A Socio-Economic Lens on Identification of Critical Source Areas in the Rock River, Vermont

Application of The Universal Soil Loss Equation & Correlation between Property Value and Non-Point Source Pollutants

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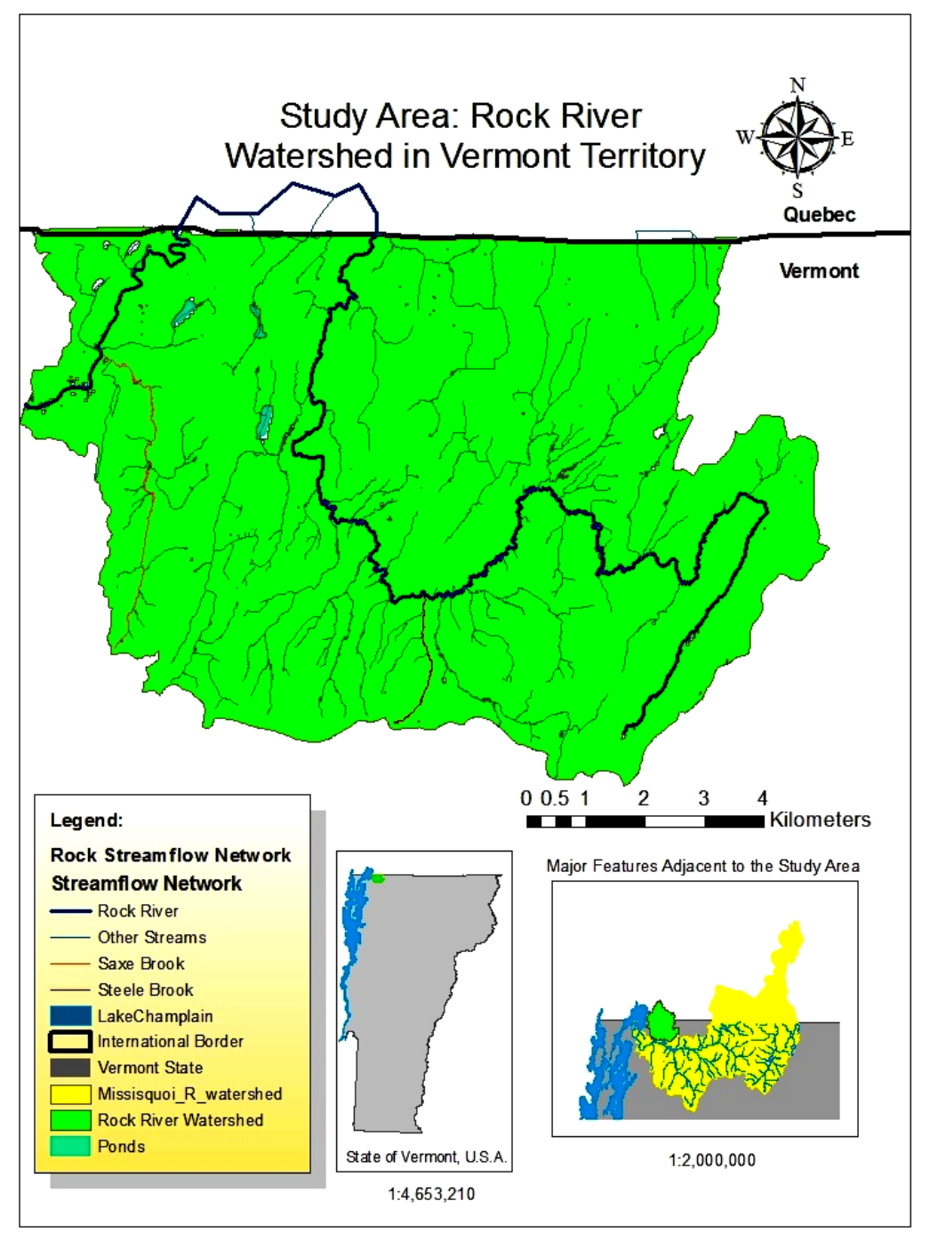
Introduction

Excessive nutrient application to agricultural land and intensive farming practices have led to an increase in sediment and sediment-bounded Phosphorus (P) transported through runoff into waterways, threatening freshwater quality. The Rock River watershed is located on the across the US-Canadian border, whose flows originate from the Highgate and Franklin counties in Vermont and into the Province of Quebec and discharges at Missisquoi Bay in the northeast arm of Lake Champlain, draining 9,090 hectares of land through a combined river length of 34 kilometers. This study focuses on the Vermont portion of the Rock River watershed, compromising 63% of the whole watershed. Total Phosphorus (TP) at the bay exceeded its total maximum daily load standard of 25µg/L by 21µg/L in 2015 and is the most deteriorated lake segment. Phosphorous loading, being one of the significant limiting factors for aquatic life exacerbates algal blooms. Moreover, the regional climate trends of increasing temperature and precipitation, the combination of higher P loading, higher temperatures, and increased erosion due to intensified storm events, further eutrophicates the bay. This in turn poses a threat to human health, diminishes recreational potential, and degrades the drinking water supply for over 200,000 residents.



