MONITORING AND MODELING SEDIMENT AND ORGANIC CARBON LOADS FROM THE DRYLAND CROPPING REGION OF THE INLAND PACIFIC NORTHWEST

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Authorization to Submit Thesis

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Abstract

Mitigation strategies to minimize the loss of soil carbon require a fundamental understanding of the dominant hydrologic flow paths, which drive runoff generation, soil erosion, and ultimately the quantity and quality of carbon exported from a landscape. The variation in climate across the Inland Pacific Northwest has resulted in unique agroecosystems, which in turn has affected long term carbon storage and transport. In this study we quantified temporal and spatial hydrologic carbon fluxes at three watershed scales (~10 ha, ~5,000 ha and ~900,000 ha) and under two tillage practices (conventional and no-till). Additionally we tested the ability of the Water Erosion Prediction Project (WEPP) model to simulate present and future field scale variability in runoff and soil carbon erosion from a ~10 ha field catchment managed under conventional tillage practices. Samples were collected on an event basis for water years 2012 and 2013 using automated ISCO samplers at all locations. Samples were analyzed for dissolved organic carbon (DOC), particulate organic carbon (POC), and suspended sediment concentrations (SSC). Results indicate that (DOC) concentrations did not significantly vary with discharge at all sampling locations but DOC concentrations were two times greater from the no-till catchment while total organic carbon loads were 97% less than thoes observed at the conventional till catchment. Future climate predictions with the WEPP model indicate that sediment and loads will be equivalent to historic levels (>20 Mg ha^{-1}) and slightly higher than current rates for runoff and carbon. Understanding the variability in hydrology as well as the trends in carbon export is an essential first step in the development of carbon budgets and full scale cropping models capable of evaluating precision-based carbon loss mitigation strategies.

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Dedication

This thesis is dedicated to my Mom and Dad for teaching me that anything I set my mind to could become a reality, and to my partner Kendall for her patience, support, humor and inspiration throughout the whole process.

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Introduction

Increasing concern over elevated greenhouse gas emissions and their effect on global climate change has generated many studies focusing on quantifying and modeling the biogeochemical cycling of carbon (C) in the past three decades. These studies have revealed an apparent imbalance in the global C budget (Cole et al. 2007) prompting work to identify a significant "missing C sink" on continents that was equivalent to about one-third of global fossil-fuel emissions (Aufdenkampe et al. 2011). Recent studies suggest that the transfer of organic C from land to oceans is an important link in the global C cycle and could account for parts of this "missing sink" (Cole et al. 2007; Battin et al. 2009; Alvarez-Cobelas et al. 2010; Aufdenkampe et al. 2011).

Riverine C fluxes arise from a complex suite of physical, biotic, and anthropogenic processes that are well-exemplified by the sources, transport, and fates of waterborne C (Meybeck, 1999). Estimates of global total organic carbon (TOC) fluxes from terrestrial systems to oceans vary greatly with estimates ranging from 0.19 Pg yr^{-1} (Kempe, 1989) to 1.9 Pg yr^{-1} (Cole et al. 2007). The global export of C from agricultural systems due to hydrologic processes and its relationship to soil organic carbon (SOC) dynamics and the global C cycle has received relatively little attention, specifically in the Dryland Cropping Region of the Inland Pacific Northwest (INPW).

Agriculture C stocks and climate change

The Intergovernmental Panel on Climate Change (IPCC) states that increases in atmospheric CO_2 since the industrial revolution have resulted from human activities: primarily from burning of fossil fuels and deforestation, but also other changes in land use such as biomass burning, crop production and conversion of grasslands to croplands (Soloman, 2007). Globally the terrestrial organic C pool is the third largest, after the ocean and geologic pools. SOC comprises 1200-1600 Pg C, almost three times greater than that stored in vegetation, 550-700 Pg C (Paustian, et al., 2001). Prior to 1920, land use change (mainly conversion to agriculture) was the predominant anthropogenic source of CO_2 emissions, exceeding that of fossil fuels (Houghton & Skole, 1990). The estimated historic losses of C from the conversion to agriculture equates to 54 Pg C for all cultivated soils (Paustian, et al., 2001). Similarly, a total net reduction in terrestrial organic C stocks of 275 Pg is estimated since the rise of agriculture, of which 41 Pg was attributed to SOC (Houghton and Skole, 1990). Thus, the conversion of native ecosystems to agriculture almost invariably results in a net loss of soil C. The historic loss of SOC provides a target for rebuilding SOC in agricultural soils while sequestering atmospheric CO_2, and improving agricultural productivity.

Research suggests that increasing SOC levels through improved agricultural management practices could be a viable global climate change mitigation strategy (Lal, 2004; Kern and Johnson, 1993). Although increasing soil organic matter (SOM) by altering management practices shows promise for sequestering C, a better accounting of all C fluxes is needed to better realize the effectiveness of these strategies (Schlesinger, 2000).

Hydrologic C fluxes defined

There are two primary forms of organic C that can be transported due to hydrologic fluxes from agricultural systems. DOC, which is produced through solubilization of SOC is operationally defined as any organic compound passing through a 0.45μm filter (Evans. et al., 2005). The second form, Particulate Organic Carbon (POC), enters rivers and streams from the erosion of soils (typically older materials) and as leaf litters (Richey, 2004). POC is considered a more labile C fraction (Chan, 2001) and is defined as any particle that will not pass through a 0.45 μm filter by the USGS. This study will mainly focus on POC and DOC loads which together equal total organic C (TOC).

Mechanisms of C transport

Previous studies have identified the mechanisms that control organic C fluxes to gain a better understanding of increased human pressures and natural constraints on the global C cycle (Hope et al. 1994; Mulholland 2003; Lerman et al. 2004; Cole et al. 2007). Environmental factors that control the transport of C include: precipitation (Clair et al. 1994), runoff (Brinson 1976), land use characteristics (Schlesinger and Melack 1981; Tipping et al. 1997), slope conditions (Dosskey and Bertsch 1994; Clark et al. 2004), and the hydrology of a catchment. Work done by Alvarez-Cobelas (2010) stated that the strength of relationships between organic C fluxes and hydrological variables in different geographic areas might help us assess how organic C fluxes are affected by future climatic and land use changes.

DOC and POC flux from agricultural systems

The flux of DOC from terrestrial landscapes due to surface runoff is a fundamental part of the global C cycle with wide-ranging consequences for aquatic chemistry and biology (Aitkenhead and McDowell, 2000). DOC plays an important role in aquatic systems by influencing light and temperature regimes, nutrient supply, microbial metabolism, acidity, trace metal transport and bioavailability, as well as water treatment and potability (Eimers et al. 2008). DOC has been referred to as "the great modulator", in that it modifies the influence and consequence of other chemicals and processes in fresh water systems (Prarie, 2008). For example, the formation of trihalomethanes that can occur when drinking water is disinfected with chlorine is linked to DOC concentrations, posing a worldwide threat to fresh water drinking supplies (Siddiqui et al. 1997). In soil solution, DOC is typically a limiting factor for denitrification, meaning the input of new DOC into the soil solution can stimulate denitrification (Sotomayor and Rice, 1996; Yeomans et al., 1992). DOC also plays an important role in the sequestration of C in subsurface soil (Lorenz and Lal, 2005).

Global estimates of DOC export from agricultural systems are variable. Schlesinger and Melack (1981) predicted that $0.7x10^{14}$ g DOC yr^{-1} is exported from cultivated lands to the ocean globally, whereas Aitkenhead and McDowell (2000) estimated this value at $0.07x10^{14}$ g yr^{-1}. Small, watershed-specific studies focusing on agricultural areas predict relatively low DOC fluxes ranging from 2 to 23 kg ha^{-1} yr^{-1} (Royer and David, 2005) where the majority of the DOC flux occurs during short duration, high volume streamflow events (Dalzell et al. 2007). Although the estimates of DOC loads vary from region to region there has been plenty of evidence that human activities (e.g. agriculture), influence the terrestrial accumulation, transfer and aquatic processing of DOC (Stanley et al. 2012).

Changes in precipitation and rainfall intensities could also potentially alter erosion rates (Pruski and Nearing 2002a) and its linear relationship with POC (Cerro et al. 2014). Loss of soil and SOC, in the form of POC, caused by erosion leads to declines in soil quality (Fahnestock et al., 1995; Lal, 1998) and productivity (Mokma and Sietz, 1992; Chengere and Lal, 1995; Lal, 1998). Lal (2002) states that, “the global significance of erosion-induced C emission into the atmosphere remains misunderstood and is an unquantified component of the global C budget.” Soil erosion can be simplified to a 3-stage process involving detachment, transport/redistribution and deposition of sediments. SOC is affected in all three stages of the process (Lal, 2002). Small-scale studies that focus on SOC export and deposition from agricultural watersheds will help develop a better understanding of the implications erosion has on the C budget both locally and globally.

Although conservation tillage has been found to increase SOC, watershed studies typically only observe slight differences in the percent organic C in transported sediment compared to plowed systems. Owens et al. (2002) examined two-year corn-soybean/rye rotations for three tillage practices (chisel, paraplow/disk, and no-till) in Ohio. The study found that the percent C bound to sediments varied little with time and that reduced tillage greatly reduced sediment loss but had much less of an impact on C bound to sediments, regardless of the management type (Chan 2001; Owens et al. 2002; Owens and Shipitalo 2011).

Similarly, Jacinthe et al. (2004) found no significant difference in the percent organic C in sediment delivered by runoff from five watersheds under different land management practices (no-till, chisel till, disk-till, pasture, forest) in Ohio. However the percent C from the no-till watershed was slightly higher than both the chisel till and disk till watersheds. Total organic C exported from the disk till watershed was greater than that from any other watershed and most of the C was mobilized during the high-intensity storms (Jacinthe et al. 2004).

Implications for a changing climate in the dryland cropping region of the IPNW

In the dryland cropping region of the IPNW there have been few studies that focus on the impacts of runoff and erosion on organic C fluxes. The topography, soil types, and precipitation gradient that exist in this region call for a better understanding of the mechanisms associated with erosion and C dynamics. Studies of this type will become increasingly important if climate predictions are even relatively accurate. Increased annual temperatures and over winter precipitation (Mote and Salathé 2010) coupled with the uncertainty of increased rainfall intensities (Pruski and Nearing 2002b) maybe a major concern for runoff, erosion and associated C loss.

The region has historically had high erosion rates, some of the highest in the country, which has contributed to the transport and redistribution of SOC over the landscape. It has been estimated that an average of 0.75 Mg of topsoil was lost for every bushel of wheat produced between 1939 and 1960 (Kaiser, 1961) and historic annual average erosion rates ranged from 22 to 67 Mg ha^{-1} yr^{-1} (USDA, 1978) during roughly this same time period. The steep topography and variability in soil types (McDaniel et al. 2008) coupled with the unique winter hydrologic process of the region (McCool et al. 2000) has led to sedimentation being one of the leading causes of stream impairment. Shifts in land management practices, such as adopting conservation tillage systems and diversifying cropping systems, have decreased erosion by approximately 1.5 million tonnes annually since the early 1970's (Ebbert and Roe, 1995), equating to an annual average erosion rate across the region of 11 Mg ha^{-1} yr^{-1}(Kok et al. 2009). These shifts in management practices have had a tremendous impact not only on erosion but on crop yield and the ability of a soil to sequester atmospheric CO_2.

Between 1982 and 1997, agricultural and land management changes in the U.S. were estimated to sequester approximately 17 million Mg C yr^{-1} with 8.2 million Mg C yr^{-1} from reducing tillage intensity (Sperow et al. 2003). In the dryland agricultural region of the IPNW conversion from conventional tillage (CT) to no-till (NT) has been responsible for the largest relative increase in SOC storage (Brown and Huggins 2012; Stockle et al. 2012). As atmospheric CO_2 concentration continues to rise, mitigation efforts to encourage C sequestration will also increase. The development of these mitigation strategies in agriculture requires a better understanding of C sources and sinks within a field.

C and sediment transport modeling

No single method can unravel the complex interplay of soil, plant, atmospheric, and surficial processes that have a bearing on the net impact of erosion on SOC dynamics (Starr et al., 2000; Starr et al., 2001). However, combining experimental methods with modeling observations has produced seemingly reliable results (Lal, 1995; Gregorich et al., 1998; (Yadav and Malanson 2009; Yadav et al. 2009). Modeling hydrologic C fluxes can lead to a better understanding of C dynamics within a field and inform site specific C based mitigation strategies, that may be either policy or economically driven (e.g. cap and trade programs). Hydrologic models can also be used with future climate predictions to help better inform adaptation strategies for land managers, farmers and policy makers alike.

The Water Erosion Prediction Project (WEPP) is a processed-based model that has been designed to address these complex processes. WEPP was developed in the 1980's to predict runoff and erosion from the field and watershed scales (Flanagan et al., 1995; Laflen et al., 1997). WEPP has the ability to handle the coupled processes of infiltration, runoff, lateral flow, percolation as well as perched water tables and complex topography and soils. The watershed version of WEPP simulates a series of processes, including the following: erosion on hillslopes; soil detachment, transport and deposition in channels and watershed runoff and sediment yield under different land use and environmental conditions (Ascough et al., 1997). WEPP has been extensively tested in small agricultural watersheds (Laflen and Elliot 1991; Liu and Nearing 1997; Pandey et al. 2008; Williams et al. 2010) and has been utilized in the IPNW dryland grain producing region, focusing on winter hydrological process (Greer et al. 2006; Singh et al. 2009). The WEPP model has also been used to examine climate induced changes to erosion and runoff in various parts of the United States (Nearing et al. 1993; Pruski and Nearing 2002c; O'Neal et al. 2005; Zhang and Nearing 2005).

To date there have been no studies that directly examine the effects of runoff and erosion on SOC within the dryland agricultural region of the IPNW. This study will accomplish this overall objective by addressing the effects of management practices and scale on hydrologic C fluxes in the region. This information will be valuable to producers as SOC is an important component of soil productivity and could help to validate agricultural lands as a sink for atmospheric C, which may become valuable if and when C markets or C-based policy is adopted.

The specific objectives for this study are to:

(1) Quantify the effect of tillage management on field-scale organic C transport in the high precipitation zone of the IPNW dryland grain production region;

(2) Compare field-, watershed-, and basin-scale organic C loading across the dryland cropping region of the IPNW;

(3) Quantify long term trends in sediment, DOC and POC loads at the outlet of the Palouse Basin at Hooper with intermittent data from 1973-2013;

(4) Assess the ability of the WEPP model to predict sediment transport from a 14 ha agricultural watershed;

(5) Use the WEPP model to predict the effect of future climate on runoff,

sediment and C loading in the high precipitation zone of the IPNW.

Materials and Methods

Study Sites

Four sampling locations were selected within the IPNW Dryland Cropping Region, all of which were contained within the Palouse River Basin (Figure 1.1**)**. The Palouse River itself drains approximately 875,000 ha of land spanning northwestern Idaho and southeastern Washington before its confluence with the Snake River. The primary land-use in the basin is dryland agriculture (67%), with some rangeland (26%) and forested areas (6%) (Sandison et al., 2003). Annual average precipitation increases with elevation from west to east, ranging from approximately 300 mm in the western portion to more than 1000 mm in the mountainous eastern headwaters. The soils in the Palouse River Basin are composed of loessal deposits, which overlay basalt lava flows. Soils follow a similar gradient to precipitation changing in type and increasing in soil organic matter moving from west to east. The United States Geologic Survey (USGS) has maintained a gauging station, with continuous streamflow and intermittent water quality data at the outlet of the Palouse River Basin in Hooper, WA (46˚45’31”N, 118˚08’52”W**)** since 1988. Prior to that (1897-1988) daily streamflow data is available to the public. For this study integrated basin wide samples were taken at this location and will be referred to as Hooper from here forward. Additionally, the Hooper site was the only perennial river that was part of this study.

The second sampling location was in the Paradise Creek Watershed (PCW), located in the southeastern portion of the Palouse River Basin. PCW is mixed land use watershed that is 62% rural, 20% urban and 18% forested **(**Brooks et al., 2010). Samples were collected at Darby road (46°44'54.65"N, 116°37'47.70"W**).** This site is a seasonal stream that received surface water from 2930 ha of the rural and forested portions of PCW.

Two smaller paired agricultural watersheds with seasonal drainage streams were sampled to address the effect of conventional and no-till practices on C concentrations and loads within the Palouse Basin. Both sites are dryland agricultural farms, under three-year winter wheat, spring wheat, and legume crop production. The no-till site was located at the R.J. Cook Agronomy Farm (CAF-NT), which is a 11 ha watershed (46°46'51.91"N, 117° 5'10.30"W) and part of the United states Department of Agriculture (USDA) Long Term Agro-ecosystem Research network. The no-till practices at this site can be characterized as a single pass direct seeding system. A grain drill with smooth coulters is used that simultaneously injects the seed while fertilizing. The cropping system consists of a three year rotation of spring pulses-winter wheat-spring barley in strips. Soil associations at this site are comprised of Naff, Thatuna, and Palouse series, with estimated slopes ranging from 1° to 13° and average manual measurements of residue cover estimated at 73%. The conventional till site (Idaho-CT) is a 14.2 ha conventional agricultural watershed located 10 km north of Moscow, ID (46°45'29.09"N, 116°56'55.54"W) and is operated by a private grower. The conventional tillage at this site can be characterized as a five pass system using the following implements, (1) a 20 cm moldboard plow; (2) field cultivator; (3) spike toothed harrow (4) anhydrogenous fertilizer applicator and (5) a grain drill with a double disk opener. The cropping system is a three year rotation of spring pulses-winter wheat-spring barley. Soils at the Idaho-CT site are comprised of Southwick, Larkin, and Latahco series with estimated slopes range from 2° to 20° and average manual measurements of residue cover estimated at 30%.

Field Sampling Methods

Continuous streamflow data and event based water samples were collected at each of the four sampling locations during the 2012-2013 water years. To achieve this pressure sensors (Campbell Scientific CS451-L) coupled with data loggers and automated water samplers (ISCO 3700) were installed and set to sample weekly or for an increase in stage height appropriate for each sampling location. At the Hooper location USGS streamflow data from the gauging station was used in conjunction with a pressure sensor and ISCO 3700. At the smaller conventional and no-till agricultural watersheds Parshall flumes were installed to better quantify surface water runoff. Pictures of all the sampling locations can be seen in Appendix A.

Sediment and C analysis

All samples collected during the 2012 water year were analyzed for total dissolved nitrogen (TDN), total dissolved carbon (TDC), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC) and suspended sediment concentrations (SSC). POC measurements were only made during the 2013 water year and therefore it was assumed that the SOC concentrations do not change over the short term and that the percent C on the delivered sediment in 2012 was similar to that in 2013. For the purposes of this study only DOC, POC, and SSC concentrations and loads will be presented.

All TDC, DOC, DIC and TDN samples were first filtered through 0.45 µm membrane filters. The filtrate was stored at 4ºC (39ºF) and then processed on a Shimadzu TOC analyzer (Shimadzu TOC Vcp) located in the (USDA) Agricultural Research Services' lab at Washington State University. DOC was measured using the Non Purgable Organic Carbon method. Each sample was purged with 2M HCl for five seconds to volatilize any inorganic C present. DIC was then taken as the difference between TDC and DOC.

Analysis of SSC and POC was a two-part process. First SSC concentrations were measured by passing the samples through 0.2 µm glass fiber filters placed in perforated porcelain dishes using the American Standard Method for suspended sediment concentration (ASTM D 3977). Second POC concentrations were measured by analyzing the total organic C in the sediments trapped on the glass fiber filters by dry combustion using a CNS Leco analyzer. Results were reported in %C in the sediments (g-C g-sed^{-1}) and multiplied by the SSC value (mg L^{-1}) to determine POC values in mg L^{-1}. If more the 5 mg of sediment was present on the filter it was scraped off and combusted. If not, sediments and filters were combusted together and the mean %C of blank filters was subtracted from the measured value. Subsets of these samples were acidified with 25 drops of 2M HCL to determine the proportion of inorganic C in the sample. In addition to quantifying suspended sediment, POC and DOC concentrations, soil samples were collected at the conventional agricultural catchment to examine the effects of erosion on C redistribution. Total C and nitrogen mass fractions were measured at 30 cm depth increments at each location by dry combustion using the same CNS Leco analyzer.

Load calculation and statistical analysis

Sediment POC and DOC loads were calculated for the Hooper, PCW, and conventional and no-till catchments. Log-log event based SSC and discharge linear relationships were developed and used to predict 15 minute SSC for each location. The SSC data were then flow weighted to predict annual loads using the Wailing Webb (1985) method for estimating river loads.

$$Load = K \times V \times \frac{\sum_{i=1}^{n} \left(C_i \times Q_i\right)}{\sum_{i=1}^{n} \left(Q_i\right)}, \qquad \textbf{(1)}$$

where, C_i is the mean sampling point concentration (mg/L), Qi is the sampling point discharge (m^3 sec^{-1}), V is the volume of water over the period measured, K is the conversion factor corresponding to the number of seconds over the period of time samples were collected. Similarly, Log-log SSC and POC linear relationships were used to calculate 15 minute POC loads and flow weighted to obtain an annual load. DOC loads for each site were predicted using the flow weighted mean DOC concentrations.

Historic (1973-2013) sediment, POC and DOC loads were calculated for the Hooper site using similar methods as described above and extrapolated under the assumption that the change in SOC is minimal over a 30-yr period (Brown and Huggins, 2012). In examining the effects of tillage on C loads, analysis of variance (ANOVA) was used to determine significant differences in soil C and POC and DOC concentrations using R.

WEPP model calibration, validation and implementation

WEPP Watershed (v.2012.8) was used to model runoff and erosion at the Idaho-CT site for water years 2012 and 2013. WEPP requires inputs for hillslopes, soils, land management and climate files. The site was represented in WEPP with 18 hillslopes each with a single overland flow element of homogeneous soil type and cropping management, which fed into five stream channels. The watershed was generated from a 2m digital elevation model manually collected at the Idaho-CT site with a survey grade GPS system. Soil files were parameterized with SURRGO soils data and field measurements of depth to restrictive layer. Restrictive layer was evaluated by inspecting soil cores for changes in bulk density and color. The soil files were run using the WEPP-UI alternate hourly seepage method developed by Boll et al. (2014). The WEPP-UI alternate hourly seepage method allows the user to define saturated hydraulic conductivity, bulk density, field capacity, wilting point and anisotropy for each representative soil layer.

Management files were developed to mimic the cropping system of the modeled catchment that was in fallow-winter wheat-spring barley rotation during 2011, 2012, and 2013, respectively. Break point climate parameters were compiled from a weather station 1.6 km away located at the PCW sampling site, maintained by the University of Idaho. The climate files spanned from January 1st 2011- December 31st 2013.

The WEPP model was calibrated by two step approach, first calibrating runoff and then sediment. Frozen soils were observed in 2012 which made it necessary to adjust the saturated hydraulic conductivity of the frozen soil layers as recommended by Singh et al. (2009). During non-frozen periods effective hydraulic conductivity at the soil surface, hydraulic conductivity of the subsurface and anisotropy of soil layers were modified to mimic the observed hydrograph. Finally percent surface cover was calibrated using the percent residue buried in rill and interrill areas for major tillage operations. These terms were modified to match observed measurements, taken with the line intercept method (Laflen et al. 1981), and simulated percent cover, similar to the approach described by Flanagan and Nearing (1995).

A list of management and soil parameters used to calibrate and run the model can be seen in Tables 1.1, 1.2 and 1.3. The model was calibrated with these parameters based on previous WEPP modeling studies (Laflen and Elliot 1991; McCool et al. 1995; Pandey et al. 2008; Singh et al. 2009; Williams et al. 2010).

The runoff data collected from the outlet was used to validate the WEPP watershed model. The Nash-Sutcliffe model efficiency coefficient (Nash and Sutcliffe, 1970) was used to determine how well the observed data fit the modeled streamflow.

$$E = 1 - \frac{\sum_{t=1}^{T}\left(Q_o^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_o^t - \overline{Q}_o\right)^2} \quad \textbf{(2)}$$

Where Q_o^t is the observed discharge (mm) at time t (days), Q_m^t is the modeled discharge at time t (days) and $\overline{Q_o}$ is the mean of the observed discharges (mm). Observed sediment data was plotted against simulated data and validated by linear regression.

Upon calibration, daily future climate data spanning 94 years (2006 - 2100) derived from downscaled versions (Abatzoglou and Brown 2012) of the general circulation model CNRM-CM5.1 (Voldoire et. al 2012) were formatted to use in WEPP. CNRM-CM5.1 was selected because it predicts moderate changes to both temperature and precipitation (Appendix B) for the region. Since WEPP requires sub-daily distribution of precipitation it was necessary to use the CLIGEN model (Nicks and Gander, 1994; Meyer et al., 2004), a stochastic weather generator, to simulate storm duration, peak intensity, time to peak intensity. CLIGEN generates these sub-daily parameters based on long term average rainfall intensity characteristics from a local weather station. The model assumes the sub-daily distribution of precipitation does not vary with time. While this assumption maybe reasonable for the present there is uncertainty about how rainfall intensities may change in the future. In order to address the sensitivity of various rainfall intensities on runoff and sediment yield, as most GCMs are not sub-daily, four potential rainfall intensity scenarios were calculated using one and two standard deviations in both positive and negative directions from the mean annual storm duration from the extreme climate predictions (RCP

8.5). The new files were then appended with the predicted future wind speed, wind direction and solar radiation and run in the calibrated WEPP model.

Model scenarios were run for two Representative Concentration Pathways (RCP's), two tillage practices, and five rainfall intensities. RCPs 4.5 and 8.5 were selected to represent moderate and extreme climate predictions, respectively. Simulations were run for both conventional and no-till management practices using a spring pea-winter wheat-spring barley rotation in an effort to assess management effects on runoff, sediment and C yield. The log-log relationship generated between SSC POC measurements was then used to estimate future POC loads and the mean annual DOC concentrations were used to predict DOC loads.

Results

Hydrologic Characteristics

Total annual precipitation during this study ranged from 583 mm to 645 mm in 2012 and from 480 mm to 533 mm in 2013, across all sites (Table 1.4). Precipitation in each sampling year was just below the annual average for the study area, which typically ranges from 545 mm to 777 mm. The maximum rainfall intensity was 8.8 mm hr^{-1}, observed on April 27th 2012 at the Idaho-CT site.

There was a large variation in total runoff for the two water years measured across all sites (Table 1.4 and Figure 1.2). More runoff was generated in 2012 than in 2013, which is consistent with precipitation totals for the two years. The excessive runoff in 2012 can further be explained by 24% of all agricultural fields in PCW that were left fallow in the spring of 2011 due to heavy spring rains (Appendix C). This resulted in greater soil moisture due to the lack of evapotranspiration entering into the 2012 growing season. In addition, the presence of frozen soils was extensive during the winter of 2012 in the high precipitation zone of the Basin (Figure 1.3). For these reasons peak discharge was observed between March 28th and April 2nd, 2012 and was driven by the presence of frozen soils coupled with a rain on snow event.

The effect of watershed management on hydrologic characteristics of the CT and NT sites is evident in Figure 1.2. The Idaho-CT site produced almost 200% more total runoff in 2012 then the CAF-NT site. Percent of annual precipitation leaving the Idaho-CT site as runoff was greater than that of the CAF-NT site. In 2012, 34.4% precipitation left the Idaho-CT site as surface runoff compared to 2% at the CAF-NT. whereas in 2013, only 10.4% of precipitation left the Idaho-CT as surface runoff compared to 0.4% at the CAF-NT sites (Table 4).

The total runoff also varied with watershed size and location (Figure 1.2). The PCW consistently generated the most runoff over the two study years. The percent of annual rainfall running off from PCW ranged from 43.9% in 2012 to 22.2% in 2013. Runoff was a lower percentage of total rainfall at Hooper ranging from 16.8% in 2012 to 14.1% in 2013.

Present trends in DOC, POC and SSC concentrations and loads

Average DOC concentrations during the two-year study ranged from 4.1 to 9.9 mg L^{-1} across all four sites. The average DOC concentration observed at the CAF-NT site was two times greater and significantly different ($p<0.05$) then those measured at the other three sampling sites (Figure 1.4a). There were no significant differences in DOC concentrations measured at the Idaho-CT, PCW and Hooper sites.

DOC concentration did not increase with increasing discharge from the sites examined in the Palouse Basin (Appendix D) . The lowest DOC concentrations (2-3.5 mg L^{-}

^{1}) were observed during peak discharge at the Idaho-CT site. Similar trends were observed at the CAF-NT site and PCW. The Hooper site exhibited little change in DOC concentrations as discharge increased but a spike in DOC concentrations, ranging from 7 to 37 mg L^{-1}, was observed over the summer months, July to early August, during low flow conditions.

While the largest DOC concentrations were measured from the CAF-NT site, it generated the least amount of total runoff and as a result delivered the lowest total DOC load of all the sites. Normalized to a per hectare basis the highest DOC load came from the PCW site in 2012 (16.4 kg ha^{-1}) followed by the Idaho-CT (10.7 kg ha^{-1}) site, Hooper (5.5 kg ha^{-1}) and finally the CAF-NT site (1.1 kg ha^{-1}) (Table 1.5). In 2013, DOC loads decreased dramatically across all sites monitored compared to 2012.

Sediment concentrations and loads followed similar trends to DOC measurements during the two sampling years at the four sites. The highest SSC concentrations were observed during peak flows in 2012 from Idaho-CT site ($4.1x10^{4}$ mg L^{-1}) followed by the Hooper site ($1.3x10^{4}$ mg L^{-1}). The overall sediment load was greatest at Hooper ($2x10^{6}$ Mg) but when normalized to a per hectare basis, the greatest total sediment yield was found at the Idaho-CT site. The greatest sediment yield recorded for the PCW in 13 years of event-based sampling occurred in 2012 (Figure 1.5). .

The observed data indicate a strong relationship between SSC and POC across all sites (Figure 1.6). Average flow weighted concentrations ranged from 0.4 to 8.3 mg L^{-1} the lowest being found at Hooper and highest at Idaho-CT. On a fraction basis, (g-C g-sed^{-1}), slightly more C was bound to CAF-NT sediments (1.4 g-C g-sed^{-1}), than the Idaho-CT site (1g-C g-sed^{-1}) though the values were not statistically different. The lowest fraction of C bound to sediments was from both PCW and Hooper (0.7 g-C g-sed^{-1}). Field measurements of SOC distribution for the Idaho-CT site can be seen in Appendix E.

With the high sediment yields, there was an associated loss in SOC from the region. Watershed size is directly related to overall sediment and organic C delivered to the outlet of each watershed (Table 1.5). While similar in size, TOC delivered from the CAF-NT site was two orders of magnitude smaller than the C delivered from the Idaho-CT site.

Historic trends in DOC, POC and suspended sediment from the Palouse Basin.

The total sediment and C yields from the Palouse Basin have declined more than two orders of magnitude from 1960 to 2012 (Figure 1.7). Total sediment yield declined from 2 million Mg yr^{-1} from 1962-1971 to 70,000 Mg yr^{-1} in years 2010-2012. Similarly the C yield at the Hooper site decreased from 25,000 Mg yr^{-1} to 4,400 Mg yr^{-1} for the same time periods. The decrease in C load has occurred primarily through the reduction in delivery of POC. During the 1960s only 12% of the total C load was delivered in the form of DOC whereas currently 83% of the total C delivered from the basin is transported as DOC (Table 1.6).

WEPP model validation

The WEPP model was calibrated for both runoff and sediment at the Idaho-CT site (Figures 1.8a and 1.8b). Nash Sutcliffe model efficiency coefficient was 0.47 for runoff, and the R^2 value for sediment was 0.842 with a p value of 2.2×10^{-16}. Observed total runoff was 228 mm in 2012 and 58.5mm in 2013 versus predicted total runoff of 227 mm in 2012 and 46 mm in 2013. While modeled total runoff was slightly less than the observed, trends in the two hydrographs were generally consistent with the exception of over prediction during peak flows and the presence of spikes in the hydrograph when no runoff was observed. The over prediction during peak flows generally coincided with the presence of frozen soil and large rain-on-snow events. Examples of the above mentioned can be seen in Figures 1.3 and 1.8a for February 26th-27th 2013 (frozen soils) and March 28th-31st (rain on snow) .

For sediment load at the outlet, WEPP slightly under predicted total loads for both water years modeled. Observed sediment loads were 79 Mg in 2012 and 1.6 Mg in 2013, while predicted sediment loads were 68 Mg in 2012 and 0.7 Mg in 2013. The general trend was over prediction during peak flows, significant under predictions during low flows in water year 2012, and under prediction of for all flows in 2013.

Examining individual hillslopes in the WEPP model revealed that erosion was delivered from 5 north facing hillslopes with predominantly Southwick soils. Manual measurements of sediment loss taken in 2012 and WEPP generated results agreed fairly well, with the exception of three south facing slopes (Appendix F). WEPP predicted that over half the sediment, 57% in 2012 and 56% in 2013, produced at the site was generated from the stream channel network. WEPP also predicted that the sediment delivery ratio (SDR) (i.e. the ratio of delivered to eroded sediment) was less than (0.6) the observed (0.74) for water year 2012, and all of the estimated deposition was occurring in stream channels. The WEPP model did not predict any sediment deposition on any of the hillslopes over the two years simulated.

Estimating total C loads with the WEPP model.

TOC losses were predicted using WEPP simulated sediment yield and streamflow along with the observed DOC and POC/SSC C relationships. Average estimates for the two years simulated were 12.8 kg ha^{-1} yr^{-1} for DOC and 56.4 kg ha^{-1} yr^{-1} for POC, resulting in a TOC load of 69.2 kg ha^{-1} yr^{-1}. The observed TOC load for the two years was 73.9 kg ha^{-1} yr^{-1}, indicating that WEPP only slightly under predicted C loads from this site.

Future sediment and C modeling with CNRM-CM5.1 climate predictions in the WEPP model

After calibration at the Idaho-CT site the WEPP model was used to predict the hydrologic and sediment response to a future climate scenario projected for water years 2006 through 2100. The future climate scenarios predict an increasing trend in annual average temperatures from the historic annual average at Moscow Idaho of 8.8ºC. Predicted increases in temperatures by 2100 were 1.5ºC for RCP 4.5 and 4ºC for RCP 8.5, on a 20-year annual basis (Figure 1.9). Increases in temperature were predicted for almost every month contributing to hotter, drier summers and warmer winters.

