TECHNICAL DOCUMENTATION FOR
SEDMODL VERSION 2.0
ROAD EROSION/DELIVERY MODEL

List of Tables

List of Figures

List of Maps (maps provided as separate Adobe Acrobat files)

1.0 INTRODUCTION

Boise Cascade Corporation and the National Council on Air and Stream Improvement (NCASI) have developed version 2.0 of SEDMODL (known as SEDMODL2), a GIS-based road erosion/delivery model. This model is designed to identify road segments with a high potential for delivering sediment to streams in a watershed and to estimate road erosion and delivery. The model uses information from an elevation grid, along with road and stream coverages to determine which segments of the road system are likely to drain to streams. The relative amount of sediment produced from these road segments is then calculated based on modified road erosion factors from the Washington Department of Natural Resources Standard Method for Conducting Watershed Analysis, surface erosion module (WDNR 1997) and the Water Erosion Prediction Project (WEPP) soil erosion model. SEDMODL2 also calculates a measure of background sediment input for comparison with total road sediment input. The comparison of road input to background input serves as a tool for land managers to determine if there is a relatively large or small input from roads in the basin.

The purpose of this model is to identify road segments that have a high potential for delivering sediment to streams based on proximity, or delivery of road drainage to the stream network. Model output consists of:

- an ArcInfo line coverage with sediment production information
- a model run documentation file
- dBase files for use in a runtime Microsoft Access application for scenario modeling
- an ArcInfo graphics file (.gra) representing a map of the project area

The delivery segments can be field verified to determine actual delivery, and road attributes can be modified to refine the road-input data.

The model is designed to be flexible enough to be run as a screening tool for basins with a minimum amount of road and stream information available (i.e. only information on road and stream location) or as a more reliable indicator of relative sediment production from with more detailed road attributes. These attributes can include the following:

- Road Use
- Surface Type
- Road Width
- Construction Year
- Culvert or Drainage Structure Locations
- Cutslope Height
- Road Prism Geometry Type
- Percent Cutslope Cover
- Road Gradient

The model can also be used as a tool to compare the relative effects of road erosion control measures in a watershed (e.g. changing road surfacing or traffic use characteristics).

1.1 Version 2.0 Updates to Road Erosion Calculations and Factors

SEDMODL2 has been updated substantially from Version 1.0, from both user flexibility and calculation perspectives. The updates to the road calculations and factors will likely result in different erosion estimates when compared to SEDMODL runs using Version 1.0. Details of the new calculations and factors, as well as the scientific basis for these factors, are included in Section 4.0. The major changes include:

a) The precipitation factor has been changed to a rainfall factor to differentiate between precipitation falling as rain versus snow.

b) The model has the ability to accommodate road age if input by the user. New roads (1-2 years old) are assigned higher erosion rates than established roads. This function allows the user to model past, present, or future erosion scenarios by specifying a construction date for different road segments and a run date.

c) Version 2.0 also allows the user to specify insloped, crowned, or outsloped road drainage configurations for different road segments. Erosion/delivery estimates are adjusted accordingly.

d) A culvert coverage can be specified in Version 2.0. If available, the culvert coverage will be used to reduce the direct delivery lengths at stream crossings if cross-drains are present that divert ditch drainage to the forest floor If a culvert coverage is not available, but the user knows cross drains are routinely constructed to divert drainage away from the stream, the user has the option of specifying a maximum delivery distance that will limit the lengths of direct delivery road segments on either side of a stream crossing.

e) The Geologic Erosion Rate has been modified to a Geologic Erosion Factor based on back-calculations from published road erosion measurements and the new factors listed above.

2.0 MODEL USES AND LIMITATIONS

2.1 Uses of the SEDMODL2 program

The SEDMODL2 program is designed to be flexible. This model (or portions thereof) can be applied for a number of different purposes:

a) Estimate background sediment

b) Determine road sediment delivery areas

c) Find road/stream intersections

d) Estimate amount of sediment from road surface erosion that is delivered to streams (past, present, and future modeling is possible in the current version)

e) Show results of road improvements

f) Use as a watershed screen to determine a background to road sediment ratio

g) Help in the development of road management plans

h) Help address sediment TMDL issues

In addition to the GIS portion of a program, a run-time version of Access is included that allows post-processing and rapid changes to road segment or model parameters. For example, if you realize that you have entered an incorrect value after the initial model run has been made, you can edit the data in the runtime Microsoft Access application that is provided. The spatial context will not change after the initial model run, meaning that any recalculations take less than a minute or two.

The empirical relationships used in the SEDMODL2 program to calculate road surface erosion and delivery to streams are based on data sets from forest roads in Idaho, Oregon, Washington, and the Appalachian Mountains (North Carolina and West Virginia). The rainfall factors are based on WEPP runs made with climates from Washington, Oregon, Idaho, northern California, and Montana. If you are running SEDMODL2 in other areas, use the results with caution. The basic principles of erosion and delivery from forest roads are universal, but different rainfall patterns, gentler topography, and different soil characteristics in other areas of the country may affect erosion and delivery rates in ways not accounted for in SEDMODL2 calculations.

2.2 Limitations of the SEDMODL2 Program

There are a number of limitations of the SEDMODL2 program that the user should be aware of when interpreting model results. These limitations relate primarily to the quality of input data (the garbage in, garbage out scenario) and situations that the program is not designed to model.

a) If stream (or road) layer are spatially misaligned or roads or streams are identified which do or do not exist on the ground, the road/stream intersections have the potential to be incorrect, which in turn alters the amount of direct delivery segments and potentially the amount of sediment delivered.

b) If road feature level attributes such as surfacing or traffic use are incomplete, the sediment production values should only be used in a relative sense (i.e. this segment of road has more sediment delivered than that one).

c) Unless road prism geometry is specified in the road coverage, the model assumes all roads are in-sloped with a ditch. This can skew sediment amounts if roads are crowned or maintained as outsloped.

d) Unless a construction year is specified, the model assumes all roads are over two years in age.

e) The model determines direct delivery from road segments to streams based on road/stream intersections. It does not predict gully formation at culvert outfalls that may result in direct connection between cross-drain structures and a stream downslope of that culvert. In certain situations, such as roads that closely parallel but do not cross streams, this can result in under-prediction of direct delivery road segments. These segments will likely be selected as indirect delivery segments.

3.0 MODEL REQUIREMENTS

3.1 Arc/INFO System Requirements

SEDMODL2 has been developed and tested on Windows workstations, however it should perform equally on Unix workstations. Due to a difference between how ArcInfo widgets and text on menus are displayed on Windows and Unix, the Unix user may need to edit the size and position of menu elements. The User Manual can be used as a guide for how menus should appear. The user should have a firm understanding of menus or be willing to read the ArcInfo documentation to learn about what is required to edit a menu.

Four Arc/INFO modules are required to run the model: Arcedit, Arcplot, INFO, and GRID. The space/memory required depends on the complexity and the size of the area being modeled. For example, with an area of 94 square miles, 2.2 miles of stream per square mile, and 4.4 miles of road per square mile; approximately 10 megabytes were required to run the model. Seventy-five percent of that space is recovered upon completion of the model run. Actual disk space requirements depend on the number and definition of attributes on each of the required layers and watershed size. Additional memory is required for the default geology coverage if you do not have a site-specific geology layer for the watershed area on your system.

3.2 GIS Data Requirements

The SEDMODL2 distribution set includes all required programs as well as regional precipitation factor and geology layers for Idaho, Washington, and Oregon. In order for the model to run, the user must provide GIS data for topography, streams, roads, and a basin boundary. The user may optionally specify basin-specific soil, geology, precipitation, or culvert location layers as well as additional information on road attributes. Precipitation factors for other states are available upon request.

Table 1. Data Layers Required for SEDMODL2. (Minimum user-supplied layers required to run SEDMODL2 are in bold)

Required Data Layer	Use in Model	Minimum User-Supplied Requirement	Optional Additional Information
Topography	Determine road drainage and delivery, road and hillside gradient	**Elevation Grid with a 40 foot resolution**	None
Streams	Location used to determine sediment delivery potential	**Stream layer**	Stream layer field checked for presence/absence of channels (1:24,000)
Roads	Determine sediment production and delivery	**Roads**	Road attributes (i.e. surfacing, traffic, gradient)
Basin Boundary	Boundary of modeling area	**Boundary of study area**	None
Precipitation	Precipitation factor	None, a precipitation factor coverage for the *lower 48 States* is supplied with the distribution set based on the 2001 PRISM monthly precipitation/snowfall data (2 km grid size)	User-specified precipitation factor coverage.
Geology	Geologic erosion rate for road erosion	None if used in *Oregon, Washington, or Idaho* (optional coverage - regional 1:500,000 geology coverage supplied with model is used). **If used in other areas, a geology coverage is required.**	User-specified geology coverage with Erodibility Factor
Soils (optional) Culverts (optional)	Soil depth and bulk density for background erosion rate Culverts or drainage structures	None (optional coverage - default values used) None (optional coverage - default values used)	User-specified soil coverage with soil depth and bulk density If provided, these features must be a point coverage and locations must be coincident with the road arc features.

3.2.1 Topographic Data

An elevation grid is required by the model to calculate road gradient, hillslope gradient and delivery lengths. A 40-foot resolution (or the new 10-meter DEM) is highly recommended for both model type runs. Using a larger grid cell size (e.g. 30-meter DEM) produces results that are unpredictable. If the best that exists is a 30-meter DEM, see Appendix B. A grid cell size smaller than 40-foot/10-meter only increases the processing time and the computer memory required (for working at a 1:24,000 scale); it also implies a false sense of accuracy in the modeled results.

