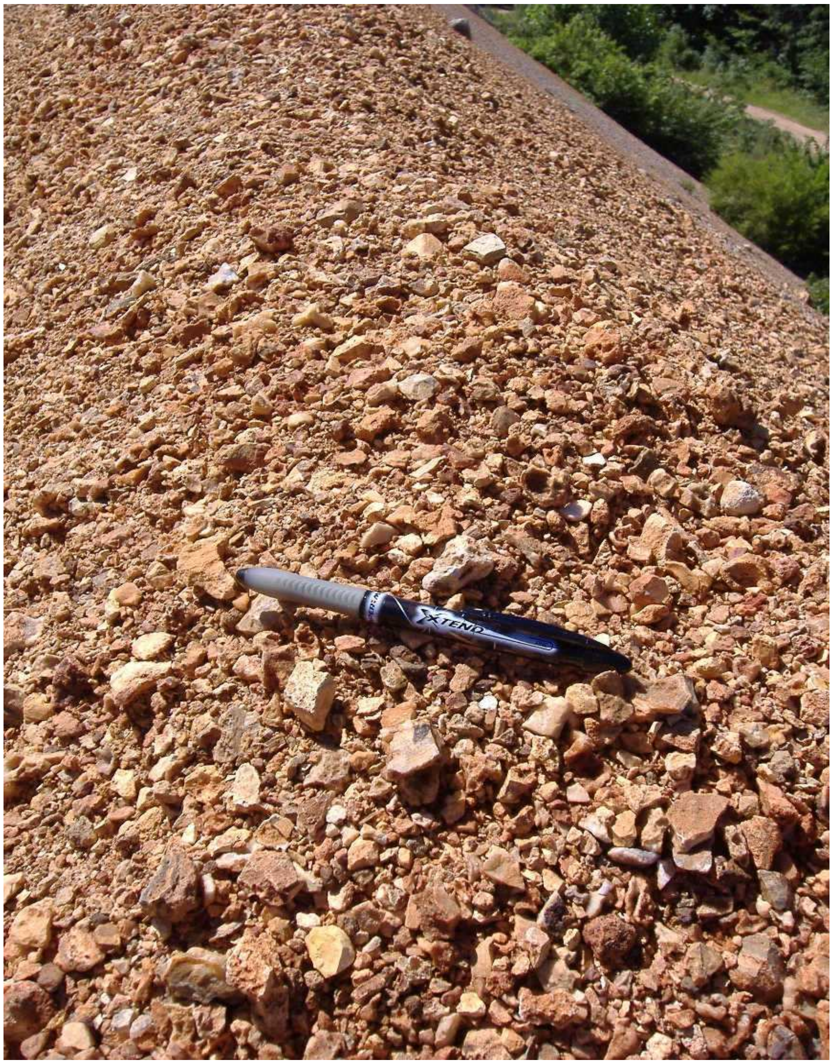
The department does not have the authority to regulate onsite wastewater treatment systems (e.g., individual home septic systems) and they are not covered through the department's NPDES permitting system. As a result, they are considered potential "nonpoint" sources of pollution. When onsite wastewater treatment systems are properly designed and maintained, they should not serve as a source of contamination to surface waters; however, onsite wastewater treatment systems do fail for a variety of reasons. When these systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration), there can be adverse effects to surface water quality. Failing septic systems are sources of nutrients that can reach nearby streams through both surface runoff and ground water flows. However, they are not known to be large contributors of inorganic sediment to local streams. Therefore, nonpoint source loading from onsite wastewater treatment systems is insignificant and will not be addressed in this TMDL.

5.2.2 Runoff from Urban Areas

Stormwater runoff from urban areas can be a significant source of inorganic sediment. The land use map for the Shibboleth Branch watershed (Appendix A) does portray 4 percent of the land use being urban, but this is currently not the case. The available land use layer (MoRAP 2005), used to create the map in Appendix A, portrays the area as it was sometime between 2000 and2004 and does not match the 2009 aerial photograph of the area (partially represented in Figure 1). The largest urban area on the land use map is illustrated in grey just northwest of the former Dresser #4 tailings pond. Even though barite mining in this area had stopped by 1999, it is possible that, in the early 2000s, this area might still have included the buildings and processing areas that formerly supported local mining. If that was the case, it could explain why this area was digitally lumped into an "urban" land use category. It is also possible that these old mined areas were mistakenly interpreted as paved urban areas during digital land use interpretation. Detailed examination of an aerial photo taken of this alleged urban area in 2009 reveals woodland, a few roads, a few houses, grassland and some barren areas. Even if roads and houses were being lumped into an "urban" land use, only a small fraction of this particular urban area portrayed on the map west and north of old Dresser #4, would actually be considered an urban land use. As a result, it is likely that considerably less than 4 percent of the watershed's land use currently supports an urban use. As such, it is unlikely that stormwater from the majority of urban land use in the watershed is contributing to the inorganic sediment impairment.

It is, however, possible that a contribution of inorganic sediment to Shibboleth Branch may come from the "home" component of the urban land use category, especially during the construction phase. As noted toward the end of Section 2.5, since the land in this mining area was sold to private concerns starting in 2004, at least eight new homes are reported to have been built, especially concentrated south of Bottom Diggins Lake in the Shibboleth Branch headwaters.

Figure 6. East end of Cadet Dam #3, looking northwest. Note Heritage Road in upper right hand corner (photograph taken Aug. 11, 2008)**.**



On-going or recent construction and disturbance is evident in the 2009 aerial photo used as a base for Figure 1. If erosion was not actively checked during construction through adoption of best management practices, a considerable amount of inorganic sediment could have, or could continue to be, entering Shibboleth Branch from these areas. In either case, however, inorganic sediment from this source would be considered point source loading given the nature and distribution of the local Tiff soils and barite tailings in the area.

5.2.3 Runoff from Agricultural Areas

Another potential source of the inorganic sediment impairment to Shibboleth Branch is runoff from agricultural nonpoint sources. Anywhere land is exposed, soil is vulnerable to erode and can be carried by stormwater into a stream, resulting in increased turbidity and inorganic sediment concentrations. Cropland is particularly vulnerable to erosion. However, since only 1.7 percent (95 acres) of land use in the watershed is in cropland, it is not believed to be a significant contributor to the inorganic sediment impairment of Shibboleth Branch.

Although there are no state-permitted concentrated animal feeding operations in the watershed, the presence of lower density livestock populations must be considered as a possible source of the inorganic sediment load in Shibboleth Branch. Livestock tend to concentrate near feeding and watering areas causing those areas to become barren of plant cover, thereby increasing the possibility of erosion during a storm event (Sutton 1990). For these reasons, overland runoff during rain events can easily carry inorganic sediment to the stream from any areas made barren by livestock related activities.

Countywide data from the National Agricultural Statistics Service (USDA NASS 2009) were combined with the size of the Shibboleth Branch watershed to estimate that there could be up to 380 cattle in the watershed[12]. The cattle that exist are most likely located on the approximately 1,373 acres (24 percent of land use) of grassland and pastureland in the watershed. Even though a pasture may be relatively large and animal densities low, animals will often concentrate near the feeding and watering areas in the field. These areas can quickly become barren of plant cover, increasing the possibility of erosion and soil runoff during a storm event. However, the estimated density of 0.28 cattle per acre (177 cattle per square mile) in the watershed is not an excessive grazing rate based on an average recommended stocking density for Missouri of 0.25 cattle per acre (Mark Kennedy, State Grazing Land Specialist, Natural Resources Conservation Service, personal communication, Nov. 30, 2009). Grazing densities recommended in Missouri by the USDA's Natural Resources Conservation Service and the department's Soil and Water Conservation Program are those that keep soil erosion to a minimum at each site. According to the National Agricultural Statistics Service, as of 2007, there were over 1,000 horses and ponies in Washington County (USDA NASS 2009) as well, and their grazing densities also have the potential to influence inorganic sediment entering the stream.

There is some documentation related to stocking rates for innovative grazing practices in the area. In 2003, 61.2 acres of pasture in the upper Mill Creek watershed were enrolled in the department's Soil and Water Conservation Program's DSP-3 Planned Grazing System practice (Kelly Farris, Washington County Soil and Water Conservation District, e-mail communications, Dec. 3-7, 2009). This District Special Practice (DSP) is a cost-share practice awarded to landowners willing to enroll their land in an intensively managed rotational grazing system. In this case, the acreage was enrolled for a period of five years. Rather than having the traditional system of one large pasture that is continuously grazed, a financial incentive is provided for dividing the pasture into smaller units, or paddocks. Livestock graze in one paddock while the other paddocks are allowed to rest so forage can grow back more quickly and vigorously. The close, hands-on management allows for a higher density of cattle per acres (i.e., higher grazing rates) than would be recommended for a continuously-grazed pasture. Adoption of this system provides more grazing control over the pasture and results in higher weaning weights in calves and improved grass reserves (Stinson and Oerly 2000). In general, higher quality pasture equates to less soil erosion and a subsequent reduction in the potential of pasture to be a nonpoint source contributor of inorganic sediment to the stream. In this particular Washington County case, the approved grazing rate for the DSP system was approximately 0.2 cows per acre for a 365-day grazing period. If the high grazing rates in the nearby approved intensive grazing system is 0.2

---

[12] According to the National Agricultural Statistics Service, as of 2007, there were approximately 21,191 head of cattle in Washington County (NASS 2009). According to the 2005 Missouri Resource Assessment Partnership (MoRAP 2005) there are 76,568 acres of grasslands in Washington County. These two values result in a cattle density of approximately 168 cattle per square mile of grasslands. This density was then multiplied by the number of square miles of grassland in the Shibboleth Branch watershed to estimate the number of cattle in the watershed.

cows per acre and the extrapolated grazing rate of 0.28 cattle per acre in the watershed is actually representative, the density of cattle in the upper Shibboleth watershed may indeed be high enough to be contributing to the inorganic sediment impairment of the stream. However, it is not known whether these densities are representative and limited field verification efforts seem to indicate the values may not be representative. Therefore, runoff from agricultural areas is not expected to significantly contribute to inorganic sediment loading to the impaired segment.

5.2.4 Riparian Corridor Conditions

Riparian corridor[13] conditions can also have a strong influence on whether inorganic sediment reaches a stream. Well-vegetated riparian areas are a vital functional component of stream ecosystems and are instrumental in the detention, removal and assimilation of sediment, excess nutrients and other pollutants before they reach a stream. In essence, they act as buffers. Therefore, a stream with a well-vegetated riparian corridor is better protected from the impacts of stormwater laden with sediment, nutrients and pesticides than is a stream with a poorly vegetated corridor. Wooded riparian corridors can also provide shade that reduces stream temperatures, which can increase the dissolved oxygen saturation capacity of the stream, and provide tree roots that stabilize streambanks and resist bank erosion more effectively than grasses, row crops or shrubbery.

As indicated in Table 12, almost 15 percent of the land in the upper Shibboleth Branch riparian corridor is classified as grassland, which could include pasture areas (MoRAP 2005). Grassland provides limited benefits in riparian corridors compared to wooded corridors and, since it may be grazed, can also be associated with livestock activities that could contribute inorganic sediment to the stream.

Note that the 12.1 percent of land cover represented in the wetland/open water category in Table 12 is partially accounted for by the presence of Powder Spring Lake, a 13-acre lake located in approximately the middle of this water body segment (WBID 2120). As mentioned in Section 2.5, Powder Spring Lake was created in the early 1960s and has likely served as a trap for any sediment entering the lake from the upper watershed of Shibboleth Branch. Wetlands are known to intercept nutrients, pesticides and sediment before these pollutants enter streams. Wooded riparian corridors, especially if the understory vegetation is thick, provide the best protection from influx of inorganic sediment. Almost 85 percent of the riparian corridor along Shibboleth Branch is classified as being in woodland, wetland or open water. A lack of good riparian corridor conditions is, therefore, not likely a major contributor to the water quality problem in Shibboleth Branch.

Table 12. Land use/land cover percentages within a 30-meter riparian corridor along Shibboleth Branch (WBID 2120)(MoRAP 2005)**.**

Land Use/Land Cover	*Shibboleth Branch Riparian Corridor (percent)*
Row and Close-grown Crops	0.3
Grassland	14.9
Forest and Woodland	72.7
Wetlands and Open Water	12.1
Total:	100.0

[13] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

5.2.5 Nonpoint Sources Summary

The primary cause of the inorganic sediment impairment to Shibboleth Branch was originally identified on Missouri's 303(d) lists as the eroding spillway on the left embankment of Bottom Diggins Dam. However, since the problem spillway was relocated to the right embankment and redesigned in 1996, and mining and the associated barite washing ceased in the watershed by 1999, abandoned mine lands (point sources) are currently thought to be the primary contributors to the continued impairment.

Land use and soils maps (Figures 2 and 3) and the information presented above suggest that nonpoint sources of inorganic sediment are minor or insignificant within the Shibboleth Branch watershed. This is due to the large areas of the watershed covered by abandoned mine areas and the Tiff soil series which are practically indistinguishable in composition from the barite mine tailings. These areas have been accounted for in the point source section of the document and would not be nonpoint source contributions to the impaired segment. Additionally, land use and soils in the watershed are not expected to cause or contribute to the impairment due to the lack of appropriate conditions that would cause sediment loading to the stream (e.g., urban areas, disturbed soils, poor riparian conditions). Potential contributions from activities within these areas of the watershed would only disturb, redisturb or redistribute materials associated with the abandoned mine lands and Tiff soil series captured in the point source wasteload allocation. Because these activities and resultant loads are already accounted for in the wasteload allocation, an additional load is not necessary as a load allocation.

6. CALCULATION OF LOAD CAPACITY

Load capacity (LC) is defined as the greatest amount of a pollutant a water body can assimilate without violating Missouri Water Quality Standards. This total load is then divided among a wasteload allocation (WLA) for point sources, a load allocation (LA) for nonpoint sources and a margin of safety (MOS). To calculate the total load (or LC), the following formula is used:

Load capacity (LC) = (design stream flow in ft^3/sec)(maximum allowable pollutant concentration in mg/L)(5.395*)
= pounds/day

*5.395 is the constant used to convert ft^3/sec times mg/L to pounds/day.

6.1 Modeling Approaches

When narrative criteria are targeted for an impaired segment, a reference approach is used. Currently, Missouri does not have a numeric criterion for inorganic sediment. Because a measurement of total suspended solids concentration is the sum of all organic and inorganic suspended solids, inorganic sediment concentration in the water column is at most equal to that of total suspended solids. Assuming the ratio of inorganic sediment to total suspended solids (TSS) is constant for a particular watershed and during a specific event, any reduction in one would parallel that of the other. Consequently, total suspended solids concentration may be used as the target for the inorganic sediment impairment.

Ecological Drainage Units (EDUs) are delineated drainage units that are described by physiographic and major riverine components. Similar size streams within an EDU are expected to contain similar aquatic communities and stream habitat conditions. Comparisons of biological, physical and chemical results between test streams and similar size reference streams within the same EDU should then be appropriate. In the case of Shibboleth Branch, data from the Ozark/Meramec Ecological Drainage Unit (No. 25) was used.

6.2 Technical Approach and Methodology

A TMDL is defined as the total amount of pollutant that can be assimilated by a receiving water body while achieving water quality standards. A TMDL is expressed as the sum of all wasteload allocations (point source loads), load allocations (nonpoint source loads), and an appropriate margin of safety, the latter of which attempts to account for uncertainty concerning the relationship between effluent limitations, modeling and water quality. The TMDL, which is also known as the load capacity (LC) of the water body, can be expressed by the following equation:

Equation 5: $TMDL = LC = \Sigma\ WLA + \Sigma\ LA + MOS$

where ΣWLA is the sum of all wasteload allocations, ΣLA is the sum of all load allocations, and MOS is the margin of safety. The objective of the TMDL is to estimate allowable pollutant loads and to allocate these loads to known pollutant sources within the watershed so appropriate control measures can be implemented and the water quality standard achieved. The Code of Federal Regulations (40 CFR §130.2 (1)) states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For sediment contamination, TMDLs are expressed as pounds per day using a load duration curve and as a mass of contaminants in a given mass of bed sediment. The load duration curve represents the maximum one-day load the water body can assimilate and maintain the water quality criterion at a given flow, while the given mass of metals per mass of sediment applies on any day in which the content in bed sediment is measured. For inorganic sediment, the TMDL is also expressed as percent of bed sediment that can be comprised of fine sediments.

