APPENDIX F
UNPAVED ROAD SEDIMENT ASSESSMENT

INTRODUCTION

This appendix presents an assessment of sediment associated with both paved and unpaved roads in the West Fork Gallatin River watershed. This project utilized a combination of GIS analysis, field data collection, WEPP roads modeling, and data analysis and extrapolation to estimate sediment loading to streams at or near road crossings. The project includes estimation of existing sediment loading conditions and identification of achievable road sediment loading reductions via the implementation of additional best management practices (BMPs).

The West Fork Gallatin River Roads Assessment consisted of four major tasks:
- Spatial (GIS) data compilation and analysis,
- Field data collection,
- Road sediment load modeling, and
- Extrapolation.

The West Fork Gallatin River Roads Assessment evaluated three sources of sediment loading from roads. These are:
- Road/stream crossings,
- Sediment from traction sanding, and
- Sediment from potential culvert failure.

Road disturbances near and adjacent to stream crossings can be a sediment source to streams. These disturbances include the road surface, cut slope, fill slope, and drainage ditch. Both paved and unpaved roads can contribute sediment to streams, although because paved roads do not contribute sediment from the road surface, they typically contribute a much smaller sediment load than unpaved roads. However, traction sand applied to paved roads in the winter has the potential to be a significant sediment source to streams. Traction sand usage in the watershed consists of application to state Hwy 64 in the winter by the Montana Department of Transportation (MDT) and application to private roads by local homeowner associations and ski areas. Undersized, improperly installed, or inadequately maintained culverts can also be sources of sediment. For instance, significant amounts of sediment may be delivered to streams if culverts fail during large runoff events, or if a culvert does not fail but is undersized, a portion of the road fill material could be eroded by water flowing over or around the culvert. The risk of culvert failure and loading of associated fill material is equal to the probability of the occurrence of a runoff event larger than the capacity of the culvert.

The following sections describe the roads source assessment in more detail. Results of the modeling and load calculations are within each section on sediment sources.

Spatial Data Compilation and Analysis

Compilation and analysis of publicly available GIS data layers identified road/stream crossings and allowed development of a field data collection strategy. Roads data covering Gallatin and Madison Counties intersected with National Hydrography Dataset (NHD) streams identified road-stream intersections. Errors in the road type attributes were corrected by field verification. The intersections (stream crossings) were then categorized by road type (paved, gravel, or dirt), land ownership, and sub-watershed. This analysis identified 98 road-stream intersections in the watershed.

The 80 square-mile West Fork Gallatin River watershed is primarily privately owned (71 %), with the remainder owned by the U.S. Forest Service (28%) and the State of Montana (1%). Total road length in the watershed is 214 miles. All 98 of the road/stream crossings are on privately owned land. **Table F-1** and **Figure F-1** presents information on road/stream crossing types in the watershed and the distribution of the assessed crossings. Although most crossings are paved, a large proportion of unpaved crossings were assessed because unpaved crossings have a much greater capacity to be sediment sources than paved crossings. **Table F-2** contains the distribution of crossings by sub-watershed. The watershed ID listed in **Table F-2** corresponds to the watershed ID label on the map in **Figure F-2** below.

Table F-1. Road/stream crossing types, West Fork Gallatin River watershed.

Road Type	Count	Percent of Crossings	Assessed	Percent Assessed
Paved	70	71%	14	20%
Gravel	17	17%	2	12%
Native/Dirt	11	11%	9	82%
Totals	98	100%	25	26%

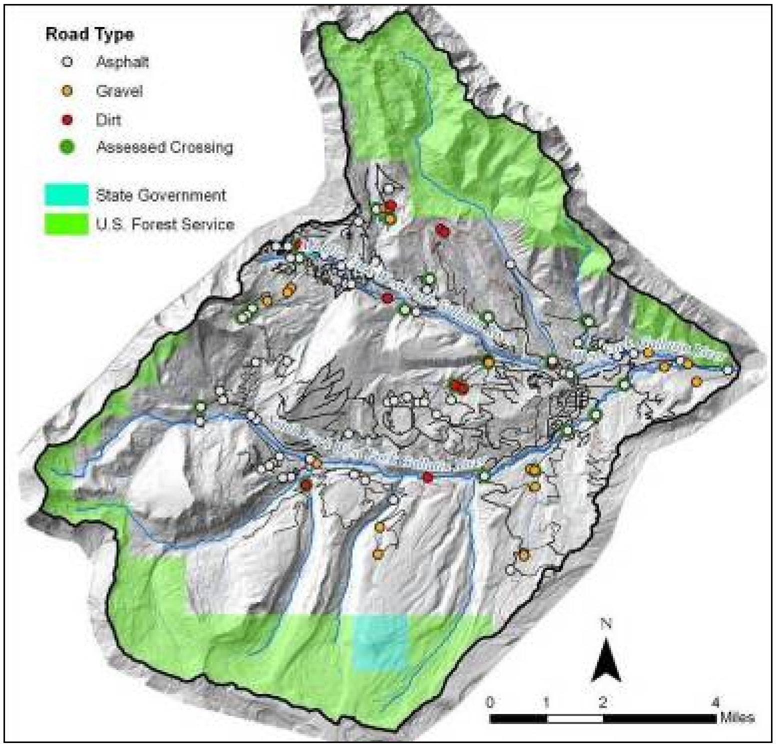


Figure F-1. Distribution and type of road/stream crossings in the project area.

Table F-2. Distribution of road/stream crossings in the West Fork Gallatin River watershed.

Watershed ID	Sub-Watershed Name	Number of Crossings	Acres	Square Miles	Crossings/ Square Mile
1	Beehive Creek	9	2066	3.2	2.8
2	North Fork West Fork Gallatin River	1	6230	9.7	0.1
3	Crail Creek	4	1367	2.1	1.9
4	West Fork Gallatin River above WWTP	6	1143	1.8	3.4
5	Upper Middle Fork West Fork Gallatin River	15	3240	5.1	3.0
6	Upper West Fork Gallatin River	4	554	0.9	4.6
7	Lowermost West Fork Gallatin River	3	794	1.2	2.4
8	Middle Fork West Fork Gallatin River	23	6205	9.7	2.4
9	Upper South Fork West Fork Gallatin River	12	6530	10.2	1.2
10	South Fork West Fork Gallatin River	14	8652	13.5	1.0
11	Muddy Creek	3	5775	9.0	0.3
12	Third Yellow Mule Creek	1	2307	3.6	0.3
13	Second Yellow Mule Creek	3	2889	4.5	0.7
14	First Yellow Mule Creek	0	3514	5.5	0.0

