# Air Quality, Emissions, Growth, and Change
# A Method to Prescribe a Desirable Future

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# Our perspective going in…

- Forecasting is hard.
- Predictions are uncertain.
- Sometimes future outcomes are undesirable.

# Our approach…

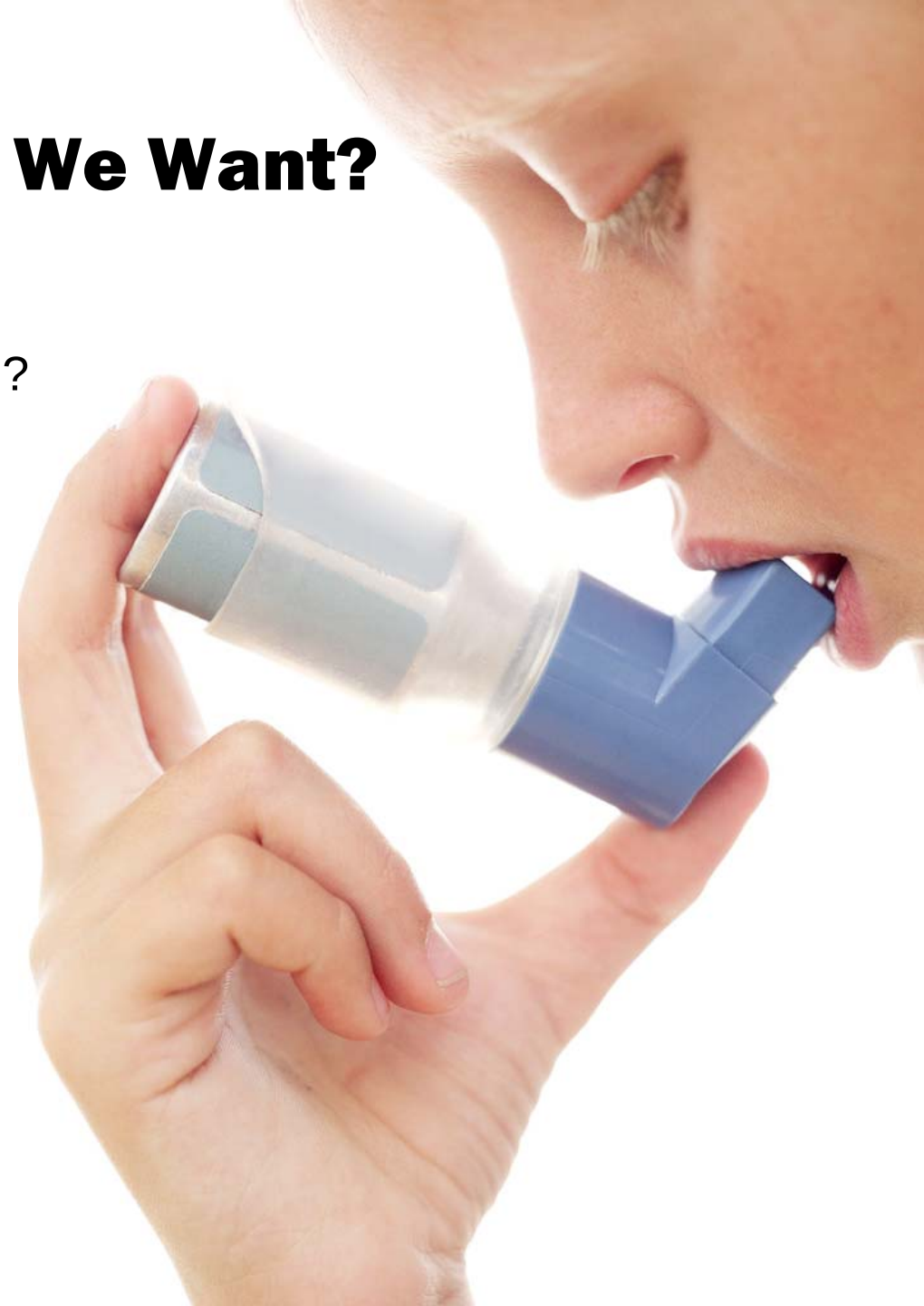
- **Predict** as little of the future as possible.
- **Plan** as much of the future as possible.

  Make air quality an input into the urban development process rather than an outcome of it.

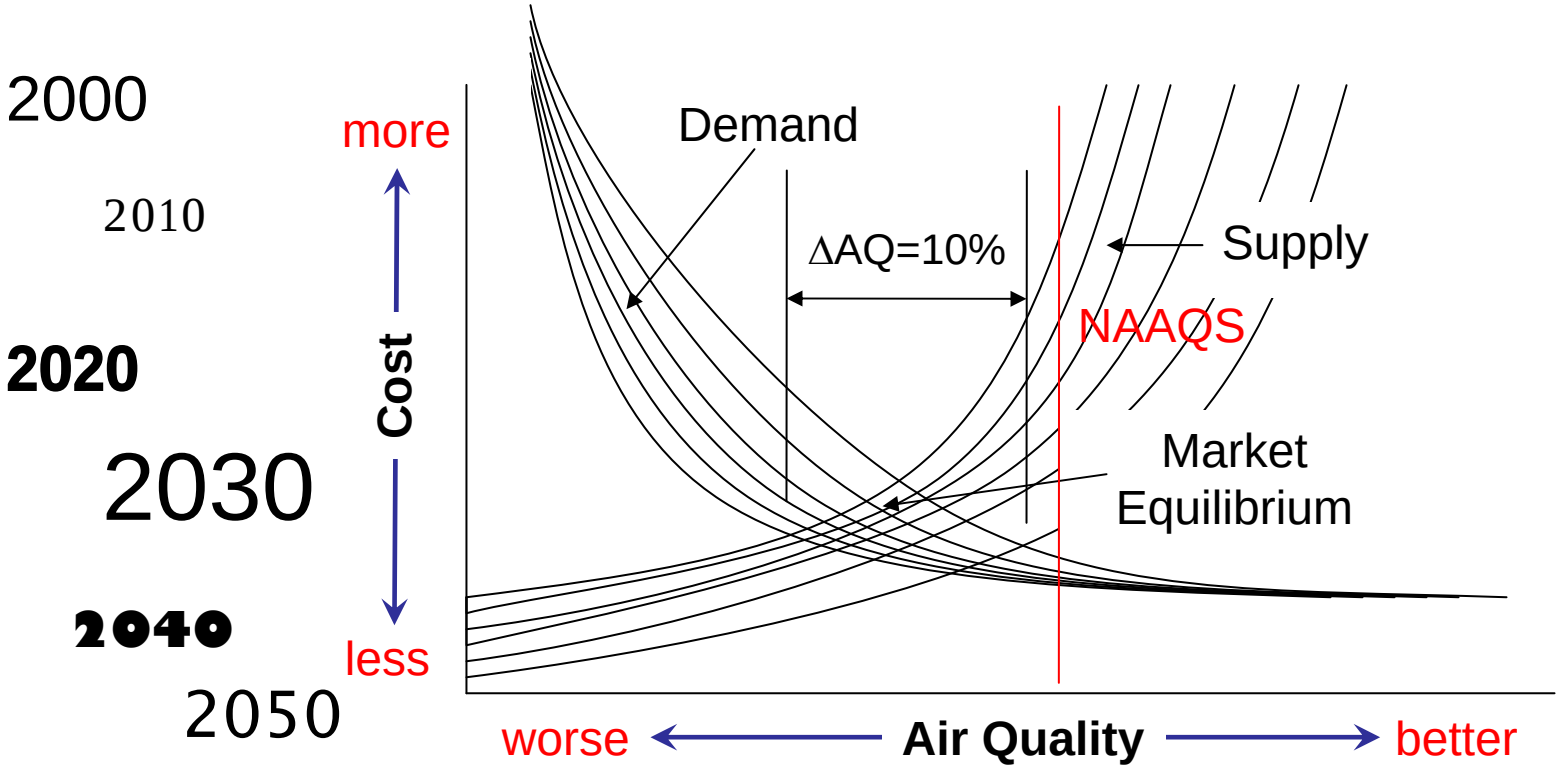
  1. What air quality do we **want** in the future?
  2. What emissions yield the desired air quality?
  3. What land uses fit the emissions profile?

