Extreme Weather at the Watershed Scale:
How to Protect Water Quality
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**Key Premise**

Human Landuse Change – current & past, has ENHANCED SUPPLY OF NUTRIENTS & POLLUTANTS

Extreme weather events, particularly large storms will provide INCREASED TRANSPORT CAPACITY

= LARGE EXPORTS OF NUTRIENTS & POLLUTANTS

Detrimental consequences for aquatic ecosystems;

Need for Innovative management
Outline of talk

• Extreme weather and storm events - Transport

• Human modifications of the landscape – Past & Current - Supply

• Magnitude of Watershed Exports

• Management Strategies and Protection of Water
Extreme weather and large storms
- Enhanced Transport
Anthropogenic increase in **Greenhouse Gases (GHG)** like CO₂

Increase in GHG concentrations is leading to increasing air temperatures

**Another key player we forget – water vapor H₂O (g) – it is also a GHG!**

Positive climate feedback– as air temperatures rise so does water vapor! *(every degree C increase = 7% increase in water vapor)*

The atmosphere is steaming up – the “**pressure cooker**” analogy

**More water vapor – mean more energy for storms!**
Not surprisingly then, ... data from past 50 years...

Increase in the % of very heavy precipitation (top 1 % of the events) from 1958 to 2012 for US.

Largest increase for the Northeast US!

Melillo et al., 2014
A barrage of tropical and/or large storms over the past few years!
Storms with a rainfall return period of 10-25 years but happening in successive years!

TS Nicole, Sep. 30, 2010
(5.9 inches)

Hurricane Irene, August 27, 2011
(6.1 inches)

Hurricane Sandy, October 29, 2012
(4.6 inches)

Hurricane Matthew
October, 2016

April 30, 2014 (~ 6 inches)

TS Andrea, June 6, 2013
(4 inches)

....and we sampled most of them! 😊
Changes in stream flow too ...........

Change in river flood events across the US from 1920 – 2008 (Peterson et al. 2013)
But along with storms – we are also going to get more intense droughts and dry periods... especially for the southwest US!

(a) No Climate Change Effects

(b) Climate Change Effects

Water Supply Sustainability Risk Index (2050)
- Extreme (29)
- High (271)
- Moderate (821)
- Low (2020)

Water Supply Sustainability Risk Index (2050)
- Extreme (412)
- High (608)
- Moderate (1192)
- Low (929)

Melillo et al., 2014
Likely increase in winter climate variability?

Wild winter of 2016 – Globally, the warmest on record! But with temperature swings.

Polar vortex variability and its implications for water & watersheds?
But it's just not the magnitude/intensity of storms......

- Large/Extreme event responses have been magnified by other simultaneous conditions.

- Example – Wet conditions in summer 2011 prior to occurrence of tropical storms Irene and Lee
  - Flooding from Irene was exacerbated by wet soils and antecedent moisture!

Hence, the challenge to define “Extreme” events....... Event attributes or ecosystem response?
Historically unprecedented erosion from Tropical Storm Irene due to high antecedent precipitation

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Irene (2011) caused the most severe erosion on record, even exceeding other events of large magnitude and intensity.
Coupled conditions for extreme events

There are other conditions too ......

Droughts -> Forest fires; followed by intense storms!

Las Conchas fire and flood 2011 in New Mexico – Dahm et al., 2015. **Very high concentrations of carbon in runoff!**
Coupled conditions for extreme events

There are other conditions too ......

• *Freeze-thaw conditions coupled with intense winter rainfall!*

  More on this later......
Human modifications of the landscape – Large Supply
Humans have dramatically altered the landscape - enhanced the supply of sediment, nutrients, and pollutants

Two examples –

**Colonial era:**
• **Mill pond legacy sediments** in the valley bottoms of eastern US (particularly the Piedmont)

**Contemporary:**
• **Phosphorus saturated soils** due to land application of Manure in Delmarva
Colonial Mill Dams & Legacy Sediments

Large number of milldams in eastern US during the colonial era...

...every mile on some streams!

