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Lower Snake River Programmatic Sediment Management Plan, Final Environmental Impact Statement

Appendix E - Evaluation of Sediment Yield Reduction Potential in Agricultural and Mixed-Use Watersheds of the Lower Snake River Basin

August 2014

Evaluation of Sediment Yield Reduction Potential in Agricultural and Mixed-Use Watersheds of the Lower Snake River Basin

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1.0 Introduction

Despite being extensively studied since the 1930's (Eakin and Brown 1939), reservoir sedimentation continues to be a serious problem in many parts of the world including the United States (Fan and Morris 1992; Dunbar et al. 1999). Nationwide, a study by Crowder (1987) indicated that 0.22% of the nation's water storage capacity is lost annually to sediment damages. Of this amount, an average of 24% of the lost volume is due to soil erosion from cropland although a considerable amount of regional variation existed in the data. The total annual cost of erosion and sedimentation in the United States was estimated to be approximately $44 billion back in 1995 (Pimentel et al. 1995). Problems associated with reservoir sedimentation include loss of several important functions including flood control capacity, firm yield, port and transportation utility, and aquatic habitat. All reservoirs exhibit some effects of sedimentation (Morris and Fan 1998) however excessive upstream sedimentation can significantly reduce the design life of downstream reservoirs or require increased frequencies of maintenance practices such as dredging (Vanoni 2006).

A number of studies have attempted to assess the economic impacts of controlling erosion (Crowder 1987; Enters 1998). Palmieri et al. (2001) proposed a framework for assessing the economic feasibility of sediment management strategies which permitted the life of dams to be prolonged indefinitely. Hansen and Hellerstein (2007) found that for 2,111 U.S. watersheds, a one-ton reduction in soil erosion provided benefits ranging from $0 to $1.38. Using the Hydrologic Simulation Program-Fortran (HSPF) model, Moltz et al. (2010) examined six BMP scenarios for sediment control in a New Mexico watershed. Ranging in cost from $1M to over $66M, they found that sediment loss measured at the basin outlet could be reduced by 3,785 to 4,522 tons/year.

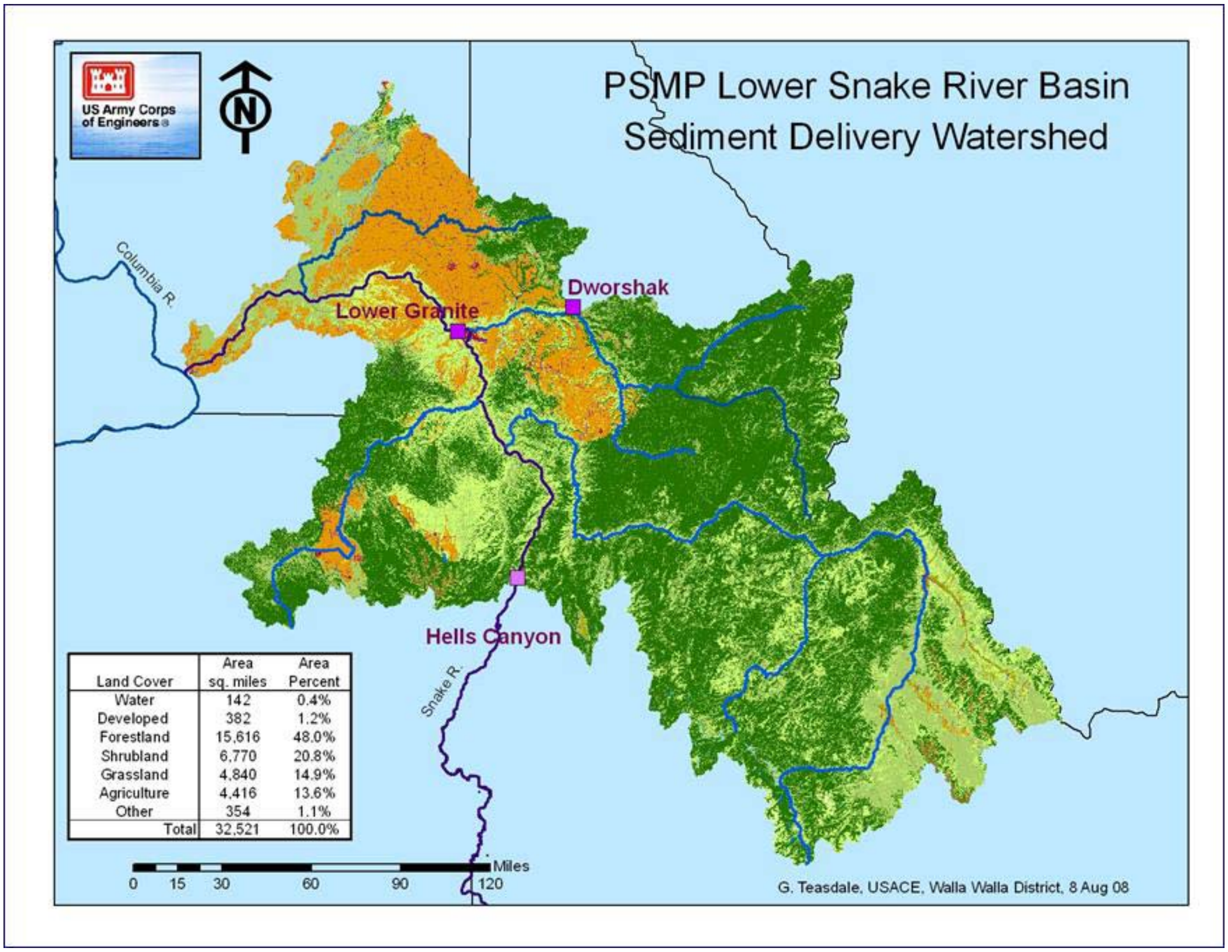
Since agricultural activities are often linked to excessive erosion rates, many studies have focused on cost-effective reduction strategies in rural watersheds. For example, in the early 1980's, a USDA study estimated that many wheat growing areas in the Snake/Clearwater had erosion rates in excess of 25 tons/ha/year (Lee 1984) so agricultural best management practices (BMPs) could effectively be used to reduce soil loss. A key to this is the measurement or prediction of sediment yield versus soil loss. Large quantitative differences may exist between upland soil erosion and downstream sediment delivery (Trimble and Crosson, 2000). Upland erosion may be deposited at other locations in the field, along fencerows, or along streams as alluvium never reaching the water course. Determining the sediment delivery ratio at the watershed scale remains a challenging area of erosion research (Vente et al. 2007).

Reservoir sedimentation is a reoccurring phenomenon near the confluence of the Snake and Clearwater Rivers at the Idaho/Washington state line. The US Army Corps of Engineers (USACE) is authorized by Congress to maintain the federal navigation channel near the Port of Lewiston, Idaho to a width of 250-feet and a depth of 14-feet. Because upstream sediment settles near the confluence of the two streams, the USACE must periodically dredge the navigation channel and the Ports of Lewiston and Clarkston. One possible alternative for reducing the frequency of dredging is to reduce or eliminate upstream sources of sediment in the basin. These sources include those from forests, rangeland, roads, agriculture, urbanization, landslides, and stream banks (TetraTech 2008). As illustrated in Figure 1, assuming the Hells Canyon Dam complex on the Snake River mainstem and Dworshak Reservoir on the North Fork of the Clearwater effectively trap upstream sediments, the area of concern would be approximately 32,000 square miles. Moreover, since approximately 14 percent of the area (4,400 sq. mi.) is classified as agricultural lands (see Figure 2) and agricultural lands are often tied to erosion sources, a detailed investigation of agricultural erosion and yield is warranted.

The overall purpose of this work is to assess the current sediment yield and the feasibility of sediment reduction measures in agricultural and mixed-use watersheds of the Lower Snake River Basin. The assessment data and findings will support development of the Programmatic Sediment Management Plan. Specific objectives are to:

- Review and summarize existing data and reports,
- Assemble supporting GIS data for the study area,
- Review agricultural sediment yield assessment methods,
- Estimate sediment yield from agricultural watersheds,
- Identify watersheds with significant sediment yield potential, and
- Evaluate agricultural sediment reduction measures.

The following report details the steps taken to quantify agricultural sediment contribution to the Lower Granite Reservoir backwater area near both Lewiston, ID and Clarkston, WA as well as tributary watersheds downstream on the lower Snake. It was not our intent to duplicate the TetraTech (2006) study or ongoing efforts by the USACE so duplication was avoided where possible. However, we did use significant amounts of this information and is so cited in this report.



Land Cover	Area sq. miles	Area Percent
Water	142	0.4%
Developed	382	1.2%
Forestland	15,616	48.0%
Shrubland	6,770	20.8%
Grassland	4,840	14.9%
Agriculture	4,416	13.6%
Other	354	1.1%
Total	32,521	100.0%

Figure 1. Contributing sediment basins in the lower Snake River watershed (USACE, 2008).

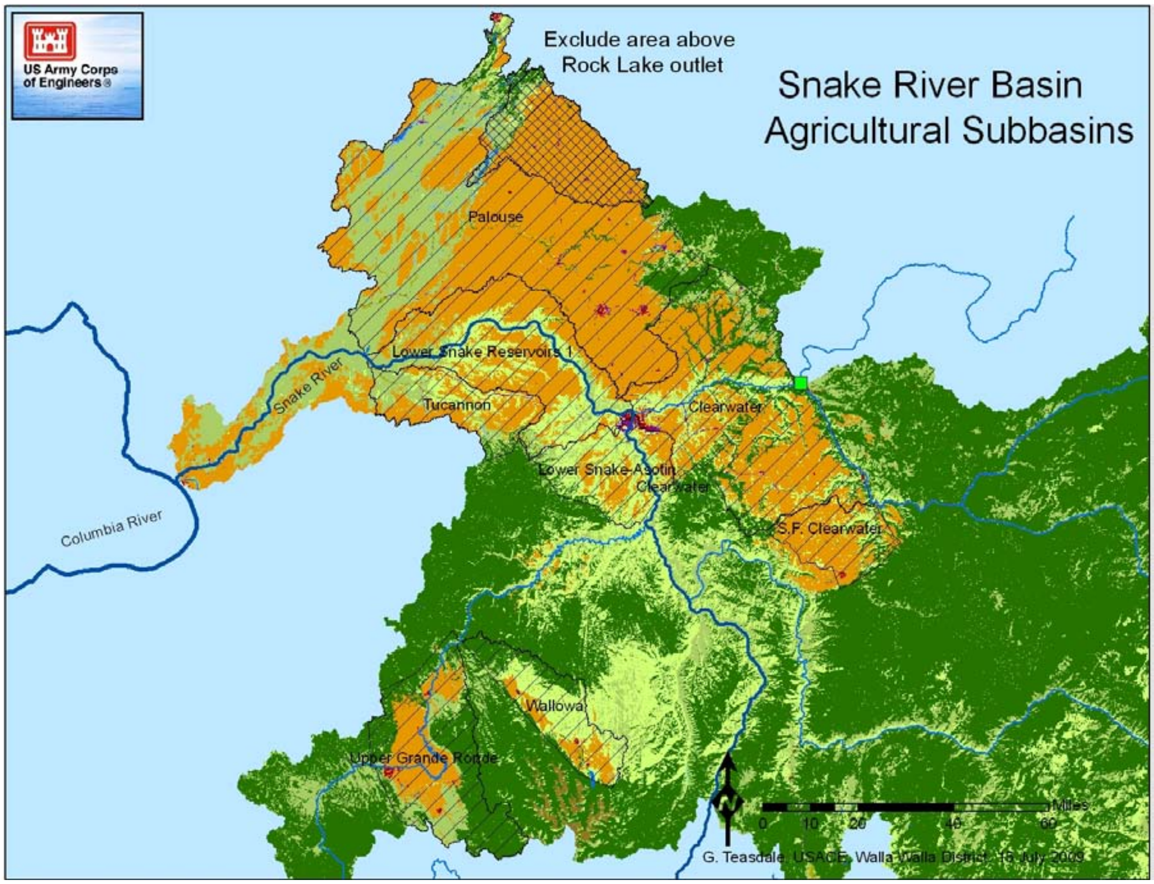


Figure 2. Study area of agricultural lands within lower Snake River watershed (USACE 2008).

2.0 Background

As an initial task, we reviewed a considerable amount of existing literature on sediment erosion, transport, and deposition with a bent towards agricultural production. Sediment generation, transport and deposition processes are discussed throughout the literature and periodically reviewed (Rose 1993; Haan et al. 1994; Prosser and Rustomji 2000). This document contains a brief summary of this literature. Because of an overwhelming amount of work in this area, we tended to focus on relevant data sets and studies conducted in the Pacific Northwest or with broad-based application nationally or globally.

Early studies of soil erosion and transport typically divided sediment sources broadly into sheet and channel supplies (Roehl 1962). Sheet erosion consisted of upland sources while channel erosion included gully, valley trenching, streambed, and stream bank erosion. Today, rather than lumping sources together, researchers recognize and have been working towards quantifying each distinct erosion component. Arguably, some theories and practices are still in their development phase and must be used with caution due to the uncertainty of results or the limited amount of validation. Furthermore, while there are many more unique sources of sediment in most watersheds, it is often difficult to distinguish between them with high degrees of precision due to the complex paths, interactions, and limited long-term data availability. Consequently, techniques that lump sediment into a single category still have potential uses.

In this report, upland erosion (sheet and rill) and channel erosion (gully and streambank) processes and models focusing on agricultural areas are examined.

1. Sheet and Rill Erosion

Computerized applications for watershed surface erosion processes can be broadly categorized into the following groups (USBR, 2006):

a. Empirical models
b. Physically-based models
c. Mixed empirical/physical models
d. GIS-based models

Empirical models of erosion rates are typically based on one of the following methods (Randle et al. 2006):

a1. Universal Soil Loss Equation (USLE) or one of its modified versions
a2. Sediment yield as a function of drainage area
a3. Sediment yield as a function of drainage characteristics

Although often criticized in the literature (often by those promoting a “better” approach), there are also staunch supporters of the USLE approach. Originally developed for small hillslope applications, the USLE and its variations have been incorporated into many catchment scale erosion and sediment transport modeling applications (Kinnell and Risse 1998; Merritt et al. 2003). However, the use of USLE outside the U.S. has been limited by the perceived lack of data for the parameters required to run the model under new conditions (Loch and Rosewell 1992).

Expressions predicting annual sediment yield as a function of drainage area (a2) are rather simple regression equations often shown as some form of Yang's (1973) unit stream power equation can be used as a rational tool for the prediction of sheet and rill erosion rate.

In 1968, the Pacific Southwest Inter-Agency Committee (PSIAC 1968) developed a sediment yield classification procedure comprised of surface geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion that predicted sediment yield as a function of nine drainage basin characteristics (a3). Strand (1975) and Strand and Pemberton (1982) developed an empirical model based solely on contributing watershed area.

2. Channel Erosion
    a. Gully erosion
    b. Valley trenching
    c. Streambed erosion
    d. Streambank erosion

Most sheet and rill erosion models omit the impact of channel erosion except in aggregate of the calibration procedure. Investigations of both ephemeral and permanent gullies is not a new field of study but it is of growing importance as research suggests that ephemeral gullies act as the conduits for sediment delivery to streams and rivers (Teasdale and Barber 2008) and permanent gullies are related to land use/land cover changes (Nyssen et al. 2006; Tebebu et al. 2010). Permanent gullies can be defined as gullies too deep to pass over with ordinary farm tillage equipment; typically deeper than 0.5 m (Poesen et al. 2003). As shown in Figure 3, ephemeral gullies are shallower. Gully erosion typically occurs because of macrorelief features of a watershed and hydrologic events. Gully erosion models range from stochastic models to process-based representations of the system (Bull and Kirkby 1997). Haan et al. (1994) provided a discussion of ephemeral gullies and headwall gullies as well as computation methods aimed at including gully erosion in sediment predictions.

Figure 3. Regional example of ephemeral gully erosion and deposition zone.

In general, there are three types of streambeds to consider: 1) bed rock, 2) coarse-bed alluvial, and 3) fine-bed alluvial (Howard et al. 1994). The governing mechanics for erosion depend upon the type of bed being considered. Stream channel incision processes have typically been modeled by excess shear stress, total stream power, or stream power per unit bed area functions. Numerous mechanistic theories of long-term river profile development have been proposed in the literature (Howard and Kerby 1983; Beaumont et al. 1992; Slingerland et al. 1997; Whipple and Tucker 1999). While the underlying assumptions may be very different, most theories revolve around: 1) detachment-limited models (e.g. stream erosion law), 2) transport-limited models, or 3) hybrid models (Tucker and Whipple 2002).

Although no particular feature is necessarily conclusive evidence by itself, bed erosion may be indicated by (Queensland Government 2009):

- vertical headcuts,
- steep or mobile riffles,
- streambed weathering,

- extensive bank erosion on both sides of the stream or river,
- headcuts on tributaries (hanging valleys),
- changes in channel widths between disturbed and undisturbed reaches,
- exposure of ancient logs and rock bars in the stream bed,
- marks on bridge pylons of the old bed level, and
- wider, shallower reaches downstream of a headcut and fewer deep holes.

These processes may be analyzed individually or in a lumped parameter fashion. For example, Flores-Cervantes et al. (2006) developed a model to estimate horizontal headcut retreat as a function of discharge, height of the headcut, upstream slope, and relevant land surface and soil properties for soil erosion.

Streambank erosion consists of two processes: basal erosion due to fluvial hydraulic force and bank failure under the influence of gravity (Duan 2005). Streambank erosion rates are determined by a complex combination of factors (Wolman 1959; Knighton 1998). These factors can be categorized into several groups:

(1) cross-sectional and longitudinal characteristics;
(2) parameters of flow conditions;
(3) rainfall conditions;
(4) temperature conditions, primarily the influence of frost;
(5) vegetation and soil erodibility; and
(6) sediment characteristics.

Each group of influencing factors contains variables that may affect streambank erosion rates.

A significant amount research has been conducted in order to analyze and predict stream bank erosion (Hooke 1979; Lawler 1986; Rosgen 1996; Simon and Darby 2002). Hooke (1979) conducted a field study of river banks and concluded that two main methods of bank erosion are corrasion and slumping and that these appeared to be associated with the influence of river flow levels and antecedent precipitation conditions, respectively. Streambank erosion and channel form have been shown to be impacted by land use changes such as afforestation and urbanization (Murgatroyd and Ternan, 2006) as well as riparian condition. For streambanks containing large quantities of silts and clays (cohesive soils), Julian and Torres (2005) found that hydraulic erosion of cohesive riverbanks is dictated by flow peak intensities. Figure 4 shows a typical example of streambank erosion in the lower Snake River basin.

It is often difficult to separate streambed from stream bank erosion and the causes of one often lead to the other. For instance, Alonso and Combs (1990) and Langendoen and Simon (2008) found that bed lowering caused bank instability and widening of stream channels. As a result, the two are often combined in a single prediction model. Complicating watershed-scale analysis of sediment is a usual change in sediment sources going downstream. Brune (1951) was one of the first to find that bottomland sources such as streambank erosion and valley trenching became more important and upland sources such as sheet and gully erosion decreased in importance as watershed area increased.

Where tied directly to agricultural activities and management options, the importance of these concepts and other controlling factors will be examined more thoroughly in the discussion of models.

Figure 4. Streambank erosion on Charley Creek near Asotin, WA.

3.0 Approach Methodologies

3.1 Assemble Supporting GIS Data for the Study Area

The first National Land Cover Dataset (NLCD) created a 30-meter resolution land cover data layer of the conterminous United States from 1992 Landsat Thematic Mapper (TM) imagery and thus was referred to as NLCD 1992 (Vogelmann et al. 2001). In 2007, Howard et al. (2007) released an updated version of the NLCE 1992 data based on Landsat 5 and Landsat 7 imagery collected in 2001 called NLCD 2001. The new database contains 16 classes of land cover, the percent tree canopy (10% increments), and the percent urban imperviousness (10% increments) for every 30-meter cell in the conterminous 48 states. The 16 land cover classes are shown in Table 1.

Table 1. NLCD 2001 land cover class descriptions.

