SUSTAINABLE URBAN ENGINEERING AND SCIENCE: Development of a Metamodel for More Informed Sustainable Urban Development: Preliminary Results

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http://sustainability.asu.edu/iishome/index.jsp

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- SCERP
- Sustainable Materials and Technologies
- MUSES
- Urban Biogeochemistry
- Urban Heat Island Initiative
- 100 Cities

Core Team Members - I would like to express my thanks to the following ASU colleagues for their contributions to this presentation:

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Additional Collaborators - I would like to express my thanks to the following ASU colleagues for their contributions to this presentation:

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- Ray Quay, the City of Phoenix Planning Department
- Chuck Redman, Director of Global Institute of Sustainability
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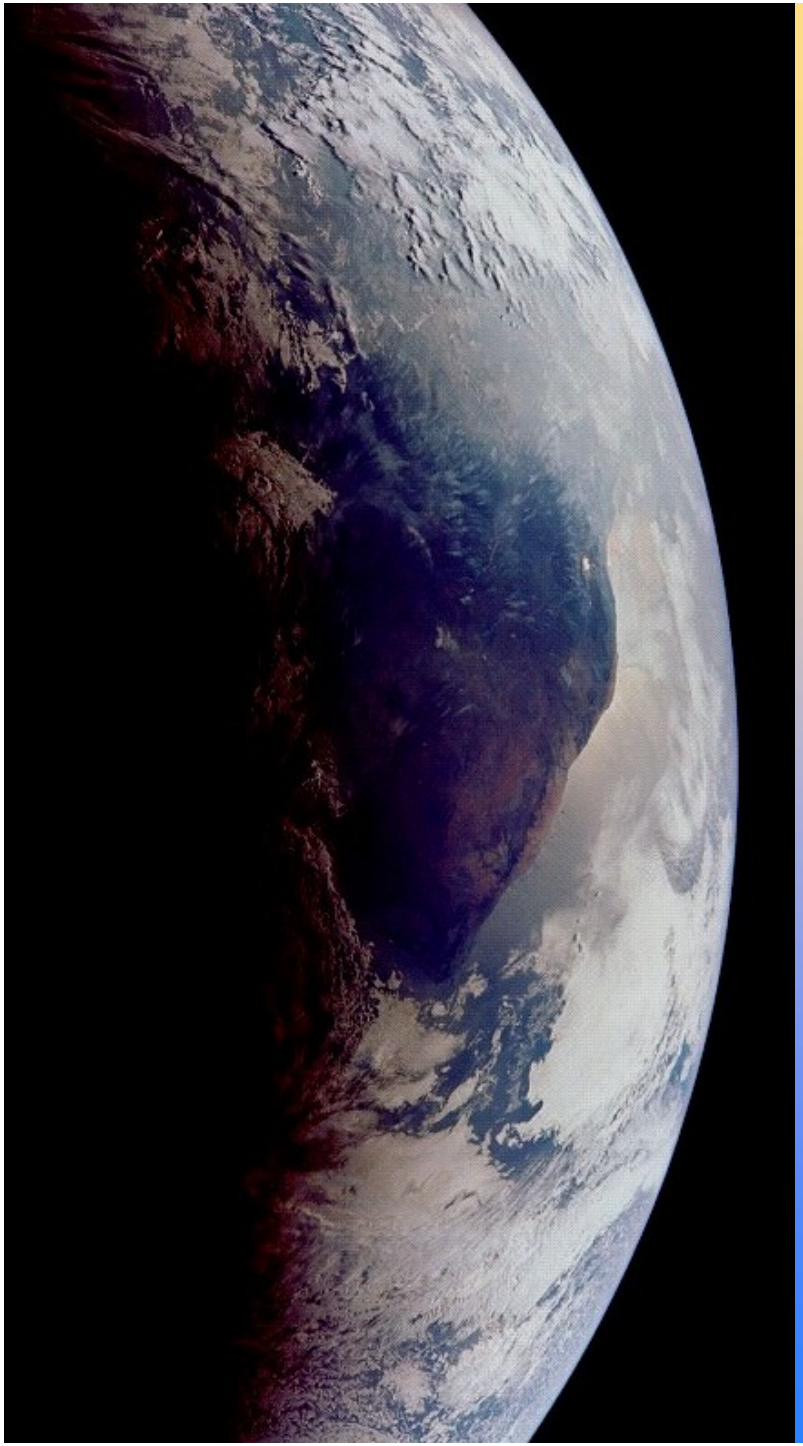
Student Investigators - I would like to express my thanks to the following ASU students for their contributions to this presentation:

- Susanne Grossman Clarke, Urban Heat Island, Dept. of Geography and Mathmatics
- Yu-Jin Choi, Air Quality Modeling, Mechanical and Aerospace Eng.
- Miles Costanza, Daniel Gerrity, Ramzy Kahhat, Peng Zhang , Industrial Ecology, Material Flow Analysis, Civil and Environmental Engineering
- Thanigaivelu Elangovan, Computer Science and Engineering
- Himanshu Joshi, School of Planning and Landscape Architecture.
- Sonja Winters, Del Webb School of Construction

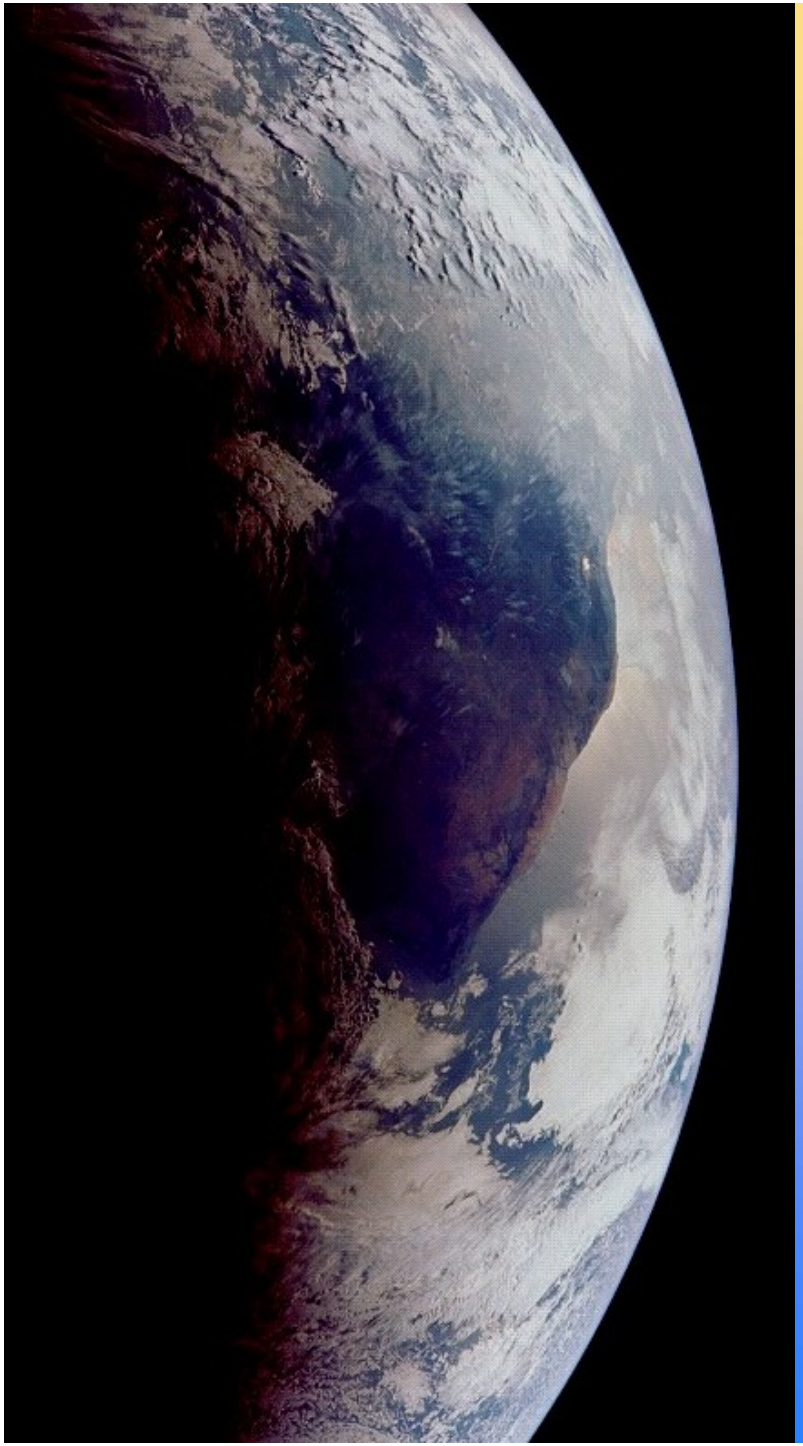


Outline

- **What is Sustainability ?**
- **Background and Vision**
- **Urban Development Simulation**
- **Material Flow Analysis**
- **Air Quality and Heat Island Simulations**
- **Conclusions**

Basic Working Definitions

- Our socioeconomic system is far from sustainable and this may cause us guilt and perhaps frustration and so there may be a tendency to just give up. Accordingly, this is a workable definition.
  - Roy F. Weston defined sustainability as, "*Sustainable Development is a process of change in which the direction of investment, the orientation of technology, the allocation of resources, and the development and functioning of institutions transition toward longer-term sustainable activities. Longer term sustainable development will meet present needs and aspirations without endangering the natural ecosystems and their capacity to absorb the effects of human activities, and without compromising the ability of future generations to meet their own needs and aspirations.*"
  - Mathis Wackernagel stated this sustainability goal succinctly as, *"Sustainability is securing peoples quality of life within the means of nature."*



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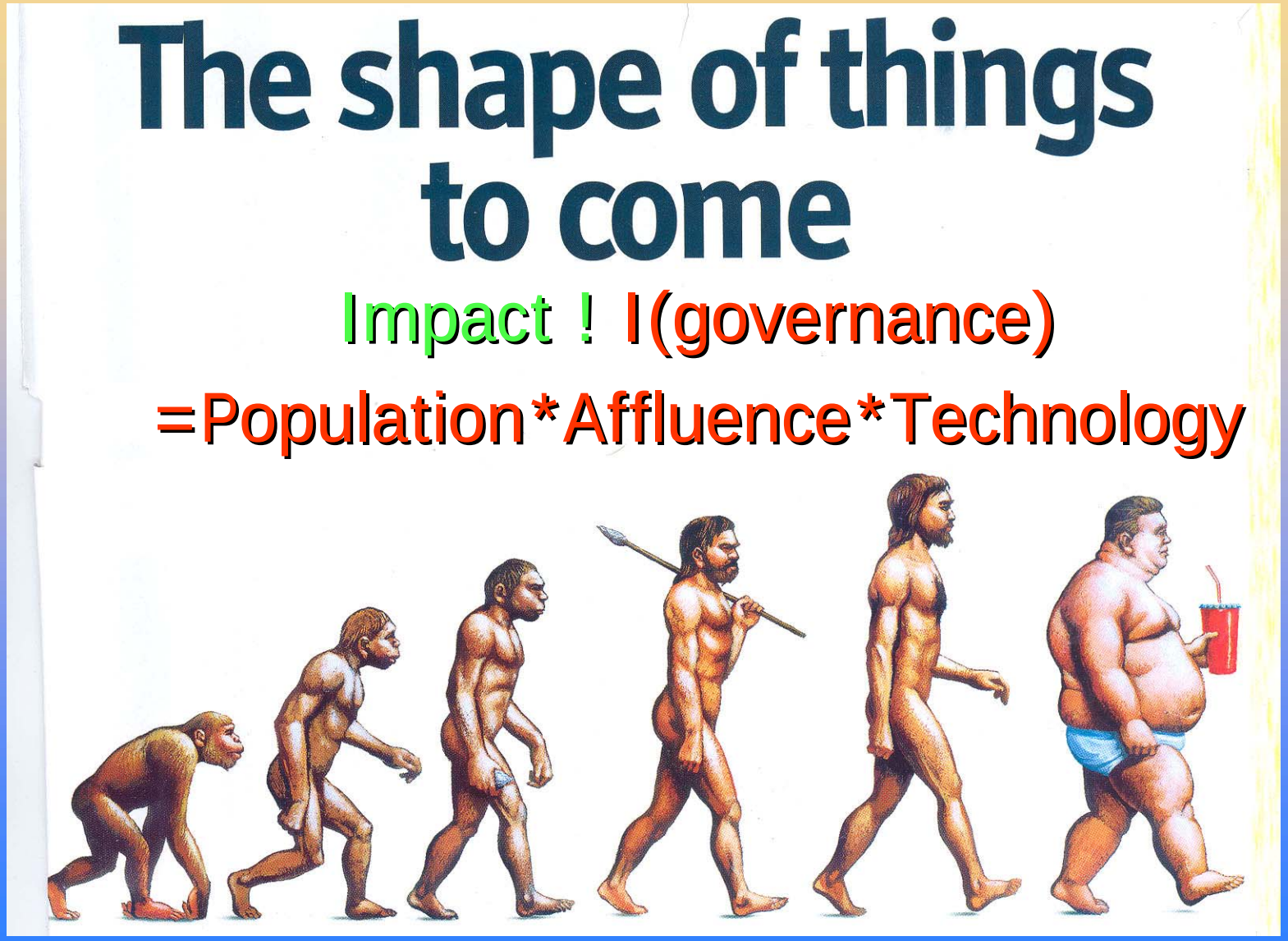
US Economy - Consumption



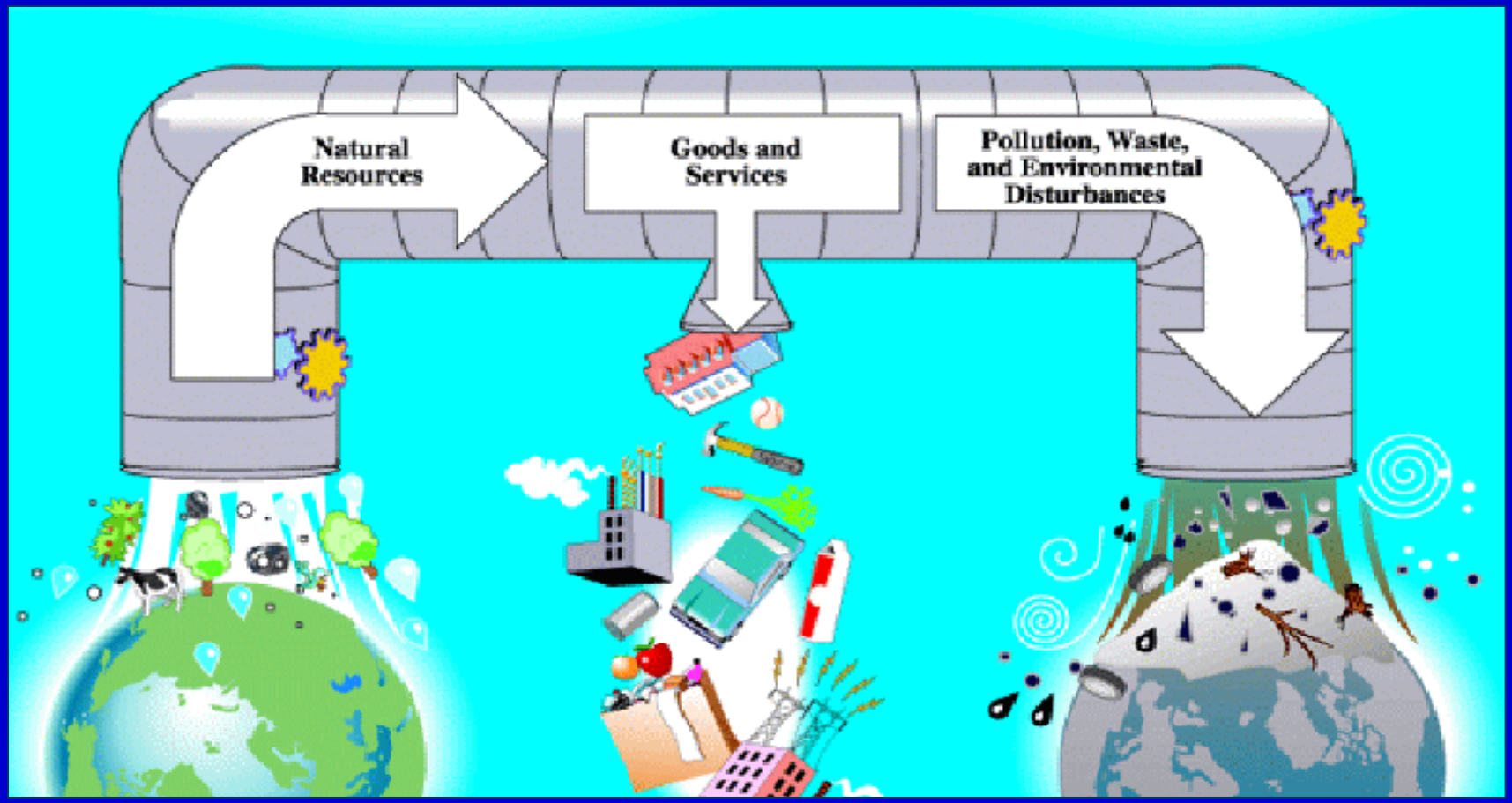
Impact ! I(governance)

=Population*Affluence*Technology

- "*Americans understand that green is not about cutting back. It's about creating a new cornucopia of abundance for the next generation by inventing a whole new industry. It's about getting our best brains ..... into innovations that will not only give us the clean-power industrial assets to preserve our American dream but also give us the technologies that billions of others need to realize their own dreams without destroying the planet. It's about making America safer by breaking our addiction to a fuel that is powering regimes deeply hostile to our values. And, finally, it's about making America the global environmental leader, instead of laggard...*"
- *"Well, I want to rename green. I want to rename it geostrategic, geoeconomic, capitalistic and patriotic. I want to do that because I think that living, working, designing, manufacturing and projecting America in a green way can be the basis of a new unifying political movement for the 21st century."*
- [Friedman, 2007]

Capitalization in Developed Word Worked Capitalism served our needs very well early on. It is a bit of altruism but it created a socioeconomic system that provided for our need. Now our needs are met. So we invent new things we do not really need and market them.

Increasing Material Uses Depletes Resources and Impacts the Enviroment



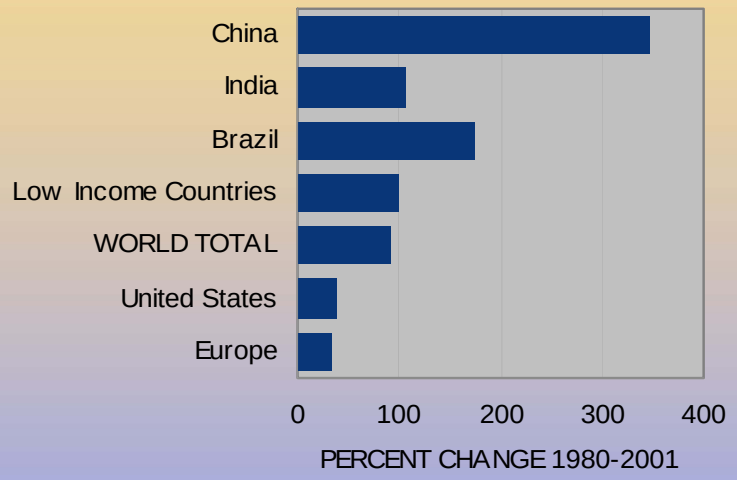
Credit: Jonathan Lash (2005)

Trends in Consumption 1980-2001, WRI

Credit: Jonathan Lash (2005)

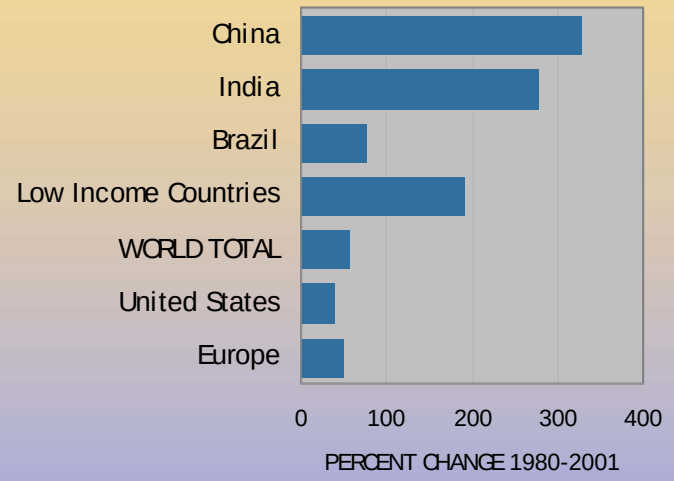
MEAT

Total Consumption in 2001: 240 million metric tons



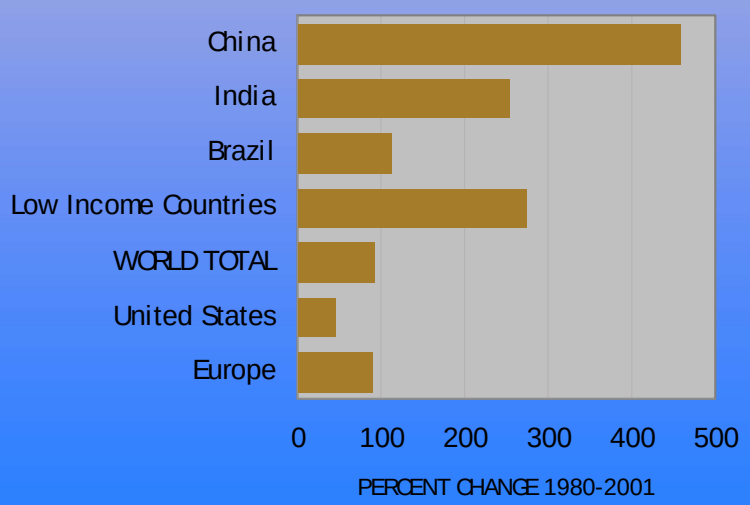
MOTOR GASOLINE AND DIESEL OIL

Total Consumption in 2001: 1.7 trillion liters



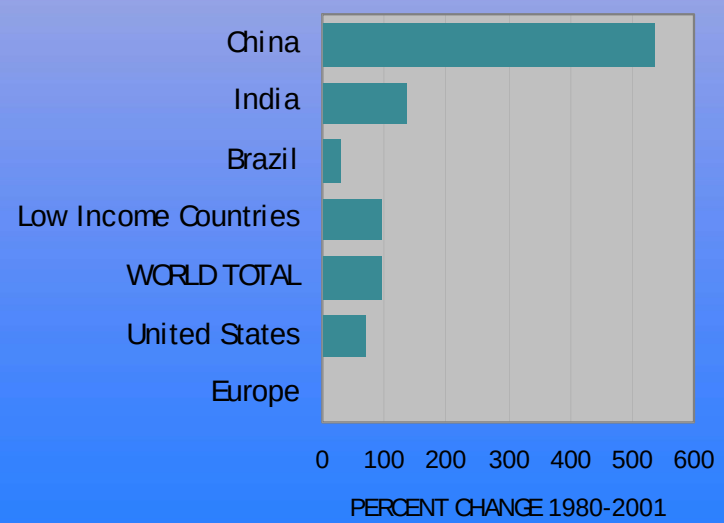
PAPER AND PAPERBOARD

Total Consumption in 2001:325 million metric tons



FISH AND FISHERY PRODUCTS

Total Consumption in 2001: 132 million metric tons



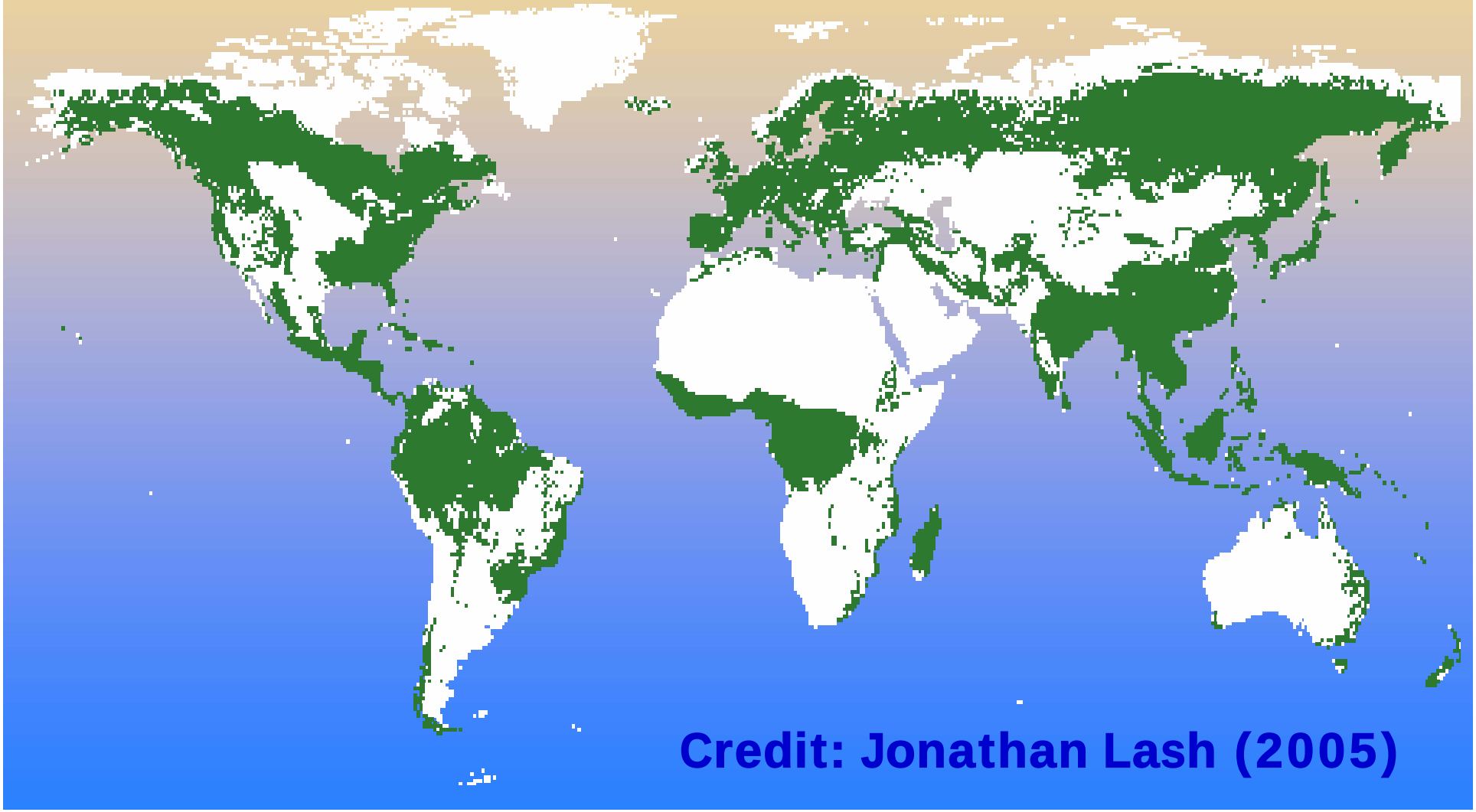
SUMMARY INDICATORS, 1996 (metric tons per capita)

	Austria[1]	Germany	Japan	Netherlands[2]	United States
Indicators Including Weight of Oxygen					
Domestic Processed Output (DPO)	12.51	13.14	11.18	19.61	25.14
Domestic Hidden Flows (DHF)	8.75	29.55	9.74	6.45	61.19
Total Domestic Output (TDO)	21.26	42.68	20.91	26.05	86.33
Net Additions to Stock (NAS)	11.50	11.46	9.69	8.31	7.71

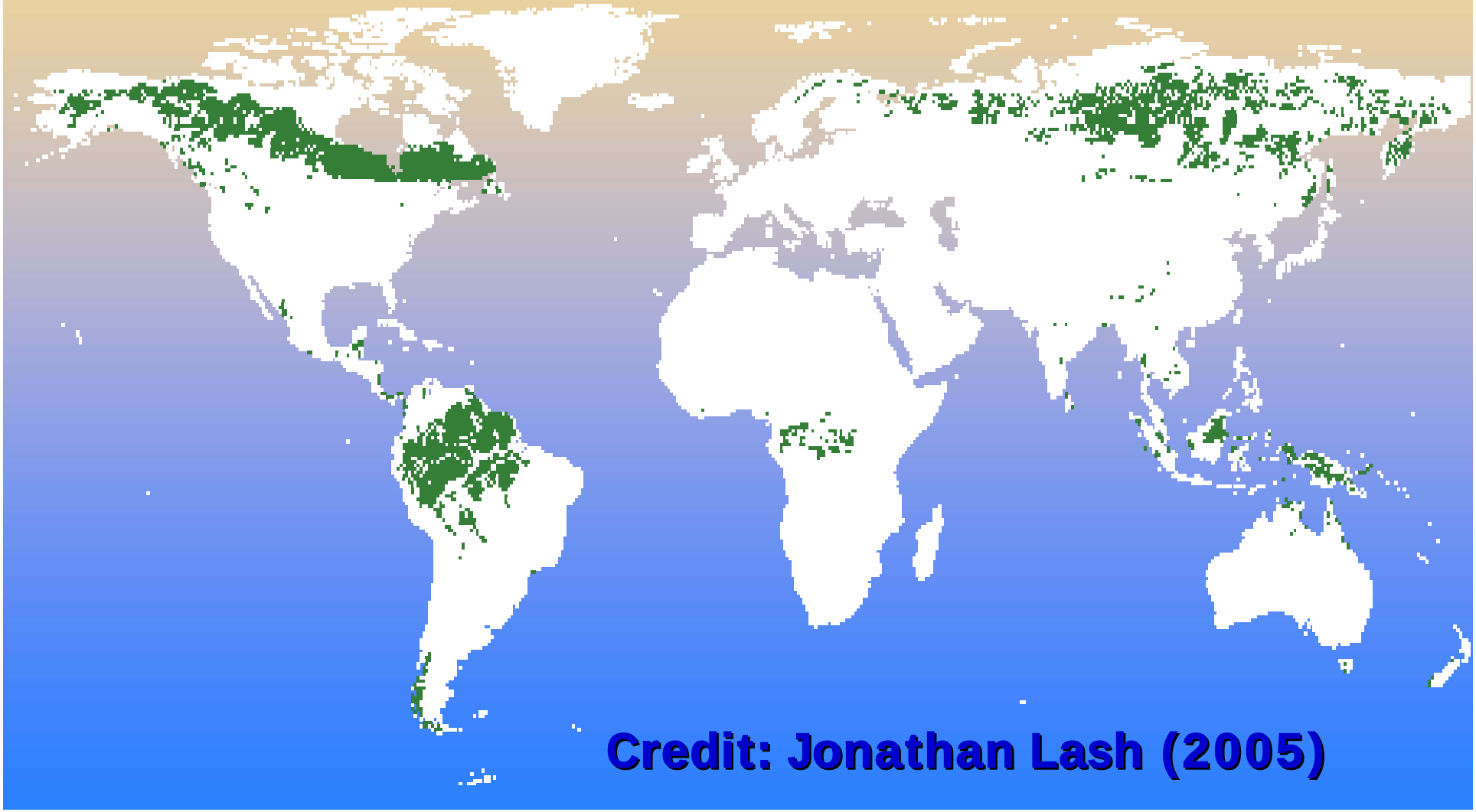
	Austria	Japan	USA
NAS/ TDO	54%	46%	9%

Mathews et al. 2000 World Resources Institute

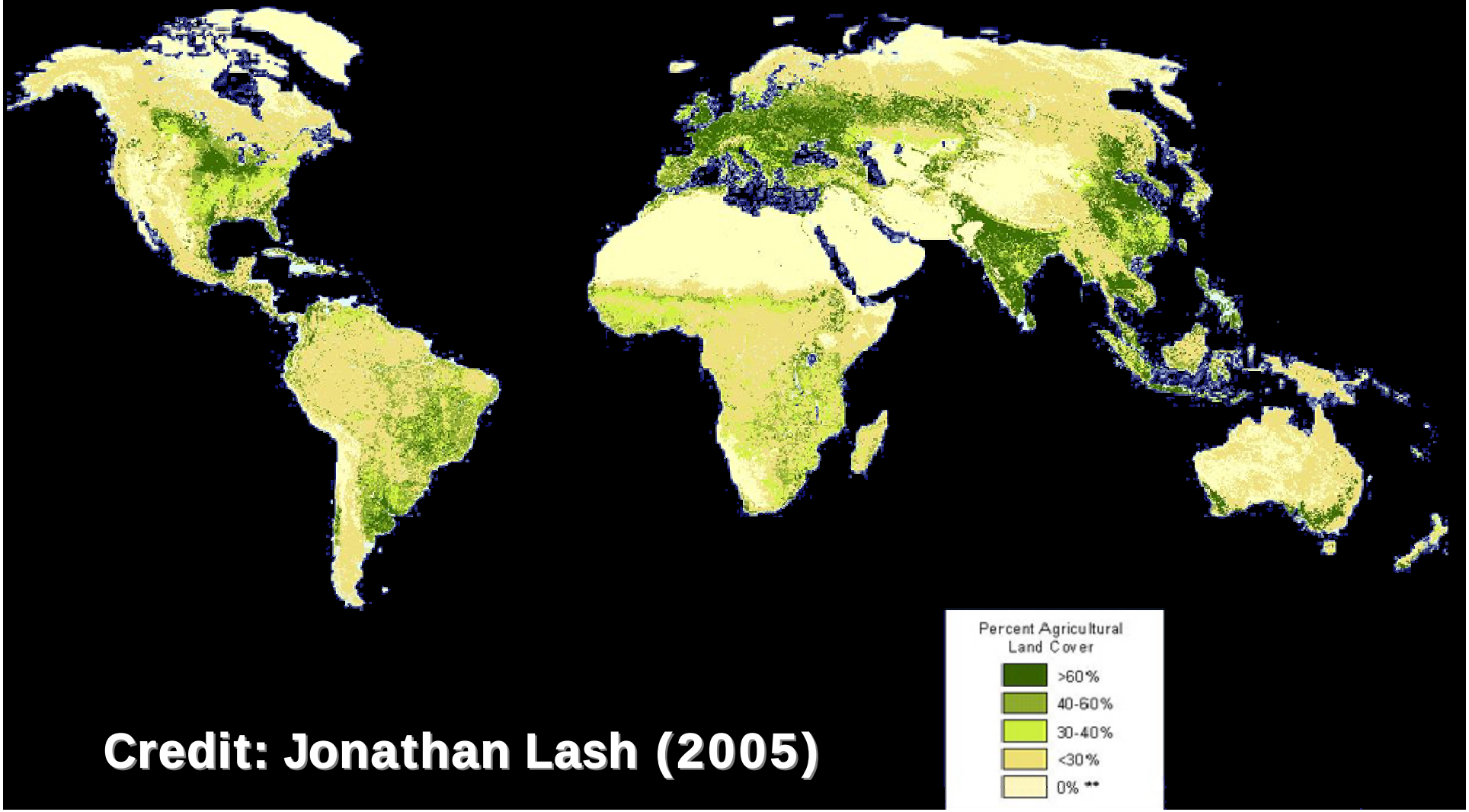
Frontier Forests 8,000 Years Ago



Frontier Forests Today

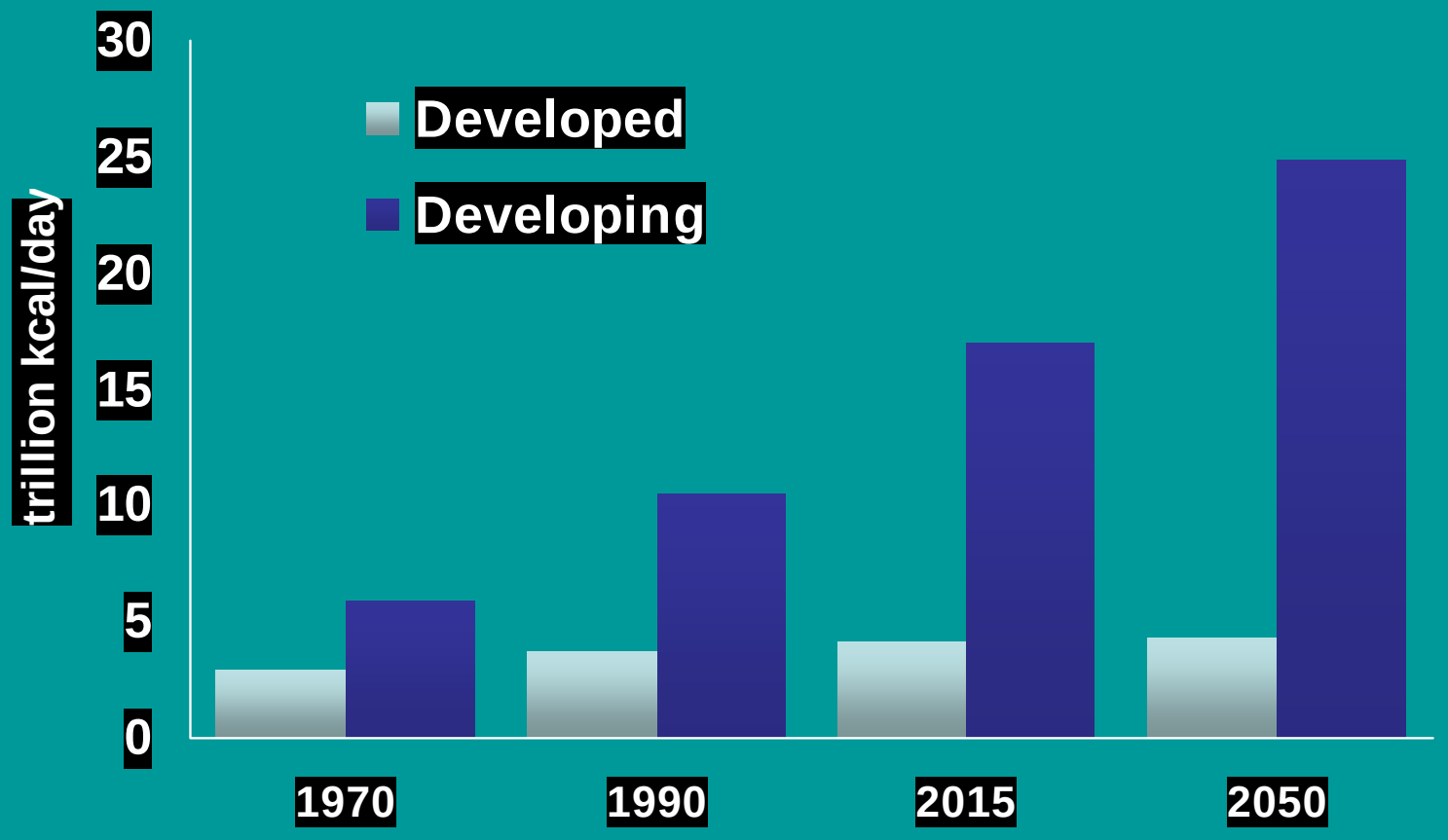


Extent of Agriculture



Credit: Jonathan Lash (2005)

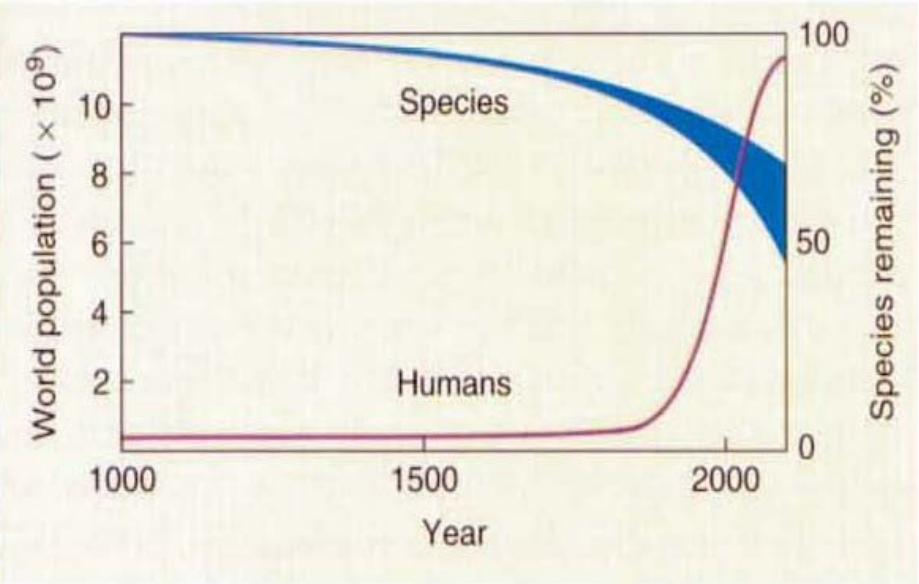
Increasing Food Demand Threatens Ecosystems



Credit: Jonathan Lash (2005)

Grand Challenge Biodiversity decline


(a) Male Pine Barrens Tree Frog
(b) Silversword
(c) Red-cockaded Woodpecker
(d) Karner Blue Butterfly
(e) Swamp Pink
(f) Whooping Cranes



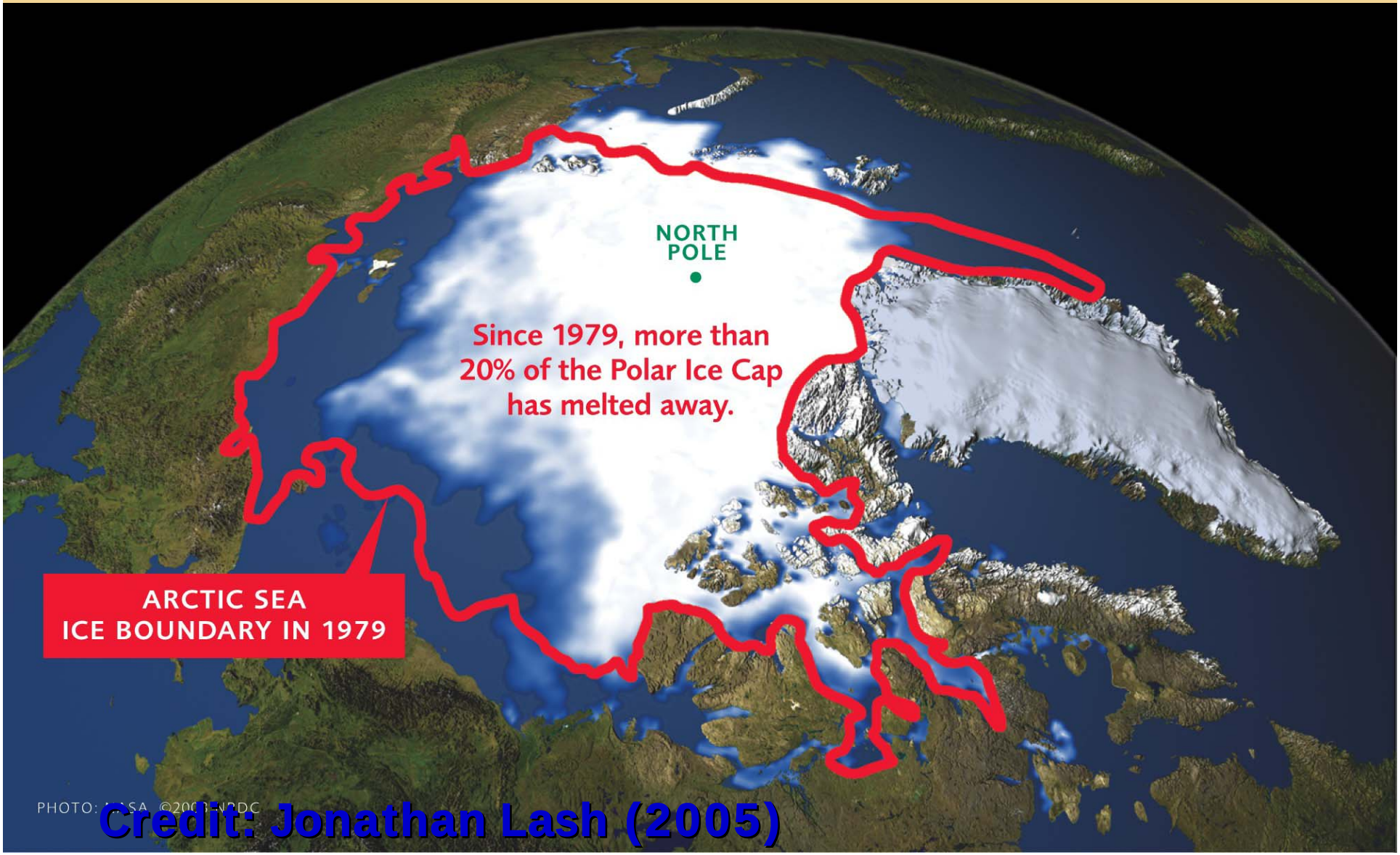
Perhaps 40,000 species per year are lost out of ~4-14 million total (but only 1.7 million are known).

