Understanding the water / forest relationship: the influence of forest cover removal on aquatic resources in the Southeastern United States

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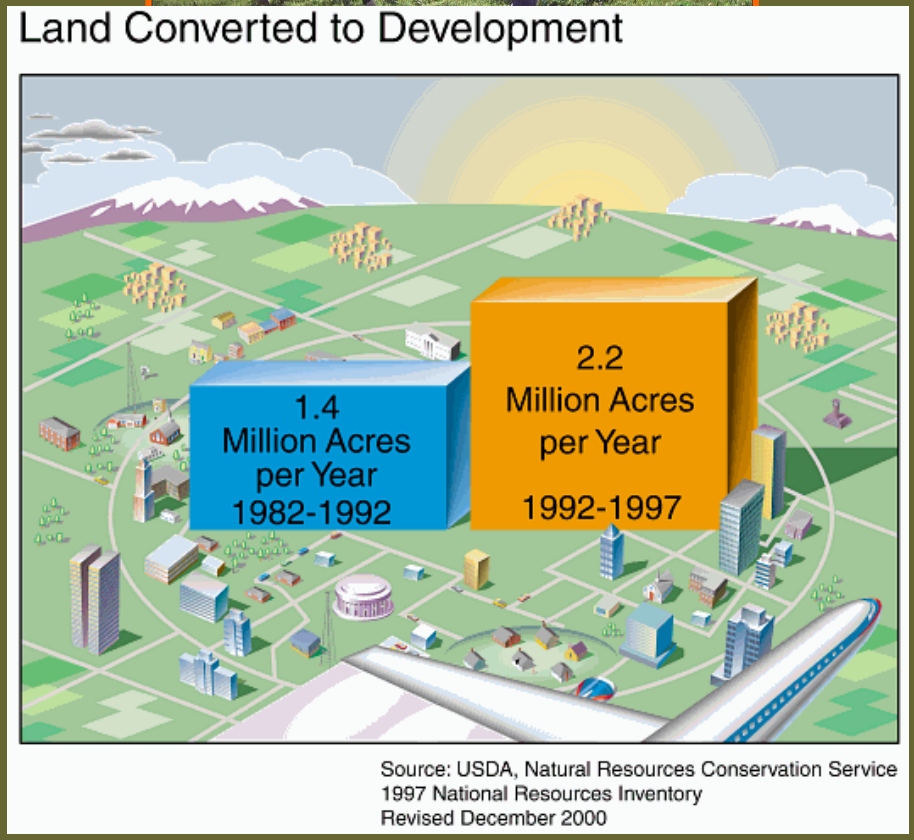
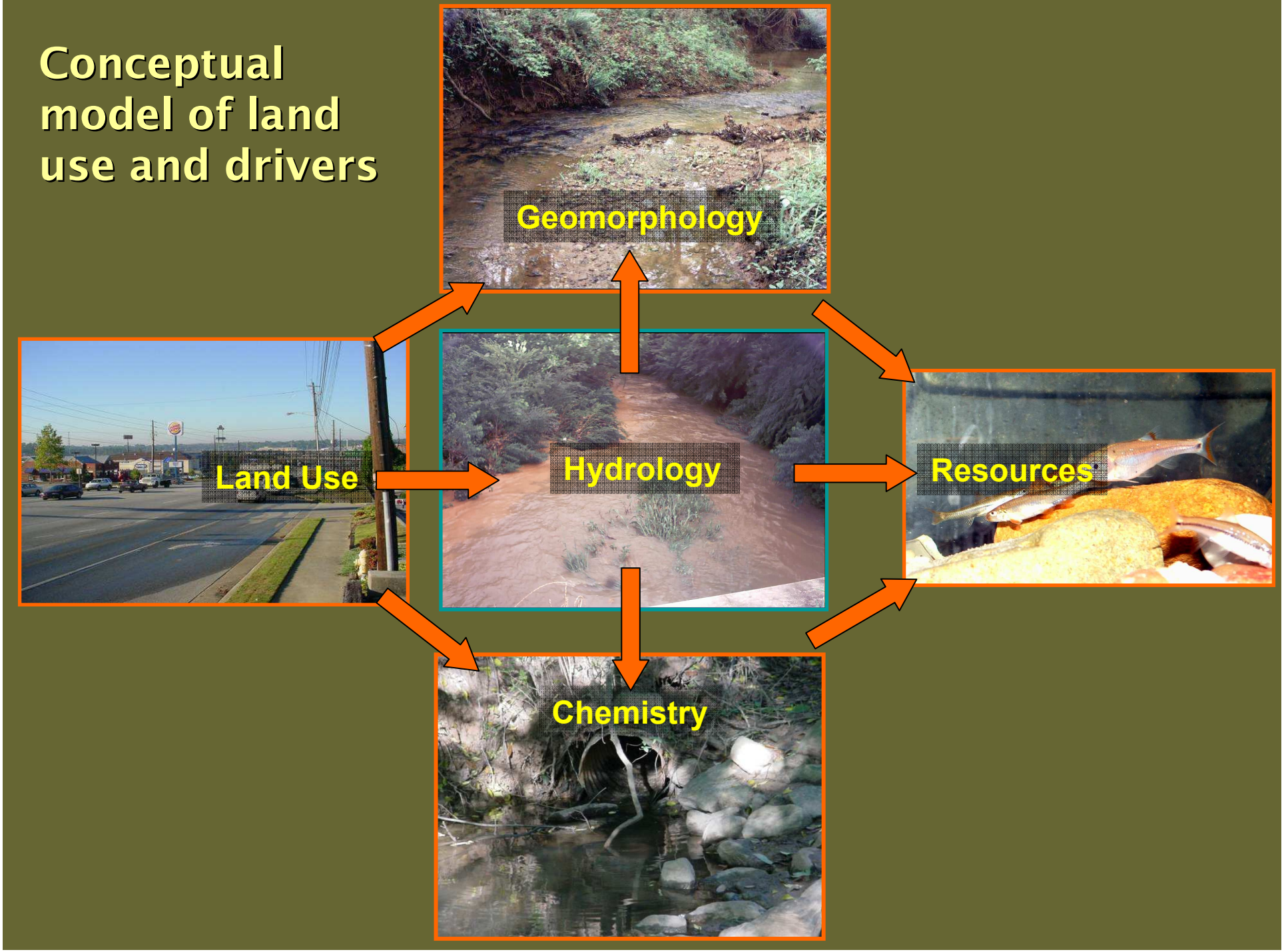
Contemporary land use/cover

- Mixed species forests

- Agriculture
  - Row crop
  - Pasture
  - Animal production
- Silviculture
  - Pine plantations
- Urbanization

