The Effect of DEM Resolution on Slope Estimation and Sediment Predictions

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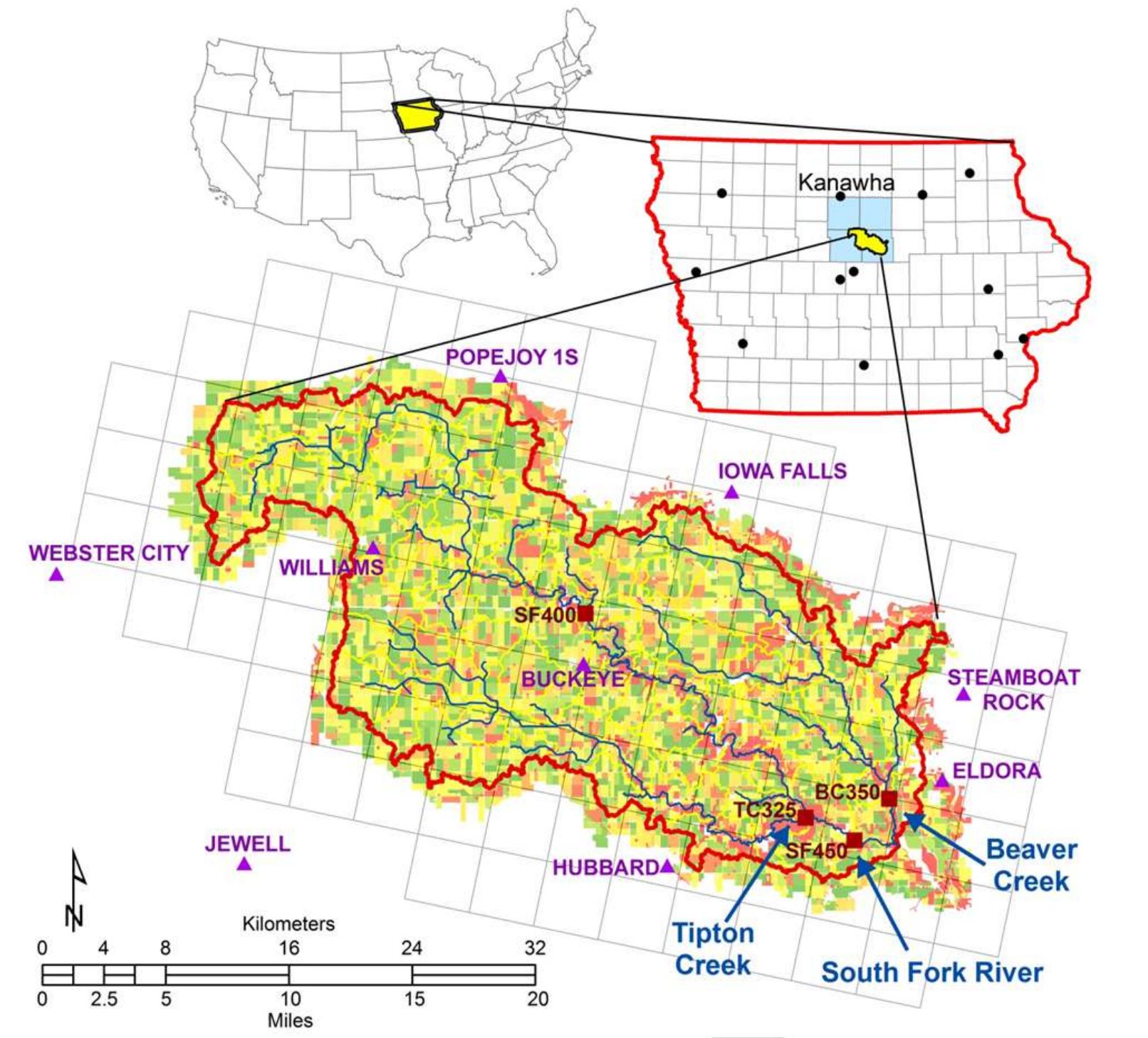
2011 International SWAT Conference -- Toledo, Spain -- June 15-17, 2011

Abstract:

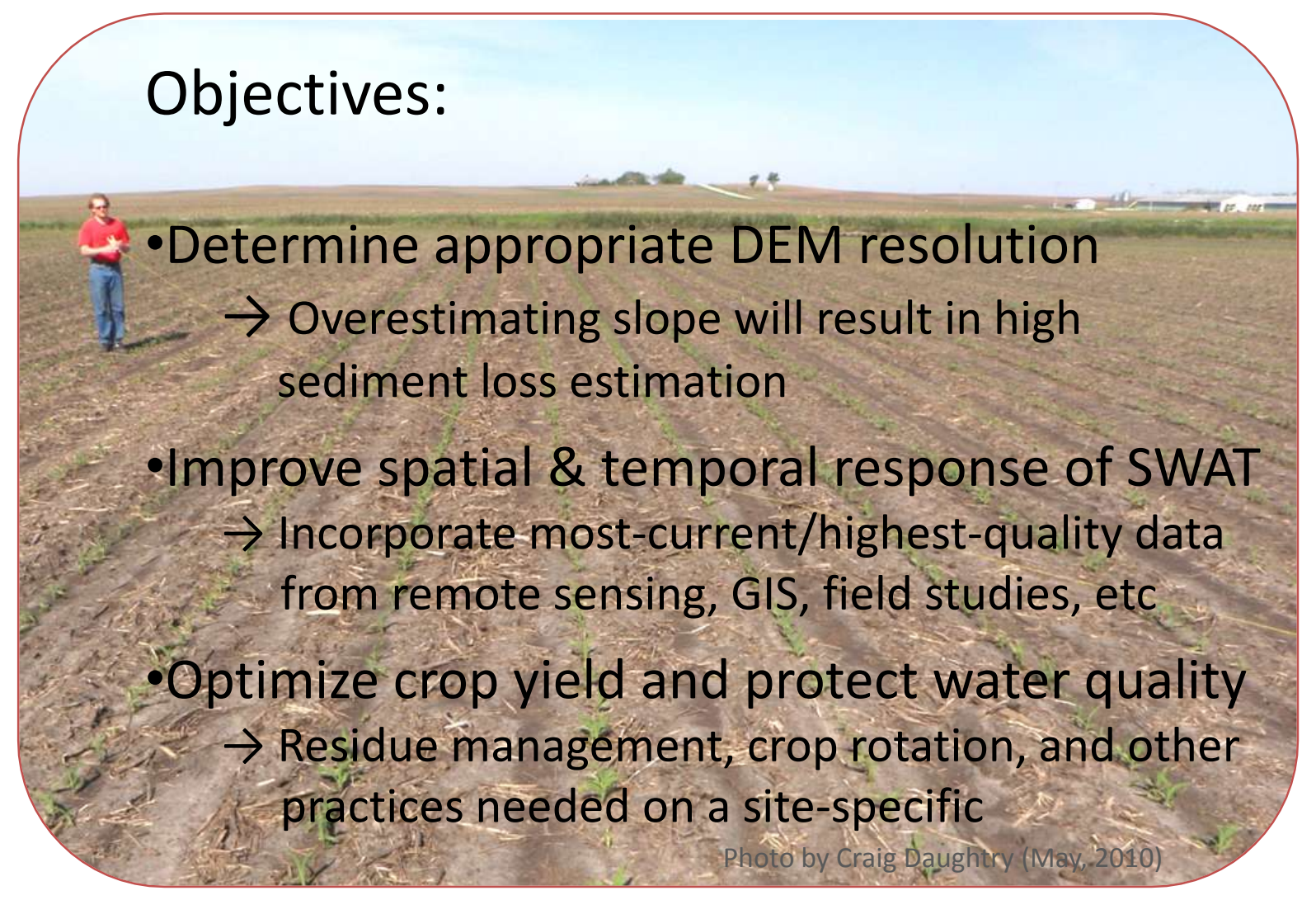
Moderate resolution (30 m) digital elevation models (DEMs) are normally used to estimate slope for the parameterization of non-point source process-based water quality models. These models, such as the Soil and Water Assessment Tool (SWAT), utilize the Universal Soil Loss Equation (USLE) and Modified USLE (MUSLE) to estimate sediment loss. USLE relies on a slope length and steepness (LS) factor which has a very significant effect on USLE outputs. For example, a four-time increase in slope potentially results in a four to 10 times increase in the LS factor and subsequent sediment estimation, depending on the slope length. Recently, the availability of much finer resolution (~2-3 m) DEMs derived from Light Detection and Ranging (LiDAR) data have increased. With the expectation of better and perhaps more accurate model erosion estimates, water quality modelers are eager to take advantage of these finer resolution information. However, the use of these finer resolution data are not always appropriate, since slope values derived from fine spatial resolution DEMs are usually significantly higher than those estimated from coarser DEMs resulting in considerable variability in model output. This paper addresses the implications of parameterizing models using slope values calculated from DEMs with different spatial resolutions (90, 30, 10, and 3 m). Here, we see a 100% increase in slope from the 90m to 3m DEMs, which has a 78% increase in soil loss estimate from the USLE. The results of a comparison among different slope calculations and associated sediment model predictions on a well-monitored watershed are presented and discussed.

