MODELING OF HYDROLOGICAL DRAINAGE AND SEDIMENT YIELD PATTERNS IN MARCELLUS SHALE DRILLING REGION USING SWAT AND TOPOGRAPHIC WETNESS INDEX

James Fricke, Bethany Shaffer, Dr. Md. Khalequezzaman, Department of Geology & Physics

LOCK HAVEN UNIVERSITY OF PENNSYLVANIA

ABSTRACT:

With the ongoing Marcellus Shale gas-well drilling activities in central Pennsylvania, Lock Haven University's Water and Soil Resources Lab has partnered with the SRBC to determine if earth disturbances due to Unconventional Natural Gas Development alter the hydrological drainage pattern of surface runoff and sediment yield to the receiving streams. There is an increased concern that sediment yield increases due to development of Marcellus Shale infrastructures and modifications of existing dirt and gravel roads. Two watersheds, namely the Marsh Creek and Baker Run, in Centre and Clinton Counties, PA were selected to assess impacts of Marcellus Shale infrastructures on surface run-off and sediment yield.

The ArcSWAT and TauDEM software were used to model topographic wetness index (TWI), flow accumulation and modification patterns, HRU, and sediment yield patterns. High resolution LiDAR data, land-use raster, and soil data were used to create TWI and HRU for the selected watersheds. The TWI was blended with the digitized earth disturbance features related to Marcellus activities to determine modification in drainage patterns.

The preliminary observations of the TWI indicate modification of the hydrologic drainage patterns due to construction of Marcellus infrastructures. The density of unpaved roads is greater (2.19 km/km^2) in sub-basins that contain Marcellus activities, as compared to the ones without Marcellus activities (0.81 km/km^2 in Baker Run and 0.42 km/km^2 in Marsh Creek). The SWAT model indicates that three out of six sub-basins in Baker Run watershed that contain Marcellus Shale infrastructures are located in areas of high surface discharge, indicating the potential to create high sediment yield to receiving streams. The TWI and SWAT models validate that Marcellus infrastructures pass through topographically wet areas and multiple land-use patterns, some of which are environmentally sensitive.

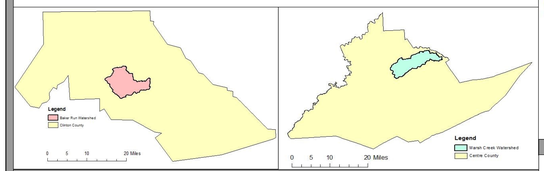


Figure 1: Locations of Baker Run Watershed and Marsh Creek Watershed within Clinton County and Centre County, PA

METHODS:

Topographic Wetness Index (TWI):

TWI was created for both Baker Run and Marsh Creek watersheds using high resolution (1m x 1m)LiDAR LAS data available on the public domain. The LAS datasets were converted to multipoint files using the LAS to Multipoint Tool found in 3D Analyst Toolbox in ArcGIS software. Multipoint files were converted to raster data files using IDW Geoprocessing Tool. TauDEM Toolbox was downloaded from Utah State University. The TauDEM Basic Grid Analysis Tool was used to remove sinks, determine flow directions, and slopes of each watershed using Pit Removal, D-Infinity Flow Directions, and D-Infinity Contributing Area methods. The Raster Calculator was used to calculate the TWI with the equation: ln(Contributing Area/Slope). Marcellus Shale gas well drilling-related infrastructures were identified by comparing NAIP aerial imagery from 2008 and 2013, and were digitized in ArcGIS. TWI layers were overlaid with digitized infrastructures to determine any modifications to surface drainage patterns caused both those infrastructures.

Soil Water Assessment Tool (SWAT):

SWAT was run using ArcGIS Software (ArcSWAT), which requires all layers to be projected into UTM projected coordinate system. The data required to run ArcSWAT analysis include landuse raster, DEM, watershed polygon, soil data, and historic weather data (1980-2010). The landuse and DEM (10m x 10m) raster data were downloaded from Pennsylvania Spatial Data Access (PASDA). The SSURGO (Soil Survey Geographic Database) datasets were downloaded from ESRI SSURGO Downloader. An ArcSWAT model simulation was created for potential output scenarios for surface hydrology, nutrient discharge, and sediment yield patterns.

Field Assessment of TWI:

Several soil samples were collected throughout the watersheds. Soil moisture content was determined in the lab to compare against the TWI values for the respective locations.