3.2.2 Road and Stream Data

SEDMODL2 is designed to run with either very little information on streams and roads (i.e. just the location of streams and roads from the linear coverages) or with road arcs attributed with surfacing, use, or other data. Model runs with more information on actual road conditions and field-checked stream locations and extents obviously produce more reliable model results. If only road and stream location data is available, the user must pick default road surfacing, width and traffic rate for all roads in the basin. Road surfacing and use varies throughout a basin, and the calculated road erosion is quite sensitive to both these variables. Model results developed from a coverage with no feature level attributes should be used only as a screening tool and to direct data gathering efforts to obtain better road information.

A road coverage with feature level attributes for:

- Road Use
- Surface Type
- Road Width
- Construction Year
- Culvert or Drainage Structure Locations (separate point coverage)
- Cutslope Height
- Road Prism Geometry Type
- Percent Cutslope Cover
- Road Gradient

produces more reliable results. This information may be keyed to a road class or type field within your road data (i.e. road class 23 may be secondary, native surfaced roads). The model allows you to select data fields from your road coverage that can be used to specify attribute information.

Checking the road coverage to ensure that all roads in the watershed are included on the coverage is important. The easiest way to do this is with recent aerial photography. Field-verified information on stream position, presence/absence of channels, and extension of drainage up hillsides is also important. The stream layer should also be edited to ensure that the stream is in the bottom of the draw/hollow/valley and not on the hillside.

Sediment calculations from model runs with good road and stream data can be used to examine a relative relationship between different values of sediment delivery or as an indicator of estimated sediment inputs. There are also some local conditions that can be observed in the field that are too detailed for this model to recognize at the scale it is generally run which result in an under- or over-prediction of lengths of road delivering and sediment input. These conditions are discussed in more detail in Section 7.0 (Model Validation Testing).

3.2.3 Rainfall Factor Data

Statewide rainfall factors for Idaho, Oregon and Washington are included with the SEDMODL2 distribution set. The rainfall factors are based on the 2001 PRISM monthly precipitation and snowfall data sets (see Section 4.2.7). Spatial resolution on the PRISM data is 1.25 arc minutes (approximately 2 km). Rainfall factors for other states are not distributed with the core SEDMODL2 distribution, but are available. Contact the SEDMODL2 distribution source for information on acquiring additional state rainfall factor coverage. Only the lower 48 states are available, please see Appendix C for a description of how to create a rainfall factor coverage if your watershed area is in Alaska, Hawaii, or Canada.

3.2.4 Geology Data

Geology coverages and erosion factors for Idaho, Oregon and Washington from state 1:500,000 scale geologic maps are included with the SEDMODL2 distribution set. These coverages are used to determine erosion rates for roads. If a better geologic coverage is available for your watershed, it can be used in place of the default layers. If you are running SEDMODL2 in another state or region, you will need to supply a geologic coverage. The geology polygons in the user-supplied coverage will need to be attributed with geologic erosion factors. Refer to Table 2 in Section 4.2.1 for guidelines on selecting appropriate erosion factors scaled to other model factors.

Note that the geologic erosion factors have been altered from Version 1.0 to fit with the updated rainfall factor. If you have a coverage used in Version 1.0, you will need to update the erosion factors for use with Version 2.0.

3.2.5 Soil Data

The model uses soil depth and bulk density to calculate average background sediment input for comparison with road surface erosion. An average soil depth of 36 inches and a bulk density of 1.4 gm/cc are used unless user-supplied soil data is specified. The user can either over-ride the default values with another value for their watershed, or provide a soil coverage with these values. If used, the soil coverage should include soil polygons attributed with soil depth in inches and bulk density in grams/cubic centimeter. The model can accommodate either an average soil depth for each polygon, or a maximum and minimum soil depth for each polygon (many soil surveys report max/min depth). If max/min depths are specified, the model will generate an average soil depth.

3.3 User Input Values

The model has been set up to run with default values for a number of variables. However, if values for the following parameters are known, they can be entered. Sections 4.2.6 and 5.1 describe how these values are used in the model and provide some insight to picking appropriate values for your watershed.

Model Parameter	Default value
Cutslope Cover (percent vegetative or rock cover)	70
Average Soil Depth (in)	36
Average Soil Bulk Density (gm/cc)	1.4

4.0 ROAD EROSION CALCULATIONS

The construction and use of roads can be a significant source of sediment in forested basins. Road construction removes vegetation from the road cutslope, fillslope, ditch, and tread, leaving these areas susceptible to erosion. Over time, the cutslope and fillslope revegetate and erosion from these sources is reduced; however, the road tread and ditch continue to be sediment sources as long as the road is in use. Research has shown that the most important factors determining how much sediment is produced from the road tread are how much the road is used, and the amount and type of road surfacing. In addition to these factors, the configuration of the road drainage system, particularly whether or not road drainage reaches the stream network, determines if sediment produced from roads has the potential to affect aquatic resources.

4.1 Road Segment Delivery

One of the goals of the model is to identify portions of the road network in a basin that deliver sediment to streams. Land managers can use this information to identify locations where road improvements would reduce sediment input to streams. The model divides the road network into three categories:

1. Segments that deliver directly to streams (i.e. at stream crossings)

2. Segments that deliver sediment indirectly to streams (i.e. roads that closely parallel streams, within 100 feet slope distance and within 200 feet slope distance).

3. Segments that do not deliver to streams (i.e. runoff is directed onto the forest floor and infiltrates). Segments in this category are dropped from further computation because sediment produced from these portions of the road network does not reach the stream system.

SEDMODL2 uses a raster based method to identify direct delivering road segments and depends on the availability of an ArcInfo GRID license. Stream crossings are defined first using a series of intersections of the road and stream layer. These crossing points are used as starting locations to trace up the road network away from the stream and identifies the point at which flow toward the stream is interrupted. The criteria for flow interruption is when the slope along the road is negative, i.e. flowing away from the stream, or a drainage structure or the maximum delivery distance if these are specified in the current model run (see discussion below). The model breaks the segment at whichever of these three potential flow interruptions is encounters first along a road segment. The flow interruption analysis is accomplished in a raster format where the roads layer has been converted to a grid.

The road segments that match with these newly defined areas of direct delivery are extracted from the road layer. The model then buffers the stream layer to 100 and 200 feet slope distance and extracts the roads with indirect delivery. Road segments that deliver directly to streams are assigned a delivery factor of 1, meaning that 100 percent of water and sediment produced from these segments is delivered to the stream network. Road segments that do not deliver to streams are deleted from road network. Road segments that deliver sediment within 200 feet and 100 feet slope distance of a stream, but not directly to a stream, are assigned a delivery factor of 10 percent (0.1) and 35 percent (0.35), respectively (WDNR 1997, Ketcheson and Megahan 1996).

4.1.1 Optional Drainage Structure Coverage

Drainage structures represented as an ArcInfo point coverage can be specified by the user to further modify the lengths of road delivering to streams. Stream passage culverts should not be included in the coverage, as these will incorrectly truncate direct delivery segments at the stream crossing. Additionally, ditch relief drainage structure locations must be coincident with the road centerline (arc). Skewed results may occur if the provided drainage structure coverage is not complete for the entire analysis area.

If a culvert coverage is specified, the model will use the drainage structure points as the furthest uphill extent of a direct delivery segment. In this way, the model will proceed from a stream crossing up a road arc until it reaches either a grid cell that is lower in elevation than the previous one OR a drainage structure. The road arc will be segmented at this point and labeled as direct delivery. The remaining portions of the road arc uphill from the drainage structure will go into the potential indirect delivery group, and indirect delivery will be determined as above.

It is imperative that the culvert layer be as complete as possible, since unmapped culverts will not restrict direct delivery and may result in improbably long delivery distances. If a complete culvert layer is not available the user may partition the watershed into two areas (with culverts mapped, without culverts mapped) and conduct two SEDMODL2 runs and then merge the results together afterwards. For the model run without culverts, the user can select a maximum delivery distance (see below) based upon the best available estimate of average culvert spacing for that area.

4.1.2 Specifying a Maximum Delivery Distance

If a culvert coverage is not available, the user can specify a maximum delivery distance. The maximum delivery distance is the maximum direct delivery length of a road arc on either side of a stream crossing. This distance could be used for cases when a land manager knows that cross drains are placed a specified distance up the road from a stream (i.e. culverts are placed 100 feet from each stream crossing to limit sediment delivery to streams; or if there is a minimum cross-drain spacing of 200 feet).

If a maximum delivery distance is specified, the model will proceed from a stream crossing up a road arc until either the maximum distance OR a grid cell that is lower in elevation that the previous on is reached.

SEDMODL2 defaults to a maximum delivery distance of 1000 feet when no drainage structure coverage or maximum delivery distance is specified.

4.2 Erosion from Delivering Segments

Erosion from roads in the basin was estimated using formulas based on empirical relationships between road use, parent material, road surfacing, road surface slope, cutslope and fillslope vegetative cover, and delivery of eroded sediment to the stream network (WDNR 1997, Beschta 1978, Bilby et al. 1989, Megahan et al. 1986, Reid and Dunne 1984, Sullivan and Duncan 1980, Swift 1984).

Sediment is produced from four components of a standard forest road prism: the cutslope, ditch, tread, and fillslope. Since actual dimensions and conditions of each of these components throughout the entire road network are not generally known, the model uses several simplifying assumptions to allow calculation of relative sediment yield.

