Urbanization and the Hydrologic Response to Storm Events

East Carolina University
1907–2007 CENTENNIAL

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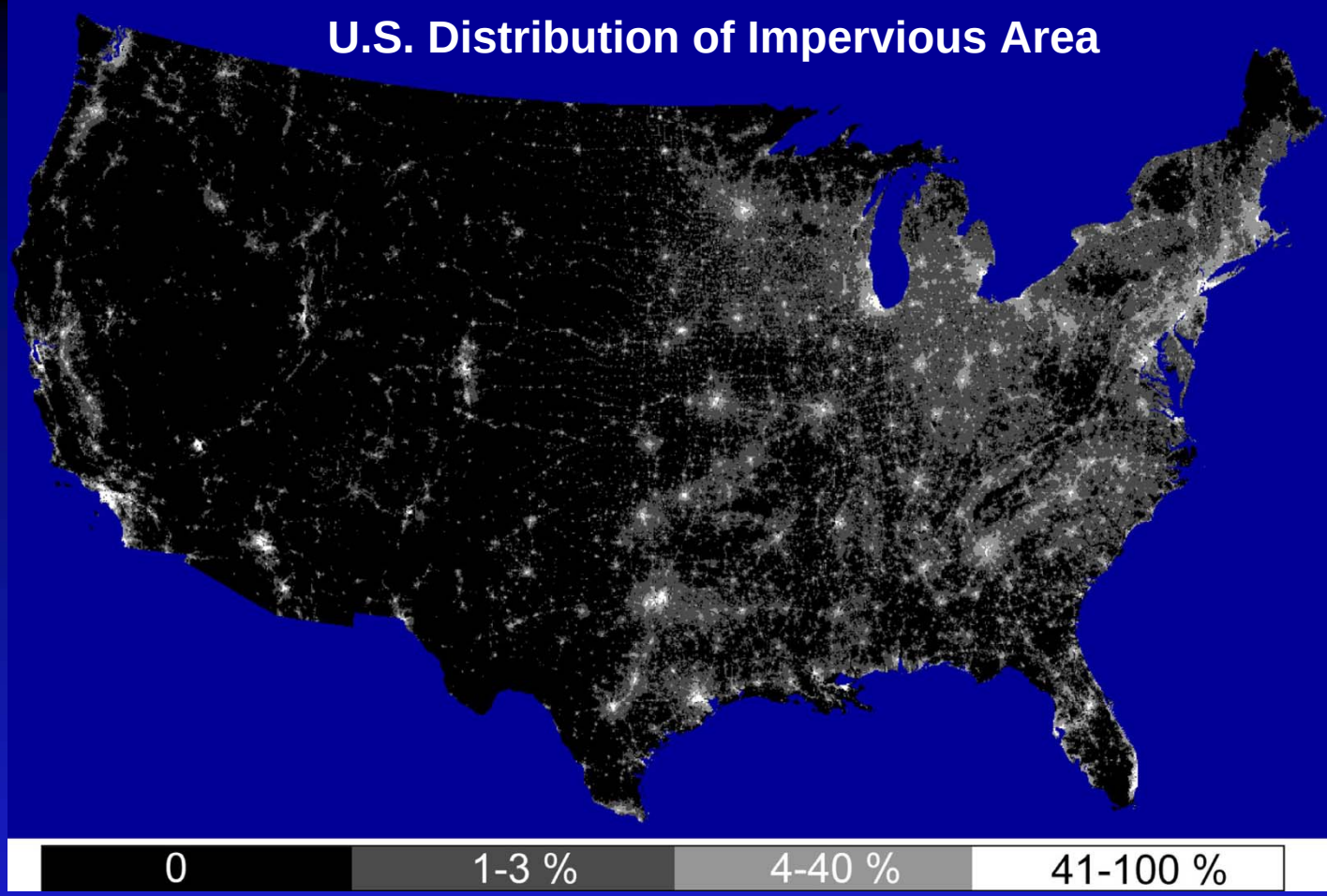
Approximately ½ the world population is in urban areas (Cohen 2003).

U.S. – 80% of population in urban areas.



- Global average impervious area – 0.43%; U.S. average 1.05% (Elvidge et al. 2007)
- US - impervious surface area/person (297m^2) (Range 0-400 m^2/ person)
- Waters affected by impervious area are concentrated in U.S., Europe, Japan, China, India.

Urban Land Use Effects on Hydrology

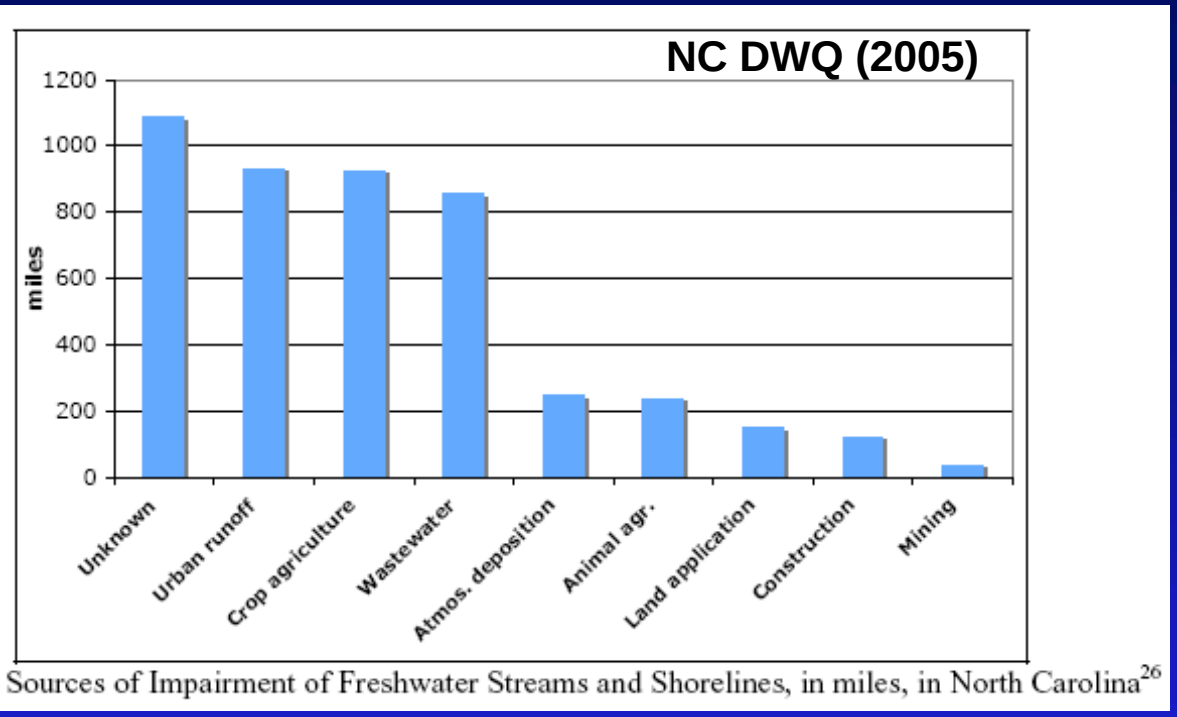
- Expansion of impervious surfaces.
- Altered sediment and water supply to stream.
- Runoff conveyed to channel by stormwater drains.
- Lag between rain-storm discharge peak is shorter , peak is larger.
- Stream channel incision/widening is common (erosion>deposition).

