US EPA ARCHIVE DOCUMENT

Assessing the effects of land use, climate, and UV radiation on river ecosystems in northeastern USA

4 November 2005 STAR Project Review

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Other co-investigators: Frank J. Pazzaglia, Richard N. Weisman, Craig E. Williamson
Collaborator: Stephen C. Peters

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Grant # R829642

Hypotheses

EXPOSURE OF STREAMS TO UV Radiation (UVR)

Attenuation through riparian canopy

- Stream canopy shading of UVR can be characterized by hemispherical camera images that correspond radiometer-measured % Transmittance for diffuse irradiance
- Stream canopy shading can be characterized by satellite images (ASTER) for both average %T and width of the stream canopy gap for high order streams

Attenuation with depth in the water versus climate change and land use

- Watershed land cover, soil, and climate can be used to predict the concentration of UV-attenuating substances. Wetlands are especially strong contributors to allochthonous DOC in streams.
- Turbidity from suspended sediments increase UV attenuation in streams, especially during storm runoff.
- UV diffuse attenuation in streams can be measured in a stirred container to overcome difficulties caused by shallow shaded sites and allow us to measure the effects of turbidity.
- Source of DOC shifts between baseflow and stormflow conditions from autochthonous (stream periphyton and biofilm) to allochthonous (wetlands and forest canopy) DOC
- Photobleaching of stream DOC reduces specific absorption and increases biolability while microbial respiration reduces DOC concentration and increases specific absorption.

BIOTIC RESPONSE TO UVR IN STREAM ORGANISMS

Microbial response

- Photobleaching of stream DOC reduces specific absorption and increases biolability allowing microbial respiration to reduce DOC concentration and subsequently increase specific absorption.

Macroinvertebrate response

- UVR Senstitivity o f stream macroinvertebrate varies among taxa
- Variation in UVR Sensitivity can influence stream macroinvertebrate trophic assemblages through direct and indirect effects

STORM RUNOFF

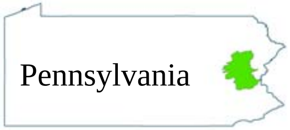
Scaling with drainage area

- Storm runoff scales more rapidly as drainage area increases when the fraction of impervious land cover is high (e.g. urban land cover) and historical patterns of storm runoff versus drainage area should respond to increases in the fraction of impervious land cover.

Stream channel morphology and land use

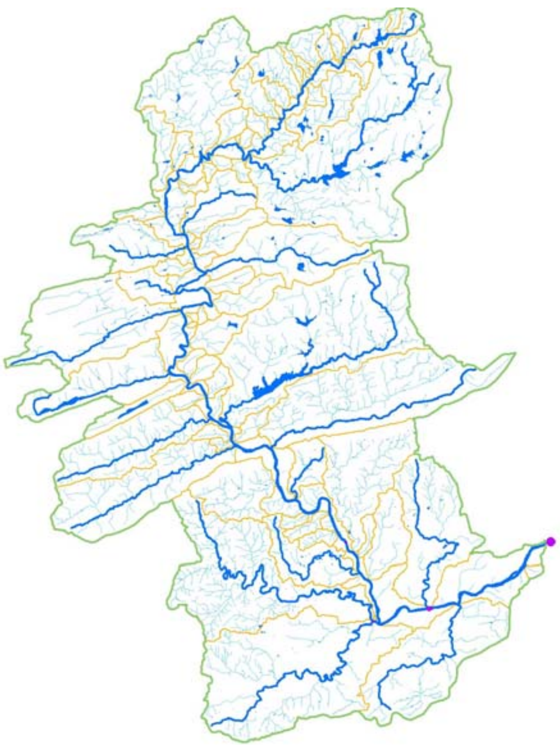
- Urbanization leads to more linear stream channels because of increased impervious surfaces and changed peak flow scaling with drainage area

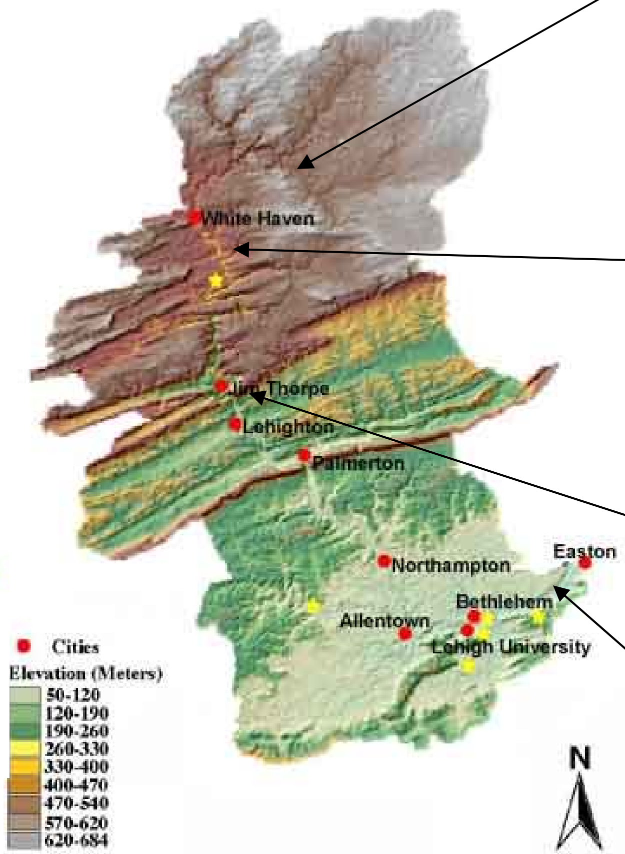
Several views of the Lehigh River Watershed

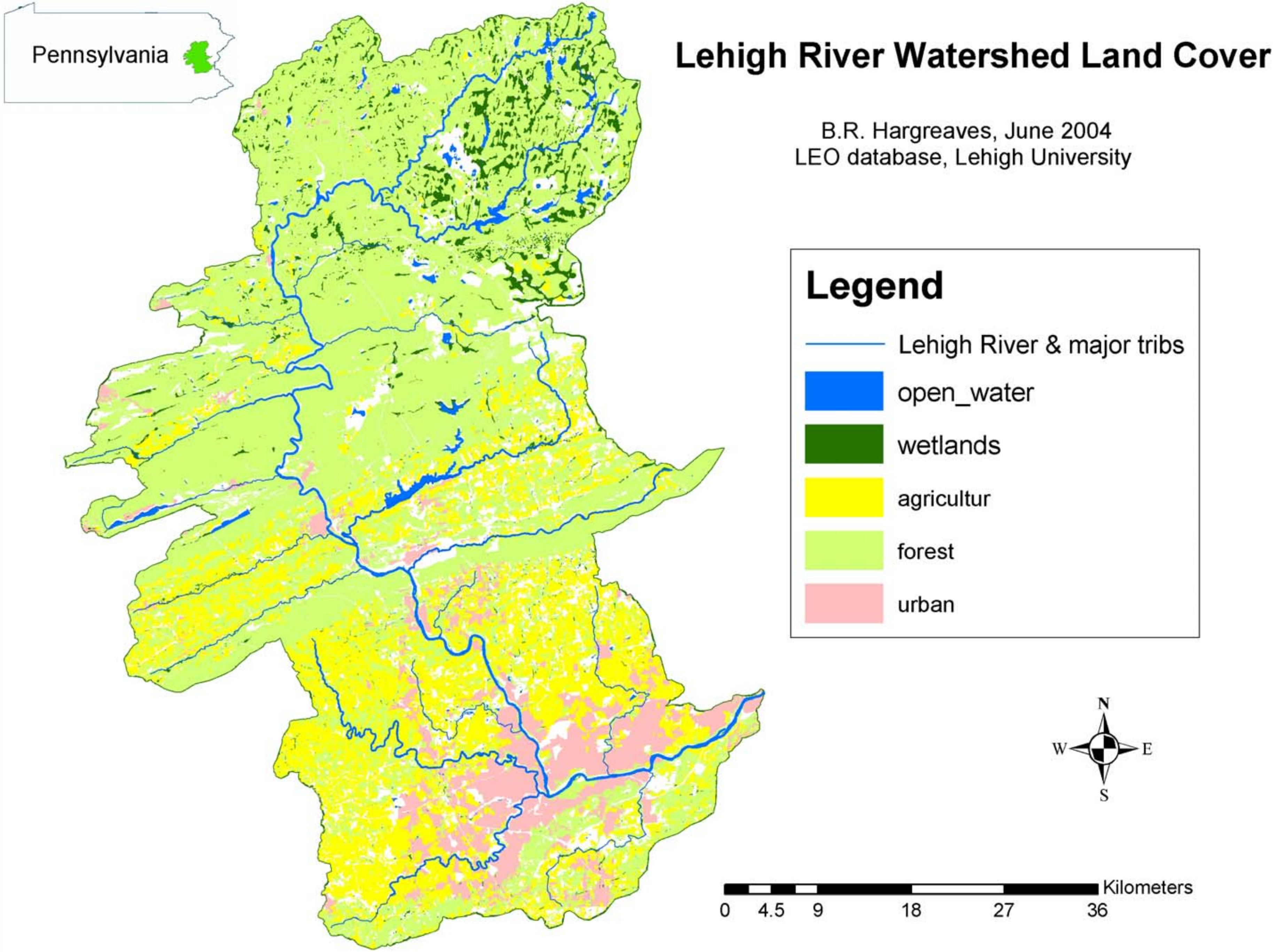


Streams & sub-basins

Elevation and cities






Lehigh River Watershed Land Cover
B.R. Hargreaves, June 2004
LEO database, Lehigh University
Pennsylvania
Legend
Lehigh River & major tribs
open_water
wetlands
agricultur
forest
urban
N
W
E
S
Kilometers
0
4.5
9
18
27
36

Climate, Land Use, and UV Radiation (Subprojects)

1. **UV attenuation in natural waters**
   - 1A. Variation with DOC concentration and optical quality (previous studies)
   - 1B. Variation with turbidity (suspended particle concentration)
2. **Stream-watershed-landcover-climate patterns & interactions**
   - 2A. Basin scale (main tributaries of Lehigh River)
   - 2B. Small watersheds across the basin
   - 2C. Paired watersheds differing in land cover
   - 2D. New method to measure UV diffuse attenuation in shallow streams
   - 2E. Stream flow versus land use via level loggers and GIS + aerial photos
3. **Photochemistry and microbial processing of DOC**
   - 3A. Photolability (photobleaching of DOC)
   - 3B. Biolability (microbial consumption of DOC)
4. **Biotic responses to UVR of stream macroinvertebrates**
   - 4A. UV Lamp Phototron experiments of UVR resistance in laboratory
   - 4B. Field experiments with controlled exposure to UVR of benthic community
5. **Shading by stream canopy**
   - 5A. Direct measurement of the canopy UVR %T (specific stream reaches)
   - 5B. Proxy measurements for UV transparency via fisheye camera images
   - 5C. Proxy measurement for UV transparency via satellite images

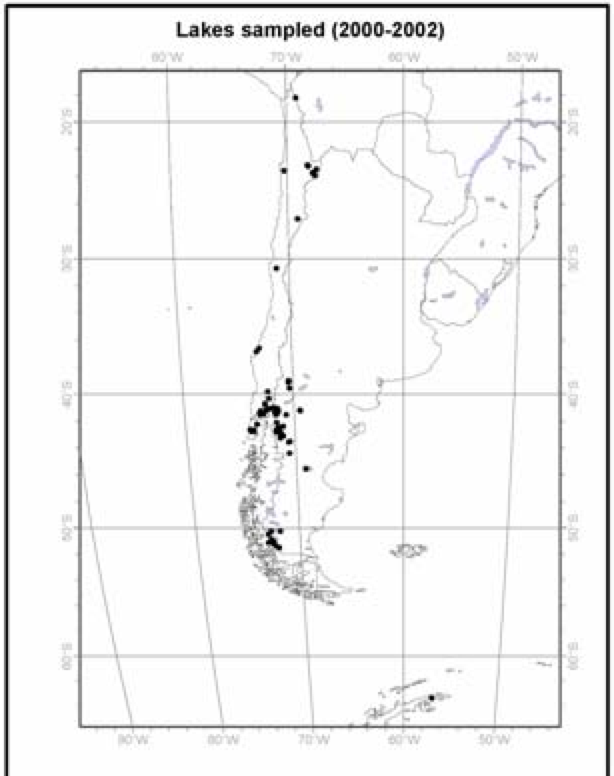
Sub-project Personnel

1. **UV attenuating factors in natural waters (Hargreaves & Morris)**
   - Patrick Belmont
   - Shannon Haight
   - Chris Forstall
2. **Stream watershed relationships (Hargreaves, Morris, Pazzaglia, Peters)**
   - Shannon Haight
   - Patrick Belmont
   - Chris Forstall
   - Josh Galster
3. **Photochemistry and microbial processing of stream DOC (Morris)**
   - Dani Frisbie
   - Lora Sterner
   - Pam Slater
4. **Biotic response to UVR exposure in streams (Williamson)**
   - Laura Shirey
   - Jeremy Mack
5. **Shading by stream canopy (Weisman & Hargreaves)**
   - Liz Tyler
   - Karen Miranda
   - Shannon Haight
   - Chris Forstall

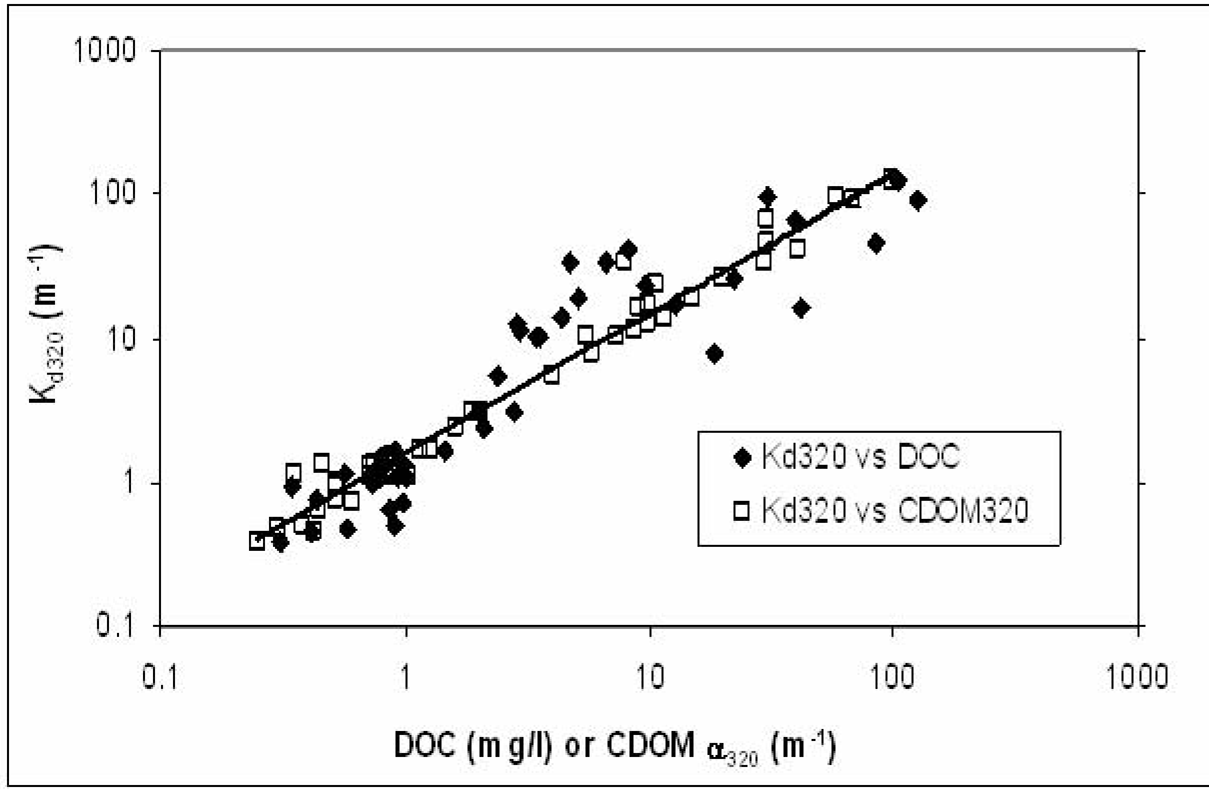
1A. DOC concentration and optical quality control UV attenuation when turbidity is low