If road prism geometry is not attributed on the road coverage, it is assumed that roads in the watershed are insloped with a ditch. Insloped roads direct water away from fillslopes, and result in only short lengths (average 50 feet) of fillslopes that deliver sediment to streams at road crossings. Field observations and calculations indicate that erosion from the short, vegetated/armored sections of fillslope that occurs at most stream crossings is much smaller than from other portions of the road prism. Therefore, the model assumes that fillslope erosion is negligible. There may be a few locations in your watershed, such as where a road closely parallels a stream for a long distance, or some unvegetated fillslopes at new road crossings where this assumption is not valid.

The model also groups erosion from the tread and ditch together, so assigned road widths described below include both the running surface and ditch widths. The result of this assumption is to apply surfacing and traffic factors to the ditch as well as the tread. These two factors will tend to even each other out since most heavily used roads (high traffic factor) have gravel surfacing (lower surfacing factor). Very heavily used gravel roads (main haul roads) will have a very high traffic factor, but applying this to the ditch is probably appropriate since these roads and ditches are likely regraded frequently, disturbing the ditch's armor layer and increasing sediment production.

The average annual volume of sediment delivered to a stream from each road segment is calculated based on the following formulas:

> Total Sediment Delivered from each Road Segment (in tons/year) = (Tread + Cutslope) x Road Age Factor
>
> Tread = Geologic Erosion Factor x Tread Surfacing Factor x Traffic Factor x Segment Length x Road Width x Road Slope Factor x Rainfall Factor x Delivery Factor
>
> Cutslope = Geologic Erosion Factor x Cutslope Cover Factor x Segment Length x Cutslope Height x Rainfall Factor x Delivery Factor

Values for each factor in the equations are obtained from either model-supplied or user-input values or from lookup tables associated with road class, surfacing, slope, or hillside slope obtained from the GIS database. These values are described below.

4.2.1 Geologic Erosion Factor

The inherent erodibility of a particular road segment is determined by soil attributes where the road is constructed. Soil erodibility is affected by the soil particle size and cohesiveness. Soils with a high silt content are most erodible; clay-dominated soils are less erodible, and soils with a high gravel component are least erodible (Goldman et al. 1986, Burroughs et al. 1992). Since most road prisms are graded into the sub-soil, erodibility is a factor of parent material (geology) and degree of weathering. Geologic erosion factors used by the model are shown in Table 2.

Table 2. Geologic Erosion Factors.

	Geologic Age of Formation[1]				
Lithology	Quaternary	Tertiary	Mesozoic	Paleozoic	Precambrian
un-weathered metamorphic rocks	-	1	1	1	1
weathered schist or gneiss	-	2	2	2	2
basalt	1	1	1	1	1
andesite	1	1	1	1	1
ash	5	5	1	1	1
tuff	5	5	1	1	1
un-weathered intrusive rocks	-	1	1	1	1
weathered granite/intrusive rocks	-	5	5	5	5

Lithology	Geologic Age of Formation[1]				
	Quaternary	Tertiary	Mesozoic	Paleozoic	Precambrian
un-weathered/ hard sedimentary rocks	-	1	1	1	1
coarse-grained soft sediments (gravelly)	1	1	-	-	-
fine-grained sediments (silt, sand)	5	5	-	-	-

[1] Some lithology/ages categories do not have geologic erosion rates because these categories do not occur (e.g. there are no Quaternary metamorphic rocks present on the earth's surface).

These factors are based on measured road erosion rates reported by researchers with surfacing, traffic, slope, and precipitation factored out (Reid 1981, Reid and Dunne 1984, Swift 1984, Dryess 1975, Ketcheson and Megahan 1996, Foltz 1996, Bilby et al. 1989, Vincent 1985, Luce and Black 1999, Kochenderfer and Helvey 1987). In addition, research and guidelines on erodibility of different soils/geologies was consulted to extend the table to geology types without road erosion measurements (André and Anderson 1961, Burroughs et al. 1992, Reinig et al. 1991, WDNR 1997). Additional detail on the road erosion measurements is included in Appendix A.

The geologic erosion factor is selected for each road segment from the geology coverage used in the model. The default geology coverage is based on the 1:500,000 scale geologic maps of Idaho, Washington and Oregon supplied with the model (Bond and Wood 1978, Huntting et al. 1961, Walker and MacLoed 1991). Geologic erosion factors for each geologic unit on the maps were assigned based on dominant lithology and age as shown in Table 2. If the user chooses their own, basin-specific geologic coverage to use to assign the geologic erosion factors, rates for various lithologies should be based on Table 2 since these rates are scaled to the precipitation and traffic factors the model uses.

4.2.2 Tread Surfacing Factor

Road surfacing factors are based on surfacing information linked to road arcs in the GIS database. Surfacing factors for various road treatments are shown in Table 3 (based on WDNR, 1997, Burroughs and King 1989, Swift 1984, Foltz and Burroughs 1990).

Table 3. Road Tread Surfacing Factor.

Surface Type	Surfacing Factor
Asphalt	0.03
Gravel	0.2
Gravel with Ruts	0.4
Pitrun	0.5
Grassed Native	0.5
Native Surface	1
Native with Ruts	2

4.2.3 Road Width and Traffic Factors

Road width and traffic factors are based on the road class assigned each road arc in the GIS database. Width and traffic factors for various road classes are shown in Table 4. Traffic factors are based on WDNR (1997), Reid and Dunne (1984), and Foltz (1996). Road widths include both the running surface (tread) and ditch. These values are based on average measurements taken during road erosion inventories on road segments that drain to streams at over 800 road segments in watersheds in Washington, Oregon, and Idaho. These measurements were made on private, state, and federal lands as part of road erosion surveys during watershed analyses.

Table 4. Road Width and Traffic Factors.

Road Class	Description	Average passes/day Log Truck	Average passes/day Pickup / car	Road Width (ft)	Traffic Factor
Highway	Highway	>5	>5	40	120
Main Haul	Heavily used by log truck traffic throughout the year; usually the main access road in a watershed that is being actively logged.	>4	n/a	30	120
County Road	Wide, county-maintained road that receives heavy residential and/or log truck use.	1-4	>10	35	50
Primary Road	Receives heavy to moderate use by log trucks throughout all or most of the year. Usually roads branching off main haul road that head up tributaries or that access large portions of the watershed.	1-4	5-10	25	10

Road Class	Description	Average passes/day Log Truck	Average passes/day Pickup / car	Road Width (ft)	Traffic Factor
Secondary Road	Receives light log truck use during the year. May occasionally be heavily used to access a timber sale. Receives car/pickup or recreational use.	<1	1-5	18	2
Spur Road	Short road used to access a logging unit. Used to haul logs for a brief time while unit is logged. On the average receives little use.	<1	<1	15	1
Abandoned/ blocked	Road is blocked by a tank trap, boulders, etc. or is no longer used by traffic.	0	0	15	0.1

Select the road use category that most closely fits each road type in your road file. Average traffic use for both log truck traffic and residential/recreational/administrative traffic (vehicles/day) is provided as a guideline. Use of specific roads by log trucks changes over time as timber sales occur in different parts of a watershed. If the purpose of your modeling is to determine average road erosion in the watershed, pick the long-term average traffic rates on each road type. If the purpose of modeling is to determine sediment input from a specific timber sale, select use rates that best fit the traffic rates on that road during the sale.

4.2.4 Road Slope Factor

A road slope factor is assigned to each road segment based on the square of the road tread slope, calculated by the GIS. The road slope factor is based on the formula:

$$\text{Road Slope Factor} = \left(\frac{\text{Road Tread Slope}(\%)}{7.5\%}\right)^2$$

with a reference slope of 7.5% (Luce and Black 1999, Reinig et al. 1991). Factors used are shown in Table 5.

Table 5. Road Slope Factor.

Road Tread Slope	Slope Factor
< 5 percent	0.2
5-10 percent	1.0
> 10 percent	2.5

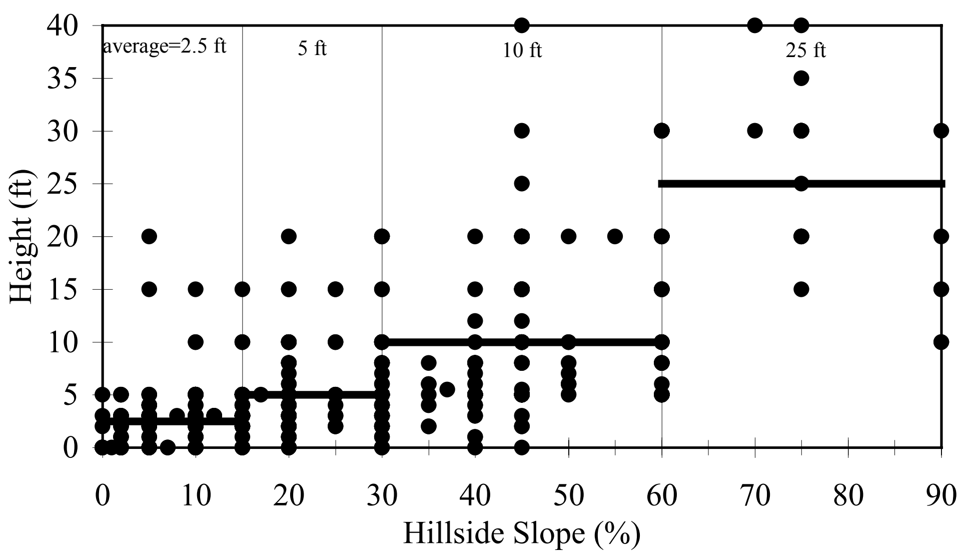
4.2.5 Cutslope Height

Cutslope height is assigned by the model based on hillside gradient unless the user specifies cutslope height as an attribute in the road coverage. The model calculates hillside gradient and groups it into one of 4 categories. Cutslope height for each gradient category (Table 6) is based on the average of cutslope heights measured during road erosion inventories, displayed on Figure 1. The field measurements were mean cutslope height over the length of road that drained to the stream. These averaged heights may be lower than expected because they take into account the low (or non-existent) cutslope height close to a stream crossing.

