*STAC Workshop: The Peculiarities of (IM)Perviousness*

# Limiting imperviousness to maintain ecological quality: Are threshold-based policies a good idea?

**April 23, 2014**

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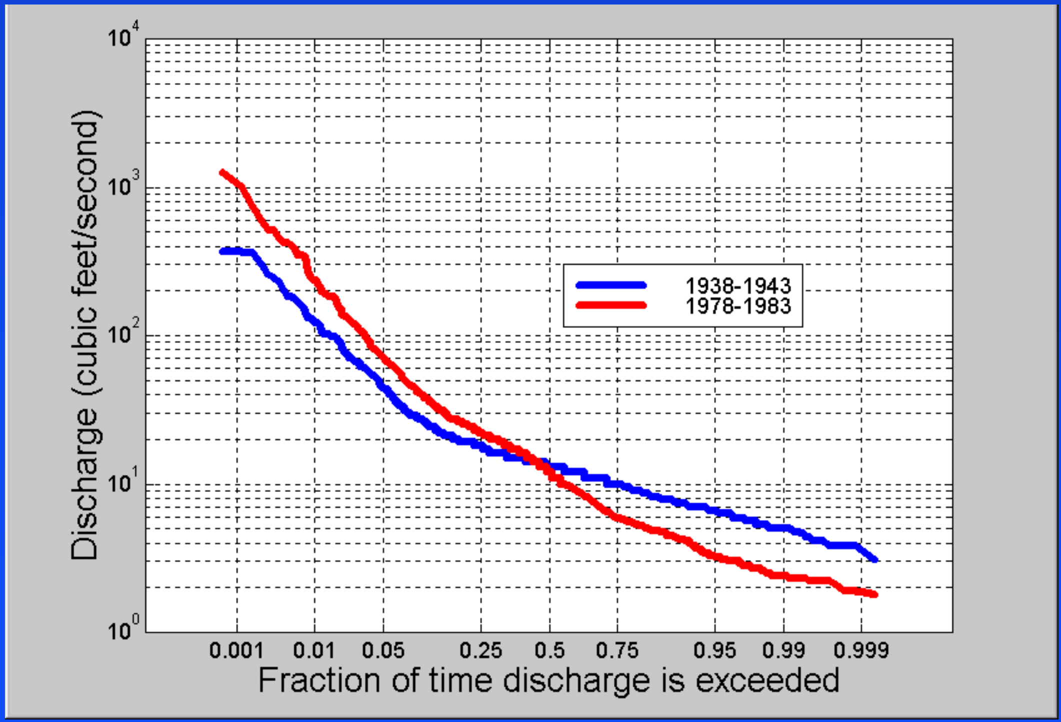
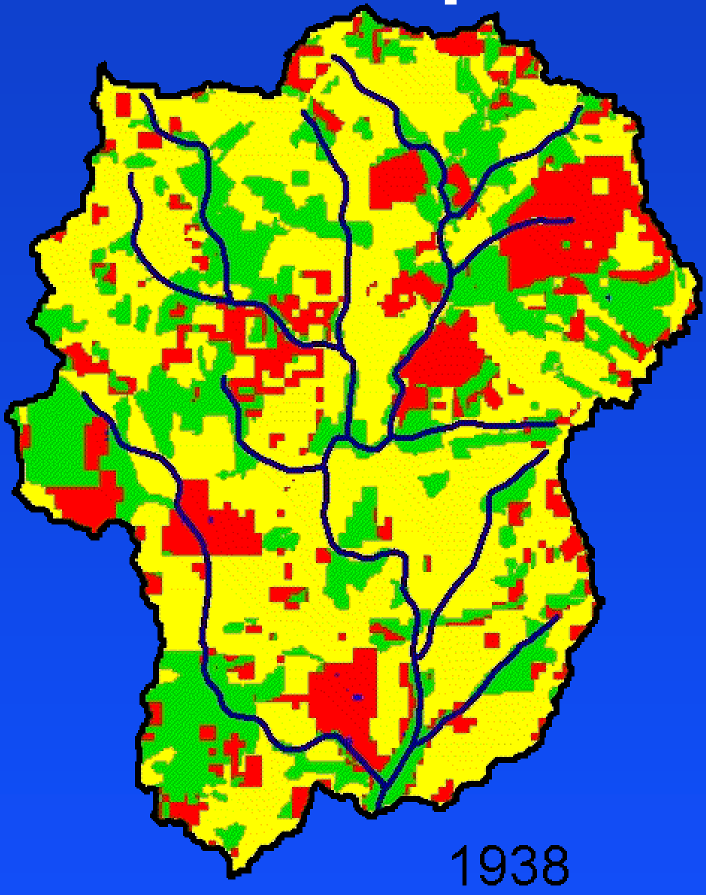
# Motivation

- We all understand that impervious surfaces lead to negative environmental consequences. However…
- How do we measure imperviousness and how do measurement methods affect absolute magnitudes?
- How do thresholds interact with the way imperviousness is organized by drainage network?
- What would “more informed” policies look like?

# Hydrologic Effects of Urbanization

- View of urbanization across landscape
- Streamflow perspective




Methods from: Moglen, G.E., and R.E. Beighley (2002). "Spatially Explicit Hydrologic Modeling of Land Use Change." *Journal of the American Water Resources Association,* 38(1): 241-253.

