APPENDIX A-6:

SEDIMENT TECHNICAL APPENDIX

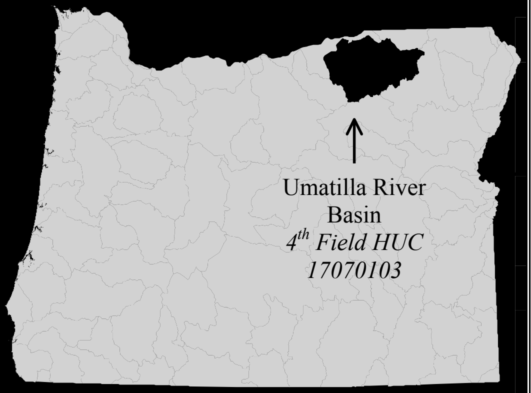
Umatilla River Basin Sediment

Total Maximum Daily Load (TMDL)

Sediment Technical Appendix A-6

August 2000

TMDL at a Glance



Basin:	**Umatilla**
Key Resources:	**Chinook Salmon** **Steelhead Trout** **Bull Trout**
Uses Affected:	**Salmonid Spawning & Rearing**
Impairment:	**Excessive Sedimentation**
Pollutant:	**Substrate fines, Turbidity, Total Suspended Solids**
Sources Considered:	**PS – Wastewater Treatment Facilities** **NPS – Forest Practices, Transportation, Agriculture, Range, Urban & Unincorporated Developments**

INTRODUCTION

This TMDL is being established to reduce the sediment load in the Umatilla River. The goal of the sediment TMDL is to meet water quality standards and to protect beneficial uses that are impaired due to excessive turbidity and sedimentation.

The following sections provide background technical information on the determination of the sediment TMDL.

Target Identification

The Environmental Protection Agency (EPA) and the State of Oregon do not have numeric water quality standards for suspended solids or streambed fines. However, excessive fine sediment is addressed through application of state narrative criteria (water quality standards section of this report). High suspended solids and turbidity can have an adverse impact on instream biological communities and, through sediment deposition, result in the formation of appreciable bottom deposits.

Sediment is also addressed through the Oregon turbidity standard, which limits allowable turbidity increases. The turbidity standard is relative – an allowable ten percent increase (water quality standards section of this report). Excessive turbidity can impair visual feeding and suspended solids can impair respiration, of fish.

The water quality impairment was designated (Clean Water Act Section 303(d) list) based on streambed surface area percent fines and greater than ten percent increase in mainstem turbidity caused by mid-basin tributaries. While numeric data and professional judgement indicate the need for sediment reduction, these data do not lend themselves to load calculations. A numeric target is needed to evaluate sediment in terms of load reduction.

Umatilla Basin fisheries managers determined through basin-specific knowledge and literature review that a maximum of 30 nephelometric turbidity units (NTU) instream turbidity (not to exceed a 48-hour duration) is protective of aquatic species and will not be detrimental to residential biological communities.

Loading Capacity

The loading capacity (LC) of a river is defined as the greatest amount of pollutant loading (mass load) that the river can receive without violating water quality standards. Turbidity cannot be expressed in terms of mass since it is a measurement of light scattering. To develop an instream sediment loading capacity in terms of mass load (pounds per day), regression analyses were performed on Umatilla River and Umatilla River tributaries TSS and turbidity data so that the approximate TSS equivalent of 30 NTU turbidity can be used as the instream target concentration. The data were collected during winter 1998-99 by the Umatilla Basin Technical Advisory Committee and analyzed at the United States Forest Service (USFS) laboratory. Sampling and analysis followed USFS quality assurance/quality control protocol.

TSS and Turbidity Data Summary

Turbidity is a measure of light that is scattered or absorbed by a fluid, and is used as a measure of cloudiness in water. Turbidity is usually associated with suspended particles, but can also be caused by the presence of organic matter. Turbidity measurements were developed to provide a simple indirect measure of suspended sediments in streams. Stream turbidity is often closely related to suspended solids concentrations, however the specific relationship varies, depending on several factors including the solids type and size. Because of these interrelationships, the impact of suspended solids and turbidity on aquatic life are often evaluated together.

Analysts should not assume a particular TSS-turbidity correlation without evaluating the local relationship between the variables.

Beschta et al. (1981) observed that turbidity in western Oregon streams is highly correlated with suspended solids. Total suspended solids increased exponentially ($y = a * b^x$) over a wide range of flow conditions where exponents usually ranged from 1.1 to 1.6. Exponential increases of 3.4 to 4.5 in bedload transport rates with increasing flow were measured. Turbidity and suspended solids usually returned to relatively low levels within 24 hours after peak flows had occurred.

In order to express the water column sediment TMDL in terms of mass load, ordinary least squares linear regression models were calculated to evaluate the association between total suspended solids and turbidity. The TMDL applies to the 14 watersheds comprising the Umatilla Basin. The regression analyses were done for all watersheds where data was available (**Figures A6-1 to A6-9**). The TSS equivalent of 30 NTU turbidity was calculated as the TMDL target concentration for those watersheds. Where data was not collected, a basin-wide mean calculated from all of the TSS and turbidity data collected in the Umatilla Basin was utilized as the watershed target, with the exception of Butter, where the target calculated for Birch was applied. The following table lists the watersheds with their associated TSS target concentration:

Table A6-1: Umatilla Basin Loading Capacities

Watershed target concentrations/loading capacities	
Watershed	TSS Target (mg/L) @ 30 NTU Turbidity
Upper Umatilla River	76
Meacham Creek	60
Squaw/Buckaroo	99
Pendleton	80*
Wildhorse	86
Tutuilla	70
McKay	72
Birch	110
Butter	110
Gulches and Canyons	80*
Stage Gulch	80*
Sand Hollow	80*
Cold Springs	80*
Lower Umatilla River	77

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* Basin-wide mean of 80 mg/l

The following regression analyses used to estimate the TSS concentration at 30 NTU turbidity include values for R^2, standard error (Se), and slope:

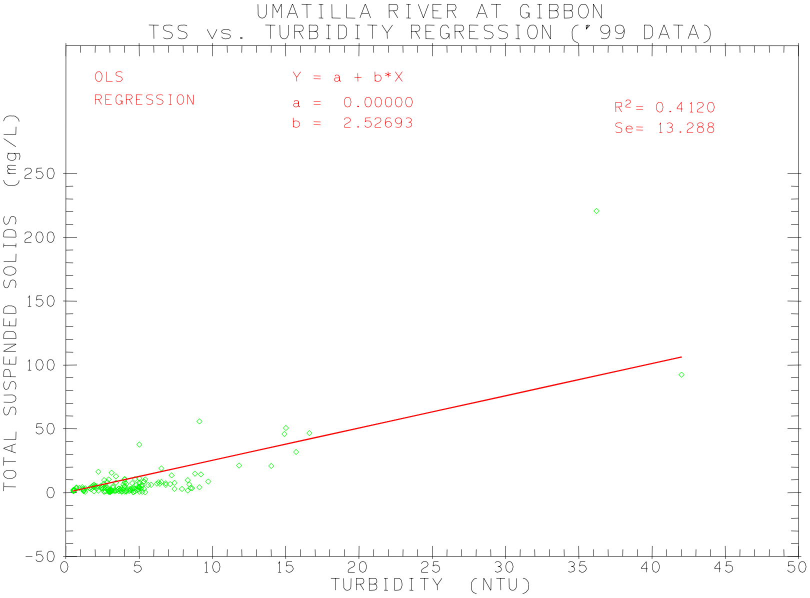


Figure A6-1: Umatilla River at Gibbon TSS vs. Turbidity

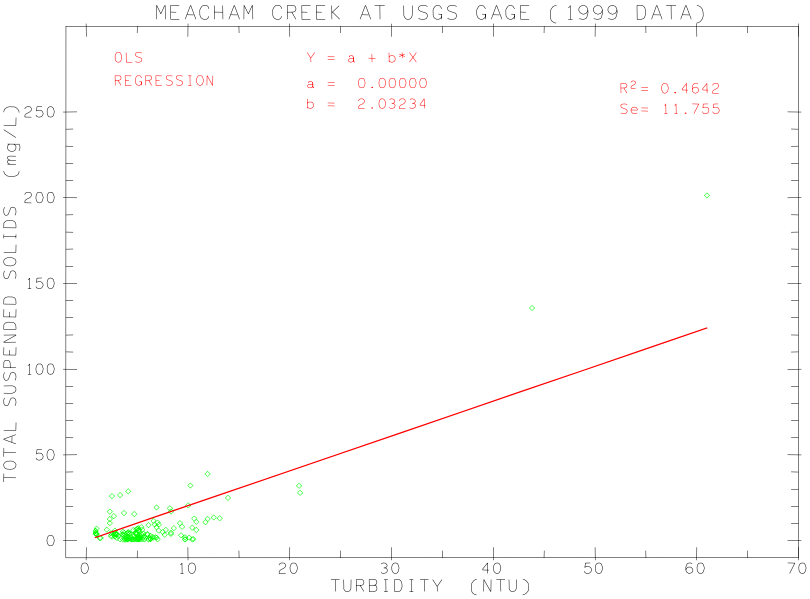


Figure A6-2: Meacham Creek TSS vs. Turbidity

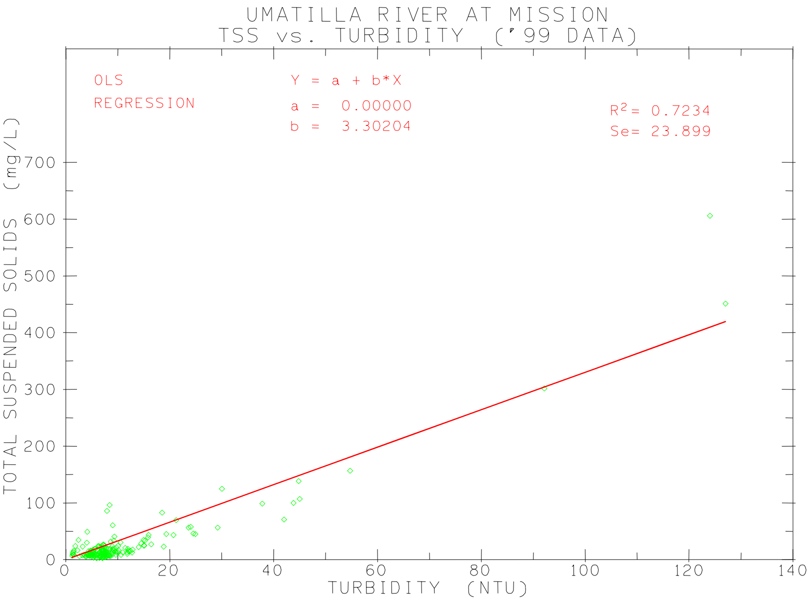


Figure A6-3: Umatilla River at Mission TSS vs. Turbidity

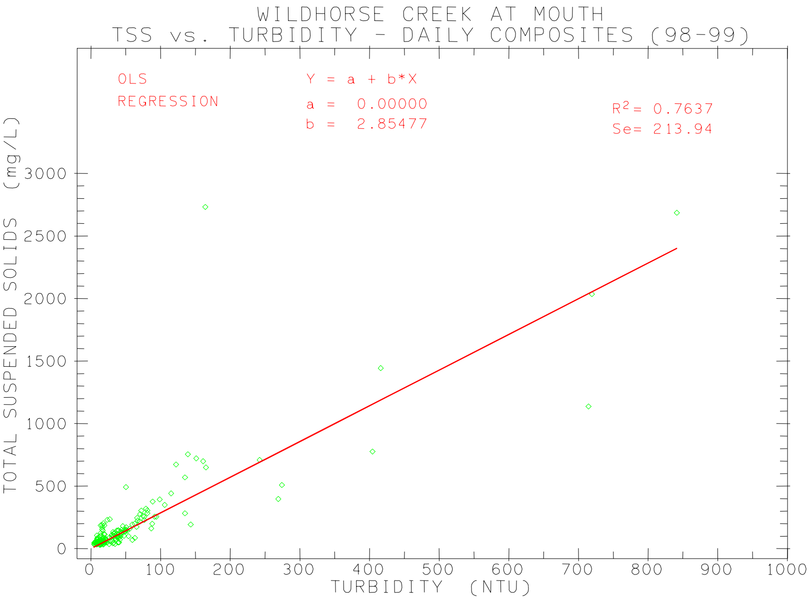


Figure A6-4: Wildhorse Creek TSS vs. Turbidity

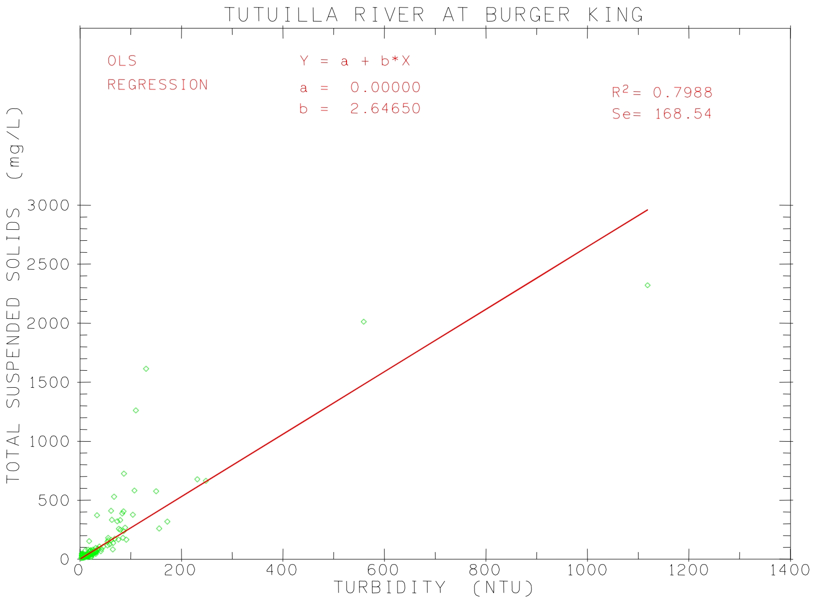


Figure A6-5: Tutuilla Creek TSS vs. Turbidity

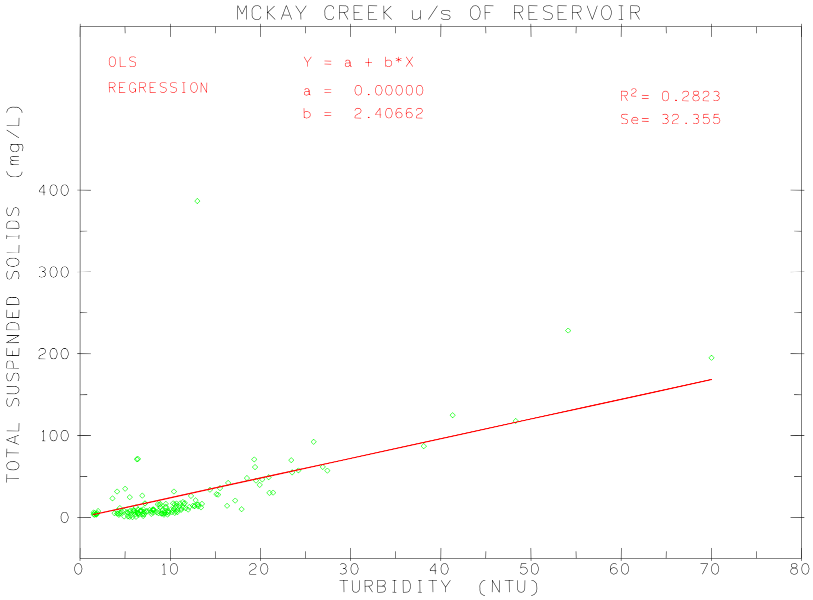


Figure A6-6: McKay Creek TSS vs. Turbidity

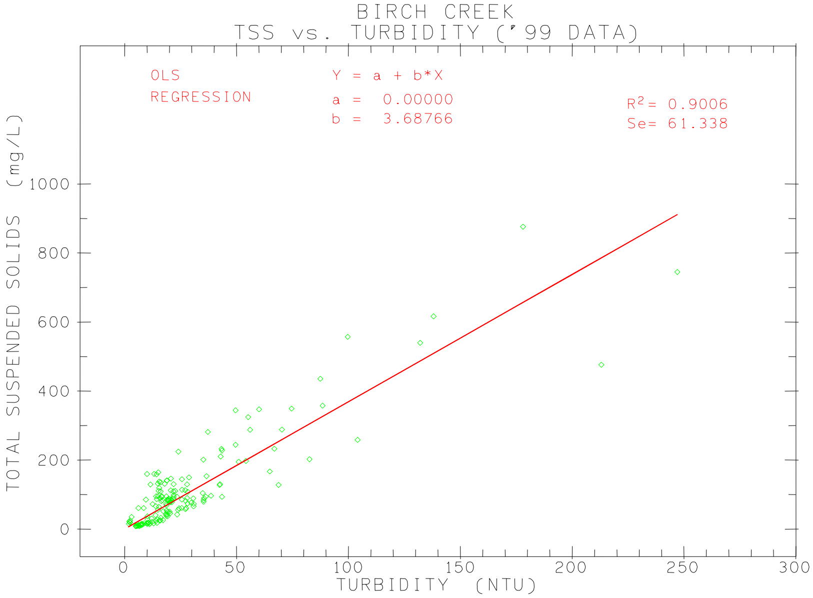


Figure A6-7: Birch Creek TSS vs. Turbidity

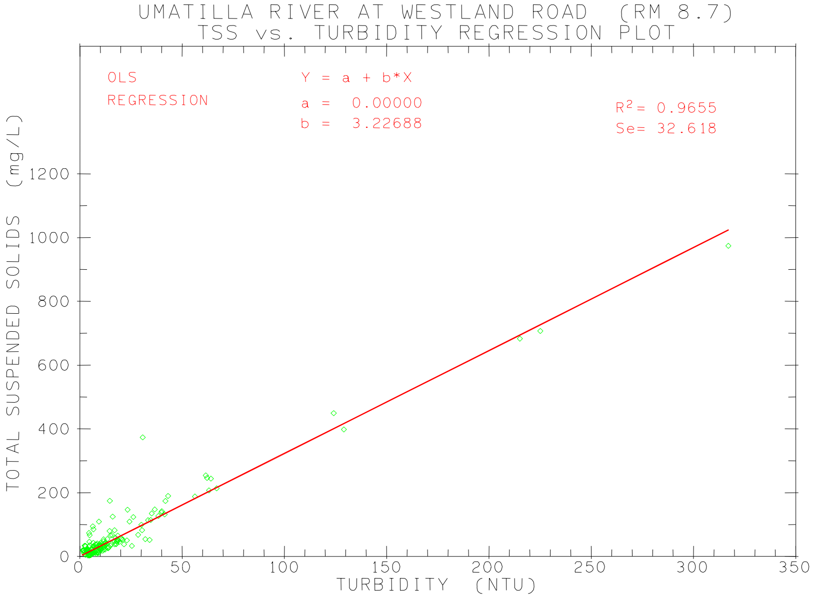


Figure A6-8: Umatilla River at Westland Road TSS vs. Turbidity

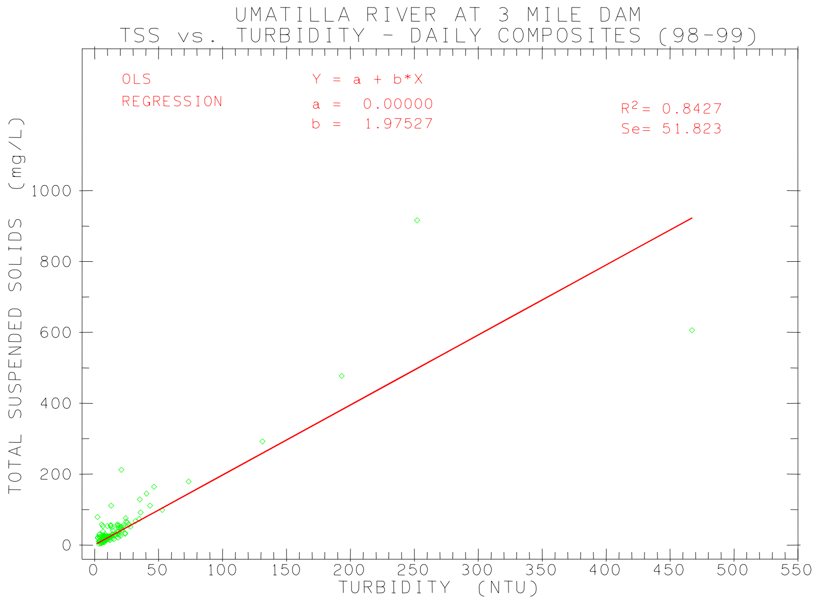


Figure A6-9: Umatilla River at 3-Mile Dam TSS vs. Turbidity

MAJOR COMPONENTS OF THE UMATILLA BASIN TSS MODEL

Model Objectives/Goals

The major objectives of the Umatilla Sediment model are:

- Estimate spatial distribution of sediment (TSS) loads across the entire Umatilla River Basin
- Provide quantitative estimates of 1) hydrology, and 2) sediment transport 3) estimate sediment (TSS) yield necessary to meet the basin-specific instream targets (T_{wq} - Soil loss tolerance for water quality concerns)

Advantages of using a GIS-based model included:

- The model uses readily available GIS data