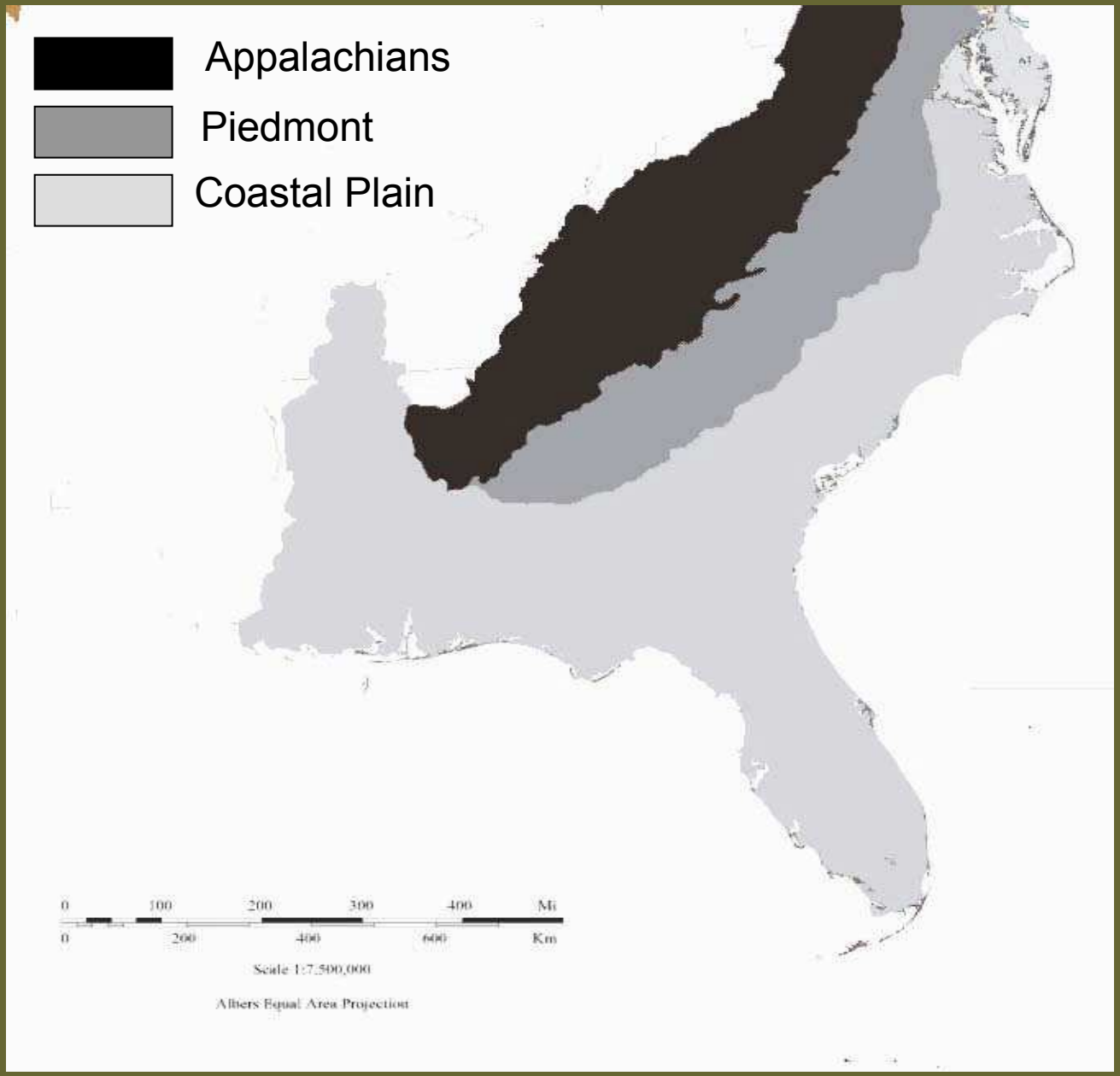


Conceptual model of land use and drivers



Difficulties in prediction and management

- Variation within and between regions
  - Types of forest
  - Extent / rates of conversion
- Processes destabilization
  - Hydrological
  - Geomorphological
- Lagging ecological responses
  - Unknown times
- Unknown effectiveness of management


Appalachians
Piedmont
Coastal Plain
0 100 200 300 400 Mi
0 200 400 600 Km
Scale 1:7,500,000
Albers Equal Area Projection

Ecoregions in the SE

- Coastal Plain
  - Extensively logged early 19th century
  - Large ag tracts
  - Increase in forest cover, silviculture
  - Urbanization restricted to coast lines
- Piedmont
  - Intense ag 18th – 20th century
  - Considerable erosion, reforestation
  - Increase in silviculture, pasture
  - Rapid urban growth last 30 years
- Appalachian Mountains
  - Logging and ag late 19th – early 20th century
  - Extensive mining and industrialization
  - Industrialization and urbanization since ’70s
  - Considerable reforestation

19th – 20th century cotton farms

Categories of influence

- Hydrology / geomorphology
- Biogeochemistry and sediment
- Aquatic biota
- Human and environmental health

- 2 scenarios
  - Forest to agriculture
  - Forest to urban

Hydrological Response

- Forest to agriculture
  - Increase watershed discharge 10-20%
  - ↑ overland flow, ↓ evapotranspiration
  - ↑ storm and base flows
- Forest to urban
  - ↑ discharge 3-5% for every 1% ↑ impervious surface
  - ↑ storm and base flows
  - Unstable hydrographs
  - Early detection
- Reduced water storage capacity
  - ↑ overland flow, ↓ infiltration
  - ↑ water export

Biogeochemistry and Sediment

- Forest to agriculture
  - ↑ sediment erosion and deposition
  - ↑ NO_3 (6-12X), NH_4
  - ↑ total P loads
  - ↓ DOC
- Forest to urban
  - ↑ sediment erosion, deposition and transport
  - 2-4X ↑ NO_3,
  - Inconsistent NH_4,P, phosphate and DOC
  - Effects seen early in development

Aquatic biota

- Forest to agriculture
  - ↑ algal biomass
  - ↓ insect diversity, richness, and shredders
  - ↓ mussel survivorship,
  - Variable fish, herpetofauna responses

- Forest to urban
  - Varied algal response
  - Macroinvertebrates track TDS and habitat quality
  - ↓ mussel abundance, often extirpation
  - ↓ fish and salamander diversity and abundance

- Ecosystem stress syndrome
  - ↓ species diversity, endemism
  - ↑ tolerant, widespread species
  - ↑ species stress and disease
  - Urban stronger per capita influence than agriculture

Environmental and human health

- Forest to agriculture
  - ↑ pesticides, herbicides
  - ↑ water-borne pathogens
  - NH_4 toxicity
  - Variable bacterial response
- Forest to urban
  - ↑ heavy metals, pesticides
  - ↑ bacterial populations
  - ↑ pharmaceuticals, organic wastewater contaminants
    - Caffeine, Ibuprofen, disinfectants
  - ↑ mussel, fish toxicity
- Stormwater runoff major source

Ecoregional differences

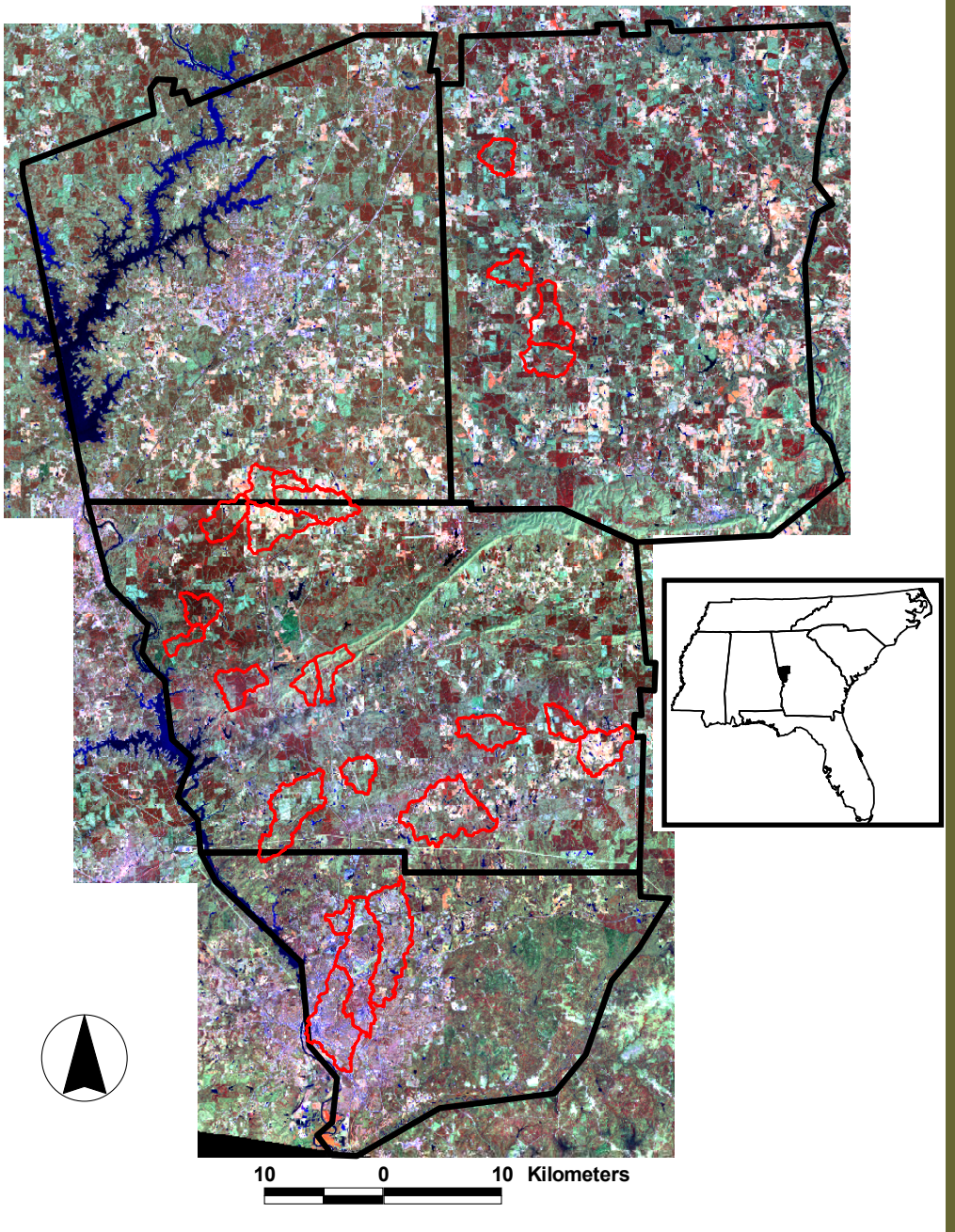
- DOC
- NH_4
- NO_3
- Runoff Potential
- Algal assemblages
- Fish diversity