(data from prior study)

44 Lakes sampled throughout wide range of climate and land cover in S. America



UV attenuation (K_{d320}) nominally proportional to [DOC]; better fit of K_d vs a_{CDOM} accounts for varied DOC quality



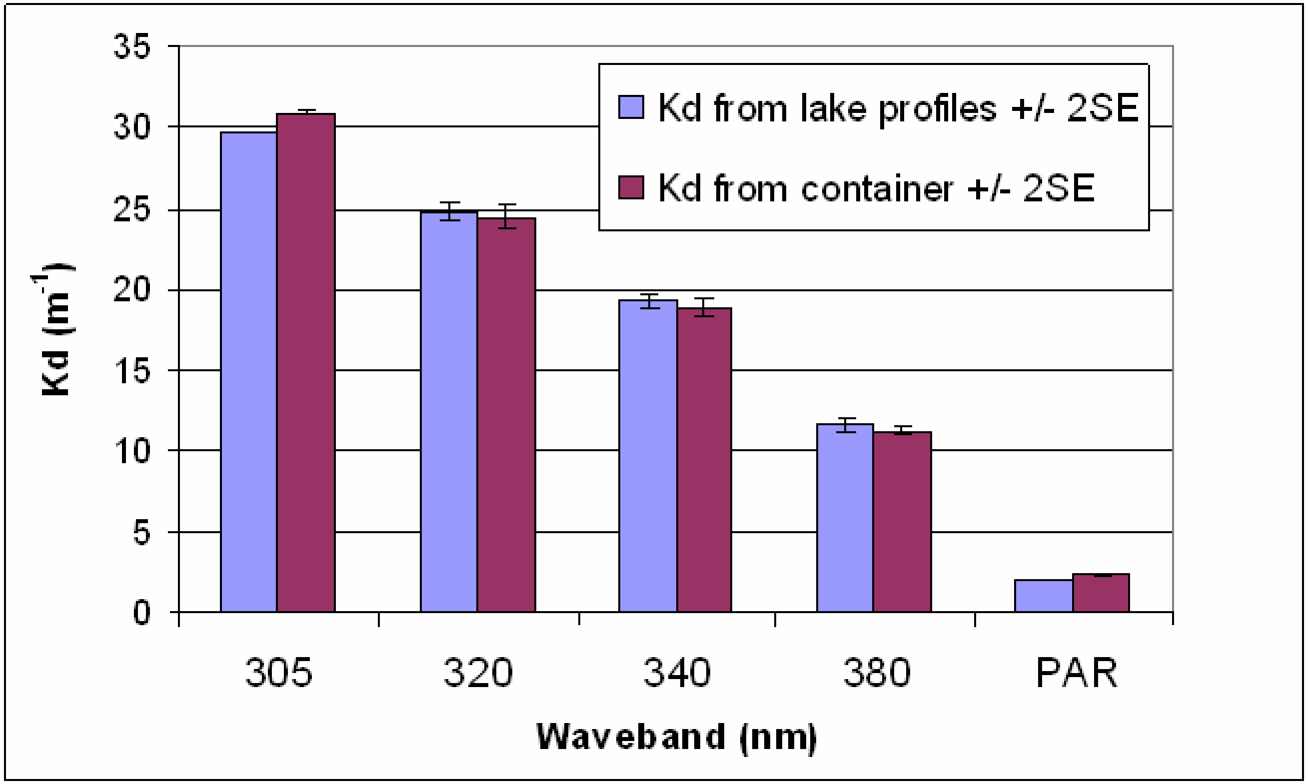
(Unpublished data, Hargreaves, Morris, Zagarese, Soto)

2D. New method for measuring K_d in stream water

- Problem: streams are shallow, fast-moving, and often shaded, making conventional depth profiles of irradiance with PUV or BIC radiometer difficult.
- Solution: near stream vary depth of water sample in stirred transparent container exposed to sunlight above PUV or BIC radiometer.
- Critical test: compare K_d's from lake profile and container measurements

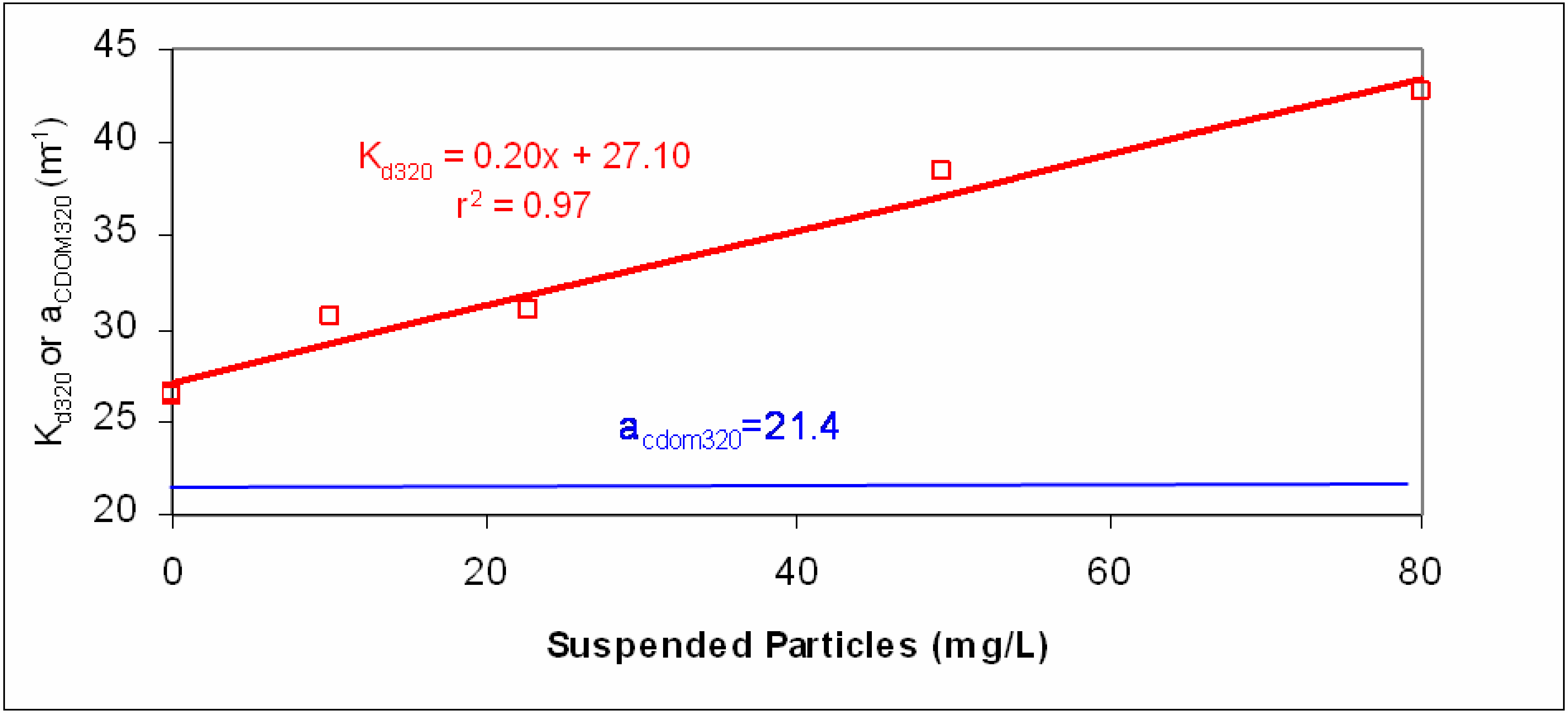
24 Oct 2003 test at Lake Nockamixon

(container K_d was 97-99% of lake K_d for 320-380, 104% for 305)



1B. Suspended particles increase turbidity and UV attenuation in streams during storm runoff

UV diffuse attenuation measured in stirred flume with four doses of stream suspended matter to GF/F filter stream water



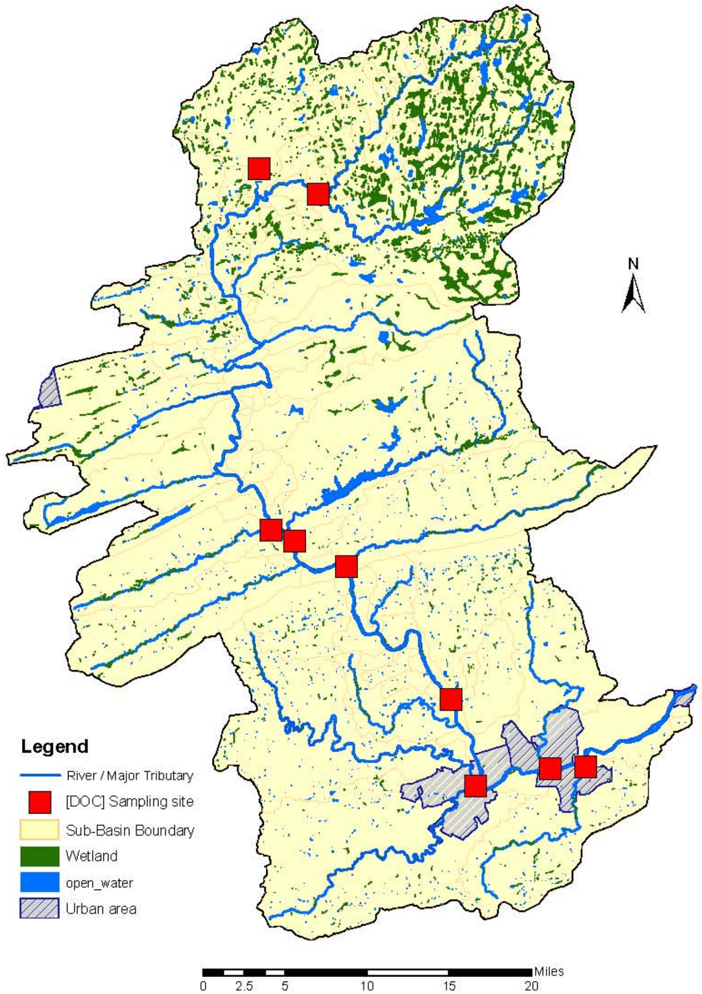
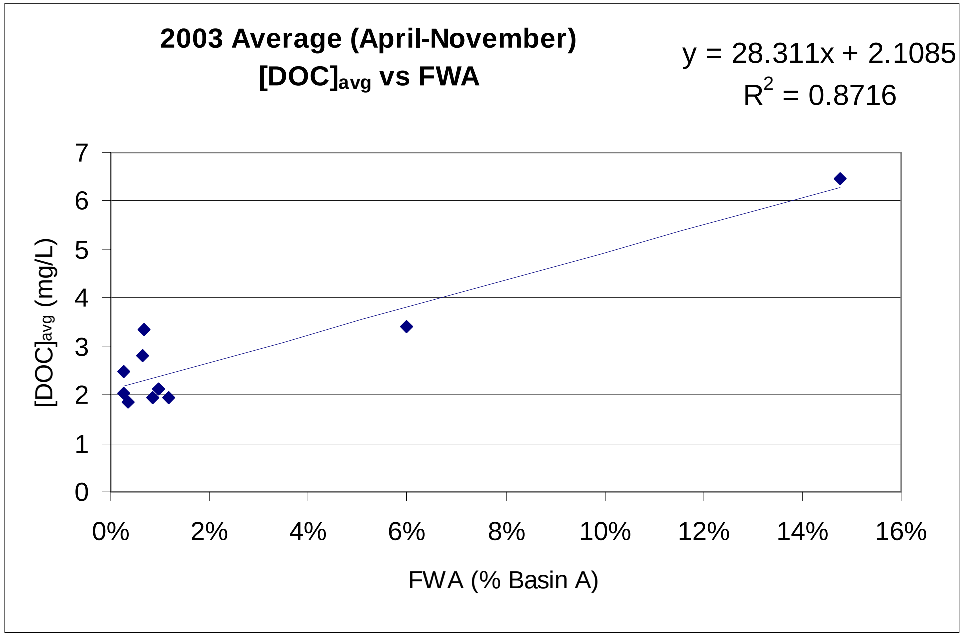


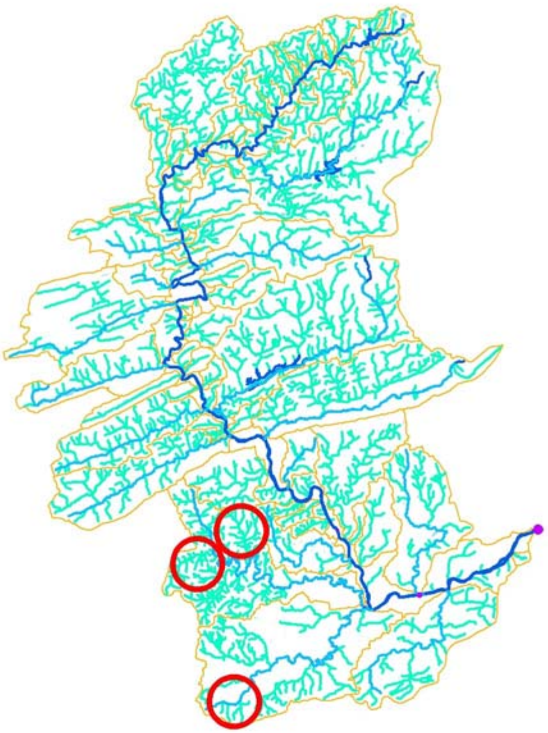
Figure 6 – The EPA group's tributary sampling sites and their catchment areas; wetland boundaries and urban areas.