E. O. Wilson (2002) *The Future of Life*

Graph from M. Soule, UCSD.

Credit: Jerald Schnoor

Rapidly Melting Sea Ice
Gulf Stream Flow Has Decreased by 30%?!



Credit: Jonathan Lash (2005)

Personal Observations – Demand Side

- Too Many Toyotas (Freedman), Not enough Pt for new battery technology
- Huizhou near Hong Kong, Printed Circuit Board Facility to Produce 1 billion square feet of Printed Circuit Board/ month, Cover the State of Rhode Island in 10 years!

Summary Thoughts

- Man had transformed ¾ of the Earth's Surface
- The Current Epoch is called the Anthropocene period!
- Urban Centers are going to continue to grow and externalize the impacts of the demand side of material use
- Time for action for ESE community to work with Social Scientists to Educate the Public on the impacts of the demand side of material use
- Where should we invest resources? Nanoscale? Microscale? Mesoscale? Megascale? Gigascale (Urban/Regional Scale)?

Importance of the Social Dimension

"What lies behind us and what lies before us are tiny matters compared to what lies within us."

Ralph Waldo Emerson

Human needs and desires drive political, social, and economic processes. Engineers provide technological solutions. It is important for the engineering community to educate society about their choices and allow them to make informed decisions regarding political choices and commerce.

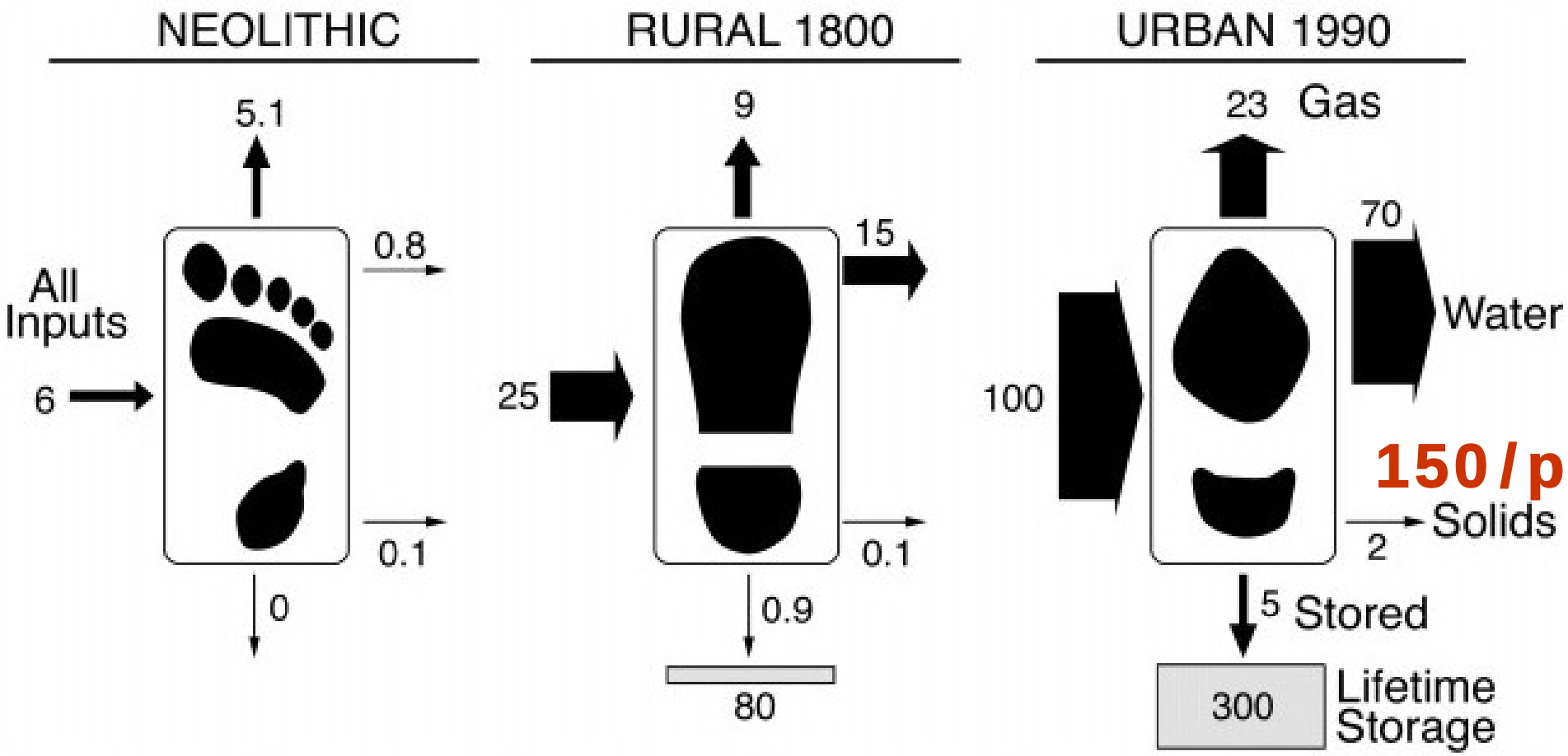
2002 Nobel Prize in Economics - DANIEL KAHNEMAN for having integrated insights from psychological research into economic science, especially concerning human judgment and decision-making under uncertainty.

Urban Transformation

- **Double the urban infrastructure in the next 35 years (Took 5,000 years to get to this point)**
- **Challenge will be to be to insure that we develop long terms social, economic and environmental assets and not liabilities.**
- **It will last more that 50 years and 80 to 90% of the impact is during the use phase.**
- **Currently 49% of the world's population and 81% of the US population lives in urban areas, a figure which is expected to grow to 61% and 87%, respectively, 2030 (UNEP, 2005)**

As Klaus Toepfer, the U.N. Environment Program chief, stated in 2005: "Cities pull in huge amounts of resources including water, food, timber, metals and people. They export large amounts of wastes including household and industrial wastes, wastewater and the gases linked with global warming. So, the battle for sustainable development, for delivering a more environmentally stable, just and healthier world, is going to be largely won and lost in our cities."

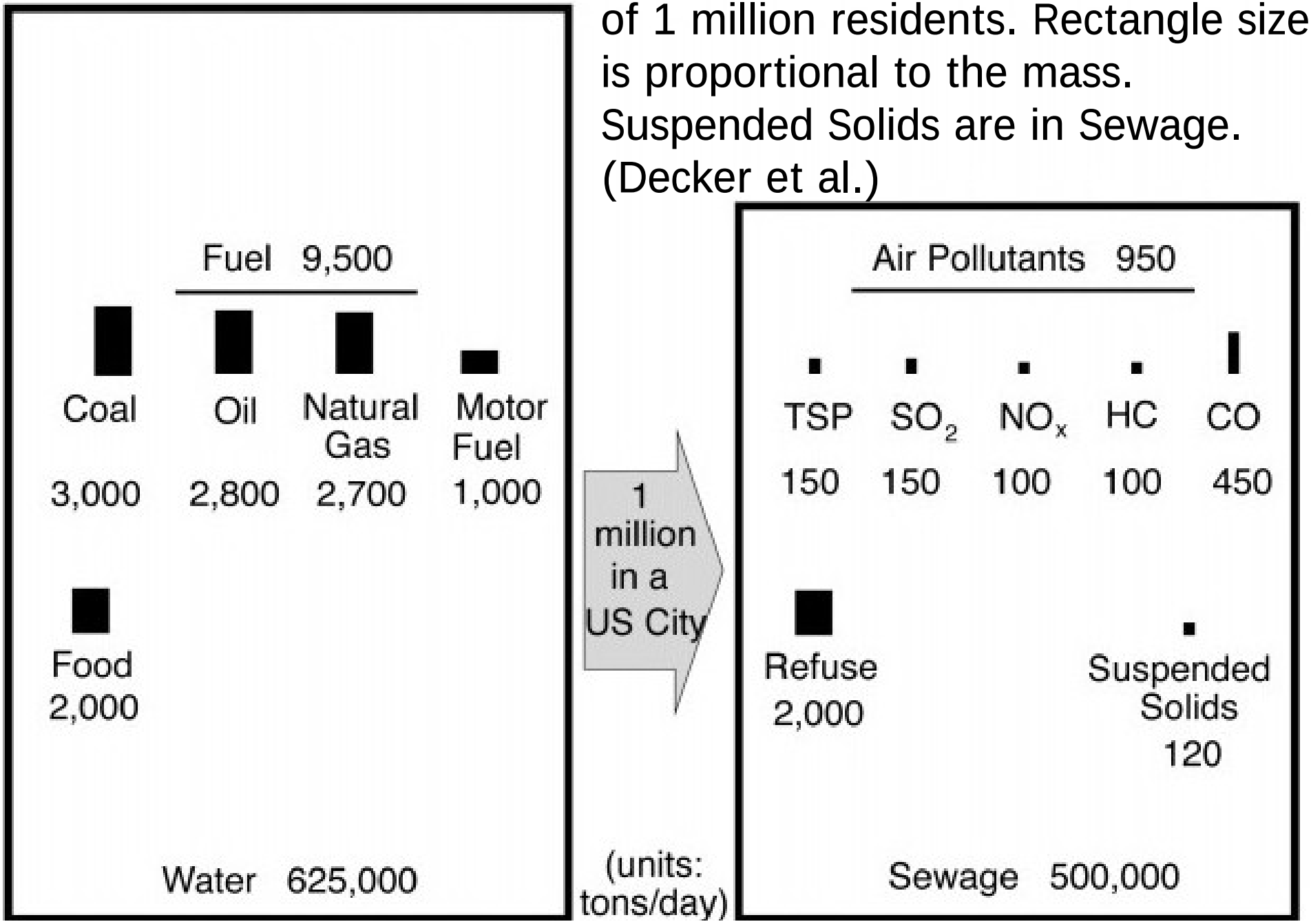
Regional/ Global Impacts: Urban Metabolism – Energy and Materials are Transformed into Durable Infrastructure and Waste



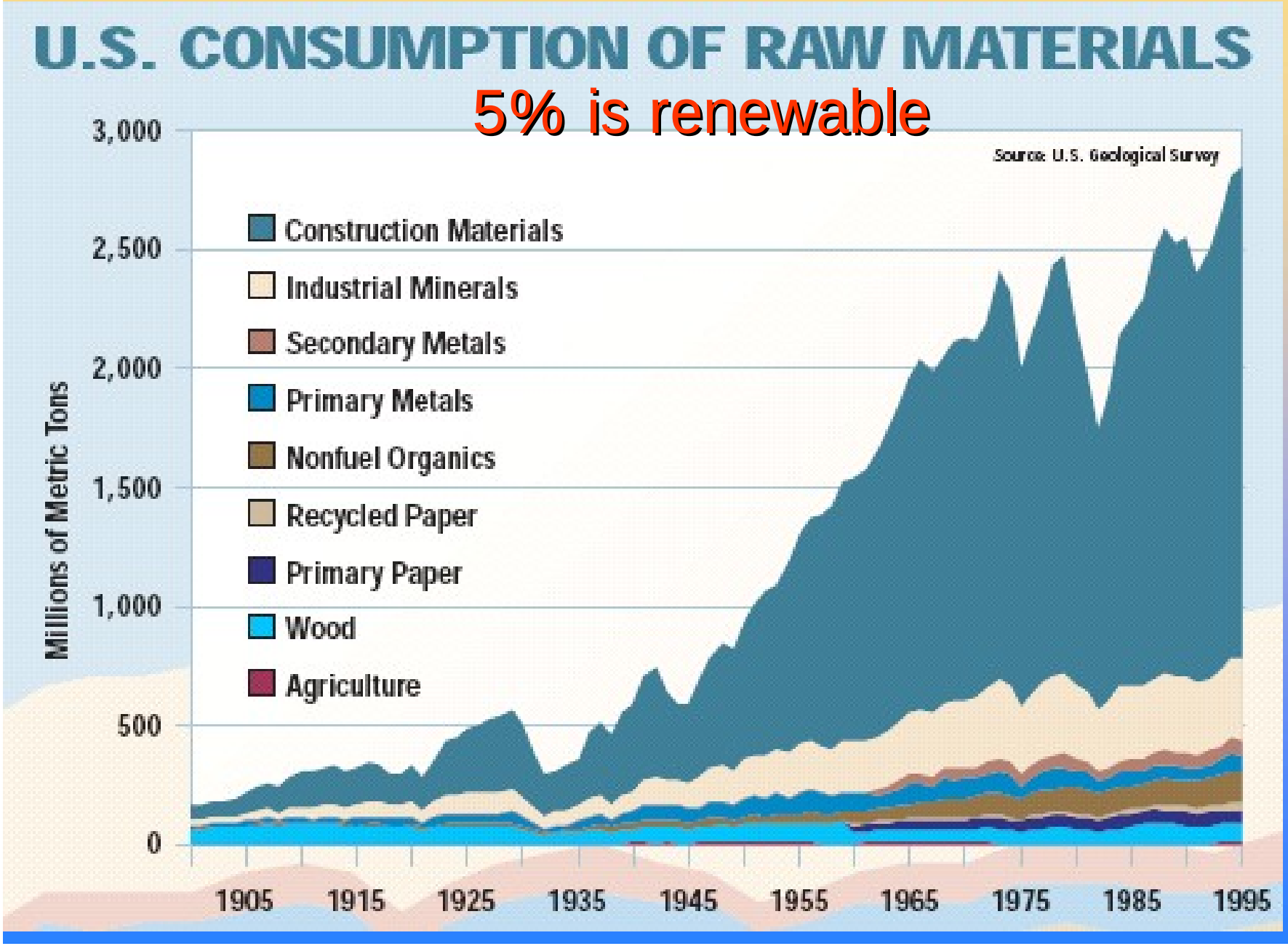
All units are tons per year per individual. Life time storage includes infrastructure and artifacts. (Decker et al.) Still increasing inputs by 2.5%/ year. P2 or Green Engineering will not be enough. (Too many Toyotas – Freedman)

Urban Metabolism

All units are tons per day for a city of 1 million residents. Rectangle size is proportional to the mass. Suspended Solids are in Sewage. (Decker et al.)



Importance of Construction



(USGS, 2000)

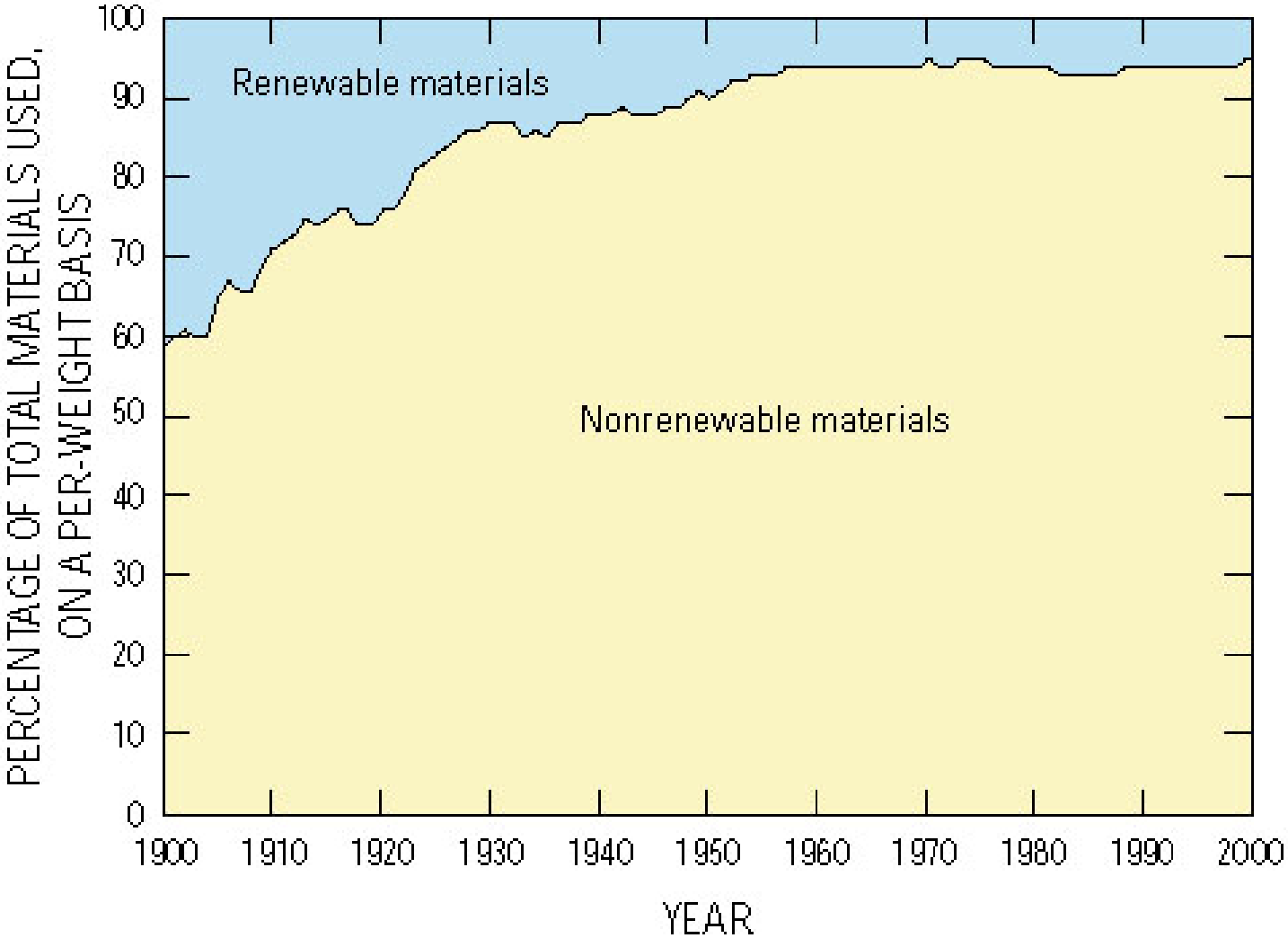


Figure 3. Renewable and nonrenewable materials used in the United States. Use of nonrenewable resources has increased dramatically in the United States during the 20th century (modified from Matos and Wagner, 1998, fig. 2).

- There are over 76 million residential and 5 million commercial buildings in the U.S.
- Collectively, these buildings consume:
  - ***65%*** *of electricity and* ***37%*** *of primary energy*
  - ***25%*** *of all water supplies and* ***30%*** *of all wood & materials*
- Collectively, these buildings generate:
  - ***35%*** *of solid waste*
  - ***36%*** *of CO2 and* ***46%*** *of SO2 emissions*
  - ***19%*** *of NOx and* ***10%*** *of fine particulate emissions*

(LEEDs US Green Building Council)

Engineering Complex Systems - Our Goals

- Predict the emergent properties of urban systems (e.g., economic structures, material, energy use, traffic and transportation patterns, urban health, heat island, land use and density, air quality, local regional and global impacts of the resource demands and waste generation)
- Understand how the flows of resources (information, energy, and materials) are utilized within the urban system of systems (Urban Metabolism) and reduce material and energy investments
- Develop the cyber infrastructure to gather information monitor, model and visualize the complex emergent properties
- Develop the pedagogy of engineering complex systems in the context of sustainability of urban systems

Cyber Infrastructure

- Tremendous Opportunity to Influence Cyber Infrastructure Implementation for Urban Sustainability
- NAE Definition
  - Human
  - Hardware
  - Software
- Examples
  - Wireless Communication
  - Sensors (Remote and Embedded)
  - Modeling
  - Data Mining and Fusion
  - Visualization

Engineering Complex Systems

The challenge that we face is to engineer the emergent patterns that are more resilient to homeland security threats and natural disasters, and become more sustainable.

Urban designers have to use and choose resources that are more sustainable including information, energy and materials. We need to consider the environment, social and social consequences.

We have to borrow from the ecology of nature which is a self organizing system that maximizes the use of information (genetic and otherwise), energy (ultimately the sun) and materials. Nature does not throw things away. Hence the term industrial ecology.

Urban Systems have to be resilient to collapses in various elements. This is similar to nature which has to be resilient to collapses in the food chain.

The model of models are aimed at understanding the industrial ecology of urban system and maximizing the use of its resources.

Complexity?

- Consists of interconnected or interwoven parts
- Involved or intricate as in structure
- Difficult to Understand because of intricacy
- Whole comprised of interconnected or interwoven parts
- Engineering Complexity – the condition of being difficult to explain and predict systems behaviors, robust operation of the same
- Large number of parts
- Interactions are not controlled
- Dynamic structure
- Do not have narrow parameters
- Do not know all possible outcomes
- Non-linear
- Risks not easily identifiable, high uncertainty

Complexity?

- Sources –
  - Too much information, too many components, too many constraints, too many parameters for consideration to accomplish a given task
  - Not enough information about the essential elements or components of a system or about their interfaces
  - Not enough information about how the elements or components will behave under known or unknown conditions that may lead to unintended consequences

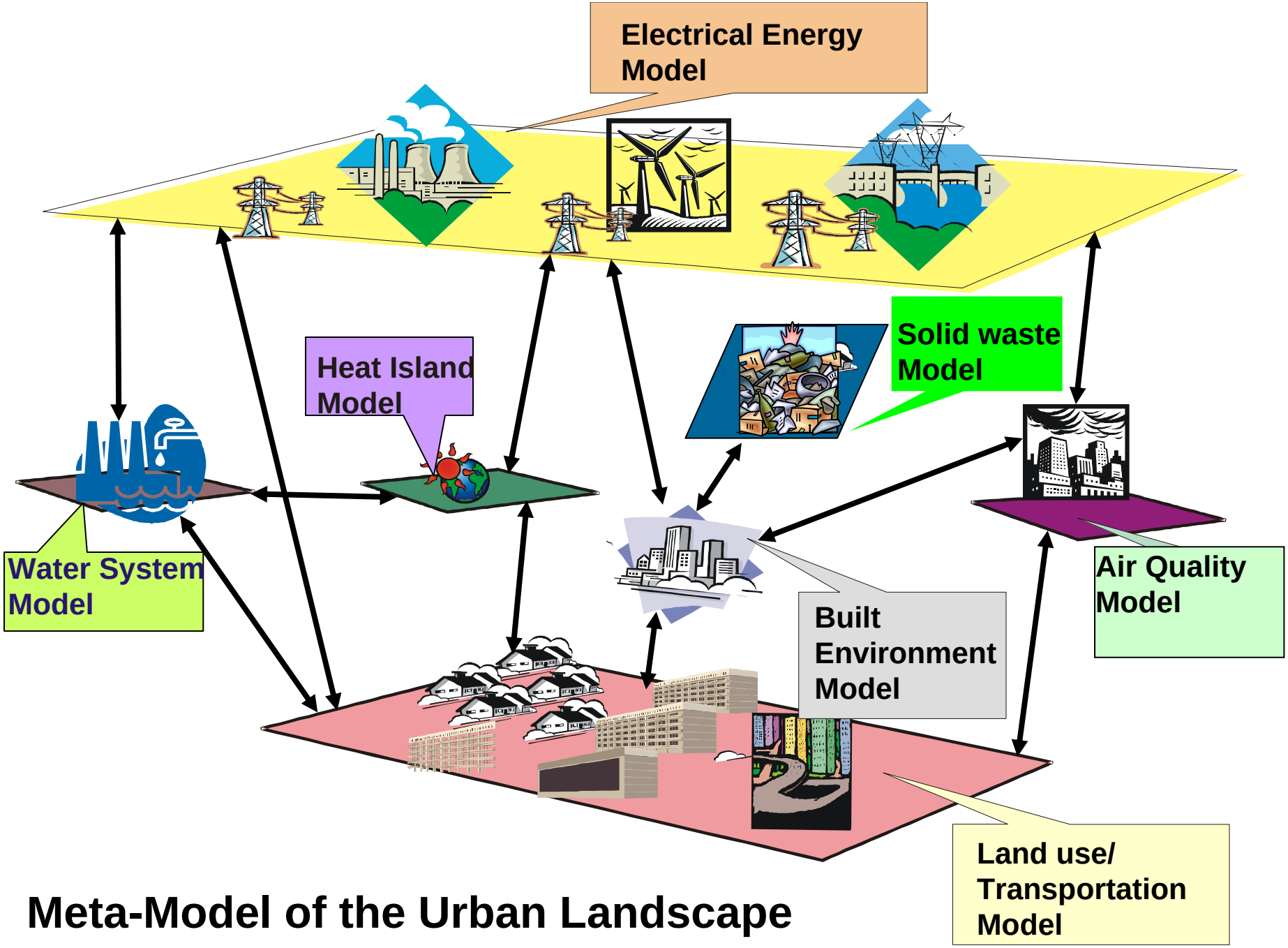
Engineering the Quality of Life and Sustainability

Goal - Develop long term endowments (renewable supplies, etc.) and decrease environmental liabilities. More efficient uses material and energy

- **Regional/ Local Issues**
  - Urban Heat Island, Dust, Noise
  - Social Justice
  - Reduce Ozone Concentration
  - Impact on local ecology
  - Open Space/ Access to Recreational Activities
  - Fish Toxicity
  - Green Algae Toxicity
  - Reduce Human Acute and Chronic Disease (e.g. asthmas and cancers)
  - Acid Deposition
  - Hydrologically Impermeable Surface Area
  - Reduce Resource Use and Waste Generation
  - Economic well being
- **Global Issues**
  - Impoverishment of Plants and Animals in order to supply societal resource needs
  - Stratospheric Ozone Depletion
  - Global Warming

Example from our Research – Metro - Phoenix

- We need to engineer the anthrosphere to demand resources and to assimilate wastes within the means of nature.
- This will require us to examine the interactions between the engineered, social and economic systems.

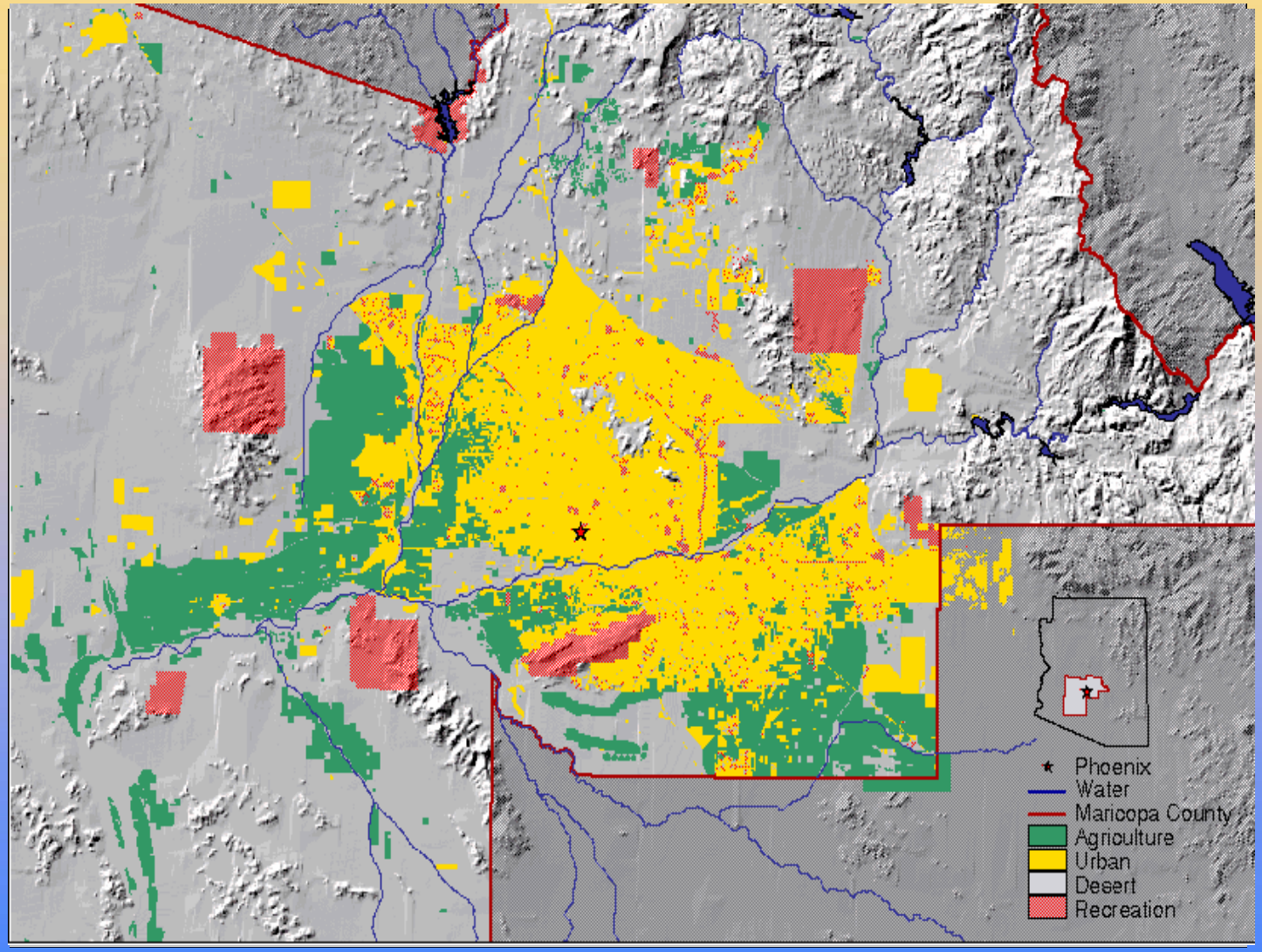


Meta-Model of the Urban Landscape System of Systems: Interaction of Models

Phoenix Development Laboratory

- Metropolitan Phoenix
  - 36% Increase In State Revenue 2005, 1 billion Surplus
  - .5 Trillion Dollars Invested in the Next Decade
  - 61,000 home building permits in 2004
  - 300,000 moved into Maricopa County in 2002
  - 14th Largest City in the US (3.3 million people, 45 % growth 1990 to 2000)
  - .5 billion board feet of lumber
  - Urban Heat Ise causes VOCs to enter the Valley and Increases Ozone, Increase Water Usage (15 degrees warmer because of Urban Growth)
  - Phoenix grows 1 mile per year
  - 35,000 Real Estate Agents
  - Sky Harbor: ~31,000 employees, $ 78 million per day of revenue
  - 50,000 new cars for sale at any one time

Central Arizona–Phoenix Historic Land Use



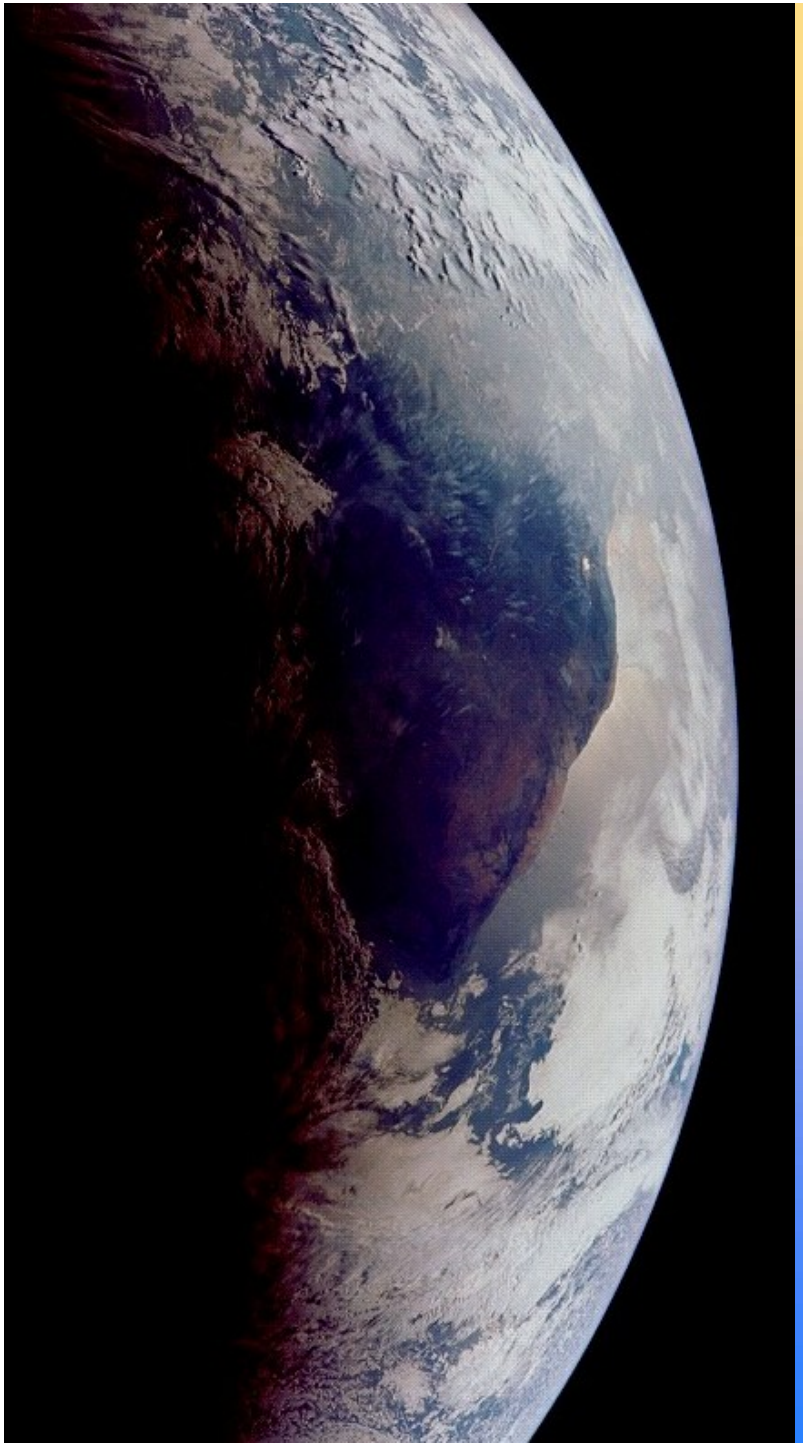
10 km

1912 1934 1955 1975 1995

Knowles-Yanez et al. 1999

IIS-CAP LTER

ASU



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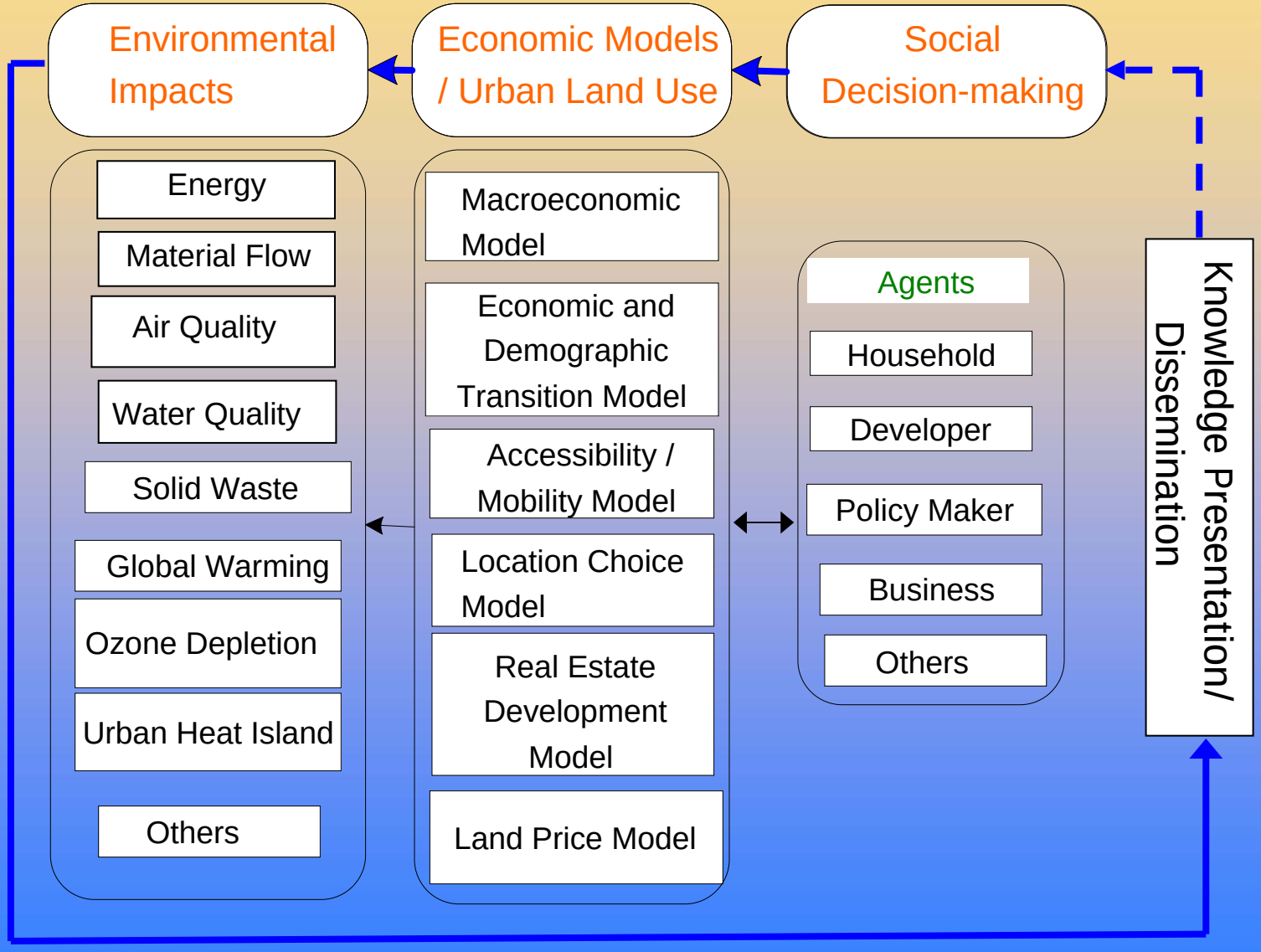
Agent Based Models That Predict Development Patterns, and Material and Energy Use (Obey the Laws of Social Interactions and Economics)

- Include Value Functions for Economic Decision Making (Maximize Wealth)
- See the Environment
- Simulate Interactions between Developers, Buyers, Policy Makers
- The new generation of urban simulation models treats cities as complex adaptive systems, composed of massive amounts of agent-actors, each represented at their own atomic scale, moving to their own clocks and agendas, and connected and interacting dynamically in economic, environmental, political, and social spaces (Benenson and Torrens, 2004).