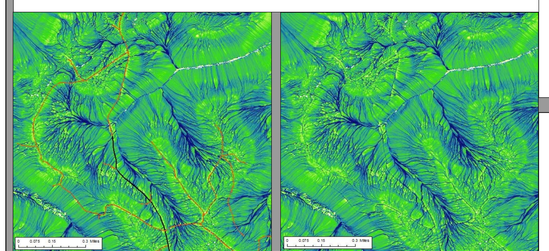
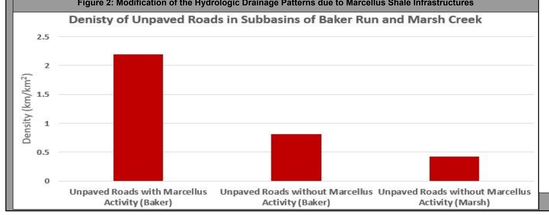


Figure 2: Modification of the Hydrologic Drainage Patterns due to Marcellus Shale Infrastructures



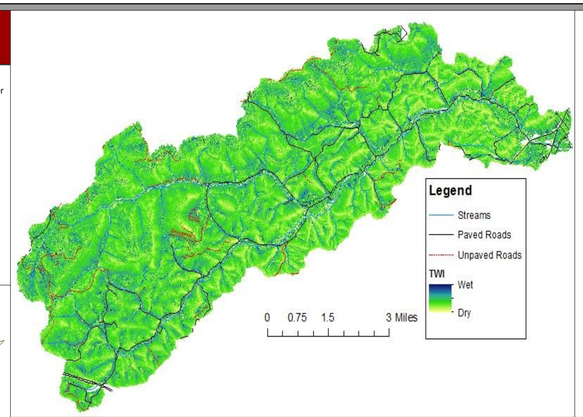


Figure 3: Topographic Wetness Index of Marsh Creek Watershed with Digitized Roads

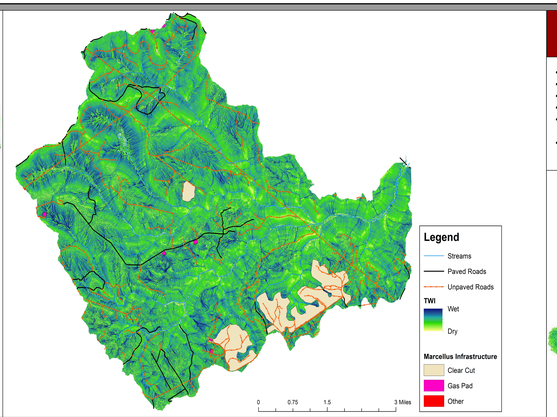


Figure 4: Topographic Wetness Index of Baker Run Watershed with Digitized Marcellus Shale Infrastructure

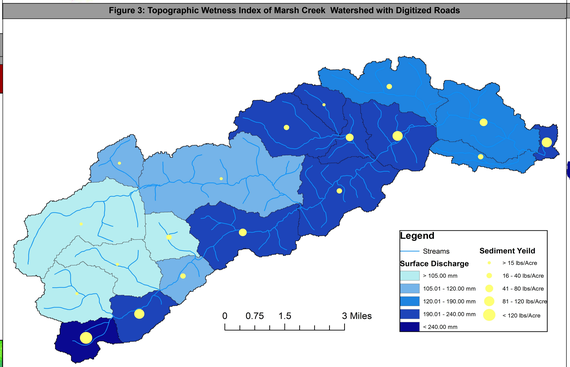


Figure 5: Comparison of Surface Water Discharge and Sediment Yield in Marsh Creek Watershed

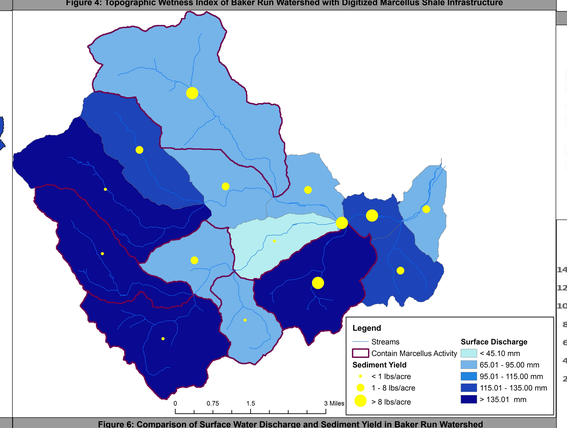


Figure 6: Comparison of Surface Water Discharge and Sediment Yield in Baker Run Watershed