- Forest conversion effects increase with gradient
  - Appalachian > Piedmont > Coastal Plain
  - Stronger response, response at lower disturbance level
  - Land use, landscape history?

- Paucity of Coastal Plain studies

West Georgia Project

- Middle Chattahoochee River Drainage, western GA, USA
- Lower Piedmont Ecoregion
- Urbanization gradient from Columbus NE



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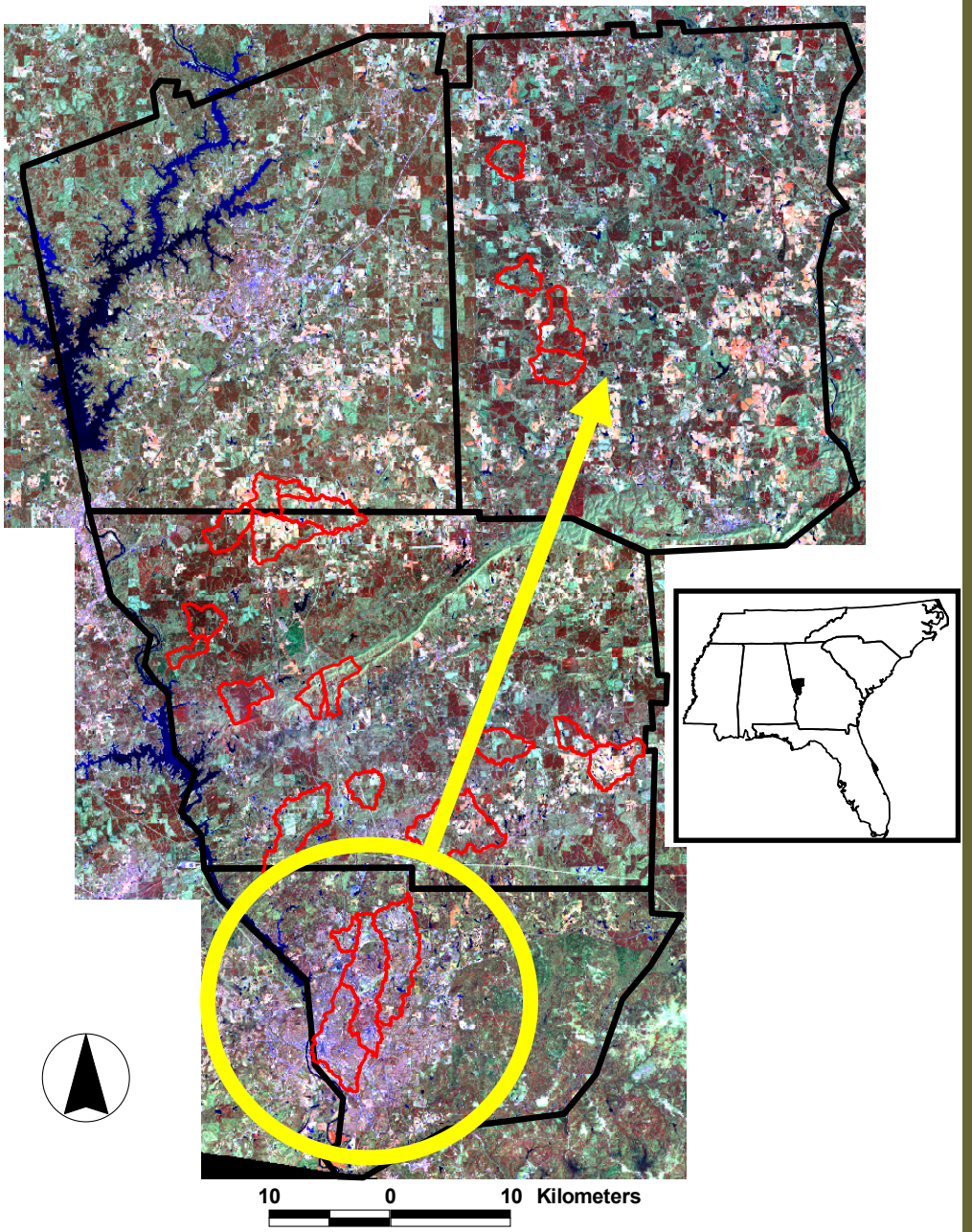


Study Area: 18 watersheds

Objective

- To determine the influence of changing LU/LC on
  - Hydrology
  - Geomorphology
  - Water quality
  - Physicochemistry
  - Microbial populations
  - Biotic assemblages

Hydrology

Table 4. Pearson's correlation coefficients for 15-min hydrology variables by the dominant land cover within 18 western Georgia streams.

Variable	Variable description	IS	Managed forest	Unmanaged forest	Pasture	Forest types combined
Max	Maximum discharge ($L\ s^{-1}$)	0.66**‡	−0.64**	−0.47*	0.20	−0.61**
Max_ha	Maximum discharge/watershed area ($L\ s^{-1}\ ha^{-1}$)	0.54*†	−0.45	−0.46*	0.15	−0.49*
3xMed	Hours the discharge is above 3x median flow	0.65**	−0.43	−0.26	−0.20	−0.34
5xMed	Hours the discharge is above 5x median flow	0.64**	−0.52*	−0.34	−0.03	−0.48*
7xMed	Hours the discharge is above 7x median flow	0.57**	−0.47*	−0.35	0.04	−0.40
>95th	# of times the discharge exceeds 95th percentile	0.52*	−0.46*	−0.36	0.16	−0.43
>99th	# of times the discharge exceeds 99th percentile	0.60**	−0.41	−0.54*	0.15	−0.50*

†* Represents significant relationship at $\alpha = 0.05$.
‡** Represents significant relationship at $\alpha = 0.01$.