In a regional analysis, the study area contributed the second highest sediment and phosphorous loading rate (1.33 ton/ha and 0.81 kg/ha respectively), plus the highest (7,522 tons) of total phosphorus outputs (Winchell, 2011). Other findings estimate that 85%-90% of total phosphorus load in the form of sediment originates from critical source areas (CSAs) classified as cropland. I speculate that the Agency of Agriculture, Food and Markets has not enforced accepted agricultural practices (AAP) in small farms as rigorously or frequently as in larger farms, although the former account for 83% of Vermont's total farms. Specifically, the small farms in Franklin County were only assigned a compliance inspector by the agency in 2013, therefore it is expected that the smaller farms may contribute more nutrient pollution than the larger farms due to their lack of oversight and knowledge regarding specific AAPs.

The manufacturing and agricultural development of the study area has been steadily growing and a 14.8% increase in the dollar value of agricultural products sold from 2007 to 2012, while both the mean household income and average annual wage is lower than the rest of the state.

Question

Considering climatic, bio-physical and bio-chemical properties of surface and subsurface ecosystems, land use practices, and competing trade-offs between profit-seeking and sustainability, what are the areas that are more susceptible to sediment erosion and phosphorus leaching in the Rock River Watershed? What are the economic values of these critical source areas?

Methodology

I. **Empirical estimation of annual soil loss (A) through the Universal Soil Loss Equation (USLE)**

$$A = R * K * LS * C * P \qquad tn/ha * yr^{-1}$$

A: average annual soil loss $MJ * mm * ha^{-1} * hr^{-1} * yr^{-1}$

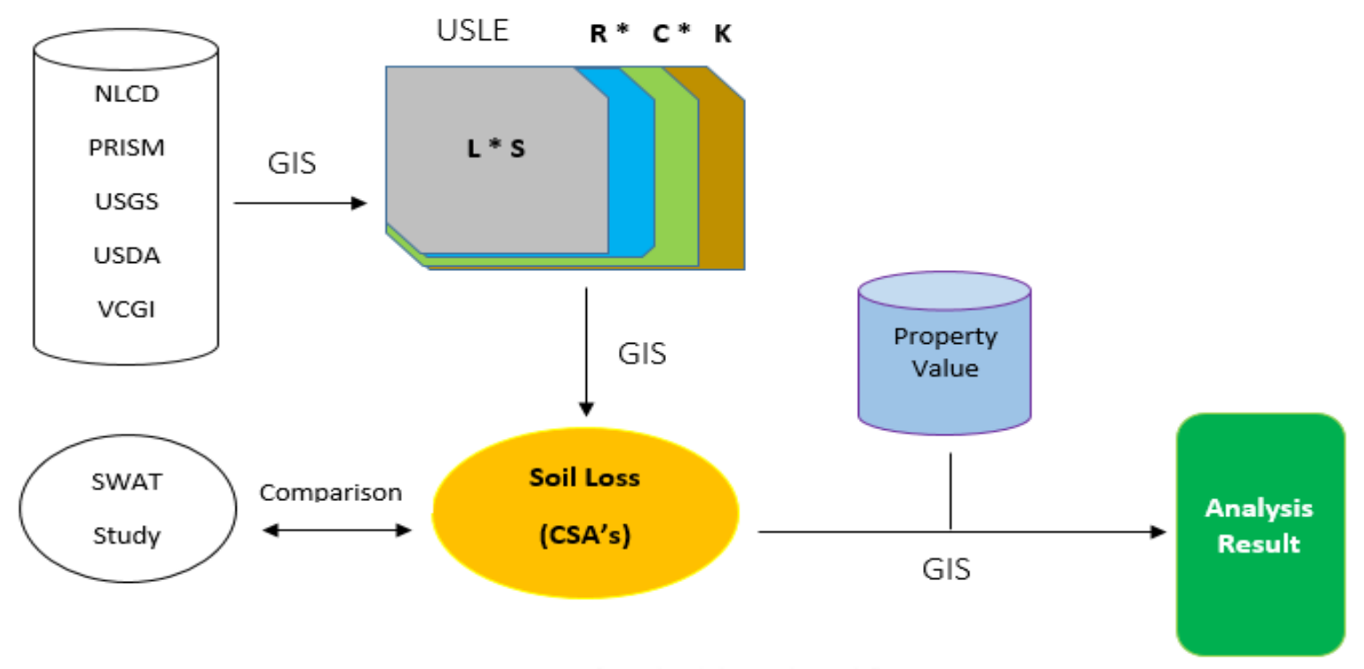
R: rainfall erosivity factor $tn * ha * hr * ha^{-1} * MJ^{-1} * mm^{-1}$

K: soil erodibility factor m

LS: topographic factor

C: cover-management factor $(1\ unit)$

P: the support practice factor.