Similar to temperature, precipitation displayed large annual and seasonal variability with differences between the RCPs. Predictions in annual precipitation ranged from 121 mm (RCP 4.5) to 142 mm (RCP 8.5) by 2100 from the historic annual average for Moscow, ID. The seasonal variably in precipitation can be seen in Figure 1.10. On a 20-year annual average basis the model predicts the increases during the autumn and winter months of November, December, February, and March and decreases during the summer months of June, July and August; and in some years moving into October and September.

Increased temperatures during the winter months led to an overall decline in the average number of days with snow per year (Table 1.7). On average the number of days with snow decreased by 25 days for RCP 4.5 and by 27 days for RCP 8.5 by 2100. Likewise, average annual snow depths, decreased by 37 mm to 51 mm by 2100 for each respective RCP. While the model did not predict any change to the average depth of frozen soils the average number of days with frozen soils also decreased (Table 1.7). Consequently, the increases in temperature caused predicted increases in evapotranspiration and large annual fluctuations in total soil water in warmer years (Figures 1.11 and 1.12). Increased precipitation lead to overall increases in total soil water, lateral flow, with relativity little effect on deep percolation (Table 1.8).

The predicted increase in soil water and total annual precipitation coupled with increased temperatures lead to increases in total annual runoff; sediment and C yield from the Idaho-CT site (Table 1.8). Runoff was extremely variable for the 94-year period. Predicted increases in runoff ranged from -5% to 47% for the respective RCP's by 2080 using 2020 as a baseline. The greatest increase (47%) in runoff for RCP 4.5 was predicted to occur during the 20-yr period 2061-2080. For RCP 8.5 a maximum increase of 44% occurred during the 20-year period 2041-2060.

As runoff increased so did total sediment and organic C loads. Sediment loads were generally higher with the extreme climate scenario (RCP 8.5) and primarily driven by precipitation, reflected in Figures 1.13 and 1.14. Increases in 20-year annual sediment load ranged from 15 Mg ha^{-1} by 2080 for RCP 4.5 to 28 Mg ha^{-1} for RCP 8.5 in 2100. Furthermore, WEPP predicted that that POC would be the largest portion of organic C leaving the site making up on average 92% and 95% of the total flux for both RCP 4.5 and 8.5 respectively (Table 1.8). POC was predicted to increase by percentages similar to sediment and DOC was predicted to increase by 30% to 43% in 2100.

The sensitivity analysis on rainfall intensity indicated that increases in rainfall intensity could lead to further increases in runoff, erosion and associated C loss. The results of changes in precipitation intensity from RCP 8.5 and its effect on sediment load can be seen in Figure 1.15. Increasing rainfall intensity by two standard deviations resulted in increases in sediment load ranging from 50 to more than 300%. The greatest increases were predicted for the beginning of the century (2006-2020). Similar trends are predicted for total runoff with increases ranging from just under 4% by 2020 and greater than 7% by 2100. Decreasing rainfall intensity decreased invariably decreased total runoff and had little effect on sediment loads.

The effect of tillage practice and future sediment and C loss

WEPP model simulations indicate that for the soils in Idaho-CT conversion to no-till will only minimally affect runoff but will significantly reduce erosion and sediment yield from the site (Table 1.8). Total sediment yield from the NT system increased by 2100 for RCP 8.5 (159%) and only slightly for RCP 4.5 (4%). The climate scenario presented in RCP 4.5 had little effect on 20 year averaged cumulative sediment load between 2006-2040, doubled sediment loads from 2041-2100 reflecting changes in precipitation during that time (Figure 1.12). A steady increase in 20-year averaged cumulative sediment loads can be seen for every successive 20yr period with RCP 8.5 (Figure 1.13). In both the RCP's 4.5 and 8.5, 20-year average sediment yields from the NT system were never predicted to be greater than 1 Mg ha^{-1} and were roughly an order of magnitude lower than the predictions from the CT system. Overall the conversion to NT from CT is predicted to reduce erosion rates on average over the entire modeling period by 91% for RCP 4.5 and by 94% for RCP 8.5. As a result of the lower predicted sediment yields reductions in total C load were also simulated after converting to a NT system (Table 1.8). Although total organic C loads from NT were less than for CT, DOC from the NT system made up a greater proportion of the total C load. On average 59% of the total C was delivered to the outlet as DOC for the NT system whereas 6% was delivered from the conventional till system.

Discussion

Annual hydrologic and climatic variability impacting runoff and erosion

Producer response to a wet spring, differences in annual precipitation and frozen soils resulted in the variability of runoff and erosion observed between water years 2012 and 2013. Above average precipitation, 30% of the annual average, between the months April and May in the spring of 2011 forced many producers to abandon planting, and leave their fields fallow for the 2011 growing season. The fallow crop rotation followed by winter wheat has historically led to excessive runoff and erosion in the region. Long-term erosion plot data collected over a 13-year period at the Palouse Conservation Field Station in Pullman WA indicated that the largest soil erosion events occur from thawing soils. Plots planted to winter wheat following summer fallow; produced 80% more runoff and 500% more erosion than 6 other cropping rotations (McCool et al., 2000). The excess soil water from fallow, the rotation and presence of argillic soil horizons, such as those found at the Idaho-CT and many other agricultural fields in the high precipitation zone of the Palouse Region lend themselves to higher water tables which contribute to saturation excess runoff.

In addition to the high percentage of fields in summer fallow during 2011, several freeze-thaw events in the winter of 2012 likely contributed to the high runoff and erosion in the region during the winter of that year (Figure 1.3). These freeze-thaw cycles are well documented for causing a high proportion of runoff and erosion in the region (Singh et al. 2009; McCool et al. 2010). Additionally at the end of March, there was a snow melt and soil thawing event that contributed to peak discharge and excessive SSC concentrations throughout the study region.

The runoff and erosion in 2013 was much lower than measured in 2012 for several reasons. First, there were fewer freeze thaw cycles in 2013. Secondly, precipitation was below average, 100 mm less than that observed in 2012, and third, the Idaho-CT was left in a much less erodible state during the winter of 2013. In October 2012, after harvesting winter wheat, the site was moldboard plowed. This resulted in the field having a much greater surface roughness and cover in 2013 than during the 2012 winter when the field was planted with winter wheat. Increased surface roughness and residue cover has been well documented as an effective strategy to reduce runoff and erosion (McCool et al. 2000)**.** The low erosion rates observed from the CAF-NT site can be partially attributed to the high surface residue cover deeper soils and less steep slopes.

Hydrology and organic C flux with management and scale.

The decrease in DOC concentration with increased streamflow for large events observed at the Idaho-CT site has been observed in previous work (Eimers et al. 2007). The inverse relationship between peak flow and DOC concentrations suggest that mixing with rainwater and snow melt along with saturated soils over the winter months slightly dilutes the soil water DOC concentrations. Although the DOC dynamics during runoff events provides insight into the flow and delivery processes, the reduction in DOC during high flows was slight, on the order of 1 mg L^{-1}, and therefore had little effect on the total DOC load. There was also little to no variation in DOC concentrations over the winter to early spring months, January-April, at all sampling sites. The low variability in comparison to the reults of Worrall and Burt 2004) could be due to cold temperatures that limit biological activity which has been shown to increase DOC concentrations in the summer months (Mulholland and Hill 1997) such as those observed at the Hooper site.

Unlike DOC, POC concentrations were strongly correlated with SSC and streamflow as found in similar studies (Caverly et al. 2013; Cerro et al. 2014). Since the percent C on the delivered sediment at each site was relatively stable (see Figure 1.6) this suggests that these simple site-specific relationships with sediment concentrations can be used to predict annual total C loads. C bound to sediment at the NT site was slightly greater than that of all the other sites but no statistically significant differences were found.

Effects of management and watershed scale on organic C fluxes.

TOC fluxes were significantly greater from the Idaho-CT site, then from the CAF-NT site (Table 1.5). Global estimates of total C fluxes from cultivated areas range from 5.3 kg ha^{-1} yr^{-1} (Aitkenhead and Mcdowell 2000) to 50 kg ha^{-1} yr^{-1} (Schlesinger et al. 1981) suggesting the range of observations in this study are similar to the range indicated for the global average. Work done by Jacinthe et al. (2004) in Ohio on conventional and no till corn, soybean systems found that conventional till systems had significantly higher C fluxes, 138 kg ha^{-1} yr^{-1}, than no till systems, 59 kg ha^{-1} yr^{-1}. They attributed these differences to tillage frequency and crop cover. The results from this study found the C fluxes to be quite a bit lower than those found by Jacinthe et al. but with similar differences in magnitude.

While the total C fluxes from the CAF-NT were less from the Idaho-CT site, DOC comprised a greater proportion of the total flux. DOC comprised 80% of the total C load for both years studied at the CAF-NT site compared to 15% and 67% of the total flux from the Idaho-CT site in 2012 and 2013, respectively. This is not surprising, as research has shown that increases in stream DOC concentrations are related to residue amendments from no-till agriculture (Stanley et al. 2012).

DOC has been called the great modular for the effect it has on light attenuation, microbial metabolism and the major role it plays in the transport of metals other organic contaminants in fresh water systems (Prairie 2008). This indicates that shifts in management from conventional to no-till systems in an effort to reduce sediment loads and sequester atmospheric CO_2 in the form of SOC could potentially alter stream ecosystem dynamics with the addition of elevated DOC concentrations from no-till agricultural systems in the region. Although the downstream effects, either positive or negative, of increased DOC concentrations are uncertain it is highly likely that changes in both land use and climate will alter light availability, temperature regimes, microbial processing and the transport and the bioavailability of toxic substances.

Historic sediment and C fluxes from the Palouse Basin.

Changes in land use discussed above have had effects on sediment, POC and DOC loads from the outlet of the Palouse Basin. The declining trends in sediment and C load can be attribute to broad changes in agricultural land management practices specifically changes in cropping systems (Kok et al. 2009) and the adoption of conservation measures (Ebert and Roe 1998; Kok et al. 2009). These changes equate to more than a 95% decrease in sediment and an 82% reduction in total C load since the 1960s. To provide some perspective, the reduction in C load expressed as CO_2 equivalent (i.e. the potential amount of CO_2 that could be released from a given amount of C) is equivalent to the CO_2 emitted from 15,736 cars per year (Table 1.6). As supported in Kok et al. 2009, assuming the reduction in sediment and C load has occurred primarily from agricultural lands, then for a typical 2000 ha farm this reduction is equivalent to the annual CO_2 emissions from 111 passenger vehicles (U.S Environmental Protection Agency, 2013).

Though it is clear that C and sediment yields are declining in the Palouse basin, the majority of the reduction is due to decreases in POC loads. The basin has shifted from a POC dominated system to a DOC dominated system over the course of 50 years with slight increases seen in 2009-2013. Additionally, the vast majority of the soil and C that is transport by erosion in the region is deposited and stored within the basin. Using conservative soil erosion estimate of 3.3 Mg ha^{-1} yr^{-1} within the Palouse basin (Kok et al. 2009) the sediment yield data measured at the Hooper station indicates that less than 5% of all the C transport by erosion with the basin will be transported out of the basin. The remaining 95% is deposited in the landscape or mineralized by during transport.

Evidence for the support of this deposition rate was observed with the C and sediment loading data collected at various watershed scales in this study. Watershed scale had an effect on C transport in the Palouse Basin. Moving from the small-scale (Idaho-CT) to the large-scale (PCW and Hooper) total C loads per unit area generally decreased. The decline in total load could be attributed to deposition of POC associated with sediments across the landscape (Lal 2003), mineralization of liable forms of DOC due to microbial respiration (Stanley et al. 2012), the sorption of DOC to sediments (McNight et al. 2002). Without directly examining the physical and chemical process that occur during the residence time of C in the channel one can only hypothesize at what is occurring. The adoption of soil conservation tillage practices has not only dramatically reduced sediment and POC export in the region but the rebuilding of lost topsoil is undoubtedly improving agricultural production.

Implications for a changing climate on sediment and organic C loads

The question then remains how will the current agricultural systems in the region respond to changes in climate and will we have the capacity to adapt and mitigate to these changes? The future climate scenarios selected in this study indicate warmer wetter winters and hotter, drier summers that predict increases in runoff, sediment and C loads for the Idaho-CT site. In the worst case, business-as-usual scenario (RCP 8.5) runoff was predicted to increase by 43%; sediment to increase by 620% (on average 28 Mg ha^{-1}) and total C losses was predicted to increase by 183% from the 2020 baseline. To put these estimates into perspective, erosion rates for the high precipitation zone of the Palouse Basin are estimated to be around 11 Mg ha^{-1} (Kok et al. 2009) and historic measure measurements from the Idaho-CT site specifically between 1938-1940 average were observed at 27 Mg ha^{-1} (Yoo and Molnau 1987).

This suggests that erosion rates could potentially increase to levels near those observed in the early 20th century before the adoption of many of the soil conservation practices. Nearing et al. (2005) and Zhang and Nearing (2005) suggest similar increases in runoff and erosion as a result of increases in precipitation in future climates in many parts of the Midwest. For this study site increased precipitation, evapotranspiration and soil water coupled with shallow soils and warmer winters with less precipitation falling as snow could explain these increases.

The implications for increases in total runoff sediment and C loads may call for the increased adoption of NT in the high precipitation zone of this region. The WEPP model predictions suggest that converting from CT to NT will decrease sediment by almost two orders of magnitude. While the adoption to NT is one potentially viable option the fact that modeled runoff was not reduced at this particular site suggests that this option alone will not mitigate problems with excessive nutrients, pesticides, and other agrichemicals delivered to streams through runoff. Innovations by farmers, researchers and extension specialists will need to reevaluate conservation measures to retain SOC within the field and employ precision based fertilizer application to reduce nutrient-rich runoff. Growers may need to plant more fall seeded crops to avoid deferred planting due to potentially wetter springs.

Land managers may want to consider the effects of conservation measures on instream C dynamics.

The mechanisms by which climate change may affect erosion are complex and are related to plant biomass production, residue decomposition, soil microbial activity, evapotranspiration rates, soil crusting and the most direct impact from climate change results from changes in precipitation (Pruski and Nearing 2002c). It is estimated that if total rainfall and intensity increase in a statistically representative manner for every 1% increase in precipitation 1.7% increase in erosion was predicted (Pruski and Nearing 2002a). Currently there are no known reliable methods to predict sub-daily changes in rainfall intensity for future climates. In this study sub-daily rainfall intensities were predicted using the CLIGEN weather generator which assumes the sub-daily distribution of rainfall intensities will not change in the future. Therefore the future forecasts in this study have inherently assumed the future rainfall intensities will not change. If rainfall intensities or the frequency of extreme precipitation events were to increase, the environmental and economic impacts could be detrimental to the agricultural based economy.

There are obvious limitations in this type of modeling exercise, the most important being the uncertainty that is presented with GCM's. The CNRM-CM5.1 model was selected because it predicts relatively moderate increases in both temperature and precipitation and solar radiation compared to the various other GCM's. While the model does not accurately represent reality it does provide insight into what one may see in the future. Secondly, the version of WEPP used to predict runoff and erosion did not take into account the effect of CO_2 fertilization which has a positive feedback on crop biomass production and thus residue production (Nearing et al. 2004). Greater amounts of surface residue could potentially decrease both modeled total runoff and sediment loads at the Idaho-CT site.

Conclusion

TOC transport from the dryland grain producing region of the IPNW has significantly declined over the last 60 years or more. From 1961-2013 broad land used changes in cropping systems and the adoption of conservation measures have decreased sediment loads by 95% and total C loads by 82%. The decrease in carbon load can be attributed the reduction of POC. Currently 83% of the total load is transported as DOC compared to 12% in the 1960s. Soil erosion and carbon transport in both an extremely high and low runoff year suggest that surface residues and soil types present at the CAF-NT significantly reduce field scale C losses by two orders of magnitude. It was observed that the no-till system had DOC concentrations twice that of the conventional till system however the total runoff from the no-till system was much lower than the conventional tillage site. Overall despite the high DOC concentrations, TOC loads were significantly less for the no-till system.

DOC concentrations were inversely related with streamflow however the overall variability was minimal, on the order of 1 ppm. The proportion of C in delivered sediments was also stable and did not change with time during a runoff event. In addition, C load measurements from nested stream monitoring stations indicate that the C loading rate per unit area decrease from the field to basin scale. This suggests that instream processing and deposition may be major factors governing the storage and transport of C in these streams.

Simulated surface runoff and sediment yield measurements over a two year period using the WEPP model agreed well with observations. The WEPP model was calibrated using saturated hydraulic conductivity, frozen soil, and surface cover parameters.

Using observed relationships between POC and SSC as well as average DOC concentrations the WEPP model was used to predict future changes in sediment and C fluxes from the region. Using a representative climate project the WEPP model indicated the region should expect increased winter precipitation with a large proportion falling as rain during the winter months, November to March, along with increased evapotranspiration and soil water leading to significant increases in total runoff, sediment and C loads. The observed increases were equivalent to historic levels for sediment and slightly higher than current rates for runoff and C.

Since the conventional till site and the no-tillage site had very distinct soil hydraulic characteristics it was difficult to distinguish the effect of tillage management on runoff and erosion. WEPP model simulations suggest that the adoption of a no-till system at the Idaho-CT site would decrease erosion and POC rates by more than an order of magnitude but have little effect on runoff and DOC fluxes. This suggests that the reduced surface runoff observed at the CAF-NT may be more related to differences in soil type than the differences in tillage management. The soils at the Idaho-CT site are predominantly argillic with a hydrologic restrictive layer which supports sustained perched water and saturation excess runoff, whereas the CAF-NT has a larger percentage of deeper, unrestricted soils. Regardless of soil type both the observed data and simulated data suggest adoption of no-tillage will decrease erosion.

It was demonstrated using the WEPP model that the erosion rates in this region are highly sensitive to increased rainfall intensity. An increase in rainfall intensity could lead to widespread increases in soil erosion in the high precipitation zone of the INPW. This finding suggest that it will be necessary to increase the adoption of management practices that maintain soil topsoil and limit further deterioration of regional streams.

Future work related to research should focus on the quality of C exported from the agricultural watersheds under different tillage practices in an effort to determine labile and recalcitrant forms. Residence times of organic C in the stream channels should also be addressed to accurately determine the fate of organic C during transport. Modeling efforts that strive to predict future changes in runoff and sediment loads should strive to better quantify accurate changes in precipitation and intensity.

Finally, history incictates that the INPW Dryland Grain Producing Region has had an uncanny ability to rebound from near environmental and economic disaster. The ability of the region to adapt to change is driven by innovators both from a grower and a research perspective that have led to crop diversification, and a variety of conservation strategies that maintain soil health and increase crop yield. If this trajectory continues like it has over the past 40+ years it is likely that adaption and mitigation strategies will enable growers to continue to farm the Palouse the way they have for the last 125 year

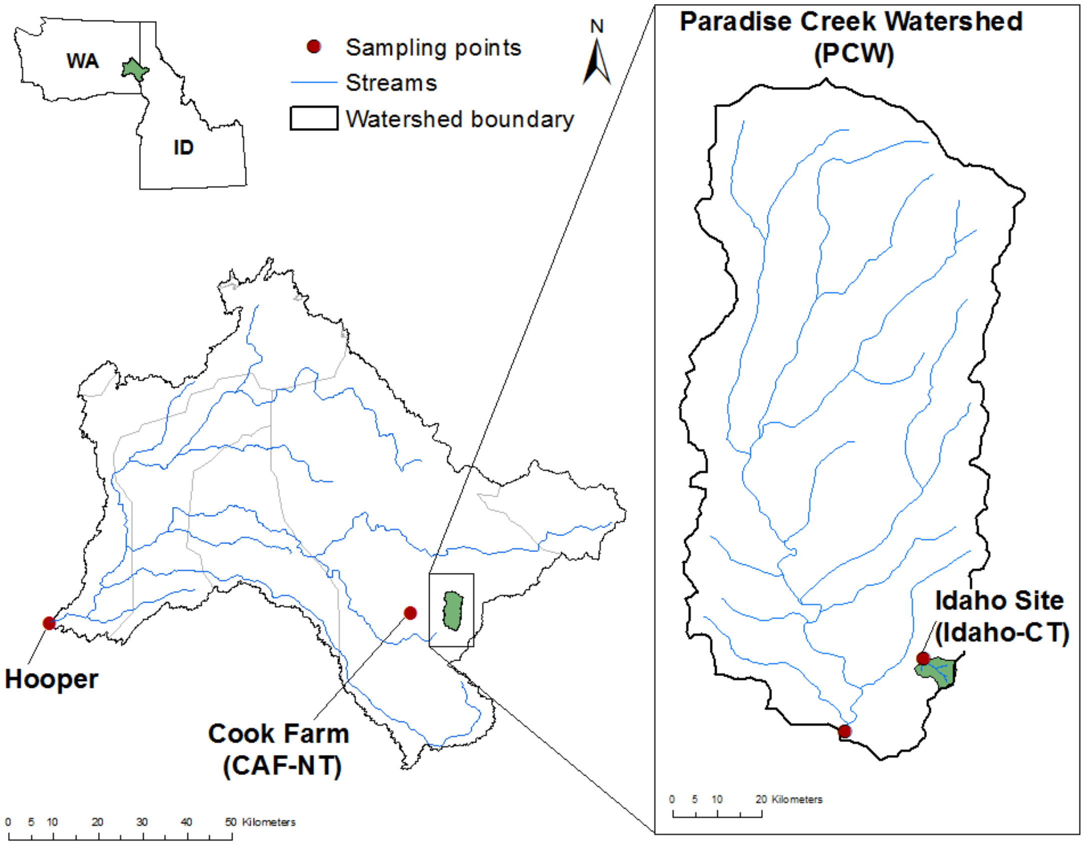

Figure 1.1 Map of the study sites. Red dots indicate sampling locations for the four watersheds; Hooper, Paradise Creek Watershed (PCW) Idaho Conventional till site (Idaho-CT) and Cook Farm (CAF-NT).

Table 1.1 Parameter values by crop type from the WEPP management files used in both model calibration and with the future climate files.

Parameter	**Values**		
Plant name	Spring pea	Winter wheat	Spring barley
Canopy cover coefficient	14	5.2	5.2
Base daily air temperature, (°C)	9	3	4
Growing degree days to emergence, (°C)	60	60	60
Height of post harvest standing residue; cutting height, m	0.15	0.152	0.152
Plant stem diameter at maturity, (m)	1	0.64	0.64
Radiation extinction coefficient	0.45	0.65	0.65
Standing to flat residue adjustment factor (wind, snow)	0.99	0.99	0.99
Max. Darcy Weisbach friction factor for living plant	0	3	3
Growing degree days for growing season, (°C)	1150	1700	1700
Harvest index	0.6	0.4	0.42
Max. canopy height, (m)	0.6	1	1
Decomposition constant to calculate mass change of both root biomass and above ground biomass	$1.01x10^{-2}$	$8.5x10^{-3}$	$8.5x10^{-3}$
Optimal temperature for plant growth, (°C)	20	15	15
Plant specific drought tolerance	0.25	0.25	0.25
In row plant spacing, (m)	0.005	0.005	0.005
Max. root depth, (m)	1	1.5	1.5
Root/shoot ratio	0.25	0.25	0.25
Period of senescence occurs, (days)	14	14	14
Max.leaf area index	5	5	5
Rill and interrill tillage intensity for non fragile crops	0.98	0.98	0.98
Number of rows of tillage implement	20	20	20
Ridge height value after tillage, (m)	$2.54x10^{-2}$	$2.54x10^{-2}$	$2.54x10^{-3}$
Fraction of surface area disturbed	0.85	0.85	0.85
Bulk density after last tillage, (g cm^{-3})	1.1	1.1	1.1
Initial frost depth, (m)	0	0	0
initial residue cropping system	fallow	fallow	fallow
Cumulative rainfall since last tillage, (mm)	152.4	153.4	154.4
Initial ridge height after last tillage, (m)	$8.0x10^{-2}$	$8.0x10^{-3}$	$8.0x10^{-4}$
initial ridge roughness after last tillage, (m)	4.99	4.99	4.99
initial snow depth, (m)	0	0	0
Depth of primary tillage layer, (m)	0.15	0.15	0.15

Table 1.2 Physical soil properties by layer used to calibrate and run the WEPP model using the alternate hourly seepage for the Idaho-CT site, parameters were gathered from SURRGO soils data base and field observations.

Soil Series	Layer	Depth	Sand	Clay	OM	CEC	Bulk Density	Hydraulic Conductivity	Field capacity	Wilting point	Anisotropy
		(m)	(%)	(%)	(%)	(meq $100g^{-1}$)	(g cm^{-3})	(mm hr^{-1})	(mm mm^{-1})	(mm mm^{-1})	
Southwick	1	0.1	11.4	20	3.5	17.5	1.45	3.8	0.306	0.16	20
	2	0.2	11.4	20	3.5	17.5	1.45	10.8	0.306	0.16	5
	3	0.709	11.4	15	1.5	17.5	1.45	32.4	0.306	0.16	1
	4	0.97	14	31	0.8	12.5	1.5	32.4	0.268	0.11	1
Larkin	1	0.1	11.6	19.5	4	30	1.23	3.8	0.291	0.14	20
	2	0.2	11.6	19.5	1	30	1.23	10.8	0.291	0.14	5
	3	0.53	11.6	19.5	1	30	1.3	32.4	0.291	0.14	1

Table 1.3 Soil physical properties by soil series used to calibrate and run the WEPP model for the Idaho-CT site.

Soil Series	texture	Aledo	Initial saturation	Rill Erodibility	Interill Erodibility	Critical sheer	Bedrock thickness	Ksat
			(mm mm^{-1})	(Kg s m^{-4})	(s m^{-1})	(N m^{-2})	(mm)	(mm hr^{-1})
Southwick	Loamy sand	0.23	0.75	$4.95x10^{6}$	$9.4x10^{3}$	3.5	1000	0.0076
Larkin	Loamy sand	0.23	0.75	$4.98x10^{6}$	$9.6x10^{-3}$	3.5	1000	0.16

Table 1.4 Total annual precipataion and annual hydrologic characteristics for each watershed for water years 2012 and 2013

Site	Area	Water Year	Precipitation	Runoff			
	(ha)		(mm)	Total (mm)	% of Annual Precipitation	Average (mm day^{-1})*	Peak (mm day^{-1})*
Hooper	647,500	2012	583	98	16.8	0.2	4
		2013	480	67	14.1		
PCW	2930	2012	645	283	43.8	0.6	28
		2013	521	115	22.2		
Idaho-CT	14	2012	643	228	34.4	1.0	31
		2013	533	58	10.9		
CAF-NT	12	2012	584	12	2.0	0.1	7
		2013	483	2	0.4		

*indicates that the measurements were averaged over the two water years sampled.

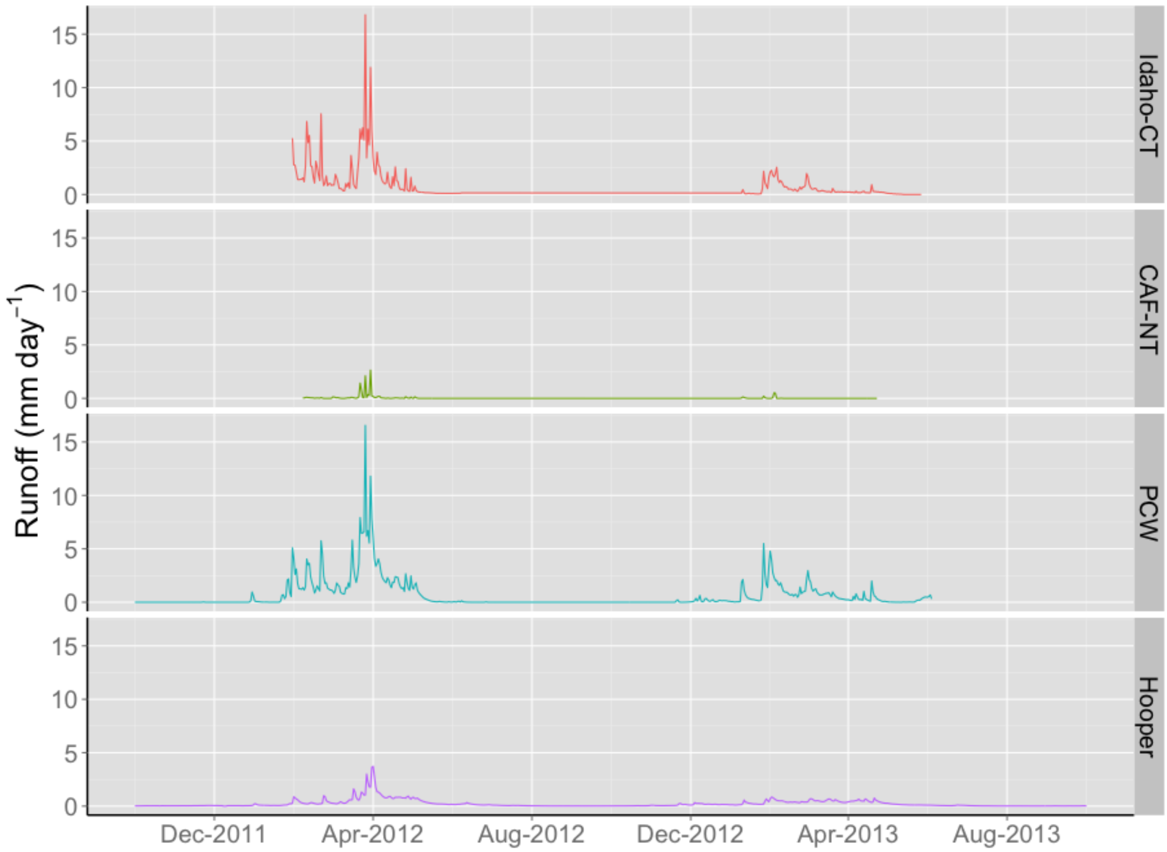

Figure 1.2 Hydrographs for water years 2012 and 2013 separated by sampling location

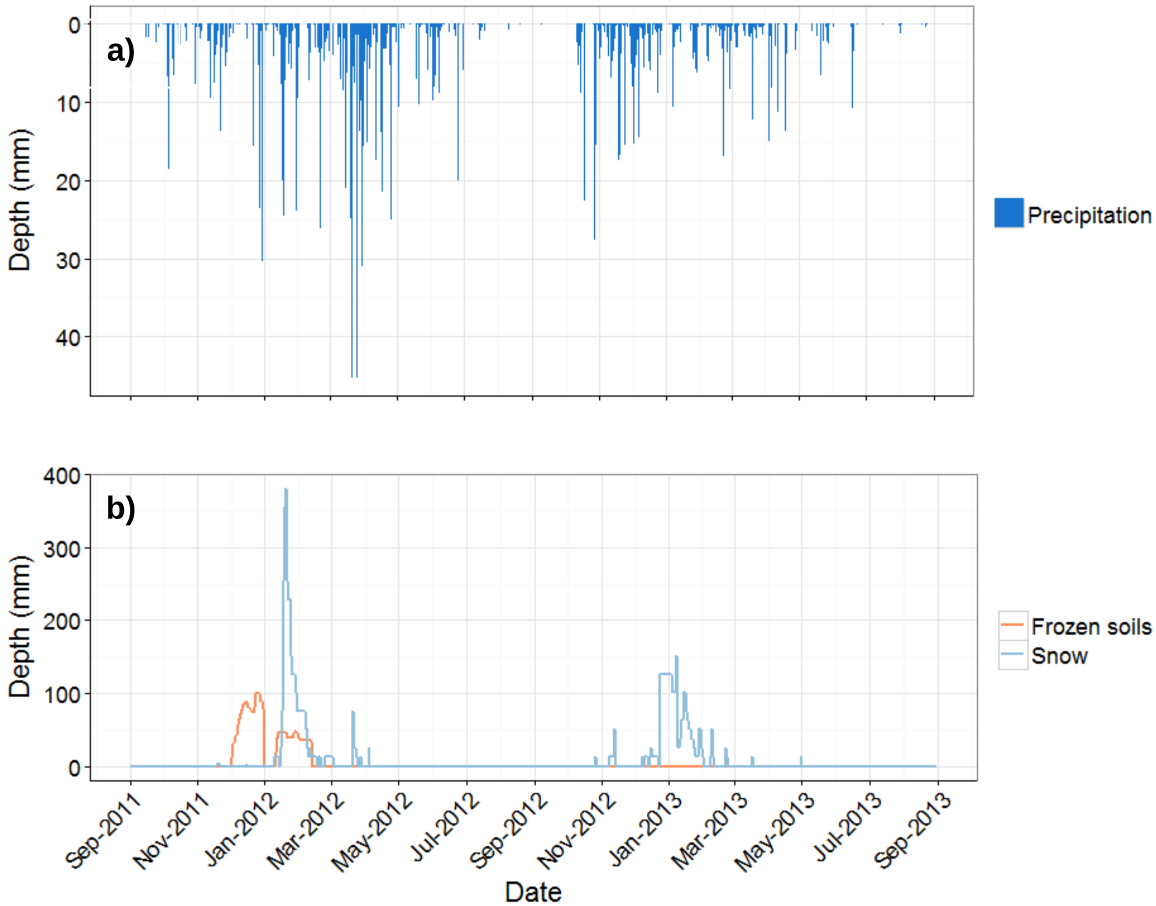

Figure 1.3 Precipitation for the Idaho-CT site a) and frozen soil and snow depths b) from the Parker Plant Science Farm for water years 2012 and 2013. The Parker farm is located 3 miles east of Moscow, ID and receives similar weather patterns to the Idaho-CT site.

