TOTAL SUSPENDED SEDIMENT AND PHOSPHORUS TRANSPORT IN RESPONSE TO STORM EVENTS IN AN AGRICULTURALLY DOMINATED WATERSHED

By: Elijah Schukow, Dr. Eric Peterson, Dr. Catherine O'Reilly, Dr. William Perry, Jack Wang

DEPARTMENT OF GEOGRAPHY, GEOLOGY, AND THE ENVIRONMENT
Illinois State University

ILLINOIS STATE REDBIRDS

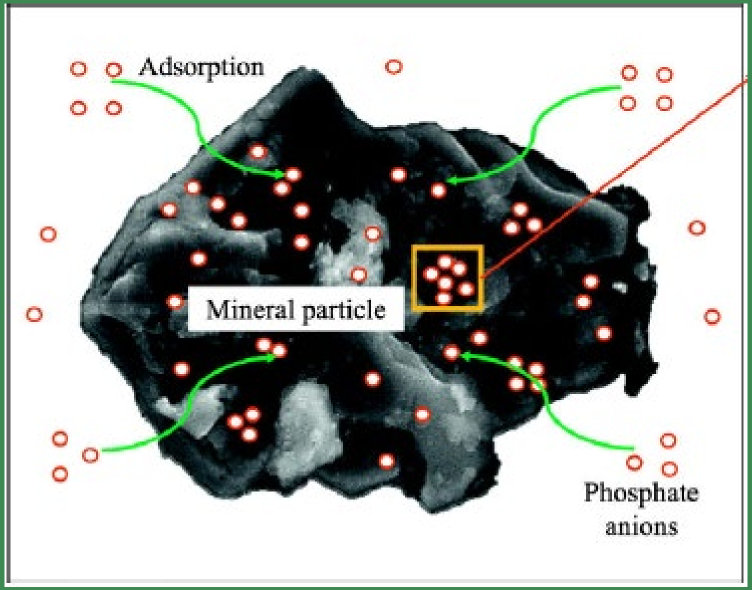
What's The Big Deal?

- Increased sediment and nutrient introduction and transport in streams have a large impact on water quality and ecological diversity
- Phosphorus
  - Excess amounts drive algal blooms (Dead Zones)

Displays the algal bloom in Lake Erie in 2017 (National Oceanic And Atmospheric Administration)

Sediment and Phosphorus Sources and Behaviors

- Turbidity
  - Turbidity can be used as an indicator for water quality and an estimate on TSS in the water
- Phosphorus comes in two forms
  - PP
  - DRP



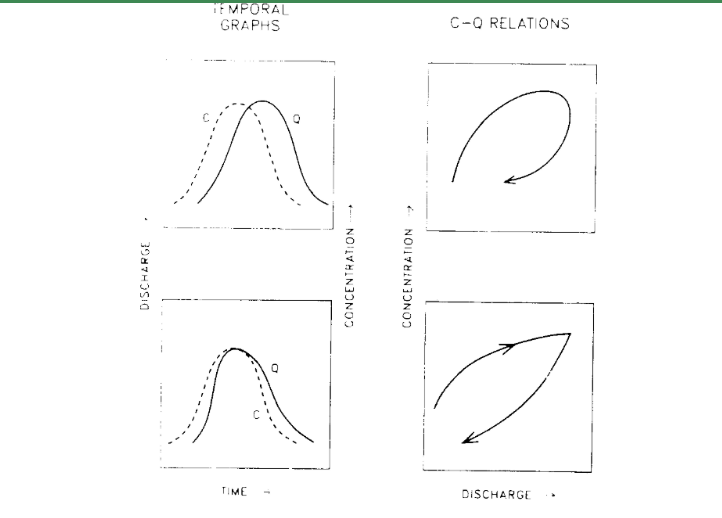
Fang et. al., 2017

Six Mile Creek "Clear Water"

