APPENDIX D
SEDIMENT CONTRIBUTION FROM ROADS

Approach
Sediment delivery from roadways was estimated using WARSEM, a Microsoft Access based model developed for and used by the State of Washington Department of Natural Resources for assessing sediment production and delivery to streams from roads under its jurisdiction. WARSEM is an empirical model and estimates sediment production and delivery based on road surfacing, road use, underlying geology, precipitation, road age, road gradient, road prism geometry (including road configuration and ditch geometry), cut slope cover, and other factors (Dube' et al 2004).

Data Sources
For a Level 3 assessment, defined in the WARSEM documentation as "detailed assessment and scenario playing," the following parameters are required and must be field verified: Road location, surfacing, geology, segment length, road width, road gradient, delivery type, road configuration and prism geometry, cut slope height, cut slope cover, and ditch width. Traffic level is a parameter that is required, but may be estimated and need not be field verified. Three parameters are optional: Ditch condition, BMPs, and road age.

Data were collected and field verified for all but two of the required parameters: Road age and geology. Road age was estimated as per the model requirements. Budget constraints did not permit sending a geologist to the field to verify these data for each sampled road segment, but, given the coarse graduation of the effect of the geology parameter on model results (high, med, and low erosion classes), the greater accuracy of our method of assigning geology data to a sample location versus that assumed by the model (GIS overlay of specific lat/long positions, as opposed to general location by public land survey section number) we do not believe that this adversely affects the validity of the results.

WARSEM uses internal datasets for its rainfall and (non-field-verified) geology parameters. The user does not enter these data directly; they are derived based on the location of the sample site. These internal datasets are only defined for Washington State. We modified the WARSEM model, adding Montana specific datasets for these parameters. The geology erosion factor parameter was derived from data obtained from GIS coverage of the USGS 1:500K geology map of Montana. Appropriate values were determined based on a table of values for a variety of geologies (Dube' et al. 2004). The rainfall factor parameter was derived form PRISM precipitation data obtained from the Spatial Climate Analysis Service at Oregon State University. The PRISM data set gives mean monthly and annual precipitation levels for the United States at a resolution of 4 kilometers.

To extrapolate the WARSEM model results from the sampled road segments to the watershed as a whole, comprehensive datasets representing the locations of roads and streams were needed. We used GIS coverage of 2000 TIGER road data for road locations and the national hydrography dataset (NHD) for stream locations. We supplemented the sparse coverage of local roads in the TIGER data by digitizing additional road locations from 1:24,000 scale digital orthophotos.

Methods

Field data collection

The WARSEM assumes that roads greater than 200 feet from a stream do not deliver sediment to that stream unless a roadside ditch or gully is present to convey flow from the road to the stream or a point within 200 feet of the stream. Buffering the stream layer by 200 feet and intersecting this buffer with the roads data using GIS methods, identified potential sample locations for collecting field data as well as road segments to which the model results would be extrapolated. The field-sampling plan for the road data allocated the samples to be taken according to attributes which could be readily identified from GIS databases and which corresponded to the WARSEM parameters with the greatest effect on model results. Potential sample locations were stratified according to:

- Road type from the TIGER data. This was assumed to be an indicator of road surface, tread width, and traffic use.
- Ownership (USFS vs. other). This was assumed an indication of road surface, slope, traffic use, and management practices.
- STATSGO soil unit. This was assumed to be indicative of cut slope and ditch condition. It offers a finer division than the gross geology of the parent material on which the road was constructed.

As the variability of these attributes over the sample locations could not be predicted, sample locations were first chosen proportionally in accordance to the frequency of each combination of the values of those attributes, and the proportions were then adjusted to ensure that the more rare combinations of these attributes would have a sufficient number of samples taken to be statistically representative. As implemented, budget considerations resulted in fewer than the recommended number of samples being taken, and those were targeted toward the permutations that represented the greatest proportion of the roads in the watershed

Field crews were trained in collecting road data according to the assumptions and specifications of the WARSEM model and provided the appropriate equipment (clinometer, measuring tape, GPS, etc) to make accurate measurements. Locations of road sampling locations are shown in **Figure D-1.**