- The model is storm-based and specific to the Umatilla Basin
- The model incorporates erosion processes that are functions of complex terrain and heterogeneous landscape
- The model is calibrated to instream TSS data
- The model can be used to calculate erosion reductions needed to meet the instream TSS target concentration

The model estimates a hydrologic budget (SCS type method and Rational Formula) and applies the Modified Universal Soil Loss Equation (MUSLE) to estimate erosion

A delivery ratio which is a function of watershed area is used to calculate the sediment delivered to streams. The sediment delivery ratio (DR) is defined as the ratio of the sediment exported from a basin (sediment yield) to the amount of sediment produced in the basin by erosion processes. Hence, the delivery ratio is determined by erosional processes as well as by transport processes. Since a decrease in DR with increasing basin size is the usual rule, sediment delivery ratios implicitly refer to the relationship between the sediment DR and basin size (Bunte and MacDonald, 1998).

Assumptions

The model assumes that general hydrologic and erosional processes occur in the winter associated with precipitation and snowmelt event. The event causes increases in overland flow resulting in upland erosion that is delivered to the stream. A simplified (lump sum) parameter was incorporated to account for stream bank erosion during major storm events.

Uncertainty

Uncertainty exists in all modeling activities and needs to be evaluated and assessed during the modeling process. The Umatilla sediment model was calibrated to measured sediment loads and concentrations for eight watersheds in the basin. The model was calibrated to fit this data set (8 watersheds) so that the model could be used in areas where no data had been collected.

On average, the measured instream load for all Umatilla River and tributary monitoring sites where both streamflow and TSS were measured amounted to 1.7 times the load predicted by the model. However, this underestimation was calculated prior to the streambank component predictions being added to the upland erosion predictions.

This model does not address several specific sediment mechanisms including bedload transport, anthropogenic impacts, mass wasting, and other catastrophic events.

Model Description

The Umatilla Sediment Model was written in ArcInfo Arc Macro Language (AML) using GRID (ESRI, 1990). The input databases include:

- Land Cover
- Soils (Slope, Hydrologic Soil Group, Soil Erosivity [K])
- Hydrography (used for creating buffer zones)
- Snow deposition patterns

Daily data (approximately 120 days in 1998 and 110 days in 1999) for rainfall and temperature was used in the model.