# Ecological Impacts: Woody Debris…

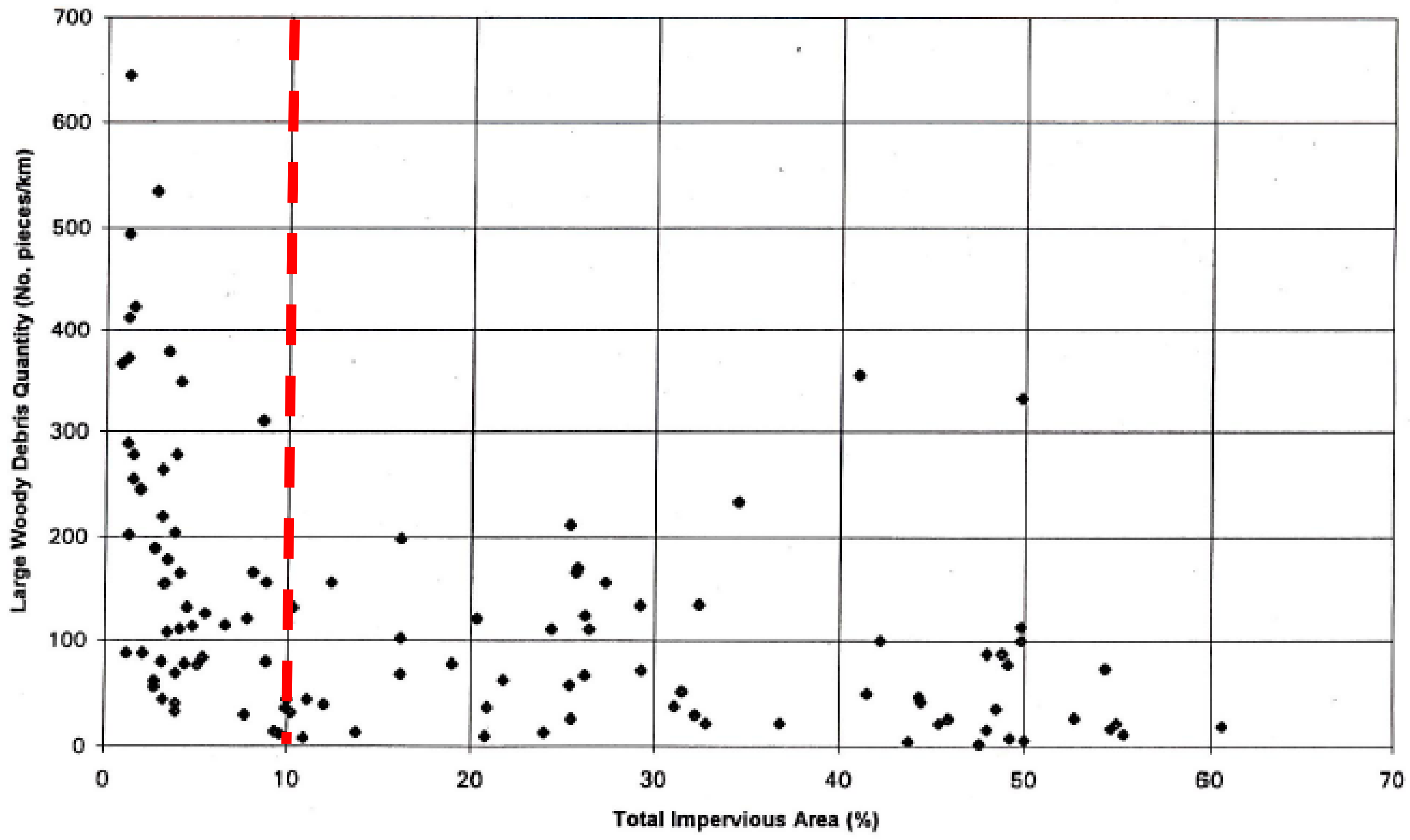



Figure A.5 - Large Woody Debris as a Function of Imperviousness (Horner *et al.*, 1996)

# Ecological Impacts: Species Sensitivity Index…

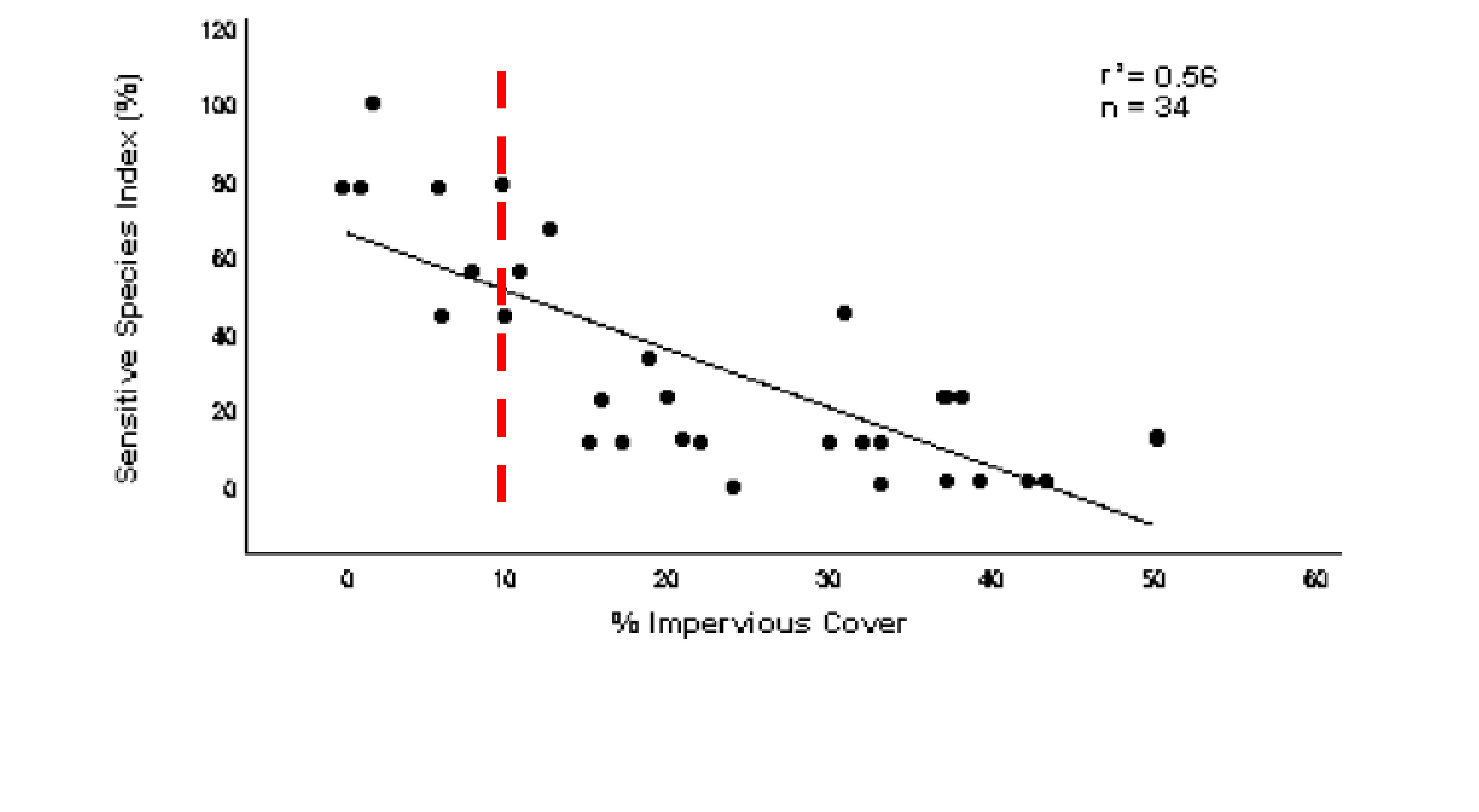



**Figure A.3 - Macroinvertebrate Abundance and Diversity as a Function of Impervious Cover for Delaware Piedmont Streams (Maxted and Shaver, 1996)**