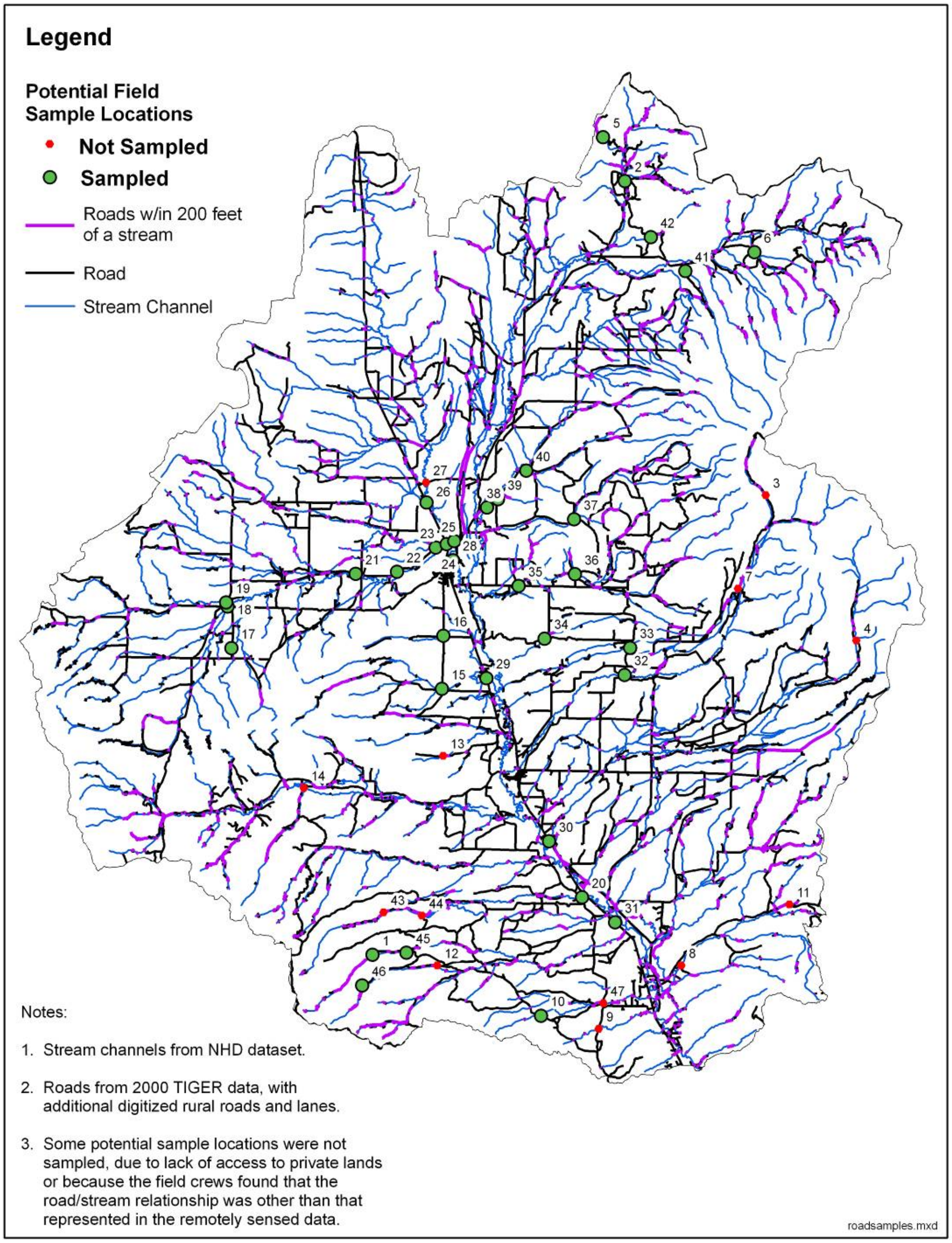

Figure D-1. Road sediment field sampling locations

When field crews noted existing BMPs at the sampled sites, the effect of the BMPs was included in the modeling of sample sites in the WARSEM by applying the appropriate model inputs to describe the observed BMPs. For example, rubber water diverters may have shortened the contributing segment length. If road surface BMPs were encountered model inputs reflected the existing field conditions. As a result, the existing BMPs were taken into account and were extrapolated throughout the watershed.

Model run and extrapolation

The WARSEM was run using the collected and derived input data, resulting in a predicted sediment delivery in tons/yr for each field sample segment. Extrapolation to the entire watershed was based on 2 parameters - Road Class and Road/Stream Orientation. Each road segment (within 200 feet of an NHD stream) in the GIS was assigned values for each of these categories. The Road Class category consisted of the following road types: 4x4, Local, Highway, Ranch, and Unknown. The Road/Stream Orientation category consisted of the following segment types: Crossing (for road segments that cross streams) and parallel (for road segments that are adjacent to streams but do not cross them). Ten extrapolation classes resulted from the combination of these parameters: 4x4Xing, LocalXing, HwyXing, RanchXing, UnknownXing, 4x4Para, LocalPara, HwyPara, RanchPara, and UnknownPara. The surveyed sites were broken down by extrapolation class and WARSEM was used to predict sediment delivery from each of the surveyed sites. An extrapolation factor was developed for each extrapolation class based on WARSEM results and the GIS.

$$ExtrapFactor = \frac{\sum_{i=1}^{n}\left[\frac{TS_i}{LGIS_i}\right]}{n} \qquad (1)$$

Where: *TS = total sediment delivery predicted by WARSEM for a given sample site (tons/year)*
LGIS = length of road within 200 ft of a stream at a given sample site as predicted by the GIS (ft)
n = number of sample sites for the extrapolation class in question

Adequate sample site data was not available to develop extrapolation factors for the following extrapolation classes: RanchXing, UnknownXing, RanchPara, and UnknownPara. To overcome this data deficit, certain assumptions were made to develop a complete set of extrapolation parameters.