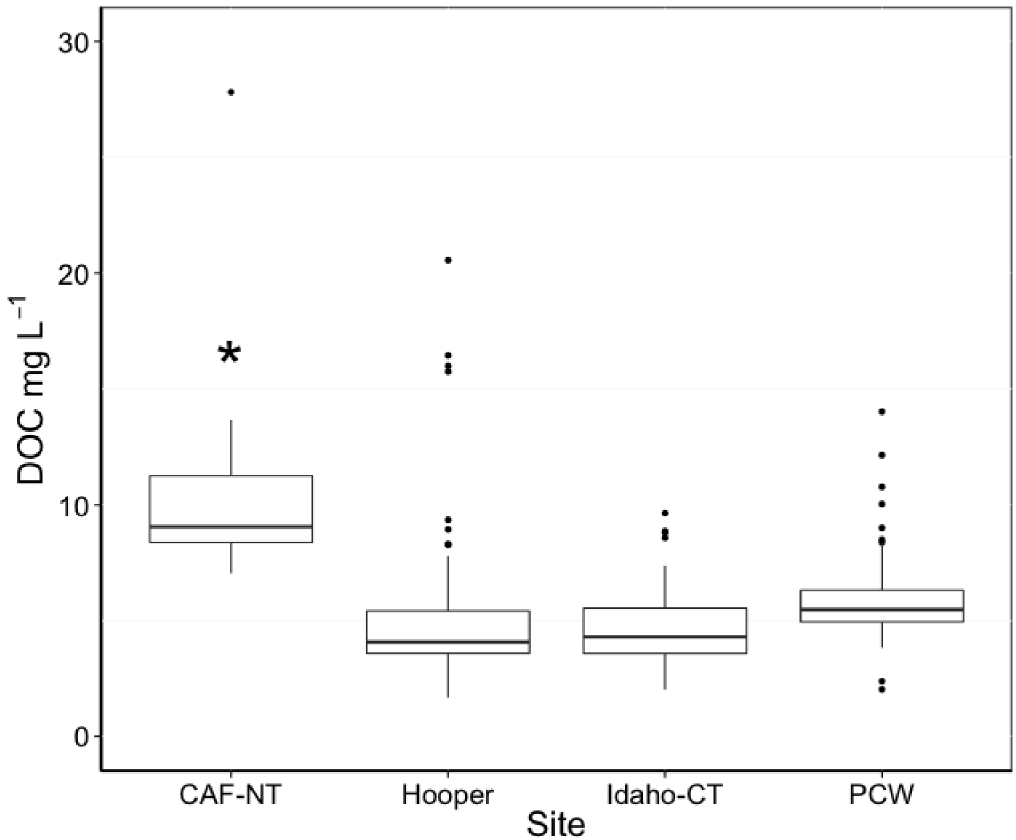

Figure 1.4 DOC concentrations from all sampling locations for water years 2012 and 2013. Upper and the lower whiskers represent the first and third quartiles. The asterisk above CAF-NT in indicates a significant difference (p value <0.05) determined stepwise with Tukey HSD.

Table 1.5 Annual average SSC DOC and POC concentrations and loads for all sampling sites during water years 2012-2013.

Site	Water year	Average Concentrations (mg L^{-1})			Annual Yield (kg ha^{-1})			
		SSC	DOC	POC	Sediment	Total OC	DOC	POC
Hooper	2012	775 ± 3047	7 ± 7	- ± -	2953 ± 5	26.2 ± 17.4	5.5 ± 5.3	20.70 ± 12.10
	2013	59 ± 41	4 ± 2	0.4 ± 0.4	34 ± 2	4.0 ± 3.7	3.8 ± 3.6	0.20 ± 0.10
PCW	2012	260 ± 457	6 ± 2	- ± -	547 ± 0.10	20.2 ± 7.5	16.4 ± 4.8	3.80 ± 2.70
	2013	198 ± 437	6 ± 2	1.2 ± 2.4	70 ± 0.01	7.2 ± 2.3	6.7 ± 1.9	0.50 ± 0.30
Idaho-CT	2012	4018 ± 5304	4 ± 1	- ± -	5617 ± 1995	69.3 ± 28.5	10.7 ± 2.9	58.60 ± 25.70
	2013	596 ± 1132	6 ± 1	8.4 ± 17.2	114 ± 42	4.3 ± 0.4	2.9 ± 0.3	1.40 ± 0.10
CAF-NT	2012	634 ± 399	10 ± 5	- ± -	73 ± 1.0	1.9 ± 0.8	1.1 ± 0.5	0.80 ± 0.30
	2013	226 ± 279	11 ± 2	1.9 ± 2.0	3 ± 0.025	0.25 ± 0.1	0.2 ± 0.1	0.05 ± 0.02

- indicates that POC measurement were not taken on the associated years.

* POC loads were calculated for 2012 using SSC concentrations POC relationships generated in 2013 under the assumption that changes in soil organic carbon occur over long periods of time, >30 years.

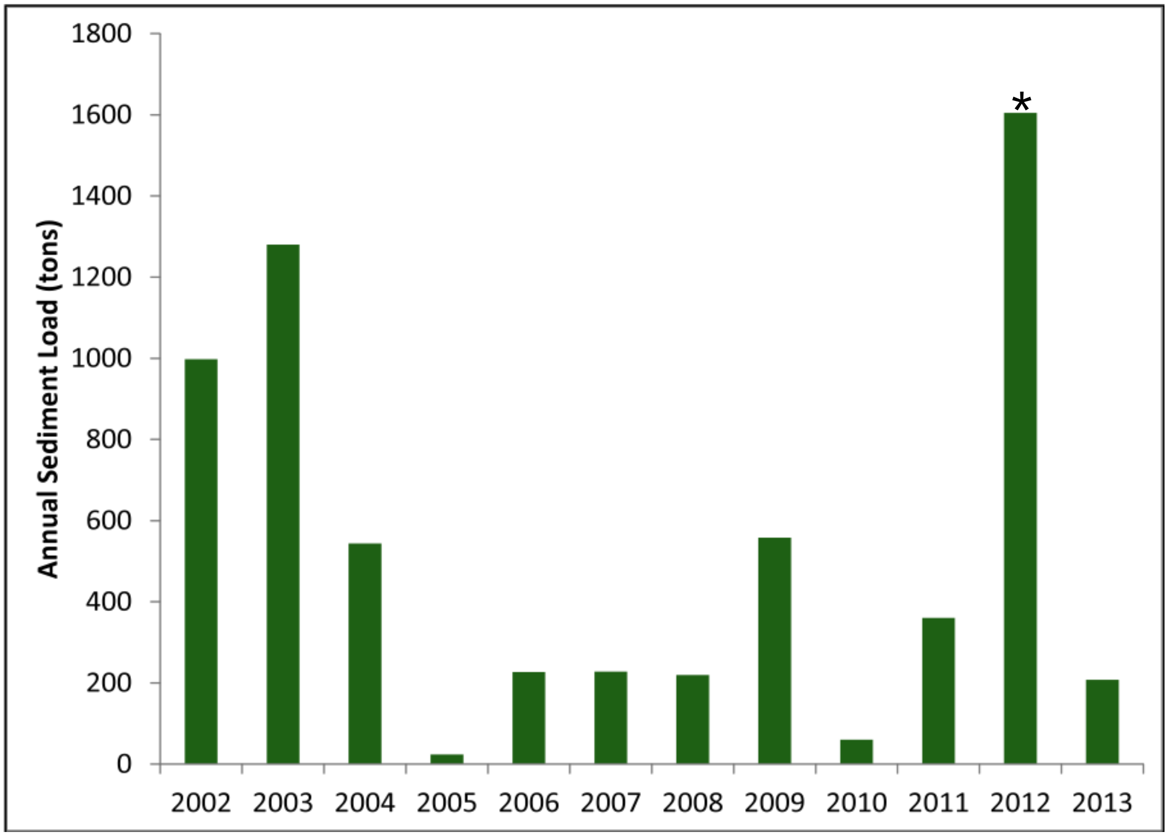

Figure 1.5 annual sediment loads from the Paradise Creek Watershed (PCW) for water years 2002 to 2013. The asterisk marks water year 2012, the highest sediment load in the 13 years that measurements were taken (Brooks et al. 2010).

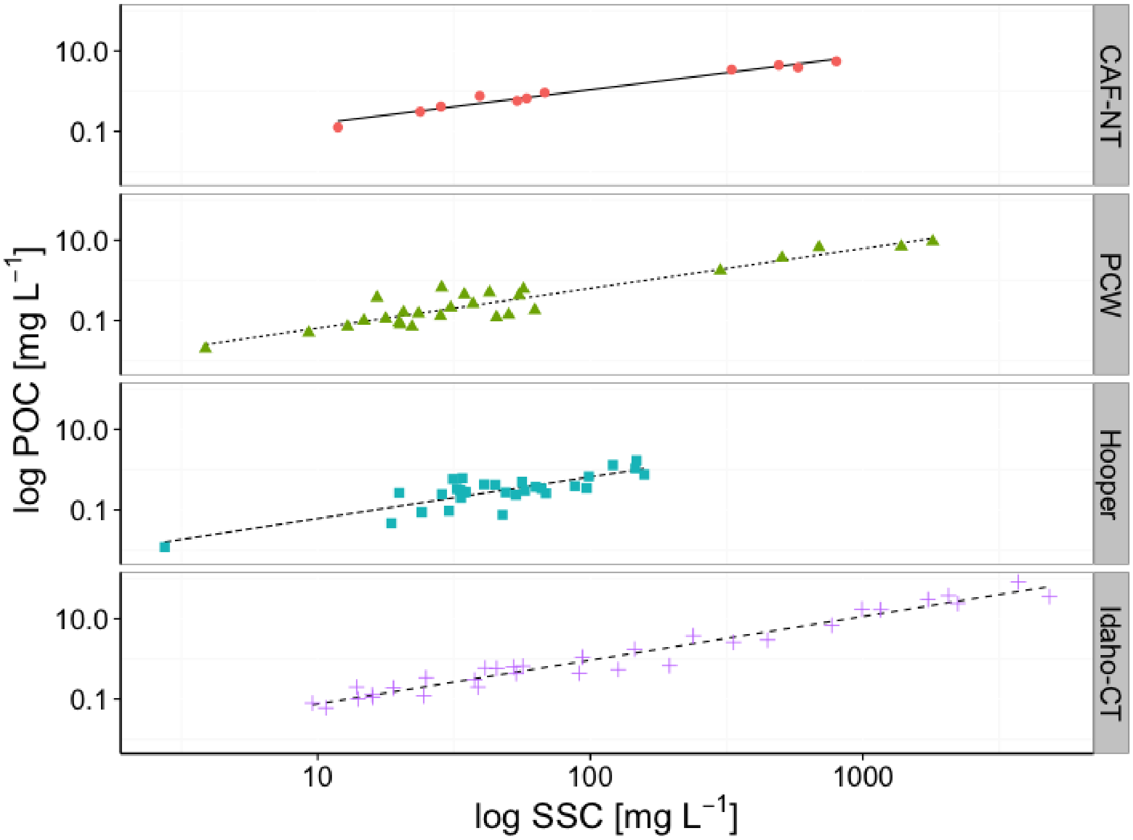

Figure 1.6 Log-log relationship between SSC concentrations for CAF-NT (R^2=0.79,p<0.01, y=0.0236$x^{0.8346}$), PCW (R^2=0.98, p<0.01, y = 0.0067$x^{0.9886}$), Idaho-CT (R^2=0.90, p<0.01, y=0.0055$x^{1.0385}$) and Hooper (R^2=0.94, p<0.01, y=0.0063$x^{1.0862}$).

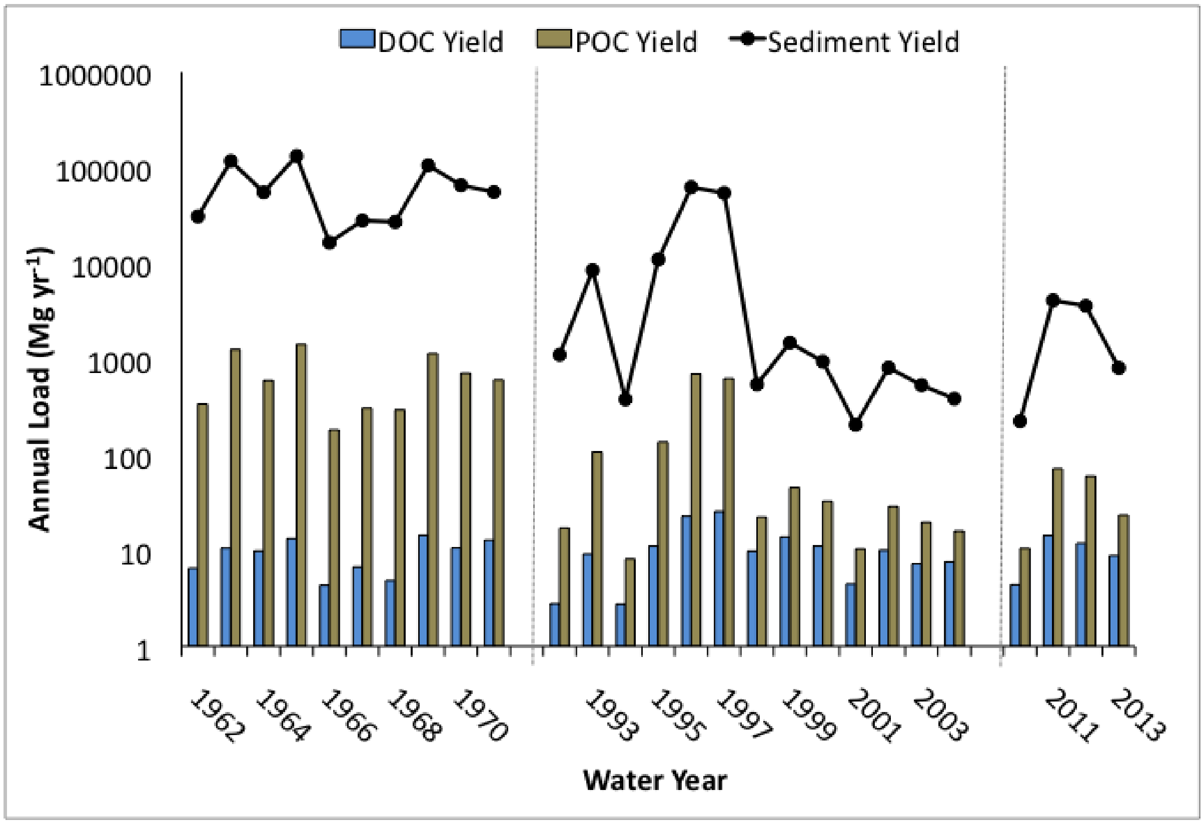

Figure 1.7 Annual estimated Sediment DOC and POC loads plotted on a log scale by water year (October 1st-October 1st) for the outlet of the Palouse Basin at Hooper, WA for three periods of sampling from 1961-1971, 1991-2004 and 2009-2013.

Table 1.6 Annual sediment and total carbon loads at the five catchment sites with time and the percentage of the total organic carbon and CO2 equivalent.

Sampling period	Site	Total Area	Time Period	Sediment Yield	Total Carbon Yield	Percentage delivered as DOC	Equivalent CO_2 emissions by number of cars**
		ha (Ag. Area)		(Mg yr^{-1})	(Mg yr^{-1})	(%)	
All years	PCW	4,890 (3,032)	1979-1995	2,000	55	63%	42
			2002-2011	700	48	85%	37
	HOOPER	647,497 (283,600)	1962-1971	2,000,000	25,000	12%	19,097
			1992-2004	360,000	7,600	48%	5,806
			2010-2012	70,000	4,400	83%	3,361
2012	Idaho-CT	14	2012	79	0.8	2%	0.6
	CAF-NT	11	2012	0.9	0.02	63%	0.0
	PCW	2,930	2012	1,600	57	84%	43.8
	Hooper	647,497	2012	120,000	6,008	68%	4,589

** Assumes 4.8 tonnes CO2 emitted vehicle^{-1}yr^{-1} (U.S Environmental Protection Agency, 2013)

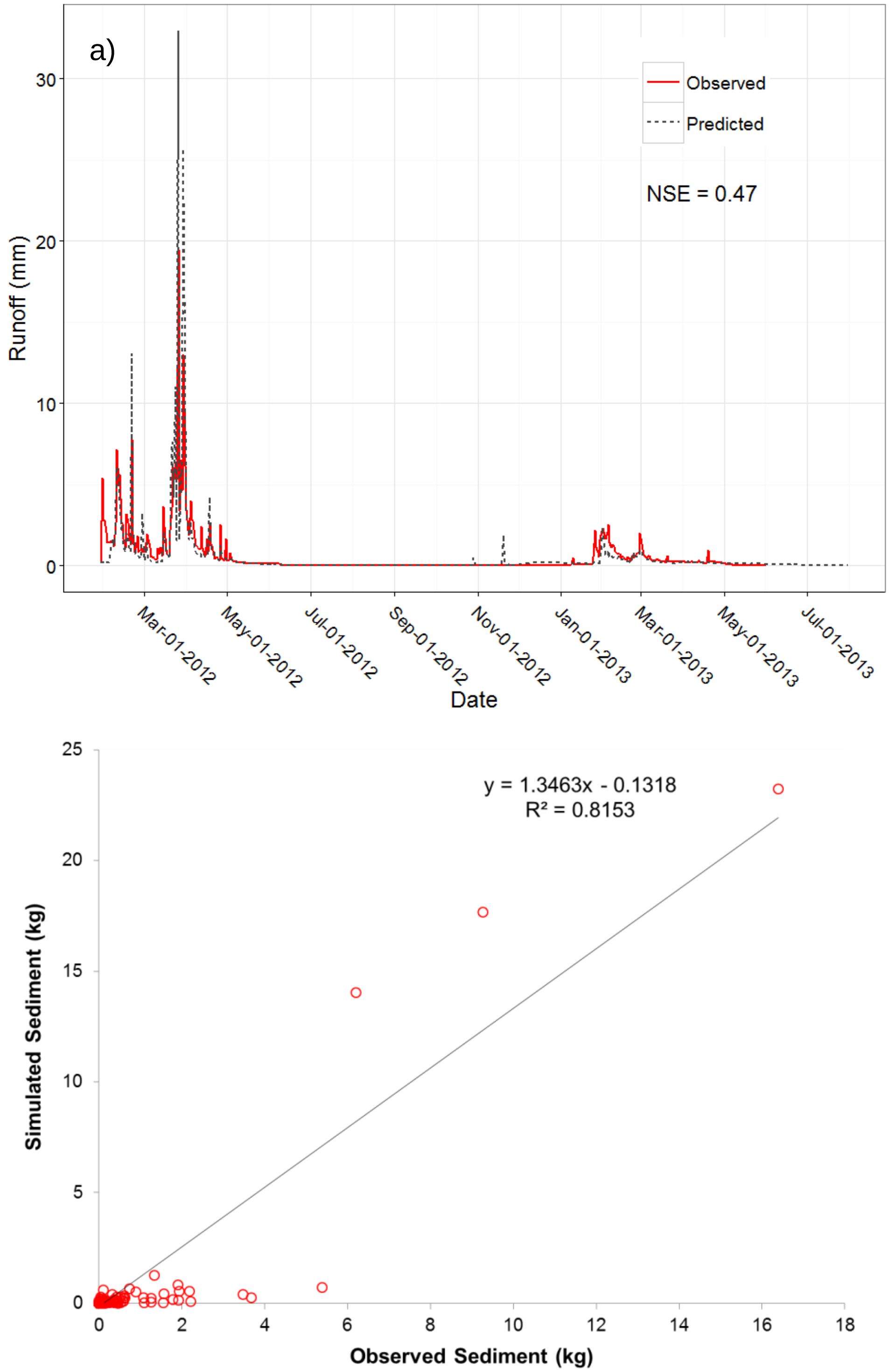

Figure 1.8 Observed and predicted runoff with Nash-Sutcliffe model efficiencies (NSE) (a) and cumulative sediment load with R^2 value slope of the line (b) at the Idaho-CT site for water years 2012 and 2013.

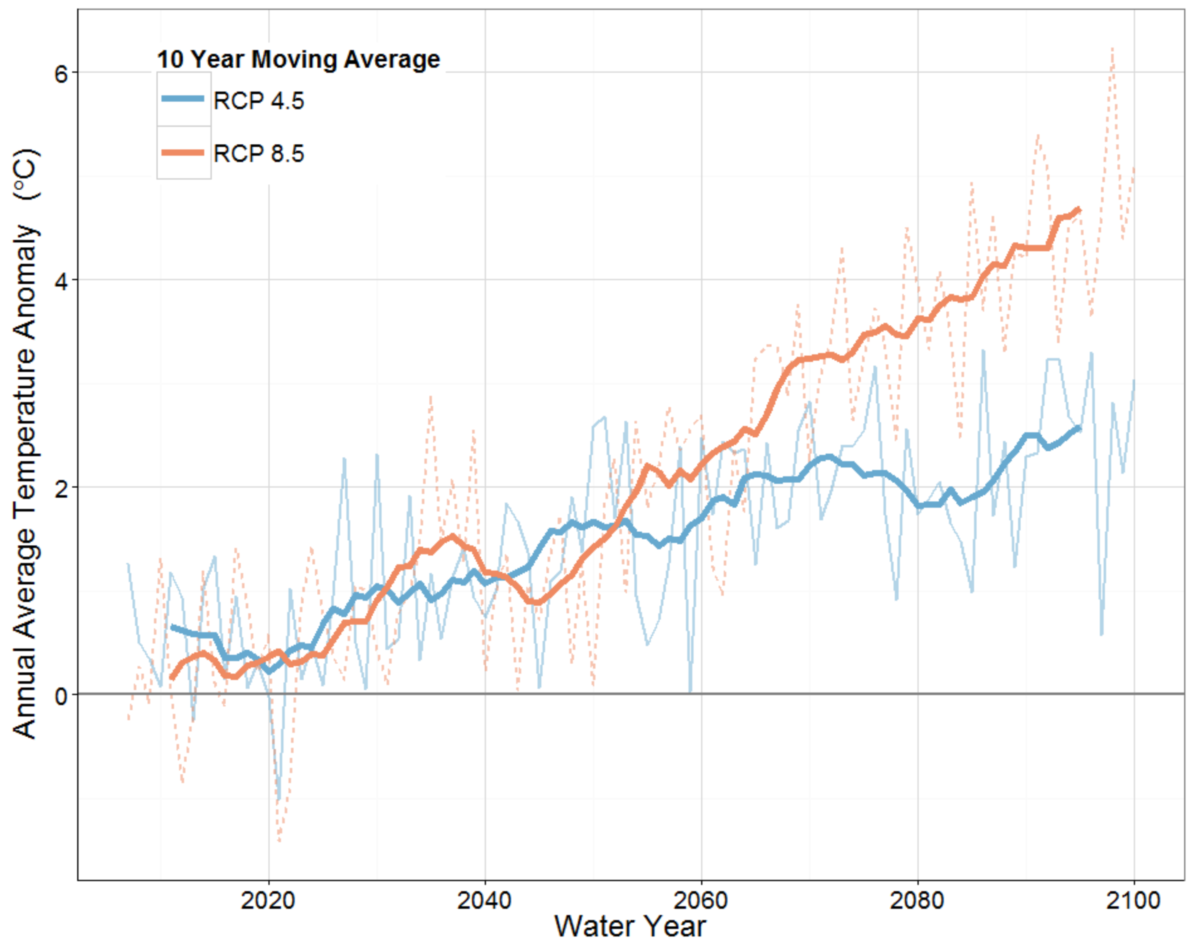

Figure 1.9. CNRM-CM5.1 predicted average annual temperature anomalys from RCP's 4.5 and 8.5. from historic annual average temperatures (1982-2010) for Moscow, ID

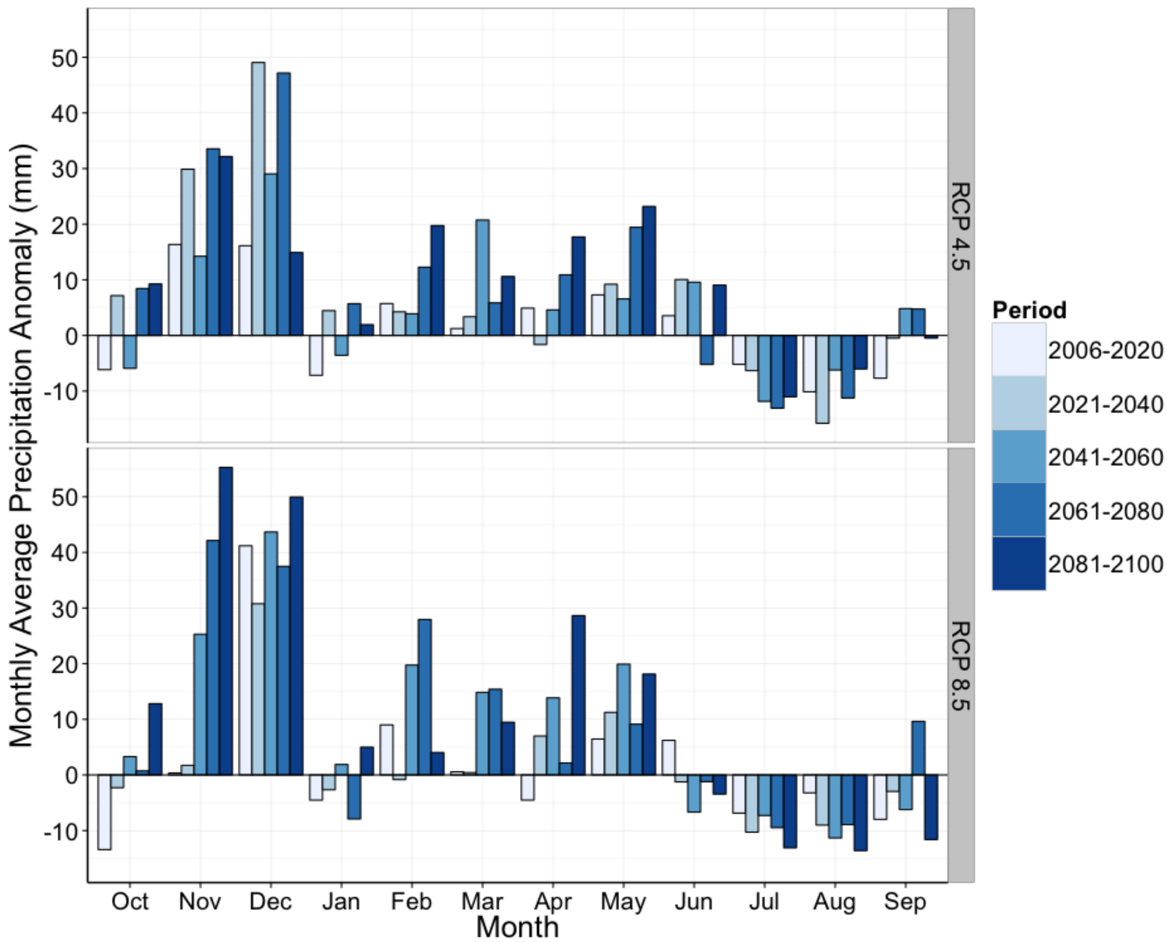

Figure 1.10 CNRM-CM5.1 predicted 20 year annual average precipitation anomaly from the historic monthly average for Moscow, ID (1982-2010).

Table 1.7 WEPP modeled 20-year averages for soil water, evapotranspiration (ET), percolation, lateral flow, snow depth, days with snow, frozen soil depth and days with frozen soils for the Idaho conventional till site.

Management	Period	RCP	Soil Water	ET	Percolation	Lateral Flow	Snow Depth	Snow	Frozen Soil Depth	Frozen Soils
	(years)		(mm)	(mm)	(mm)	(mm)	(mm)	(days)	(mm)	(days)
Conventional till (SP-WW-SB)	2006-2020	4.5	3,204	443	11	46	96	53	41	38
		8.5	3,292	466	11	46	141	64	34	30
	2021-2040	4.5	3,335	449	13	62	135	54	42	33
		8.5	3,260	472	11	44	96	45	35	29
	2041-2060	4.5	3,309	460	13	58	48	30	44	32
		8.5	3,378	485	13	64	87	38	40	29
	2061-2080	4.5	3,324	462	13	66	84	33	37	23
		8.5	3,352	505	13	59	50	20	37	21
	2081-2100	4.5	3,408	479	13	67	60	28	44	25
		8.5	3,379	514	13	66	59	14	37	15
No till (SP-WW-SB)	2006-2020	4.5	3,227	451	11	46	96	53	41	38
		8.5	3,300	486	10	39	141	64	34	30
	2021-2040	4.5	3,361	460	13	61	135	54	42	33
		8.5	3,276	491	10	37	96	45	35	29
	2041-2060	4.5	3,342	475	12	55	48	30	44	32
		8.5	3,398	506	12	57	87	38	40	29
	2061-2080	4.5	3,335	475	13	61	84	33	37	23
		8.5	3,356	523	12	51	50	20	37	21
	2081-2100	4.5	3,417	497	13	61	60	28	44	25
		8.5	3,383	534	12	56	59	14	37	15

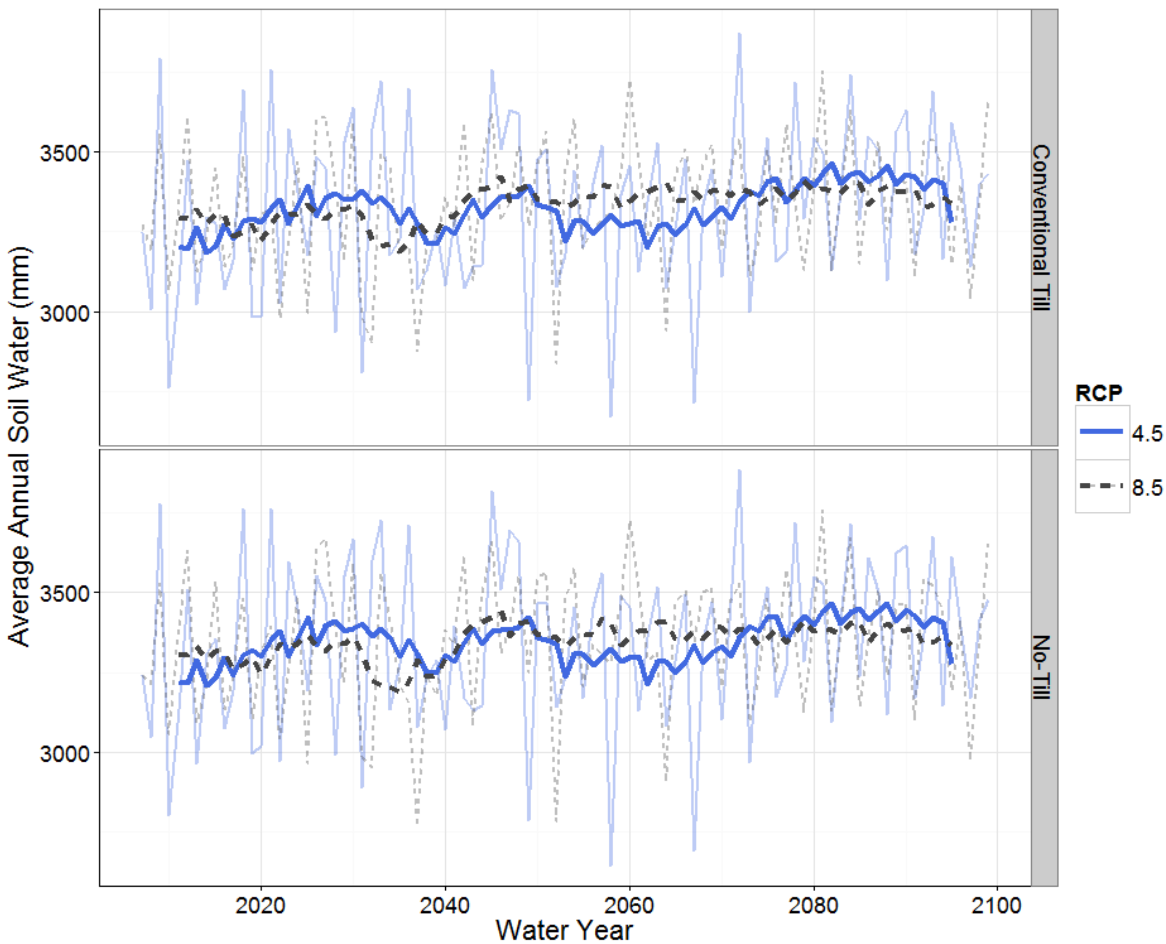

Figure 1.11 WEPP predicted average annual soil water, light colored lines, and 10 year moving averages, dark lines, for RCP's 4.5 and 8.5 and conventional and no-till management practices at the Idaho-CT site.