NLCD Land Cover Classes	
Open Water	Evergreen Forest
Perennial Ice/Snow	Mixed Forest
Developed, Open Space	Shrub/Scrub
Developed, Low Intensity	Grassland/Herbaceous
Developed, Medium Intensity	Hay/Pasture
Developed, High Intensity	Cultivated Crops
Barren Land	Woody Wetlands
Deciduous Forest	Emergent Herbaceous Wetlands

The US Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) has also used remote sensing to develop information specifically related to agricultural cropland. The NASS Cropland Data Layer (CDL) is a raster, geo-referenced, crop-specific land cover data layer with a ground resolution of 56 meters (0.77 acres) and is available through the geospatial data gateway (http://datagateway.nrcs.usda.gov/). A local example of the images is presented in Figure 5. According to the metadata, the NASS CDL is produced using satellite imagery from the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during the current growing season. In some states, cropland data layers used Landsat 5 TM and or Landsat 7 enhanced thematic mapper plus (ETM+) satellite imagery to supplement the classification. Ancillary classification inputs include: the US Geological Survey (USGS) National Elevation Dataset (NED), the USGS National Land Cover Dataset 2001 (NLCD 2001), and the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) 250 meter 16 day Normalized Difference Vegetation Index (NDVI) composites. Agricultural training and validation data are derived from the Farm Service Agency (FSA) Common Land Unit (CLU) Program. The NLCD 2001 is used as non-agricultural training and validation data. The strength and emphasis of the CDL is agricultural land cover in that it has far more crop types than the NLCD data set. Table 2 lists some of the more than 75 crop and land use types readily available for Washington.

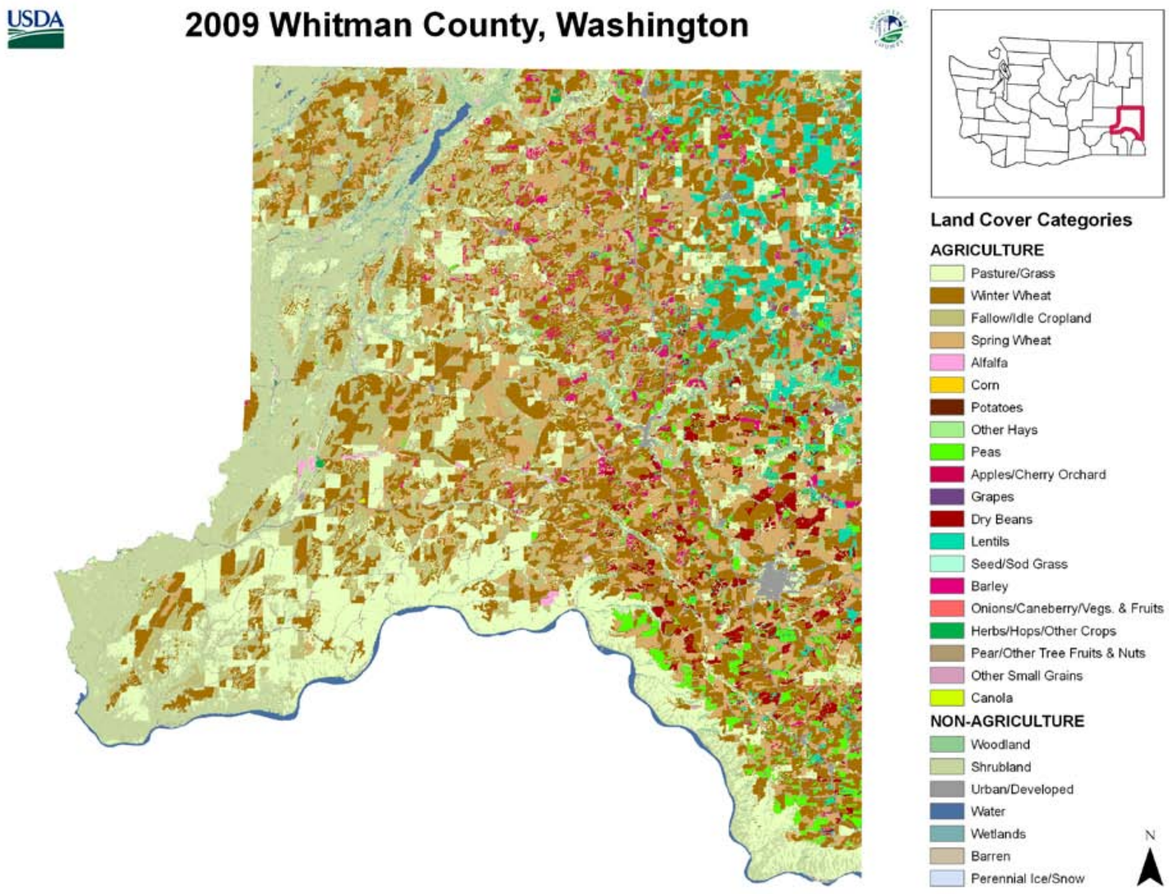


Figure 5. Example CDL data layer for Whitman County, Washington

Prior to 2006, the classification process used to create the CDL was based on a maximum likelihood classifier approach using an in-house software package. The CDL relied mainly on data from the Landsat TM/ETM satellite which had a 16-day revisit. And the in-house software limited the use of only two scenes per classification. Since 2006, Leica Geosystems ERDAS Imagine software has been used in the pre- and post- processing of all raster-based data. ESRI ArcGIS has been used to prepare the vector-based training and validation data. Rulequest See5.0 has been used to create a decision tree based classifier as opposed to the maximum likelihood classifier. The strength of the CDL is in its agricultural classifications. Due to the extensive agricultural training data provided by the Farm Service Agency, the major crop types for a CDL state will normally have a classification accuracy of 85% to 95%.

Table 2. NASS CDL 2007 major agricultural land cover class descriptions for Washington.

CDL Land Cover Classes	
Corn	Apple/Cherry Orchards
Pasture/Grass	Peaches
Winter Wheat	Grapes
Spring Wheat	Dry Beans
Alfalfa	Lentils
Cotton	Seed/Sod Grass
Potatoes	Barley
Other Hay	Onions/Caneberry/Vegetables/Fruits
Peas	Herbs
Fallow	Hops
Flaxseed	Pears/other
Other Small Grains	Canola
Rape Seed	Wetlands
Sugarbeets	Mustard

The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental U.S. NAIP imagery is acquired at a one-meter ground sample distance (GSD) with a horizontal accuracy that matches within six meters of photo-identifiable ground control points, which are used during image inspection. The FSA imagery acquisition cycle was 5-years beginning in 2003, 2008 was a transition year, and a 3-year cycle began in 2009. NAIP imagery products are available either as digital ortho quarter quad tiles (DOQQs) or as compressed county mosaics (CCM). DOQQs are available on-line at http://gis.apfo.usda.gov/arcgis/services. CCMs are available for free download through the USDA Geospatial Data Gateway, http://datagateway.nrcs.usda.gov/.

3.2 Summary and Review of Existing Data and Reports

Compilation of reports and data related to agricultural sediment yield

Reports and information related to agricultural sediment yield were compiled for the study region. A detailed list of available reports is provided in Appendix A of this report. As studies of erosion and sediment yield in mixed-land use watersheds typically address sources other than strictly agriculture, the evaluation will occasionally refer to these other sources.

Evaluation of reports and data

TetraTech (2006) provided an overview of sediment sources and yield for the Lower Snake River Basin with additional reference to management and restoration opportunities. Information compiled in TetraTech (2006) was partly derived from the comprehensive assessment of ecosystem components in the interior Columbia Basin by Quigley and Arbelbide (1997). In the Lower Snake River Basin, agriculture and urban land use are 23% of the total land area (see Table 3). The Lower Snake River Basin does not include areas that contribute sediment below Lower Granite Dam such as the Palouse River Basin.

The Salmon River subbasin is not part of the analysis of this project. This subbasin, however, should be considered as potential sources of coarse grained sediments due to hydrologic and riparian disturbances. TetraTech (2006) identifies the Lemhi watershed as having a rating of high hydrologic disturbance, high surface soil erosion hazard in Pahsimeroi, Lemhi, and Lower Salmon watersheds, high sediment delivery hazard in the Lower Salmon and Little Salmon watersheds. Furthermore, highly erodible cropland occurs in the northern edge of the Lower Salmon watershed. Out of 89 water bodies in this subbasin listed in Section 303(d) in 1998, 88 were listed for sediment concerns.

Table 3. Land Cover of Agriculture/Urban above Lower Granite Dam

(derived from Table 2 in TetraTech 2006).

Geographic area	Agriculture/Urban percentage
Salmon subbasin	3
Clearwater subbasin (not incl. North Fork Clearwater)	24
Lower Snake River basin – Hells Canyon Dam to Clearwater	22
Grande Ronde subbasin	17
Lower Snake River basin – Clearwater to Columbia	79
Total Lower Snake River Basin area	23

The Natural Resources Conservation Service (NRCS) has produced sediment loss estimates at the country level to identify the highest potential for sediment and nutrient loss from farm fields, wind erosion, and soil quality degradation, areas of the country that would likely benefit the most from conservation practices (Potter et al. 2006; NRCS 1997). They used the National Nutrient Loss and Soil Carbon (NNLSC) database from 1997 National Resource Inventory (NRI) points to represent cropland land use patterns and resource conditions. Erosion by water includes sheet and rill erosion and excludes gully erosion. Within an 8-digit hydrologic unit, dot counts represent acreage totals correctly plus or minus one dot to account for remainders. Map 5083 does not show rates of erosion or how much erosion has occurred, and each dot on the map represents 5000 acres. Data also were not collected on Federal land, and data are not available for Alaska or the Pacific Basin.

Potter et al. (2006) estimated sediment loss using MUSLE. The West was sparsely covered, and non-irrigated crops only included barley, spring wheat and winter wheat. The range of soil loss in tons/ac was 0.5 to 1.3 for these crops. Tillage practices in the West reduced sediment loss from 2.1 using conventional tillage to 1.3 and 0.8 for all crops (irrigated and non-irrigated) using mulch tillage and no-till, respectively. Conservation practices evaluated for the Western part of the USA included terraces, which are not typically used in the study area. None of the subbasins in the study area were identified as critical areas in the NRI CEAP study. This can be due to sparse coverage of the area, or the type of data input in the EPIC model for the purposes of the model simulations.

Clearwater River Subbasin:

Land ownership in this subbasin is 62% federal, 1% Nez Perce Tribe, 3% State of Idaho, and 33% private. Agricultural land use occurs in the Middle Fork Clearwater (18%), South Fork Clearwater (23%), and Clearwater (57%). Agriculture consists of wheat-barley and rangeland. Surface erosion hazard is high in Middle Fork Clearwater and Clearwater watersheds, and moderate to high in the South Fork Clearwater watershed. Sediment delivery hazard is mod-high or high in all watersheds within this subbasin (see Table 19 in TetraTech 2006). The South Fork and Clearwater River watersheds have Highly Erodible Lands according to NRCS (1997). Surface erosion was estimated by Boll et al. (2001) for agricultural areas within the basin. Teasdale and Barber (2005) estimated ephemeral gully erosion in the Potlatch River watershed at less than 0.5 tons/acre. In 1998, 540 stream segments were 303(d) listed (70% in Lower Clearwater, 19% in Middle Fork Clearwater, and 9% in South Fork Clearwater). The TetraTech report lists several that have been delisted since that time.

Overall TetraTech (2006) concluded that agricultural and forest management in the Clearwater, South Fork Clearwater and Middle Fork Clearwater watersheds are most promising for sediment reductions. BMPs have been published in the Idaho Agricultural Pollution Abatement Plan (Resource Planning Ltd. 2003) for agriculture (including grazing), but they are largely voluntary at this time. Restoration of riparian areas, and limiting field erosion and delivery to streams are important.

The Potlatch River basin is part of the Clearwater River subbasin. Total area of the Potlatch Basin is 1540 km^2 (590 mi^2). The upper watershed is predominately forestland of mixed ownership. The southern part of the watershed is the easternmost extension of the Palouse prairie and is dissected by deep canyonlands of the lower tributary drainages. Land use is predominantly dryland agriculture intermixed with areas of rural residential development. Dechert (2004) used RUSLE2 model to predict surface erosion from the agricultural segments of the watershed. The study area covered 736 km^2 (284 mi^2) of land situated in the lower Potlatch River basin. Six subbasins (Big Bear, Cedar, Little Bear, Little Potlatch, Middle Potlatch, and Pine Creek) are located in the lower watershed as part of the Northwestern Wheat and Range Region. Table 4 illustrates the erosion values used by Teasdale and Barber (2008) in their analysis of ephemeral gullies in the system.

There are other sources of sediment in the basin other than cropland agriculture. Figure 6 shows an example of a clear-cut section of forest near Helmer, Idaho. Logging activities such as this have been shown to contribute significant amounts of sediment.

Table 4. RUSLE2 surface erosion rates for the Potlatch agricultural watersheds. (Adapted from Dechert, 2004)

Subbasin	Mean Surface Erosion (mton/km^2)	Standard Deviation (mton/ km^2)	Mean Surface Erosion (ton/acre)	Standard Deviation (ton/acre)
Big Bear	802.8	2,060.0	3.57	9.16
Cedar	524.0	1,805.8	2.33	8.03
Little Bear	645.4	1,675.4	2.87	7.45
Little Potlatch	1,540.5	1,603.4	6.85	7.13
Middle Potlatch	1,164.9	1,742.9	5.18	7.75
Pine	951.3	2,473.8	4.23	11.00

Figure 6. Clear-cut logging near Helmer, ID in the Potlatch basin.

Snake River Basin (below Hells Canyon Dam):

This subbasin consists of Hells Canyon, Imnaha, and Lower Snake Asotin. The Asotin watershed contains 47% agricultural/urban land, including grassland and cropland at lower elevations. Hydrologic disturbance is high in the Lower Snake – Asotin watershed. For the Asotin, a review of the Asotin County Conservation District Subbasin Plan shows the changes in stream channel and riparian areas, gully erosion, and other man-made changes. The subbasin plan addresses these issues. Surface soil erosion and sediment delivery hazards are high in the entire subbasin.

The NRCS analysis of cropland found that the geographic area had no areas of highly erodible cropland and no areas of highly erodible or non-highly erodible cropland with excessive erosion above the tolerable soil erosion rate, except for some areas in the lower elevations of the Lower Snake-Asotin watershed (NRCS 2000). Tammany Creek is mentioned as having sheet and rill erosion, in addition to grazing lands, and other sources. Excessive erosion was estimated at 3,000 tons per year during Dec-Jun. Imnaha and Asotin creek are also reviewed, but there is no clear indication how much sheet and rill erosion play a role in the overall erosion and sediment delivery. Agricultural BMPs include no-till/direct seeding, but no percentages of implementation are provided. Figure 7 illustrates a typical direct seeding operation within the Asotin Creek watershed. Research has demonstrated that this type of BMP is highly effective in reducing sediment loading. Imnaha is considered in good condition. Asotin's plan is considered as an improvement that will reduce sediment considerably.

Figure 7. Direct seed winter wheat in stubble in Asotin County.

Grande Ronde River Subbasin:

This Oregon subbasin has on average 17% agriculture/urban, with 22% in Upper Grande Ronde, 17% in Wallowa, and 11% in Lower Grande Ronde. Private ownership occurs at lower elevations, comprising about half of the subbasin. Cropland erosion may be present, but it is not the major source for sediment originating in the subbasin. Hydrologic disturbance is high in Upper Grande Ronde. Surface erosion hazard and sediment delivery hazard are high in all watersheds in this subbasin. Upper Grande Ronde and Wallowa watersheds have some highly erodible cropland. Several stream segments (20 in the Grande Ronde subbasin, two in the Lower Grande Ronde, and four in the Wallowa) were on 303(d) list in 1998. Practices that improve vegetative conditions are high priorities for improving water quality in the subbasin. Agricultural improvements have been achieved through CRP, CREP and WRP. In addition to reducing streambank erosion, creation of wetlands and filter strips for drainage from agricultural areas is important.

Lower Snake River Basin (Mouth to Lower Granite Reservoir):

Watersheds in this region include Palouse, Rock, Tucannon, and Lower Snake basins. These basins are mostly downstream of Lower Granite Reservoir. Dryland agriculture dominates this subbasin with 79% on average. Private ownership is at 92%. Sediment source in this area is wind-blown loess, producing fine sediment (silts and clays). A combination of conventional, conservation and no-tillage is used, with the majority in conservation or no-till. In addition to sheet and rill erosion, gully erosion is a major source of sediment. CRP is found on highly erodible land. Surface soil erosion hazard is high in all watersheds in this subbasin. Sediment delivery hazard is high in Tucannon. Conservation efforts, in particular as part of STEEP, have reduced erosion and sediment delivery in the Palouse region (see Brooks et al. 2010). NRCS (2000) indicates extensive areas with excessive erosion on highly erodible lands. TetraTech (2006) reviewed studies done in the watersheds of this subbasin.

A major recommendation from TetraTech (2006) is to do a screening effort to identify the watersheds and subwatersheds with the highest sediment production. A distinction should be made if the source is natural or man-made, and focus on the man-made watersheds to suggest further reductions. This study has followed this recommendation.

In a Tri-state effort in WA, OR, and ID, Kok et al. (2009) investigated the long-term impacts of conservation farming in the Pacific Northwest Wheatland. They found that soil erosion was reduced from 20 tons/ac/yr to 5 tons/ac/yr since 1975. Specific changes in farming practices related to erosion are summarized here. The moldboard plow (see Figure 8) has been replaced by less aggressive equipment such as chisel plows, sweeps, and field cultivators that conserve surface residues (see Figure 9). Most tillage following legume crops has been eliminated and reduced by 80% to 90% after spring cereals and 40% after winter wheat. Fallow land was reduced from 13% in high precipitation zone to zero. Fallow reduced somewhat in the intermediate precipitation zone, but shifted from tillage fallow to chemical fallow (see Figure 10). In the low precipitation zone, fallowing is still present on about the same acreage as 30 years ago, but conservation tillage fallow and chemical fallow have increased dramatically. Conservation tillage has become standard practice on most farms. Crop rotations have increased from 2-yr wheat-pea to 3-yr winter wheat-spring cereal - grain legume. The trend of increased use of no-till was initiated and is likely to continue. Increased yields have increased the amount of residue, which affects the soil erosion process, but in the high precipitation zone the high residue prevents adoption of no-till. Figure 1a shows soil erosion reductions in for 1975, 1990, and 2005 for the high, intermediate, and low precipitation zone, for different farming systems.

Figure 8. Aftermath of moldboard plow tillage.

McCool and Roe (2005) did analysis of soil erosion reduction in the Palouse River basin, focusing on winter erosion and conservation practices. While the hazards related to winter hydrology (predominantly frozen soil) were reduced from 1979 to 1994, the increase in conservation practices contributed to reduced soil erosion.

Figure 9. Example of high residue cropland.

Figure 10. Chemical fallow (upper) versus traditional fallow (lower).

Brooks et al. 2010 reported on long-term sediment loading trends in the Paradise Creek watershed. They found a statistically significant decreasing trend in overall sediment load based on detailed event-based sampling from 2001-2009 and three day-per week grab samples collected over the last 28 years. This decreasing sediment load can be attributed to conversion from conventional tillage systems to minimum tillage and perennial grasses through the Conservation Reserve Program, practices initiated in the late 1970s and early 1980s. Over the last 10 years (1999 to 2009) management practices have targeted gully erosion and stream bank failures. Preliminary modeling results and empirical evidence indicate that delayed reduction in sediment load at the watershed outlet may be caused by sediment storage in the stream channel.

The importance of infrequent large storms in producing large sediment loads is demonstrated at the USGS Suspended Sediment Database of major rivers in the United States (http://co.water.usgs.gov/sediment/selHistogram.cfm) which includes a histogram of the proportion of suspended sediment discharged during 1, 10, and 100 percent of the year at Hooper WA (see Figure 11). As illustrated in the figure, the majority of sediment loading at this location occurs in short, high flow periods. This has severe implications on design of sediment BMPs with large structures needed for meaningful reduction. Note that sediment collection at the Hooper station was only active from 1962 to 1971.