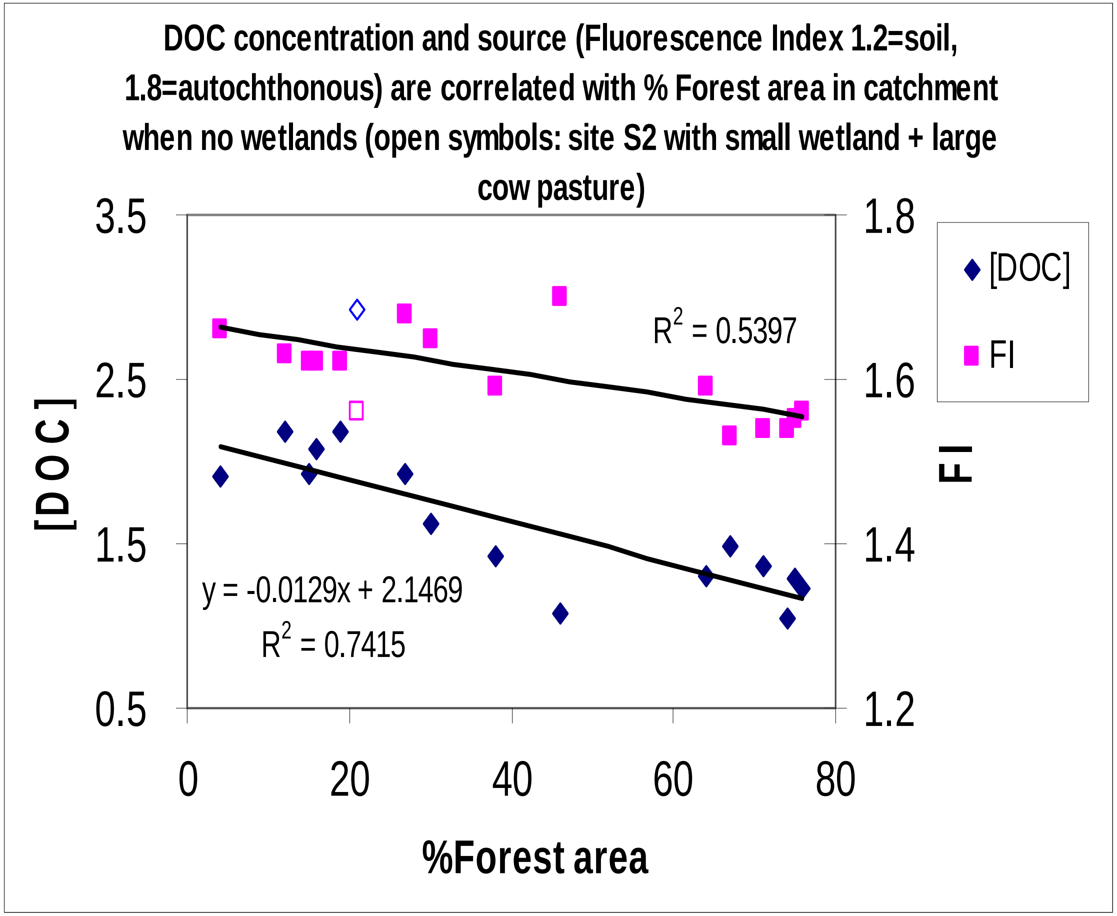
2A. [DOC] can be predicted from wetland area in large catchments (but the relationship varies seasonally)



2B. When wetlands are absent, small watershed DOC concentration & quality vary with forest vs agriculture land cover

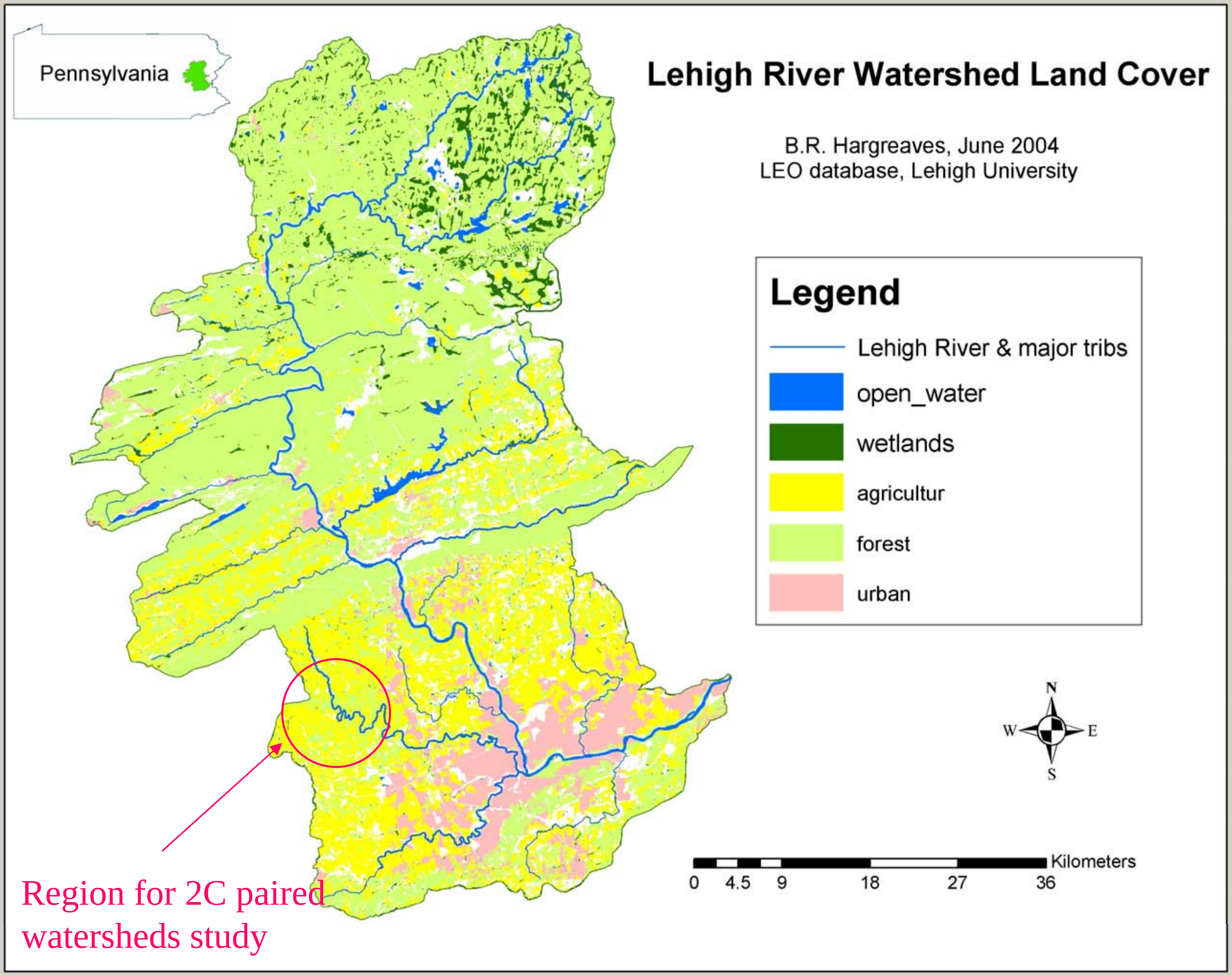
(non-forest DOC derived morre from algae; forest DOC more from terrestrial sources)





2C. Small watershed comparison with automated samplers

- Assumptions
  - Ultraviolet radiation (UVR) harmful to lotic organisms
  - CDOM & particulate matter attenuate UVR
- Goals:
  - Characterize sources of CDOM
  - Understand impact of land use change on CDOM sources
- Strategy:
  - Paired watershed approach
  - Examine geochemical & hydrologic response to storm events


Pennsylvania
Lehigh River Watershed Land Cover
B.R. Hargreaves, June 2004
LEO database, Lehigh University
Legend
Lehigh River & major tribs
open_water
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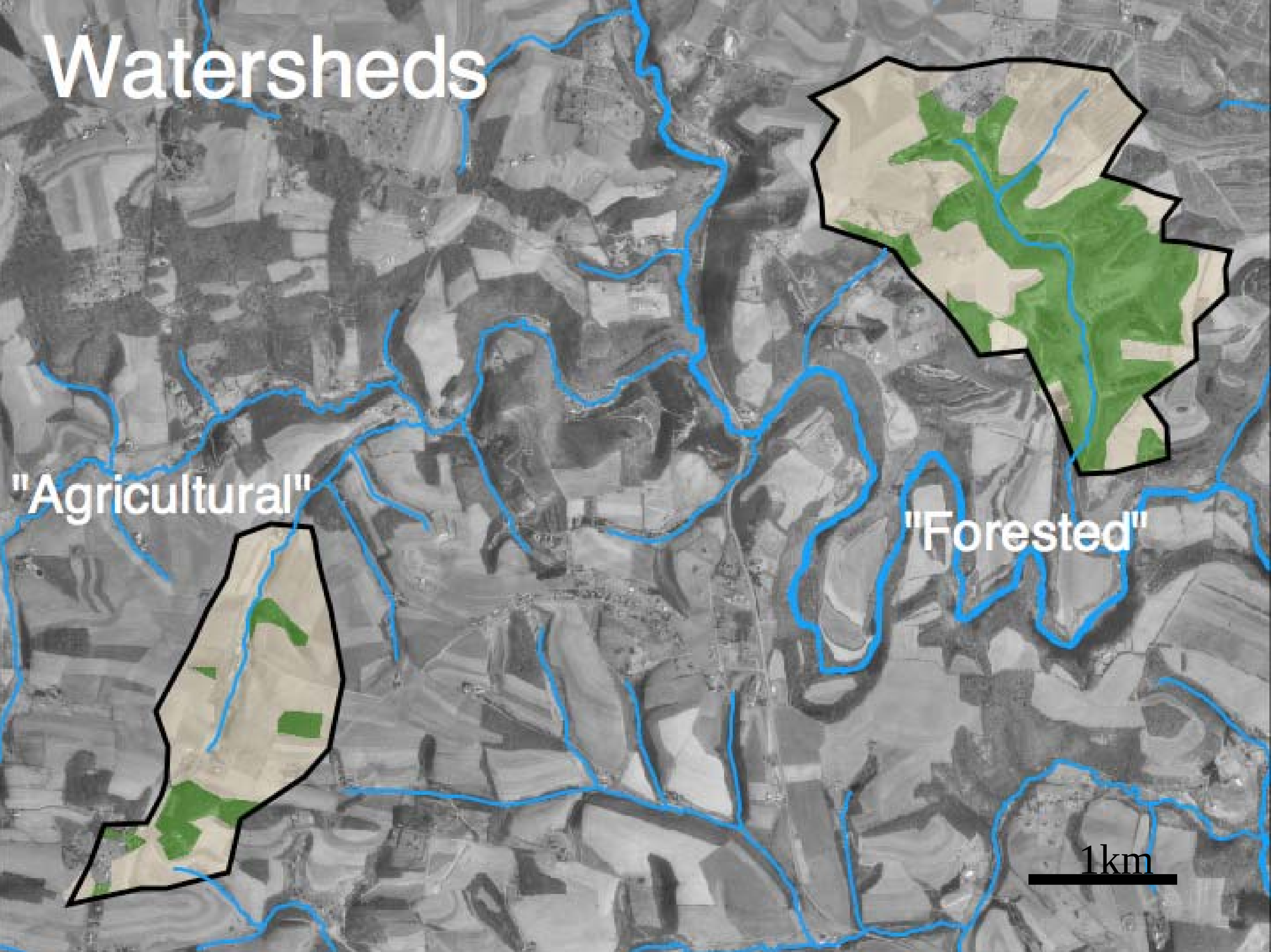
agricultur
forest
urban
N
W
E
S
Kilometers
0
4.5
9
18
27
36
Region for 2C paired
watersheds study


Watersheds
"Agricultural"
"Forested"
1km

Agricultural Site

Forested Site

Canopy
(Summer)

Stream
Channel
(Spring)

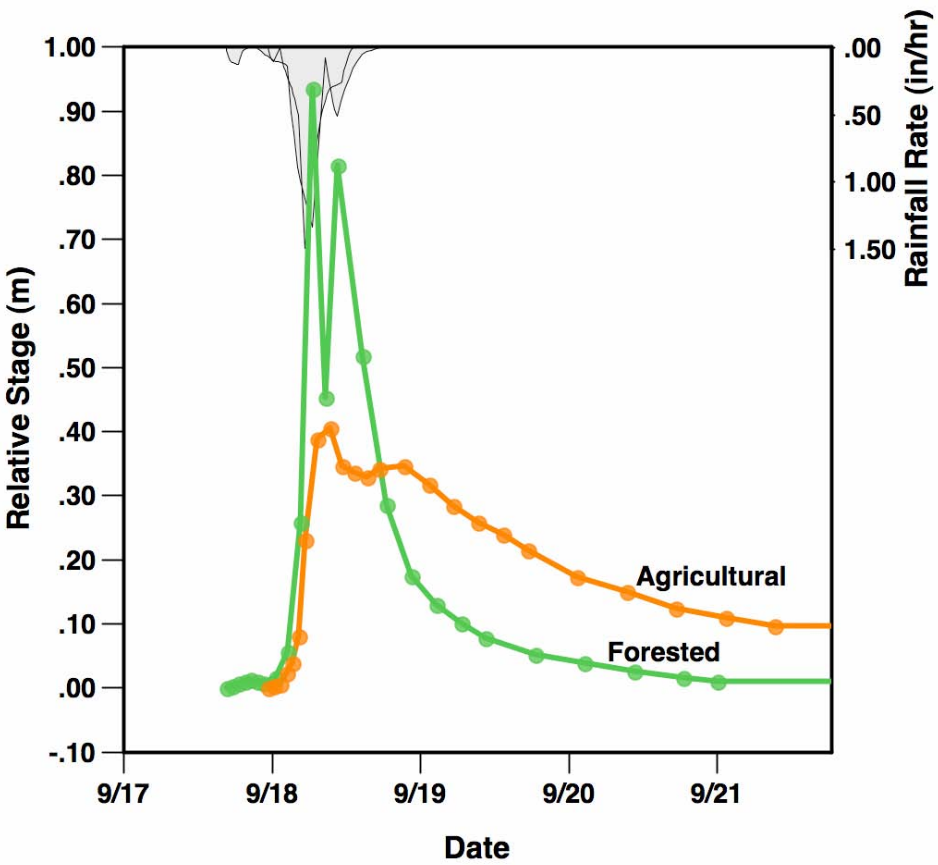
Automated stream sampler and datalogger

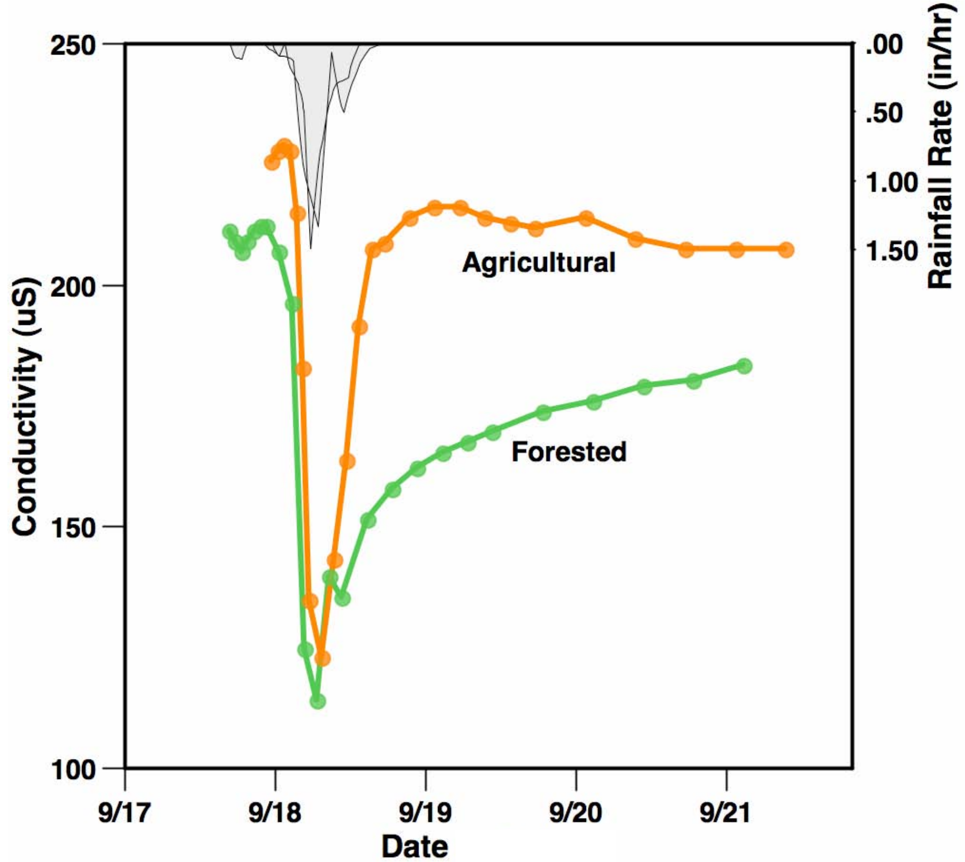
(triggered by rain or water level) inside Rubbermaid garden storage unit.