W. Wright Rd.
Greenville, NC

Reedy Branch,
Greenville, NC

Land Use Effects on Streams in North Carolina

Urban runoff is the primary cause of stream impairment in North Carolina



Sources of Impairment of Freshwater Streams and Shorelines, in miles, in North Carolina[26]

[26] NC Division of Water Quality. 2005. "Nonpoint Source Pollution Reduction Report: 2005 Annual NPS Report to the U.S. Environmental Protection Agency." Available at: http://h2o.enr.state.nc.us/nps/index.html.

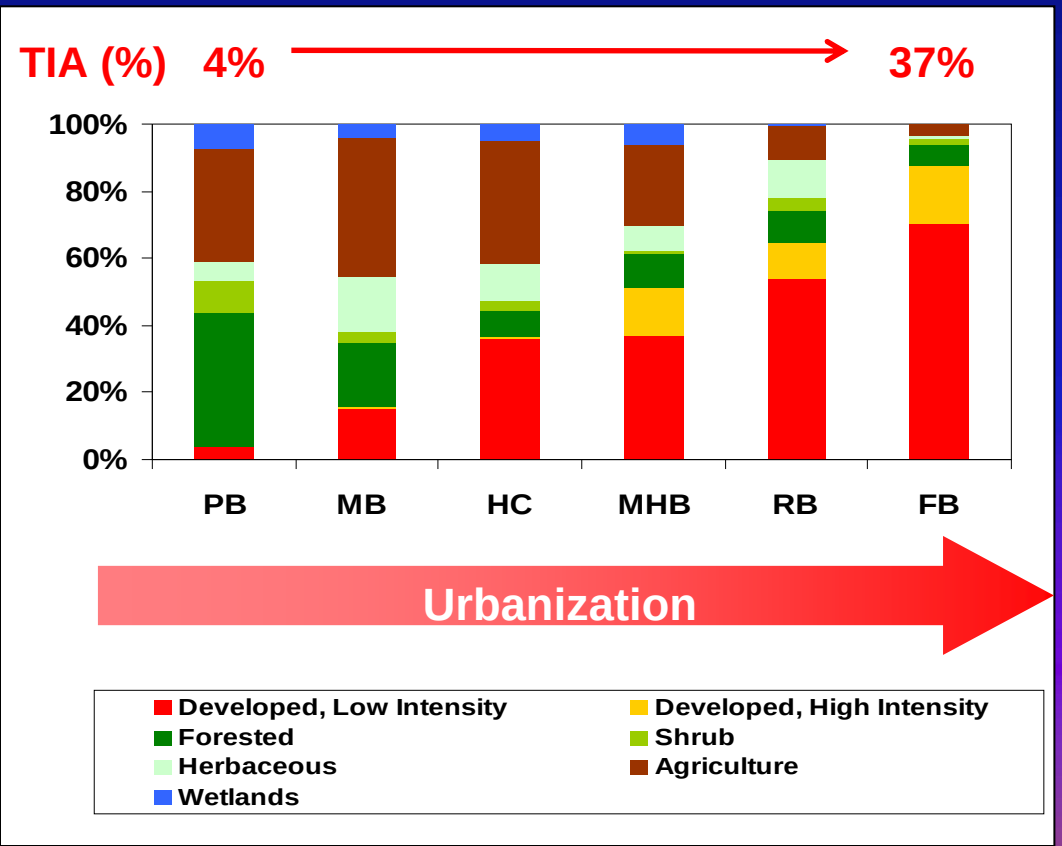
SE US
Urban land-use expanding-
Conversion of ag. and forest lands

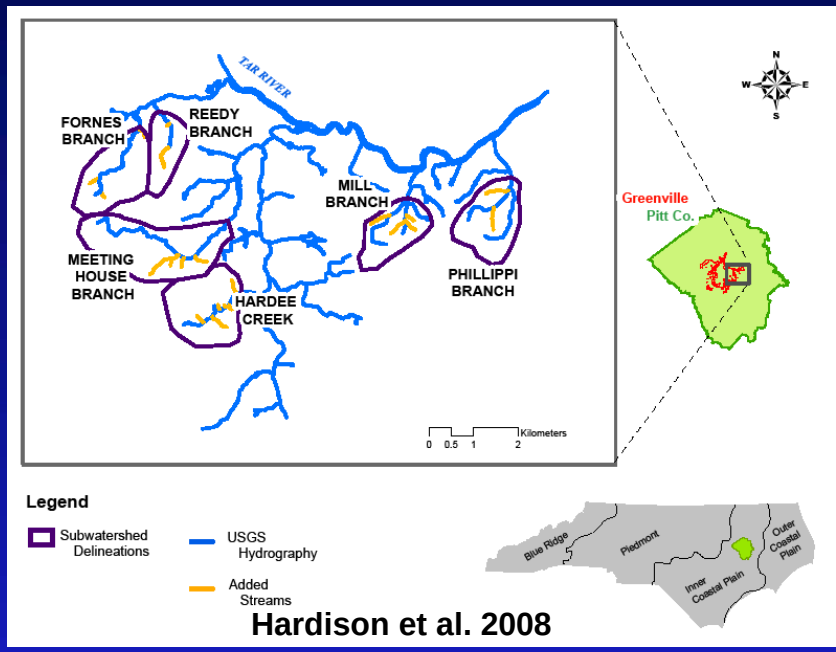
KILOMETERS
0
25
50
Albemarle Sound
Pamlico Sound
Atlantic Ocean
SOUTHERN SHORES
GREENVILLE
NORTHAMPTON
HERTFORD
GATES
PASQUOTANK
CAMDEN
CURRITUCK
PERQUIMANS
CHOWAN
BERTIE
HALIFAX
NASH
EDGECOMBE
MARTIN
WASHINGTON
TYRRELL
DARE
HYDE
BEAUFORT
PITT
WILSON
GREENE
WAYNE
LENOIR
CRAVEN
PAMLICO
JONES
CARTERET
ONSLOW
DUPLIN
PENDER
Roanoke Rapids
Rocky Mount
Elizabeth City
Kitty Hawk
Kill Devil Hills
Nags Head
Manteo
Duck
Columbia
Plymouth
Oak City
Williamston
Washington
Belhaven
Goldsboro
Kinston
New Bern
Havelock
Morehead City
Jacksonville
Phelps Lake