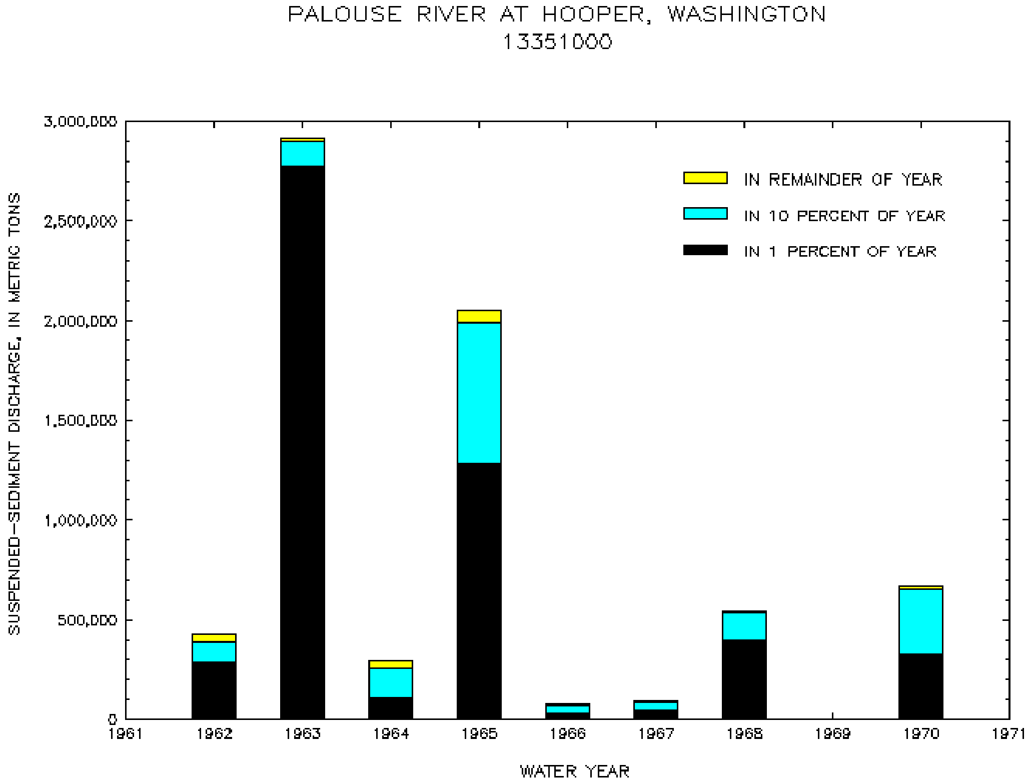


Figure 11. Suspended sediment is transported from the Palouse River Basin.

This phenomenon can be seen at other locations throughout the study area. An extreme case in point occurred during the 1997 flood where sediments were scoured from long reaches of tributary streams leaving gravel bars and relatively poor riparian conditions in several areas. Figure 12 illustrates this on George Creek near Asotin, Washington. This can be a source of sediment downstream for years.

Figure 12. Scour of sediments on George Creek as a result of 1997 flood.

See Appendix A for a database of related to studies (spreadsheet: AppendixA-Database-reports.xls). We are compiling information in watershed specific reports guided by the following questions:

<u>Data related to sediment yield from agricultural watersheds</u>

i. Compilation of reports and data related to agricultural sediment yield
ii. Written evaluation of the reports and data
iii. Database listing of reports and data
iv. Transfer of reports datasets to Corps

3.3 Review of Agricultural Sediment Yield Assessment Methods

There are numerous methods for determining soil erosion/sediment yield estimates. Soil erosion models range from detailed plot scale models to coarse watershed scale estimates. The two primary objectives that drive model selection in this study are the desire to: (1) quantify the sediment yield from a large region and (2) evaluate the potential for reducing sediment load for specific areas through implementation of best management practices.

Fundamentally and as previously stated, soil erosion models can be classified into three primary categories:

- empirical,
- semi-empirical/conceptual, and
- physically-based models.

Empirical models are often developed in regions having a large observation data set and are often simple models based on a few easily measured parameters. The USLE and subsequent revised-USLE (RUSLE) model are examples of an empirical modeling approach. RUSLE was developed from large, long term experimental datasets collected over many years at various locations around the US. RUSLE provides long term average hillslope scale soil erosion rates using climate, soils, slope length, slope steepness, crop rotation, and tillage parameters. It is a well accepted approach which can be applied to large areas through raster-based GIS calculations. This approach has been used in several TMDL watershed studies in the Snake River Basin. However empirical approaches are limited to regions which have long-term experimental data and assessment of management practices are often limited by data availability.

Semi-empirical models attempt to make empirical models more transferable to other regions which lack experimental data sets by including some physically-based processes. The SWAT model and the RUSLE-2 models are examples of semi-empirical models. Erosion prediction in the SWAT model is based on the Modified USLE (MUSLE) approach where the climate factor (R), calculated in RUSLE based on mean annual rainfall characteristics, is based on daily runoff from rainfall. The MUSLE approach allows SWAT to predict daily erosion rates rather than 30 year average erosion rates through RUSLE. Although this adaptation allows the SWAT model to predict erosion for individual storms, the accuracy of the model is directly related to its ability to predict surface runoff. However, daily runoff in the SWAT model is simulated using curve-number (CN) approach which is also a semi-empirical approach. The CN approach was developed using large watershed datasets which related precipitation to runoff using various soil and vegetative factors. As with the empirical RUSLE approach the accuracy of the CN approach relies heavily on large experimental watershed data sets. In the absence of these datasets the accepted approach in the SWAT model is to calibrate the curve number until observed and predicted streamflow best match.

Physically-based models are based on fundamental hydrologic processes and erosion prediction is based on soil detachment, transport, and delivery mechanisms. Physically-based models rely only on measurable soil, vegetative, climate, and topographic parameters. Although these models are adaptable to any region, the data requirements are often excessive and, because of their complexity, are often difficult to use. The Water Erosion Prediction Project (WEPP) model is an example of physically-based soil erosion models. The model uses physics-based equations to describe hydrologic and sediment generation and transport processes at hillslope scales. WEPP processes can be categorized as erosional processes, hydrological processes, plant growth and residue processes, water use processes, hydraulic processes and soil processes (Laflen et al. 1991). A detailed description of the WEPP model is provided below.

WEPP simulates soil detachment, deposition, transport and delivery through hillslope, channel, and structural impoundment units within a watershed (Flanagan and Nearing 1995). The model is based fundamentally on infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. Processes in WEPP include rill and interrill erosion, sediment transport, and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration and erodibility, climate, and effect of soil random roughness. Each hillslope can be divided into multiple overland flow elements to simulate flow from one land type to another (e.g., drainage from a disturbed upland area through a grass buffer).

Since its inception, the WEPP model was to become a wide-spread, physically-based management tool for the evaluation of management techniques. Much time and money was spent conducting experiments on a wide range of soil types across the country to develop parameter sets for soil, residue, and vegetative properties. Management files describing key temporal modifications to the plant, residue, and soil system (e.g., tillage, harvest) were developed for a wide variety of agriculturally- and forestry-based systems. The model accepts long term daily climate data or single storm event data. An auxiliary climate generator program, CLIGEN (Nicks and Lane 1989), creates long term climate files if meteorological data are not available.

There are numerous other physically-based models that have been proposed in the literature. Wicks and Bathurst (1996) developed a physically-based, spatially distributed erosion and sediment yield model called SHESED. The model is capable of simulating surface erosion as well as channel processes.

Parsons et al. (2001) examined agricultural non-point source water quality models including AGNPS, ANNIE/WDM, BLTM, CREAMS, EPIC, and others. Based on a number of previous limited evaluation studies conducted by others, they also compiled tables of model characteristics such as event or continuous simulation, spatial scale, computational time step, target audience, physiographic validation, user interface, hydrologic features, chemical transport, snowmelt, erosion, economics, and documentation.

Wheater et al. (1993) developed a classification system describing the process representation of the model as empirical, conceptual or physical-based. Merritt et al. (2003) used that system to review a range of models shown in Table 5 that explicitly consider sediment and sediment-associated pollutants. In addition to reviewing input requirements, output, and limitations, this review included a summary indicating which models included land surface sediment generation, transport, and deposition as well as rainfall-runoff processes and stream sediment generation, transport, and deposition.

Table 5. Summary of erosion and sediment transport models.

Model	Type	Scale	Reference
Water Quality:			
AGNPS	Conceptual	Small catchments	Young et al. 1987
ANSWERS	Physical	Small catchments	Beasley et al. 1980
CREAMS	Physical	Field (40-300 ha)	Knisel 1980
EMSS	Conceptual	Catchment	Vertessey et al. 2001
HSPF	Conceptual	Catchment	Johanson et al. 1980
IHACRES-WQ	Empirical-Conceptual	Catchment	Jakeman et al. 1990
IQQM	Conceptual	Catchment	DLWC 1995
LASCAM	Conceptual	Catchment	Viney and Sivalapan 1999
SWRRB	Conceptual	Catchment	
Erosion:			
GUEST	Physical	Plot	Yu et al. 1997
LISEM	Physical	Small catchment	Rose et al. 1997
PERFECT	Physical	Field	Littleboy et al. 1992b
SEDNET	Empirical/conceptual	Catchment	Prosser et al. 2001c
TOPOG	Physical	Hillslope	
USLE	Empirical	Hillslope	Wischmeier and Smith 1978
WEPP	Physical	Hillslope/catchment	Laflen et al. 1991
Stream Transport:			
MIKE-11	Physical	Catchment	Hanley et al. 1998

The Merritt et al. (2003) review clearly stated that computer technology has led to an explosion of models and that covering every model was not feasible. Kalin and Hantush (2003) conducted a cursory review of numerous sediment models for TMDL BMPs including SWAT and ANNAGNPS before focusing comparison efforts on a kinematic erosion (KINEROS-2) model (Smith et al. 1995) and a WMS-adapted gridded surface subsurface hydrologic analysis (GSSHA) model (Downer and Ogden 2002).

Aksoy and Kavvas (2005) conducted a review of hillslope and watershed scale erosion and sediment transport models. While some models overlapped those in the Merritt et al. (2003) study, their review also included the empirical model SEDD and physically-based models EUROSEM, KINEROS, WESP, CASC2D-SED, SEM, and SHESED (Wicks and Bathurst 1996). Even this is not an exhaustive list of models. Models such as LISEM (Hessel et al. 2003) report promise with respect to erosion and transport prediction but lack sufficient use to gauge the applicability of the model to watershed scale approaches.

Streambank and Streambed Erosion Models:

The location, timing, and magnitude of streambank erosion are difficult to predict. USDA researchers at the National Sedimentation Laboratory developed a channel evolution model referred to as CONCEPTS (conservational channel evolution and pollutant transport system) (Langendoen and Simon 2008) in response. The resistance of fine-grained materials to hydraulic and geotechnical erosion, the impact of pore-water pressures on failure dimensions and shearing resistance, and the role of riparian vegetation on matric suction, streambank permeability, and shearing resistance are used in CONCEPTS. The model was calibrated and tested using five years of data from Mississippi where the top-bank widened by over 11 feet. This may be typical of streams in the south and Midwest where streambanks have reportedly contributed as much as 80% of the total suspended load, but few examples of this rapid bank retreat exist here in the Pacific Northwest. Consequently, the data sets necessary to locally calibrate the CONCEPTS model do not exist and using the model without calibration would likely lead to significant errors in prediction due to parameter uncertainty.

Consider only the uncertainty in the resistance of fine-grained materials to hydraulic and geotechnical erosion component (commonly referred to as bed shear stress). There are many ways to estimate the critical shear stress found in the literature. Clark and Wynn (2007) compared field measurements of critical shear stress to Shield's Diagram and several empirical methods and found results were different by as much as four orders of magnitude. Similarly, we examined a number of critical bed shear stress relationships. Theories developed for bed shear velocity and bed shear stress estimation are based on specific assumptions such as flow condition (e.g. laminar/turbulent flow, depth of water etc.), particle size of bed load, velocity distribution, and channel roughness (Kim et al. 2000). These theories can be grouped into three categories: (1) first-order moment statistics methods (mean)including the log profile (LP) method, average shear velocity method and quadratic stress law method; (2) second-order moment statistics (variance) including the Turbulent Kinetic Energy (TKE) method or Covariance (COV) method (also known as Reynolds stress method); and (3) spectral analysis methods such as the Inertial Dissipation (ID) method (Kim et al. 2000; Pope et al. 2006; Westenbroek, 2006).

The effect of methodology on critical shear stress using five different sizes of sand particles was examined by Rashid (2010). The particle size characteristics of these five different types of sediment are described in Table 6. These sand sizes are typical of the sand fractions found in the lower Snake River study area. Shear stresses were estimated using Shields' (1936), Log-profile (LP), Prandtl's, Turbulent Kinetic Energy (TKE), Reynolds stress (RS) method, and an equation proposed by Kim et al. (2000). Results of these analyses are shown in Table 7. As indicated, results can vary by an order of magnitude depending on approach. Local calibration of models is therefore essential.

Table 6. Physical properties of test sands.

Name of the sand type	Passed through (Sieve # - Opening in mm)	Retained at (Sieve # - Opening in mm)	Nominal size (mm)
A	20 - 0.850	25 - 0.710	0.780
B	25 - 0.710	40 - 0.425	0.567
C	40 - 0.425	50 - 0.300	0.360
D	60 – 0.250	80 – 0.180	0.215
E	100 – 0.150	200 – 0.075	0.113

Table 7. Critical bed shear stress for different sizes of sand particles.

Sand Type	Particle Size mm	Shields' N/m^2	LP N/m^2	Prandtl N/m^2	TKE N/m^2	Reynolds N/m^2	Kim et al. N/m^2
A	0.780	0.0425	0.1147	0.2786	0.1064	0.1355	0.0455
B	0.567	0.0300	0.0927	0.2252	0.0683	0.1035	0.0419
C	0.360	0.0208	0.0655	0.1992	0.0465	0.0758	0.0346
D	0.215	0.0180	0.0358	0.1623	0.0257	0.0308	0.0112
E	0.128	0.0149	0.0591	0.1715	0.0397	0.0686	0.0298

As in all sediment prediction phases, there is considerable uncertainty in streambed erosion calculations. Relatively small-scale phenomenon can have large impacts. For example, Smith et al. (2006) found a four-fold increase in bedload transport at bankfull discharge when large woody debris was removed previously stored upslope of debris buttresses or in low-energy hydraulic environments. Beck (1987) identified sources of inaccuracy due to: errors of aggregation, numerical errors of solution, errors of model structure, uncertainty due to unobserved system input disturbances (natural variability), and measurement errors associated with observed input and output field data.

Sediment Fate and Transport Models (Stream Transport):

Sediment transport models are available from a number of sources depending on the data set being used to calibrate and validate the model output. The two leading classes of river erosion models are detachment-limited and transport-limited (Tucker and Whipple, 2002). Models range from 1-dimensional analyses such as HEC-HMS (USACE model), 2-dimensional models such as SED2D, and 3-dimension models such as EFDC. The driving mechanisms within each type of model can be very different and most require significant calibration over a range of flow rates in order to produce reasonable results.

Three sediment transport modeling packages called CCHE1D, CCHE2D, and CCHE3D are in various stages of development by the National Center for Computational Hydroscience and Engineering at the University of Mississippi. CCHE1D uses a one-dimensional, non-equilibrium approach for the total-load transport. Flow and sediment calculations are initially decoupled but a coupled procedure is adopted in the sediment module to simultaneously solve the nonuniform sediment transport, bed change and bed material sorting equations. The sediment transport capacity is determined by four formulas: 1) Wu et al.’s (2000) formula, 2) the SEDTRA module (Garbrecht et al. 1995), 3) the modified Ackers and White equation (Proffit and Sutherland 1983), and 4) the modified Engelund and Hansen’s formula (Wu and Vieira 2002).

CCHE2D model is a depth-averaged two-dimensional (2D) model for flow and sediment transport in rivers. It has two versions, one based on the Efficient Element Method (EEM) and the second based on the Finite Volume Method (FVM). The EEM-based version adopts the fully decoupled procedure for flow and sediment transport, while the FVM-based version adopts the semi-coupled procedure similar to that used in CCHE1D model. The FVM-based CCHE2D model is capable of simulating the mophodynamic processes in vegetated open channels, and the salinity and cohesive sediment transport in river estuaries. In both versions, the nonuniform total-load transport is simulated using the non-equilibrium approach. Sediment transport capacity can be determined by van Rijn’s (1984) formula, Wu et al.’s (2000) formula, the SEDTRA module (Garbrecht et al. 1995), the modified Ackers and White’s formula (Proffit and Sutherland 1983), or the modified Engelund and Hansen's formula (Wu and Vieira 2002). The effect of secondary flow on the main flow and sediment transport in curved channels has also been considered in both versions. An enhanced version of the CCHE2D model was created to study alluvial channel migration by Duan et al. (2001).

CCHE3D simulates open-channel flows using the hydrostatic pressure assumption or solving the full Navier-Stokes equations. The CCHE3D sediment transport model is capable of computing general channel aggradation and degradation, local scour around hydraulic structures, sediment transport near water intake facilities, and other complex phenomenon.

3.4 Estimation of Sediment Yields from Agricultural Watersheds

Soil erosion was estimated for all agricultural watersheds using the GIS-based RUSLE modeling approach. This is the currently accepted approach for estimating long term soil erosion from agricultural areas by the USDA-Natural Resource Conservation Service. One of the most widely used watershed models, Soil Water Assessment Tool (SWAT), is based fundamentally on the RUSLE approach. The most recent version of the RUSLE approach is RUSLE2. RUSLE2 has improved physically-based algorithms for tracking soil residue and organic matter changes for a wide range of tillage practices. Rather than relying on empirical C factors, developers created a user-friendly interface to more directly capture changes in the residue cover for specific tillage operations. Crop residue build-up and decay is directly related to tillage and crop yields. Although RUSLE2 provides a more detailed assessment of effects of conservations practices on soil erosion from specific hillslopes, it has not been developed to be applied to large watersheds. The SWAT model can be applied to large regions, however soil erosion prediction has been linked to event based runoff predictions following the MUSLE adaptation of the USLE approach. Unfortunately the runoff prediction in the SWAT model is based on the SCS-Curve Number approach which has not been fully adopted or developed for the low-intensity rainfall event characteristics of the Pacific Northwest. In this analysis we have chosen to use a GIS-based RUSLE analysis which has been used successfully to estimate soil erosion for several watersheds in the Clearwater basin (see Boll et al. 2001 and IDEQ 2003) as a large-scale, Tier II screening approach and we have used the RUSLE2 and WEPP models as more detailed hillslope-scale Tier I assessments at specific locations in the basins later in this report.

Tier I Hillslope-scale Assessment

One of the greatest challenges in conducting watershed-scale soil erosion models is identifying the type of tillage practices being used in each watershed. Fortunately a recent study was conducted by Kok et al. (2009) where farmer interviews and interviews with scientists from the NRCS were used to identify current tillage practices and identify how farming practices have changed over the last thirty years. Drive-by windshield surveys were also conducted throughout the Palouse region to quantify the percent of farmers who have adopted no-tillage, reduced tillage, and conventional tillage practices. With this information Kok et al. (2009) was able to use the RUSLE2 model to conduct a Tier I assessment of the impact of current conservation practices on soil erosion throughout the region. Soil erosion rates were simulated using RUSLE2 for typical farming practices from 1975, 1990, and 2005 in the high, intermediate, and low precipitation zones of the dryland wheat farming regions of Washington, Oregon, and Idaho. One of the most important contributions of the Kok et al. (2009) study was developing a record of specific tillage practices for each of the precipitation zones and estimating the percentage of farmers in the region which followed a specific tillage practice. Simulated erosion rates for specific suites of tillage practices were weighted using estimates of the percent of the area that the particular practice had been applied to provide an average erosion rate for each precipitation zone.

The RUSLE2 analysis performed by Kok et al. (2009) showed significant reductions in overall sediment load within each precipitation zones. The analysis showed that erosion rates were reduced by one half in the high and intermediate zones from 1975 to 1990 as a result of the increased adoption of conservation tillage on more than half the land. Similarly soil erosion reduced by another 50% between 1990 and 2005 in the intermediate and high precipitation zones. In total the analysis showed a 75% reduction in soil erosion in the intermediate and high precipitation zones from 1975 to 2005. Reductions in the low precipitation zones were not as high showing a 50% decrease in erosion from 1975 to 2005. Kok et al. (2009) attributed the decrease in soil erosion to the following major changes:

1.) Decrease in the use of the moldboard plow
2.) Decrease in the number of tillage operations from 6-7 passes to 2-5 passes
3.) Decrease in the practice of burning stubble
4.) Increase in wheat yields yielding more residue
5.) Increase soil organic matter and surface residue cover
6.) Decrease in the use of summer fallow in the high precipitation zone
7.) Increase in conservation tillage, including no-till
8.) Conversion of most erodible land to the Conservation Reserve Program (CRP).

