Assessing the Interactive Effects of Landscape, Climate, And UV Radiation on River Ecosystems: Modeling Transparency to UVR and the Response of Biota

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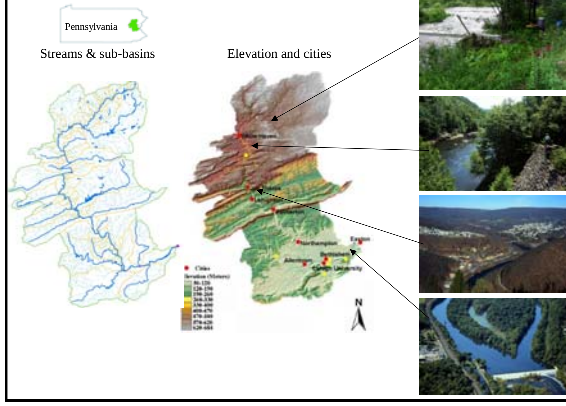
Objectives

- Our overall objective is to determine how current properties of the Lehigh River and its watershed (including land use, land cover, riparian forest canopy, and stream channel morphology) interact with climate and solar radiation to determine UV exposure and response of aquatic organisms.
- We will also establish how temperature affects UV resistance of organisms, how dissolved oxygen is affected by UV exposure, and how stream animals have adapted in order to survive UV exposure.
- Our results should help us predict ecological responses to UVR in other watersheds, and to predict responses to future changes land use, climate patterns and stratospheric ozone.

Several views of the Lehigh River Watershed



What we knew at the start of this project about exposure of aquatic organisms to UVR from work in lakes

•UV radiation is primarily attenuated by dissolved organic carbon molecules (DOC) in lake.

•DOC concentration and optical qualities (absorbance per unit of DOC) vary depending on prior photobleaching and whether the source is from soil or from algae within the aquatic system.

•Climate influences both [DOC] and DOC quality.

•Different taxa of organisms vary in their resistance and behavioral responses to UVR.

•Turbidity should be a more important factor in streams and rivers than in lakes because the moving water can cause erosion and keep fine particles suspended.

Approach-1

- Our approach to studying UVR exposure and its biological impact in streams combines the use GIS datasets, laboratory & field experiments, and intensive field measurements of stream and water properties throughout the Lehigh River watershed of NE Pennsylvania.
- We are working at small and large spatial and temporal scales to tease apart how UV exposure is influenced by variations in climate and watershed properties, including natural and anthropogenic changes to these.

Approach-2

- Modeling the sources, loading, and transport of dissolved organic matter is central to our effort because [DOC] has been shown to control underwater UVR attenuation in most aquatic systems.
- We are also examining suspended sediment and its relationship to stream channel morphology.
- At a monthly time scale we are sampling across the entire Lehigh River watershed to characterize seasonal patterns for concentration and quality of DOC.
- In specific sub-basins (including natural experiments with paired catchments) we are using automated samplers to characterize changes in water quality on an hourly time scale during storm hydrographs.

Approach-3

- At a decadal temporal scale we are using a collection of aerial photographs to explore the relationship between changes in land use and stream channel morphology that influence storm runoff and sediment transport.
- At monthly and hourly temporal scales we are combining measurements of [DOC] and UV attenuation with other optical and chemical measurements (particulate spectral absorption, turbidity, cdom spectral fluorescence, specific conductance, pH, dissolved oxygen) to help us predict UVR attenuation and ecological impacts of UVR exposure.

Approach-4

- We are testing the UVR resistance of benthic macroinvertebrates from selected sites using a laboratory solar simulator instrument at a range of water temperatures and conducting in-stream experimental manipulations of UVR exposure.
- We are developing a model to predict the role of forest canopy on exposure of low order streams to UVR using a combination of GIS data, field measurements (combining hemispherical photography of forest canopy with incident UVR measurements) and data on stream orientation and terrain elevation.