Urban Land-Use Gradient in Greenville, NC

Urban (>15% TIA) → **Rural (<15% TIA)**

Watersheds range from 4-37% TIA (Total Impervious Area)



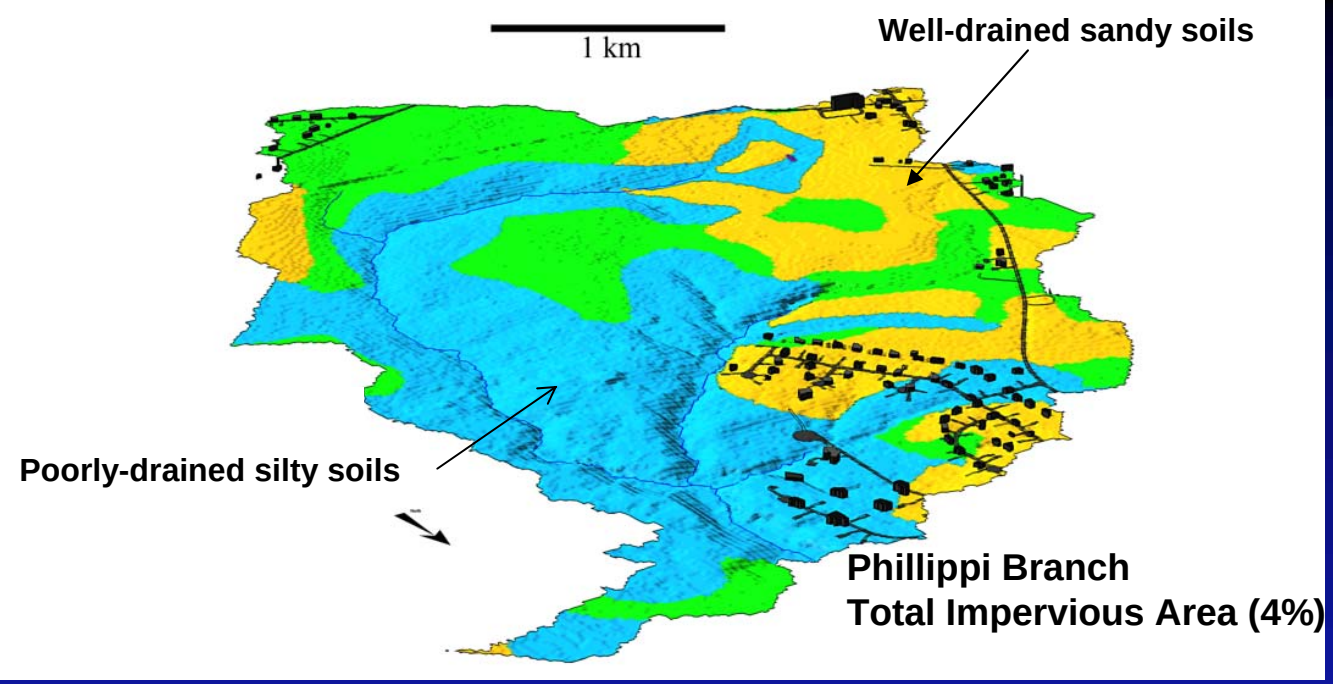


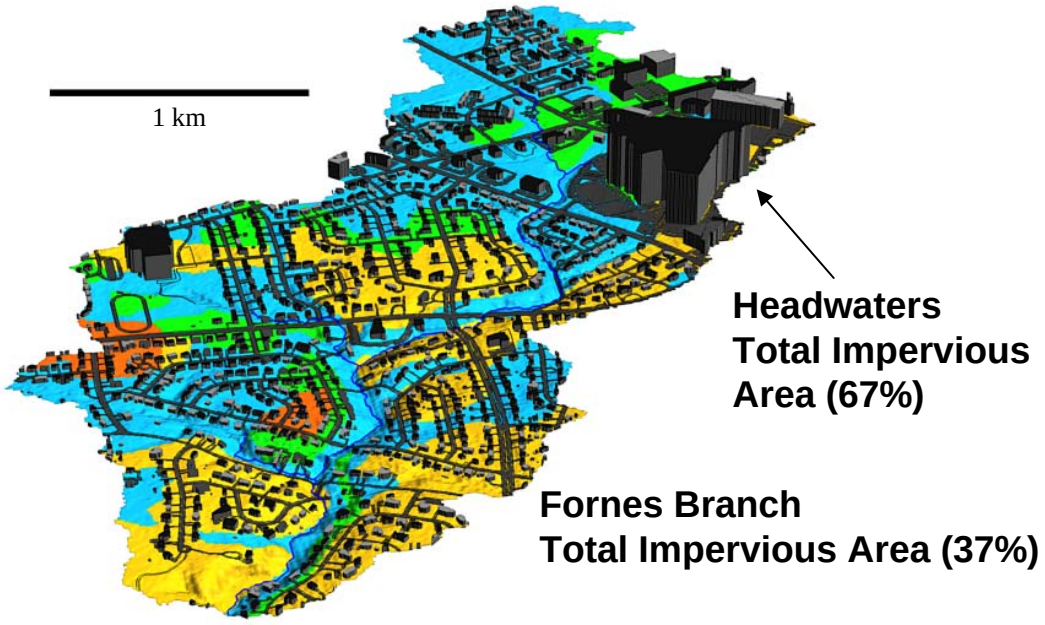
Hardison et al. 2008

6 Low-order catchments (1.19 - 3.46 km²)

40 stream reaches (20 urban, 20 rural)