# What Air Quality Do We Want?

- Depends on who you ask…
  - Mothers of asthmatic children?
  - Absentee owners of smokestack industries?
  - Beleaguered politicians?
- Assume a consensus could be reached (a lengthy exercise in public policy).
- For testing purposes only, we asked an economist.
- Other scenarios.



# What air quality do we want?
# An economic approach



## What emissions yield the desired air quality?

# The Forward Method

"Predict the change in emissions and you can predict the change in air quality."

$$\Delta \mathbf{EP} = \Delta\chi$$

where

$\Delta\mathbf{E}$ is the change in emissions,
$\mathbf{P}$ is a transformation matrix, and
$\Delta\chi$ is the change in air quality

## What emissions yield the desired air quality?

# The Inverse Method

"State the change in air quality desired and you can calculate the change in emissions needed."

$$\Delta \mathbf{E} = \mathbf{P}^{-1} \Delta \chi$$

where

$\Delta \mathbf{E}$ is the change in emissions,
$\mathbf{P}$ is a transformation matrix, and
$\Delta \chi$ is the change in air quality

## What emissions yield the desired air quality?

# The Inverse Method: Kalman Filter

(subject to agreement)

"State the change in air quality desired ($\hat{\Delta\chi}$) and you can calculate the change in emissions needed ($\hat{\Delta E}$)."

(constrained by what can and cannot be readily changed)

$$\Delta\mathbf{E} = \mathbf{C}\mathbf{P}^T(\mathbf{P}\mathbf{C}\mathbf{P}^T+\mathbf{N})^{-1}\Delta\chi$$

where

$\Delta\mathbf{E}$ is the change in emissions,

$\mathbf{P}$ is a transformation matrix,

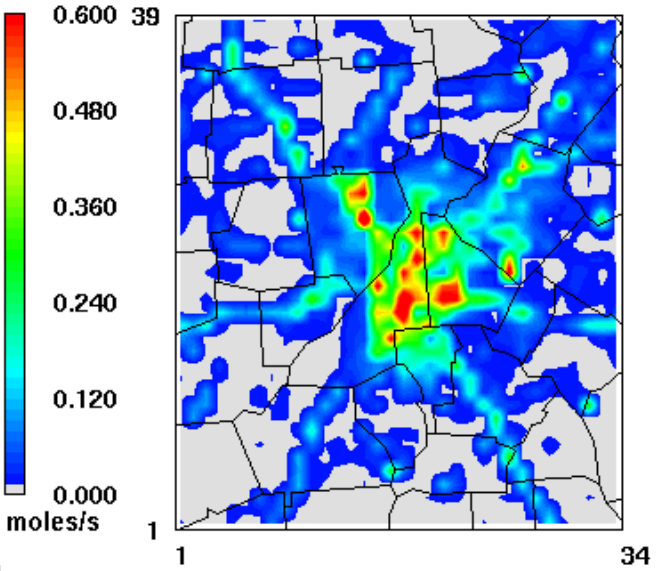
$\Delta\chi$ is the change in air quality,

$\mathbf{N}$ is the noise matrix (degree to which people agree)

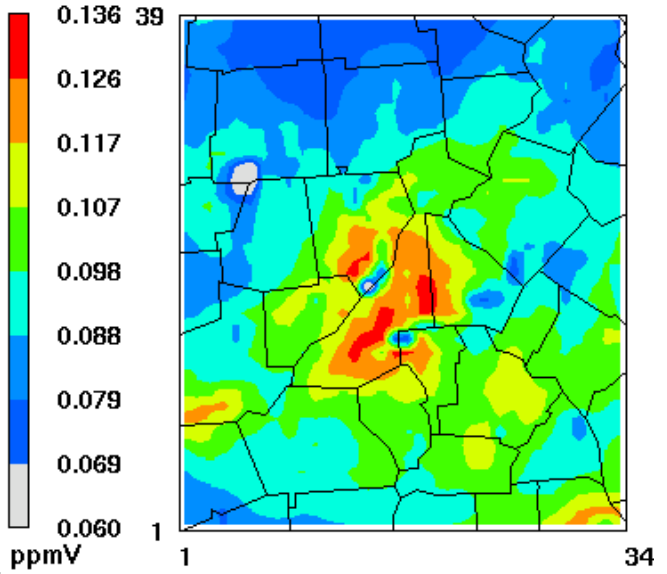
$\mathbf{C}$ is the covariance matrix (degree to which sources can change)

# What emissions yield the desired air quality?

Original Mobile Source NOx



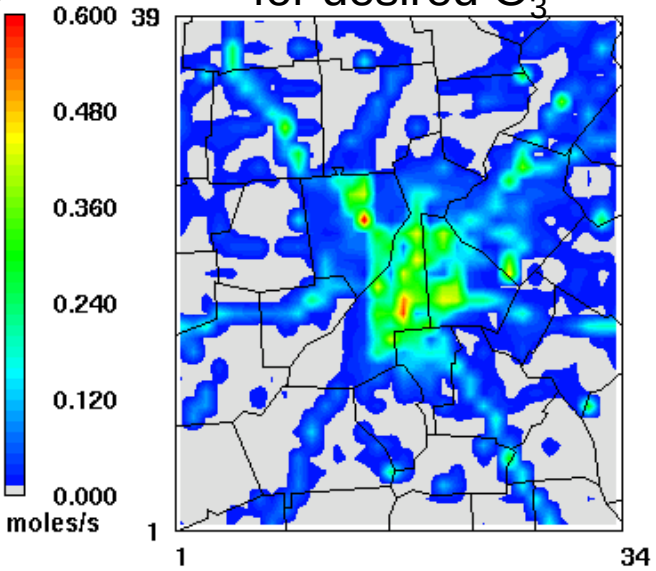

Original Ozone



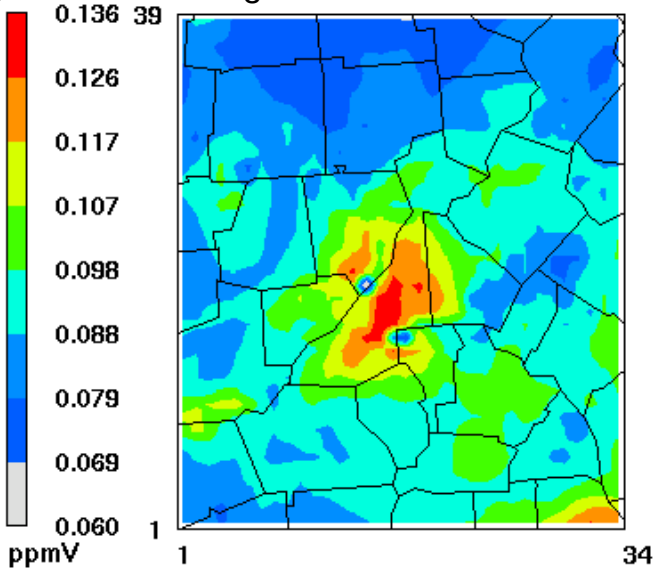

Needed emissions reductions to achieve desired $O_3$

| | |
|---|---|
| Mobile (13 core counties) | 29% |
| Mobile (elsewhere) | 0% |
| Area | 76% |
| Nonroad | 0% |
| Point | 59% |

Needed Mobile NOx for desired $O_3$




$\Delta O_3$ = -10% (desired)



# What land uses fit the emissions profile?

SMARTRAQ Travel Survey
8000 Households

Strategies for Metropolitan Atlanta Regional Transportation and Air Quality (completed, 2004)

**Household Travel Survey**

- 13 county Atlanta, GA region
- 8,069 households
- 17,500+ people
- 116,000+ trips
- 64,600+ locations
- 15,000+ vehicles