6.2.1 TMDL Target Determination

In the case of inorganic sediment where the TMDL is targeting a narrative standard, a reference approach is taken. A series of United States Geological Survey (USGS) sampling stations and results for non-filterable residue (Appendix B) were used to calculate the 25th percentile of suspended sediment concentrations at various flows across the region in which Shibboleth Branch is located. Using the data from these sites, the 25th percentile of suspended sediment concentrations is 5 mg/L. This concentration is used as a numeric translator for the narrative inorganic sediment standard. A more in-depth discussion of this procedure is outlined in Appendix C.

Dissolved metals targets were calculated based on the applicable chronic criterion for dissolved cadmium, lead, and zinc at the watershed 25th percentile hardness of 160 mg/L.

6.2.2 Stepwise Explanation of How TMDL Calculations were Performed

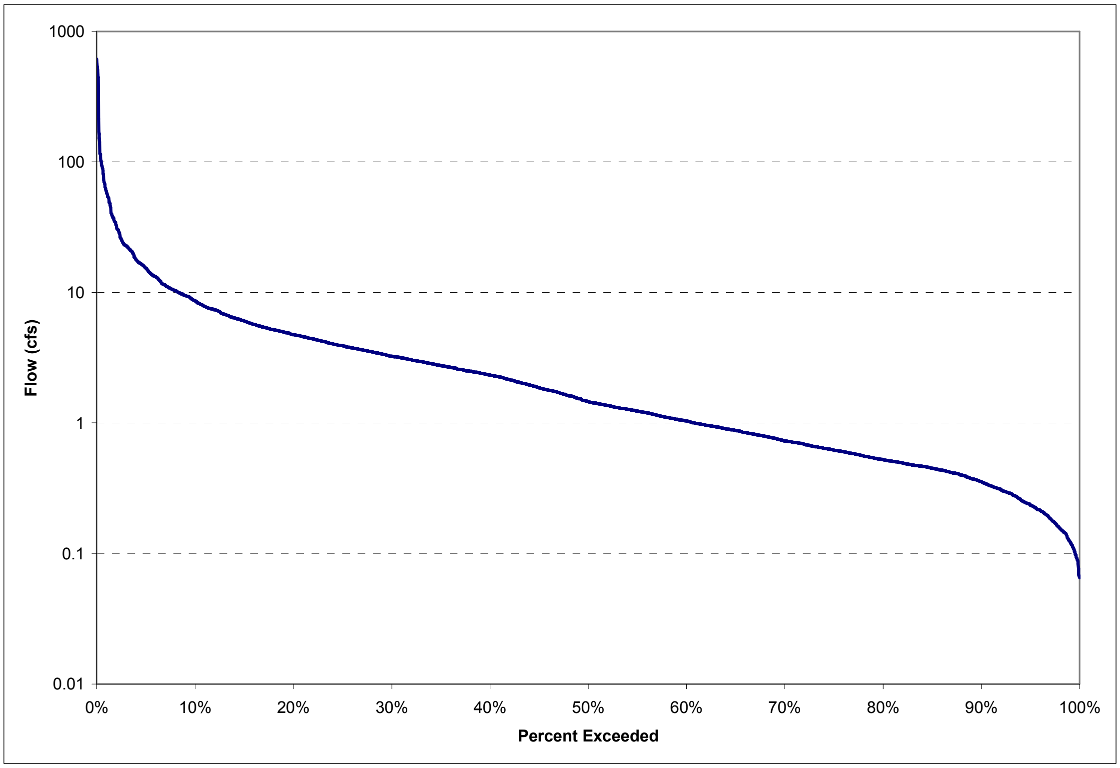
6.2.2.1 Load Duration Curves

The following discussion provides a summary of the steps involved in the calculation of key components of the Shibboleth Branch TMDLs for inorganic sediment.

Step 1: Develop a flow duration curve. A flow duration curve is a graph depicting the percent of time in which a given flow is equaled or exceeded. An estimated flow duration curve for Shibboleth Branch was developed for this TMDL. A synthetic flow regime was developed based on the level of stream flow measured in gaged streams in the same region of the state, specifically the Ozark/Meramec Ecological Drainage Unit (EDU defined in Sections 2.1 and

6.1). The USGS gage stations for Big Creek at Des Arc (07037000), South Fork Saline Creek near Perryville (07020550), East Fork Black River near Centerville (07061900) and the Bourbeuse River near High Gate, MO (07015720) were used to develop a flow duration curve based on flow per square mile in the drainage area (Figure 7). A graph of the normalized flow durations for the reference streams and the resulting estimated synthetic flow duration curve can be found in Appendix C.

Figure 7. Synthetic flow duration curve for Shibboleth Branch.



Step 2: Develop load duration curve (TMDL). Similar to a flow duration curve, the load duration curve depicts the percent of time in which a given sediment load is equaled or exceeded. When using the numeric non-volatile suspended solids translator to calculate the load duration curve, the resulting curve also represents the TMDL. In brief, the load duration curve is developed from a regression of data points from throughout the Ozark/Meramec EDU that account for date, estimated flow, and sediment concentration. Loading is calculated in tons per square mile of watershed per day. From this, a target for sediment loading is calculated, based on the 25th percentile of total suspended solids concentrations in the region. Load duration curves were also calculated for dissolved cadmium, lead, and zinc. Targets for dissolved metals were using criteria based on the 25th percentile of hardness data within the Ozark/Meramec EDU, which is 160 mg/L $CaCO_3$. Further details to this approach may be found in Appendix C and calculations are presented in Section 7. Data from Shibboleth Branch necessary to populate current conditions on the load duration curve was collected by the department in the fall of 2008, and the spring and fall of 2009.

Step 3: Calculate the margin of safety. The margin of safety can be either implicit or explicit. In this case, the margin of safety is both. The margin of safety for this TMDL is further explained in Section 7.7.

Step 4: Estimate current point source loading. The main point source contributor of inorganic sediment loading to Shibboleth Branch is the abandoned mine land area. In light of the limited water quality data available for the Shibboleth Branch watershed, the maximum detected concentration was used to estimate current loading from point sources. The estimated current point source loading can then be used to calculate point source load reductions for the watershed (Step 8).

Step 5: Calculate Wasteload Allocation. The wasteload allocation (WLA) is the maximum allowable amount of the pollutant that can be assigned to point sources. The wasteload allocation portion of the TMDL is an instream pollutant allocation expressed as pounds per day (lbs/day) and used to allocate pollutant loading to point sources of pollutants within the watershed. Such sources may be diverse and are predominantly subject to permitting requirements. However, as mentioned in Section 5.1.1, active and abandoned mine areas can be classified as point sources due to the nature of mining and milling activities, regardless if they are currently covered by a discharge permit (USEPA 1993a). The Cimbar Performance Materials and Dresser abandoned mine land areas may therefore collectively be considered a point source even though there are no State Operating Permits issued in the watershed. Mine tailings from these areas are historically thought to have been the main contributor of inorganic sediment to the impaired water body segment.

The wasteload allocation is equal to the available load capacity after accounting for the margin of safety and load allocation. In the case of cadmium, lead, and zinc, the predominant land uses (i.e., forest and grassland) contribute a negligible amount of loading of these metals to the watershed. This is generally supported by water quality data collected from water bodies not likely to be affected by the abandoned mine lands. Due to the extremely minor contribution of these metals from nonpoint sources within the watershed, it is reasonable to allocate the entire loading capacity for dissolved cadmium, lead, and zinc to point sources.

In the case of inorganic sediment, the predominant land uses (i.e., forest and grassland) may contribute a minor amount of the overall inorganic sediment pollutant loading to the watershed. However, the amount of inorganic sediment loading from forest, grassland, and agricultural land use types is not as significant as that derived from the abandoned mine land areas. The lack of total suspended solids data makes it problematic to calculate the amount, however small, that other land uses contribute to pollutant loading of inorganic sediment. There is reassurance, however, that sediment runoff from forest and grassland areas is likely to be minor due to the stability and nature of the available vegetative cover. The abundance of vegetation in these areas reduces the erosional effects of stormwater runoff by limiting stormwater velocity, lessening raindrop impact and providing greater soil infiltration (USEPA 1993b). For these reasons, the amount of contribution from these sources is believed to be less than the explicit margin of safety used for this pollutant. Likewise, agricultural impacts are expected to be equally minimal due to the small percentage of land in the watershed (1.7 percent) that is row crop. Therefore, due to the small contribution of inorganic sediment from nonpoint sources in the watershed, it is reasonable to allocate the entire loading capacity for inorganic sediment to point sources.

The wasteload allocation for dissolved cadmium, lead, and zinc and inorganic sediment at any given percentile flow exceedance can be calculated from the TMDL load duration curve by solving Equation 5 for the wasteload allocation component:

Equation 6. WLA (lb/day) = TMDL (lb/day) – MOS (lb/day) – LA (lb/day)

where WLA equals wasteload allocation, MOS equals the margin of safety, and LA equals the load allocation.

Step 6: Estimate current nonpoint source loading. In Step 5 above, nonpoint source loading of inorganic sediment and metals to the watershed are expected to be minor. This is generally supported by the lack of impairment for these pollutants in nearby streams and watersheds with similar land use types. Therefore, for the purposes of this TMDL, current nonpoint source loading of inorganic sediment and dissolved cadmium, lead, and zinc is set to zero.

Step 7: Calculate load allocation. The load allocation (LA) is the maximum allowable amount of the pollutant that can be assigned to nonpoint sources. The load allocation is also an instream pollutant allocation expressed in pounds per day (lbs/day), similar to the wasteload allocation. It is used to allocate pollutant loading to nonpoint sources of pollutants within a watershed. Such sources may be diverse and difficult to identify and are not subject to permitting requirements. Because the predominant source of inorganic sediment and heavy metals loading to Shibboleth Branch derives from point sources, the load allocation portion of the TMDL is set to zero.

Step 8: Estimate load reduction. Point source load reduction was calculated by subtracting the wasteload allocation (Step 5) from the current point source loading estimate (Step 4) as shown in the following equation:

Equation 7: Point source load reduction (lb/day) = Current point source load (lb/day) – Wasteload Allocation (lb/day)

The percent point source load reduction can be calculated using the following equation:

Equation 8: Percent point source load reduction = (point source load reduction [lb/day]/ Current point source loading [lb/day]) * 100

As stated in Step 6, load allocation reductions are not necessary because nonpoint source loading of inorganic sediment and heavy metals are expected to be minor. Results of all the aforementioned calculations are discussed in Section 7.

6.2.2.2 Bed Sediment Mass Targets

Sediment targets for cadmium, lead, and zinc were set using the percent of those metals in a given mass of sediment such that the target level is consistent with the threshold effect concentration (MacDonald *et al*. 2000). While a threshold effect concentration level has not been established for barium, reduction in sediment concentrations of cadmium, lead and zinc should reduce metals toxicity in Shibboleth Branch. The inorganic sediment target is also represented by calculating the percent fine sediment by mass.

To address the impairment for inorganic sediment as percent fine sediment and cadmium, lead, and zinc in bed sediment, a relationship was generated using data for percent fine sediment and the specific mass of sampled sediment from the stream bottom collected from control streams. These are West Fork of Huzzah Creek and Shoal Creek. This relationship is independent of segment location and refers to any location from which a sample is taken. As such, the bed sediment TMDLs are instantaneous and apply on any given day.

A percent fine sediment target of 15 percent was developed using the median of the 75th percentiles from each of the control sites on the reference streams. The load capacity curve and table (Figure 8, Table 13) were developed based on the mass of fine sediment that could be contained within a bottom sediment sample of a given mass. For example, a 100 mg bottom sediment sample should contain no more than 15 mg of fine sediment.

Bed sediment metal TMDLs for Shibboleth Branch were developed using the results of the percent fine sediment load capacity curve (Figure 8 and Table 13) and the metals equilibrium partitioning methodology (Section 4.3). Load capacities were calculated based on the percent of a given sediment sample mass that could be composed of cadmium, lead, and zinc such that the threshold effect levels for these metals was not exceeded. Because metals contamination in sediment is typically associated with the fine sediment fraction, the maximum load capacity for bed sediment metals should not be more than the allowable percentage of fine sediment in a given sample. To arrive at an acceptable concentration of bed sediment metals within a given sample, the fine sediment TMDL curve was multiplied by the metal-specific threshold effects concentration (TEC) as shown in Equation 9.

Equation 9. TMDL Mass Metal in Sediment = TMDL Mass Fine Sediment * Metal TEC

The resulting bed sediment load capacity curves for cadmium, lead, and zinc represent the maximum amount of those metals allowed in a given sample where the entire allowable fine sediment fraction are fine sediment metals. As with the percent fine sediment load capacity, the bed sediment load capacity values for cadmium, lead, and zinc apply on any given day.

6.2.3 Reduction Target

The advantage of load duration curve and bed sediment approaches is avoidance of the constraints associated with using a single-flow critical condition during the development of a TMDL. To determine the amount of load reduction necessary to comply with the chronic criterion for dissolved cadmium, lead, and zinc, in-stream critical conditions were evaluated. According to the load duration curve, water quality data were only available at relatively low flow conditions in the Shibboleth Branch watershed. Therefore, the percentage of pollutant load reduction was estimated based on this flow condition.

7. RESULTS OF TMDL AND POLLUTANT ALLOCATIONS

Following is a discussion of the results of the TMDL process for Shibboleth Branch and an evaluation of potential sources and pollutant allocations. Section 6.2.2 discussed the specific steps taken to develop each of these components.

7.1 TMDL Calculations

The TMDLs for bed sediment cadmium, lead, zinc, and percent fine sediment are shown in Figure 8. Table 13 provides a tabular expression of these TMDLs at varying masses of sediment in any particular sample. These TMDLs are mass dependant and apply at any point in either segment of Shibboleth Branch.

Calculation of the regression for total suspended solids against flow within the Ozark/Meramec EDU yielded the following relationship:

Equation 10: $\ln(\text{sediment yield(lbs/day)} = 1.25299 \cdot \ln(\text{flow(cfs)}) + 2.4233 \quad (R^2 = 0.8263)$

7.2 TMDL Pollutant Allocation and Reductions

Figure 9 shows the inorganic sediment load duration curve for Shibboleth Branch. This load duration curve is the inorganic sediment TMDL. Section 6.2.2 discussed the specific steps taken to develop each of these components. As also mentioned in Section 6.2.2, the wasteload allocation component is equal to the available load capacity after accounting for the margin of safety and load allocation. Because the margin of safety for non-volatile suspended solids is explicit (10 percent of the load capacity), the wasteload allocation is set at the load capacity minus the margin of safety and load allocation which is set at zero. In Figure 9, the area below the TMDL curve would therefore equal the wasteload allocation and margin of safety components at each flow exceedance range.

Figures 10, 11 and 12 present Shibboleth Branch load duration curves for dissolved cadmium, lead and zinc. Tables 14 through 17 present Load Capacity (LC), Wasteload Allocation (WLA), Load Allocation (LA), and Margin of Safety (MOS) values for inorganic sediment and dissolved cadmium, lead and zinc. TMDL load capacity values were converted from tons/day to lbs/day by dividing by a conversion factor of 2,000.

Figure 8. TMDL for bed sediment: cadmium, lead, zinc and fine sediment.