Urban Land-Use

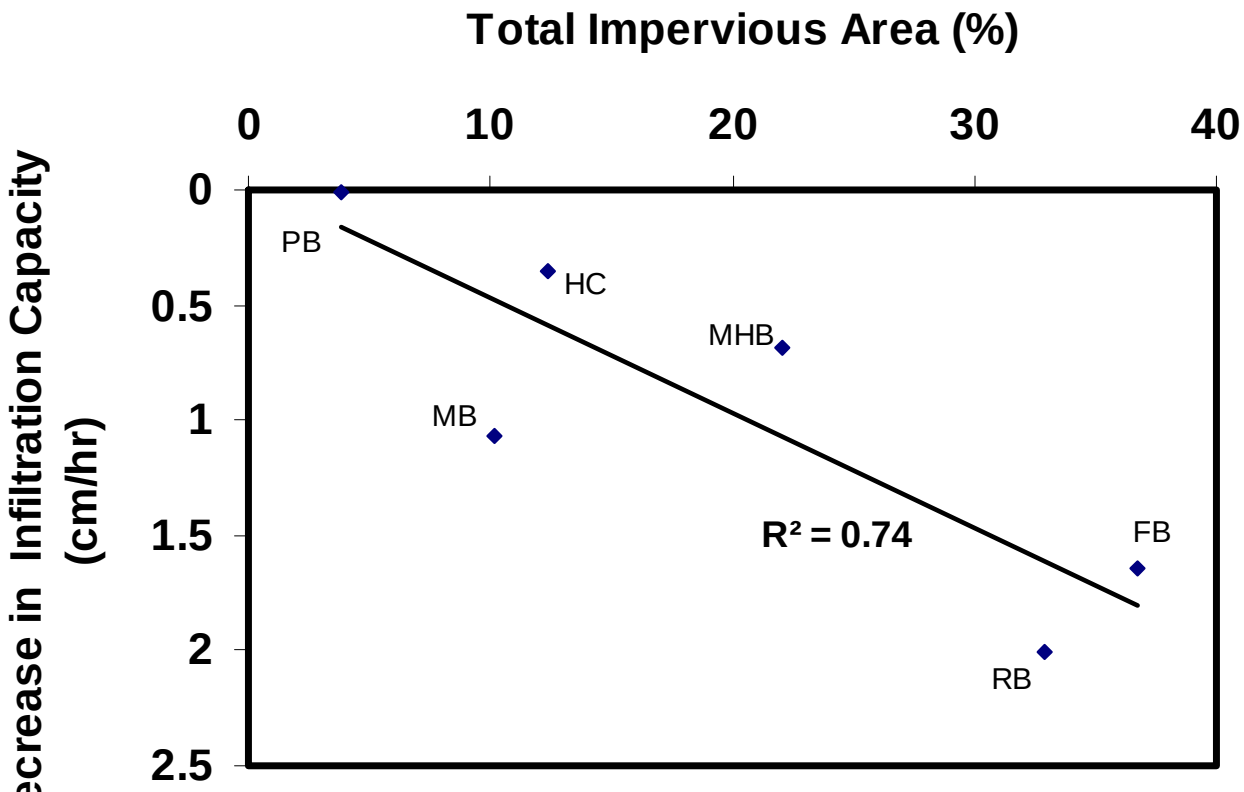




Urban Land-Use Effect on Catchment-Scale Infiltration Capacity

No Change

Maximum Decrease

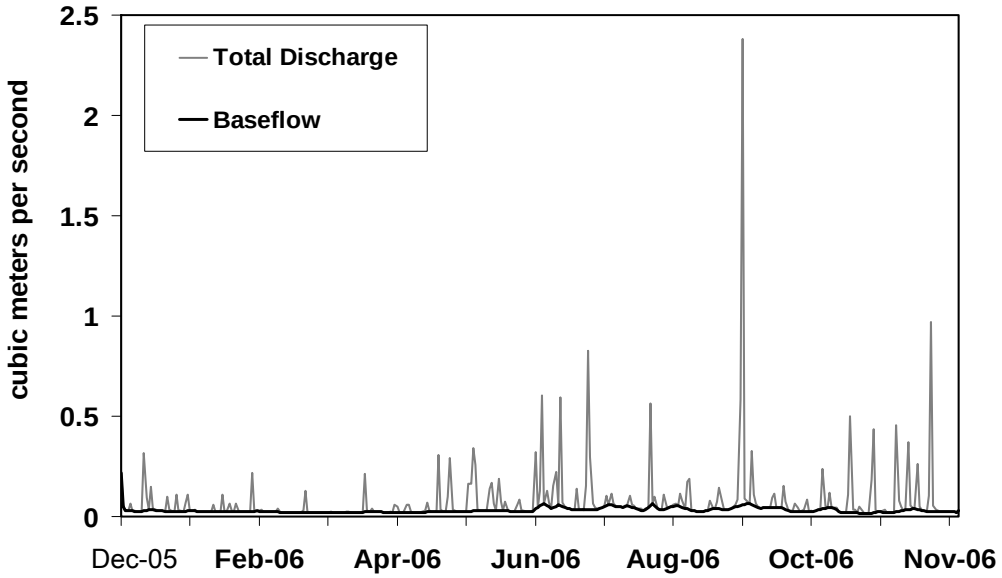


Mean watershed infiltration capacity = 6 cm/hr
Maximum decrease in infiltration capacity= 34%

As urban areas expand the land's ability to soak up rain water decreases.

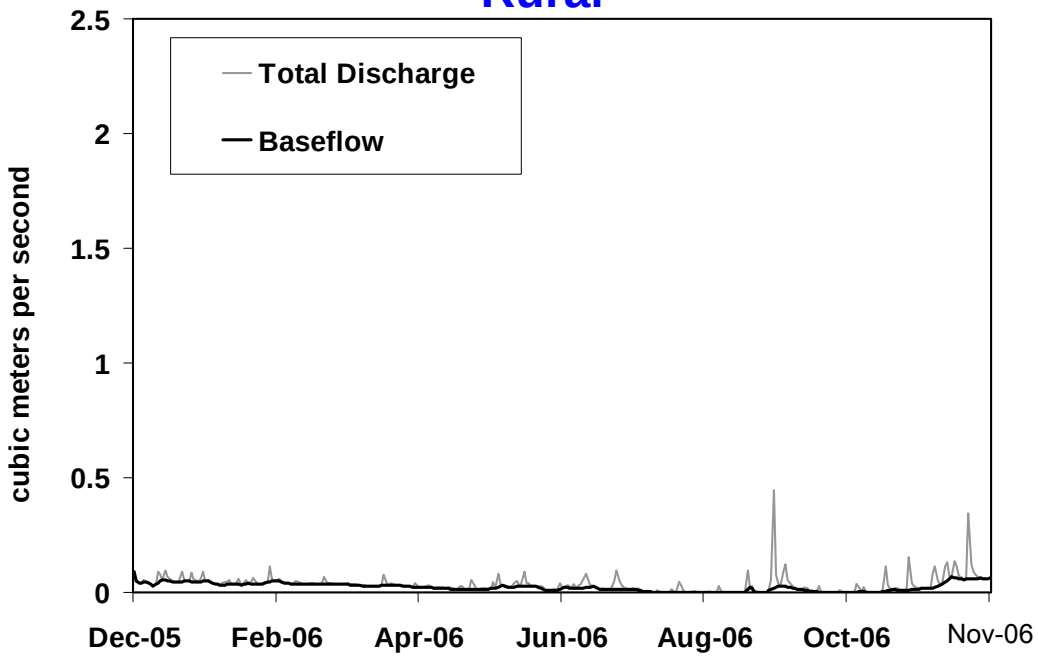
Changes in Stormwater Runoff due to Urbanization