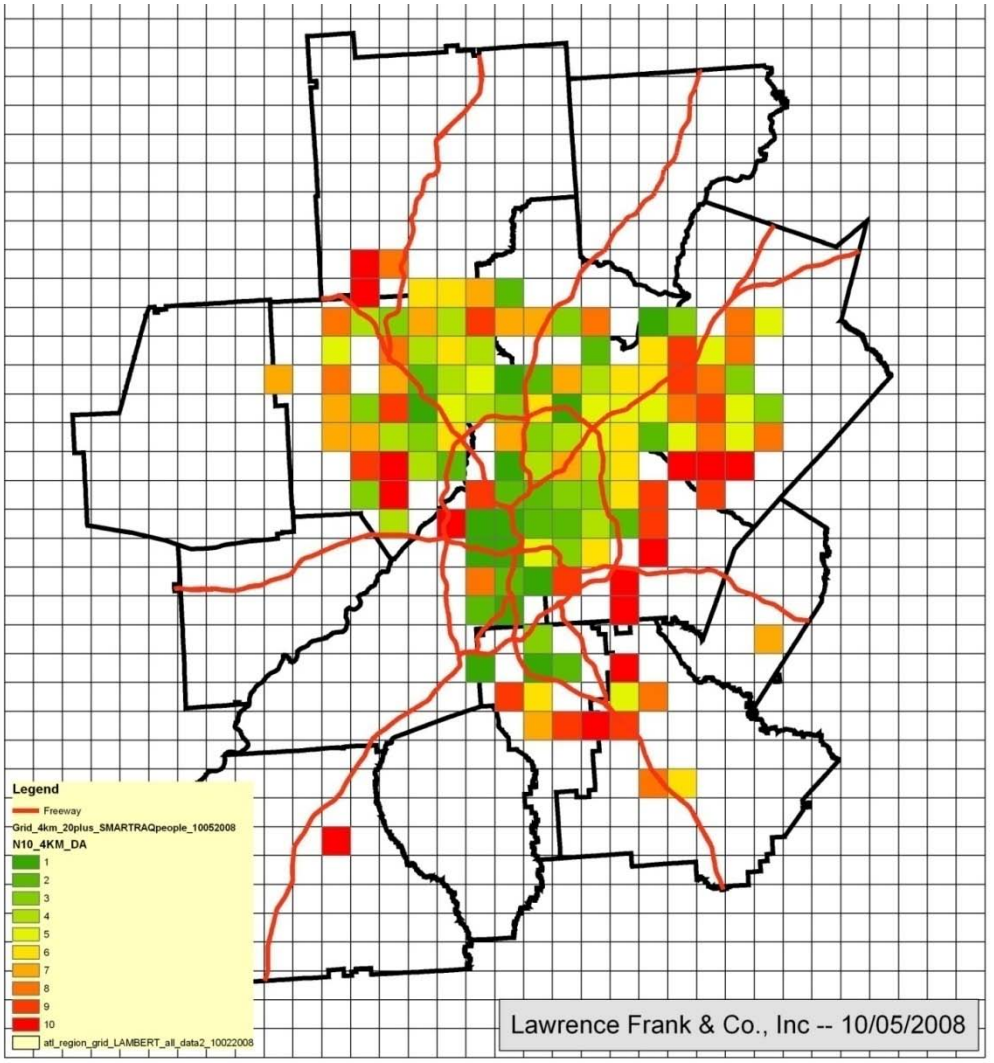
SMARTRAQ: land use as a predictor of household transportation related emissions

We continue the “inverse” theme and use the SMARTRAQ database to identify land use characteristics that are suited for a stated (desired) emissions budget.

# What land uses fit the emissions profile?

# Not Everyone Pollutes the Same

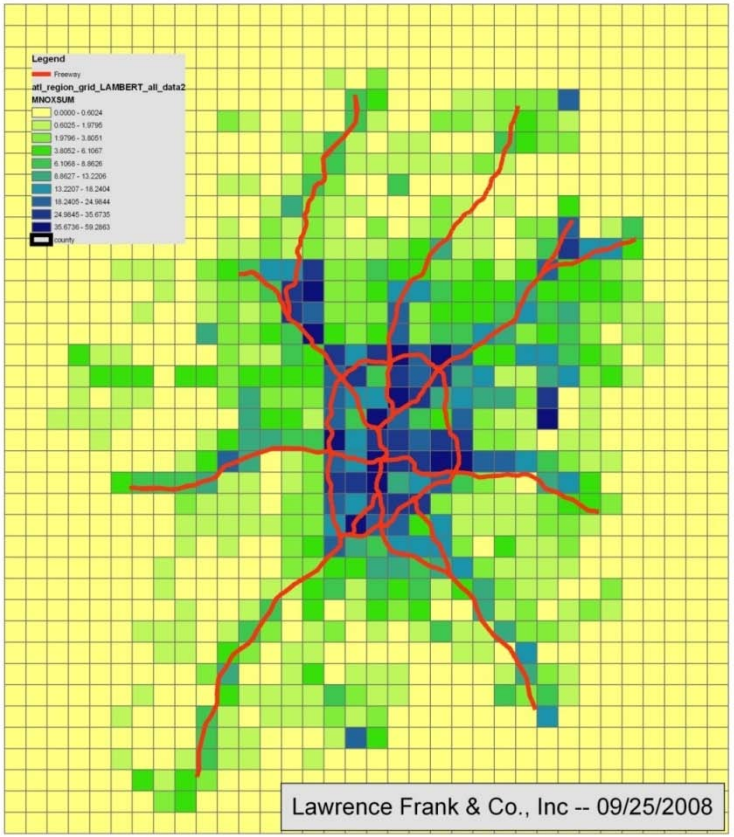
| Decile 4km grid | Per person weekday NOx (grams) |
|---|---|
| 1 | 18 |
| 2 | 20 |
| 3 | 22 |
| 4 | 23 |
| 5 | 25 |
| 6 | 26 |
| 7 | 27 |
| 8 | 28 |
| 9 | 32 |
| 10 | 37 |



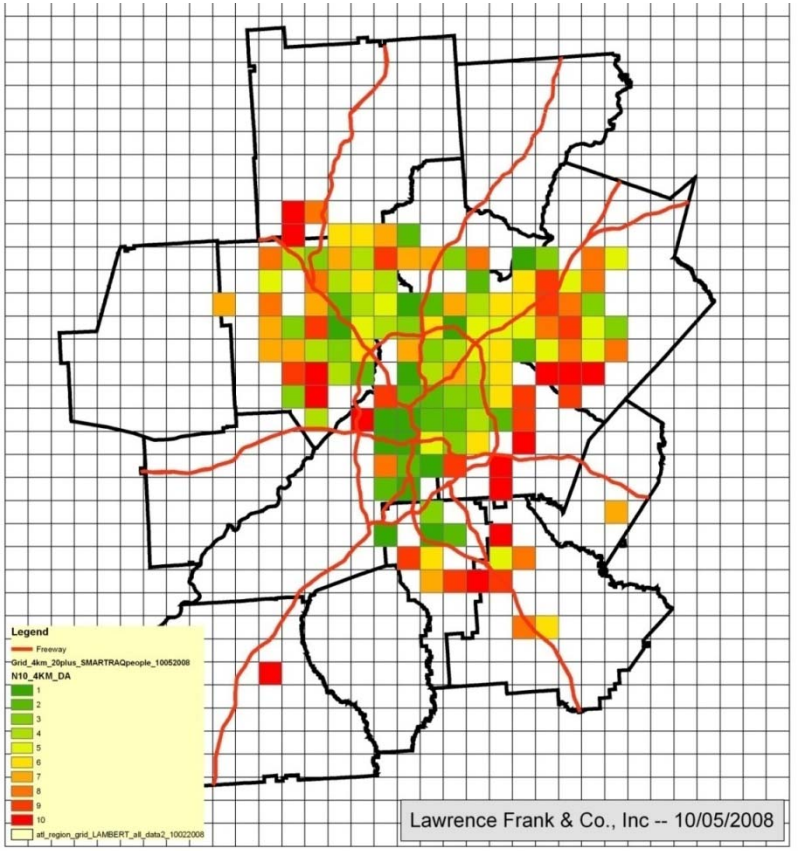
# What land uses fit the emissions profile?

