APPENDIX G
SEDIMENT CONTRIBUTION FROM ROAD EROSION

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 was 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 by 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 from 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. Of the 47 permutations of ownership, road type, and soil type found in the basin, the 44 sampled locations captured 14. Those 14 categories encompass 82% of the roads (by length) in the Big Hole watershed. A more complete description of the sampling methodology can be found in the Road Sediment Sampling Plan.

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 G-1.**

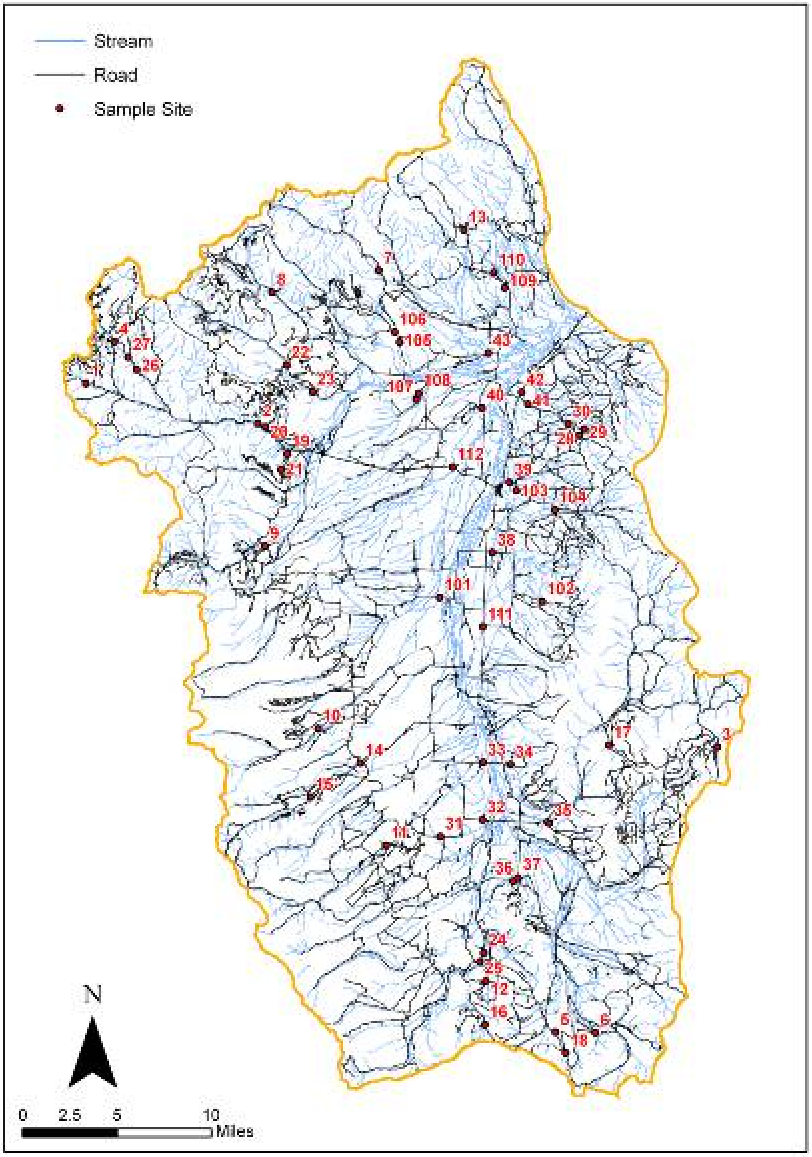

Figure G-1. Road sediment field sampling locations

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.

<u>Model run and extrapolation</u>
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 three parameters – lumped road class, road/stream orientation, and geology erosion factor. Each road segment (within 200 feet of an NHD stream) in the GIS was assigned values

for each of these categories. Extrapolation parameters were selected based on their relevance to road sediment production in the watershed. Based on an initial extrapolation attempt it was discovered that road class was not as important a factor as originally anticipated. Sediment production rates were nearly the same for 4x4, local, and ranch roads, but significantly different for highways. This makes sense in the rural Big Hole because essentially all non-highway road segments are dirt roads. To simplify the extrapolation process and reduce the number of extrapolation factors requiring data, the road class category was converted to a lumped road class, which includes only 2 classes – 4x4/local/ranch (4LR), and highway (HWY). The road/stream orientation category consisted of the following segment types: crossing (Xing) for road segments that cross streams, and parallel (Para) for road segments that are adjacent to streams but do not cross them. Geology erosion factor within the upper Big Hole was classified either low (G1) or high (G5) according to the WARSEM standards.