Urban



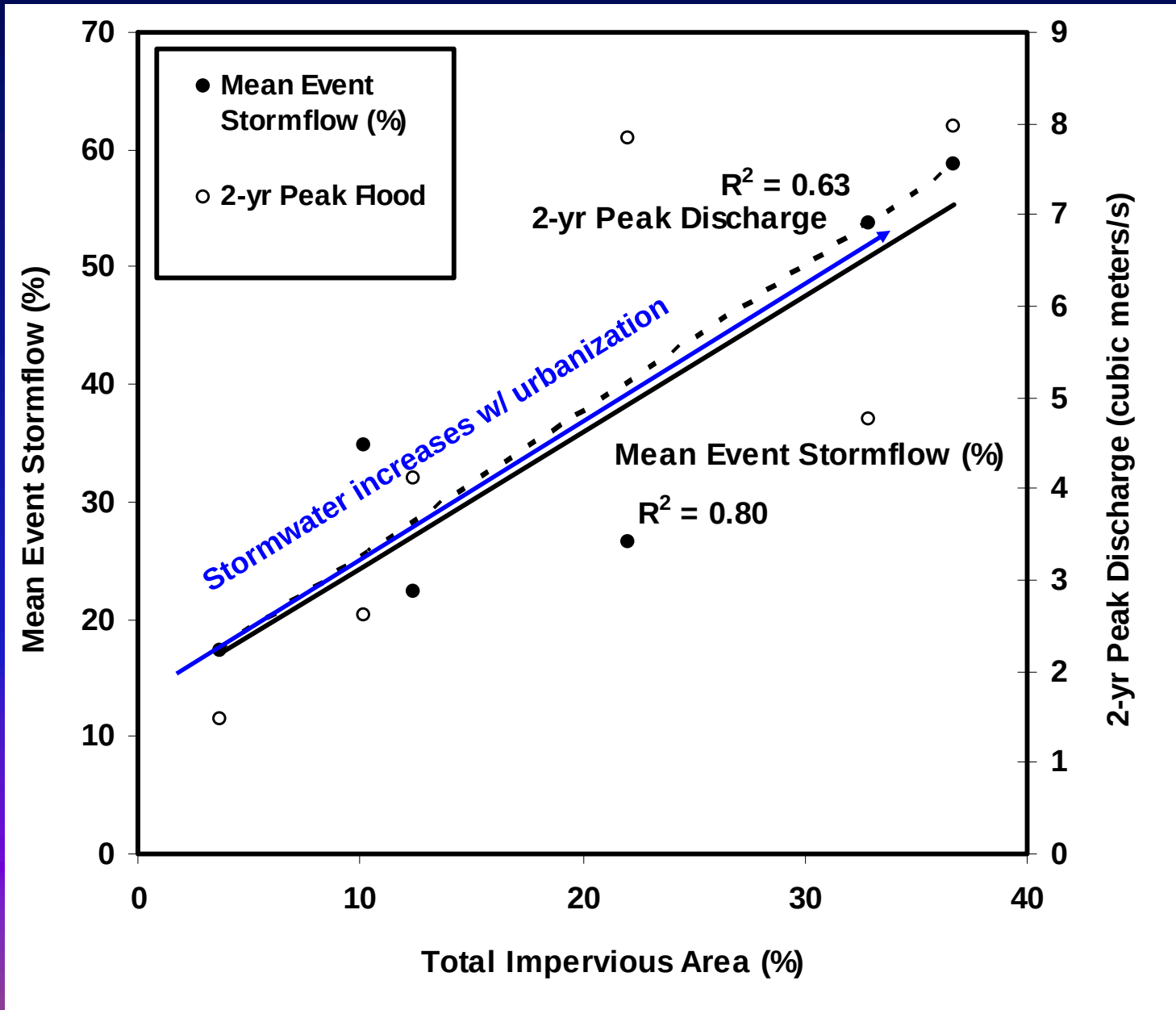
Urban stream (37% TIA)
Storm Runoff = 38% of annual flow

Rural



Rural stream (10% TIA)
Storm Runoff = 17% of annual flow

Stormwater runoff and peak floods have increased by over 3 X due to urban expansion in Greenville, NC