Example: 50-year Storm Event

- September 18, 2004
  - Fully “leafed” canopy
  - 5-7” rain
  - 50 year storm event
- Water Samples
  - Streamwater during events
  - Precipitation (open vs under canopy in both watersheds)
- Datasonde measurements
  - pH, conductivity, temperature, turbidity

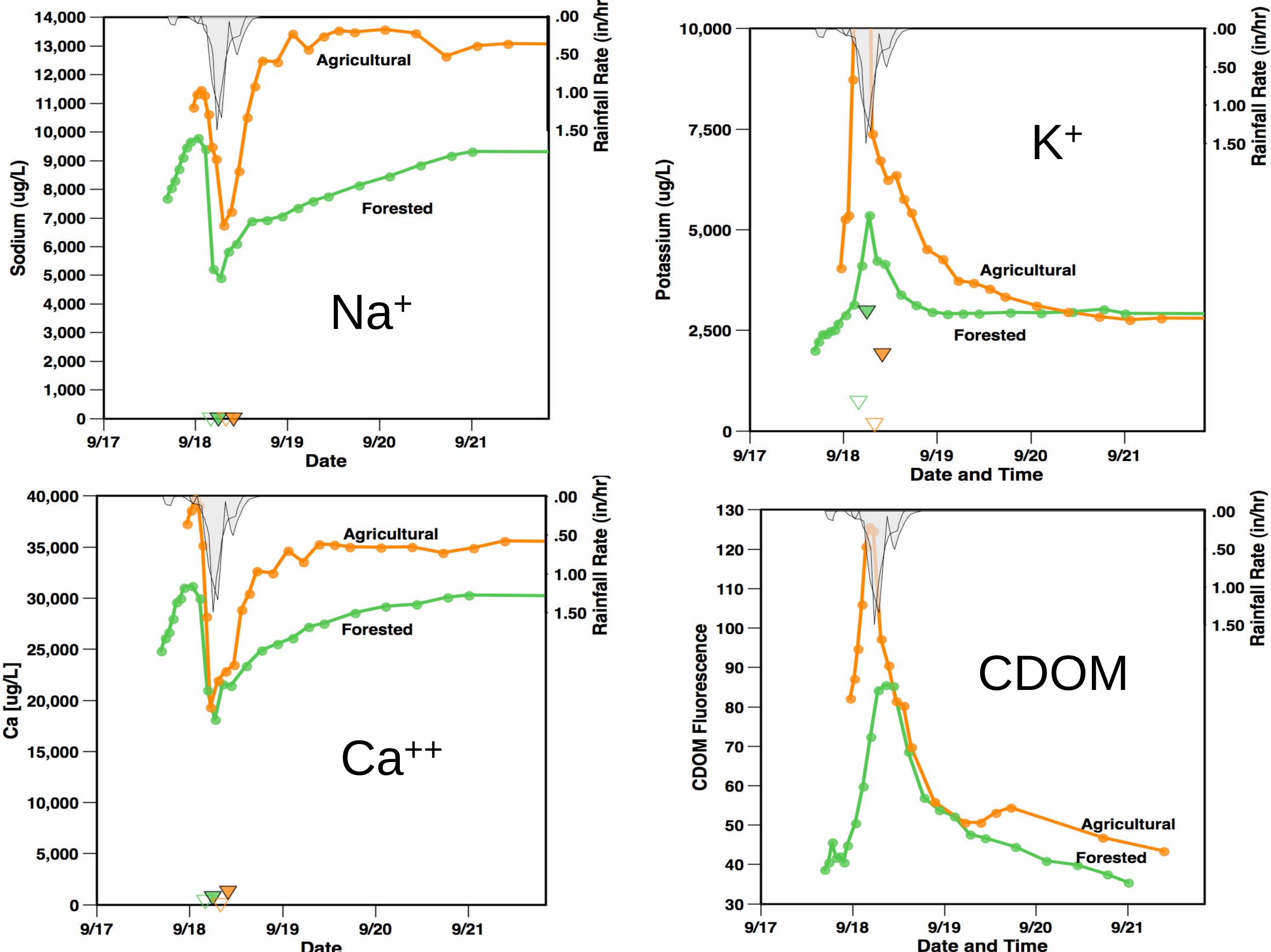
Rainfall, Streamflow & Conductivity





Forest: Flow returns RAPIDLY
Agricultural: Flow returns SLOWLY

Forest: Chemistry evolves SLOWLY
Agricultural: Chemistry evolves RAPIDLY



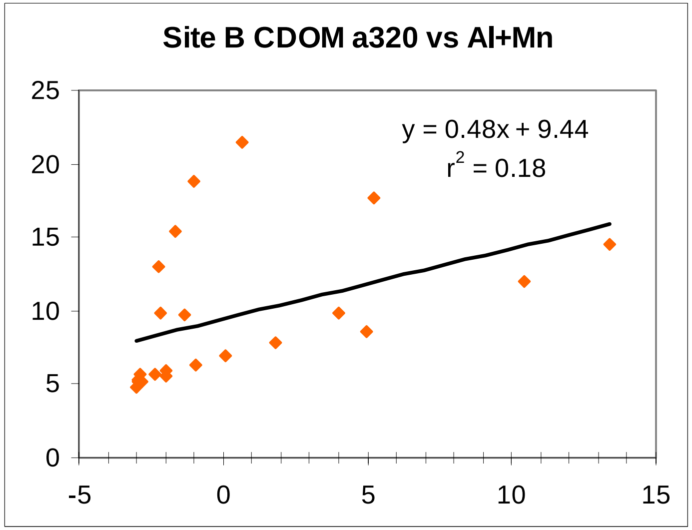
Na+
Sodium (ug/L)
Date
Rainfall Rate (in/hr)
Agricultural
Forested
K+
Potassium (ug/L)
Date and Time
Ca++
Ca [ug/L]
CDOM
CDOM Fluorescence
9/17
9/18
9/19
9/20
9/21

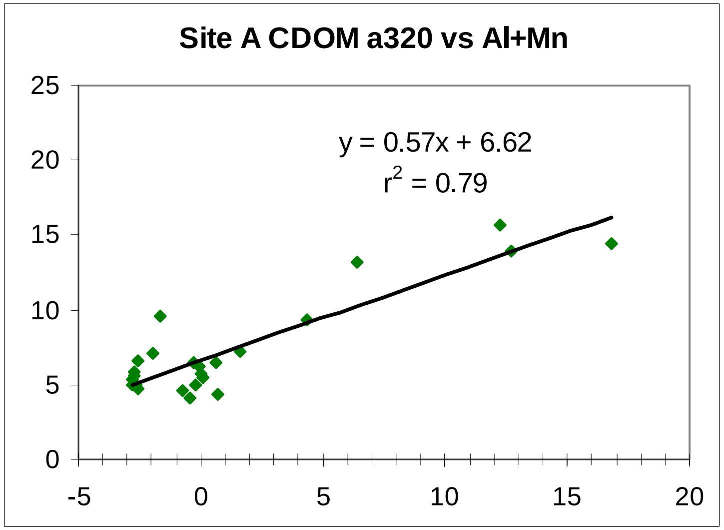
Either Potassium (K^+) or two trace metals (Al+Mn) can predict CDOM changes in storm hydrograph

Agricultural site | Forested site

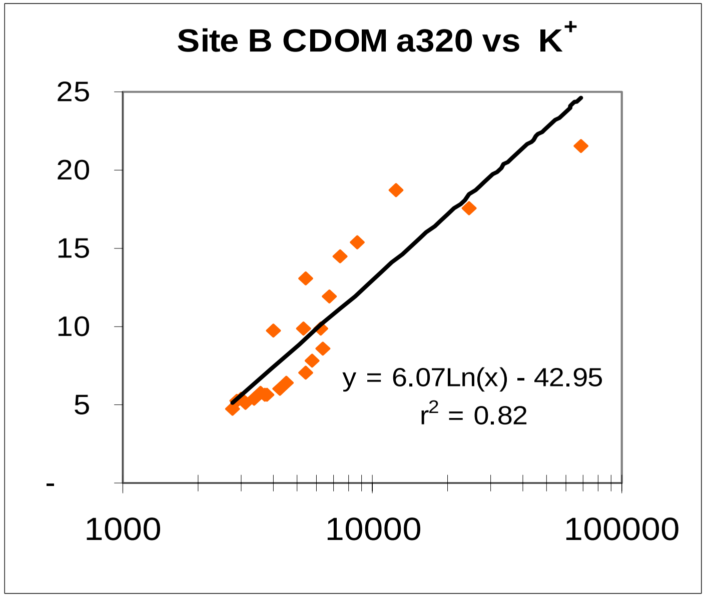
Al+Mn

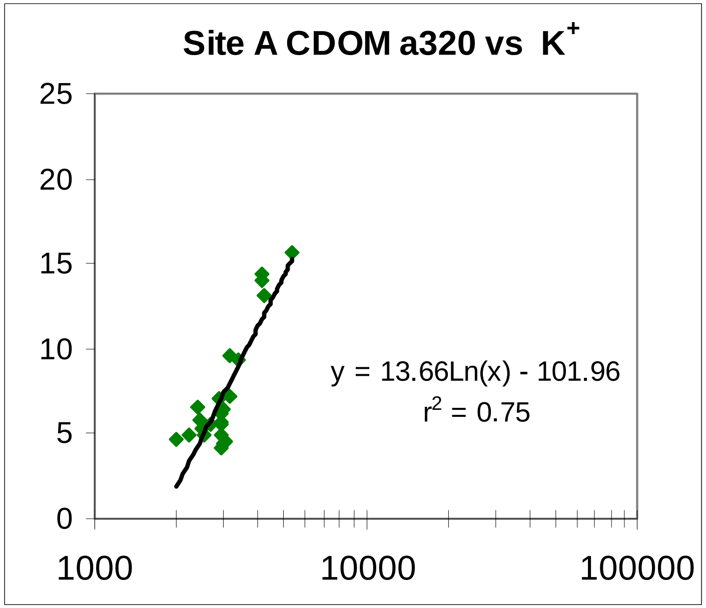
(high in canopy throughfall, nil in baseflow)





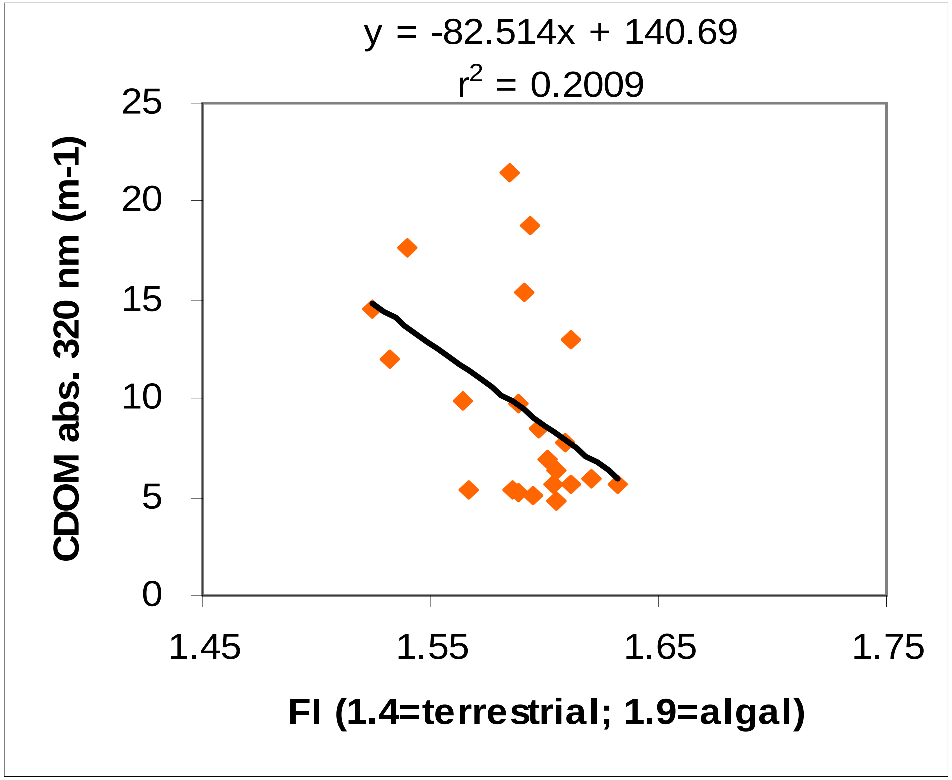
K^+ (high in canopy throughfall & fertilizer, moderate in baseflow)