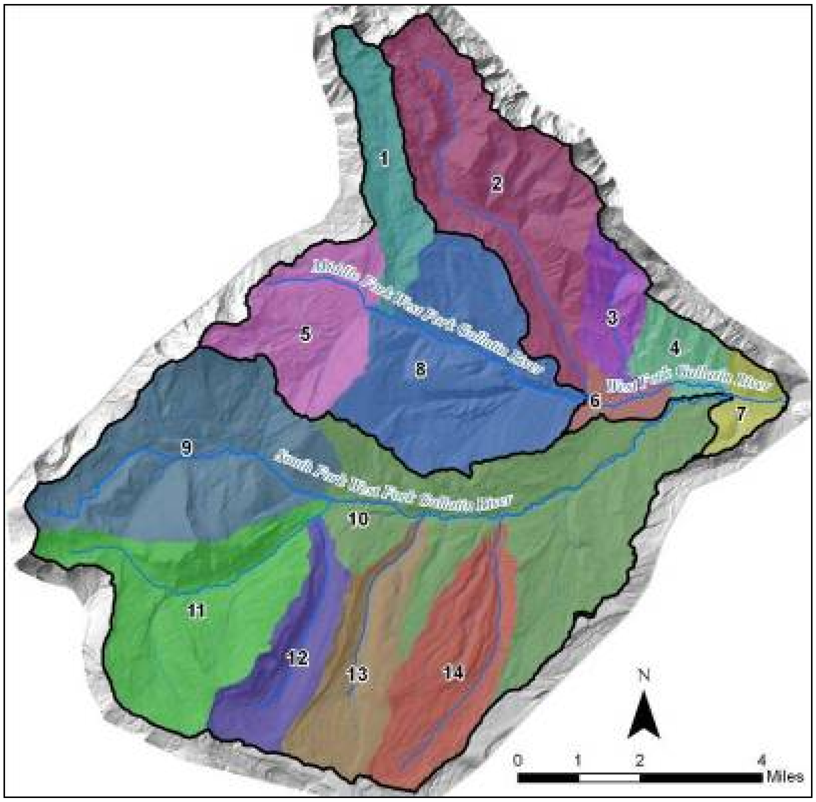


Figure F-2. Sub-watershed delineation in the West Fork Gallatin River watershed.

Field Data Collection

Field crews along with Montana DEQ personnel conducted a field reconnaissance in early October 2008. The field reconnaissance, along with the spatial data component, assisted with identification of representative areas for field data collection. Field data collection forms were developed and reviewed by Montana DEQ. Field data collection was limited by access to private lands. Where access to private land was granted, field crews assessed those stream crossings. When landowners could not be reached, or did not grant permission, stream crossings were not assessed.

Field personnel collected data from 25 road crossings in late October, 2008. The surfaces of 14 of the 25 crossings were asphalt, two were gravel, and nine were native/dirt. Road sediment sources evaluated were:

- Road crossings
- Traction sand
- Potential culvert failure

SEDIMENT FROM ROAD CROSSINGS

The Water Erosion Prediction Project (WEPP) model was the tool chosen for assessment of sediment delivered from road/stream crossings (http://forest.moscowfsl.wsu.edu/fswepp/). Based on the large percentage of paved roads and other TMDL-related roads assessments in Montana, parallel road segments were assumed to be an insignificant source and not included in the analysis. Data collected in the field included the required inputs for the WEPP model. Field data included measurements of each overland flow element (road, fillslope, and buffer). This included:

- soil type,
- rock percent,
- road design,
- road surface type,
- traffic level,
- road width,
- road length (contributing length),
- road gradient,
- fillslope length,
- fillslope gradient,
- buffer length, and
- buffer gradient.

WEPP Modeling

WEPP is a process based, field scale, erosion prediction model that includes a graphical user interface for runoff and erosion prediction. The United States Department of Agriculture-Agricultural Research Service (USDA-ARS) developed WEPP in 1985 (Flanagan and Nearing, 1995) and the U.S. Forest Service developed the interface of the WEPP model, WEPP:Road (Elliot et al., 1999). The WEPP:Road interface (http://forest.moscowfsl.wsu.edu/fswepp/) allows users to predict sediment delivery rates based on various road conditions. The WEPP model was used for predicting sediment delivered from both paved and unpaved roads. Paved surfaces do not generate much sediment within the model, however, both paved and unpaved roads can deliver sediment from the cutslope, fillslope, or ditch.

Field data collected for each crossing were entered into the model. The WEPP model also generates climate input using the Rock:Clime Model version 2004.04.26 (Elliot et al., 1999b). Climate generated for the Big Sky, MT area was modified from the Mystic Lake, MT weather station, the nearest station with similar climate and sufficient data in the correct format for use in the WEPP model. The Mystic Lake climate data were then adjusted for elevation and average annual precipitation to more closely represent Big Sky conditions. All model runs were 50-year simulations, simulating the 50-year average annual sediment load from roads at each assessed crossing. A 30-50 year period of record is typical for this type of simulation (Elliot et al., 1999).

Model simulations yielded two types of output, simple and detailed. The standard WEPP road results window displays the simple output. Following the results link within this window displays the detailed output. The detailed output includes total sediment detachment and total sediment deposition. The difference between total sediment detachment and total sediment deposition gives the current sediment delivery rate for each road crossing. The total sediment detachment is the amount of sediment that would be delivered to the stream if there were no existing BMPs present to mitigate sediment delivery. Thus, the detailed data provides the current sediment load and a means to calculate the current level of sediment mitigation from BMPs.

Modeling Results

Table F-3 on the following page presents WEPP modeling results for the assessed road/stream crossings. It includes the crossing assessment site ID as well as the corresponding sub-watershed (i.e. Middle Fork, South Fork, or West Fork). The sediment detachment values (column three) are the estimated existing amount of sediment detached and transported in the road surface, fill slope, and buffer combined, whereas the sediment deposition values (column four) indicate the existing amount of sediment deposited after detachment and reflects when the capacity of existing BMPs to retain sediment and reduce sediment delivery to streams. Therefore, the sediment delivery values (column five) are the difference between sediment detachment and sediment deposition and represent sediment delivered to the stream at each crossing.

BMP sediment delivery values (column six) represent the sediment detachment calculation reduced by 85 percent, which is the desired reduction in sediment loading. The 85 percent represents full BMP implementation and reflects literature values, which are described further in the “Best Management Practices” section of this report. Finally, BMP sediment reduction values (column seven) are the loading reductions needed to achieve the 85 percent reduction associated with the BMP sediment delivery loads (i.e. BMP Sediment Delivery minus [existing] Sediment Delivery). Because the existing level of BMP implementation and sediment removal efficiency varies by site, the percent reduction needed to achieve the 85 percent reduction is variable from site to site.

It is acknowledged that the existing load and potential reductions are variable from crossing to crossing, but for the purposes of the source assessment and extrapolation, average values were derived for each road crossing type (**Table F-4**). Road type is a combination of road surface (paved, gravel, native/dirt) and traffic level (low, high). Based on the average load per crossing type and number of identified crossings per watershed, annual sediment loads were extrapolated by road type and to each 303(d) listed subwatershed and the entire West Fork Gallatin River watershed (**Tables F-4 and F-5**). For the entire watershed, road crossings are estimated to contribute 8.1 tons per year of sediment to streams. Full BMP implementation should reduce this sediment load to 2.8 tons per year. This represents a 65 percent reduction from the current 8.1 tons delivered.