Progress to date: DOC loading models from GIS analysis and stream measurements

1. Small watersheds study #1: [DOC] is correlated with %forest and %agriculture (no wetlands in this study)
2. Basin survey: [DOC] is correlated with %wetlands area; seasonal and storm variation at each site is correlated inversely with specific conductance.
3. Catchment discharge is correlated with area; useful for modeling DOC loading.
4. DOC source depends strongly on in-stream production except in areas with high %wetlands area
5. Storm hydrograph analysis suggests that in-stream algal DOC is correlation with deep flow path while DOC from soil follows a shallow flow path

More Progress to date (2)

6. We have established strong spatial correlations between UV attenuation and [DOC], between [DOC] and wetland area, and between sub-basin discharge and total area.
7. Strong temporal correlations exist between [DOC] and specific conductance, indicating a role for shifts between surface water and groundwater.
8. Suspended sediments strongly influence UV attenuation during storm runoff.
9. We observed a surprising shift from soil-derived DOC to algal-derived DOC across the watershed (based on spectral fluorescence measurements).

More Progress to date (3)

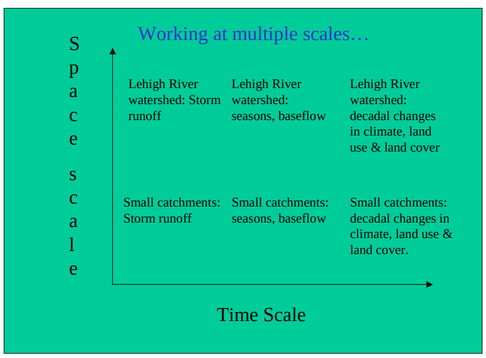
10. Both photolability and biolability of river DOC varied seasonally and variations were correlated with specific conductance and DOC source, but photobleached DOC did not accumulate in the system during this unusually wet period.
11. Aquatic macroinvertebrates varied in their resistance to UVR and appeared to generally lack temperature sensitive photoenzymatic repair mechanisms for UVR-induced DNA damage.
12. UVR reaching low order streams was strongly influenced by forest canopy, in particular, by the fraction of sky visible.

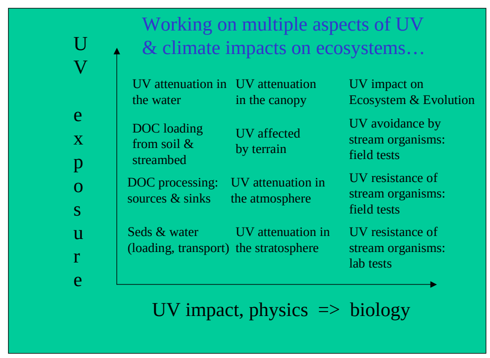
What's next (1)…

1. We are now exploring the influence of flow path on concentration and quality of DOC during storm runoff (using ion composition analysis and automated sampling from paired catchments)
2. We will continue to explore watershed properties to refine our model for DOC loading (evaluating effects of land cover, slope and soil type).
3. We will complete our canopy assessment and optical model development; UV-B intensity at the stream surface should depend more on sky visibility than orientation of the stream relative to the path of the sun because of the dominance of diffuse light over direct light for UV-B wavelengths.

What's next (2)…

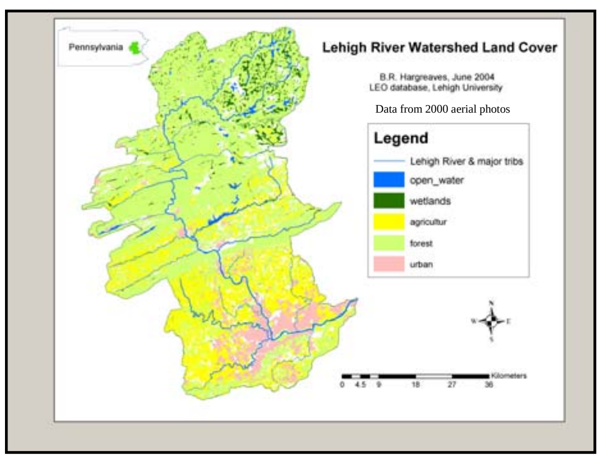
4. We will test macroinvertebrates in stream manipulations of UVR exposure to look for behavior responses.
5. We will complete our quantitation of the impact on dissolved oxygen of DOC respiration and photobleaching.
6. We will complete analysis of stream channel morphology and the relationship to current and historical aerial photographs and relate this to suspended sediment.
7. We will continue evaluating the relationship of stream channel morphology to storm runoff, suspended sediments, and UV attenuation.