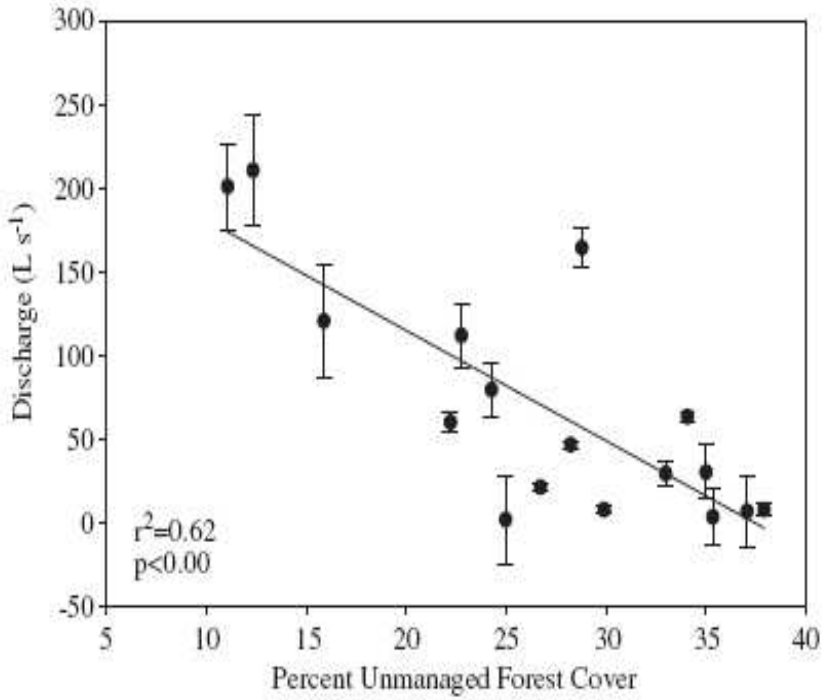
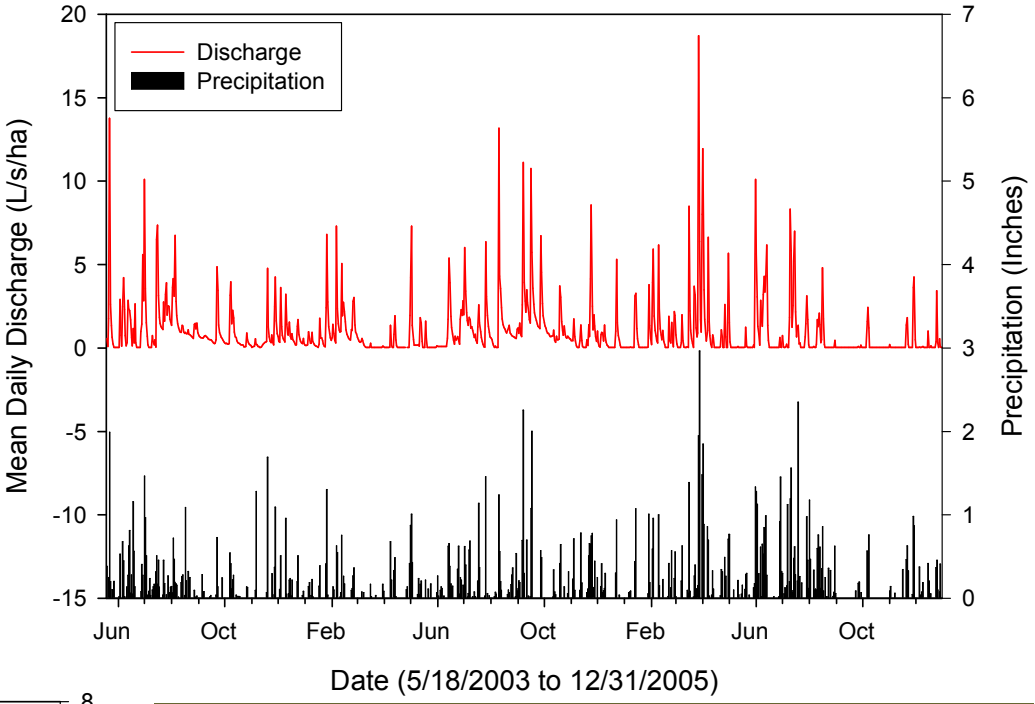
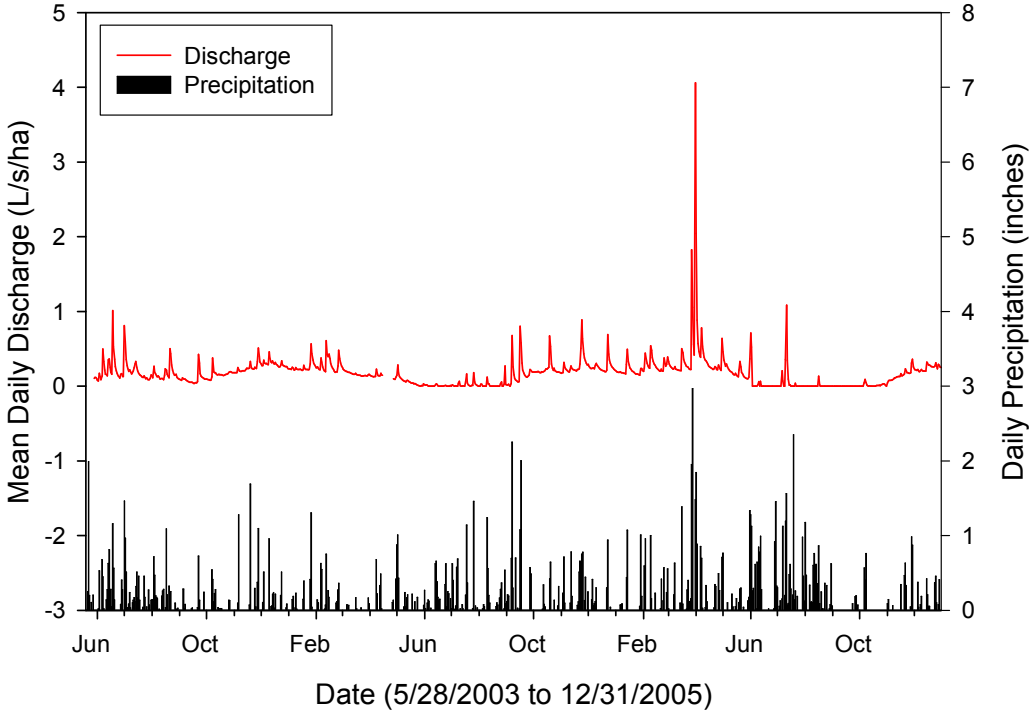


Fig. 2. Median (± 1SE) stream discharge relationships with percent unmanaged forest in western Georgia watersheds.

Hydrology of an urbanized watershed: flashy, peak flows correspond to rainfall events