Eight extrapolation classes resulted from the combination of these 3 parameters: 4LRXingG1, 4LRXingG5, HWYXingG1, HWYXingG5, 4LRParaG1, 4LRParaG5, HWYParaG1, HWYParaG5. 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 were not available to develop extrapolation factors for the following extrapolation classes: HWYParaG1, and HWYParaG5. To overcome this data deficit, the following assumptions were made to develop a complete set of extrapolation parameters.

The HWYParaG1, and HWYParaG5 factors were developed by scaling (multiplying) the HWYXingG1, HWYXingG5 factors by the extrapolation factor ratios 4LRXingG1/4LRParaG1 and 4LRXingG5/4LRParaG5 respectively. These ratios were found to be

4LRXingG1 / 4LRParaG1 = 0.881543662000298 and
4LRXingG5 / 4LRParaG5 = 0.0661288010471528 .

The missing extrapolation factors were then determined by the following equations:

HWYParaG1 = 0.881543662000298 * HWYXingG1 and
HWYParaG5 = 0.0661288010471528 * HWYXingG5

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. Because roads do not naturally exist, the standard practice has been to compare existing loads to loads that might be expected following the application of specific sediment reducing BMPs. The WARSEM allows users to evaluate the potential effects of many different road BMPs. The following BMP scenarios were modeled: installing silt fences in ditches at all crossings, installing other ditch BMPs at crossings, returning rutted roads to original condition, and applying length reducing BMPs at crossings.

> *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%.
>
> *Other Ditch BMPs at All Crossings* - This is a prediction of sediment loads if alternates to silt fence such as slash, rock weirs, or vegetation were installed in ditches at all road/stream *crossings*. Based on best professional judgment and extensive field observations, the project team feels that these measures are less effective at reducing sediment delivery, but longer term/lower maintenance solutions than silt fence and hay bales. Therefore, predicted deliveries (existing conditions) were reduced by 15%.
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> *Restoring Rutted 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. All reductions from altering road surface conditions can be based on the following matrix (**Table G-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 the left side of the table to the condition listed at the top of the table. Due to feasibility, however, the only investigated road surface BMP was restoring rutted road surfaces to their original condition.

Table G-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

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.

Results

Table G-2 contains existing sediment loads from unpaved roads as well as potential reductions associated with the various BMP scenarios based on the WARSEM as extrapolated to the 6th code HUC subwatersheds.

Table G-2. Existing and potential sediment loads from unpaved roads by 6th code HUC.

