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Agricultural conservation practices can help mitigate the impact of climate change

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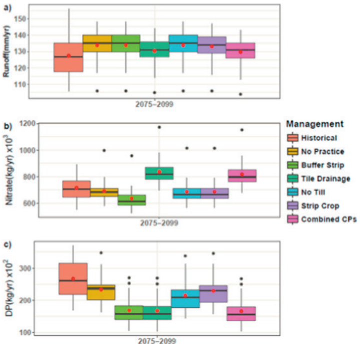
HIGHLIGHTS

- Climate change impacts hydrology, nutrient cycling and erosion potentially degrading water quality
- Agricultural conservation practices can mitigate the impact of climate change on water quality
- Targeting on critical source areas results in nearly the same water quality protection as widespread targeting

GRAPHICAL ABSTRACT

Climate change alters watershed and field level hydrology, nutrient cycling, and erosion.
Agricultural best management practices can mitigate the impact of climate change on water quality.



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ABSTRACT

Agricultural conservation practices (CPs) are commonly implemented to reduce diffuse nutrient pollution. Climate change can complicate the development, implementation, and efficiency of agricultural CPs by altering hydrology, nutrient cycling, and erosion. This research quantifies the impact of climate change on hydrology, nutrient cycling, erosion, and the effectiveness of agricultural CP in the Susquehanna River Basin in the Chesapeake Bay Watershed, USA. We develop, calibrate, and test the Soil and Water Assessment Tool-Variable Source Area (SWAT-VSA) model and select four CPs; buffer strips, strip-cropping, no-till, and tile drainage, to test their effectiveness in reducing climate change impacts on water quality. We force the model with six downscaled global climate models (GCMs) for a historic period (1990–2014) and two future scenario periods (2041–2065 and 2075–2099) and quantify the impact of climate change on hydrology, nitrate-N (NO_3-N), total N (TN), dissolved phosphorus (DP), total phosphorus (TP), and sediment export with and without CPs. We also test prioritizing CP installation on the 30% of agricultural lands that generate the most runoff (e.g., critical source areas-CSAs). Compared against the historical baseline and with no CPs, the ensemble model predictions indicate that climate change results in annual increases in flow (4.5 ± 7.3%), surface runoff (3.5 ± 6.1%), sediment export (28.5 ± 18.2%) and TN export (9.5 ± 5.1%), but decreases in NO_3-N (12 ± 12.8%), DP (14 ± 11.5), and TP (2.5 ± 7.4%) export. When agricultural CPs are simulated most do not appreciably change the water balance, however, tile drainage and strip-cropping decrease surface runoff, sediment export, and DP/TP, while buffer strips reduce N export. Installing CPs on CSAs results in nearly the same level of performance for most practices and most pollutants. These results suggest that climate change will influence the performance of agricultural CPs and that targeting agricultural CPs to CSAs can provide nearly the same level of water quality effects as more widespread adoption.

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1. Introduction

Climate change has the potential to impact hydrology and diffuse nutrient export from agricultural landscapes (Ahmadi et al., 2014; Howarth et al., 2006; Records et al., 2014). In the humid temperate Eastern US, climate predictions suggest that precipitation quantity (during the winter/spring), and intensity (during the growing season) will continue to increase, which cause greater diffuse nutrient and sediment export from agricultural landscapes (Chang et al., 2001; Cousino et al., 2015). This increased export has a number of deleterious consequences for receiving water bodies; accelerated eutrophication, and harmful algal blooms (Burgin and Hamilton, 2007), undesirable changes in the river structure and function, and decreasing storage capacity or flood control of reservoirs (Cerco, 2016; DePhilip and Moberg, 2010). In addition, the loss of valuable nutrients and topsoil from agricultural fields decreases productivity or increases management intensity (Lal, 1998).

Agricultural conservation practices (CPs) are increasingly and widely used to reduce impact of diffuse pollutant export from agricultural landscapes (Ullrich and Volk, 2009). For instance, conservation tillage or no-till, enhances soil organic carbon, soil quality, and soil aggregation leading to less soil erosion in agricultural landscapes (Roldán et al., 2007). CPs such as riparian vegetation, strip-cropping, and buffer strip can all help reduce diffuse pollutants, by reducing inputs to the crop, enhancing sequestration of nutrients in plant tissue, or reducing surface and subsurface losses due to hydrologic pathway alterations (Carpenter et al., 1998). However, it is not clear what impact a changing climate will have on the function of CPs. For instance, increased precipitation volume and intensity may overwhelm many CPs like riparian buffers, but higher temperatures, longer growing seasons, and more rainfall might cause that same buffer to mature more quickly, thus trapping more sediment and sequestering more nutrients. Thus, agricultural conservation practices need to be assessed for performance under a changing climate (Hatfield and Prueger, 2004).