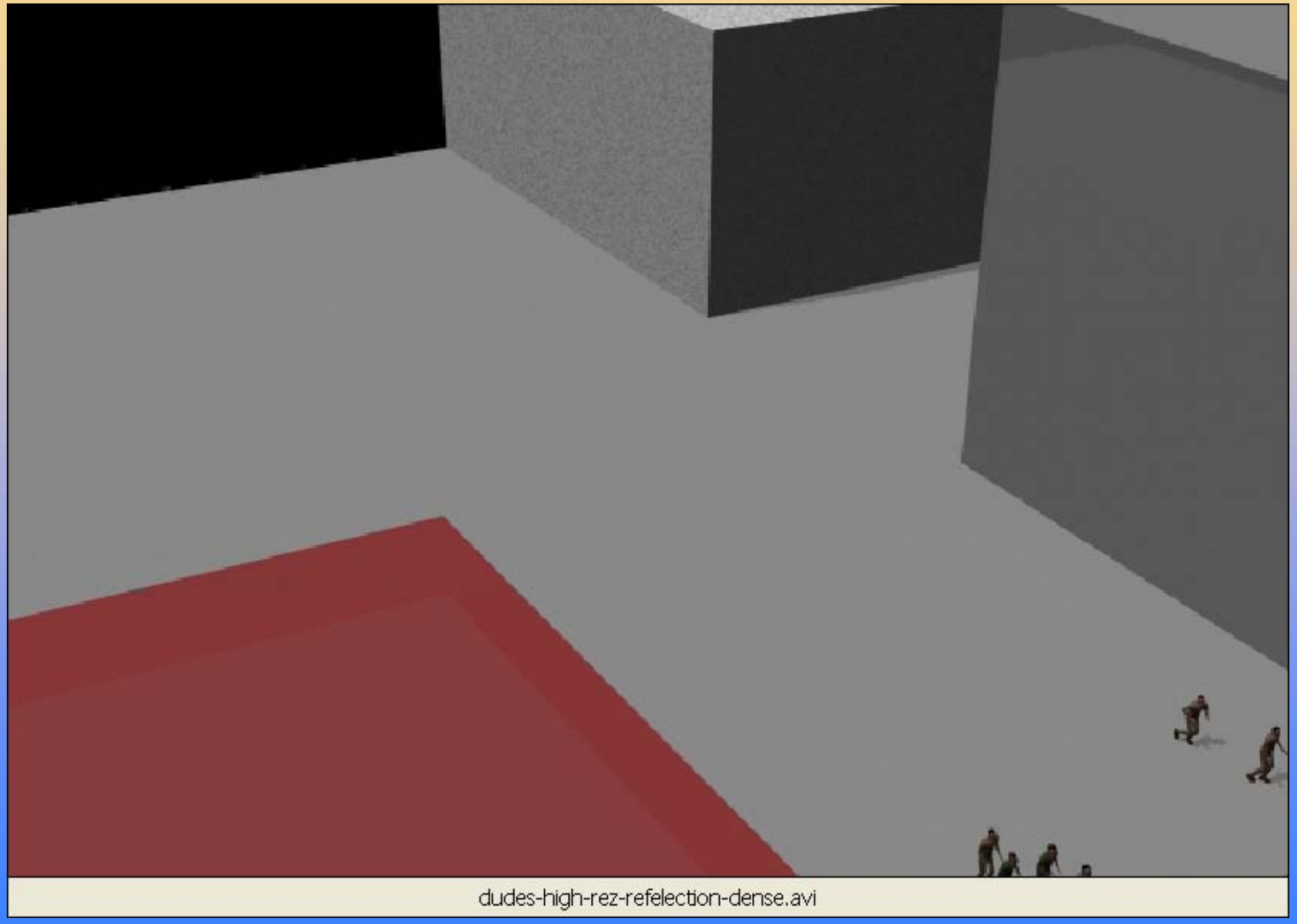
Agent Based Models Coupled with Deterministic Models

- Examine the interactions between:
- Social Decision Making
- Land Use
- Local and Regional Impacts: Air and Water Quality, Waste Disposal, Urban Heat Ise
- Global Impacts: Greenhouse Gas Contribution and Stratospheric Ozone Depletion
- Resource Demand: Energy and Material
- Economy

Framework of agent based models

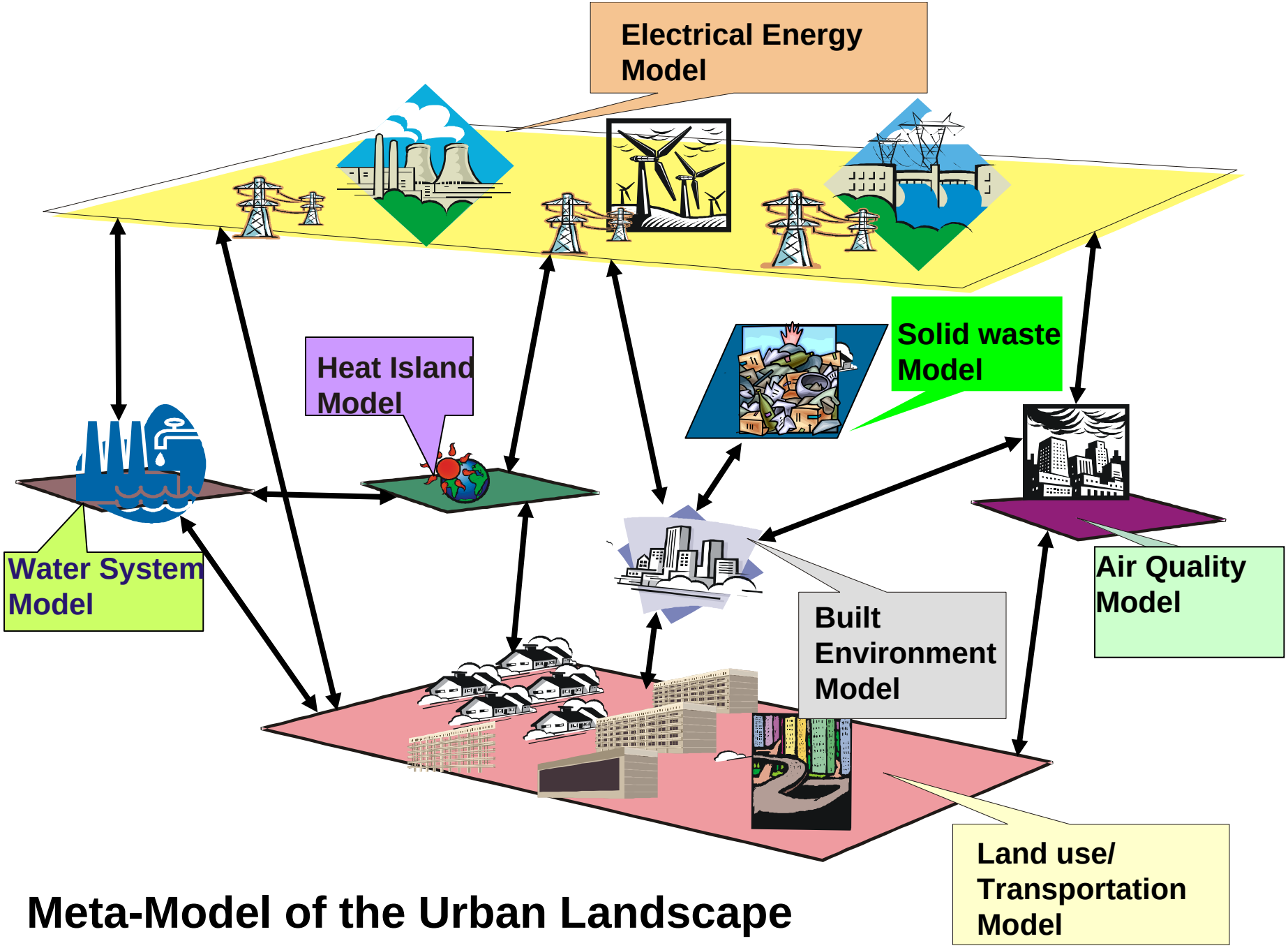


Agent Based Modeling: Simulation of Pedestrian Activity – Agents Obey Laws of Physics



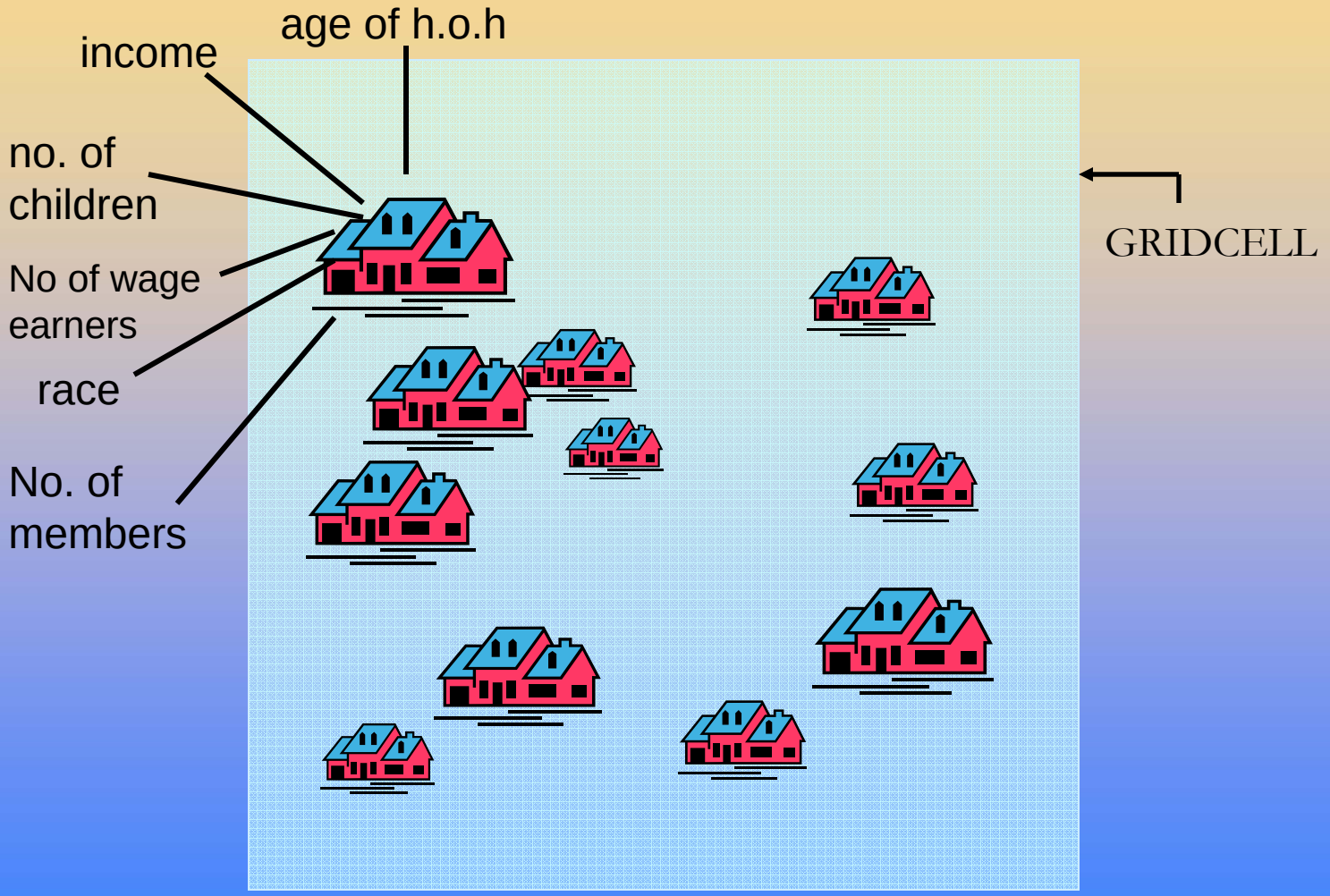
Agent-agent- Panic (Torrens)

Movies – Historical Growth Chicago



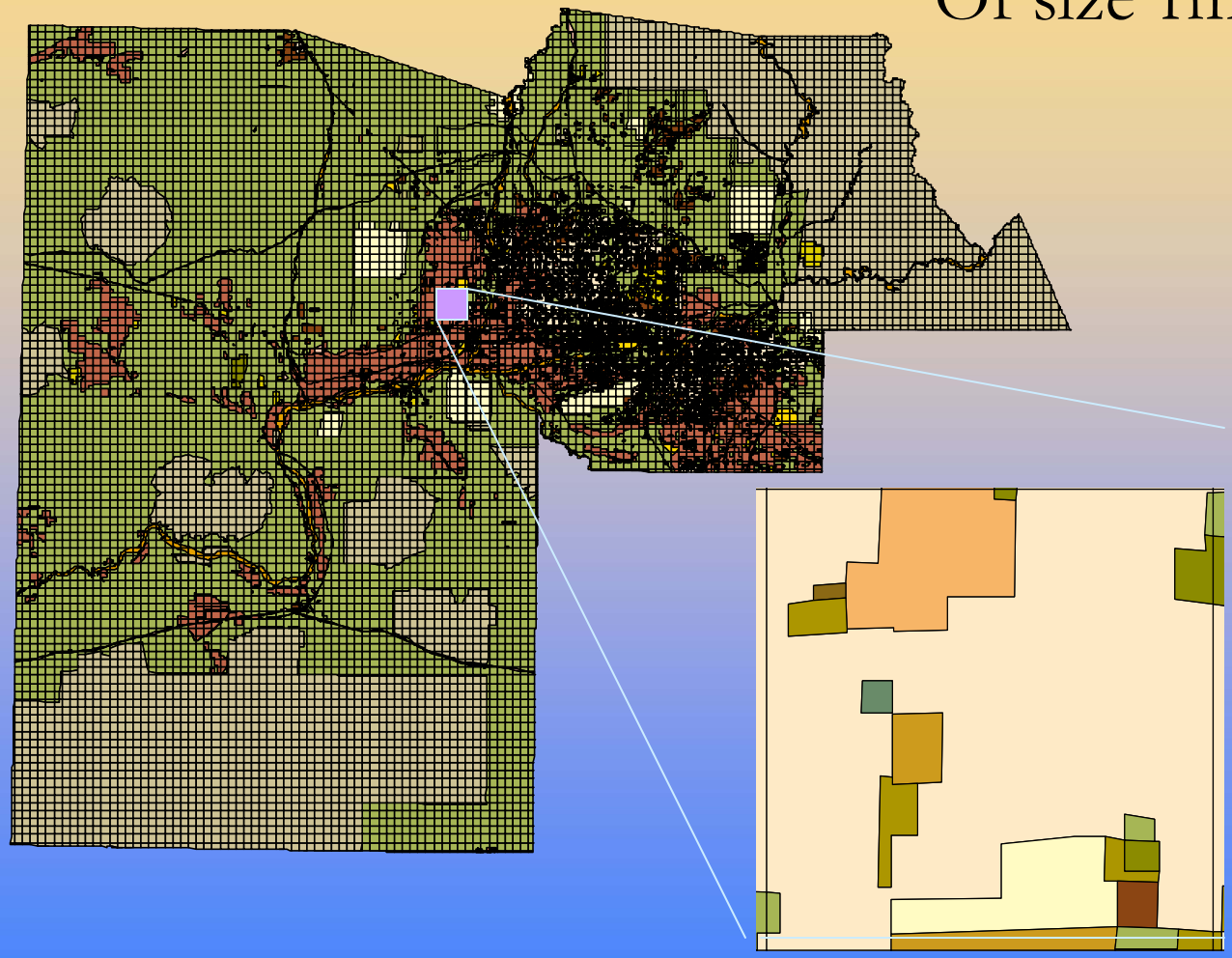
Meta-Model of the Urban Landscape System of Systems: Interaction of Models

HOUSEHOLD CHARACTERISTICS



GRIDCELLS

Total 9511 Gridcells
Of size 1mile X 1mile



Altogether UrbanSim requires about 60 tables

- These tables include:
  - Database Tables about Development Types
  - Database Tables about Employment
  - Estimation Data Writer Tables
  - Database Tables about Events
  - Database Tables about Geographies
  - Database Tables about Grid Cells
  - Database Tables about Households
  - Database Tables about Indicators
  - Model Configuration Tables
  - Database Tables about Transportation Analysis Zones

Output Tables

- Population and Households by Type
  - Income
  - Age
  - Household Size
  - Children
  - Workers
- Employment by Industry Sector
- Land Use and Density
- Housing Units, Commercial Square Feet, Prices by Type

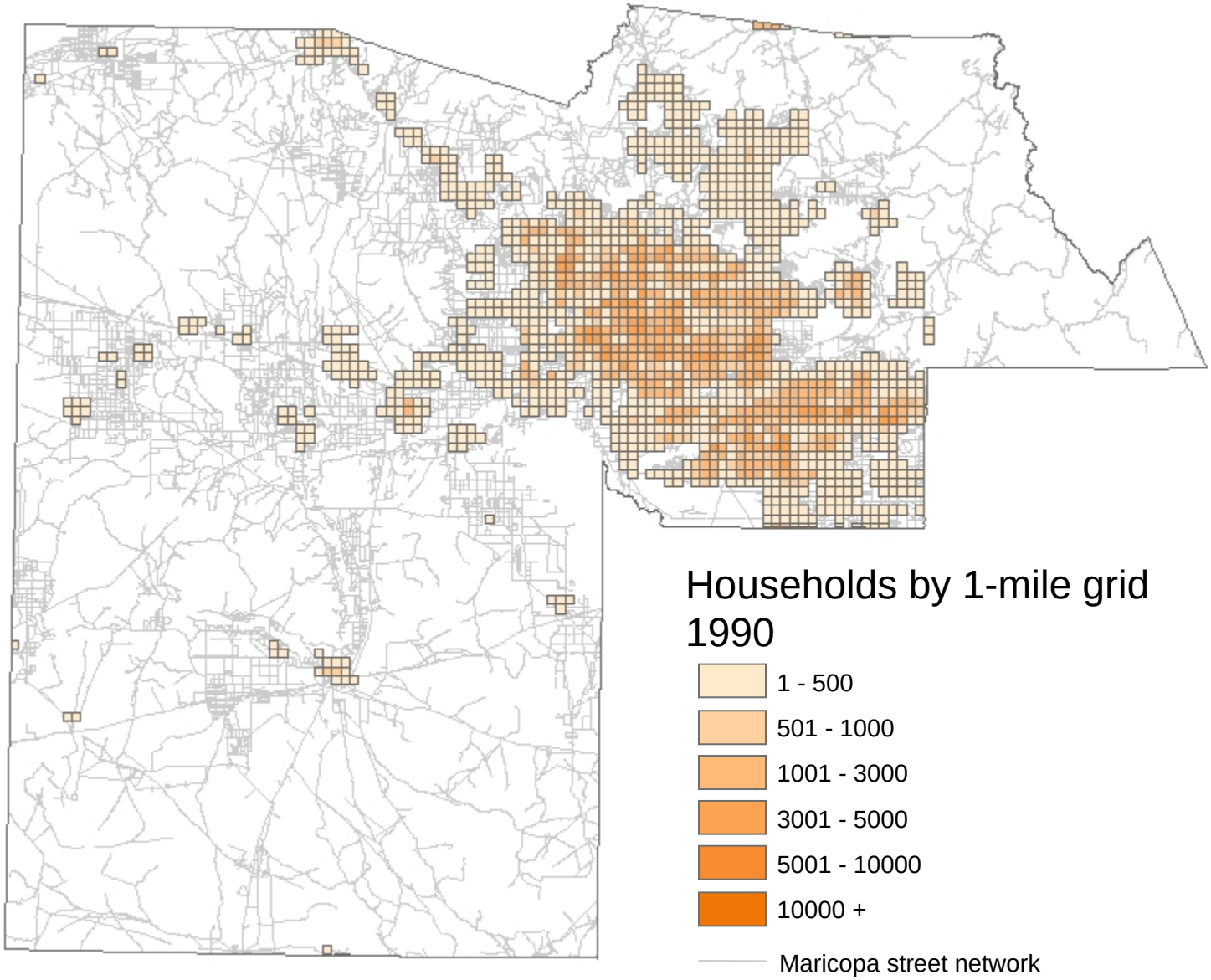
JOB SECTORS AND TABLE PROPERTIES

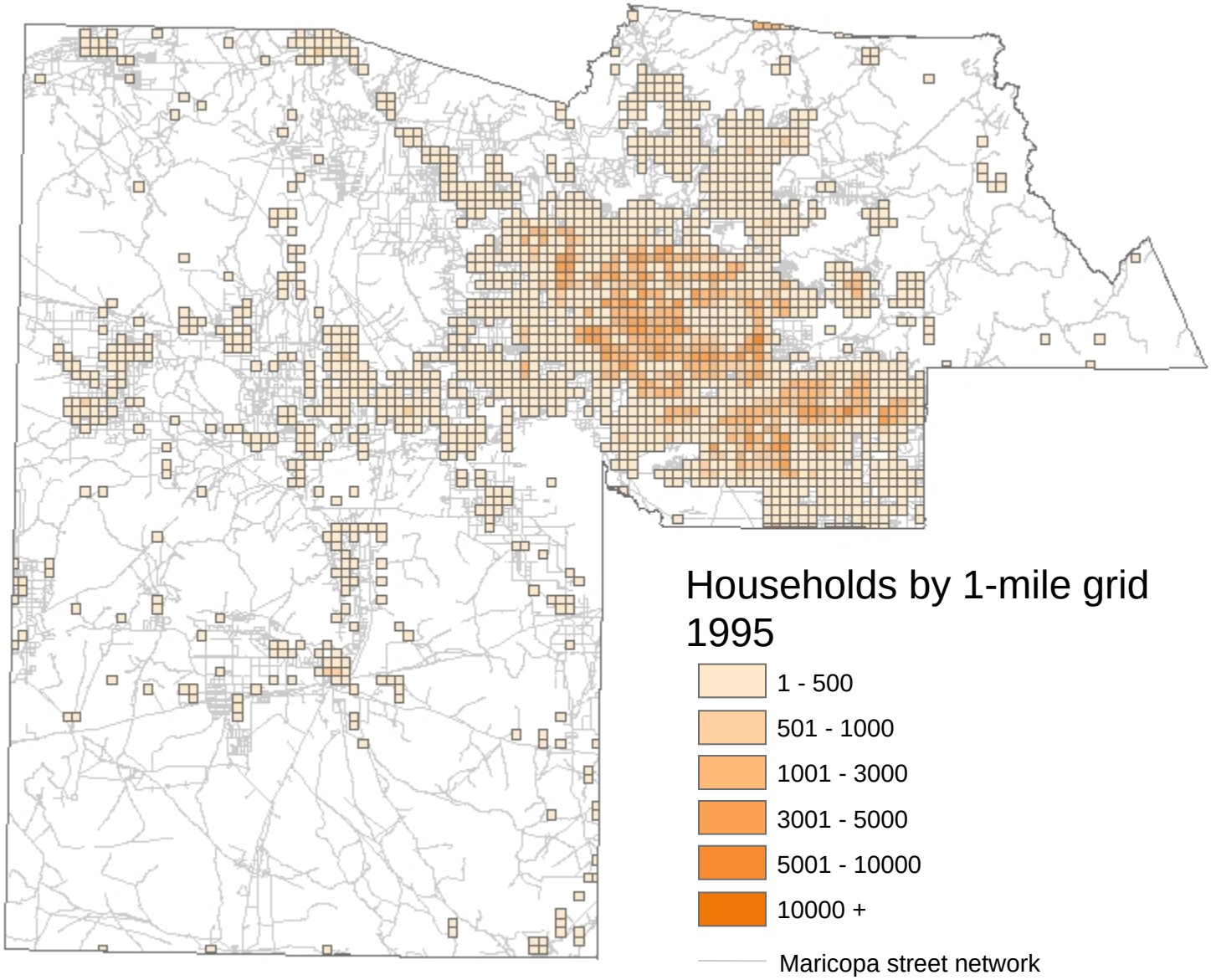
	SECTOR_ID	NAME
1	1	Natural Resources and Mining
2	2	Construction
3	3	Manufacturing
4	4	Transportation and Utilities
5	5	Wholesale Trade
6	6	Retail Trade
7	7	Finance, Insurance and Real Estate
8	8	Services
9	9	Government
10	10	Other

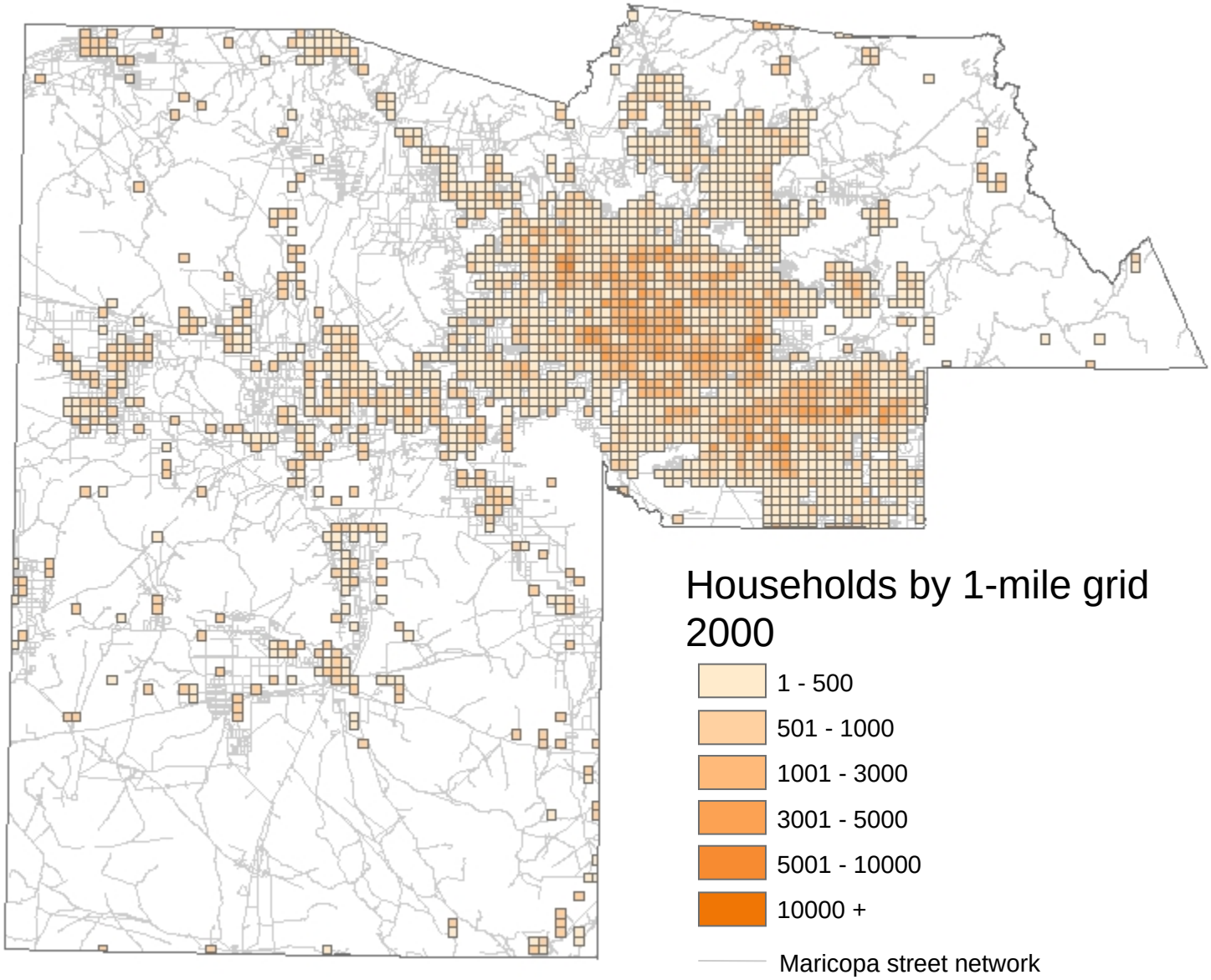
JOB_ID	Integer	Unique identifier
GRID_ID	INTEGER	Grid cell this job exists in; zero if currently not assigned to a grid cell
HOME_BASED	BOOLEAN	True if home-based
SECTOR_ID	INTEGER	Sector this job belongs to

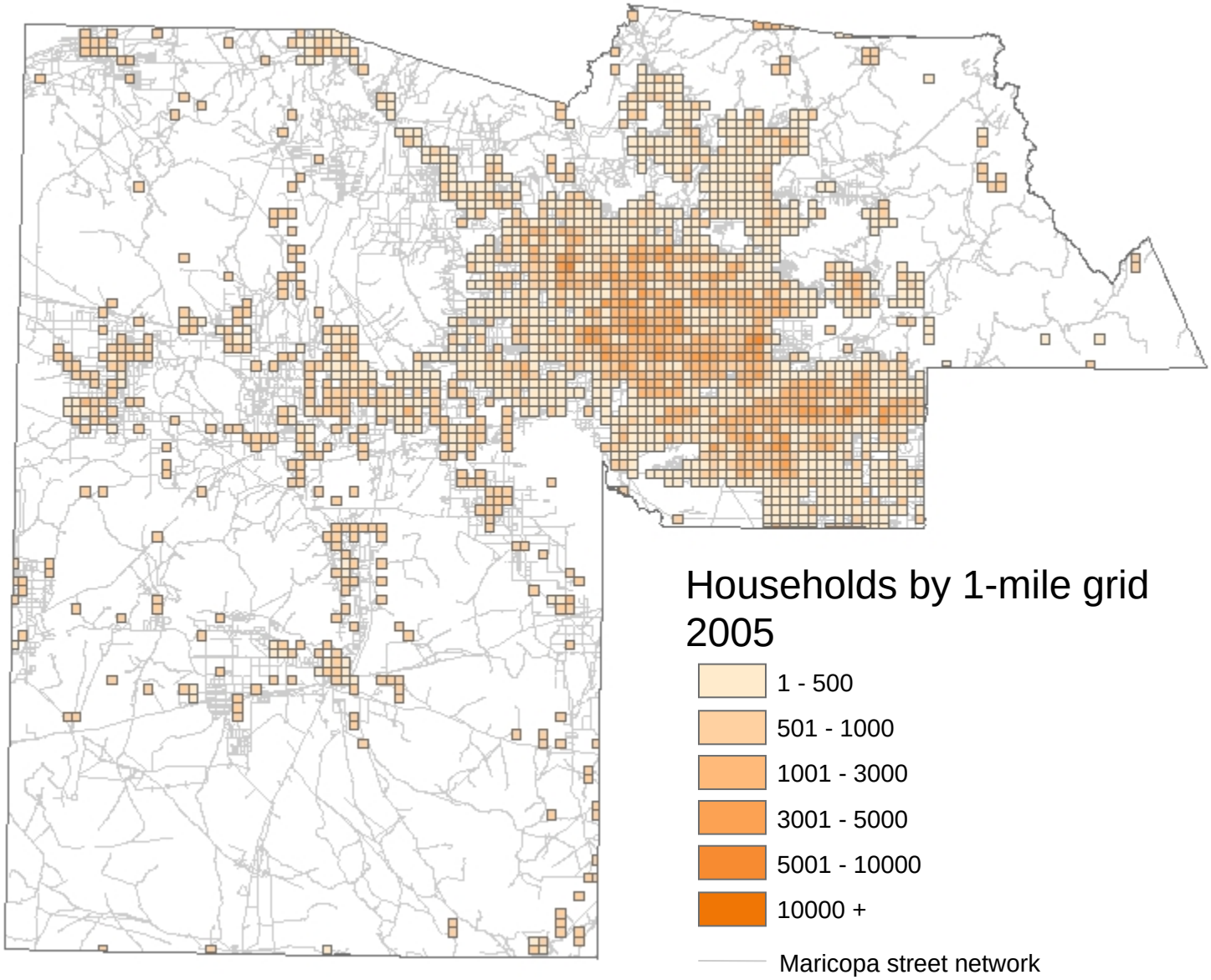
Simulating Household Location from **1990 to 2040** In Maricopa County