The spatial resolution of the data is 984.1 meters and there are over 120,000 cells in the Umatilla River Basin. The GIS processing was performed with ArcInfo version 7.2.1 on an NT 4.0 workstation with 384 MB of RAM and 50 GB of local disk storage.
Figure A6-10 is a schematic of the model:

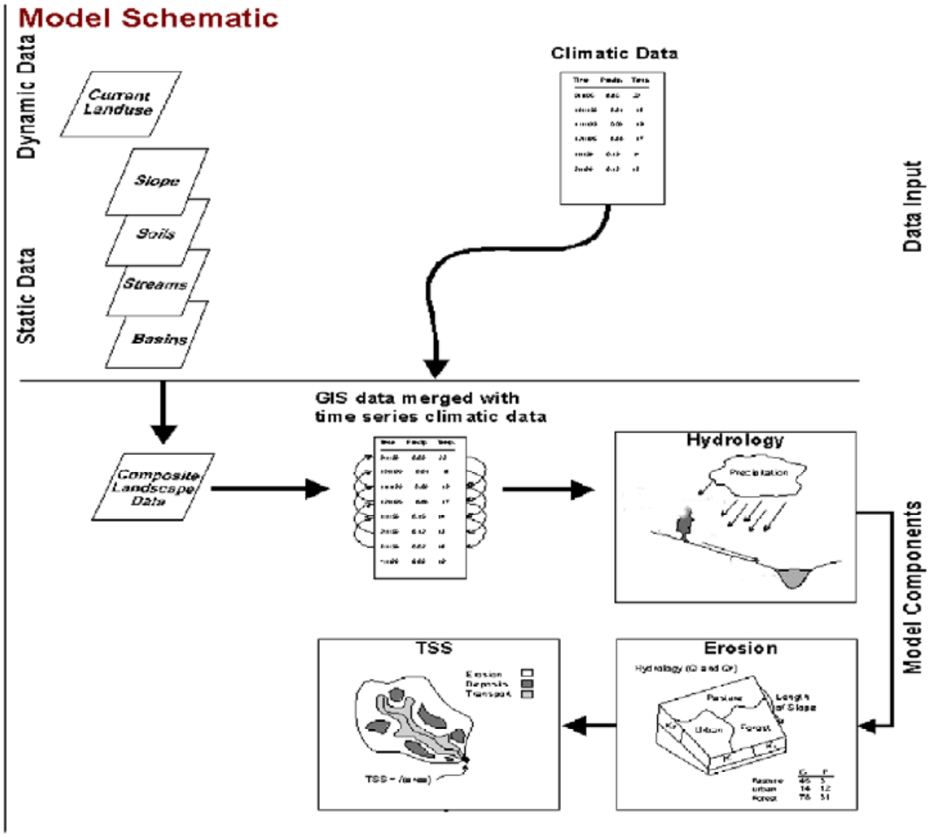


Figure A6-10: Erosion Model Schematic

Hydrology Model

Peak Flow – Rational Method

One of the most widely used methods for estimating peak flow in ungaged watersheds is the Rational Method (Pilgrim and Cordery, 1993; Gray, 1990). The form of the equation is:

$$Qp = CiA$$

Where,

Qp = peak flow in cfs
C = runoff coefficient
A = area in acres
I = rainfall intensity in inches/hour

The following image of the Umatilla Basin highlights the climate stations where precipitation and snow pack data used in the model were collected:

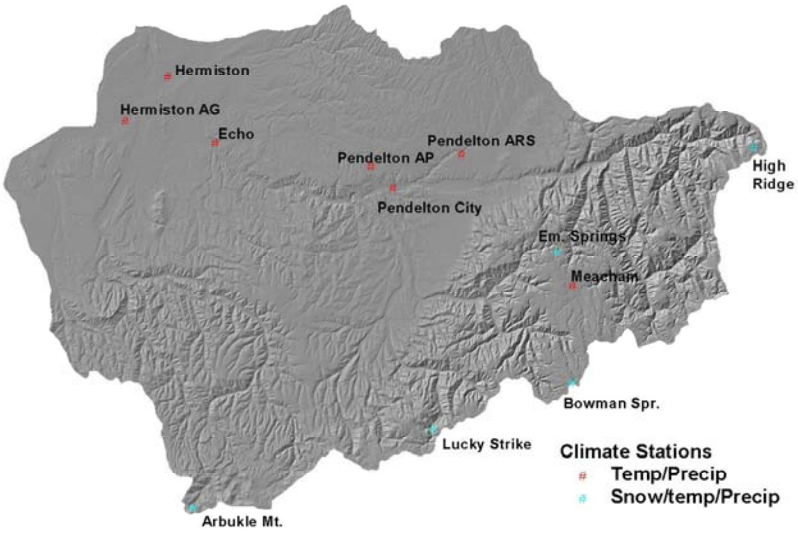


Image A6-1: Climate Stations

Flow Volume – SCS Methods

The runoff volume was estimated using the Soil Conservation Services (SCS) runoff depth estimation (USDA, 1973; Maidment, 1993):

$$Q = \frac{(P-0.02S)^2}{P+0.8S}$$

Where,

Q = runoff depth in inches

P = rainfall in inches

S = storage parameters = $\frac{1000}{CN}$

CN = curve number which is a function of land use (see McCuen, 1998 for Curve Numbers)

Snow Melt – Temperature Index

Snow melt was estimated with a temperature based index. The equation used in the basin was:

$$SM = M\,T$$

if $T > 38\ ^{o}F$

Where,

SM = snow melt in inches

T = temperature in degrees Celsius

M = melt factor coefficient (approximately 2 degrees Celsius)

The snow melt model was tested at the SNOTEL sites and had high correlations ($r^2 > 0.90$ for 5 sites; df > 110).

Runoff

Flow Movement

The travel time of water was estimated by kinematic wave routing (Henderson and Wooding, 1963; Novotny and Chesters, 1981). Travel time (or time of concentration):

$$Tc = 6.9\ [(d\ n^{0.6})/(i^{0.4}\ S^{0.3})]$$

Where,

Tc = overland flow travel time in hours

n = manning overland flow coefficient

S = Slope in percent

i = rainfall intensity in mm/hour

d = distance of overland flow in meters

The distance of the overland flow path was estimated based on buffer zones away from the hydrography. Water that had travel times greater than 24-hour increments were partitioned in to future days. No re-freezing processes were incorporated into the model. Travel times greater than 168 hours (> 7 days) were assumed to be recharging the deep aquifers.