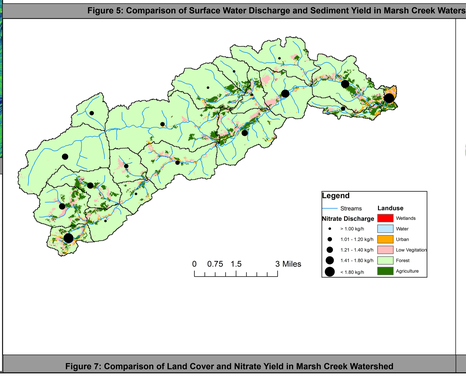


Figure 7: Comparison of Land Cover and Nitrate Yield in Marsh Creek Watershed

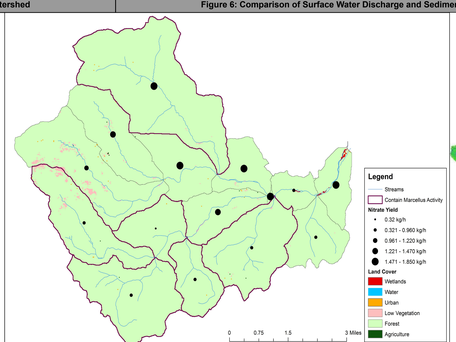


Figure 8: Comparison of Land Cover and Nitrate Yield in Baker Run Watershed

CONCLUSIONS:

- TWI maps reveal surface drainage modification associated with Marcellus Shale related infrastructures.
- Higher density of unpaved roads in Marcellus Shale drilling region implies construction and modification of existing dirt and gravel road infrastructure.
- SWAT simulation models are a useful tool for identifying sub-basins with high surface run-off, nutrient discharge, and sediment yield to receiving streams.
- TWI maps and SWAT simulation models can be used in conjunction to identify topographically wet and environmentally sensitive areas.
- TWI values seem to have no strong relationship to the moisture content of our study area, implying that soil moisture content depends on more variables (e.g. soil composition, porosity, permeability, and landuse) than TWI takes into account.
- ArcSWAT is a useful tool in managing and planning (e.g. BMPs in agriculture and forest areas) various landuse within a watershed.

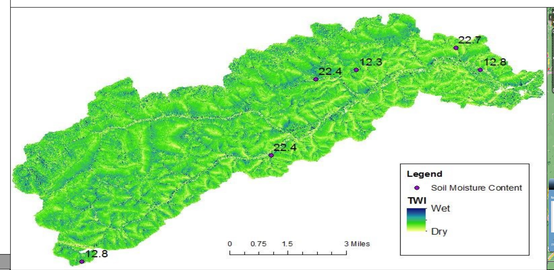
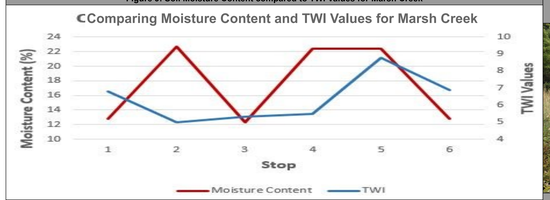
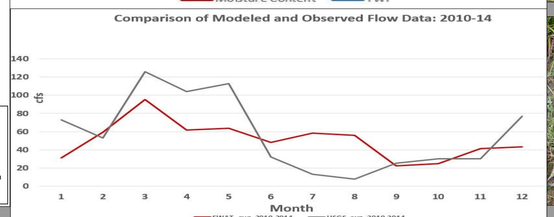


Figure 9: Soil Moisture Content compared to TWI Values for Marsh Creek

EPA Nitrogen and Phosphorus Pollution Data for Marsh Creek



Topographically Dry Area



Topographically Wet Area

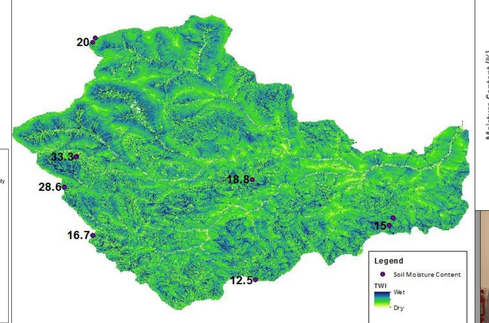
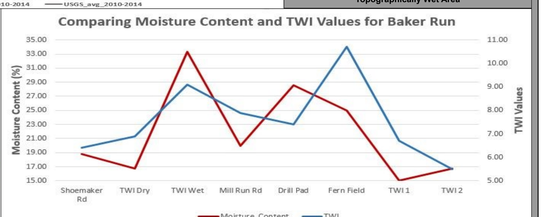


Figure 10: Soil Moisture Content compared to TWI Values for Baker Run



FUTURE REASEARCH:

The outcome of this research project lead us to pursue new research directions. With an external grant from Geisinger Environmental Health Institute (GEHI) we plan on studying geo-chemical signatures of soil and sediments collected from various landuses, which will then be compared against geochemical signatures of the suspended sediment collected from the streams to determine the origin of turbidity in receiving streams.