# Ecological Impacts: the "10 percent" threshold...

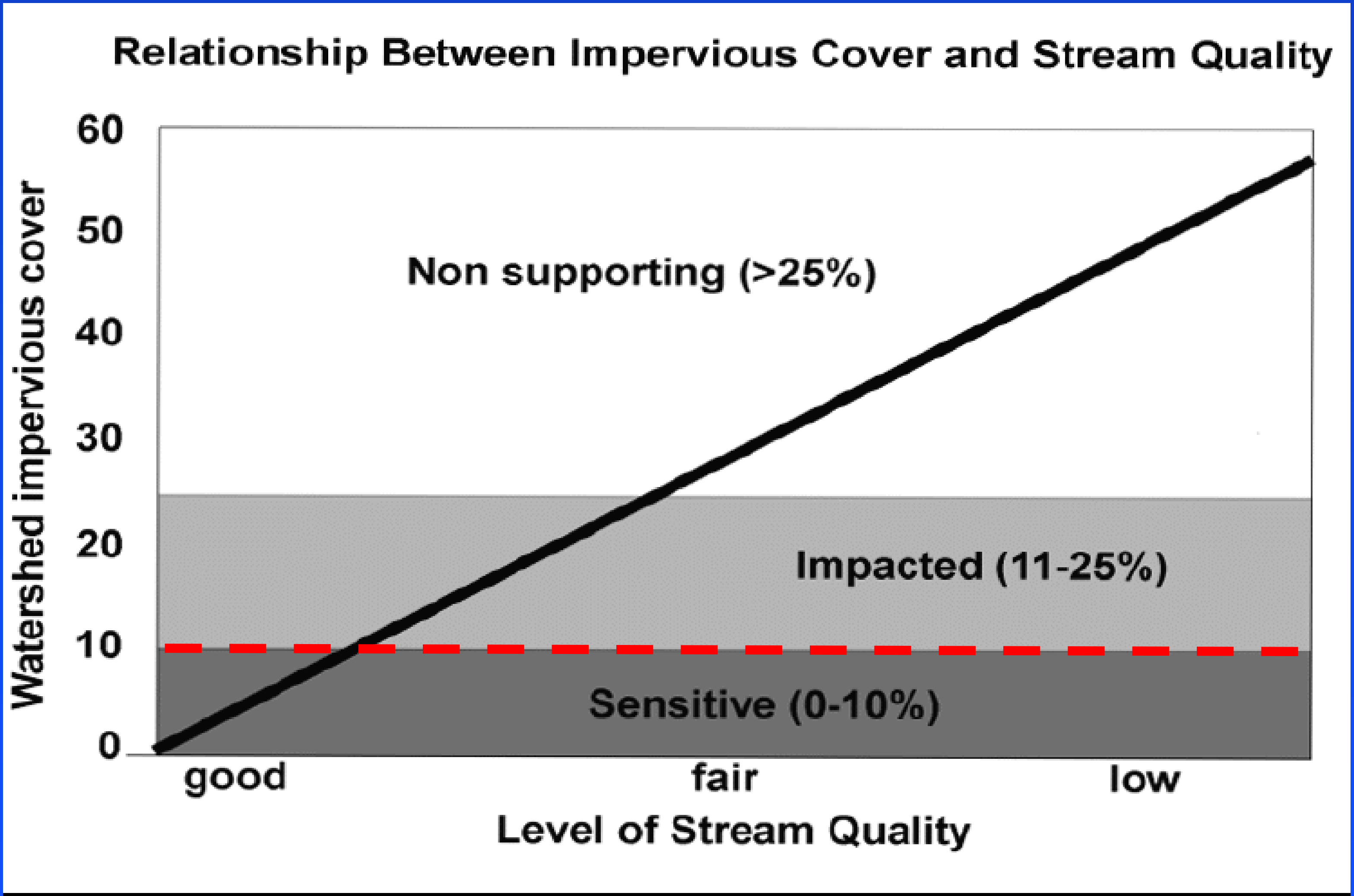
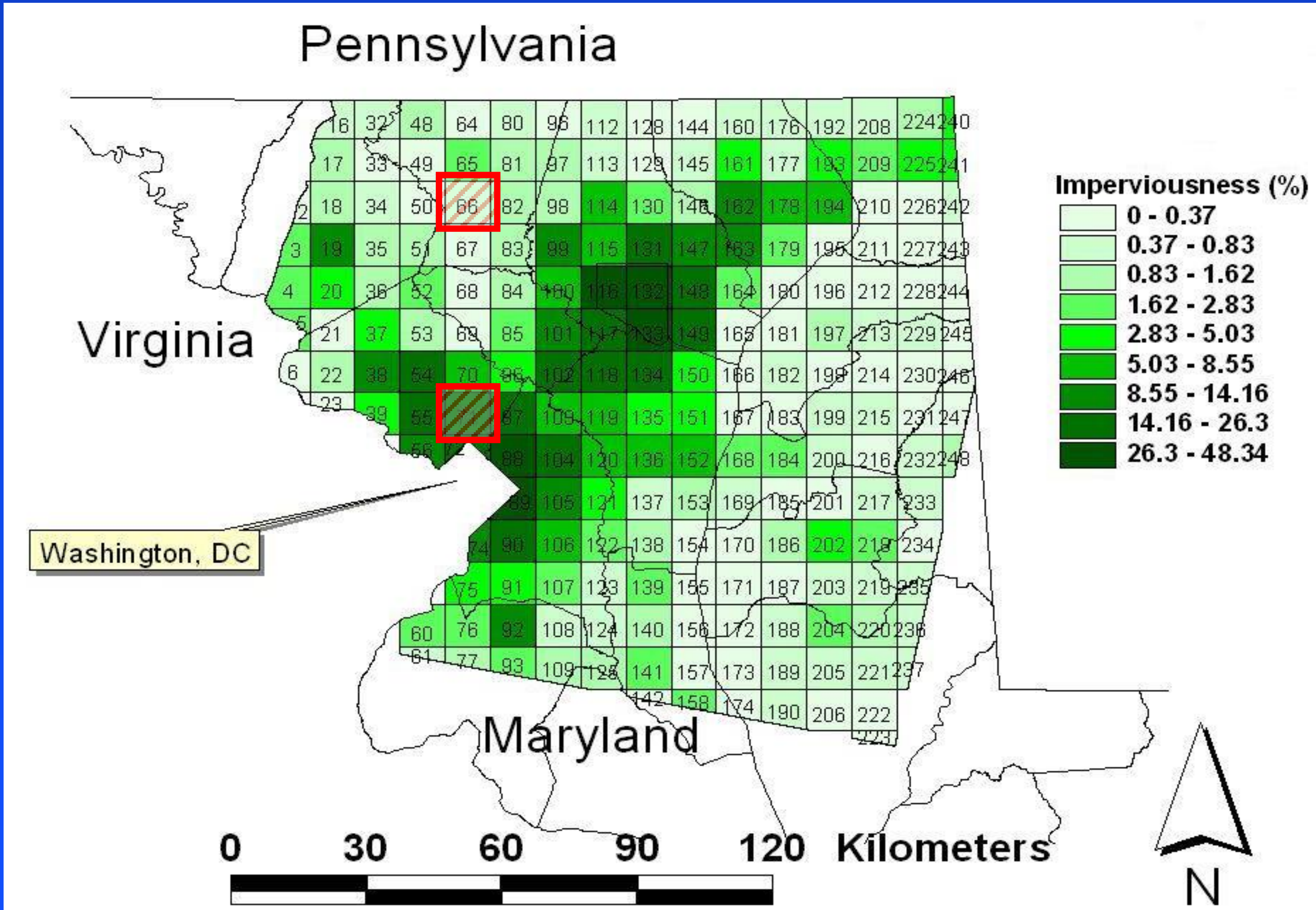



Figure 1.1 - The Impervious Cover Model (CWP, 1998)

# An experiment with NLCD Imperviousness...



# Three Ways to Measure Imperviousness…

**Method 1:** Direct assessment from the 2001 National Land Cover Dataset (NLCD).

**Method 2:** Inference from generalized land use then applying the NRCS (SCS, 1986) imperviousness.

**Method 3:** Direct application of the known road network from TIGER dataset (assuming ***all*** roads are 20 feet wide).