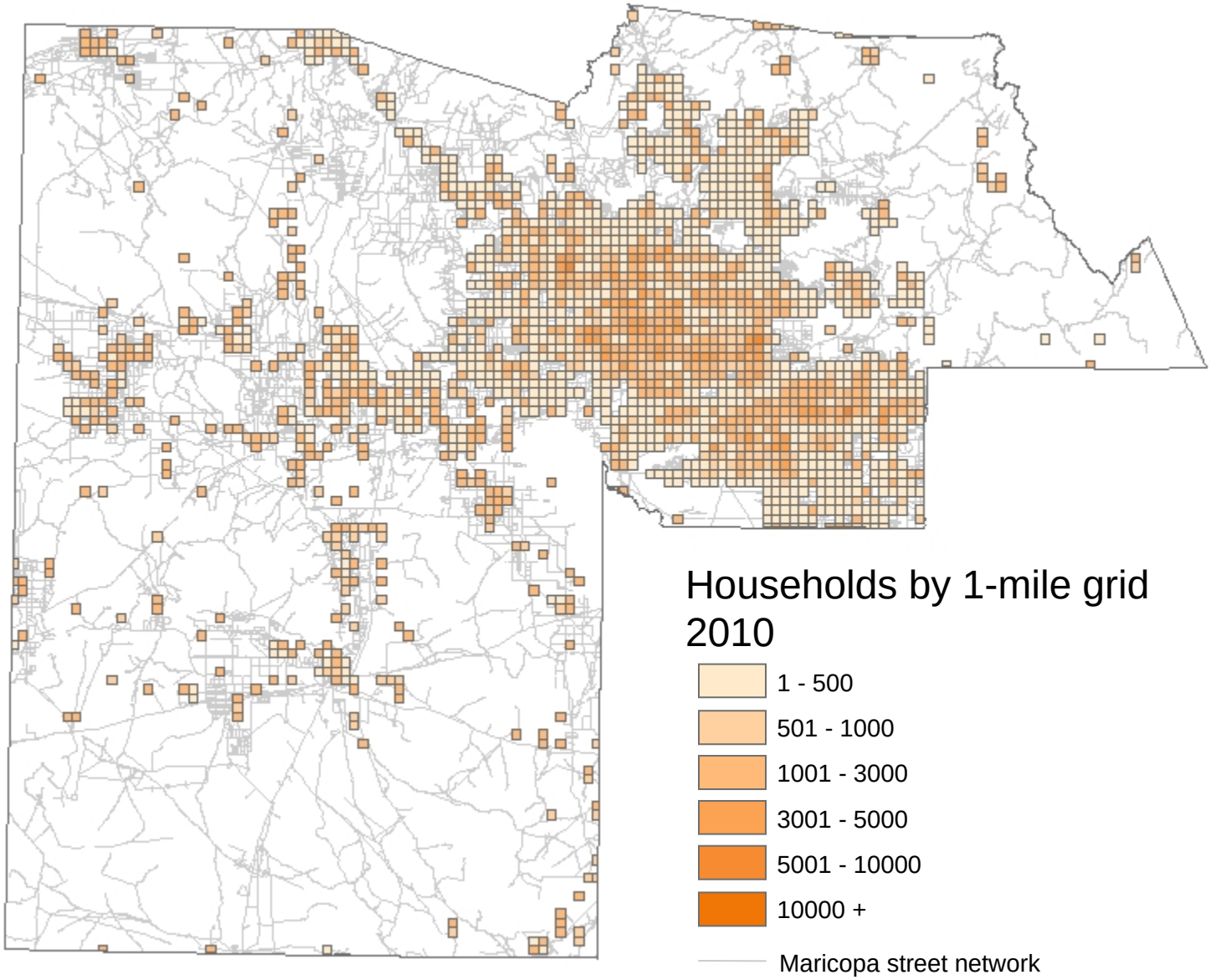
Business as usual scenario

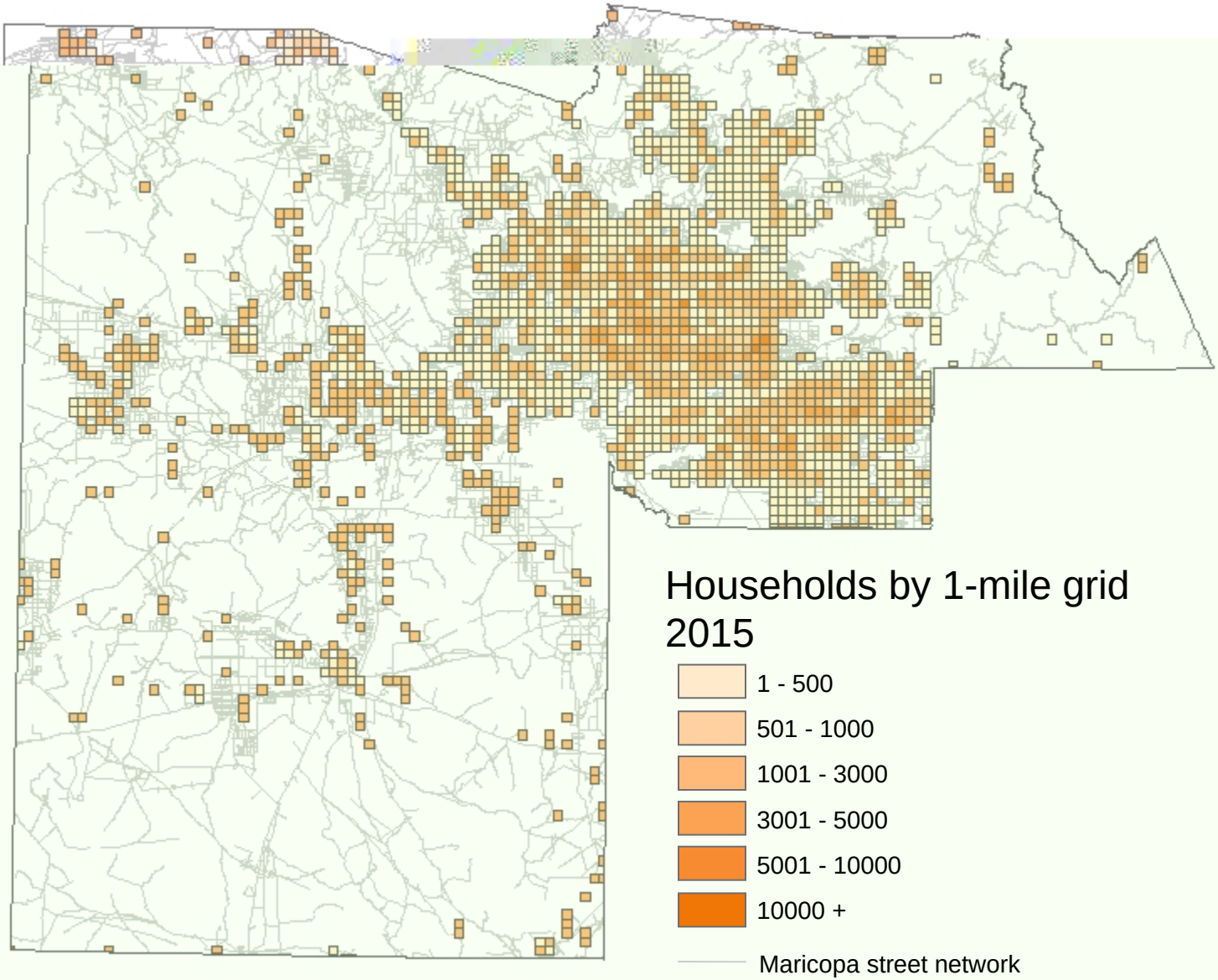

Households by 1-mile grid
1990
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

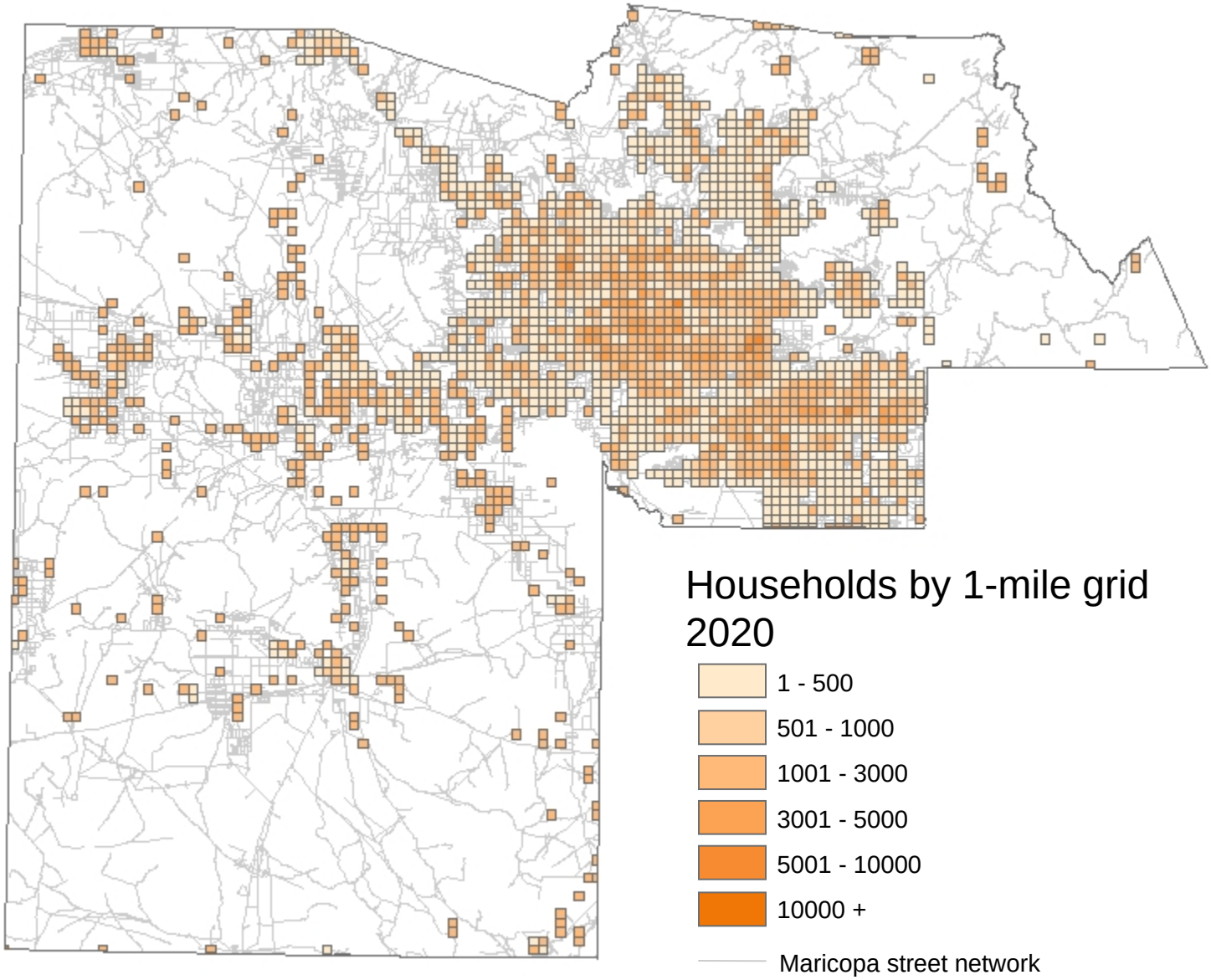

Households by 1-mile grid
1995
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

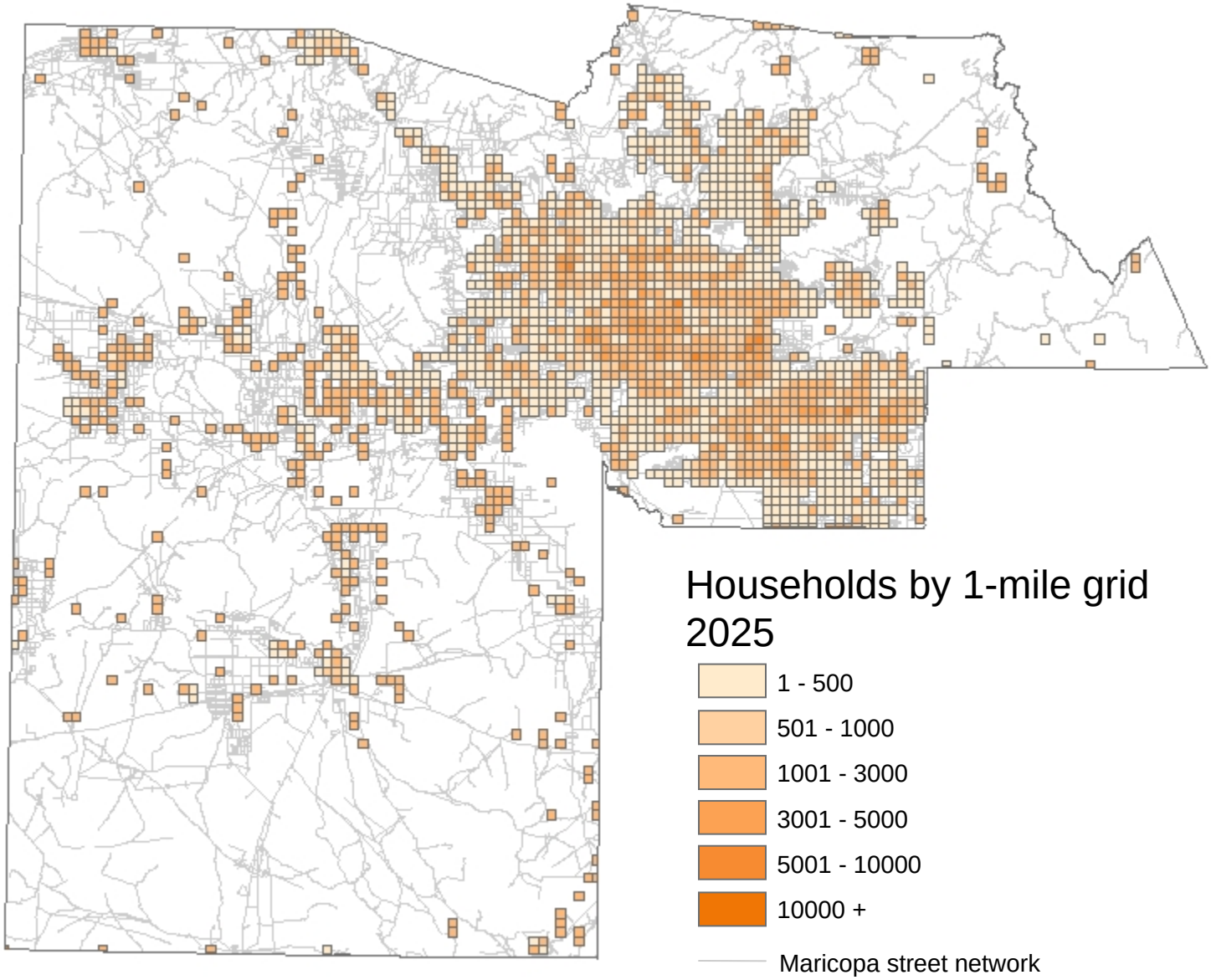

Households by 1-mile grid
2000
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

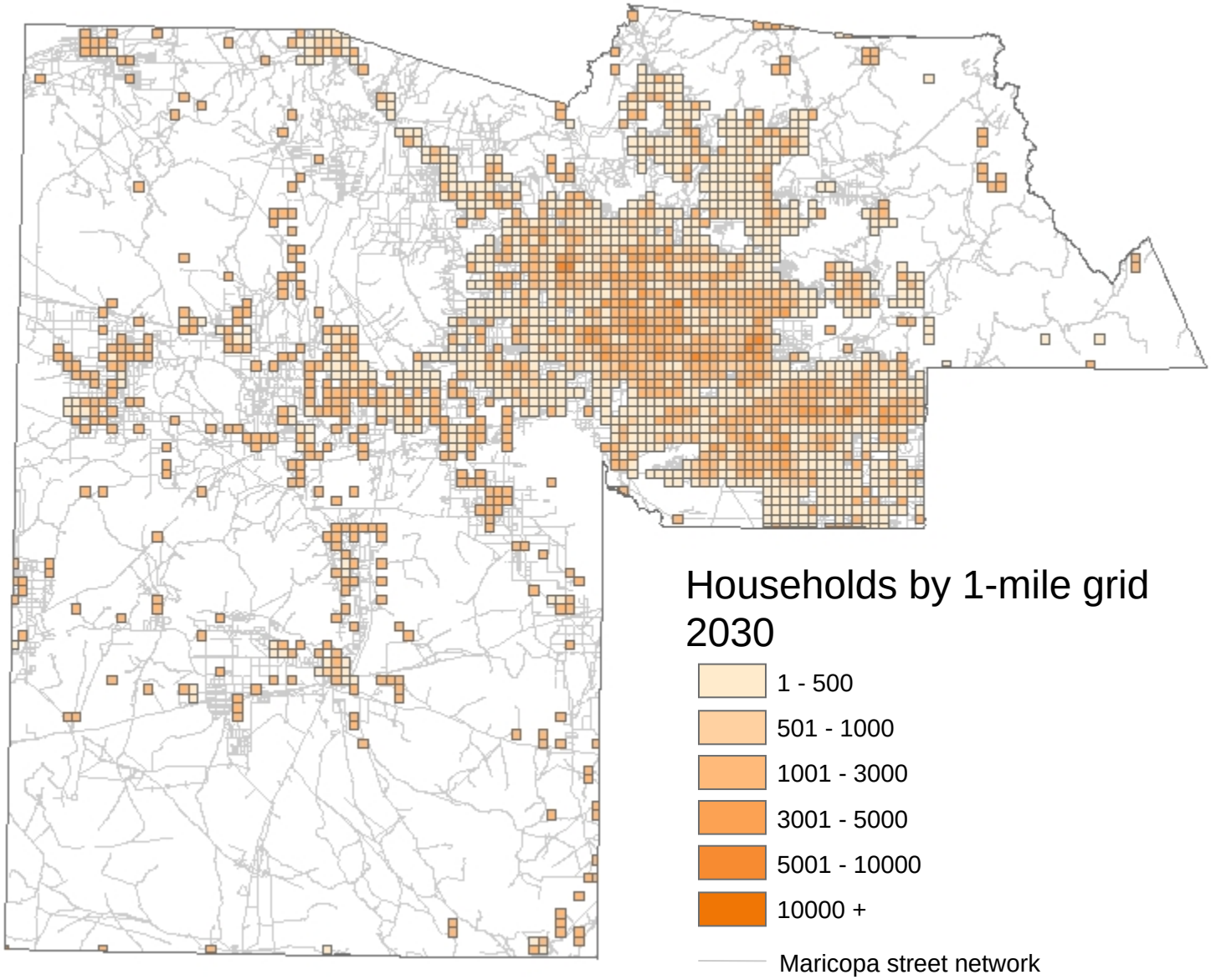

Households by 1-mile grid
2005
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

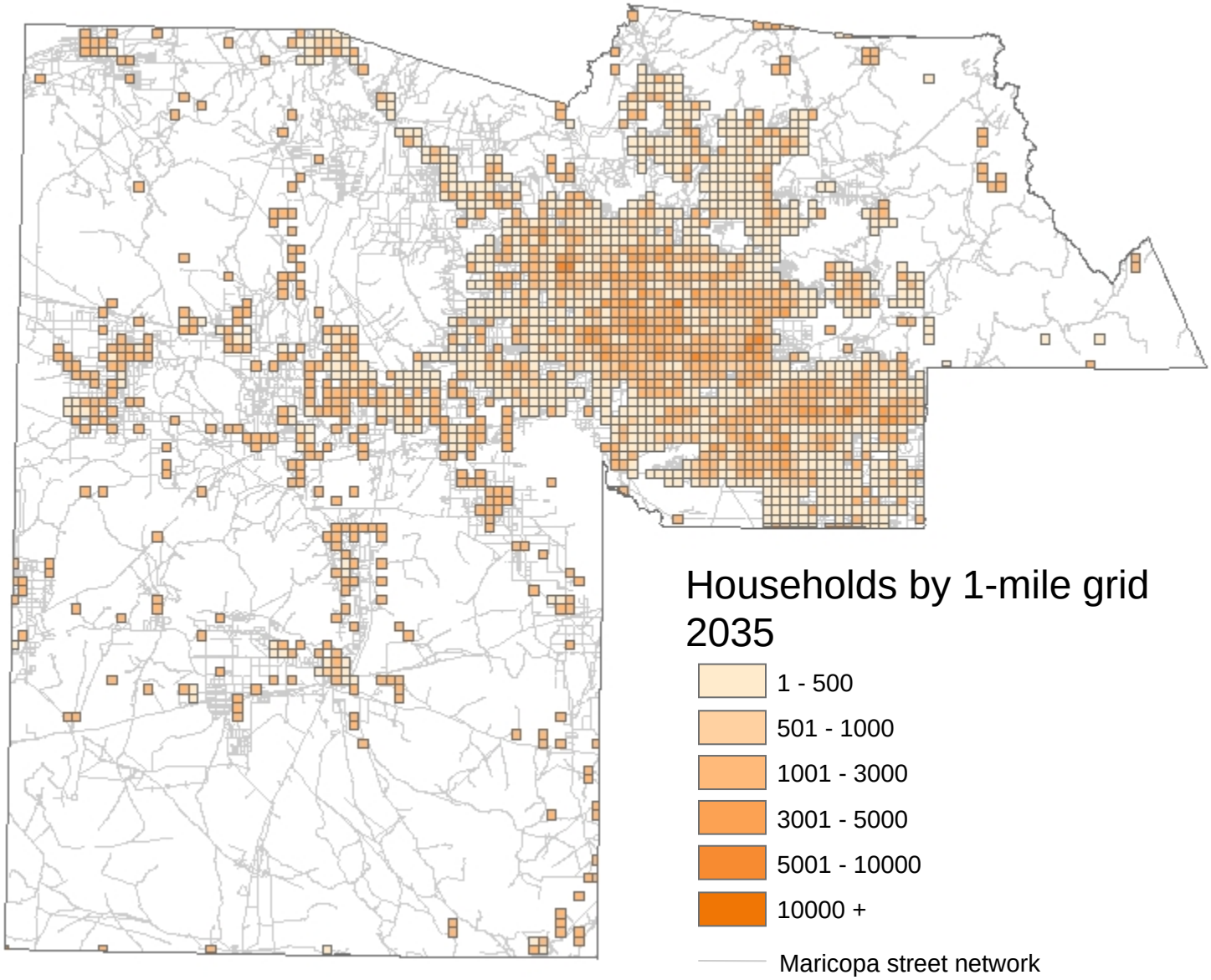

Households by 1-mile grid
2010
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

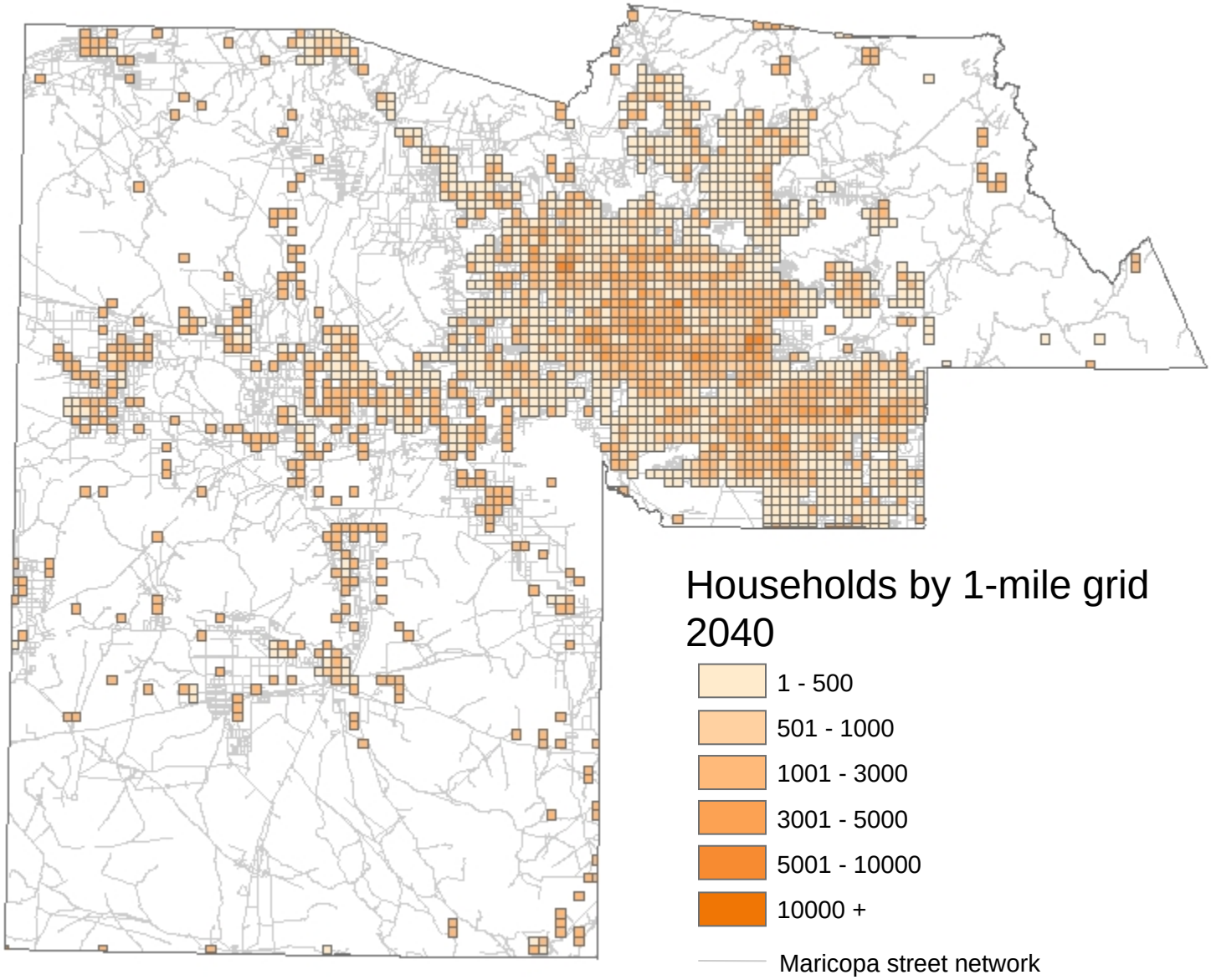

Households by 1-mile grid
2015
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network


Households by 1-mile grid
2020
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network


Households by 1-mile grid
2025
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network


Households by 1-mile grid
2030
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

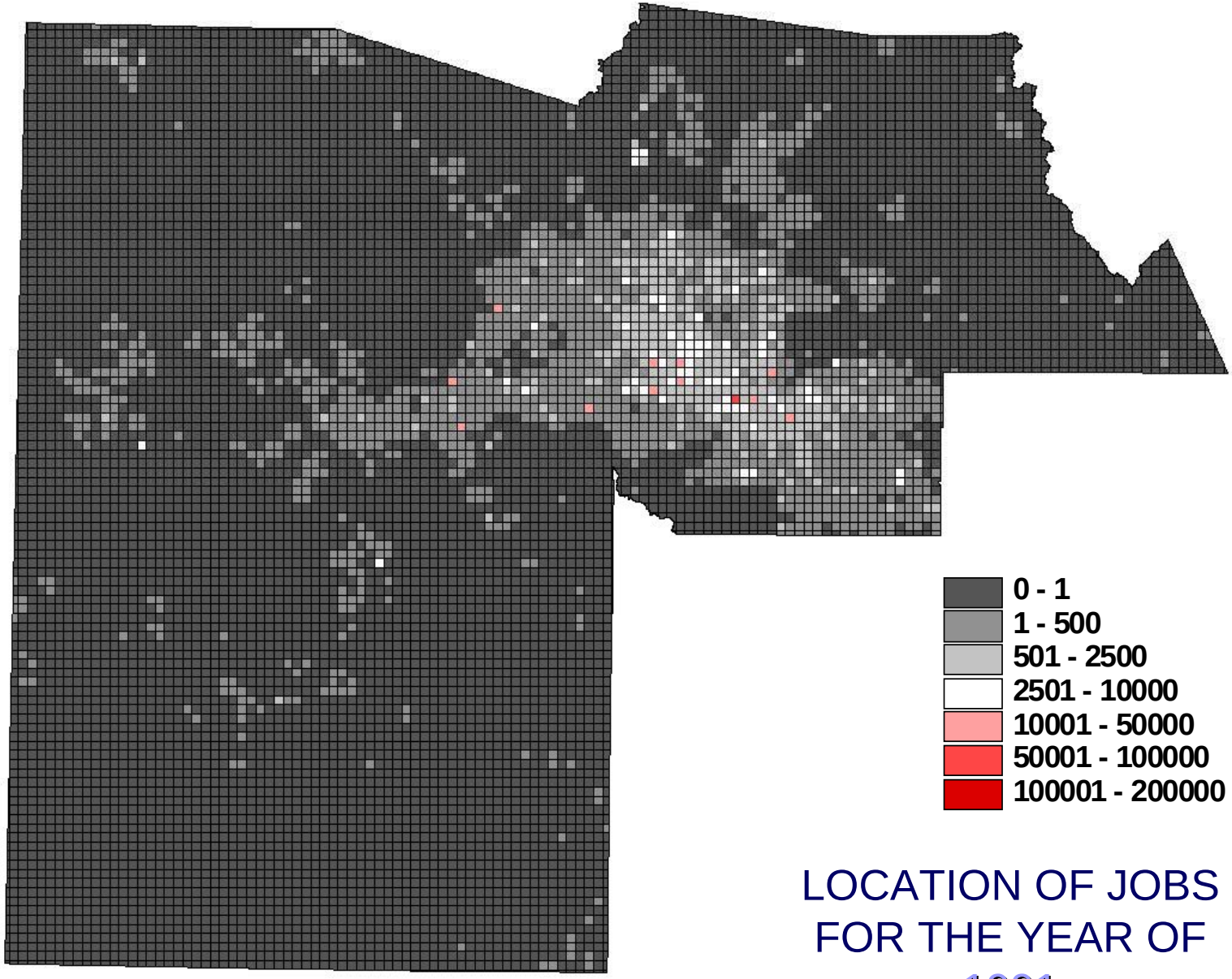

Households by 1-mile grid
2035
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network


Households by 1-mile grid
2040
1 - 500
501 - 1000
1001 - 3000
3001 - 5000
5001 - 10000
10000 +
Maricopa street network

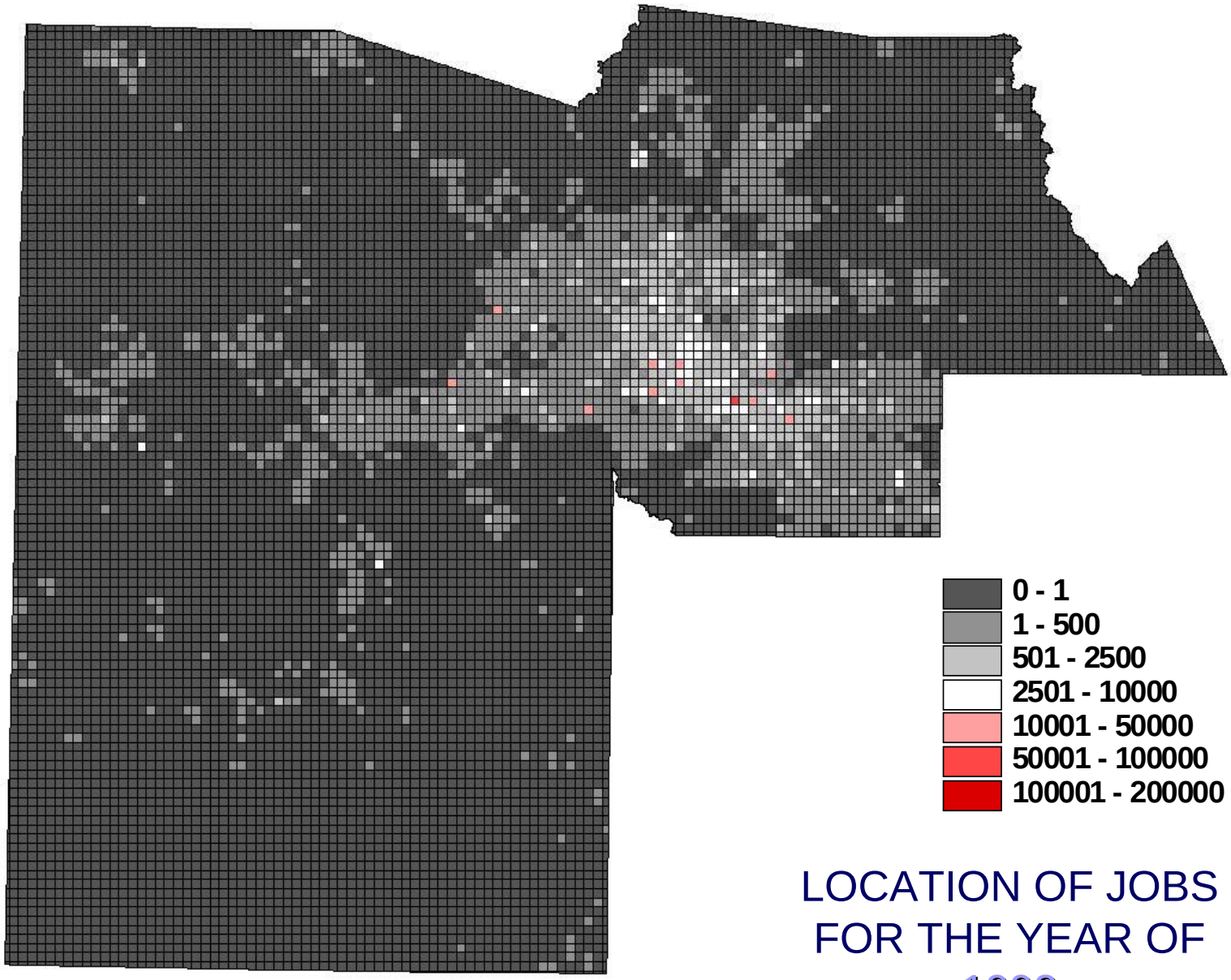
Simulating Employment Location from **1990 to 2010** In Maricopa County

Business as usual scenario

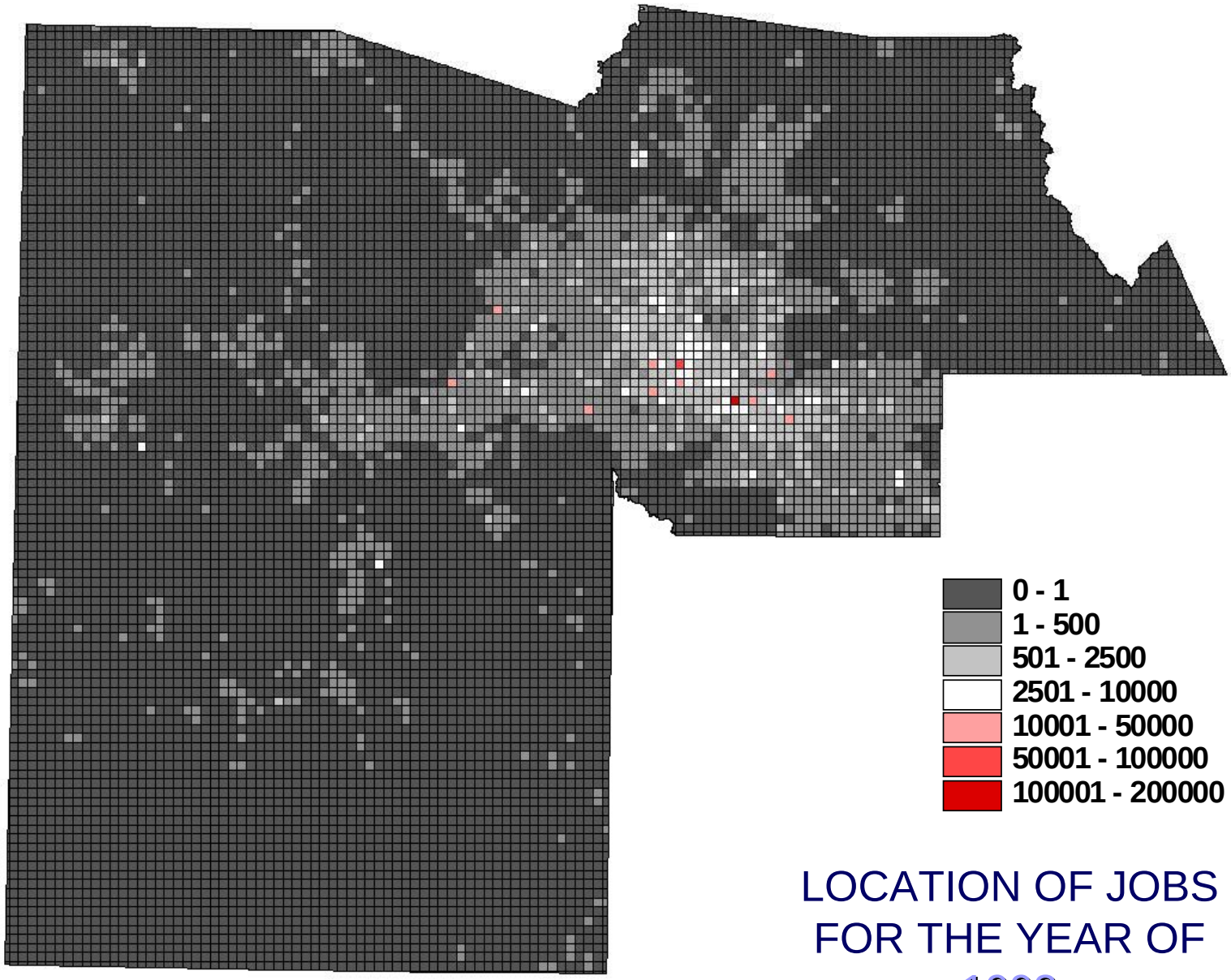
(Guhathakurta, Konjevod, Li, Crittenden, Elangovan, *Joshi)*