Overview of Methodological Workflow

II. **Development of Critical Source Area Definitions**

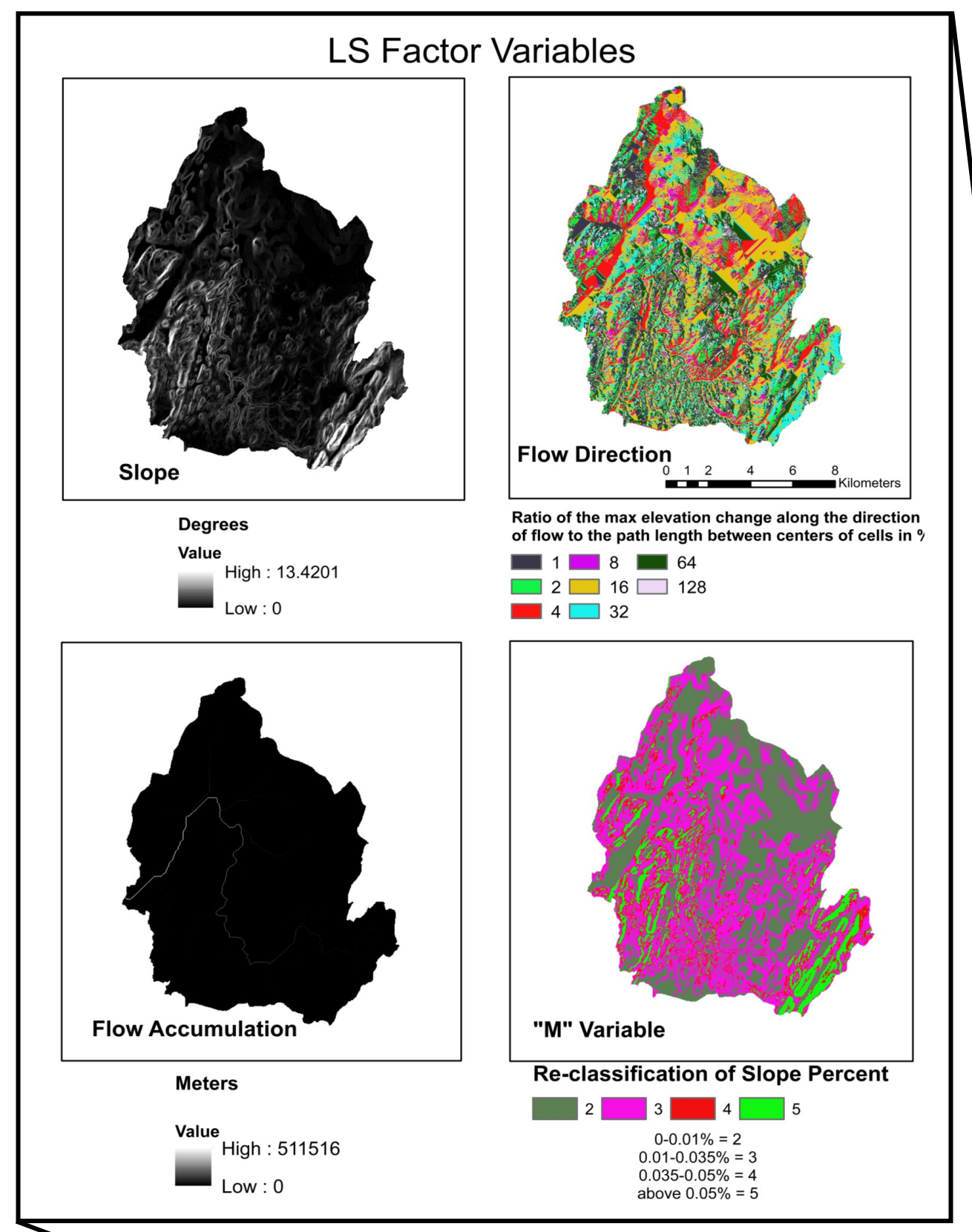
- Determine maximum P amount per unit area utilizing Vermont's Water Quality Standards §3-01(A)(2)(c), "small drainage area into a lake". $kg/ha * yr^{-1}$
- Previous SWAT results were used to define P CSAs: those >5.4 or 1.4% study area

III. **Validation through a comparison of sediment load to a previous study (Winchell, 2011).**

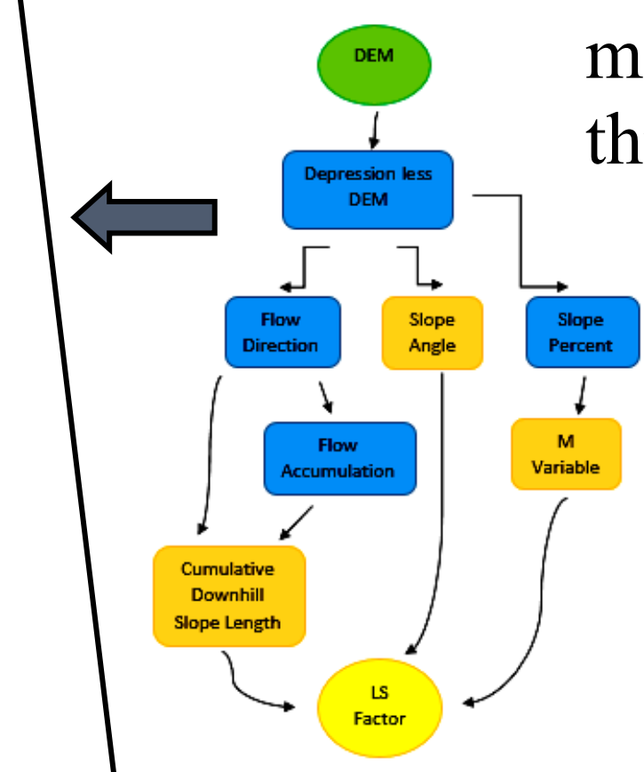
- The estimation of sediment with another method: Soil and Water Assessment Tool (SWAT).