In this study, we assess the effects of climate change on hydrology, water quality, and the effectiveness of agricultural conservation practices in Susquehanna River Basin. The Susquehanna River watershed is the largest source of nutrients and sediment to the Chesapeake Bay estuary and has been the focus of intensive agricultural CP implementation to reduce nutrient and sediment export from agricultural lands. The installation of CPs is largely driven by the U.S. Environmental Protection Agency (USEPA) Total Maximum Daily Load (TMDL) regulation to reduce nutrient and sediment to the Bay by approximately 25%. However, a major uncertainty with respect to CPs in the watershed is the complicating influence of climate change on their function and efficacy. The Susquehanna River basin is already experiencing the impact of a changing climate, with increasing temperatures reducing winter snowpack and increasing winter runoff, and more frequent high -intensity rainfall events mobilizing more sediment (Hayhoe et al., 2007). The predicted changes to climate in the region include continued increases in temperature, anywhere between 1 and 5 °C, dependent on emissions scenarios and season, more precipitation in the winter and spring, primarily as rainfall rather than snowfall, and less rainfall in the late summer and fall (Sheffield et al., 2013).

These changes in precipitation and temperature are likely to alter the timing and magnitude of streamflow and nutrient/sediment production and transport in the watershed. For instance, increased spring nutrient export from the watershed and delivery to estuary can set up conditions that cause particularly acute summer hypoxia (Boesch et al., 2001), and drier conditions in the summer and fall have been shown to increase the buildup of soil nutrients that can subsequently be flushed from the system when wet conditions return (Kaushal et al., 2008; Wetz and Yoskowitz, 2013). Temperature changes can alter nutrient cycling, plant growth, evapotranspiration, and soil water content, which all impact the availability and transport of nutrients from agricultural fields. Thus, CPs designed and installed to handle historic weather conditions may not function as well under a changing climate.

In this paper, we quantify the impact of climate change on agricultural CPs using the Soil and Water Assessment Tool-Variable Source Area (SWAT-VSA) model (Easton et al., 2008). SWAT-VSA is used because it is an existing platform to represent agricultural CPs, can simulate hydrologic and biogeochemical processes that are affected by climate change, and can easily incorporate many common agricultural CPs (Arabi et al., 2008). We analyze the results of each climate model, as well as the ensemble model mean, for their impact on hydrology and water quality with and without four CPs on agricultural lands in the Susquehanna River basin. In an effort to define optimal CP placement in the watershed, we leverage the ability of SWAT-VSA to represent the VSA hydrology that dominates the region and prioritize CP placement on the 30% of the agricultural lands that cause the greatest runoff, nutrient, and sediment losses (e.g., CSAs). The CSA targeting approach could provide a means for watershed managers or conservation personnel to prioritize CP placement across the landscape ultimately lowering costs and increasing water quality improvements.

2. Materials and methods

2.1. Study area description

The Susquehanna River basin contributes >50% of freshwater to the Chesapeake Bay, drains approximately 71,000 km^2, or 42% of the Bay watershed (Ko and Baker, 2004) and it's flow largely controls salinity in the Bay (Gibson and Najjar, 2000). The Susquehanna River Basin encompasses drainage areas in the states of New York, Pennsylvania, and Maryland, has six major sub-basins: Upper, Chemung, Middle, West Branch, Juniata, and Lower subbasins (Fig. 1) with elevations ranging from −10 to 960 m. The climate varies along a north -south gradient, with the northern portion of the basin receiving more precipitation (1240 mm/yr) than the lower basin (838 mm/yr) (DePhilip and Moberg, 2010). The land use of the basin consists of forest (70%), agriculture (22%), developed (7%), and water (1%). Soils are mainly silt loam or silty clay loam (Ray et al., 2016) with soil hydrologic group C ratings dominating, which have a moderately high runoff potential when thoroughly wetted (NRCS, 1998). The northern region of the basin is typified by steep to moderate hillslopes of glacial origins with shallow permeable soils, underlain by a restrictive layer that causes perched water tables to form. Soil depth ranges from <50 cm to >1 m and is underlain by a fragipan restricting layer (e.g. coarse-loamy, mixed, active, mesic, to frigid Typic Fragiudepts, Lytic or Typic Dystrudepts common to glacial tills). The southern region of the basin was never glaciated.

2.2. SWAT model description

The Soil and Water Assessment Tool (SWAT) model is a process-based, semi-distributed watershed model developed to simulate landscape processes and predict the impact of land management practices on water availability and water quality (Arnold et al., 1998). SWAT requires weather, soil, land cover, and land management data to simulate surface and subsurface hydrology and various chemical, nutrient, and sediment fluxes. In SWAT, the watershed is divided in to subbasins and then further in to hydrologic response units (HRUs), which are unique combinations of soil type and land use. SWAT-VSA reconceptualizes the standard SWAT to account for areas of the landscape subject to variable saturation dynamics (Easton et al., 2008). In SWTA-VSA the area of each HRU is defined by the coincidence of land use and wetness index class determined from a Topographic Index (TI) to differentiate areas of the landscape with respect to their moisture storage and saturation index (Easton et al., 2008). SWAT-VSA has been shown to provide better predictions of soil moisture and runoff generation than the standard SWAT model in watersheds with similar physical characteristics and climate to the study watershed (Easton et al., 2008). The version of SWAT-VSA used here also includes modifications to the P