Water Resources Research

COMMENT

10.1002/2015WR018494

This article is a comment on *Gupta et al.* [2015], doi:10.1002/2015WR017323.

**Key Points:**

- Subsurface tile drainage alters water cycle dynamics
- Quantifying the nature of subannual hydrologic change and its cascade to sediment and nutrient transport is essential for management

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**Citation:**
Foufoula-Georgiou, E., P. Belmont, P. Wilcock, K. Gran, J. C. Finlay, P. Kumar, J. A. Czuba, J. Schwenk, and Z. Takbiri (2016), Comment on "Climate and agricultural land use change impacts on streamflow in the upper midwestern United States" by Satish C. Gupta et al., *Water Resour. Res.*, *52*, 7536–7539, doi:10.1002/2015WR018494.

Received 11 DEC 2015
Accepted 18 AUG 2016
Accepted article online 6 SEP 2016
Published online 24 SEP 2016



# Comment on "Climate and agricultural land use change impacts on streamflow in the upper midwestern United States" by Satish C. Gupta et al.

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**Abstract** This comment cautions against dismissing agricultural practices as a significant cause of hydrologic change in Midwestern agricultural landscapes.

In a recent paper, *Gupta et al*. [2015] considered the important issue of quantifying the relative contributions of climate and land use/land cover (LULC) change on the observed hydrologic changes in Midwestern agricultural landscapes. They reached the conclusion that "higher streamflows for most watersheds in the Upper Midwest are mainly due to increased precipitation" (p. 5315), implying that LULC changes exerted minimal effect on the hydrologic response of agricultural landscapes.

Undoubtedly, both climate and land use change are affecting the hydrology of Midwestern agricultural landscapes in complex ways that are not easy to unravel. Higher temperatures have led to earlier snowmelt and a longer growing season [*Walsh et al*., 2014]. Changes in precipitation have been reported in total volumes and in the intensity, duration, and frequency of extreme storms [see, e.g., *Groisman et al*., 2012]. Progressive conversion of wetlands to cultivated land and replacement of small grains with corn and soybean [see, e.g., *Foufoula-Georgiou et al*., 2015, Figure 2; *Lark et al*., 2015] are altering evapotranspiration and water cycle dynamics. Even though the specifics of the expansion and intensification of subsurface agricultural tile drainage have been poorly documented (e.g., as described by *Sugg* [2007]), Gupta et al.'s dismissal of agricultural tile drainage as a significant contributor to changes in hydrologic response is not supported by rigorous analyses and is thus counterproductive [see also *Schilling*, 2016; *Schottler et al*., 2016].

Subsurface tile drainage in low-relief landscapes and poorly drained soils of the agricultural Midwest is installed to increase row-crop production by allowing an earlier planting season and providing favorable soil moisture conditions for crop growth. The flushing of snowmelt and spring rainfall through tiles accelerates the drainage of saturated soils within the root zone and promotes drier soil conditions that benefit farm equipment operation. After planting that typically occurs in April and May, the unsaturated vadose zone augmented by tiles provides favorable conditions for crop growth. Tile drains are most active during March through June before crops have matured, and this contribution of tile discharge to streamflow can be significant especially in smaller watersheds. A recent study concluded that tile discharge accounted for 55% of the annual watershed discharge in a 389 ha subwatershed in Ohio [*Williams et al*., 2015]. During the mid to late summer, increased root uptake and interception by crops prevent tile drainage except in response to large rainfall events. Given the benefits of earlier planting times and enhanced crop growth, the continued installation and expansion of drain tiles calls for careful consideration of their spatial and temporal effects on hydrology.

The critical questions that need to be answered are (1) to what extent and how exactly has climate and LULC change affected the hydrologic response of intensively managed agricultural landscapes; (2) what frequencies and what time scales of the hydrologic response have been most affected; (3) when during the year is each of the causes of change dominant; and finally, (4) what are the environmental, ecological, and socioeconomic consequences of hydrologic change? Answering these questions is critical for informing management actions that ensure agricultural productivity while also protecting the environmental integrity of these landscapes.

Gupta et al. analyzed only annual volumes (not daily, or event-scale, or seasonal streamflows). Using the premise that a change in how the watershed converts precipitation to streamflow would be reflected in a change of the relationship between annual Q and annual P they used linear regressions (of lnQ to P) to establish that this relationship (their Model 2) has significantly changed post-1975, implying LULC effects, in only 10 out of 29 analyzed watersheds in Iowa and Minnesota (although change was documented in five out of eight watersheds in the intensively agricultural Minnesota River Basin (MRB)—see their Tables 1 and 2 for the watersheds that had intercepts significantly different at the 5% level. This led them to conclude that in most watersheds the observed streamflow changes are driven by climate change and not LULC. Such an analysis (even ignoring its lack of robustness documented in *Belmont et al*. [2016] is diverting efforts away from understanding hydrologic changes of relevance to environmental consequences and is counterproductive in integrating scientific knowledge into decision making.