Coupled with extensive agricultural erosion = large valley bottom legacy sediments

Source:
http://www.pbs.org/wgbh/nova/next/earth/dam-removals/
Mill dams backed up water, reduced flow velocities, resulted in sediment deposition behind the dam.

Covered the pre-colonial sediments. 1-10 feet!

Dam breaching resulted in channel cutting into sediments.

Walter & Merritts, 2008
1877 Map showing the Mill dams on Big Elk Creek

Red arrows indicate 1877 mill dam locations

Scotts Mill dam

HistoricMapWorks.com
Most of these small mill dams have breached.... but the valley bottoms are full of fine sediments and continue to erode!

Scotts Mill dam that was breached in 1930 by DuPont

Legacy sediments still stored behind the dam

Big Elk Creek, Maryland, April 2017
Millpond legacy sediments represent a large supply of sediments & nutrients in watersheds
Manure application in Delmarva

Large Poultry Industry

~600 chickens per person on Maryland eastern shore!

Sussex, DE – highest poultry production

Surplus manure!
Manure application in Delmarva

Manure rich in Phosphorus; N:P = 3:1

Crop needs = 8:1

Land application for N over decades has resulted in **surface soils saturated with phosphorus (P)**

Nearly 20% of farmland in Maryland has P in excess of 150 ppm.

P application banned for soils > 500ppm

Elevated P soils (legacy P) can result in high concentrations of P in runoff

Manure on field ready for application
Watershed Exports
(Transport + Supply)
Large exports from watersheds

Combination of large supply and extreme storm transport has resulted in elevated exports of sediments and nutrients. Some examples: Big Elk Creek in Maryland Piedmont – during and after a spring flood in 2014.
Irene contributed a large proportion of the annual flux!

In just 59 hrs, Tropical storm Irene (2011) contributed:

- **44%** (24.5 kg/ha) of annual **Organic Carbon** flux for 2011
- **1/3** of annual **N** flux for 2011

2011 annual stream exports

- **Total OC:**
  - Irene 44%
  - Total = 55.2 kg/ha

- **Total N:**
  - Irene 32%
  - Total = 6.4 kg/ha

*Dhillon & Inamdar, 2013, Geophysical Research Letters.*
Susquehanna River – 50% flow to Chesapeake Bay

Tropical storm Lee (Sep 2011) 6-12 inches; sediment = 19 million tons

Hurricane Agnes (June 1972) - rainfall - 8-18 inches; sediment = 30 Million tons (10-25 years worth of sediment in few days!)

Average annual sediment flow = 1.5 Million tons!
But, its not always the largest storms............ that produce the largest exports

A combination of unique conditions could yield extreme responses.
Rainfall & Freeze Thaw effects

Bank erosion due to freeze-thaw

Freeze-thaw loosened the bank sediments for fluvial erosion

Particularly in watersheds with mill pond legacy sediments!

Inamdar et al., GRL, 2017, In review

Before storm

After storm
Rainfall & Freeze Thaw effects

February 2016 – intense rainfall following freeze-thaw yielded very high sediment exports!

Sediment Concentration ~ 4000 mg/L

Chocolate runoff!!

Inamdar et al., 2017, GRL, In review
Rainfall & Freeze Thaw effects

Seen at the larger drainage scale too – 314 square miles – Brandywine Creek
9 year turbidity data at every 15 minutes!
Management strategies & protection of water
Watershed management & protection?

Clearly these large/extreme events will have major management implications.

So how do we address these extreme events?

What management/protection strategies can we put in place?

• Reduce the SUPPLY!
  • Reduce the inputs of nutrients and pollutants
  • Stream bank stabilization and restoration?
Watershed management & protection?

Mitigate the TRANSPORT

- Best management practice (BMP) design for large events?
Watershed management & protection?

Removal of mill dams for enhancing habitat and safety – consider the fate of legacy sediments too.
Conclusions

• Extreme weather and large storms will increase transport and exports of nutrients/pollutants

• Pay more attention to the largest events – monitoring!

• We need to reduce the supplies on the landscape

• Re-evaluate our watershed best management practice (BMP) designs
Questions?