IV. **Overlay phosphorous and sediment load CSAs with property values.**

- Utilized property price per acre ($/acre) data for the period between 1999 and 2003 estimated via artificial neural network (ANN) method.

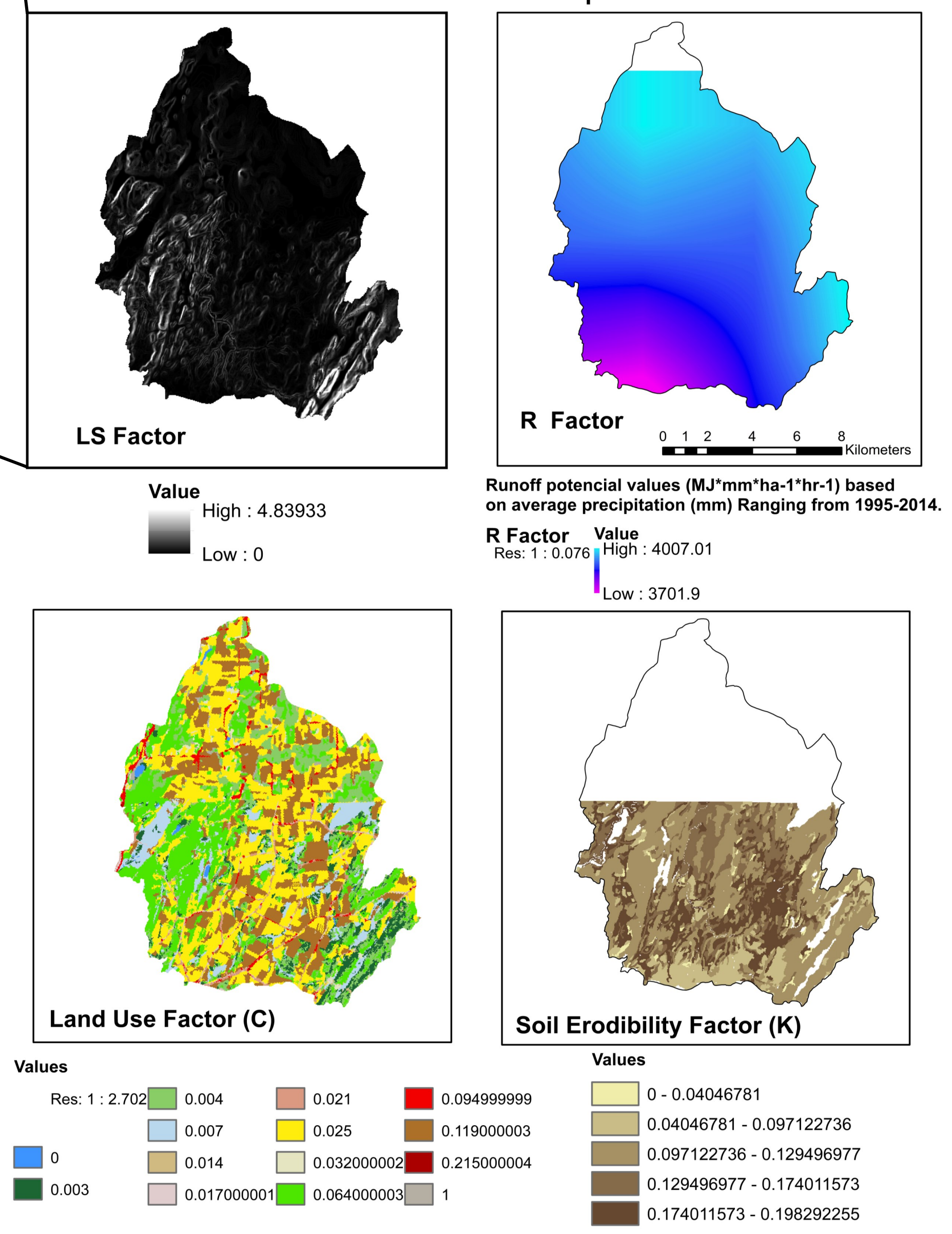


Visualization of USLE workflow



- Literature recompilation and mathematical creation of factor values through:
  - Model builder
  - Bilinear & spline interpolations
  - Reclassification tool
  - Conversion to SI units
  - Estimation of unknown values via random # statistical function

