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Modelling the Impact of Climate Change and Agricultural Management Practices on Soil Erosion in the Agricultural Basin of Lakes Prespa[#]

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Abstract: Soil erosion and sedimentation are a problem of interest for many land uses across the Albania, particularly for agricultural areas where the soil surface is disturbed by harvest, planting, and cultivation of the soil. The objective of this study was to investigate the effects of climate change and agricultural land management on surface erosion and suspended sediment concentrations in the Lakes Prespa basin. Many hydrological models have been developed which examine suspended sediment. The DHSVM (Distributed Hydrology Soil Vegetation Model) model was used to evaluate channel and soil surface erosion, as well as sediment yield in streams. In this study, the DHSVM model was calibrated using data for the period of (2010–2016), and was also used to predict results for the year 2045 using statistically downscaled global climate data. The results show that as the projected climate–driven intensity of storms increase, more runoff is predicted in the Lakes Prespa basin. Three tillage scenarios were incorporated into DHSVM for winter wheat cultivation: conventional till, reduced till, and no till. Sensitivity of the model to surface erosion and changes in channel sediment bed depth were both evaluated for several parameters that relate to erosion. Observations have shown that suspended sediment concentrations can drastically increase, but model results do not yet display large fluctuations in suspended sediment concentrations which are typically observed in nature as a result of storm and erosion events. In the long term, continued improvements to this preliminary model of the Lakes Prespa basin can provide better insight into the effects of climate change on the riparian habitat of carp in the basin and the sediment budget of the surrounding area.

Keywords: *agricultural management practices, climate change, DHSVM model, Lakes Prespa, soil erosion*

Introduction

Certain cropping practices and rain-on-snow events in the Lakes Prespa region produce sediment losses. This sediment is either deposited down slope or transported to a nearby stream or lake. Suspended sediment is a pollutant in many water systems and contributes to impairment of streams. The purpose of this study is to analyse the effects of climate change and tillage practices on erosion and generation of suspended sediment in the Lakes Prespa basin. It is identified tillage conversion (from CT to direct seeding) as a viable method of significantly reducing sediment delivered to the stream from cropland areas. The relatively dry climate of these regions, storm rainfall, varying land use, and phenomena such as ephemeral rivers, result in unique patterns and correlations in sediment yield and runoff. Climate change and agricultural practices, particularly surface treatments to the land, can impact surface runoff and suspended sediment generation. Runoff and sediment generation are strongly related, and runoff flows in rills and gullies typically carry suspended sediment loads downstream.

Another factor that can affect formation of these channels and overland flow is land use. Agricultural land use and its implications were a critical part of this study. Current management practices can influence overland flow, infiltration rates, and erosion during rainstorm events. Runoff erosion and sedimentation depend on the process of entrainment, transport, and deposition of sediment by the forces from raindrop impact and runoff over the soil surface (Rai & Mathur, 2007).

For this study, the DHSVM model (Distributed Hydrology- Soil-Vegetation Model; Wigmosta *et al*., 1994) was applied over the Lakes Prespa Basin. Climate trends were considered to predict past and

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future events, as well as the effects of tillage and residue management scenarios. Three tillage practices were incorporated into the model: conventional tillage (CT), reduced tillage (RT), and no-till (NT).

Changes in climate can dramatically affect runoff and we evaluated if adapting tillage practices can ameliorate erosion and generation of suspended sediment under future climate scenarios. A model analysis of climate change impacts on runoff and erosion in this basin was not performed previously.

Rainfall is an important factor when considering erosion processes within the basin. Rainfall typically controls how much water is available for erosion and transport of sediment over land. Semi-arid climates can be described as having high rainfall variability from year to year (Meerkerk *et al*., 2009). Inconsistent rainfall is common to semi–arid regions (Kassie *et al.*, 2009). During high intensity rainfall events, which occur irregularly, semi–arid catchment are susceptible to floods. Such flash floods can be catastrophic (Cammeraat, 2004) and can transport large amounts of sediment. Generally speaking, saturated soil in semi–arid catchments, which has become saturated from a recent storm event, is more susceptible to erosion than relatively dry soil (Cammeraat, 2004). Effects of land use, particularly agriculture, in combination with climate patterns can be a source of high volumes of runoff, especially during rain on snow events, in this semi–arid region.