Mobile Source NOx Emissions

"Where you drive" (CMAQ)




"Where you live" (SMARTRAQ)

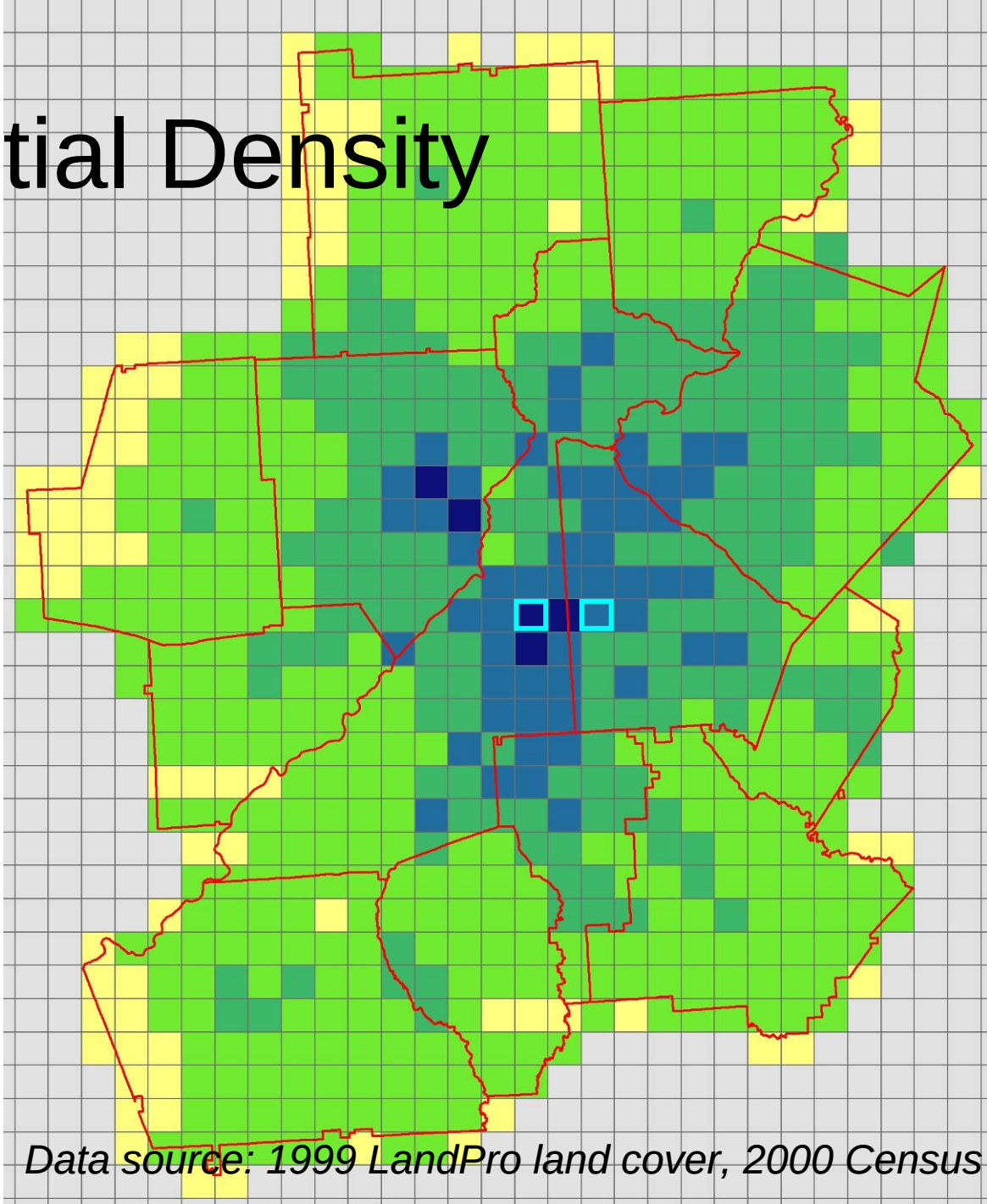


# Key findings between land use and travel emissions

- Residential density, intersection density, and land use mix shown to have a significant inverse association with per capita NOx emissions.
  - Chapman, Jim , Frank, Lawrence (2004). “Integrating Travel Behavior and Urban Form Data to Address Transportation and Air Quality Problems in Atlanta.” Final Report. Deliverable # V.30 under GDOT Research Project No. 9819, Task Order 97-13, 267.
- Found a single index of walkability (incorporating land use mix, street connectivity, net residential density, and retail floor area ratios) to be significantly negatively associated with per capita NOx emissions.
  - Frank, Lawrence, Sallis JF, Conway T, Chapman J, Saelens B, Bachman W (2006). “Multiple Pathways from Land Use to Health: Walkability Associations with Active Transportation, Body Mass Index, and Air Quality.” Journal of the American Planning Association Vol. 72 No. 1.
- Residential density found to have a significant negative relationship with household vehicle emissions.
  - Frank, L. D., Stone, B., & Bachman, W. (2000). Linking land use with household vehicle emissions in the central Puget Sound: Methodological framework and findings. *Transportation Research D, 5* (3), 173–196.