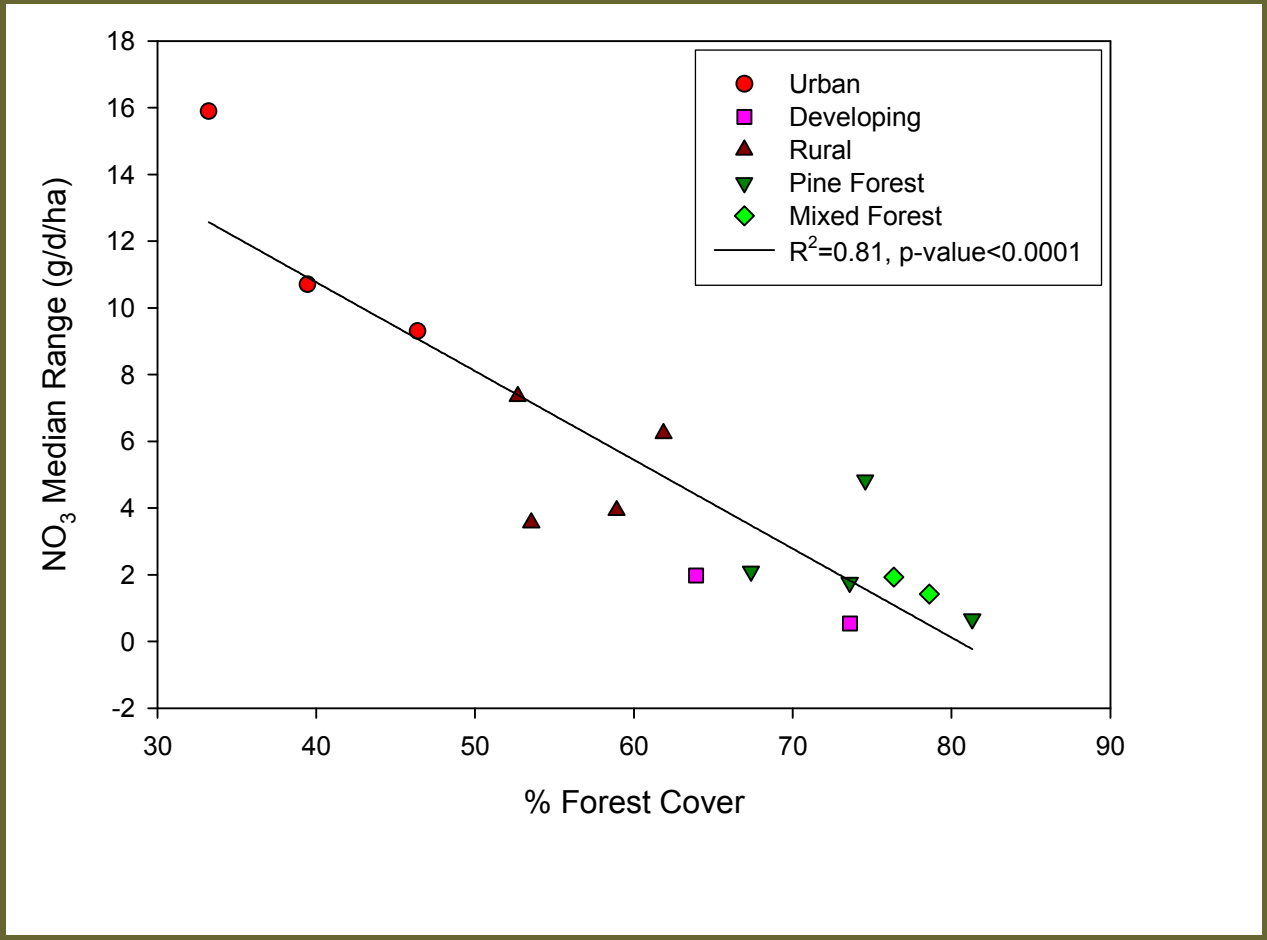


Hydrology of a forested watershed: stable, higher discharge in winter and spring

Spearman correlation coefficients between water quality parameters and land cover percentages for baseflow and stormflow						
	Baseflow			Stormflow		
Variable	% IS	% Forest	% Ag	% IS	% Forest	% Ag
Conc. (mg/L)						
TDS	**0.71**	**-0.47**	**-0.49**	**0.65**	**-0.46**	**-0.38**
TSS	0.03	**-0.19**	**0.16**	**0.31**	**-0.27**	-0.04
Cl	**0.81**	**-0.77**	**-0.28**	**0.60**	**-0.62**	-0.07
NO_3	**0.22**	**-0.58**	**0.15**	**0.35**	**-0.66**	0.09
SO_4	**0.48**	**-0.28**	**-0.65**	**0.59**	**-0.40**	**-0.45**
Na	**0.53**	**-0.21**	**-0.35**	**0.39**	**-0.16**	-0.15
NH_4	0.07	**-0.26**	0.08	**0.52**	**-0.61**	**-0.20**
K	**0.47**	**-0.53**	**-0.26**	**0.50**	**-0.63**	-0.14
P	**0.13**	**-0.17**	0.07	0.07	0.03	-0.05
DOC	**0.48**	**-0.25**	**-0.25**	**0.40**	-0.10	**-0.20**
Fecal Coliforms (MPN/100mL)	**0.39**	**-0.35**	**-0.29**	**0.43**	**-0.35**	**-0.34**

Bold values significant at alpha=0.05, IS=Impervious Surface

Nitrate yield median ranges for 2003-2005 across a forest cover gradient



Cross-section of an urban stream channel in WestGA

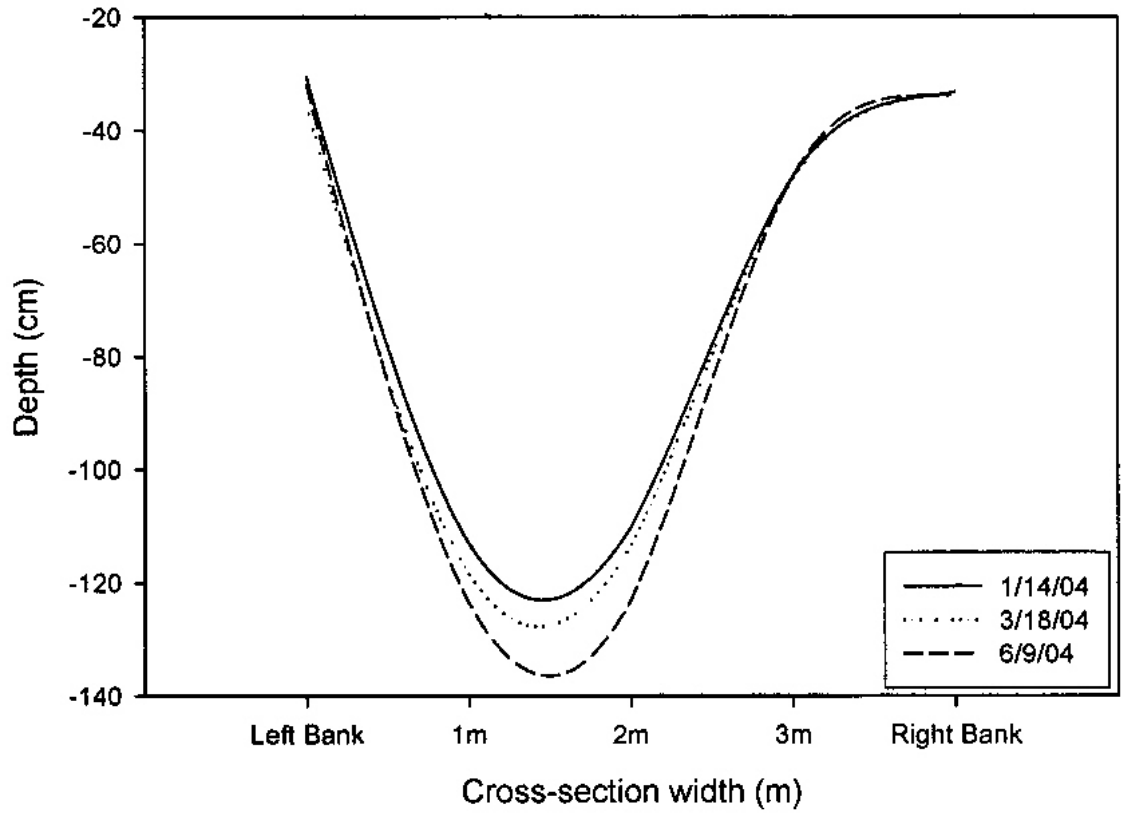


Figure 4. Cross-section of an urban channel in the erosional phase of development (dominant land use: 48% urban, 31% forested, and 19% pasture).