USLE Factor Maps

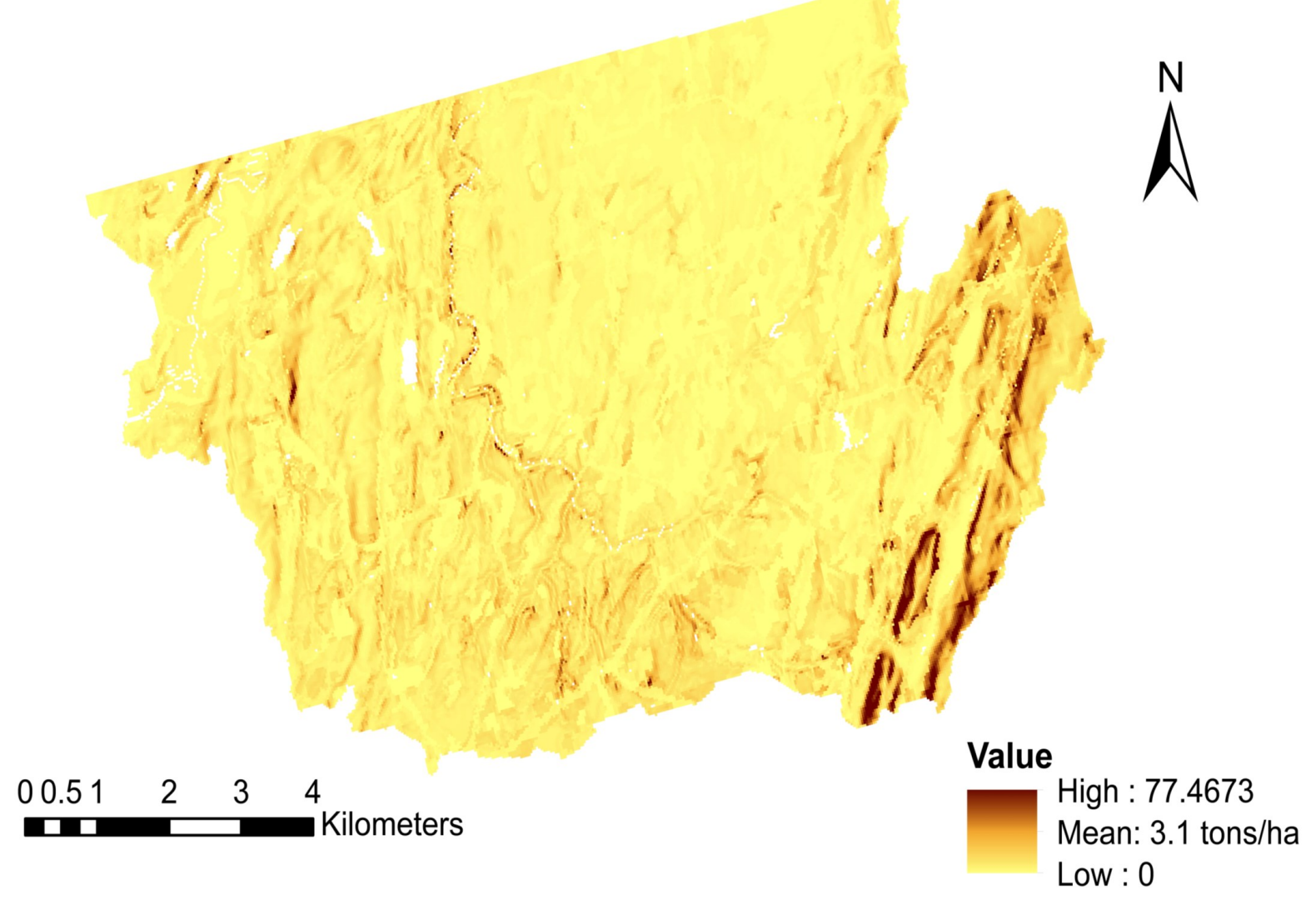


C Values for each 2001 Land Cover Classification		
NLCD #	Classification	C Value
11	Open Water	0
21	Developed Open Space	0.017
22	Developed Low Density	0.021
23	Developed Medium Density	0.095
24	Developed High Density	0.215
31	Barren	1
41	Deciduous Forest	0.064
42	Evergreen Forest	0.003
43	Mixed Forest	0.004
52	Shrub/Scrub	0.014
71	Grassland/Herbaceous	0.032
81	Pasture/Hay	0.025
82	Cultivated Crops	0.119
90	Woody Wetlands	0.007
95	Emergent Herbaceous Wetlands	0.003

Discussion of Results

- My analysis delineates the Rock River Watershed into a spectrum of areas ranging from no sheet and rill erosion to a maximum sediment load of 709,514 tons and a mean annual value 28,614 tons.
- The maximum annual sediment loading rate of 77.5 tons/ha is spatially situated on the steepest regions, as is congruent with early warmings of USLE, while its mean value is almost thrice as large as the previous study, indicating a possible overestimation of erosion.