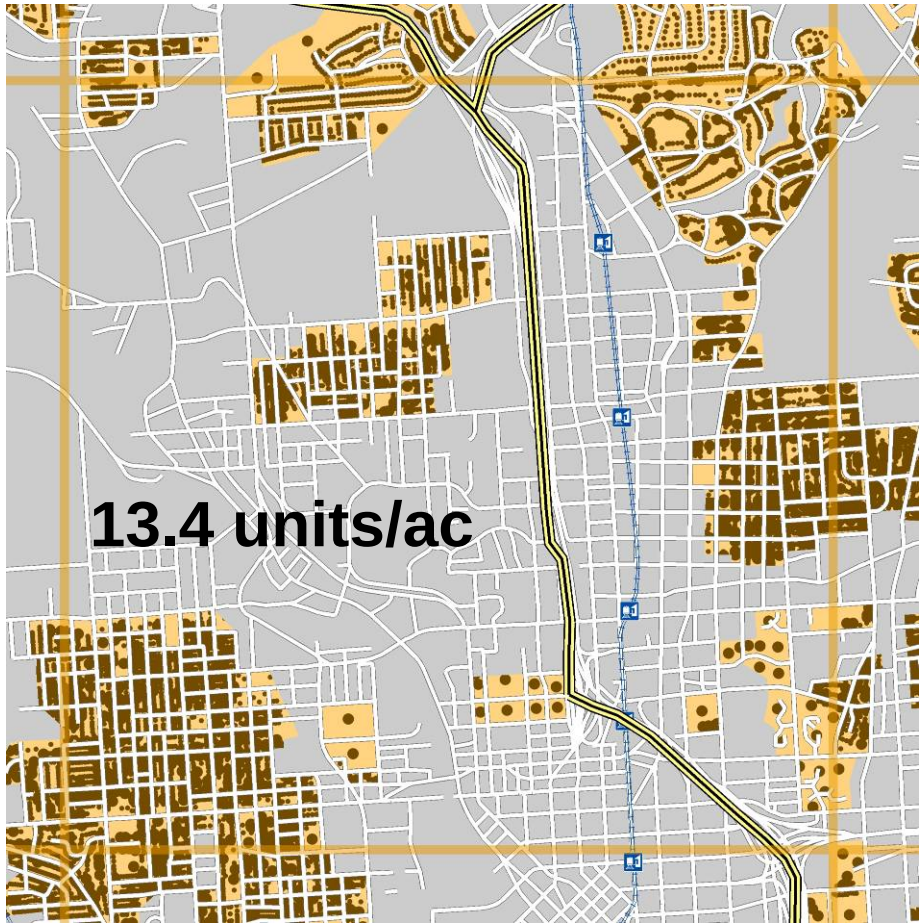
# Net Residential Density

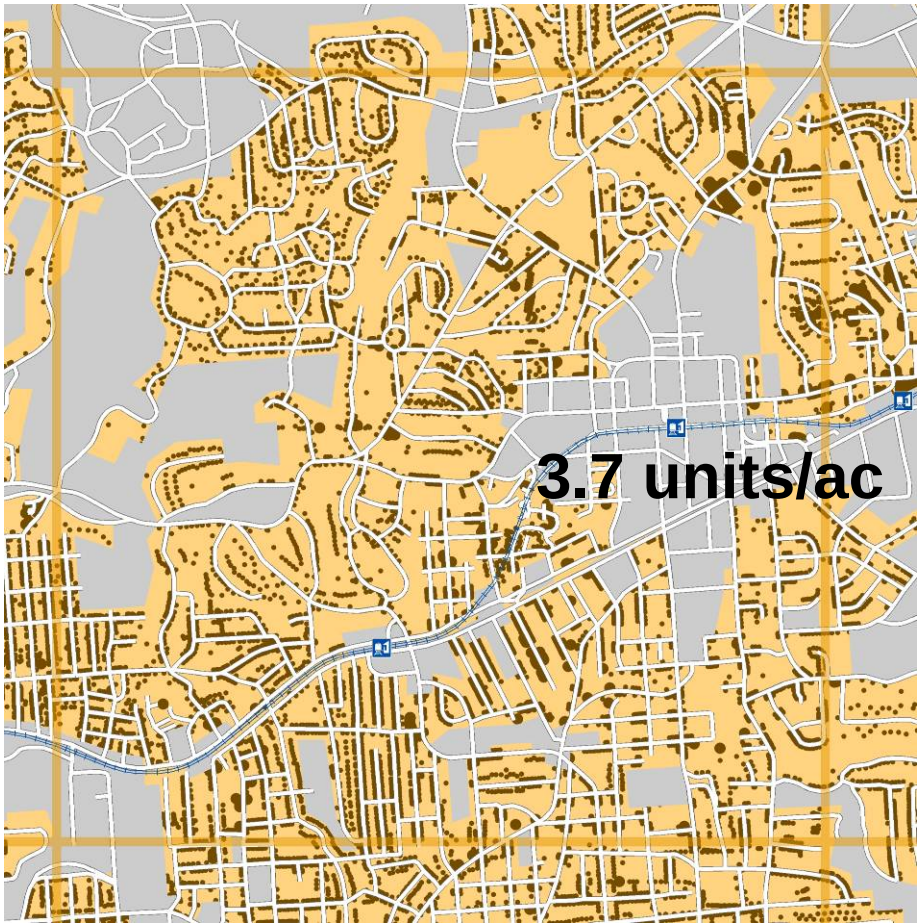
- # residential units / residential acre
- Range of 0 - 13.4 units/ac