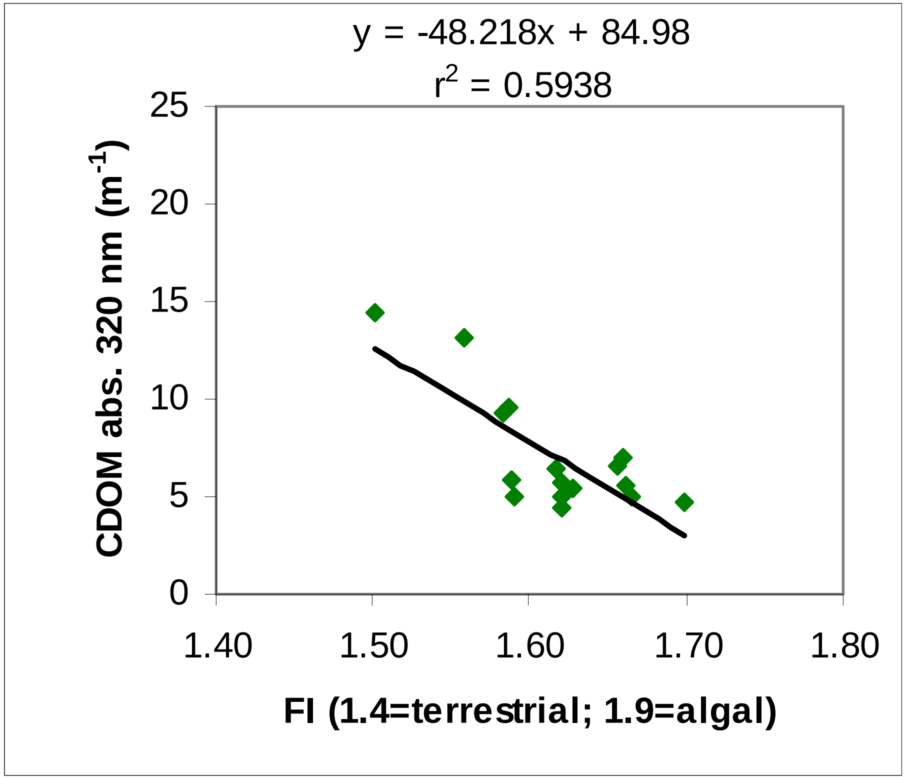


CDOM quality changes during storm runoff: **terrestrial fluorescence index (FI<1.6) during storm peak**, **algal signal (FI>1.6)** during baseflow

Agricultural site



Forested site



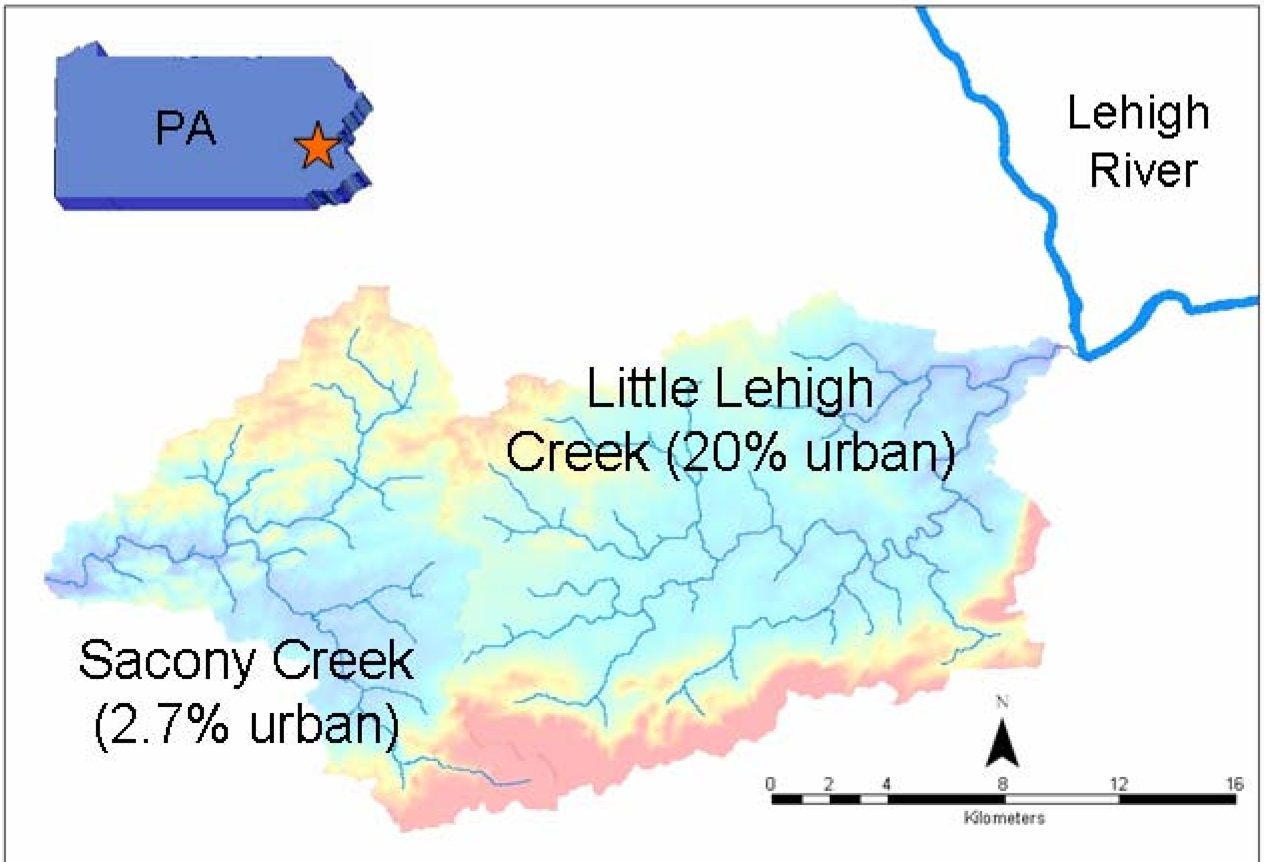
2C Conclusions

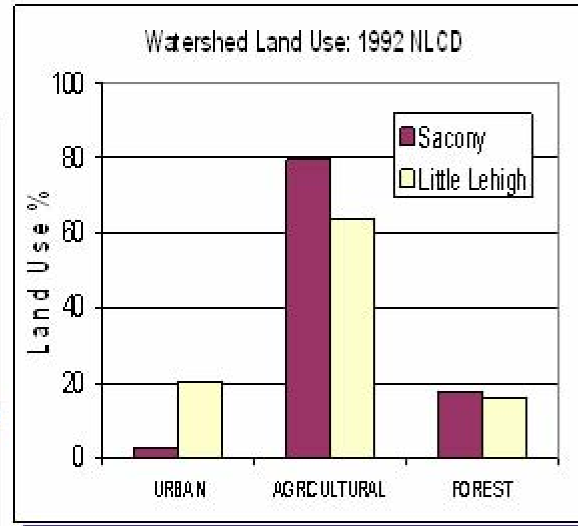
- Storm events increase CDOM (and turbidity, not shown)
- Increases in CDOM during storm are derived primarily from shallow flowpaths
- Approx 10% - 80% of storm CDOM is derived from throughfall/canopy interaction
- Baseflow CDOM derived partly from stream biofilm

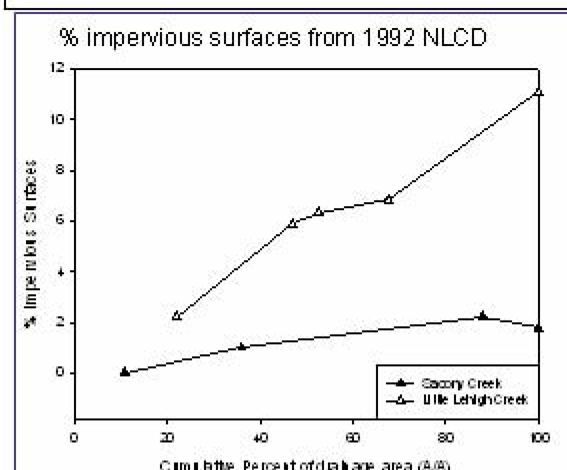
2E. Quantifying the effects of urbanization on two watersheds:

- How does discharge scale with variation in drainage area in an urban region?
  - Measure discharge at multiple points along stream with miniature level loggers
  - Scaling relationship: $Q = kA^c$ where Q = discharge, A = drainage area, and k and c are constants

Is discharge scaling influenced by land cover (Little Lehigh Creek has more urban land cover than Sacony Creek)?





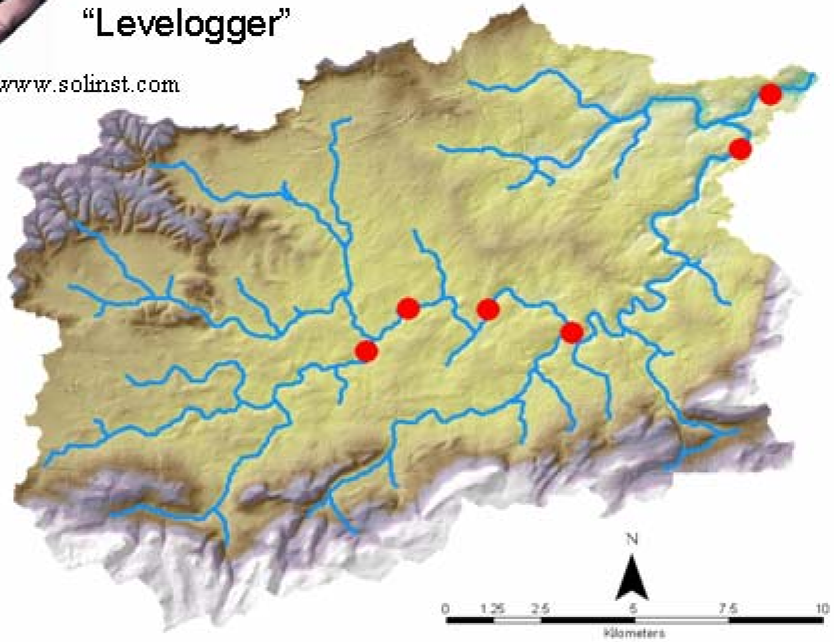


2E. Quantifying the effects of urbanization on two watersheds

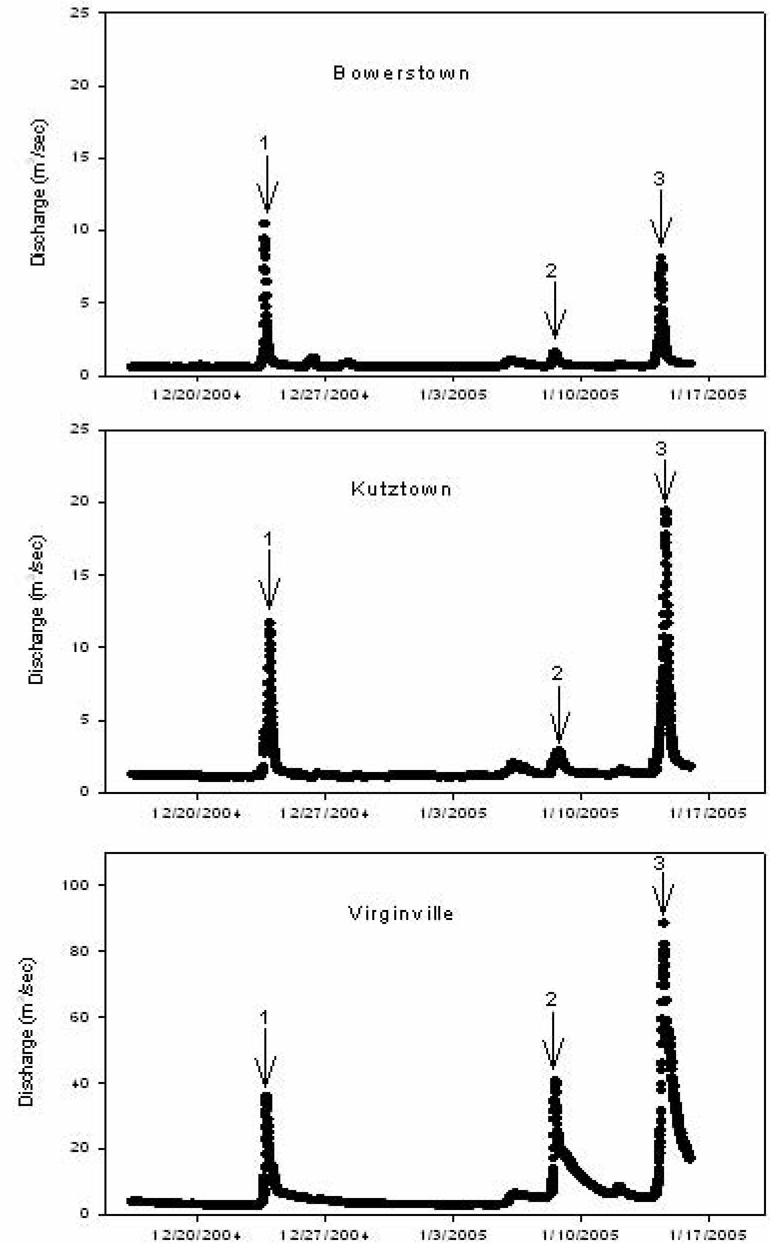
Solinst "Levelogger"

www.solinst.com

Little Lehigh Creek Watershed



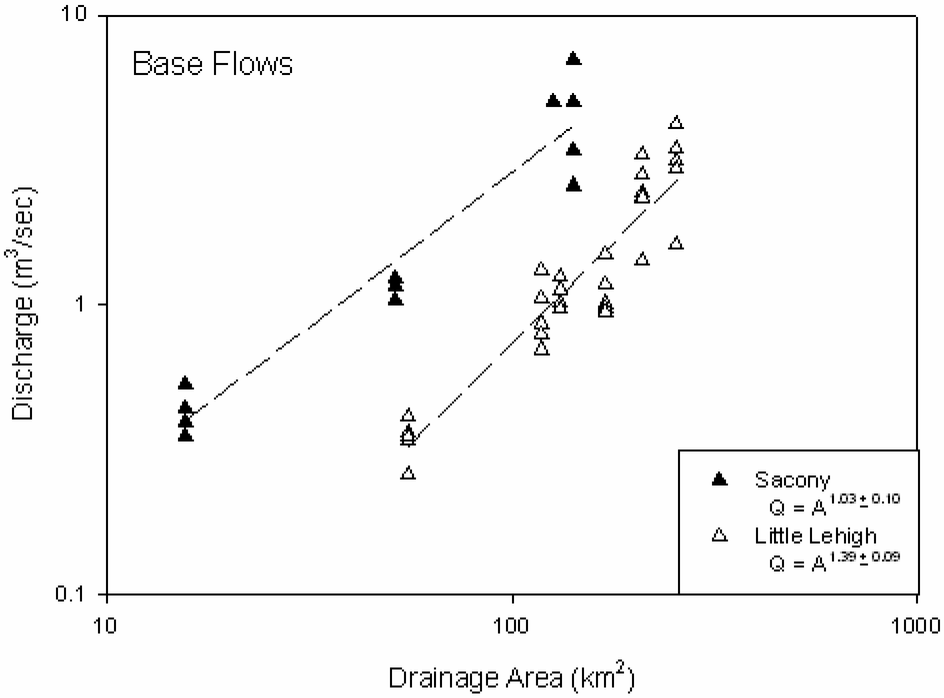
- Peak flows and base flows were compiled from each gaging station
- Scaled to local drainage area (A)
- Linear regression through the data to solve for "c"

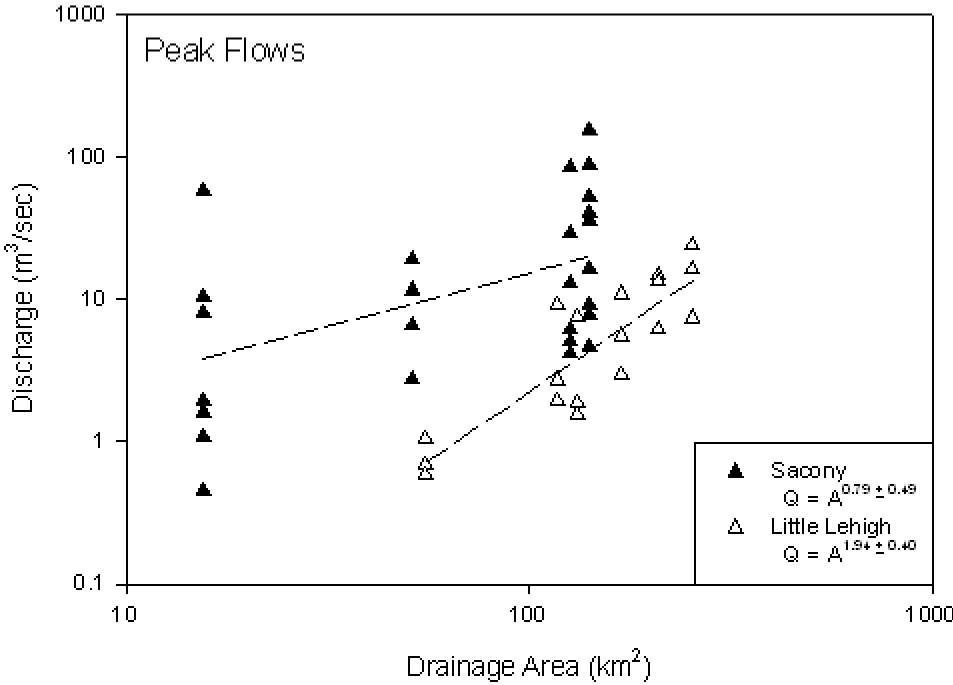


2E. Discharge appears to scale differently in Little Lehigh and Sacony watersheds

- Little Lehigh Creek shows a more rapid increase in storm discharge as drainage area increases (higher slope, "c").