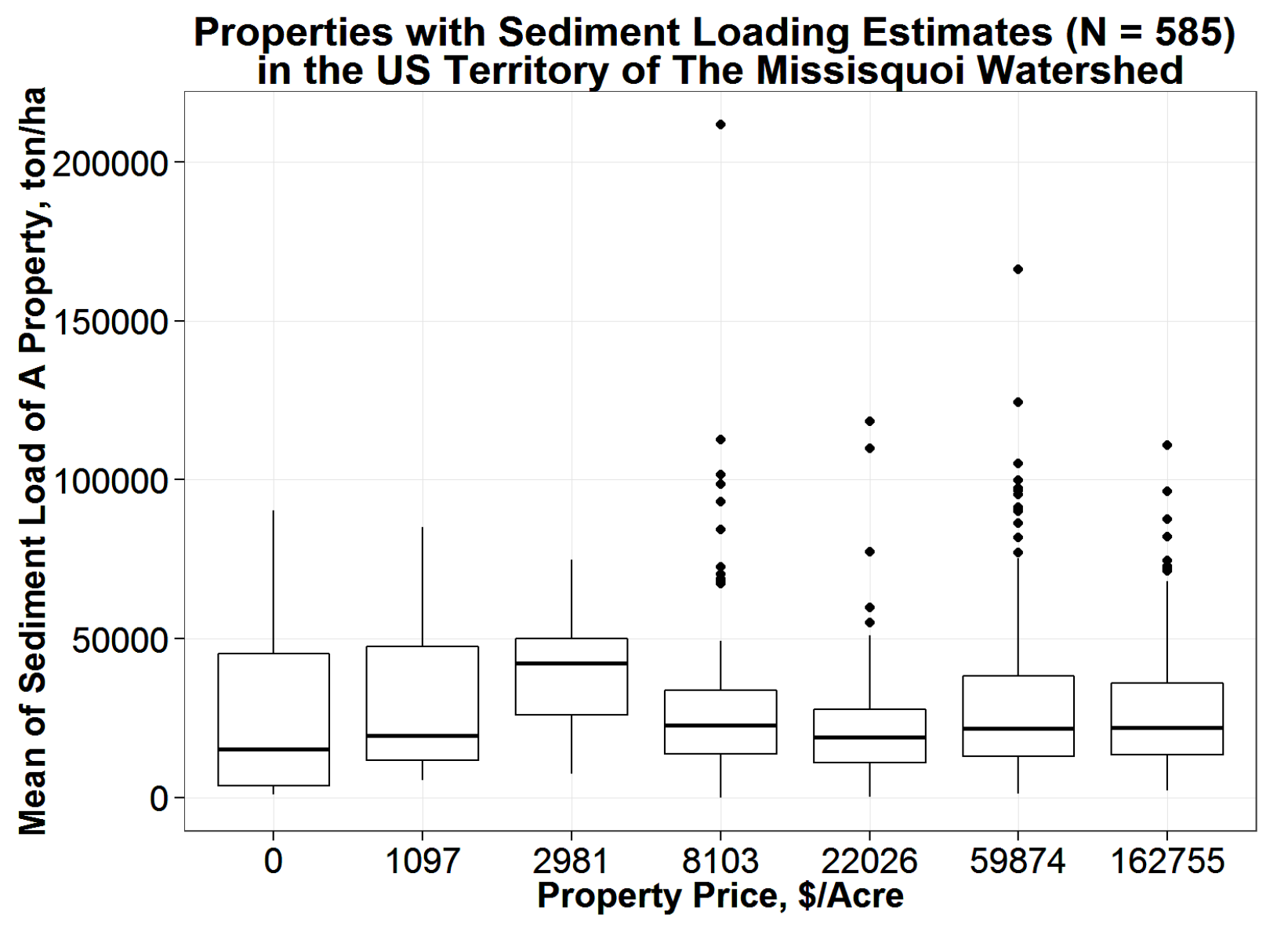
USLE Result: Annual Sediment Loading Rate