Image A6-2 illustrates the processes modeled with time-of-concentration component of the model:

Time of Concentration - How long does it take water to travel?

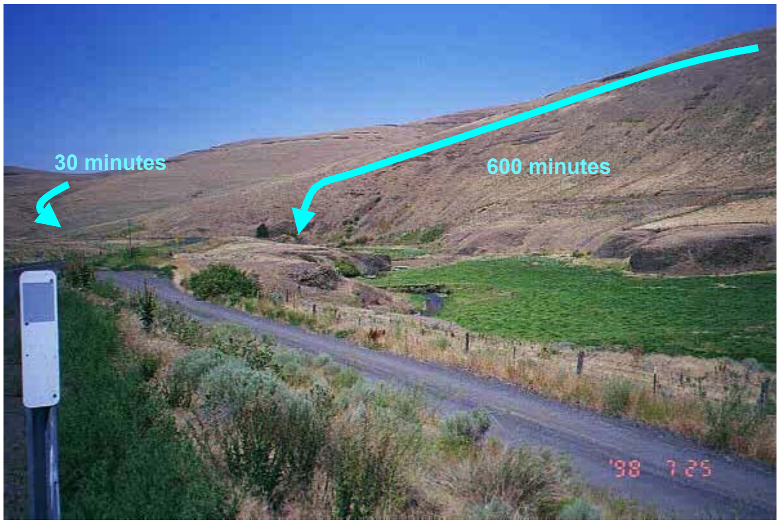


Image A6-2: Time of Concentration

Erosion Model

Slope – Length Estimates

Slope-length was estimated from slope, using the equation proposed by Moore and Burch (1986):

$$LS = (area/22.13)^{0.4}\,(\sin(S)/0.0896)$$

Where,
area = polygon area in hectares
S = slope in percent

Novotny and Chesters (1981) also provide nomographs for verifying the LS parameters.

Image A6-3 shows the impact of slope on time-of-concentration and erosion:

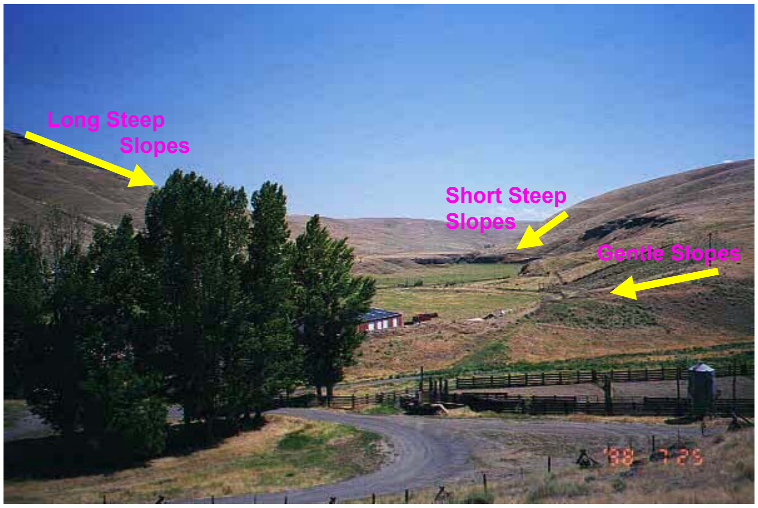


Image A6-3: Slope Impact on Time of Concentration and Erosion

Modified Universal Soil Loss Equation

Estimates of erosion were generated using the Modified Universal Soil Loss Equation (Williams and Berndt, 1977;Shen and Julien, 1993). This is an event based modified version of the Universal Soil Loss Equation (USLE) originally formulated by Wischmeier and Smith (1965). The general form of the MUSLE model is:

$$Y = 11.8(Qp\ Q)^{0.56}\ K\ LS\ CP$$

Where,

Y = event soil loss (tons/hectare)
Qp = peak runoff (m^3/sec)
Q =event runoff volume (m^3)
K = soil erosivity
LS = slope – length
CP = a cropping/erosion factor (used in calibration)

Data for the soil erosivity (K was obtained from the detailed soil data surveys from Umatilla and Morrow County (SSURGO Digital Data Bases, USDA).

Image A6-4 illustrates the some of the land uses in the model. Land use impacts peak flow, time of concentration, and erosion.

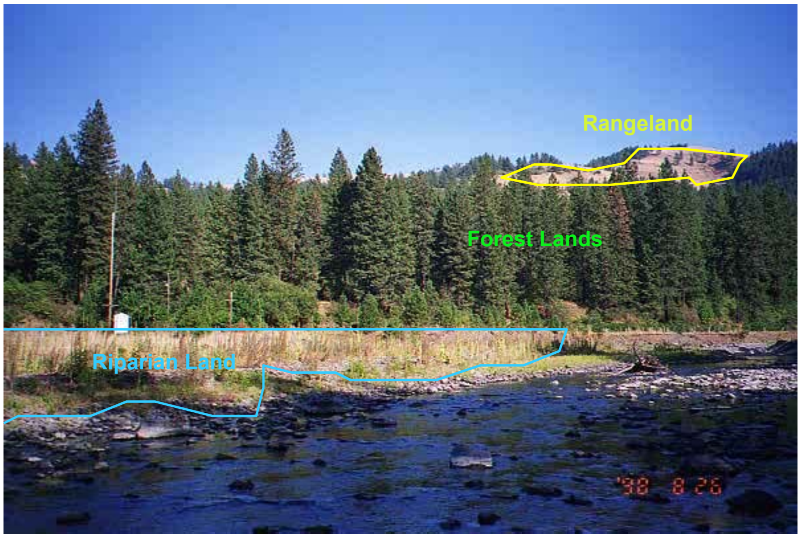


Image A6-4: Land Use Impacts

Image A6-5 shows the predominant land uses in the Umatilla Basin:

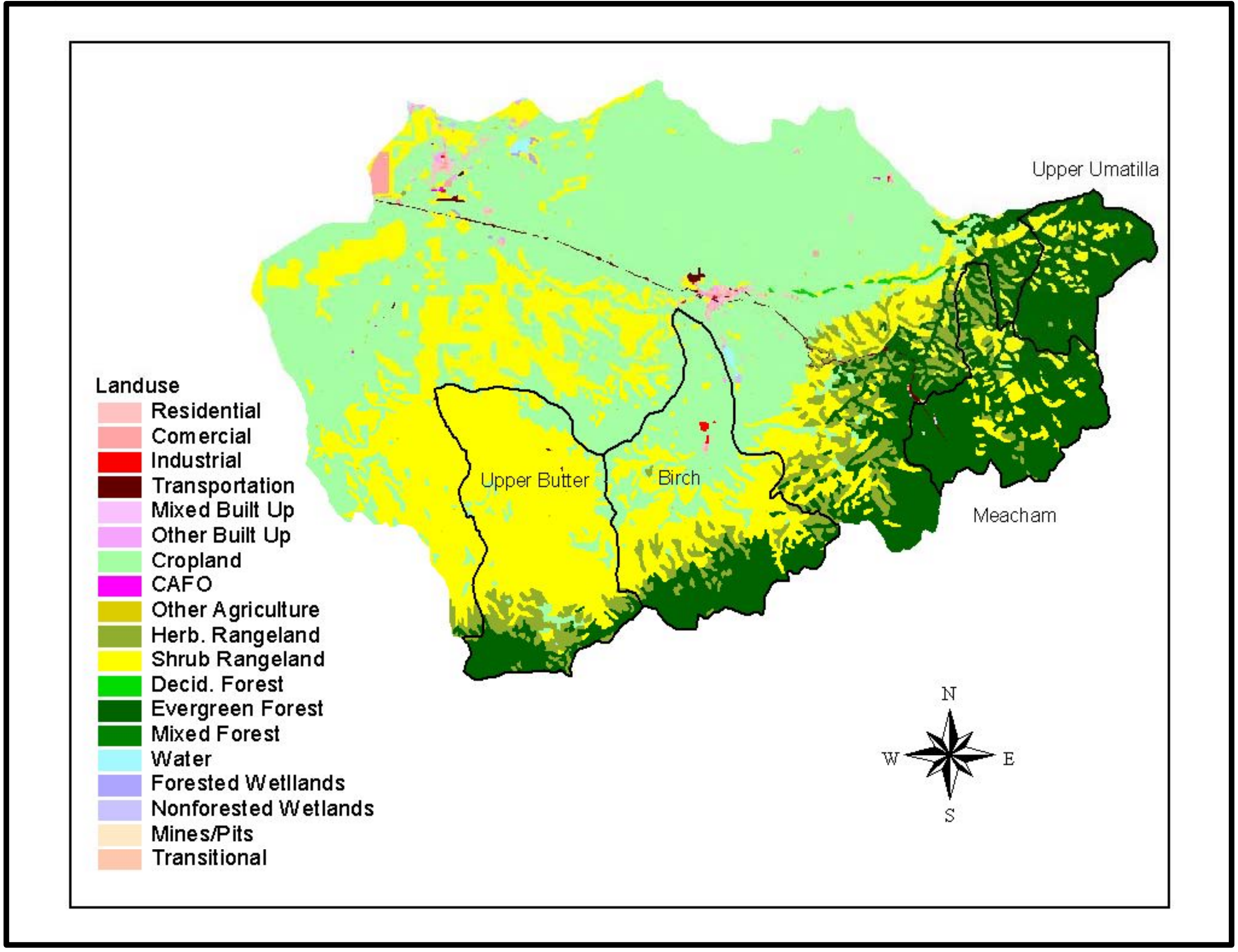


Image A6-5: Umatilla Basin Land Uses

Erosion Model: Sediment Delivery

The amount of total suspended solids transported in a stream is not necessarily the same as the upland erosion due to the contribution of stream bank erosion and hill-slope storage of upland sediment. The delivery ratio is a percentage of upland sediment reaching the stream. Roehl (1962; Novotny and Olem, 1994; Fraiser, et al 1996) has demonstrated that the fraction of sediment delivered is inversely related to the drainage area with the following formula:

$$Y_{DR} = 2.04\ A^{-0.25}$$

Where,

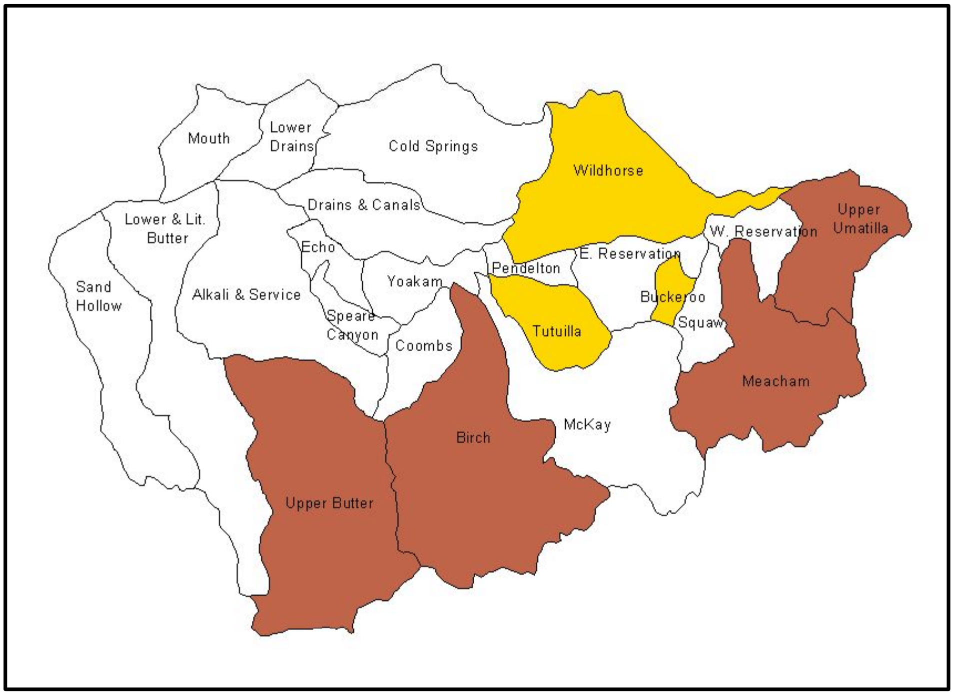
Y_{DR} = delivery ratio

A = area (square miles)