*Data source: 1999 LandPro land cover, 2000 Census*

# Net Residential Density




4km grid boundaries

Transit rail

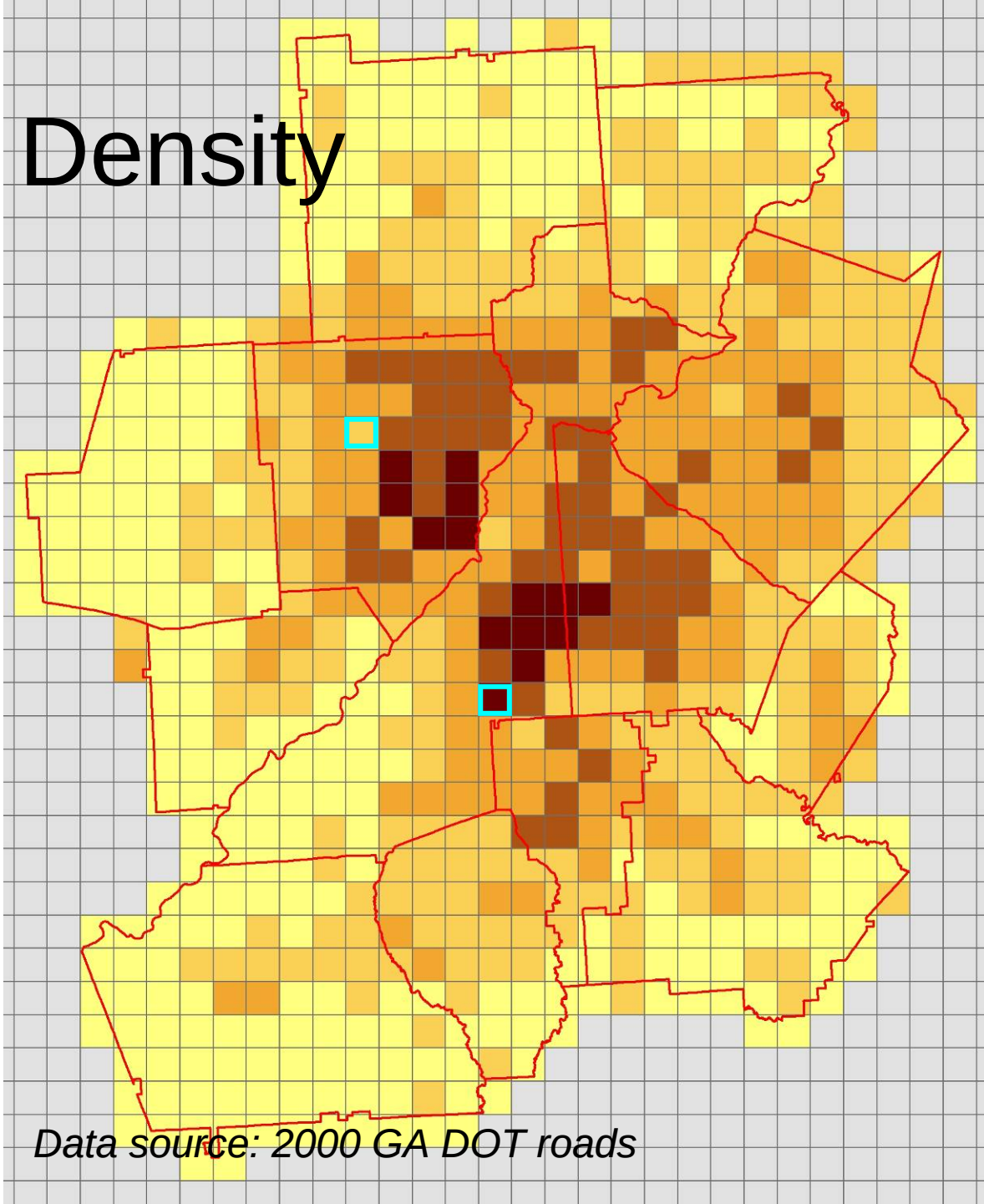
Highway

Residential units

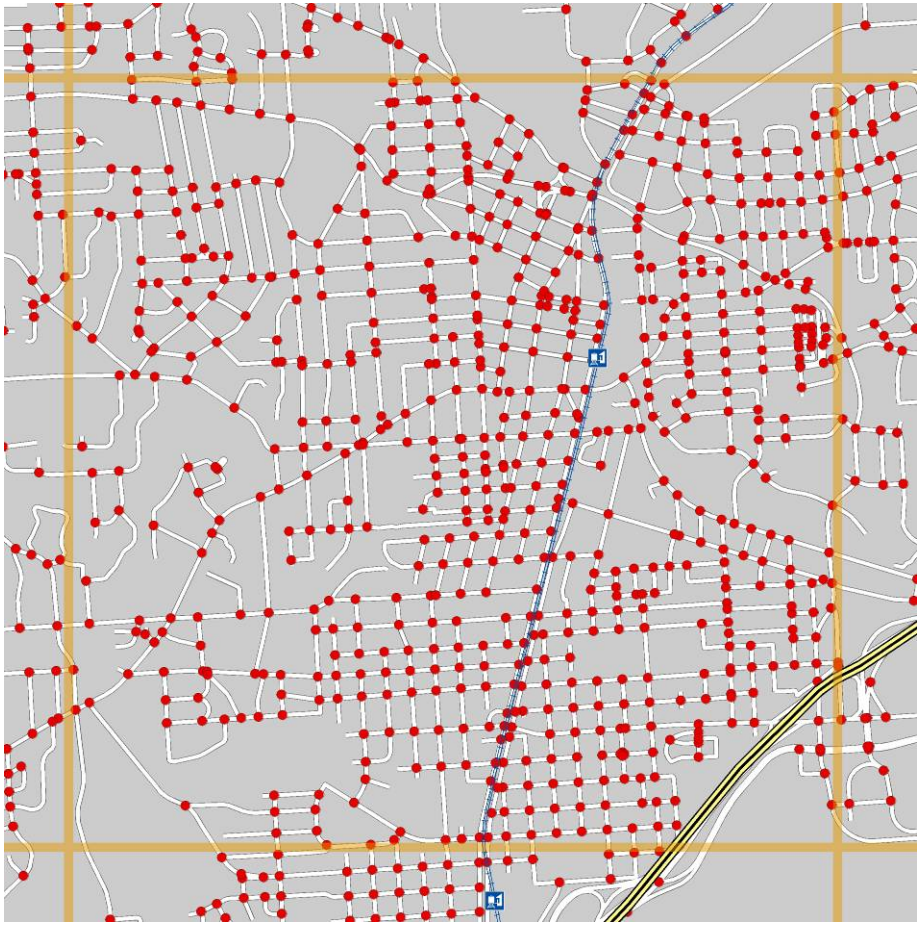
Residential land

# Intersection Density

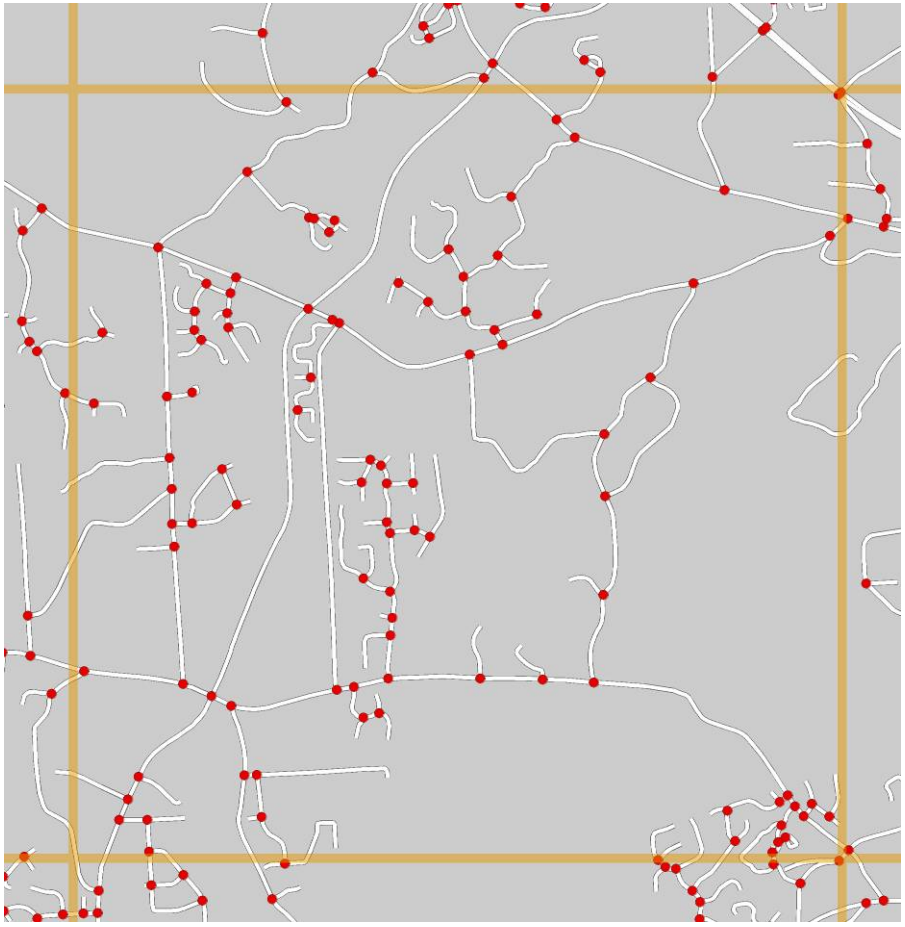
- # intersections (at least 3-way) / $km^2$
- Range of 0 - 60.9 int/$km^2$