# Method 2 elaboration

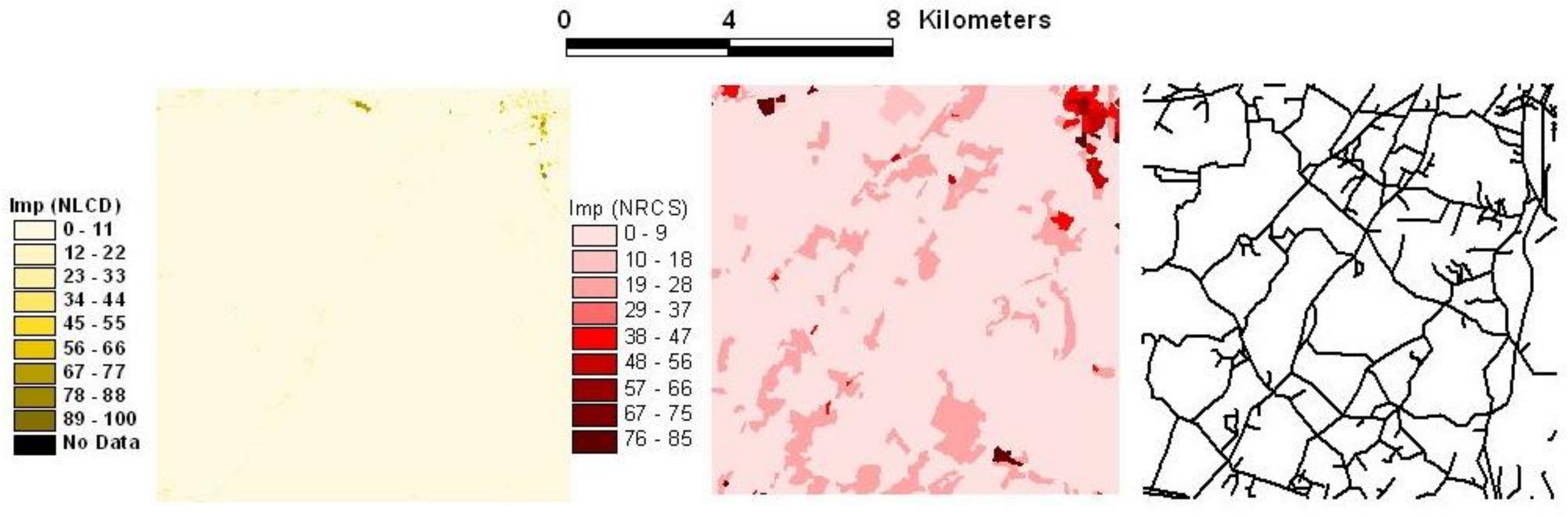
## Table 2-2a from SCS TR-55 (1986) document

| Cover description cover type and hydrologic condition | Average percent impervious area [2/] | -- CN for hydrologic soil group -- A | B | C | D |
|---|---|---|---|---|---|
| Urban districts: | | | | | |
| Commercial and business | 85 | 89 | 92 | 94 | 95 |
| Industrial | 72 | 81 | 88 | 91 | 93 |
| Residential districts by average lot size: | | | | | |
| 1/8 acre or less (town houses) | 65 | 77 | 85 | 90 | 92 |
| 1/4 acre | 38 | 61 | 75 | 83 | 87 |
| 1/3 acre | 30 | 57 | 72 | 81 | 86 |
| 1/2 acre | 25 | 54 | 70 | 80 | 85 |
| 1 acre | 20 | 51 | 68 | 79 | 84 |
| 2 acres | 12 | 46 | 65 | 77 | 82 |

**Imperviousness coefficients for various land uses**

# Box 66: Low Intensity Imperviousness …

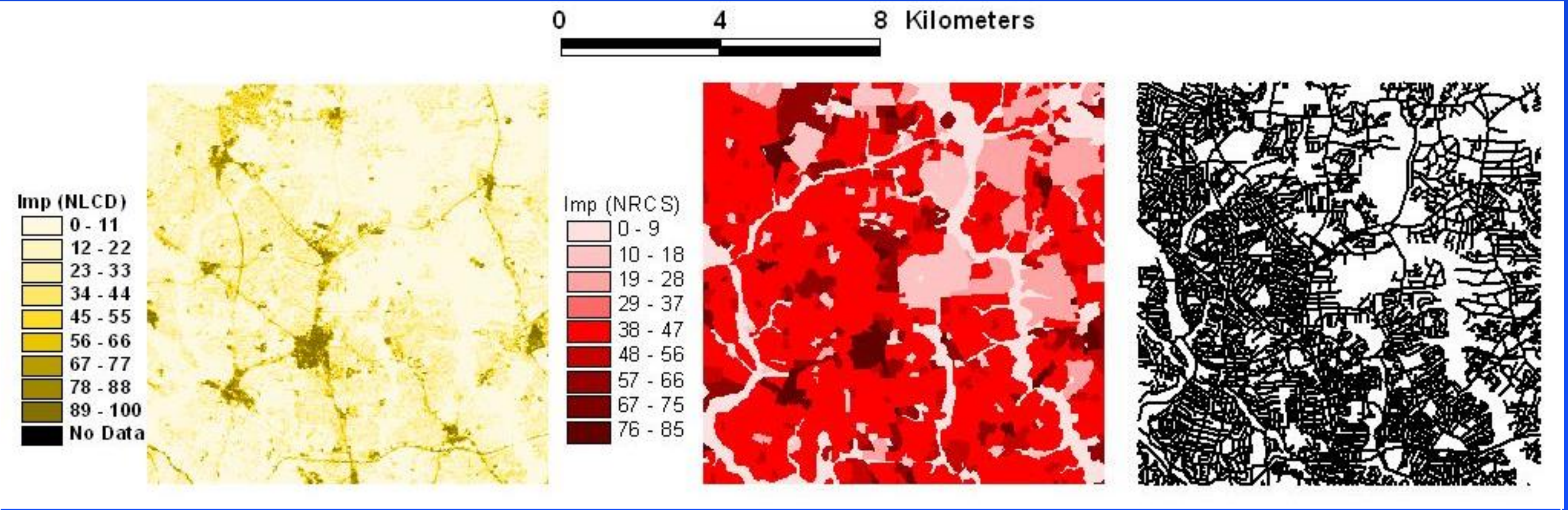
- More imperviousness from roads alone than from NLCD.
- Method 1 is 10% of Method 2.




| Method 1: | Method 2: | Method 3: |
| --- | --- | --- |
| *I*=0.40% | *I*=4.73% | *I*=1.20% |