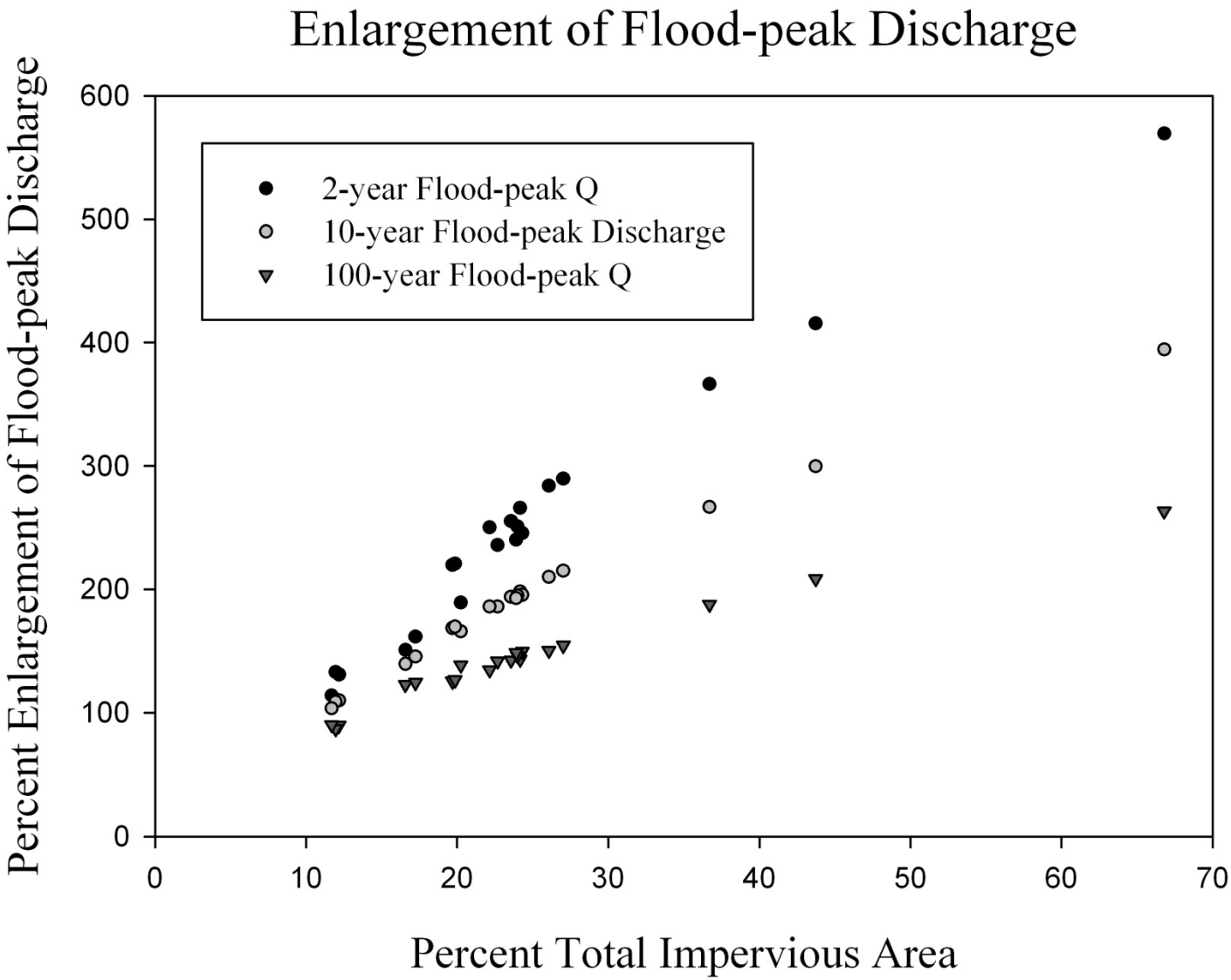


24 stormflow estimates
4 storm events @
6 sites

Peak flood estimates from USGS model by Mason et al. (2002)

More frequently occurring floods are more enlarged due to urban land-use

i.e. 2 yr flood Increases due to urbanization are much larger than 100 yr flood increases



Stormwater Increases Cause Channel Incision and Widening for Headwater Urban Streams

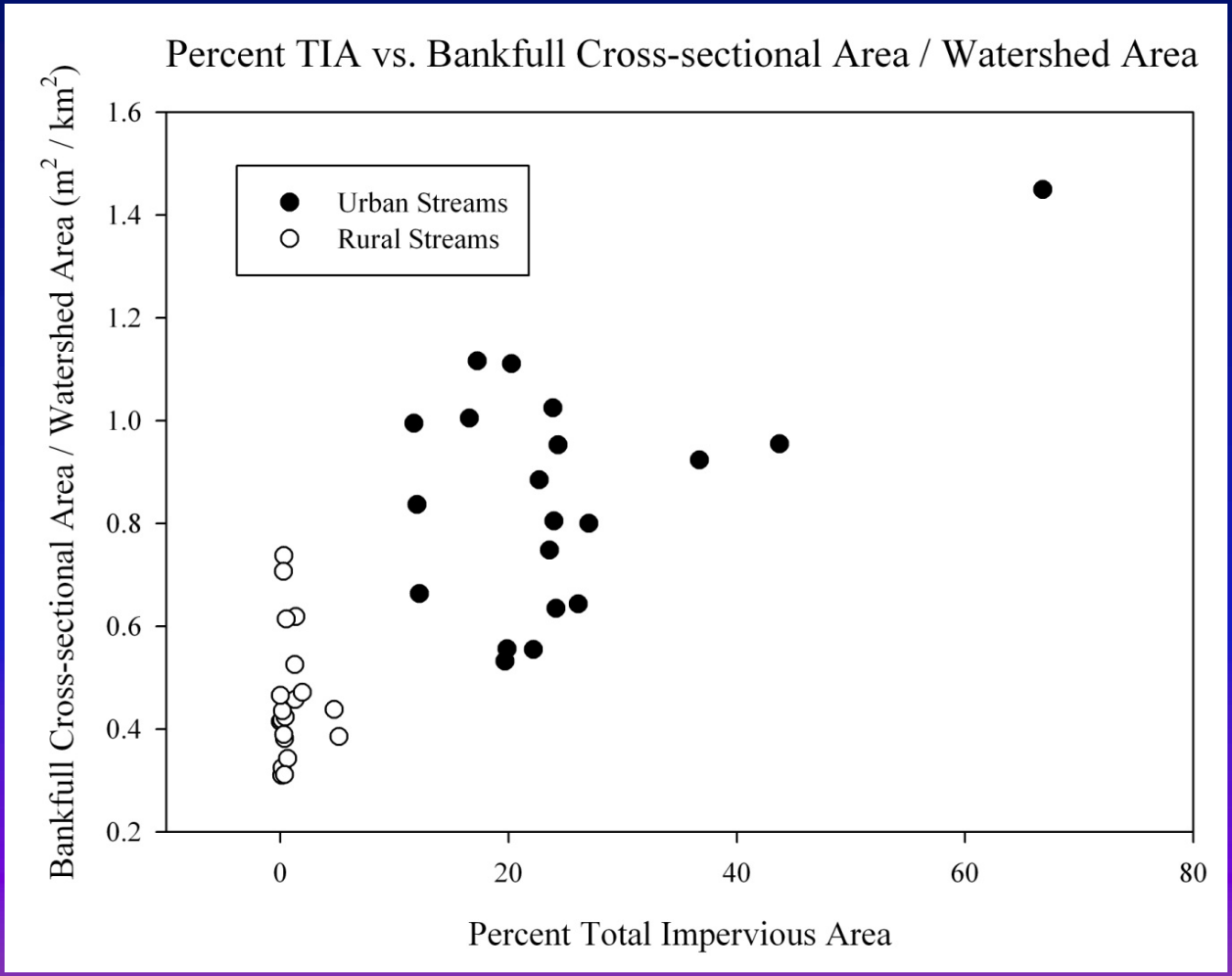
Rural Streams

- Minor incision
- Surface water more likely to interact w/ riparian zone

Urban Streams

- Incised
- Surface water rarely interacts with riparian zone
- Urban streams were more incised (0.53 m deeper)