Table 6. Cutslope Height.

Hillside Gradient	Cutslope Height (ft)
0-15 percent	2.5
15-30 percent	5
30-60 percent	10
> 60 percent	25

Figure 1. Field-Averaged Cutslope Height versus Hillside Slope (based on unpublished field measurements taken during road Boise Cascade inventories in Washington, Idaho, and Oregon)



4.2.6 Cutslope Cover Factor

SEDMODL2 assigns a Cutslope Cover Factor based on the percent vegetation or rock cover on the cutslopes that protect bare soil from erosion. There are three methods to specify cutslope cover: (1) use model default value; (2) model user specifies a single cover value for the entire watershed; and (3) road coverage contains cutslope cover attributes.

The model uses a default value of 70 percent vegetative and/or rock cover on cutslopes, with a corresponding cover factor of 0.254. The 70 percent cover value was the average of cutslope cover during the road erosion inventories. The model user has an option of entering a user-specified default cover value for cutslopes in their watershed, or providing feature level attributes for cutslope cover on the road coverage.

Table 7 lists cover factors SEDMODL2 uses if other percent cover values are specified by the user (based on WDNR 1997 and Burroughs and King 1989).

Table 7. Cutslope Cover Factor.

Percent Vegetation or Rock Cover	Cover Factor
100	0.1023
90	0.1500
80	0.2003
70	0.2540
60	0.3116
50	0.3742
40	0.4435
30	0.5222
20	0.6155
10	0.7700
0	1.0000

4.2.7 Rainfall Factor

The rainfall factor in SEDMODL2 has been significantly modified from Version 1.0. In Version 1.0, the precipitation factor was based on average annual <u>total</u> precipitation (rain plus snow). However, studies of road erosion have shown that road erosion resulting from snowmelt runoff is an order of magnitude lower than from the equivalent amount of rain runoff (Vincent 1979). The rainfall factor in Version 2.0 is based on average annual <u>rainfall</u> amount, obtained from the 2001 PRISM climatic data.

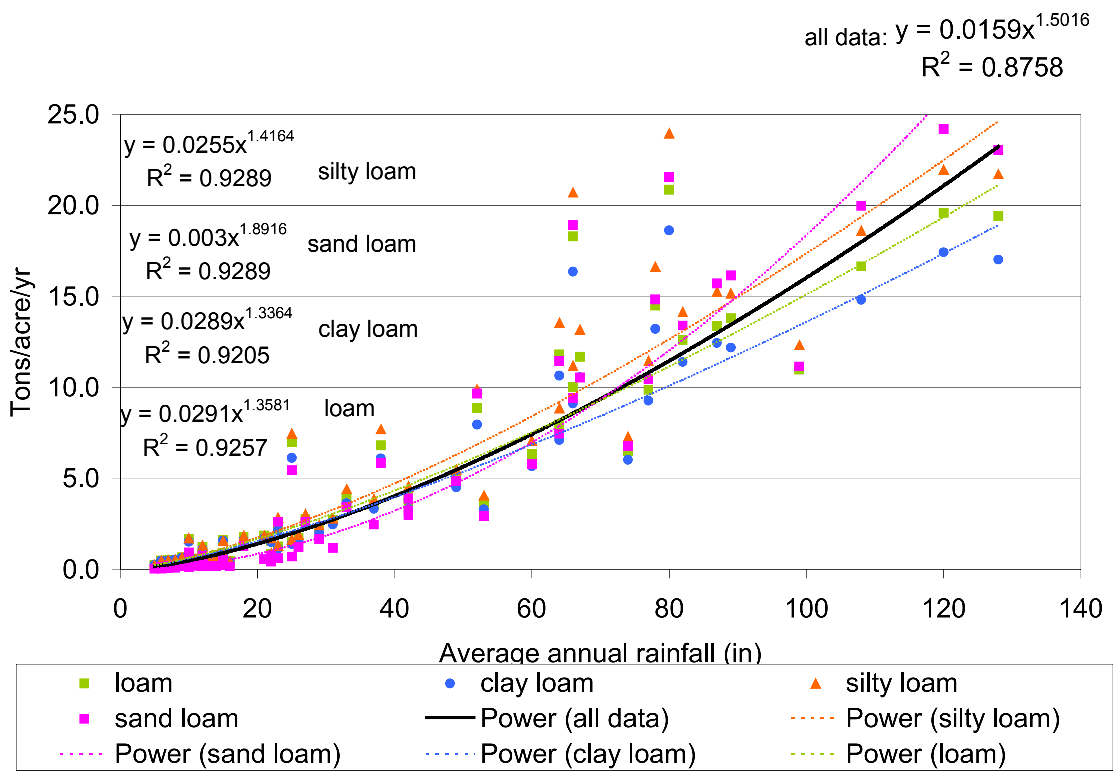
A few road erosion studies have measured erosion from the same road segments over several years with a range of precipitation values (Luce and Black 1999, Swift 1984). Best-fit power functions to data from these two studies yields equations of the form:

$$\text{Erosion} = a\left[\text{Rainfall}\right]^2$$

However, the range of precipitation values in the data sets was limited, with a range from 35-70 inches in the Swift study and 60-80 in the Luce and Black study.

In order to determine if the above relationship was valid over a wider climatic range, the Water Erosion Prediction Project (WEPP) model was used to estimate road surface erosion (Elliot et al. 1999). The WEPP:Road interface was used to calculate road erosion from a standard road configuration over a wide variety of climatic stations (74 different locations) in Washington, Oregon, Idaho, California, and Montana. The standard road configuration used was an insloped, 4% gradient, native-surfaced, 200-foot long, 15-foot wide road. The four standard WEPP soil types (silt loam, sandy loam, clay loam, and loam) were run for each climate. Figure 2 shows the results of the WEPP run for each climate station, with predicted erosion plotted against the total rainfall from the PRISM data.

Figure 2. Predicted Erosion (WEPP) versus Average Annual Rainfall (PRISM).



The WEPP results follow a similar power function form as the Swift and Luce and Black data sets, but over the much wider climatic range. The exponent based on the WEPP data for clay, silt, and loam soils is 1.3 to 1.4, with an exponent of 1.9 for sandy soils. The exponent for all soil types combined is 1.5. The relationship for all soil types combined was used to obtain the rainfall factor for Version 2.0.

A rainfall factor is assigned for each road segment from the Rainfall Factor coverage supplied with the model (rainfall factor coverage available for the lower 48 states). The factor was derived based on the average annual rainfall (from the PRISM data) and the following formula:

$$\text{Rain Factor} = 0.016\left[\text{Average Annual Rainfall(inches)}\right]^{1.5}$$

4.2.8 Delivery Factor

Delivery from each road segment is assigned by the model based on whether or not the segment drains directly or indirectly to a stream as described in Section 3.1 and displayed in Table 8 (based on Ketcheson and Megahan 1996):

Table 8. Road Delivery Factors.

Drainage from Road Segment Flows	Percent of Sediment Delivering
Directly to Stream	100
Within 100 feet of stream	35
Within 200 feet of stream	10

4.2.9 Road Age Factor

The current version of SEDMODL2 provides the user with the ability to model past, current, and future road erosion through the Road Age Factor. In order to apply the road age factor, the road coverage must be attributed with the year of road construction. During the SEDMODL2 run, the user is given the opportunity to enter the Reference Year. If the construction year on a particular road segment is prior to the Reference Year, the road is included in the model run. If the construction year is in the future compared to the Reference Year, the road is dropped from analysis. In this way, the user can enter a Reference Year of 1950, and obtain the road surface erosion for only roads that were on the ground at that time. Specifying a date in the future can be used to model potential erosion from roads that are laid out but not yet constructed.

In addition, the construction year is used to increase the sediment production from "new" road segments, those less than 2 years old. Research on road erosion has shown that new or rebuilt roads have a much higher erosion rate during the first 1-2 years following construction than in subsequent years (Ketcheson et. al 1999, Luce and Black 1999, Megahan 1974). The majority of erosion from new roads comes from fillslopes, cutslopes, and ditches until these areas revegetate and/or armor. Monitoring of recovery following construction shows an exponential decline in erosion rates. When compared to the long-term road erosion rate, the first year following construction yields approximately 10 times the long-term rate, the second year yields twice the long-term rate, and subsequent years are at the long-term rate. These factors are used in SEDMODL2 if the user specifies road construction year on the road coverage as shown in Table 9.

Erosion control measures on newly constructed roads and/or sediment retention measures have been shown to effectively reduce sediment input from fresh road cutslopes and fillslopes (Burroughs and King 1989). If the new roads in your watershed have effective erosion control measures, the Road Age Factor of 10 may be too high for the initial year (although a factor of more than 1 is likely appropriate). This can be altered in the Microsoft Access Application after initial processing by SEDMODL2.

Table 9. Road Age Factor.