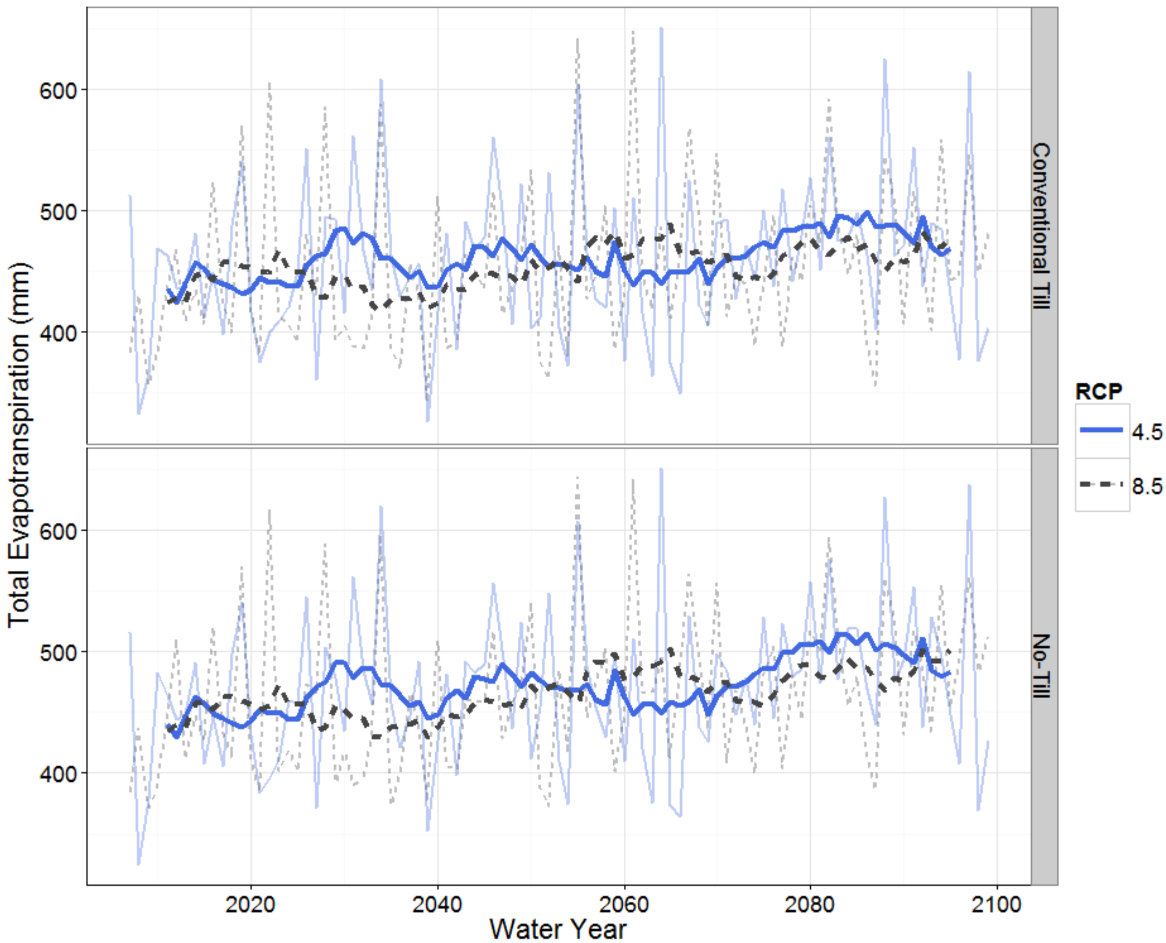

Figure 1.12 WEPP predicted average annual total soil evapotranspiration, light colored lines, and 10 year moving averages, dark lines, for RCP's 4.5 and 8.5 and conventional and no-till management practices at the Idaho-CT site.

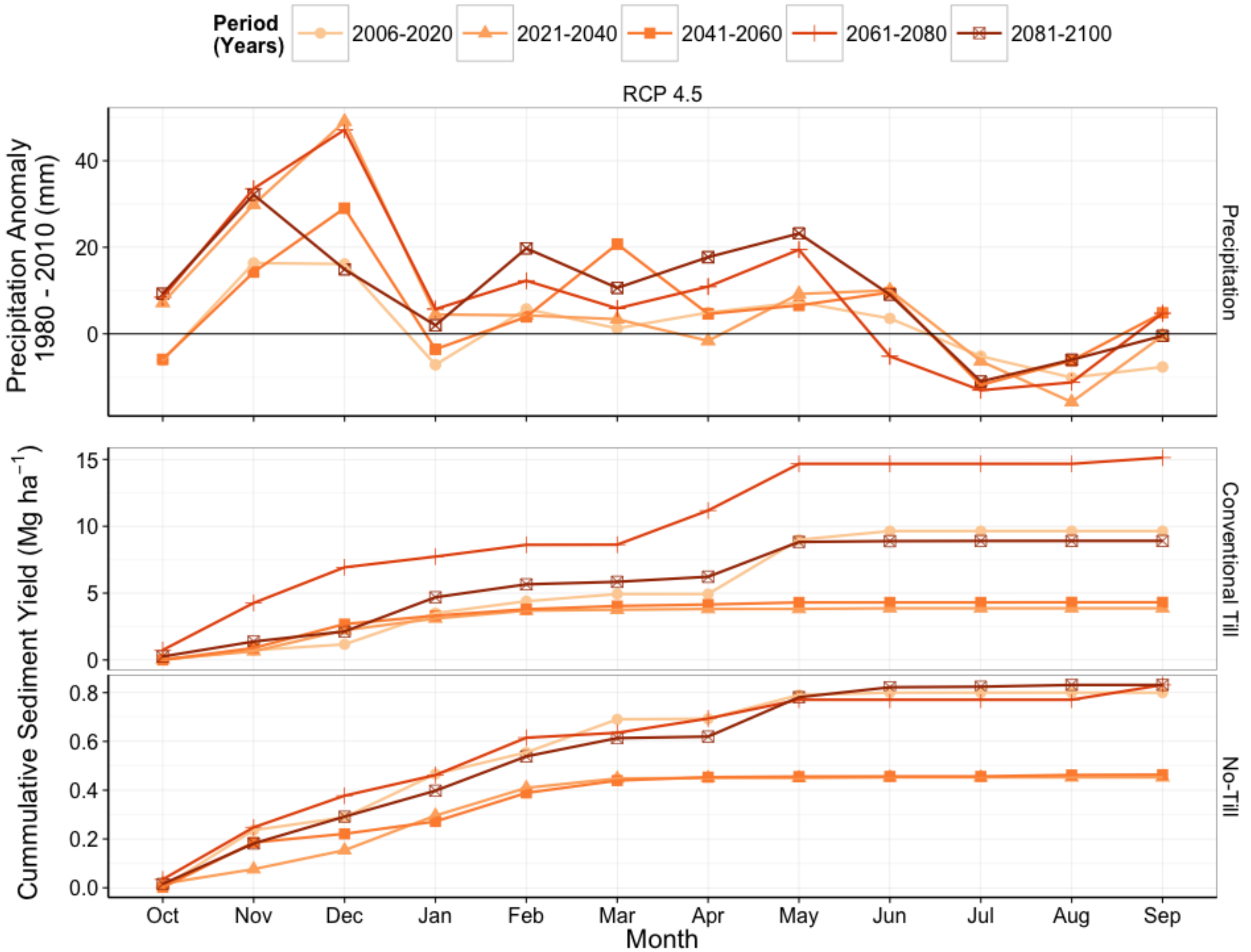

Figure 1.13 Predicted average monthly precipitation (top) and average monthly cumulative sediment load by 20-year period for RCP 4.5 and conventional and no till management at the Idaho-CT site.

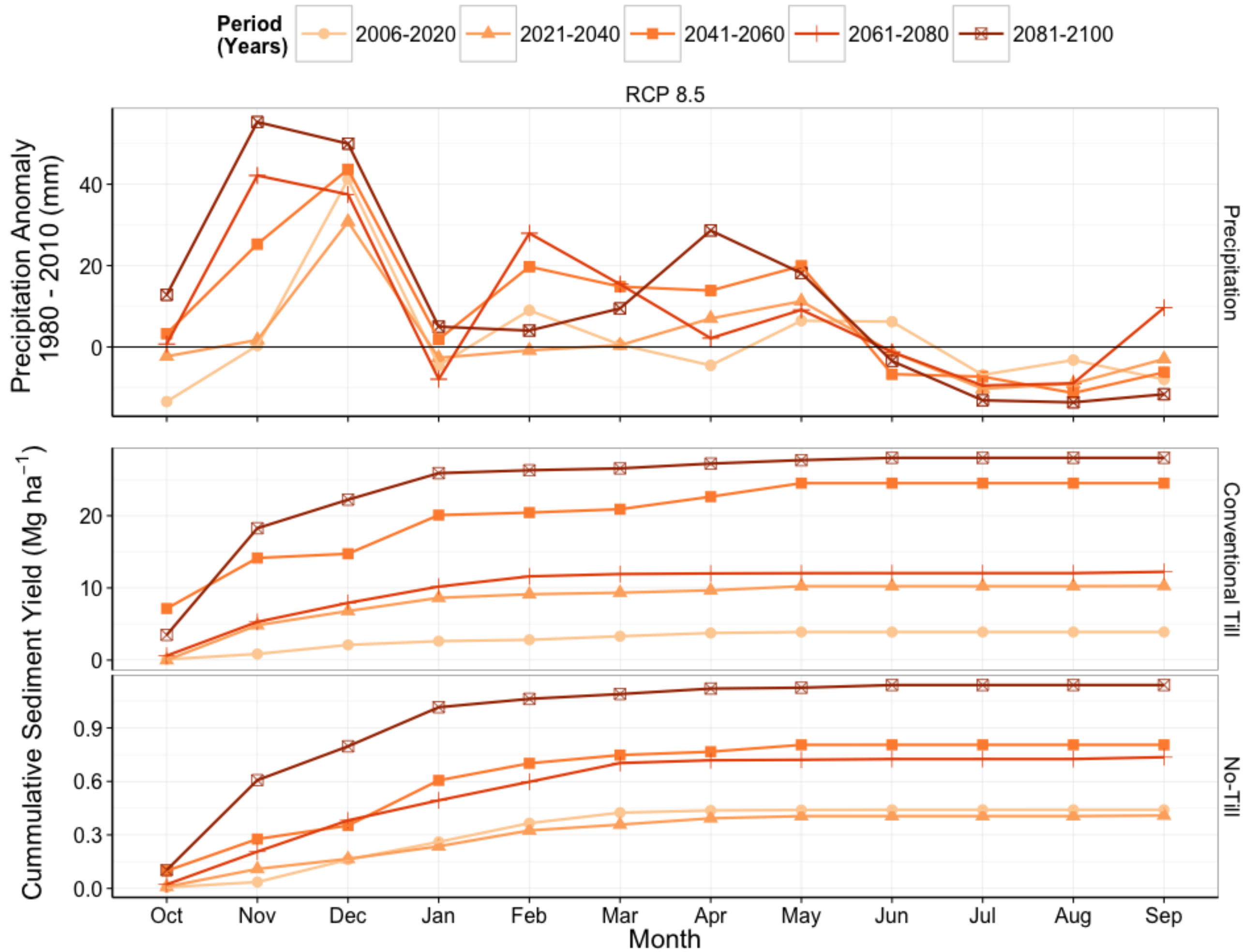

Figure 1.14 Predicted average monthly precipitation (top) and average monthly cumulative sediment load (bottom) by 20-year period for RCP 8.5 and conventional and no-till managements at the Idaho-CT site.

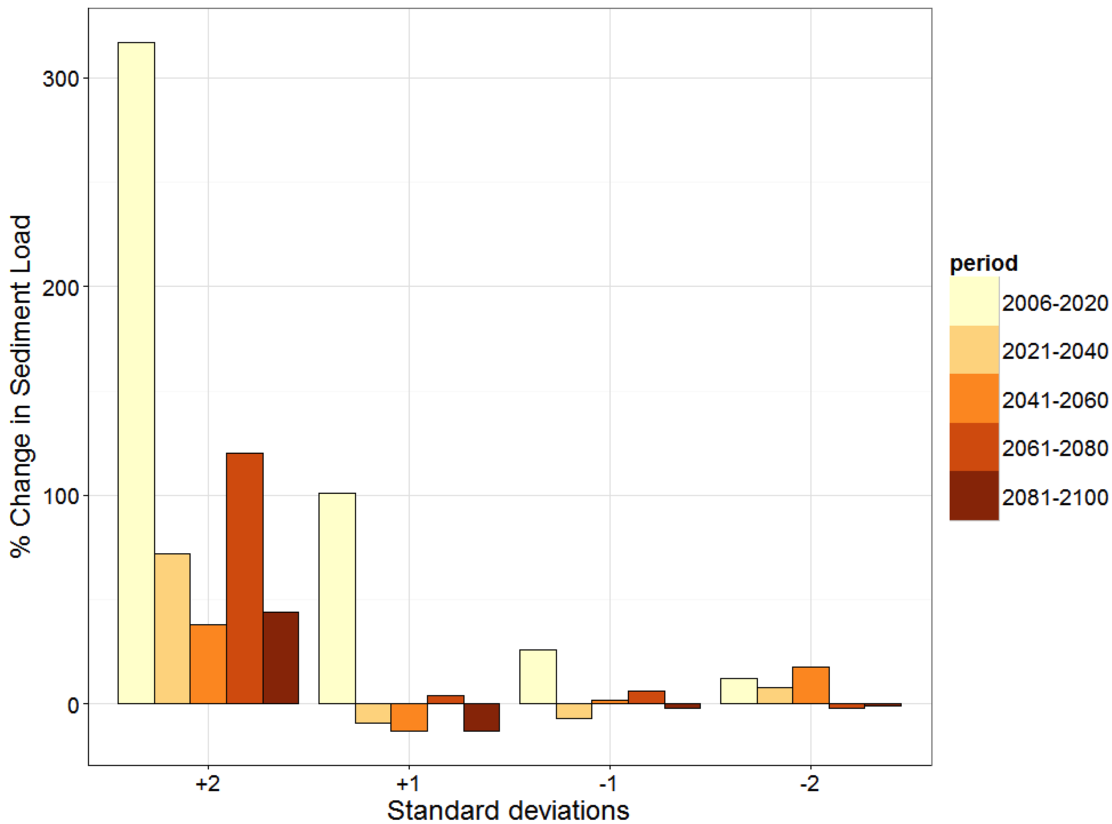

Figure 1.15 Rainfall intensity sensitivity analysis and the predicted change in sediment load for the RCP 8.5 climate scenario at the Idaho-CT site. The x-axis represents changes in storm duration by one and two standard deviations in both directions from the mean storm duration predicted by the RCP 8.5 scenario. The y-axis represents a percent change in sediment load from the predicted sediment load of the RCP 8.5 scenario. Colored bars are 20-year averages.

Table 1.8 20 year averages and changes from 2020 for total precipitation, total runoff, sediment and organic carbon loads from the WEPP watershed model for the Idaho-CT site using CNRM-CM5.1 and climate data for RCP's 4.5 and 8.5.

Management	Period	RCP	Total Precip.	Total Runoff	Sediment Load	POC Load	DOC Load	Δ Precip.	Δ Total Runoff	Δ Sediment load	Δ POC Load	Δ DOC load
	(years)		(mm)	(mm)	(Mg ha^{-1})	(Mg ha^{-1})	(Mg ha^{-1})	(mm)*	(%)	(%)	(%)	(%)
Conventional till (SP-WW-SB)	2006-2020	4.5	706 ± 134	83 ± 56	10 ± 12	1.0 ± 1.2	0.05 ± 0.03	19				
		8.5	711 ± 80	83 ± 38	4 ± 6	0.4 ± 0.6	0.05 ± 0.02	23				
	2021-2040	4.5	781 ± 140	111 ± 65	4 ± 6	0.4 ± 0.6	0.06 ± 0.04	93	34%	-60%	-60%	34%
		8.5	709 ± 137	78 ± 51	10 ± 15	1.0 ± 1.6	0.05 ± 0.03	22	-7%	161%	160%	-7%
	2041-2060	4.5	754 ± 121	85 ± 50	4 ± 6	0.4 ± 0.6	0.05 ± 0.03	66	3%	-56%	-55%	3%
		8.5	799 ± 106	120 ± 52	25 ± 48	2.5 ± 4.9	0.07 ± 0.03	111	44%	530%	526%	44%
	2061-2080	4.5	806 ± 130	122 ± 73	15 ± 21	1.5 ± 2.2	0.07 ± 0.04	119	47%	56%	56%	47%
		8.5	805 ± 127	113 ± 62	12 ± 23	1.2 ± 2.3	0.07 ± 0.04	117	35%	214%	212%	35%
	2081-2100	4.5	809 ± 106	108 ± 49	9 ± 14	0.9 ± 1.4	0.06 ± 0.03	121	30%	-8%	-8%	30%
		8.5	829 ± 105	119 ± 58	28 ± 38	2.8 ± 3.9	0.07 ± 0.03	142	43%	620%	615%	43%
No till (SP-WW-SB)	2006-2020	4.5	706 ± 134	83 ± 56	0.8 ± 1	0.08 ± 0.11	0.08 ± 0.06	19				
		8.5	711 ± 80	84 ± 38	0.4 ± 1	0.05 ± 0.10	0.09 ± 0.04	23				
	2021-2040	4.5	781 ± 140	112 ± 73	0 ± 1	0.05 ± 0.07	0.11 ± 0.07	93	35%	-44%	-41%	35%
		8.5	709 ± 137	79 ± 53	0.4 ± 0	0.04 ± 0.05	0.08 ± 0.05	22	-5%	-9%	-9%	-5%
	2041-2060	4.5	754 ± 121	87 ± 53	0.5 ± 0	0.05 ± 0.05	0.09 ± 0.05	66	5%	-43%	-41%	5%
		8.5	799 ± 106	119 ± 52	0.8 ± 1	0.09 ± 0.11	0.12 ± 0.05	111	42%	84%	79%	42%
	2061-2080	4.5	806 ± 130	122 ± 74	0.8 ± 1	0.09 ± 0.07	0.12 ± 0.08	119	47%	2%	4%	47%
		8.5	805 ± 127	113 ± 63	0.7 ± 1	0.08 ± 0.08	0.11 ± 0.06	117	35%	68%	64%	35%
	2081-2100	4.5	809 ± 106	105 ± 53	0.8 ± 1	0.09 ± 0.08	0.11 ± 0.05	121	27%	4%	3%	27%
		8.5	829 ± 105	115 ± 59	1.1 ± 1	0.12 ± 0.11	0.12 ± 0.06	142	37%	159%	149%	38%

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Chapter 2: Developing interdisciplinary modeling lessons within the context of the Next Generation Science Standards

Introduction

Recent trends in education in the United States indicate that students leaving high school are ill prepared to join the workforce in careers related to science, technology, engineering and mathematics (STEM). A study done by the Program for International Student Assessment in 2006 identified that students in the United States ranked 21st of 30 developed nations in math and science literacy (Schleicher, 2007). This troubling realization prompted scientists, educators, and policy makers to call for a greater focus on STEM education in the traditional science and technology classrooms. The motivation was in part to better train the workforce of tomorrow, and in part to maintain the United States' standing as a competitive and innovative leader in the global economy.

In 2012, the National Research Council released *A Framework for K-12 Science Education* (Schweingruber et al., 2012) as a guide for a new set of science standards that would better prepare students for STEM related careers. The result of this framework was the Next Generation Science Standards (NGSS) released in April of 2013. The NGSS require that students develop deep understanding of core disciplinary ideas, are able to provide evidence of their knowledge through scientific and engineering practices, and are able to connect concepts across multiple disciplines (Pruitt, 2014). Many states have been slow to adopt the NGSS for a variety of reasons. Some of which include being satisfied with current state science standards, the political climate of the state, the uncertainty surrounding the assessment of the NGSS, and the lack of quality materials developed specifically for the NGSS (Pruitt, 2014).

A key component of the *Framework for K-12 Science Education* that was used in the NGSS, is developing and using models in the classroom (Schweingruber, H., Keller, T., and Quinn. H., 2012). Specifically, one of the NGSS for high school students in Earth and Human Activity (HS-ESS3-5) states that students should be able to “Analyze data using computational models in order to make valid and reliable scientific claims.” (NGSS Lead States, 2013). Furthermore, statistics from the U.S. Department of Education have shown that only a quarter of all computer, math and science teachers surveyed in U.S. public schools have tried to expose their students to computer based modeling exercises more than once (Gray et al., 2010). Reasons for limited use of computer based models in the classroom could be attributed to the lack of appropriate and accessible activities, as well as finding the time needed for both the teacher to learn the program, and the students to run the program (Repenning et al., 2013).

A stronger understanding of computer based modeling in the classroom is becoming even more important as many STEM professions are now using modeling based tools to inform policy and management decisions. Modeling efforts are commonly conducted in both science and engineering to examine changes in natural and man-made systems that are difficult to quantify with traditional field-based measurements. With increasing access to technology, there has been a boom in computer-based tools that help guide environmental planning and management decisions for policy makers, land managers and stakeholders. These tools, formally referred to as decision support systems (DSS), are generally comprised of models, databases and assessment tools packaged in a user-friendly interface. DSS were first developed in the 1960s in the business sector (Morton 1971) but have been adapted for the sustainable management of environmental systems due to the complex interactions between ecological, human and economic subsystems (Matthies et al., 2007). Thus, the models behind many DSS are complex in nature and often require a high level of understanding to be able to use the tool effectively. This being said, a developer can tailor the complexity of the tool to a specific end-user. Matthies et al., (2007) lumped end-users into three groups (1) environmental scientist or systems analyst, (2) environmental manager or decision maker, and (3) environmental stakeholder, e.g. landholder, conservation groups (Matthies et al., 2007).

Evidence of designing a DSS to a specific end-user, group two, was seen in work done by Elliot (2004) when the Watershed Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995) was simplified into user-friendly online tools for U.S. Forest Service employees. Prior to the development of the online tools an informal survey in 1995 found that only 2 employees were using the WEPP model. When the online tools were introduced and demonstrated users increased to 600 by 2001. User numbers then doubled by 2003 and included individuals from federal, state, university and private organizations (Elliot, 2004).

An additional example of a DSS that was designed for groups two and three is the Hydrologic Characterization tool (HCT). The HCT was developed as a quantitative planning and decision support tool for the selection and placement of conservation practices over a landscape (Brooks et al., 2014). This web-based, user-friendly tool quantifies the movement of water through dominant hydrologic flow paths that generate runoff, soil erosion and related pollutants from a hillslope using a modified version of the WEPP model. The user defines site specific climate, management, soil and slope types that are input into the WEPP model which runs in the background of the HCT interface. Users can also select various management scenarios in order to assess their effects on hydrology and sediment and pollutant loads. The

HCT provides monthly and hillslope graphical output, as well as tables of annual data. With minimal training and a basic understanding of core disciplinary concepts associated with hydrology and soil science, HCT is comprehendible to a broad audience for use as a planning or educational tool.

Although the NGSS are slow to take hold in many parts of the country there is an obvious need for education materials that meet the criteria of the NGSS. Lesson plans and activities that bridge multiple disciplines and focus on modeling efforts will become increasingly important as we move further into the age of DSS to better train our future workforce. With these needs in mind, this paper outlines a NGSS lesson plan developed by an interdisciplinary team of researchers that uses both physical and computer based models to explore soil infiltration, runoff, and erosion.

Approach

Developing an interdisciplinary lesson plan

An interdisciplinary team of graduate students from the University of Idaho was formed to develop a lesson plan for high school science and agricultural technology classrooms in Idaho, Washington and Oregon. The team was comprised of M.S. and Ph.D. students in the disciplines of soil science, water resources management, economics and education. Team members were all research assistants in the Regional Approaches to Climate Change for Pacific Northwest Agriculture (REACCH) grant funded through the National Institute of Food and Agriculture (#2011-68002-30191).

The topics of soil infiltration, runoff and erosion were selected because of their regional significance. The dryland cropping region of the Inland Pacific Northwest, has had a long history of soil erosion (Ebbert and Roe, 1998; Papendick, 1996; Kok et al. 2009; Brooks et al., 2010) negatively impacting the environment and local economies, making the topic relevant to local students in the region. The lesson was developed under the criteria that it would be cost effective to implement in the classroom, include relevant scientific literature, align with NGSS, and incorporate aspects of each of the associated team members' research.

Integrating soil science, economics, hydrology and education

With the topic and criteria developed for the lesson plan the team was then tasked with integrating their respective disciplines. The lesson plan was titled "Water and Erosion of the Soil" and the approach taken was to develop visual aids for teachers through three PowerPoint presentations. The presentations focused on major themes in hydrology, soil science and modeling. The presentations for both hydrology and soil science incorporated aspects of economics. An inquiry-based lab activity titled "Soil Infiltration and Runoff" (Appendix G) was developed to demonstrate principles covered in the PowerPoint presentations. In the lesson students are given the opportunity to physically model and measure runoff, soil erosion and infiltration under various rainfall intensities, slope steepness, and residue cover. Two extension activities were added to address (1) the economics of soil water and erosion (Appendix H), and (2) computer modeling of runoff and erosion with the HCT (Appendix I). In the economics extension students read selected pieces of scientific literature and complete a worksheet to calculate the effects of infiltration and erosion on crop yields. In the computer modeling extension activity students simulate soil erosion and runoff with the HCT mimicking what they had physically modeled in the Soil Infiltration and Runoff lab. The students then simulate and explore different conservation measures in the model and examine the ability of these measures to mitigate runoff, sediment and pollutant loads.

Outcomes

The “Water and Erosion of the Soil” lesson plan and supplementary materials were compiled (Appendices F,G and H) and presented to 19 high school science and agricultural education teachers during the summer of 2013 at a REACCH-sponsored teacher workshop in Moscow, ID. Presentations included an introduction to modeling, the use of models in science, and demonstrations of the soil infiltration and runoff experiment and the HCT. The participants were engaged and interested in these topics.

All of the “Water and Erosion of the Soil” lesson plan materials were compiled into a water and soils unit, and incorporated into a semester long curriculum developed by the REACCH education team. The curriculum focuses on climate change issues in agriculture and was based on REACCH related research (Regional Approaches to Climate Change for Pacific Northwest Agriculture, 2014). The participants in the 2013 teacher workshop agreed to teach the curriculum during the 2013-2014 school year, and give their students pre- and post-knowledge surveys to evaluate the effectiveness of the curriculum. The results of the surveys are still pending and should be released in the next several months.

Preliminary feedback was received through a personal communication with a high school agricultural education and technology teacher in southern Idaho. The teacher used the “Soil infiltration and runoff” lab and computer modeling extension activities in his classroom. They noted that the lab went really well and the students especially liked physically modeling runoff and erosion once it was adapted to work with his curriculum. When asked about the computer modeling activity he said “it was at a pretty high level for his students so they did not end up spending that much time with it”. When asked if he thought the computer simulation were valuable he indicated that he would rather have more hands-on activities for his classroom.

Discussion

Lessons learned from creating an interdisciplinary lesson for high school science classrooms.

Bringing current, relevant research into the classroom can be a complicated task particularly when integrating multiple disciplines. While the lesson plan presented here was cohesive in content with clear links across disciplines, there are common challenges that arise when implementing interdisciplinary lesson plans in the classroom. The first challenge is identifying independent core disciplinary concepts that can then facilitate students' ability to make connections between core concepts across disciplines (Pruitt, 2014). While the lesson plan presented attempted to bridge the disciplinary concepts of soil science, hydrology and economics, it was done so in a stepwise manner that may be too segmented for students to be able to make the cross-disciplinary connections. Better integration of the concepts of modeling and economics throughout the lesson, or even the lab activity may have aided in students making the cross discipline connections. As researchers it was easy to identify the core concepts in our respective disciplines but gauging the level of understanding high school students will have in one day was not as easy. In communicating science, whether it is interdisciplinary or not, it is beneficial to have your target audience in mind and to simplify the concepts to the knowledge level of the audience.

Secondly, developing a lesson plan from a research perspective does not always take into account challenges that teachers face on a daily basis in their classrooms. Some of these challenges include, but are not limited to, small budgets, time constraints, adhering to the state curriculum, and the willingness to use and have access to various forms of technologies in the classroom. The "Water and Erosion of the Soil" lesson plan attempted to address several of the above-mentioned challenges by outlining specific criteria prior to creating the lesson. The

19 teachers that agreed to teach the curriculum will provide feedback for the REACCH education team on how well the lesson fit within the context of their classrooms to assess whether these challenges were met adequately. This iterative process will help refine the "Water and Erosion of the Soil" lesson and the rest of the curriculum to address some of the challenges teachers face in implementing lessons developed for the NGSS.

Finally, as an interdisciplinary group of graduate students preparing these lessons, there were several challenges that needed to be overcome. Some of the key challenges with interdisciplinary work include linguistic and conceptual divides, validation of evidence, societal context of research, perceived nature of the world and reductionist versus holistic science (Eigenbrode et al., 2007). For this group, learning to communicate outside of one's respective discipline, taking a more holistic approach to the problems associated with soil erosion and differences in individual pedagogies were some of the biggest challenges. Had the lesson been created from a single disciplinary perspective, hydrology for instance, the economic importance of soil water may have not been accounted for. Interdisciplinary work has enabled us to view the world from different perspectives and communicate our research in a way that is not only relevant to our respective disciplines but to larger audiences. Finally, integrating real-world science and management tools into the science classroom is beneficial not only for students and teachers and also for researchers.

Integrating models with the NGSS in the classroom

Developing and using models in the classroom was one of the core ideas presented in the NGSS. Schweingruber et al (2012) stated "models should increasingly be used across the grades in both instruction and curriculum materials as student's progress through their science education. Curricula will need to stress the role of models explicitly and provide students with modeling tools so that students come to value this core practice and develop a level of facility in constructing and applying appropriate models." The "Water and Erosion of the Soil" lesson plan used both physically and computer based models to examine runoff and soil erosion. The goal was to teach students about the processes associated with runoff and erosion using a hands-on, physical model in the classroom. Investigating how computer models try to mathematically represent these complex processes followed this. Students would apply the computer model, based on the same processes they observed in the physically based activity and use technologies currently being employed by scientists and land managers in the real world. This process enables students to gain an understanding of how models are used to support management decisions in STEM related fields, a practice that will no doubt become increasingly valuable as students enter the work force. Furthermore, as students start to understand the influence of science, engineering and technology on society and the natural world (Schweingruber et al., 2012) they may help bridge the gap between model developer and end users as we move into the future.

The reluctance to apply computer models in the classroom was highlighted by the personal communication with the teacher at Castleford high school. This is interesting in a generation where most kids regularly utilize mobile phones, social media computer games and apps. It seems there is a great opportunity to communicate science through these medias and develop computer models that are appropriate for science education.

Conclusion

The push for STEM education and the implementation of the NGSS from state and national levels calls for new practices and activities in science curriculums. The lesson plan presented here attempts to ease this transition by incorporating relevant interdisciplinary science in conjunction with physical and computer based models in a simple format that teachers can implement into their classrooms. The feedback from the 19 teachers which will instruct the iterative approach taken by the REACCH education team to create a useable NGSS curriculum for teachers nationwide is still pending. Addressing challenges related to implementing the NGSS in the U.S. is a pivotal first step for changing science education in the U.S. In the words of John F. Kennedy, "change is the law of life, those who look only to the past or present are certain to miss the future. "

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Appendices

Appendix A:

Pictures of study sites

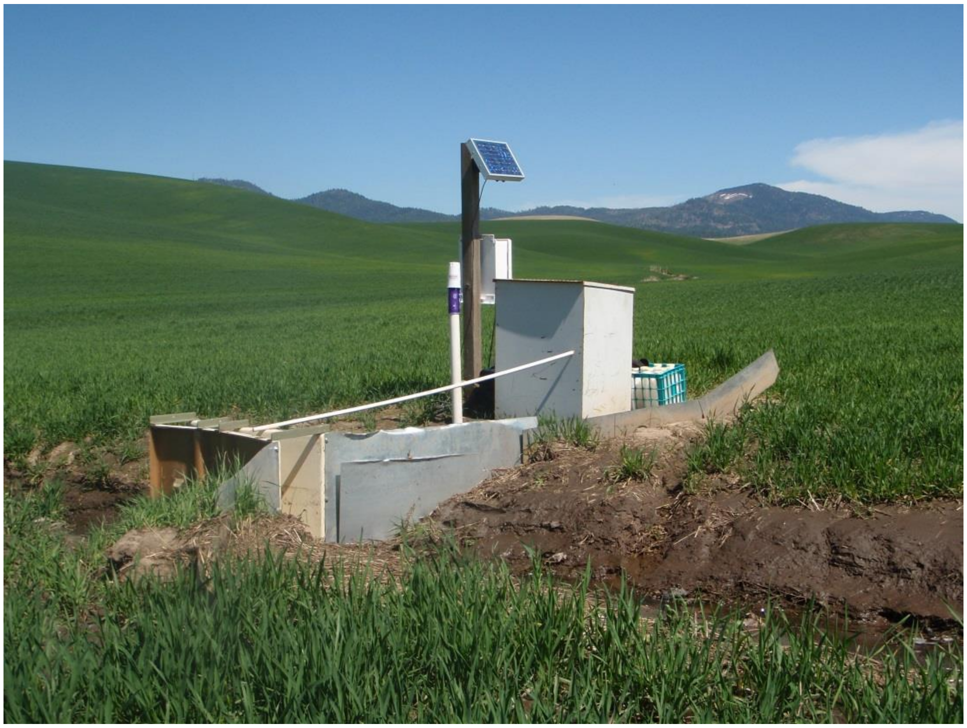


Figure A.1 Photo of the instrumentation at the Idaho-CT site.

Figure A.2 Photo of the instrumentation at the CAF-NT site

Figure A.3 Photo of the PCW sampling site at flood stage. ISCO water samplers are housed in the shelter in the top left of the photo

Figure A.4 Photo from the Hooper sampling site on the Palouse River

Appendix B:

Comparison of precipitation anomalies for 14 GCM's at Pullman, WA

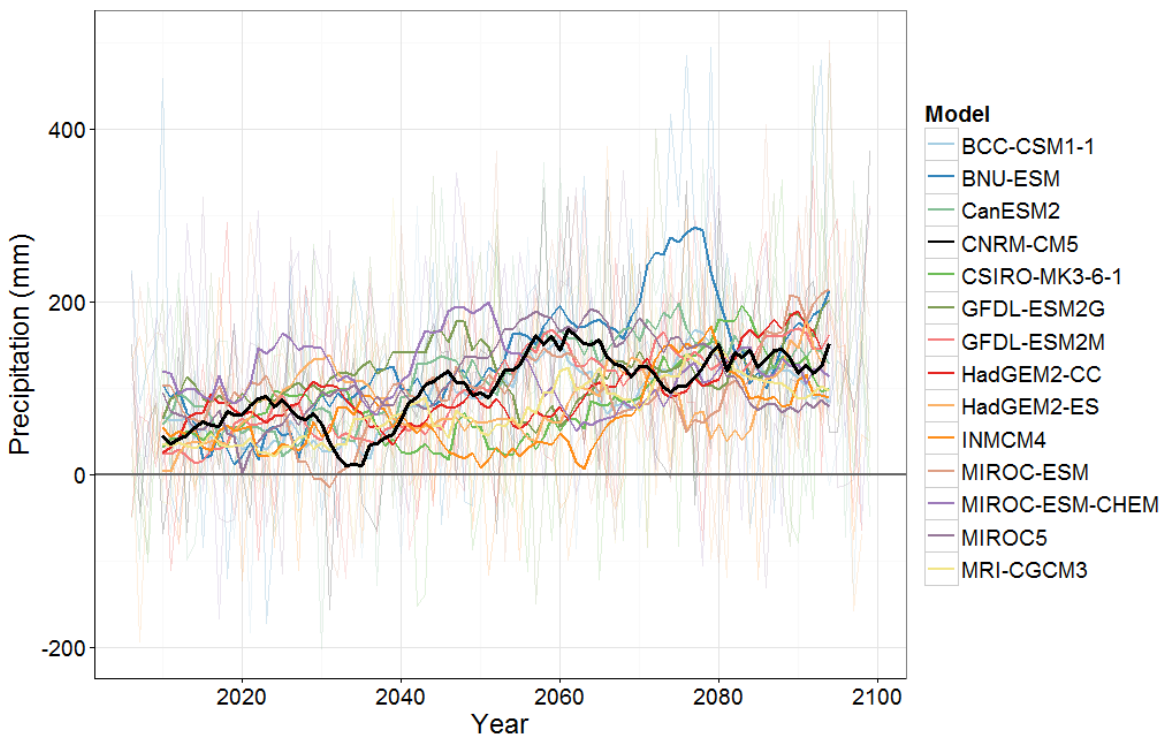


Figure B.1 A comparison of precipitation anomalies for 14 GCM's at Pullman WA. Anomalies are calculated from the annual average precipitation for Pullman form 1980-2010 and represented by the grey line at zero. The light colored lines are the predicted annual totals from each GCM and the darker lines represent 10 year moving averages. CNRM-CM 5.1 is highlighted in black.