Tillage is an agricultural management practice that prepares the soil for planting. The way tillage is performed can affect runoff and sediment generated from the field. Farmers employ a variety of tilling practices which disturb the soil and remove vegetation and topsoil cover in the Palouse (Kok *et* al., 2009). Tillage increases the land surface roughness in cultivated areas and the soil then crumbles, forms a crust, and infiltration is hindered (Cammeraat, 2004). Changes to infiltration in this manner promote runoff off of the crop area and onto downhill areas. Soil disturbance can be minimized through conservation tillage (Kassie *et al*., 2009; Kok *et al*., 2009; McCool et al., 2003). Conservation tillage is a method where crop residue is left on the field and significantly less plowing than what is practiced in conventional tillage. No–till and RT are both considered conservation tillage. Conservation tillage promotes water retention in the soils, which can be beneficial in semi–arid regions. Varying slopes, soils, and land management practices affect infiltration and the magnitude of runoff events and channel routing within the watershed (Cammeraat, 2004).

Materials and Methods

The Model

The Distributed Hydrology Soil Vegetation Model version 3.0 (DHSVM; Wigmosta *et al*., 1994), a research process–based model, was used to simulate hydrologic and sediment processes in the Lakes Prespa Basin. DHSVM was thought to be advantageous for this study because of its ability to model complex hydrological processes, including erosion processes, snow melt, evapotranspiration, lateral subsurface flow, and infiltration. DHSVM explicitly simulates the relationships found in a catchment between hydrology, vegetation, and climate (Wigmosta *et al*., 2009). Use of this model will contribute to a more complete view of how climate change may impact stream flow and erosion events for the Lakes Prespa Basin.

DHSVM was chosen for this study, although other applicable models do exist. An advantage of using DHSVM and its sediment module is that in addition to the typical erosion processes, DHSVM models complex hydrologic processes. DHSVM is able to provide a ‘snapshot’ of various processes happening across the basin. Inputs such as lateral hydraulic conductivity, soil cohesion, and leaf area index (LAI) over agricultural areas are some of DHSVM’s parameters which are of interest because land treatments over cropland can influence the magnitude of runoff and erosion. It is possible to apply DHSVM for various agricultural practices by changing vegetation parameters seasonally. During the months of October to April, agricultural vegetation parameters were defined to represent a harvested and tilled field. Vegetation parameters specific to the growing season were assigned for the remaining months.

The sediment module is comprised of three main parts: mass wasting, hill slope erosion, and road erosion. All of these mechanisms predict erosion and deliver sediment to the stream network, which is combined with channel flow and routed through the channel. Only hill slope (surface) erosion was run for this project. The surface erosion portion of the sediment module did not include processes for rill erosion. Rill erosion is a significant source of erosion for agricultural areas (Teasdale & Barber 2008). According to Doten *et al*. (2006) rill erosion can be simulated through the adjustment of the detachment efficiency parameter β_{de}, but we did not find that to be true. Mass wasting was considered, but the initial results did not produce any erosion when it was run for select times of high saturation.

For computational feasibility, the hill slope erosion module was turned on only for major events. Assuming a high correlation between stream flow and SSC, a stream threshold was established which would determine when hill slope erosion would be simulated. Dates were determined for when the stream flow exceeded a certain initial threshold of 40%. If 60% of stream flows for the model run were greater than 10 m^3/s, the threshold would be 10 m3/s. Figures depicts a model run where surface erosion was running the whole time, and shows that this 40% threshold captures over 95% of the hill slope erosion. Other stream thresholds were examined and it was determined that a 25% stream threshold would be reasonable for computation time and would capture over 85% of the surface erosion. The 40% threshold was applied for this study.

Data Sources

Overview of data source

a. Climate data: The driving inputs to the model were the climate input files. There were two types of sources of climate data: historical data and measured in meteorological stations in Lakes Prespa Basin for daily precipitation, maximum and minimum air temperature, wind speed, incoming shortwave & long-wave radiation, and relative humidity. These data were then adjusted for orographic effects using the Parameter–elevation Regressions on Independent Slopes Model (PRISM) as described by Maurer *et al.* (2002). All climate data were disaggregated to 3–hourly using a method described by Cuo *et al.* (2009). The statistically downscaled data were used for creating the future climate inputs. The historical climate inputs were perturbed using a delta change statistical downscaling approach using nine different global climate models (GCMs). The GCMs were forced with two greenhouse gas emission scenarios: A1B and B1. A1B is a high emission scenario and B1 is a conservative low emission scenario. This results in 18 total future DHSVM runs. Each climate change scenario was processed to DHSVM format from VIC climate inputs for the future scenarios using the same process described for historical data. Additionally, Mote and Salathé (2010) evaluated each GCM and were able to determine a precipitation and temperature bias for each emission scenario. Each GCM was assigned a weight based on its precipitation and temperature bias.