Although there has been wide-spread adoption of conservation or ‘reduced’ tillage practices throughout the region, no-till farming has not been widely adopted. Kok et al. (2009) estimated using drive-by windshield surveys and interviews that as of 2005 no-till was only being practiced on 10% of the land in both the high and intermediate precipitation zones.

Interviews with growers indicate that problems with excessive surface residues and weed control have limited the full adoption of no-till. The Kok et al. (2009) RUSLE2 analysis indicates that current soil erosion rates could decrease by 50% or more if no-till practices were widely adopted in all three precipitation zones.

Tier II Assessment GIS-Based RUSLE

Although at the hillslope-scale, a Tier I analysis provides a detailed assessment of specific tillage practices, it is impractical to apply this approach to large basins. A GIS-based RUSLE approach was used to estimate 30 m resolution erosion rates for large watersheds (see Fernandez et al. 2003; IDEQ 2003; Boll et al. 2001; Mitasova et al. 1996). The input requirements for this approach are a digital elevation model (DEM), 30 year average precipitation map, soil survey map with associated NRCS database, a land cover map, and a map delineating crop rotations and tillage practices.

L and S factors

The slope length (L) and slope steepness (S) factor are calculated directly from the DEM using the following equations:

$$L = (m + 1)\left[\frac{A * d_{xy}}{22.13}\right]^{0.5} \qquad (1)$$

$$S = \left[\frac{sin(b)}{0.0896}\right]^{0.6} \quad \text{for slopes} \geq 9\% \qquad (2)$$

$$S = 10.8 sin(b) + 0.03 \quad \text{for slopes} < 9\% \qquad (3)$$

where m is a constant equal to 0.5, A is the upslope contributing area (number of cells including current cell), d_{xy} is the resolution of GIS map (should be no greater than 30 m), and b is the land slope (radians).

Following the approach of Fernandez et al. (2003) and recommendations by Renard et al. (1997) the upslope contributing area was limited to 120 m slope length (i.e. an upslope contributing area of 4 cells using a 30 m resolution DEM). The S factor equations used in this study were derived by McCool et al. (1993), for soils that are thawing, in a weakened state, and subjected primarily to surface flow (Renard et al., 1997).

K factor

The soil erodibility or K factor in RUSLE characterizes both the susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. K factors were obtained from county level (1:20,000) NRCS Soil Survey Geographic (SSURGO) data, where available, and taken from the state level (1:250,000) Soil Geographic (STATSGO) database if county level SSURGO maps were unavailable.

R factor

The rainfall-runoff erosivity or R factor characterizes the effect of raindrop impact and the amount and rate of runoff likely to be associated with rain (Renard et al. 1997). McCool (2001) developed a unique relationship for the R factor in the Northwestern Wheat and Range Region (NWRR). In these dryland farming regions the effect of soil freezing results in much higher R factors than would normally be calculated using the low intensity characteristic rainfall patterns found in this climate. The R factor is calculated directly from mean annual precipitation using the following equation.

$$R = -48 + 0.306P_r \tag{4}$$

where P_r is the mean annual precipitation in mm. In this analysis, 800 m resolution Parameter-elevation Regressions on Independent Slopes Model (PRISM) maps representing the mean annual precipitation for 1971-2000 were used to calculate the R factor.

C and P factors

One of the most challenging issues in conducting watershed scale analysis of soil erosion is acquiring information on crop rotations and tillage practices. Although there are detailed land use maps that capture the distribution of specific crops over large areas using remote sensing images, there are few maps which identify the specific cropping rotation for each field. In order to address this problem the National Agricultural Statistics Service (NASS) has begun an effort in the last few years of acquiring 56 m resolution land use maps that delineate specific crops for the entire US. These maps are called Cropland Data Layers (CDL) and could potentially be used to identify future crop rotations.

Although accurate crop rotation maps could improve future erosion predictions, there are few maps which delineate the type of tillage practices that are being used by the growers in the region. Since erosion prediction is highly sensitive to crop type and tillage type the accuracy of any erosion model is limited by how accurately the cropping and tillage practices are represented.

In this study we used the Kok et al. (2009) study to develop cropland (C Factor) and tillage practice (P Factor) maps for the NWRR. As described by Kok et al. (2009) dryland farming practices can be roughly lumped into precipitation zones: low (< 15 inches), intermediate (> 15 in and < 19 in), and high (> 19 inches). Growers in the low precipitation zone must use summer fallow to retain enough soil moisture to grow wheat every other year or every third year, depending upon the grower. Some growers in the intermediate zone still practice summer fallow, however summer fallowing is not required in the high precipitation zone. Crop yields are highest in the high precipitation zone which results in high surface residue after harvest.

Since the Kok et al. (2009) analysis used the RUSLE2 model which internally corrects for the effect of crop rotation and tillage practice on erosion, C factors were not calculated or supplied in the paper. The C factors for each suite of tillage operations were calculated by inverting RUSLE equation and solving for the C factor using the predicted erosion rate provided by the RUSLE2 analysis, see equations 5 and 6 below.

$$A = RKLSCP \tag{5}$$

$$C = \frac{A}{RKLSP} \tag{6}$$

where A is the average annual soil erosion in tons/ac/yr.

The R, K, L, and S factors were set to typical values for hillslopes in each region. The P factor was set to 0.91 following the recommendations of Fernandez et al (2003) and Boll et al (2001) which assumes farmers generally till on the contour rather than up and down the slope. Table 4 shows the equivalent C factors calculated for each cropping practice described by Kok et al. (2009). The weighted average C factor was calculated using the estimated percentage of each region using a specific cropping practice. As expected the C factors for each region are higher in 2005 than in 1975 as a result of the increased adoption of conservation practices.

Table 8. Equivalent C factors calculated cropping practices described by Kok et al. (2009).

Precip Zone	Year	Description	Percent Used	Erosion tons/ac	C factor
High	1975	Conventional Till H-1a	60	15.2	0.117
		Conventional Till H-1b	20	21.4	0.165
		Conventional Till H-1c	20	17.8	0.138
		Weighted Average		**17.6**	**0.136**
	1990	Conventional Till H-2a	50	13.4	0.103
		Reduced Till H-2b	35	5.4	0.041
		Reduced Till H-2c	15	6.7	0.052
		Weighted Average		**9.1**	**0.071**
	2005	Conventional Till H-3a	40	7.8	0.060
		Reduced Till H-3b	50	2.2	0.017
		No Till H-3c	10	0.9	0.007
		Weighted Average		**4.5**	**0.034**
Intermediate	1975	Conventional Till I-1a	80	12.0	0.104
		Conventional Till I-1b	10	12.9	0.112
		Conventional Till I-1c	10	14.9	0.129
		Weighted Average		**12.5**	**0.108**
	1990	Conventional Till I-2a	20	9.8	0.085
		Conventional Till I-2b	10	12.9	0.112
		Reduced Till I-2c	50	4.9	0.043
		Reduced Till I-2d	20	3.1	0.027
		Weighted Average		**6.2**	**0.054**
	2005	Reduced Till I-3a	30	1.8	0.015
		Reduced Till I-3b	50	4.0	0.035
		Reduced Till I-3c	10	4.5	0.039
		No Till I-3d	10	0.9	0.008
		Weighted Average		**3.1**	**0.027**
Low	1975	Conventional Till L-1a	75	8.9	0.111
		Conventional Till L-1b	25	8.7	0.108
		Weighted Average		**9.1**	**0.114**
	1990	Conventional Till L-2a	75	6.2	0.078
		Conventional Till L-2b	25	7.6	0.095
		Weighted Average		**6.2**	**0.078**
	2005	Conventional Till L-3a	75	5.4	0.067
		Reduced Till L-3b	15	2.5	0.031
		Reduced Till L-3c	10	1.8	0.022
		Weighted Average		**4.9**	**0.061**

Results

The GIS-based RUSLE model was applied to 14 watersheds within the Lower Snake River Basin, see Figure 13. The distribution of major land use classes is provided in Figure 14. This map was created from the 2009 NASS Cropland Data Layer. All forested, perennial grass, and scabland areas were excluded from the RUSLE analysis. It was assumed that all grassland would remain as a perennial grass. It is possible that some of this grassland may be farmed again in the future if the CRP contract is not renewed. Figure 15 shows the distribution of the K-factor within each of the study watersheds and Figure 16 shows the distribution of the mean annual precipitation for the region as defined by PRISM. Figure 17 shows the 30 m resolution average annual erosion map calculated using the weighted average C-factors for each precipitation zone as described in the previous section. As seen in Figure 17 the highest erosion rates tend to occur from agricultural areas located in the high precipitation zones (e.g. Clearwater watershed). Most of the average annual erosion rates are less 3 tons/ac in the western regions of the study area. Table 9 provides a summary of the predicted erosion by watershed. Figure 18 and Figure 19 provide a graphical distribution of the average erosion in million tons/year from each watershed and average annual erosion rates in tons/ac within each watershed. Although the RUSLE model predicted that the Palouse watershed contributes highest total erosion, both the Clearwater and Lower Snake-Tucannon watersheds have higher simulated erosion rates. Interestingly the highest erosion rates were predicted for the Little Salmon and Hell’s Canyon watershed however according to the land use map each of these watersheds contain less than 1 square mile of actively farmed agriculture area. Likely the little agricultural areas in this region have been improperly classified by the land use map.

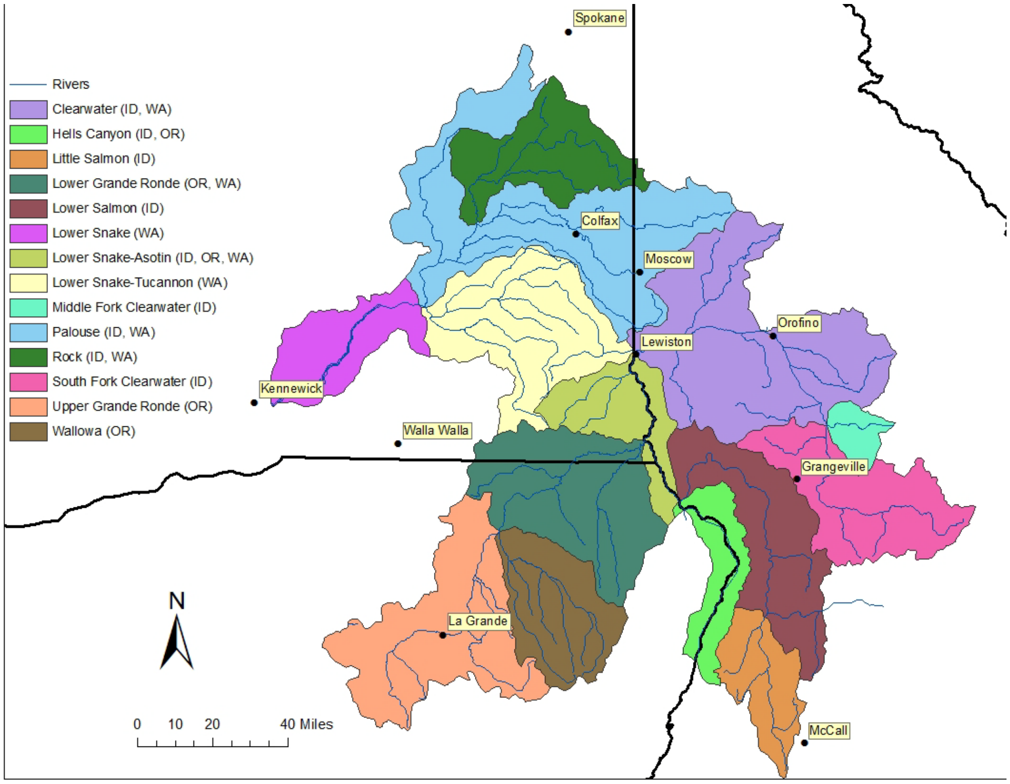


Figure 13. Agricultural watersheds within the Snake River Basin.

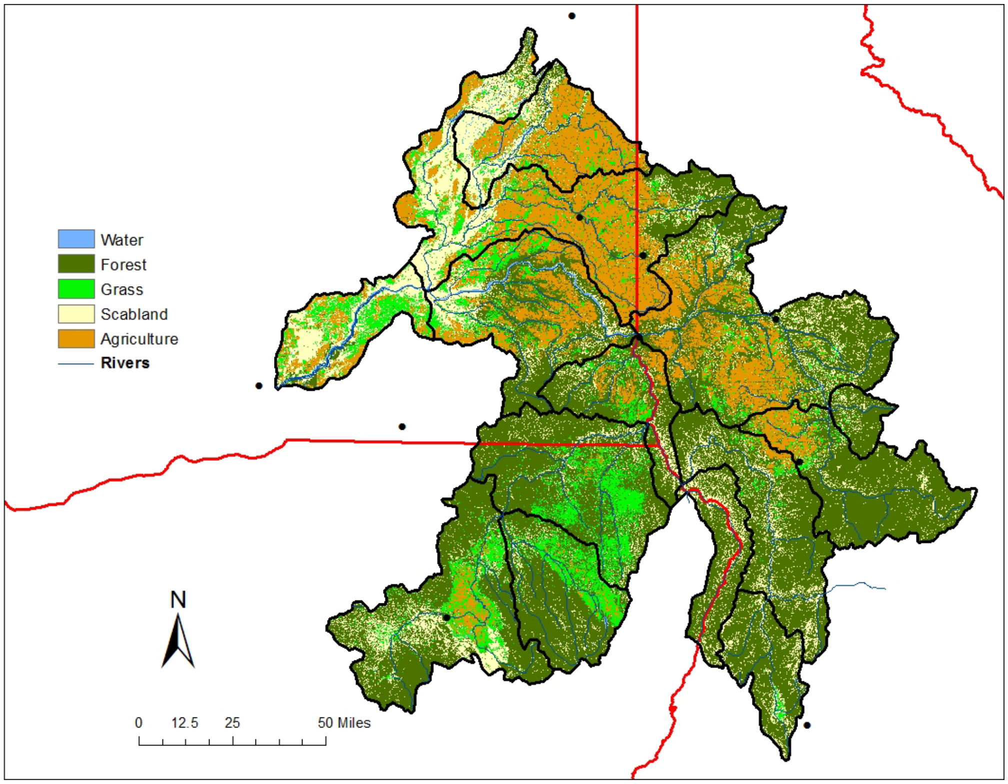


Figure 14. Distribution of major land uses within the study area.

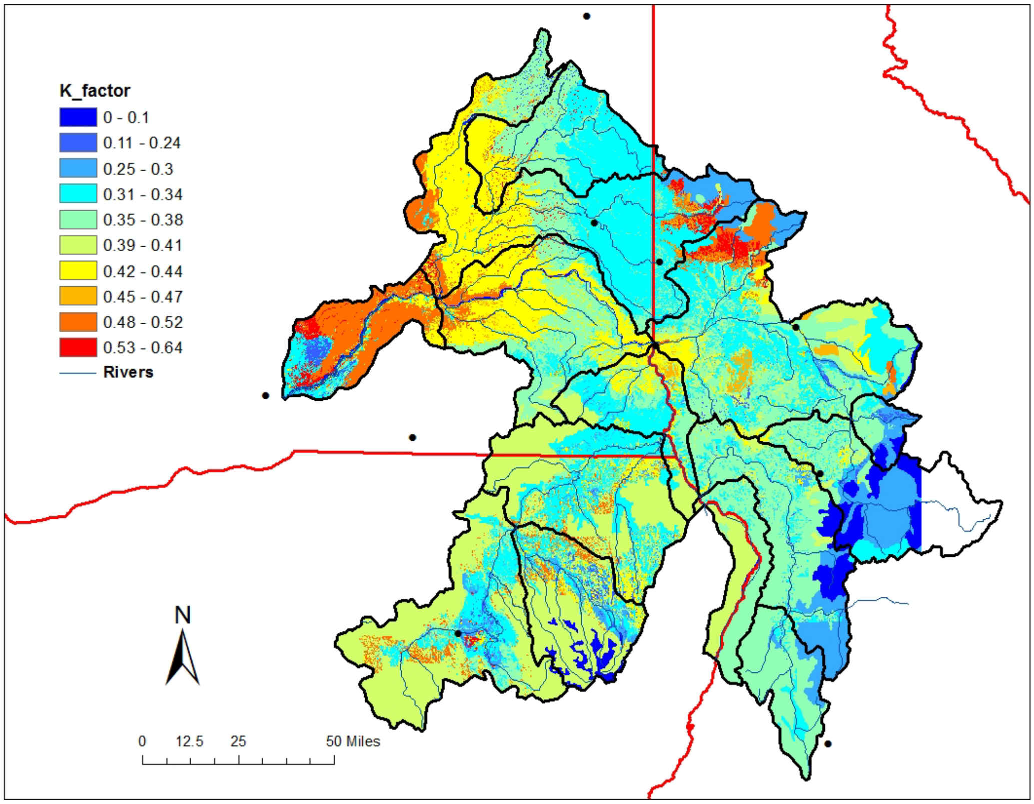


Figure 15. K-factor map developed from SSUGO and STATSGO databases.

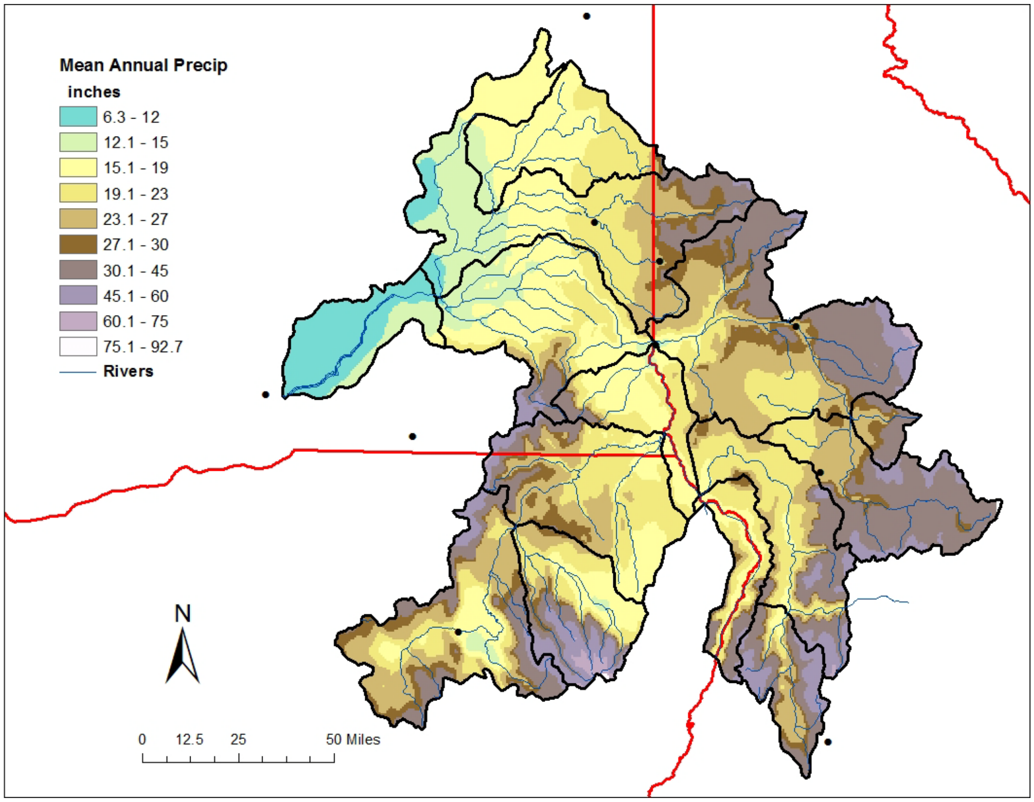


Figure 16. Mean annual precipitation (1971-2000) within the study area.