- This is consistent with its greater urban land cover and % impervious surfaces.



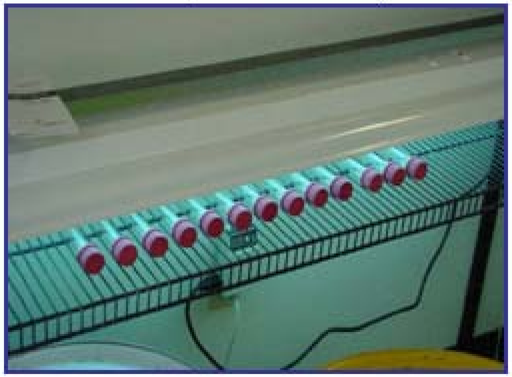


2E. Land use changes since 1947

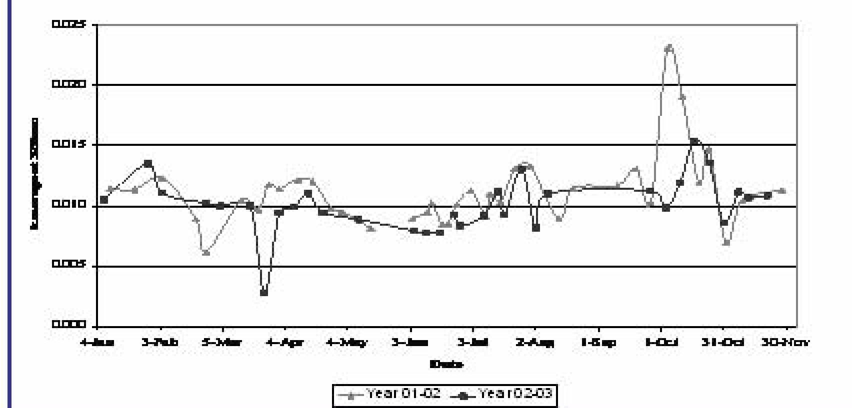
Little Lehigh Creek near Trexlertown, PA

3A. What is the photochemical processing of CDOM?: photolability "k"
("k" = fraction of sample photobleaching per 2 days of summer sun)

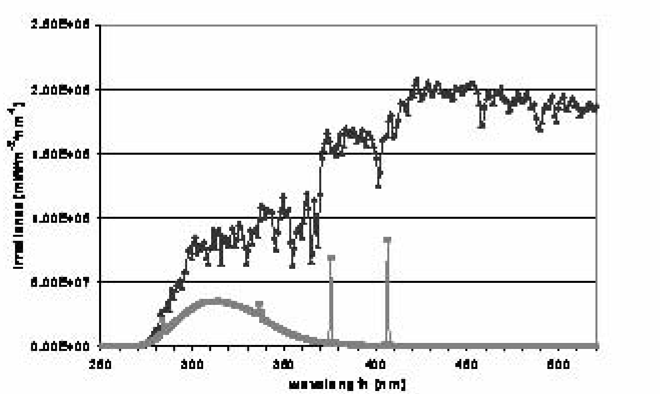
Exposure of sample in quartz tubes to UV fluorescent lamp for two days



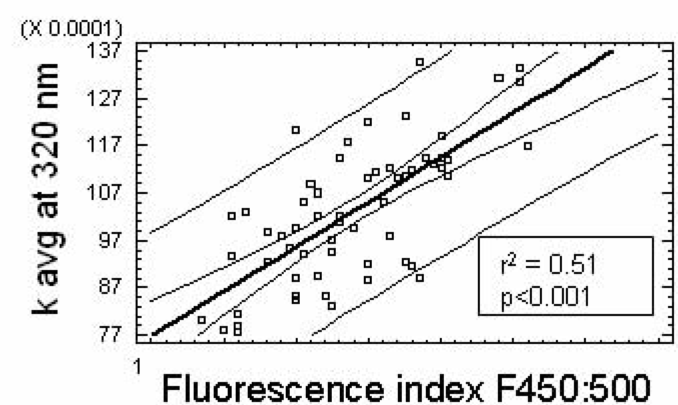
The exponential rate constant "k" varies seasonally



Lamp spectrum differs from solar irradiance but 48-hr exposure causes photobleaching similar to two days in summer sun.



Algal DOC (FI>1.6) is more easily bleached.

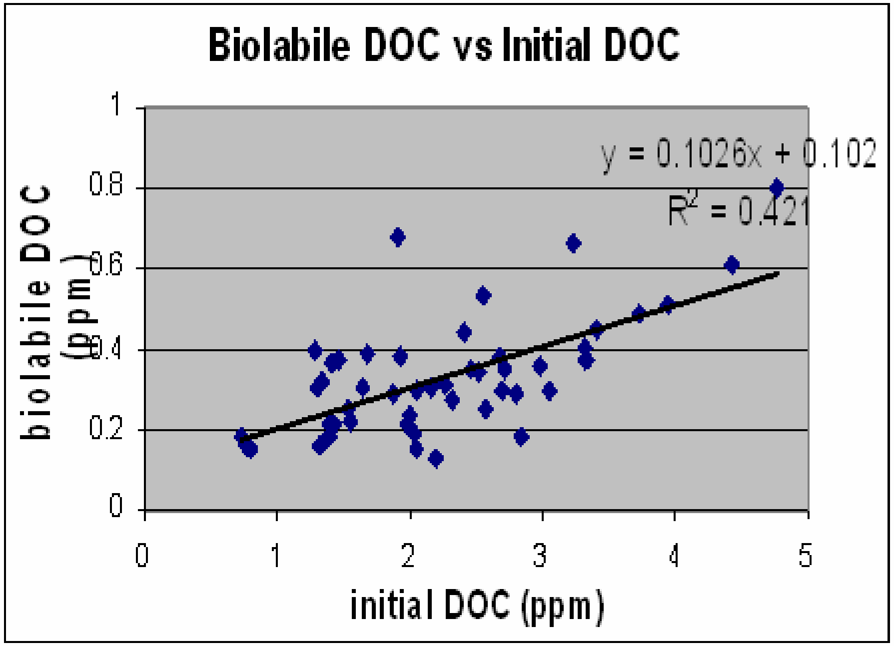


3B. Microbial processing of CDOM:
What is the biolability of Lehigh River water?
Is biolability influenced by photobleaching?

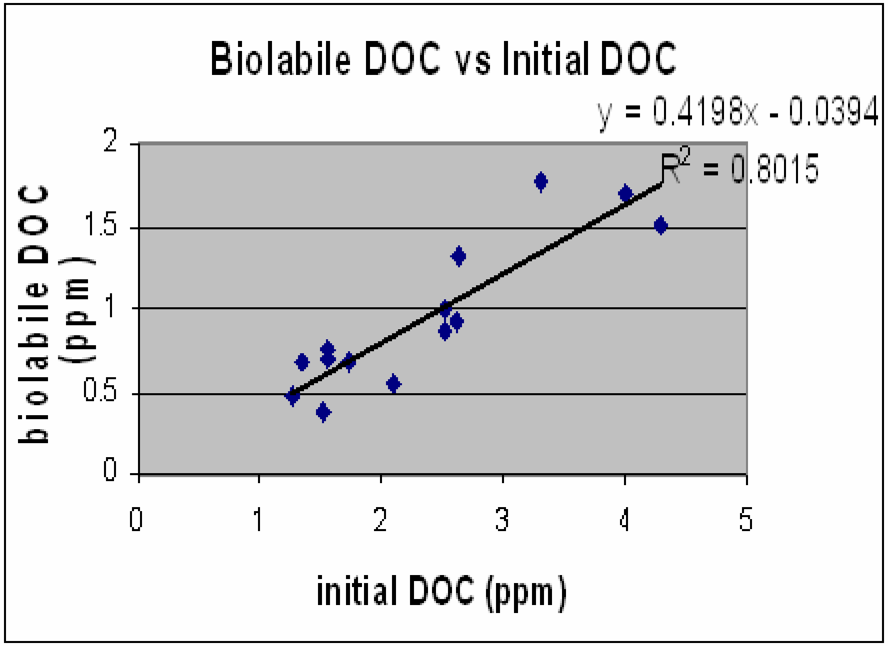
- Bioreactors
  - Low pressure glass chromatography columns
  - Borosilicate glass beads
  - Kept in the dark with Al foil
  - Continuously supplied with water using a peri pump
  - PEEK tubing
  - Feed water
  - Experiments~5vol

3B. Microbial processing of CDOM:
--What is the biolability of Lehigh River water?
--Is biolability influenced by photobleaching?

10-15% of Lehigh River DOC is biolabile (consumed readily by bacteria)



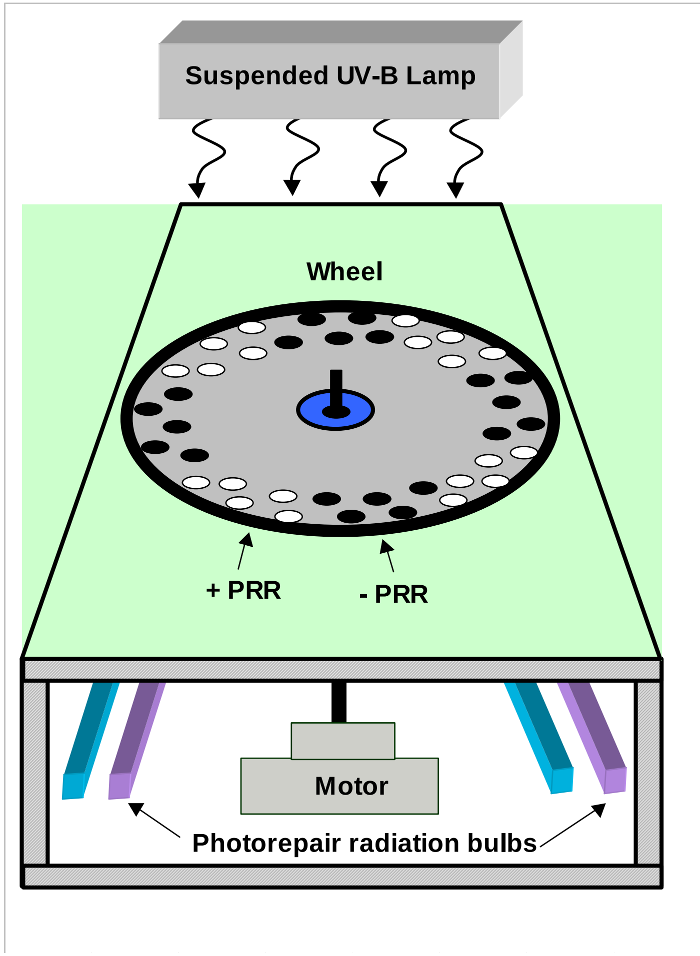
After photobleaching for equivalent of two summer days, 40% of Lehigh River DOC is biolabile



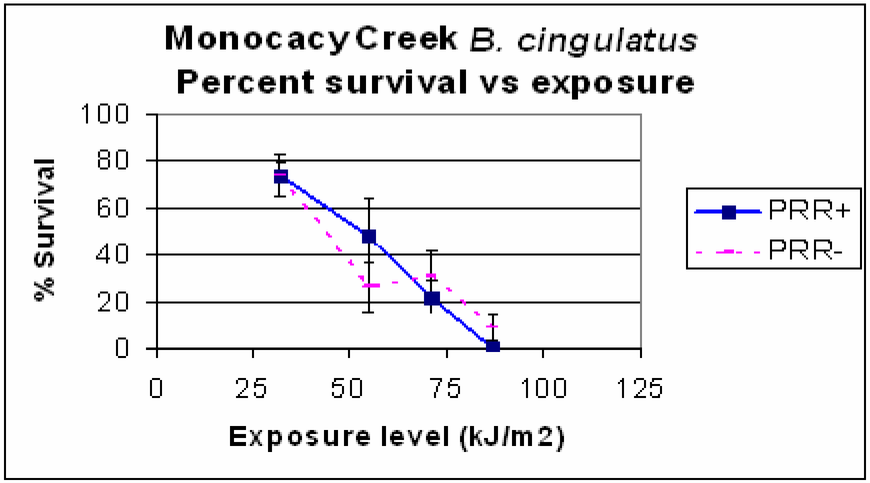
4A. UVR impact on stream macroinvertebrates (lab tests in UV Lamp Phototron)