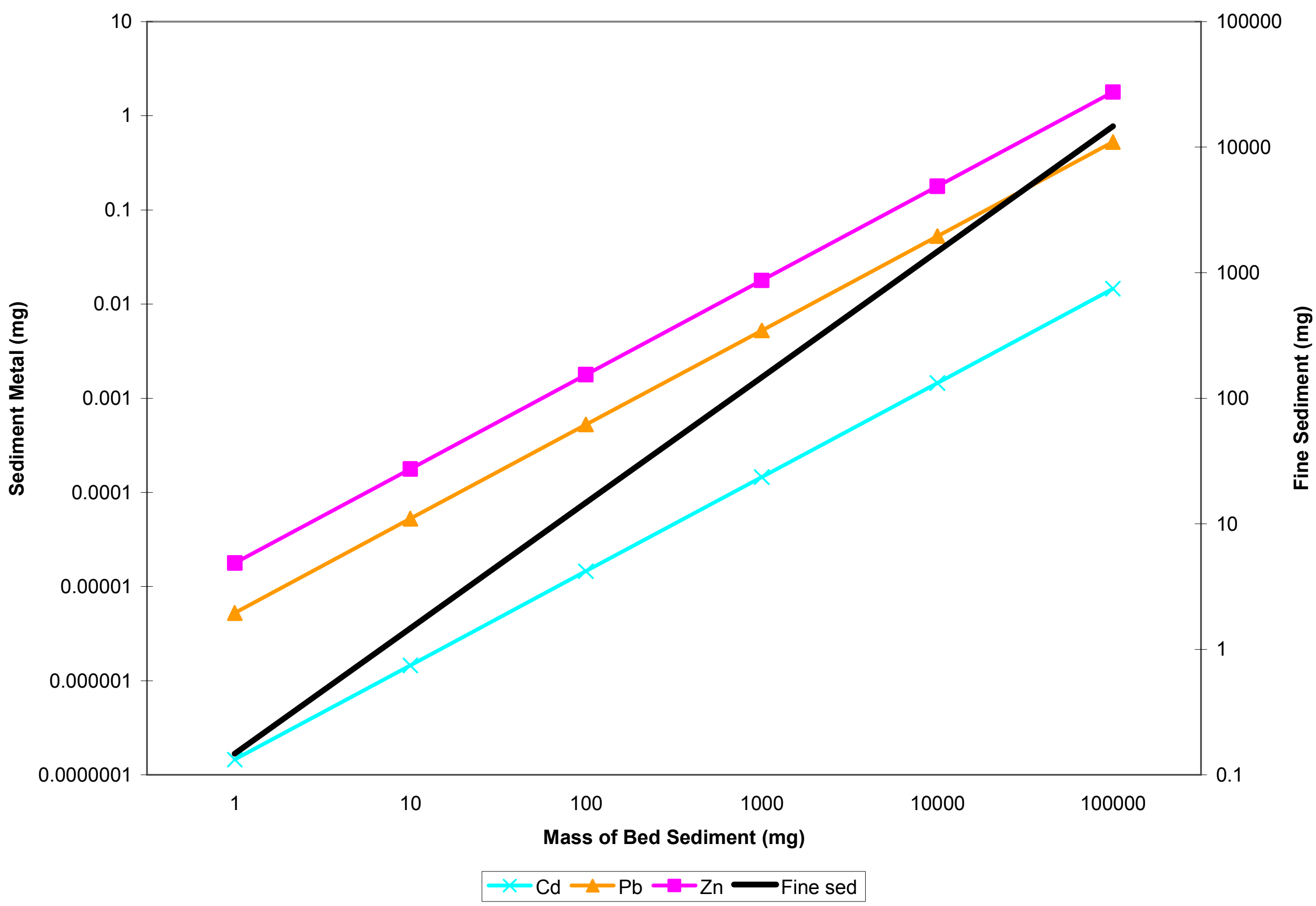


Table 13. Shibboleth Branch bed sediment TMDLs.

Mass of Sample (mg)	*TMDL Mass Fine Sediment (mg)*	*TMDL Mass Cadmium (mg)*	*TMDL Mass Lead (mg)*	*TMDL Mass Zinc (mg)*
1	0.15	$1.485*10^{-7}$	$5.37*10^{-6}$	$1.815*10^{-5}$
10	1.5	$1.485*10^{-6}$	$5.37*10^{-5}$	$1.815*10^{-4}$
100	15	$1.485*10^{-5}$	$5.37*10^{-4}$	0.001815
1,000	150	$1.485*10^{-4}$	0.00537	0.01815
10,000	1,500	0.001485	0.0537	0.1815
100,000	15,000	0.01485	0.537	1.815

The TMDL line for inorganic sediment was derived by adjusting the distribution of the sediment data from the Meramec/Ozark EDU such that the median of the new distribution is the same as the 25^{th} percentile value of the unadjusted EDU data.

Equation 11: Sediment yield (lbs/day) = $e^{(1.25299*\ln(flow(cfs))+2.4233)}$

Any allocation of waste load allocations and load allocations will be made in terms of dissolved cadmium, lead, and zinc, sediment cadmium, lead, and zinc, suspended sediment, and percent fine bed sediment reductions. In calculating the TMDLs for these pollutants, the average condition was considered across seasons to establish both TMDL endpoints and desired reductions. To best represent the average condition, the criteria for dissolved cadmium, lead, and zinc were multiplied by the median daily flow across all flow conditions. This is represented graphically by the integrated area under their respective load duration curves (Figures 10, 11 and 12) and in tabular form (Tables 15, 16 and 17). Bedded sediment targets are expressed graphically in Figure 8 and in tabular form in Table 13.

7.3 Wasteload Allocations for Shibboleth Branch Watershed

The wasteload allocations for dissolved cadmium, lead, and zinc, and sediment were estimated by using Equation 6 provided in Section 6:

Cadmium (implicit Margin of Safety)
WLA (0.0007 lb/day) = TMDL (0.0007 lb/day) – LA (0.0 lb/day)

Lead (implicit Margin of Safety)
WLA (0.008 lb/day) = TMDL (0.008 lb/day) – LA (0.0 lb/day)

Zinc (implicit Margin of Safety)
WLA (0.3054 lb/day) = TMDL (0.3054 lb/day) – LA (0.0 lb/day)

Sediment (10 percent Margin of Safety)
WLA (8.6 lbs/day) = TMDL (9.56 lbs/day) – MOS (0.96 lbs/day) – LA (0.0 lb/day)

The wasteload allocations for dissolved cadmium, lead, and zinc and inorganic sediment must be achieved at the outlets to each segment. As seen in Figures 9 through 12, wasteload allocation increases with increasing flow. The wasteload allocation for bedded sediment and metals in sediment must be met at any point in each segment.

It should be noted, that while a WLA has been calculated for point sources, including any unpermitted abandoned mines, any allocation does not reflect an authorization to discharge from an unpermitted point source. Discharging pollutants to waters of the state without a permit is a violation of both state and federal clean water law. Should it become necessary to permit currently unpermitted abandoned mines or tailings piles, those areas must follow the department's permit application and antidegradation processes and will be evaluated in light of this TMDL.

The load reductions necessary to achieve water quality standards will be obtained from the Cimbar Performance Minerals abandoned mine lands area. However, while a wasteload allocation was calculated for the unpermitted abandoned mine land, any allocation given does not reflect an authorization to discharge from an unpermitted point source.

7.4 Load Allocation for Shibboleth Branch Watershed

The dissolved cadmium, lead, and zinc load allocation for the Shibboleth Branch watershed was set at zero due to negligible nonpoint source loading of these metals to the impaired segments. The inorganic sediment load allocation for the Shibboleth Branch watershed was also set at zero due to minor inorganic sediment loading to the impaired segments. As stated in Section 6, the amount of contribution from these sources is believed to be less than the explicit margin of safety used for this pollutant so no allocation is necessary. The load allocation for the watershed is set at zero for these pollutants because activities within the watershed, present and historic, have disturbed, redisturbed, redistributed and reused materials associated with the abandoned mine lands captured in the point source wasteload allocation. Because these activities and resultant loads are already accounted for in the wasteload allocation, an additional load is not necessary as a load allocation.

While nonpoint sources of inorganic sediment and metals are minor or negligible under critical low-flow conditions, historic and legacy inorganic sediment and metals within the stream system can be sources of these pollutants, especially during higher flows. As conservative pollutants, inorganic sediment and metals do not degrade and historic pollutants can become re-suspended into the water column and carried downstream via natural fluvial processes. Significant inorganic sediment and metals suspension and re-deposition can occur during and immediately following high-flow storm events. This process allows previously unavailable inorganic sediment and metals to enter the water column and become a water quality concern as a secondary source of metals contamination. However, because the source of these materials is from abandoned mine areas and associated with the point source (wasteload allocation) portion of the TMDL, the load allocation does not reflect this secondary contribution to stream loading.

Figure 9. Load duration curve for inorganic sediment in Shibboleth Branch.

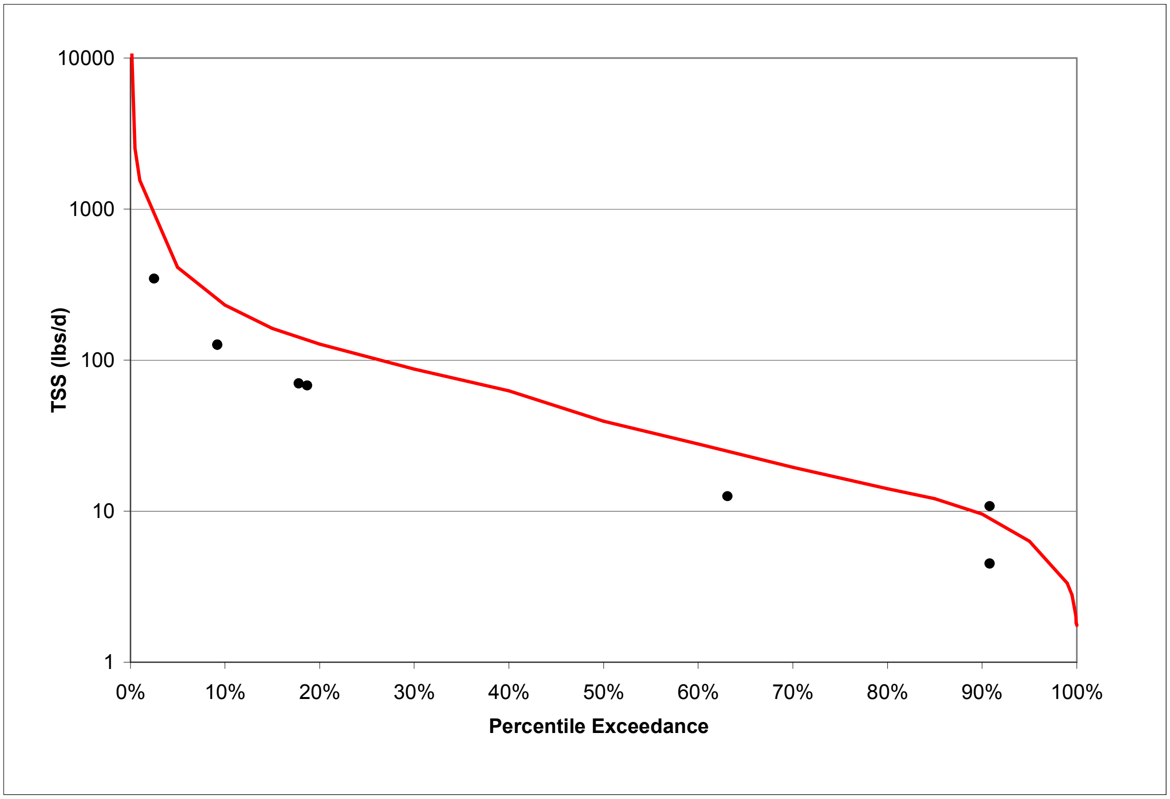


Table 14. Shibboleth Branch TMDL for inorganic sediment.

% Flow Exceedence	Estimated Flow (cfs)	Sediment TMDL (lbs/day)	Sediment MOS (lbs/day)	Sediment LA (lbs/day)	Sediment WLA (lbs/day)
99	0.124	3.33	0.33	0	3.00
95	0.235	6.31	0.63	0	5.68
90	0.355	9.56	0.96	0	8.60
80	0.522	14.06	1.41	0	12.65
50	1.458	39.25	3.93	0	35.32
20	4.736	127.51	12.75	0	114.76
10	8.608	231.74	23.17	0	208.57
5	15.335	412.84	41.28	0	371.56
1	57.719	1817.03	181.70	0	1635.33

Figure 10. Load duration curve for dissolved cadmium in Shibboleth Branch.

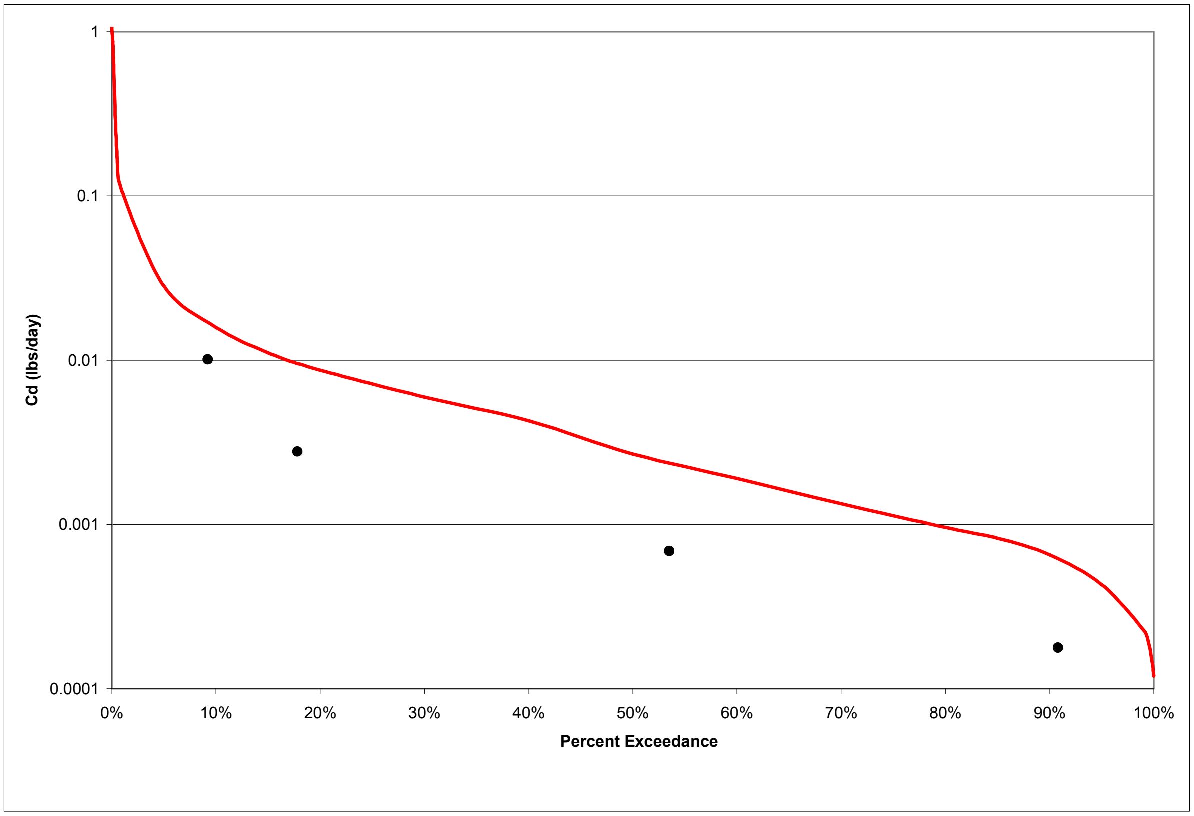


Table 15. Shibboleth Branch TMDL for dissolved cadmium.

% Flow Exceedence	Estimated Flow (cfs)	Cadmium TMDL (lbs/day)	Cadmium MOS (lbs/day)	Cadmium LA (lbs/day)	Cadmium WLA (lbs/day)
99	0.124	0.0002	--	0	0.0002
95	0.235	0.0004	--	0	0.0004
90	0.355	0.0007	--	0	0.0007
80	0.522	0.001	--	0	0.001
50	1.458	0.0027	--	0	0.0027
20	4.736	0.0087	--	0	0.0087
10	8.608	0.0158	--	0	0.0158
5	15.335	0.0282	--	0	0.0282
1	57.719	0.1061	--	0	0.1061

Figure 11. Load duration curve for dissolved lead in Shibboleth Branch.