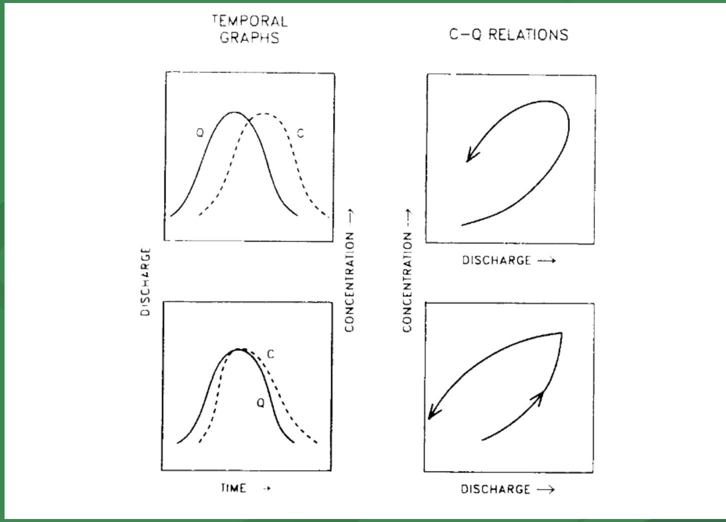
Six Mile Creek "Turbid Water"

Hysteresis Patterns

- A way to gain understanding
- What is hysteresis?
- These relationships can be separated into 3 classes:
  1. Figure eight
  2. **Clockwise loop**
  3. **Counterclockwise loop**



Williams 1989



Williams 1989

Hysteresis Index (HI)

$$HI = C_{RL} - C_{FL}$$

Averaged HI can then be used to describe each hysteresis event

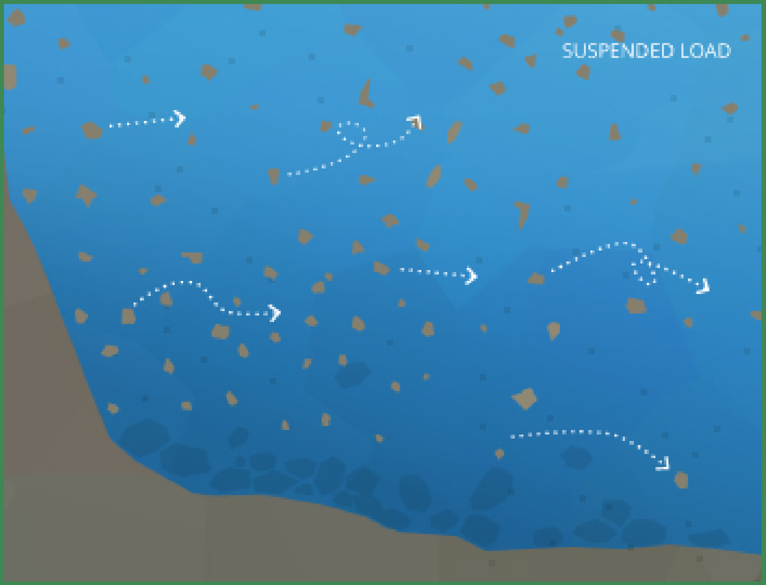
Flushing Index (FI)

$$FI = C_{Qpeaknorm} - C_{initialnorm}$$

Describes the slope or gradient of the loops

Research Questions

1) Do turbidity and total phosphorus follow similar transport behaviors in the same watershed?
   a. Is the flushing index (FI) and hysteresis index (HI) observed during storm events among turbidity and discharge, and total phosphorus and discharge similar?
   b. How do the flushing index (FI) and the hysteresis index (HI) values compare between season?