Model Calibration Watersheds

Image A6-6 illustrates the watersheds where streamflow and TSS data were available for model calibration:

Modeling Watersheds



Brown watersheds are initial calibration watersheds
Tan watersheds are additional TSS data collection

Image A6-6: Calibration Watersheds

Erosion Model: Stream Bank Contributions

Streambank erosion in the Umatilla Basin is a significant source of sediment. This is apparent in agency habitat surveys, monitoring observations, and is reflected in flow and TSS data patterns. Streambank sources are typically difficult to incorporate in nonpoint source models due to the scale of the data required and the stochastic nature of the stream bank erosion process. Therefore, an empirical analytical approach was chosen to characterize the relative sediment input from streambanks.

Relatively high streamflow causing streambank erosion was determined to be a function of watershed area. Plots of measured instream TSS data and flow over time using the 1998 and 1999 data were visually inspected to estimate the flow magnitude at which streambank erosion contributions begin to occur (flow levels above which TSS/flow ratio abruptly increases). These flows were plotted against non-forested watershed area. Forested areas exhibit dramatically lower concentrations of TSS, generally less than the levels of concern. The statistical relationship between observed flows causing bank erosion and non-forested watershed area (expressed as percentage of total watershed) had a strong statistical relationship (r^2=0.97; S.E. = 91.98) **(Figure A6-11)**:

$$\text{Bcfs} = 1265-12.6\text{NF}$$

Where,

Bcfs = discharge when stream bank erosion occurs
NF = Non-forested watershed / total watershed area (in percent)

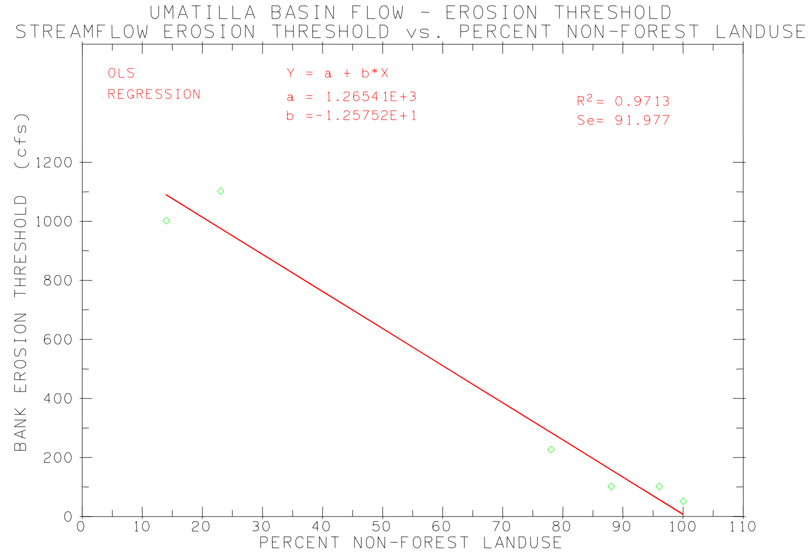


Figure A6-11: Bank Erosion Threshold vs. Non-forest Landuse

Plots of measured instream TSS over time using the 1998 and 1999 data were visually inspected to estimate a streambank erosion factor; the multiplier used to account for the TSS contributed by streambank erosion (Y axis in **Figure A6-12**). The bank erosion factor as a function of non-forested rivermiles was estimated by a regression analysis (**Figure A6-12**) (r^2=0.98; S.E.= 0.38):

$$EF_{rm} = 1.24+0.0208RM$$

Where,

EF_{rm} = stream bank erosion factor as a function of non-forested rivermiles

RM = river miles in non-forested areas

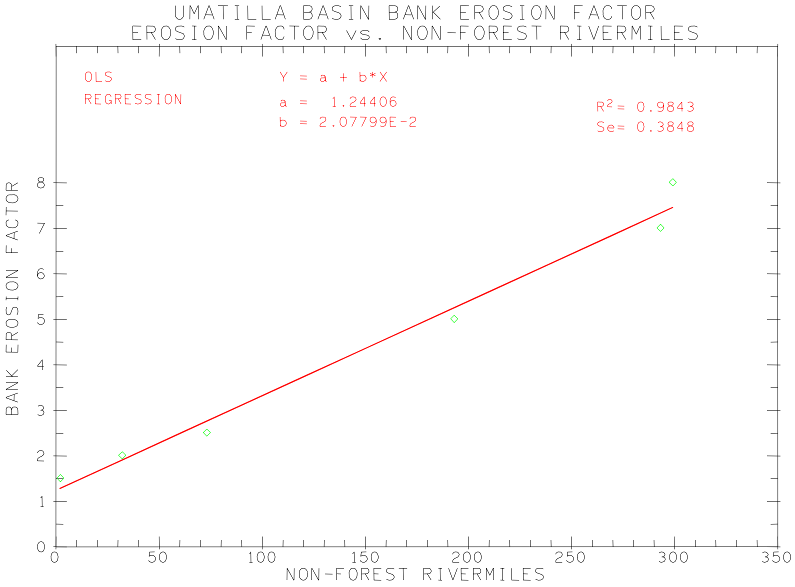


Figure A6-12: Bank Erosion Factor vs. Non-forest Rivermiles

To obtain the streambank portion of the load allocation, the modeled sediment yield to the stream from upland erosion was multiplied by the stream bank erosion factor (EF_{rm}) during periods when the bank erosion initiating discharge (Bcfs) occur.

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