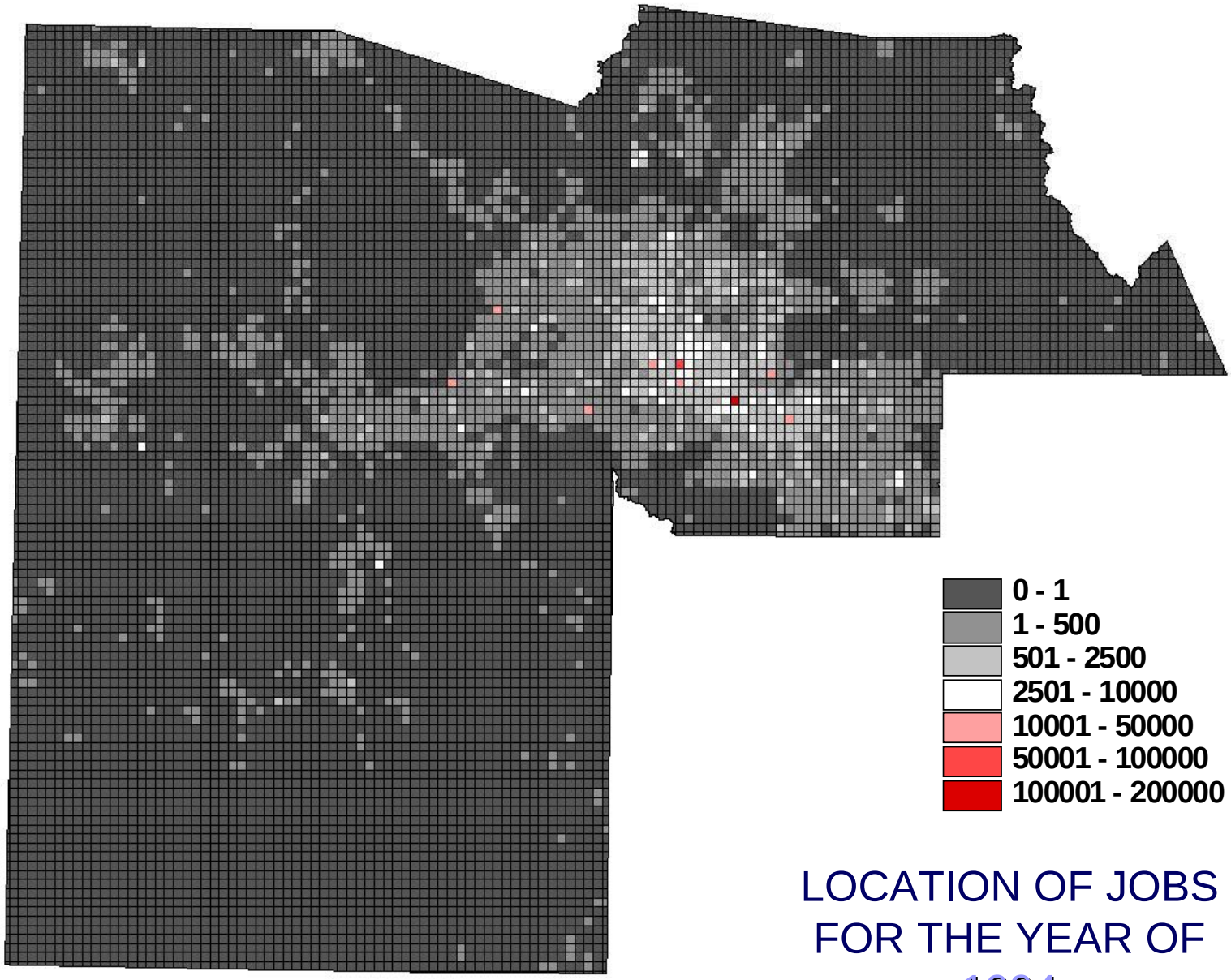
LOCATION OF JOBS
FOR THE YEAR OF
1991



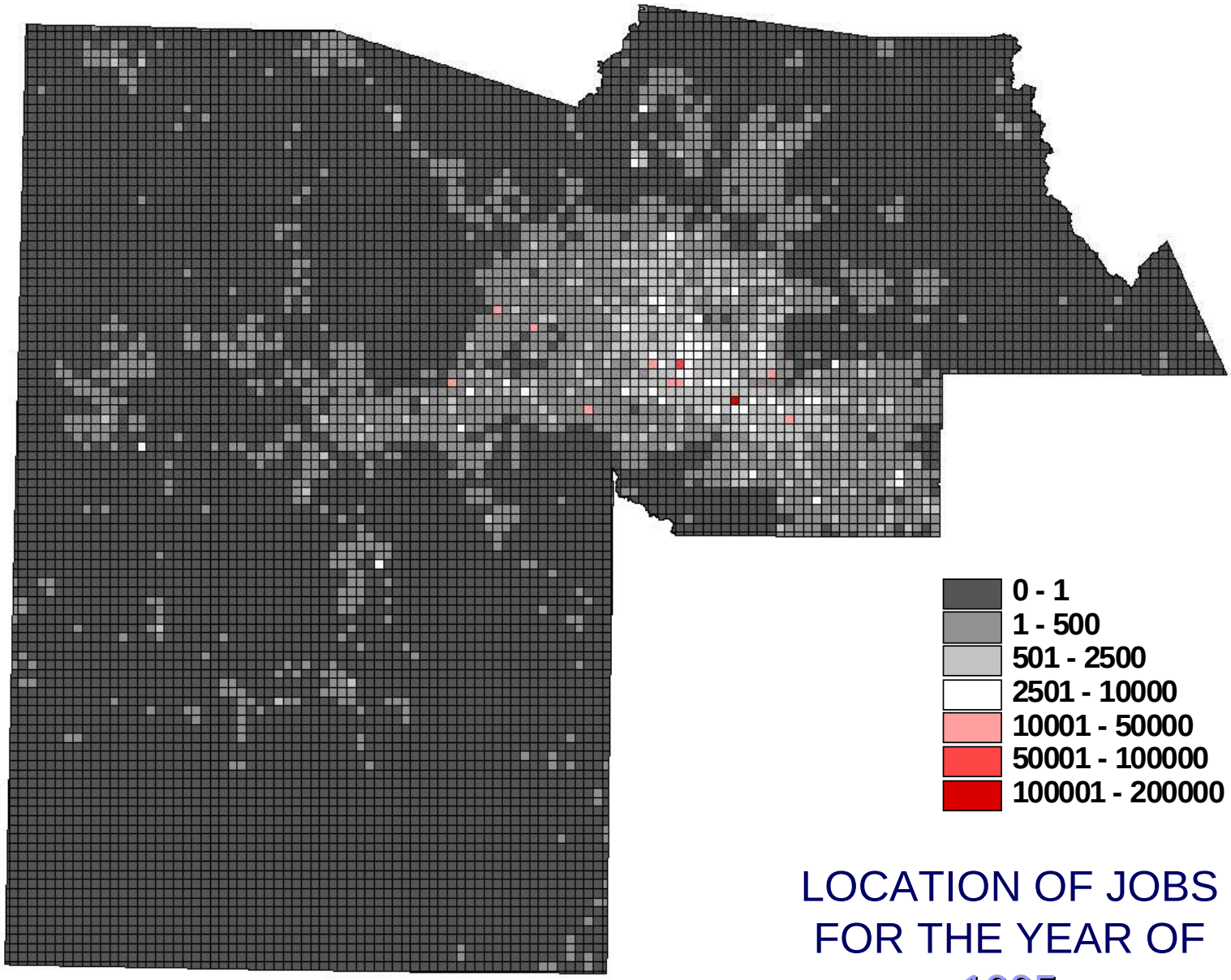
LOCATION OF JOBS
FOR THE YEAR OF
1992



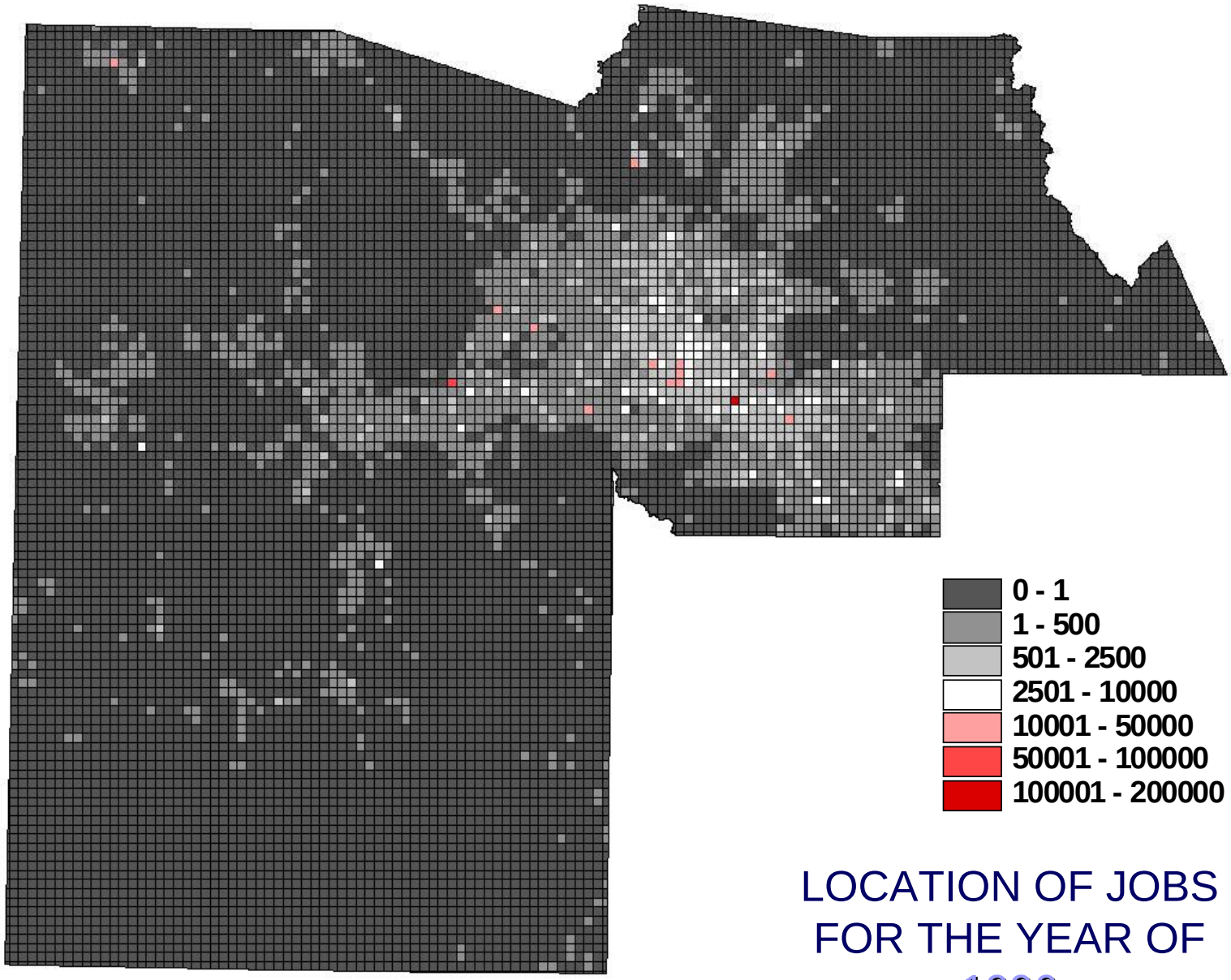
LOCATION OF JOBS
FOR THE YEAR OF
1993



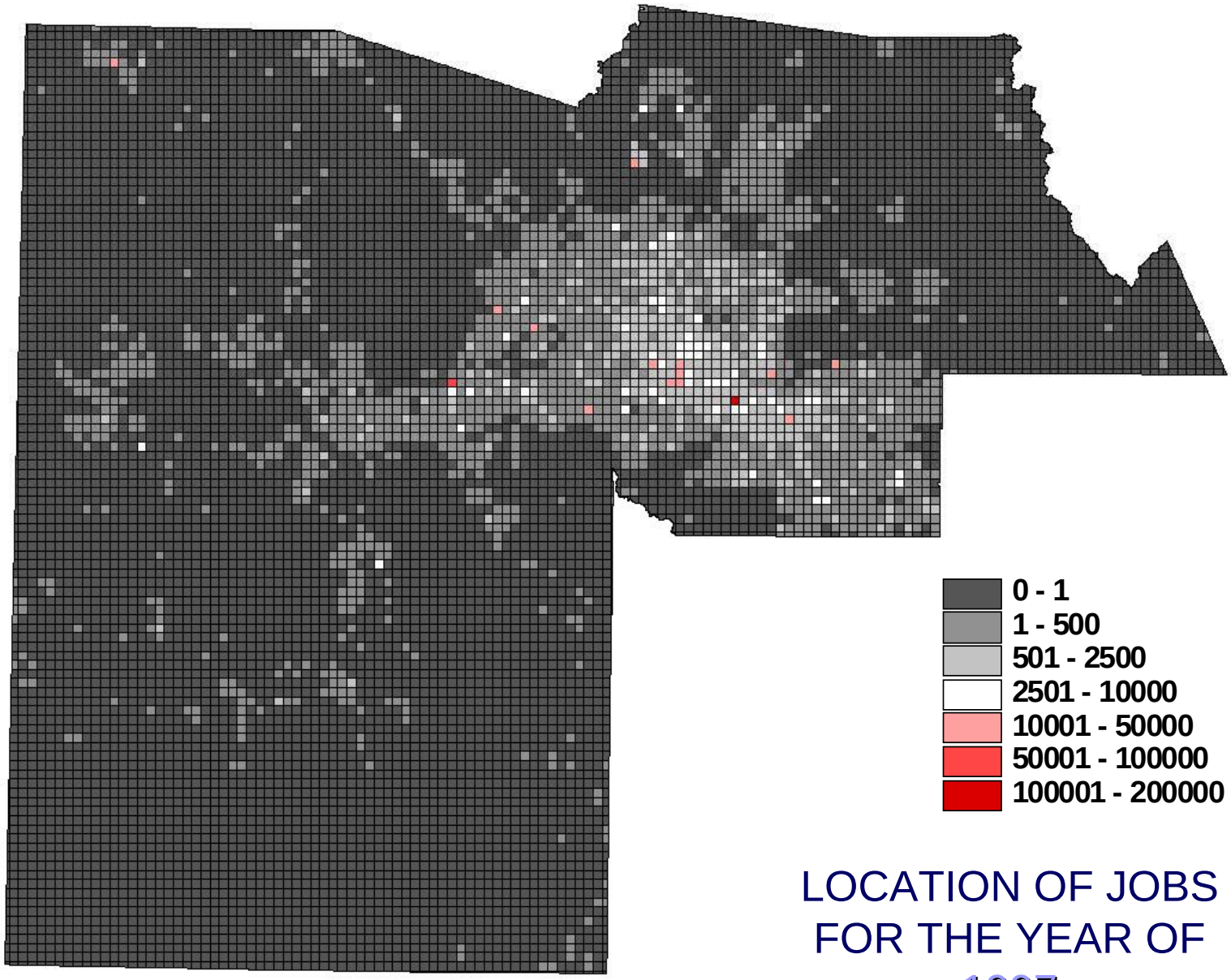
LOCATION OF JOBS
FOR THE YEAR OF
1994



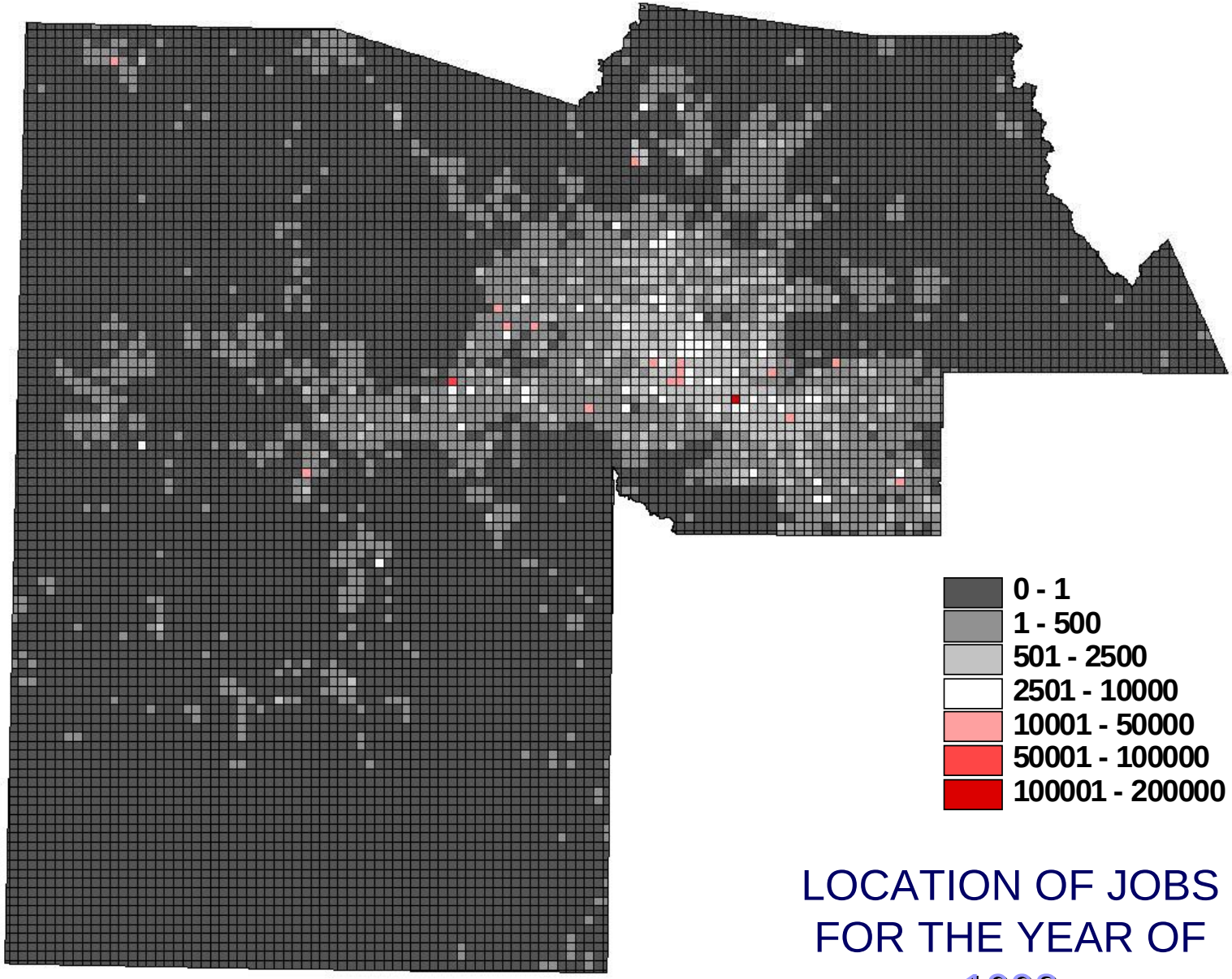
LOCATION OF JOBS
FOR THE YEAR OF
1995



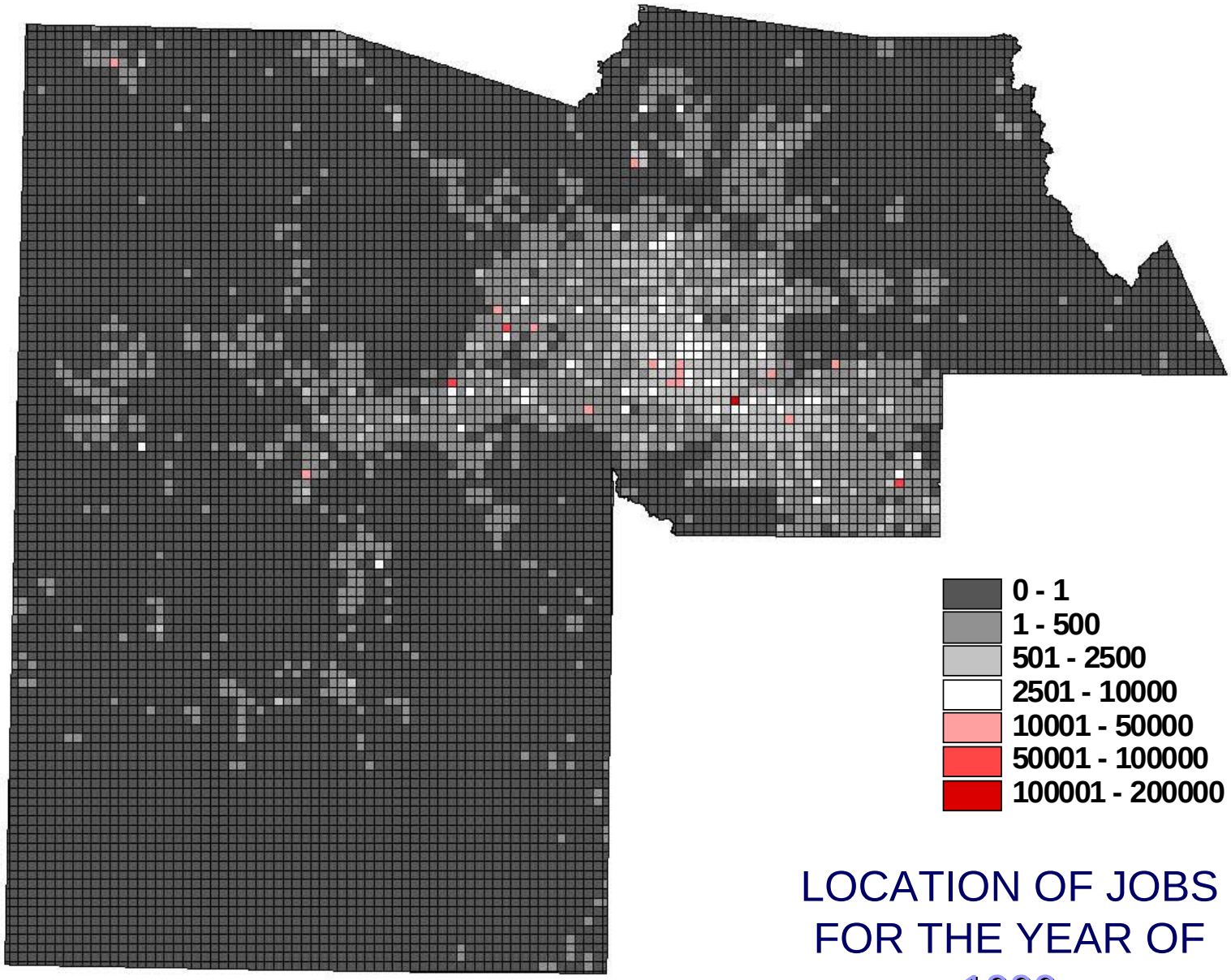
LOCATION OF JOBS
FOR THE YEAR OF
1996



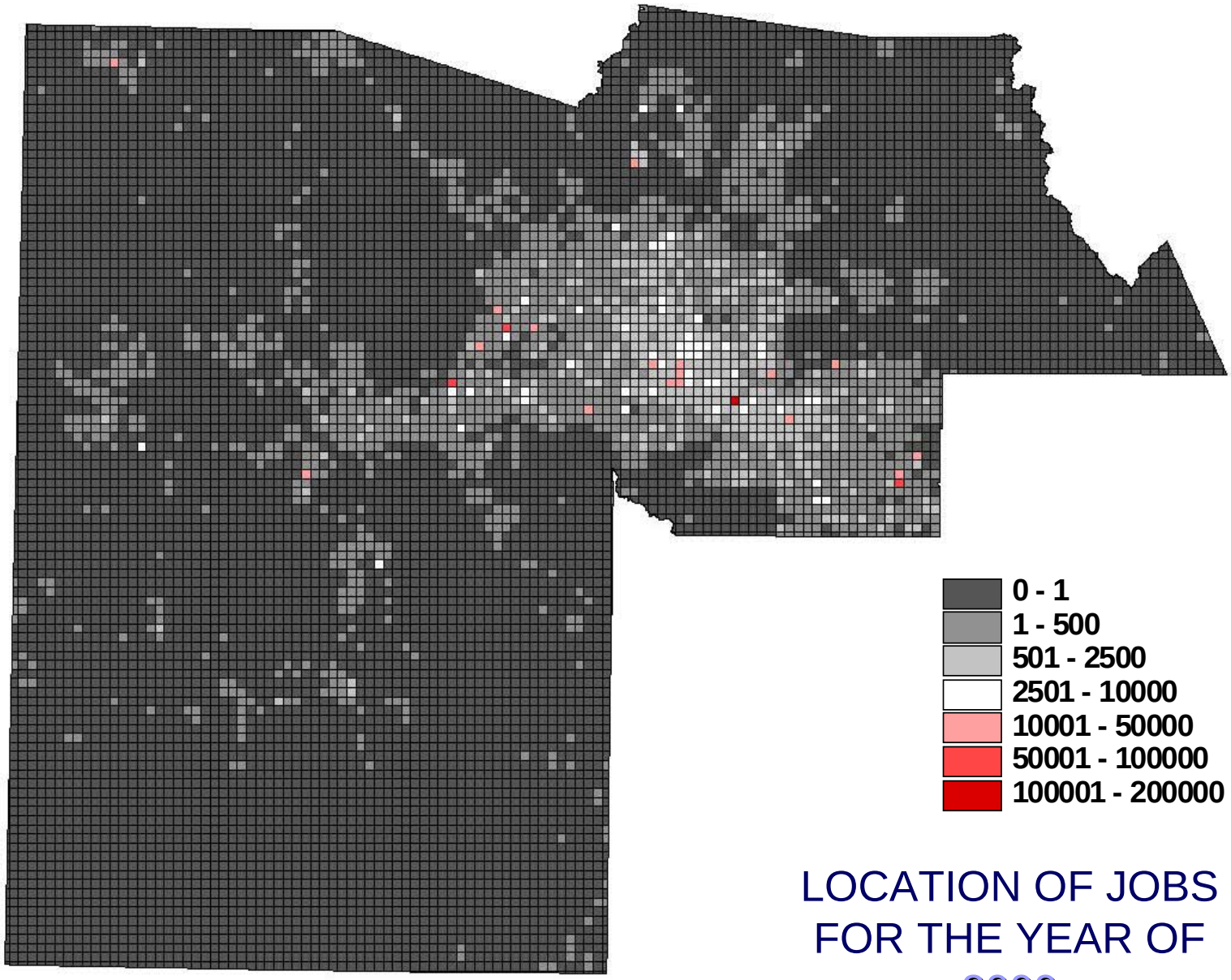
LOCATION OF JOBS
FOR THE YEAR OF
1997



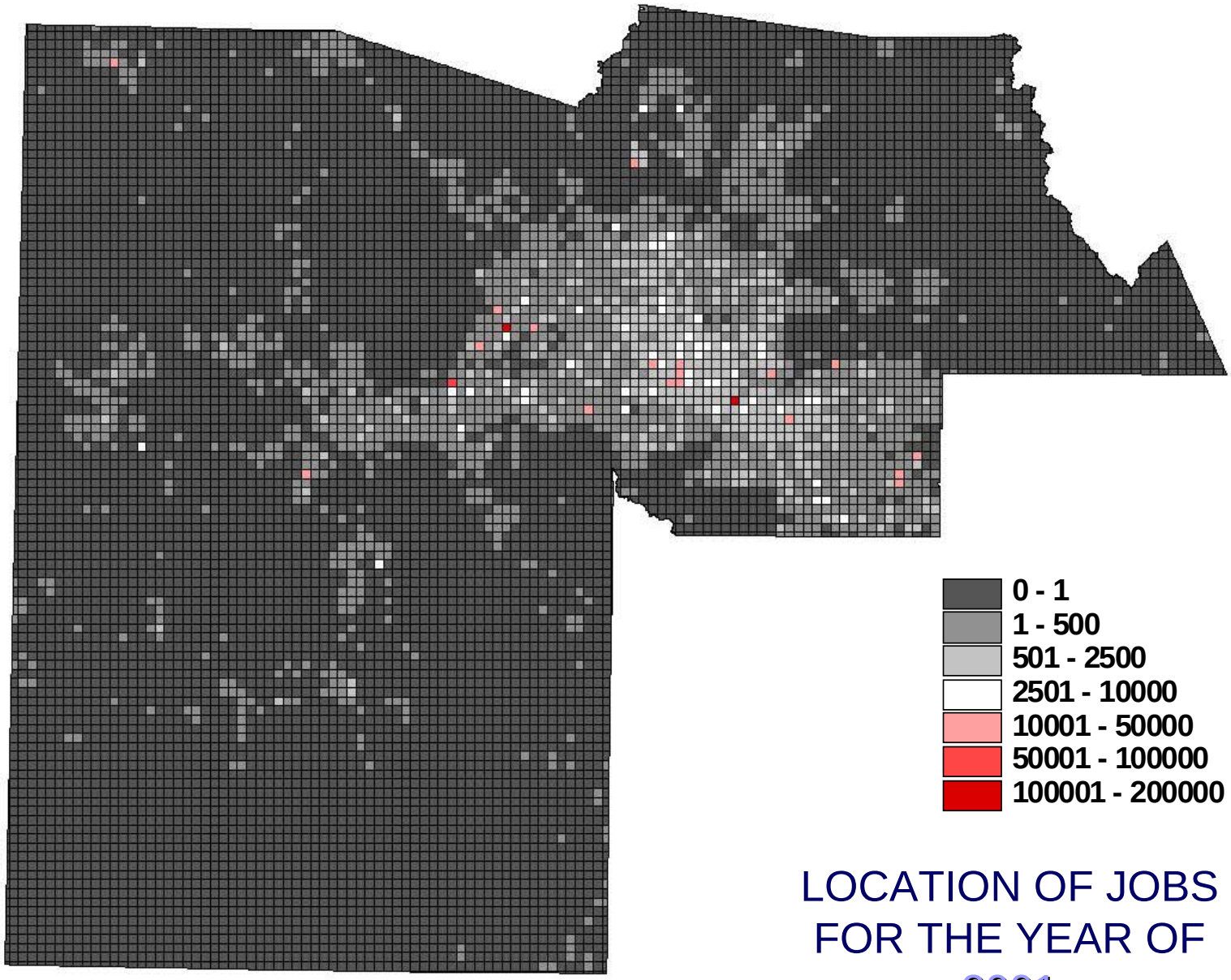
LOCATION OF JOBS
FOR THE YEAR OF
1998



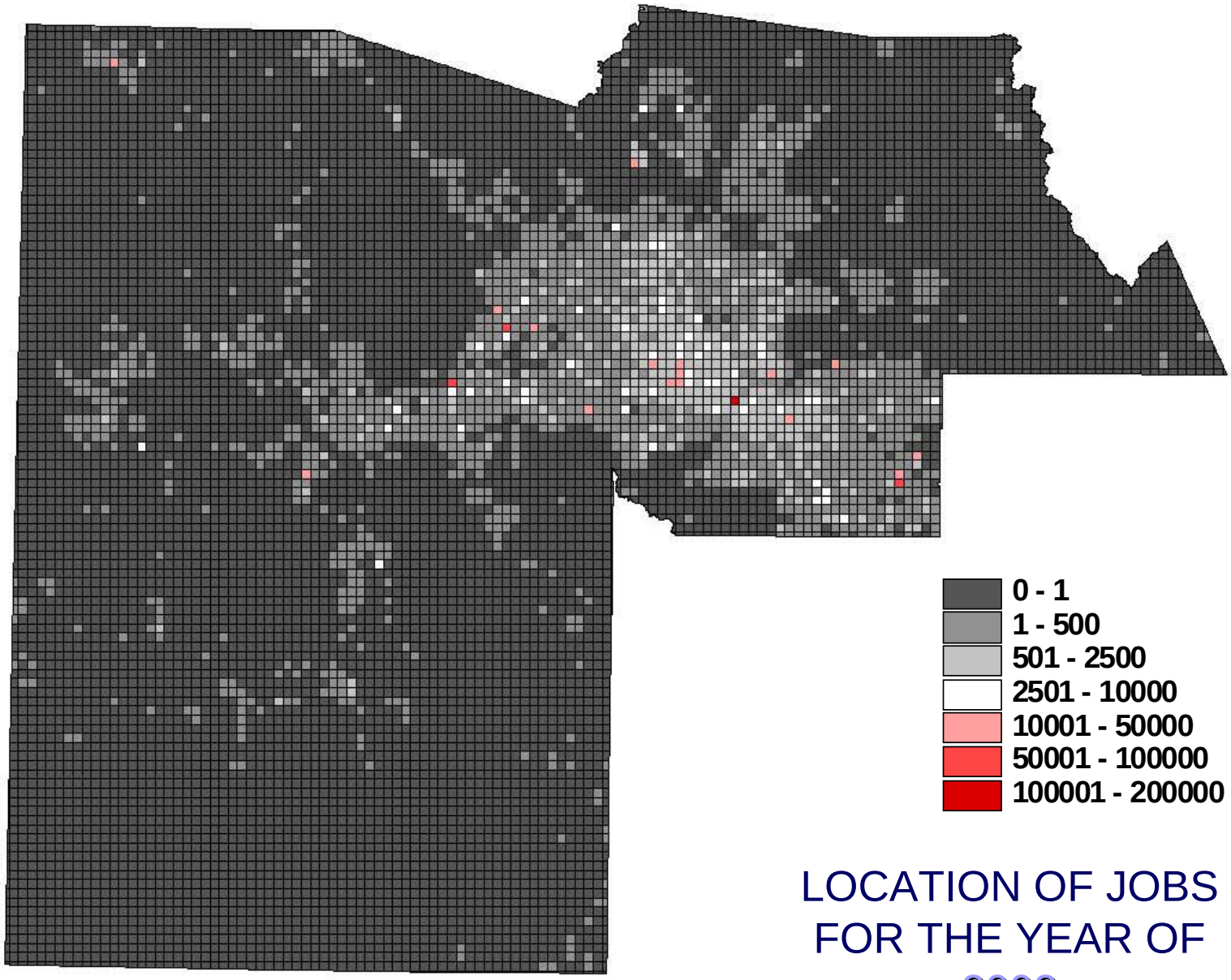
LOCATION OF JOBS
FOR THE YEAR OF
1999



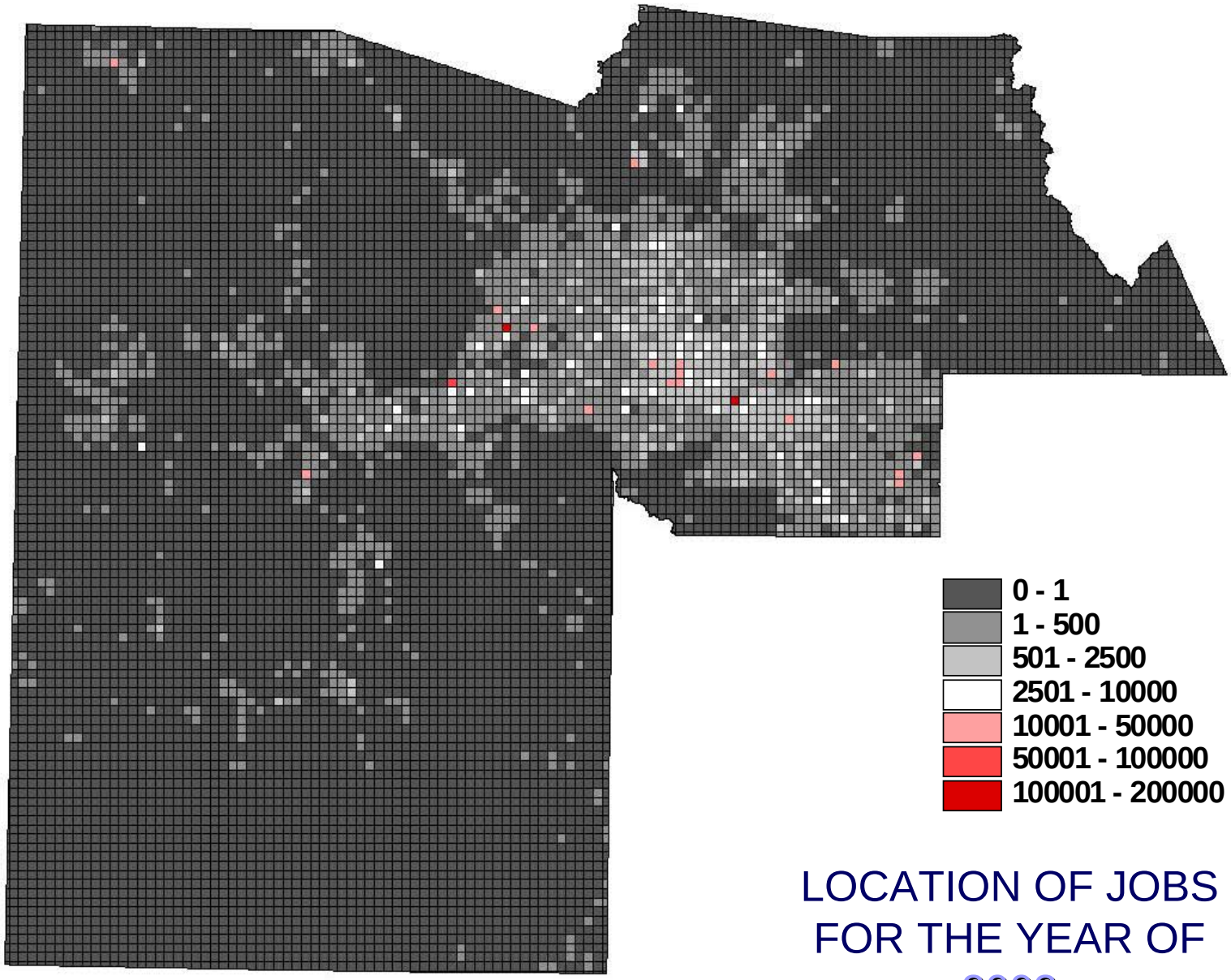
LOCATION OF JOBS
FOR THE YEAR OF
2000



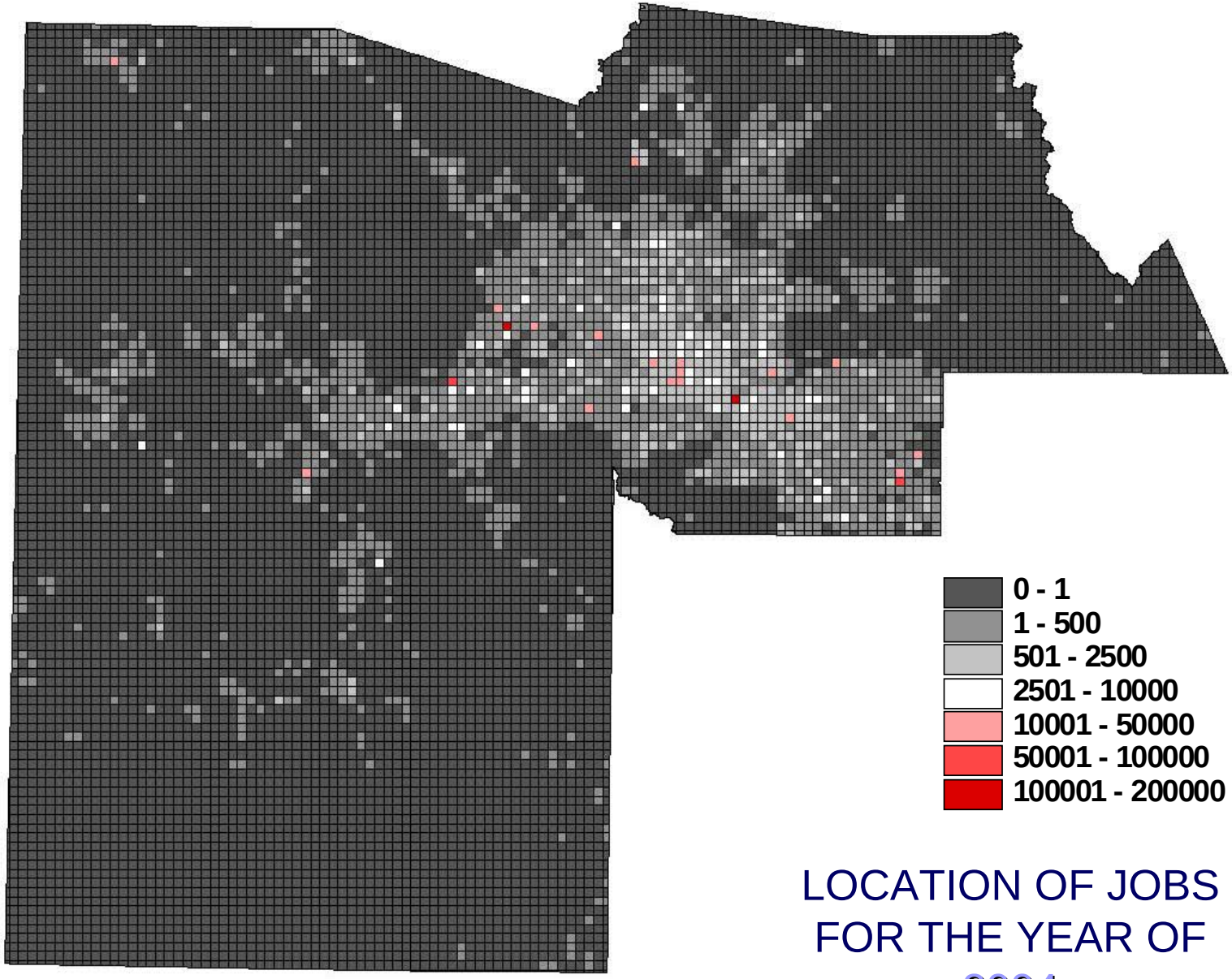
LOCATION OF JOBS
FOR THE YEAR OF
2001



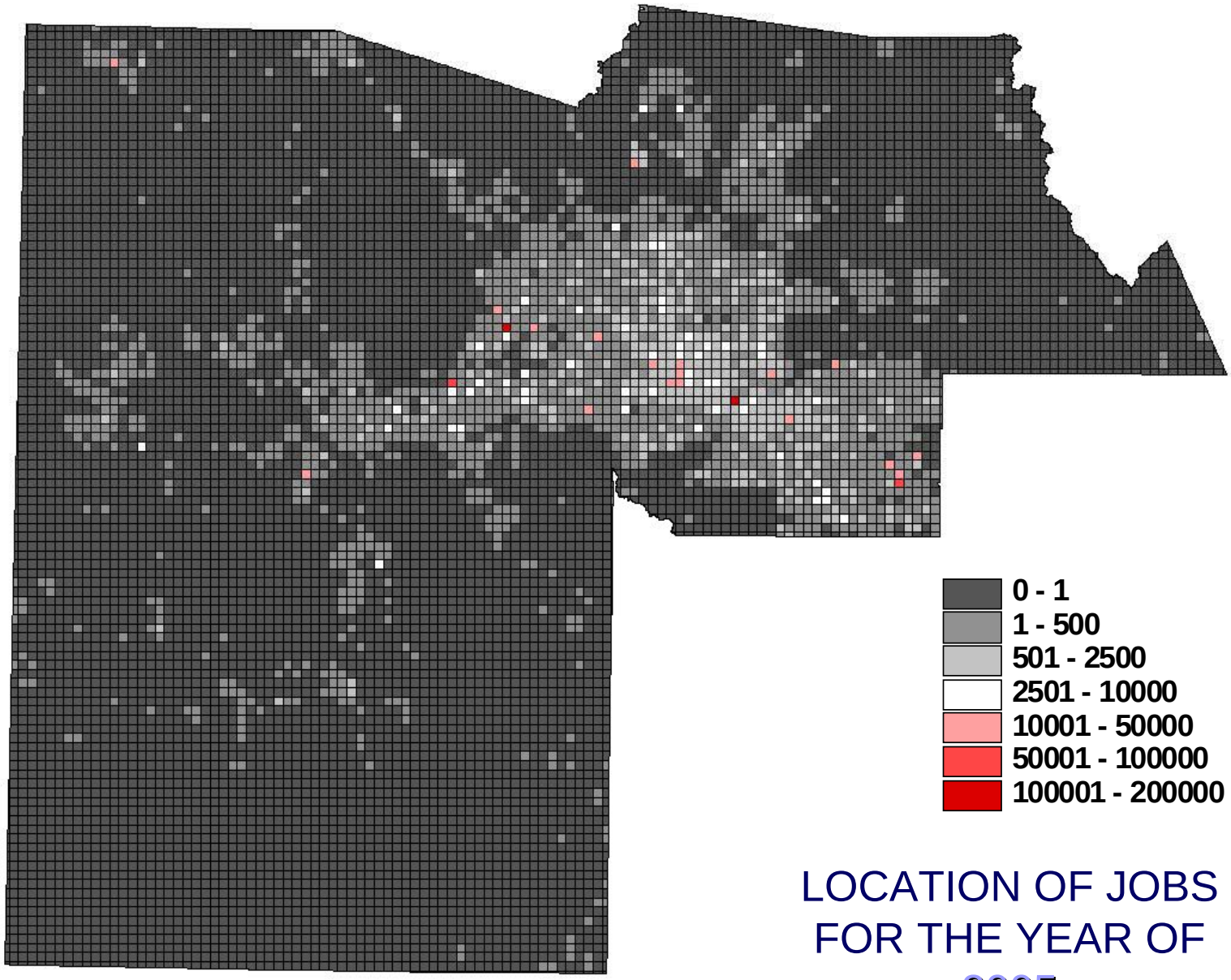
LOCATION OF JOBS
FOR THE YEAR OF
2002



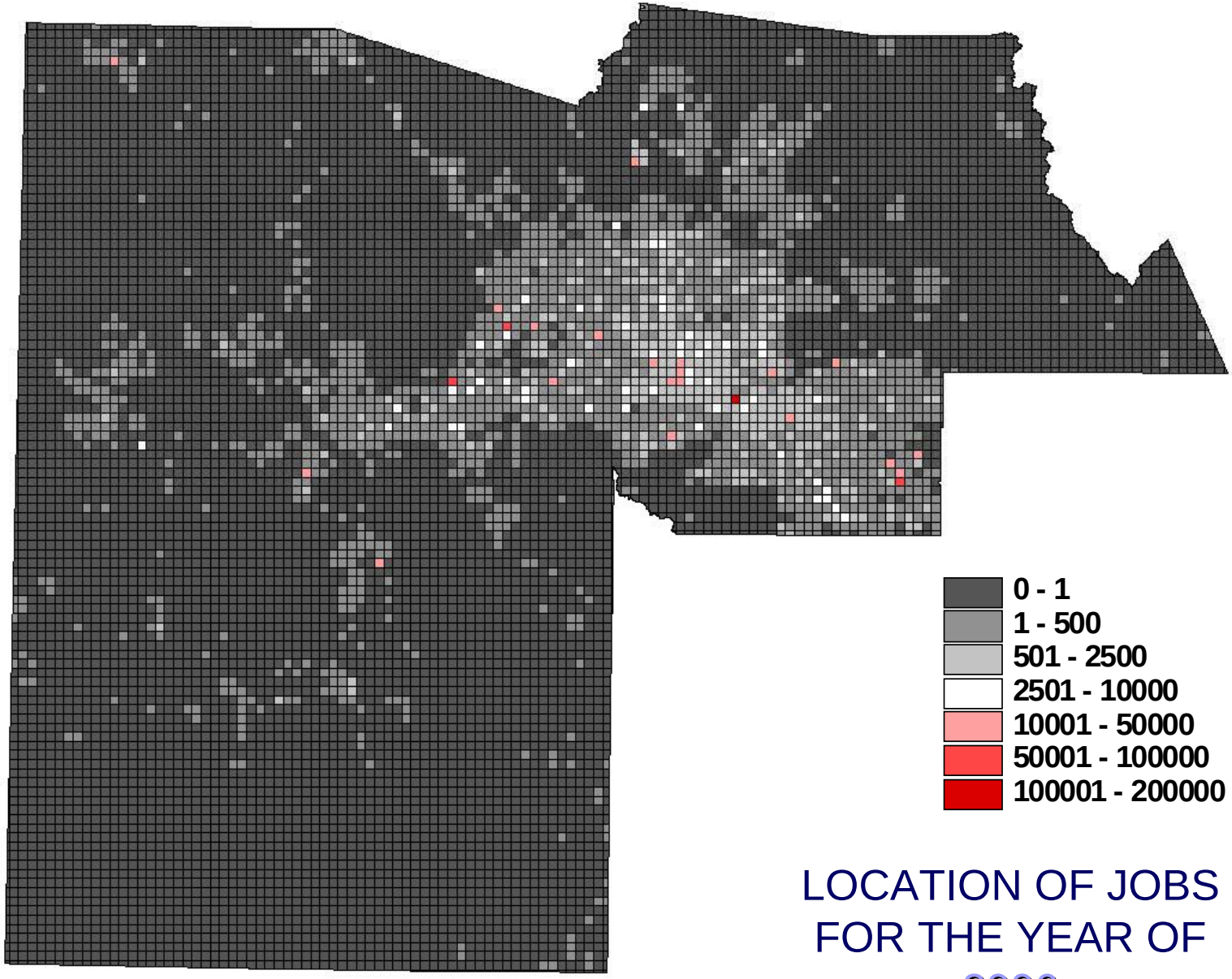