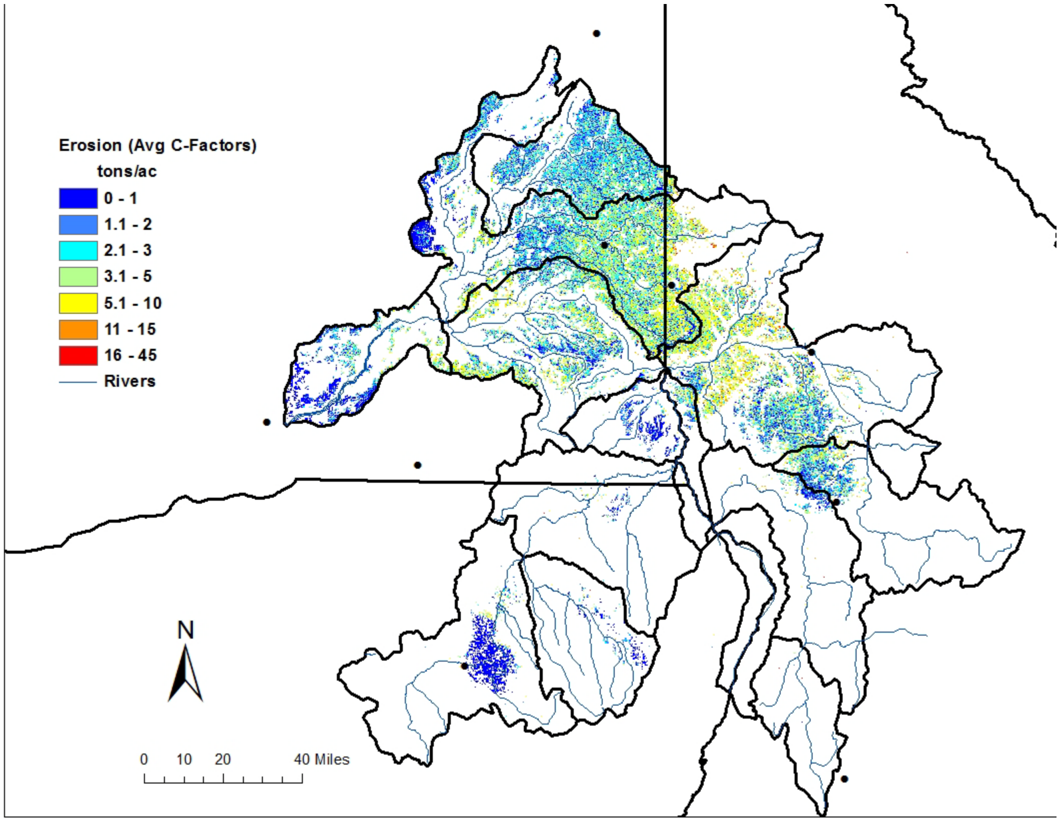


Figure 17. Average erosion rates (tons/ac) from agricultural areas within the study area.

Table 9. Average erosion rates and total erosion within each major watershed in the study area.

Name	**HUC ID**	**Area (mi^2)**	**Pct Ag. Area**	**Avg. Erosion (tons/ac/yr)**	**Erosion (Million tons/yr)**
Palouse (ID, WA)	17060108	2351	43.8%	3.3	2.17
Clearwater (ID, WA)	17060306	2319	25.6%	4.1	1.58
Lower Snake-Tucannon (WA)	17060107	1461	28.6%	3.4	0.91
Rock (ID, WA)	17060109	973	53.3%	2.5	0.84
South Fork Clearwater (ID)	17060305	1174	10.4%	2.8	0.22
Lower Snake (WA)	17060110	734	22.5%	1.9	0.20
Lower Snake-Asotin (ID, WA, OR)	17060103	713	11.5%	1.9	0.10
Lower Salmon (ID)	17060209	1232	3.0%	2.2	0.05
Upper Grande Ronde (OR)	17060104	1636	6.1%	0.8	0.05
Wallowa (OR)	17060105	935	2.2%	1.3	0.02
Lower Grande Ronde (OR, WA)	17060106	1506	0.7%	2.2	0.02
Little Salmon (ID)	17060210	589	0.1%	12.4	0.00
Middle Fork Clearwater (ID)	17060304	204	0.3%	4.7	0.00
Hells Canyon (ID, OR)	17060101	532	0.1%	7.5	0.00

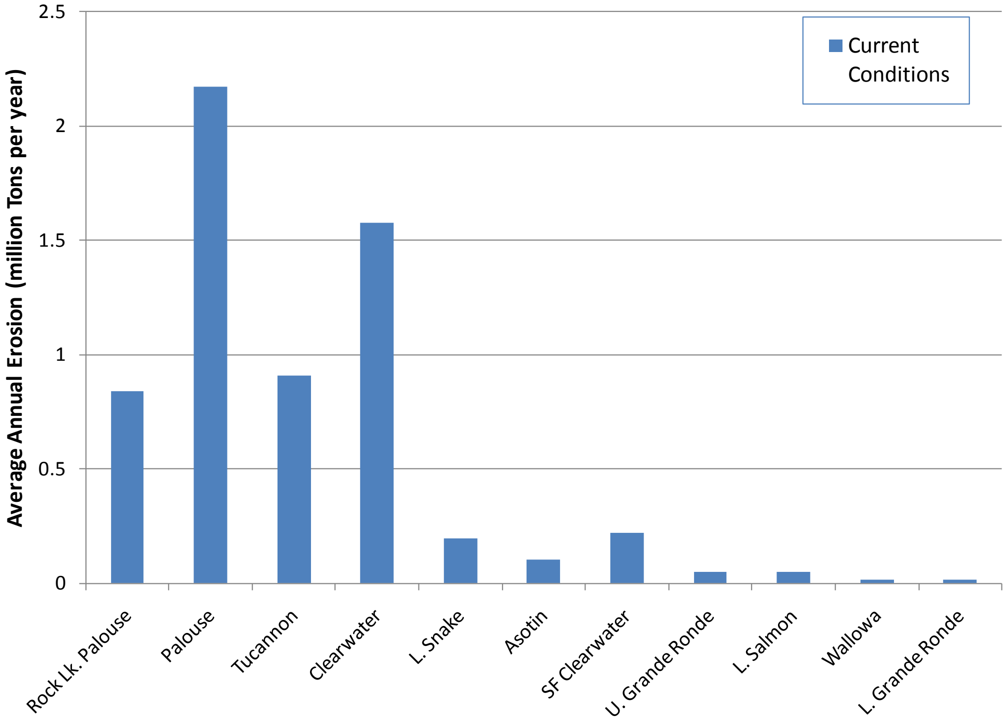


Figure 18. Average erosion (million tons per year) from agricultural areas within each watershed for current farming practices.

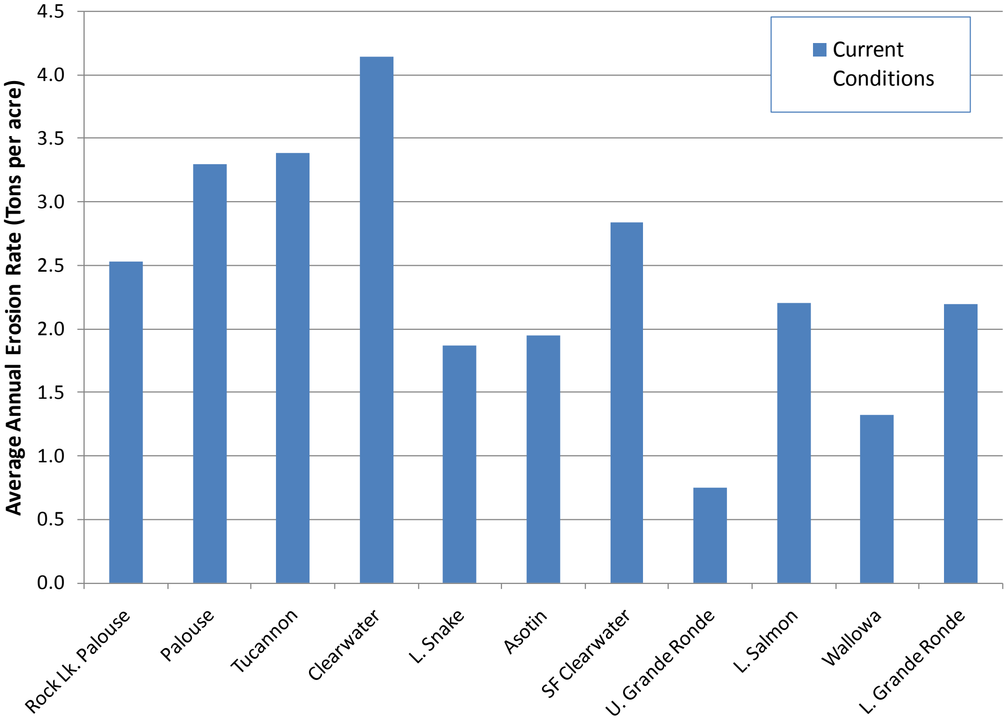


Figure 19. Average erosion rates (tons/ac/year) from agricultural areas within each watershed for current farming practices.

As a means of comparison the RUSLE model was used to predict soil for three hypothetical scenarios. Figure 20 and Figure 21 indicate the change in overall soil erosion if the entire agricultural area within each basin were farmed using conventional, reduced, and no till practices. The C-factors for this analysis were taken from the individual cropping scenarios for each precipitation zone as described by Kok et al. (2009), see Table 8. Similar to the Kok et al. (2009) study the high and intermediate precipitation zones are more sensitive to type of tillage practice than the low precipitation zones. Full adoption of no-tillage practices would drop the overall sediment load by 75% or more.

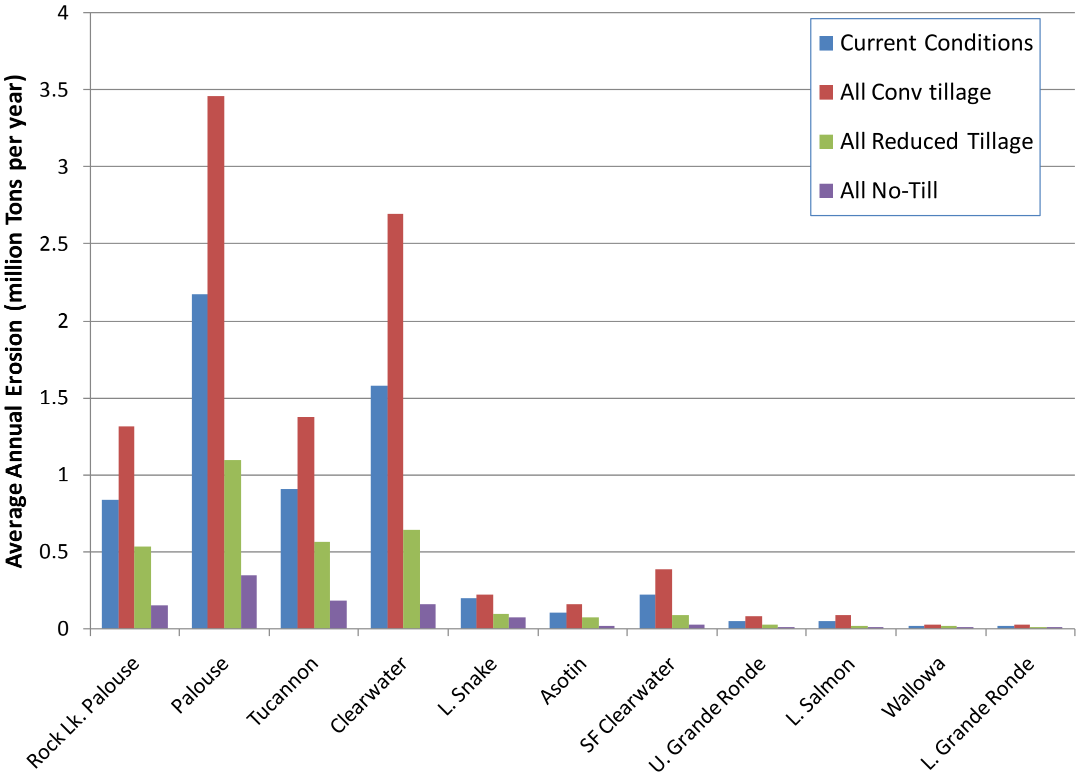


Figure 20. Comparison of average erosion (million tons per year) from agricultural areas within each watershed under current conditions versus a condition where all agricultural and was farmed using conventional, reduced, and no-till practices, respectively.

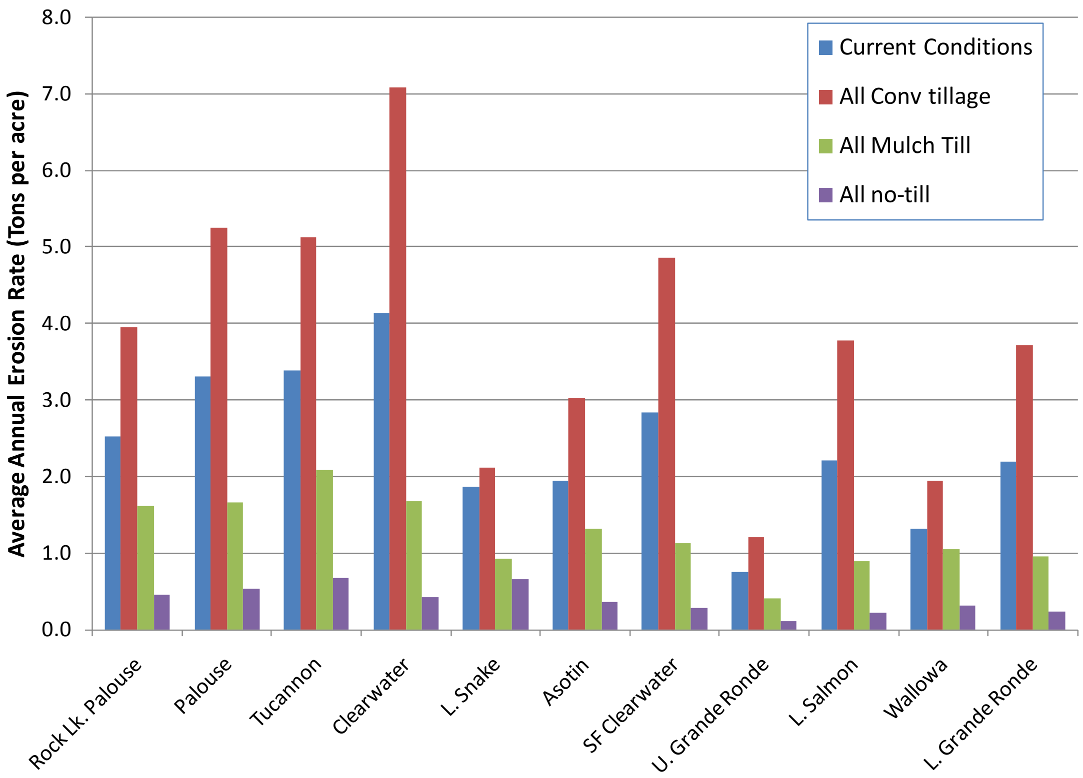


Figure 21. Comparison of average erosion rates (tons per acre per year) from agricultural areas within each watershed under current conditions versus a condition where all agricultural and was farmed using conventional, reduced, and no-till practices, respectively.

Sediment Yield

Since the primary interest of this project is to estimate sediment loading to the Lower Snake River Dams rather than gross erosion rates on the hillslopes, the total erosion predictions from the RUSLE approach were corrected to account for deposition and storage of sediment between the hillslope and watershed outlet. The standard approach for estimating the sediment yield uses a sediment delivery ratio (SDR). Vanoni (1975) developed an empirical relationship which related the SDR calculated from observed data across the US to watershed area. This relationship was described by the following equation.

$$SDR = 0.003567[\ln(A_{ws})]^2 - 0.060465[\ln(A_{ws})] + 0.295745 \quad (7)$$

where A_{ws} is the watershed area in square miles.

The sediment delivery ratio and sediment yield for each of the agricultural watersheds in the Lower Snake River Basin are presented in Table 10. It should be noted that the relationship developed by Vanoni (1975) was based on watershed ranging in size from 1 square mile to 300 square miles. The relationship between watershed area and SDR was assumed to be applicable to much larger watersheds in this study. Further research would be necessary to confirm this assumption.

Table 10. Sediment yield predicted for all watersheds using the sediment delivery ratio (Vanoni, 1975).

Name	HUC ID	Area (mi^2)	Erosion (Million tons/yr)	SDR	Sed Yield (Million tons/yr)
Palouse (ID, WA)	17060108	2351	2.17	0.041	0.09
Clearwater (ID, WA)	17060306	2319	1.58	0.041	0.07
Lower Snake-Tucannon (WA)	17060107	1461	0.91	0.045	0.04
Rock (ID, WA)	17060109	973	0.84	0.049	0.04
South Fork Clearwater (ID)	17060305	1174	0.22	0.047	0.01
Lower Snake (WA)	17060110	734	0.20	0.052	0.01
Lower Snake-Asotin (ID, WA, OR)	17060103	713	0.10	0.052	0.01
Lower Salmon (ID)	17060209	1232	0.05	0.046	0.00
Upper Grande Ronde (OR)	17060104	1636	0.05	0.044	0.00
Wallowa (OR)	17060105	935	0.02	0.049	0.00
Lower Grande Ronde (OR, WA)	17060106	1506	0.02	0.044	0.00
Little Salmon (ID)	17060210	589	0.00	0.055	0.00
Middle Fork Clearwater (ID)	17060304	204	0.00	0.075	0.00
Hells Canyon (ID, OR)	17060101	532	0.00	0.057	0.00

Validation to Observed Data

The decrease in soil erosion from the agricultural fields has lead to significant decreases in sediment load at the outlet of major rivers in the region, particularly in the Palouse region (see Brooks et al. 2010; Kok et al. 2009; McCool and Roe 2005; and Ebbert and Roe 1998). One of the longest records of flow and sediment concentration in the Palouse region has been acquired at a gage located on the Palouse River at Hooper, WA (USGS 13351000). Data from this gage has been used to document changes in sediment loading with time by Ebbert and Roe (1998). In order to update the Ebbert and Roe (1998) analysis we acquired streamflow and sediment concentration data for the Hooper gage and organized the data into three major time periods: 1961-1971, 1992-1997, and 1998-2010. Figure 22 shows the streamflow versus suspended sediment concentration as a log-log scatter plot. As seen in the figure, there is a noticeable shift in relationship between suspended sediment concentration and streamflow over time.