No data were collected from Ranch road segments. It was assumed that Ranch roads include both 4x4 and Local roads on private land. The ratio of 4x4 segments to Local segments within 200 feet of a stream was 14.4% : 85.6%. This ratio was used to create a road class weighted average extrapolation factor for Ranch roads by the following equations:

RanchXing = 0.856 (LocalXing) + 0.144 (4x4Xing)

RanchPara = 0.856 (LocalPara) + 0.144 (4x4Para)

Road segments not shown on the TIGER dataset and subsequently digitized to enhance the coverage of the data did not have a specific road class assigned to them. It was assumed that the Unknown road segments included both 4x4 and Local roads. The ratio of 4x4 segments to Local segments within 200 feet of a stream was 14.4% : 85.6%. This ratio was used to create a road class weighted average extrapolation factor for Unknown roads by the following equations:

UnknownXing = 0.856 (LocalXing) + 0.144 (4x4Xing)

UnknownPara = 0.856 (LocalPara) + 0.144 (4x4Para)

The resulting units of the extrapolation factor are Tons of sediment per year per foot of GIS measured length. Prediction of the sediment delivered from all roads in the GIS was accomplished by multiplying the length of a given road segment in the GIS by the extrapolation factor for the matching extrapolation class.

BMP Application Scenarios

The TMDL process requires the comparison of existing loads to natural background levels and to levels where reasonable land, soil, and water conservation practices are in place. The WARSEM allows users to evaluate the potential effects of many different road BMPs. The following BMP scenarios were modeled: *Installing Settling Basins at All Crossings, Installing Silt Fences at All Crossings, Applying Road Surface BMPs to Contributing Segments, and Applying Length Reducing BMPs at Crossings.*

> *Settling Basins at All Crossings* – This is a prediction of sediment loads if effective settling basins were installed at all road/stream *crossings*. Based on literature values, WARSEM assumes that using properly sized and designed settling basins that do not overtop during large storms can result in trap efficiencies of 85%. Therefore, predicted deliveries (existing conditions) were reduced by 85%.
>
> *Silt Fences at All Crossings* - This is a prediction of sediment loads if silt fences or hay bales were installed at all road/stream *crossings*. Based on existing research, WARSEM assumes that using these BMPs can result in trap efficiencies of 25%. Therefore, predicted deliveries (existing conditions) were reduced by 25%.
>
> *Road Surface BMPs* – All reductions from altering road surface conditions were based on the following matrix (**Table D-1**) that was developed from WARSEM road surface parameters. The numbers in the matrix are multipliers used to determine the resulting sediment delivery if the road surface is changed from the condition listed at left side of the table to the condition listed at the top of the table.

Table D-1. Road Surface Sediment Reduction Multiplier Matrix

			TO						
			native/ruts	***native***	***grassed***	***pit run***	***gravel/ruts***	***gravel***	***asphalt***
			2	***1***	***0.5***	***0.5***	***0.4***	***0.2***	***0.03***
FROM	***native/ruts***	***2***	1	0.5	0.25	0.25	0.2	0.1	0.015
	native	***1***	x	1	0.5	0.5	0.4	0.2	0.03
	grassed	***0.5***	x	x	1	1	0.8	0.4	0.06
	pit run	***0.5***	x	x	x	1	0.8	0.4	0.06
	gravel/ruts	***0.4***	x	x	x	x	1	0.5	0.075
	gravel	***0.2***	x	x	x	x	x	1	0.15
	asphalt	***0.03***	x	x	x	x	x	x	1

From the WARSEM manual,

> "Unsurfaced (native) roads are often referred to as dirt roads. They have not had any gravel or other surface applied to them. In a few cases, the underlying rock is so hard the road appears to have a gravel surface, and should be coded as such, but these instances are rare."
>
> "Gravel surfacing refers to a good layer of gravel, with few fines, dust, or dirt on the surface. You should be able to see mostly gravel-sized particles on these road surfaces."
>
> "Pitrun surfaces refer to poor quality or very worn gravel surfaces with lots of fines or dust. Gravel particles are visible, but most of the surface is worn down into fine particles."

Asphalt surfacing refers to roads that are paved with tarmac or blacktop (aka. Asphalt), and grassed surfacing refers to native ground or pitrun roads that are covered with grasses (either planted or naturally occurring).

Several BMP scenarios were based on changing road surfacing. Each is described in detail below.

Upgrade All Contributing Road Surfaces to Gravel – This is a prediction of sediment loads if the surfaces of all contributing road segments are changed to gravel. Roads segments that currently have Gravel or asphalt surfaces remain unchanged.

Upgrade All Contributing Road Surfaces One Level – This is a prediction of sediment loads if the surfaces of all contributing road segments are upgraded one level. For example, gravel upgraded to asphalt, or native upgraded to pit run. Note that no surfaces were upgraded to a grassed surface as that practice is likely not feasible in many parts of the Shields.

Upgrade All Contributing Road Surfaces One Level (No Paving) – This is a prediction of sediment loads if the surfaces of all contributing road segments are upgraded one level, but none are changed to pavement. For example, pit run upgraded to gravel, or native upgraded to pit run. Note that gravel surfaced roads will not be upgraded to asphalt. Note that no surfaces were upgraded to a grassed surface as that practice is likely not feasible in many parts of the Shields.