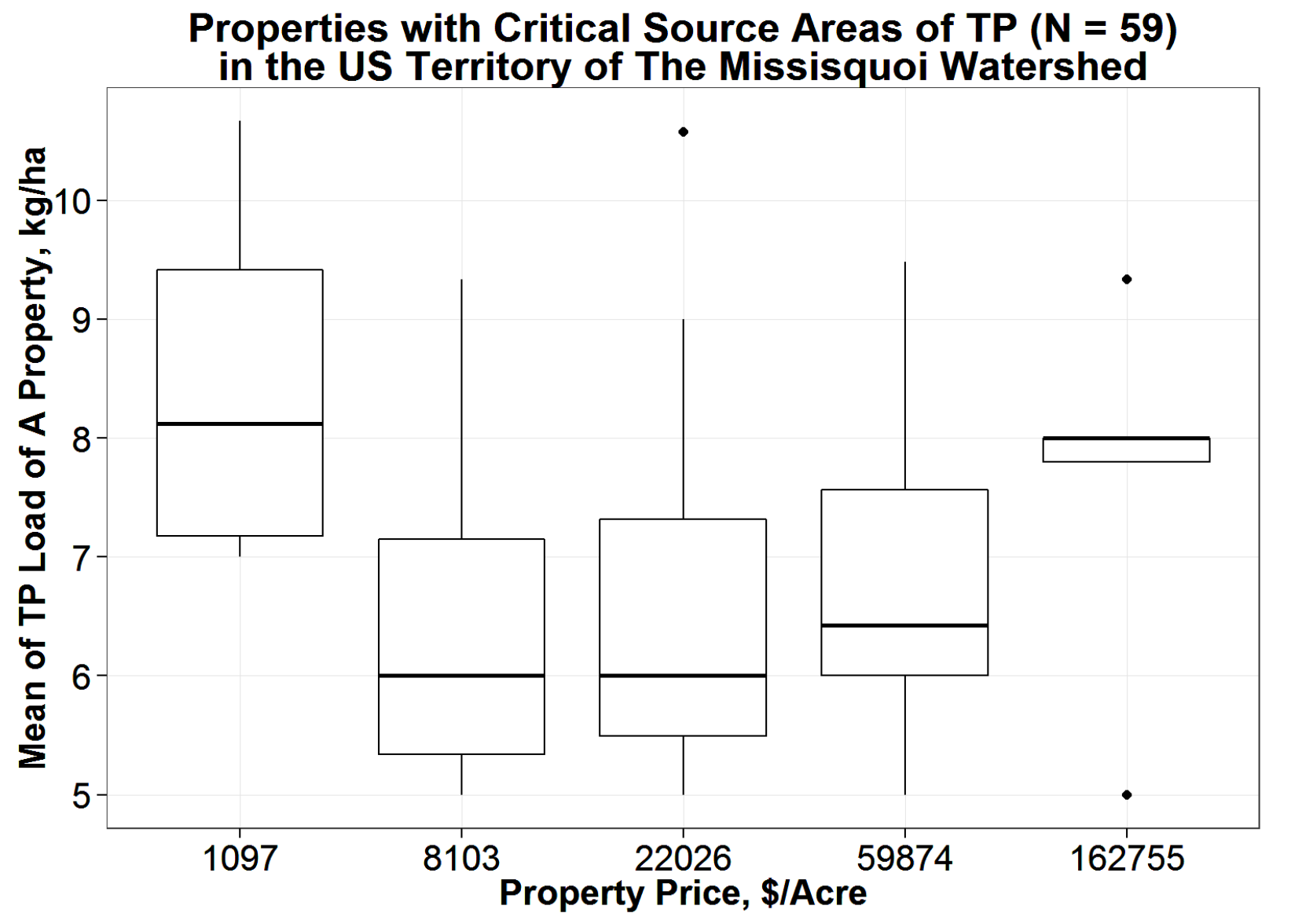


- CSAs were defined as sediment rates greater than 11.2 ton/ha annually, the upper erosion limit for agricultural sustainability (Miller, 2007).
- Utilizing the threshold value for sustainable erosion, the sediment loading risk was significant in 368 ha, or 4.02% of the total study area.
- Considering the average surface discharge for three years (13,395,001,305 L/yr from 2012-2014) obtained from the USGS monitoring station #04294140 representing the runoff collected by the Rock River (extrapolated for the size of the watershed on the US territory), and state's maximum allowable P export rate per hectare (0.012 mg/L) annually into tributaries, then the total study area's phosphorus load should not exceed 42.26 kg/yr. When this allowable P export is compared to SWAT's estimated TP load (7,522 kg/yr.) and, then the severity of the river's pollution level is revealed and corroborates why the State has classified 28.3 km of the river as impaired because of agricultural runoff and nutrient enrichment.