South Fork of the Iowa River



Background:

Estimation of Sediment and Nutrient Loss Through Modeling

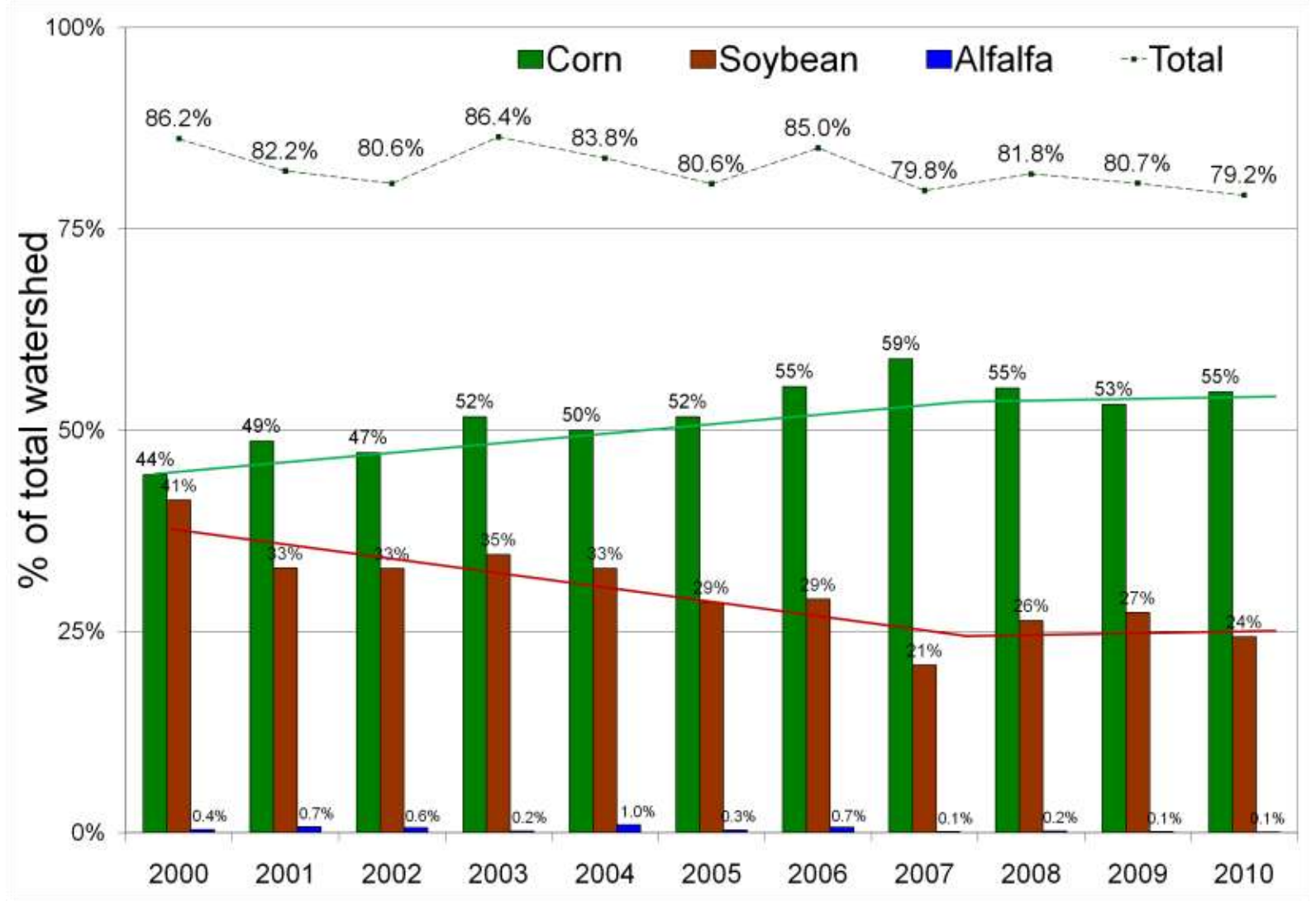


Objectives:

- Determine appropriate DEM resolution
  - → Overestimating slope will result in high sediment loss estimation
- Improve spatial & temporal response of SWAT
  - → Incorporate most-current/highest-quality data from remote sensing, GIS, field studies, etc
- Optimize crop yield and protect water quality
  - → Residue management, crop rotation, and other practices needed on a site-specific

Photo by Craig Daughtry (May, 2010)

Corn Production Increased to Meet Biofuels Goals



Water Quantity

Photo by Alan Stern (May, 2009)

Water Quality

Photo by Mauro Di Luzio (Sept, 2009)

Methods:

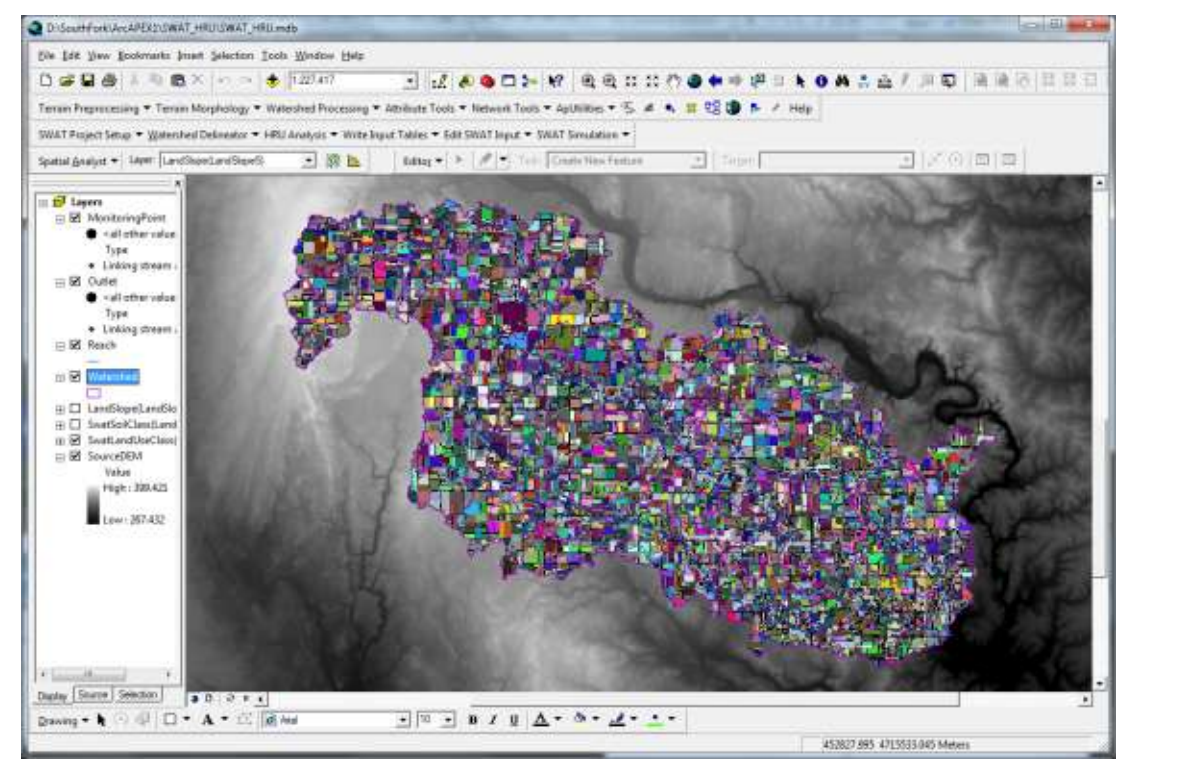
SWAT

SWAT2009: SWAT was developed by the USDA ARS over the past decades. Soil and Water Assessment Tool has proven to be an effective tool for evaluating water resource and nonpoint source pollution problems across the globe (Arnold et al., 1998; Arnold and Fohrer, 2005).

SWAT's Major Components:

•Hydrology (water balance)	•Pesticides
•Weather (actual/simulated)	•Groundwater
•Sediment	•Lateral Flow
•Nutrients (Nitrogen & Phosphorus)	•Management Scenarios
•Crop Growth	•Bacteria

SWAT is a continuous time model that operates on monthly to sub-daily time-steps. The model is physically-based and uses readily available spatial and temporal inputs. It is computationally efficient, capable of simulating long-term yields in large watersheds for determining the impact of land management practices.



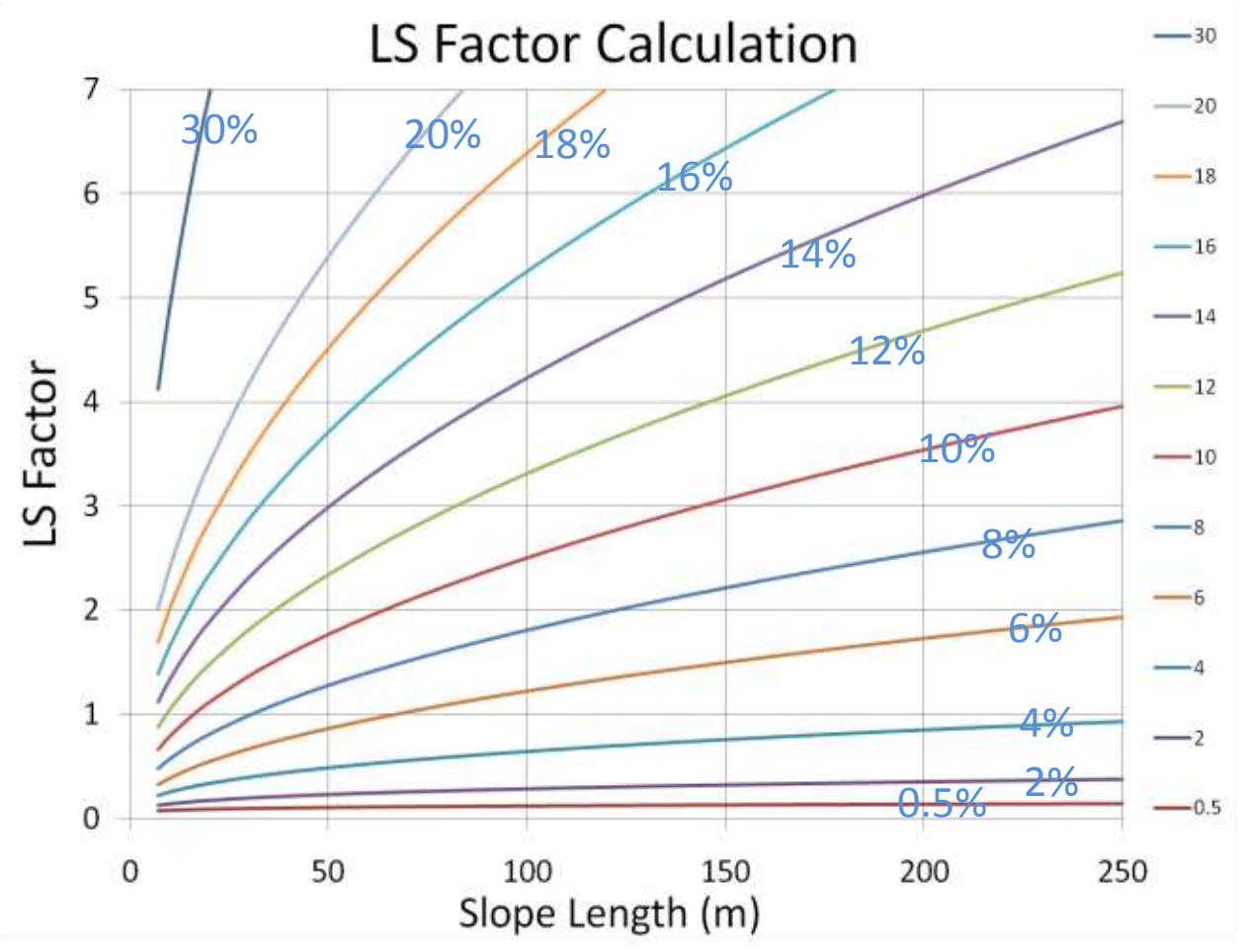
USLE

SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977) to estimate single event sediment yield and also calculates average annual soil loss with the USLE (Wischmeier and Smith, 1978) for comparative purposes.

$$A = R \times K \times LS \times C \times P$$

Where:

