Long-term temporal variation of nitrate concentration-stream discharge (C-Q) relationship for an agricultural watershed in Midwest USA

Wenlong Liu (wliu4@ncsu.edu) *, Shiyong Tian, Mohamed Youssef, Francois Birgand, George Chescheir

* North Carolina State University, Biological and Agricultural Engineering, Raleigh, North Carolina United States.

Introduction

• Nutrients export from agricultural watersheds have long been recognized as a critical cause of eutrophication in receiving surface water bodies.
• Since 1970s, many changes have occurred in intensively managed, agricultural watersheds in U.S., including increased weather extremes, enhanced artificial drainage, timing and rate of fertilizer applications, and implementation of conservation tillage practices.
• Nutrient concentration – discharge relationship (C-Q relationship) can identify periods and locations influencing the change in nutrient export in stream discharge, which could help infer the relationship between observed changes in nutrient export to factors that cause these changes.
• We hypothesize that the long-term pattern of C-Q relationship would change in response to changes in climate, land use, and management practices that happened over the past 40 years.
• To test the hypothesis, we analyzed the long-term variation of nitrate C-Q relationship in an agricultural watershed in Ohio across different time scales, using a dataset of relatively high-frequency measurements of stream flow and nitrate concentrations.

Watershed description

• Honey Creek Watershed, Ohio, U.S.
• Land use: 84% of agricultural and 10% of forest.
• 90% of soil is classified as poorly drained.
• Data were provided by the Ohio Tributary Monitoring program that is operated by the National Center for Water Quality Research at Heidelberg University.
• Measured stream flow data USGS station 04197100 from Jan 1976 to April 2017 was used in this study.
• Nitrate concentration was based on 21,191 water quality samples.
• Water quality samples were taken at least once per day and three or four samples per day during storm events.

Composite C-Q relationship

• Power equation:
  \[ C = aQ^b \] (log C = log a + b(log Q) )
  \( b \to 0.1 \text{ flushing} \)
  \( b \to 0.1 \text{ Chemostatic} \)
  \( b \to 0.1 \text{ Dilution} \)

• Slope (b) represents the chemo-dynamics of C-Q relationship

• Weighted Regressions on Time, Discharge and Season (WRTDS)
  \[ \ln(C) = P_0 + P_1t + P_2 \ln(Q) + P_3 \sin(2\pi t) + P_4 \cos(2\pi t) + e \]
  \( P_3 \) as an indicator of C-Q relationship (similar to slope).

• Decompose overall C-Q relationship into different years, discharge ranges and seasons.

Metrics to characterize hysteresis patterns

• Hysteresis Index (HI):
  - Quantifies the direction and strength of hysteresis loop.
  - HI > 0 clockwise loop
  - HI < 0 anti-clockwise loop
  - Flushing Index (FI):
    - Quantifies the concentration or dilution of nitrate at the rising limb.
    - FI > 0 Nitrate flushing during events
    - FI < 0 Nitrate dilution during events

Preliminary results and discussion

• Long-term inter-annual pattern of C-Q relationship:
  - Relatively stable at decadal scales.
  - No significant change in storm hysteresis patterns at decadal scales.
  - 75% of nitrate export contributed by flow greater than 5 m³/s.

• Long-term inner-annual variation of C-Q relationship:
  - Significant seasonality in long-term C-Q relationship.
  - Shifted seasonality observed in composite C-Q relationship.
  - Possibly caused by changed fertilizer timing.
  - Timing: Fall to late spring.

Results and discussion Cont’d

• Insights from the seasonality of C-Q relationship:
  - Take corn as an example.
  - Primarily driven by climatically conditions and agricultural activities.
  - Spring to early summer is the most vulnerable period.
  - Adapted fertilizer timing and types changed the seasonal patterns of C-Q relationship.

Summary

• Long-term C-Q relationship remained relatively stable during the observation period, primarily due to enhanced artificial drainage and increased fertilization quantity.
• Seasonal pattern of C-Q relationship indicated that late spring to early summer is the most sensitive period for nitrate export.
• Seasonal pattern shifted due to adaptation of fertilizer management.

Acknowledgement

The valuable long-term daily water quality data were provided by the Ohio Tributary Monitoring program that is operated by the National Center for Water Quality Research at Heidelberg University.