LOCATION OF JOBS
FOR THE YEAR OF
2003



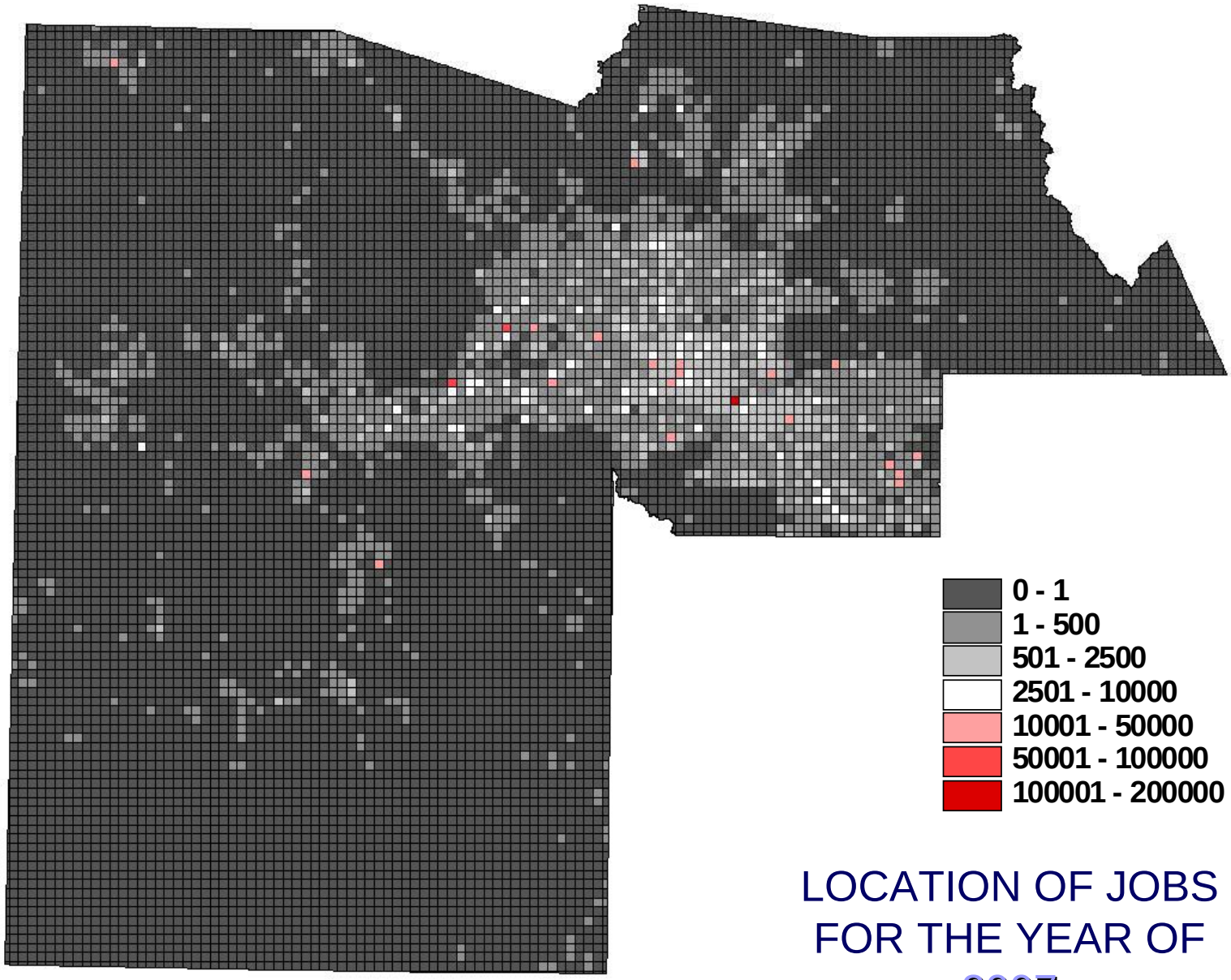
LOCATION OF JOBS
FOR THE YEAR OF
2004



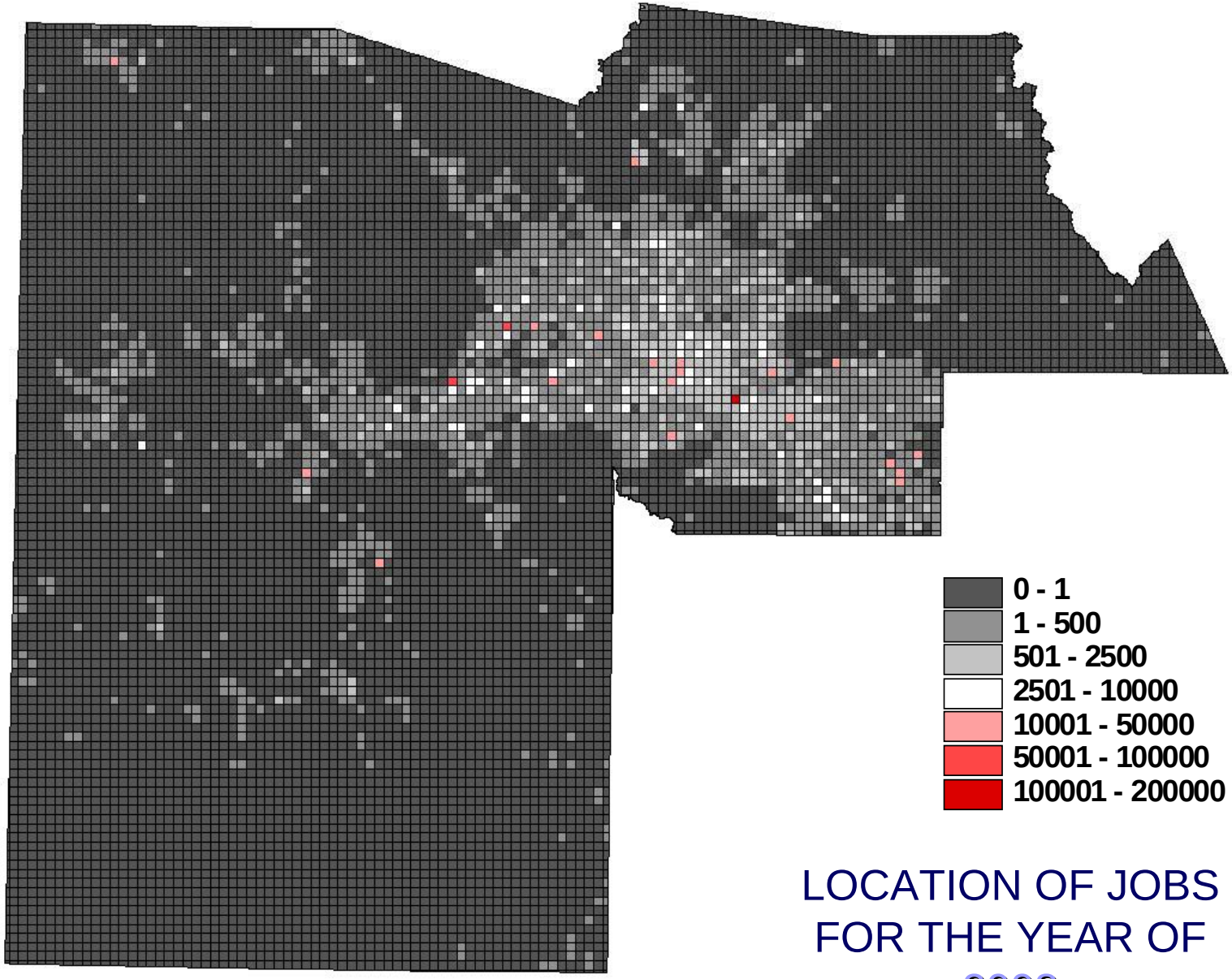
LOCATION OF JOBS
FOR THE YEAR OF
2005



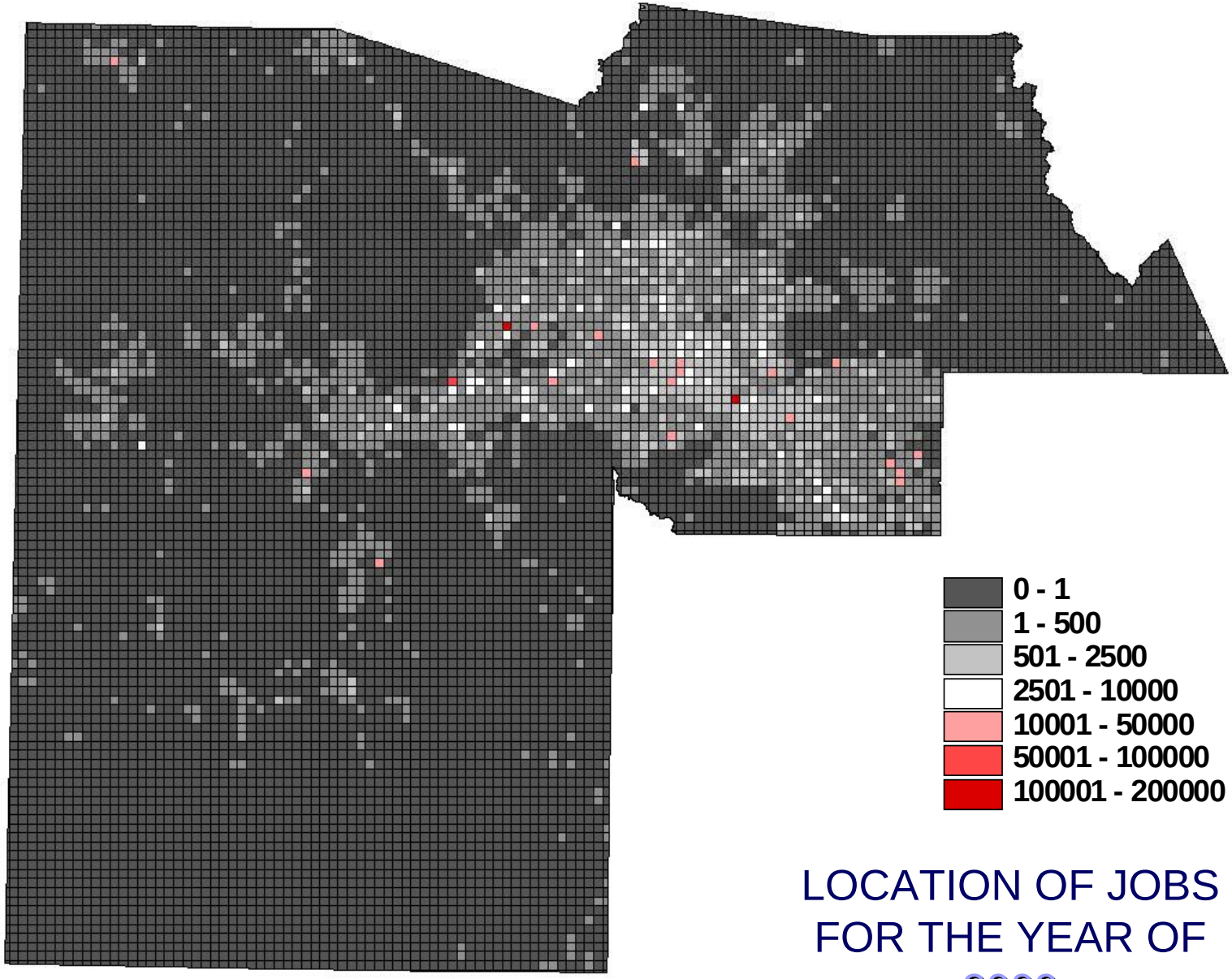
LOCATION OF JOBS
FOR THE YEAR OF
2006



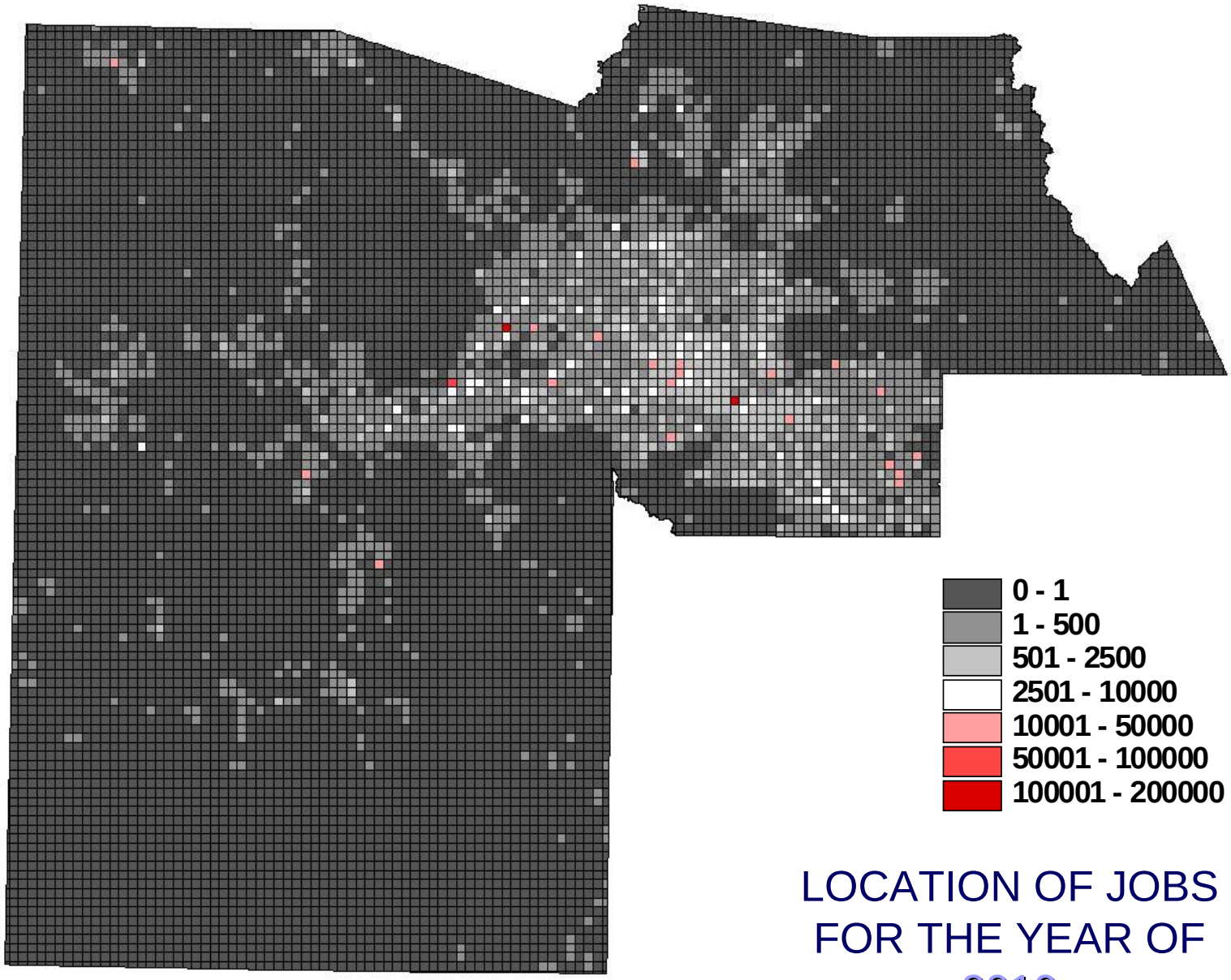
LOCATION OF JOBS
FOR THE YEAR OF
2007



LOCATION OF JOBS
FOR THE YEAR OF
2008

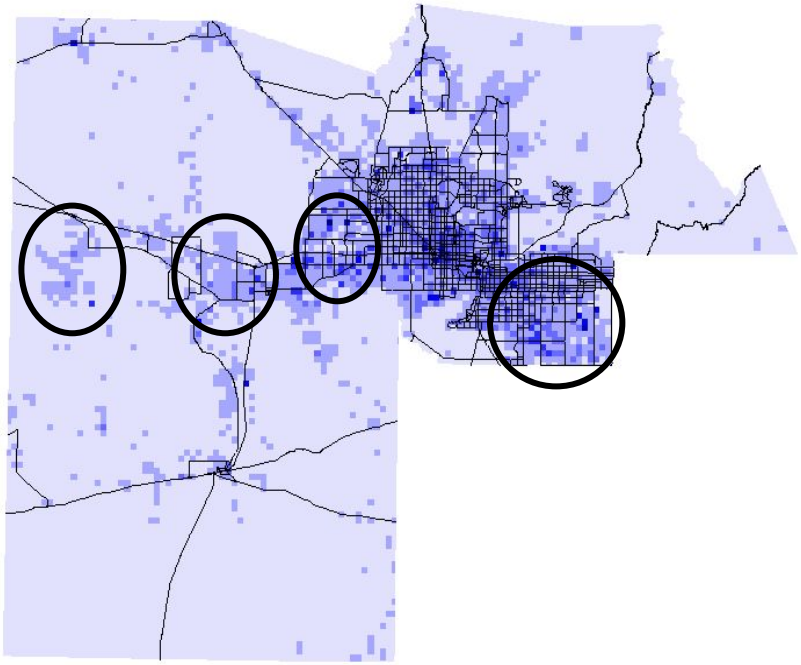


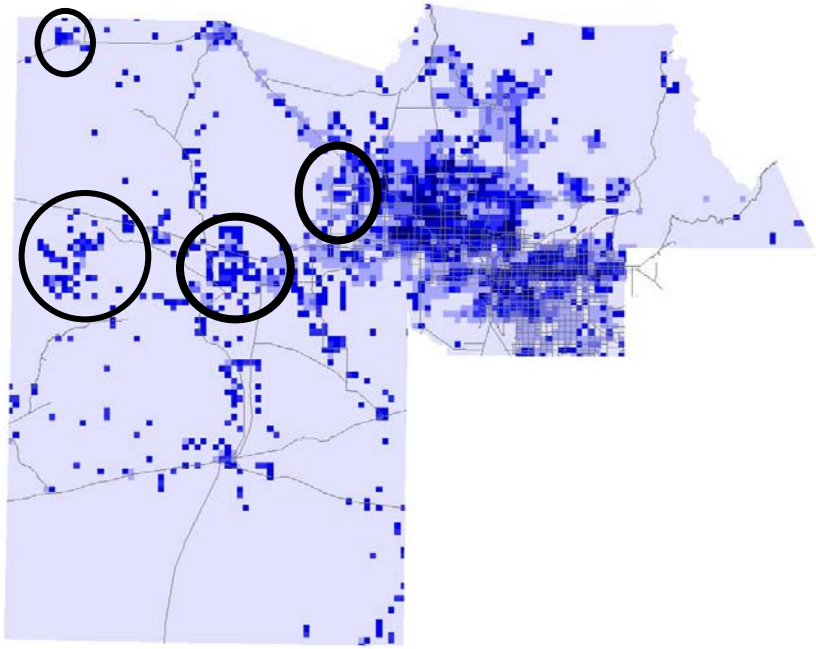
LOCATION OF JOBS
FOR THE YEAR OF
2009



LOCATION OF JOBS
FOR THE YEAR OF
2010

Spatial expanding of households and jobs



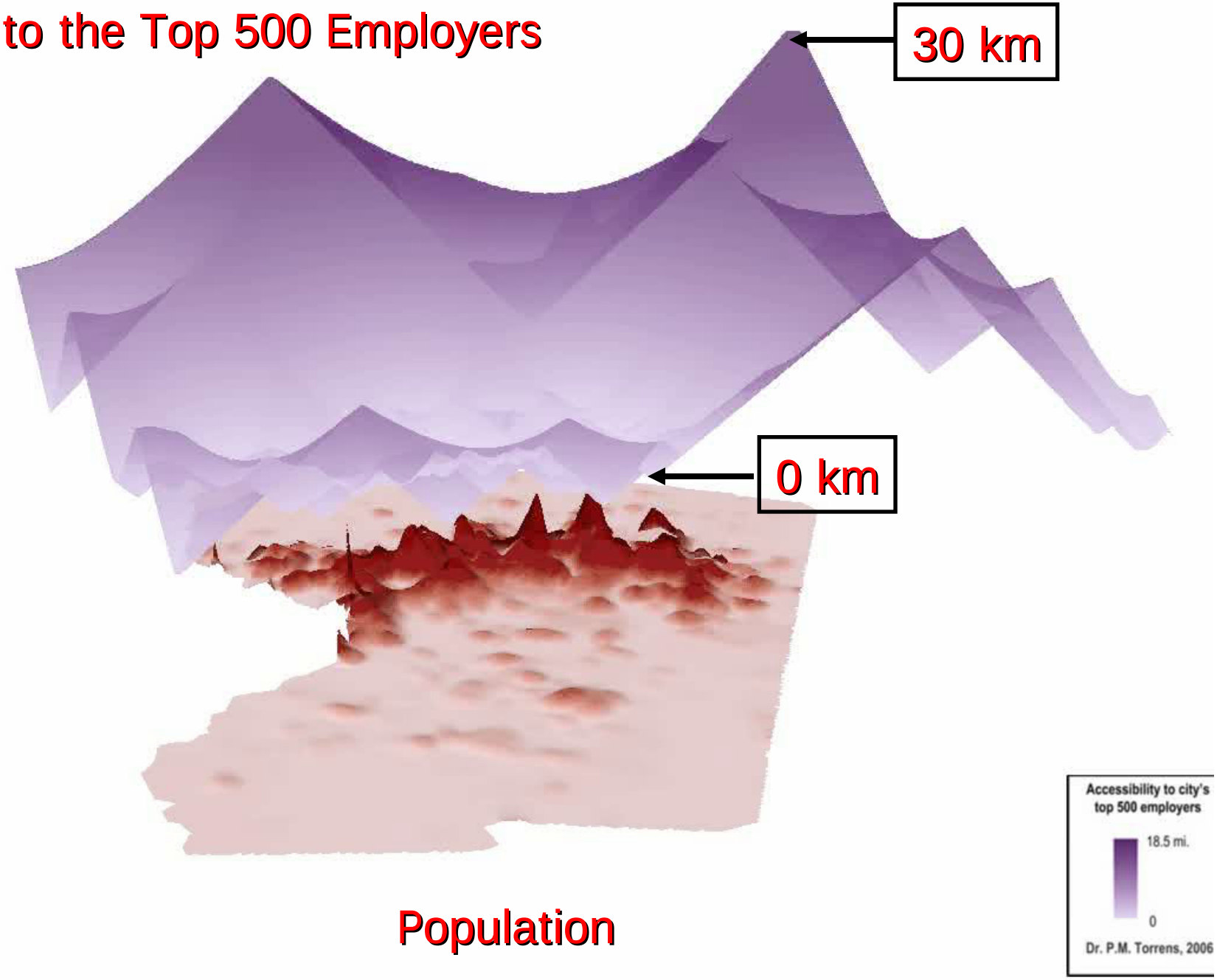


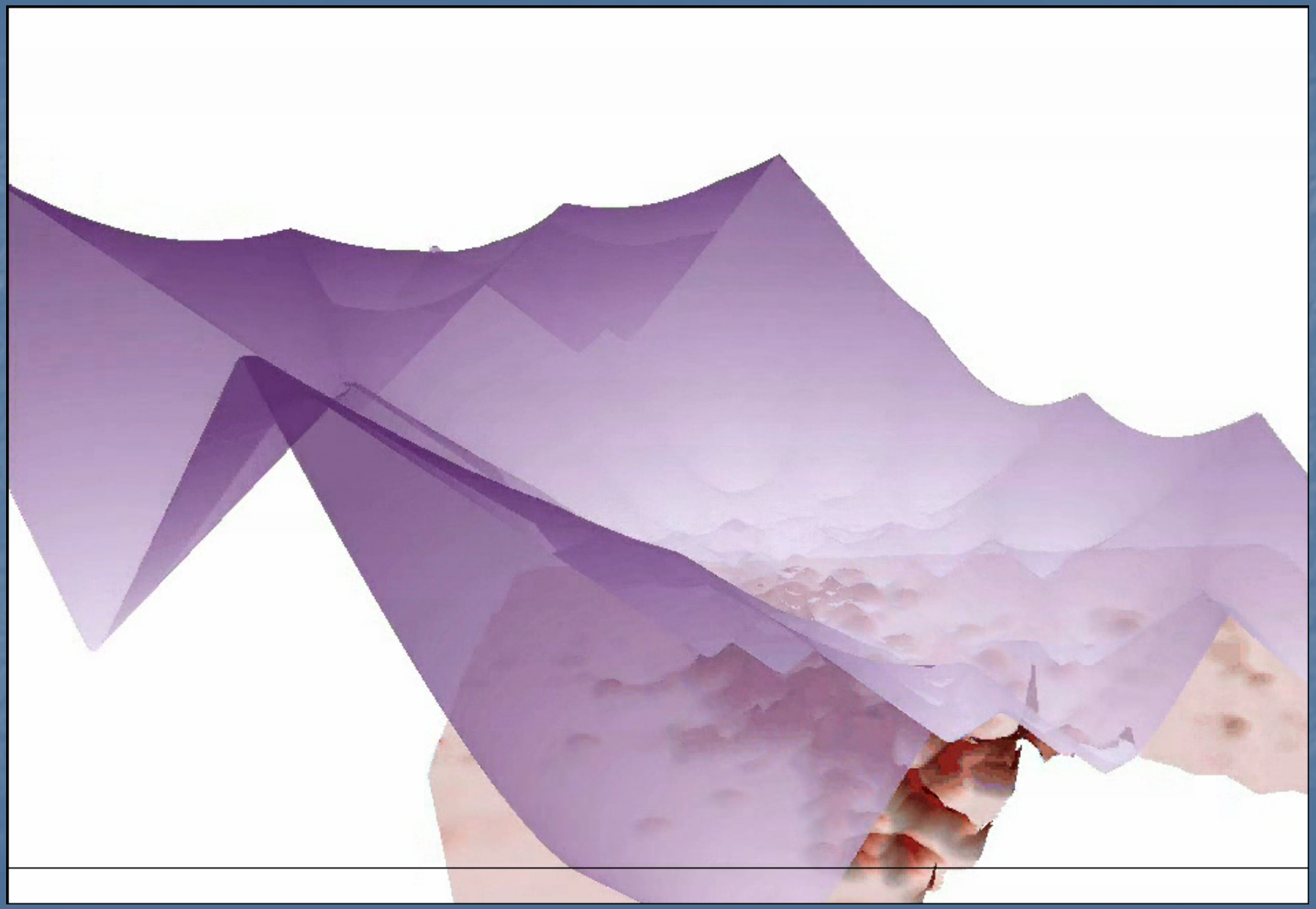
Distribution of Households in 2015

Distribution of Jobs in 2015

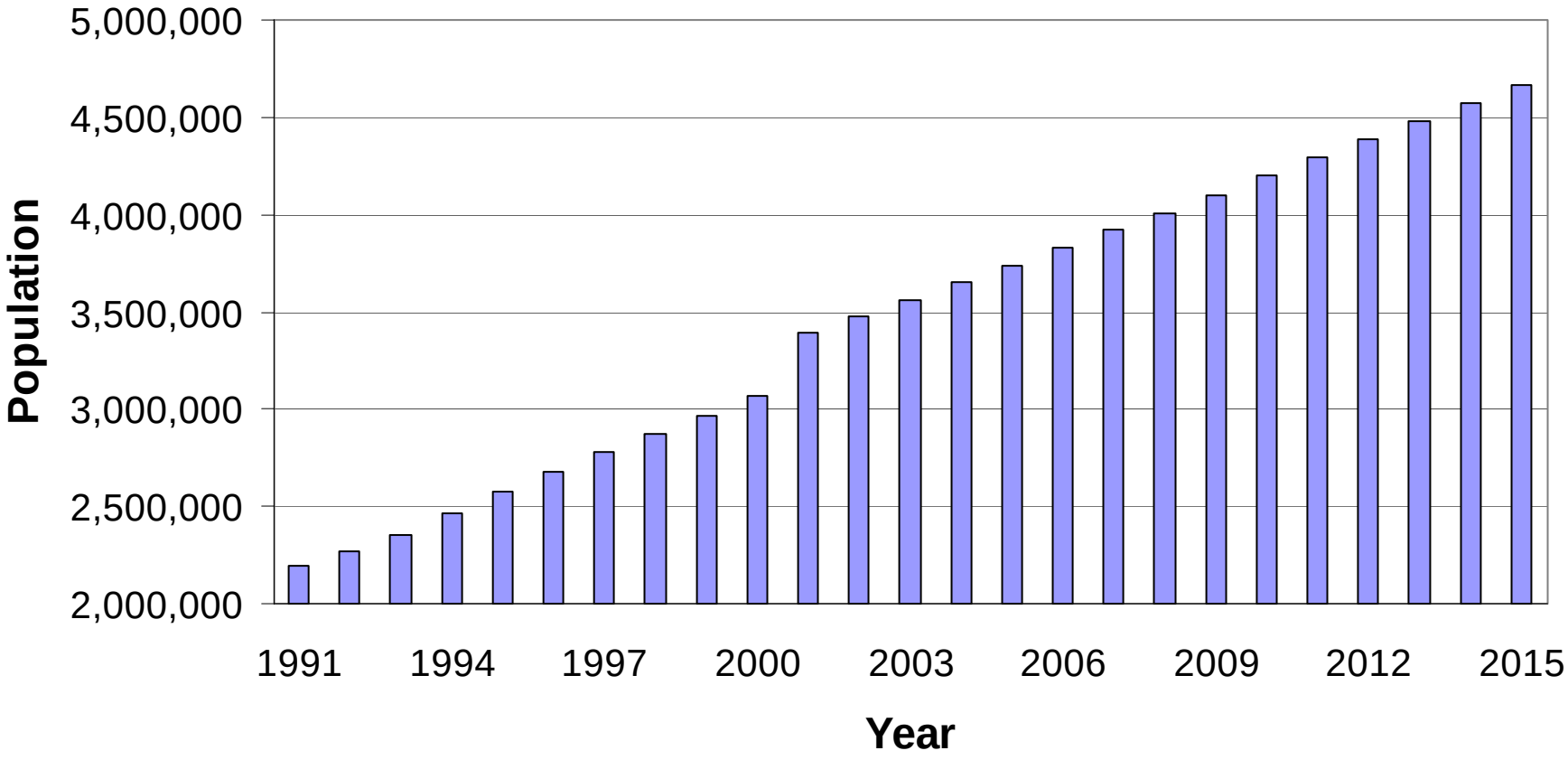
Highlighted are new communities and areas that accommodate households and jobs in 2010 compared to 1990. The projection has been proved by the observed building activities and job market movements.