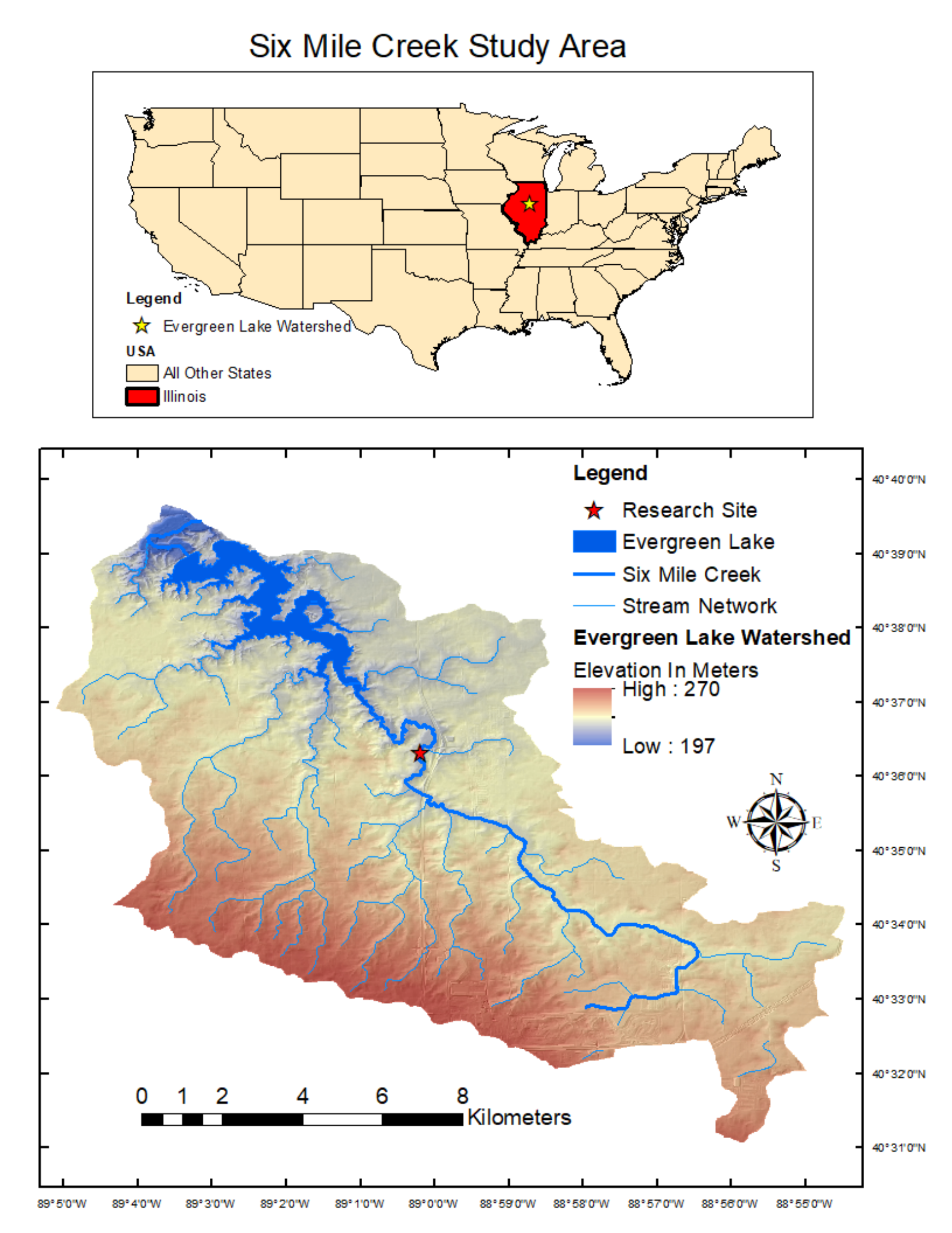


Fondriest Environmental, Inc.

https://taurus.ag

Study Site

- This study will take focus on Six Mile Creek (SMC) and its watershed
  - Part of Evergreen Lake watershed
  - Located McLean County Illinois
  - 106.5 Km^2 in size
  - Land usage is agricultural and grass land (87% row crops)
  - Sampling station is 0.8 km upstream from Evergreen Lake
- Data availability
  - April 2016 – January 2019
  - Turbidity, discharge, and total phosphorus data is available