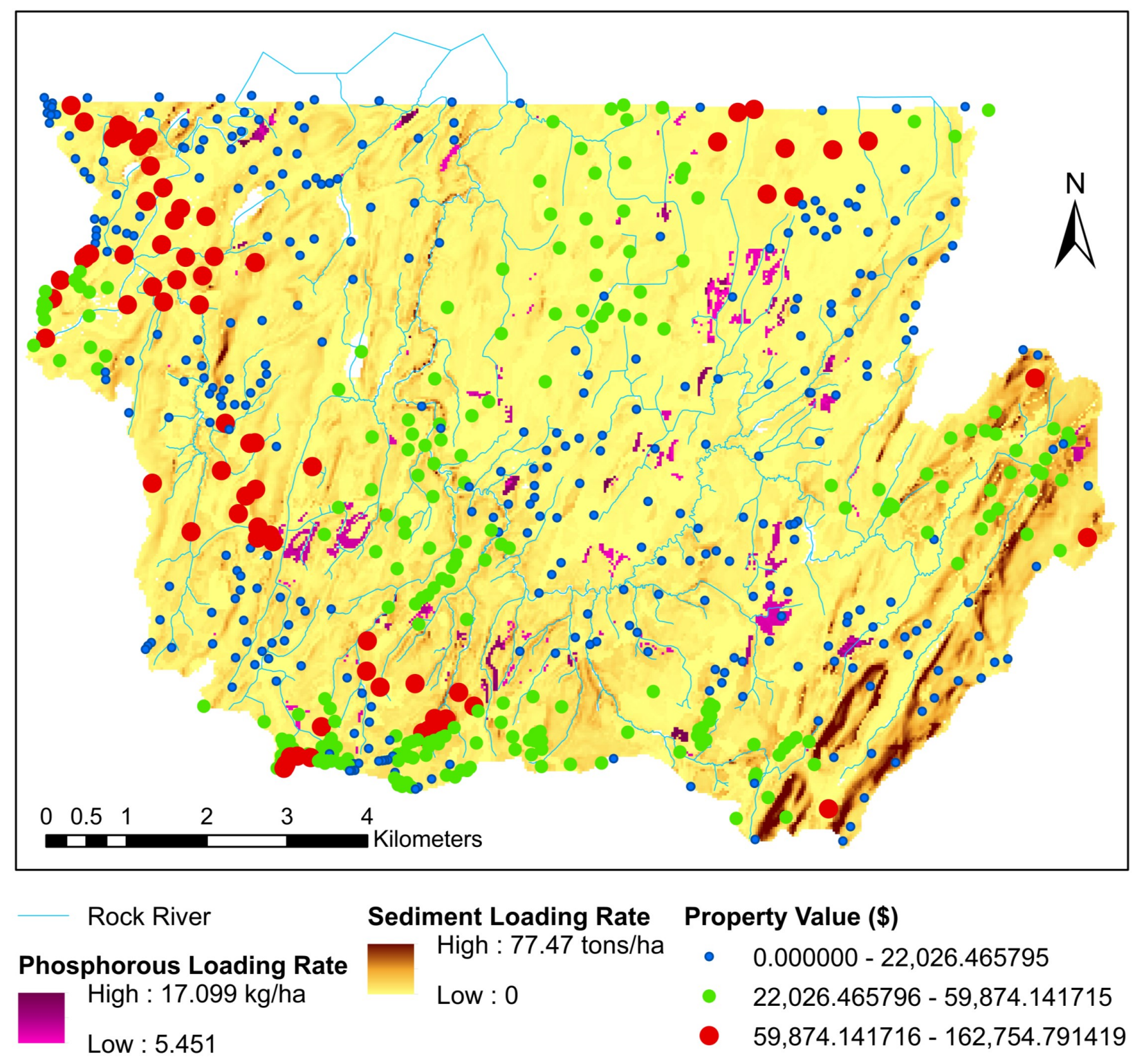
- Possible reasons for why USLE over predicts soil loss in comparison to the SWAT study:
  1. R factor was not calculated directly from the relationship between raindrop kinetic energy and its intensity.
  2. Deviation from the optimal result in slope lengths <122m. The slope did however, conform to the optimal slope angle (1-18%), with a mean slope percent of 1.65%.
  3. Loss of accuracy when I calculated each factor in the US unit system & later corrected estimates by converting all my data to SI units.
- When the median values are compared across all price categories, properties with price of $2981/acre are most likely to have higher sediment load (~42,000 tons/ha) when compared to properties of other price groups. Although not the lowest property group, it is in the lower value spectrum.
- The highest estimated mean TP load for CSAs (defined as >5.4 kg/ha), is associated to properties of $1097/Acre. The TP load in this lowest price group is significantly higher than those of $8130, $22026, and $59874 groups. However, the TP load for the lowest property group is not significantly different from the highest property group.

This could be explained by low price areas which may be marginal farmlands (or these farmlands are not located in prime agricultural areas), and that the highest price areas are those food-productive farmlands with excessive nutrient inputs.





Spatial Correlation Between Sediment vs. Phosphorous Critical Source Areas and Estimated Property Values



Conclusions

High phosphorous loading rates can be observed in both the highest and lowest property value groups, suggesting the causes for nutrient pollution vary at different locations. Further insight into other possible causes of erosion vulnerability, and hence for contributing to pollution, are needed. Sediment and nutrient loads from properties of both lowest and highest property values have been contributing significantly to Lake Champlain's water quality degradation. In the face of regulation changes, future analysis is needed to improve the USLE approach by utilizing field measurements. It would also be very valuable to explore whether small farms could have caused more erosion due to their less likely potential for investing in best management practices or due to the lack of regulatory enforcement. Furthermore, future studies for estimating the value of prime soil lost annually from cropland could be a powerful tool to incentivize better soil conservation practices.

Selected References

Miller, R. W., & Gardiner, D. T. (2007). Soil Erosion Soils in our environment (Eleventh Edition ed., pp. 365-374). New Jersey: Prentice hall.

Winchell, M. F., et al. (2015). "Using SWAT for sub-field identification of phosphorus critical source areas in a saturation excess runoff region. "Hydrological Sciences Journal-Des Sciences Hydrologiques 60(5): 844-862.

Wischmeier, W. and D. Smith (1978). "Predicting rainfall erosion losses: a guide to conservation planning. Washington: United States Department of Agriculture, 1978. 58p." Agriculture handbook 537.

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