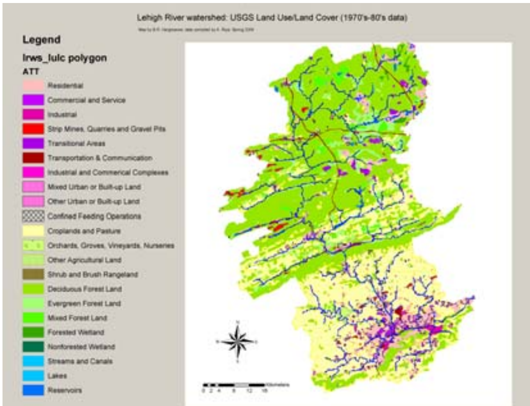


Results

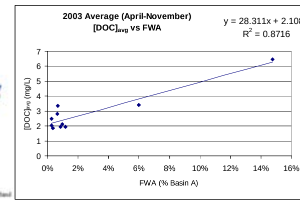
- GIS data: Land cover and Land use
- Predicting [DOC] from wetland area
- Predicting [DOC] from forest area and slope in the absence of wetlands
- Variation in DOC quality: source & reactivity
- Turbidity and stream channel morphology
- Organismal Resistance and avoidance of UVR
- Stream canopy role in UVR exposure



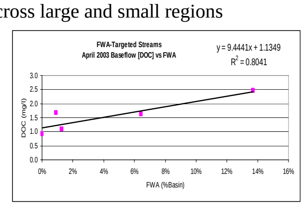
This map of 1970’s –1980’s data has details but lacks information on wetland area

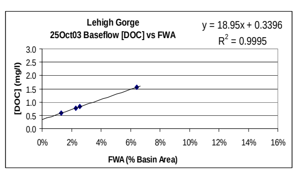


[DOC] can be predicted from wetland area in large catchments (but the relationship varies seasonally)

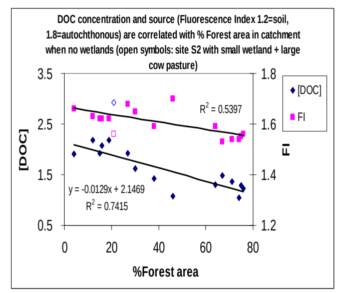


[DOC] correlated with wetland area across large and small regions

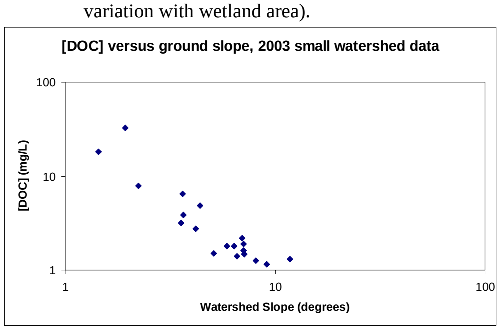




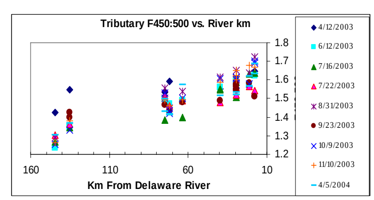
When wetlands are absent, small watershed [DOC] and DOC quality vary with forest cover or agriculture cover

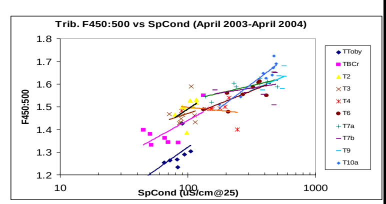


Preliminary data on variation in [DOC] with ground slope (need to sort out the co-variation with wetland area).