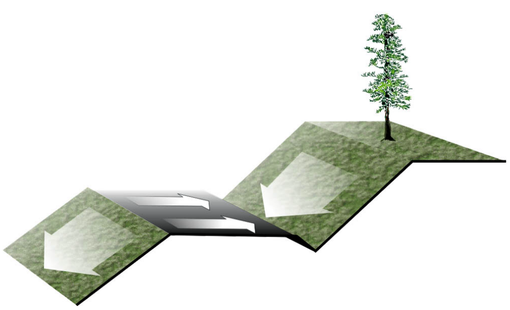
Road Age (Reference Year minus Construction Year)	Road Age Factor
0-1	10
2	2
>2 or no construction year specified	1

If the year of construction for a road segment is not attributed on the road coverage, SEDMODL2 includes all roads in the analysis, and models them as being greater than two years old (Road Age Factor = 1).

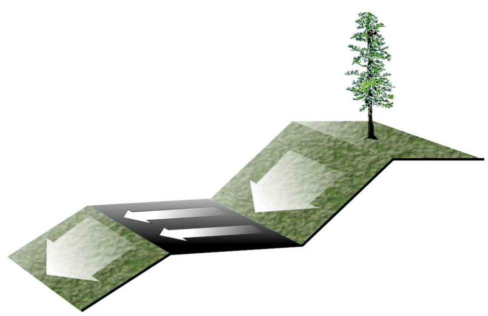
4.2.10 Segment Length/Road Drainage Configuration

The road drainage configuration (insloped/outsloped/crowned) determines the flow path of water and sediment from each portion of the road prism (Figure 3).

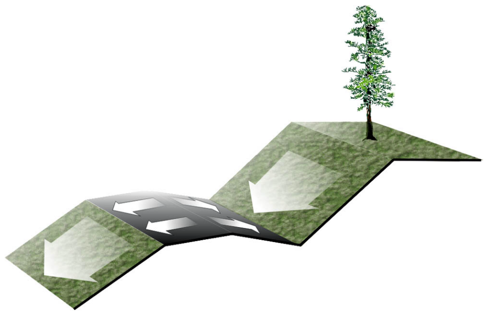
Figure 3. Generalized Runoff Flow Paths for Different Road Drainage Configurations.



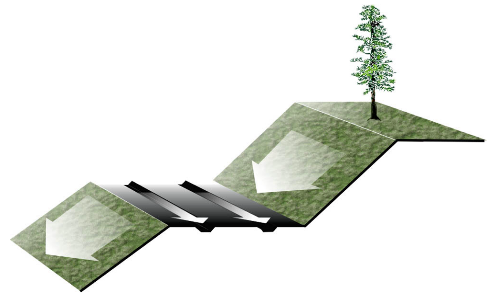
Insloped with ditch



Outsloped



Crowned



Outsloped with wheel tracks

SEDMODL2 allows input of the road drainage configurations as an attribute of the road layer. If no feature-level attributes are assigned to the road layer, the model assumes all roads are insloped with ditch, and the total segment length is used for calculations. If roads are attributed as outsloped or crowned, segment lengths or widths used for calculations are modified as shown in Table 10.

Table 10. Segment Lengths/Widths Used for Different Road Drainage Configurations.

	Segment Length/Width used in SEDMODL2	
Road Drainage Configuration	Tread	Cutslope
Insloped (use this configuration for Outsloped with wheel tracks)	Entire segment length, width	Entire segment length
Outsloped	50 feet, total width	50 feet
Crowned	Half of total road width for entire segment length	Entire segment length

Note that it is difficult to maintain a truly outsloped road drainage if the road is used by vehicles. In most cases, even with a good gravel surfacing, wheel tracks form quickly and collect and direct runoff down the wheel tracks rather than across the road to the fillslope. The water continues down the wheel tracks until a driveable dip or low point (such as a stream crossing) is reached to divert the water off the road tread. Consider carefully whether roads in your watershed function as true outsloped roads before choosing this road configuration.

5.0 BACKGROUND SEDIMENT INPUT

Calculation of the background sediment yield (the rate of sediment input into streams assuming undisturbed conditions in the basin) is useful because it allows us to compare the amount that road erosion in the basin has changed sediment input.

The major downslope sediment transport processes that provide sediment to streams in undisturbed basins include soil creep and mass wasting. In some watersheds, other natural processes such as glacial erosion or streambank erosion can contribute significant amounts of sediment. The model assumes that soil creep is a simple measure of background erosion. In steep, wet watersheds mass wasting may provide as much or more than background soil creep. Including only soil creep may underestimate background sediment yield. In steep, wet watersheds it is likely that road-related mass wasting is also a significant sediment source. Mass wasting is not included in the road surface erosion estimates. If there are significant other natural or management-related inputs of sediment in your basin, you should take this into account in the interpretation of model results.

5.1 Soil Creep

Soil creep is the slow downslope movement of soil resulting from gravitational forces and in our discussions includes soil movement resulting from biological activities such as animal burrowing and soil attached to roots of fallen trees. The sediment yield from soil creep is estimated using the following formula:

Annual Sediment Yield from Soil Creep = Length of Stream Channel * 2 banks* Soil Depth * Average Creep Rate * Soil Bulk Density

The length of channel from the GIS stream database is overlain with the slope angle coverage to determine the average creep rate. A creep rate of 0.04 inches/yr (1 mm/year) is used for slopes less than 30 percent; a rate of 0.08 inches/year (2 mm/year) is used for steeper slopes (WDNR 1997). Stream channel length is multiplied by 2 to account for creep from both sides of the stream. The model applies an average soil depth of 36 inches throughout the basin unless the user inputs another value. The calculated soil creep volume is multiplied by the soil bulk density (1.4 gm/cc unless user input) and a conversion factor to convert the units of annual sediment yield to tons/yr for comparison with road erosion estimate.

6.0 MODEL OUTPUT

Graphic display of the model results is viewed using Arcplot. SEDMODL2 generates an ArcInfo graphics file (.gra) that can be plotted if a plotter is available. Because SEDMODL2 utilizes a number of GIS processes that result in splitting road arcs into shorter segments it is difficult to visualize the cumulative sediment of connected road segments. To address this issue, SEDMODL2 groups arcs together onto a route on the basis of surface type and delivery type. This route is used for mapping purposes to symbolize the total sediment produced by these grouped segments. Each unique grouped segment on the route is identified by the item Seg_ID. Seg_ID also exists on the arc features so the user can easily located the arcs that make up a route. Because of the scale that an analysis area is mapped at, it is beyond the capabilities of SEDMODL2 to automate the labeling of the routes without overlapping labels. Because of the versatility and ease of use of ArcView, a user can create large-scale maps for field use and easily resolve overlapping labels. Refer to a Appendix D for a directions on mapping SEDMODL2 results using ArcView.

SEDMODL2 produces a map of the watershed showing the basin boundary, streams, and roads. Roads are color coded by relative amount of sediment delivered to streams. A map legend displays estimated total sediment input from soil creep and road erosion, and the ratio of road erosion:soil creep. The two numbers are provided for comparison; if total road erosion is less than half of soil creep (i.e. the ratio is less than 0.5), it is likely that overall, roads in the basin are having a relatively minor effect of water quality and aquatic resources. If road input is 50-100 percent of soil creep (ratio 0.5 to 1.0), roads are likely having a small but chronic effect. If road input is greater than background input (ratio over 1), roads are likely having a noticeable effect on water quality and aquatic resources (WDNR 1997). Whatever the overall results for the watershed, land managers should look at the map to identify road segments with high sediment yields (pink, red, or orange segments). These road segments may have local effects on the stream and may warrant further investigation.

7.0 MODEL VALIDATION TESTING

The SEDMODL2 program estimates road surface erosion by selecting segments of a road network that deliver sediment to streams, and then applying empirical relationships based on the characteristics of each road segment to calculate the average amount of sediment eroded from the road and delivered to the stream network. In order to test the validity of the model results on a watershed basis, a data set consisting of the amount of sediment delivered to streams from just road surface erosion in that watershed is required. Few, if any, data sets exist that have measured just this component of sediment reaching a stream on a watershed basis. Most erosion/sediment input studies have measured either erosion/delivery from individual road segments, or have measured the total sediment load of a stream, which includes sediment from a variety of road, mass wasting, and other sources. A component of the SEDMODL2 application that can be tested with existing data sets on a watershed-wide scale is selection of direct delivery road segments.

SEDMODL2 selects direct delivery road segments by intersecting the road and stream layers, and then determining the length of road on each side of the stream crossing that drains to the crossing. If a drainage structure layer is used, or a maximum delivery distance is specified, the model will end the direct delivery segment at that location if it is encountered before the end of the segment that drains toward the crossing. During a field inventory of direct delivery road segments, the inventory crew selects direct delivery segments in much the same way, but the crew has the advantage of being able to see features that are not included on the GIS layers, such as small scale topographic features, gullies from culvert outfalls that connect road drainage from cross drains directly to a stream, and whether or not streams actually exist on the ground.

Direct delivery segments selected by SEDMODL2 runs in three watersheds were compared to field-identified direct delivery segments to test how well the model performs this function. The watersheds included the Upper Little Klickitat WAU near Goldendale, Washington; the Elk Creek watershed near Medford, Oregon; and the Gold Fork watershed near McCall, Idaho. Characteristics of the three watersheds are described in Table 11.

Table 11. Characteristics of Watersheds used for Direct Delivery Testing.