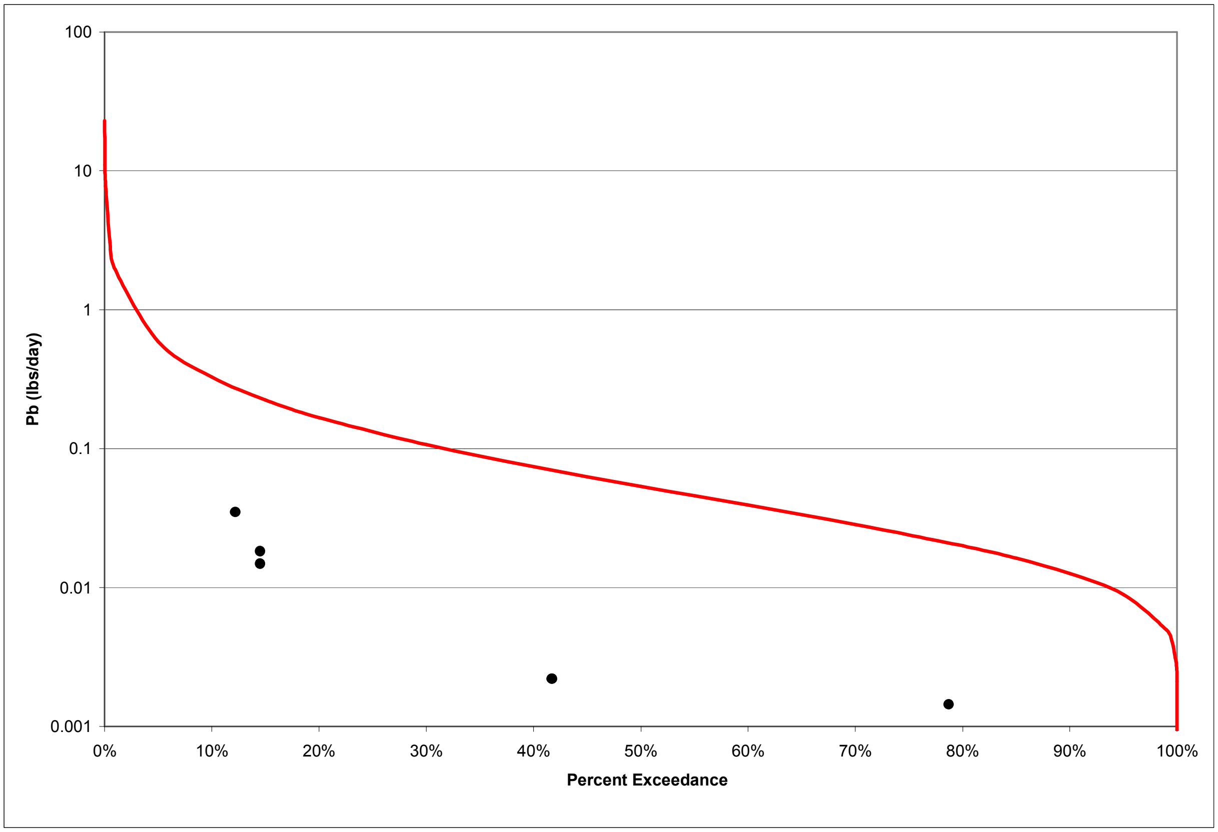


Table 16. Shibboleth Branch TMDL for dissolved lead.

% Flow Exceedence	Estimated Flow (cfs)	Lead TMDL (lbs/day)	Lead MOS (lbs/day)	Lead LA (lbs/day)	Lead WLA (lbs/day)
99	0.124	0.0028	--	0	0.0028
95	0.235	0.0053	--	0	0.0053
90	0.355	0.008	--	0	0.008
80	0.522	0.0118	--	0	0.0118
50	1.458	0.0329	--	0	0.0329
20	4.736	0.1069	--	0	0.1069
10	8.608	0.1942	--	0	0.1942
5	15.335	0.346	--	0	0.346
1	57.719	1.3023	--	0	1.3023

Figure 12. Load duration curve for dissolved zinc in Shibboleth Branch.

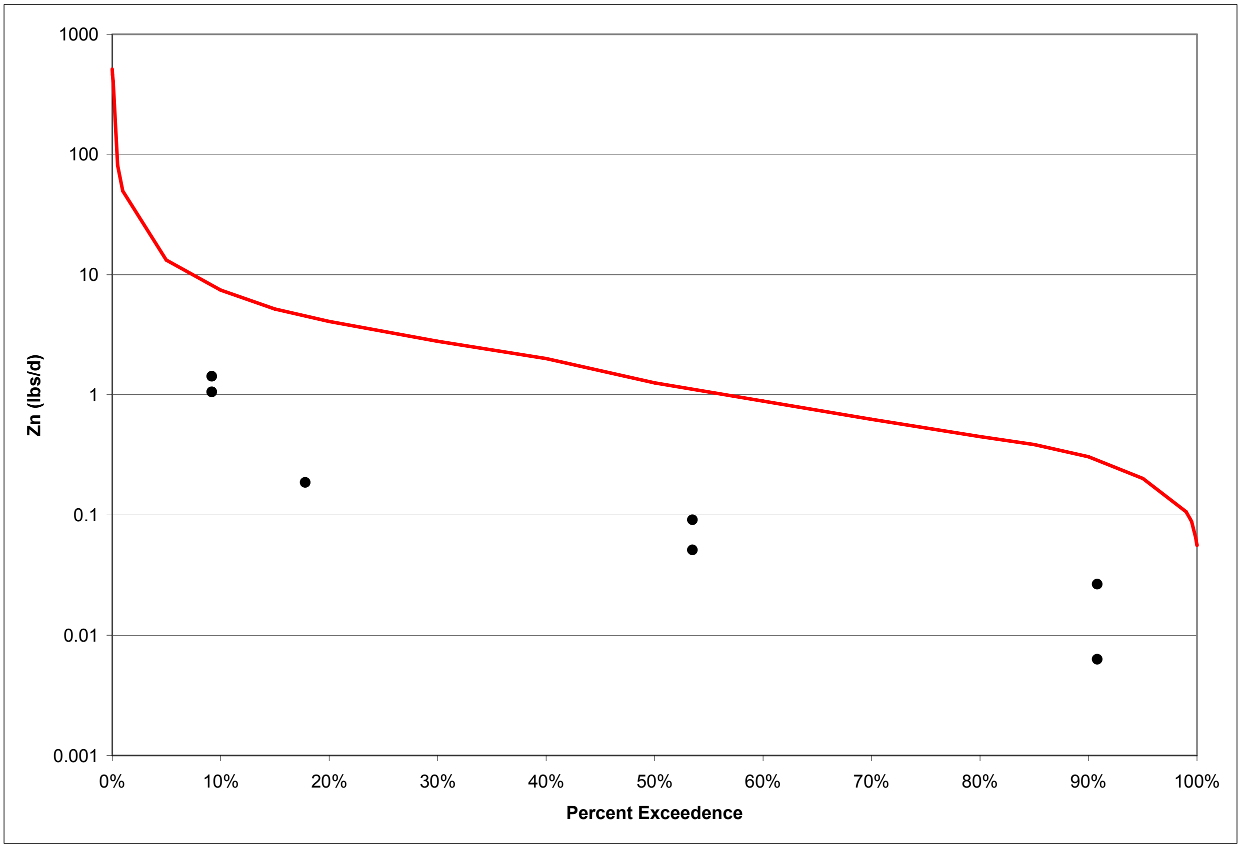


Table 17. Shibboleth Branch TMDL for dissolved zinc.

% Flow Exceedence	Estimated Flow (cfs)	Zinc TMDL (lbs/day)	Zinc MOS (lbs/day)	Zinc LA (lbs/day)	Zinc WLA (lbs/day)
99	0.124	0.1064	--	0	0.1064
95	0.235	0.2017	--	0	0.2017
90	0.355	0.3054	--	0	0.3054
80	0.522	0.4491	--	0	0.4491
50	1.458	1.2538	--	0	1.2538
20	4.736	4.0729	--	0	4.0729
10	8.608	7.4023	--	0	7.4023
5	15.335	13.1868	--	0	13.1868
1	57.719	49.6335	--	0	49.6335

7.5 Point Source Load Reduction

The anticipated average wasteload allocation (WLA) reduction from point sources (i.e., abandoned mine lands) was calculated by subtracting the average WLA during low flow conditions (90th percentile) from the total current point source loading as described in Section 6.2.2, Step 4. The maximum total suspended solids (TSS) concentration in the dataset is 6 mg/L (Appendix A-2):

Average Current point source loading = max. TSS concentration (6 mg/L) * modeled stream flow from sample date (0.76 cfs) * 5.354
= 24.60 lb/day

Percent Reduction = [(Current load – WLA)/ Current load] * 100
= [(24.60 – 13.55)/24.60] * 100
= 45%

The accumulation of stream bed sediment, metals concentrations within the sediment, and low macroinvertebrate scores indicate a significant violation of the narrative criteria cited in Section 3.2. It is probable that sediment loading of the stream occurs mainly during high flow events that have not been captured by water quality sampling.

For percent fine sediment cover in the stream bed, the anticipated WLA reduction from the point source (Cimbar Performance Minerals abandoned mine lands) was calculated by subtracting the median of the 75th percentile for cover in the control streams from the central median percent cover in Shibboleth Branch.

Percent Reduction = [(% cover in Shibboleth Branch – % cover in control streams)/ % cover in Shibboleth Branch]*100
= [(35 –15)/35] * 100
= 57%

For heavy metals in fine bed sediment, the anticipated WLA reduction from the point source was calculated by subtracting the consensus based Threshold Effects Concentration for each of the metals measured in sediment from their maximum respective sediment concentrations in Shibboleth Branch.

$$\text{Percent Reduction} = \frac{\text{max. sediment metal concentration (mg/kg)} - \text{TEC (mg/kg)}}{\text{max. sediment metal concentration (mg/kg)}} * 100$$

Results of this calculation are found in Table 18.

Table 18. Percent reductions for heavy metals in Shibboleth Branch sediments.

Metal	*Maximum Sediment Concentration (mg/kg)*	*Threshold Effect Concentration (mg/kg)*	*Percent Reduction*
Cadmium (Cd)	9.52	0.99	90
Lead (Pb)	836	35.8	96
Zinc (Zn)	845	121	86

7.6 Nonpoint Source Load Reduction

Because there are negligible nonpoint source loading of dissolved cadmium, lead, and zinc and minor nonpoint source loading of inorganic sediment to the impairments in Shibboleth Branch, no reduction in nonpoint source loading is necessary under this TMDL.

7.7 Margin of Safety

Federal regulations at 40 CFR §130.7(c)(1) require that TMDLs take into consideration a margin of safety (MOS) that is usually added to a TMDL to account for the uncertainties inherent in the calculations and data gathering. The margin of safety is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the margin of safety can be achieved through one of two approaches:

A. Explicit – Reserve a numeric portion of the load capacity as a separate term in the TMDL.
B. Implicit – Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

This TMDL relies on both implicit and explicit margin of safety derived from a variety of calculations and assumptions. In deriving the dissolved cadmium, lead and zinc TMDLs, an implicit margin of safety was applied by using chronic water quality criteria for these metals and using the resulting values for both water column and interstitial water (porewater) targets. To set inorganic sediment metal TMDLs for cadmium, lead and zinc, Threshold Effect Concentrations (TECs) for these metals in sediment were used. TECs should be used to identify sediments that are unlikely to be adversely affected by sediment-associated contaminants. In contrast, the Probable Effects Concentration (PEC) should be used to identify sediments that are likely to be toxic to sediment-dwelling organisms (MacDonald *et al.* 2000). TECs for metals toxicity in sediment was chosen over PECs because it is a level below which no toxicity should occur and is thus protective of chronic and sub-chronic exposure. The conservative assumptions and factors used in this method should account for any uncertainties in the loading calculations. The margin of safety for percent fine sediment was also implicit because the WLA percent reduction targets the 75th percentile of the reference population frequency distribution. Due to the lack of available inorganic sediment data, an explicit margin of safety of 10 percent was applied when deriving the inorganic sediment TMDLs.

7.8 Uncertainty Discussion

This TMDL document was prepared using data and assumptions that contribute a degree of uncertainty to the process. Following is a list of operating assumptions needed to support the TMDL analysis and calculations.

- The estimated flow for the outlets of each segment is directly related to the flow per square mile of the seven USGS gages used to develop the outlet flow record.
- The 25th percentile water hardness value of samples located in the area of Shibboleth Branch is representative of those conditions within Shibboleth Branch.
- Equilibrium partitioning calculations estimating pore water concentrations from bulk sediment were used to confirm the general nature of the impairment expressed as instream, aqueous phase concentrations.

- The contribution of dissolved cadmium, lead, and zinc from nonpoint sources in the Shibboleth Branch watershed is negligible. The contribution of inorganic sediment from nonpoint sources is minor and that any amount of contribution from these sources is believed to be less than the explicit MOS used for this pollutant.
- The current point source loading estimates calculated using the maximum detected dissolved cadmium, lead, and zinc concentration is representative of the actual point source loading at the low flow condition (90th percentile exceedance).

The load duration curve method was used to calculate pollutant specific TMDLs for the impaired segment of Shibboleth Branch. Because the load duration curve method relies on measured water quality data, regional water hardness data, and a wide range of "flow exceedance" data, it represents a complete range of flows and pollutant loads anticipated in Shibboleth Branch. However, the lack of water quality data at mid to high stream flows did not allow for calculation of pollutant load reductions at these flow conditions. These data would have been beneficial to include in the analysis since the majority of inorganic sediment and metals in sediment can be expected to be contributed during mid to high stream flow conditions. As result, there is some uncertainty as to the actual pollutant reductions necessary to achieve water quality standards during these stream conditions.

7.9 Consideration of Critical Condition and Seasonal Variation

Federal regulations at 40 CFR §130.7(c)(1) require TMDLs take into consideration seasonal variation in applicable standards. The impairment of Shibboleth Branch is due to inorganic sediments being carried into the water body through stormwater runoff. These conditions are more likely to occur during seasonal periods having significant precipitation. The TMDL load duration curve, however, represents flow under all possible stream conditions. The advantage of a load duration curve approach is that it avoids the constraints associated with using a single-flow critical condition during the development of the TMDL. Because the TMDL is applicable under all flow conditions, it is also applicable for all seasons. Seasonal variation is therefore implicitly taken into account within the TMDL calculations.

8. IMPLEMENTATION

Past barite mining in the Shibboleth Branch watershed left a legacy of related land disturbance, including creation of barite tailings dams. When it rains, the water suspends the fine particles of sediment and metals and carries them to the waterways in the watershed. These particles impair aquatic life due to metals toxicity and/or through loss of habitat due to excessive sedimentation. The following implementation strategies should be considered to ensure the improvement of water quality within the Shibboleth Branch watershed addressed by this TMDL.

8.1 Point Sources

Point source reductions are typically implemented through discharge permits administered through the Missouri State Operating Permit program to meet the requirements of Missouri's Water Quality Standards and State Operating Permits. The abandoned barite mine lands have been identified as a source of the inorganic sediment impairment to Shibboleth Branch. While the old barite mined areas are currently not covered by a Missouri State Operating Permit, future remedial actions must take into consideration the wasteload allocations established for inorganic sediment and metals found in this TMDL. These wasteload allocations and other requirements to improve water quality may be incorporated into any future Missouri State Operating Permits (either site-specific industrial or stormwater) or other appropriate enforceable documents.

The unvegetated faces of the dams in the Shibboleth Branch watershed may be a potential source of inorganic sediment (See Section 5.1.3 and Figure 6). It has been suggested that adding vegetative cover to the bare areas on the dams could aid in reducing water erosion and thereby reduce the potential of sediment from the dam faces entering Shibboleth Branch. However, as discussed in Section 2.5, barite tailings dams are different from traditional dams in many ways. Due to the nature of the material making up the dams, their face is most stable at a 1:1 slope, compared to the 3:1 seen on traditional dams. The slope is too steep to maintain the depth of topsoil needed to support permanent, non-woody vegetation on the dam faces. The soil would simply slide downhill (Glenn Lloyd, the department's Dam and Reservoir Safety Program, personal communication, April 16, 2010). Any work done on the dams or the spillways in the future should ideally involve implementation of appropriate best management practices (BMPs) to control soil erosion and reduce the amount of sediment reaching Shibboleth Branch.

8.1.1 Federal Superfund Site

It is important to note that Pond Creek is in the Washington County Lead District – Potosi National Priority Listing (Superfund) site. The site encompasses an area greater than 45 square miles in the eastern portion of Washington County, Missouri. Soil and/or groundwater are contaminated with arsenic, barium, cadmium and lead resulting from mining, milling and smelting activities. A Remedial Investigation (RI) was initiated in January 2008. The RI will characterize the numerous tailings ponds and streams, determine the extent of groundwater contamination and characterize the residential surface soil. Superfund remedial actions may impact Pond Creek (Frances Klahr and Kathy Rangen, the department's Hazardous Waste Program, e-mail communications, Sept. 2 and 3, 2010, respectively).

8.1.2 Residential Home Building South of Bottom Diggins Lake

It is difficult to estimate future development within the watershed. Any activities disturbing one or more acres of land within the Shibboleth Branch watershed must be covered by a permit issued by the department's Water Protection Program. Disturbances of under one acre of land within the watershed should ideally involve implementation of appropriate BMPs to control soil erosion.

8.1.3 Washington County Roads

Local unpaved roads are constructed in the ubiquitous Tiff soil type and are thus potential sources of sediment in Shibboleth Branch. The county is encouraged to follow best management practices when conducting road maintenance involving the Tiff soil series in order to minimize disturbance and subsequent contributions of sediment to Shibboleth Branch.