The emission scenarios were assigned equal weights. These weights were applied to the modelled stream flow outputs for 18 different future climate inputs. We averaged the climate change scenarios' model streamflow outputs and produced a GCM average model output for the year 2045.

b. Sediment observations and field work: Two informal drive–by surveys were conducted in the Lakes Prespa in October and November of 2016. Based on the Kok *et al.* (2009) study of conservation strategies, a generous estimate would be to classify 40–50% of farmland in the Lakes Prespa Basin as farms which employ conservation tillage practices. The purpose of these trips was to connect in–field experience with literature descriptions of this basin and its agricultural areas. Through these trips, a deeper understanding of different land uses in the basin was gained. There appeared to be more conservation tillage and residue management employed in the lower reaches of the basin. Most notably, the degree to which tillage was employed varied drastically from field to field. In the span of a few kilometres, we observed many types of seeding, tillage, and residue management.

Another field endeavor was the assembly and implementation of an in–stream turbidity sensor. The sensor used is a Campbell Scientific OBS–3+ Turbidity Sensor. It measures turbidity in Nephelometric Turbidity Units (NTU) with a near infrared light, photodiode, and a daylight rejection filter. A zebra-tech LTD hydro–wiper was attached to the sensor, ensuring that the observation window would frequently be cleaned off by the brush on the hydro–wiper. The hydro–wiper was also designed to reset its position in the event it was hit by a rock or debris in the stream. The sensor was attached to four 3–meter piping sections which guided the cabling down the stream bank to a stationary depth, which was off the stream bed, but deep enough to remain submerged most, if not all, of the year. The sensor was connected to a Campbell Scientific data-logger, housing for the instruments, a 12 volt battery, and a 10 W solar panel. The turbidity sensor was calibrated before field installation by submersion into a container with a known suspended sediment concentration (SSC).

c. Static model inputs: DHSVM was run with 150 m grids over the 1210 km^2 Lakes Prespa Basin. The inputs described in this section were used consistently for many model runs with varying climate inputs.

d. Vegetation: DHSVM requires a vegetation grid where each cell is defined by a single vegetation type. Vegetation classified as cropland was additionally classified as a unique tillage type: CT, RT, or NT. In this way, dozens of vegetation types were simplified to 14 basic vegetation types (water, evergreen needle-leaf forest, deciduous broadleaf forest, mixed cover, closed shrub-land, open shrub-land, grassland, cropland (assumed CT), bare ground, urban and built-up, cropland (assumed RT), cropland (assumed NT)).
e. Soil: The classified surface texture of the basin revealed three soil types: silt loam, loam, and cobbly silt loam.
f. Elevation: The Digital Elevation Model (DEM) was used to create the soil depth grid with the specified range of soil depth. In this way, soil depth is dependent on the cumulative drainage area for the cell of interest as well as the slope.
g. Stream network: Inputting spatial data describing the stream network allows for routing of flow and suspended sediment within the model. The stream input is an Arc coverage file and is created by the user by computing the flow direction of the grid cells across the basin and defining a threshold source area that must flow to a grid cell to result in the formation of a stream segment. The threshold source area that determines the location and number of the stream segments was adjusted until the stream network resembled the observed stream network.
h. Other parameters: Other parameters specified in the input file include the gradient of the subsurface flow, infiltration type, and snow and soil roughness. The gradient of the subsurface flow was defined to follow topography. The infiltration rate was specified as dynamic. Dynamic infiltration has not yet been fully tested, and the user is warned that it is a "work in progress" when running the model with dynamic infiltration. The dynamic infiltration was desired over the alternative, static infiltration, because of its inclusion of infiltration excess runoff. Dynamic infiltration is based on a parameter-efficient hydrologic infiltration model developed by Smith & Parlange (1978). The infiltration model is able to accurately describe when ponding begins, the way infiltration decays near saturation, and it is sensitive to the antecedent soil moisture conditions. When surface water is present and dynamic infiltration is being utilized, the infiltrability of the soil is dependent of the mean capillary drive of the soil, the saturated hydraulic conductivity, and the amount of water accumulated in the top soil layer. In contrast, when static infiltration is being utilized, the infiltrability of the soil is simply the depth of surface water divided by the time interval. The soil and snow roughness's were both 0.02 m.