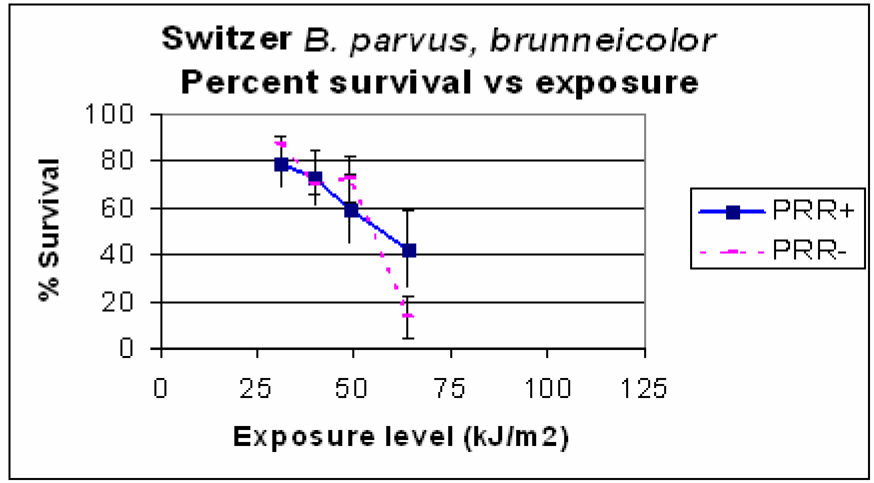
- Mayfly nymphs collected at each site
- Dominant species (as determined by quantitative samples) of approximately the same size were isolated
- Placed in replicate quartz dishes with 5 organisms in each dish, in filtered spring water
- Incubated at 10 degrees C overnight
- Following morning placed in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

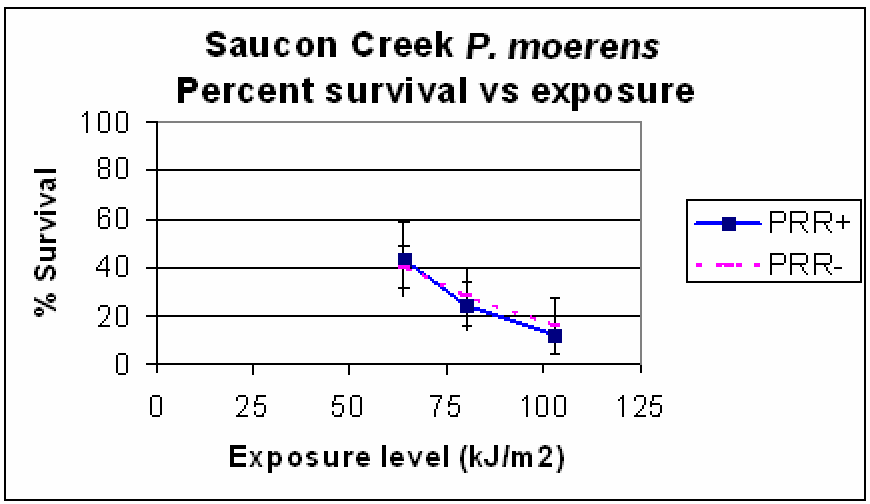


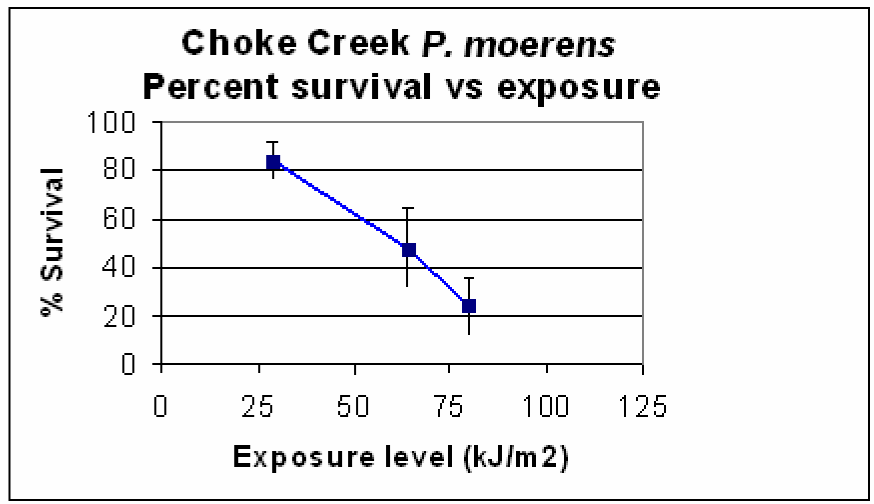



4A. UV Lamp Phototron Results: LE50 dose that allowed 50% survival









4A. Comparison of UVR resistance of stream mayflies with other invertebrates (note that Chironomid midge flies are more sensitive)

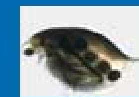
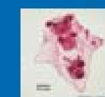
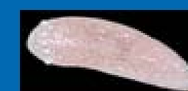
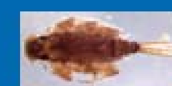
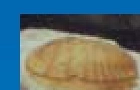
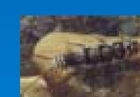
Lake invertebrate	Daphnia		15 kJ/m^2
Stream invertebrate	Chironomidae		16 kJ/m^2
Lake invertebrate	Asplanchna		20 kJ/m^2
Stream invertebrate	Planaria		<31kJ/m^2
Stream invertebrate	**Ephemeroptera (mayflies)**		**33-64 kJ/m^2**
Stream invertebrate	Trichoptera/Hyrdopsychidae (caddisflies)		56 kJ/m^2
Stream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

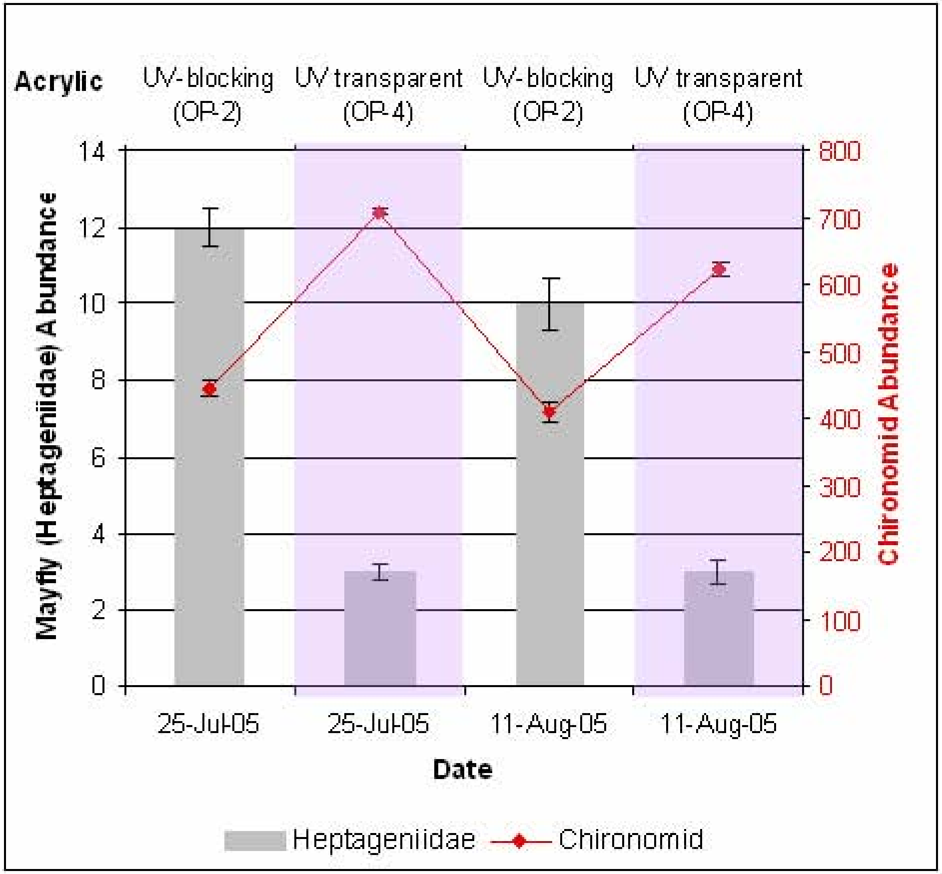
Cliff White

4B. UV Impact on stream macroinvertebrates measured by manipulating UV *in situ* at 2 stream sites (partly open canopy & forested canopy)

Partly-open canopy

Artificial benthic substrate

Grazers (e.g. mayfly nymphs) were less abundant in UVR treatment, apparently allowing more algal growth in which Chironomids (UV sensitive) could find refuge from UVR



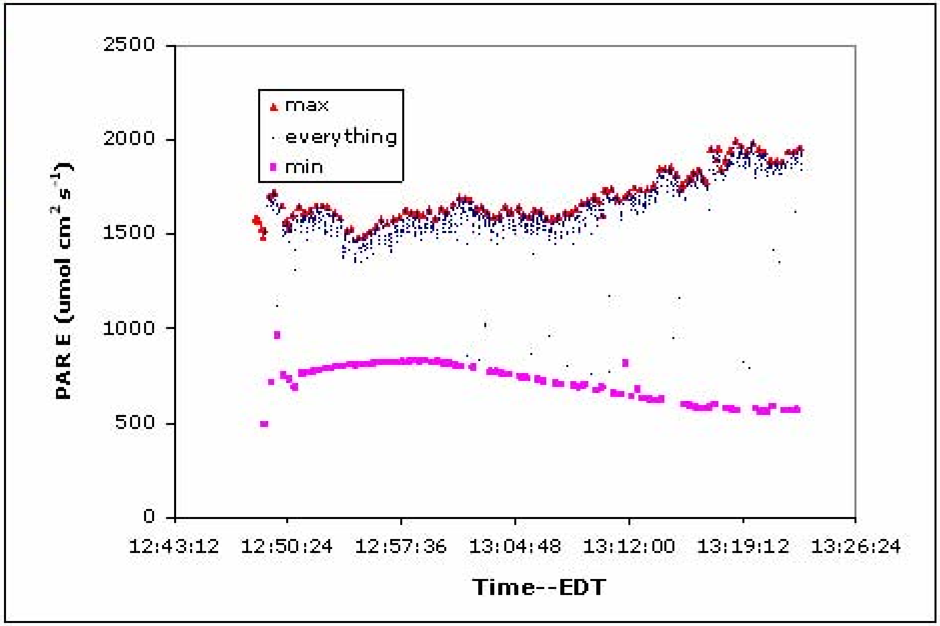
5A. UVR Penetration of Stream Canopy: Shadowband radiometer measures diffuse (skylight) and direct (sun) PAR irradiance

<=Band rotates 180° each 30 seconds, casting shadow briefly over sensor to record diffuse irradiance (skylight)

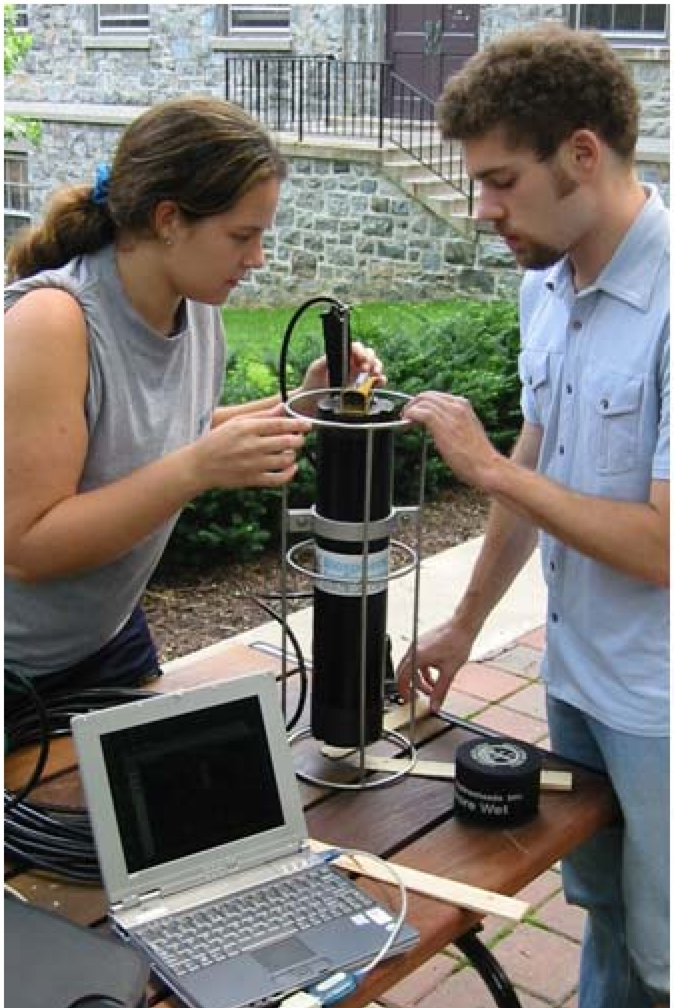
Sample shadowband record=>

"Max"=direct+diffuse

"Min" =diffuse only

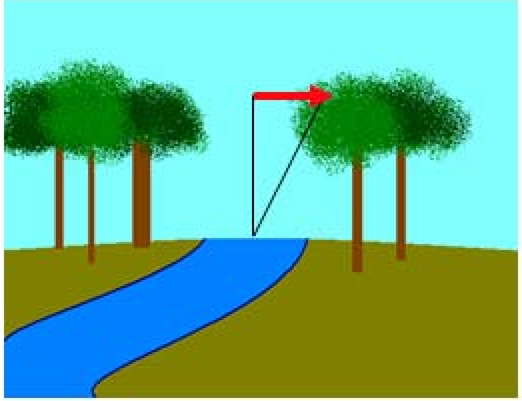


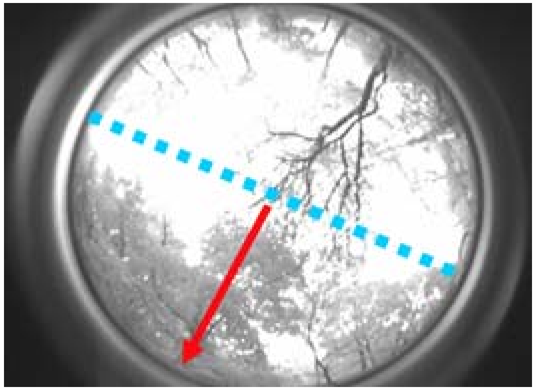
5A. UV radiometer measures canopy transmittance by comparing under-canopy and open-field irradiance (adjusted for changing sky conditions with shadowband PAR data)



5B. From hemispherical camera images we can calculate stream canopy openness (Sky View Factor)

We modified the commercial hemispherical camera system with a battery-powered extension to keep our computer on the stream bank