Access to the Top 500 Employers

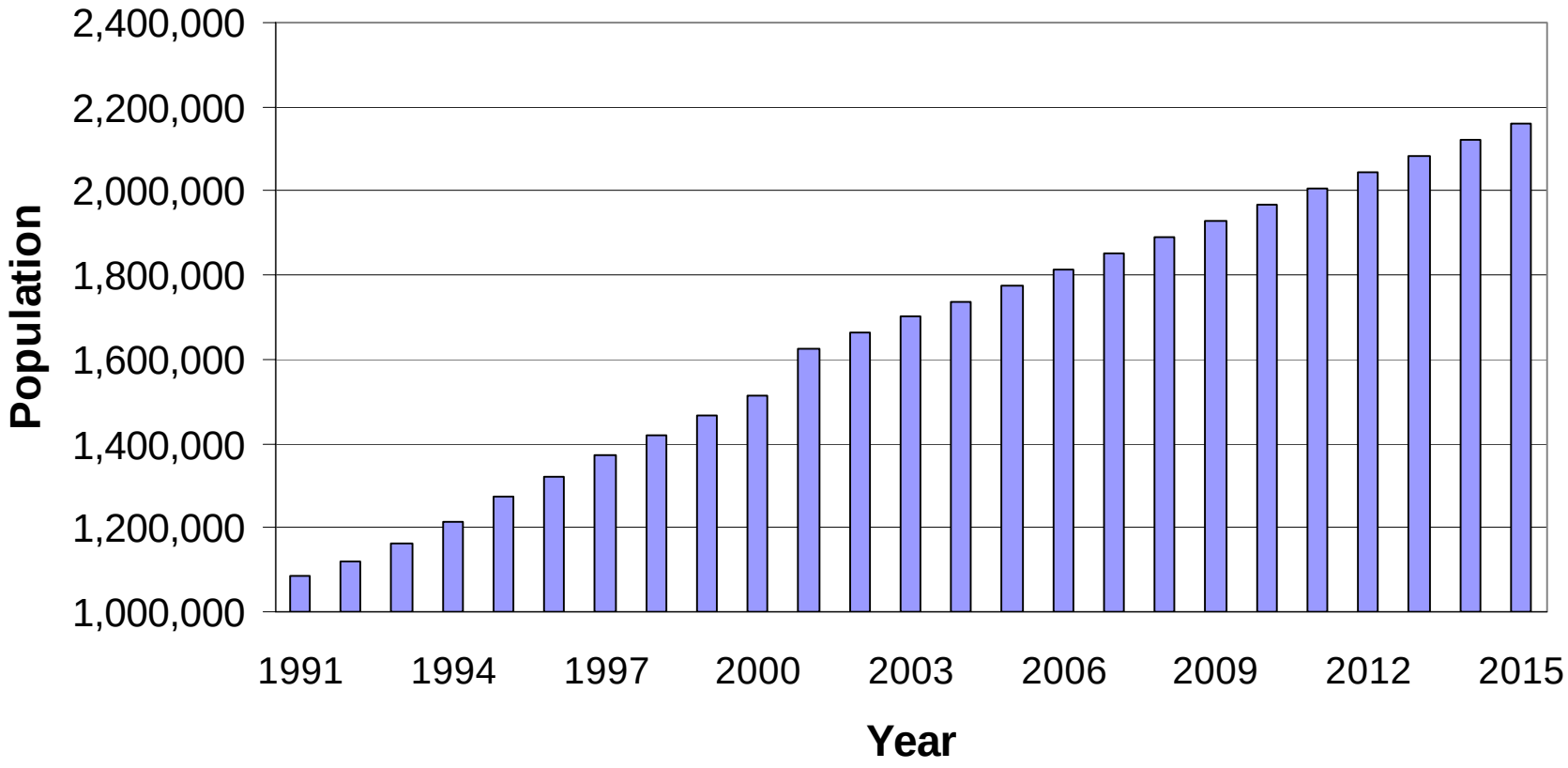




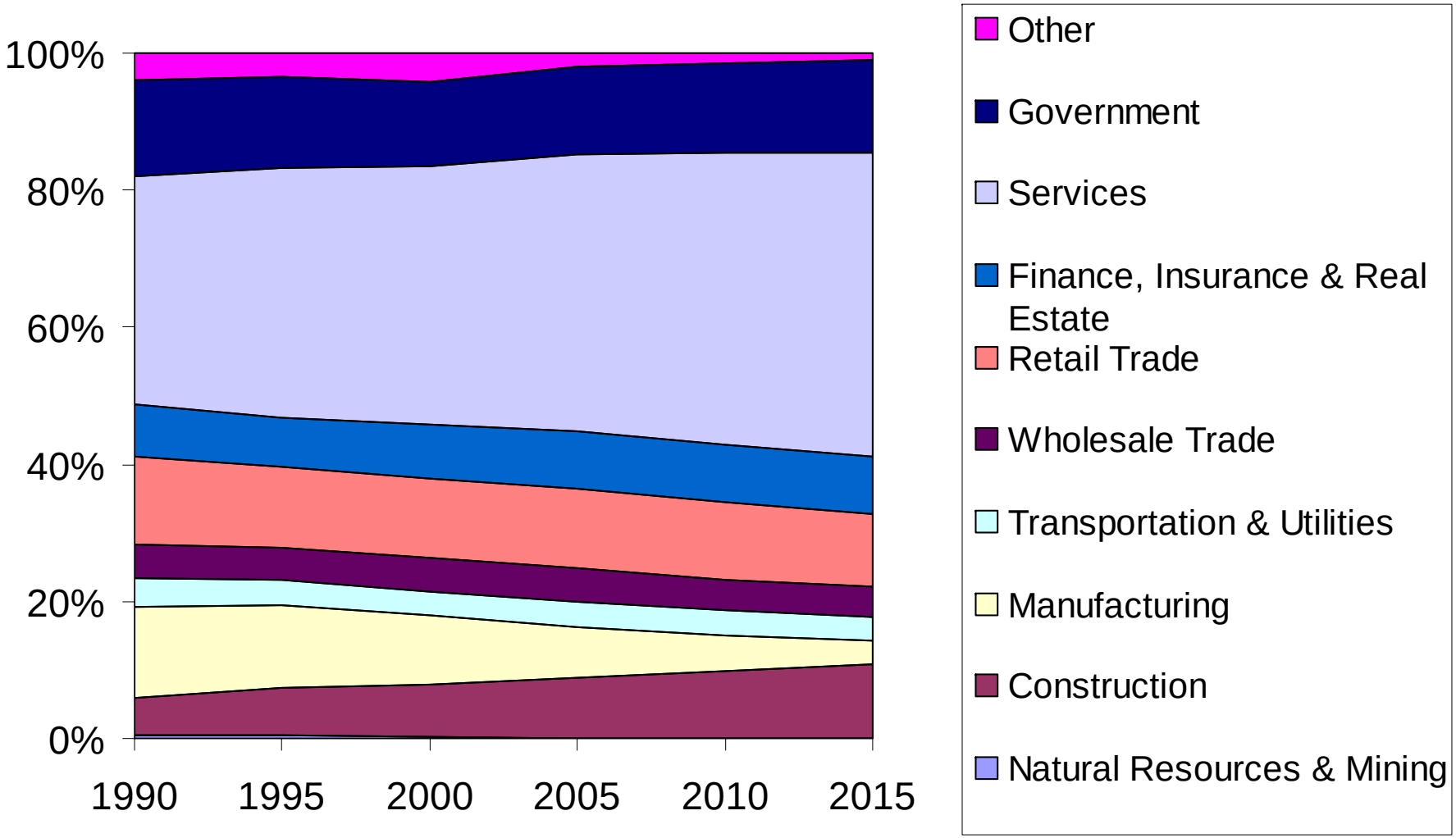
Population Growth
From 1990 to 2015



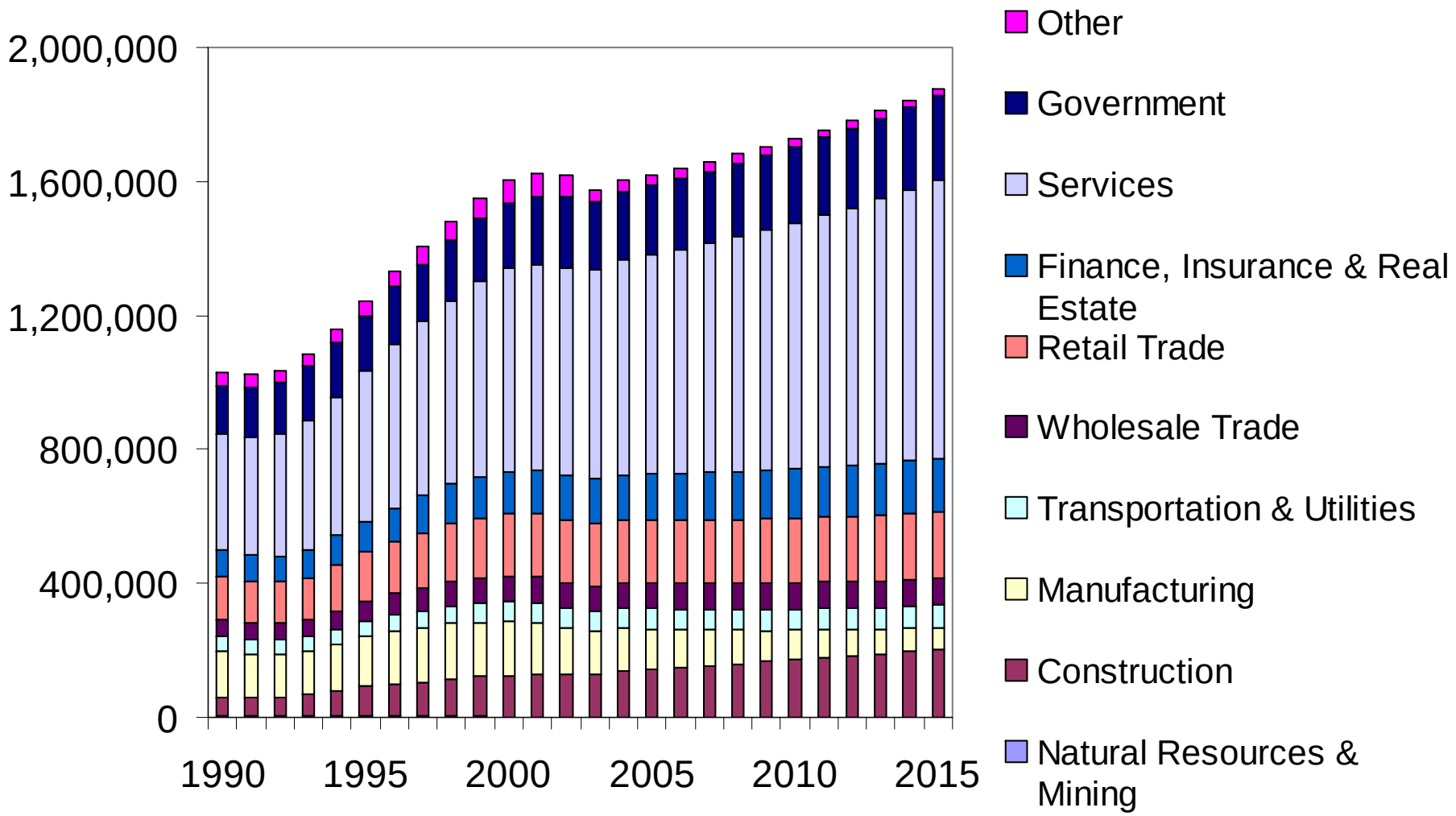
Change of Household From 1990 to 2015



Employment Percentage by Sectors From 1990 to 2015



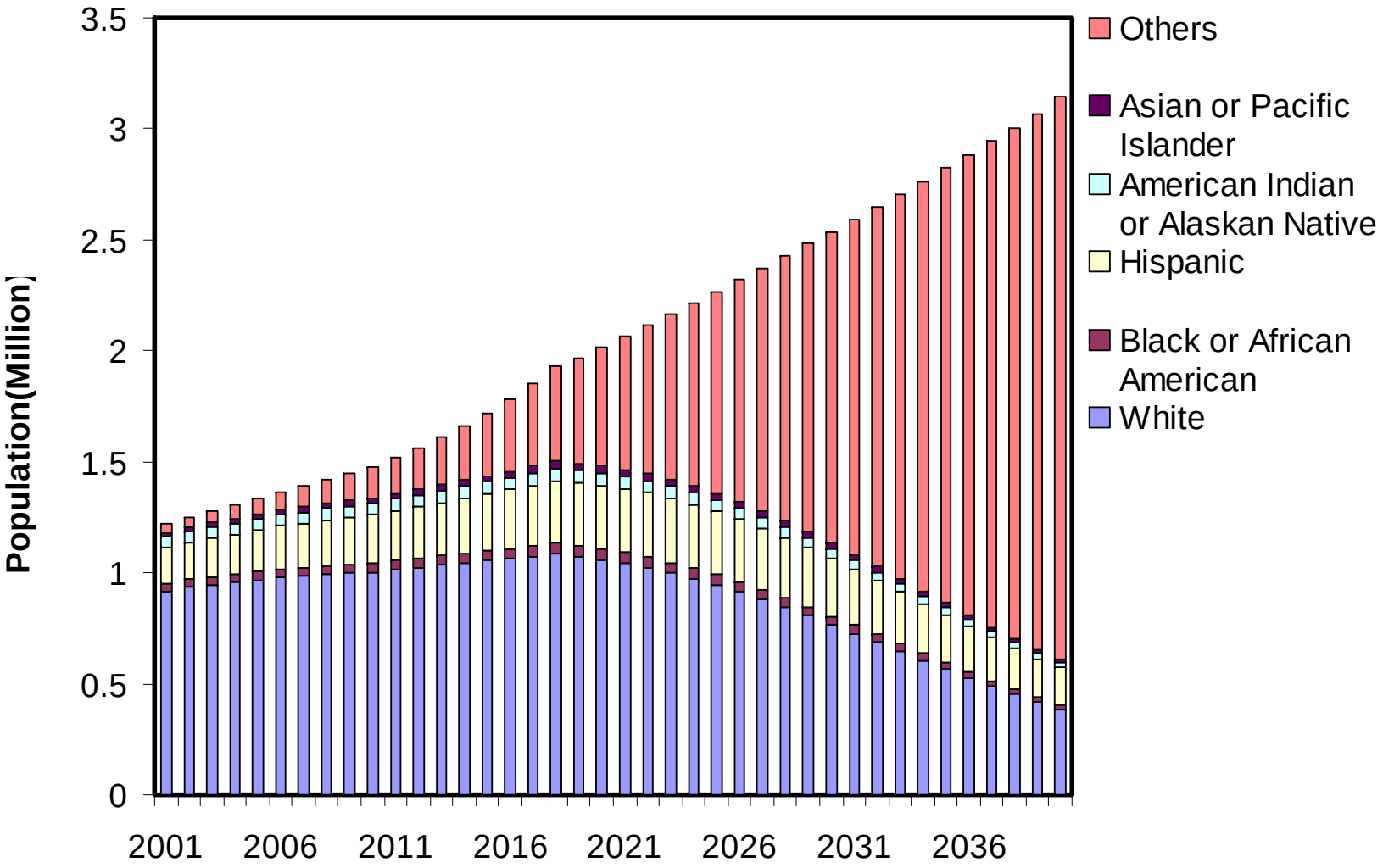
Change of Employment by Sectors From 1990 to 2015



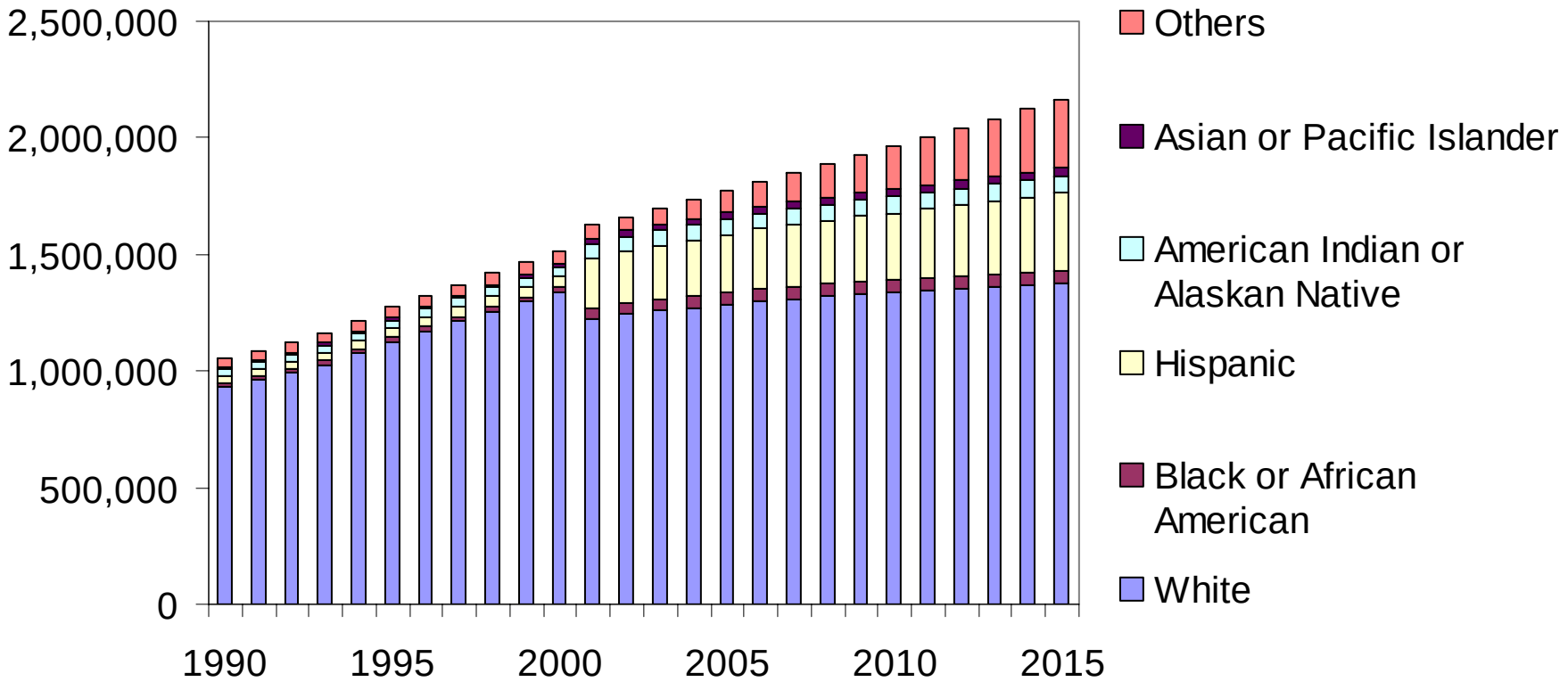
Changing Household Characteristics between 1990 and 2015

Race/ethnicity	Households 2015	Households 1990	Change	% Change
White	1,033,167	701,753	331,414	47%
Black	44,136	11,188	32,948	294%
Hispanic	247,946	24,315	223,631	920%
American Indian/ Alaskan	54,932	21,628	33,304	154%
Asian / Pacific Islander	26,834	6,147	20,687	336%
Other	217,501	28,031	189,470	676%
Total	1,624,516	793,062	831,454	105%

Demographic Profile of Household From 2000 to 2040



Demographic Profile of Household From 1990 to 2015



Land Use Scenarios

- Three General Plan Scenario (slow growth, General Plan growth, fast growth)
- Dispersed Polynucleated City
- Strong Central City
- Resort Mecca
- Transportation Influenced
- General Plan Scenarios, buildout population constant, buildout year varies
- Maricopa County population totals constant, Phoenix totals allowed to vary

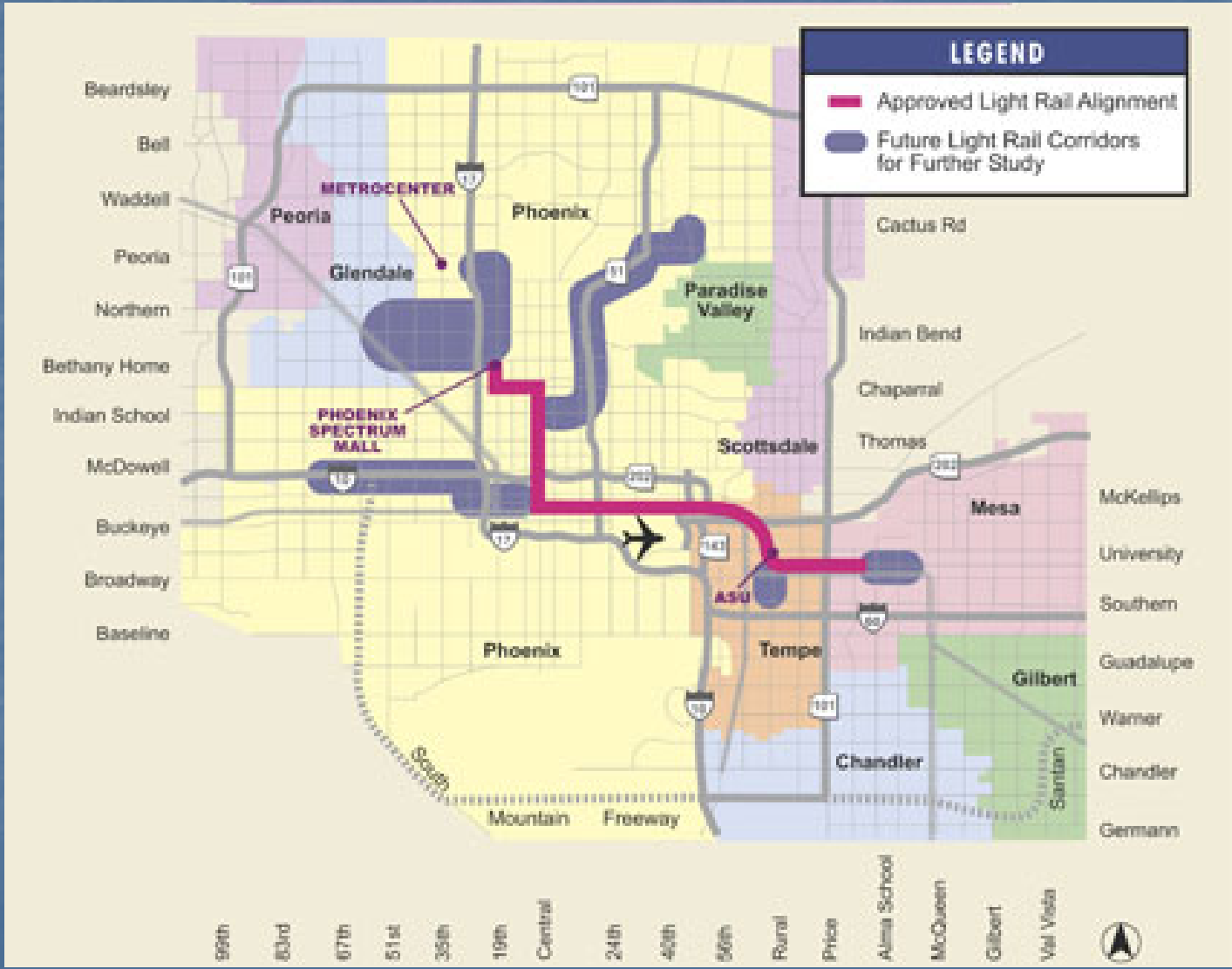
ASSESSMENT OF THE IMPACTS OF THE LIGHT RAIL ON URBAN GROWTH IN THE PHOENIX METROPOLITAN REGION USING URBANSIM

(Guhathakurta, Joshi, Konjevod)

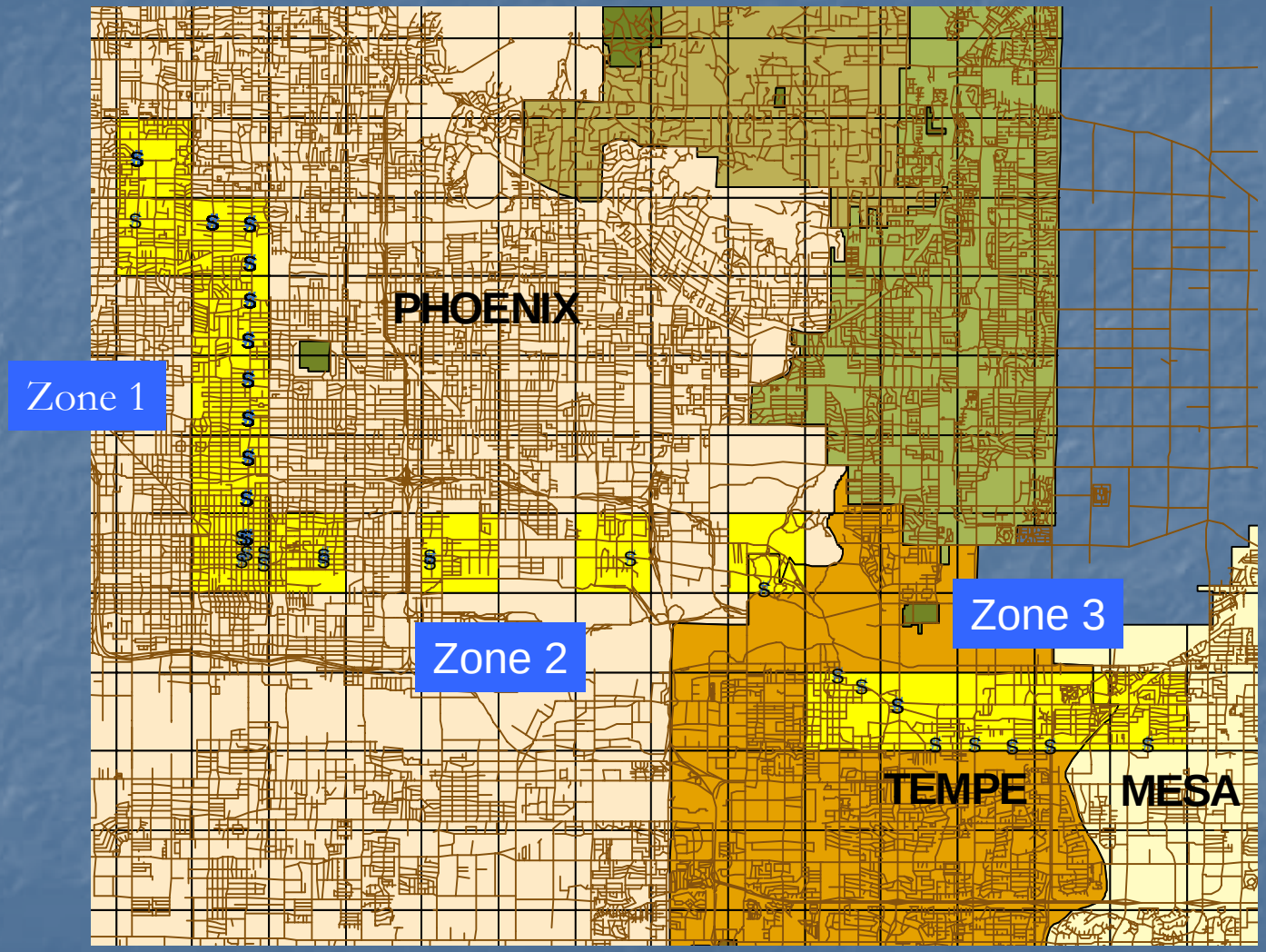
The Central Phoenix / East Valley Light Rail Transit Project

- 32 transit stations, 20.3 miles, within the cities of Phoenix, Tempe, and Mesa
- Connects Phoenix's central business district, the Sky Harbor International Airport, Arizona State University, several community college campuses, and event venues that currently draw about 12 million people each year from the region
- First phase expected to commence operation in 2008

PLANNED LIGHT RAIL CORRIDORS IN PHOENIX METROPOLITAN AREA



Light Rail Stations



Key Findings

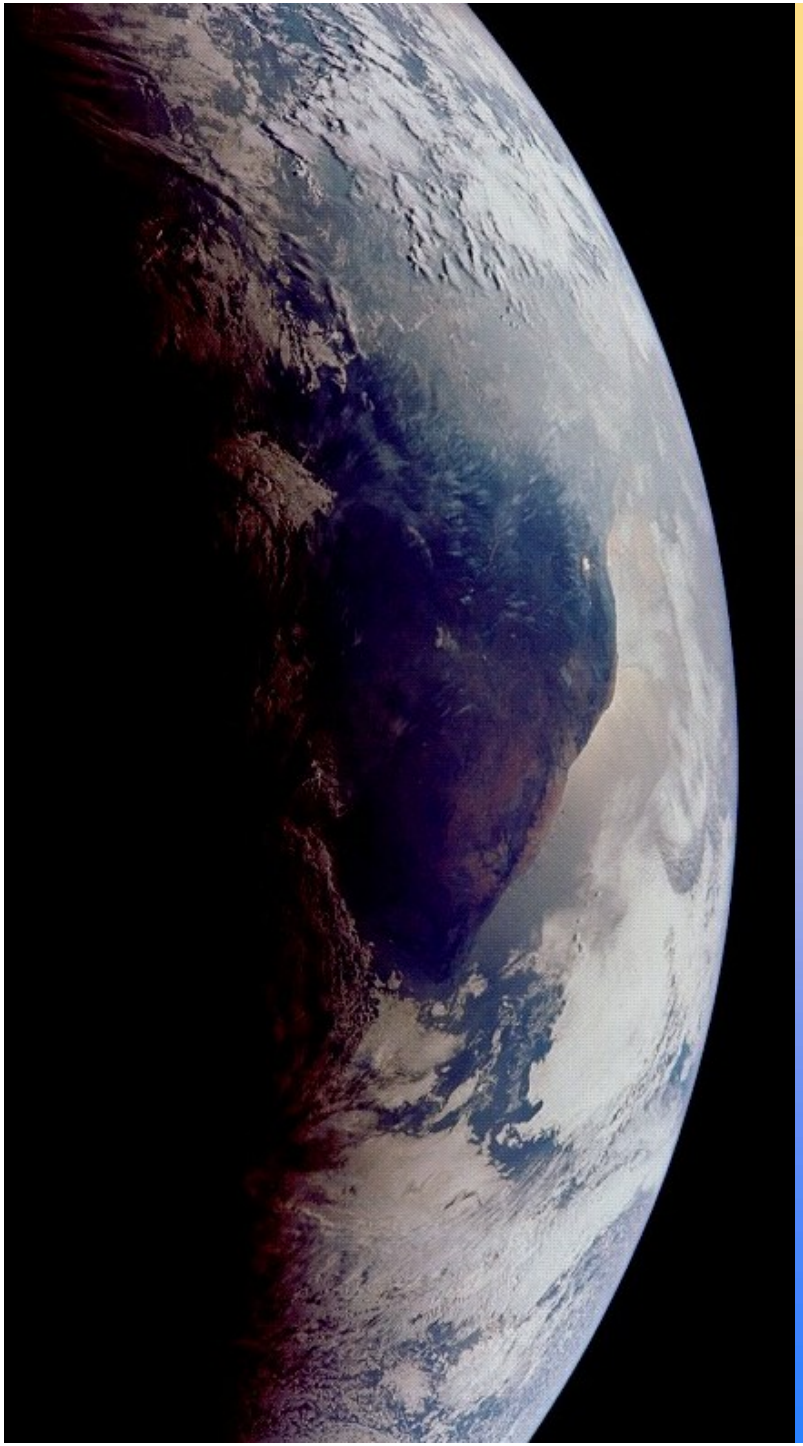
- Scenario with light rail suggests higher household density in the Phoenix region (Zones 1 and 2) while in Tempe (Zone 3) significant fall in density is predicted by the model
- In this scenario the average incomes in Phoenix tends to either decrease or remain the same while the average income in Tempe area tends to increase
- Without Light rail the proportion of white households is decreasing while that of Hispanic and other race households are increasing in all three zones
- With Light Rail, in Phoenix region (zones 1 and 2), trend is unchanged. However, in Tempe (zone 3) the proportion of White households is predicted to increase

Background

- Computer gaming mimicking real life: SimCity, Maxis

Background

- Computer gaming mimicking real life (!) (State of Emergency, Rockstar Games)



Outline

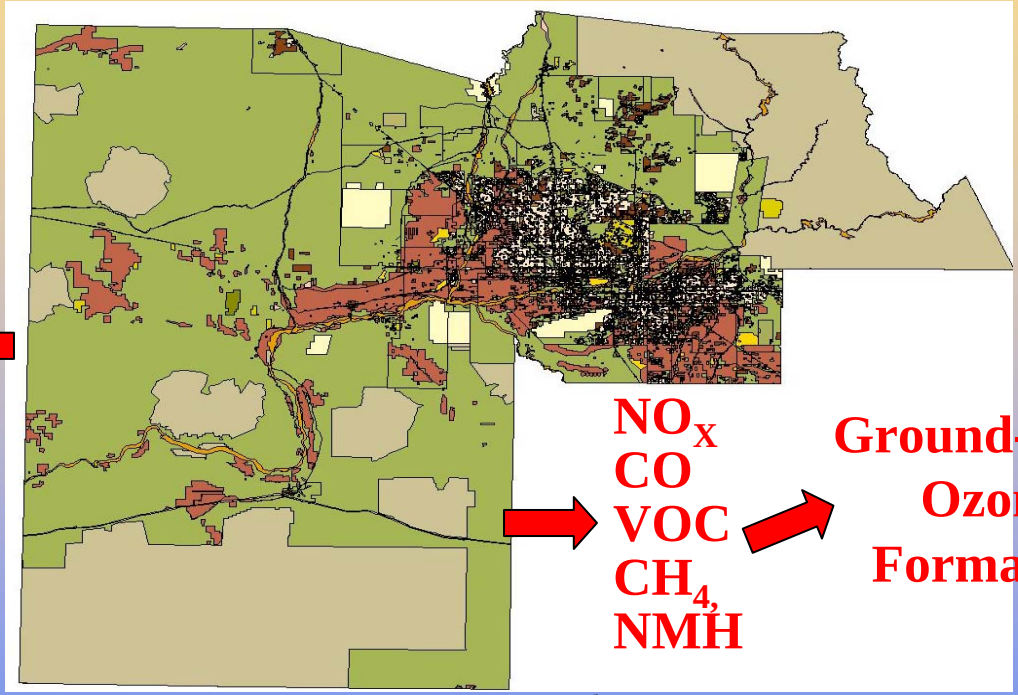
- What is Sustainability ?
- Background and Vision
- Urban Development Simulation
- Material Flow Analysis
- Air Quality and Heat Island Simulations
- Conclusions

Components of Metamodel

Urban Growth Simulation

Material Demands Quantification

- Fine aggregate
- Coarse aggregate
- Wood material
- Limestone
- Sand
- Clay and shale
- Gypsum
- Iron and steel
- Cement
- Aluminium



NO_x
CO
VOC
CH_4,
NMH

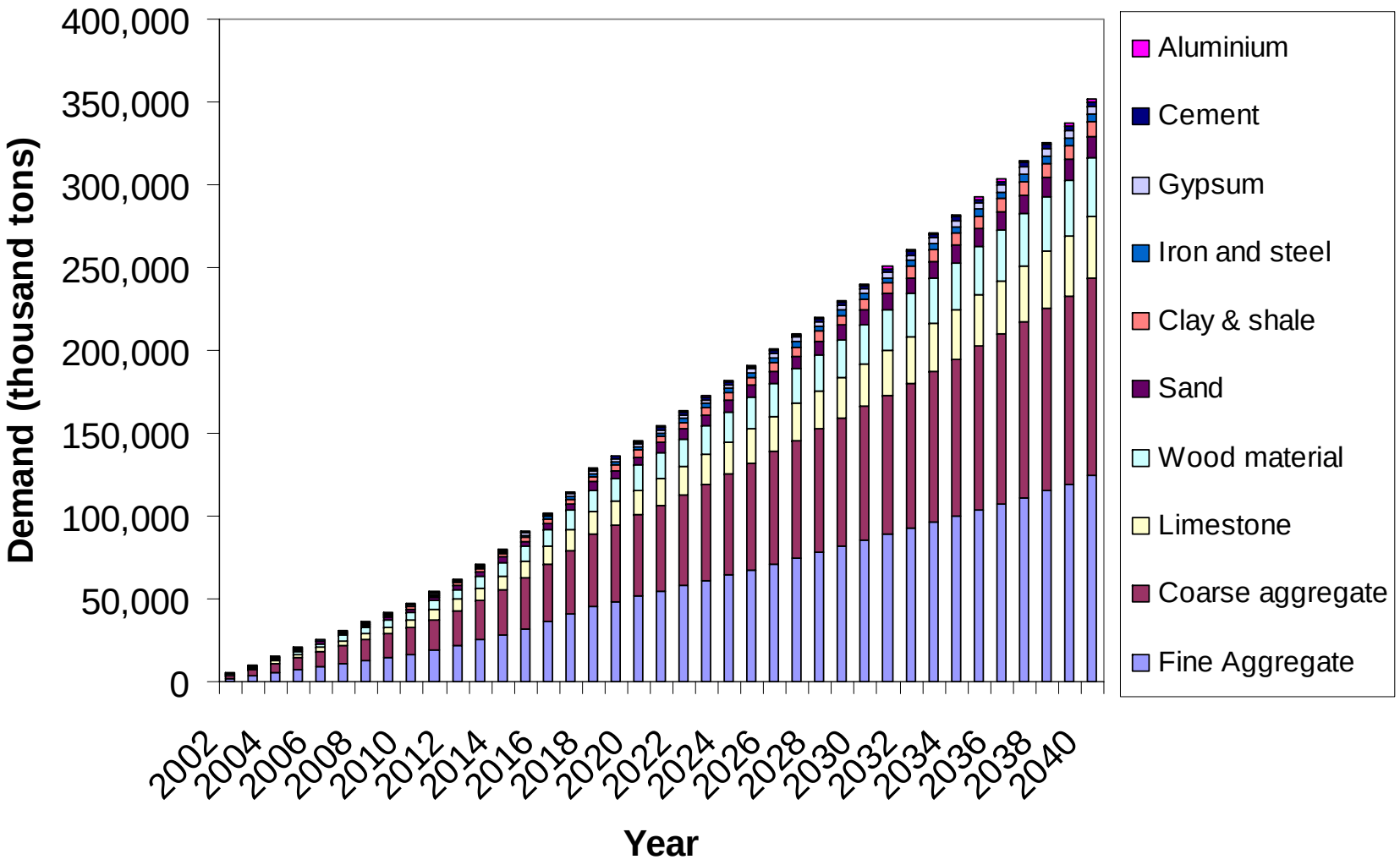
Ground-level Ozone Formation

Environmental Impact Quantification

Construction → Operation & Maintenance → Demolition → Disposal and Reuse → Extraction → Manufacturing → Transportation → Construction

Life-Cycle Analysis

Cumulative Residential Construction Material Demands From 2002 to 2040

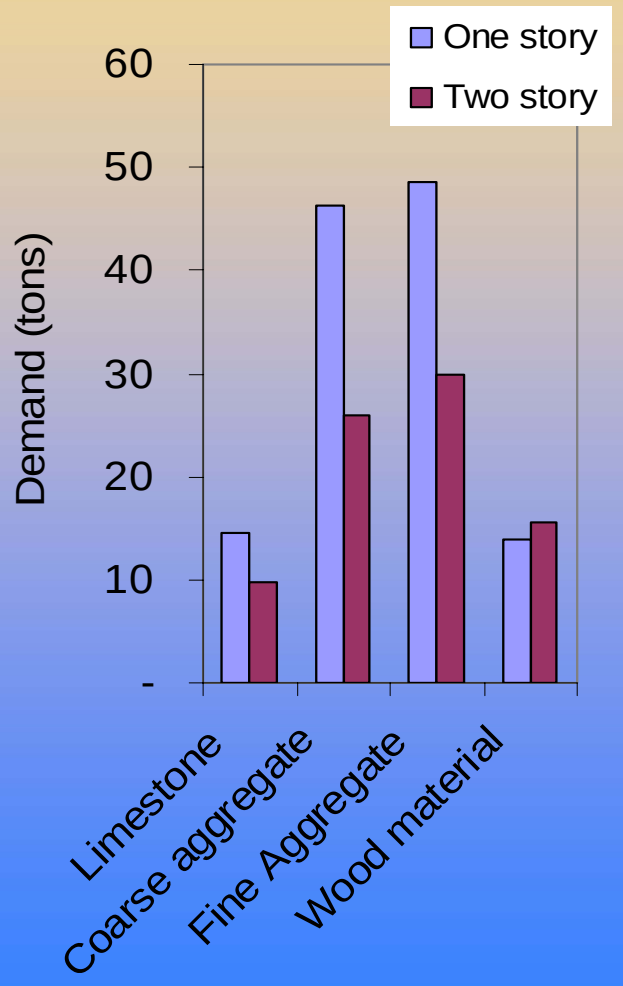


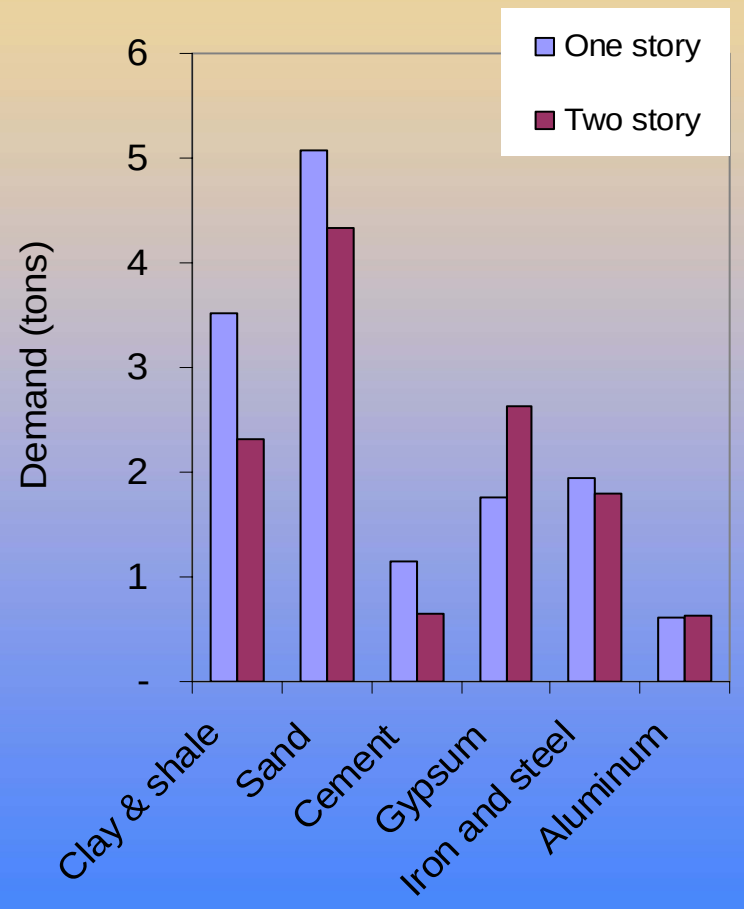
Material Flow Analysis Single Home Housing Type

Two out of the 16 house designs were choose to do the preliminary material flow analysis. Both designs are of median square footage for Phoenix houses in 2003 and have stucco exteriors with concrete tile roofs, and post tension foundations.