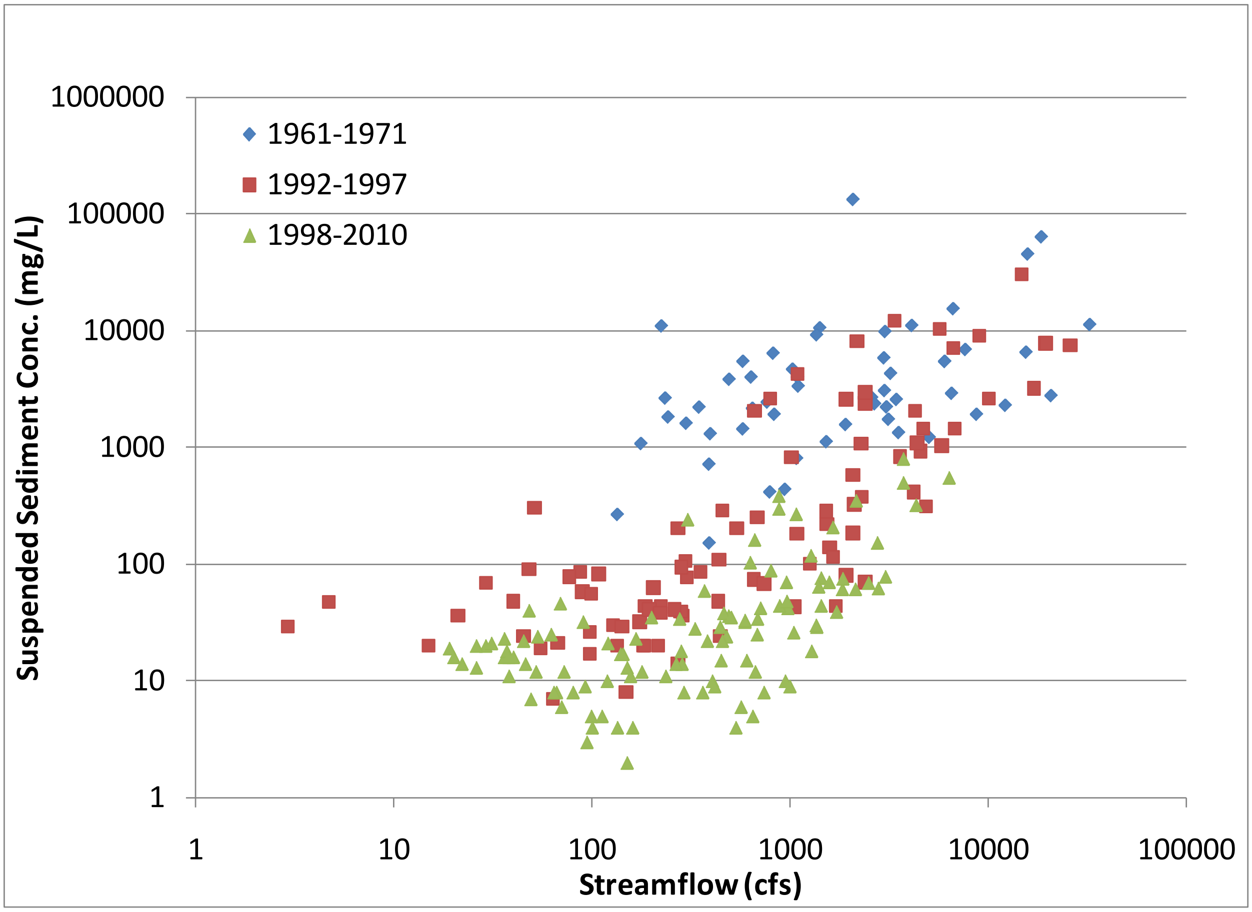


Figure 22. Observed streamflow versus observed suspended sediment concentration measured on the Palouse River at Hooper, WA.

Ebbert and Roe (1998) estimated that in average annual sediment load at the Hooper gage on the Palouse river from 1993-1996 was 1.4 tons/ac-ft. According to the streamflow data collected at the Hooper gage the average annual streamflow volume is 432,000 ac-ft/yr. This means that the average annual sediment load in the early 1990s was approximately 0.6 million tons per year. According to the analysis in this study the average annual sediment yield from the agricultural areas in the Palouse basin is currently 0.09 million tons of sediment per year. Assuming that the majority of the sediment derived from agricultural sources this implies that the sediment yield has decreased by 68% since the early 1990s. Although it is difficult to quantify, Figure 22 generally indicates there has been a 50% decrease in average sediment concentration over a wide range of observed streamflows at the Hooper gage since the early 1990s. Although the current sediment yield estimates are largely based on a extrapolated SDR values, the magnitude of sediment load estimated by the GIS-based RUSLE approach is roughly corroborated by the observed data at the Hooper gage.

Over the last 10 years sediment load has also been measured using detailed event-based water sampling in the Paradise creek watershed located near Moscow, ID in the high precipitation zone of the Palouse watershed. The average annual sediment load from 2002 to 2008 from this 19.9 sq. mil watershed was measured at 860 tons per year (Brooks et al. 2010). During this time nearly all farmers have been using reduced tillage practices. The predicted erosion rate for this watershed using the GIS-based RUSLE analysis is 8,800 tons per year. According to the Vanoni (1975) relationship the SDR for this watershed is 0.15. Multiplying the average annual erosion by the SDR results in an average annual sediment yield of 1320 tons per year. This predicted sediment yield value is roughly 50% over the sediment yield observed. This over-prediction could possibly be due to the fact that the 7 year average sediment yield does not include an extreme flood event. The RUSLE provides 30 year average erosion estimates and therefore would incorporate more extreme events. Brooks et al. (2010) also calculated sediment load for Paradise creek from three day per week grab samples taken at the outlet of the watershed from 1988 to the present. Using these data it was estimated that the extreme 1996 flood year carried 10,000 tons of sediment. By including this year in the analysis the average annual observed sediment yield is 1900 tons per year which is higher than the sediment yield predicted by the GIS-based RUSLE approach. From this analysis we feel confident that the sediment yield predictions provided by the GIS-based RUSLE approach are reasonable.

Particle Size Assessment

Of particular importance in this project is quantifying the relative sediment distribution of the soil delivered to the Lower Snake River Dams. Since the majority of the sediment deposited in the Snake River is sand it is particularly important to assess the fraction of sand delivered by each watershed to the Snake River from the agricultural areas. From basic erosion mechanics it is well understood that the larger particles (i.e. sands) have a faster settling velocity than the finer particles (i.e. clays and silts) and therefore sands will tend to deposit preferentially in a water column sooner than silts and clays. Hillslopes having a large toe slope will tend to have deposition which will result in an 'enrichment' in the proportion of silts and clays and a decrease in the proportion of sands. The proportion of sand in steep hillslopes which do not experience deposition should theoretically never be greater than the fraction of sand in the detached sediment. Knowing this it then it is reasonable to assume that the portion of sand in the eroded sediment will be no greater than the fraction of sand in the original soil. Using this assumption we estimated the maximum percent sand in the eroded sediment as the average sand content of the agricultural soils in the watershed. Figure 23 shows the distribution of percent sand in all the agricultural watersheds in the Lower Snake River Basin. Comparing Figure 23 with Figure 14 it is clear that the agricultural soils have a much lower sand content then the non-agricultural soils. Nearly all agricultural soils in the major contributed agricultural watersheds are composed of less than 20% sand. Figure 24 shows that the sand content of the surface soil horizons in all agricultural regions are less than the sand content for the non-agricultural regions. It is also important to remember that the sand content in these figures are for the surface soils. Most forested soils are covered with an ash layer and the soil horizons beneath this ash layer are typically much greater. Agricultural soils in the study area are typically much deeper and rather than the sand content increasing with depth, the clay content will more often increase with depth below the soil surface.

By assuming that the proportion of sand in the sediment delivered to the outlet does not decrease due to preferential deposition Table 11 shows the total sand delivered from agricultural areas from each of the major watersheds in the Lower Snake River Basin. As discussed above this is likely an over-estimate of the actual sand delivered to the outlet since the sand will tend to settle out more rapidly than the silt and clay as it moves to the watershed outlet. We estimated the likely over-prediction of sediment using the WEPP model at typical slopes within the low, intermediate, and high precipitation zones. The deposition of sediment is more likely on toe slopes below steep sections of the hillslope. We used the WEPP model to predict the erosion and deposition for a three piece hillslope where the upslope, mid slope and toe slope steepness were 5%, 35%, and 5% respectively. Each segment length was set at 328 ft (100 m). The 30 year simulation was based on a Palouse soil with a reduced tillage operation and a winter wheat, spring barley, pea rotation and a high precipitation climate (Moscow, ID). The sand content of the original soil was 9%. The sand content in the soil delivered to the outlet of the hillslope was reduced by half this at 5.4%. This reduction in sand content was similar for a range of soil types and cropping practices. Overall it is clear that the agricultural areas contribute mostly silts and clays to the Snake River.

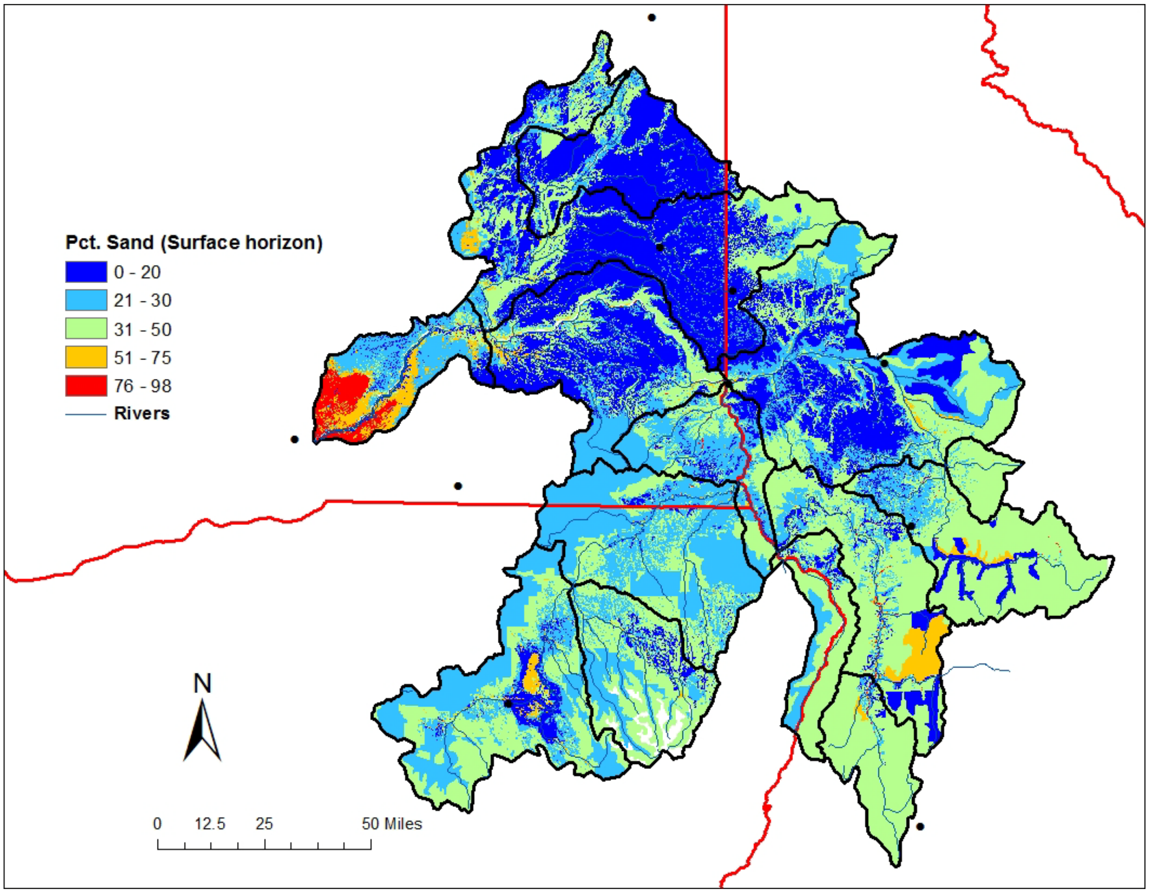


Figure 23. Percent sand content in the surface soil horizon taken from the SSURGO and STATSGO databases.

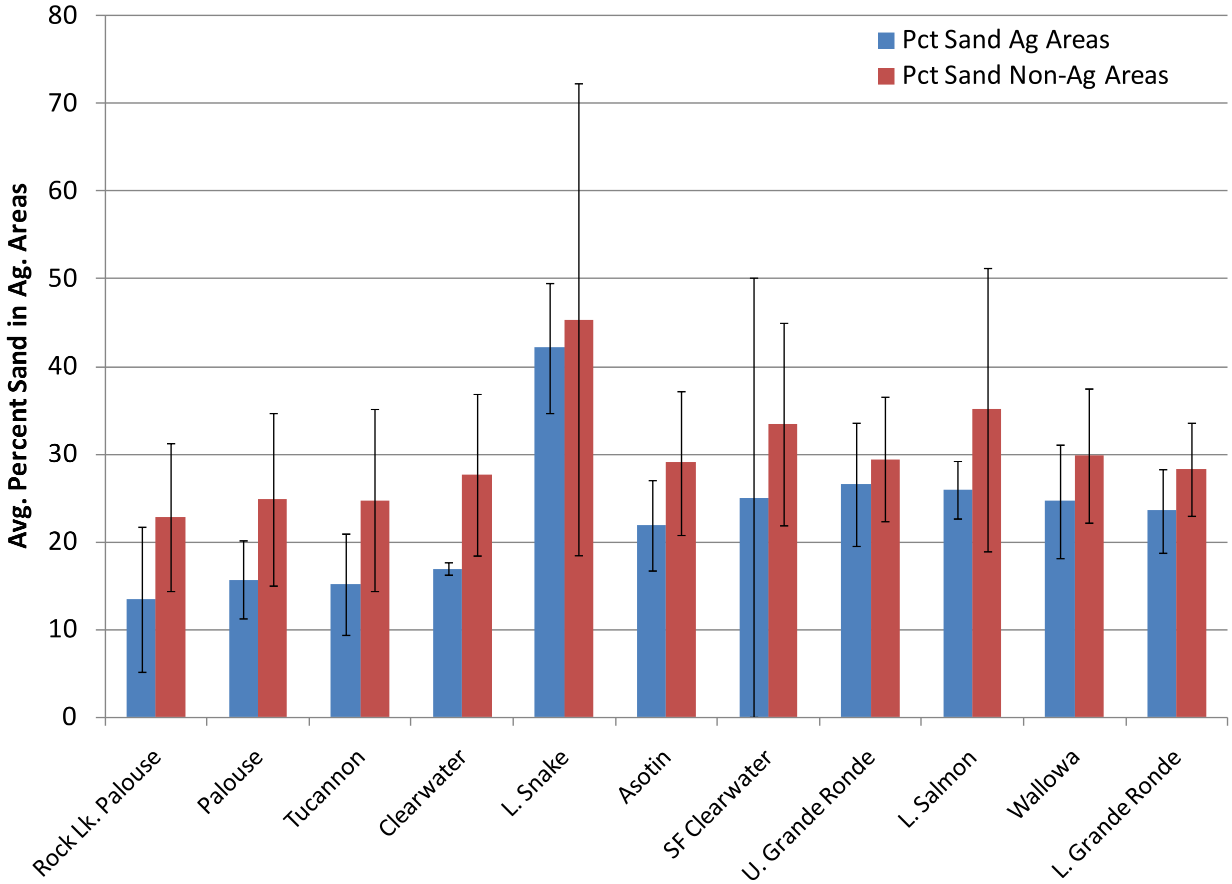


Figure 24. Average percent sand content of the surface soil horizon for both agricultural and non-agricultural areas of the major watersheds in the Lower Snake River Basin. Error bars on each column represent one standard deviation.

Table 11. Total sand delivered from agricultural areas. Note this numbers should be considered a maximum value since preferential deposition of sand is neglected.

Name	**HUC ID**	**Area (mi^2)**	**Total Sediment Yield (million tons/yr)**	**Mean % Sand**	**Total Sand (million tons/yr)**
Palouse (ID, WA)	17060108	2351	0.09	15.72	1.4E-02
Clearwater (ID, WA)	17060306	2319	0.07	16.93	1.1E-02
Lower Snake-Tucannon (WA)	17060107	1461	0.04	15.15	6.1E-03
Rock (ID, WA)	17060109	973	0.04	13.49	5.5E-03
South Fork Clearwater (ID)	17060305	1174	0.01	25.03	2.6E-03
Lower Snake (WA)	17060110	734	0.01	42.12	4.3E-03
Lower Snake-Asotin (ID, WA, OR)	17060103	713	0.01	21.86	1.2E-03
Lower Salmon (ID)	17060209	1232	0.00	25.98	6.2E-04
Upper Grande Ronde (OR)	17060104	1636	0.00	26.58	5.6E-04
Wallowa (OR)	17060105	935	0.00	24.69	2.1E-04
Lower Grande Ronde (OR, WA)	17060106	1506	0.00	23.55	1.6E-04
Little Salmon (ID)	17060210	589	0.00	35.19	5.3E-05
Middle Fork Clearwater (ID)	17060304	204	0.00	35.31	4.4E-05
Hells Canyon (ID, OR)	17060101	532	0.00	35.96	2.7E-05

3.5 Watersheds with Significant Sediment Yield Potential

Although considerable achievements have occurred with respect to implementing agricultural BMPs in the basin, Figure 25 and Figure 26 indicate there is more work to do. The upper panel in Figure 25 shows farming to the very edge of the waterway while Figure 26 shows a similar practice along a road-side ditch.

Figure 25. Examples of ongoing agricultural practices contributing to sediment delivery.

Figure 26. Ephemeral gullies leading to surface erosion connections to nearby waterway.

Table 11 in the previous section contained the amount of sand coming from each agricultural subbasin in the study area. Sand, by most standard definitions, has particle sizes ranging from 62.5 microns to 2,000 microns (2 mm). This is approximately equivalent to sieve designations of #230 (63 microns) and #10 (2 mm). In examining 24 sediment core samples from the confluence area of the Snake and Clearwater River collected by the USGS and provided to WSU by the USACE, it was found that on average, less than 7% of the soil was finer than a #200 sieve (75 microns). In other words, over 93% of the soil was classified as sand. In fact, approximately 64% could be classified as medium to coarse sand (retained on #70 sieve or larger). Given the relatively low % sand fractions and loads in Table 11, meaningful reduction in the sizes of materials settling in the pool may be difficult to achieve. Nevertheless, the next section of this report demonstrates how much erosion could be reduced even if the particles are finer than those of primary concern.

In terms of total sediment load, it appears that the Palouse is still the most significant contributor in terms of total load. This may be a concern downstream of the confluence in the lower Snake River basin but is not a concern to Lower Granite pool. The largest contributor to this segment is the Clearwater River basin (including the Potlatch and Lapwai subbasins). However the percent sand in this watershed is relatively low.

3.6 Evaluation of Agricultural Sediment Reduction Measures

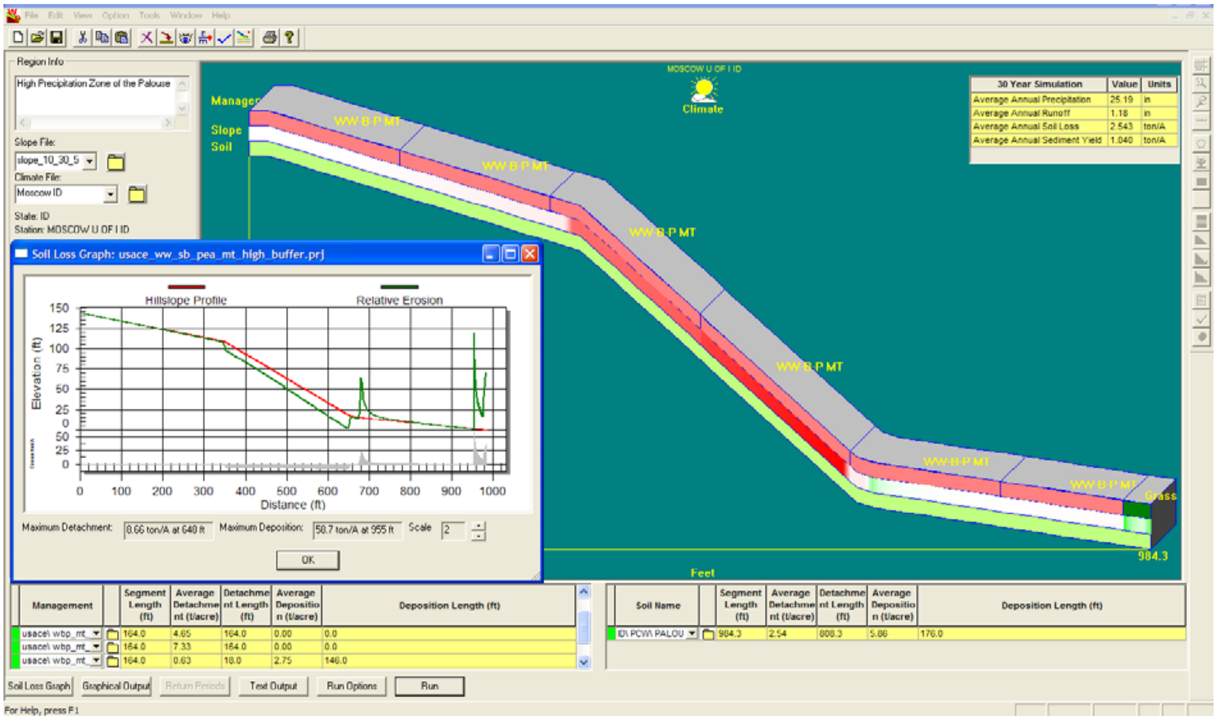
Adoption of even modest practices such as that shown in Figure 27 will help reduce erosion and delivery of fine sediments in the study area. Wider adoption of no-till (or direct seeding) as illustrated in Figure 28 would have a more profound impact. The Tier I WEPP analysis that follows helps to quantify potential impacts.