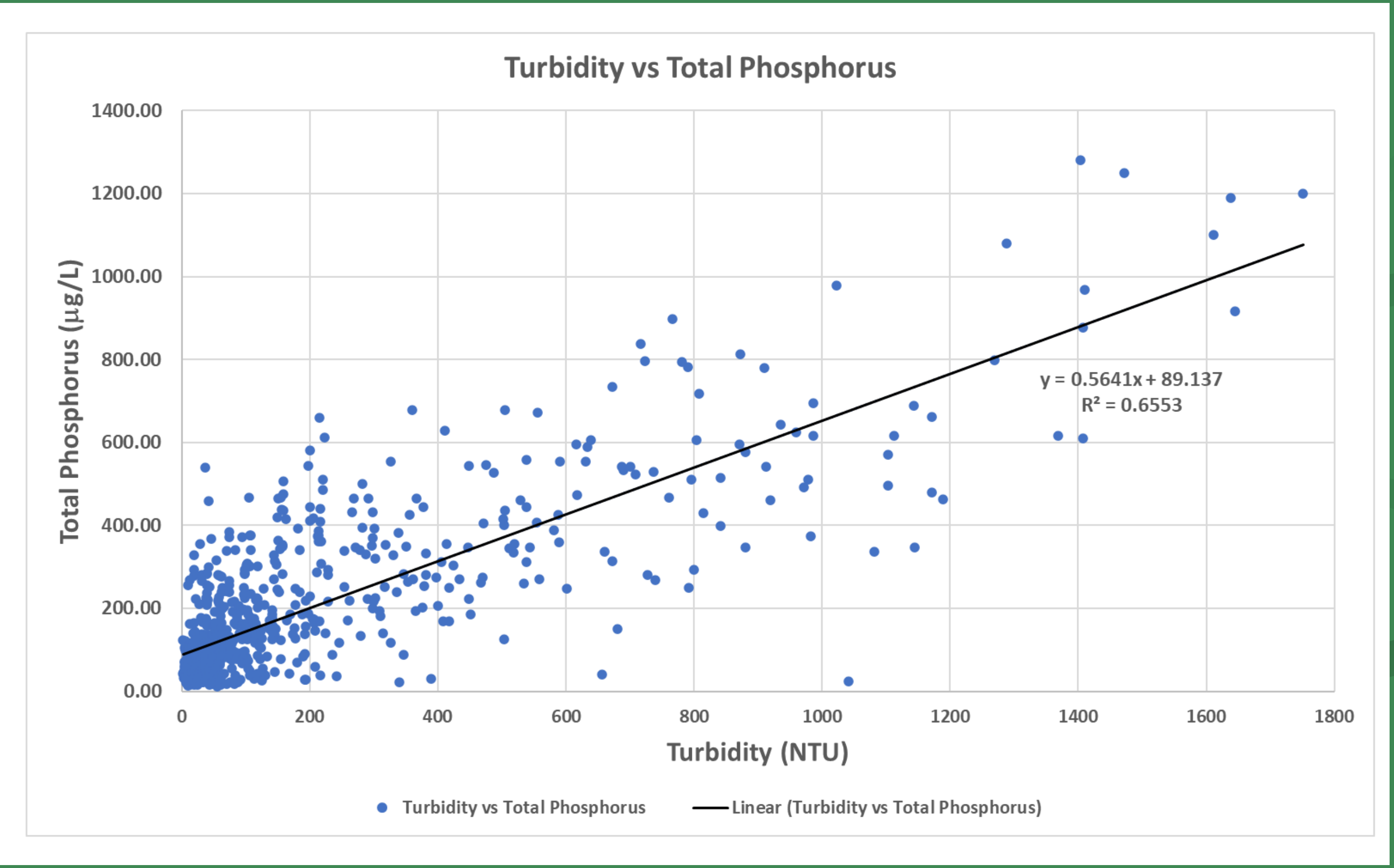


Methods

- SMC study site collected 15-min interval data for turbidity and discharge during the study period
- Water samples collected from automated sampler were analyzed for their nutrient and major ion concentrations (Not at 15-min interval)
- Data available was normalized to allow comparison among storm events for both small- and large-scale storms
  - $Normalized\ Qi\ = \frac{Qi - Qmin}{Qmax - Qmin}$
  - $Normalized\ Ci\ = \frac{Ci - Cmin}{Cmax - Cmin}$
- Normalized variables were then plotted vs time and concentrations vs discharge to identify hysteresis patterns for each storm event