Table F-3. WEPP modeling results for sediment contributed to streams from assessed road/stream crossings.

Road Crossing ID[2]	**Sub-watershed**	**Sediment Detachment[3]**	**Sediment Deposition[3]**	**Sediment Delivery [3]**	**BMP Sediment Delivery [4]**	**BMP Sediment Reduction[5]**	**% Reduction Between Existing and BMP Load**
		lbs/year [6]					
C1	SF	1875	1558	317	281	36	11%
C2	SF	--	--	--	--	--	--
C3	MF	118	35	84	18	66	79%
C4	MF	52	36	16	8	8	50%
C5	MF	162	146	16	24	0	0%
C6	MF	107	20	87	16	71	82%
C7	MF	479	102	377	72	306	81%
C8	MF	4	1	3	1	3	67%
C9	MF	99	42	57	15	42	74%
C10	MF	593	325	268	89	186	67%
C11	MF	279	43	235	42	194	82%
C12	WF	8016	5670	2346	1202	1143	49%
C13	MF	88	72	16	13	3	19%
C14	MF	209	42	167	31	136	81%
C15	MF	194	162	32	29	3	9%
C16	MF	1571	431	1140	236	905	79%
C17	MF	2994	727	2267	449	1818	80%
C18	WF	0	0	0	0	0	--
C19	WF	40	7	34	6	28	82%
C20	WF	--	--	--	--	--	--
C21	WF	4	0	4	1	3	75%
C22N	MF	218	20	198	33	165	83%
C22S	MF	83	17	65	12	53	82%
C23	SF	0	0	0	0	0	--
C24	SF	63	8	55	9	45	84%
C25	SF	95	55	40	14	26	65%
C26	SF	25	5	20	4	16	80%
C27	SF	337	196	141	51	90	64%

[1]. Model results are obtained through the WEPP detailed results output.

[2]. Crossings C2 and C20 are located on the crown of a road and do not contribute sediment to a drainage. Crossing C22 (C22N and C22S) were treated as separate roads because C22N was gravel and C22S was paved.

[3]. Modeled results of the 50-year average of total annual sediment detached, deposited, and delivered to the stream.

[4]. Reduced sediment delivery based on an 85% sediment reduction rate for a vegetated buffer.

[5]. Reduction in sediment due to the implementation of BMPs.

[6]. Sediment is presented in lbs per area of contributing road segment.

SF= South Fork West Fork Gallatin River, MF=Middle Fork West Fork Gallatin River, WF=West Fork Gallatin River

Table F-4. Summary of road crossing sediment loading by road type for the West Fork Gallatin River watershed.

Road Surface	Traffic Level	Number of Crossings	Average Modeled Sediment Yield per Crossing Type	Total Sediment Yield	Average Sediment Yield with BMPs	Total Sediment Yield with BMPs
			tons/year	**tons/year**	**tons/year**	**tons/year**
Paved	Low	55	0.03	1.4	0.01	0.4
Paved	High	15	0.23	3.5	0.11	1.6
Graveled	Low	15	0.02	0.3	0.01	0.2
Graveled	High	2	0.10	0.2	0.02	0.0
Native/Dirt	None/Low	11	0.25	2.8	0.07	0.7
Totals:		**98**		**8.1**		**2.9**

Table F-5. Sediment loading from road/stream crossings, West Fork Gallatin River watershed.

303(d) Watershed	Sub-Watershed Name	Number of Crossings (Surface - Traffic)						Existing Sediment Load (tons/yr)	Existing Sediment Load (tons/yr)	Desired Sediment Load (tons/yr)
		All	**Paved Low**	**Paved High**	**Gravel Low**	**Gravel High**	**Native/ Dirt Low**			
Middle Fork West Fork Gallatin River	Uppermost Middle Fork West Fork Gallatin River	15	8	4	1	1	1	1.5	4.8	1.7
	Beehive Creek	9	4	1	3		1	0.6		
	Middle Fork West Fork Gallatin River	23	13	2		1	7	2.6		
South Fork West Fork Gallatin River	Upper South Fork West Fork Gallatin River	12	11	1				0.5	2.1	0.7
	Third Yellow Mule Creek	1					1	0.3		
	Muddy Creek	3	2		1			0.1		
	Second Yellow Mule Creek	3	1		2			0.1		
	First Yellow Mule Creek	0						0.0		
	South Fork West Fork Gallatin River	14	5	3	5		1	1.2		
West Fork Gallatin River	North Fork West Fork Gallatin River	1	1					0.0	1.2	0.4
	Upper West Fork Gallatin River	4	2	2				0.5		
	Crail Creek	4	4					0.1		
	Lower West Fork Gallatin River	6	4	1	1			0.4		
	Lowermost West Fork Gallatin River	3		1	2			0.3		
	TOTALS:	83	47	11	14	1	10	**8.1**	**8.1**	**2.8**

SEDIMENT FROM TRACTION SAND APPLICATION

The harsh winter climate and mountain setting of the watershed requires the application of traction sand to paved roads, typically from November through May. This sand can accumulate on road surfaces and then be transported to streams during snowmelt and from runoff during warmer months.

Field crews identified road crossings where tractions sand was likely to be a significant sediment source. Road sanding rates for Montana Hwy 64 from MDT and snow removal contractors working for Big Sky area homeowner associations provided the data necessary to develop sand application rates. These rates were then applied to the paved road crossings in the watershed.

Application Rates

Traction sand delivery for all privately owned paved was based on an application rate of 120 cubic yards over 15 miles of road, which was provided by the Big Sky Homeowners Association. Using an average road width of 17 feet and the application rate of 120 cubic yards annually, traction sand would cover the road to a depth of 0.03 inches. The traction sand estimate for Hwy 64 was based on the average annual volume and tonnages applied to the nine-mile stretch of the highway from Hwy 191 to the West Fork Gallatin River watershed boundary in Madison County between 2005 and 2008 (**Table F-6**). Using an average road width of 26 feet, the average yearly application of 2,850 cubic yards of traction sand would cover the road to a depth of 0.75 inches.

Table F-6. Road sanding rates from MDT for Montana Highway 64.

Year	**Road Sand Application**	
	cubic yards	**tons**
2005	2,736	3,797
2006	3,554	4,932
2007	2,025	2,810
2008	3,084	4,280
Average	2,850	3,955

Assessment Approach

Contributing road lengths for the assessed road/stream crossings (discussed under “Field Data Collection”) were used for the traction sand load analysis. For Hwy 64, the road length multiplied by the measured width and the 0.75 inch depth equals the volume of traction sand available for delivery each year. Field observations of six road crossings on Hwy 64 indicate that much of the traction sand is retained by the vegetated buffer between the road and stream; however, significant volumes of traction sand also build up along guardrails and other barriers at the edges of roads (**Figure F-3**). From these observations and literature-based values for buffer effectiveness (see the Best Management Practices section below), it was estimated that approximately 15 percent of the applied sand is delivered to streams on a yearly basis.