# Box 71: High Intensity Imperviousness …

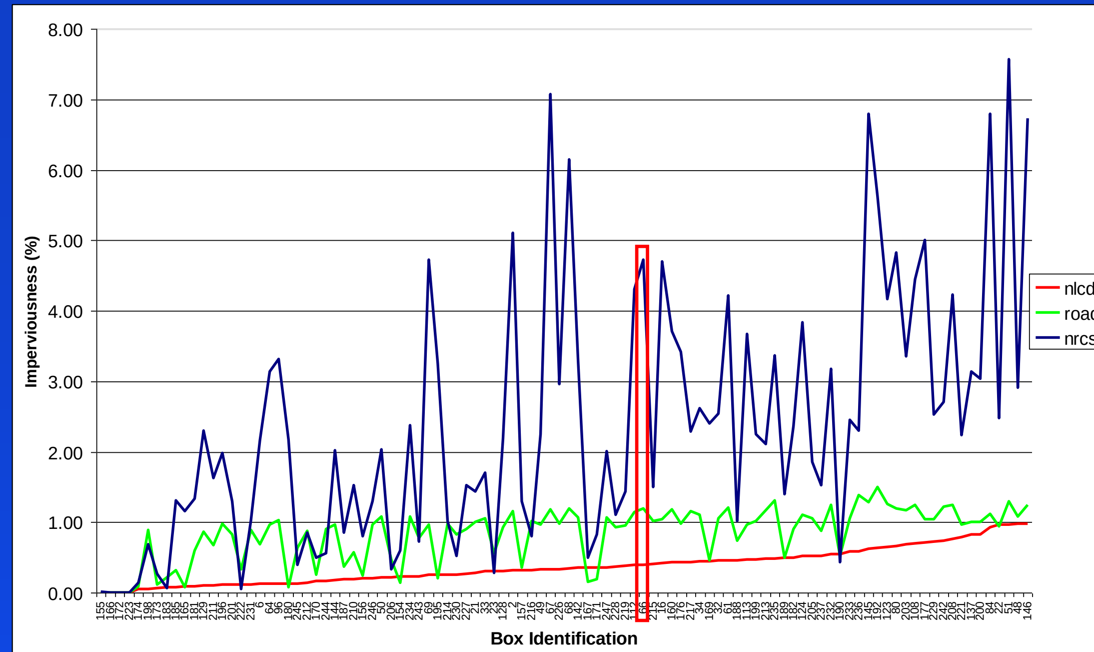
- Roads under-predict – not useful method for high intensity development.
- Method 1 is half of Method 2.

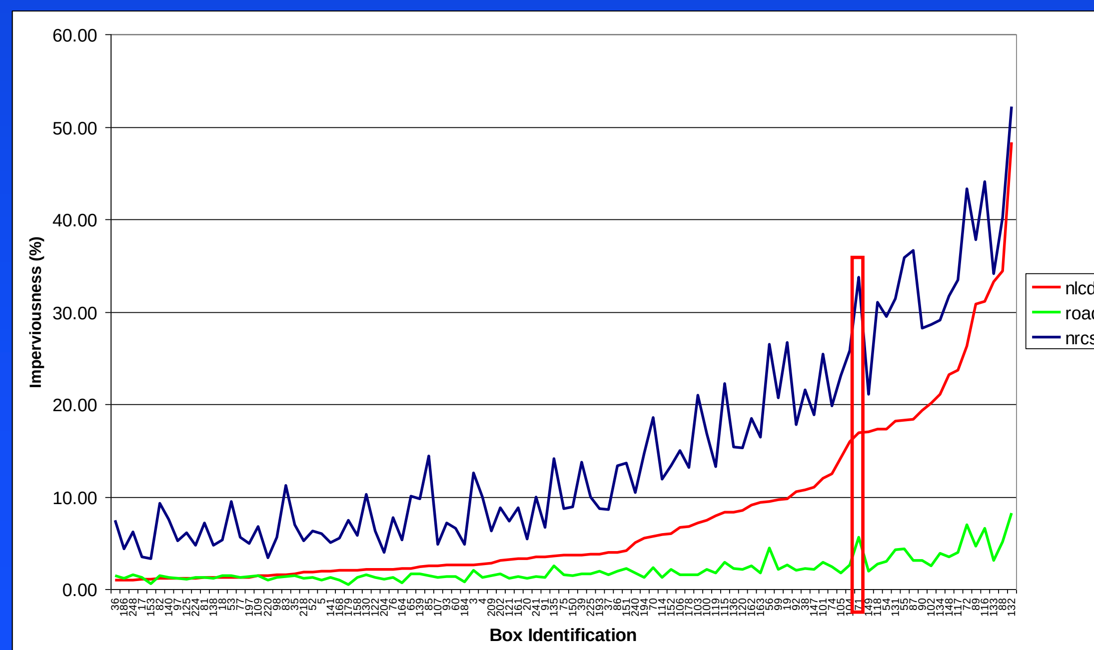



| Method 1: | Method 2: | Method 3: |
|---|---|---|
| $I$=16.86% | $I$=33.74% | $I$=5.65% |

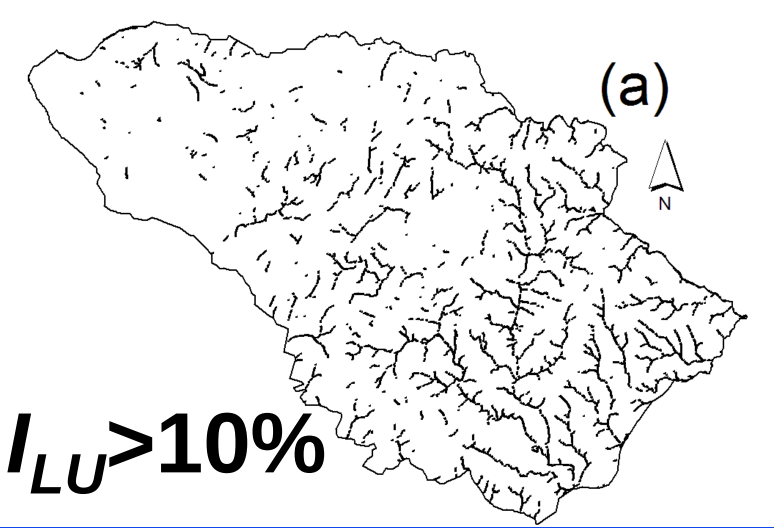
# Imperviousness Across Maryland …

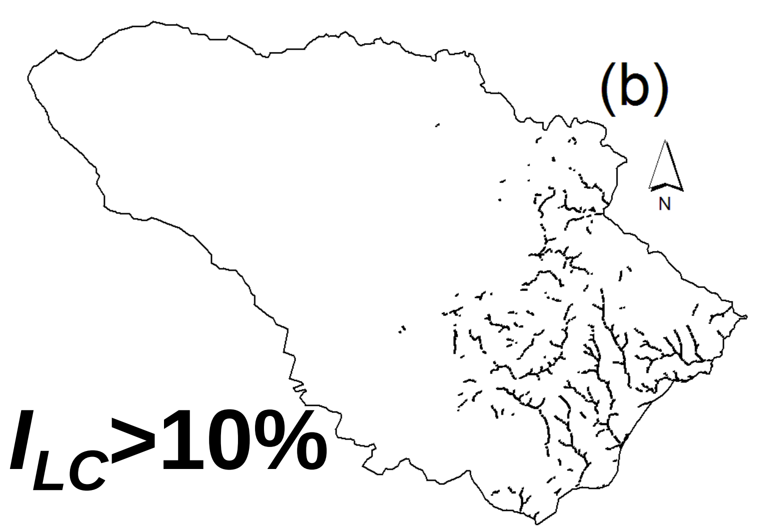
- NLCD under-prediction at low intensity.
- Systematic difference between NLCD and NRCS approach (~ factor of 2).