Appendix C:

Map of fallow fields in the Palouse Basin during 2011

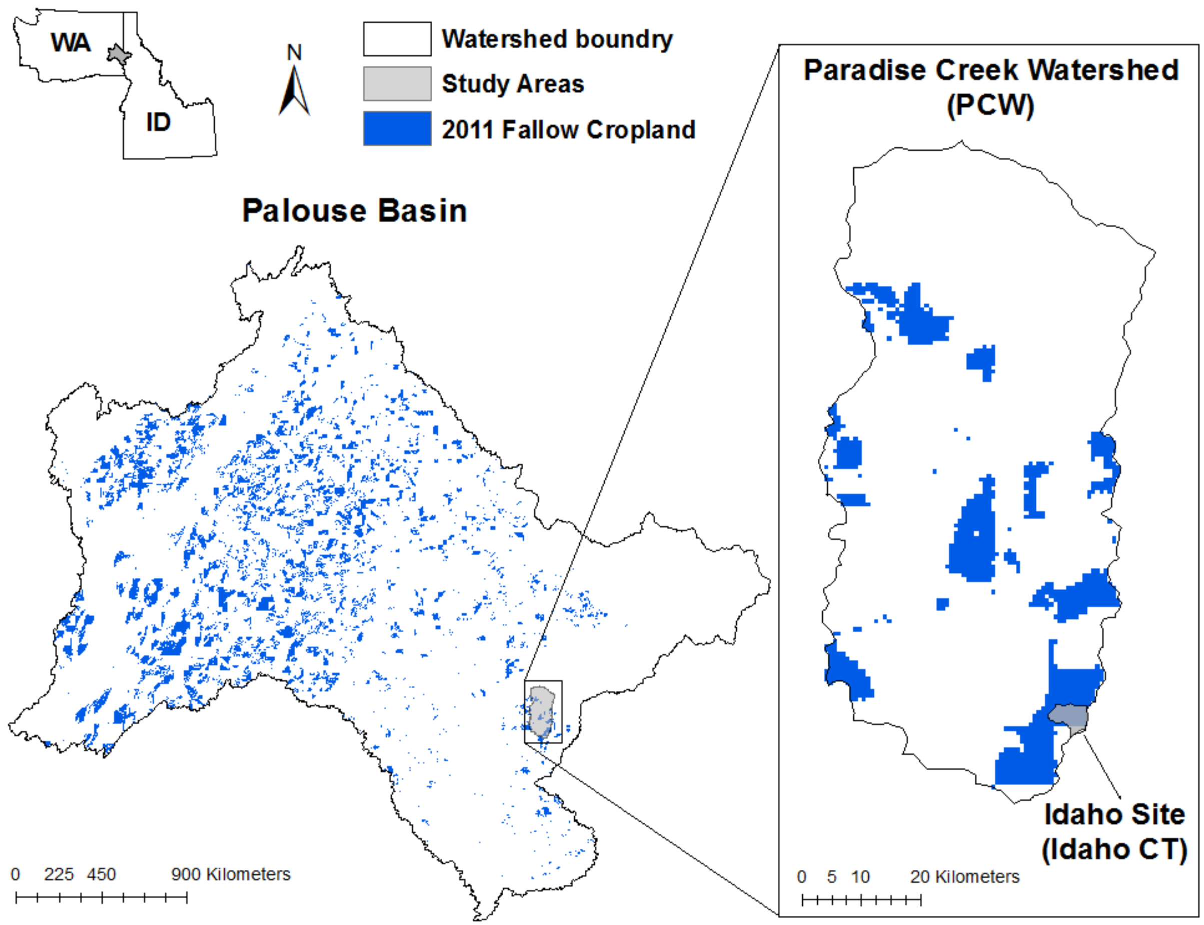


Figure C.1 Agriclutural lands in fallow during the 2011 growing season. Areas were estimated from USDA's Croplands Data Layer for the region**.**

Appendix D

Carbon, nitrogen, sediment and discharge data by site for water years 2012 and 2013

Table D.1 All runoff, carbon, nitrogen and sediment measurements taken during water years 2012 and 2013 by sampling site.

Site	Date time	RO	TDC	TDN	C:N	DOC	DIC	SSC	Sed	Sed N	Sed C	TN	TC	OC	IC	TPC	POC
		$m^3\ sec^{-1}$	$mg\ L^{-1}$	$Mg\ L^{-1}$	$Mg\ L^{-1}$	$mg\ L^{-1}$	$mg\ L^{-1}$	$mg\ L^{-1}$	g	g	g	g-N g-sed^{-1}	g-C g-sed^{-1}	g-OC g-sed^{-1}	g-IC g-sed^{-1}	$mg\ L^{-1}$	$mg\ L^{-1}$
Idaho-CT	1/26/12 10:12	0.001	6.8	55.1	0.1	5.1	1.7										
Idaho-CT	1/30/12 1:33	0.002	7.2	60.6	0.1	4.6	2.6	848									
Idaho-CT	1/30/12 3:31	0.004	9.4	61.8	0.2	6.8	2.6	1142									
Idaho-CT	1/30/12 6:51	0.007	6.6	48.0	0.1	5.0	1.6	1001									
Idaho-CT	1/30/12 7:32	0.009	9.3	77.7	0.1	5.4	4.0	879									
Idaho-CT	1/30/12 23:19	0.007	8.2	60.0	0.1	6.0	2.2	1269									
Idaho-CT	1/31/12 7:34	0.004	6.9	61.9	0.1	5.7	1.2	170									
Idaho-CT	2/1/12 7:35	0.003	6.1	54.8	0.1	5.0	1.1	38									
Idaho-CT	2/1/12 17:04	0.008	7.4	43.8	0.2	4.3	3.1	1762									
Idaho-CT	2/1/12 20:57	0.005	5.4	48.4	0.1	4.5	0.9	413									
Idaho-CT	2/2/12 7:02	0.003	5.7	54.2	0.1	4.5	1.2	90									
Idaho-CT	2/4/12 7:10	0.002	7.3	56.3	0.1	5.0	2.3	61									
Idaho-CT	2/4/12 14:23	0.004	6.3	54.4	0.1	3.6	2.7	1672									
Idaho-CT	2/5/12 6:14	0.002	4.9	60.4	0.1	3.8	1.2	131									
Idaho-CT	2/5/12 13:51	0.004	4.7	53.2	0.1	3.4	1.2	3192									
Idaho-CT	2/6/12 13:14	0.004	4.6	52.4	0.1	3.5	1.1	3846									

Idaho-CT	2/7/12 7:21	0.002	5.9	60.1	0.1	4.1	1.8	246
Idaho-CT	2/7/12 12:44	0.004	5.6	54.1	0.1	3.8	1.7	2254
Idaho-CT	2/7/12 22:59	0.002	5.9	57.7	0.1	3.8	2.1	532
Idaho-CT	2/9/12 10:02	0.004	5.2	41.8	0.1	3.8	1.4	3353
Idaho-CT	2/9/12 14:01	0.006	4.8	49.3	0.1		4.8	2799
Idaho-CT	2/10/12 9:35	0.009	5.1	45.8	0.1	3.6	1.5	3554
Idaho-CT	2/10/12 10:14	0.012	5.0	44.4	0.1	3.9	1.1	5141
Idaho-CT	2/10/12 11:36	0.015	4.8	39.3	0.1	4.1	0.7	5043
Idaho-CT	2/10/12 14:10	0.023	8.4	35.8	0.2	6.7	1.8	10787
Idaho-CT	2/10/12 16:53	0.015						7331
Idaho-CT	2/11/12 3:54	0.006	4.8	41.8	0.1	3.7	1.0	909
Idaho-CT	2/11/12 13:12	0.008						
Idaho-CT	2/11/12 14:48	0.012	4.2	38.2	0.1	3.5	0.7	4229
Idaho-CT	2/11/12 20:27	0.008	4.3	43.8	0.1	3.7	0.6	1081
Idaho-CT	2/12/12 11:32	0.012	5.2	33.2	0.2	4.0	1.2	
Idaho-CT	2/12/12 11:56	0.015						7352
Idaho-CT	2/12/12 23:15	0.004	5.1	46.3	0.1	3.8	1.3	575
Idaho-CT	2/13/12 11:15	0.006	7.5	37.5	0.2	4.8	2.7	1254
Idaho-CT	2/14/12	0.004	6.4	39.9	0.2	4.0	2.4	211

	1:31							
Idaho-CT	2/14/12 15:07	0.008	7.3	36.3	0.2	5.7	1.6	7073
Idaho-CT	2/14/12 20:15	0.004						384
Idaho-CT	2/15/12 18:27	0.002	6.1	46.9	0.1	4.4	1.8	301
Idaho-CT	2/17/12 9:13	0.004	5.3	38.5	0.1		5.3	1904
Idaho-CT	2/17/12 10:16	0.006	4.5	36.5	0.1		4.5	11429
Idaho-CT	2/18/12 0:32	0.012	5.0	37.2	0.1	3.7	1.3	
Idaho-CT	2/18/12 5:06	0.004	6.2	39.7	0.2	3.9	2.3	582
Idaho-CT	2/18/12 11:32	0.006	3.9	31.2	0.1	3.3	0.6	16071
Idaho-CT	2/19/12 11:25	0.006	4.3	48.5	0.1	3.2	1.1	
Idaho-CT	2/21/12 3:26	0.006	5.9	34.5	0.2	4.2	1.7	3225
Idaho-CT	2/21/12 7:44	0.012	3.8	33.2	0.1	2.9	0.9	3253
Idaho-CT	2/21/12 10:46	0.027	4.5	28.2	0.2	3.1	1.4	7202
Idaho-CT	2/25/12 0:30	0.006	4.8	34.1	0.1	3.5	1.3	4775
Idaho-CT	2/25/12 0:39	0.012						8456
Idaho-CT	3/3/12 14:08	0.006	5.0	37.2	0.1	3.7	1.3	2017
Idaho-CT	3/4/12 9:42	0.006	4.9	15.5	0.3	3.4	1.5	3791
Idaho-CT	3/11/12 9:26	0.012						9727
Idaho-CT	3/11/12 13:56	0.002						615

Idaho-CT	3/13/12 6:22	0.006	6.7	10.0	0.7	3.7	3.0	9291
Idaho-CT	3/13/12 13:33	0.002						549
Idaho-CT	3/15/12 3:58	0.006	6.1	10.6	0.6	3.8	2.3	5120
Idaho-CT	3/15/12 21:38	0.019						14225
Idaho-CT	3/16/12 0:26	0.006	6.0	12.2	0.5	4.3	1.7	2524
Idaho-CT	3/16/12 9:23	0.019						10907
Idaho-CT	3/16/12 10:26	0.006						1424
Idaho-CT	3/17/12 9:06	0.002	4.2	7.5	0.6		4.2	65
Idaho-CT	3/20/12 13:37	0.006						2522
Idaho-CT	3/20/12 14:22	0.011						11055
Idaho-CT	3/21/12 19:43	0.006	4.8	9.9	0.5	2.0	2.8	1442
Idaho-CT	3/21/12 20:34	0.012						1997
Idaho-CT	3/21/12 21:07	0.019	3.4	5.8	0.6	2.2	1.2	3509
Idaho-CT	3/22/12 5:57	0.006	4.8	10.5	0.5	3.2	1.6	1930
Idaho-CT	3/22/12 6:33	0.002	4.7	12.7	0.4	3.0	1.6	2040
Idaho-CT	3/22/12 21:35	0.004						6561
Idaho-CT	3/23/12 11:51	0.012						1063
Idaho-CT	3/24/12 12:47	0.023	4.4	10.7	0.4	3.0	1.3	
Idaho-CT	3/24/12	0.012						618

	18:19							
Idaho-CT	3/25/12 5:21	0.004	4.2	9.2	0.5	2.7	1.5	970
Idaho-CT	3/25/12 10:09	0.012	7.3	7.6	1.0	5.5	1.8	
Idaho-CT	3/25/12 23:15	0.023	5.7	4.3	1.3	3.4	2.3	6314
Idaho-CT	3/26/12 0:09	0.036						11609
Idaho-CT	3/26/12 1:35	0.051	5.1	7.2	0.7	3.7	1.3	
Idaho-CT	3/26/12 3:26	0.036						4841
Idaho-CT	3/26/12 4:42	0.051						1910
Idaho-CT	3/26/12 7:50	0.036						6379
Idaho-CT	3/26/12 8:03	0.023	4.4	7.1	0.6	3.2	1.1	10995
Idaho-CT	3/26/12 9:09	0.022	4.1	5.8	0.7	2.8	1.3	
Idaho-CT	3/26/12 9:41	0.036	4.7	7.9	0.6	3.5	1.2	
Idaho-CT	3/26/12 13:04	0.022	5.7	9.1	0.6	4.0	1.7	2858
Idaho-CT	3/26/12 15:13	0.012	5.7	9.1	0.6	4.0	1.7	4750
Idaho-CT	3/28/12 1:44	0.023						41961
Idaho-CT	3/28/12 7:43	0.023	4.2	11.4	0.4	3.0	1.1	6093
Idaho-CT	3/28/12 7:51	0.036	4.8	8.4	0.6	3.1	1.7	7470
Idaho-CT	3/28/12 9:31	0.023	3.3	12.9	0.3	3.3	0.0	2296
Idaho-CT	3/30/12 5:44	0.023	3.6	11.3	0.3	3.0	0.6	4125

Idaho-CT	3/30/12 6:27	0.052	2.8	7.1	0.4	2.1	0.6	12864
Idaho-CT	3/30/12 11:34	0.036	4.6	11.0	0.4	3.8	0.8	8176
Idaho-CT	3/30/12 13:30	0.023						2636
Idaho-CT	3/30/12 15:03	0.012	5.7	17.7	0.3	4.3	1.4	
Idaho-CT	3/30/12 23:17	0.023						2650
Idaho-CT	3/31/12 0:26	0.012						501
Idaho-CT	3/31/12 17:20	0.012	5.5	12.3	0.4	3.8	1.6	2820
Idaho-CT	3/31/12 19:42	0.012	5.6	16.3	0.3	4.1	1.5	
Idaho-CT	4/2/12 2:01	0.004	5.7	16.8	0.3	3.3	2.4	35
Idaho-CT	4/4/12 15:24	0.023	4.5	6.3	0.7	2.9	1.6	2668
Idaho-CT	4/4/12 22:15	0.004	7.5	18.7	0.4	3.5	4.0	159
Idaho-CT	4/5/12 20:42	0.004						18
Idaho-CT	4/6/12 13:09	0.012						547
Idaho-CT	4/6/12 17:10	0.004						63
Idaho-CT	4/11/12 22:49	0.012	10.9	3.0	3.7	5.2	5.7	
Idaho-CT	4/12/12 0:57	0.004						249
Idaho-CT	4/12/12 13:26	0.012						2828
Idaho-CT	4/12/12 17:38	0.012	12.3	2.7	4.5	7.0	5.3	2525
Idaho-CT	4/12/12	0.023	9.4	2.5	3.8	5.5	4.0	4986

	18:35													
Idaho-CT	4/12/12 19:46	0.004	9.5	10.8	0.9	5.5	3.9	322						
Idaho-CT	4/20/12 0:28	0.004	5.1	3.0	1.7	4.8	0.3	742						
Idaho-CT	4/23/12 23:51	0.004						1910						
Idaho-CT	4/26/12 9:29	0.024	5.5	1.7	3.2	4.3	1.2	10013						
Idaho-CT	4/26/12 9:31	0.038	8.7	0.5	17.2	8.6	0.1	1340						
Idaho-CT	4/26/12 13:00	0.005	6.1	1.4	4.4	5.9	0.3	12359						
Idaho-CT	4/30/12 7:16	0.013	4.7	1.4	3.5	4.7	0.0	2103						
Idaho-CT	5/3/12 21:26	0.013	6.5	2.1	3.2	6.4	0.2							
Idaho-CT	5/24/12 22:10	0.000						1976						
Idaho-CT	1/10/13 21:16	0.001	8.5	7.2	1.2	5.0	3.5	46	34.1	1.3	0.2	0.0		
Idaho-CT	1/19/13 13:11	0.000	8.1	7.8	1.0	4.9	3.3	25	16.1	1.1	0.2	0.4	1.3	0.3
Idaho-CT	1/25/13 20:21	0.002	11.1	8.8	1.3	6.3	4.7	19	12.6	0.9	0.1	0.3	1.0	0.2
Idaho-CT	2/1/13 15:54	0.006						239	47.6	0.2	1.6	0.5	1.6	3.7
Idaho-CT	2/1/13 20:28	0.004	11.1	10.5	1.1	8.8	2.3	57	31.5	0.1	1.0	0.3	1.2	0.7
Idaho-CT	2/2/13 3:14	0.002												
Idaho-CT	2/3/13 14:32	0.004	7.6	10.7	0.7	5.5	2.1	45	25.1	0.1	0.9	0.3	1.3	0.6
Idaho-CT	2/4/13 6:19	0.002	7.7	11.4	0.7	5.6	2.1	16	8.7	0.0	0.4	0.3	0.7	0.1
Idaho-CT	2/4/13 15:37	0.006						335	131.6	0.2	2.3	0.2	0.8	2.6

Idaho-CT	2/4/13 20:31	0.004						54	37.8	0.1	0.9	0.3	0.8			0.4	
Idaho-CT	2/6/13 5:32	0.002						25	8.6	0.0	0.3	0.3	0.5			0.1	
Idaho-CT	2/19/13 13:38	0.001	8.6	10.0	0.9	6.1	2.5	14	15.7	0.1	0.5	0.3	0.7			0.1	
Idaho-CT	2/22/13 21:56	0.002	8.2	9.8	0.8	6.2	1.9	14	9.1	0.1	0.6	0.5	1.5			0.2	
Idaho-CT	2/24/13 0:00	0.001	7.5	11.0	0.7			145	127.3	0.3	3.2	0.2	1.2			1.8	
Idaho-CT	2/25/13 13:43	0.002	7.3	10.8	0.7	4.4	2.8	11	9.8	0.0	0.3	0.3	0.6			0.1	
Idaho-CT	2/28/13 11:53	0.003	7.3	10.4	0.7	5.7	1.6	94	63.0	0.2	1.6	0.3	1.2			1.1	
Idaho-CT	2/28/13 14:49	0.005	7.1	9.7	0.7	5.1	2.0	2059	381.2	0.9	10.2	0.3	1.8			37.6	
Idaho-CT	3/1/13 6:45	0.003	7.8	9.3	0.8	5.6	2.1	38	23.7	0.1	0.6	0.3	0.8			0.3	
Idaho-CT	3/2/13 9:31	0.002	10.8	9.3	1.2	5.7	5.1	16	10.2	0.0	0.5	0.2	0.8			0.1	
Idaho-CT	3/7/13 19:41	0.001	8.6	10.1	0.9	4.7	3.9	10	8.0	0.0	0.5	0.3	0.8			0.1	
Idaho-CT	3/14/13 19:50	0.001	10.8	10.4	1.0	4.7	6.1	41	17.1	0.2	0.9	0.5	1.4			0.6	
Idaho-CT	3/20/13 12:57	0.002	9.6	6.3	1.5	5.2	4.4	2230	61.1	0.2	1.1	0.2	1.1	1.1		23.8	29.5
Idaho-CT	3/20/13 13:10	0.003	8.2	5.7	1.4	4.7	3.5	3716	163.5	0.2	2.2	0.2	2.2	1.7	0.5	81.2	64.5
Idaho-CT	3/20/13 15:26	0.002	11.7	9.8	1.2	3.1	8.5	447	21.9	0.1	0.7	0.1	0.7	0.5	0.1	2.9	2.3
Idaho-CT	3/21/13 2:46	0.001	8.3	9.8	0.8	4.7	3.5	39	11.1	0.1	0.3	0.4	0.5	0.4	0.1	0.2	0.1
Idaho-CT	3/28/13 2:55	0.001	10.4	8.3	1.3	4.8	5.6										
Idaho-CT	4/4/13 3:05	0.000	15.7	2.2	7.1	7.3	8.5										
Idaho-CT	4/4/13	0.001	18.0	1.1	15.9	9.6	8.3	992	50.9	0.2	1.8	0.2	1.8	1.3	0.4	17.4	13.5

	20:36															
Idaho-CT	4/4/13 23:27	0.000	17.1	4.1	4.2	7.4	9.7	52	6.5	0.1	0.5	0.5	1.2			0.6	
Idaho-CT	4/7/13 10:52	0.001	12.2	5.8	2.1	6.8	5.5	4829	299.4	0.0	0.4	0.3	0.7	0.7	0.0	35.3	1.4
Idaho-CT	4/7/13 22:00	0.000	12.0	6.2	2.0	5.7	6.4	91	11.4	0.1	0.3	0.4	0.5			0.4	
Idaho-CT	4/12/13 21:01	0.001	11.7	3.3	3.6	6.2	5.6	1162	39.5	0.1	1.3	0.3	1.5			16.9	9.5
Idaho-CT	4/13/13 12:24	0.000	12.6	5.5	2.3	7.3	5.3	127	12.5	0.1	0.3	0.3	0.4	0.3	0.2	0.5	0.4
Idaho-CT	4/19/13 6:41	0.001	10.0	3.1	3.3	8.9	1.1	769	26.7	0.1	0.9	0.1	0.9	0.8	0.1	6.9	6.4
Idaho-CT	4/19/13 7:44	0.003	9.7	4.7	2.1	5.8	3.9	1733	77.3	0.2	1.7	0.2	1.7	1.3	0.5	29.8	28.7
Idaho-CT	4/19/13 18:09	0.001	9.9	8.0	1.2	6.3	3.7	195	25.0	0.1	0.4	0.1	0.4	0.3	0.1	0.7	0.6
CAF-NT	2/7/12 0:00	0.000	18.5	28.6	0.6	12.2	6.4										
CAF-NT	2/15/12 9:30	0.000						98	3.1								
CAF-NT	3/21/12 15:52	0.000	10.7	33.8	0.3	7.4	3.3										
CAF-NT	3/22/12 9:52	0.000	8.7	16.6	0.5	8.4	0.3	271	19.8								
CAF-NT	3/22/12 21:52	0.002						265	12.5								
CAF-NT	3/24/12 9:57	0.000	11.0	31.3	0.4	10.2	0.9	1422	23.8								
CAF-NT	3/24/12 12:56	0.000	15.1	37.5	0.4	11.1	4.0										
CAF-NT	3/26/12 0:55	0.000	12.0	22.2	0.5	8.2	3.8										
CAF-NT	3/26/12 12:55	0.003	10.9	9.9	1.1	8.5	2.3	1466	99.2								
CAF-NT	3/26/12 12:55	0.003	19.5	1.1	17.7	8.9	10.6	602	105.4								

CAF-NT	3/26/12 12:55	0.003	15.2	5.5	2.8	8.7	6.4	1034	102.3
CAF-NT	3/26/12 13:30	0.002	11.9	11.6	1.0	7.9	4.0	837	61.2
CAF-NT	3/26/12 19:44	0.000	11.4	27.0	0.4	8.5	3.0	426	19.5
CAF-NT	3/26/12 19:44	0.000						543	21.2
CAF-NT	3/26/12 19:44	0.000						309	17.7
CAF-NT	3/26/12 20:10	0.000						701	36.1
CAF-NT	3/28/12 0:55	0.000						991	24.2
CAF-NT	3/28/12 1:44	0.000	71.6	34.8	2.1	27.8	43.8		
CAF-NT	3/28/12 7:44	0.000	11.2	9.8	1.1	10.1	1.1	889	30.9
CAF-NT	3/28/12 19:44	0.000	22.9	7.9	2.9	9.1	13.8		
CAF-NT	3/29/12 1:44	0.000	14.4	26.2	0.6	8.3	6.2	298	67.2
CAF-NT	3/29/12 20:10	0.002	10.0	10.9	0.9	7.5	2.5	499	50.8
CAF-NT	3/30/12 6:10	0.004	8.6	11.0	0.8	7.0	1.6	564	59.0
CAF-NT	3/30/12 12:05	0.009	8.5	8.2	1.0			255	34.3
CAF-NT	3/30/12 12:05	0.009							
CAF-NT	3/30/12 14:10	0.004						767	63.1
CAF-NT	3/30/12 18:10	0.001						646	10.1
CAF-NT	4/5/12 13:26	0.001						1275	211.0
CAF-NT	4/5/12	0.000	16.2	16.7	1.0			165	14.0

	16:00														
CAF-NT	4/24/12 2:45	0.000	36.9	14.0	2.6	7.4	29.5	256	7.5						
CAF-NT	1/9/13 15:12	0.000	16.3	4.2	3.9	9.2	7.1								
CAF-NT	1/10/13 13:24	0.000	23.6	6.6	3.6	11.7	11.9	491	252.3	4.3	0.4	0.2	0.9	4.4	5.1
CAF-NT	1/10/13 14:26	0.000	29.2	3.8	7.7	13.6	15.5	330	218.2	5.2	0.6	0.3	1.0	3.4	3.4
CAF-NT	1/10/13 15:26	0.000	25.9	7.0	3.7	12.7	13.1	578	369.1	5.2	0.5	0.2	0.7	3.9	3.9
CAF-NT	1/10/13 17:26	0.000	24.3	6.8	3.6	13.3	11.0	799	650.2	10.1	0.8	0.2	0.7	5.5	5.5
CAF-NT	1/26/13 0:00	0.000						24	23.0	1.2	0.2	0.4	1.3	0.3	0.3
CAF-NT	1/26/13 5:08	0.000	16.0	5.1	3.1	10.9	5.1	12	7.9	0.8	0.2	0.4	1.1	0.1	0.1
CAF-NT	1/26/13 6:08	0.000	15.1	5.2	2.9	10.7	4.4	58	12.5	0.1	0.6	0.4	1.1	0.7	0.7
CAF-NT	1/26/13 10:00	0.000	13.8	4.8	2.9	8.7	5.1	39	17.5	0.2	1.0	0.6	1.9	0.8	0.8
CAF-NT	1/26/13 10:08	0.000						54	11.5	0.1	0.5	0.4	1.1	0.6	0.6
CAF-NT	1/26/13 12:08	0.000	17.4	6.1	2.9	13.6	3.9	28	19.7	0.2	0.9	0.5	1.5	0.4	0.4
CAF-NT	1/26/13 15:29	0.000	14.7	5.6	2.6	9.0	5.7	68	20.5	0.1	0.9	0.4	1.4	0.9	0.9
PCW	11/17/11 15:35	0.000						3							
PCW	11/22/11 23:32	0.019						63							
PCW	11/23/11 15:16	0.004						24							
PCW	11/27/11 5:32	0.000						4							
PCW	11/27/11 8:31	0.000						5							

PCW	12/4/11 5:40	0.000						5
PCW	12/18/11 5:59	0.000						3
PCW	12/28/11 4:52	0.002						7
PCW	12/28/11 19:27	0.013						7
PCW	12/29/11 7:36	0.044						17
PCW	12/30/11 6:00	0.103						23
PCW	12/30/11 9:11	0.193						52
PCW	12/30/11 10:15	0.309						110
PCW	12/30/11 13:07	0.552						444
PCW	12/31/11 8:48	0.213						48
PCW	1/1/12 5:59	0.048						39
PCW	1/10/12 18:39	0.008	15.8	12.5	1.3	10.8	5.1	18
PCW	1/17/12 17:29	0.001						8
PCW	1/21/12 22:45	0.120	9.9	2.2	4.4	2.0	7.8	7
PCW	1/26/12 0:07	0.428	9.2	7.0	1.3	4.9	4.3	13
PCW	1/30/12 8:47	1.004	7.6	17.5	0.4	4.2	3.3	49
PCW	1/30/12 12:16	2.037	7.8	16.9	0.5	4.2	3.6	95
PCW	1/30/12 16:33	2.971	8.2	14.7	0.6	4.7	3.5	101
PCW	1/30/12	2.952	7.9	15.8	0.5	5.2	2.7	106

	20:08							
PCW	1/31/12 6:09	1.640	9.4	14.8	0.6	5.6	3.8	0
PCW	2/1/12 5:15	0.800	8.6	19.1	0.5	5.3	3.3	21
PCW	2/8/12 6:23	0.427	10.8	14.4	0.8	5.2	5.6	24
PCW	2/10/12 10:28	1.031	10.3	20.4	0.5	5.2	5.1	68
PCW	2/10/12 17:04	2.015	9.0	20.6	0.4	4.9	4.1	725
PCW	2/11/12 2:15	1.382	11.1	18.6	0.6	5.1	6.0	87
PCW	2/15/12 21:45	0.429	9.4	15.3	0.6	4.1	5.4	184
PCW	2/21/12 8:39	1.024						64
PCW	2/21/12 11:08	2.027	7.5	12.8	0.6	3.8	3.7	1616
PCW	2/21/12 14:01	3.477	7.0	11.2	0.6	4.3	2.8	2219
PCW	2/21/12 16:32	3.898						545
PCW	2/21/12 19:37	3.022						592
PCW	2/22/12 6:01	1.640						132
PCW	2/23/12 9:27	0.775	13.0	7.7	1.7	6.0	7.0	53
PCW	3/3/12 8:16	0.295						861
PCW	3/4/12 14:54	0.766	11.8	11.3	1.0	4.4	7.3	306
PCW	3/7/12 6:12	0.293	11.2	6.8	1.7	4.2	7.0	30
PCW	3/12/12 6:17	0.419						30

PCW	3/14/12 6:17	0.454	10.8	5.5	2.0	4.9	5.8	30
PCW	3/15/12 14:30	1.048						128
PCW	3/15/12 23:21	2.008						746
PCW	3/16/12 3:37	2.597						451
PCW	3/16/12 22:24	1.380						65
PCW	3/20/12 17:57	1.321	12.7	3.9	3.2	9.0	3.7	298
PCW	3/21/12 23:21	2.279						719
PCW	3/22/12 3:17	2.821						254
PCW	3/22/12 14:05	2.317	10.1	4.7	2.1	6.2	3.9	163
PCW	3/22/12 17:37	3.613						527
PCW	3/22/12 20:27	3.456						260
PCW	3/23/12 4:21	1.966						116
PCW	3/23/12 14:11	2.365	5.0	4.1	1.2	4.7	0.3	189
PCW	3/24/12 17:37	3.498	7.9	5.0	1.6	4.6	3.3	
PCW	3/25/12 7:27	1.674						42
PCW	3/25/12 22:01	2.626	11.9	2.0	6.1	6.3	5.6	123
PCW	3/26/12 3:55	5.799	8.1	4.7	1.7	5.0	3.1	2100
PCW	3/26/12 8:30	9.218	7.3	3.5	2.1	5.0	2.3	1732
PCW	3/26/12	9.045	11.7	0.0		5.1	6.6	234

	9:36							
PCW	3/27/12 1:06	2.874	9.6	5.0	1.9	6.1	3.5	50
PCW	3/28/12 9:38	2.336	7.9	6.0	1.3	5.4	2.5	441
PCW	3/28/12 13:06	3.133	7.4	5.9	1.3	5.2	2.2	190
PCW	3/28/12 16:57	2.751	8.1	6.1	1.3	5.3	2.8	
PCW	3/30/12 4:31	2.655	8.9	6.3	1.4	5.5	3.4	
PCW	3/30/12 8:46	4.214	11.2	1.6	7.1	5.7	5.5	
PCW	3/30/12 13:31	6.407	7.2	5.7	1.3	5.5	1.6	
PCW	3/30/12 19:06	3.921	9.1	5.3	1.7	5.6	3.5	
PCW	3/30/12 22:12	3.090	10.6	5.0	2.1	6.8	3.8	
PCW	3/31/12 9:31	2.496	9.8	2.5	4.0	6.1	3.7	
PCW	3/31/12 18:41	2.352	10.0	2.7	3.7	5.4	4.7	
PCW	3/31/12 22:16	3.090						185
PCW	4/10/12 14:31	0.658	10.3	2.6	3.9	5.5	4.8	
PCW	4/17/12 14:41	0.577	14.0	1.0	13.7	6.1	7.9	375
PCW	4/24/12 14:51	0.457	11.3	1.9	6.1	6.1	5.2	37
PCW	4/26/12 12:51	1.599	14.4	1.5	9.6	7.4	7.0	581
PCW	4/28/12 4:11	0.454	15.6	1.1	13.6	5.8	9.8	25
PCW	5/5/12 4:21	0.419	13.2	1.5	8.7	4.5	8.7	22