Figure F-3. Typical build up of traction sand adjacent to a guardrail along Hwy 64. Crossing C12, North Fork West Fork Gallatin River.

However, some of the sand that remains in the buffer or along the road may also eventually be delivered to streams. To approximate the effect of sand accumulating along the road over several years, it was assumed that sand stored in sand berms that form along the sides of the road is available for delivery for a period of five years. Based on this assumption, up to 56 percent of the traction sand applied to the contributing road area in a given year is delivered to streams over a five-year period. This percentage is based on the sum of the estimated percentage available annually over the five year period, which is presented in **Table F-7**. For example, 15 percent of winter 2008-2009 traction sand is delivered to streams in 2009, 15 percent of the remaining winter 2007-2008 traction sand is delivered in 2009 (15% X 85%=12.8%), and so on for five years. It is acknowledged that this is a rough estimate of potential traction sand delivered to streams but annual traction sand loads were estimated in this manner because the accumulation of residual traction sand was observed as a potentially significant sediment source that could be reduced.

Table F-7. Estimated yearly sediment delivery for traction sand on Highway 64.

Road Sand Delivery	Date Applied	Percent Delivered in 2009
First Year	Winter 2008-2009	15.0%
Second Year	Winter 2007-2008	12.8%
Third Year	Winter 2006-2007	10.8%
Fourth Year	Winter 2005-2006	9.2%
Fifth Year	Winter 2004-2005	7.8%
	Total Delivery in 2009	55.6%

Results

Based on the application rate for Hwy 64 and private roads and assuming 56 percent as the yearly sediment delivery rate for traction sand at all paved crossings, 138 tons of traction sand per year is delivered to streams from road/stream crossings along Hwy 64 and 17 tons of traction sand are delivered to streams from all other paved crossings.

Table F-8 lists the sediment loads from traction sand for the sub-watersheds in the project area. Overall, traction sand contributes 155 tons per year of sediment to streams in the West Fork Gallatin River watershed. Implementation of BMPs for traction sand could reduce the delivery of traction sand to streams from the current 56 percent of sand applied to roads to 15 percent of sand applied. This represents a 73 percent reduction from current levels. This is effectively equivalent to preventing roadside accumulation from year to year but the reduction could be achieved by a combination of BMPs, which may include a lower application rate, street sweeping, barriers to divert runoff carrying traction sand away from road crossings, improving maintenance of existing BMPs, altering plowing speed at crossings, and structural control measures. It is acknowledged that public safety is a primary factor in the usage of traction sand, and the reduction in loading from traction sand is anticipated to be achieved by improving BMPs without sacrificing public safety. BMPs are described in more detail in the “Best Management Practices for Roads” section below.

Table F-8. Sediment loading from traction sand for the West Fork Gallatin River watershed.

303(d) Sub-watershed	Sub-Watershed	Number of Crossings				Existing Traction Sand Sediment Load (tons/yr)	Desired Traction Sand Sediment Load, 15% Delivery (tons/year)
		All Types	Total Paved	Hwy 64	Private Paved		
Middle Fork West Fork Gallatin River	Upper Middle Fork West Fork Gallatin River	15	12	2	10	33.5	9.0
	Beehive Creek	9	5	1	4	16.4	4.4
	Middle Fork West Fork Gallatin River	23	15	2	13	34.3	9.3
South Fork West Fork Gallatin River	Upper South Fork West Fork Gallatin River	12	12		12	3.4	0.9
	Third Yellow Mule Creek	1	0		0	0.0	0.0
	Muddy Creek	3	2		2	0.6	0.2
	Second Yellow Mule Creek	3	1		1	0.3	0.1
	First Yellow Mule Creek	0	0		0	0.0	0.0
	South Fork West Fork Gallatin River	14	8		8	2.3	0.6
West Fork Gallatin River	North Fork West Fork Gallatin River	1	1		1	0.3	0.1
	Upper West Fork Gallatin River	4	4	2	2	31.2	8.4
	Crail Creek	4	4		4	1.1	0.3
	Lower West Fork Gallatin River	6	5	1	4	16.4	4.4
	Lowermost West Fork Gallatin River	3	1	1	0	15.3	4.1
	TOTALS:	98	70	9	61	**155**	**42**

CULVERT ASSESSMENT

Field crews assessed the water conveyance structures at the 25 measured crossings to determine whether they are barriers to fish passage, and whether they are at risk for failure during high flow. Culverts that fail can deliver significant sediment to streams. Of the 25 assessed crossings, eight are bridges, 14 are corrugated metal culverts, two are corrugated plastic culverts, and one is a concrete culvert.

The bridge crossings assessed during the field data collection had no fish passage issues and were removed from this analysis. The bridges were also adequately sized to convey large flows and not likely to fail even under extreme flood events. In addition, since bridges do not have a large amount of fill covering them, the amount of sediment potentially delivered to streams in the event of a bridge failure is low. Therefore, both the fish passage analysis and the potential sediment from culvert failure analysis excluded road/stream crossings with bridges.

Data collected at each crossing for the fish passage and culvert failure potential assessments included:

- Structure type,
- Structure size,
- Structure slope,
- Upstream bankfull width,
- Upstream bankfull height,
- Fill height, length, and width,
- Outlet invert height,
- Outlet pool depth,
- Comments, and
- Photos.