Repair All Rutted Contributing Road Surfaces to Original Condition – This is a prediction of sediment loads if the surfaces of all contributing road segments classified as rutted are upgraded to their initial condition. For example, rutted native surfaces are upgraded to native surfaces.

Apply Length Reducing BMPs at Crossings - This is a prediction of sediment loads if length reducing BMPs are applied to all crossing segments. Because BMPs must be selected on a site-by-site basis, no specific length reducing BMP was applied. Rather, the assumption was that one or more length reducing BMPs would be applied in a manner such that the length of the contributing segment would be reduced to 500 ft per crossing (USFS roads) or 100 ft per crossing (for all other roads). It is important to note that in reality, BMPs may not be applicable at some sites due to specific constraints and the actual result of applying BMPs will vary from site to site. The lengths of 500 ft and 100 ft were intended to represent reasonable average contributing lengths resulting from BMP installation at crossings and are not formal goals. Forest Service roads were treated differently from those owned by other agencies or private individuals to reflect the effect that varying topography, road management policy, and economic feasibility between owner categories.

Hybrid Scenario: Typically, all reasonable land, soil, and water conservation practices is a combination of road BMPs. Applying length reducing BMPs is one of the most widely used and most effective methods of reducing sediment loads but is not practical in all instances. In this regard, reductions for an additional scenario were calculated outside of the WARSEM. This scenario is a hybrid of two modeled scenarios: A reduction in the road contributing length at 60% of roads and an upgrade of contributing road surfaces by one level (with no paving) at 40% of roads. This hybrid of two modeled scenarios was selected as an example to illustrate the potential for sediment reduction by approximating BMP upgrades and is not a formal goal for all crossings. Achieving this reduction in sediment loading from roads may be occur through a wider variety of methods such as diverting water from road surfaces, ditch BMPs, and cut/fill slope BMPs.

Results

Table D-2 contains the existing load from unpaved roads by subwatershed and the existing load normalized by the length of contributing roads in each subwatershed. Loads are also included for the upper and lower Shields River watersheds, which are made up of the subwatersheds. **Table D-3** contains the results of the existing conditions and BMP scenario modeling based on 6^{th} code HUC subwatersheds, and also for the upper and lower Shields River watersheds. The existing conditions and reductions for each BMP scenario are also presented by ownership and road class for 6^{th} code HUC subwatersheds (**Tables D-4 and D-5**, respectively), and for the entire Shields River watershed by ownership, road class, and road orientation (**Table D-6**). The load for the lower Shields is cumulative and includes the sediment load from the upper Shields.

Table D-2. Existing and normalized existing loads from unpaved roads by subwatershed. Subwatersheds with an asterisk (*) are within the upper Shields watershed. Watersheds with a sediment TMDL are in bold.

	Total contributing length within 200 ft of a stream	Existing Conditions	Normalized Existing Conditions
Subwatershed Name	(Miles)	(Tons/yr)	(tons/mi/yr)
Adair Creek	**8.6**	**11**	**1.30**
Bangtail Creek	**6.5**	**4**	**0.65**
Canyon Creek	**7.8**	**8**	**0.98**
Carrol Creek*	**3.8**	**4**	**1.05**
Cottonwood Creek East*	**7.1**	**5**	**0.76**
Cottonwood Creek West*	**6.8**	**8**	**1.12**
Daisy Dean Creek*	**6.2**	**7**	**1.13**
Dry Creek*	**4.5**	**6**	**1.36**
Elk Creek*	**7.6**	**12**	**1.57**
Falls Creek	**14.8**	**14**	**0.97**
Horse Creek*	**12.3**	**17**	**1.34**
Lower Brackett Creek	**6.4**	**6**	**0.86**
Lower Flathead Creek*	**6.7**	**7**	**1.04**
Lower Shields River-Chicken Creek	**19.7**	**24**	**1.20**
Lower Shields River-Crazyhead Creek	**11.1**	**11**	**0.97**
Meadows Creek*	**11.8**	**7**	**0.61**
Middle Shields River-Antelope Creek*	**8.4**	**9**	**1.10**
Middle Shields River-Spring Creek	**3.2**	**4**	**1.31**
Muddy Creek*	**8.1**	**7**	**0.90**
Porquepine Creek*	**10.5**	**11**	**1.02**
Potter Creek*	11.5	11	0.97
Rock Creek	**6.6**	**9**	**1.43**
Upper Brackett Creek	**18.0**	**23**	**1.25**
Upper Flathead Creek*	**2.6**	**3**	**1.05**
Upper Shields River-Antelope Creek*	**12.8**	**12**	**0.96**
Upper Shields River-Bennett Creek*	**18.4**	**19**	**1.06**
Upper Shields River-Kavanaugh Creek*	**7.9**	**8**	**1.02**
Willow Creek	**17.7**	**13**	**0.73**
Upper Shields	147.7	155	1.05
Lower Shields	267.4	280	1.05

Table D-3. Sediment Contribution and Potential Reductions from Unpaved Roads by Subwatershed. Subwatersheds with an asterisk (*) are within the upper Shields watershed. Watersheds with a sediment TMDL are in bold.