PCW	5/12/12 4:31	0.091	20.0	1.3	15.5	14.0	6.0	17
PCW	5/19/12 4:41	0.016	15.9	1.6	10.1	4.3	11.6	32
PCW	5/26/12 4:51	0.007	15.6	1.4	11.4	4.1	11.5	15
PCW	6/2/12 5:01	0.005	19.2	1.0	19.9	4.7	14.6	16
PCW	6/5/12 1:30	0.014	27.1	0.5	58.4	10.0	17.1	
PCW	6/9/12 5:11	0.017	27.0	0.7	38.5	4.1	22.9	
PCW	6/13/12 15:58	0.002	21.1	0.9	24.4	4.6	16.5	
PCW	6/19/12 3:11	0.000	22.1	0.9	23.9	5.3	16.9	
PCW	6/26/12 12:24	0.001	25.8	1.2	22.3	6.3	19.6	
PCW	6/26/12 19:10	0.009	23.6	1.4	17.3	6.9	16.6	
PCW	6/28/12 1:25	0.001	23.6	1.0	23.5	6.3	17.3	
PCW	10/29/12 1:42	0.000	24.0	1.2	20.5	5.5	18.5	
PCW	10/29/12 12:30	0.000	23.2	1.1	20.4	6.1	17.1	
PCW	11/13/12 17:12	0.000	23.5	2.1	11.0	7.2	16.3	
PCW	11/20/12 8:58	0.037	17.8	4.9	3.6	8.4	9.4	
PCW	11/20/12 18:16	0.085	20.0	3.9	5.2	8.3	11.7	
PCW	11/22/12 8:56	0.013	18.3	2.2	8.2	6.6	11.7	
PCW	11/30/12 15:42	0.010	20.3	1.4	14.5	5.7	14.6	
PCW	12/4/12	0.057	17.7	2.7	6.7	6.6	11.1	

	13:07													
PCW	12/7/12 20:13	0.267	16.2	6.3	2.6	5.0	11.2							
PCW	12/21/12 14:21	0.023	18.0	8.6	2.1	6.2	11.8							
PCW	12/23/12 2:58	0.069	16.0	7.7	2.1	5.3	10.7							
PCW	12/23/12 2:58	0.069	19.7	5.8	3.4	5.2	14.5							
PCW	1/6/13 3:17	0.014	14.9	1.9	7.9	5.1	9.9							
PCW	1/8/13 0:02	0.017	17.3	5.6	3.1	5.6	11.8							
PCW	1/9/13 6:08	0.124	16.5	5.0	3.3	6.9	9.6							
PCW	1/9/13 12:31	0.438	13.8	6.7	2.1	5.5	8.3							
PCW	1/9/13 16:24	1.058	13.4	11.5	1.2	5.9	7.5							
PCW	1/11/13 19:33	0.405	16.1	11.9	1.4	5.2	10.9							
PCW	1/14/13 11:18	0.105	16.1	10.2	1.6	4.8	11.3	13	6.6	0.6	0.1	0.3	0.6	0.1
PCW	1/19/13 13:24	0.047	14.8	8.8	1.7	5.9	8.9	1804	237.9	0.8	0.2	0.3	0.5	9.3
PCW	1/25/13 11:07	0.200						9	8.6	0.0	0.2	0.3	0.5	0.1
PCW	1/25/13 15:29	0.583	14.2	9.3	1.5	6.9	7.4	50	10.6	0.1	0.2	0.3	0.3	0.1
PCW	1/25/13 22:45	1.318	15.0	12.3	1.2	7.4	7.6	63	10.4	0.1	0.2	0.3	0.3	0.2
PCW	1/28/13 7:49	0.568	12.8	10.3	1.3	5.6	7.3	31	16.0	0.1	0.5	0.3	0.7	0.2
PCW	1/30/13 17:55	2.346	14.3	11.9	1.2	6.9	7.4	505	49.9	0.1	1.0	0.2	0.7	3.6
PCW	1/31/13 9:26	1.275						55	16.5	0.1	0.5	0.3	0.8	0.4

PCW	2/4/13 9:42	0.582	17.9	8.9	2.0	6.4	11.6	43	15.2	0.1	0.6	0.4	1.2			0.5	
PCW	2/11/13 14:42	0.278	10.7	5.3	2.0	4.3	6.4	28	12.5	0.0	0.3	0.3	0.5			0.1	
PCW	2/18/13 10:01	0.151						17	12.9	0.2	1.0	0.7	2.3			0.4	
PCW	2/23/13 0:05	0.483	13.7	6.0	2.3	5.0	8.7	23	9.7	0.0	0.3	0.3	0.6			0.2	
PCW	2/25/13 17:20	0.463	23.5	6.4	3.7	12.1	11.4	37	11.3	0.1	0.4	0.3	0.7			0.3	
PCW	2/26/13 10:44	0.164	10.5	6.8	1.6	4.9	5.7	57	31.9	0.1	0.9	0.3	1.1			0.6	
PCW	2/26/13 17:20	0.444	11.9	6.5	1.8	4.7	7.3	35	17.6	0.1	0.7	0.4	1.3			0.4	
PCW	2/27/13 13:19	0.184	17.2	7.1	2.4	8.5	8.7	18	9.0	0.0	0.3	0.3	0.6			0.1	
PCW	2/27/13 17:19	0.412	9.7	7.5	1.3	2.4	7.3	29	15.5	0.1	1.1	0.4	2.3			0.7	
PCW	2/28/13 17:04	1.076	16.7	4.2	4.0	5.2	11.5	300	31.0	0.1	0.6	0.3	0.6			1.8	
PCW	3/4/13 2:18	0.505	16.4	4.8	3.4	4.9	11.5										
PCW	3/11/13 2:25	0.252	15.0	2.4	6.2	5.1	9.9	15	7.2	0.1	0.4	0.4	0.7			0.1	
PCW	3/18/13 2:35	0.269	16.4	2.3	7.3	4.9	11.5	4	1.7	0.1	0.2	0.4	0.5			0.0	
PCW	3/25/13 2:45	0.122	20.7	1.4	15.2	6.4	14.3	20	7.1	0.0	0.2	0.3	0.4			0.1	
PCW	4/11/13 14:00	0.063	18.2	2.1	8.6	5.7	12.5	20	7.5	0.1	0.2	0.4	0.5			0.1	
PCW	4/20/13 14:44	0.245	48.5	2.2	22.0	7.8	40.7	22	5.0	0.1	0.2	0.4	0.3	0.2	0.1	0.1	0.1
PCW	4/23/13 6:56	0.072	24.9	1.4	17.6	7.8	17.1										
PCW	4/26/13 9:03	0.029	20.1	1.4	14.5	5.5	14.6										
PCW	4/26/13	0.029	20.9	1.9	11.3	6.6	14.3	21	5.8	0.1	0.1	0.1	0.8	0.5	0.3	0.2	0.1

	9:05																
PCW	5/17/13 14:16	0.002						1383	63.6	0.0	0.0	0.0	0.5	0.4	0.2	6.9	4.8
PCW	5/17/13 15:26	0.007						45	11.0	0.1	0.1	0.1	0.3			0.1	
PCW	5/22/13 15:26	0.003						690	58.8	0.1	0.1	0.1	1.0	1.2		6.6	8.3
Hooper	1/26/12 13:00	8.300	14.7	3.3	4.5	2.0	12.7										
Hooper	2/29/12 14:00	21.445	10.3	2.9	3.6	4.7	5.6										
Hooper	3/4/12 14:00	15.949	10.7	3.4	3.1	3.9	6.8										
Hooper	3/5/12 14:00	19.660	17.8	3.3	5.4	3.7	14.1										
Hooper	3/10/12 14:00	19.915	15.3	3.3	4.6	3.7	11.5										
Hooper	3/14/12 14:00	49.292	13.5	2.0	6.6	4.5	9.0										
Hooper	3/16/12 14:00	40.510	15.4	2.4	6.4	4.4	11.0										
Hooper	3/17/12 14:00	131.161	16.0	2.2	7.4	6.8	9.2										
Hooper	3/18/12 14:00	93.768	13.8	2.4	5.7	6.0	7.7										
Hooper	3/20/12 14:00	45.892	11.5	2.7	4.4	5.1	6.5										
Hooper	3/23/12 14:00	115.014	13.0	3.3	4.0	4.9	8.1										
Hooper	3/24/12 14:00	88.669	12.4	5.3	2.3	6.5	5.9										
Hooper	3/27/12 14:00	242.776	13.2	4.6	2.9	5.1	8.1										
Hooper	3/29/12 14:00	137.677	12.1	5.3	2.3	5.9	6.3										
Hooper	3/31/12 14:30	269.122	11.0	3.7	3.0	5.2	5.8										

Hooper	3/31/12 14:30	269.122	10.8	2.9	3.7	6.4	4.4	
Hooper	4/1/12 14:30	281.303						13709
Hooper	4/4/12 14:30	97.450	21.0	3.6	5.8	4.3	16.7	481
Hooper	4/5/12 14:30	104.816	13.4	4.0	3.3	3.6	9.8	264
Hooper	4/6/12 14:30	92.635	12.1	4.3	2.8	3.6	8.5	103
Hooper	4/11/12 14:30	57.790	15.6	4.2	3.7	3.6	12.0	61
Hooper	4/14/12 14:30	68.272	10.5	1.4	7.3	2.9	7.5	74
Hooper	4/17/12 14:30	51.841	9.8	1.4	7.2	2.8	7.0	37
Hooper	4/20/12 14:30	62.040	9.6	1.3	7.5	3.3	6.3	36
Hooper	4/26/12 14:30	54.674	3.5	0.8	4.7	3.3	0.3	52
Hooper	4/27/12 14:30	73.088	4.2	0.8	5.6	4.0	0.2	62
Hooper	4/30/12 14:30	47.592	4.1	1.0	3.9	3.8	0.3	45
Hooper	5/1/12 14:30	64.873	5.1	1.0	5.0	4.9	0.2	40
Hooper	5/5/12 14:30	55.524	5.3	1.1	4.9	5.1	0.1	31
Hooper	5/10/12 14:30	30.878	5.9			5.4	0.5	12
Hooper	5/15/12 14:30	20.680	2.9	0.7	4.0	2.6	0.3	42
Hooper	5/17/12 14:30	18.102	20.6	0.8	25.1	20.6	0.0	
Hooper	5/24/12 14:30	14.759	14.3	0.8	17.0	2.8	11.6	
Hooper	5/31/12	12.748	9.2			8.9	0.3	

	14:30							
Hooper	6/7/12 14:30	12.946	7.6			7.4	0.2	
Hooper	6/12/12 12:46	24.816	15.0			4.2	10.8	
Hooper	6/12/12 14:30	24.249	19.4	0.9	20.9	9.3	10.1	350
Hooper	6/19/12 14:30	10.397	11.0	11.6	1.0	4.5	6.5	30
Hooper	6/26/12 14:30	8.442	4.6	1.1	4.1	5.1		26
Hooper	6/29/12 14:30	10.227	5.3	1.0	5.4	3.2	2.1	32
Hooper	7/3/12 14:30	6.657	3.3	0.4	9.5	8.3		20
Hooper	7/5/12 15:54	6.459	9.2	1.2	7.6	3.0	6.2	
Hooper	8/3/12 10:56	2.125	41.4	1.5	27.1	16.5	25.0	
Hooper	8/6/12 14:30	2.011	75.4	0.6	135.6	39.0	36.4	
Hooper	8/7/12 14:30	1.813	37.8	0.4	101.9	37.9		
Hooper	8/14/12 14:30	1.246	6.9	0.3	23.4	7.1		
Hooper	8/21/12 14:30	1.105	15.9	0.2	63.9	15.8	0.1	
Hooper	8/24/12 14:30	1.161	6.5	0.4	17.3	6.4	0.1	
Hooper	9/17/12 14:30	1.161	3.9	0.4	10.0	2.7	1.1	
Hooper	9/24/12 14:30	1.190	8.3	0.5	16.8	8.3	0.1	
Hooper	10/1/12 14:30	1.388	6.0	0.5	13.0	3.8	2.2	
Hooper	10/8/12 14:30	1.671	6.3	0.7	9.1	6.2	0.2	

Hooper	10/26/12 14:00	2.521	35.0	1.6	22.3	6.1	28.9							
Hooper	11/1/12 14:30	6.062	26.2	1.2	22.6	4.0	22.2							
Hooper	11/7/12 14:30	3.484	26.9	0.9	31.0	3.1	23.8							
Hooper	11/7/12 15:30	3.484	24.7	0.9	26.7	3.2	21.6							
Hooper	11/7/12 19:00	3.428	25.7	0.2	108.2	3.6	22.1							
Hooper	11/8/12 15:00	3.286	33.0	0.9	36.6	3.1	29.9							
Hooper	12/17/12 12:30	11.813	27.3	2.5	10.9	3.5	23.8	29	17.9	0.1	0.6	0.4	0.9	0.2
Hooper	1/10/13 7:13	12.550	25.6	2.9	8.9	3.5	22.1							
Hooper	1/10/13 19:18	22.351	23.0	3.7	6.2	2.7	20.3	56	29.0	0.1	0.8	0.3	0.9	0.5
Hooper	1/10/13 21:40	38.810	18.1	3.0	6.1	2.1	16.0							
Hooper	1/13/13 10:35	25.428	19.1	5.2	3.7	5.5	13.7							
Hooper	1/15/13 15:00	19.042	22.8	5.8	3.9	5.1	17.7	33	14.2	0.1	0.5	0.4	0.9	0.3
Hooper	1/27/13 8:26	26.019	26.3	5.1	5.1	3.8	22.5	35	21.2	0.1	0.6	0.3	0.8	0.3
Hooper	1/27/13 14:31	41.598	14.6	2.8	5.2	1.7	12.9	121	45.5	0.2	1.2	0.3	1.1	1.3
Hooper	1/28/13 2:33	54.540	21.7	5.9	3.7	3.6	18.1	148	34.9	0.1	1.0	0.4	1.1	1.7
Hooper	1/29/13 16:58	37.280	21.2	5.8	3.6	7.8	13.4	66	12.4	0.1	0.3	0.3	0.5	0.3
Hooper	1/31/13 10:44	45.326	16.2	5.2	3.1	4.2	11.9	99	20.9	0.1	0.5	0.3	0.7	0.7
Hooper	1/31/13 14:16	59.490						146	35.7	0.1	0.8	0.3	0.7	1.1
Hooper	2/3/13	54.391	17.2	4.3	4.0	7.8	9.5							

	8:06																
Hooper	2/4/13 6:28	47.592	15.7	3.7	4.2	5.4	10.3	34	18.7	0.1	0.9	0.5	1.8			0.6	
Hooper	2/5/13 9:59	41.360	11.6	3.4	3.4	4.8	6.8										
Hooper	2/11/13 21:57	29.462	17.7	3.8	4.6	3.7	14.0	3	8.0	0.0	0.2	0.3	0.4			0.0	
Hooper	2/18/13 22:05	30.595	15.9	3.1	5.1	4.1	11.8										
Hooper	2/22/13 0:21	25.524	15.7	2.9	5.4	3.6	12.1										
Hooper	2/22/13 10:56	24.391	16.2	2.9	5.6	4.5	11.7										
Hooper	2/24/13 3:36	29.462	20.6	3.1	6.6	3.3	17.3	30	10.1	0.0	0.3	0.0	0.3			0.1	
Hooper	3/1/13 21:34	37.110	22.2	3.8	5.9	3.6	18.6	24	10.9	0.1	0.4	0.1	0.4			0.1	
Hooper	3/3/13 1:26	50.142	20.2	4.0	5.1	4.1	16.2	158	20.0	0.1	0.5	0.1	0.5	0.5		0.8	0.8
Hooper	3/6/13 20:17	37.110	21.3	1.9	11.0	5.9	15.4	45	4.0	0.1	0.9	0.1	0.9	0.5	0.5	0.4	0.2
Hooper	3/7/13 11:09	36.544	17.6	1.5	11.8	4.0	13.5										
Hooper	3/11/13 18:23	32.011	21.2	2.6	8.3	3.8	17.5	19	8.4	0.0	0.2	0.0	0.2		0.2	0.0	
Hooper	3/20/13 9:53	37.110	17.6	1.5	12.0	3.5	14.1	48	13.5	0.1	0.2	0.1	0.2	0.2		0.1	0.1
Hooper	3/22/13 6:34	47.025	17.4	1.7	10.1	3.1	14.3	57	17.3	0.1	0.3	0.4	0.5	0.1	0.4	0.3	0.1
Hooper	3/26/13 21:21	28.329	21.0	2.0	10.6	3.2	17.8	34	11.4	0.1	0.3	0.4	0.6			0.2	
Hooper	4/6/13 7:29	36.261	20.0	0.6	33.1	3.9	16.1	34	8.7	0.1	0.4	0.4	0.8			0.3	
Hooper	4/8/13 23:13	47.592	21.0	1.6	12.7	16.0	5.0	63	15.2	0.1	0.4	0.4	0.6	0.2	0.4	0.4	0.1
Hooper	4/11/13 5:03	36.544	18.6	1.8	10.1	4.2	14.5	49	12.3	0.1	0.3	0.3	0.6	0.3	0.3	0.3	0.1

Hooper	4/14/13 3:39	39.093	20.2	1.1	17.9	5.6	14.6	32	8.7	0.1	0.5	0.5	1.0			0.3	
Hooper	4/14/13 7:40	50.708	19.4	2.0	9.8	4.6	14.8	97	17.9	0.1	0.3	0.3	0.4	0.2	0.2	0.3	0.2
Hooper	4/15/13 18:35	42.776	19.6	2.0	9.7	5.3	14.3										
Hooper	4/18/13 23:35	26.827	21.3	2.2	9.6	4.0	17.3										
Hooper	4/20/13 20:52	39.093	22.1	2.3	9.5	3.6	18.5	88	19.8	0.1	0.4	0.4	0.4	0.2	0.3	0.4	0.2
Hooper	4/21/13 0:45	63.173	18.1	2.3	8.0	3.7	14.4										
Hooper	4/22/13 10:31	42.493	20.7	1.9	10.8	6.7	14.0	69	11.2	0.1	0.3	0.3	0.4	0.1	0.2	0.3	0.1
Hooper	4/23/13 17:17	37.677				5.0		31	7.8	0.1	0.6	0.3	1.9	0.6	1.3	0.6	0.2
Hooper	4/24/13 16:36	32.295				4.3											
Hooper	4/25/13 19:51	28.612				3.7											
Hooper	4/28/13 1:27	23.286				3.4		53	14.4	0.0	0.4	0.0	0.4	0.4	0.0	0.2	0.2
Hooper	5/2/13 13:30	18.810				4.1											
Hooper	5/4/13 10:07	16.062				3.6											
Hooper	5/7/13 10:41	13.541				3.4		41	19.2	0.2	1.1	0.2	1.1			0.4	
Hooper	5/13/13 20:02	9.887				3.9		20	10.1	0.2	1.3	0.2	1.3	1.5		0.3	0.3
Hooper	5/16/13 1:23	9.235				6.1											
Hooper	5/16/13 1:25	9.235				3.8											
Hooper	5/23/13 1:28	7.847				3.9											

Appendix E:

Soil carbon and nitrogen sampling at the Idaho CT site

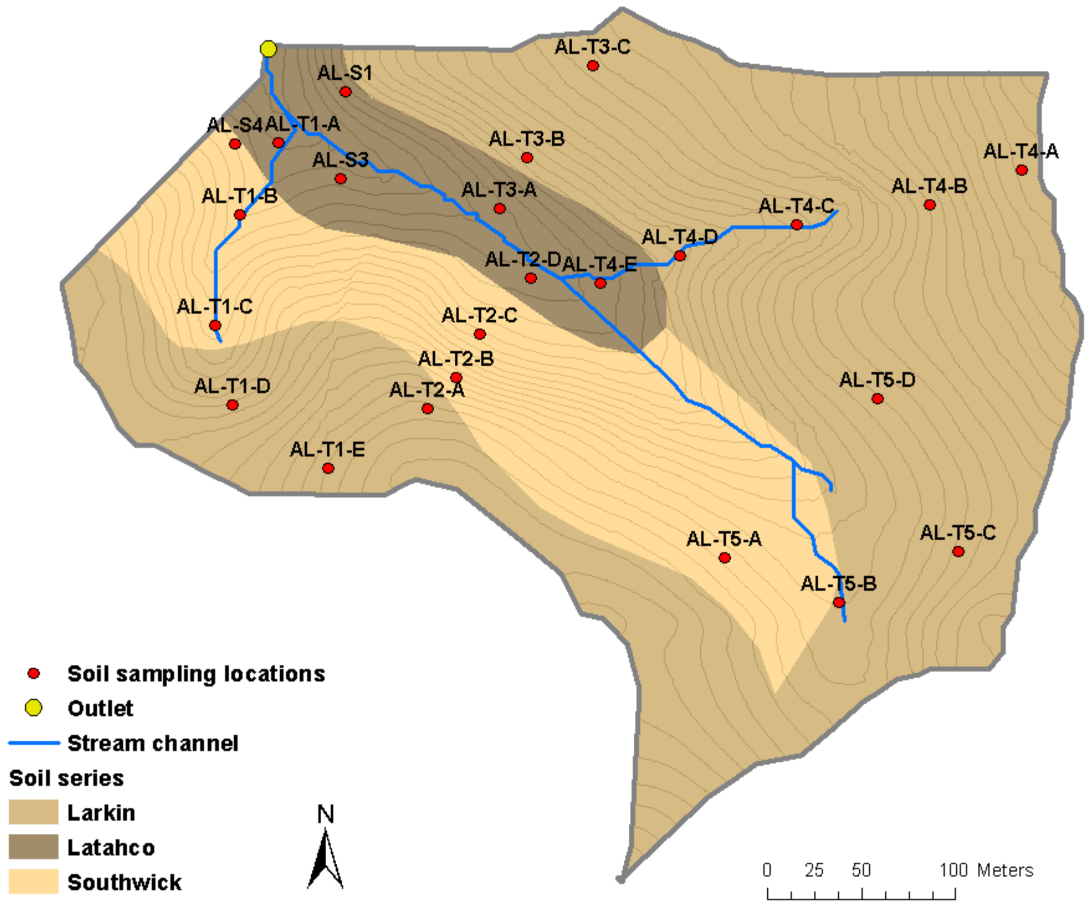


Figure E.1 Soil sampling locations at the Idaho-CT site. Samples were collected during the spring of 2013 at 30 cm increments down to 120 cm in triplicates for each sampling location.

Table E.1 Soil physical and selected chemical properties data from the Idaho-CT site during the spring of 2013.

Location	Depth	TN	TC	NH_4^+	NO_3^--N	Bulk density	Gravimetric soil water	Volumetric soil water
	cm	g/g	g/g	mg/g	mg/g	g/cm^3	g/g	g/g
AL-S1	0-15	0.16	2.09	0.002	0.007	1.02	0.27	0.30
AL-S1	0-15	0.16	2.09	0.002	0.007	1.34	0.27	0.38
AL-S1	0-15	0.16	2.09	0.002	0.007	1.18	0.27	0.34
AL-S1	15-30	0.13	1.63	0.001	0.003	1.47	0.34	0.50
AL-S1	15-30	0.13	1.63	0.001	0.003	1.17	0.34	0.37
AL-S1	15-30	0.13	1.63	0.001	0.003	1.19	0.34	0.33
AL-S1	30-60	0.11	1.48	0.001	0.003	1.36	0.31	0.52
AL-S1	30-60	0.11	1.48	0.001	0.003	1.37	0.31	0.49
AL-S1	30-60	0.11	1.48	0.001	0.003	1.53	0.31	0.51
AL-S1	60-90	0.09	1.21	0.001	0.003	1.56	0.34	0.57
AL-S1	60-90	0.09	1.21	0.001	0.003	1.44	0.34	0.44
AL-S1	60-90	0.09	1.21	0.001	0.003	1.42	0.34	0.46
AL-S1	90-120	0.04	0.73	0.004	0.001	1.40	0.33	0.47
AL-S1	90-120	0.04	0.73	0.004	0.001	1.57	0.33	0.53
AL-S2	0-15	0.09	1.18	0.001	0.001	1.22	0.22	0.32
AL-S2	0-15	0.09	1.18	0.001	0.001	1.28	0.22	0.33
AL-S2	0-15	0.09	1.18	0.001	0.001	1.62	0.22	0.44
AL-S2	15-30	0.01	0.40	0.001	0.001	1.41	0.26	0.37
AL-S2	15-30	0.01	0.40	0.001	0.001	1.65	0.26	0.50
AL-S2	15-30	0.01	0.40	0.001	0.001	1.37	0.26	0.36
AL-S2	30-60	0.03	0.38	0.001	0.001	1.40	0.24	0.32
AL-S3	0-15	0.16	2.08	0.001	0.002	0.99	0.24	0.26
AL-S3	0-15	0.16	2.08	0.001	0.002	1.03	0.24	0.26
AL-S3	0-15	0.16	2.08	0.001	0.002	1.25	0.24	0.33
AL-S3	15-30	0.13	1.86	0.001	0.003	1.27	0.24	0.32
AL-S3	15-30	0.13	1.86	0.001	0.003	1.26	0.24	0.32
AL-S3	15-30	0.13	1.86	0.001	0.003	1.36	0.24	0.36
AL-S3	30-60	0.12	1.59	0.002	0.004	1.33	0.26	0.36
AL-S3	30-60	0.12	1.59	0.002	0.004	1.31	0.26	0.37
AL-S3	30-60	0.12	1.59	0.002	0.004	1.40	0.26	0.34
AL-S3	60-90	0.06	0.97	0.001	0.002	1.44	0.23	0.45
AL-S3	60-90	0.06	0.97	0.001	0.002	1.50	0.23	0.44
AL-S3	60-90	0.06	0.97	0.001	0.002	1.30	0.23	0.39
AL-S4	0-15	0.14	1.86	0.002	0.006	1.06	0.21	0.27
AL-S4	0-15	0.14	1.86	0.002	0.006	1.14	0.21	0.30
AL-S4	0-15	0.14	1.86	0.002	0.006	1.05	0.21	0.25
AL-S4	1q5-30	0.09	1.13	0.001	0.002	1.32	0.25	0.33

AL-S4	15-30	0.09	1.13	0.001	0.002	1.11	0.25	0.28
AL-S4	15-30	0.09	1.13	0.001	0.002	1.15	0.25	0.29
AL-S4	30-60	0.05	0.79	0.001	0.002	1.32	0.24	0.33
AL-S4	30-60	0.05	0.79	0.001	0.002	1.41	0.24	0.39
AL-S4	30-60	0.05	0.79	0.001	0.002	1.35	0.24	0.34
AL-T1-A	0-30	0.12	1.65	0.001	0.002	1.30	0.30	0.37
AL-T1-A	0-30	0.12	1.65	0.001	0.002	1.22	0.30	0.37
AL-T1-A	0-30	0.12	1.65	0.001	0.002	1.42	0.30	0.36
AL-T1-A	30-60	0.08	1.23	0.001	0.002	1.54	0.25	0.35
AL-T1-A	30-60	0.08	1.23	0.001	0.002	1.40	0.25	0.35
AL-T1-A	30-60	0.08	1.23	0.001	0.002	1.52	0.25	0.34
AL-T1-A	60-90	0.09	1.42	0.002	0.002	1.49	0.27	0.48
AL-T1-A	60-90	0.09	1.42	0.002	0.002	1.44	0.27	0.40
AL-T1-A	60-90	0.09	1.42	0.002	0.002	1.63	0.27	0.45
AL-T1-A	90-120	0.10	1.22	0.001	0.003	1.32	0.33	0.48
AL-T1-A	90-120	0.10	1.22	0.001	0.003	1.63	0.33	0.47
AL-T1-B	0-30			0.001	0.002	1.69	0.27	0.49
AL-T1-B	0-30			0.001	0.002	1.79	0.27	0.51
AL-T1-B	0-30			0.001	0.002	1.67	0.27	0.44
AL-T1-B	30-60	0.13	1.65	0.001	0.002	1.53	0.27	0.47
AL-T1-B	30-60	0.13	1.65	0.001	0.002	1.47	0.27	0.43
AL-T1-B	30-60	0.13	1.65	0.001	0.002	1.29	0.27	0.46
AL-T1-B	60-90	0.10	1.47	0.001	0.002	1.55	0.31	0.48
AL-T1-B	60-90	0.10	1.47	0.001	0.002	1.74	0.31	0.53
AL-T1-B	60-90	0.10	1.47	0.001	0.002	1.67	0.31	0.54
AL-T1-B	90-120	0.05	0.91	0.001	0.002	1.45	0.32	0.46
AL-T1-B	90-120	0.05	0.91	0.001	0.002	1.72	0.32	0.55
AL-T1-B	90-120	0.05	0.91	0.001	0.002	1.37	0.32	0.43
AL-T1-C	0-30	0.12	1.66	0.001	0.003	1.64	0.26	0.41
AL-T1-C	0-30	0.12	1.66	0.001	0.003	1.74	0.26	0.16
AL-T1-C	0-30	0.12	1.66	0.001	0.003	1.56	0.26	0.42
AL-T1-C	30-60	0.13	1.70	0.001	0.002	1.35	0.29	0.43
AL-T1-C	30-60	0.13	1.70	0.001	0.002	1.30	0.29	0.41
AL-T1-C	30-60	0.13	1.70	0.001	0.002	1.53	0.29	0.50
AL-T1-C	60-90	0.09	1.34	0.001	0.002	1.53	0.31	0.43
AL-T1-C	60-90	0.09	1.34	0.001	0.002	1.55	0.31	0.52
AL-T1-C	60-90	0.09	1.34	0.001	0.002	1.78	0.31	0.57
AL-T1-C	90-120					1.18		0.45
AL-T1-C	90-120					1.79		0.58
AL-T1-D	0-30	0.14	1.82	0.001	0.005	1.35	0.24	0.34
AL-T1-D	0-30	0.14	1.82	0.001	0.005	1.51	0.24	0.37
AL-T1-D	0-30	0.14	1.82	0.001	0.005	1.43	0.24	0.30
AL-T1-D	30-60	0.09	1.07	0.001	0.003	1.46	0.25	0.43

AL-T1-D	30-60	0.09	1.07	0.001	0.003	1.62	0.25	0.43
AL-T1-D	30-60	0.09	1.07	0.001	0.003	1.27	0.25	0.39
AL-T1-D	60-90	0.05	0.69	0.001	0.002	1.59	0.24	0.41
AL-T1-D	60-90	0.05	0.69	0.001	0.002	1.77	0.24	0.48
AL-T1-D	60-90	0.05	0.69	0.001	0.002	1.68	0.24	0.38
AL-T1-E	0-30	0.13	1.68	0.001	0.002	1.19	0.26	0.31
AL-T1-E	0-30	0.13	1.68	0.001	0.002	1.44	0.26	0.40
AL-T1-E	0-30	0.13	1.68	0.001	0.002	1.33	0.26	0.37
AL-T1-E	30-60	0.05	0.88	0.001	0.002		0.24	0.45
AL-T1-E	30-60	0.05	0.88	0.001	0.002	1.70	0.24	0.39
AL-T1-E	30-60	0.05	0.88	0.001	0.002	1.35	0.24	0.40
AL-T1-E	60-90	0.05	0.63	0.001	0.001	1.60	0.23	0.34
AL-T1-E	60-90	0.05	0.63	0.001	0.001	1.68	0.23	0.36
AL-T1-E	60-90	0.05	0.63	0.001	0.001	1.59	0.23	0.35
AL-T1-E	90-120	0.04	0.44	0.001	0.002	1.59	0.23	0.34
AL-T2-A	0-30	0.08	1.06	0.001	0.001	1.72	0.24	0.43
AL-T2-A	0-30	0.08	1.06	0.001	0.001	1.58	0.24	0.47
AL-T2-A	0-30	0.08	1.06	0.001	0.001	1.59	0.24	0.43
AL-T2-A	30-60	0.05	0.66	0.001	0.001	1.46	0.23	0.34
AL-T2-A	30-60	0.05	0.66	0.001	0.001	1.37	0.23	0.28
AL-T2-A	30-60	0.05	0.66	0.001	0.001	1.73	0.23	0.47
AL-T2-A	60-90	0.03	0.45	0.001	0.001	1.61	0.22	0.29
AL-T2-A	60-90	0.03	0.45	0.001	0.001	1.71	0.22	0.38
AL-T2-A	60-90	0.03	0.45	0.001	0.001	1.62	0.22	0.34
AL-T2-A	90-120	0.02	0.43	0.001	0.001	1.75	0.21	0.40
AL-T2-A	90-120	0.02	0.43	0.001	0.001	1.60	0.21	0.32
AL-T2-B	0-30	0.12	1.47	0.001	0.002	1.47	0.24	0.36
AL-T2-B	0-30	0.12	1.47	0.001	0.002	1.47	0.24	0.35
AL-T2-B	0-30	0.12	1.47	0.001	0.002	1.38	0.24	0.34
AL-T2-B	30-60	0.10	1.27	0.001	0.002	1.36	0.25	0.37
AL-T2-B	30-60	0.10	1.27	0.001	0.002	1.44	0.25	0.39
AL-T2-B	30-60	0.10	1.27	0.001	0.002	1.33	0.25	0.35
AL-T2-B	60-90	0.07	0.88	0.001	0.001	1.47	0.26	0.42
AL-T2-B	60-90	0.07	0.88	0.001	0.001	1.46	0.26	0.42
AL-T2-B	60-90	0.07	0.88	0.001	0.001	1.42	0.26	0.47
AL-T2-B	90-120	0.03	0.51	0.001	0.001	1.63	0.22	0.35
AL-T2-B	90-120	0.03	0.51	0.001	0.001	1.56	0.22	0.33
AL-T2-B	90-120	0.03	0.51	0.001	0.001	1.61	0.22	0.36
AL-T2-C	0-30	0.15	1.87	0.000	0.005	1.22	0.26	0.30
AL-T2-C	0-30	0.15	1.87	0.000	0.005	1.32	0.26	0.32
AL-T2-C	0-30	0.15	1.87	0.000	0.005	1.27	0.26	0.31
AL-T2-C	30-60	0.13	1.64	0.000	0.004	1.27	0.28	0.35
AL-T2-C	30-60	0.13	1.64	0.000	0.004	1.26	0.28	0.34