FISH PASSAGE

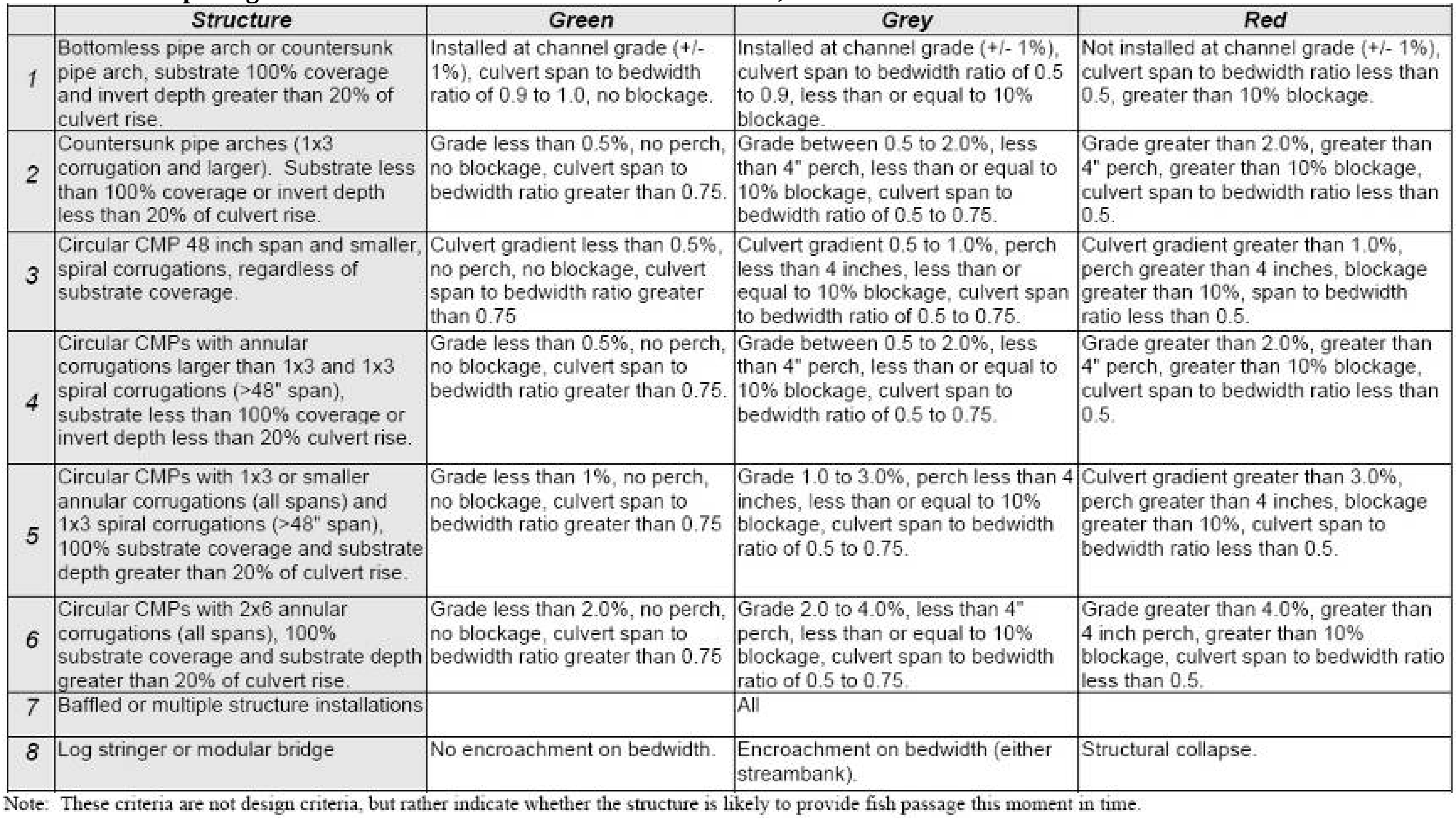
Approach

Measurements collected at the assessed road/stream crossings provided the data to determine if the culverts were fish passage barriers at the flow condition at the time the measurements were taken. This evaluation used criteria from the document A Summary of Technical Considerations to Minimize the Blockage of Fish at Culverts on the National Forests of Alaska (U.S. Forest Service, 2002). The analysis evaluates large (>48-inches) and small (<48-inches) culverts differently and uses site-specific information to classify culverts as green (passing all life stages of salmonids), red (partial or total barrier to salmonids), or grey (needs a more detailed analysis). Indicators used in the classification are:

- Culvert slope,
- Culvert perch (outlet drop),
- Culvert blockage, and
- Constriction ratio (the ratio of the culvert width to bankfull width).

The criteria for the indicators for different culvert types are shown in **Table F-9**.

Table F-9. Fish passage evaluation criteria from U.S. Forest Service, 2002.



	Structure	*Green*	*Grey*	*Red*
1	Bottomless pipe arch or countersunk pipe arch, substrate 100% coverage and invert depth greater than 20% of culvert rise.	Installed at channel grade (+/- 1%), culvert span to bedwidth ratio of 0.9 to 1.0, no blockage.	Installed at channel grade (+/- 1%), culvert span to bedwidth ratio of 0.5 to 0.9, less than or equal to 10% blockage.	Not installed at channel grade (+/- 1%), culvert span to bedwidth ratio less than 0.5, greater than 10% blockage.
2	Countersunk pipe arches (1x3 corrugation and larger). Substrate less than 100% coverage or invert depth less than 20% of culvert rise.	Grade less than 0.5%, no perch, no blockage, culvert span to bedwidth ratio greater than 0.75.	Grade between 0.5 to 2.0%, less than 4" perch, less than or equal to 10% blockage, culvert span to bedwidth ratio of 0.5 to 0.75.	Grade greater than 2.0%, greater than 4" perch, greater than 10% blockage, culvert span to bedwidth ratio less than 0.5.
3	Circular CMP 48 inch span and smaller, spiral corrugations, regardless of substrate coverage.	Culvert gradient less than 0.5%, no perch, no blockage, culvert span to bedwidth ratio greater than 0.75	Culvert gradient 0.5 to 1.0%, perch less than 4 inches, less than or equal to 10% blockage, culvert span to bedwidth ratio of 0.5 to 0.75.	Culvert gradient greater than 1.0%, perch greater than 4 inches, blockage greater than 10%, span to bedwidth ratio less than 0.5.
4	Circular CMPs with annular corrugations larger than 1x3 and 1x3 spiral corrugations (>48" span), substrate less than 100% coverage or invert depth less than 20% culvert rise.	Grade less than 0.5%, no perch, no blockage, culvert span to bedwidth ratio greater than 0.75.	Grade between 0.5 to 2.0%, less than 4" perch, less than or equal to 10% blockage, culvert span to bedwidth ratio of 0.5 to 0.75.	Grade greater than 2.0%, greater than 4" perch, greater than 10% blockage, culvert span to bedwidth ratio less than 0.5.
5	Circular CMPs with 1x3 or smaller annular corrugations (all spans) and 1x3 spiral corrugations (>48" span), 100% substrate coverage and substrate depth greater than 20% of culvert rise.	Grade less than 1%, no perch, no blockage, culvert span to bedwidth ratio greater than 0.75	Grade 1.0 to 3.0%, perch less than 4 inches, less than or equal to 10% blockage, culvert span to bedwidth ratio of 0.5 to 0.75.	Culvert gradient greater than 3.0%, perch greater than 4 inches, blockage greater than 10%, culvert span to bedwidth ratio less than 0.5.
6	Circular CMPs with 2x6 annular corrugations (all spans), 100% substrate coverage and substrate depth greater than 20% of culvert rise.	Grade less than 2.0%, no perch, no blockage, culvert span to bedwidth ratio greater than 0.75	Grade 2.0 to 4.0%, less than 4" perch, less than or equal to 10% blockage, culvert span to bedwidth ratio of 0.5 to 0.75.	Grade greater than 4.0%, greater than 4 inch perch, greater than 10% blockage, culvert span to bedwidth ratio less than 0.5.
7	Baffled or multiple structure installations		All	
8	Log stringer or modular bridge	No encroachment on bedwidth.	Encroachment on bedwidth (either streambank).	Structural collapse.

Note: These criteria are not design criteria, but rather indicate whether the structure is likely to provide fish passage this moment in time.

Results

Table F-10 lists the number of culverts by fish passage classification. Thirteen of the 17 assessed culverts fail the fish passage criteria and two require additional analysis to determine fish passage (rows 3 and 4 in **Table F-9**). This leaves two culverts (12 percent) that meet fish passage criteria. All of the culverts that received a red classification failed due to slope. Five of these also failed the outlet drop criteria. The two culverts that fall in the gray category do so because of a low constriction ratio. **Figure F-4** shows the spatial distribution of assessed culverts and associated fish passage classification.