Tillage and residue management scenarios

Tillage and residue management was considered for the agricultural areas of the basin. Tillage refers to tilling the soil and altering the surface before planting or after harvest. Residue management refers to the amount of residue that is left on the surface of the field after harvest. This thesis examined a combination of these factors. The conventional tillage (CT) scenario involves two primary assumptions. The first assumption is that the fields are tilled such that most, if not all, of surface vegetation is removed. The second assumption is that little to no additional surface residue is left on the surface. These result in a disturbed top soil that is more susceptible to erosion and raindrop impact, and reduced soil cohesion. The most conservative scenario is no–till (NT). No–Till assumes that the soil is not tilled and that soil disturbance is largely limited to planting and harvest activities designed to have a minimal impact. The NT scenario also assumes that 90% of the field surface is covered by residue such as straw. Reduced till (RT) is a compromise between CT and NT with moderate disturbance of the soil and a 60% residue cover.

The model was run to examine sensitivity to tillage practices. For CT, RT, and NT scenarios there are two assumed seasons: winter and growing season. Winter season is for the time period after harvest and before spring plant growth begins to dominate the field surface. For this project, the winter season was defined as October – April.

Several vegetation parameters were dependent on tillage practice. LAI affects processes within DHSVM such as soil moisture as described in Wigmosta *et al.* (1994), snow and rain interception, radiation attenuation, and evapotranspiration. In the post-harvest case, LAI represents the decaying surface residue. For the modelled NT scenario, surface residue decays from 95% cover to 60% cover, and the RT scenario has an LAI decrease from 60% cover to 30% over the winter season. This change in surface residue over the surface was altered to represent the range of percent cover that is associated with NT and RT (Kok *et al*., 2009). These winter LAI values are all less than 1 (100% cover) and were assumed to be reasonable because cropland LAI is listed by NASA LDAS as slightly greater than 1 for the growing season. In reality, the growing season changes from year to year based on changes in climate and when the land managers choose to plant and harvest. This shift in growing season was not considered for this project, and it was not assumed that LAI would change with climate.

RUSLE, and its C factor were used to inform values for detachment efficiency (β_{de}) and soil cohesion within agricultural areas because the C factor represents increased erosion as a result of changing tillage within RUSLE. Changes to soil cohesion and detachment efficiency for tillage practices were based on a relationship between values of the C index used within RUSLE for extreme CT and NT scenarios. There are six factors that determine soil loss within RUSLE: the rainfall–runoff erosivity factor (R), the soil erodibiity factor (K), the slope length factor (L), the slope steepness factor (S), the cover management factor (C), and the supporting practices factor (P) (Renard et al. 1995). Within RUSLE, the C index is a function of surface cover, tillage practice, soil consolidation, and various other parameters relative to erosion and the transport capacity of surface runoff. The C index represents the increased susceptibility to erosion when the land surface is changed and is the RUSLE factor that can be most easily managed by changing agricultural practices (McCool et al. 2003). C is dependent on ground cover, the surface roughness, canopy cover, soil consolidation, prior cropping, and dominant tillage practices (McCool et al. 2003). A C factor of zero represents a soil that is well–protected and tillage practices do not increase its susceptibility to erosion (Fu et al. 2006). A conventionally tilled field would have a greater C factor than a field with CT management. Based on typical C factor values for the greater Palouse region, the C factor was estimated to decrease by a magnitude of 2.06 for a NT scenario as compared to a CT scenario. Assuming that the RUSLE C factor and detachment efficiency (β_{de}) have an inverse relationship, the β_{de} of CT soil should be approximately twice the value of the β_{de} for NT soil. β_{de} is related to soil cohesion (Cs) by Equation 1.

$$\beta_{de} = 0.79\ e^{-0.6Sc} \tag{1}$$

It was found in this study that soil cohesion (Cs) needed to decrease by a factor of 1.6 to increase detachment efficiency by a factor of 2.06. As described by Doten et al. (2006), β_{de} is used within DHSVM to represent particle detachment. In addition to the default scenario of CT, four different tillage scenarios were examined. The five scenarios were as follows: default scenario of 100%–CT; scenario 1 with 50%–CT, 25%–RT, and 25%–NT; scenario 2 with 50%–RT and 50%–NT; scenario 3 of 100% RT; and scenario 4 of 100% NT. As discussed before, the placement of conservation tillage was assumed to be in the lower reaches of the basin.