Correlations Among Variables

- For the duration of the study period, 791 data points for both turbidity and total phosphorus were available
- The correlation between these variables was found to have an overall R^2 value of 0.66 and a r value of 0.81
- Classified as a strongly positive correlation



Linear Model

- Based on the correlations between the variables a linear model for total phosphorus was generated in RStudio

- The model was created to generate high frequency 15-minute interval data for the total phosphorus variable
  - This allows for more detailed hysteresis patterns to be generated

- The total phosphorus model used the independent variables turbidity and discharge to predict total phosphorus concentration

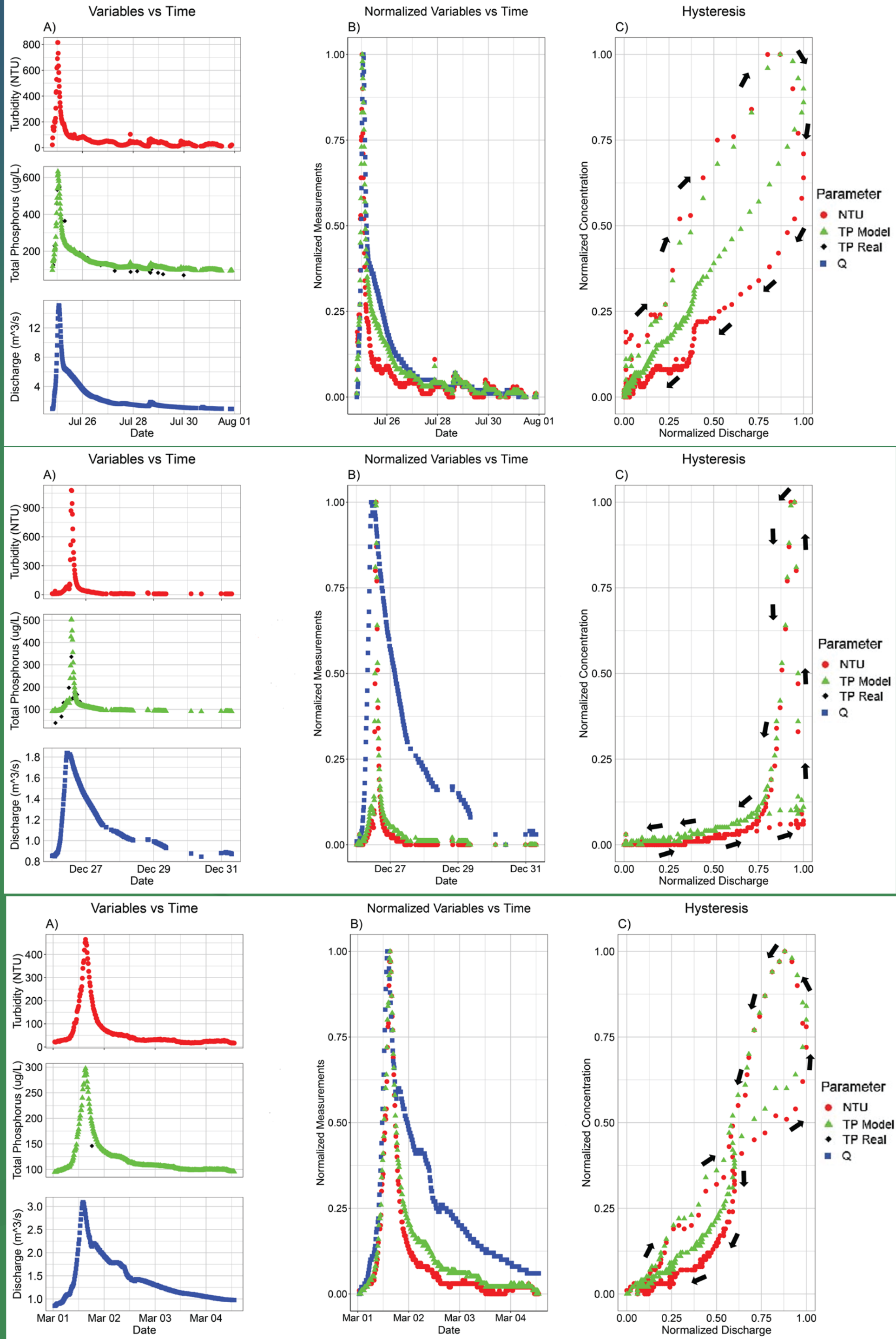
- The model produced an $R^2 = 0.73$ and a standard error of 78.02 μg/L
  - $TP\ \frac{\mu g}{L} = 0.369 * Turbidity\ (NTU) + 19.62 * Discharge\ \left(\frac{m^3}{s}\right) + 70.25$