Subwatershed Name	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	(Miles)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)	(Tons/yr)
Adair Creek	8.6	11	2	8	7	5	8	8	2	5
Bangtail Creek	6.5	4	1	3	3	2	3	3	1	2
Canyon Creek	7.8	8	1	6	6	4	5	6	2	3
Carrol Creek*	3.8	4	1	3	2	2	3	3	1	2
Cottonwood Creek East*	7.1	5	1	4	4	3	4	4	1	2
Cottonwood Creek West*	6.8	8	1	6	5	4	5	6	1	3
Daisy Dean Creek*	6.2	7	1	5	4	3	5	5	1	3
Dry Creek*	4.5	6	1	5	3	3	4	5	1	2
Elk Creek*	7.6	12	2	9	7	6	8	9	2	5
Falls Creek	14.8	14	2	11	13	7	10	11	3	6
Horse Creek*	12.3	17	3	12	10	8	12	12	3	7
Lower Brackett Creek	6.4	6	1	4	4	3	4	4	1	2
Lower Flathead Creek*	6.7	7	1	5	4	3	5	5	1	3
Lower Shields River-Chicken Creek	19.7	24	4	18	15	11	17	18	4	10
Lower Shields River-Crazyhead Creek	11.1	11	2	8	8	5	8	8	2	4
Meadows Creek*	11.8	7	1	5	7	3	5	5	2	3
Middle Shields River-Antelope Creek*	8.4	9	1	7	5	4	7	7	2	4
Middle Shields River-Spring Creek	3.2	4	1	3	3	2	3	3	1	2
Muddy Creek*	8.1	7	1	6	5	3	5	6	1	3
Porquepine Creek*	10.5	11	2	8	6	5	8	8	2	4
Potter Creek*	**11.5**	**11**	**2**	**8**	**7**	**5**	**8**	**8**	**2**	**5**

Table D-3. Sediment Contribution and Potential Reductions from Unpaved Roads by Subwatershed. Subwatersheds with an asterisk (*) are within the upper Shields watershed. Watersheds with a sediment TMDL are in bold.

Subwatershed Name	**Total contributing length within 200 ft of a stream**	**Existing Conditions**	**Settling Basins**	**Silt Fences**	**Upgrade All Contributing Road Surfaces to Gravel**	**Upgrade All Contributing Road Surfaces One Level**	**Upgrade All Contributing Road Surfaces One Level (no paving)**	**Repair All Rutted Road Surfaces to Original Condition**	**Apply Length Reducing BMPs at Crossings**	**Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)**
Rock Creek	6.6	9	1	7	5	4	7	7	2	4
Upper Brackett Creek	18	23	4	17	13	11	16	17	5	9
Upper Flathead Creek*	2.6	3	0	2	2	1	2	2	1	1
Upper Shields River-Antelope Creek*	12.8	12	2	9	7	6	9	9	2	5
Upper Shields River-Bennett Creek*	18.4	19	3	15	15	9	14	15	6	8
Upper Shields River-Kavanaugh Creek*	7.9	8	1	6	4	4	6	6	2	3
Willow Creek	17.7	13	2	10	10	6	9	10	3	5
Upper Shields	**147.7**	**155**	**25**	**117**	**98**	**73**	**110**	**116**	**32**	**62**
Lower Shields	**267.4**	**280**	**46**	**211**	**185**	**131**	**199**	**210**	**56**	**113**
Percent Reduction (from existing load)			84%	25%	34%	53%	29%	25%	80%	60%

Table D-4. Sediment contribution and potential reductions from unpaved roads by subwatershed and road ownership. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Ownership	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
Adair Creek	**Private/State**	**8.6**	**11**	**2**	**8**	**7**	**5**	**8**	**8**	**2**	**5**
	USFS	**0.0**									
Bangtail Creek	**Private/State**	**6.1**	**4**	**1**	**3**	**3**	**2**	**3**	**3**	**1**	**2**
	USFS	**0.4**	**<1**	**<1**	**<1**	**<1**	**0**	**<1**	**<1**	**<1**	**<1**
Canyon Creek	**Private/State**	**6.6**	**7**	**1**	**5**	**6**	**3**	**5**	**5**	**1**	**3**
	USFS	**1.2**	**1**	**<1**	**1**	**1**	**<1**	**1**	**1**	**<1**	**<1**
Carrol Creek*	**Private/State**	**3.8**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**2**
	USFS	**0.0**									
Cottonwood Creek East*	**Private/State**	**4.0**	**5**	**1**	**3**	**3**	**2**	**3**	**3**	**1**	**2**
	USFS	**3.1**	**1**	**<1**	**1**	**1**	**<1**	**1**	**1**	**<1**	**<1**
Cottonwood Creek West*	**Private/State**	**6.8**	**8**	**1**	**6**	**5**	**4**	**5**	**6**	**1**	**3**
	USFS	**0.0**									
Daisy Dean Creek*	**Private/State**	**6.2**	**7**	**1**	**5**	**4**	**3**	**5**	**5**	**1**	**3**
	USFS	**0.0**									