AL-T2-C	30-60	0.13	1.64	0.000	0.004	1.21	0.28	0.33
AL-T2-C	60-90	0.08	1.02	0.000	0.002	1.34	0.26	0.38
AL-T2-C	60-90	0.08	1.02	0.000	0.002	1.44	0.26	0.38
AL-T2-C	60-90	0.08	1.02	0.000	0.002	1.45	0.26	0.38
AL-T2-D	0-30			0.000	0.004	1.35	0.29	0.37
AL-T2-D	0-30			0.000	0.004	1.66	0.29	0.50
AL-T2-D	30-60			0.000	0.003	1.42	0.33	0.51
AL-T2-D	30-60			0.000	0.003	1.21	0.33	0.43
AL-T2-D	30-60			0.000	0.003	1.61	0.33	0.53
AL-T2-D	60-90	0.10	1.20	0.000	0.003	1.28	0.39	0.45
AL-T2-D	60-90	0.10	1.20	0.000	0.003	1.57	0.39	0.49
AL-T2-D	60-90	0.10	1.20	0.000	0.003	1.29	0.39	0.39
AL-T2-D	90-120	0.13	1.78	0.001	0.003	1.69	0.31	0.46
AL-T2-D	90-120	0.13	1.78	0.001	0.003	1.76	0.31	0.43
AL-T3-A	0-30	0.12	1.53	0.001	0.002	1.71	0.24	0.39
AL-T3-A	0-30	0.12	1.53	0.001	0.002	1.56	0.24	0.34
AL-T3-A	0-30	0.12	1.53	0.001	0.002	1.27	0.24	0.27
AL-T3-A	120-150	0.06	0.97	0.001	0.002	1.43	0.33	0.41
AL-T3-A	30-60	0.10	1.39	0.000	0.003		0.23	0.41
AL-T3-A	30-60	0.10	1.39	0.000	0.003	1.29	0.23	0.31
AL-T3-A	30-60	0.10	1.39	0.000	0.003	1.48	0.23	0.33
AL-T3-A	60-90	0.12	1.62	0.001	0.003	1.32	0.28	0.37
AL-T3-A	60-90	0.12	1.62	0.001	0.003	1.34	0.28	0.41
AL-T3-A	60-90	0.12	1.62	0.001	0.003	1.16	0.28	0.31
AL-T3-A	90-120	0.12	1.51	0.001	0.002	1.35	0.31	0.42
AL-T3-A	90-120	0.12	1.51	0.001	0.002	1.65	0.31	0.48
AL-T3-B	0-30	0.11	1.47	0.001	0.005	1.55	0.21	0.33
AL-T3-B	0-30	0.11	1.47	0.001	0.005	1.39	0.21	0.27
AL-T3-B	0-30	0.11	1.47	0.001	0.005	1.38	0.21	0.29
AL-T3-B	30-60	0.05	0.74	0.001	0.002	1.47	0.21	0.31
AL-T3-B	30-60	0.05	0.74	0.001	0.002	1.44	0.21	0.20
AL-T3-B	30-60	0.05	0.74	0.001	0.002	1.43	0.21	0.25
AL-T3-B	60-90	0.04	0.44	0.001	0.002	1.53	0.21	0.28
AL-T3-B	60-90	0.04	0.44	0.001	0.002	1.46	0.21	0.22
AL-T3-B	60-90	0.04	0.44	0.001	0.002	1.56	0.21	0.32
AL-T3-C	0-30	0.10	1.33	0.001	0.005	1.38	0.23	0.25
AL-T3-C	0-30	0.10	1.33	0.001	0.005	1.36	0.23	0.28
AL-T3-C	0-30	0.10	1.33	0.001	0.005	1.37	0.23	0.29
AL-T3-C	30-60	0.06	0.83			1.40	-3.92	0.30
AL-T3-C	30-60	0.06	0.83			1.45	-3.92	0.29
AL-T3-C	30-60	0.06	0.83			1.53	-3.92	0.16
AL-T3-C	60-90	0.04	0.50	0.001	0.002	1.55	0.21	0.28
AL-T3-C	60-90	0.04	0.50	0.001	0.002	1.48	0.21	0.25

AL-T3-C	60-90	0.04	0.50	0.001	0.002	1.55	0.21	0.28
AL-T4-A	0-30	0.13	1.71	0.001	0.007	1.41	0.21	0.29
AL-T4-A	0-30	0.13	1.71	0.001	0.007	1.51	0.21	0.31
AL-T4-A	0-30	0.13	1.71	0.001	0.007	1.43	0.21	0.33
AL-T4-A	30-60	0.08	1.00	0.001	0.003	1.27	0.21	0.28
AL-T4-A	30-60	0.08	1.00	0.001	0.003	1.40	0.21	0.30
AL-T4-A	30-60	0.08	1.00	0.001	0.003	1.35	0.21	0.30
AL-T4-A	60-90	0.04	0.69	0.000	0.003	1.44	0.21	0.32
AL-T4-A	60-90	0.04	0.69	0.000	0.003	1.39	0.21	0.30
AL-T4-A	90-120	0.03	0.45			1.53		0.31
AL-T4-B	0-30	0.10	1.37	0.001	0.006	1.34	0.21	0.27
AL-T4-B	0-30	0.10	1.37	0.001	0.006	1.42	0.21	0.31
AL-T4-B	0-30	0.10	1.37	0.001	0.006	1.40	0.21	0.29
AL-T4-B	30-60	0.05	0.72	0.001	0.004	1.42	0.21	0.30
AL-T4-B	30-60	0.05	0.72	0.001	0.004	1.31	0.21	0.27
AL-T4-B	30-60	0.05	0.72	0.001	0.004	1.40	0.21	0.28
AL-T4-B	60-90	0.04	0.53	0.001	0.004	1.54	0.19	0.31
AL-T4-B	60-90	0.04	0.53	0.001	0.004	1.43	0.19	0.28
AL-T4-C	0-30	0.12	1.60	0.001	0.005	1.27	0.24	0.31
AL-T4-C	0-30	0.12	1.60	0.001	0.005	1.64	0.24	0.37
AL-T4-C	0-30	0.12	1.60	0.001	0.005	1.26	0.24	0.40
AL-T4-C	30-60	0.12	1.75	0.001	0.003	1.35	0.28	0.37
AL-T4-C	30-60	0.12	1.75	0.001	0.003	1.27	0.28	0.32
AL-T4-C	30-60	0.12	1.75	0.001	0.003	1.36	0.28	0.39
AL-T4-C	60-90	0.09	1.46	0.001	0.003	1.50	0.27	0.43
AL-T4-C	60-90	0.09	1.46	0.001	0.003	1.56	0.27	0.46
AL-T4-C	90-120	0.07	1.06	0.001	0.004	1.66	0.31	0.49
AL-T4-C	90-120	0.07	1.06	0.001	0.004	1.64	0.31	0.52
AL-T4-C	90-120	0.07	1.06	0.001	0.004	1.41	0.31	0.32
AL-T4-D	0-30	0.13	1.68	0.001	0.006	1.92	0.25	0.49
AL-T4-D	0-30	0.13	1.68	0.001	0.006		0.25	0.59
AL-T4-D	30-60	0.11	1.48	0.001	0.003	1.48	0.25	0.41
AL-T4-D	30-60	0.11	1.48	0.001	0.003	1.35	0.25	0.38
AL-T4-D	30-60	0.11	1.48	0.001	0.003	1.30	0.25	0.37
AL-T4-D	60-90	0.09	1.18	0.001	0.003	1.49	0.28	0.38
AL-T4-D	60-90	0.09	1.18	0.001	0.003	1.46	0.28	0.46
AL-T4-D	60-90	0.09	1.18	0.001	0.003	1.43	0.28	0.40
AL-T4-D	90-120	0.06	0.84			1.60		0.42
AL-T4-D	90-120	0.06	0.84			1.41		0.48
AL-T4-D	90-120	0.06	0.84			1.45		0.38
AL-T4-E	0-30	0.12	1.67	0.001	0.001	1.78	0.29	0.53
AL-T4-E	0-30	0.12	1.67	0.001	0.001		0.29	0.57
AL-T4-E	0-30	0.12	1.67	0.001	0.001		0.29	0.60

AL-T4-E	30-60	0.09	1.35	0.001	0.002	1.75	0.28	0.48
AL-T4-E	30-60	0.09	1.35	0.001	0.002		0.28	0.52
AL-T4-E	30-60	0.09	1.35	0.001	0.002	1.75	0.28	0.51
AL-T4-E	60-90	0.07	1.05	0.001	0.001		0.29	0.57
AL-T4-E	60-90	0.07	1.05	0.001	0.001	1.58	0.29	0.47
AL-T4-E	60-90	0.07	1.05	0.001	0.001	1.66	0.29	0.52
AL-T5-A	0-30	0.15	2.06	0.001	0.009	1.40	0.25	0.26
AL-T5-A	30-60	0.12	1.49	0.001	0.006	1.55	0.26	0.26
AL-T5-A	60-90	0.07	0.96	0.001	0.004	1.77	0.24	0.34
AL-T5-B	0-30	0.14	2.01	0.001	0.007	1.33	0.25	0.34
AL-T5-B	30-60	0.10	1.28	0.000	0.005	1.77	0.26	0.43
AL-T5-C	0-30	0.16	2.07	0.001	0.008	1.20	0.35	0.22
AL-T5-C	30-60	0.10	1.53	0.001	0.004	1.37	0.36	0.28
AL-T5-C	60-90	0.06	0.96			1.24		0.34
AL-T5-C	90-120	0.03	0.68	0.001	0.005	1.49	0.33	0.31
AL-T5-D	0-30	0.14	1.69	0.001	0.008	1.41	0.27	0.25
AL-T5-D	30-60	0.04	0.70	0.001	0.003	1.37	0.24	0.27
AL-T5-D	60-90	0.04	0.45	0.000	0.002	1.52	0.23	0.32
AL-T5-D	90-120	0.04	0.43	0.001	0.002	1.81	0.22	0.37

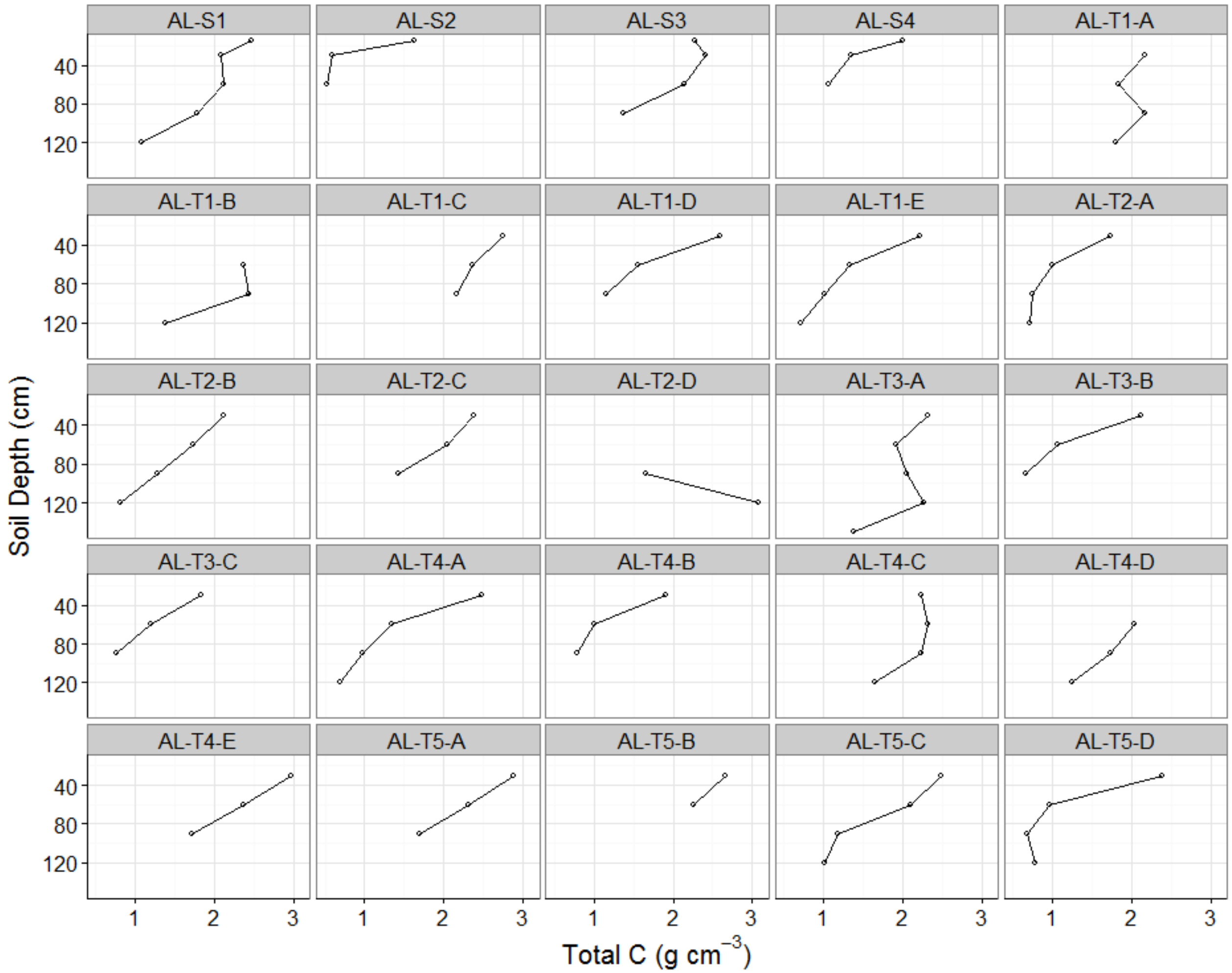


Figure E.2 Total soil carbon (g cm^{-3}) with depth for all sampling sites at the Idaho-CT site during the spring of 2012.

Appendix F:

Observed and simulated soil loss form the Idaho-CT site

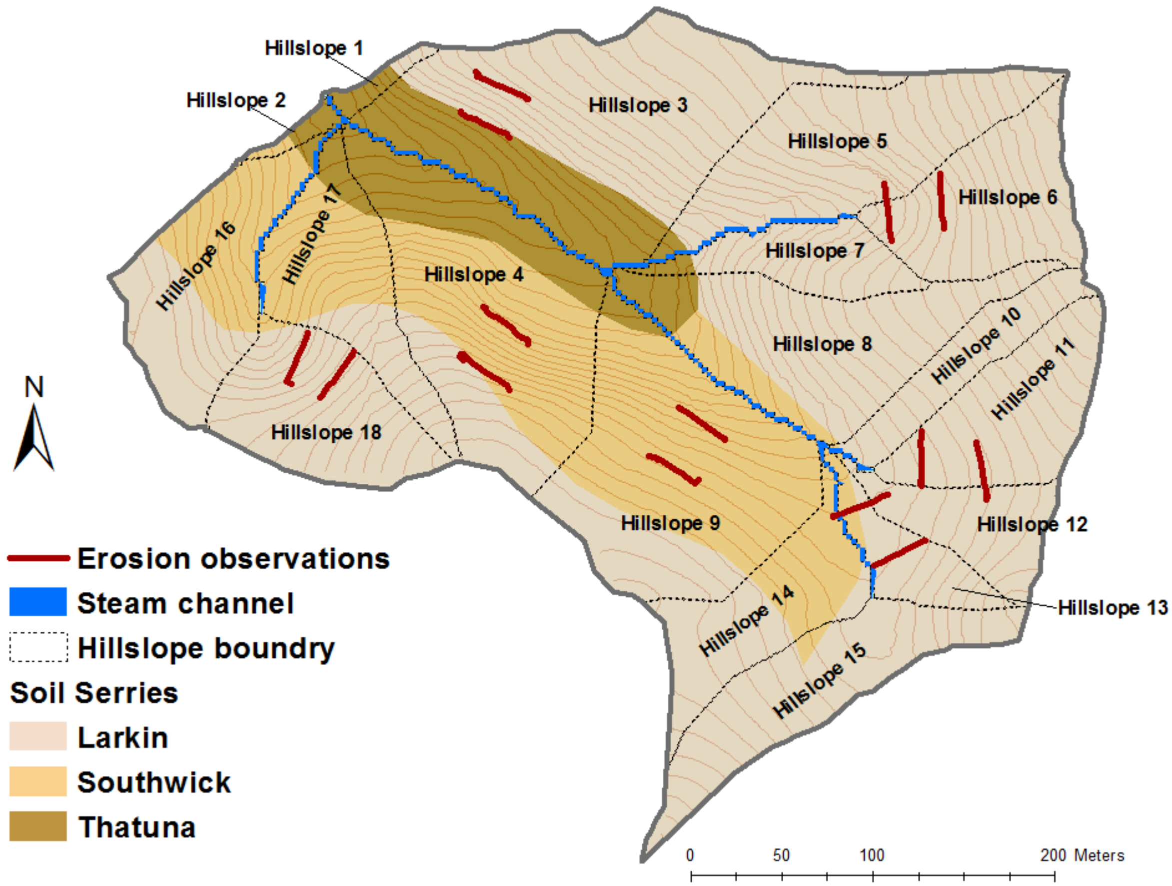


Figure F.1 Map of soil erosion measurement (red lines) and hillslopes defined in WEPP taken manually at the Idaho-CT during the 2012 water year.

Table F.1 Observed and simulated soil loss by hillslope with SDR's from the Idaho-CT site for water year 2012.

Hillslope	Soil Series	Observed Soil loss (kg)	Simulated soil loss (kg)	Difference (%)	Observed SDR	Simulated SDR
Hill 1	Larkin	n.d*	350	-	0.78	0.6
Hill 2	Larkin	n.d*	0	-		
Hill 3	Larkin	18	3354	198		
Hill 4	Southwick	8453	49183	141		
Hill 5	Larkin	n.d*	0	-		
Hill 6	Larkin	1598	6922	125		
Hill 7	Larkin	n.d*	0	-		
Hill 8	Larkin	n.d*	0	-		
Hill 9	Southwick	5151	12633	84		
Hill 10	Larkin	n.d*	95	-		
Hill 11	Larkin	3420	0	-200		
Hill 12	Larkin	n.d*	0	-		
Hill 13	Larkin	1976	0	-200		
Hill 14	Southwick	n.d*	0	-		
Hill 15	Larkin	n.d*	0	-		
Hill 16	Southwick	n.d*	0	-		
Hill 17	Southwick	n.d*	0	-		
Hill 18	Southwick	13439	192	-194		

*n.d. indicates that data was not collected for that particular hillslope

Appendix G:

Materials for the “Water and Erosion of the Soil” lesson plan

WATER AND EROSION OF THE SOIL

AG 515 – D

UNIT OBJECTIVE

After completion of this unit, students should be able to view soil as a living component of the agricultural ecosystem. Students will study soil, conservation techniques, no-till farming, soil macro-organisms, and erosion. Special focus will be on soil complexity and erosion.

SPECIFIC OBJECTIVES AND COMPETENCIES

After completion of this unit, the student should be able to:

1. Define terms related to water and erosion
2. Describe the traditional distribution of precipitation for your area
3. Contrast future precipitation predictions and historical allocations
4. Describe the relationship between snow pack and seasonal reservoir water levels
5. Discuss the impacts of changing precipitation patterns on dryland farming practices
6. List and describe three farming practices designed to reduce erosion
7. Describe the relationship between fertilizer application and rainfall
8. List three practices that farmers can adapt to account for changes in water allocations on dryland farms
9. Match soil water holding capacity to cropping systems

SUGGESTED ACTIVITIES

I. Suggested activities for instructor
   A. Print materials to supplement unit, or create PDF catalog on student digital devises.
      i. Literature
         1. Service, R. F. (2004). As the west goes dry. *Science, 303*(5661), 1124-1127. doi: 10.1126/science.303.5661.1124
         2. Columbia Basin Fact Sheet. http://www.usbr.gov/climate/SECURE/docs/columbiabasinfactsheet.pdf (On the CD)
   B. Load PPT to local machine and make any necessary copies of materials.
   C. Provide students with objective sheet and discuss.
   D. Provide students with information and assignment sheets, and laboratory exercises.
   E. Discuss information and assignment sheets.
   F. Demonstrate and discuss procedures outlined in laboratory exercises.
   G. Conduct the laboratory activities with the students and discuss the results.
   H. Arrange for a field trip to land site for evaluation, sampling and discussion.
   I. Review and give test.
   J. Reteach and retest if necessary.

II. Instructional materials
   A. Objective sheet
   B. Suggested activities
   C. Information sheet
   D. Assignment sheet
   E. AS 1--
   F. Answers to assignment sheet
   G. Instructor notes for laboratory exercises
   H. Laboratory exercises
   I. LE 1--
   J. Answers to laboratory exercises
   K. Test
   L. Answers to test
   M. Erosion Lab Activity

III. Unit References
   A. Western Water Assessment (http://wwa.colorado.edu/)
   B. Palouse Basin: Community water information system (http://wr.civil.uidaho.edu/cwis/palouse/)
   C. Water Resources, Washington State Department of Ecology (http://www.ecy.wa.gov/programs/wr/wrhome.html)

D. Climate Impacts Group (http://cses.washington.edu/cig/pnwc/pnwc.shtml)
E. Project WET

WATER AND EROSION OF THE SOIL

AG 515 – D

INFORMATION SHEET

1. Terms and definitions
   A. Soil—The mineral and organic matter that supports plant growth on the earth's surface; it is a mixture of particles of rock, organic materials, living organisms, air and water
   B. Aggregate—Mass or cluster of soil particles such as a crumb or granule
   C. Leaching—Removal of water soluble soil components from the soil by the downward action of water
   D. Erosion—Process in which soil particles undergo detachment, transport, and deposition.
   E. Hydrologic cycle-- The continuous movement of water on, above and below the surface of the Earth
   F. Runoff-- Occurs when the soil is infiltrated to full capacity (saturated) and excess water from rain, snowmelt, or other sources flows over the land.
   G. Watershed—A geographically defined area where all of the water that comes into or under it drains into one body of water. The size of which is defined by the body of water into which it collects.
   H. Hydrology-- Branch of science concerned with the study of the properties and movement of water.
   I. Conservation tillage—Tillage practices that conserve soil by leaving crop residues on the field and reducing the amount of soil disturbance.
   J. No-till—Farming practice that does not require seedbed disturbance or preparation prior to planting. Machinery deposits seeds and fertilizer through existing ground cover.
2. Water **(Slide 1)** *Teaching Idea: Use handout As the West Goes Dry . This isn't so much a climate change discussion as a look at trends, and discuss what we do. The why isn't really important anymore; it's how do we deal with the reality that water availability has changed over the past several decades. Farmers and all water users need to understand how it's changing and find ways to adapt.*
   A. Water availability is one of the most limiting factors in crop production across the Western US. Changes in when water is available have impacts on every aspect of crop production.
3. Objectives **(Slide 2)** *Teaching Idea:*
   A. Define terms related to water and erosion
   B. Describe the traditional distribution of precipitation for your area
   C. Contrast future precipitation predictions and historical allocations
   D. Describe the relationship between snow pack and seasonal reservoir water levels

   E. Discuss the impacts of changing precipitation patterns on dryland farming practices
   F. List and describe three farming practices designed to reduce erosion
   G. Describe the relationship between fertilizer application and rainfall
   H. List three practices that farmers can adapt to account for changes in water allocations on dryland farms
   I. Match soil water holding capacity to cropping systems

4. Terms **(Slide 3)** *Teaching Idea:*
   A. Hydrologic cycle
   B. Runoff
   C. Watershed
   D. Erosion
   E. Hydrology
5. Hydrologic cycle **(Slide 4)** *Teaching Idea: Students know the cycle. This is a place to discuss how these stages relate to our area? What does the precipitation fall as? Where is it stored? How does that affect me as a student? Hand out the Basin Report for the Columbia basin. Discuss its implications.*
   A. Precipitation
   B. Evaporation
   C. Condensation
   D. Runoff
   E. Transpiration
6. Runoff Defined **(Slide 5)** *Teaching Idea:*
   A. Surface Runoff: is the water flow that occurs when soil pores are completely full of water (saturated) and no further water can infiltrate. At this point additional water from rain, snowmelt, or other sources flows over the land.
7. Watershed defined: **(Slide 6)** *Teaching Idea: Review the larger range of the Columbia watershed, and discuss the local watershed, its storage capacity, and who uses the water locally.*
   A. A watershed is the area of land where all of the water that is under it or drains from it goes into the same place. They come in all shapes and sizes.
8. Local storehouses for water **(Slide 7)** *Teaching Idea: Find Local photos or articles*
   A. Reservoirs:
9. Local storehouses for water **(Slide 8)** *Teaching Idea:*
   A. Snow pack:
10. Local storehouses for water **(Slide 9)** *Teaching Idea:*
    A. Aquifers:
11. Average Historical Precipitation distribution for the Inland PNW **(Slide 10)** *Teaching Idea: http://cses.washington.edu/cig/maps/index.shtml has maps of historical rainfall by time of year. They could be used to look at the entire region.*

    A. Average annual precipitation ranges from 6 inches in South Central WA to 24 inches near Moscow ID.

12. Projected Annual Precipitation for the Inland PNW **(Slide 11)** *Teaching Idea:*
    A. Climate Change is expected to change annual rainfall distribution and amounts
    B. Models predict a 1-2% annual increase in precipitation for the region
    C. (image of projected rainfall distribution)
13. How Rainfall Distribution Impacts Farming -Why does it matter when it rains? **(Slide 12)** *Teaching Idea:*
    A. Dryland farming relies on stored soil water and precipitation that falls during crop growth
    B. Soils are limited in the amount of water that can be stored
    C. Less precipitation in summers when plants are actively growing can reduce the amount of water available to plants
    D. Increase in Fall and Spring rains can lead to muddy conditions when farmers need to be in the field planting
14. How much soil water do dryland crops need? **(Slide 13)** *Teaching Idea: Use Available-water-and-wheat-yield-EM049E.pdf and discuss how the changes in water directly impact the economics of the farmer and the region.*
    A. Crop yield is directly related to the amount of water stored in soil at planting and related to precipitation during plant growth
15. The Bottom Line **(Slide 14)** *Teaching Idea: This is a good place to tie back into the farm case studies from the last chapter. Discuss the disturbance of the soil and its impact on evaporation of soil water.*
    A. Dryland farming uses moisture in the soil profile
    B. More stored water the more production per acre
    C. It is estimated for every additional inch of water available to wheat in a winter wheat – summer fallow system will produce 7 bushels/acre
    D. Finding ways to prevent water from running off or evaporating increases the profits for farmers
16. Why does precipitation matter to irrigated farms? **(Slide15)** *Teaching Idea: Discussion should go back to reservoirs, when the water will collect, and when it is drawn out the fastest. Pose the question, if the reservoir is going dry who gets the water, cities, or farmers and why? This would be a great class debate if you have the flexibility and time. Its deeper thinking requirement is what the common core is focused upon.*
    A. Irrigation practices rely on stored precipitation in reservoirs.
    B. Changes in precipitation distribution will have potential impacts on water available for irrigation.
    C. Warmer wetter winters = less water stored in snowpack

17. Cultivation practices to increase soil moisture: **(Slide 16)** *Teaching Idea:*
    A. In drier areas many farmers will have a fallow season as part of their crop rotation to have additional stored water
    B. Fallow land has nothing grown on it for a season
18. Cultivation practices to increase soil moisture **(Slide 17)** *Teaching Idea:*
    A. Reduced Tillage: tilling with the intent on leave 30% or more of the field covered crop residues.
    B. Reducing tillage increases soil organic matter which increases the soils ability to store water
19. Cultivation practices to increase soil moisture **(Slide 18)** *Teaching Idea:*
    A. No-Till: Is a practice that minimizes soils disturbance and results in increased residue retention.
    B. This practice optimizes soil organic matter content which increases the soil's water holding capacity
20. Erosion **(Slide 19)** *Teaching Idea:*
    A. Erosion: is the detachment transport and deposition of soil particles due to the impact from rain drops, movement of water, and wind.
21. Cultivation practices to reduce runoff and erosion **(Slide 20)** *Teaching Idea:*
22. How does precipitation and soil moisture affect fertilizer application? **(Slide 21)** *Teaching Idea:*
    A. Fertilizer application rates are determined by an anticipated crop yield.
    B. In a wet year potential crop yield is greater than in a dry year. This would mean more fertilizer would have to be applied to a crop in a wet year to fulfill their nutrient requirements.
    C. In wetter years there is greater potential for fertilizer loss due to runoff and erosion. It's a double edge sword.
23. Rain on Frozen Soil **(Slide 22)** *Teaching Idea:*
    A. When rain falls on frozen soils water is unable to infiltrate the soil. It is similar to rain falling on pavement, excessive runoff happens when this occurs
    B. If soil is bare, it is easy for this water to erode soils
24. Activity/Lab **(Slide 23)** *Teaching Idea: Run as many different simulations through the lab as you have time for. The dollar store is where the pans were purchased so having multiples shouldn't cost much. Make students do a complete lab report and present their findings on the scenario they were assigned.*
    A. Soil infiltration and Runoff
25. Review Questions **(Slide 24)**
    A. What are the 5 parts of the hydrologic cycle?
    B. Name the three locations where water can be stored?
    C. In your own words define runoff and erosion.

D. How does soil moisture affect crop yield?

E. What cultivation practices can increase infiltration and decrease runoff and erosion?

Name: ________________________
Date: _____________________
Period: ___________________

Soil Infiltration and Runoff Lab
Student Worksheet

Management practices for agricultural fields can have lasting effects on soil physical properties and the environmental quality of streams surrounding the farm. In this lab you will test the effect of a variety of soil physical properties and management practices on water runoff, erosion and infiltration from a small soil plot. **Infiltration** can be defined as the movement of water into the soil profile while **runoff** occurs when water from precipitation does not infiltrate the soil profile and flows over the soil surface. Linked to runoff is **erosion**, which is the detachment, transport and redistribution of soil particles by either water or wind. Good water infiltration in a farm field has many benefits, it increases crop yields by increasing the amount of moisture available throughout the growing season and decreases runoff, which in turn can decrease erosion.

Discuss:
Identify two problems associated with eroded soil from an agricultural field.

Brainstorm one practice a farmer could implement that may help improve water infiltration.

Describe a weather event that could cause greater than average runoff.

Objectives:
In this experiment you will:

- Measure infiltration and runoff from a soil sample
- Compare the effect of soil texture, crop residue (dead plant material) or other factors on infiltration and runoff
- Measure grams of soil lost to erosion

Materials:

- Aluminum bread pan (inner pan)
- Sturdy bread pan slightly larger than disposable (catch pan)
- 12 oz. Gatorade bottle with holes in the lid
- Soil sample
- 400 mL beaker
- Dixie cups
- Ruler

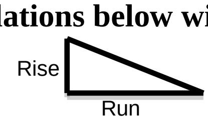
Procedure:

1. Mark the catch pan with three slope positions at 1”, 1.5”, and 2” from the inside end of the pan.
2. Place the inner pan inside the catch pan and fill the inner pan with soil level with cut out drain, DO NOT pack the soil in.

3. Place the inner pan with soil inside of the catch pan as shown in the diagram (page 4) and clip in place.
4. Calculate the slope (rise/run) of the soil surface and record on the data sheet on page 3.
5. Fill water bottle with 200 mL of water.
6. Pour water over the upper 2/3's of the soil surface by gently shaking the bottle roughly 2-3 inches above the surface of the soil.
7. Stop when the water begins to come out much more slowly.
8. There should be about 10 mL of water remaining in the bottle.
9. Let sit for 1 minute
10. Weigh a paper cup and write the weight, treatment and run number on the cup.
11. Pour water from the catch pan into the labeled and weighed paper cup.
12. Cover the cup to decrease evaporation and allow sediment to settle in the cup overnight (we will separate soil from the runoff water later).
13. Repeat steps 6-12 and record in your data sheet.
14. Fill water bottle with 100 mL
15. Remove lid, use two fingers to cover part of the opening and pour over the upper portion of the soil
16. Pour the water and soil into a weighed and labeled paper cup as before.
17. Prepare your second treatment as directed by your teacher and record the slope in your data sheet.
18. The next day, keeping the soil in your cup, carefully pour the water into the beaker record in your data sheet as *volume of runoff.*
19. Weigh the cup with soil in it and subtract the weight of the cup. This is the *weight of eroded soil*.*

*If you have time, the soil in the cup could be air-dried (24 hours at room temperature) to remove water before weighing. This will give a more accurate value for soil loss.

Calculations: the calculations below will help you fill in the data table.



1. Slope=*Rise(cm)/Run(cm)*
2. Weight of eroded soil (g) = Weight of cup and soil (g) – weight of cup (g)

Data:

Run	Treatment	1:	2:
	Slope = rise/run		
1	Volume of water added	190	190
	Volume of runoff		
	Weight of eroded soil		
2	Volume of water added	190	190
	Volume of runoff		
	Weight of eroded soil		
3	Volume of water added	90	90
	Volume of runoff		
	Weight of eroded soil		

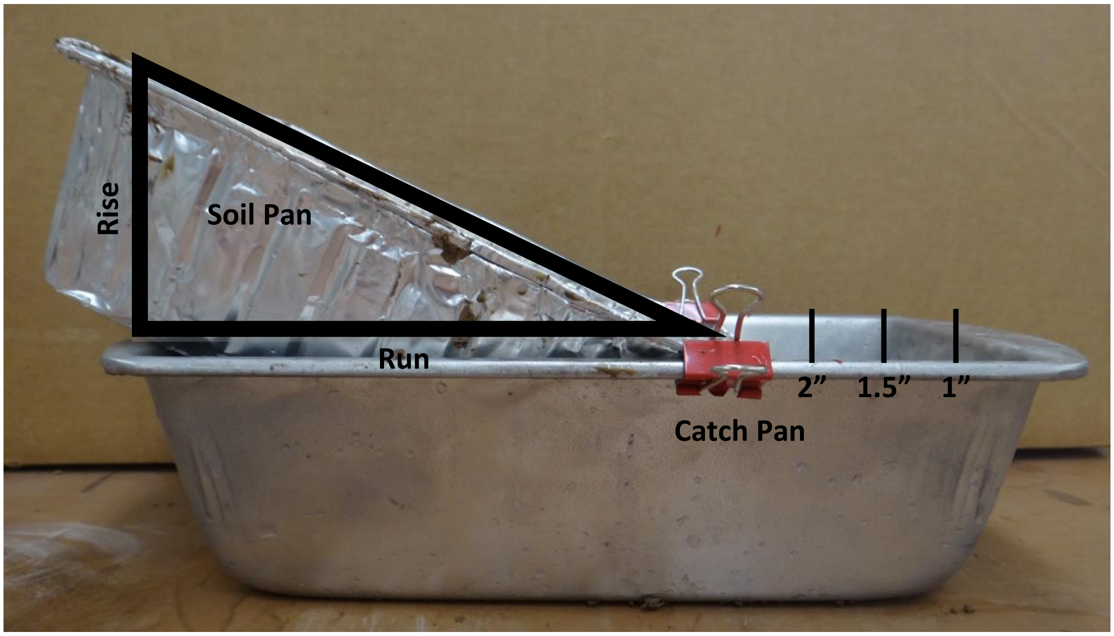
Analysis:

1. Which treatment had the lowest erosion rate (weight of eroded soil)?

2. Which treatment had the highest infiltration (lowest runoff)? How does this treatment reduce runoff?

3. Did runoff and erosion change with repeated wettings? What role did existing soil moisture play in infiltration and runoff?