Figure 27. Conventional tillage surrounded by mulch till and stubble.

Figure 28. Direct seed practice.

Tier I Analysis using WEPP:

The Tier I, hillslope-scale analysis of Kok et al. (2009) was extended in this project to investigate the effects of specific management practices on both sediment detachment and delivery of sand, silt, and clay particle size classes. The WEPP model was used to examine these sediment delivery processes. WEPP management files were parameterized using the crop rotations and tillage practices described by Kok et al. (2009) for the low, intermediate, and high precipitation zones. The WEPP model was used to simulate 30 year average annual soil detachment (i.e. erosion) and sediment delivery (i.e. yield) for typical soils and climates for each of these regions, see Figure 29. The characteristic hillslope chosen for this analysis had three individual 100 m linear segments having slope steepness of 10%, 30%, and 5% for up-slope, mid-slope, and toe-slope sections, respectively. An Athena silt loam was used in the low precipitation zone and a Palouse silt loam soil was used for the intermediate and high precipitation zone scenarios. The CLIGEN model, a stochastic weather generator model used in the WEPP model, was used to develop 30 year daily weather files for each region. Weather files were developed for Harrington, WA, Pomeroy, WA, and Moscow, ID to represent climates in the low, intermediate, and high precipitation zones, respectively. The mean annual precipitation amounts at Harrington, WA, Pomeroy, WA, and Moscow, ID are 13, 16, and 25 inches, respectively.



Region Info

High Precipitation Zone of the Palouse

Slope File: slope_10_30_5

Climate File: Moscow ID

State: ID

Station: MOSCOW U OF I ID

Soil Loss Graph: usace_ww_sb_pea_mt_high_buffer.prj

Maximum Detachment: 8.66 ton/A at 648 ft

Maximum Deposition: 58.7 ton/A at 955 ft

Scale: 2

30 Year Simulation	Value	Units
Average Annual Precipitation	25.19	in
Average Annual Runoff	1.18	in
Average Annual Soil Loss	2.543	ton/A
Average Annual Sediment Yield	1.040	ton/A

Management	Segment Length (ft)	Average Detachment (t/acre)	Detachment Length (ft)	Average Deposition (t/acre)	Deposition Length (ft)
usace\ wbp_mt_	164.0	4.65	164.0	0.00	0.0
usace\ wbp_mt_	164.0	7.33	164.0	0.00	0.0
usace\ wbp_mt_	164.0	0.63	18.0	2.75	146.0

Soil Name	Segment Length (ft)	Average Detachment (t/acre)	Detachment Length (ft)	Average Deposition (t/acre)	Deposition Length (ft)
ID\ PCW\ PALOU	984.3	2.54	808.3	5.86	176.0

For Help, press F1

Figure 29. A screenshot of the WEPP model. Notice the exaggerated hillslope profile indicating the relative location of deposition and scour.

Overall soil detachment (i.e. erosion) rates simulated by the WEPP model for each of the crop-tillage scenarios were similar in magnitude and had the same relative trends as those determined using the RUSLE2 model by Kok et al. (2009), see Table 12. The greatest detachment rates (9.56 tons/acre) occurred with conventional tillage practices in the high precipitation zone. Conversion from conventional tillage to reduced or mulch tillage in the high precipitation zone decreases erosion rates to 2.51 t/ac. No-till practices reduced detachment rates in the high precipitation zone down to 0.39 tons/ac which is very close to the detachment rates for a perennial grass, 0.28 t/ac.

The amount of soil delivered at the end of the hillslope can be substantially less than the amount of soil detached along the hillslope. This is particularly true for highly eroding slopes. For example, the overall amount of sediment delivered at the end of the slope (i.e. to a stream network) for conventional tillage practices in the high precipitation zone is roughly a third, 3.27 t/ac, of the amount of sediment detached along the slope, 9.56 t/ac. In contrast there is very little difference between overall sediment detached and delivered for no-till practices, see Table 12.

Table 12. Sediment detachment and delivery by particle size class for each of the crop-tillage scenarios described by Kok et al. (2009).

Precip Zone	Rotation	Tillage	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Detached Sand (tons/ac)	Delivered Sand (tons/ac)	Detached Silt (tons/ac)	Delivered Silt (tons/ac)	Detached Clay (tons/ac)	Delivered Clay (tons/ac)
High	WW–SG–P	Conv.	9.56	3.27	1.08	0.18	6.47	2.30	2.01	0.79
	WW–SG–P	Reduced	2.51	1.62	0.28	0.11	1.70	1.14	0.53	0.36
	WW–SG–P	No-Till	0.39	0.39	0.04	0.04	0.27	0.27	0.08	0.08
	CRP/Grass	None	0.28	0.28	0.03	0.03	0.19	0.19	0.06	0.06
Interm.	WW–SB–P	Reduced	0.55	0.37	0.06	0.04	0.37	0.25	0.12	0.08
	WW–SB–F	Reduced	1.93	1.37	0.22	0.15	1.30	0.93	0.41	0.29
	WW–SB–CF	Reduced	1.90	1.30	0.21	0.14	1.28	0.88	0.40	0.28
	WW–SG–P	No-Till	0.07	0.05	0.01	0.01	0.05	0.03	0.02	0.01
	CRP/Grass	None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low	WW–F	Conv.	3.89	2.34	0.66	0.35	2.53	1.56	0.70	0.43
	WW–SB–CF	Reduced	2.77	1.86	0.47	0.27	1.80	1.24	0.50	0.35
	WW–F	Reduced	1.19	0.63	0.20	0.09	0.77	0.42	0.22	0.12
	CRP/Grass	None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

WW- winter wheat, SG – spring grain (e.g. barley or wheat), P – peas, SW – spring wheat, CRP – conservation reserve program, F – tilled fallow, CF – chemical fallow, L – lentils.

When looking at the actual sand, silt, and clay particle size classes it is clear that the majority of the soil delivered to the end of a slope is composed of silt-sized particles in all precipitation zones. Sand sized particles are not only a small part of the original soil (11.3% for a Palouse silt loam, 16.9% for an Athena silt loam) these larger particles preferentially deposit faster than the silt- and clay-sized particles and therefore the sediment delivered at the end of the hillslope is even further enriched with silt and clay sized particles. As seen in Table 12, although soil detachment rates for conventional tillage in the high precipitation zone are 9.56 t/ac, the detachment rate for the sand sized particles is only 1.08 t/ac. In addition, of the 1.08 t/ac of sand only a tenth, 0.18 t/ac, is delivered to the stream at the end of the slope.

As described by Kok et al. (2009) the most widespread soil conservation practice adopted in the Palouse region has been the conversion from conventional tillage to reduced or mulch tillage. Three other relatively common management practices used in the region are conversion of erosive cropland to perennial grass through the conservation reserve program (CRP), installation of gully plugs in the high precipitation zone, and to a lesser extent grass buffer strips along streams. Gully plugs are small catch basins having a perforated riser pipe that intercepts surface runoff and pipes the water to a stream or grass buffer. The purpose of the gully plug is to intercept the runoff before flow velocities can increase and generate a gully. Gully plugs are typically installed 1/3rd of the distance from the top of the slope above the steepest section of the slope. The effectiveness of each of these practices was analyzed for each precipitation zone using the WEPP model. Table 13 summarizes the reduction in sediment load for each management practice in the high precipitation zone for the various crop-tillage practices.

As seen in this Table 13, the reduction in overall delivered sediment load for a typical hillslope under conventional tillage in the high precipitation zone with a 30 foot grass buffer, 1.99 t/ac, is not quite as effective as adopting reduced tillage practices over the entire hillslope, 1.62 t/ac. However notice that the buffer strip was more effective at reducing the delivery of sand-sized particles, 0.07 t/ac, than converting to reduced tillage practices alone, 0.11 t/ac. The last two columns in Table 13 identify the percent reduction in overall sediment delivered sediment and the sand size class. As seen in this table, adding a 30 ft grass buffer reduces the overall delivered sediment load by 39.3% but reduces the delivered sand fraction by 61.9%.

Adding a gully plug to a hillslope is more effective under conventional tillage than a 30 ft buffer strip alone at reducing overall sediment load (41.1% reduction) however a buffer strip is more effective at reducing the delivery of sand sized particles. As seen in Table 13, the WEPP model predicted only a 24.9% reduction in delivered sand with a gully plug as opposed to a 61.9% reduction delivered sand with a grass buffer strip. Notice that the trend in differences between the effectiveness of a 30 ft grass buffer and a gully plug are very similar if the field is currently being farmed under reduced tillage or no tillage.

Table 13. Assessment of the effectiveness of CRP, 30 ft grass buffer, gully plugs, and conservation tillage at reducing the detachment and delivery of sand, silt, and clay sized particles to streams in the high precipitation zone using the WEPP model.

Tillage	BMP	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Detached Sand (tons/ac)	Delivered Sand (tons/ac)	Detached Silt (tons/ac)	Delivered Silt (tons/ac)	Detached Clay (tons/ac)	Delivered Clay (tons/ac)	Reduction in Delivered sediment (pct)	Reduction in Delivered Sand (pct)
Conv.	None	9.56	3.27	1.08	0.18	6.47	2.30	2.01	0.79		
	30’ Buffer	9.26	1.99	1.05	0.07	6.27	1.42	1.95	0.50	39.3%	61.9%
	Gully Plug	4.01	1.93	0.45	0.14	2.71	1.36	0.84	0.43	41.1%	24.9%
Reduced	None	2.51	1.62	0.28	0.11	1.70	1.14	0.53	0.36		
	30’ Buffer	2.54	1.04	0.29	0.04	1.72	0.75	0.54	0.25	35.8%	61.8%
	Gully Plug	0.35	0.31	0.04	0.03	0.24	0.21	0.07	0.07	81.0%	73.6%
No-Till	None	0.39	0.39	0.04	0.04	0.27	0.27	0.08	0.08		
	30’ Buffer	0.40	0.35	0.05	0.03	0.27	0.25	0.08	0.07	10.7%	37.2%
	Gully Plug	0.04	0.04	0.01	0.00	0.04	0.03	0.01	0.01	89.3%	89.2%
CRP	Grass	0.28	0.28	0.03	0.03	0.19	0.19	0.06	0.06		

The enrichment of clay sized particles is greatest with conventional tillage practices in the high precipitation zone, see Table 14. The deposition of sand sized particles leads to an enrichment of clay sized particles in the delivered sediment. Table 14 identifies the percent sand, silt, and clay in the delivered sediment for a Palouse silt loam soil hillslope composed of 11.3% sand, 67.7% clay, and 21.1% clay. Under conventional tillage practices alone the amount of sediment delivered to the toe slope exceeds the transport capacity of the surface runoff which leads to deposition. This topographic effect alone leads to enrichment of clay from 21.1% in the detached sediment to 24.1% in the delivered sediment. In contrast, the deposition of sand reduces the portion of sand from 11.3% in the detached sediment to 5.6% in the delivered sediment. Adding a 30 ft grass buffer at the end of the slope reduces the proportion of sand in the delivered sediment even further down to 3.5%. The enrichment of clay and depletion of sand in the delivered sediment is not as important in reduced tillage and no-tillage fields since the overall sediment load is often less than the transport capacity of the water resulting in less deposition of sediment.

As expected the most effective management technique is conversion of the entire field to perennial grass (i.e. CRP). Conversion to CRP essentially eliminates erosion in the intermediate and low precipitation zones and delivers very negligible sand in the high precipitation zone, see Table 12 and Table 14.

The selection of the appropriate management practice must include an economic analysis which was beyond the scope of this project. However it should be noted that these WEPP simulations support the findings of Kok et al. (2009) and agree with current trends in overall sediment load recorded at the Hooper, WA stream gage station that the conversion to reduced tillage and no-tillage practices alone is very effective a reducing the delivery of sediment to streams. Installation of buffer strips, conversion to CRP, and, to a lesser extent, installation of gully plugs all take land out of production and therefore would not be as attractive an option for regional farmers without economic incentives.

Table 14. Particle size breakdown of detached and delivered sediment for a Palouse Silt Loam soil (11.3% sand, 67.7% silt, 21.1% clay) in the high precipitation zone.

Tillage	BMP	Total Detached Sediment (tons/ac)	Total Delivered Sediment (tons/ac)	Delivered Sand (%)	Delivered Silt (%)	Delivered Clay (%)
Conventional	None	9.56	3.27	5.6%	70.3%	24.1%
	30 ft Grass Buffer	9.26	1.99	3.5%	71.4%	25.1%
	Gully Plug	4.01	1.93	7.1%	70.6%	22.4%
Reduced/Mulch	None	2.51	1.62	7.1%	70.4%	22.5%
	30 ft Grass Buffer	2.54	1.04	4.2%	72.0%	23.7%
	Gully Plug	0.35	0.31	9.9%	68.7%	21.4%
No-Till	None	0.39	0.39	11.2%	68.0%	21.1%
	30 ft Grass Buffer	0.40	0.35	7.8%	71.7%	20.7%
	Gully Plug	0.04	0.04	11.3%	67.8%	21.0%
CRP	Perennial grass	0.28	0.28	10.6%	68.1%	21.1%

Importance of Extreme Events:

The delivery of sediment in natural systems is dominated by extreme events. This has been described early in the report with observed data at the Hooper, WA stream gage station and has been observed in sediment cores extracted in the backwater pools above the dams. It has also been visually observed in location such as the floodplain of Tenmile Creek (see Figure 30) where the finer grain sediments and soils have been totally washed away leaving only larger gravels and cobbles. In this section we quantify the effects of management practices on the frequency of sediment delivery events using the WEPP model.

Figure 30. Sediment scour on Tenmile Creek as a result of flooding.

The importance of extreme events was captured by analyzing daily output over a 30 year simulation using the WEPP model. Figure 31 presents a relationship between the percent of storm events and the total 30 year delivered sediment load for a single hillslope under conventional tillage practices in the high precipitation zone. Storm events were defined as any day in which the model simulated sediment leaving the hillslope. As seen in Figure 31, over half the total sediment load from this hillslope was delivered in only 10% of the events. Nearly all the sediment load, 95%, was delivered by only 30% of the events.

Adopting reduced tillage practices reduces the overall magnitude of events and increases the number of years where no erosion will occur. Figure 32 provides a distribution of annual sediment loads for conventional, reduced, and no-tillage practices for a single hillslope located in the high precipitation zone. Figure 32 indicates that the WEPP model predicted that 3 out of 30 years no sediment was delivered from a hillslope under conventional tillage in the high precipitation zone. In addition, Figure 32 shows for 15 out of the 30 years the overall delivered sediment load for conventional tillage was between 0-100 lbs/ft. During one out of the 30 years the delivered sediment load for conventional tillage was as high as 1300 lb/ft. In contrast to the conventional tillage reduced tillage increased the number of years without any delivery of sediment from 2 out of 30 years with conventional tillage to 14 out of 30 years. For no-tillage the model indicated that 23 out of 30 years had no delivered sediment. The highest delivered annual sediment load for reduced tillage and no-tillage was 1000 lb/ft and 300 lb/ft, respectively.

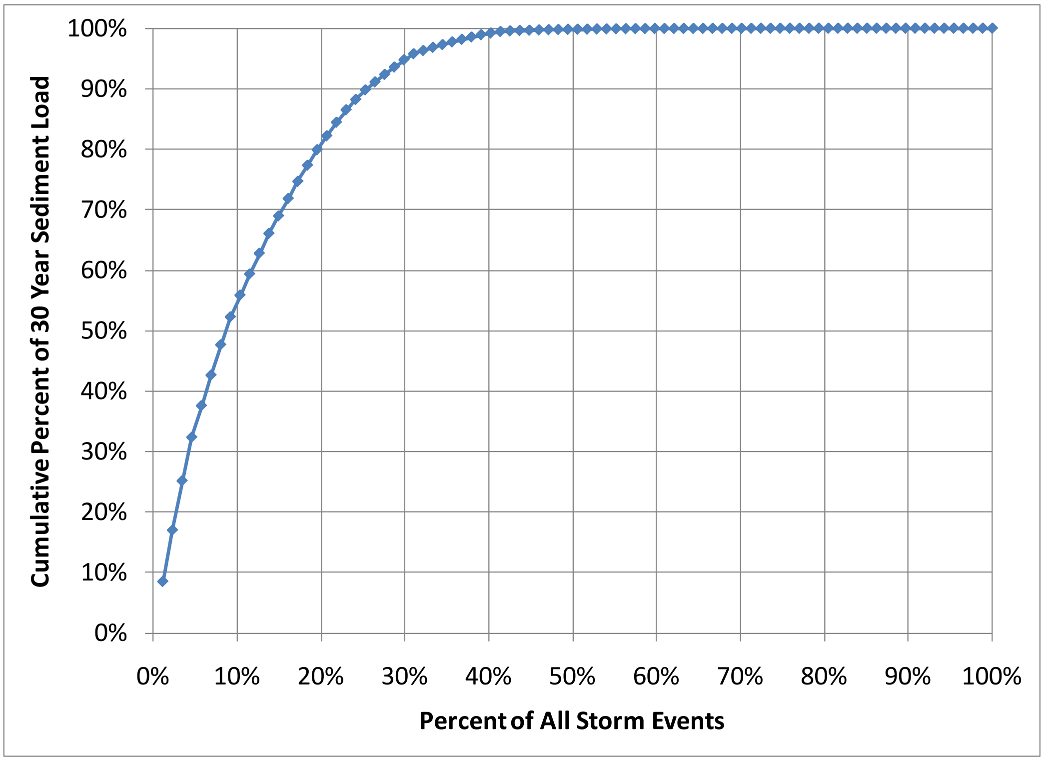


Figure 31. Proportion of the average annual sediment load versus percent of all storm events as predicted by the WEPP model for conventional tillage practices in the high precipitation zone of the Palouse.

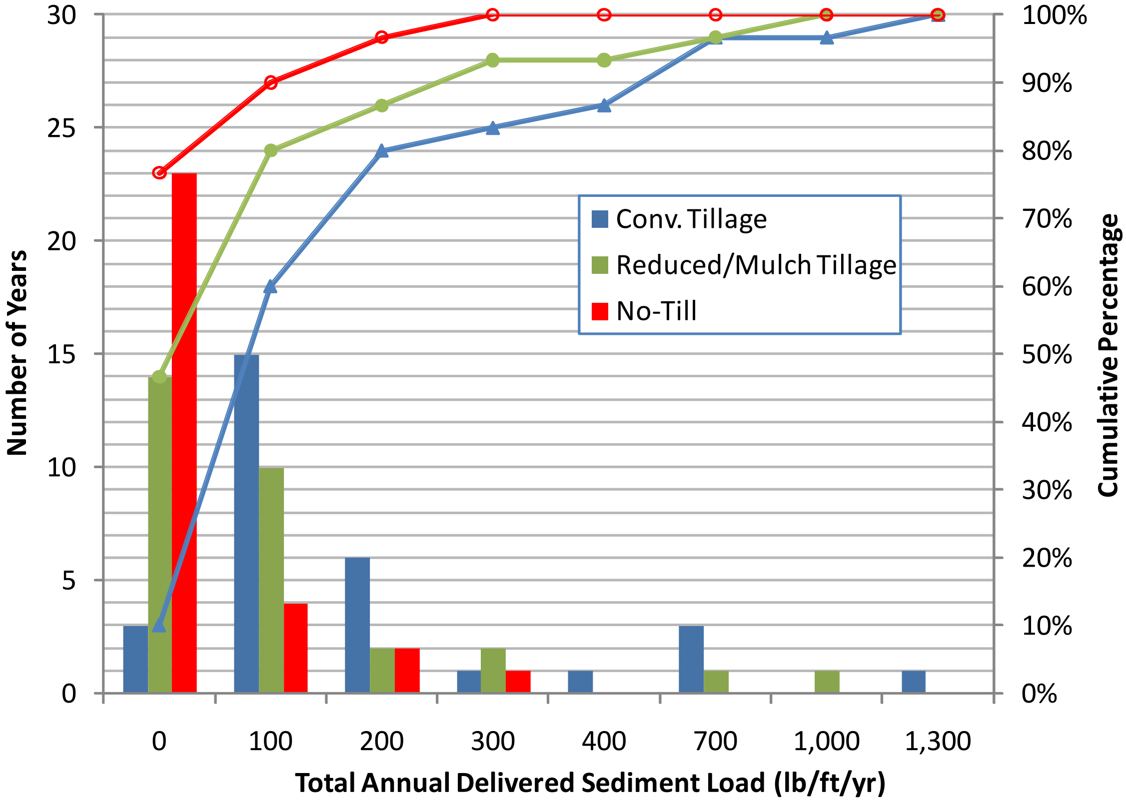


Figure 32. The effect of tillage practice on annual sediment load in the high precipitation zone for a 30 year simulation using the WEPP model. Lines indicate cumulative percent sediment load for all 30 years of the simulation.