Table D-4. Sediment contribution and potential reductions from unpaved roads by subwatershed and road ownership. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Ownership	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
Dry Creek*	**Private/State**	**4.5**	**6**	**1**	**5**	**3**	**3**	**4**	**5**	**1**	**2**
	USFS	**0.0**									
Elk Creek*	**Private/State**	**7.6**	**12**	**2**	**9**	**7**	**6**	**8**	**9**	**2**	**5**
	USFS	**0.0**									
Falls Creek	**Private/State**	**14.8**	**14**	**2**	**11**	**13**	**7**	**10**	**11**	**3**	**6**
	USFS	**0.0**									
Horse Creek*	**Private/State**	**12.3**	**17**	**3**	**12**	**10**	**8**	**12**	**12**	**3**	**7**
	USFS	**0.0**									
Lower Brackett Creek	**Private/State**	**6.4**	**6**	**1**	**4**	**4**	**3**	**4**	**4**	**1**	**2**
	USFS	**0.0**									
Lower Flathead Creek*	**Private/State**	**6.7**	**7**	**1**	**5**	**4**	**3**	**5**	**5**	**1**	**3**
	USFS	**0.0**									
Lower Shields River-Chicken Creek	**Private/State**	**19.7**	**24**	**4**	**18**	**15**	**11**	**17**	**18**	**4**	**10**

Table D-4. Sediment contribution and potential reductions from unpaved roads by subwatershed and road ownership. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Ownership	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	USFS	**0.0**									
Lower Shields River-Crazyhead Creek	**Private/State**	**11.1**	**11**	**2**	**8**	**8**	**5**	**8**	**8**	**2**	**4**
	USFS	**0.0**									
Meadows Creek*	**Private/State**	**3.8**	**2**	**<1**	**2**	**2**	**1**	**1**	**1**	**<1**	**1**
	USFS	**8.0**	**5**	**1**	**4**	**5**	**2**	**4**	**4**	**2**	**2**
Middle Shields River-Antelope Creek*	**Private/State**	**8.4**	**9**	**1**	**7**	**5**	**4**	**7**	**7**	**2**	**4**
	USFS	**0.0**									
Middle Shields River-Spring Creek	**Private/State**	**3.2**	**4**	**1**	**3**	**3**	**2**	**3**	**3**	**1**	**2**
	USFS	**0.0**									
Muddy Creek*	**Private/State**	**8.1**	**7**	**1**	**6**	**5**	**3**	**5**	**6**	**1**	**3**
	USFS	**0.0**									
Porquepine Creek*	**Private/State**	**10.5**	**11**	**2**	**8**	**6**	**5**	**8**	**8**	**2**	**4**

Table D-4. Sediment contribution and potential reductions from unpaved roads by subwatershed and road ownership. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Ownership	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	USFS	**0.0**									
Potter Creek*	**Private/State**	**11.5**	**11**	**2**	**8**	**7**	**5**	**8**	**8**	**2**	**5**
	USFS	**0.0**									
Rock Creek	**Private/State**	**5.7**	**9**	**1**	**7**	**5**	**4**	**6**	**7**	**2**	**4**
	USFS	**0.0**									
Upper Brackett Creek	**Private/State**	**15.1**	**19**	**3**	**15**	**11**	**9**	**14**	**15**	**3**	**8**
	USFS	**2.9**	**3**	**<1**	**2**	**2**	**2**	**2**	**2**	**1**	**1**
Upper Flathead Creek*	**Private/State**	**2.6**	**3**	**<1**	**2**	**2**	**1**	**2**	**2**	**1**	**1**
	USFS	**0.0**									
Upper Shields River-Antelope Creek*	**Private/State**	**12.8**	**12**	**2**	**9**	**7**	**6**	**9**	**9**	**2**	**5**
	USFS	**0.0**									
Upper Shields River-Bennett Creek*	**Private/State**	**5.0**	**6**	**1**	**5**	**4**	**3**	**4**	**5**	**1**	**3**
	USFS	**13.3**	**13**	**2**	**10**	**11**	**6**	**9**	**10**	**5**	**5**