Climate change scenarios

The climate change scenarios described in section 3.3.2.1 were used as the climate input for a 11 year period corresponding to 2006 – 2016 to analyse the modelled stream flow. The 18 future climate change scenarios predicting climate for the 2040s were input into DHSVM for 30-year runs centred on 2045. From these results, we calculated a weighted average (based on the biases of the GCMs in reproducing historical data) of the simulated stream flow to produce an average of the GCM modelled results. Five tillage scenarios were considered in this study and were run in combination with the climate change scenario, and compared to one another. This particular GCM was chosen because it had the smallest overall bias after considering both the precipitation and temperature biases. Sediment results were not analysed for future climate scenarios because the precipitation events were based on daily precipitation amounts, which are not appropriate for modelling erosion events.

Results and Discussions

Model calibration

DSHVM was calibrated over the time period 2003 – 2010 with automated calibration runs based on silt loam soil parameters. Calibration was achieved by adjusting the following soil parameters that control subsurface flow: lateral conductivity, exponential decrease in vertical conductivity, and porosity. Silt loam was the dominant soil type, encompassing over 90% of the basin, and it was for this soil type that parameters were adjusted to calibrate the modelled stream flow. These parameters were run in combination with one another for a reasonable range of values, resulting in hundreds of runs in an effort to maximize the model efficiency (E) (Nash & Suttcliffe 1970).

E relates to how well the calculated hydrograph matches the observed hydrograph in terms of shape and volume in consideration of total variances of both flows (Whitaker et al. 2003) (see Equation 1). Values can range from negative infinity to one and a value less than zero indicates that the mean of the observed data are a better predictor than the model. The coefficient of determination, D, was also calculated for each run (see Equation 2). D relates to how well a linear relationship relates modelled and observed stream flow (Whitaker *et al*., 2003).

Calibration was performed for the silt loam soil with an automated calibration process and for the time period Aug. 2010-April 2016. The parameters which produced the best E! did not necessarily produce a good visual fit. Results from the automated calibration were ranked based on their E! and the run with the best visual fit among these was determined. This run had a porosity of 0.64, lateral conductivity of 0.0001 m/s and an exponential decrease with depth in vertical conductivity of 3.

Streamflow comparison and SSC results

The model results were compared to stream flow simulated in 1966 – 1984 and sediment module results during 2006 – 2016.

Streamflow comparison

DHSVM modelled stream flow was compared to reconstructed stream flows from 2006 – 2016. When compared to the reconstructed stream flow with the DHSVM, the reconstructed flow had greater average flows. This was expected because similar results were found during part of the calibration time period (2014 D. 2015) when comparing the Lakes Prespa records and the DHSVM output. Overall, reconstructed runoff was similar to the modelled stream flow predicted via DHSVM.

For this time period, the modelled flow had an E of 68%, D of 84%, a relative bias of 10%, and an R value of 0.8 comparing modelled and observed.

Field work and sediment module evaluation

The sediment module was run for the time period of sediment analysis and evaluation with measured precipitation inputs because 3–hourly precipitation forcing were needed to model surface and channel bed erosion. The surface erosion dates defined for this simulation are December 2015 through September 2016, and then any day during October 2003-April 2010 where stream flow meets the 40% stream threshold. Overall, the model performed very poorly. The modelled SSC varied greatly at different locations in the basin.