8.2 Nonpoint Sources

Nonpoint source reductions are currently not necessary to reduce pollutant loading of inorganic sediment and metals to the Shibboleth Branch watershed. Reductions obtained by implementing the wasteload allocations found in this TMDL should restore water quality in Shibboleth Branch. However, BMPs employed within the watershed must continue to be implemented to ensure antidegradation requirements are met. Further nonpoint source reductions in the watershed may be implemented in the future through BMPs funded wholly or in part by Section 319 grants[14] or various cost-share opportunities available through the department's Soil and Water Conservation Program and the federal Natural Resources Conservation Service.

Potential follow-up projects include field observation and inventory of the area to determine whether all grassland areas in the watershed are grazed, the condition of that grassland, and if the extrapolated rate of 0.28 cattle per acre is accurate. However, physically canvassing an entire watershed would likely require manpower and landowner consent beyond the department's means. The information needed to make this assessment may or may not be available through the local Soil and Water Conservation District (SWCD) or Natural Resources Conservation Service office, and then only if landowners voluntarily enrolled and participated in the available programs and adopted associated best management practices (BMPs) to reduce soil loss using cost-share. Considering the soil type in the immediate watershed, adoption of BMPs to ensure adequate erosion control in grazing areas would be prudent. However, a records survey by the Washington County SWCD revealed few participants in the county (Kelly Farris, Washington County SWCD, e-mail communication, Dec. 2009).

9. MONITORING PLAN

A sediment and biological monitoring study was completed for Shibboleth Branch in Sept. 2009. The department intends to conduct follow up biological monitoring on Shibboleth Branch to confirm the status of the macroinvertebrate community. Biomonitoring is scheduled for both segments of this stream for the 2011 State Fiscal Year, along with monitoring for heavy metals in sediment. Any additional water quality data that is collected in the Shibboleth Branch watershed will be evaluated in light of this TMDL.

10. REASONABLE ASSURANCE

In most cases, "Reasonable Assurance" in reference to TMDLs relates to the certainty to which point sources will reduce pollutant loading to impaired water body segments. Currently, there are no permitted point source discharges of inorganic sediment and heavy metals within the Shibboleth Branch watershed. However, the abandoned barite mine lands are considered a point source for the purposes of this TMDL. Wasteload allocations to improve water quality may be incorporated into a Missouri State Operating Permit (either site-specific industrial or stormwater) or other appropriate enforceable document to ensure wasteload allocation reductions are achieved. Any assurances that nonpoint source contributors of inorganic sediment will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources can be found in Section 8.2 of this TMDL.

11. PUBLIC PARTICIPATION

EPA regulations require that TMDLs be subject to public review (40 CFR 130.7). Before finalizing this TMDL, the department's Water Protection Program notified the public that a comment period was open for 45 days, from April 30 to June 14, 2010, by placing a Public Notice, the draft TMDL, and the associated TMDL Information Sheet on the department's

[14] Under section 319, State, Territories and Indian Tribes receive grant money that support a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects.

website, making them available to anyone with access to the Internet. Public notices to comment on the draft TMDL were also distributed via mail and electronic mail to stakeholders in the watershed, or other potentially impacted parties. In this case, those receiving the public notice announcement included the Missouri Clean Water Commission, the Missouri Water Quality Coordinating Committee, Washington County Commission, Cimbar Performance Minerals, 29 Stream Team volunteers in the area, the Potosi Independent Journal, and the two state legislators representing Washington County. No comments were received. After the comment period closed, the department submitted the TMDL and supporting documents to EPA's Region 7 office in Kansas City, Kan., for their review.

12. ADMINISTRATIVE RECORD AND SUPPORTING DOCUMENTATION

An administrative record on the Shibboleth Branch TMDL has been assembled and is being kept on file with the department. It includes any studies, data, modeling and calculations on which this TMDL is based, as well as any documents related to public participation including all written comments and responses.

13. REFERENCES

Alexander, J.L. and R.A. Clay. 1997. Missouri Department of Natural Resources' Dam and Reservoir Safety Program, Registration Permit (for Bottom Diggins Dam). Registration Permit No. R-431, Renewed Jan. 29, 1997 to expire Jan. 29, 2000 (2 pp) based on Jan. 27, 1997 memorandum from Robert Clay summarizing his Jan. 8, 1997 on-site visit. 4 pp.

Alexander, J.L. 2008. Missouri Department of Natural Resources' Dam and Reservoir Safety Program, Registration Permit (for Bottom Diggins Dam). Registration Permit No. R-431, Renewed Jan. 25, 2008 to expire Jan. 25, 2011. 2 pp.

Besser, J.M., W.G. Brumbaugh, A.L. Allert, B.C. Poulton, C.J. Schmitt, and C.G. Ingersoll. 2009. Ecological impacts of lead mining on Ozark streams: Toxicity of sediment and pore water. Ecotoxicology and Environmental Safety 72(2009) 516-526.

Clay, R.A. 2006. Missouri Department of Natural Resources' Dam and Reservoir Safety Program, Inspection Report, Bottom Diggins Dam (MO 30750), Washington County. 7 pp.

Duchrow, R.M. 1977. The effects of barite tailings pond dam failure upon the water quality of Mill Creek and Big River, Washington County, Missouri. Missouri Department of Conservation. Dinglell-Johnson Project F-19-R-3 Study W-3, Job No. 3. Final Report. Prepared Aug. 19, 1977. 48 pp.

____________. 1982. Effects of barite tailings on benthos and turbidity of two Ozark streams. Transactions of the Missouri Academy of Science. Vol.16. 11 pp.

Hansen, D.J., D.M. DiToro, W.J. Berry, W.S. Boothman, R.M. Burgess, G.T. Ankley, D.R. Mount, J.A. McGrath, L.D. LaRosa, H.E. Bell, M.C .Reiley, C.S. Zarba. 2005. Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: Metal Mixtures (Cadmium, Copper, Lead, Nickel, Silver, and Zinc). EPA/600/R-02/011.

Hjulstrøm, F., 1939. Transportation of debris by moving water, in Trask, P.D., ed., Recent Marine Sediments; A Symposium: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 5-31.

Kohnke, H. and D.P. Franzmeier. 1995. Soil Science Simplified. Waveland Press, Inc., P.O. Box 400, Prospect Heights, IL, 60070. 162 pp.

Kuester, D.R. 1964. Part V. The benthos of the streams in the Meramec River Basin as related to water quality. pp. 24-48, *in* Water quality in the Big, Bourbeuse, and Meramec River basins. Missouri Water Pollution Board, Jefferson City, Missouri.

MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 38(2000), 20-31.

MoDNR (Missouri Department of Natural Resources). 2002a. Invertebrate Sampling near Barite AMLs in Washington County. Missouri Department of Natural Resources, Water Pollution Control Program, P.O. Box 176, Jefferson City, Missouri 65102-176. 7 pp.

MoDNR (Missouri Department of Natural Resources). 2002b. Biological criteria for wadeable/perennial streams of Missouri. Missouri Department of Natural Resources, Environmental Services Program, P.O. Box 176, Jefferson City, Missouri 65102. 32 pp.

MoDNR (Missouri Department of Natural Resources). 2009. Title 10 - Department of Natural Resources, Division 20 - Clean Water Commission. [Online WWW]. Available URL: http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf [Accessed Nov. 20, 2009]

MoDNR (Missouri Department of Natural Resources). 2010a. Dam and Reservoir Safety Program's Regulated Dam Report by County [Washington County]. [Online WWW]. Available URL [Accessed March 12, 2010]: http://www.dnr.mo.gov/env/wrc/damsft/Crystal_Reports/damsfty_state_nid_regulated.pdf

MoDNR (Missouri Department of Natural Resources). 2010b. Title 10 - Department of Natural Resources, Division 40 – Land Reclamation Commission. [Online WWW]. Available URL: http://www.sos.mo.gov/adrules/csr/current/10csr/10csr.asp#10-20 [Accessed March 12, 2010]

MoDNR (Missouri Department of Natural Resources). 2010c. The Land Reclamation Act. Revised Missouri State Statutes 444.760-444.790 Land Reclamation Commission. [Online WWW]. Available URL: http://dnr.mo.gov/forms/regulations.pdf [Accessed March 12, 2010]

MoDNR (Missouri Department of Natural Resources). 2010d. Biological Assessment and Fine Sediment Study Report: Tributaries of Mill Creek and Mineral Fork, Washington County, Fall 2008 – Spring 2009 – Fall 2009. Missouri Department of Natural Resources, Environmental Services Program, P.O. Box 176, Jefferson City, Missouri 65102-176. 48 pp + Appendices.

MoRAP (Missouri Resource Assessment Program). 2005. Missouri Landcover 2000-2004. Aug. 22, 2005. Retrieved April 26, 2007, from http://www.msdis.missouri.edu.

Rabeni, C.F., R.J. Sarver, N. Wang, G.S. Wallace, M. Weiland, and J.T. Peterson. 1997. Biological Criteria for Streams of Missouri: A Final Report to the Missouri Department of Natural Resources, Missouri Cooperative Fish and Wildlife Research Unit, Columbia, Missouri. 283 pp.

Sarver, R.J., S. Harlan, Rabeni, C.F., and S.P. Sowa. 2002. Biological Criteria for Wadeable/Perennial Streams of Missouri. Missouri Department of Natural Resources, Environmental Services Program. P.O. Box 176. Jefferson City, MO 65102.

Stinson, J. and M. Oerly. 2000. Amazing Graze; Rotation Improves Pasture and Herd. Missouri Resources. Vol.17, No. 3. pp. 3-7.

Sutton, Alan L. 1990. Animal Agriculture's Effect on Water Quality Pastures and Feedlots. WQ-7. School of Agriculture. Purdue University Extension. [Online WWW]. Available URL: http://www.ces.purdue.edu/extmedia/wq/wq-7.html [Accessed Nov. 23, 2009].

U.S. Census Bureau. 2008. 2008 Population Estimates. [Online WWW]. Available URL: http://www.census.gov [Accessed Nov. 17, 2009].

USDA (United States Department of Agriculture) NRCS (Natural Resources Conservation Service). 2005. U.S. Department of Agriculture. Soil survey of Washington County, Missouri [Online WWW]. Available URL: http://soildatamart.nrcs.usda.gov/Manuscripts/MO221/0/Washington_MO.pdf [Accessed Oct. 27, 2009].

USDA (United States Department of Agriculture) NRCS (Natural Resources Conservation Service). 2006. U.S. Department of Agriculture. Soil Survey Division. Series Name/Query Facility. Available URL: http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdnamequery.cgi?-P [Accessed Nov. 8, 2009].

USDA (United States Department of Agriculture) NRCS (Natural Resources Conservation Service). 2007. U.S. Department of Agriculture. SSURGO 2007 [computer file]. Retrieved from http://SoilDataMart.nrcs.usda.gov Oct. 28, 2009.

USDA (United States Department of Agriculture) NASS (National Agricultural Statistics Service, U.S. Department of Agriculture). 2009. 2007 Census of Agriculture: Missouri State and County Data [Online WWW]. Updated Sept. 2009. Vol. 1, Geographic Area Series, Part 25, AC-07-A-25. Available URL: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_2_County_Level/Missouri/mov1.pdf [Accessed Nov. 20, 2009].

USEPA (United States Environmental Protection Agency). 1993a. Memo: NPDES Permit Issues and Hard Rock Mines. U.S. EPA Region VIII, Denver, Colorado.

USEPA (United States Environmental Protection Agency). 1993b. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA 840-B-

92-002. [Online WWW]. Available URL: http://www.epa.gov/owow/nps/MMGI/Chapter3/ch3-2h.html [Accessed 01 Oct. 2009]

USEPA (United States Environmental Protection Agency). 1999. Understanding Variation in Partition Coefficient, K_d, Values. Volume II: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (^3H), and Uranium. EPA 402-R-99-004B.

USEPA (United States Environmental Protection Agency). 2006a. Development of Suspended Sediment Targets using Reference Load Duration Curves, EPA Region 7, Kansas City, KS. (See Appendix C of this Shibboleth Branch TMDL)

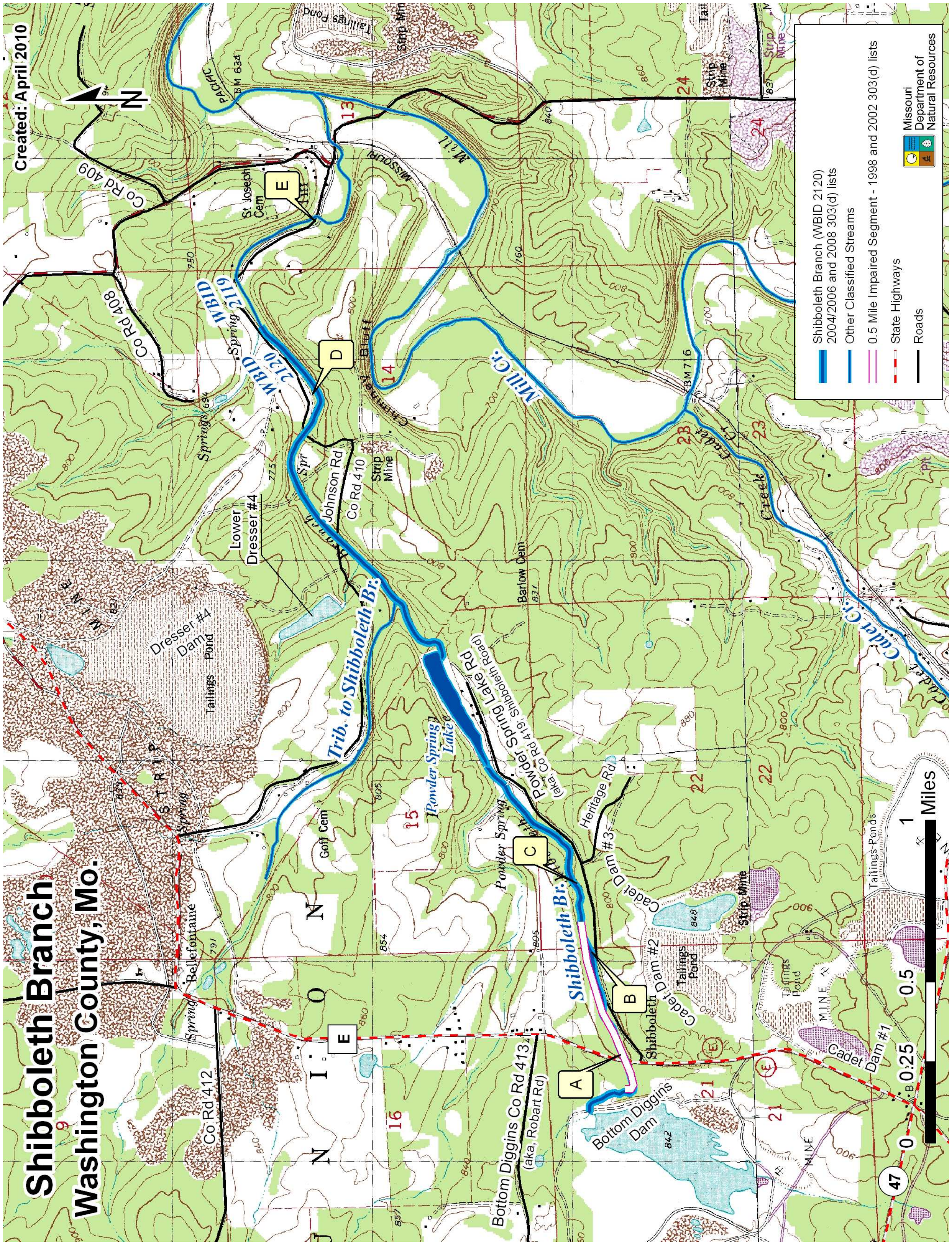
USEPA (United States Environmental Protection Agency). 2006b. Framework for Developing Suspended and Bedded Sediments (SABS) Water Quality Criteria, Environmental Protection Agency, EPA-822-R-06-001, May 2006.

USEPA (United States Environmental Protection Agency). 2010. Ecoregion Nutrient LDC Generator. EPA Region 7, Kansas City, KS. (See Appendix C of this Shibboleth Branch TMDL)

USGS (United States Geological Service). 1990 (Data Entry Feb. 1, 1990). Geographic Names Information System (GNIS). [Online WWW]. Available URL: http://geonames.usgs.gov/pls/gnispublic/ [Accessed Dec. 17, 2009].

Appendix A
Map of Sampling Sites on Shibboleth Branch and Associated Water Column Chemistry Data

A-1: Topographic Map of Shibboleth Branch (Both Segments) Sampling Sites



Appendix A (*continued*)
Map of Sampling Sites on Shibboleth Branch and Associated Water Column Chemistry Data

A-2: Water Column Chemistry Data from Shibboleth Branch Used in TMDL Development.