Table F-10. Assessed culverts and fish passage criteria.

Culvert Classification or Indicator	Definition of Indicator	Number of Culverts	Percentage of Culverts Assessed
Green	High certainty of meeting juvenile fish passage at all flows.	2	12%
Grey	Additional analysis is required to determine juvenile fish passage ability.	2	12%
Red	High certainty of not providing juvenile fish passage at all desired stream flows.	13	76%

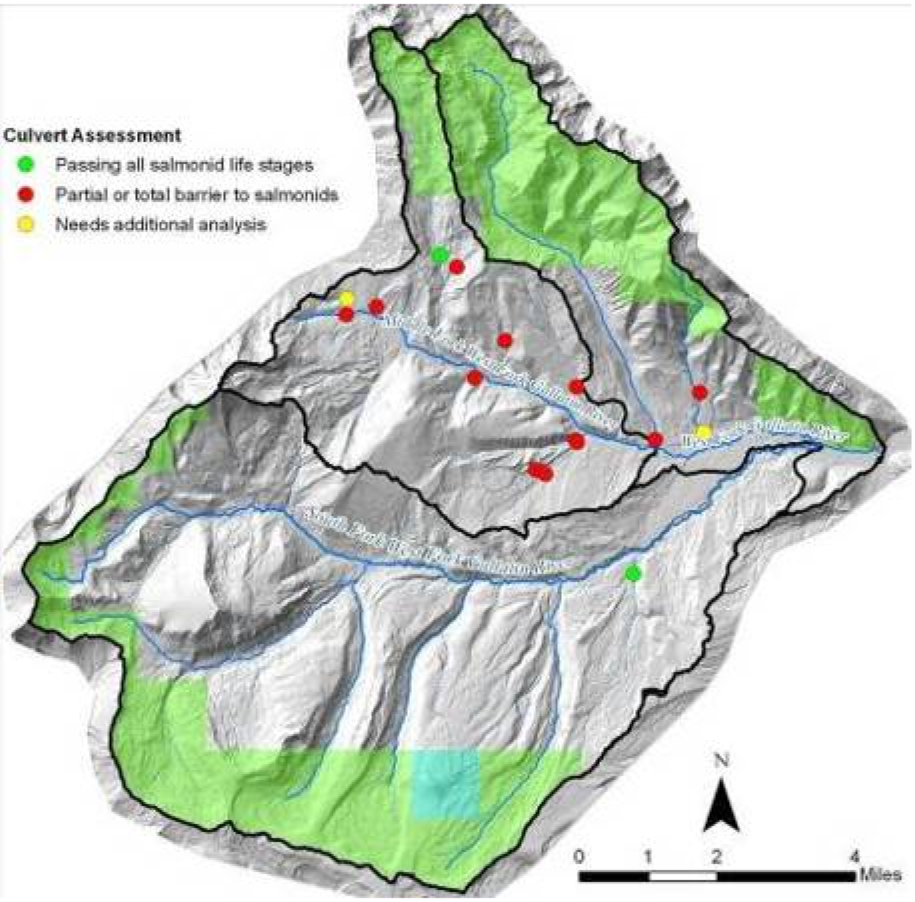


Figure F-4. Distribution and rating of culverts evaluated for fish passage.

SEDIMENT FROM POTENTIAL CULVERT FAILURE

Approach

Regional regression equations allow calculation of flood frequency and magnitude in areas where stream gage data is not available (Parrett and Johnson, 1998). These equations allow using basin or channel characteristics to calculate peak discharges for flood events of various frequencies. This analysis used the bankfull width measured above the 17 assessed culverts to calculate discharge (Q) for 2, 5, 10, 25, 50, and 100 year flood frequencies.

The next step is to establish the flow capacity of the assessed culverts. This analysis used design criteria for highway culverts (UDFCD, 2008 and Herr, 1972) to determine whether the existing culverts are adequately sized to convey discharge at the calculated flood discharges. **Figure F-5** is an example culvert capacity chart (Figure UC-8 in UDFCD, 2008) that illustrates the relationship between the culvert headwater (water height at inlet) and discharge, for various culvert sizes, culvert slopes, and lengths.

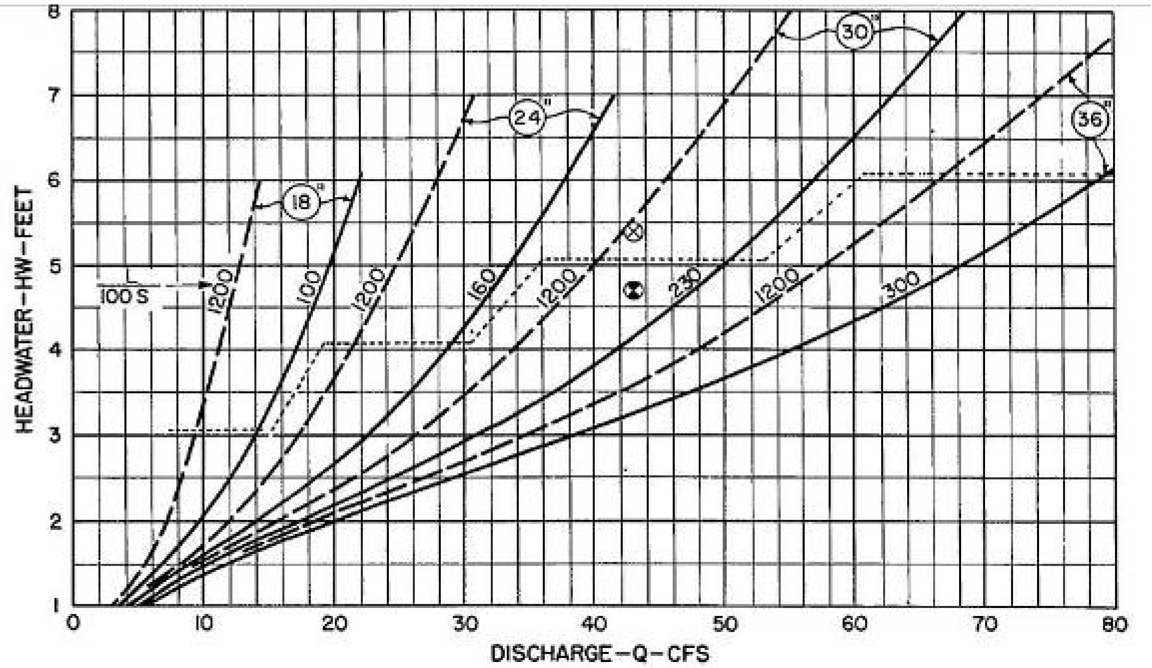


Figure F-5. Example culvert capacity chart (Figure UC-8 in UDFCD, 2008).

The culvert headwater was calculated as the fill height minus one foot. Field observations indicate that water height, and thus the headwater; will typically reach one foot below the fill height before it overtops the road in a low spot. In some cases, this height was greater than the maximum recommended headwater height for the culvert diameter (the top of the capacity curves in **Figure F-5**). In these cases, the headwater was taken as the maximum value of the capacity curve.