# Intersection Density



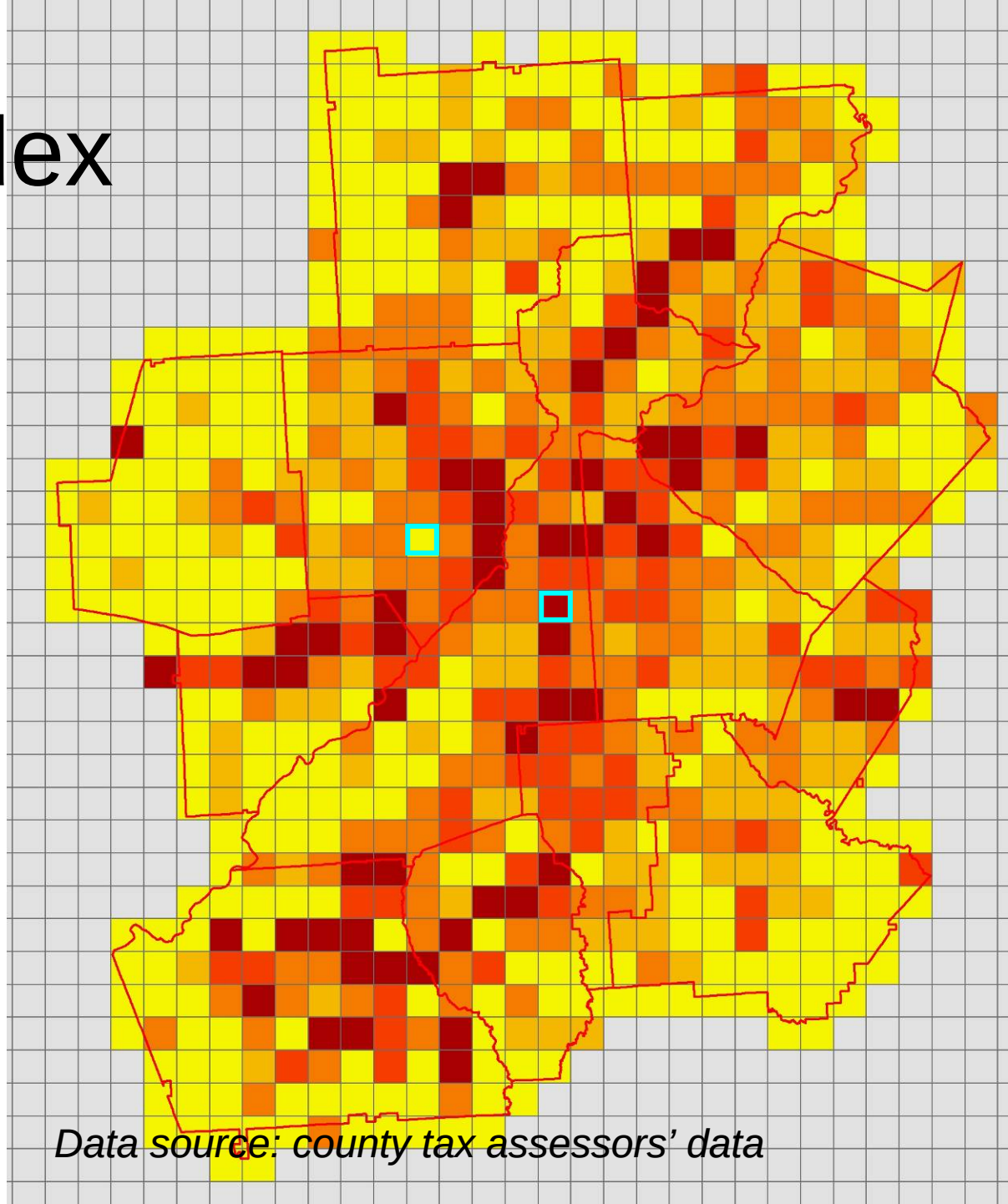
**43.5 int/km²**



**6.1 int/km²**

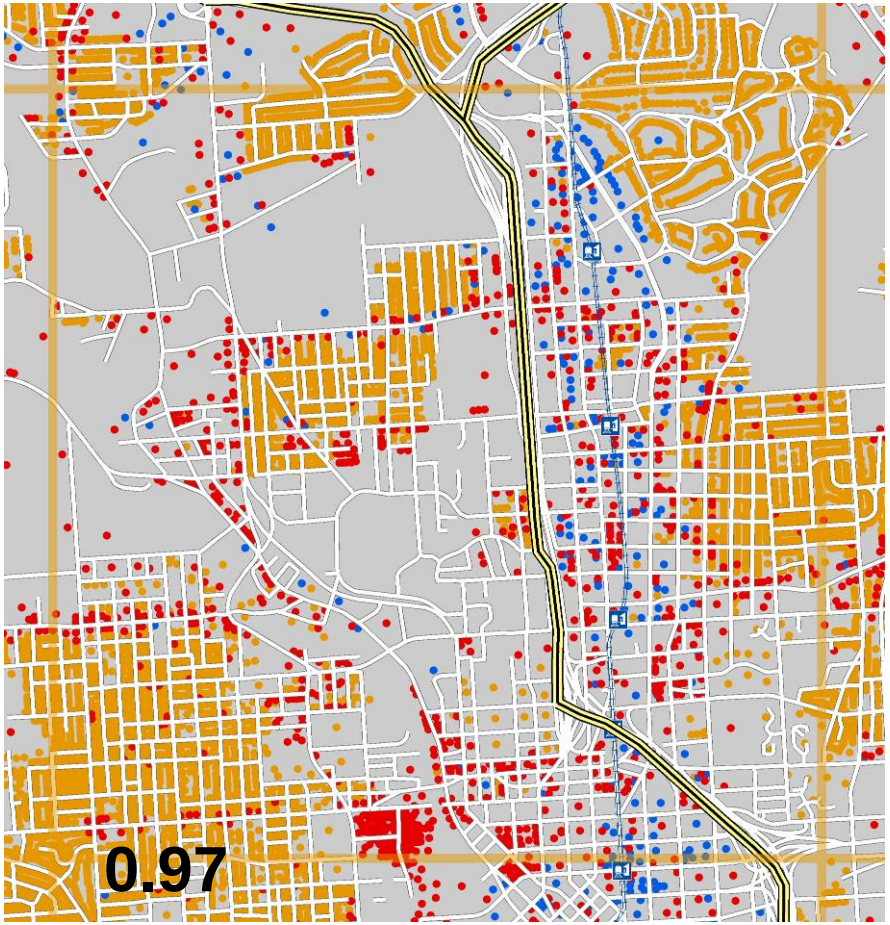
# Use Mix Index

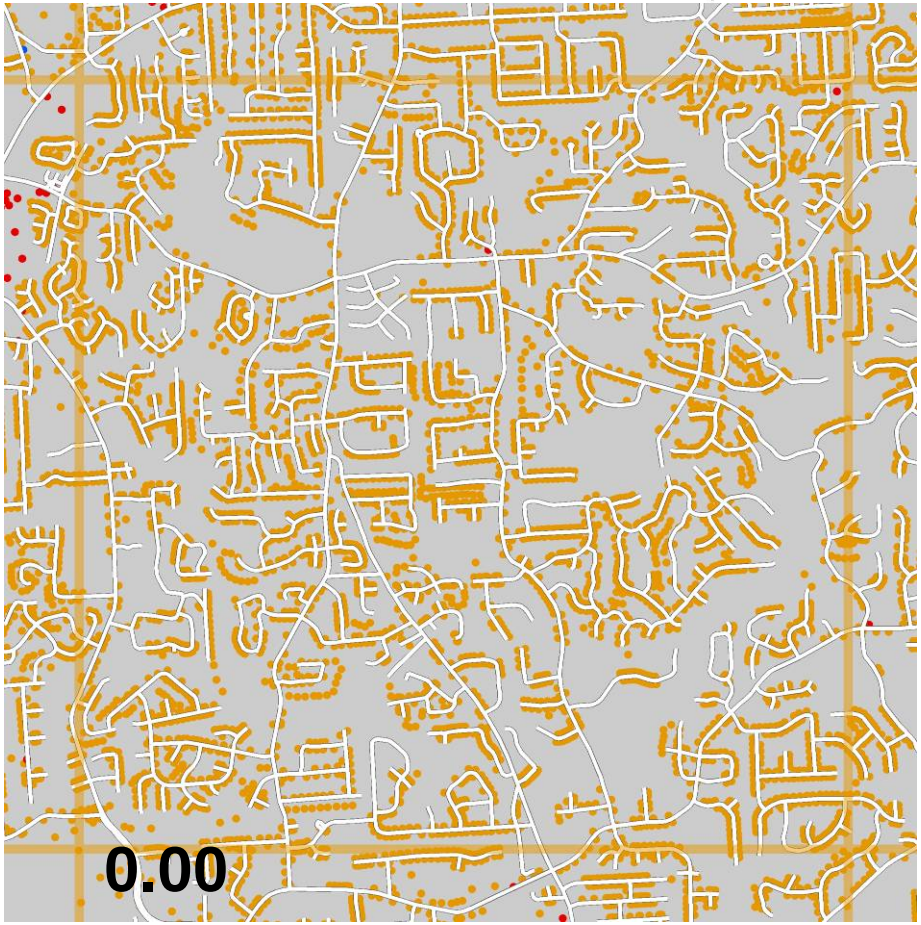
- Relative evenness of commercial, office, and residential square footage
- Range of
  0 (single land use) –
  1 (perfectly mixed)