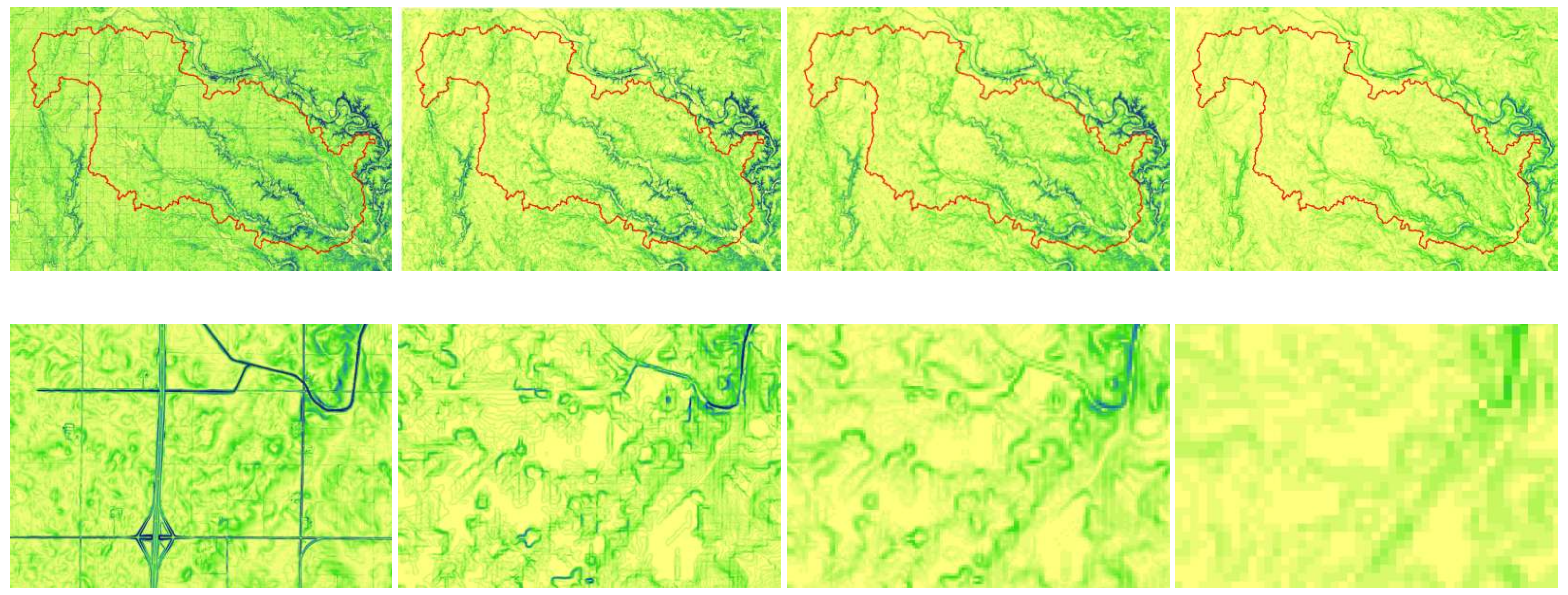
- ➢A = average annual soil loss in tons/acre
- ➢R = rainfall and runoff erosivity index for a geographic location from a lookup table
- ➢K = soil erodibility factor from a lookup table
- ➢LS = slope steepness and length factor from:
  - $LS = [0.065 + 0.0456(\text{slope}\%) + 0.006541(\text{slope}\%^2)] * (\text{slope length(ft)} / 72.5)^{v}$
  - v= 0.2 for slope <1, 0.3 for 1≤ slope <3, 0.4 for 3≤ slope <5, and 0.5 for slope ≥5%
- ➢C = cover management factor from a lookup table
- ➢P = conservation practice factor from a lookup table



Input:

Slope Derived from Various DEM Resolutions

3 Meter | 10 Meter | 30 Meter | 90 Meter

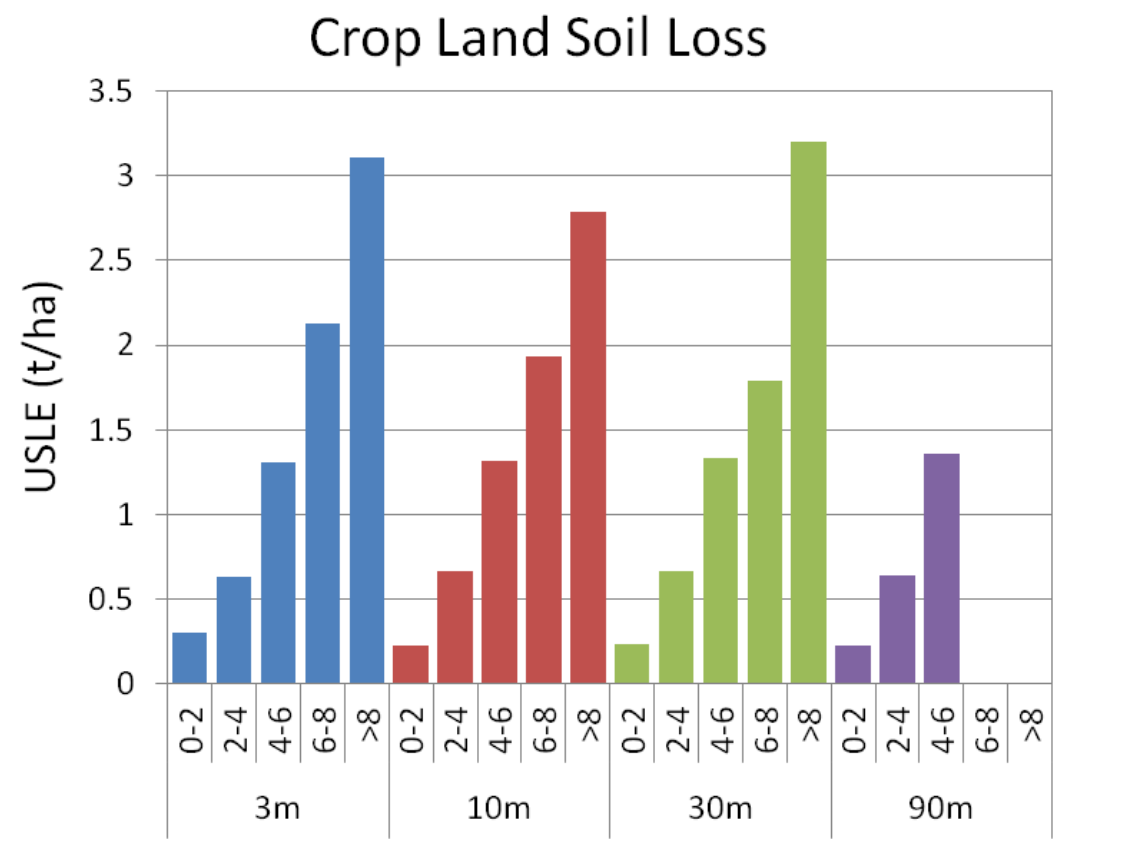


- 3 m DEM: Shows influence of ditches and streams
- 10 m DEM: Stream features still visible but not roads
- 30 m DEM: Only large streams visible
- 90 m DEM: Filters out most features

Table 1: Values assigned by the GIS interface based on the various DEM inputs.