Hysteresis Patterns Observed

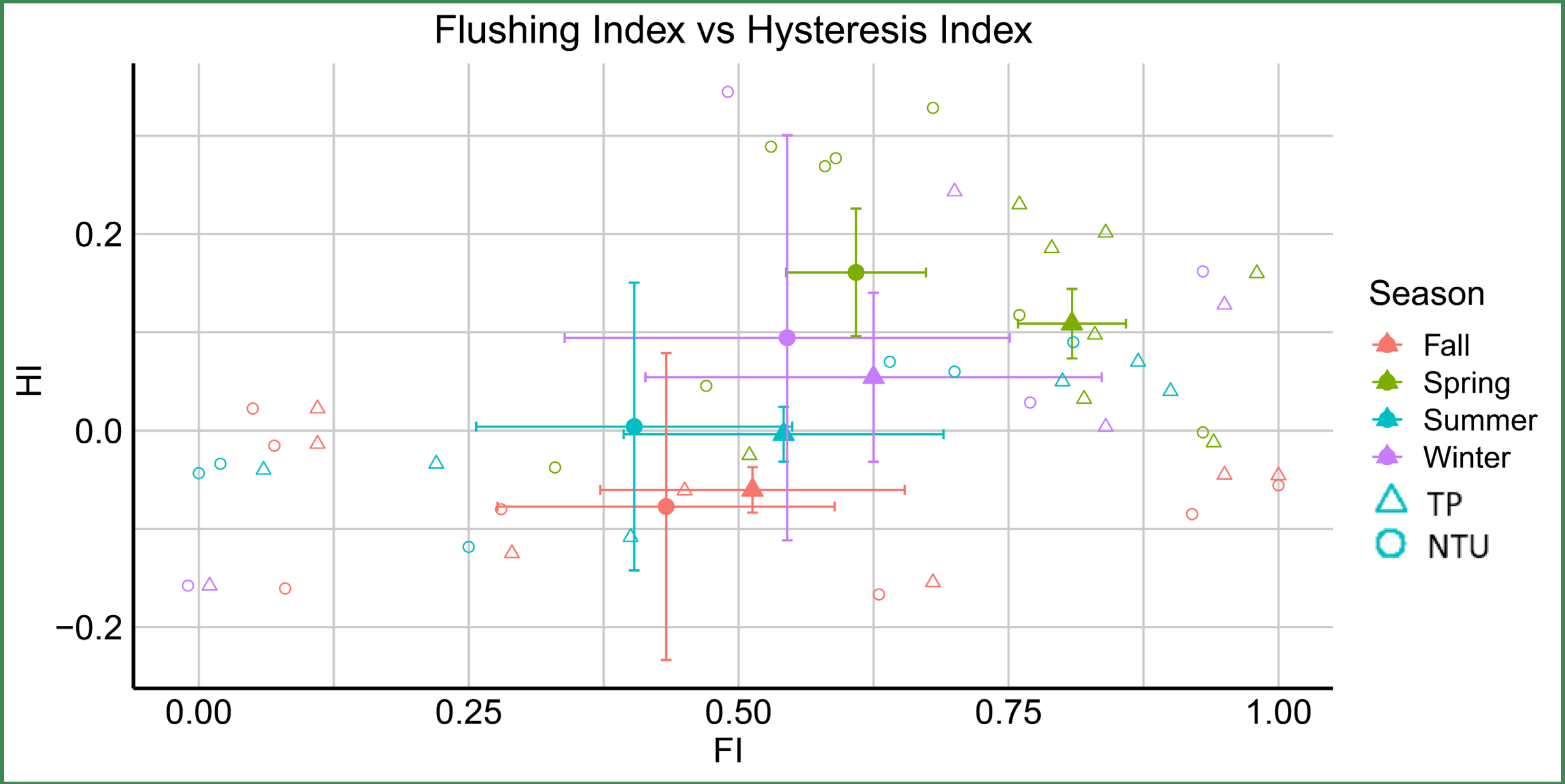
- The figures on the right represent examples of some of the most common types of hysteresis patterns observed for this study