Changes in DOC quality across the watershed: Fluorescence Index (F450:500 emission ratio with 370 nm excitation) indicate that soil (wetlands) is the major source of DOC on the Pocono Plateau but algal DOC is the dominant form downstream.



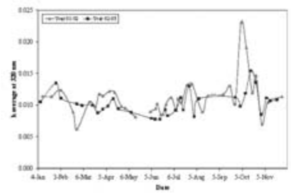


Photobleaching by sunlight is one process that changes DOC in the water. We test for **photolability** with a laboratory test using particle-free river water.

- Experiments were run using batches of samples corresponding to 7 dates
  - Samples were passed through a Peristaltic pump
  - Distributed into quartz test tubes in triplicate
  - Tubes were placed on a wire rack beneath dual tubes of a Q Panel 340 lamp
  - Exposure time for all samples was 48 hours

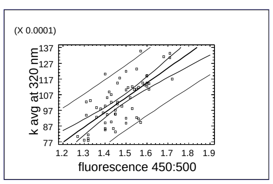
The reactivity of CDOM (UV-absorbing components of DOC) varies seasonal in the Lehigh River

Two years of seasonal variation in photolability at 320 nm (k320) for CDOM in the Lehigh River near Bethlehem, PA.

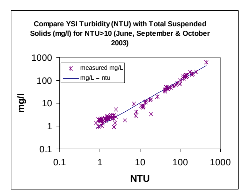


What causes photolability (k) to vary?

Strongest correlation of variations in photolability "k320" is with Fluorescence Index, a measure of DOC source (algal=1.8, soil=1.2). Algal DOC is more rapidly bleached.



The YSI 6136 turbidity sensor has proven to be extremely stable and sensitive. NTU readings correspond closely to the concentration of total suspended solids (dry mass, mg/L). We expect to use this relationship to predict UV attenuation by particles.



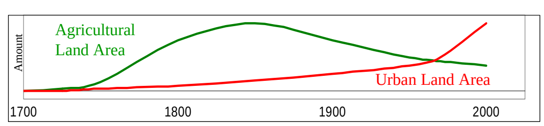
Stream Morphology Quantification

- Leopold et al. (1964) studied alluvial channels in the Piedmont Region of Maryland and Virginia & found pool and riffle spacing to average 5-7 times the width of the reach.
- It appears from recent high resolution surveys in our region that the pool-riffle spacing is longer than 5-7 times the average reach. Furthermore, pools and riffles are subdued in their morphology and locally absent from many stream reaches.
- We hypothesize that this anomaly reflects the initial response of a channel that is presently in the widening process as a consequence of rapid changes in land use.
- Link to UVR: suspended sediments will change in response to peak discharge and water velocity.

Background

www.ejpau.media.pl

Conceptual history of local land use and stream channel behavior over the past 200 yrs



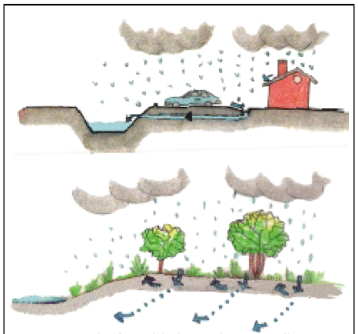
"Natural" Streams

Channels narrowing and aggrading

Channels widening and incising

Urbanization of a watershed

- Increase in impervious surface
- More runoff in less time

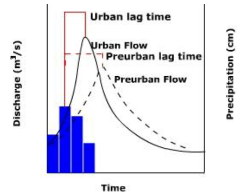


www.rmi.org/images/other/W-ReevalStormwater.pdf

Background

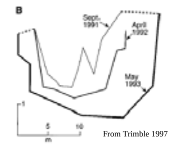
Effects of Urbanization

- Storm Discharge:
  - increased flows over shorter durations following urbanization



http://www.uwsp.edu/geo/faculty/ritter/images/lithosphere/fluvial/urban_hydrograph.jpg