Diagrams:



Teacher Resources/Preparations

Pre-lab Answers:
Identify two problems associated with eroded soil from an agricultural field.
1. loss of productivity on eroded farm field- farmers have to add greater amounts of fertilizer to buffer the effects of nutrient loss
2. Impaired water quality- nutrients move into aquatic systems with eroded soil. These nutrients may cause algal blooms, low dissolved oxygen and fish kills. This process is known as eutrophication. Decreased light penetration due to high sediment loading in streams may also negatively impact aquatic plants that provide valuable habitat for fish.
3. sediment removal- removal of sediment from roads and road side ditches causes increased costs to municipalities.
4. Human health effects- fine particles carried from agricultural areas by wind may become lodged in the lungs of people downwind. For more information on PM 10 and agriculture see http://www.pnw-winderosion.wsu.edu/.

Brainstorm one practice a farmer could implement that may help improve water infiltration?

The best way to prevent erosion is to implement practices that protect soil aggregates from the damaging effects of raindrop impaction and those that reduce runoff. These include using reduced tillage or no-till farming, maintain surface residue or use mulches on small farms, plant crops with deep taproots (these tap roots break through plow pans and other layers that restrict water flow), strip cropping on steep slopes, terracing, increase organic matter through practices (organic matter promotes good soil structure and infiltration, plant high residue crops

Describe a weather event that could cause greater than average runoff.
Two weather events that are known to increase erosion include, 1) Rainfall on frozen ground and 2) intense precipitation events. Frozen topsoil prevents infiltration, reduces infiltration and results in more runoff and greater erosion. Every soil has a certain capacity for infiltration. When the infiltration capacity is exceeded, water will begin to runoff. This can happen rapidly when precipitation occurs at a high intensity (depth of rainfall/unit time).

Assemble Apparatus:
1. Prepare bread pans according to the diagram provided
2. Fill with soil material to the level of the drainage slot
    a. For earthworm and plant experiments you will need to bring the no earthworm/plant soil to a similar soil moisture level (see below)
3. Outer pan can be used to restore the shape of the inner pan
4. Water bottle: use Gatorade bottle or other bottle with wider open. Using a very small bit drill 10-12 holes in the lid. You will need to gently shake the bottle to get water to come out. Water will stop coming out easily when there is about 10ml left in the bottle.

Soil Materials:
This lab experiment will allow many potential variables to be tested. Below is a list of variables you may wish to compare

1. Vegetation, ground cover and soil organisms– vegetation or ground cover can help reduce soil erosion. Plants can be grown in the containers prior to the lab to show how soil with vegetation reduces erosion. Dead plant material can also be added to the soil surface to imitate the effect of mulches or crop residue on soil erosion rates. Earthworms can be added to a soil to test the impact of burrows on infiltration.
   - Crop residue: add varying amounts of straw or leaf litter to the surface of the bread pan
     - Materials: soil, straw/leaf litter
   - Effect of plants: set up ahead of time to have some pans with plants growing in them recommend set up at least **2 weeks** ahead of time. Weigh tins and dry soil before planting
     - Materials: soil, seed (wheat, grass, peas, beans, etc.)
   - Effect of earthworms: Also requires set up ahead of time. Add a few earthworms to the pan and maintain at 20-25% moisture for **1week** before testing. Weigh tin and dry soil before wetting to appropriate moisture and adding worms.
     - Materials: soil, earthworms
2. Slope – the slope of the land can largely change erosion and runoff. Difference slopes can be created by moving the pan with soil to make it steeper or more level.
   - Slope: vary the angle of the top bread pan
     - Soil
3. Soil physical properties – sand, silt, and clay particles and the proportion of each changes water infiltration. Sand and organic soils will have high infiltration rates, while clayey soils will generally have slower rates. Soil compaction reduces the size and connectedness of pores, reducing infiltration.
   - Soil texture: Use varying soil textures by adding different amounts of sand to top soil.
     - Materials: Top soil, sand
   - Compaction: compare loosely filled and compacted pans.
     - Materials: soil
   - Frozen soil: Pre wet and freeze soil **1 day** lead time
     - Materials: Soil

Other suggestions:

- You may want to have students compare the various treatments and runs using a bar graph or by marking the level of soil and water on the outside of cups or other graphical representation
- You may want to have students graph the amount of soil and water lost by the amount of water added.

Extensions:

1. Which type of soil management practice would increase infiltration and decrease erosion and why? Till or No-till?
2. How do you think earthworms influence infiltration and erosion?
3. How does erosion affect crop yields within a field?
4. How do runoff and erosion effect streams adjacent to an agricultural field?

5. Does the amount of runoff/erosion change with repeated water applications? Why might this be?
6. What do farmers in your area do to decrease runoff and erosion?
7. Visit: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ Select one of the incentive programs listed under finical assistance on the NRCS website. Once you have selected and read about one of the programs use a paragraph to describe how it could potentially help to increase infiltration or decrease runoff and erosion. If the program does not relate directly to infiltration, runoff or erosion describe how the program designed to help the farmer?
8. See attached worksheet on the economics of soil and water loss.

Appendix H:

Extension activity for the economics of water infiltration and erosion

Economics of Water Infiltration and Erosion

According to study conducted by Washington State University Extension, every inch of available water in a dryland winter wheat summer fallow system results in approximately seven bushels per acre (Schillinger, et all. 2012).

1. If management practices leave a cultivated field bare with exposed soil evaporation and runoff results in a loss of an estimated 2 inches of stored soil moisture. What is the estimated economic loss for a 60 acre field? Assume the price of wheat is $6/bu.

2. How much would the farmer gain if he left residue on the surface? Assume that residue cover eliminated 1 inch of water loss?

3. Soil erosion carries valuable topsoil from the landscape and negatively impacts land productivity. When soil conservation efforts are put in place, the resulting benefits can range from $0.26 to $1.27 per ton of soil per acre conserved. In the early part of industrial agricultural the Palouse region, for example, was estimated to have a soil erosion rate over 9 tons per acre per year. If a conventional tillage farm, on the Palouse, switched to a no-till system, eliminating essentially all soil erosion what would be the per acre benefit if a ton of soil in this region was estimated to be worth $0.50/ton?

References:

Schillinger W., Schofstoll S., Alldredge J. Washington State University Extension and USDA. *Predicting Wheat Grain Yields Based on Available Water*. Bulletin EM049E. Pullman, WA. April 2012.

Hansen L., Ribaudo M. United State Department of Agriculture Economics Research Service. *Economic Measures of Soil Conservation Benefits*. Technical Bulletin 1922. September 2008.

Ebbert. J. C., Roe R. D. U.S Department of Agriculture NRCS and USGS. Soil Erosion in the Palouse River Basin: Indications of Improvement. USGS Fact Sheet 069-98. July 1998.

Answer Key to Extensions:

1. Which type of soil management practice would increase infiltration and decrease erosion and why? Till or No-till?
   No-till will increase infiltration rates and decrease erosion. No-till increases surface roughness which decreases the velocity with which water can flow over the surface thus decreasing the detachment of soil particles. No-till also leaves residue on the surface that protect soil aggregates from raindrop impaction. Raindrops fall at high velocity and transfer energy to the aggregates that they strike. This energy breaks down aggregates releasing small diameter particles that can be easily transported off-site.
   Tilling disturbs soil and breaks down aggregates overtime. Decreased aggregate stability and crushed macropores, decreases infiltration and increases runoff and erosion. Tillage also results in accelerated decomposition of organic matter, a factor very important to the development of stable aggregates.
2. How do you think earthworms influence infiltration and erosion?
   Earthworms burrow through the soil, creating what are, many times, large and connected soil pores. The large pores facilitate the rapid movement of water into the soil.
3. How does erosion affect crop yields within a field?
   Erosion can decrease crop yields in areas that are heavily eroded by exposing less productive subsoil.
4. How do runoff and erosion affect streams adjacent to an agricultural field?
   Excessive nutrients in runoff from agricultural fields due to fertilizer application can affect aquatic life in streams. Nutrients such as N and P can cause an increase in algae growth which over time can cause a decrease in dissolved oxygen (DO). This is known as ***eutrophication.*** *Most aquatic life requires on certain levels of DO to survive. Erosion from agricultural fields affects the ability of light to penetrate the water and can fill in small spaces between rocks on the stream bed, which many fish species depend on for spawning. More sediment = less light in the water which can hinder the ability of fish to its hunt prey, increase stream temperatures, and reduce plant growth.*
5. Does the amount of runoff/erosion change with repeated water applications? Why might this be?
   This will depend on each experiment but in theory as soil moisture increases (trials 2 or 3) more runoff and erosion should occur.

6. What do farmers in your area do to decrease runoff and erosion?
   This will depend on where you live. On the Palouse farmers will plant buffer strips, practice contour cropping, install sediment basins or tile drains, and convert to reduced tillage or no-till management.
7. Visit: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/
   Select one of the incentive programs listed under finical assistance on the NRCS website. Once you have selected and read about one of the programs use a paragraph to describe how it could potentially help to increase infiltration or decrease runoff and erosion. If the program does not relate directly to infiltration, runoff or erosion describe how the program is designed to help the farmer?

Answers for Economic Worksheet:

1. If cultivation leaves the ground exposed to evaporation and run off and results in an estimated loss of 2 inches of soil moisture what is the economic loss for a 60 acre field? Assume the price of wheat is $6/bu.
   2 inches x 7 bushes per inch x 60 acres = 840 bushel loss
   840 bushels x $6/bu = $5040 loss on 60 acres
2. How much would the farmer gain if he left residue, which eliminated 1 inch of water loss?
   1 inch x 7 bushes per inch x 60 acres = 420 bushel gain
   420 bushels x $6/bu = $2520 OR 5040/2 = $2520
3. If a conventional tillage farm on the Palouse switched to a no-till system, eliminating all soil erosion what would be the per acre benefit if a ton of soil in this region was estimated at $0.50/ton?
   9 tons of soil per acre x $0.50/ton = $4.50 per ac

Appendix I:

Extension activity for computer modeling erosion

ASSIGNMENT SHEET #1—USING COMPUTERS TO MODEL EROSION

Name________________________________ Score____________

Part I

Scientists utilize models to try and recreate complex systems. Models are one of the most important tools used to determine the effects of changes on a system. Models have been developed for nearly every natural process on earth. While none of these simplified models can predict with 100% confidence what will happen, they do reasonably mimic the natural world to provide scientists, land managers, and farmers with another tool to help them determine the impact of their management decisions on the land they work.

The Hydrologic Characterization tool was developed to better understand the impacts of management decisions on water and erosion. In this activity you will use this computer model to determine the practices that create the lowest erosion rates.

Procedure:

A. Go to http://wepp.ag.uidaho.edu/cgi-bin/HCT.pl
B. Select the “REACCH” region. *This region includes most of Eastern Washington, parts of Northern Idaho, and Northeastern Oregon.* And select START.
C. Select Washington from the dropdown menu and click select.
D. Choose the Pomeroy_WA climate file.
E. Select one of the slope options.
F. Add three different soil types: Palouse, Naff, and Southwick. Select soil type and click “add soil type” for each of the three types.
G. Select “ww_barley_fallow_Int_Precip”. This is the coding used to describe a Winter wheat, barley, fallow rotation used in an intermediate precipitation region.
H. Click “add management practice” three times so you have three management practices that are the same.
I. Next change the tillage practices so that each scenario has a different tillage practice.
J. Click Select Files. This should bring up a page showing 9 runs.
K. Click “Verified.”
L. Print the resulting tables.

Essay Question 1 (One page answer double spaced, 12pt. Times Roman font, 1” margins, 1.5 line spacing): Using the data from the tables created by the model, compare and contrast the effects of soil type and tillage practice on erosion rates.

Essay Question 2 (One page answer double spaced, 12pt. Times Roman font, 1” margins, 1.5 line spacing): Change the slope variable and compare and contrast the results.

Instructor Notes:
The soil types represented are the three most typical in the region.
Southwick is a soil that has a restrictive layer around 1 meter down, Naff is a clay knob soil type that has about 40 cm of topsoil, and Palouse is a very deep soil with good permeability.
SAMPLE OUTPUT:

Yearly Output Tables

Average Yearly Output for the Entire Slope

Run	Slope	Soil	Management	Tillage	Buffer (m)	Perc (mm)	Lateral (mm)	Runoff (mm)	Erosion (kg/ha)	Detail View
Run1	Mod Steep	palouse 152cm	ww_barley_fallow_Int_Precip	NT	-No Buffer-	16.4	0	1.1	0	○
Run2	Mod Steep	palouse 152cm	ww_barley_fallow_Int_Precip	MT	-No Buffer-	22.7	0	0.9	0	○
Run3	Mod Steep	palouse 152cm	ww_barley_fallow_Int_Precip	CT	-No Buffer-	25.4	0	1.4	240.3	○
Run4	Mod Steep	naff 43cm	ww_barley_fallow_Int_Precip	NT	-No Buffer-	91.9	1.6	2.9	0	○
Run5	Mod Steep	naff 43cm	ww_barley_fallow_Int_Precip	MT	-No Buffer-	103.8	1.6	2.9	0	○
Run6	Mod Steep	naff 43cm	ww_barley_fallow_Int_Precip	CT	-No Buffer-	107.1	1.6	3.5	283.9	○
Run7	Mod Steep	southwick 97cm	ww_barley_fallow_Int_Precip	NT	-No Buffer-	13.8	3.9	12.2	12.9	○
Run8	Mod Steep	southwick 97cm	ww_barley_fallow_Int_Precip	MT	-No Buffer-	17.5	5.2	10.9	0	○
Run9	Mod Steep	southwick 97cm	ww_barley_fallow_Int_Precip	CT	-No Buffer-	17.8	5.7	11.1	858.8	○
	View Monthly Detail									OFE Detail

PALOUSE SERIES

The Palouse series consists of deep, well drained soils formed in loess on hills. Slopes are 0 to 60 percent. The average annual precipitation is about 21 inches, and the mean annual air temperature is about 48 degrees F.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls

TYPICAL PEDON: Palouse silt loam - cultivated on a 12 percent south slope at 2,600 feet elevation. (Colors are for dry soil unless otherwise noted)

Ap--0 to 7 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; moderate fine granular structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; neutral (pH 6.6); abrupt smooth boundary. (6 to 10 inches thick)

A--7 to 14 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; weak medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; many fine pores; neutral (pH 6.6); clear wavy boundary. (6 to 10 inches thick)

AB--14 to 24 inches; grayish brown (10YR 5/2) heavy silt loam, very dark grayish brown (10YR 3/2) moist; surface os peds are very dark brown or black when moist; weak fine subangular blocky structure; very hard, friable, slightly sticky, plastic; many fine roots; many very fine pores, 20 percent of coarse pores and channels partially filled with dark colored surface material; neutral (pH 6.8); gradual wavy boundary. (8 to 12 inches thick)

Bw1--24 to 40 inches; pale brown (10YR 6/3) heavy silt loam, brown (10YR 4/3) moist; surface soft peds are dark brown when moist; weak medium prismatic and moderate medium and fine subangular blocky structure; very hard, friable, sticky, plastic; many fine roots; many very fine pores; few thin clay films on prism faces; 5 to 10 percent of area occupied by worm holes partially filled with dark A horizon material; neutral (pH 7.0); gradual wavy boundary. (12 to 16 inches thick)

Bw2--40 to 60 inches; pale brown (10YR 6/3) heavy silt loam, brown (10YR 4/3) moist; weak coarse prismatic and moderate very fine blocky structure; hard, friable, sticky, plastic; few fine roots; few fine and many very fine pores; large worm holes about 5 inches apart; neutral (pH 7.2).

TYPE LOCATION: Whitman County, Washington; about 4 miles southeast of Pullman, Washington, at 280 feet north of county road and 970 feet east of west line of sec. 27, T. 14 N., R. 45 E.

RANGE IN CHARACTERISTICS: The mean annual soil temperature ranges from 47 to 52 degrees F. These soils are usually moist but are dry in all parts between 4 and 12 inches from 60 to 75 consecutive days in the summer and fall. Thickness of solum and depth to bedrock ranges from 40 to more than 60 inches. The mollic epipedon is 20 to 40 inches or more thick. The control section is silt loam or silty clay loam with 20 to 35 percent clay.

The A horizon has value of 4 or 5 dry, 2 or 3 moist and chroma of 1 to 3 dry or moist. It has weak or moderate platy, granular or blocky structure. Reaction is medium acid to neutral.

The AB horizon has value of 4 or 5 dry and chroma of 2 or 3 moist and dry. It is silt loam or silty clay loam. Reaction is slightly acid or neutral.

The Bw horizon has value of 4 to 6 dry, 3 or 4 moist, and chroma of 2 to 4 moist and dry. It is silt loam or silty clay loam with 18 to 35 percent clay. Structure is weak or moderate subangular blocky or prismatic. Reaction is slightly acid or neutral in the upper part and slightly acid to slightly alkaline in the lower part.

A Bt horizon is present is some pedons.
COMPETING SERIES: This is the Carlton series. Carlton soils have a faint to distinct yellowish brown to reddish brown mottles in the lower part of the Bw horizon.
GEOGRAPHIC SETTING: Palouse soils are on hills at elevations of 1,600 to 4,500 feet. Slopes are 0 to 60 percent. These soils formed in Late Wisconsin loess which contains some volcanic ash in the upper part. Summers are warm and dry; winters are cool and moist. The average annual precipitation ranges from 18 to 24 inches. Average January temperature is 27 to 30 degrees F, average July temperature is 67 to 70 degrees F. The mean annual temperature ranges from 46 to 51 degrees F. and on the average frost-free season is about 100 to 160 days.
GEOGRAPHICALLY ASSOCIATED SOILS: These are the Caldwell, Garfield, Gwin, Latah, Latahco, Mondovi, Naff, Thatuna, Tilma, and Waha soils. Caldwell and Mondovi soils have irregular distribution of organic matter with depth. Garfield soils have an ochric epipedon and have a fine argillic horizon. Gwin soils have a lithic contact at 10 to 20 inches. Latah and Tilma soils have a fine textured argillic horizon. Latahco soils are frigid. Naff and Thatuna soils have an argillic horizon. Waha soils are fine-loamy and have a lithic contact at 20 to 40 inches.
DRAINAGE AND PERMEABILITY: Well drained; slow to rapid runoff; permeability is moderate.
USE AND VEGETATION: Used mainly for dryland cropland. Small grains, peas, lentils, alfalfa, and grasses for hay and pasture are common crops. Native vegetation is Idaho fescue, bluebunch wheatgrass, Sandberg bluegrass, arrowleaf balsamroot, common snowberry, and wild rose.
DISTRIBUTION AND EXTENT: Southeastern Washington, northeastern Oregon, and northern Idaho. Series is extensive.
MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Portland, Oregon
SERIES ESTABLISHED: Latah County, Idaho, 1915.
REMARKS: Diagnostic horizons and features recognized in this pedon are a mollic epipedon from the surface to 24 inches with a base saturation of less than 75 percent in some part and a cambic horizon from 24 to 60 inches.

NAFF SERIES

The Naff series consists of very deep, well drained soils formed in Holocence and late Pleistocence loess deposits. Naff soils are on loess hills and plateaus. The mean annual precipitation is about 20 inches and the mean annual air temperature is about 48 degrees F.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Typic Argixerolls

TYPICAL PEDON: Naff silt loam, cultivated on a 10 percent northwest facing slope, at an elevation of 2,630 ft. (Colors are for dry soil unless otherwise noted.)

Ap--0 to 8 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; weak thick platy and moderate fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine roots; neutral (pH 6.6); abrupt smooth boundary. (6 to 10 inches thick)

A--8 to 17 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; weak coarse prismatic and moderate fine granular structure; hard, friable, slightly sticky and plastic; many very fine and fine roots; many very fine pores; slightly acid (pH 6.4); clear wavy boundary. (5 to 10 inches thick)

BA--17 to 26 inches; brown (10YR 5/3) silt loam, brown (10YR 4/3) moist; moderate fine prismatic structure; hard, firm, sticky and plastic; many very fine and fine roots; many very fine pores; peds and pores coated with clean very fine sand and silt grains; few thin clay films visible below coatings on peds; neutral (pH 6.6); gradual wavy boundary. (8 to 20 inches thick)

Bt1--26 to 61 inches; pale brown (10YR 6/3) silty clay loam, brown (10YR 4/3) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; very hard, firm, very sticky and very plastic; common fine roots; many very fine pores; thin clay films on peds and in some pores; coating of clean silt or very fine sand on prism faces, few black (10YR 2/1)manganese coatings and very fine concretions; neutral (pH 6.8); gradual wavy boundary. (25 to 40 inches thick)

Bt2--61 to 80 inches; pale brown (10YR 6/3) silty clay loam, brown (10YR 5/3) moist; moderate medium prismatic structure parting to moderate fine subangular blocky; hard, firm, sticky and plastic; few very fine roots; many very fine pores; thin continuous clay films on peds and in pores; common black (10YR 2/1) manganese coatings and very fine concretions; neutral (pH 6.8). (20 to 30 inches thick)

TYPE LOCATION: Spokane County, Washington; About 5.7 miles southeast of Fairfield, WA; 800 feet south and 85 feet west of the northeast corner of section 2, T.21N., R.45E. Willamette Meridian; USGS Tekoa Mountain, WA. topographic quadrangle (Latitude - 47 degrees, 20 minutes, 43.1 seconds North; Longitude - 117 degrees, 4 minutes, 2.6 seconds West). NAD83.

RANGE IN CHARACTERISTICS: The mean annual soil temperature ranges from 47 to 52 degrees F. These soils are usually moist but are dry in all parts between depths of 4 and 12 inches for 60 to 75 consecutive days following the summer solstice. The mollic epipedon ranges from 10 to 20 inches. The particle-size control section averages from 30 to 35 percent clay.

The A horizon has value of 4 or 5 dry, 1 to 3 moist, and chroma of 1 or 2 moist or dry. Reaction is moderately acid to neutral.

The BA horizon has value of 5 or 6 dry, 3 or 4 moist, and chroma of 2 to 4 moist and dry. Texture is silt loam or silty clay loam. Reaction is slightly acid or neutral.

The Bt horizon has hue of 10YR or 7.5YR, value of 5 or 6 dry, 3 to 5 moist, and chroma of 3 to 6 moist or dry. In some pedons, the peds in the upper part of the Bt horizon are coated with light gray very fine sand and silts in amounts from a few grains to 1 mm thick. Texture is silt loam or silty clay loam. Reaction is slightly acid to slightly alkaline.

COMPETING SERIES: These are the Darrah and Uhlorn series. Darrah soils have Btb horizons with 35 to 50 percent clay in the lower part of the series control section containing up to 5 percent gravel and/or cobbles. Uhlorn soils have a lithologic discontinuity in the lower part of the series control section and contain up to 10 percent gravel and/or veins of lime in the lower part of some pedons.

GEOGRAPHIC SETTING: Naff soils are on nearly level to very steep uplands, including hills and plateaus. The dominant slope range is 0 to 40 percent. These soils formed in Holocene and late Pleistocene loess deposits. They occur at elevations between 1,800 to 3,200 feet. The annual precipitation is 18 to 22 inches. Summers are warm and dry and winters are cool and moist. The mean annual temperature ranges from 47 to 50 degrees F. and the frost free season ranges from 120 to 160 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Caldwell, Garfield, Latah, Latahco, Palouse, Thatuna and Larkin soils. Caldwell, Latah, and Latahco soils are on bottomlands. Garfield soils have an ochric epipedon and are on eroded ridgetops. Palouse soils lack an argillic horizon and have a mollic epipedon more than 20 inches thick. Thatuna soils have a seasonally perched water table ranging from 24 to 48 inches from the mineral soil surface. Larkin soils have a base saturation less than 75 percent between 10 and 30 inches and have a lithologic discontinuity where they occur over basalt residuum.

DRAINAGE AND SATURATED HYDRAULIC CONDUCTIVITY: Well drained; moderately high saturated hydraulic conductivity.

USE AND VEGETATION: Naff soils are used mainly for crop production. Common crops grown include small grains, dry peas and lentils, hay and forage. Natural vegetation is Idaho fescue, bluebunch wheatgrass, Sandberg bluegrass, arrowleaf balsamroot, common snowberry, and wild rose.

DISTRIBUTION AND EXTENT: Eastern Washington and Northwest Idaho; MLRA 9. Series is of large extent.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Spokane, Washington, 1961.

REMARKS: Diagnostic horizons and features recognized in this pedon are;

Mollic epipedon - the zone from the surface to 17 inches (the Ap and A horizons)

Argillic horizon - the zone from 26 to 80 inches (the Bt1 and Bt2 horizons).

ADDITIONAL DATA: NSSL pedon numbers 86P0073, 86P0068, 85P0245, and 99P0330

SOUTHWICK SERIES

The Southwick series consists of very deep, moderately well drained soils that formed in loess over silty sediments. Southwick soils are on dissected loessial hills on plains and plateaus. Slopes are 3 to 40 percent. The mean annual precipitation is about 23 inches and the mean annual temperature is about 46 degrees F.

TAXONOMIC CLASS: Fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls

TYPICAL PEDON: Southwick silt loam-cultivated; on a 4 percent east-southeast facing slope at 3,100 feet elevation. When described on July 8, 1987, the soil was moist throughout. Textures are apparent as determined in the field. (Colors are for dry soil unless otherwise noted.)

Ap1--0 to 6 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; moderate fine and medium subangular blocky structure parting to moderate fine and medium granular; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine and few fine tubular pores; many wormcasts; slightly acid (pH 6.2); gradual wavy boundary.

Ap2--6 to 15 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine and few fine tubular pores; slightly acid (pH 6.2); gradual wavy boundary. (Combined thickness of the Ap horizon is 0 to 20 inches thick)

A--15 to 22 inches; dark grayish brown (10YR 4/2) silt loam, very dark brown (10YR 2/2) moist; moderate fine and medium subangular blocky structure; hard, firm, slightly sticky and slightly plastic; common very fine roots; common very fine tubular pores; neutral (pH 6.7); clear wavy boundary. (5 to 15 inches thick)

Bw1--22 to 26 inches; brown (10YR 5/3) silt loam, dark brown (10YR 3/3) moist; weak medium and coarse subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine roots; common very fine and few fine tubular pores; slightly acid (pH 6.5); clear wavy boundary.

Bw2--26 to 34 inches; pale brown (10YR 6/3) silt loam, brown (10YR 4/3) moist; moderate medium and coarse subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; common very fine tubular pores; slightly acid (pH 6.3); clear wavy boundary. (Combined thickness of the Bw horizon is 6 to 15 inches thick)

E--34 to 38 inches; light gray (10YR 7/2) silt loam, grayish brown (10YR 5/2) moist; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few very fine roots; common very fine and fine tubular pores; slightly acid (pH 6.3); abrupt wavy boundary. (1 to 5 inches thick)

Btxb--38 to 60 inches; brown (10YR 5/3) and yellowish brown (10YR 5/4) silty clay loam, brown (10YR 4/3) and dark yellowish brown (10YR 4/4) moist; moderate coarse prismatic structure; very hard, brittle, very firm, moderately sticky and moderately plastic; few very fine roots between prisms; common very fine tubular pores; many prominent clay films on faces of peds and lining pores; common prominent silt coats on prism faces; common, fine iron-manganese stains and accumulations; slightly acid (pH 6.5).

TYPE LOCATION: Nez Perce County, Idaho; about 3.4 miles northeast of Lenore, ID; about 1,300 feet north and 2,300 feet east of the southwest corner of sec. 18, T. 37 N., R. 1 W.; USGS Lenore, ID topographic quadrangle; Latitude - 46 degrees, 32 minutes, 49.95 seconds North; Longitude - 116 degrees, 30 minutes, 17.7 seconds West; NAD 83.

RANGE IN CHARACTERISTICS:

Depths to diagnostic horizons and features are measured from the top of the first mineral layer
Thickness of mollic epipedon - 15 to 30 inches
Depth to argillic horizon - 28 to 38 inches
Xeric soil moisture regime; consecutive days dry, moisture control section - 45 to 60 in late summer and early fall
Mean annual soil temperature - 47 to 54 degrees F.
The layer from 38 to 60 inches has characteristics of a fragipan. More review is needed as many pedons appear to meet fragipan criteria.
Particle-size control section (weighted average)
Clay content - 27 to 35 percent

Some pedons have an Oi horizon

Ap and A horizon
Value - 3 to 5 dry, 2 or 3 moist
Chroma - 2 or 3, dry or moist
Clay content - 15 to 27 percent
Reaction - moderately acid to neutral

Bw horizon (a Bt in some pedons)
Hue - 10YR or 7.5YR
Value - 4 to 6 dry, 2 to 4 moist
Chroma - 2 or 3, dry or moist
Clay content - 15 to 27 percent
Reaction - moderately acid to neutral

E horizon
Hue - 7.5YR to 2.5Y
Value - 6 to 8 dry, 4 to 6 moist
Chroma - 2 or 3 dry
Texture - SIL, SI

Clay content - 10 to 23 percent
Reaction - moderately acid to neutral

Btxb/E horizon - present in some pedons

Btxb horizon
Hue - 10YR or 7.5YR
Value - 4 to 7 dry, 3 to 5 moist
Chroma - 3 to 6 dry, 3 or 4 moist
Texture - SIL, SICL
Clay content - 23 to 35 percent
Bulk density - 1.60 to 1.70 g/cc
Reaction - moderately acid to neutral

Btb horizon present in some pedons
Hue - 10YR or 7.5YR
Value - 4 to 7 dry, 3 to 5 moist
Chroma - 3 or 4 dry or moist
Clay content - 27 to 38 percent
Reaction - moderately acid to neutral

COMPETING SERIES: This is the Thatuna series. Thatuna soils are dry for 60 to 80 days in late summer and early fall.

GEOGRAPHIC SETTING: The soils are on dissected loess hills on plains and plateaus. Slopes range from 3 to 40 percent, but 3 to 15 percent slopes are predominant. Elevation is 1,700 to 3,500 feet. The soils formed in loess, possibly of two ages (Pinedale, Bull Lake). The mean annual precipitation is 22 to 30 inches. The mean annual temperature is 45 to 52 degrees F. The frost-free period is 90 to 180 days.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Agatha, Driscoll, Gwin, Kettenbach, Keuterville and Larkin soils. Agatha soils are on backslopes of north-facing canyons and have a frigid soil temperature and are deep to hard basalt bedrock. Driscoll soils are on summits of loess hills on basalt plateaus and have a silty clay subsoil texture. Gwin soils are shallow to hard basalt bedrock and are on summits and shoulders of basalt plateaus. Kettenbach soils are loamy-skeletal and moderately deep to hard basalt bedrock and are on summits and shoulders of basalt plateaus. Keutterville soils are loamy-skeletal and are very deep and are on basalt plateaus. Larkin soils are on south-facing slopes of loess hills on basalt plateaus do not have an E horizon and do not have a perched water table.

DRAINAGE AND PERMEABILITY: Moderately well drained; moderately high saturated hydraulic conductivity in the upper part and moderately low or very low in the lower part. There is a perched water table is at its uppermost limit from December to June.

USE AND VEGETATION: This soil is used mainly for wheat, barley, peas, hay, pasture and timber production. The natural vegetation is mainly an overstory of ponderosa pine.

Understory is common snowberry, white spirea, and rose.

DISTRIBUTION AND EXTENT: Northern Idaho; MLRA 9. The series is moderately extensive.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: Portland, Oregon

SERIES ESTABLISHED: Nez Perce and Lewis Counties, Idaho, 1917.

REMARKS: Diagnostic horizons and features recognized in this pedon:

Mollic epipedon - the zone from 0 to 22 inches (Ap1, Ap2, and A horizons).
Albic horizon - the zone from 34 to 38 inches (E horizon); the soil is not an alboll in that the albic horizon does not directly underly the mollic epipedon and there are no redox concentrations in or below the albic horizon.
Argillic horizon - the zone from 38 to 60 inches (Btxb horizon).
Cambic horizon - the zone from 22 to 34 inches (Bw1 and Bw2 horizons)
Oxyaquic feature - the zone beginning at 34 inches having saturation with water for 30 or more cumulative days.
Particle-size control section - the zone from 38 to 58 inches (part of the Btxb horizon).
This pedon does not meet the aquic subgroup criteria based on the absence of redox depletions (zones of chroma less than those in the matrix) within 30 inches of the mineral soil. The Btxb horizon is not considered as meeting fragipan criteria but further review is needed.

The classification of this series has been revised as of 5/2000 from fine-silty, mixed, mesic Boralfic Argixerolls to fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls based on revision to Soil Taxonomy.
The type location was moved from Benewah County, ID in 12/2010 to the current location to reflect a non-vitrandic subgroup.

Further MLRA 9 investigation is needed to determine several classificastion issues (vitrandic/non-vitrandic; fragipan/non-fragipan; alboll/non-alboll) and to evaluate slope and landform of existing mapped Southwick components and their relationship to these classification issues.

ADDITIONAL DATA: This soil has been sampled in Nez Perce County by NSSL. Laboratory sample number 86P 880, soil survey sample number S86ID 069 00