Climate change scenarios

The model output of the climate change scenarios contributed to the analysis of the modelled hydrology. The changes to mean monthly temperature and precipitation were analysed for a 30 year period, historically and in the future. The statistically downscaled future metrological data were derived by perturbing the historical record (Elsner *et al*., 2010). As a result, overlapping time periods can be compared directly and the climate change effect can be analysed. As a result of these changes in climate, the stream flow is predicted to increase by as much as 25% during February with greater stream flow than what has been observed historically during the winter months. The spread in the stream flow results indicates the range of uncertainty for the future simulated stream flows. For example, during the months of January and June, the range of uncertainty for the future stream flow is 18.6 – 44.4 m^3/s and 1.4 – 2.4 m^3/s, respectively. On average, stream flow is expected to decrease more rapidly during the spring in the year 2045 than it has over 2006 – 2016. Also, more precipitation in the winter is falling as rain instead of snow. This will lead to more runoff events on frozen or thawing soil (assuming the soil still freezes regularly) which lends to decreased soil cohesion of the soil and more surface erosion from the basin (Bullock, 1988).

The spread in model results is greatest for the month of December, which indicates a high uncertainty pertaining to the specific amount of runoff we can expect to that month. This dramatic shift in peak flow is predicted by miroc_3.2 (for both the A1B and the B1 scenarios) predicted climate data. Miroc_3.2 was the GCM with the least weight out of the nine employed for this study, based on its performance in the Pacific Northwest (Mote & Salathé, 2010). However, we can be more confident that stream flow will increase in the winter, because the majority of the future stream flows are above the historical trend, and decrease in the spring because that is what the overall trend indicates.

Tillage and residue management scenarios

Four tillage and residue management scenarios were modelled for the Lakes Prespa basin under a future climate scenario, cnrm_cm3_A1B. The scenarios represent a varying degree of conservation tillage. Results indicate that changing the tillage practices will not affect the timing of runoff events. Climate will have the dominant effect on the magnitude of runoff events across the basin, which is demonstrated here by the change induced by the future climate scenario cnrm_cm3_A1B. Depiction of mean monthly stream flow suggests that adopting conservation tillage does not significantly decrease model–simulated surface runoff. December shows a trend in mean stream flow for the month with scenario 1 and the cnrm_cm3 scenario (100%–CT) having the greatest runoff and scenario 4 (100%–NT) having slightly less stream flow runoff (23.1 m^3/s as compared to 24.9 m^3/s). The differences between the scenarios on a mean monthly time scale appear to be negligible for many of the other months.

The four tillage scenarios were also run with the NCDC climate inputs to analyse their effect on sediment and runoff. The results show a map detailing the change in sediment depth per grid cell in the Lakes Prespa Basin. A negative (positive) number corresponds with a decrease (increase) in sediment depth for the change to sediment depth. Sediment flux is the sediment flux out of the cell. A number greater than zero indicates that more sediment is leaving the cell than entering, while a number less than zero indicates that more sediment is entering the grid cell than being transported out.

To better understand how sediment is generated and transported for this time period, runoff was also analysed. Knowledge of the runoff mechanisms occurring for this time period, over the entire basin and area of interest, aids in the understanding of how tillage affects surface runoff and the consequential surface erosion. For the erosion events for the period of interest, DHSVM models infiltration excess. Results show the surface runoff, or Horton overland flow, in meters over the designated time period for the entire watershed. We know that this runoff is infiltration excess and not saturation excess, because soil saturation was also determined spatially for this time period, and at most the soil across the basin is 64% saturated.

There is a slight decrease in surface runoff in the area of interest when the agricultural areas within the area of interest are modelled as NT soil instead of CT or RT soil. Results show the surface runoff for the area of interest. There is a decrease in surface runoff in the area of interest when the agricultural areas within the area of interest are modelled as NT soil instead of CT or RT soil. There is little change between the sediment flux distributions after changing from CT (upper right) to RT (lower left). When all of the agricultural lands are changed to NT, one grid cell changes (lower right). The range of depicted soil flux is from –27 to approximately 500 m^3. Within the entire basin, at least one grid cell has a flux of 934,000 m^3 during this time period.