Watershed Impervious Area Effects:
Bankfull Cross-Sectional Area

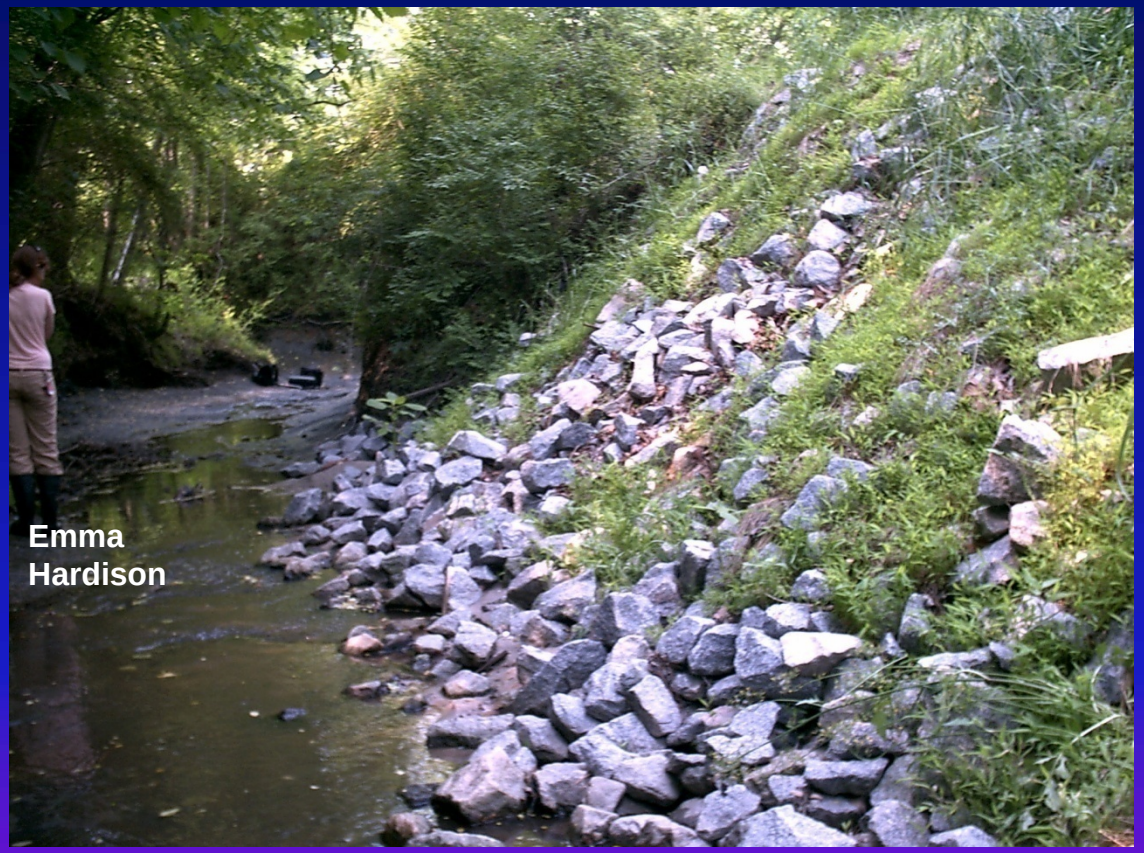


As TIA increased bankfull cross-sectional area increased.

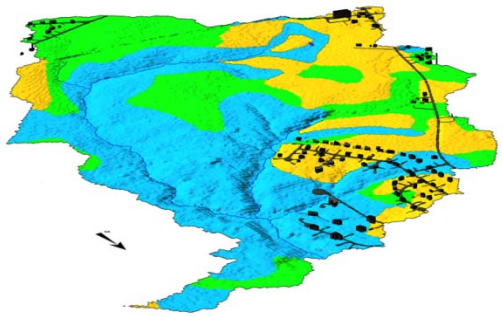
>10% TIA
67% larger x-sectional area

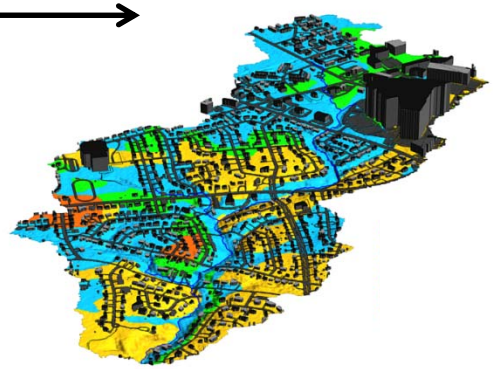
How do changes in channel morphology affect hydrology?

Fornes Branch
Greenville, NC
(37% TIA)



Increasing urbanization

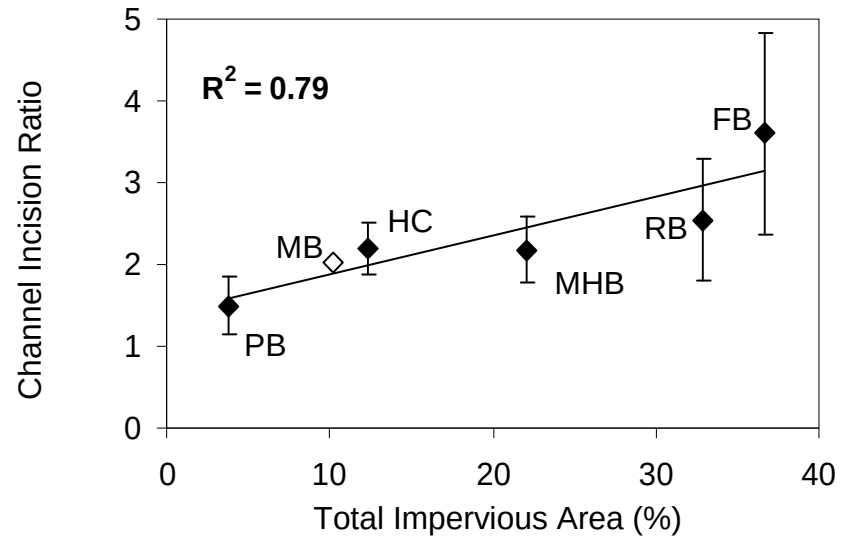


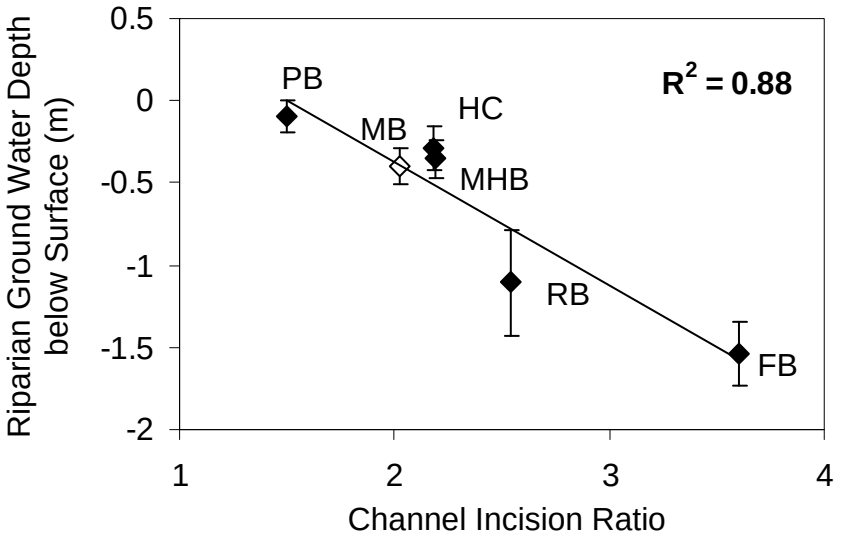


4% TIA

37% TIA

Channel Incision and Floodplain Water Table Decline





Channels incise, floodplain groundwater levels drop and become more seasonally variable.