	3m		10m		30m		90m	
Avg. Slope Length (m)	102.4		115.6		115.7		118.0	
Average Slope (m/m)	0.0301		0.0146		0.0142		0.0115	
LS Factor	0.4848		0.2396		0.2355		0.2086	
Slope Class Delineations	*HRU Count*	Area km^2	*HRU Count*	Area km^2	*HRU Count*	Area km^2	*HRU Count*	Area km^2
0-2	*569*	426	*880*	664	*873*	660	*916*	701
2-4	*380*	275	*126*	87	*135*	93	*117*	78
4-6	*41*	30	*19*	14	*22*	14	*12*	7
6-8	*3*	2	*4*	2	*4*	4	--	--
>8	*78*	55	*21*	21	*15*	17	*1*	2
Total	*1071*	788	*1050*	788	*1049*	788	*1046*	788

Crop Land Soil Loss

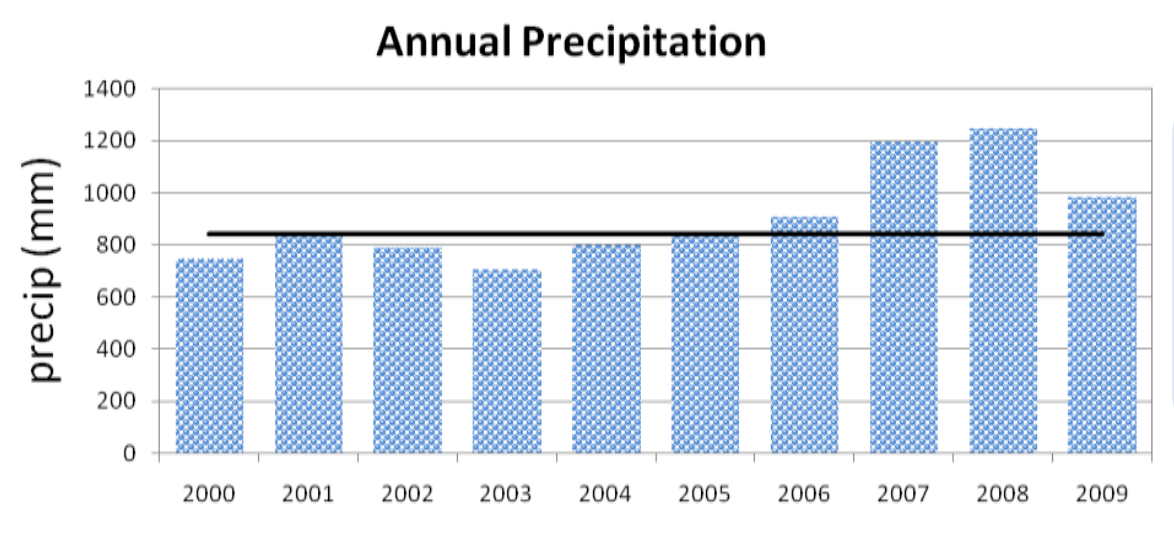


- Average LS Factor for 3m DEM ~2x greater than others
- HRU delineation differs the most in the 2-4% slope class

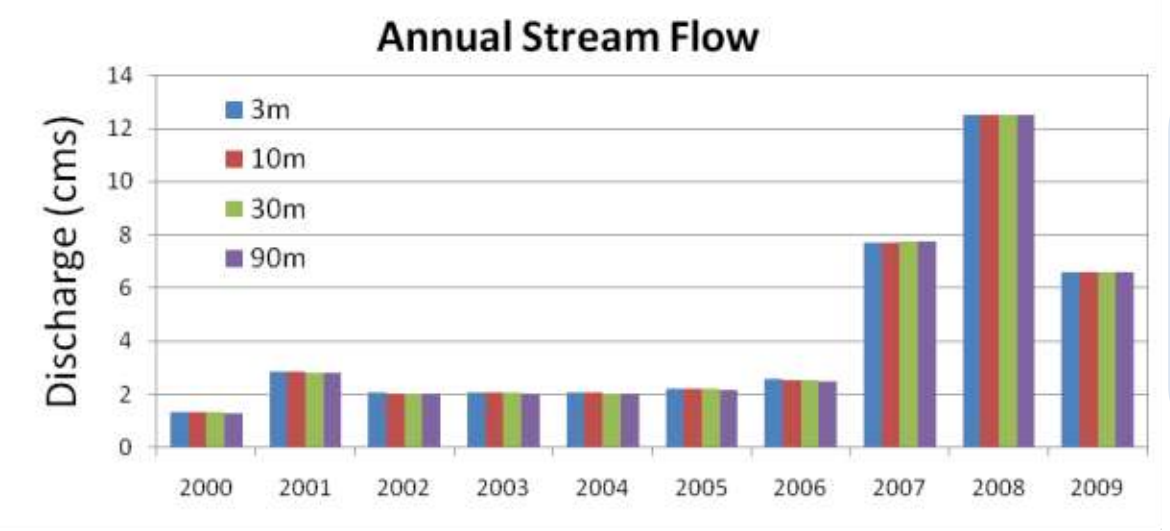
2-4% slope class contributes more sediment per hectare along with more area contributes most difference

Results:

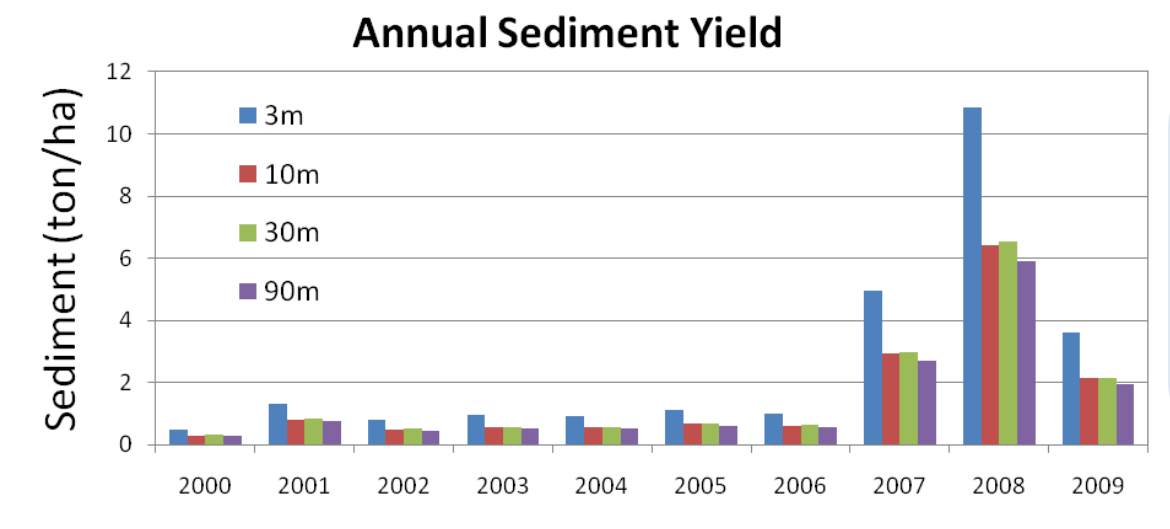
Basin-Wide SWAT Output



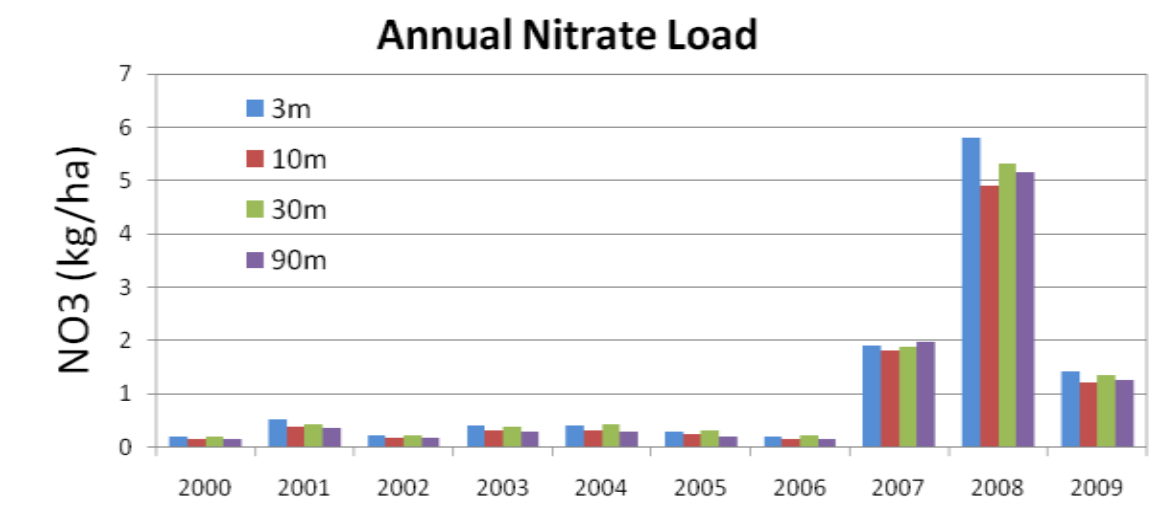
10-year rainfall: Above average for the last four years



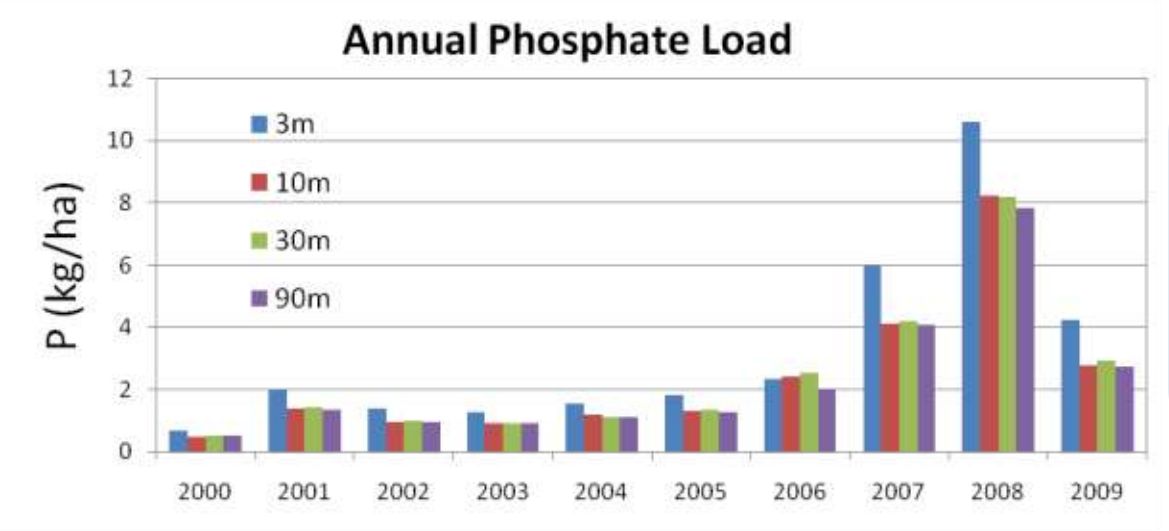
Annual Stream Flow: Not effected by slope



Sediment Yield: Effected by slope



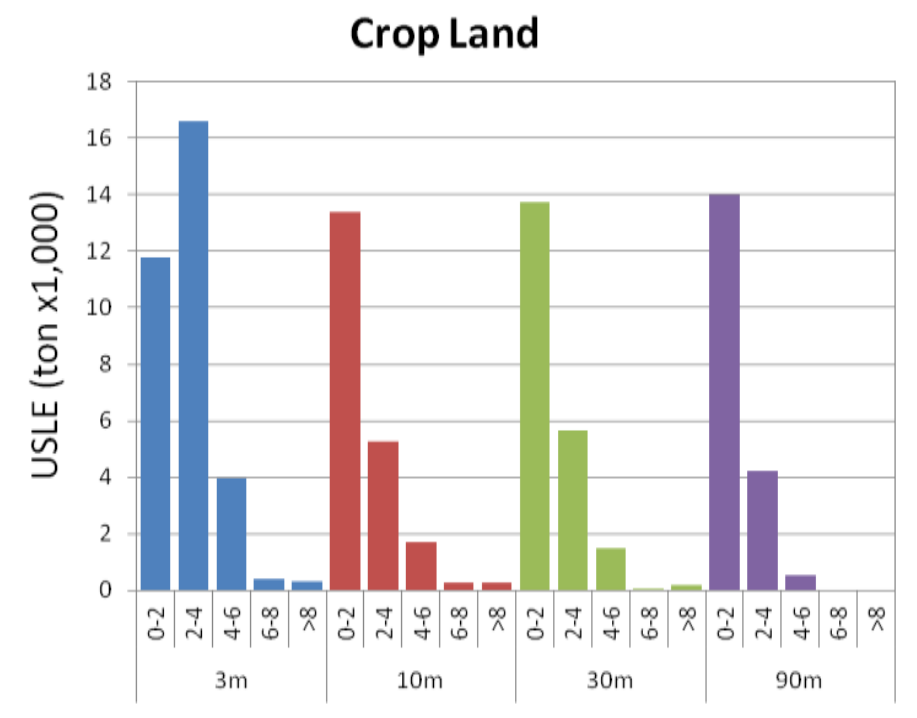
Nitrate Load: Not largely effected by slope