Watershed	Location	Elevation Range	Annual Precip-itation (in)	Dominant Geology	Dominant Vegetation	Road Density (mi/sq mi)	Stream Density (mi/sq mi)
Upper Little Klickitat	Northeast of Goldendale WA	1,658-5,823 feet	22	Columbia River Basalt	Grassland/ Ponderosa pine, Douglas fir	5.1	2.3
Elk Creek	North of Medford, Oregon	1,450-5,800 feet	44	Western Cascade volcanics (basalt, andesite, tuff, lahars)	White fir, Douglas fir, Shasta red fir, mountain hemlock	4.1	2.7
Gold Fork	Southeast of McCall, Idaho	4,820-8,900 feet	38	Idaho batholith granite and gneiss; grusy (decomposed)	Ponderosa pine, Douglas fir, lodgepole pine, western larch	3.9	2.8

In each watershed, SEDMODL2 was run with just the road layer; no culverts or maximum delivery distance was used. This provides an indication of how well the model performs as a screening tool with the minimum required layers. For comparison purposes, the direct delivery lengths that the model selected and those that were identified in the field were overlain for that portion of the road network that was inventoried on the ground. This resulted in four subsets of the road network:

1. Segments that both the model and the field work identified as direct delivery segments;

2. Segments that were only identified as direct delivery by the field work (the model missed these segments);

3. Segments that the model identified as direct delivery but the field work did not (the model over-predicts the direct delivery length); and

4. Segments that were identified as NOT delivering directly by both the model and the field work.

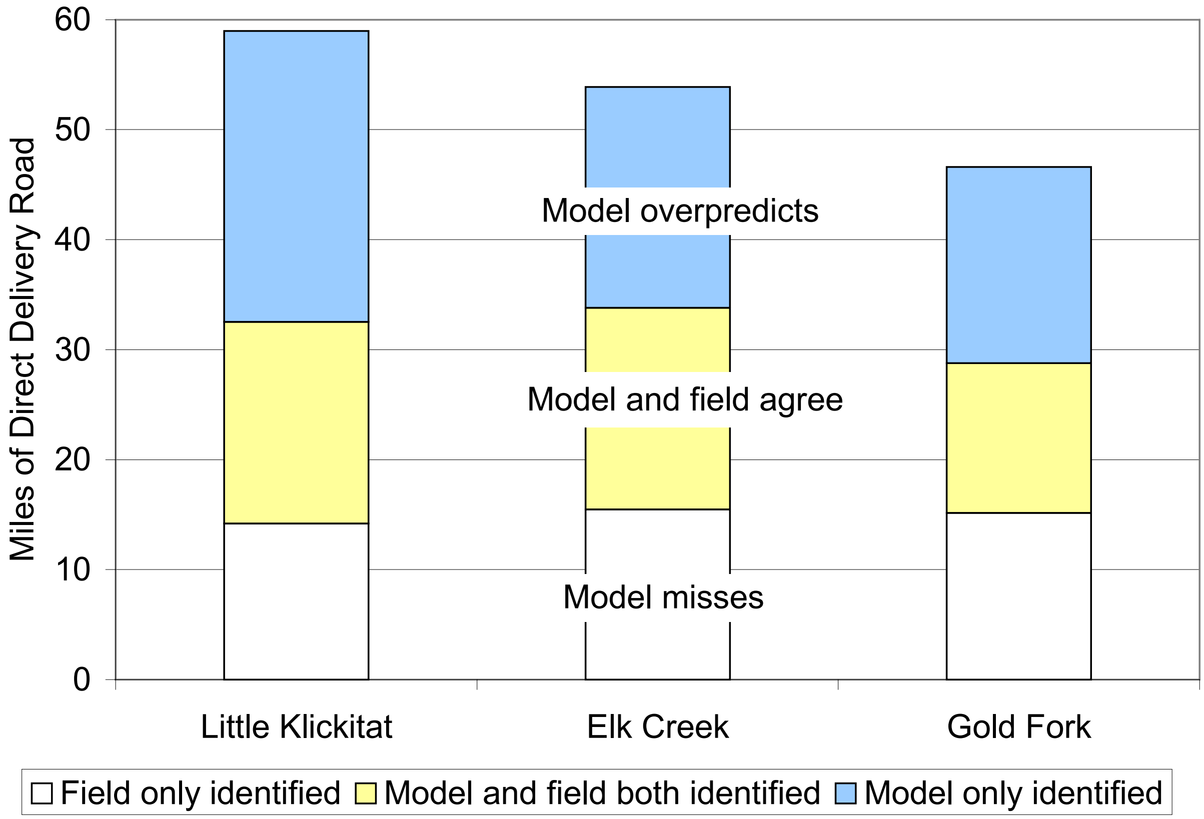
The results of the testing in the three watersheds is displayed on Maps 1, 2, and 3 (included as separate Adobe Acrobat files); Table 12 and Figure 4.

Table 12. Comparison of SEDMODL2 and Field Identified Direct Delivery Segments.

Watershed	Total Miles Field Identified	Total Miles Model Identified	Overlap Between Modeled & Field (mi)	Percent Agree-ment	Field Located Only (mi)	Percent Missed	Model Identified Only (mi)	Percent Over-estimated
Upper Little Klickitat	32.5	44.8	18.3	56%	14.2	44%	26.5	81%
Elk Creek	33.8	38.4	18.3	54%	15.5	46%	20.1	59%
Gold Fork	28.8	31.5	13.6	47%	15.2	53%	17.9	62%

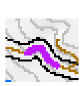
(Note that the miles in this table are miles of road identified as direct delivery segments, not total miles of road in the watershed).

Figure 4. Comparison of field-checked and SEDMODL2 Selection of Direct Delivery Road Segments.

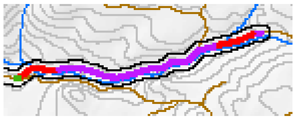


In each of the watersheds, the total miles identified as direct delivery by the model and in the field are comparable. However, the overlap between the model and the field results are approximately half of the field identified miles. The model misses (under-predicts) about half of the miles identified in the field, and the model over-predicts an additional 60-80% of the length identified in the field. Examination of the maps of each watershed (Maps 1, 2, and 3) illustrates the situations where the model either misses or over-predicts direct delivery segments. The following section includes clips from the maps. On the clips, streams are shown in bright blue; road segments identified by <u>both</u> SEDMODL2 and the field survey are in red; road segments identified only in the field (model misses) are purple, and segments identified only by SEMODL (over-prediction) are green.

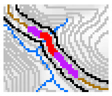
Cases where the model misses segments include:



- Streams were identified in field that were not included on the GIS stream layer;



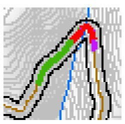
- Roads closely parallel but do not cross streams (these are usually identified as indirect delivery segments); gullies at cross drain outlets form direct connection with stream;



- Small-scale topography or road construction/grading practices resulted in a longer segment of road delivering at a stream crossing than predicted based on DEM topography.

Cases where the model over-predicts segments include:

- Streams were included on the GIS stream layer that were not on the ground;



- Cross-drains (culverts/driveable dips) or small-scale topographic features were present in the field that reduced the direct delivery segment length.

These situations should be considered during interpretation of model results in a particular watershed.

Addition of more information on cross drains, or specifying a maximum delivery distance (maximum distance from a stream crossing that will be identified as direct delivery) can reduce the length of road that is over-predicted. Available cross drain coverages were used in SEDMODL2 runs in the three watersheds, and runs with a maximum delivery distance of 1,000 feet were completed for comparison with the original runs (Table 13). The reduction in direct delivery length varied by watershed and situation, but resulted in a 4 to 29 percent reduction in direct delivery length compared to runs without culverts or maximum distances specified.

Table 13. Effects of Including a Culvert Coverage or Specifying a Maximum Delivery Distance.

Watershed	Percent Reduction in Direct Delivery Length	
	Run with culvert layer	Specify 1,000 foot maximum delivery distance
Upper Little Klickitat	4%	29%
Elk Creek	13%	7%
Gold Fork	17%	4%

8.0 MODEL DEVELOPMENT

This model was originally developed by Boise Cascade under the direction of Domoni Glass, Project Manager for the Boise Cascade PNW Watershed Project. Wayne Wold of Boise Cascade was responsible for development of the GIS components of the model. Kathy Dubé of Watershed GeoDynamics (formerly of Harza Engineering Company) assisted with adapting erosion equations and input variables for general use based on road erosion surveys in 6 watersheds in Washington, Oregon, and Idaho and published road erosion literature. Marc McCalmon of Terra GIS Solutions was responsible for developing the user interface and contributed to model programming. Version 2 received funding and technical assistance from NCASI.

Questions regarding the model should be directed to NCASI.

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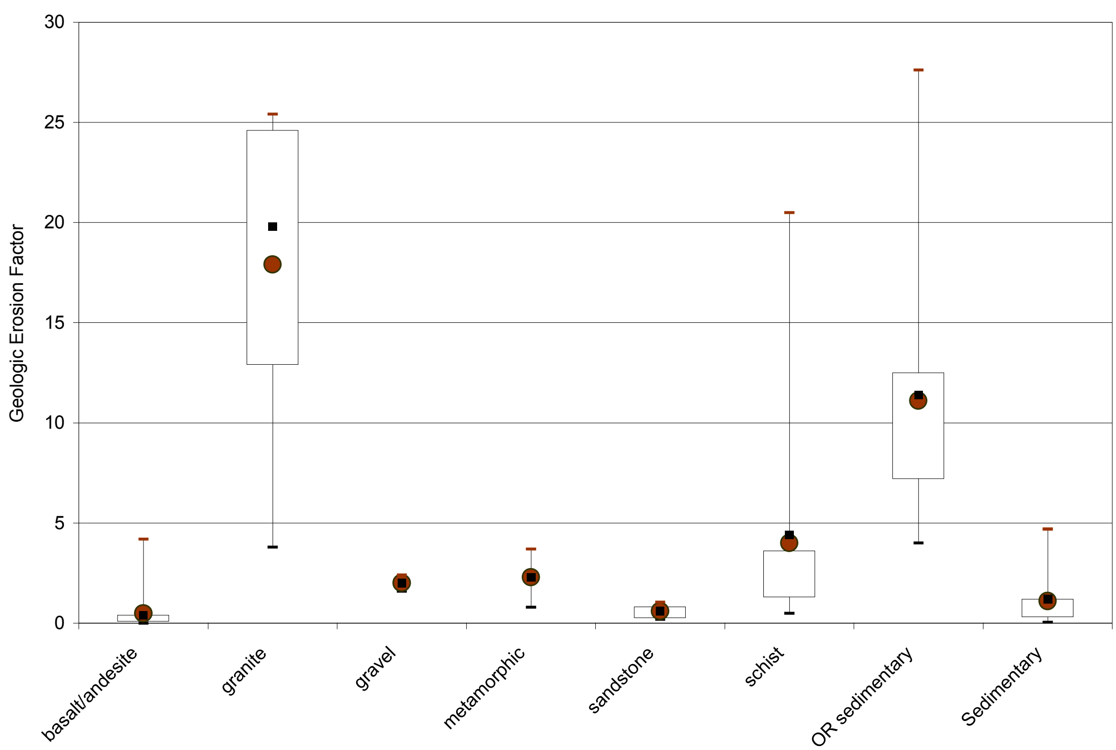
APPENDIX A. ROAD EROSION MEASUREMENTS