The relationship seen between conservation tillage employed and total runoff is expected, with scenario 4 having the least amount of runoff, and scenarios 1 & 5 having the most. However, the total amount of runoff is less with scenario 5 than with scenario 1, even though twice the amount of farmland is assumed to be CT. Scenario 4, the NT scenario, has the least amount of area that experiences erosion and the smallest erosion rate for the time period. The model results for the remaining tillage scenarios and the current scenario do not indicate a clear relationship between changing tillage practices and the amount of runoff generated and sediment eroded from the land surface. It has been estimated in other studies that by changing management practices from CT to direct seeding (NT), erosion from cropland areas in the Lakes Prespa Basin would reduce by as much as 78%, and we only observe a 19% reduction for this time period of interest. Figures depicts the mean change in sediment depth and the sediment flux for the different scenarios, also shows that the model is not responding to changes in tillage as it should for large runoff events. The average values and standard deviations for sediment flux and change to sediment bed depth are similar for all tillage scenarios.

Conclusions

The purpose of this research was to model the effects of climate change on suspended sediment in the Lakes Prespa Basin. Future climate change scenarios predicted more and earlier winter precipitation, and higher temperatures throughout the year. It is clear from the climate change scenarios that the intensity of storm events is predicted to increase for the year 2045 for this region.

For the Lakes Prespa Basin, the increase in temperature and precipitation may result in higher runoff rates accompanied with more stream pollution. Regionally, projections of climate change vary more than emission scenarios, and the uncertainty of these projections can be reduced by using a multimodel ensemble (Mote & Salathé 2010), which was the approach used in this study. These sources of uncertainty must be considered when viewing model results.

All erosion results must be viewed in consideration of the fact that rill erosion not being simulated in the model. Effects of tillage conservation were examined spatially for erosion over a 4 km^2 area for two outputs, sediment flux and change in sediment depth. This showed the model's sensitivity to tillage appeared to be minimal. Investigating the erosion rate of tillage scenarios across agricultural areas shows that the model is not as sensitive to conservation tillage management as it should be, and that the erosion rates predicted for the basin are magnitudes larger than what has been quantified in the past (Teasdale and Barber). It was discovered that classifying all of the land as NT did significantly reduce runoff. The erosion rate over NT agricultural areas was estimated to be $2.61x10^{12}$ kg/ha or greater during the 3-hour period of interest, which is $3.5x10^{8}$ times the estimated annual value (7413 kg/ha) estimated for the entire year. This huge discrepancy was also seen when examining results for the entire basin, which indicates that the model is currently overestimating erosion across the whole basin, including agricultural areas, (although most of the eroded sediment does not reach the channel but is re-deposited back on the hill-slope). To investigate if tillage conservation can ameliorate climate change, different tillage scenarios were run for a single climate change scenario. Because the model was not as sensitive to changes in tillage as it should be, these model results cannot be used to infer the impacts of future management scenarios for farmers in the Lakes Prespa Basin.

It was observed that most (over 99%) of sediment generated from the hill-slopes was not being transported to the stream network. The sediment module was initially evaluated for its ability to produce sediment generated from forest road and burned areas (Doten & Lettenmaier, 2004), and more adjustments are needed to apply it to agricultural areas. The fact that much of the suspended sediment is coming from the sediment initialized in the channel, which is based on the debris flow grain size distribution, was another limiting factor on analysing the SSC concentrations. This may also be the result of incorrect channel parameters. The simulated SSC values were compared to IDEQ samples, and appeared to miss extreme events or overestimate SSC during months were this is little runoff and low stream-flow. Observations have shown that suspended sediment concentrations can vary drastically in this river, but model results do not yet display large fluctuations in suspended sediment concentrations which are typically observed in nature as a result of storm and erosion events.

Therefore, the sediment module results are not indicative of processes that influence tillage implementation and sediment generation in the Lakes Prespa Basin. We can still infer results from the hydrology results for historical and future climate. The future climate will be the driving factor which determines the timing of runoff events. For example, climate change may lead to further problems if more frequent and intense storm events lead to a great amount of sediment generation. This study supports further investigation into other phenomena that are anticipated to be dramatically affected by climate change, such as increased delivery of nitrates and phosphates to the stream.

Additional work can be done to make DHSVM suitable for modelling hillslope erosion over agricultural areas. A more sophisticated method of representing rills could be added to the model where runoff and soil cohesion of the soil would determine the fraction each grid cell that is rills, and what the area of these rills would be. Erosion is generated in this basin when rills and gullies are formed, and water incision of these channels generates sediment throughout the year (Teasdale and Barber, 2008). User control over the d50 and d90 of the channel bed material, independent of the debris flow grain size, would prevent the channel bed material from constantly eroding during the model run. Currently, only fractional coverage of the overstory can be controlled, and it would be beneficial for the user to be able to adjust fractional coverage of the understory. In this manner, LAI, which affects leaf drip impact, would not need to be adjusted.