Mineral Phosphorus: Slightly effected by slope

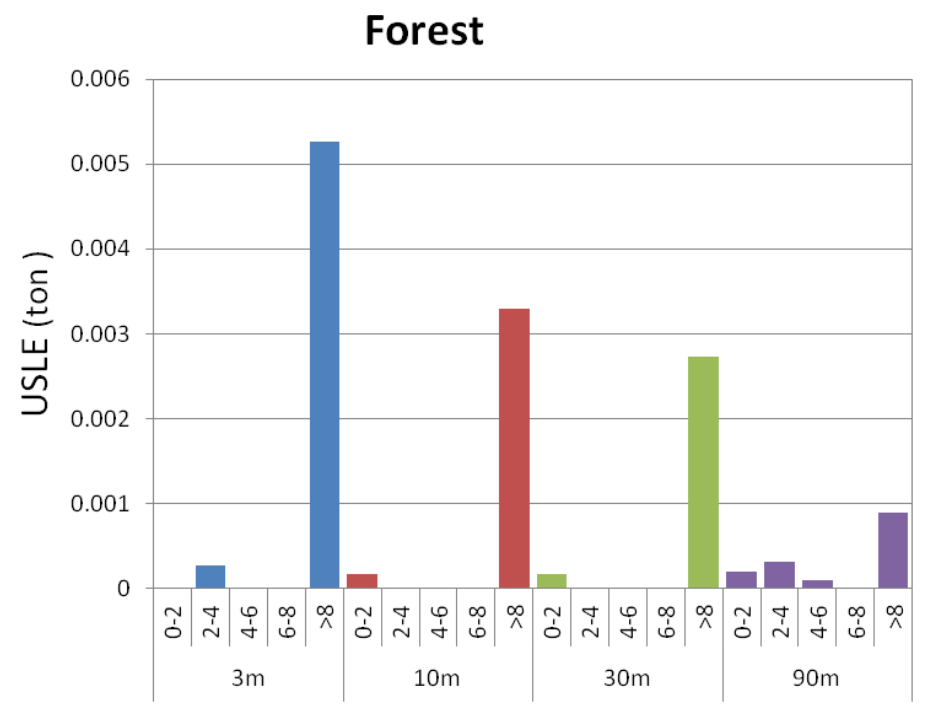
SWAT Output by Land Cover

Note: y-axis scale differs



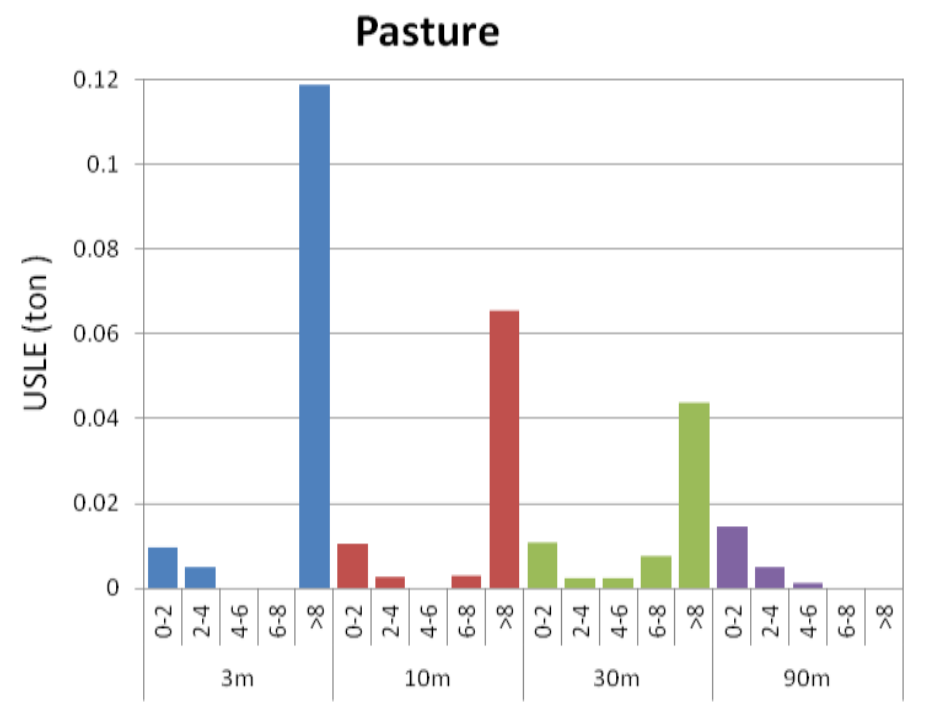
Crop Lands: 2-4% Slope class makes up most of the difference

Crop lands are largest contributor



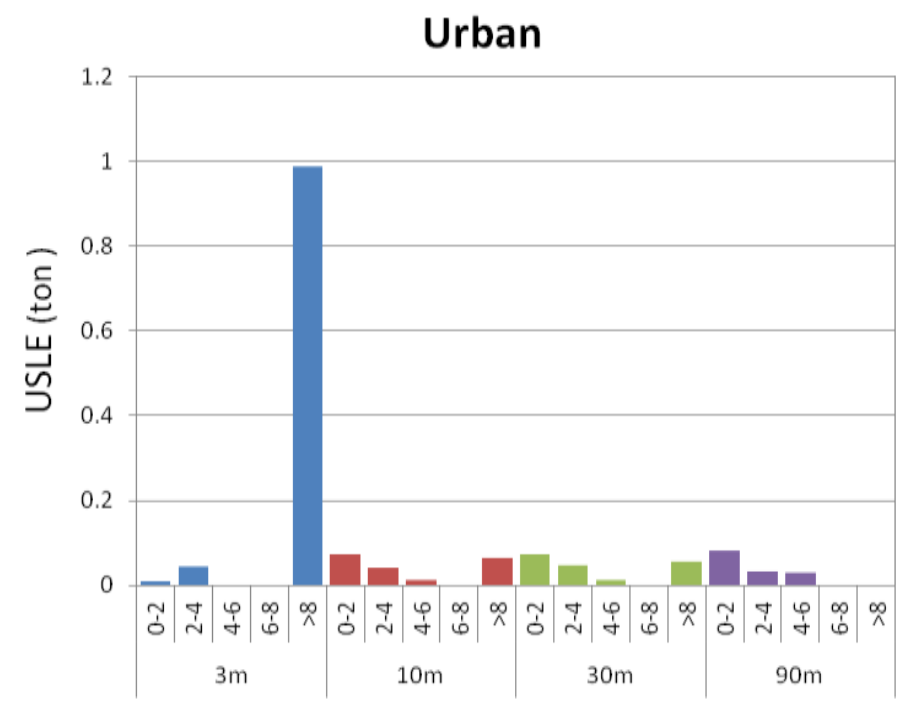
Forest: Area largely higher slopes

Likely areas of higher slope (∴ not cropped)



Pasture: 3 m DEM mostly >8% slope

Possible artifact of ditches and streams



Urban: 3 m DEM mostly >8% slope

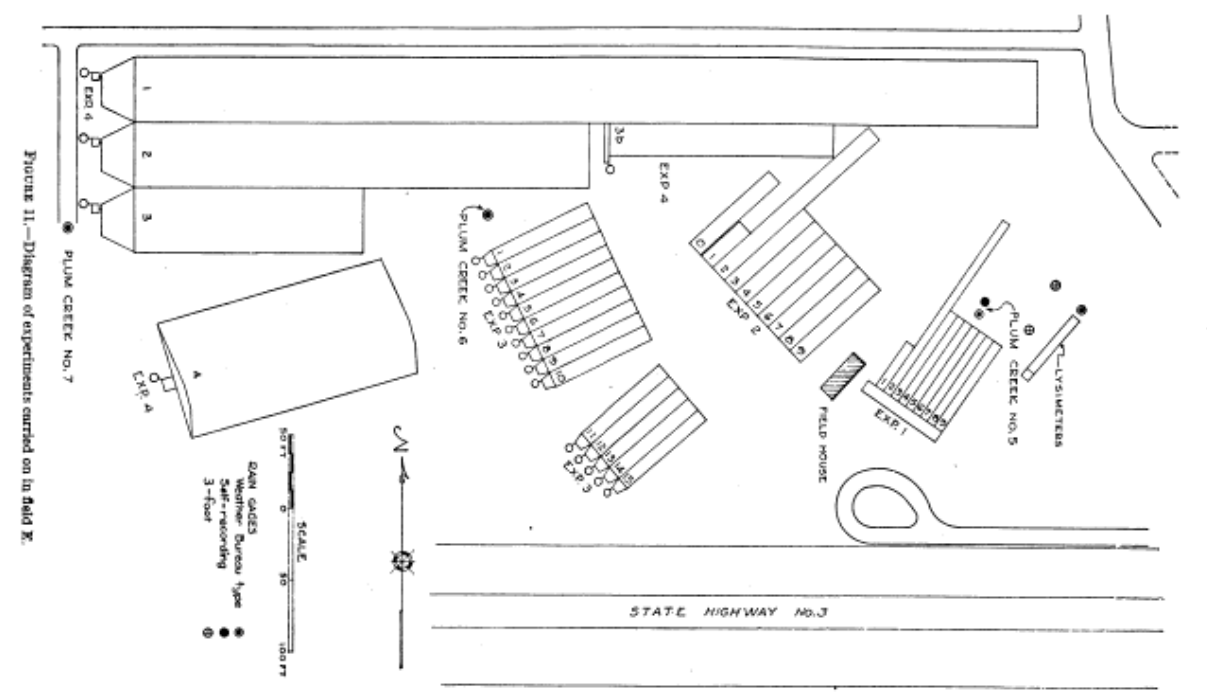
Possible artifact of ditches and streams