*Data source: county tax assessors' data*

# Use Mix Index




4km grid boundaries

Transit rail

Highway

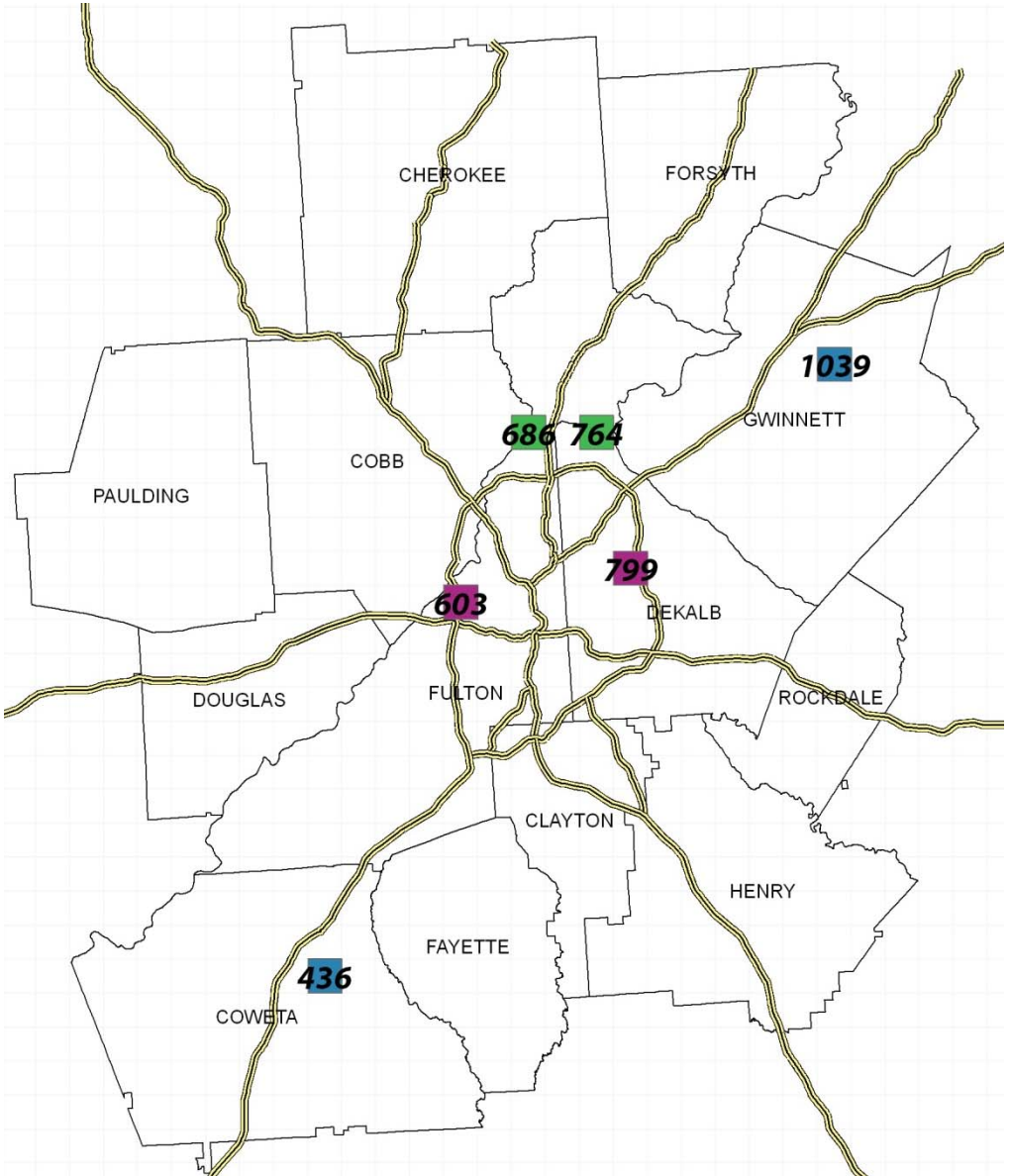
Commercial parcel

Residential parcel

Office parcel

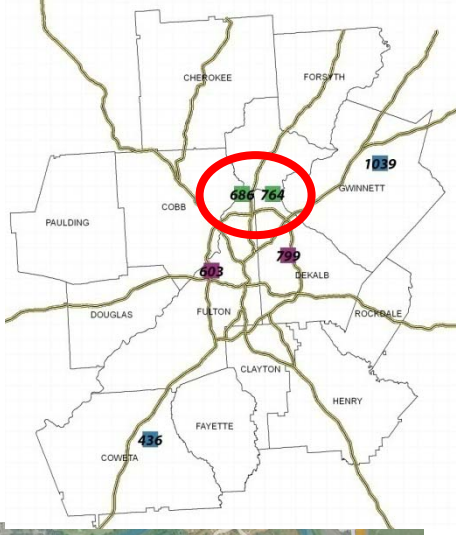
# Comparison Areas

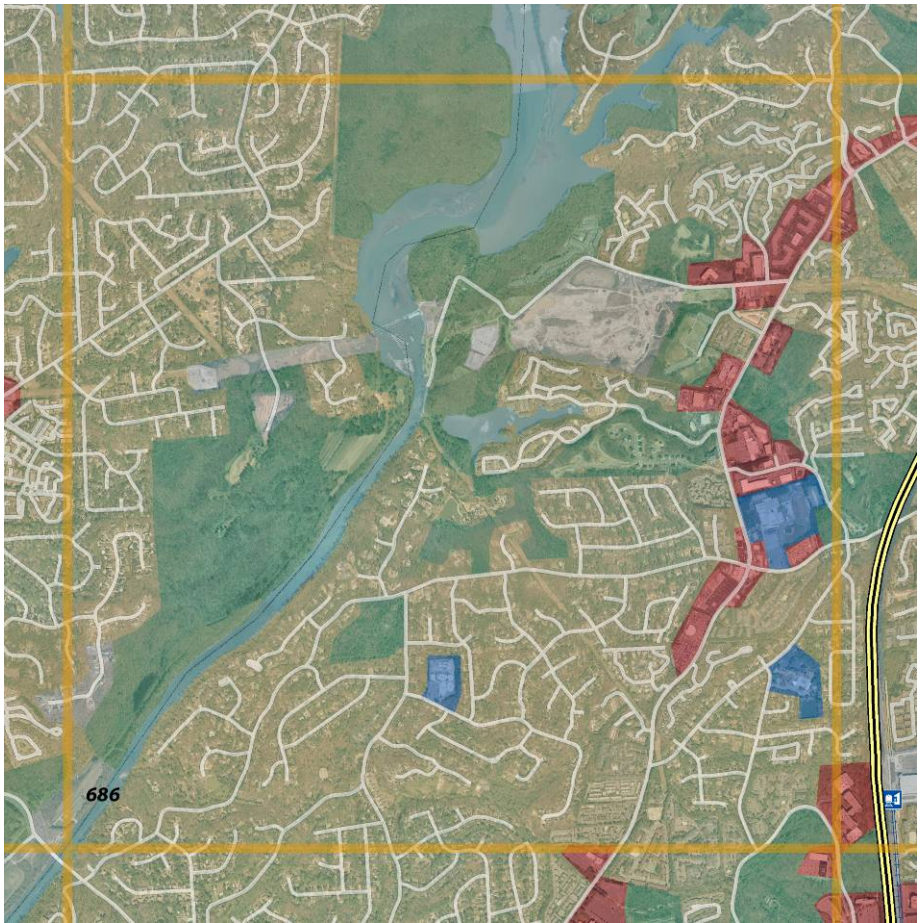
- Selected to highlight regional differences in emissions while controlling for transportation accessibility



# Compare Sandy Springs vs. Chamblee (east and west of GA-400)

Greenspace
Commercial
Industrial
Institutional
Water
Residential



# Sandy Springs & Chamblee

| | Grid 686<br>Sandy Springs (W) | Grid 764<br>Chamblee (E) |
|---|---|---|
| NOx per capita per wkday | **19.06 (~28% less than Chamblee)** | **26.32** |
| **Normalizing factors (deciles)** | | |
| Distance to CBD | 24.6 km (5) | 27.9 km (6) |
| Length of highway | 0.0 km (3) | 0.0 km (3) |
| Distance to nearest highway ramp | 5.8 km (7) | 6.0 km (7) |
| Distance to nearest rail station | 6.4 km (3) | 7.2 km (3) |
| Number of bus stops | 3.6 stops/sq km (7) | 3.4 stops/sq km (7) |
| **Urban form factors** | | |
| Net res. density | **3.23 units/ac** | **1.41 units/ac** |
| Mixed use index | **0.34** | **0.11** |
| Intersection density | **15.75 int/km$^2$** | **21.88 int/km$^2$** |

# Sandy Springs & Chamblee

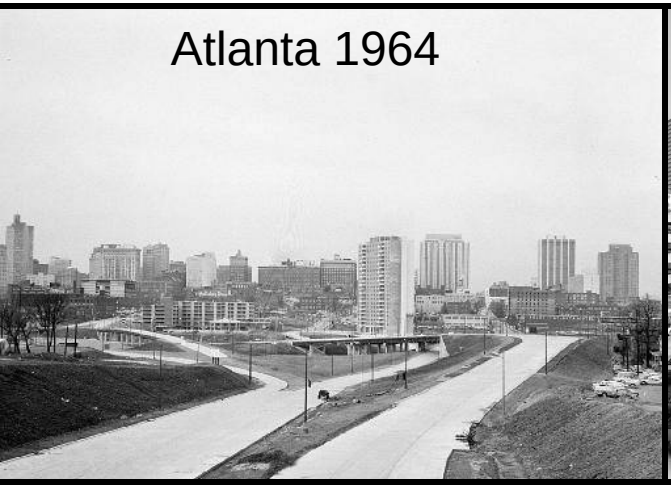
| | | Grid 686 Sandy Springs (W) | | Grid 764 Chamblee (E) | |
|---|---|---|---|---|---|
| | | SMARTRAQ participants | Mean | SMARTRAQ participants | Mean |
| | NOx per capita per weekday | 50 | 19.06 | 48 | 26.32 |
| Demographics | Age | 50 | 41.0 | 48 | 43.5 |
| | % female | 50 | 48.0 | 48 | 41.7 |
| | % liscense (16+yr) | 45 | 97.8 | 39 | 100.0 |
| | Household size (# of people) | 50 | 2.3 | 48 | 1.9 |
| | Household vehicles | 50 | 2.5 | 48 | 2.2 |
| | Vehicle Age (years) | 41 | 6.8 | 38 | 6.1 |
| Travel Behavior | Mean # miles traveled by motor vehicle (per capita weekday) | 46 | 20.3 | 46 | 30.3 |
| | Mean # trips made by motor vehicle (per capita weekday) | 46 | 3.4 | 46 | 3.5 |
| | % weekday trips (all modes) by transit | 50 | 0.3 | 48 | 0.0 |
| | %, weekday trips (all modes) by walking | 50 | 0.0 | 48 | 0.0 |

# Household Income

| Household Annual Income | Grid 686 Sandy Springs (W) | Grid 764 Chamblee (E) |
|---|---|---|
| Less than $10,000 | | |
| $10,000-$19,999 | | |
| $20,000-$29,999 | 4% | |
| $30,000-$39,999 | 16% | |
| $40,000-$49,999 | 2% | 6% |
| $50,000-$59,999 | 8% | 6% |
| $60,000-$74,999 | 10% | 13% |
| $75,000-$99,999 | 24% | 23% |
| $100,000 or more | 36% | 52% |
| Total | 100% | 100% |

# Long-term Air Quality ~~Forecasting~~ Planning

## Air Quality, Emissions, Growth, and Change: A Method to Prescribe a Desirable Future



Planning → Development → Emissions → Air Quality → Values

Values → Air Quality → Emissions → Development → Planning

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