Cross-section of a mixed forest stream channel in WestGA

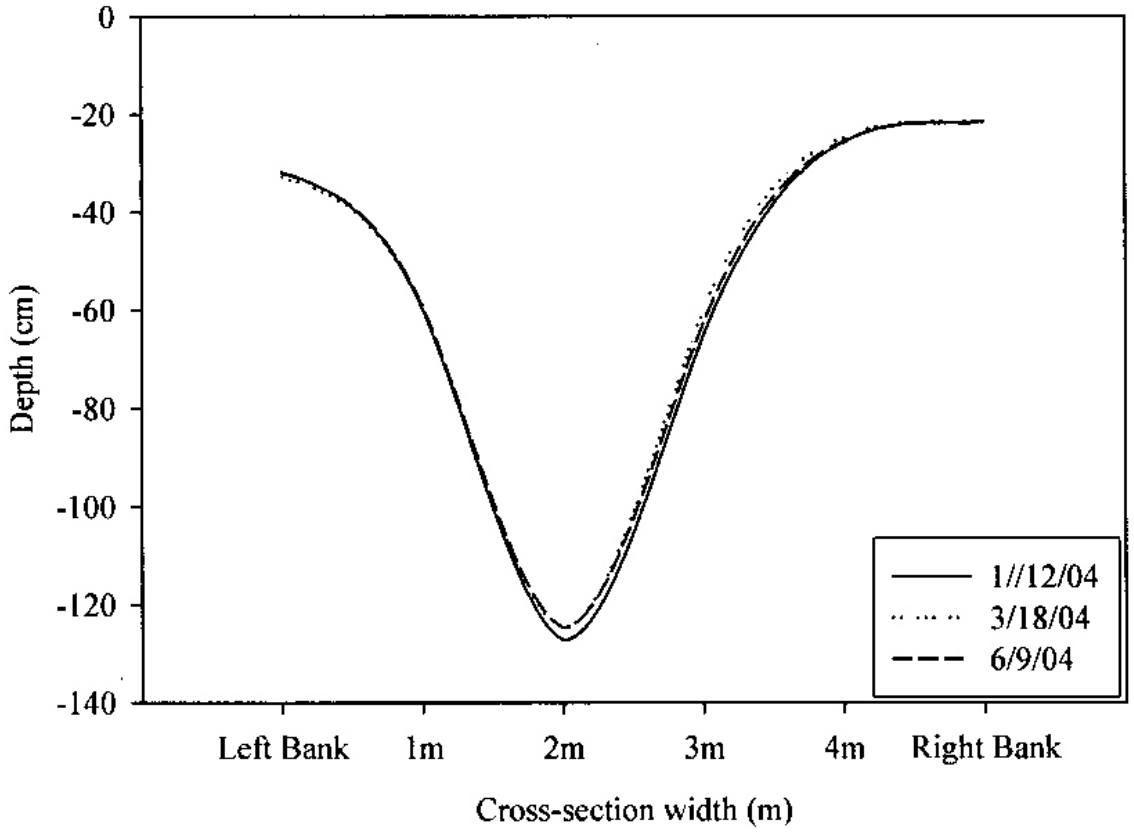


Figure 5. Cross-section of stable channel in a watershed dominated by mixed forest (dominant land use: 94% forested, 6% pasture).

Fecal coliform

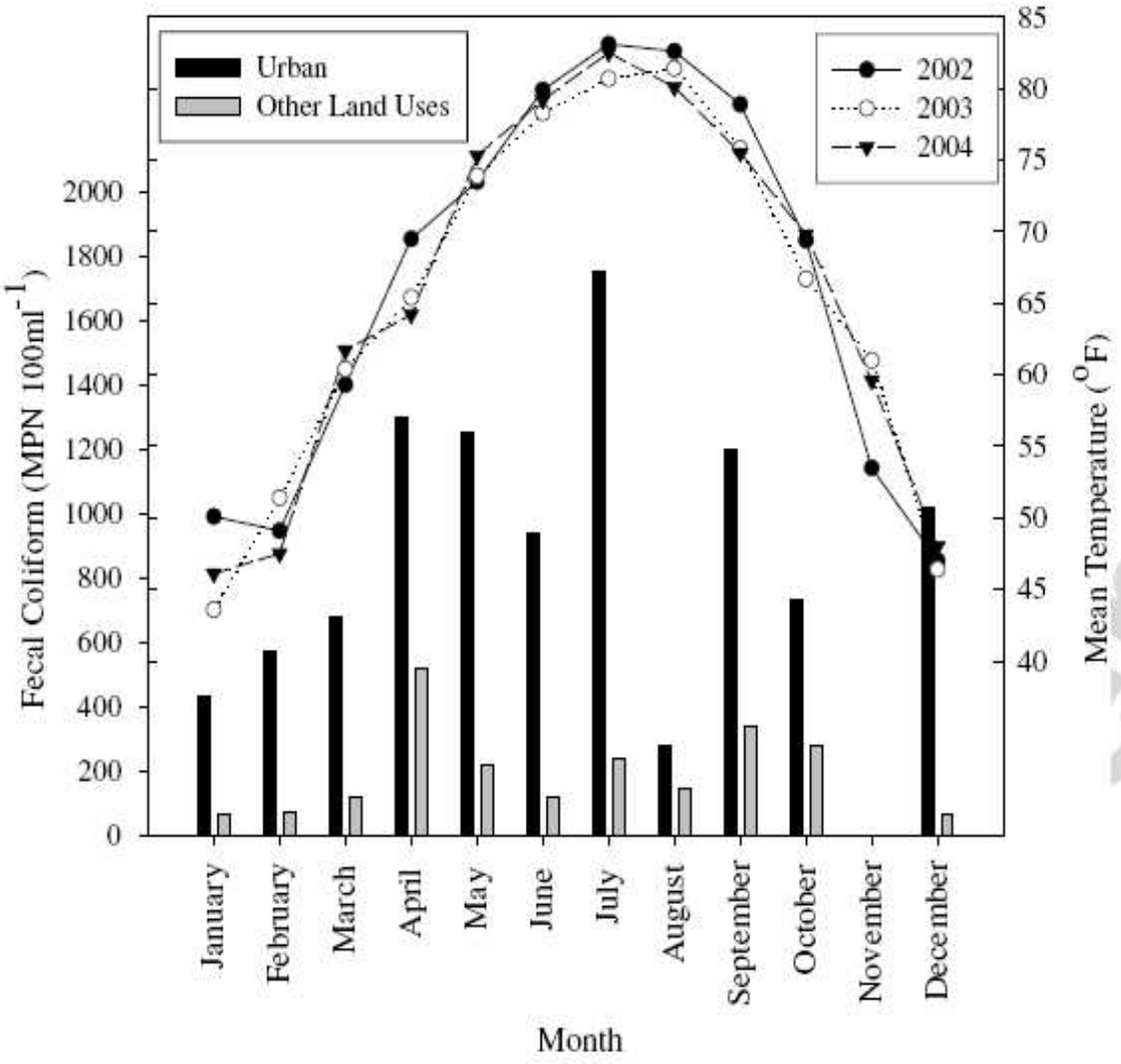


Figure 3 Monthly fecal coliform counts (bars) of urban watersheds versus all other land uses combined in relation to mean annual air temperature (trend lines).