Table F-11 tabulates the site specific conditions of the assessed culverts. In addition to location, size, and slope of the culverts, **Table F-11** lists the:

- Calculated runoff events (Qx),

- Culvert headwater,
- Maximum capacity of the culvert (cfs),
- Maximum Q event that will pass through the culvert, and
- Amount of fill material at risk for failure.

Two of the road crossings (C7 and C17) are configured such that prior to overtopping, water will flow along the road ditch, downstream to a nearby road crossing. This mitigates the risk of failure at the assessed crossing but increases the risk at the downstream crossing by increasing the drainage area.

A common BMP for culverts is to design them to accommodate the 25-year storm event; this capacity is specified as a minimum in both the International Building Code Standards for 2006 (ICC 2006) and Water Quality BMPs for Montana Forests (DNRC 2006), and it is typically the minimum used by the USFS. Therefore, fill was only assumed to be at-risk in culverts that cannot convey a 25-year event.

Results

Table F-12 summarizes the results of the culvert analysis. These data suggest that all culverts assessed will convey a two-year (Q2) runoff event, but one culvert is not adequately sized to convey a five-year event, four will not convey a 10-year event, and three will not convey a 25-year event. An estimated 67 of the 98 crossings in the watershed have culverts, and the percentage of crossings at risk was estimated by dividing the number of crossings failing at a given discharge by the total number of crossings with culverts (67).

In many cases, if the culvert cannot convey a flood flow, water will overtop the crossing, but the crossing will not fail and the sediment load is not delivered. The probability of culvert failure is unknown, but is set at 25 percent in this analysis. If the average sediment load at risk of failure is multiplied by the number of crossings, the 25 percent probability of failure, and annual probability of the relevant level of discharge (i.e. Q5, Q10, or Q25), this yields the yearly potential sediment delivery (**Table F-12**).

Almost half of the assessed culverts will not convey a 25-year event, and based on the culvert analysis, 323 tons of road fill are at risk of eroding into streams within the watershed annually. Although passing the 25-year event was used in the BMP analysis, other considerations such as fish passage, the potential for large debris loads, and the level of development and road density upstream of the culvert should also be taken into consideration during culvert installation and replacement, and may necessitate the need for a larger culvert. For instance, because an increase in road density (and impervious surfaces) may increase the peak discharge and/or the frequency of events close to or greater than the 25-year event, a higher level of BMPs may be necessary to minimize sediment loading to streams and attain water quality standards. Particularly in areas with a high level of growth, increasing road density, or a large proportion of undersized culverts (<25-year event), meeting the 100-year event is recommended for new and replacement culverts. This capacity typically allows for aquatic organism passage and corresponds to the guideline for the USFS, BLM, and USFWS for fish-bearing streams (INFISH 1995), and it should help offset some of the risk from undersized culverts and provide a greater margin of safety for changes in hydrology associated with future growth.

Table F-11. Potential culvert failure data analysis table.

Site ID	Sub-watershed	Structure Type	Culvert Diameter (ft)	Slope (%)	Upstream Bankfull Width (ft)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Hw (ft)	Max Capacity (cfs)	Maximum Q Event	Fill (tons)	Comments
C4	Beehive Creek	CMP	1.6	22	1.9	2	8	17	35	58	89	7	42	Q25	257	
C7	Upper Middle Fork West Fork Gallatin River	CMP	2	10	4	7	24	47	89	139	201	7	42	Q5	1418	Will spill before culvert fails
C9	Middle Fork West Fork Gallatin River	CMP	2	9	2.2	2	10	20	42	69	105	6	38	Q10	216	
C16	Middle Fork West Fork Gallatin River	CMP	2	5	4.6	9	30	57	106	164	234	7	42	Q5	115	
C19	Crail Creek	CMP	2	8	4	7	24	47	89	139	201	6	38	Q5	195	
C6	Upper Middle Fork West Fork Gallatin River	CMP	2	8	3.5	6	20	39	76	119	174	7	42	Q10	815	
C14	Middle Fork West Fork Gallatin River	CMP	3	7	7.3	21	61	107	190	281	388	10	110	Q10	1405	
C11	Middle Fork West Fork Gallatin River	CPP	3	4	5	11	34	64	118	181	257	3	28	Q2	189	
C8	Middle Fork West Fork Gallatin River	CC	3	2	4	7	24	47	89	139	201	6	80	Q25	450	
C17	Middle Fork West Fork Gallatin River	CMP	4	11	4.2	8	26	50	95	147	212	12	215	Q100	964	Will spill before culvert fails
C18	Upper West Fork Gallatin River	CMP	4	2	2.8	4	14	28	57	92	136	7	145	Q100	183	
C22	Middle Fork West Fork Gallatin River	CMP	4	5	5	11	34	64	118	181	257	11	195	Q50	1019	
C5	Upper Middle Fork West Fork Gallatin River	CMP	4	1	2.7	4	13	27	55	88	131	5	103	Q50	247	
C15	Middle Fork West Fork Gallatin River	CPP	4	5	6.5	17	51	91	164	246	342	12	215	Q25	2026	
C25	South Fork West Fork Gallatin River	CMP	5	1	9.5	34	91	155	264	383	517	6	125	Q5	202	
C3	Beehive Creek	CMP	7	2	11.3	46	118	197	327	469	624	19	625	Q100	1117	

Table F-11. Potential culvert failure data analysis table.

Site ID	Sub-watershed	Structure Type	Culvert Diameter (ft)	Slope (%)	Upstream Bankfull Width (ft)	Q2 (cfs)	Q5 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)	Hw (ft)	Max Capacity (cfs)	Maximum Q Event	Fill (tons)	Comments
C12	Upper West Fork Gallatin River	CMP	12	3	10	37	98	166	281	407	546	24	1425	Q100	4402	

CMP - Corrugated Metal Pipe
CC - Concrete Culvert
CPP - Corrugated Plastic Pipe

Table F-12. Summary results of potential culvert failure sediment load analysis.

Calculated Discharge Event	Number of Culverts Passing	Number of Culverts Failing	Percent Passing	Percent Failing	Average Sediment at Risk of Failure (tons)	Number of Crossings at Risk	Yearly Probability of Discharge	Sediment Delivery (tons/yr)
Q2	17	0	100%	0%			0.5	
Q5	16	1	94%	6%	189	4	0.2	37
Q10	12	5	71%	29%	482	16	0.1	190
Q25	9	8	53%	47%	812	12	0.04	96
Q50	6	11	35%	65%			0.02	
Q100	4	13	24%	76%			0.01	
				TOTALS:	1484	32		**323**

BEST MANAGEMENT PRACTICES

BMP efficiencies vary by the type of BMP implemented. Based on the average literature value for sediment reduction associated with vegetated buffers, 85 percent was used as the desired reduction factor for additional BMP implementation for road crossings and traction sand. The following studies support the 85 percent BMP reduction factor:

- Oat buffer strips, six meters in length, reduced sediment mass by 76 percent (Hall et al., 1983).
- Mickelson et al. (2003) determined that the first few meters of the buffer strip trapped the majority of deposited sediment. Buffer strips 4.6 meters long and with a drainage area to buffer strip area ratio of 10:1 reduced sediment by 71 percent while the 9.1 meters long buffer strip with a ratio of 5:1 reduced sediment delivery by 87 percent.
- Grassed waterways reduced suspended sediment concentrations by 94 and 98 percent in wet and dry antecedent moisture conditions, respectively (Asmussen et al., 1977).
- Han et al. (2005) determined that vegetative filter strips, 10 meters in length, were effective at removing more than 85 percent of the incoming total suspended sediment from highway runoff.