Further exploration on the application of modelling tillage within DHSVM, or another model, and its impact on surface erosion for this basin will lend to a greater understanding of how tillage and employing surface residue management can ameliorate the negative effects of climate change while retaining the other positive effects, such as increased infiltration and soil moisture for this dryland farming area. An influential factor will continue to be the individual manager of the land and their adoption of best management practices and willingness to adapt to changes, whether that is increased precipitation or a change in wheat prices. In the long-term, this research can lead to examination of the effects of climate change on the riparian habitat of rainbow and steelhead trout in the Potlatch basin.

References

Cammeraat E, (2004) Scale dependent thresholds in hydrological and erosion response of a semi-arid catchment in southeast Spain, *Agriculture Ecosystems & Environment*, **104**, 317–332.

Cuo L, Lettenmaier D, Alberti M, Richey J, (2009) Effects of a century of land cover and climate change on the hydrology of the Puget Sound basin, Hydrological Processes, **23**, 907-933.

Doten CO, Lettenmaier DP, (2004) *Prediction of Sediment Erosion and Transport with the Distributed Hydrology–Soil–Vegetation Model*, edited, Seattle, WA.

Doten C, Bowling L, Lanini J, Maurer E, Lettenmaier D, (2006) A spatially distributed model for the dynamic prediction of sediment erosion and transport in mountainous forested watersheds, *Water Resources Research*, **42**, 1–15.

Elsner M, Cuo L, Voisin N, Deems J, Hamlet A, Vano J, Mickelson K, Lee S, Lettenmaier D, (2010) Implications of 21st century climate change for the hydrology of Washington State, *Climatic Change*, **102**, 225–260.

Fu G, Chen S, McCool D, (2006) Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS, *Soil & Tillage Research*, **85**, 38–49.

Kassie, M., Zikhali, P., Manjur, K., Edwards, S. (2009). Adoption of Sustainable Agriculture Practices: Evidence from a Semi–arid Region of Ethiopia, Natural Resources Forum 39, 189–198.

Kok H, Papendick R, Saxton K, (2009). STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands, Journal of Soil and Water Conservation, 64: 253–264.

Maurer, E Wood, A Adam, J Lettenmaier, D Nijssen, B. (2002). A long–term hydrologically based dataset of land surface fluxes and states for the conterminous United States, Journal of Climate, 15: 3237–3251.

McCool DK, Foster GR, Yoder DC, Weesies GA, McGregor KC, Bingner RL, (2003) Revised Universal Soil Loss Equation, Version 2. U.S. Department of Agriculture–Agricultural Research Service, Washington, D.C 77 pp.

Meerkerk AL, van Wesemael B, Bellin N, (2009) Application of connectivity theory to model the impact of terrace failure on runoff in semi-arid catchments, **23**,: 2792–2803.

Mote, P. & Salathe, E. (2010). Future climate in the Pacific Northwest, Climatic Change, 102: 29–50.

Nash JE, Sutcliffe JV, (1970) River flow forecasting through conceptual models. Part 1 – a discussion of principles, Journal of Hydrology, **10**, 282–290.

Rai RK, Mathur, BS, (2007). Event-Based Soil Erosion Modeling of Small Watersheds, Journal of Hydraulic Engineering, 12: 559–572.

Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC, (1997) Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, pp. 404.

Smith RE, Parlange JY, (1978) A Parameter–Efficient Hydrologic Infiltration Model, *Water Resources Research*, **14**, 533-538.

Teasdale G, Barber M (2008) Aerial Assessment of Ephemeral Gully Erosion from Agricultural Regions in the Pacific Northwest, *J. Irrigation & Drainage Engineering–ASCE*, **134**, 807–814.

Whitaker, A, Alila, Y, Beckers J, Toews D, (2003). Application of the distributed hydrology soil vegetation model to redfish creek, British Columbia: model evaluation using internal catchment data, *Hydrological Processes*, **17**, 199–224.

Wigmosta MS, Vail L, Lettenmaie D, (1994) A distributed hydrology-vegetation model for complex terrain, *Water Resources Research*, **30**, 1665–1679.