Table D-4. Sediment contribution and potential reductions from unpaved roads by subwatershed and road ownership. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Ownership	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
Upper Shields River-Kavanaugh Creek*	**Private/State**	**7.9**	**8**	**1**	**6**	**4**	**4**	**6**	**6**	**2**	**3**
	USFS	**0.0**									
Willow Creek	**Private/State**	**13.5**	**12**	**2**	**9**	**8**	**5**	**8**	**9**	**2**	**5**
	USFS	**4.2**	**1**	**<1**	**1**	**2**	**1**	**1**	**1**	**1**	**1**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
Adair Creek	**Local**	**2.2**	**3**	**<1**	**2**	**2**	**1**	**2**	**2**	**1**	**1**
	Ranch	**0.4**	**1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**6.0**	**8**	**1**	**6**	**5**	**4**	**5**	**6**	**1**	**3**
Bangtail Creek	**4x4**	**3.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**0.8**	**1**	**<1**	**1**	**<1**	**<1**	**1**	**1**	**<1**	**<1**
	Ranch	**0.0**	**<1**	**0**	**<1**	**<1**	**<1**	**<1**	**<1**	**0**	**0**
	Unknown	**2.5**	**3**	**1**	**2**	**2**	**1**	**2**	**2**	**1**	**1**
	US HWY	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canyon Creek	**4x4**	**0.6**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**0.6**	**1**	**<1**	**1**	**<1**	**<1**	**1**	**1**	**<1**	**<1**
	Unknown	**6.7**	**7**	**1**	**5**	**6**	**3**	**5**	**5**	**1**	**3**
Carrol Creek*	**Local**	**3.0**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**1**
	MT HWY	**0.8**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
Cottonwood Creek East*	**4x4**	**1.3**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**4.3**	**5**	**1**	**4**	**2**	**2**	**3**	**4**	**1**	**2**
	Ranch	**0.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**0**	**<1**	**<1**	**<1**
	Unknown	**1.3**	**<1**	**<1**	**<1**	**1**	**<1**	**<1**	**<1**	**<1**	**<1**
	US HWY	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cottonwood Creek West*	**4x4**	**0.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Local	**4.5**	**6**	**1**	**5**	**3**	**3**	**5**	**5**	**1**	**3**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	Unknown	**1.6**	**1**	**<1**	**1**	**1**	**1**	**1**	**1**	**<1**	**1**
	US HWY	**0.7**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Daisy Dean Creek*	**4x4**	**0.4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Local	**4.5**	**6**	**1**	**4**	**3**	**3**	**4**	**4**	**1**	**2**
	Unknown	**1.3**	**1**	**<1**	**1**	**1**	**1**	**1**	**1**	**<1**	**1**
Dry Creek*	**4x4**	**0.1**	**<1**	**0**	**<1**	**0**	**0**	**0**	**<1**	**<1**	**0**
	Local	**2.2**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**1**
	MT HWY	**0.7**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**1.4**	**2**	**<1**	**2**	**1**	**1**	**2**	**2**	**<1**	**1**
Elk Creek*	**Local**	**4.9**	**9**	**1**	**6**	**4**	**4**	**6**	**6**	**1**	**3**
	Ranch	**0.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**2.6**	**3**	**1**	**2**	**2**	**2**	**2**	**2**	**1**	**1**
Falls Creek	**Local**	**2.0**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**1**
	Ranch	**0.0**	**<1**	**0**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**12.8**	**11**	**2**	**8**	**12**	**5**	**8**	**8**	**2**	**4**
Horse Creek*	**Local**	**9.0**	**14**	**2**	**10**	**7**	**6**	**10**	**10**	**2**	**6**
	Ranch	**0.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**3.1**	**2**	**<1**	**2**	**3**	**1**	**2**	**2**	**<1**	**1**
Lower Brackett Creek	**4x4**	**1.0**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**2.2**	**3**	**<1**	**2**	**1**	**1**	**2**	**2**	**<1**	**1**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	Unknown	**3.2**	**3**	**<1**	**2**	**3**	**1**	**2**	**2**	**1**	**1**
Lower Flathead Creek*	**4x4**	**0.7**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**3.8**	**6**	**1**	**5**	**3**	**3**	**4**	**5**	**1**	**3**
	MT HWY	**1.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Ranch	**0.3**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**0.7**	**<1**	**<1**	**<1**	**1**	**<1**	**<1**	**<1**	**<1**	**<1**
	US HWY	**0.2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Lower Shields River-Chicken Creek	**4x4**	**1.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**10.7**	**17**	**3**	**13**	**8**	**8**	**12**	**13**	**3**	**7**
	Ranch	**0.6**	**1**	**<1**	**1**	**1**	**<1**	**1**	**1**	**<1**	**<1**
	Unknown	**6.2**	**6**	**1**	**4**	**6**	**3**	**4**	**4**	**1**	**2**
	US HWY	**1.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Lower Shields River-Crazyhead Creek	**4x4**	**0.5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Local	**2.1**	**3**	**1**	**2**	**2**	**1**	**2**	**2**	**1**	**1**
	Ranch	**1.0**	**1**	**<1**	**1**	**1**	**1**	**1**	**1**	**<1**	**<1**
	Unknown	**6.6**	**6**	**1**	**5**	**6**	**3**	**5**	**5**	**1**	**3**
	US HWY	**1.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Meadows Creek*	**4x4**	**4.4**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**2.1**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**2**
	Ranch	**0.0**	**0**	**0**	**0**	**<1**	**0**	**0**	**0**	**0**	**0**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	Unknown	**5.4**	**3**	**1**	**2**	**5**	**1**	**2**	**2**	**1**	**1**
Middle Shields River-Antelope Creek*	**4x4**	**1.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**6.0**	**9**	**1**	**7**	**4**	**4**	**6**	**7**	**2**	**4**
	Ranch	**0.3**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	US HWY	**0.8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Middle Shields River-Spring Creek	**4x4**	**0.4**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**1.5**	**3**	**<1**	**2**	**1**	**1**	**2**	**2**	**<1**	**1**
	Ranch	**0.1**	**0**	**0**	**0**	**<1**	**0**	**0**	**0**	**0**	**0**
	Unknown	**1.1**	**1**	**<1**	**1**	**1**	**1**	**1**	**1**	**<1**	**1**
	US HWY	**0.2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Muddy Creek*	**4x4**	**0.4**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**3.5**	**3**	**1**	**2**	**2**	**1**	**2**	**2**	**1**	**1**
	Unknown	**4.2**	**4**	**1**	**3**	**4**	**2**	**3**	**3**	**1**	**2**
Porquepine Creek*	**4x4**	**1.8**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**6.6**	**8**	**1**	**6**	**4**	**4**	**6**	**6**	**1**	**3**
	Ranch	**0.3**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**1.8**	**2**	**<1**	**2**	**2**	**1**	**2**	**2**	**<1**	**1**
Potter Creek*	**4x4**	**1.0**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**6.1**	**10**	**2**	**8**	**5**	**5**	**7**	**8**	**2**	**4**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	Unknown	**2.3**	**1**	**<1**	**1**	**2**	**<1**	**1**	**1**	**<1**	**<1**
	US HWY	**2.0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Rock Creek	**4x4**	**0.8**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**5.6**	**9**	**1**	**7**	**5**	**4**	**6**	**7**	**2**	**4**
	Unknown	**0.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	US HWY	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Upper Brackett Creek	**4x4**	**0.3**	**<1**	**0**	**<1**	**0**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**5.6**	**5**	**1**	**4**	**3**	**2**	**4**	**4**	**1**	**2**
	MT HWY	**0.6**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Ranch	**0.8**	**<1**	**<1**	**1**	**1**	**<1**	**1**	**1**	**<1**	**<1**
	Unknown	**10.6**	**16**	**3**	**12**	**10**	**8**	**12**	**12**	**3**	**7**
Upper Flathead Creek*	**Local**	**2.0**	**3**	**<1**	**2**	**1**	**1**	**2**	**2**	**<1**	**1**
	MT HWY	**0.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Ranch	**0.6**	**<1**	**<1**	**<1**	**1**	**<1**	**<1**	**<1**	**<1**	**<1**
Upper Shields River-Antelope Creek*	**4x4**	**0.2**	**<1**	**0**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**11.1**	**11**	**2**	**9**	**6**	**5**	**8**	**9**	**2**	**5**
	Ranch	**0.0**	**0**	**0**	**0**	**<1**	**0**	**0**	**0**	**0**	**0**
	Unknown	**1.4**	**1**	**<1**	**1**	**1**	**<1**	**1**	**1**	**<1**	**<1**
Upper Shields River-Bennett Creek*	**4x4**	**1.9**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**