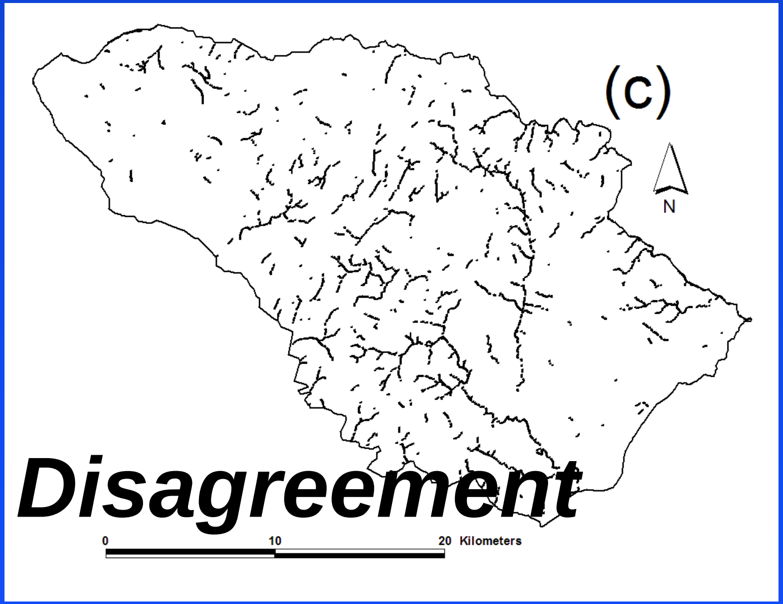


# Mapping the imperviousness threshold in Howard County, Maryland

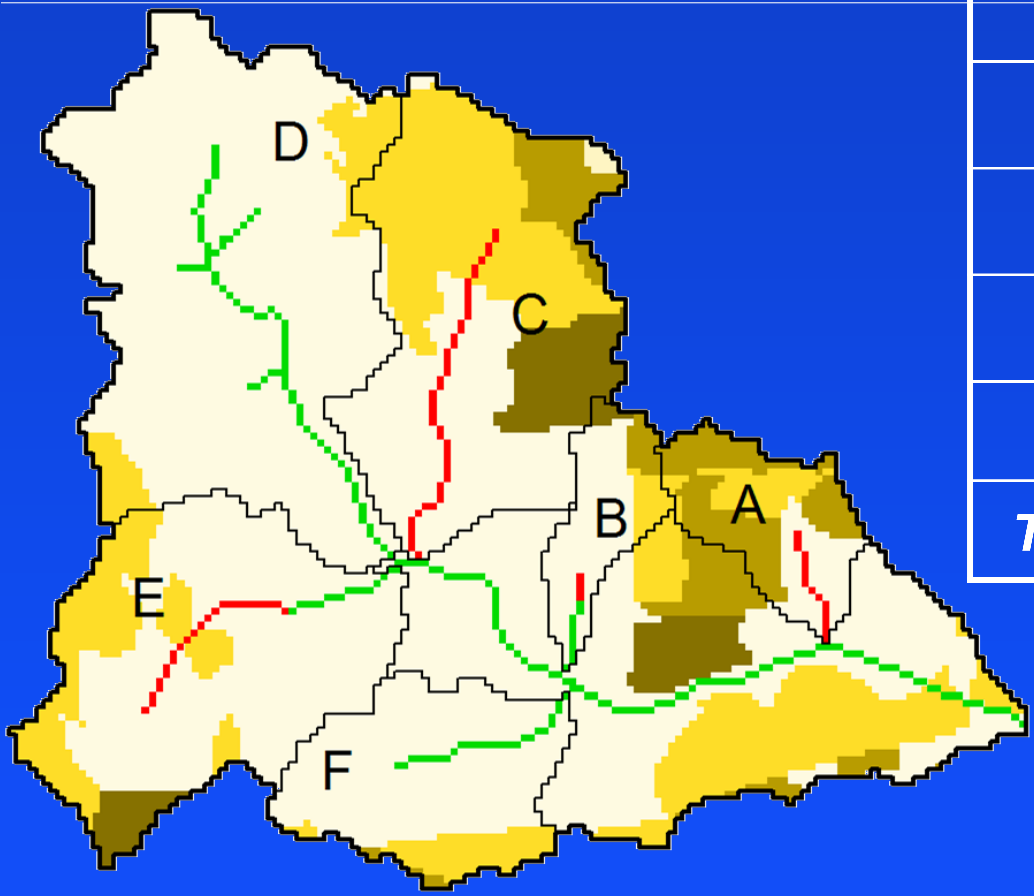


# Distribution of Imperviousness within a Watershed

| Water shed | Area ($km^2$) | %I at Outlet | % Over Thresh |
|---|---|---|---|
| A | 0.46 | 24.2 | 100.0 |
| B | 0.32 | 8.9 | 28.6 |
| C | 1.72 | 18.5 | 100.0 |
| D | 2.42 | 1.7 | 0.0 |
| E | 1.57 | 8.2 | 61.0 |
| F | 0.81 | 4.2 | 0.0 |
| *Total* | *9.45* | *9.8* | *28.8* |




Moglen, G.E. and S. Kim, (2007). "Limiting imperviousness: Are threshold-based policies a good idea?" *Journal of the American Planning Association*, 73(2): 161-171.

# Problem Summary

- There is considerable evidence of severe ecological impacts if imperviousness > 10%
- But…
  - How do we **measure** imperviousness? (Measurement methods differ greatly)
  - *Where* do we measure imperviousness? (Outlet and internal values can conflict)
  - How should this **inform policy**?

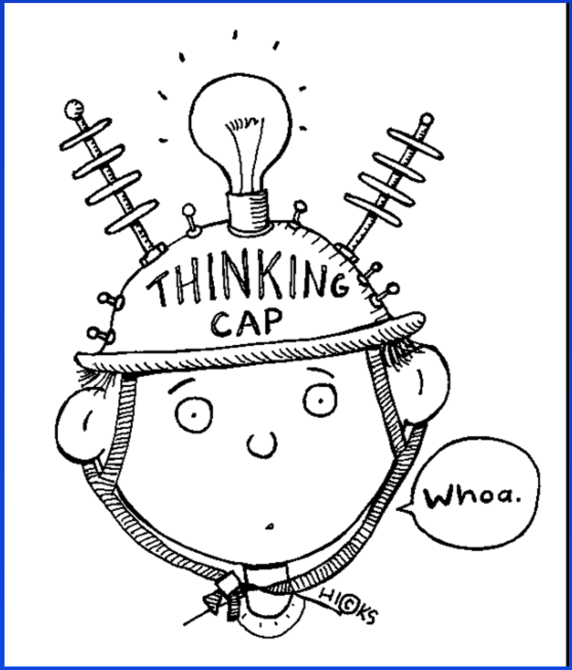
# Policy Implications…

- *Limit imperviousness per property to 8%, agriculture excepted.   Nationally recognized scientific research by the Center for Watershed Protection demonstrates that impervious surface contributes significantly to water quality decline.  Stream water quality begins to deteriorate from "good" to "fair" once imperviousness in the watershed exceeds 8%.*

  **-Maryland Sierra Club Recommendation**

- ***Question: Is this a good idea?***
- ***Answer: No.  Wrong for several reasons.***

# Optimization of a Threshold-Based Policy




- Thought experiment:
  - Total amount of imperviousness is externally prescribed.
  - Goal: Maintain aggregate imperviousness less than a fixed threshold ( $I_t$ ) *as much as possible* at all points ( $x$ ) in the stream network.
  - Optimize across watershed.