Streams become disconnected from their floodplains.

Urban Channel Enlargement in Headwater Areas

reduces the connection between stream and floodplain

valuable floodplain functions lost

(flood water and sediment storage, nutrient processing)

Urban

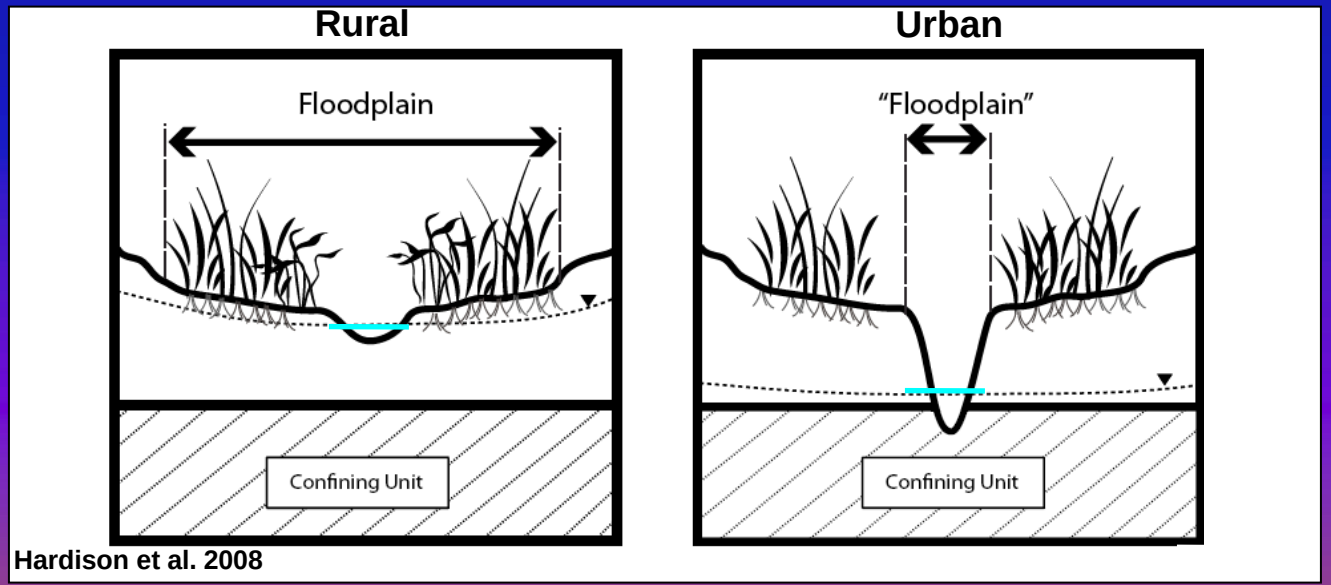
Rural

Summary

Coastal Plain urbanization alters hydrology and storm response along tributary streams:

- Reducing infiltration and groundwater recharge
- Increasing stormwater runoff (greater increases for more frequently occurring storms)
- Incising and widening stream channels (also channelization may have occurred)
- Reducing the connection between stream and floodplain in upper parts of watershed
- Decreasing floodplain flood water storage and function as a sediment /nutrient sink
- Increasing flood risk in lower parts of the watershed

Surface water level



Hardison et al. 2008

Impervious Area Projections for North Carolina

10% TIA threshold for stream impairment

By 2030- TIA expected to expand 3-4 times the current extent. Streams in watersheds with greater than 10% TIA will increase by 3,272 miles.

Urban stormwater will affect more NC watersheds in the future, particularly in Piedmont.

Coastal / Coastal Plain areas also will be affected.

Exum et al. (2005)

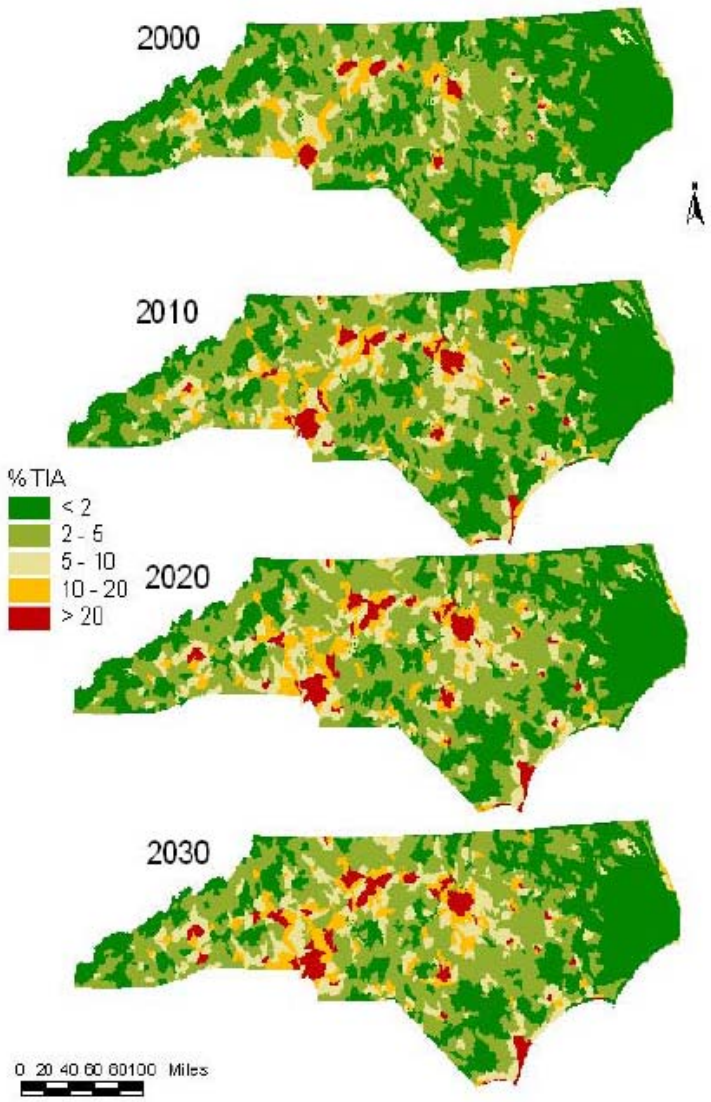


Figure 5.17 North Carolina impervious cover out to 2030. Impervious cover as %TIA (percent total impervious area) by 14 digit HUC calculated using the Multiple Data Source approach. Data sources used in the calculation include 1993 NLCD commercial and industrial cover, 2000 Census data, county level population projections from North Carolina Office of State Budget & Control Board and U.S. DOT data for interstates and other major highways.

Thanks for your attention!

Acknowledgments

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