Conclusions:

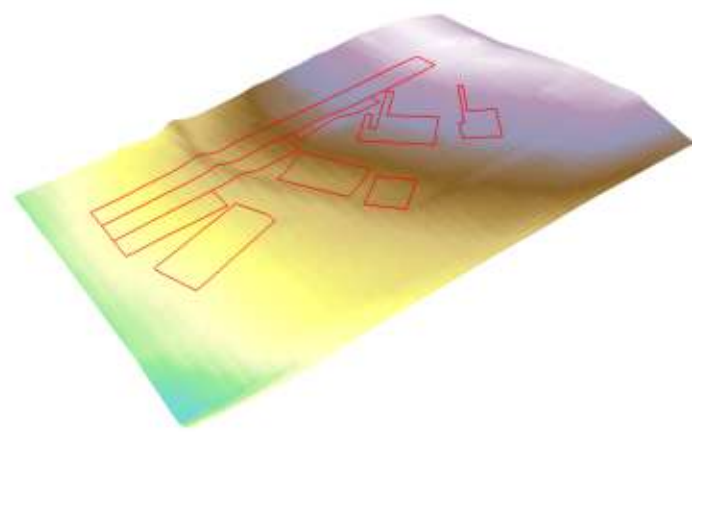
LiDAR offers finer spatial resolution but it is not necessarily appropriate for the parameterization of existing water quality models, since it results in higher slope calculations and shorter slope lengths, which changes the magnitude of sediment loss estimates. Slope is often overlooked as a calibration point since it is seen as a quantitatively measured value, as opposed to a modeled or interpolated value. Depending on the scale of a project it may be appropriate to resample the 3m DEM to 10 or 30 m to match the slope distribution used in the original empirical relationship in the USLE. The influence of DEM scale on model results should be tested in other regions with varying geomorphology.

Future Work:

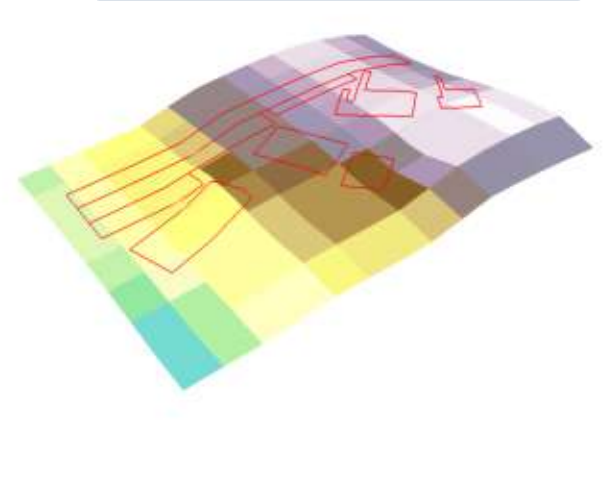
USLE Original Plot with Modern DEM Overlay



3 Meter



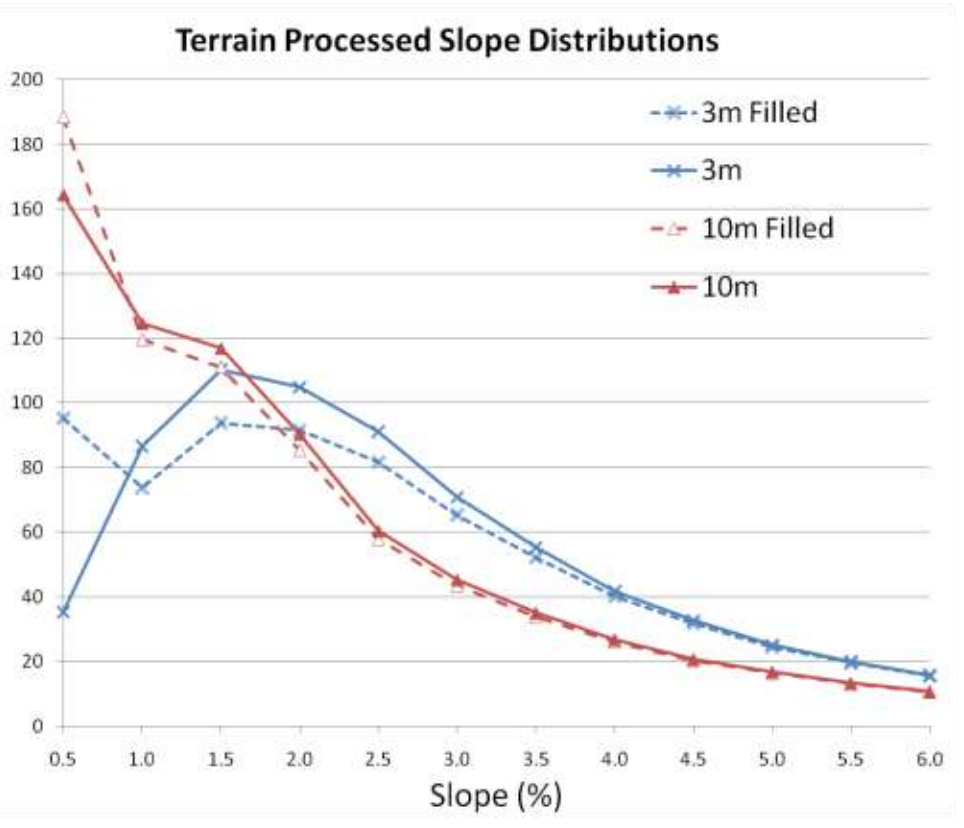
30 Meter



3 m and 30 m DEM average 11% while values reported by Browning et al (1947) average 8.33%

Check other test plots

Effect of "Filling" DEM



"Filling" increases low slopes and slightly decreases higher slopes

Be aware of induced error to grids

Acknowledgements:

Thank you to ARS headquarters for supporting this research and postdoc. And to NASA's Applied Sciences Program and USDA-NRCS for additional funding. We would like to acknowledge Greg Thessen and Brad Parks of USDA-NASS-Iowa Field Office for coordinating surveys and field permissions, Kevin Cole of USDA-ARS-NLAE for collection and processing of hydrologic data, and the enumerators for Hardin County. Most of all, many thanks to our late colleague Dr. Paul Doraiswamy.