- A) Displays the variables, turbidity, total phosphorus, and discharge over the duration of the storm
- B) Displays the normalized variables over the duration of the storm
- C) Displays the hysteresis pattern observed when the normalized total phosphorus and turbidity are plotted against normalized discharge

- From top down: (ID 10) Clockwise hysteresis pattern, (ID 21) Counterclockwise hysteresis pattern, (ID 44) Counterclockwise figure-eight hysteresis pattern



HI and FI Comparisons Cont.



- Patterns in HI and FI behavior was represented by season
- Patterns in HI indicate that the variables NTU and TP are from proximal or in stream sources during the Spring and Winter and are from distal or up stream sources in the Summer and Fall
- FI was always positive except for one occasion suggesting a concentrating effect and both NTU and TP being flushed into the system at the SMC Watershed

Conclusion

- Overall, the HI values and FI values observed during storm events among turbidity and discharge and among total phosphorus and discharge were behaving similarly across seasons
  - Due to this relationship if we can better understand and monitor sediment transport this could be used to handle total phosphorus transport as well.
- More positive HI values observed in the Spring and Winter and more negative HI values observed in the Summer and fall could be driven by:
  - There is a greater tile drainage influence during these seasons Spring and Winter causing the concentration variables to peak before discharge
  - And a lower tile drainage influence taking place during the Summer and Fall causing the influx of sediments and nutrients to be delayed in the SMC Watershed
- High frequency data is this key aspect when looking into these relationships. Even though we had 15-min interval data available for turbidity and discharge a linear model was needed to handle total phosphorus
  - Ultimately having a sensor in the stream that also capture high frequency nutrient data at 15 minutes or even higher intervals could be a great step moving forward with this research.

Acknowledgements

- I would like to thank and acknowledge
  - City of Bloomington Joe Darter, Jill Mayes, Rick Twait
  - LEA Lab, and all students involved in data collection for this project before myself

References

- Allan, J. D., & Castillo, M. M. (2007). *Stream ecology: Structure and function of running waters*. Dordrecht: Springer.
- Borah, D K, M Bera, and S Shaw. 2003. "Water, Sediment, Nutrient, And Pesticide Measurements in An Agricultural Watershed IN Illinois During Storm Events." 46(3): 657–74.
- Bowes, Michael J., William A. House, and Robin A. Hodgkinson. 2003. "Phosphorus Dynamics along a River Continuum." *Science of the Total Environment* 313(1–3): 199–212.
- Bowes, Michael J., William A. House, Robin A. Hodgkinson, and David V. Leach. 2005. "Phosphorus-Discharge Hysteresis during Storm Events along a River Catchment: The River Swale, UK." *Water Research* 39(5): 751–62.
- Bowes, M. J. et al. 2015. "Characterising Phosphorus and Nitrate Inputs to a Rural River Using High-Frequency Concentration-Flow Relationships." *Science of the Total Environment* 511: 608–20.
- Dinnes, Dana L. et al. 2002. "Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils." *Agronomy Journal* 94(1): 153–71.
- Fernandez, C., J. Q. Wu, D. K. McCool, and C. O. Stöckle. 2003. "Estimating Water Erosion and Sediment Yield with GIS, RUSLE, and SEDD." *Journal of Soil and Water Conservation* 58(3): 128–36.
- Fondriest Environmental, Inc. "Turbidity, Total Suspended Solids and Water Clarity." Fundamentals of Environmental Measurements. 13 Jun. 2014. Web. < https://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/ >.
- Garnett Williams. 1989. "Sediment Concentration Versus Water Discharge During Single Event.Pdf." *Journal of Hydrology* 111: 89–106. https://www.sciencedirect.com/science/article/pii/0022169489902540.
- Gentry, L. E. et al. 2007. "Phosphorus Transport Pathways to Streams in Tile-Drained Agricultural Watersheds." *Journal of Environmental Quality* 36(2): 408–15.