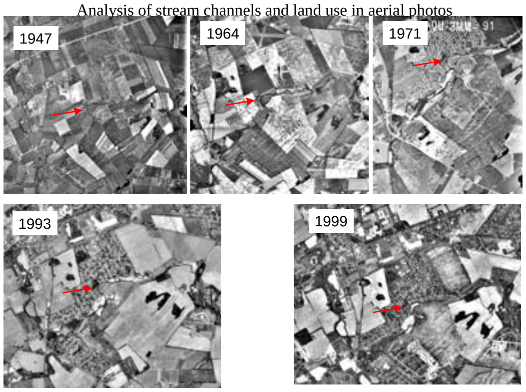
- Stream channel:
  - Initial increases in sediment delivery followed by decreases in sediment delivery to streams.
  - Increased channel erosion.



From Trimble 1997

Stream channel cross section on 3 dates

How does land use affect stream channel shape?
Analysis of stream channels and land use in aerial photos



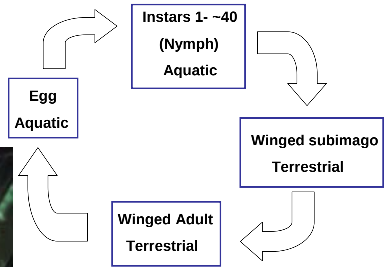
Aerial photographs digitized from Pennsylvania archives in Harrisburg for a reach of the Little Lehigh Creek between Trexlertown and Allentown, roughly near the town of East Texas (Josh Galster). Red arrow indicates same site in each photo.

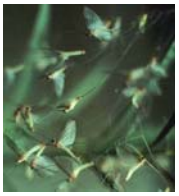
UV exposure of stream organisms: focus on mayfly nymphs

- Regularly exposed during drift
- Different mayflies have different behaviors which may cause different exposures to UV
  - **Heptageniidae: flat "grazers" that rarely enter drift**
  - **Baetidae: streamlined "swimmers" that are frequently in drift searching for better patches of food.**

Life Cycle of Order Ephemeroptera (Mayflies)

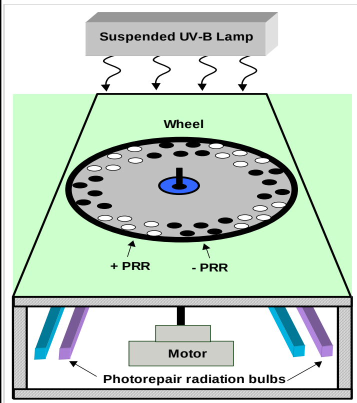
- Small insects found throughout the world
- Incomplete metamorphosis





Phototron experiments

- **Mayfly nymphs collected at each site**
- **Dominant species (as determined by quantitative samples) of approximately the same size were isolated**
- **Placed in replicate quartz dishes with 5 organisms in each dish, in filtered spring water**
- **Incubated at 10°C overnight**
- **Following morning placed in UV lamp phototron**



5 mayfly nymphs per dish

5 dishes per treatment

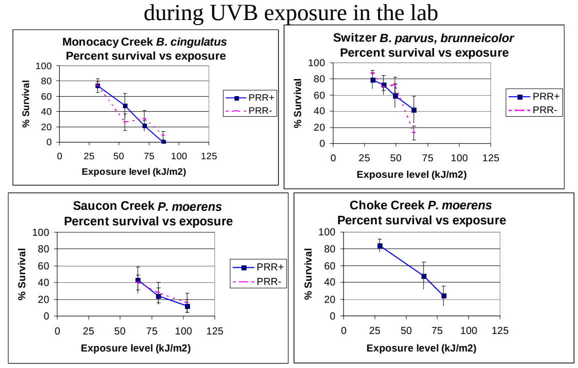
Placed on 40 spaces on rotating wheel

UV-B from above doses controlled by meshes

UV-A from below

Black disk was placed under 5 of 10 dishes receiving same UV-B dose to tease out effects of UV-A