Sample Site	Sample No.	Yr	Mo	Day	Time	Flow	C	DO	pH	SC	TSS	TRB	DBA	DCD	DPB	DZN	Hard
D	810008*	2008	9	25	1200	5.7	18	7.9	8.3	365		10.2	748	0.099	0.12499	13.1	198
E	810007*	2008	9	25	1000	6.43	17	8	8.2	371		2.44	758	0.099	0.12499	7.35	206
E	901088*	2009	1	22	1050	4.37					2.499						
D	901089*	2009	1	22	1115	2.38					2.499						
A	912189†	2009	3	25	1100	1.17					2.499						
C	912190†	2009	3	25	1215	1.022					2.499						
D	912006*	2009	3	25	1120	6.7	11	10.8	8.5	375	2.499	5.98	609	<0.2	0.32	28.1	184
E	912005*	2009	3	25	945	9.63	10	11.3	8.5	386	2.499	6.56	604	<0.2	0.26	20.9	189
A	911097†	2009	3	26	1040	1.4	12		7.8	276	2.499						
B	912012*	2009	4	1	1100	3.03	11	9.2	8	265	2.499	3.83	980	0.099	0.52	6.63	124
A	911104†	2009	4	28	1220	1.5	16	8.8	7.9	257	2.499						
B	912051*	2009	9	15	1210	0.49	20	7.4	8.1	336	2.499	1.3	1680	<0.2	<0.25	3.51	173
D	912050*	2009	9	15	1015	3.4	19	7.2	8.3	455	6	4.19	858	<0.2	0.35	14.8	243

Sample Site	Site Names	Additional Note	WBID
A	"Just below Hwy E" or "100 yds below Hwy. E"	All sites within 100 yds downstream of Hwy. E	2120
B	Shibboleth Br. 0.4 mi. below Hwy. E	ESP's Site #3	2120
C	Shibboleth Br. 0.6 mi below Hwy. E, Near Heritage Rd.		2120
D	Shibboleth Br. @ CR 410 (Johnson Rd.) xing #2	ESP's Site #2	2120
E	Shibboleth Br. @ CR 410 (Johnson Rd.) xing #4	ESP's Site #1	2119

Where:	Means:
*	Collected by DNR ESP staff
†	Collected by DNR WPP/ WQMA Section staff
Flow	in cubic feet per second (cfs)
C	Water Temperature in degrees Celsius
DO	Dissolved Oxygen (mg/L)
pH	Measurement of acidity/alkalinity
SC	Specific Conductance (µS)
TSS	Total Suspended Solids (mg/L)
TRB	Turbidity (in NTUs)
DBA	Dissolved Barium (µg/L)
DCD	Dissolved Cadmium (µg/L); PEC = 4.98 mg/kg dry weight
DPB	Dissolved Lead (µg/L); PEC = 128 mg/kg dry weight
DZN	Dissolved Zinc (µg/L); PEC = 459 mg/kg dry weight
Hard	Hardness as CaCO3

Appendix B

Shibboleth Branch TMDL Methodology

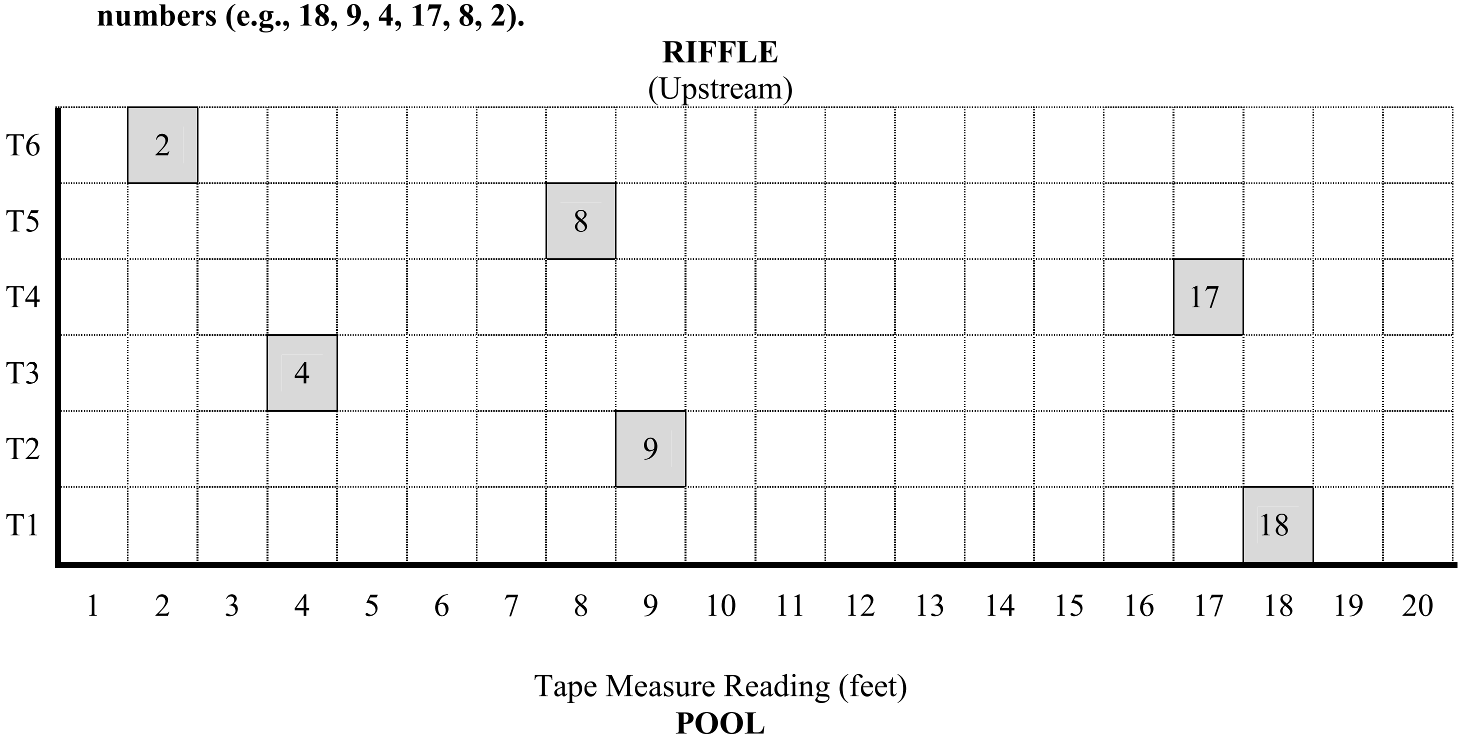
Fine Sediment Coverage Estimations

The relative percentage of fine sediment (<2.0 mm) coverage was visually estimated for each station. The visual estimates were conducted within a metal square (quadrat) that was randomly located in sample areas called grids (Figure B-1). Each station contained three grids. This method allowed for estimation and comparison of benthic fine sediment between stations.

In order to ensure sampling method uniformity, grids were located at lower margins of riffles or runs and the upper margin of pool habitats in areas of relatively laminar flow. This arrangement or placement of grids was similar to previous fine sediment assessment projects done by the WQMS (MDNR-WQMS Reports: Flat River 2001, MDNR 2001; Upper Big River 2001-2002, MDNR 2003a). Water velocity was no greater than 0.5 feet per second (fps), which allows fine sediment sized particles (<2.0mm) to settle from transport after high flow events, according to the Hjulstrøm Diagram (Hjulstrøm 1939; See "References" section of this TMDL) for threshold transport and settling velocities. A Marsh-McBirney flow meter was used to determine maximum velocity within the proposed grid. Depths did not exceed three (3.0) feet. Grids did not include eddies, bends, downstream of vegetation, or large obstructions that have turbulent flow.

Once a suitable area was identified, a virtual grid was constructed (Figure B-1). A 100-foot tape measure anchored across the stream became the downstream transverse edge of a virtual grid of

Figure B-1. Virtual grid of transects (T) and quadrats (in gray, numbered) for estimating percent fine sediment. Example: stream 20' wide; quadrat placement based on random numbers (e.g., 18, 9, 4, 17, 8, 2).



six contiguous transects. Each transect was 12 inches deep and as wide as the useable grid and was identified by holding a retractable tape measure perpendicular to the 100-foot tape. The useable grid width included the width of the stream with relatively laminar flow that excluded eddies, vegetation, and large obstructions. Random numbers, equating to one foot increments, were drawn to determine where the quadrat was placed along each transect. The quadrat was placed within the transect, with the downstream edge contacting the downstream transect edge. Two observers estimated/recorded the percent of fine sediment within the quadrat. The estimates were accepted and recorded if the two observations were within a ten percent margin of error or rejected and repeated until the margin of error was reached. Another random number was drawn and the quadrat was randomly placed in the next transect upstream where the next observation was made. This continued until fine sediment was estimated in each of the six quadrats (one per transect) and the results are summarized in Table B-1.

Table B-1. Fine sediment deposition measurements in Shibboleth Branch and control streams (percentages).

Shibboleth Br #3	Shibboleth Br #2	Shibboleth Br #1	W. Fk Huzzah Cr.	Shoal Cr.
6	13	40	3	3
3	13	43	3	1
90	55	15	3	1
25	68	517	7	1
7	37	33	7	7
13	19	20	1	1
5	7	77	4	23
6	13	13	3	20
5	81	23	2	23
85	5	10	3	87
5	23	7	70	80
3	13	15	53	63
90	33	43	3	3
17	73	77	1	15
87	85	80	5	7
87	80	85	7	20
95	95	77	2	8
95	95	67	3	13

To address the impairment for inorganic sediment as percent fine sediment and cadmium, lead, and zinc in sediment, a relationship was generated using percent fine sediment data and the specific mass of sampled sediment from the stream bottom. This relationship is independent of segment location and refers to the location of the sample taken. As such, the bed sediment load capacities are instantaneous and apply on any given day.

The percent fine sediment target of 15.45 percent was developed using control sites in reference streams that are described in Table 4 in Section 4.2.1 of this TMDL. The load capacity curve and table were developed based on the mass of fine sediment that could be contained within a bottom sediment sample of a given mass.

The bed sediment metal load capacity was generated using the equilibrium partitioning methodology described in the TMDL. The load capacity was calculated based on the percent of a sediment mass that could be composed of metals such that the Threshold Effect Concentration was not exceeded. As with the percent fine sediment target, this load capacity applies on any given day.

Load Duration Curves

To develop the dissolved cadmium, lead, and zinc load duration curve (LDC) for Shibboleth Branch, a synthetic flow duration curve was developed based on the level of stream flow measured in gaged streams within the same region of the state. The U.S. Geological Survey (USGS) gage stations used are shown in Table B-2.

Table B-2. USGS Gage stations used to develop flow regime for Water Body ID 2120.

USGS No.	Site Name	Drainage Area (mi^2)
07037000	Big Creek @ Des Arc	99.6
07020550	S Fork Saline Cr near Perryville	55.3
07061270	E Fk Black R near Centerville	52.2
07061900	Logan Cr at Ellington	139
07015720	Bourbeuse River near High Gate	135

The median discharge per square mile was calculated for these streams and applied to the upper segment of Shibboleth Branch based its drainage area of 8.82 mi^2.

Once a flow regime was calculated, an estimated Total Suspended Solids (TSS) concentration was derived from streams with measured concentrations in the region (Table B-3). The LDC for suspended sediment was generated based on the 25th percentile of all TSS data. The LDCs for dissolved cadmium, lead, and zinc were generated based on the numeric criterion calculated using the 25th percentile of hardness data in the region (Table B-4).

Table B-3. Water quality sites used for calculation of 25th percentile total hardness and total suspended solids.

USGS No. or Agency	Site Name	Hardness Data	TSS Data
Mo DNR	Big R. @Washington State Park	X	
Mo DNR	Big R. 0.7 mi.bl. Eaton Br.	X	
Mo DNR	Big R. DS of Clear Cr.	X	
Mo DNR	Big R. just ab. Furnace Cr.	X	
Mo DNR	Big R. near Belgrade	X	
07018100	Big R. near Richwoods	X	X
Mo DNR	Big R. upstream of Bonne Terre	X	
Mo DNR	Big R. upstream of Mill Creek	X	
375232090325 800	Big River @ Bone Hole	X	X
Mo DNR,	Big River @ St Francois State Park	X	
07012700, Mo DNR	Big River at Irondale	X	X
Mo DNR	Big River below Desloge	X	X

USGS No. or Agency	Site Name	Hardness Data	TSS Data
Mo DNR	Big River just bl. Cedar Cr.	X	
Mo DNR	Big River just bl. Flat River	X	
Mo DNR	Big River nr. Washington St.Pk.	X	
07016500	Bourbeuse R. above Union	X	X
Mo DNR	Brazil Cr. @ Campground	X	X
Mo DNR	Brazil Cr. @Thicky Ford	X	
07017605	Coonville Creek nr. Mouth	X	X
Mo DNR	Courtois Cr. @ Goodwater,ab.Viburnum tailings	X	X
07014200	Courtois Cr. @Hwy 8	X	X
Mo DNR	Courtois Cr. ab. Bass Creek Resort	X	
Mo DNR	Courtois Cr. ab. Indian Cr. @old Hwy C	X	
Mo DNR	Courtois Creek 4 mi. N. of Courtois, MO.	X	
Mo DNR	Crooked Cr. @ Chandler Rd.	X	X
Mo DNR	Crooked Cr. @ County Line	X	
Mo DNR	Crooked Cr. just ab. trib. from Casteel Mine	X	
Mo DNR	Crooked Creek 3 mi. WSW of Viburnum, Mo.	X	X
Mo DNR	Cub Cr. 2 mi. NE of Courtois, Mo.	X	
Mo DNR	E. Fk. Huzzah Cr. @ CR 530	X	X
Mo DNR	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	X	
Mo DNR	Eaton Br. @CR nr mouth	X	
Mo DNR	Eaton Branch nr mouth	X	
07019220	Fenton Cr.@Hwy 141	X	X
07019120	Fishpot Cr.@Valley Park	X	X
Mo DNR	Flat River Cr.@Hwy B	X	X
Mo DNR, UMR	Flat River Cr.@Main Street,Flat River,MO	X	X
Mo DNR	Flat River Cr.@Rivermines	X	X
Mo DNR	Fountain Farm Branch nr. Mouth	X	X
Mo DNR	Fourche Renault Cr. ab. Hwy 185	X	
Mo DNR	Furnace Cr. 0.4 mi US of Big R.	X	
Mo DNR	Goose Cr. 3.2 mi.bl. Tailings pond	X	
07019185	Grand Glaize Cr. @Valley Park	X	X
07140104	Heads Cr. @ Hwy. 30	X	X
Mo DNR	Huzzah Cr. @ US of Davisville Rd.	X	
07014000	Huzzah Cr. @Hwy 8	X	X
07014300	Huzzah Cr. nr mouth	X	X
Mo DNR	Indian Cr. 4.5 mi.bl. Mary's Cr.	X	
Mo DNR	Indian Cr.@ old Hwy C, 2 mi.bl. Viburnum tailings	X	
07019072	Kiefer Cr. nr. Ballwin	X	X
Mo DNR	L. Courtois Cr. 100 yds.bl. Mary's Cr.	X	
Mo DNR	L. Courtois Cr. 50 yds.ab. Mary's Cr.	X	
Mo DNR	Mary's Cr. 30 yds. Ab. Mouth	X	
07019317	Mattese Cr. @Ringer Rd. bridge	X	X
Mo DNR	Meramec R. @ MDC Short Bend CA	X	
07019280	Meramec R. @ Paulina Hills,MO.	X	X
07010350	Meramec R. above Cook Station		X
07019000	Meramec R. nr. Eureka	X	X
07014500	Meramec R. nr. Sullivan,MO.	X	X
Mo DNR	Mill Cr. @Tiff,Mo.	X	
Mo DNR	Mill Creek ab. Hwy 47	X	

USGS No. or Agency	***Site Name***	***Hardness Data***	***TSS Data***
Mo DNR	Mill Creek bl. Tiff	X	
Mo DNR	Mineral Fork @Hwy 47	X	
Mo DNR	Mineral Fork ab. Kingston CA	X	
Mo DNR	Mineral Fork bl. Hwy F	X	
Mo DNR	Pond Cr. nr. Mouth	X	X
Mo DNR	Shaw Br. @ St. Joe S. P.	X	X
Mo DNR	Shibboleth Cr. @ CR 410(Johnson Rd.) xing #2	X	X
Mo DNR	Shibboleth Cr. @ CR 410(Johnson Rd.) xing #4	X	X
Mo DNR	Shibboleth Cr. @Hwy E		X
Mo DNR	Shibboleth Cr. 0.4 mi. bl. Hwy. E	X	X
Mo DNR	Shibboleth Cr. Nr Heritage Rd.		X
Mo DNR	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd. inters.	X	X
Mo DNR	Shoal Creek 2 mi. NE of Davisville, Mo.	X	
Mo DNR	Spring Cr. @ CR 416		X
07019260	Sugar Cr. Nr. Paulina Hills	X	X
Mo DNR	Trib. To Old Mines Cr.(Salt Pine Cr.)@ Hwy.21	X	X
Mo DNR	Trib. To Old Mines Creek @ Hwy. 21	X	X
Mo DNR	Trib. To Pond Cr. @ Pond Creek Rd.	X	X
Mo DNR	W. Fk. Huzzah Cr. @ Hwy. 32	X	
Mo DNR	Trib. To Turkey Cr. Nr. Mouth		X
Mo DNR	Trib2. To Turkey Cr. Nr. Mouth		X
Mo DNR	Turkey Cr. @Hwy 47, ab. Chat pile		X
Mo DNR	W. Fk. Huzzah Cr. @ Hwy. 32		X
Mo DNR	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	X	
07019090	Williams Cr. nr.Peerless Park	X	

Table B-4. Data used in calculating applicable hardness value.