References continued

- House, W. A. et al. 1998. "Reactions of Phosphorus with Sediments in Fresh and Marine Waters." *Soil Use and Management* 14(s4): 139–46.
- Hanna, Laura A. 2013. "Dissolved and Suspended Sediment Transport Dynamics in Two Agriculturally Dominated Watersheds, Mclean County, Illinois." (August). https://my.ilstu.edu/~ewpeter/theses/Hanna_2013.pdf.
- Kronvang, Brian, Anker Laubel, and Ruth Grant. 1997. "Suspended Sediment and Particulate Phosphorus Transport and Delivery Pathways in an Arable Catchment, Gelbæk Stream, Denmark." *Hydrological Processes* 11(6): 627–42.
- Lake Bloomington Watershed Plan, Lake Bloomington Watershed Planning Committee, June 22, 2008.Bloomington, IL
- Lloyd, C. E.M., J. E. Freer, P. J. Johnes, and A. L. Collins. 2016. "Using Hysteresis Analysis of High-Resolution Water Quality Monitoring Data, Including Uncertainty, to Infer Controls on Nutrient and Sediment Transfer in Catchments." *Science of the Total Environment* 543: 388–404. http://dx.doi.org/10.1016/j.scitotenv.2015.11.028.
- Lloyd, C. E.M., J. E. Freer, P. J. Johnes, and A. L. Collins. 2016. "Technical Note: Testing an Improved Index for Analysing Storm Discharge-Concentration Hysteresis." *Hydrology and Earth System Sciences* 20(2): 625–32.
- Mastrocicco, M. et al. 2014. "Modelling Groundwater Residence Time in a Sub-Irrigated Buffer Zone." *Ecohydrology* 7(3): 1054–63.
- Rabalais, N.N., Turner, R.E., and Wiseman, W.J., 2002, Gulf of Mexico hypoxia, a.k.a. "The dead zone": Annual Review of Ecology and Systematics, v. 33, p. 235–263, doi:10.1146/annurev.ecolsys.33.010802.150513.
- Schilling, Keith E. et al. 2020. "Total Phosphorus Export from Iowa Agricultural Watersheds: Quantifying the Scope and Scale of a Regional Condition." *Journal of Hydrology* 581(November 2019): 124397. https://doi.org/10.1016/j.jhydrol.2019.124397.
- Vaughan, M. C. H., Bowden, W. B., Shanley, J. B., Vermilyea, A., Sleeper, R., Gold, A. J., … Schroth, A. W. (2017). *High-frequency dissolved organic carbon and nitrate measurements reveal differences in storm hysteresis and loading in relation to land cover and seasonality. Water Resources Research, 53(7), 5345–5363*. doi:10.1002/2017wr020
- https://www.fondriest.com/environmental-measurements/parameters/hydrology/sediment-transport-deposition/
- https://taurus.ag/importance-of-phosphorus-to-crops/
- https://socratic.org/questions/what-is-the-definition-of-the-phosphorus-cycle
- https://www.noaa.gov/media-release/noaa-partners-predict-large-summer-harmful-algal-bloom-for-western-lake-erie

- Thank you for watching and listening to this presentation!

- Any Questions??