Identification of Source Areas:

One common observation in watershed studies is that the majority of the sediment comes from a few source areas. In this section we quantify the importance of source areas relative to overall sediment load for each of the agriculturally dominated watersheds in the Lower Snake River basin using the erosion simulation by the RUSLE approach.

The 30-meter spatial resolution erosion maps predicted using RUSLE approach, described elsewhere in the report, were reclassified into two classes based on predicted erosion rates. The portion of the overall soil erosion for the entire watershed coming from each class was then quantified and presented in Figure 33 and Figure 34. These two figures show the proportion of overall erosion in each watershed derived from areas having erosion rates exceeding 5 t/ac and 10 t/ac, respectively. As seen in Figure 33 nearly 60% of the overall erosion in the Clearwater basin is derived from slightly more than 30% of the watershed area. Similarly nearly 16% of the overall erosion in the Clearwater watershed is derived from less than 5% of the watershed area. This trend is consistent among all the agriculturally dominant watersheds in the Lower Snake River basin.

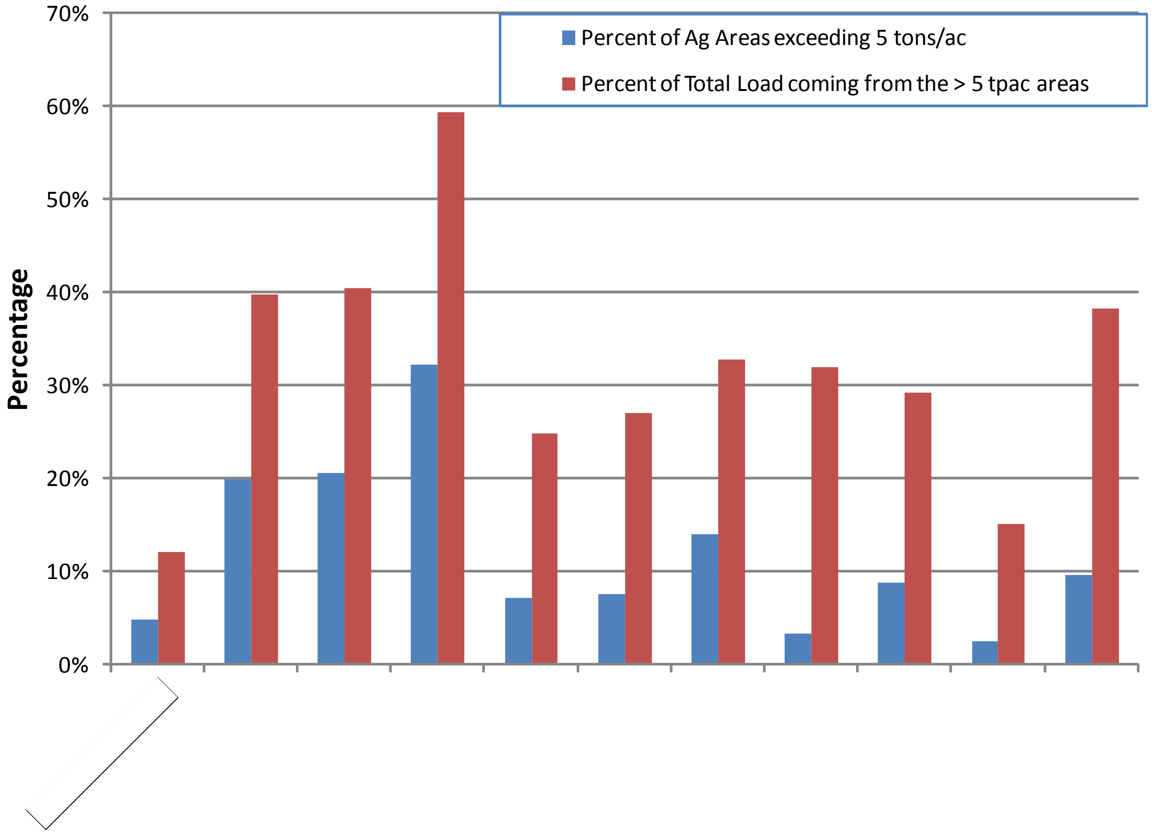


Figure 33. The proportion of the overall sediment load for specific watersheds coming from areas having erosion rates exceeding 5 t/ac as simulated using the RUSLE approach.

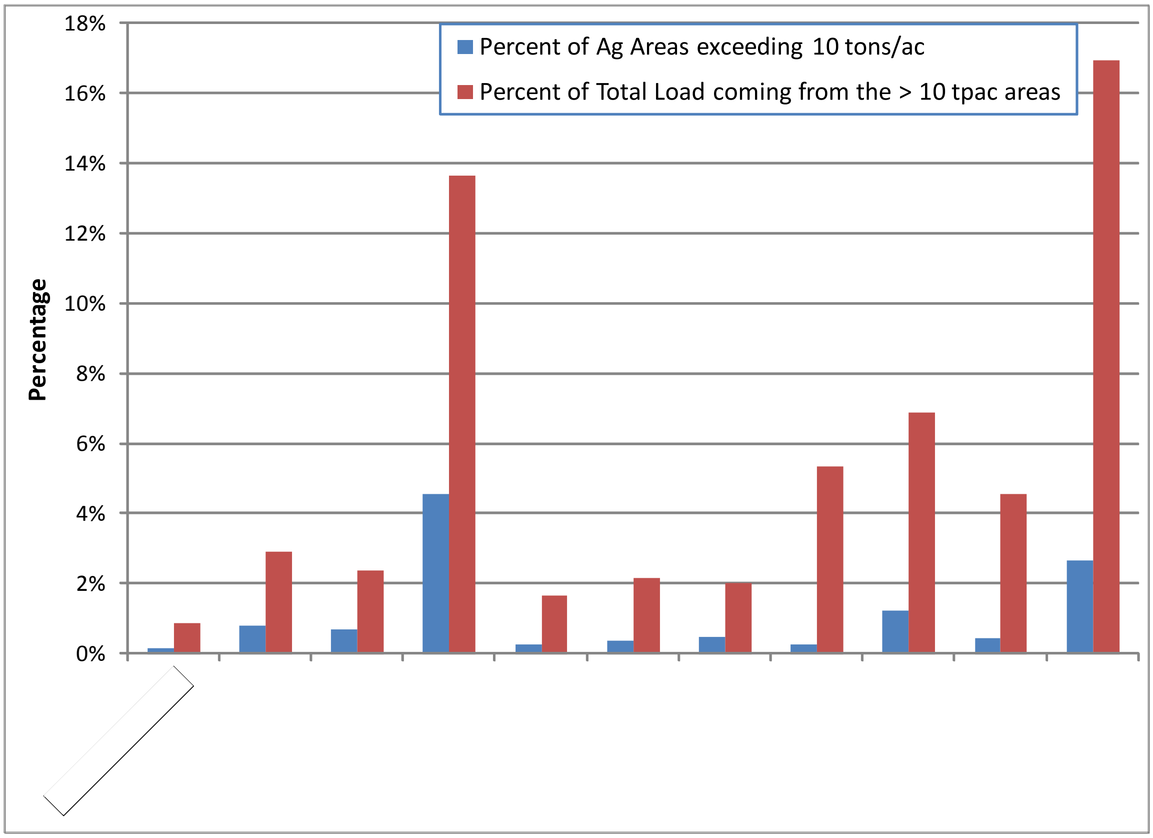


Figure 34. The proportion of the overall sediment load for specific watersheds coming from areas having erosion rates exceeding 10 t/ac as simulated using the RUSLE approach.

<u>Importance of Conservation Reserve Program:</u>

As seen in the following section the majority of sediment often is derived from a relatively small portion of the overall watershed. The primary implication of this is that management practices which focus on the highly erosive areas of a watershed will likely provide the greatest reduction in sediment load per dollar invested. This conceptual idea has been the primary motivation behind the Conservation Reserve Program which provides land owners with annual payments to establish and maintain perennial grass cover for a minimum of 10 years on highly erodible land. This program, which was started in the mid 1980s, has been widely adopted throughout the Lower Snake River Basins. With the exception of Whitman County, WA, the number of acres enrolled in the CRP program has gradually increased since 1986, see Figure 35. Interestingly there was a substantial increase in the number of acres enrolled in CRP in Whitman County from 1999 to 2007. As of 2007, the proportion of the total agricultural land enrolled in the CRP ranges from near 5% in Lewis and Nez Perce counties in Idaho to as high as 37% in Asotin County, WA, see Figure 36. Despite the substantial increase in number of acres enrolled in the CRP from 1999 to 2007 in Whitman County, the relative proportion of CRP ground to total agricultural farmland is relatively small, less than 20%, compared to many of the counties in the Lower Snake River basin.

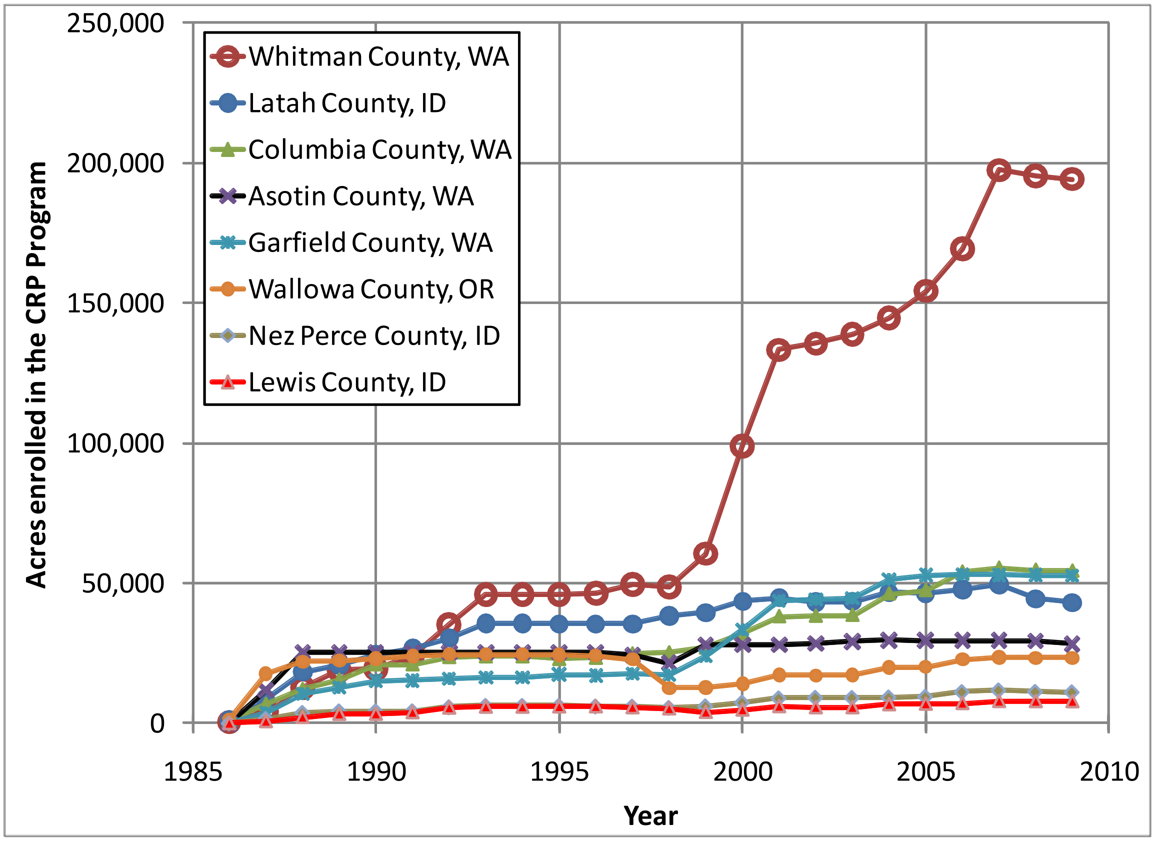


Figure 35. Number of acres enrolled in the Conservation Reserve Program (CRP) per year since 1986 by county in Washington, Oregon, and Idaho.

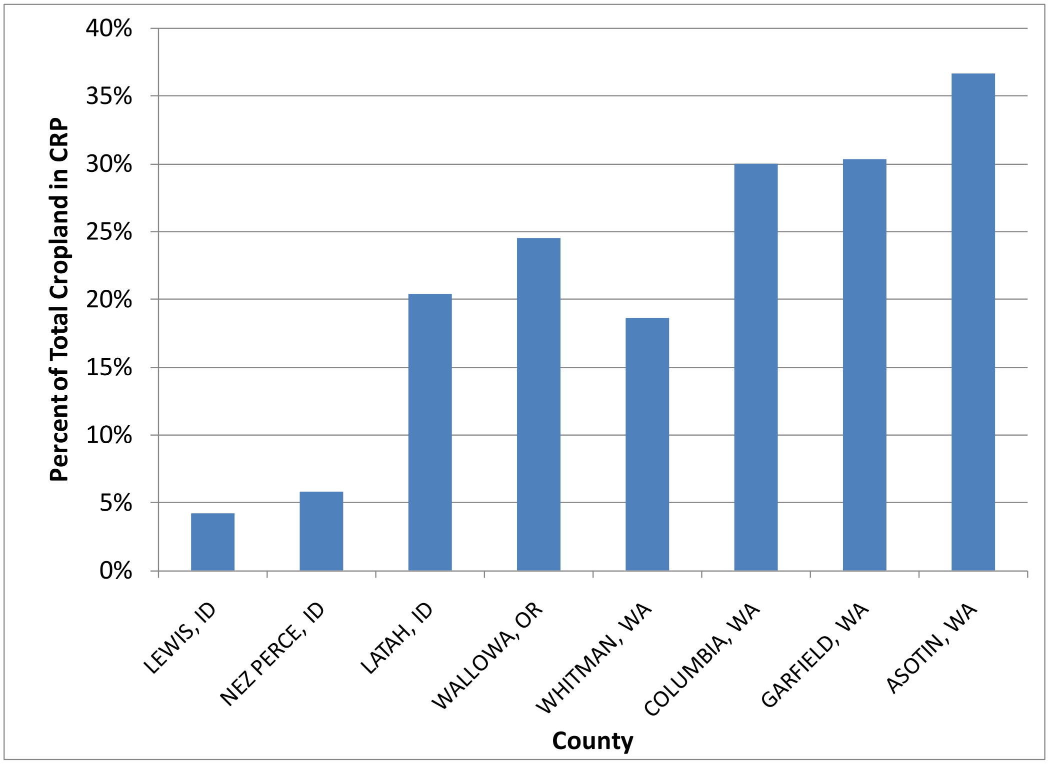


Figure 36. Percent of the total cropland area enrolled in the Conservation Reserve Program (CRP) in 2007 by county in Washington, Oregon, and Idaho.

As a government program to pay landowners to preserve land rather than produce a product, the benefits of the CRP is often closely scrutinized and debated in the public and political sectors. However as seen in this erosion modeling exercise, the long term consequences of elimination of CRP on sediment loading could be devastating to the ecosystems in the basin. As seen in Figure 36, on average 20% of all agricultural cropland in the Lower Snake River basin is enrolled in CRP program. Assuming the CRP ground was successfully applied to the most erodible fields in a watershed, then the transition of this land back to active cropland could greatly increase the overall erosion rates in the watershed. According to Figure 33 using the RUSLE approach, the most erodible 20% of land in the Palouse and Tucannon watershed contribute 40% of the overall sediment load. This implies that the conversion of CRP back to cropland could potentially double the amount of delivered sediment in each watershed. Although it is unlikely that all CRP ground has been adopted in the most erosive areas, or that all CRP ground will be converted back to cropland, the increase in sediment load is likely to be very significant if the CRP program were to be eliminated. As seen in Table 13 and Table 14, if the CRP program were to be eliminated or scaled back then this analysis would highly recommend that operators follow reduced or no-till farming practices on this highly erosive ground to minimize the increase in sediment load. Adding buffers and gully plugs to most highly erosive areas should also be encouraged.

Beneficial Sediment Characteristics:

Finally, it should be pointed out that any effort to reduce sediment downstream should be evaluated in context of the potential impacts to tributary streams in the area. Lane et al. (1996) demonstrated that the timing of flow and sediment supply processes is critical in determining the nature of morphological changes in both the short and long-term at the local level. Several of the streams in the study area are already sediment starved with respect to certain grain size categories. Avoiding unintended consequences of watershed-scale restoration would require adopting a comprehensive framework such as the one proposed by Shields et al. (2003).

4.0 Summary and Recommendations

In spite of significant reductions in agricultural sediment yields over the past couple of decades because of BMP adoption, there are still areas where large quantities of fine grain sediments reach tributary stream channels. Adoption of agricultural BMPs such as no-till (or reduced tillage), grassed buffer strips, cattle fencing, and riparian corridors appear to be reasonably effective at reducing sediment loads. However, while there are important ecological and sustainability reasons that efforts to expand agricultural BMPs should continue (Montgomery 2007), the impacts on US Army Corps of Engineers dredging frequency near the confluence of the Snake and Clearwater Rivers would likely be quite small. The grain size fractions found in the USGS core data from the confluence area are considerably larger than most of the agricultural soils. Furthermore, results of the WEPP modeling included in this report indicate very little of the sand sized particles reach the stream.

According to the erosion modeling conducted in this report, the highest priority for minimizing erosion in the Lower Snake River basin should be focused on adoption of reduced tillage practices. Drive-by surveys indicate many farmers still follow traditional conventional tillage practices which leave little surface residue cover and have the greatest risk of erosion. The RUSLE2, the GIS-based RUSLE approach, and the WEPP model all indicate that the highest erosion rates occur in the high precipitation zone in areas where operators still follow conventional tillage practices. Both buffer strips and gully plugs are effective at minimizing the erosion and sediment yield however, since both these practices take land out of production and require annual maintenance, these practices would likely require financial incentives to encourage widespread adoption. Adoption of no-till should be highly encouraged however more research and outreach is likely necessary to dispel owner and operator concerns over potential risks of this technique. Since the majority of the sediment load in many of the watersheds in the Lower Snake River basin is derived from a relatively small fraction of the total watershed area conservation reserve program (CRP) has likely been a significant factor in the reduction of sediment load observed over the last 25 years. Elimination of the CRP program could potentially double the amount of sediment load delivered by the agriculturally dominated watersheds in the lower Snake River Basin.

With respect to controlling streambank and stream channel scour, there is simply not enough long-term data to develop accurate assessment with existing modeling tools. We observed a few obvious down-cutting situations and a few streambank scour reaches during our field assessment and the literature generally supports the conclusion that changes in land use typically leads to increases in bank-full flows that produces additional stream bed aggradation. It is difficult, however, to quantify the overall impact on sediment deposition in Lower Granite Pool due in part because of insufficient data sets. Furthermore, after a thorough examination of the causes of these types of erosion, it is unclear what steps the USACE could take with respect to significantly modifying the hydrographs. Some of the streambank erosion occurred within established riparian zones so simply laying cause-effect on poor riparian conditions does not seem appropriate. After all, large woody debris recruitment in some watersheds requires some periodic undercutting of tree/root systems. Finally, while models such as CONCEPTS, WEPP, and CCHE2D represent state-of-the-art constructs, none of the models produces uncalibrated results with enough confidence to site restoration projects. The sensitivity of these solutions was shown using critical bed shear calculations.

It is also important to note that elimination of all sediment is generally not a desired course of action. Schmidt et al. (2007) found that the area of sand bars exposed at low discharge in Hells Canyon has decreased 50 percent since dam closure at the Hells Canyon Complex. The adverse impacts of Hells Canyon Dam on the downstream riparian ecosystem were investigated and summarized by Braatne et al. (2008). Therefore, it is important to recognize that sediment is in part a natural process so eliminating all sediment should not be a goal.

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