Road erosion measurements from a variety of locations, geologies, and climatic zones were compiled to provide insight into the Geologic Erosion Factors (Table A-1). The annual sediment yield from each study (in tons/acre/yr) were normalized to a reference road condition by dividing by the appropriate Rainfall Factor, Traffic Factor, Surfacing Factor, and Road Slope Factor. The resulting value is the Geologic Erosion Factor that would be required in SEDMODL2 calculations to obtain the measured erosion rate. An average Geologic Erosion Factor was calculated for each study, and then for each geology (Figure A-1).

Figure A-1. Geologic Erosion Rates Calculated from Road Erosion Measurements. Dark circles are average value for each geology; boxes show 25th and 75th percentile values, and bars show maximum and minimum values for geology. Based on values shown in Table A-1.



The road erosion measurements from most geologies result in a Geologic Erosion Factor of close to 1, suggesting that the erosion rates from the WEPP model, combined with the traffic, surfacing, and road slope factors adequately predict erosion for most competent rock types. However, erosion from on the granitic, schist, and deeply weathered sedimentary is 4 to 15 times greater than predicted. The values for the roads on granitic soils were primarily measured from newly constructed roads. A road age factor of 4 was used for all these values since the specific road age was not always available. As a result, these values are likely 2-3 times higher than SEDMODL2 would predict for a 1-year old road. Based on Figure A-1 and studies of relative erodibility between different geologies (André and Anderson 1961, Burroughs et al. 1992, Reinig et al. 1991, WDNR 1997), the Geologic Erosion Factors in Table 2 were established. Additional road erosion measurements in different geologies and soil types would be helpful to further refine these factors.

Table A-1. Road Erosion Measurements used in Development of SEDMODL2 Geologic Erosion Factors

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[1]	Average Geologic Erosion Factor for Study
Bilby et. al (1989)	Southwest WA	andesite/ basalt	110		110	Heavy	Pitrun	16	14.4	0.0	0.3
			110		110	Heavy	Pitrun	22	5.4	0.5	
			110		110	Heavy	Pitrun	6	3.1	0.4	
Toth (2000)	Central WA	basalt	37	50%	19	Light	Gravel	0	7	0.0	0.6
			37	50%	19	Light	Gravel	1	7	4.2	
			37	50%	19	Light	Native	0	8	0.2	
			37	50%	19	Light	Native	0	8	0.1	
			37	50%	19	Heavy	Native	0	4	0.0	
			37	50%	19	Heavy	Native	1	8	0.1	
			31	50%	16	Light	Gravel	0	7	0.3	
			31	50%	16	Light	Gravel	0	7	0.7	
			31	50%	16	Light	Native	0	8	0.1	
			31	50%	16	Light	Native	0	8	0.3	
			31	50%	16	Heavy	Native	0	4	0.1	
			31	50%	16	Light	Native	1	8	0.7	

[1] Sediment Yield Normalized by rain, surfacing, traffic, and slope factors

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[2]	Average Geologic Erosion Factor for Study
Ketcheson et. al (1999)	Idaho batholith	weathered granite	35	65%	12	Varied	Native	15	5	24.6	24.6
Megahan and Kidd (1972)	Idaho batholith	weathered granite	28	60%	11	Light/new road	Native	62	7.5	25.4	14.6
			28	60%	11	Light	Native	2	7.5	3.8	
Megahan et al. 1986	Idaho batholith	weathered granite	43	65%	15	Varied/new road	Gravel	37	7.5	24.9	24.9
Reinig et. al (1991)	Idaho batholith	granite	35	?	15	Light	Native	8	5	19.4	19.4
Vincent (1985)	Idaho batholith	weathered granite	35	54%	16	None/new road	Native	9	7	12.9	15.7
			35	54%	16	None/new road	Native	16	9	13.4	
			35	54%	16	None	Native	15	13	24.2	
			35	54%	16	None/new road	Native	31	13	12.5	
Bilby et. al (1989)	Southwest WA	Glacial outwash	52	0%	52	Mainline	Gravel	26	2.5	1.6	2.0
			52	0%	52	Mainline	Gravel	24	2	2.4	
Dubé (unpublished data)	Trinity River, CA	metasedimentary rocks	50		50	Mod	Gravel	18	7	3.7	3.7
Paulson (1997)	North-western WA	metamorphic/ glacial weathered	90		90	Light	Gravel	2	7	0.8	0.8

[2] Sediment Yield Normalized by rain, surfacing, traffic, and slope factors

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[3]	Average Geologic Erosion Factor for Study
Toth (2000)	Central WA	sandstone	37	50%	19	Heavy	Native	1	5	0.2	0.6
			37	50%	19	Heavy	Gravel	0	7	0.2	
			37	50%	19	Heavy	Gravel	2	7	1.0	
			37	50%	19	Heavy	Native	3	6	0.3	
			37	50%	19	Light	Native	1	6	0.8	
			37	50%	19	Light	Native	0	4	0.3	
			37	50%	19	Light	Native	1	7	0.8	
			31	50%	16	Light	Native	0	5	0.2	
			31	50%	16	Light	Native	1	6	1.0	
			31	50%	16	Heavy	Native	2	6	0.4	
			31	50%	16	Heavy	Native	2	4	0.6	
			31	50%	16	Heavy	Gravel	2	7	0.9	
			31	50%	16	Heavy	Native	4	7	0.5	

[3] Sediment Yield Normalized by rain, surfacing, traffic, and slope factors

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[4]	Average Geologic Erosion Factor for Study
Swift (1984)	Appalachian Mountains	weathered gneiss/schist	78	5%	74	Light/new road	Native	52	5	2.9	2.3
			94	5%	87	moderate/new road	Native	160	5	1.4	
			78	5%	74	Light/new road	Native	55	5	3.0	
			80	5%	80	Light	Native	18	5	3.5	
			78	5%	74	Light/new road	Pitrun	50	10	1.4	
			94	5%	87	moderate/new road	Pitrun	120	10	0.5	
			78	5%	74	Light/new road	Pitrun	115	10	3.2	
			80	5%	80	Light	Pitrun	25	10	2.5	
			78	5%	74	Light/new road	Gravel	4	5	1.1	
			94	5%	87	moderate/new road	Gravel	14	5	0.6	
			78	5%	74	Light/new road	Gravel	8	5	2.2	
			80	5%	80	Light	Gravel	5	5	4.9	
			78	5%	74	Light/new road	Gravel	12	6	2.3	6.5
			94	5%	87	moderate/new road	Gravel	120	6	3.6	
			78	5%	74	Light/new road	Gravel	75	6	14.4	
			80	5%	80	Light	Gravel	30	6	20.5	
			78	5%	74	Light/new road	Pitrun	26	8	1.1	
			94	5%	87	moderate/new road	Pitrun	170	8	1.2	
			78	5%	74	Light/new road	Pitrun	65	8	2.8	
			80	5%	80	Light	Pitrun	40	8	6.1	

[4] Sediment Yield Normalized by rain, surfacing, traffic, and slope factors

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[4]	Average Geologic Erosion Factor for Study
Foltz (1996)	1992-95	sedimentary rocks	13	0%	13	Light	Pitrun	12	12	11.6	11.1
			47	48%	25	mod	Pitrun	343	12	27.6	
			29	0%	29	Heavy	Pitrun	302	12	9.5	
			71	0%	71	None	Pitrun	37	12	14.9	
			13	0%	13	Light	Gravel	3	12	7.9	
			47	48%	25	mod	Gravel	20	12	4.0	
			29	0%	29	Heavy	Gravel	64	12	5.1	
			71	0%	71	None	Gravel	8	12	8.1	
Luce and Black (1999)	Western OR	sedimentary rocks	79	0%	79	Light	Gravel	5	7.5	2.3	1.7
			79	0%	79	Light	Gravel	2	7.5	1.1	
Kochender-fer and Helvey (1984)	Appalachian Mountains	sedimentary rocks	52	0%	52	None/new road	Gravel	4	7	4.7	1.3
			60	0%	60	Heavy	Gravel	7	7	0.5	
			55	0%	55	Heavy	Gravel	6	7	0.5	
			55	0%	55	Heavy	Gravel	6	7	0.6	
			52	0%	52	Light/new road	Native	38	9	1.1	
			60	0%	60	Heavy	Native	53	9	0.5	
			55	0%	55	Heavy	Native	51	9	0.5	
			55	0%	55	Heavy	Native	48	9	0.5	
			52	0%	52	Light/new road	Pitrun	3	11	0.1	
			60	0%	60	Heavy	Pitrun	10	11	0.1	
			55	0%	55	Heavy	Pitrun	7	11	0.1	
			55	0%	55	Heavy	Pitrun	7	11	0.1	
			52	0%	52	Heavy	Gravel	4	3	1.9	
			60	0%	60	Heavy	Gravel	8	3	3.2	
			55	0%	55	Heavy	Gravel	9	3	4.1	
			55	0%	55	Heavy	Gravel	4	3	1.8	