Experimental Results: Mayfly nymph mortality during UVB exposure in the lab



UV-B Resistance of aquatic invertebrate taxa

(in order of increasing resistance)

Lake:	Daphnia	15 kJ/m^2
Stream:	Chironomidae	16 kJ/m^2
Lake:	Asplanchna	20 kJ/m^2
Stream:	Planaria	<31kJ/m^2
Stream:	**Ephemeroptera** (mayflies)	**33-64 kJ/m^2**
Stream:	Trichoptera/Hyrdopsychidae (caddisflies)	56 kJ/m^2
Stream:	Coleoptera/Psephenidae (water pennies)	>102 kJ/m^2
Stream:	Plecoptera (stone flies)	>102 kJ/m^2

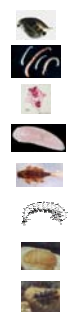
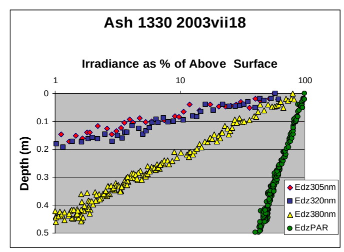


Photo Credits:
http://www.cladocera.uoguelph.ca/ http://biodidac.bio.uottawa.ca North American Benthological Society
http://www.cals.ncsu.edu/ Cliff White

The underwater UV environment for mayflies

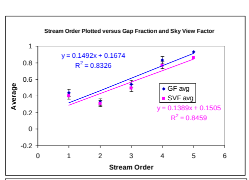
- The BIC radiometer directly measured the rate of UV attenuation in the water column
  - Submerged in the water
  - Records the irradiance at four wavelengths several times each second
  - Provides a stream of data used to calculate an attenuation coefficient. Allows us to determine how much 320-nm light is reaching a specific depth.



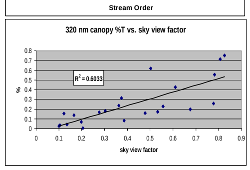
How does canopy cover affect UVR exposure in streams?

Preliminary data using a 180-degree image with a digital plant canopy imager compared to UVR measurements with radiometer.

http://www.cid-inc.com



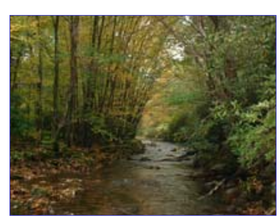
GF and SVF computed from camera image



%320 nm irradiance computed from radiometer measurements

Future challenges to complete model for canopy role:

1. Measuring UV %T of canopy and canopy Sky View Factor (SVF) throughout watershed
2. Correlating UV%T and canopy SVF for different geographic regions;
3. Exploring influence of terrain elevation, age of tree stands, and stream morphology on SVF and its relationship to UV%T
4. Exploring the effects sun angle and stream orientation relative to sun angle on UV%T



(photos from USACE 2001 study of LRW water quality: http://www.nap.usace.army.mil/cenap-dp/projects/Lehigh2001/)

Areas of Continuing Focus

- GIS data: Land cover and Land use
- Predicting [DOC] from wetland area (season, climate?)
- Predicting [DOC] from land cover, soil type, and slope in the absence of wetlands (season, climate?)
- Variation in DOC quality: source & reactivity (season, climate?)
- Turbidity, storm runoff, & stream channel shape
- Land use and stream channel morphology
- Organismal Resistance and avoidance of UVR
- Stream canopy and terrain versus UVR exposure