# Optimization of a Threshold-Based Policy

$$\min f = \sum_{i=1}^{N} I_p(\mathbf{x}_i)$$

$$I_p(\mathbf{x}) = \begin{cases} 0 & I(\mathbf{x}) < I_t \\ I(\mathbf{x}) & I(\mathbf{x}) \geq I_t \end{cases}$$

# Optimization can be posed in different ways…

- Different patterns of low density sprawl

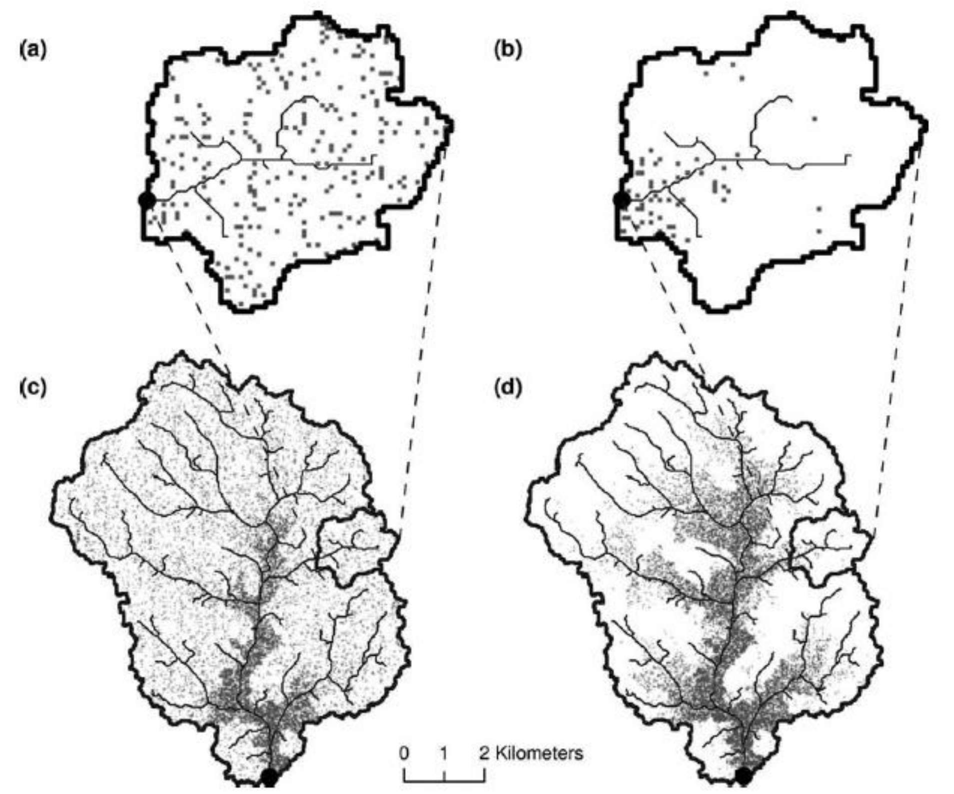
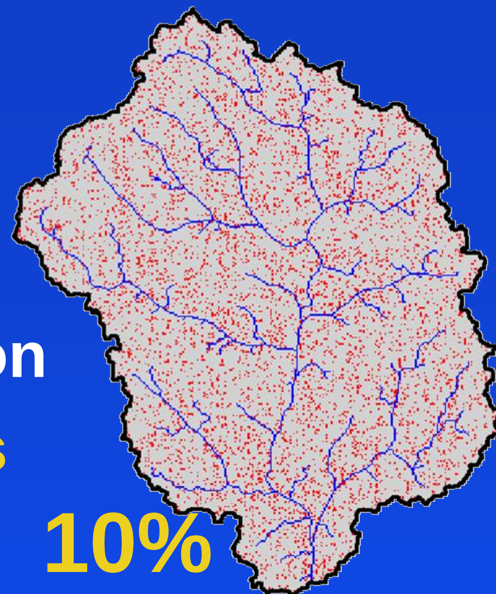



**Fig. 5.** (a) Subwatershed showing the distribution of urban development when $f_4$ is minimized and (b) same subwatershed when $f_1$ is minimized. (c) Urban pattern derived from the minimization of $f_4$ and (d) from the minimization of $f_1$.

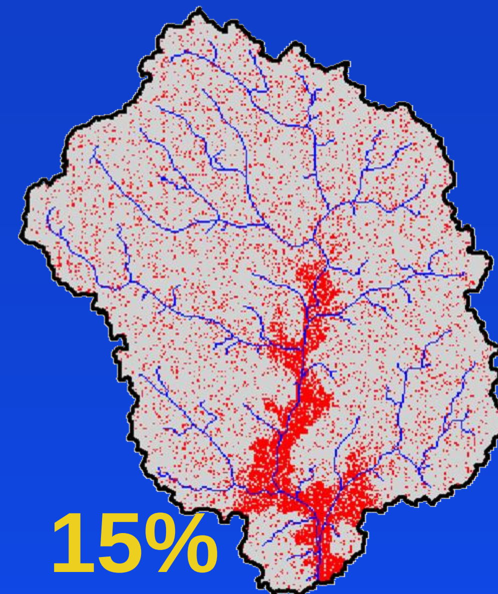

- Mejia, A.I. and G.E. Moglen, (2009). "Spatial Patterns of Urban Development from Optimization of Flood Peaks and Imperviousness-Based Measures." *Journal of Hydrologic Engineering*, ASCE, 14(4): 416-424. April 2009.
- Moglen, G.E., (2009). "Hydrology and Impervious Areas." *Journal of Hydrologic Engineering,* ASCE, 14(4): 303-304.