Org	Site	Site Name	Hardness
MDNR	2080/8.5	Big R. @Washington State Park	268
MDNR	2080/8.5	Big R. @Washington State Park	238
MDNR	2080/55.6	Big R. 0.7 mi.bl. Eaton Br.	263
MDNR	2080/55.6	Big R. 0.7 mi.bl. Eaton Br.	192
MDNR	2080/73.4	Big R. DS of Clear Cr.	210
MDNR	2080/73.4	Big R. DS of Clear Cr.	220
MDNR	2080/73.4	Big R. DS of Clear Cr.	150
MDNR	2080/71.8	Big R. just ab. Furnace Cr.	168
MDNR	2080/71.6	Big R. near Belgrade	240
MDNR	2080/71.6	Big R. near Belgrade	240
MDNR	2080/71.6	Big R. near Belgrade	160
USGS	2074/53.0	Big R. near Richwoods	210
USGS	2074/53.0	Big R. near Richwoods	170
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	310
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	260
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	290
USGS	2074/53.0	Big R. near Richwoods	200
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	160
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	180
USGS	2074/53.0	Big R. near Richwoods	180
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	300
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	260
USGS	2074/53.0	Big R. near Richwoods	290
USGS	2074/53.0	Big R. near Richwoods	140
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	310
USGS	2074/53.0	Big R. near Richwoods	150
USGS	2074/53.0	Big R. near Richwoods	190
USGS	2074/53.0	Big R. near Richwoods	230
USGS	2074/53.0	Big R. near Richwoods	270
USGS	2074/53.0	Big R. near Richwoods	200
USGS	2074/53.0	Big R. near Richwoods	250
USGS	2074/53.0	Big R. near Richwoods	210
USGS	2074/53.0	Big R. near Richwoods	240
USGS	2074/53.0	Big R. near Richwoods	280
USGS	2074/53.0	Big R. near Richwoods	190
MDNR	2080/20.4	Big R. upstream of Bonne Terre	261
MDNR	2080/20.4	Big R. upstream of Mill Creek	297
MDNR	2080/20.4	Big R. upstream of Mill Creek	229
USGS	2080/48.6	River River @ Bone Hole	170
USGS	2080/48.6	River River @ Bone Hole	290
USGS	2080/48.6	River River @ Bone Hole	240
USGS	2080/48.6	River River @ Bone Hole	160
USGS	2080/48.6	River River @ Bone Hole	200
USGS	2080/48.6	River River @ Bone Hole	220
USGS	2080/48.6	River River @ Bone Hole	330
USGS	2080/48.6	River River @ Bone Hole	320
USGS	2080/48.6	River River @ Bone Hole	240
MDNR	2080/32.4	BigRiver @ St. Francois State Park	264
MDNR	2080/32.4	BigRiver @ St. Francois State Park	234
USGS	2080/65.5	Big River at Irondale	130
USGS	2080/65.5	Big River at Irondale	190
USGS	2080/65.5	Big River at Irondale	180

Org	Site	Site Name	Hardness
USGS	2080/65.5	Big River at Irondale	140
USGS	2080/65.5	Big River at Irondale	160
USGS	2080/65.5	Big River at Irondale	160
USGS	2080/65.5	Big River at Irondale	210
USGS	2080/65.5	Big River at Irondale	209
USGS	2080/65.5	Big River at Irondale	162
MDNR	2080/42.5	Big River below Desloge	264
MDNR	2080/42.5	Big River below Desloge	304
MDNR	2080/42.5	Big River below Desloge	213
MDNR	2080/68.3	Big River just bl. Cedar Cr.	240
MDNR	2080/68.3	Big River just bl. Cedar Cr.	170
MDNR	2080/41.9	Big River just bl. Flat River	247
MDNR	2080/41.9	Big River just bl. Flat River	228
MDNR	2080/11.6	Big River nr. Washington St. Pk.	287
USGS	2034/21.5	Bourbeuse R. above Union	95
USGS	2034/21.5	Bourbeuse R. above Union	73
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	170
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	97
USGS	2034/21.5	Bourbeuse R. above Union	69
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	160
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	66
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	190
USGS	2034/21.5	Bourbeuse R. above Union	71
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	75
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	80
USGS	2034/21.5	Bourbeuse R. above Union	130

Org	Site	Site Name	Hardness
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	140
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	170
USGS	2034/21.5	Bourbeuse R. above Union	63
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	110
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	59
USGS	2034/21.5	Bourbeuse R. above Union	100
USGS	2034/21.5	Bourbeuse R. above Union	88
USGS	2034/21.5	Bourbeuse R. above Union	150
USGS	2034/21.5	Bourbeuse R. above Union	84
USGS	2034/21.5	Bourbeuse R. above Union	160
USGS	2034/21.5	Bourbeuse R. above Union	130
USGS	2034/21.5	Bourbeuse R. above Union	120
USGS	2034/21.5	Bourbeuse R. above Union	180
USGS	2034/21.5	Bourbeuse R. above Union	100
MDNR	1983/12.5	Brazil Cr. @ Campground	137
MDNR	1983/12/5	Brazil Cr. @ Campground	116
MDNR	1983/0.8	Brazil Cr. @ Thicky Ford	176
MDNR	1983/0.8	Brazil Cr. @ Thicky Ford	193
USGS	2177/0.2	Coonville Creek nr. Mouth	270
USGS	2177/0.2	Coonville Creek nr. Mouth	210
USGS	2177/0.2	Coonville Creek nr. Mouth	190
USGS	2177/0.2	Coonville Creek nr. Mouth	160
USGS	2177/0.2	Coonville Creek nr. Mouth	280
USGS	2177/0.2	Coonville Creek nr. Mouth	260
USGS	2177/0.2	Coonville Creek nr. Mouth	250
USGS	2177/0.2	Coonville Creek nr. Mouth	220
USGS	2177/0.2	Coonville Creek nr. Mouth	260
USGS	2177/0.2	Coonville Creek nr. Mouth	110
USGS	2177/0.2	Coonville Creek nr. Mouth	140
MDNR	1947/2.0/1.0	Courtois Cr. @ Goodwater, ab. Viburnum	143
MDNR	1947/2.0/1.0	Courtois Cr. @ Goodwater, ab. Viburnum	83.7
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210
USGS	1943/15.7	Courtois Cr. @ Hwy 8	210

Org	Site	Site Name	Hardness
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	160
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	110
USGS	1943/15.7	Courtois Cr. @ Hwy 8	140
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	250
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	230
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	78
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	130
USGS	1943/15.7	Courtois Cr. @ Hwy 8	240
USGS	1943/15.7	Courtois Cr. @ Hwy 8	150
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	190
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	230
USGS	1943/15.7	Courtois Cr. @ Hwy 8	170
USGS	1943/15.7	Courtois Cr. @ Hwy 8	200
USGS	1943/15.7	Courtois Cr. @ Hwy 8	220
USGS	1943/15.7	Courtois Cr. @ Hwy 8	140
MDNR	1943/5.1	Courtois Cr. ab. Bass Creek Resort	183
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	150
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	190
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	170
MDNR	1943/29.5	Courtois Cr. ab. Indian Cr. @ old Hwy C	130
MDNR	1943/23.4	Courtois Creek 4 mi. N. of Courtois, MO	260
MDNR	1943/23.4	Courtois Creek 4 mi. N. of Courtois, MO	170
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	353
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	465
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	192
MDNR	1928/3.5	Crooked Cr. @ Chandler Rd.	325
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	332
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	280
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	320
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	246

Org	Site	Site Name	Hardness
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	259
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	260
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	362
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	364
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	243
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	351
MDNR	1928/3.5/0.1	Crooked Cr. ! County Line	423
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	820
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	549
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	593
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	398
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	261
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	179
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	427
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	274
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	163
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	295
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	383
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	548
MDNR	1928/3.5/3.7	Crooked Cr. just ab. trib. from Casteel Mine	368
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	240
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	200
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	318
MDNR	1928/0.5	Crooked Creek 3 mi. WSW of Viburnum, Mo.	172
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	220
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	150
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	234
MDNR	1948/0.4	Cub Cr. 2 mi. NE of Courtois, Mo.	184
MDNR	1926/1.0	E. Fk. Huzzah Cr. @ CR 530	183
MDNR	1926/1.0	E. Fk. Huzzah Cr. @ CR 530	153
MDNR	1925/2.3	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	220
MDNR	1925/2.3	E. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	160
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	539
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	321
MDNR	2166/0.2	Eaton Br. @ CR nr mouth	536
MDNR	2166/0.05	Eaton Branch nr mouth	597
MDNR	2166/0.05	Eaton Branch nr mouth	422
MDNR	2166/0.05	Eaton Branch nr mouth	375
MDNR	2166/0.05	Eaton Branch nr mouth	715
MDNR	2166/0.05	Eaton Branch nr mouth	581
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	120
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	420

Org	Site	Site Name	Hardness
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	200
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	310
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	300
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	95
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	320
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	120
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	360
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	100
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	290
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	340
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	140
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	390
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	450
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	610
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	158
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	365
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	98
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	480
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	422
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	140
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	550
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	150
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	530
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	500
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	220
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	92
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	510
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	430
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	150
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	600
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	600
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	130
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	450
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	170
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	570
USGS	3595/0.5/0.9	Fenton Cr. @ Hwy 141	510
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	48
USGS	2186/1.7	Fishpot Cr. @ Valley Park	220
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	65

Org	Site	Site Name	Hardness
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	340
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	86
USGS	2186/1.7	Fishpot Cr. @ Valley Park	190
USGS	2186/1.7	Fishpot Cr. @ Valley Park	240
USGS	2186/1.7	Fishpot Cr. @ Valley Park	45
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	72
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	260
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	42
USGS	2186/1.7	Fishpot Cr. @ Valley Park	85
USGS	2186/1.7	Fishpot Cr. @ Valley Park	150
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	290
USGS	2186/1.7	Fishpot Cr. @ Valley Park	160
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	170
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	45
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	150
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	210
USGS	2186/1.7	Fishpot Cr. @ Valley Park	66
USGS	2186/1.7	Fishpot Cr. @ Valley Park	300
USGS	2186/1.7	Fishpot Cr. @ Valley Park	250
USGS	2186/1.7	Fishpot Cr. @ Valley Park	87
USGS	2186/1.7	Fishpot Cr. @ Valley Park	200
USGS	2186/1.7	Fishpot Cr. @ Valley Park	230
USGS	2186/1.7	Fishpot Cr. @ Valley Park	60
USGS	2186/1.7	Fishpot Cr. @ Valley Park	330
USGS	2186/1.7	Fishpot Cr. @ Valley Park	100
USGS	2186/1.7	Fishpot Cr. @ Valley Park	180
USGS	2186/1.7	Fishpot Cr. @ Valley Park	160
USGS	2168/5.9	Flat River Cr. @ Hwy B	120180
USGS	2168/5.9	Flat River Cr. @ Hwy B	240

Org	Site	Site Name	Hardness
USGS	2168/5.9	Flat River Cr. @ Hwy B	140
USGS	2168/5.9	Flat River Cr. @ Hwy B	160
USGS	2168/5.9	Flat River Cr. @ Hwy B	210
USGS	2168/5.9	Flat River Cr. @ Hwy B	240
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	99
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	279
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	305
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	97
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	104
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	188
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	219
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	422
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	185
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	202
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	238
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	76
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	144
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	221
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	242
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	309
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	186
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	359
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	240
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	191
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	85
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	195
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	138
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	281
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	214
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	153
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	220
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	172
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	100
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	160
MDNR-DPHP	2168/5.9	Flat River Cr. @ Hwy B	100
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	316
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	133
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	359
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	307
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	101
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	122
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	385
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	319

Org	Site	Site Name	Hardness
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	540
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	495
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	686
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	789
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	95
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	259
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	321
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	381
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	225
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	460
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	254
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	740
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	502
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	379
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	317
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	139
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	389
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	124
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	313
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	269
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	194
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	400
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	277
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	180
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	480
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	300
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	180
MDNR-DPHP	2168/3.9	Flat River Cr. @ Main Street, Flat River, MO	100
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	450
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	126
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	376
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	389
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	138
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	95
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	171
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	239
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	1030
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	203
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	189
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	705
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	83
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	276
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	330

Org	Site	Site Name	Hardness
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	517
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	495
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	281
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	453
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	323
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	339
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	124
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	385
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	146
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	273
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	198
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	100
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	153
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	250
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	189
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	120
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	260
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	160
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	200
MDNR-DPHP	2168/4.4	Flat River Cr. @ Rivermines	100
MDNR	3657/0.1	Fountain Farm Branch nr. Mouth	215
MDNR	3657/0.1	Fountain Farm Branch nr. Mouth	231
MDNR	2084/1.8	Fourche Renault Cr. ab. Hwy 185	205
MDNR	2084/1.8	Fourche Renault Cr. ab. Hwy 185	147
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	280
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	280
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	240
MDNR	2140/0.4	Furnace Cr. 0.4 mi US of Big R.	268
MDNR	2010/1.0	Goose Cr. 3.2 mi. bl. Tailings pond	235
MDNR	2010/1.0	Goose Cr. 3.2 mi. bl. Tailings pond	173
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	75
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	390
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	350
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	120
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	100
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	240
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220

Org	Site	Site Name	Hardness
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	220
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	170
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	585
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	380
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	320
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	140
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	260
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	260
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	390
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	290
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	230
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	410
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	240
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	170
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	530
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	130
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	340
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	410
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	270
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	330
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	140
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	200
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	180
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	290
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	280
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	310
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	480

Org	Site	Site Name	Hardness
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	370
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	360
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	300
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	380
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	150
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	190
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	160
USGS	2184/3.2	Grand Glaize Cr. @ Valley Park	210
USGS	2181/0.3	Heads Cr. @ Hwy. 30	260
USGS	2181/0.3	Heads Cr. @ Hwy. 30	280
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	225
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	209
MDNR	1903/18.2	Huzzah Cr. @ US of Davisville Rd.	224
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	170
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	180
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	170
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	140
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	160
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	206
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	189
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	203
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	86
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	140
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	200
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	180

Org	Site	Site Name	Hardness
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	220
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	190
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	210
USGS	1903/6.9	Huzzah Cr. @ Hwy 8	150
USGS	1903/1.3	Huzzah Cr. nr mouth	170
USGS	1903/1.3	Huzzah Cr. nr mouth	210
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	440
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	214
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	254
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	176
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	170
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	158
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	212
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	174
MDNR	1999/9.0	Indian Cr. 4.5 mi. bl. Mary's Cr.	182
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	260
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	310
MDNR	1946/0.1	Indian Cr. @ old Hwy C, 2 mi. bl. Viburnum	210
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	91
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	120
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	280
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	320
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	64
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	81
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	250
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	310
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	100
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	86
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	310
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	230
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	75
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	80
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	64
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	280