High levels of fecal coliform in urban streams

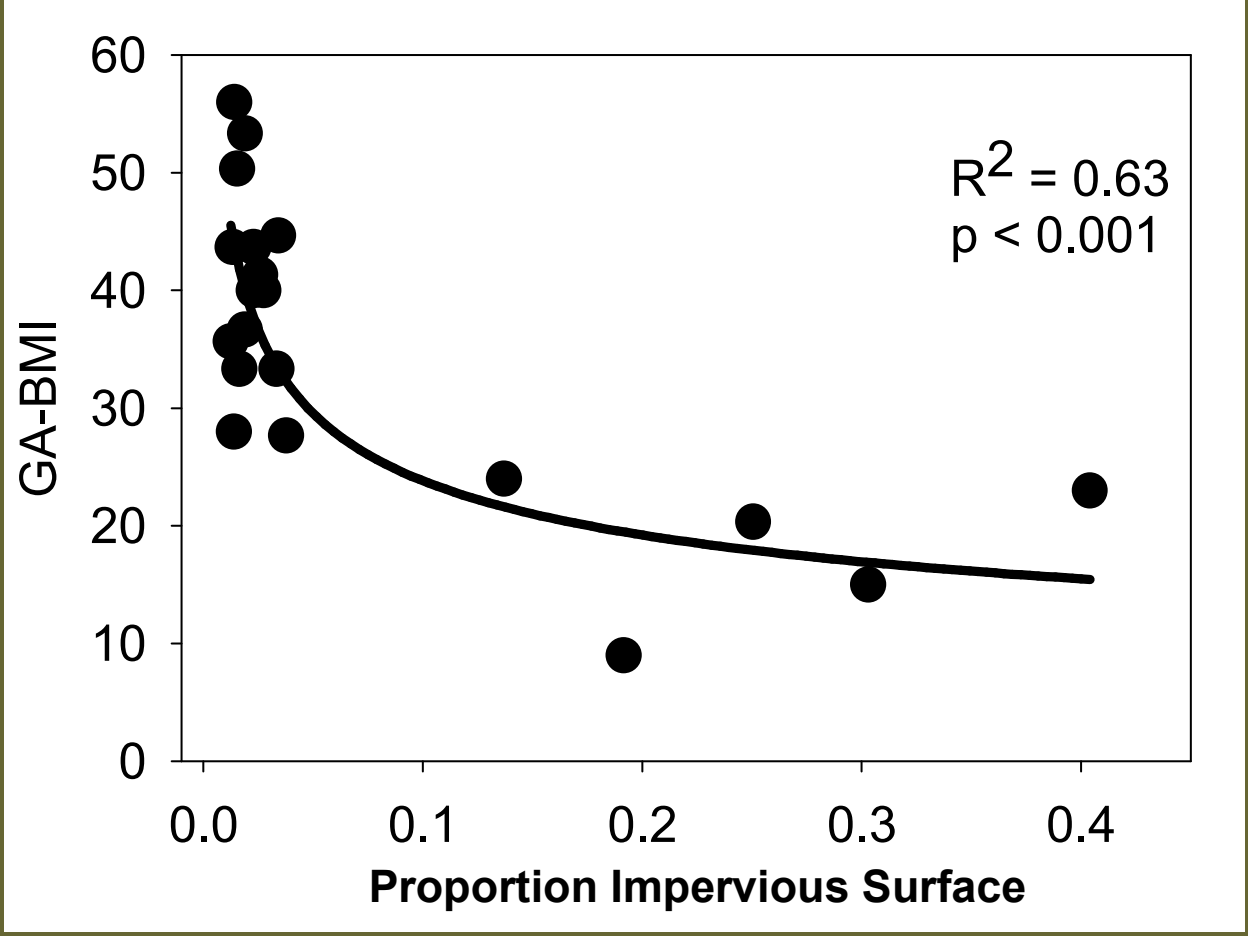
Observations with > 15,000 colonies / 100 ml

Obs	Date	Land Use	ID	FC
1	11/4/2004	Developing	SB2	35,000
2	1/20/2005	Urban	BR	25,000
3	3/17/2005	Urban	BR	20,000
4	4/8/2005	Urban	BR	16,000
5	6/2/2005	Urban	BR	17,000
6	11/16/2005	Urban	BU2	70,000

Inverts – LU/LC relationships

Georgia Benthic Macroinvertebrate Index

www.gaepd.org



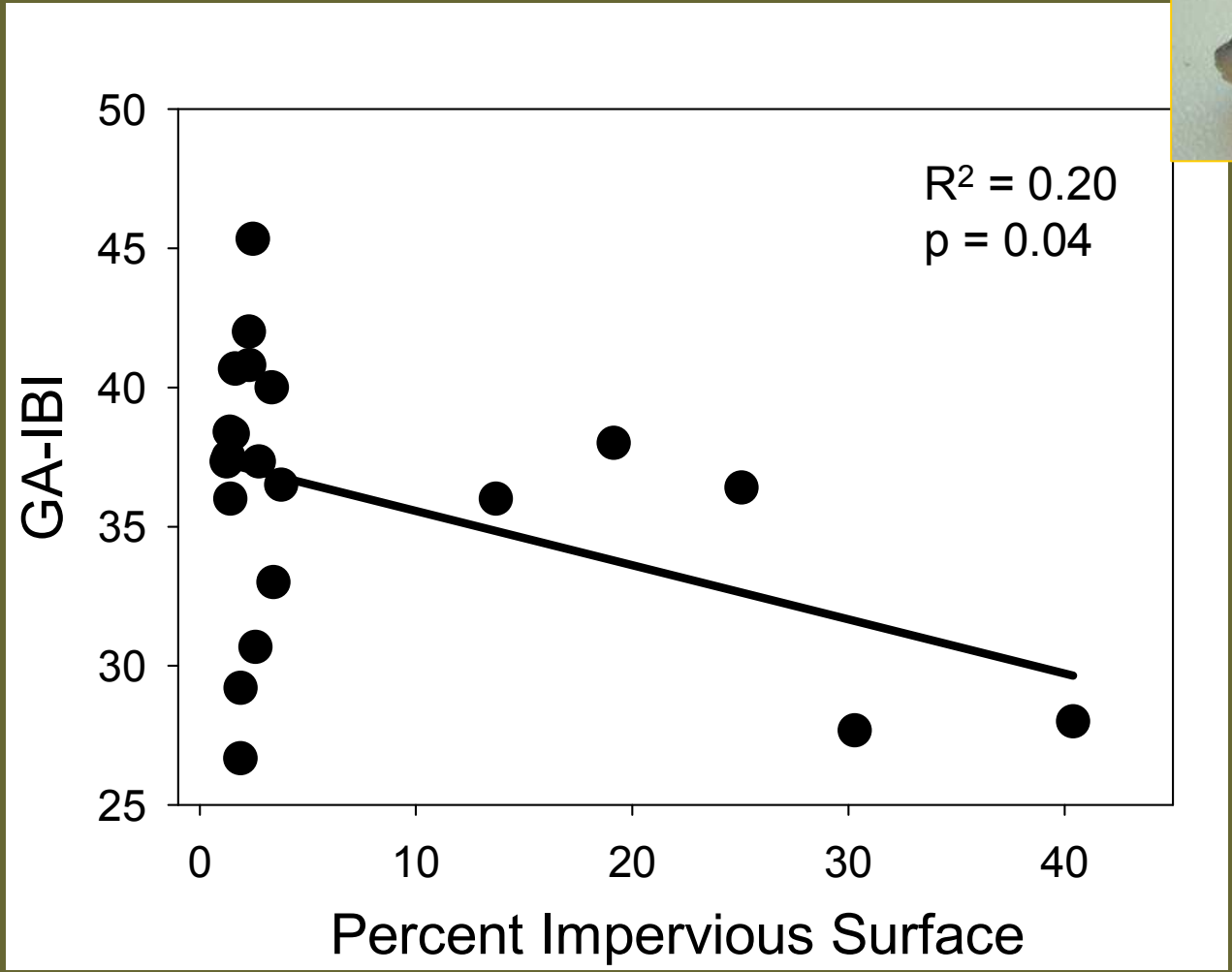
- % Shredders
- % Scrapers
- # Swimmers

- % Plecoptera
- % Oligochaete
- # Coleoptera

Acroneuria sp.

Fish – Index Biotic Integrity (IBI)