Table D-5. Sediment contribution and potential reductions from unpaved roads by subwatershed and road class. Subwatersheds with an asterisk (*) are within the upper Shields watershed.

Subwatershed	Road Class	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
	Local	**4.4**	**8**	**1**	**6**	**4**	**4**	**6**	**6**	**2**	**3**
	Ranch	**0.3**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**11.7**	**11**	**2**	**8**	**11**	**5**	**8**	**8**	**3**	**4**
Upper Shields River-Kavanaugh Creek*	**4x4**	**2.0**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**5.4**	**7**	**1**	**6**	**4**	**3**	**5**	**6**	**1**	**3**
	Ranch	**0.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**0.2**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
Willow Creek	**4x4**	**5.5**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Local	**3.4**	**4**	**1**	**3**	**2**	**2**	**3**	**3**	**1**	**2**
	Ranch	**0.1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**
	Unknown	**8.7**	**8**	**1**	**6**	**8**	**4**	**6**	**6**	**2**	**3**
	US HWY	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table D-6. Sediment contribution and potential reductions from unpaved roads for the Shields River watershed by ownership, road class, and road orientation. This includes loads associated with both the upper and lower Shields 303(d) segments.

	Total contributing length within 200 ft of a stream	Existing Conditions	Settling Basins	Silt Fences	Upgrade All Contributing Road Surfaces to Gravel	Upgrade All Contributing Road Surfaces One Level	Upgrade All Contributing Road Surfaces One Level (no paving)	Repair All Rutted Road Surfaces to Original Condition	Apply Length Reducing BMPs at Crossings	Hybrid BMPs (60% length reduction and 40% upgrade of road surface 1 level)
Ownership										
Private/State	233.4	255	41	192	162	120	182	191	46	103
USFS	33.1	25	4	19	22	12	18	19	10	10
Road Class										
4x4	28.8	2	<1	1	1	1	1	2	2	1
Local	119.8	168	27	127	84	79	120	126	31	68
MT HWY	3.3	1	<1	1	1	1	1	1	<1	<1
Ranch	5.5	6	1	4	5	3	4	4	1	2
Unknown	103.7	103	17	78	94	48	73	77	22	42
US HWY	6.3	0	0	0	0	0	0	0	0	0
Road Orientation										
Parallel	109.6	4	1	3	3	2	3	3	1	2
Crossing	157.8	276	41	207	136	130	195	206	51	111
Shields River Watershed										
	267.4	280	46	211	185	131	199	210	56	113