Road Sediment Modeling And "What If" Scenario Summary Table	Existing Conditions	Settling Basins @ All Crossings	Silt Fences @ All Crossings	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 Contributing Road Surfaces to Original Condition	Apply Length Reducing BMPS at Crossings to Reduce Contributing Length to 500 ft for USFS Roads and 100 ft for OTHER Roads
Sub Watershed Name	(Ton/yr)	(Ton/yr)	(Ton/yr)	(Ton/yr)	(Ton/yr)	(Ton/yr)	(Ton/yr)	(Ton/yr)
Andrus Creek	86.51	15.60	65.65	21.15	41.73	41.73	86.43	61.25
Berry Creek	1.31	0.28	1.01	0.33	0.63	0.63	1.31	1.09
Big Swamp Creek	32.53	6.59	24.90	7.32	15.99	15.99	32.48	29.11
Big Hole River-Big Swamp Creek	90.67	17.61	69.18	22.57	43.69	43.69	90.57	56.54
Big Hole River-McVey Homestead	66.62	14.97	51.43	17.05	32.09	32.09	66.51	42.21
Big Hole River-Saginaw Creek	87.24	15.46	66.13	21.35	42.05	42.05	87.16	66.67
Big Hole River-Spring Creek	86.00	16.51	65.56	21.34	41.44	41.44	85.90	53.61
Big Hole River-Squaw Creek	45.50	8.60	34.65	11.22	21.95	21.95	45.45	28.08
Big Hole River-Wisdom	91.37	16.03	69.21	22.34	44.04	44.04	91.29	57.37
Big Lake Creek	42.61	9.40	32.84	10.86	20.52	20.52	42.54	29.26
Bull Creek	67.63	11.24	51.04	16.31	32.63	32.63	67.58	44.44
Doolittle Creek	76.92	14.22	58.48	18.98	37.07	37.07	76.84	61.58
Englejard Creek	59.53	10.53	45.12	14.57	28.69	28.69	59.47	45.52
Fox Creek	27.28	5.96	21.01	6.88	13.16	13.16	27.24	21.32
Francis Creek	71.05	11.84	53.63	17.24	34.24	34.24	71.00	51.12
Headwaters Big Hole River	43.49	9.19	33.40	11.00	20.95	20.95	43.43	35.04
Howell Creek	29.86	4.78	22.49	7.05	14.46	14.46	29.84	19.10
Johnson Creek	66.82	11.77	50.63	16.05	32.32	32.32	66.76	54.43
Joseph Creek	5.36	1.60	4.26	1.46	2.58	2.58	5.34	4.55
Little Lake Creek	47.90	8.41	36.28	10.78	23.41	23.41	47.86	39.66
Lower Governor Creek	100.49	19.97	76.81	25.06	48.44	48.44	100.36	61.76
Lower Rock Creek	29.10	7.48	22.75	7.66	14.01	14.01	29.04	18.85
Lower Trail Creek	62.03	12.94	47.59	30.79	40.35	40.35	61.96	39.05
Lower Warm Springs Creek	109.22	19.22	82.75	26.69	52.65	52.65	109.13	77.70
May Creek	1.67	0.28	1.27	0.41	0.81	0.81	1.67	1.37
McVey Creek	45.66	7.53	34.44	11.06	22.00	22.00	45.63	33.46
Miner Creek	40.14	8.19	30.74	10.07	19.34	19.34	40.09	30.16
Mussigbrod Creek	26.51	7.21	20.83	7.07	12.76	12.76	26.44	18.68
North Fork Bighole River	82.98	17.39	63.69	20.27	40.22	40.22	82.85	50.14
Old Tim Creek	37.72	7.04	28.70	7.84	18.78	18.78	37.65	36.01
Pine Creek	5.20	2.29	4.35	1.59	2.50	2.50	5.17	4.58
Pintler Creek	49.02	7.83	36.90	11.81	23.63	23.63	48.99	31.03
Plimpton Creek	48.77	8.56	36.95	11.45	23.71	23.71	48.72	30.65
Ruby Creek	109.87	24.84	84.86	28.16	52.92	52.92	109.68	89.17
Schulz creek	1.63	0.70	1.35	0.49	0.78	0.78	1.62	1.43
Stanley Creek	22.78	3.60	17.14	5.48	10.98	10.98	22.76	13.59
Steel Creek	99.65	17.11	75.37	24.24	48.03	48.03	99.57	67.85
Swamp Creek	67.33	13.83	51.59	16.93	32.43	32.43	67.24	44.84
Tie Creek	40.01	7.73	30.51	9.95	19.28	19.28	39.96	32.82
Upper Governor Creek	53.55	9.26	40.52	12.99	25.84	25.84	53.50	39.13
Upper Rock Creek	82.53	15.01	62.67	20.31	39.77	39.77	82.45	56.79
Upper Trail Creek	31.81	11.20	25.75	9.03	15.31	15.31	31.68	26.97
Upper Warm Springs Creek	16.90	3.16	12.86	3.38	8.45	8.45	16.87	16.90
West Fork Ruby Creek	53.20	10.98	40.78	13.39	25.63	25.63	53.13	38.58
Grand Total	2343.95	453.96	1788.07	592.00	1142.27	1142.27	2341.19	1663.45