Source	Location	Geology	Precipitation (inches)	Percent of Precipitation as Snow	Rain (in)	Traffic Use	Surfacing	Annual Sediment Yield (t/ac/yr)	Road Gradient (%)	Geologic Erosion Factor[4]	Average Geologic Erosion Factor for Study
Wald (1975)	Olympic Peninsula, WA	sedimentary rocks	196	0%	196	Mod	Gravel	27	6.4	0.8	1.0
			196	0%	196	Light	Gravel	2	3	1.2	
Reid (1981)	Olympic Peninsula, WA	sedimentary rocks	140	0%	140	Mainline	Gravel	382	5.5	1.1	0.7
			140	0%	140	Temp non-use	Gravel	51	5.5	0.9	
			140	0%	140	Mod	Gravel	32	5.5	2.2	
			140	0%	140	Light	Native	3	5.5	0.2	
			153	0%	153	Mainline	Gravel	500	10	0.4	
			153	0%	153	Temp non-use	Gravel	65	10	0.3	
			153	0%	153	Mod	Gravel	40	10	0.7	
			153	0%	153	Light	Native	4	10	0.1	
			153	0%	153	None	Native	1	10	0.0	

APPENDIX B. TOUCHING UP A 30 METER DEM

If the best elevation data available is a 30 meter DEM, the user may want to consider "touching it up". One method of doing so is as follows:

1) SEDMODL2 will not actually use a DEM, so the first step is to convert it to an elevation grid using the *DEMGRID* command in GRID.
2) While still in GRID, draw the elevation grid using *GRIDPAINT*. Draw it as a grayshade (*gridpaint* <grid> *value identity wrap gray*) and **note** the location of any banding or other anomalies that typically occur with DEM's.
3) Create a contour coverage from the elevation grid at the ARC> prompt (*latticecontour* <elevation grid> <out cover> <interval> # *elev* # *1*). I recommend a 40 foot interval. The elevation attribute will be called **elev** in your new linear coverage.
4) Build the new contour coverage as a line.
5) Digitize (with either a digitizing board or "heads-up") a number of points with elevation values on top of this new contour coverage (as a separate elevation point coverage). You should concentrate on adding points (with their associated elevations) in the areas you **note**d in #2 above, in flat valleys and, to a lesser degree, ridgetops. The points you add should be no closer than 40 feet together. The purpose of this part is to touch up areas that may be lacking in good data. In the next step you will use these points while creating a new TIN. The best way to do this is to mark points on an existing contour map and digitize directly from it.
6) Use *CREATETIN* to generate a new surface. The following command sequence should be followed:

   a. *createtin* <new tin> *40 40 1* <watershed boundary> (you can substitute watershed boundary for any bounding polygonal coverage you have).
   b. *cover* <linear contour coverage> *line elev mass 60*
   c. *cover* <point elevation coverage> *point elev mass 60*
   d. *end*
7) Note that it is best if you buffer the watershed boundary so when clipped the elevation grid extends at least 2 cells beyond the watershed boundary.
8) Use *TINLATTICE* to create a new elevation grid *(tinlattice* <new tin> <new elevation grid>)
9) You now have a new elevation grid! Keep in mind that it is probably better than the DEM you started with, but there may still be some significant problems with it. If you still don't like it, you can *fill* it and do some other things but I won't go into that here. You should also kill the TIN that was created because this takes up a lot of memory.

APPENDIX C. DEVELOPING A RAINFALL FACTOR COVERAGE

The rainfall factor coverage distributed with SEDMODL2 was developed using data acquired from the Climate Source LLC, Corvallis, OR. The following information describes how the climatic data used to develop the rainfall factor was derived, as well as how a user who wishes to develop a rainfall coverage for areas outside the 48 contiguous states can use site-specific precipitation data to derive a rainfall factor coverage for their watershed.

Development of PRISM climatic data

The climatic data included United States Average Monthly Measurable Precipitation and 30-year average snowfall (depth of freshly fallen snow), 1961-90. This data was developed by Chris Daly, Wayne Gibson, and George Taylor of the Spatial Climate Analysis Service at Oregon State University. The Publication Date was August, 2000. Grids of 1961-1990 mean monthly precipitation produced with the PRISM modeling system served as the base maps for the calculation of maps of 1961-1990 mean number of days with measurable precipitation.

Using station data obtained from the National Climatic Data Center, non-linear, US-wide regression functions relating mean precipitation to mean number of days with measurable precipitation were created for all months. These monthly functions were applied to the mean monthly precipitation grids to produce a "first guess" grid for mean number of days with measurable precipitation. The residuals between observed and regression-predicted number of days with measurable precipitation were calculated for all stations for each month. These point residuals were interpolated to a grid using inverse-distance weighting. The monthly residual grids were then added to the monthly first guess grids to obtain the final grids for monthly mean number of days with measurable precipitation. An annual grid was produced by summing the monthly grids. A Gaussian filter was applied to increase the resolution of the grids from the base resolution 2.5 arc-minutes (~4 km) to 1.25 arc-minutes (~2 km). This filter is a modification of the Barnes filter (Barnes, 1964), originally adapted by Dr. Stephen Esbensen of Oregon State University, and later modified for use here by Wayne P.Gibson, also of Oregon State University.

Grids of 1961-1990 Mean Monthly and Annual Precipitation and wet-day temperature produced with the PRISM modeling system served as the base maps for the calculation of maps of 1961-1990 Mean monthly and annual snowfall.

Using station data obtained from the National Climatic Data Center, non-linear, US-wide regression functions relating mean wet-day temperature to the ratio of snowfall over precipitation (SOP) were created for all months. These monthly functions were applied to mean monthly mean wet-day temperature grids produced by the PRISM modeling system to produce "first guess" grids for SOP. The residuals between observed and regression-predicted SOP were calculated for all stations for each month and for the year. These point residuals were interpolated to a grid using inverse-distance weighting.

Because there was a strong relationship between the magnitude of the residual and the first-guess value (typical for precipitation-related elements), a scaling function was developed to account for this in the residual interpolation. The monthly residual grids were then added to the monthly first guess grids to obtain the final grids for monthly SOP. The monthly SOP grids were then multiplied by mean monthly precipitation grids produced by the PRISM modeling system to obtain final grids of monthly snowfall. An annual grid was produced by summing the monthly grids. A Gaussian filter was applied to increase the resolution of the grids from the base resolution 2.5 arc-minutes (~4 km) to 1.25 arc-minutes (~2 km). This filter is a modification of the Barnes filter (Barnes, 1964), originally adapted by Dr. Stephen Esbensen of Oregon State University, and later modified for use here by Wayne P. Gibson, also of Oregon State University.

Derivation of SEDMODL2 Rainfall Factor

Rainfall has a direct affect on erosion and snow cover can reduce the erosion potential of a road system. To address the affect of snow fall the average monthly rainfall and average monthly depth of snow grids where processed using ESRI's Grid module.

Each monthly depth of snowfall grid was converted to a rainfall equivalent of 10%. This monthly snow water equivalent is subtracted from the average monthly rainfall amount to produce adjusted monthly rainfall grids. The map algebra for this is:

Adjusted month rainfall = (average month rainfall - (average month depth of snowfall * 0.1))

This map algebra is based on a 10% snow water equivalent. You may use site-specific data if it is available for your watershed.

Each of the 12 adjusted rainfall grids are combined into an annual precip grid. The map algebra for this is:

Annual precip grid = (m01 + m02 + m03 + m04 + m05 + m06 + m07 + m08 + m09 + m10 + m11 + m12)

Values less than 0 will occur for snow dominated areas and are adjusted to a zero value using the following map algebra:

Adjusted Average Annual Rainfall = con(annual precip grid < 0, 0, annual precip grid)

The following formula can be applied using a series of grid functions:

Precip Factor = 0.016 * [Adjusted Average Annual Rainfall]^1.5

1. Raise the Adjusted Average Annual Rainfall to the 1.5 power and multiply by .016

Rainfall = .016 * POW (Adjusted Average Annual Rainfall, 1.5)

2. These are floating point grids up to this point. Since we want to create a polygon coverage we need to convert the floating point grid to an integer grid, but in order to preserve the decimal precision we need to multiply by 10,000. After a polygon

coverage is created we can divide by 10,000 to restore the decimal precision. The grid function for this calculation is:

Final Average Annual Rainfall = int (Rainfall * 10000)

3. Convert the grid to a polygon converge using the following function:

   Rainfall_p = gridpoly (Final Average Annual Rainfall)

4. SEDMODL2 looks to see if an item named pfact exists on the Rainfall Factor polygon coverage. If it doesn't exist then the user is prompted to identify the item that contains the precipitation factor. It is recommended that the user add the pfact item and that it be defined as follows
   pfact 6 6 n 3

5. The final step involves calculating the pfact item equal to the value in the Grid-Code item and to restore the decimal precision by dividing the pfact value by 10,000. The math for this can be stated as:
   reselect area > 0
   calculate pfact = grid-code / 10000