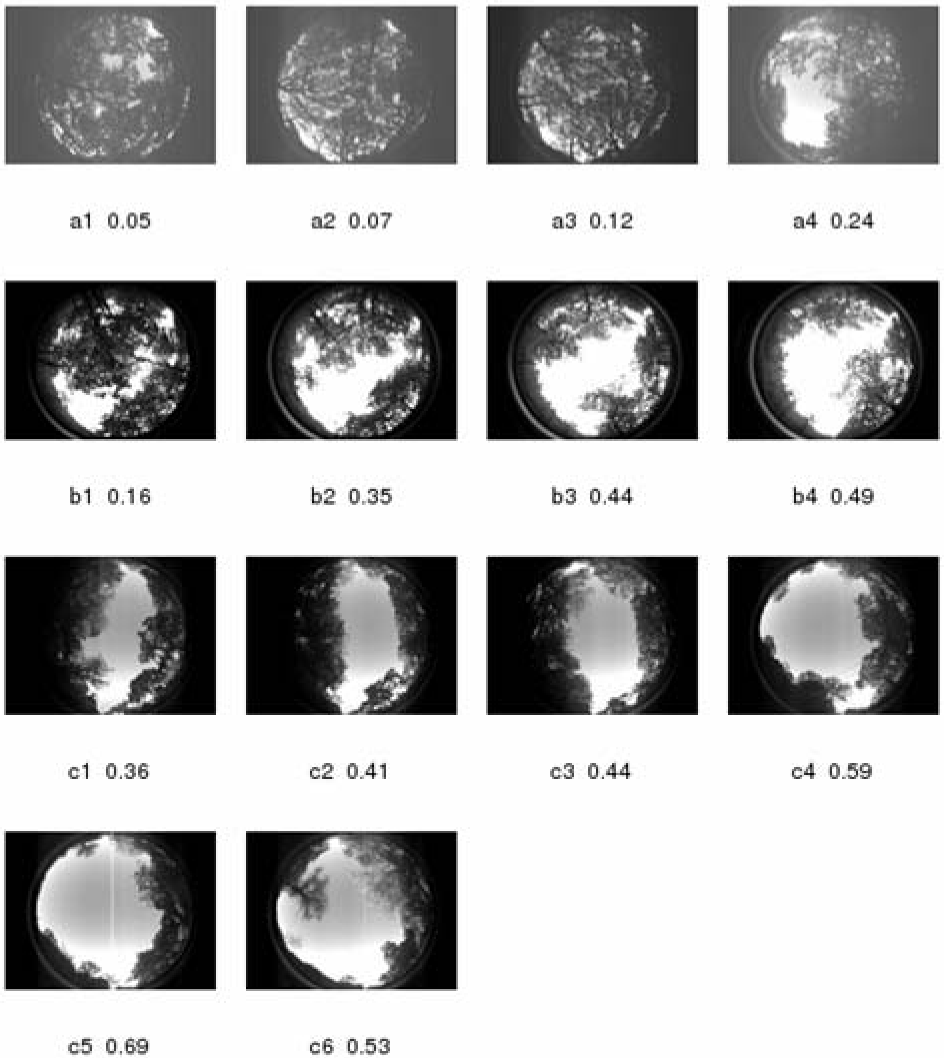




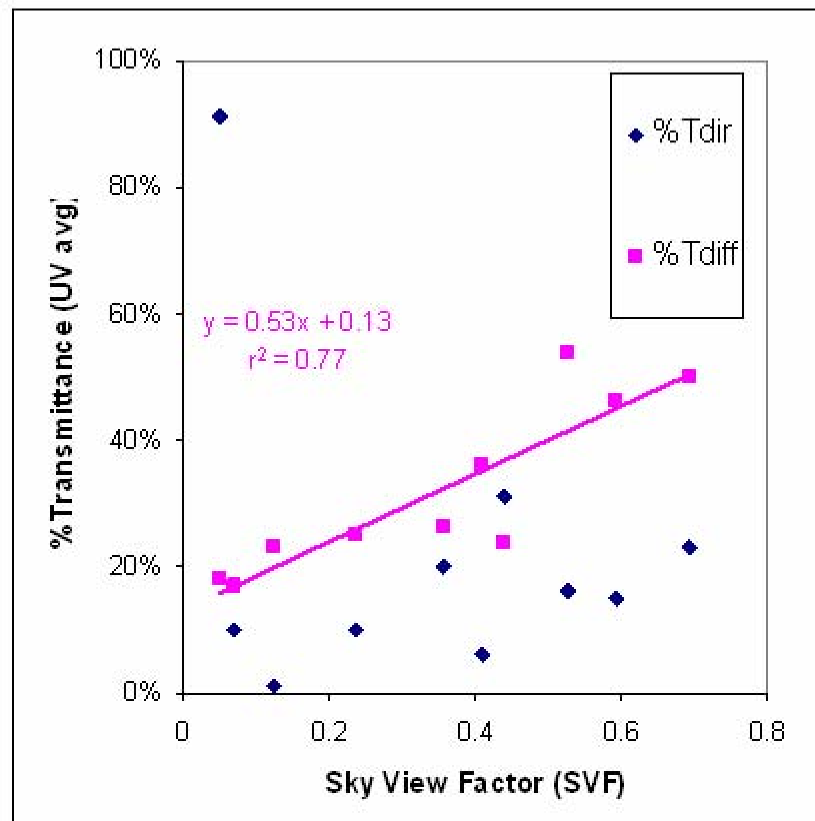
Upper: **The degree to which tall objects shade the stream channel depends upon their height, h, and distance, r, from the center of the stream.** Lower: **Hemispherical photo.**

5A & 5B: Fisheye camera image "SVF" of canopy is correlated with diffuse transmittance (%T_{diff}) in UV & VIS wavebands

Sample of hemispherical photos
& calculated sky view factors



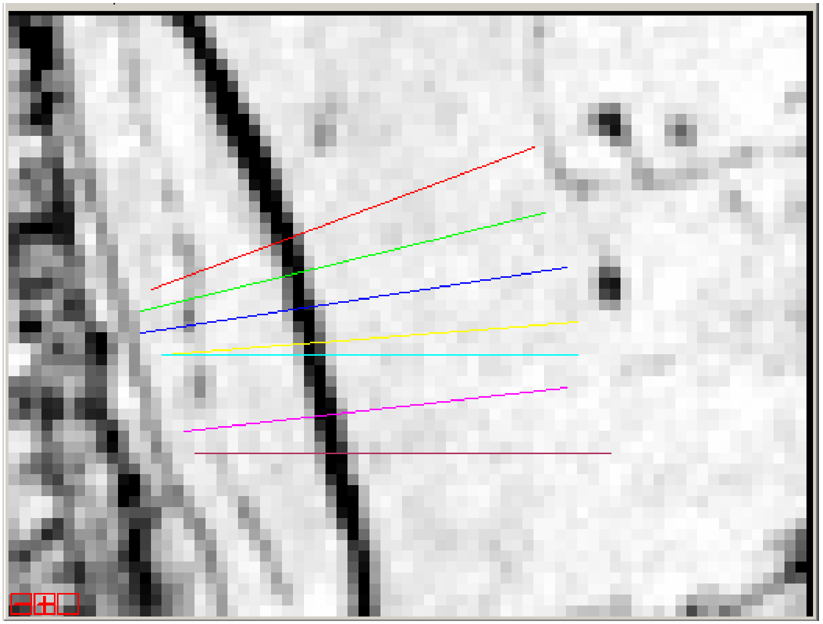
Canopy Transmittance for **diffuse irradiance (%T_{diff})** is correlated with canopy openess (SVF) determined by fisheye images

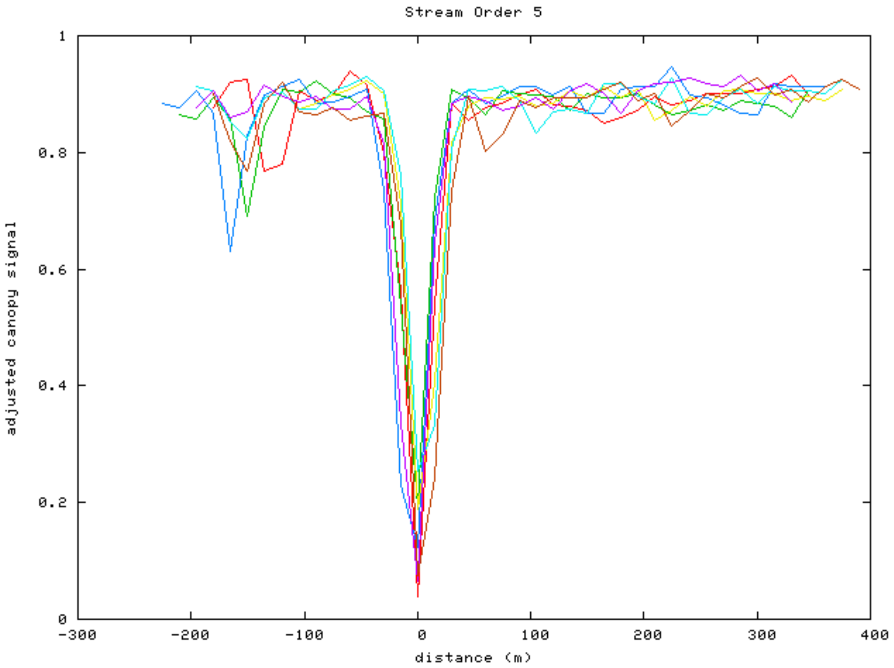


5C. UVR exposure of streams across the Lehigh River watershed

- We are developing a calibration to use satellite images of land cover (IR bands indicate vegetation) to estimate SVF and %Tdiff for low order streams and other forested areas.
- We are developing an algorithm to use satellite images to estimate canopy gap for high order streams
  - Comparing water and vegetation signals in IR bands)
  - Plotting multiple stream transects on satellite image (grid data) registered with stream polylines using georeferenced black & white aerial photographs as a test.

5C. Satellite-based measurement of canopy characteristics—canopy gap for high order streams





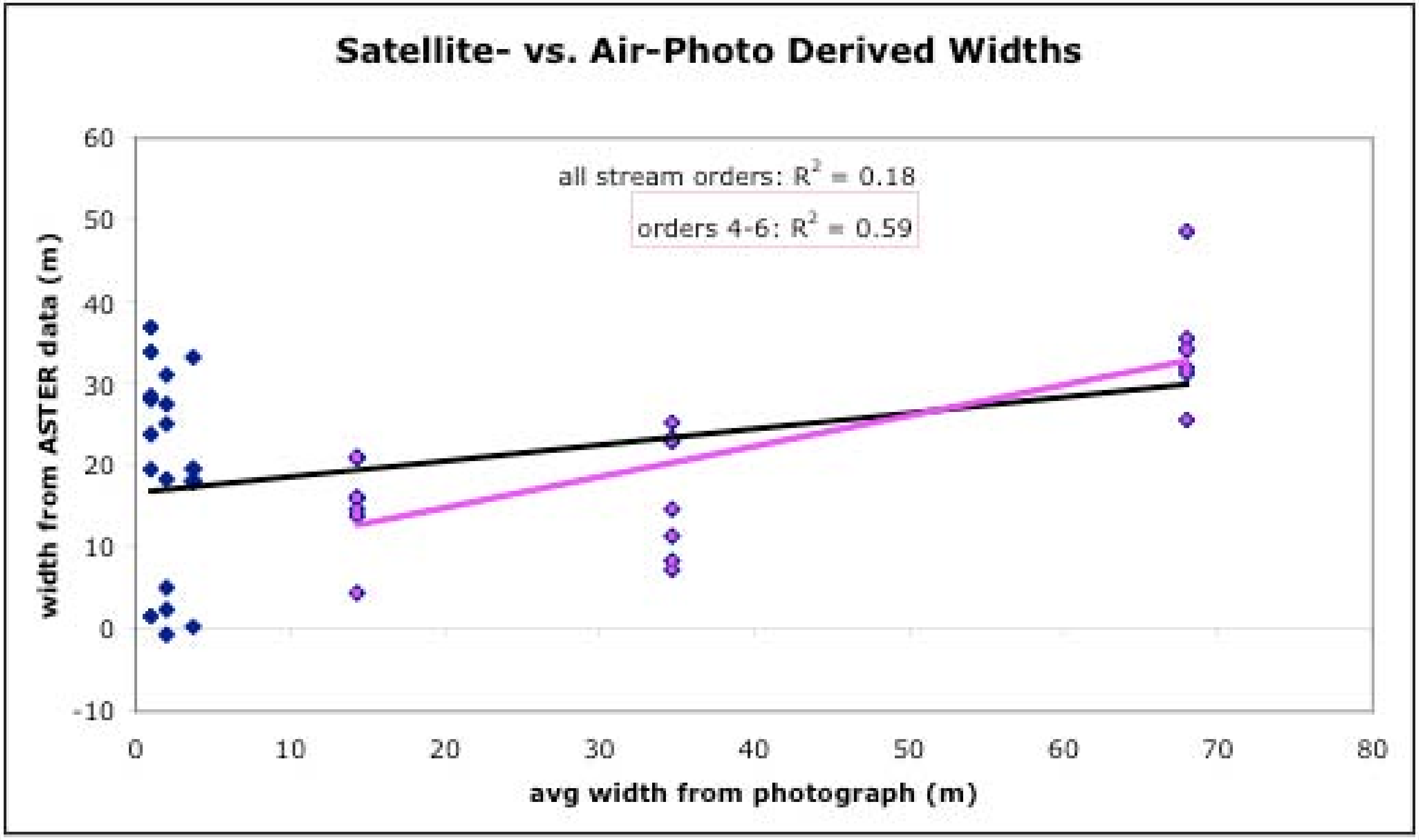
Transects across a satellite image of a fifth-order stream
Light pixels = higher values = more vegetation-like signal,
Dark pixels = lower values = more water-like signal.

The dip in the graph shows the strong water signal from the stream channel center.

5C. Satellite-derived gap index vs. measured canopy gap

- **For stream orders 4-6,** promising correlation (r2=0.59) of satellite-derived canopy gap and gap width measured using aerial photography

- **For stream orders <4**, gap is too small for 50m pixel resolution of satellite data



Summary

Climate, Land Use, and UV Radiation in the Lehigh River ecosystem

- **UV attenuation in natural waters**
  - Attenuation varies with DOC concentration and optical quality as in previous studies
  - K_{dUV} varies linearly with turbidity & suspended particle concentration

- **Stream-watershed-landuse-climate patterns & interactions**
  - Basin scale: DOC concentration predicted from wetlands area
  - Small watersheds across the basin: [DOC] varies inversely with %Forest land cover when wetlands are absent.
  - Paired watersheds differing in land cover: Canopy contributes strongly to DOC in storm runoff
  - New stirred container method measures UV diffuse attenuation of water from shallow streams (lake-tested)
  - Storm discharge increases more rapidly with drainage area in stream catchments that have experienced urbanization.
  - UV attenuation will increase in the future if precipitation increases

Summary (continued)

Climate, Land Use, and UV Radiation in the Lehigh River ecosystem

- **Photochemistry and microbial processing of DOC**
  - Photolability (fractional photobleaching of DOC) varies seasonally and with source of DOC (algal DOC is more easily bleached)
  - 15-40% of stream DOC is consumed by bacteria (they can use more DOC after it has been photobleached)
- **Biotic responses to UVR of stream macroinvertebrates**
  - UV Lamp Phototron lab experiments show that mayfly nymph UVR resistance is moderate
  - Filter-feeding Chironomids increase while periphyton-scraping Mayfly nymphs decrease when exposed to UVR in stream experiments (opposite from UVR sensitivity; indirect effect of UVR may be mayfly removal on algal refuge for Chironomids?)
- **Shading by stream canopy**
  - Direct measurement of the canopy UVR %T (specific stream reaches) shows that diffuse transparency is correlated with camera-derived canopy openness.
  - Proxy measurement for UV transparency via satellite images (work in progress) confirms that higher order streams have more open canopy gap.