Georgia Department of Natural Resources

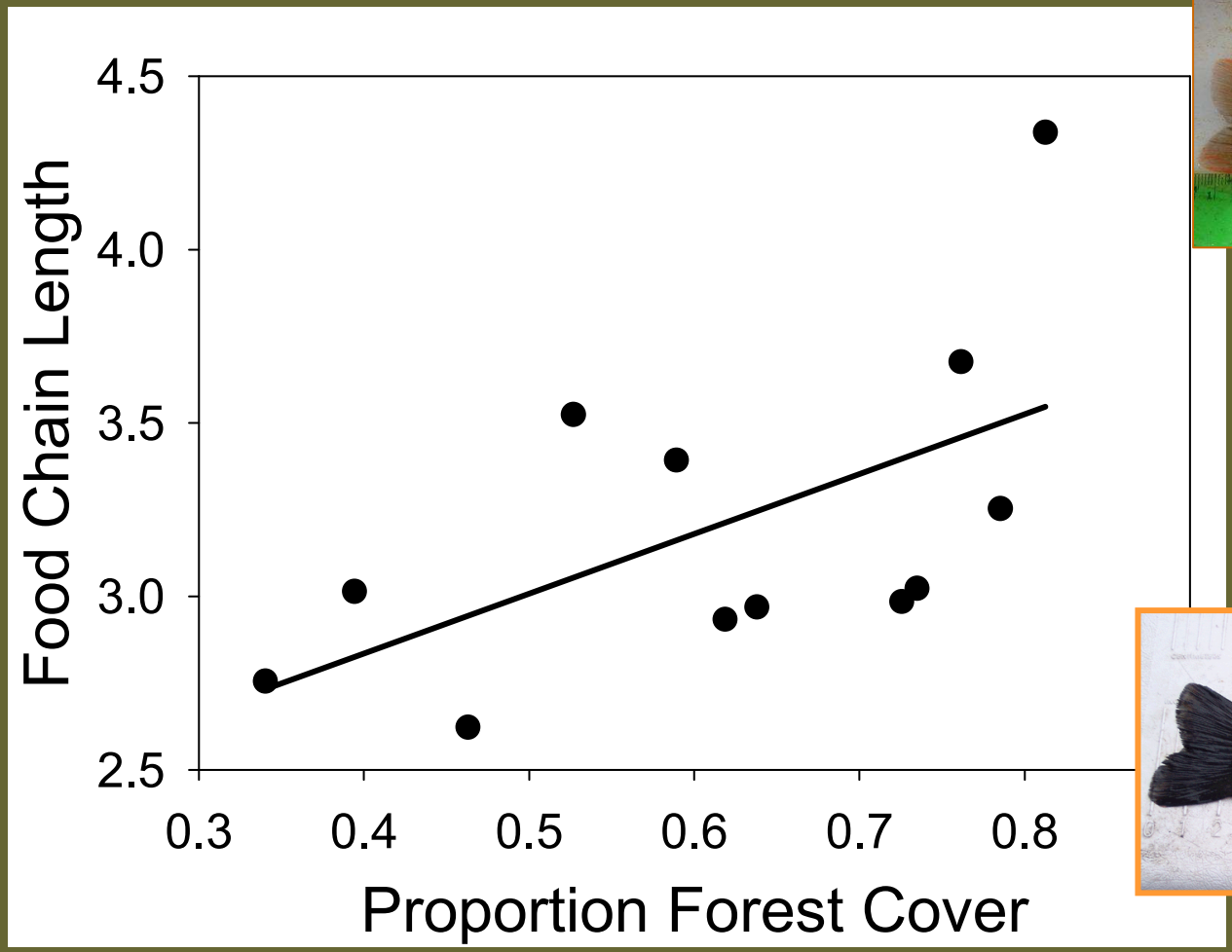


- % Tolerant
- # Sensitive
- % D.E.L.T.

- % Insectivorous
- % Omnivorous
- % Lithophils

Food webs –Max Trophic Position

$(\delta^{15}N_{\text{top consumer}} - \delta^{15}N_{\text{base}}) + \lambda / 3.4$



Summary

- Hydrology & geomorphology
  - ↑ stability with forest cover
  - ↑ discharge with urbanization
- Water quality
  - ↓ nitrates, sediments with forest
  - ↑ stability with forest cover
  - ↑ fecal coliforms with urbanization
- Biota
  - ↑ integrity with forest
  - Different response shapes
  - ↑ FCL with forest cover
  - Strong linkages with DO, habitat, hydrology

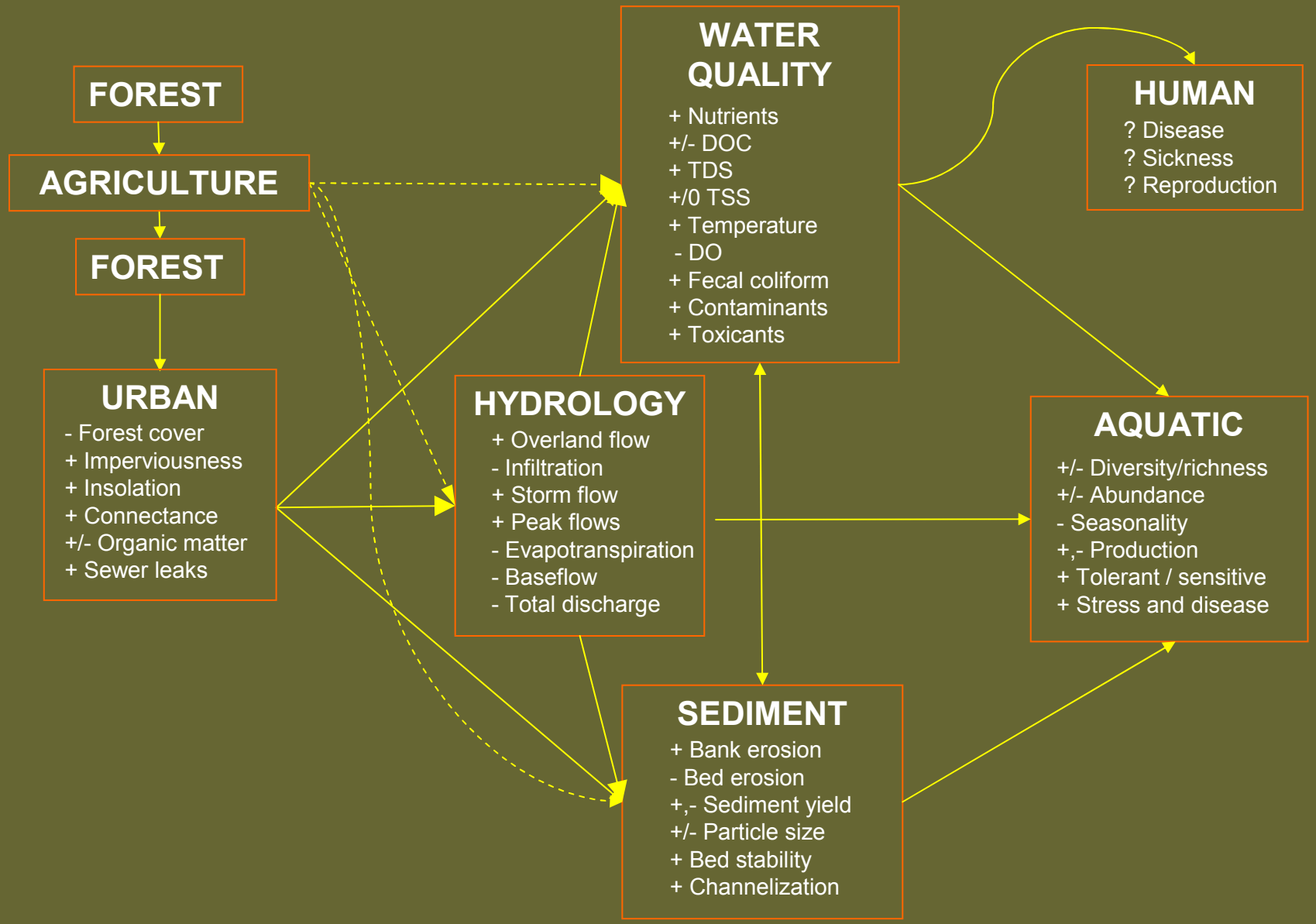
Conclusions – Forest conversion

- Elevated discharge
  - 5:1 increase with impervious surface
  - Proportionally higher in CP
- Biotic changes
  - Macroinvertebrates best indicator
  - CP assemblages more resilient
- Water quality changes
  - Elevated nutrients, sediments
  - Local, regional differences
  -
- Human health concerns
  - Elevated levels and exposure to contaminants
  - Need more directed study

Conclusions – Forest conversion

- Impervious surface thresholds?
  - <5 - 10% for chemistry, biota
  - Higher in CP
  - May be overly simplistic
- Management techniques work!
  - BMPs, SMZs, erosion and runoff control
  - Add value to restoration efforts
- Needs / Implications
  - Spatial arrangement of development
  - Land use history
  - Coastal Plain and epidemiological studies
  - Management / restoration couplings

Forest to Urban Conversion



Acknowledgements

- Ge Sun
- Paul Barten
- Jim Vose

- Jon Schoonover
- Jackie Crim
- Kyle Barrett

- Photo Credits
  - GA DNR
  - VA DCR
  - New Deal Network
  - NC Business History
  - Grey Villet
  - Corbis