Org	Site	Site Name	Hardness
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	561
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	297
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	151
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	108
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	322
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	296
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	85
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	340
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	260
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	330
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	230
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	110
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	320
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	350
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	140
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	330
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	350
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	65
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	380
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	180
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	270
USGS	3592/0.5/0.8	Kiefer Cr. nr. Ballwin	290
MDNR	2002/1.7	L. Courtois Cr. 100 yds. bl. Mary's Cr.	533
MDNR	2002/1.8	L. Courtois Cr. 100 yds. bl. Mary's Cr.	209
MDNR	2002/1.8	L. Courtois Cr. 100 yds. bl. Mary's Br.	222
MDNR	3661/0.1	Mary's Cr. 30 yds. ab. Mouth	492
MDNR	3661/0.1	Mary's Cr. 30 yds. ab. Mouth	619
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	67
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	67
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	43
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	51
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	160
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	320
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	360
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	280
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	310

Org	Site	Site Name	Hardness
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	180
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	320
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	62
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	270
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	92
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	230
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	250
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	415
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	204
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	267
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	280
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	240
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	155
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	615
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	195
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	210
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	380
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	140
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	300
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	260
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	60
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	270
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	430
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	84
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	370
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	370
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	88
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	260
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	390
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	120
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	340
USGS	3596/0.9/2.5	Mattese Cr. @ Ringer Rd. bridge	340
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	195
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	215
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	185
MDNR	1871/14.8	Meramec River @ MDC Short Bend CA	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	66
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	86
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	230
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	220
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	220
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	240
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	83
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	130
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	160
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	120
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	200
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	180

Org	Site	Site Name	Hardness
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	170
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	210
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	140
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	190
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	150
USGS	2183/10.2	Meramec River @ Paulina Hills, MO.	110
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	110
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	45
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	220
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	120
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	260
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	86
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	230
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	92
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	210

Org	Site	Site Name	Hardness
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	91
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	200
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	210
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	110
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	72
USGS	2185.12.3	Meramec R. nr. Eureka	190
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	150
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	2185.12.3	Meramec R. nr. Eureka	130
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	160
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	140
USGS	2185.12.3	Meramec R. nr. Eureka	170
USGS	2185.12.3	Meramec R. nr. Eureka	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	150
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200

Org	Site	Site Name	Hardness
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	100
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	160
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210

Org	Site	Site Name	Hardness
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	110
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	120
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	220
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	140
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	110
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	190
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	210
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	200
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	180
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	130
USGS	1846/4.1	Meramec R. nr. Sullivan, MO	170
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	230
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	226
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	272
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	169
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	186
MDNR	2118/3.2	Mill Cr. @ Tiff, Mo.	249
MDNR	2118/8.5	Mill Creek ab. Hwy 47	256
MDNR	2118/8.5	Mill Creek ab. Hwy 47	160
MDNR	2118/2.9	Mill Creek bl. Tiff	244
MDNR	2118/2.9	Mill Creek bl. Tiff	189
MDNR	2081/5.5	Mineral Fork @ Hwy 47	250
MDNR	2081/5.5	Mineral Fork @ Hwy 47	194
MDNR	2081/5.5	Mineral Fork @ Hwy 47	261

Org	Site	Site Name	Hardness
MDNR	2081/5.5	Mineral Fork @ Hwy 47	190
MDNR	2081/5.5	Mineral Fork @ Hwy 47	176
MDNR	2081/5.5	Mineral Fork @ Hwy 47	223
MDNR	2081/5.5	Mineral Fork @ Hwy 47	207
MDNR	2081/5.5	Mineral Fork @ Hwy 47	240
MDNR	2081/2.5	Mineral Fork ab. Kingston CA	245
MDNR	2081/2.5	Mineral Fork ab. Kingston CA	200
MDNR	2081/12.5	Mineral Fork bl. Hwy F	249
MDNR	2081/12.5	Mineral Fork bl. Hwy F	192
MDNR	2127/0.1	Pond Cr. nr. Mouth	202
MDNR	2127/0.1	Pond Cr. nr. Mouth	220
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	330
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	206
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	426
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	412
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	135
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	184
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	281
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	885
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	237
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	236
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	605
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	201
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	561
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	465
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	196
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	185
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	180
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	320
MDNR-DPHP	2170/0.6	Shaw Br. @ St. Joe S.P.	160
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	198
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	184
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	243
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	206
MDNR	2120/0.3	Shibboleth Cr. @ CR 410 (Johnson Rd.) xing	189
MDNR	2120/2.3	Shibboleth Cr. 0.4 mi. bl. Hwy E	124
MDNR	2120/2.3	Shibboleth Cr. 0.4 mi. bl. Hwy E	173
MDNR	1934/6.1	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd.	213
MDNR	1934/6.1	Shoal Cr. nr. Big Shoal Creek Rd./Stotler Rd.	171
MDNR	1934/5.2	Shoal Creek 2 mi. NE of Davisville, Mo..	240
MDNR	1934/5.2	Shoal Creek 2 mi. NE of Davisville, Mo..	160
USGS	2191/0.8	Sugar Cr. nr. Paulina Hills	200
USGS	2191/0.8	Sugar Cr. nr. Paulina Hills	240

Org	Site	Site Name	Hardness
MDNR	2113/0.1	Trib. To Old Mines Cr. (Salt Pine Cr.)@	242
MDNR	2113/0.1	Trib. To Old Mines Cr. (Salt Pine Cr.)@	272
MDNR	2114/0.1	Trib. To Old Mines Creek @ Hwy. 21	235
MDNR	2114/0.1	Trib. To Old Mines Creek @ Hwy. 21	232
MDNR	2128/0.8	Trib To Pond Cr. @ Pond Creek Rd.	100
MDNR	2128/0.8	Trib To Pond Cr. @ Pond Creek Rd.	158
MDNR	1923/0.1	W. Fk. Huzzah Cr. @ Hwy. 32	146
MDNR	1923/0.1	W. Fk. Huzzah Cr. @ Hwy. 32	121
MDNR	1922/3.2	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	220
MDNR	1922/3.2	W. Fk. Huzzah Cr. 4 mi. S. of Dillard, Mo.	130
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	210
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	180
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	89
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	78
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	260
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	73
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	160
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	53
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	220
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	71
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	130
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	210
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	190
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	280
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	140
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	200
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	54
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	230
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	83
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	250
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	84
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	290
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	280
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170

Org	Site	Site Name	Hardness
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	260
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	85
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	240

Org	Site	Site Name	Hardness
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	140
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	190
USGS	3594/0.7/0.1	Williams Cr. nr. Peerless Park	170

Appendix C

Reference Approach to Develop Suspended Sediment TMDL Load Duration Curves

Overview

This procedure is used when a lotic system is placed on the 303(d) impaired water body list for a pollutant and the designated use being addressed is aquatic life. In cases where pollutant data for the impaired stream is not available a reference approach is used. The target for pollutant loading is the 25th percentile calculated from all data available within the ecological drainage unit (EDU) in which the water body is located. Additionally, it is also unlikely that a flow record for the impaired stream is available. If this is the case a synthetic flow record is needed. In order to develop a synthetic flow record, calculate an average of the log discharge per square mile of USGS gaged rivers within the region. (Ideally, the drainage area for each of these should be entirely contained within the EDU. However, due to the small size of the Shibboleth Branch watershed, and the lack of gaging stations in smaller watersheds within the Ozark/Meramec EDU, four of the five gaging stations used in this study are outside the EDU but within the Ozark ecoregion.) From this synthetic record develop a flow duration from which to build a load duration curve for the pollutant within the EDU.

From this population of load durations follow the reference method used in setting nutrient targets in lakes and reservoirs. In this methodology the average concentration of either the 75th percentile of reference lakes or the 25th percentile of all streams in the region is targeted in the TMDL. For most cases available pollutant data for reference streams is also not likely to be available. Therefore follow the alternative method and target the 25th percentile of load duration of the available data within the EDU as the TMDL load duration curve. During periods of low flow the actual pollutant concentration may be more important than load. To account for this during periods of low flow the load duration curve uses the 25th percentile of EDU concentration at flows where surface runoff is less than 1 percent of the stream flow. This results in an inflection point in the curve below which the TMDL is calculated using this reference concentration.

Methodology

The first step in this procedure is to locate available pollutant data within the area of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are recorded to create the population from which to develop the load duration. Both the date and pollutant concentration are needed in order to match the measured data to the synthetic flow record.

Secondly, collect average daily flow data for gages with a variety of drainage areas for a period of time to cover the pollutant record. From these flow records normalize the flow to a per square mile basis. Average the daily discharge for each day in the period of record. For each gage record used to build this synthetic flow record calculate the Nash-Sutcliffe statistic (see box below) to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square mile is used to develop the load duration for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow.

Nash-Sutcliffe Statistic

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_o})^2}$$

E = efficiency of model: 100% indicates that model is perfectly matched to observed data
Q_o^t = observed discharge at time t
Q_m^t = modeled discharge for time t
$\overline{Q_o}$ = average of observed discharges

The watershed-size normalized data for the individual gages were calculated and compared to a pooled data set including all of the gages. The result of this analysis is displayed in the following figure and table:

Table C-1: Nash-Sutcliffe Statistics for Reference Gages

Stream	USGS gage #	Watershed area (mi^2)	Period of Record	Nash-Sutcliffe Statistic (%)
Big Creek	07037000	99.6	10/01/2001 - 05/03/2004	92
Bourbeuse River	07015720	135	01/01/2000 - 08/10/2010	91
E Fork Black River	07061270	52.2	10/01/2001 - 08/10/2010	82
Logan Creek	07061900	139	01/01/2000 - 08/10/2010	99
S Fork Saline Creek	07020550	55.3	01/01/2000 - 08/10/2010	98

This demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

The next step is to determine the target range for inorganic sediment. All data points within the EDU that include sediment concentrations concurrent with flow are compiled. The distribution of sediment is recalculated so that the median value of the adjusted distribution is equal to the 25^{th} percentile of the original distribution while the minimum values remain constant. From the adjusted range, the load is calculated *[(mg/L) * (cfs) * 5.395 = lbs/day]* and log transformed. A regression calculation is performed against the log of the instantaneous flow. Results are found in Figure C-2:

Figure C-1: Modeled and Reference Flow Duration Curves

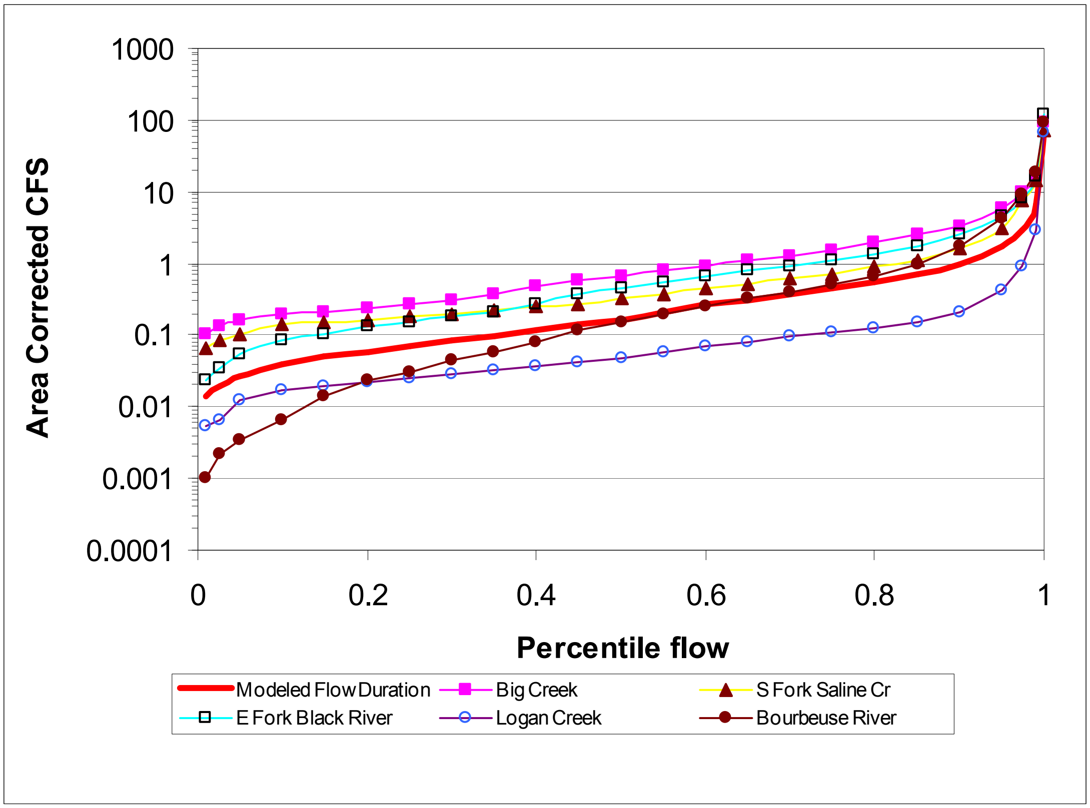
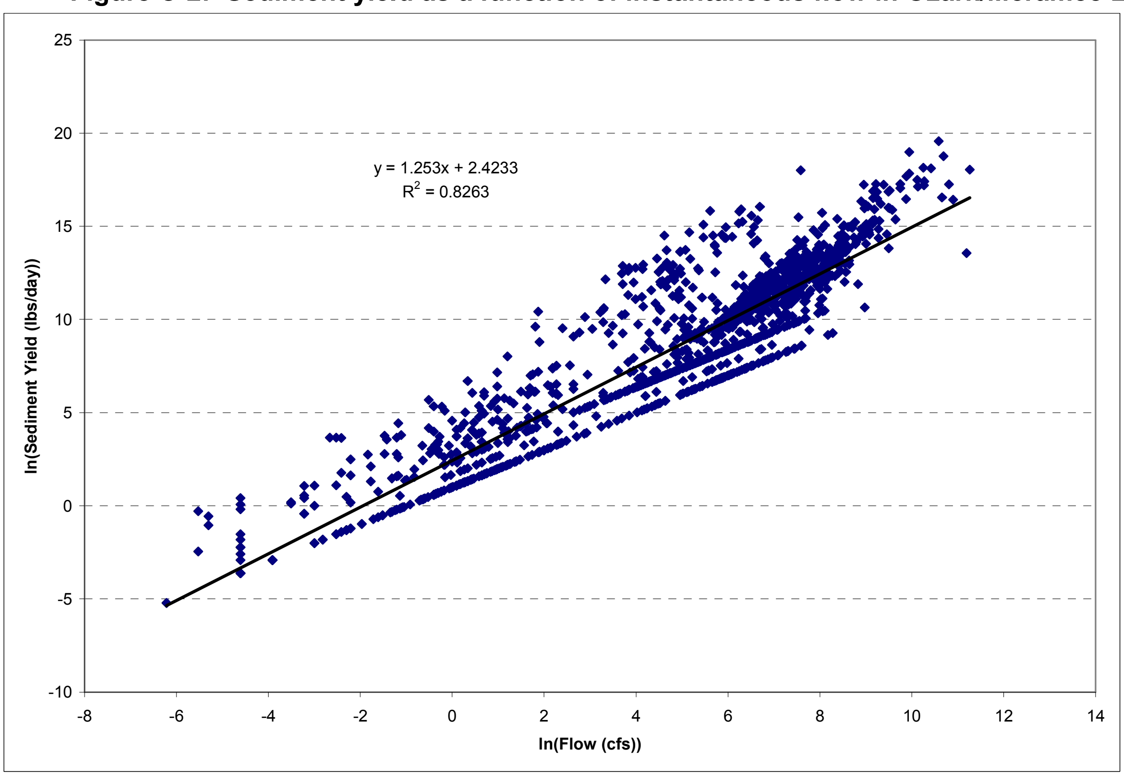


Figure C-2: Sediment yield as a function of instantaneous flow in Ozark/Meramec EDU.



The load duration curve was then calculated by back transforming the regression equation:

*Sediment yield (lbs/day)=exp(1.2538 * ln (flow) + 2.4233)*

This is then applied to the range of flows modeled in the FDC. For the metals, this some procedure is used, except that the target load is calculated directly from chronic limits in the water quality standards, based on hardness levels calculated for the EDU (see Appendix B of this TMDL).

To apply this process to a specific watershed, use the individual watershed data compared to the above TMDL curve that has been multiplied by the watershed area. Data from the impaired segment is then plotted as a load (lbs/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis. Results for TSS and dissolved metals (cadmium, lead and zinc) can be found in Figure 9 and Figures 10 – 12, respectively.

(Sources: USEPA 2006a, USEPA 2010 – See References section of this Shibboleth Branch TMDL)

For more information contact:
Environmental Protection Agency, Region 7
Water, Wetlands, and Pesticides Division
Total Maximum Daily Load Program
901 North 5th Street
Kansas City, KS 66101
Web site: www.epa.gov/region07/water/tmdl.htm