We note that one of the unsubstantiated arguments by Gupta et al. is that increased volume and event-based streamflow in the growing season of May–June despite the absence of increased precipitation during that period of time is due to carry-over of soil moisture from previous seasons and previous years. This unfounded claim contradicts the very premise of subsurface tile drainage and is also inconsistent with the documented increase in base flow due to LULC [see *Schilling*, 2016, and references therein]. Although soil moisture data are not available to disprove the assertion of carry-over and long-term memory of soil moisture, we note that Gupta et al.'s Figure 5 (albeit produced from a single field station in the MRB) is inconsistent with the carry-over hypothesis as it shows that the monthly average available soil moisture in the month of June is the same before and after LULC change, so soil water carry-over from fall to spring (indicating a possible interseasonal climate-related effect) is not the likely cause of the observed increasing daily streamflows in June.

As part of an NSF-funded Water Sustainability and Climate interdisciplinary project focused in the predominantly agricultural MRB (a 44,000 km$^2$ basin included in the Gupta et al.'s study area), we have begun a comprehensive effort aimed at quantifying the hydrologic changes and the cascade of these changes from hydrology to sediment production and transport, to nutrient and phosphorous cycling, to river ecology [e.g., *Foufoula-Georgiou et al*., 2015; *Schaffrath et al*., 2015; *Hansen et al*., 2016]. In terms of hydrologic change, our analysis of daily streamflow has clearly demonstrated the effects of LULC on the daily hydrologic response. Specifically, we have shown that during the growing season of May–June (where precipitation change has been minimal and thus one can isolate the climatic and LULC signatures [see *Foufoula-Georgiou et al*., 2015, Figure 5]) LULC has (1) strengthened the dependence between daily precipitation and the rising limb of the daily hydrograph, illustrating a tighter coupling between precipitation and conversion to streamflow, (2) changed the nature of the falling limbs of the daily hydrographs, with increased variability of daily streamflow decrements in the absence of previous day precipitation, illustrating a more "punctuated" hydrograph recession, and (3) most drastically affected the rainfall-runoff relationship at intermediate frequencies.

The postglacial geomorphic history of the MRB makes it especially vulnerable to an intensified hydrology, especially at the event scale, as for example the streamflow changes reported in *Novotny and Stefan* [2007] and *Dadaser-Celik and Stefan* [2009]. Catastrophic postglacial incision of the main stem Minnesota River Valley has caused Minnesota River tributaries to be among the fastest incising rivers in the world over the Holocene [*Gran et al*., 2013], characterized by steep knick zones and tall, actively eroding bluffs [*Day et al*., 2013a, 2013b]. Indeed, recent studies have clearly documented an increased near-channel sediment production [*Belmont et al*., 2011] and stream morphologic changes such as channel widening [*Lenhart et al*., 2013; *Schottler et al*., 2014]. At the same time, a decline in macroinvertebrates, sensitive fish species, and native mussels has also been reported [*Kirsch et al*., 1985; *Musser et al*., 2009] in Minnesota streams. These changes have impaired 336 river reaches in the MRB under the Clean Water Act for excessive sediment and nutrients as well as degraded aquatic life [*Carlisle et al*., 2011]. This alarming fact is one reason the State of Minnesota passed an amendment to the Minnesota constitution (the Clean Water, Land, and Legacy Amendment) that increases the state sales tax during 2009–2034 with a portion of this revenue devoted to protecting, enhancing, and restoring water quality in lakes, rivers, and streams [*Minnesota's Clean Water*

*Roadmap*, 2014; *Legislative Coordinating Commission*, 2015]. Over half a billion dollars have already been appropriated from the Clean Water Fund during 2009–2015 and several billion dollars will still be spent by 2034. It is imperative and urgent to ensure that the best available science guides management decisions towards sustainable solutions, respecting both the environment and regional economics.

We hope that this comment will serve as an impetus for increased effort in getting to the heart of the difficult problem of partitioning and attributing the effect of climate and LULC changes on the hydrologic and environmental changes observed in Midwestern agricultural landscapes. Particularly, as legislators and watershed managers seek to improve water quality, they need reliable, innovative and sensible answers from the scientific community now more than ever towards developing solutions for economic prosperity and environmental sustainability.

## Appendix A

Prompted by the reply to our comment, we add the following clarification. *Novotny and Stefan* [2007] is cited as providing evidence that "increased streamflow in the upper Midwestern United States is mainly due to increased precipitation in recent years." Quoting directly from *Novotny and Stefan* [2007, p. 331]: "Precipitation is a significant but most likely not the only cause of streamflow changes in Minnesota. Land use changes (e.g., urbanization or agricultural drainage) may have contributed to the trends. To gauge the influence of these factors additional studies would be required." Specifically, for the Minnesota River Basin (MRB) follow-up work by these authors concluded that "Over the five river basins analyzed, the Minnesota River Basin has experienced the largest streamflow changes compared to the other four basins. The likely cause of these changes is not only the change in precipitation (climate) but also the change in agricultural practices" [*Dadaser-Celik and Stefan*, 2009, p. 89; H. Stefan, personal communication, 2016].

**Acknowledgment**
This research was funded by NSF grant EAR-1209402 under the Water Sustainability and Climate Program.

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