# Optimization of a Threshold-Based Policy

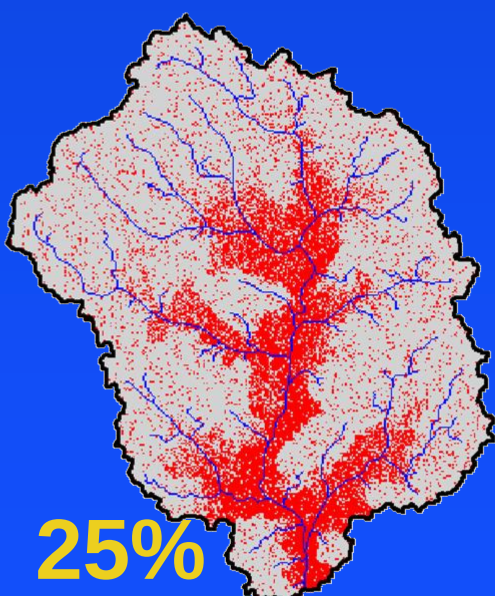
- Optimized development patterns as function of **total impervious area**



10%



15%



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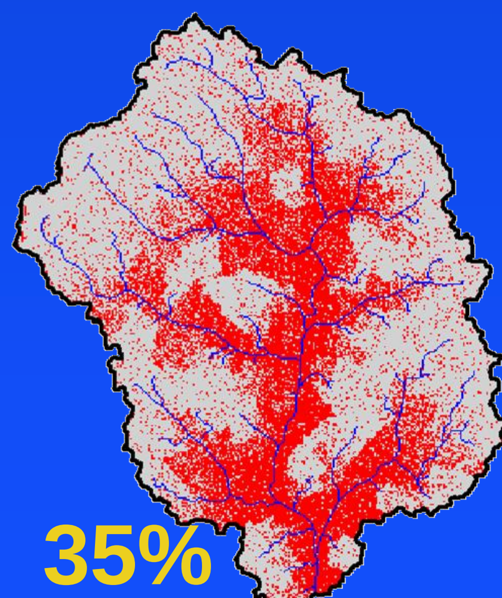

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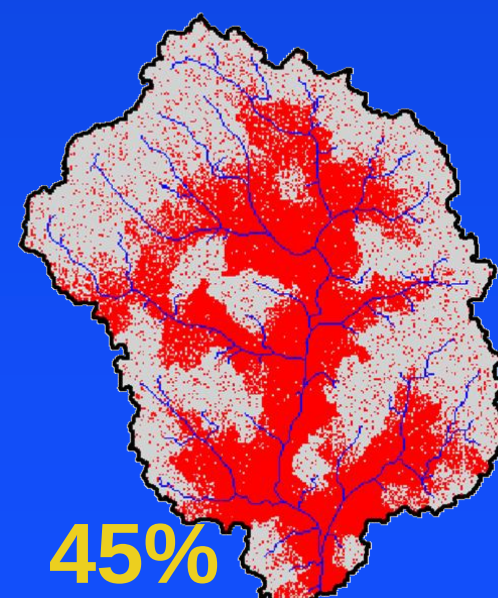
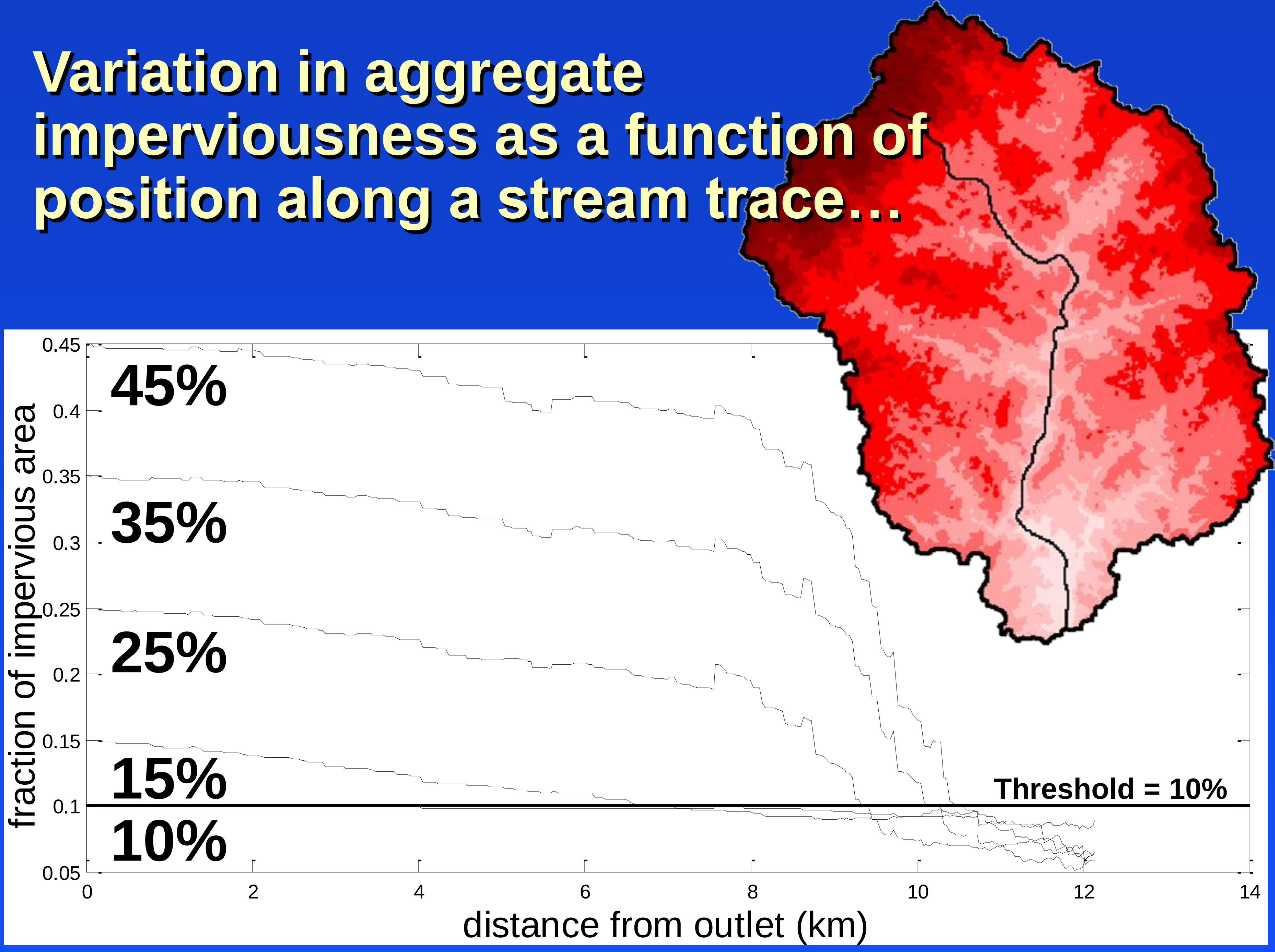


45%

# Variation in aggregate imperviousness as a function of position along a stream trace…



# Optimization Conclusions

- **Simple threshold viewed only from some arbitrary watershed outlet perspective misses internal variations (earlier *JAPA* figure).**
- **Optimization of naïve objective function suggests spatial patterns for location of imperviousness to support ecological goals.**
- **Because optimization is naïve, we need to further constrain the process to recognize other external goals or space limitations.**

# What *SHOULD* we do?

- Recognize there are no easy answers.
- <u>Understand</u> the science influencing policy.
- Avoid "one-size fits all" thresholds.
- Tailor planning to hydrologic environment:
  - "Deny": Identify precious water resources to protect.
  - "Accept": Strategically orient planned development to concentrate degradation.
  - "Engineer": Use BMPs to mitigate impacts.