A reduction of 85 percent was chosen as a goal based on literature values but because of existing BMPs and the varying effectiveness of BMPs, it may not be achievable in some areas but a greater amount of reduction may be possible in other areas. Additionally, the reduction factor was based on effectiveness of buffers but buffers are not a formal BMP goal and are only one aspect of BMPs that may be used for road crossings and traction sand to achieve the necessary reductions. Additional details regarding the BMP scenario for each source category are discussed below.

Road Crossings

For each WEPP-modeled road crossing, the total sediment detached represented a condition with no BMPs and the total sediment deposited represents the effect of existing BMPs. Therefore, the total sediment delivered is the detached minus the deposited sediment. In all road crossings evaluated, there was some level of BMPs already in place. Reductions listed in **Table F-13** represent the additional reduction in sediment delivery that equates to 15 percent of the total detached sediment load.

Implementation of BMPs for roads could include increased vegetation in the road ditch and buffer, adding check dams, rocks, or fiber rolls to ditches, reducing the contributing road length through the use of water bars or drainage dips, or re-surfacing dirt and gravel roads.

Traction Sand

The desired reduction aims to decrease the amount of traction sand delivered to streams from 56 to 15 percent. Implementation of BMPs for road traction sand include structural methods such as swales, detention basins, and vegetative filter strips or non-structural methods such as improved snow fences or storage, street sweeping, altering application rates, and using advanced snowplow technology. Additionally, traction sand applicators range from permanent MDT employees to seasonal staff, and traction sand loading may be decreased by improved staff training for traction sand BMPs and/or utilization of MDT BMP publications such as Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water (Staples et al. 2004) and fact sheets.

Culvert Failure

The BMP approach used for the culvert analysis used the 25-year event as a minimum, but because an increase in road density (and impervious surfaces) may increase the peak discharge and/or the frequency of events close to or greater than the 25-year event, a higher level of BMPs may be necessary to minimize sediment loading to streams and attain water quality standards. Particularly in areas with a high level of growth, increasing road density, or a large proportion of undersized culverts (<25-year event), meeting the 100-year event is recommended for new and replacement culverts. This capacity typically allows for aquatic organism passage and corresponds to the guideline for the USFS, BLM, and USFWS for fish-bearing streams (INFISH 1995), and it should help offset some of the risk from undersized culverts and provide a greater margin of safety for changes in hydrology associated with future growth.

SEDIMENT LOAD ANALYSIS SUMMARY

Based on the roads source assessment, traction sand and potentially fill from failing culverts are the largest sediment sources associated with roads within the West Fork Gallatin River watershed. Sediment loading associated with roads is similar within the South Fork and West Fork subwatersheds and greatest within the Middle Fork watershed, which is where most of the ski resort and residential development is concentrated.

Table F-13. Summary of sediment sources in the West Fork Gallatin River watershed evaluated in this study.

303(d) Sub-watershed	Current Crossing Sediment Load (tons/yr)	Desired Crossing Sediment Load (tons/yr)	Current Traction Sand Sediment Load (tons/yr)	Desired Traction Sand Sediment Load (tons/yr)	Current Potential Culvert Failure Sediment Load (tons/yr)	Desired Culvert Failure Sediment Load (tons/yr)
Middle Fork West Fork Gallatin River	4.8	1.7	84.2	22.7	155.0	0.0
South Fork West Fork Gallatin River	2.1	0.7	6.5	1.8	109.0	0.0
West Fork Gallatin River	1.2	0.4	64.4	17.4	59.0	0.0
	8.1	**2.9**	**155.0**	**41.8**	**323.0**	**0.0**

Roads Assessment Uncertainty

Natural processes such as sediment erosion and delivery from roads or other landscape features, associated with rainfall and runoff are very complex and modeling of these processes requires significant simplification. Notably, the models have limited temporal resolution, and do not account well for seasonal and event scale processes. Additionally, the roads model was not calibrated and is acknowledged to be a very rough estimate of loading associated with roads. The model is intended to identify the relative sediment contribution from roads and areas that should be examined more closely to locate where BMPs would be most beneficial. The WEPP model used for the West Fork Gallatin River provides estimates of yearly sediment loads based on a 50-year average of climatic conditions. Sediment models tend to over predict annual sediment loads under normal or low runoff conditions and under predict annual loads under high runoff conditions. Therefore, the intent is that the average annual sediment load predicted should be applicable over long periods of time that include both low, average, and high runoff years. It is possible that sediment delivery to streams in a watershed such as the West Fork Gallatin River can be minimal for many consecutive years and then very high during the next year.

The annual estimate of traction sand application is based on actual application rates but there is a large degree of uncertainty regarding the delivery rate and amount of traction sand retained from year to year because the estimate is based on a combination of field observations and literature-based values and no measurements were conducted. Additionally, traction sand is reclaimed in the spring near Meadow Village (personal comm. R. Edwards, 2010), indicating the delivery rate likely differs between Hwy 64 and private roads in the watershed.

For the culvert assessments, peak flows generated for each culvert using regression equations may over or under estimate peak discharge, and therefore peak flows computed by a different method could result in different conclusions regarding culvert capacity. Because problems related to undersized (or improperly installed or maintained) culverts may range from being a chronic source of sediment during storm events to contributing a substantial load to a stream during complete failure, the greatest amount of uncertainty related to the culvert assessment is identifying the probability of culvert failure and estimating the annual load related to culverts. Despite the high degree of uncertainty related to annual loading associated with culverts, they were included in the analysis to identify the potential significance of loading associated with culverts and aid in TMDL implementation.

The fish passage assessment is intended to be a rapid assessment tool and it is acknowledged that instead of being strictly a barrier or non-barrier, fish passage for a particular culvert is more likely a continuum based on factors such as fish species, size, migration pattern relative to stream hydrology, and jumping ability. Additionally, although fish barriers are generally considered a negative, in some instances, they are a barrier that separates native and non-native fish. Therefore, prior to replacing culverts classified as fish barriers, each culvert should be evaluated individually.

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EXAMPLES OF CULVERTS AND BMPS

Bottomless corrugated steel culvert.

Perched corrugated steel culvert.

Example of concrete culvert.

Corrugated plastic culvert, fish passage barrier.

Erosion of road fill material adjacent to perched corrugated steel culvert.

Correct culvert installation.

Fiber wattles used to control road ditch erosion.