House Plane Model Story	Number of Bedrooms	Baths	Total Concrete Sq. Ft.	Lumber BD FT	Total Livable SF
1	4	2	2989	13464	2142
2	4	2 1/2	1541	10162	2220

Construction material demands
one-story vs. two-story house





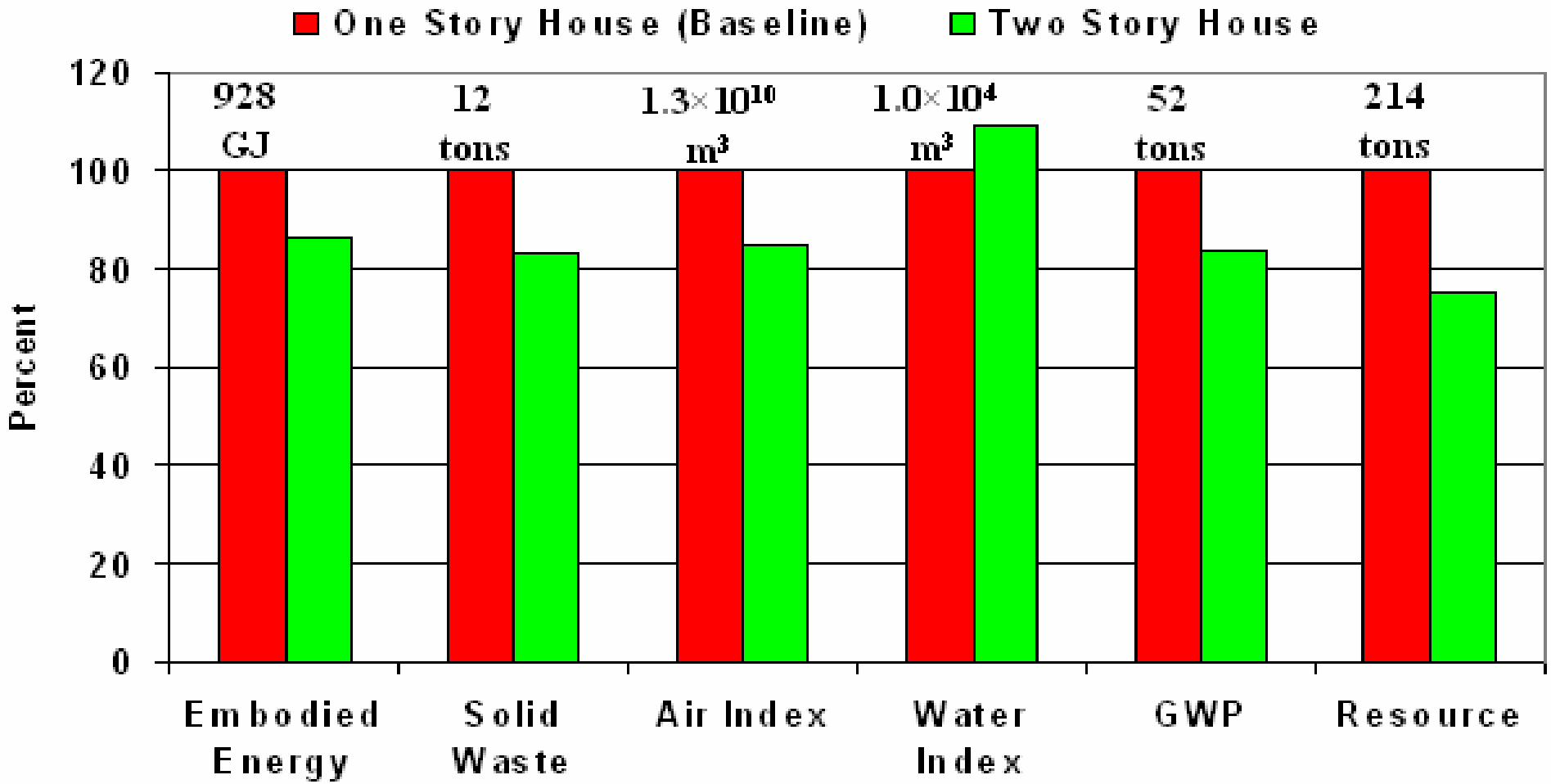
Construction Material Demands for the Residence Development

- Compared with the one-story residence scenario, the two-story residence scenario saves 44% cement, 41% aggregate, 33% limestone, 34% clay and shale, and 15% sand, but consumes 50% more gypsum and 13% wood.
- Totally, the two-story residence scenario will use 32% less raw construction materials by mass than the one-story residence scenario.

Life-cycle Impacts of Two House Designs

- If the impact from the operational energy consumption is not considered, the life cycle impacts of the two-story house are less than those of one-story house in general. The embodied energy of the two-story house (828 GJ) is 11% less than that of the one-story house (928 GJ), and the two-story house generates 17% less solid waste, 15% less air pollution, and 16% less green house gas emissions. The lower environmental impacts of the two-story house are due to its lower construction material demands.

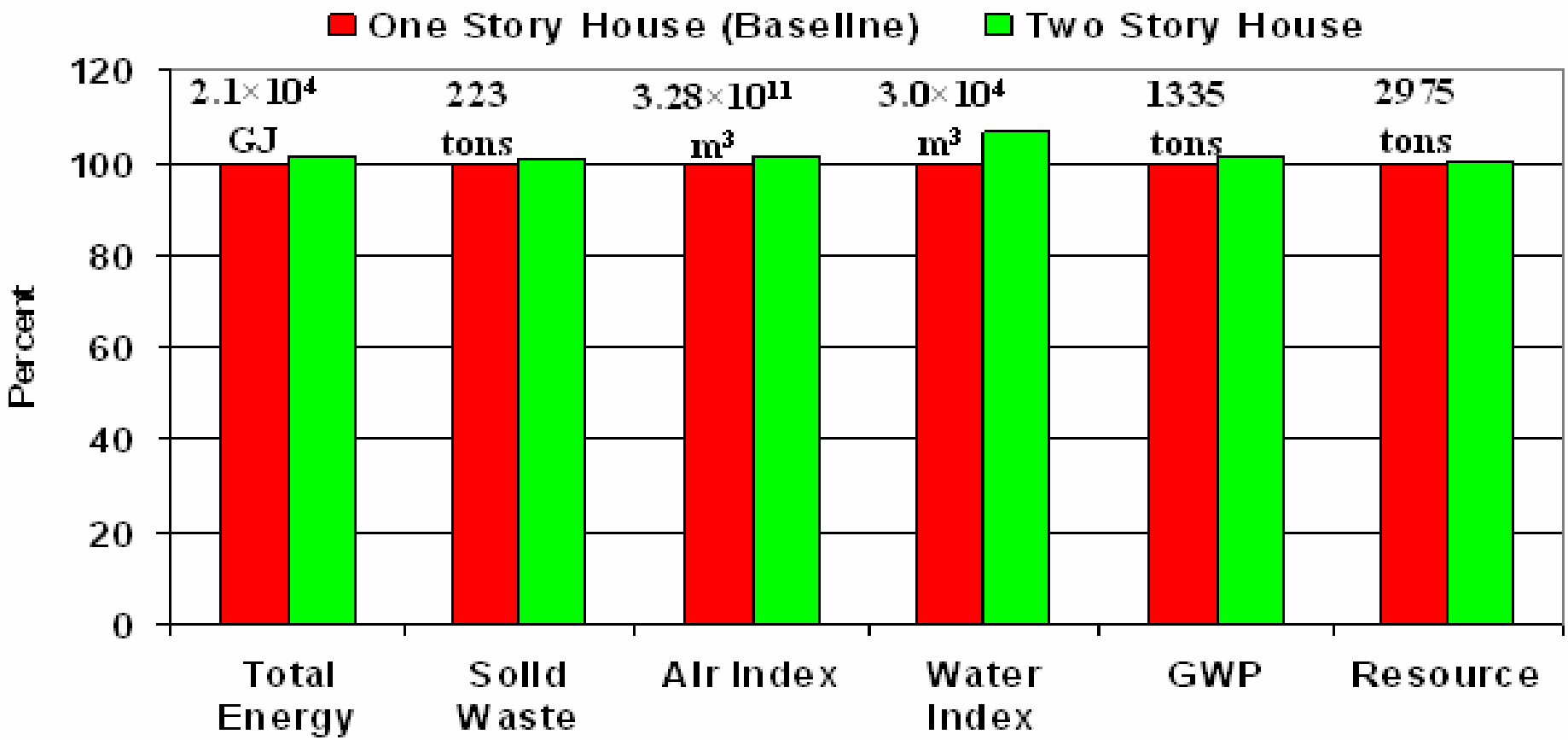
Environmental Effects of One-Story and Two-Story House Designs (without operational energy)



Life-cycle Impacts of Two House Designs

- The annual operational energies estimated by eQUEST are 31,820 kWh for one-story design and 32,450 kWh for two-story design. 2% more operational energy for two-story design results from 3.6% more floor area of two-story design compared with one-story design.
- Based on the annual operational energy and assuming the life span of the residential buildings being 50-year, the life cycle impacts of two house designs are estimated. It was found that the two-story design has a slightly larger life cycle impacts than the one-story design.

Life-Cycle Impacts of Two Building Designs (With Operational Energy)



Example Home Framing Scenarios

(Sawhney, Crittenden, Li, Winter, Abedrabbo)

Wall Systems

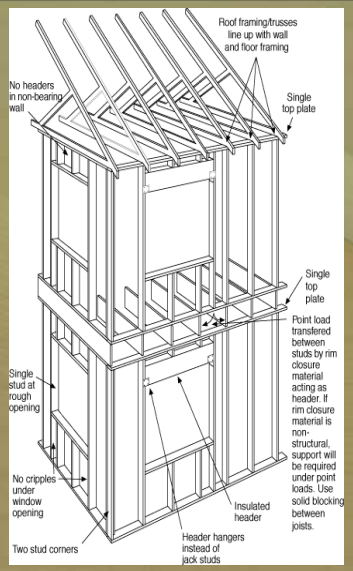
- Traditional Wood Framing
- Wood Stud framing using Advanced Framing Technology
- Engineered Wood Stud Framing
- Structural Insulated Panel Wall (SIPS)
- Combination Steel/Wood Framing
- Light Gauge Steel Framing
- Light Gauge Steel Framing with Foam Insulation
- Concrete Tilt-up Wall
- Structural Concrete Block with Foam Insulation
- Insulated Concrete Form Wall (ICFS)
- Autoclaved Aerated Concrete Wall

Traditional Wood Framing

- 2” X 6” dimensional stud lumber
- 16” on center vertical stud placement
- Benefit - current standard for residential construction

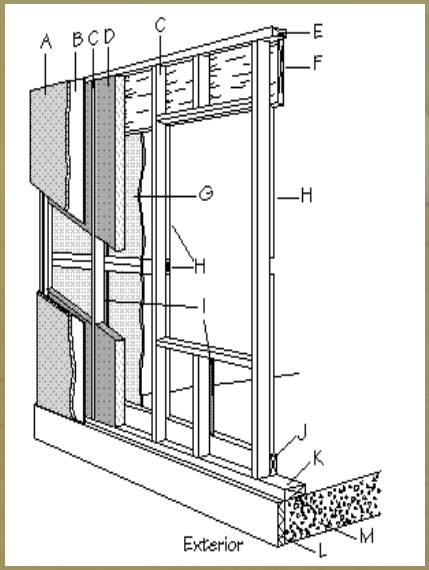
Advanced Wood Framing Technology

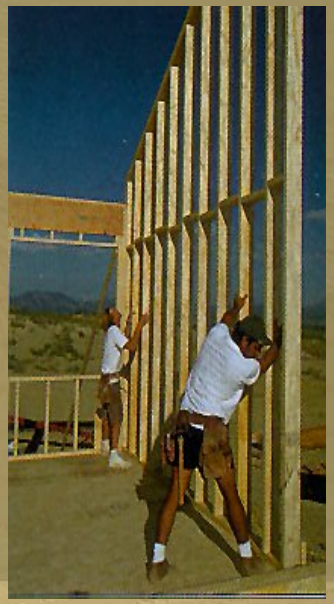
- Constructed of 2” x 6” Lumber, 24” on centers
- Optimum Value Engineering (OVE) reduces amount of lumber required
- Benefits: Less Lumber used



Engineered Wood Stud Framing

- Made of Engineered Wood 2” x 6” – 24” on centers
- Engineered Wood is made from ground up small trees and reassembled into panels and beams
- Polyethylene Insulation
- Benefits: Engineered wood is stronger than traditional lumber and has less defects (warping, splits, knots), it also generates less waste



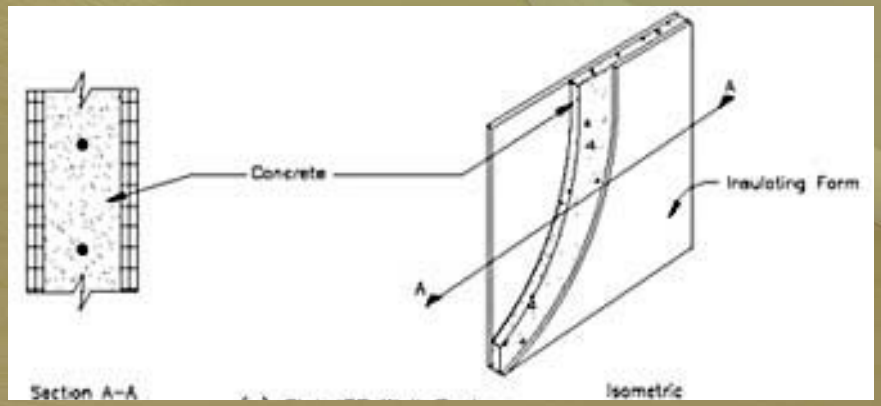


Light Gauge Steel Framing

- Produced in thicknesses of 14 to 24 gauge
- Shapes: C – shape stud and U-shaped track.
- One to one substitution for wood framing members.
- Can be used for both non-load bearing and load-bearing applications.
- Benefits – 28% recycled material; construction waste 100% recyclable; resistant to corrosion, warping, fire and termites; can be order to length; weighs two-thirds less than conventional materials.

Insulated Concrete Form Wall

- Made of Rigid Plastic Forms (polystyrene) that are filled with reinforced concrete
- Plastic forms serve as insulation
- Benefits: Useful for foundation walls, strong, and energy efficient, lower labor costs

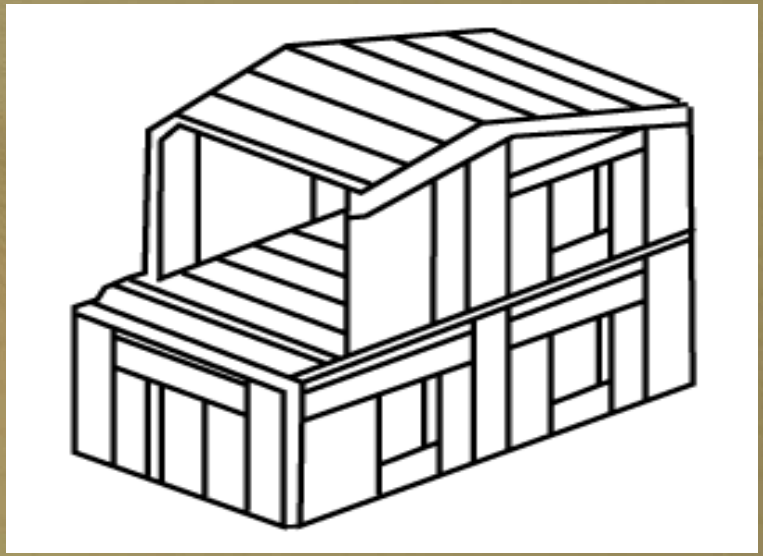


Tilt Up Concrete

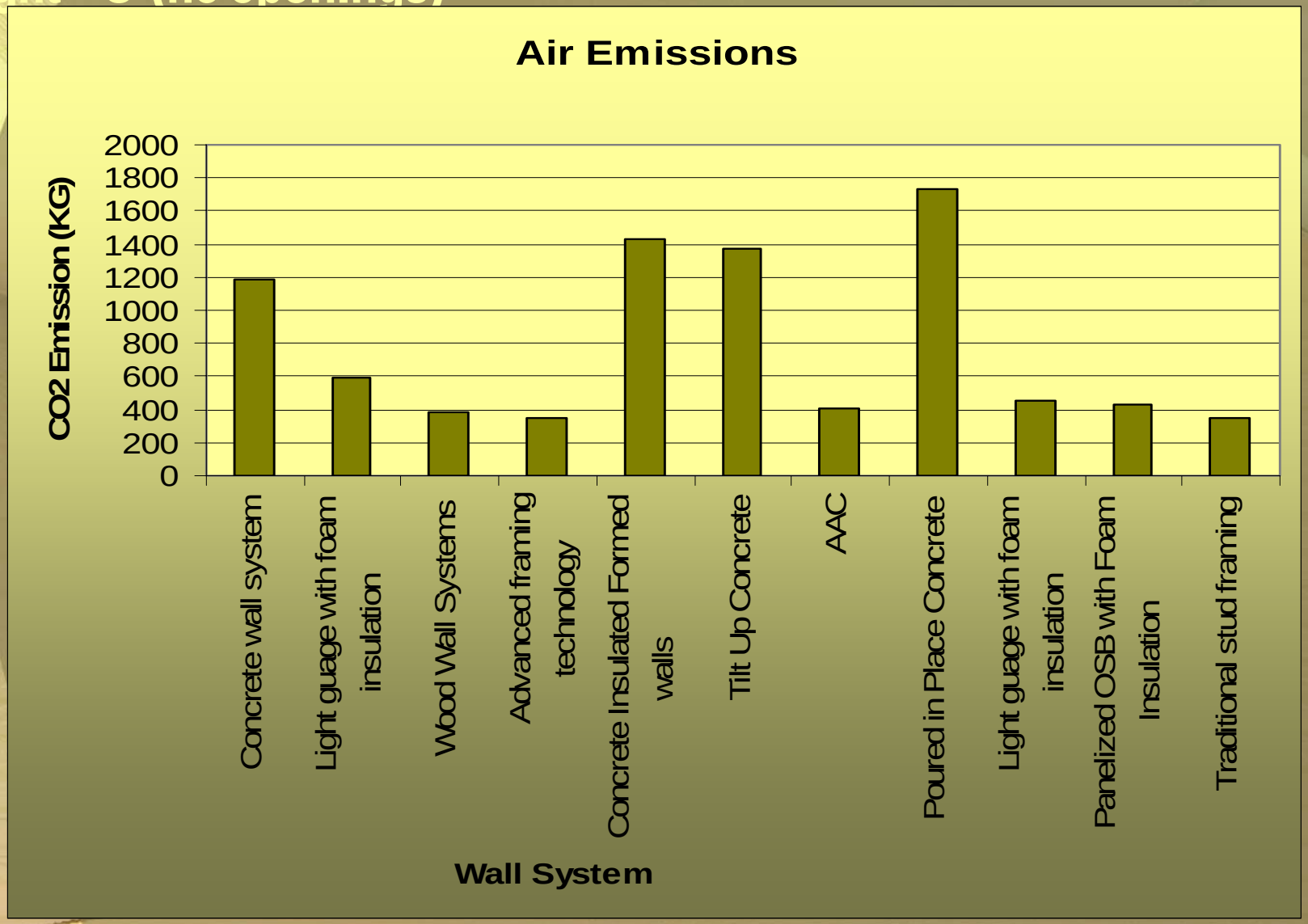
- Concrete walls cast in place.
- Easily adaptable
- Benefits: low cost, speedy construction time

Autoclaved Aerated Concrete

- Porous closed cell masonry material
- One-third the weight of stone concrete
- Benefits: Fire resistant, moisture resistant, speed of construction



Air Emissions - Primary Design of Wall:
Length – 20'
Height – 8' (no openings)



Paving Description #1

- Pavement
  - Two lane one mile section of roadway
    - 25 feet by 1 mile
  - No curbing/sidewalks included
  - Material
    - 1” Bituminous concrete wearing course
    - 2” Bituminous concrete binding course
    - 6” Subbase course
    - Compacted subgrade

(Sawhney, Crittenden, Li, Winter, Abedrabbo)

Paving Material Quantity #1

Material	Depth (in)	Width (ft)	Length (mile)	Material Required
Granual Subbase (aggregate)	6	25	1	4888.89[1] Tons
Base (concrete)	2	25	1	814.82[2] Cubic
Pavement (hot mix)	1	25	1	825.00[3] Tons
Topping (road oil/emulsion)		25	1	1173.33[4] Gals

[1] Granite Construction Inc. Aggregate Calculator (6" base rock sample with a density of 4000 lbs/cubic yard)
http://www.graniteconstruction.com/construction-materials/aggregate-calculator.cfm

[2] Granite Construction Inc. Concrete Volume Calculator (2")
http://www.graniteconstruction.com/construction-materials/concrete-calculator.cfm

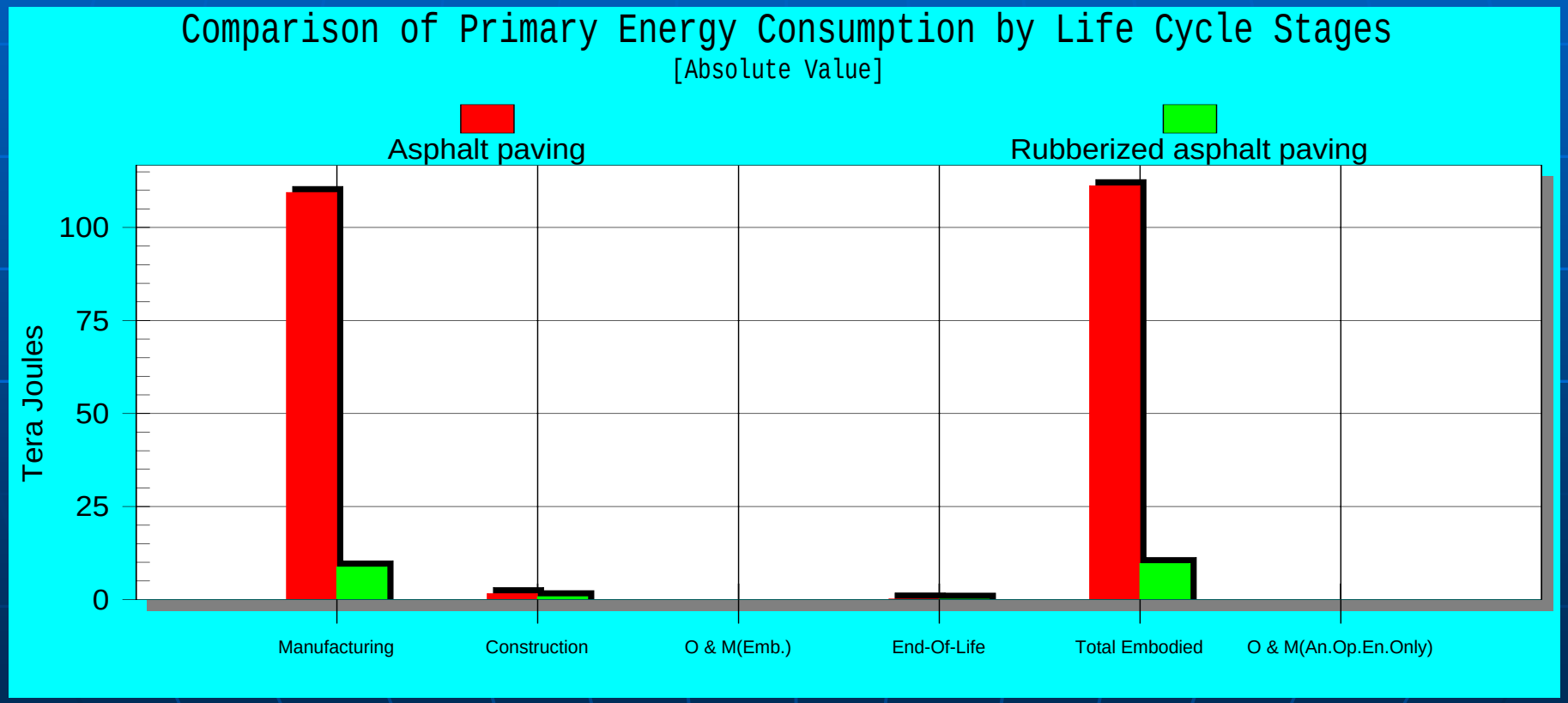
[3] Granite Construction Inc. Hot Mix Calculator (1")
http://www.graniteconstruction.com/construction-materials/roadmaterials-calculator.cfm

[4] Granite Construction Inc. Road Oil/Emulsion Calculator (.08 gal/sq yard distribution rate)
http://www.graniteconstruction.com/construction-materials/roadmaterials-calculator.cfm

Energy Consumption

Asphalt roofing vs. Rubberized Asphalt Paving

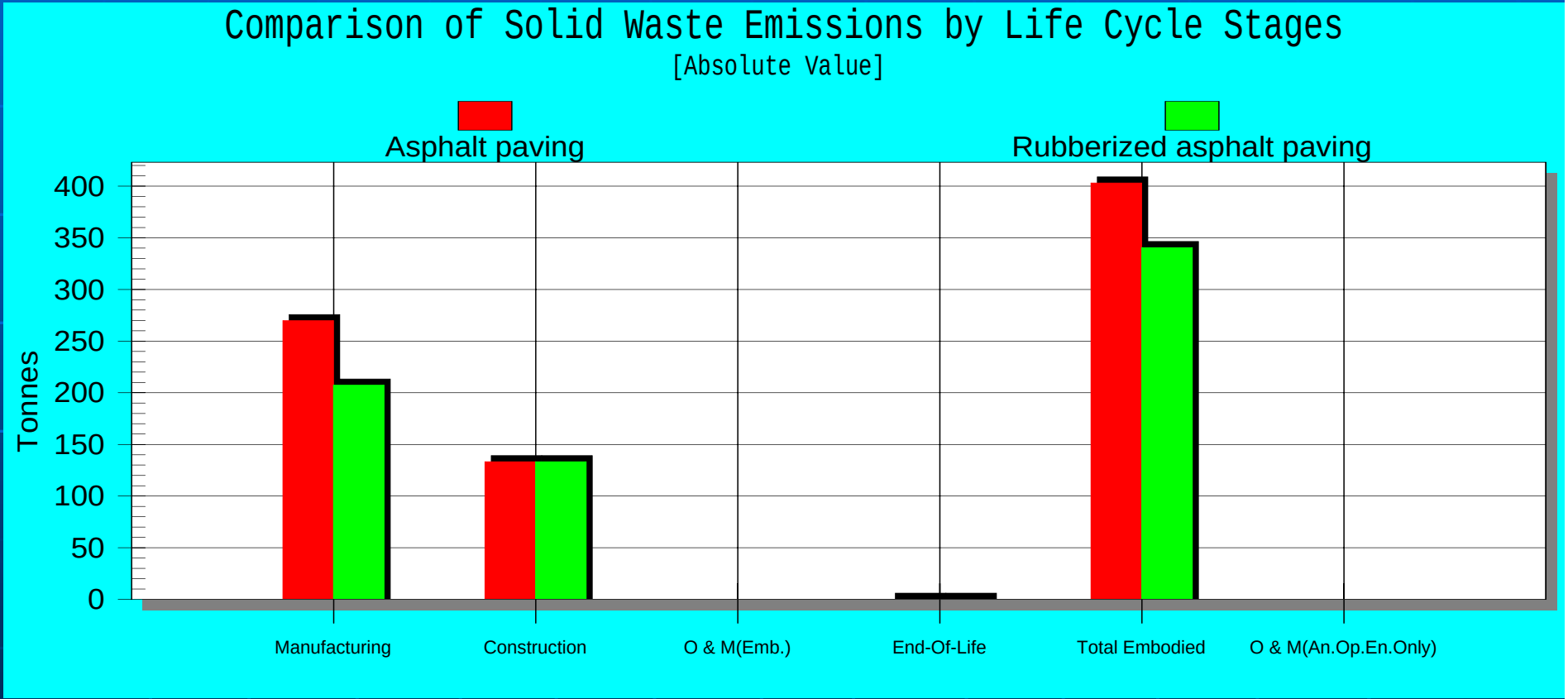
8” 4000psi Concrete slab



Solid Waste Emissions

Asphalt roofing vs. Rubberized Asphalt Paving

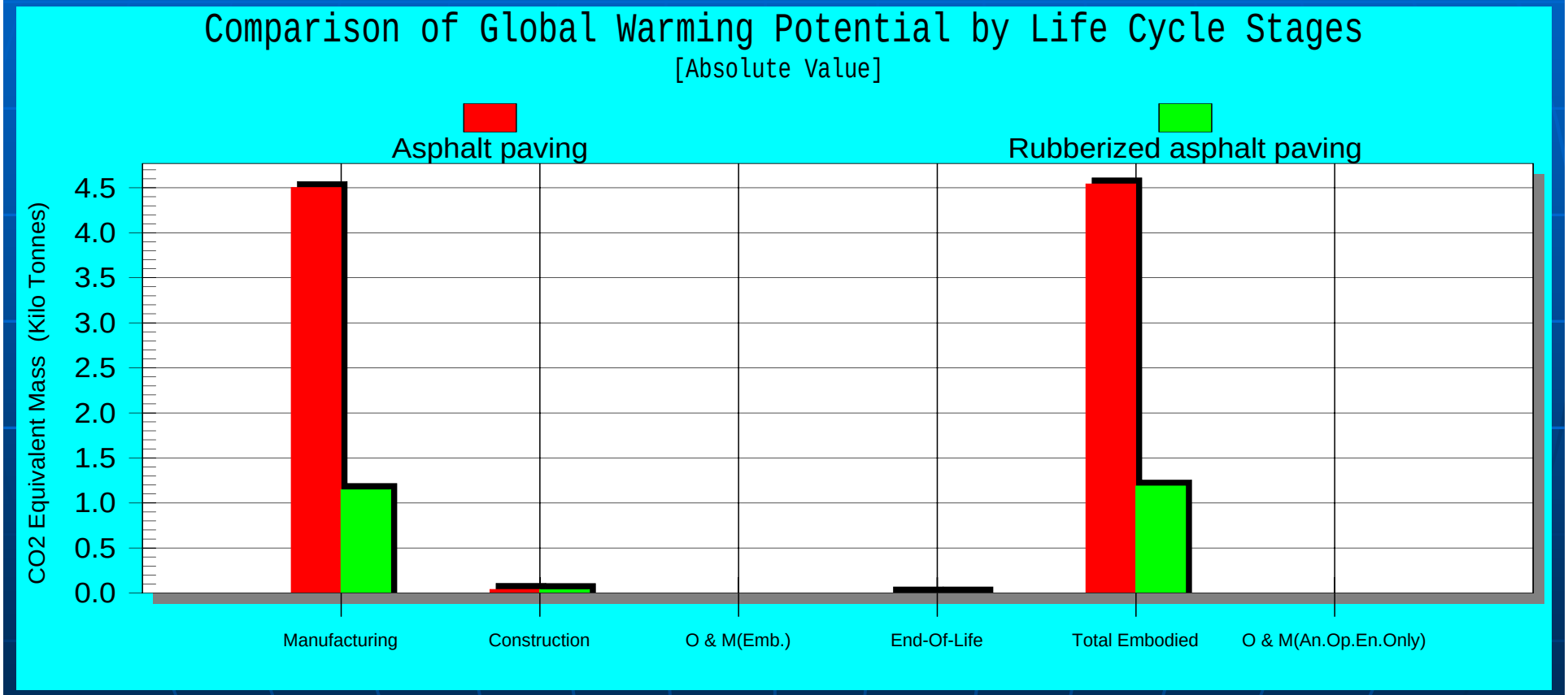
8” 4000psi Concrete slab



Global Warming Potential

Asphalt roofing vs. Rubberized Asphalt Paving

8” 4000psi Concrete slab

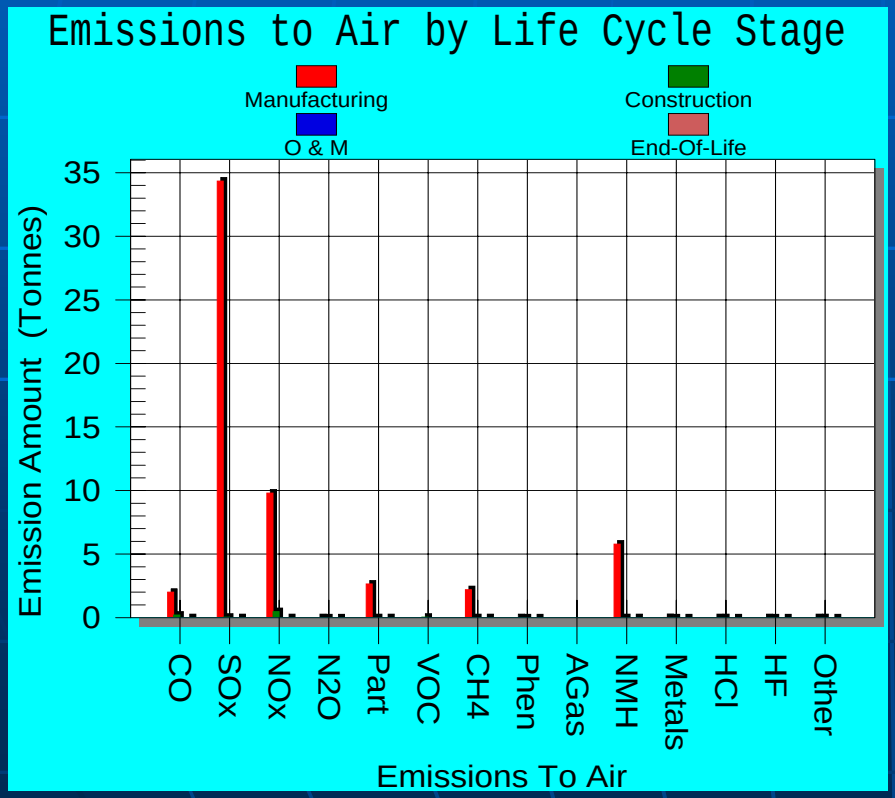


Emissions to Air

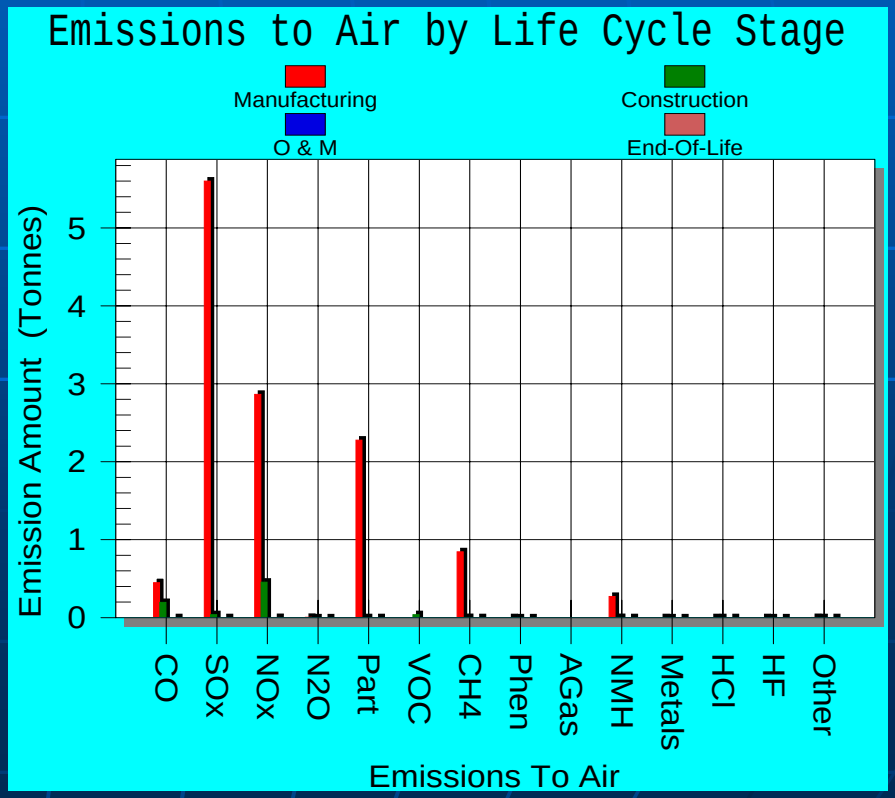
Asphalt roofing vs. Rubberized Asphalt Paving

8” 4000psi Concrete slab

Asphalt roofing Paving



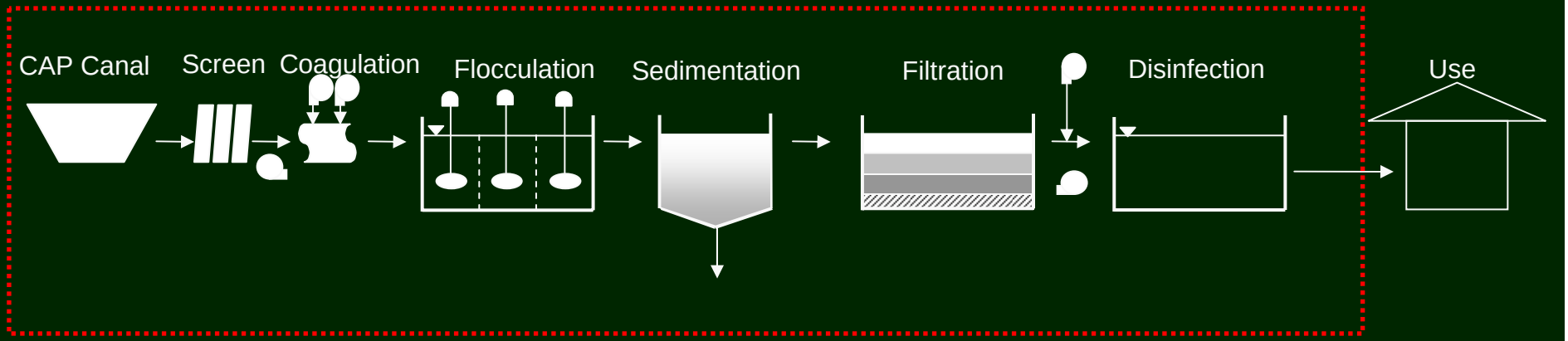
Rubberized Asphalt Paving



Importation - Central Arizona Project (CAP) Plant

- Source – Central Arizona Project
- Traditional Water Treatment Processes

Importation - CAP Plant - System Diagram



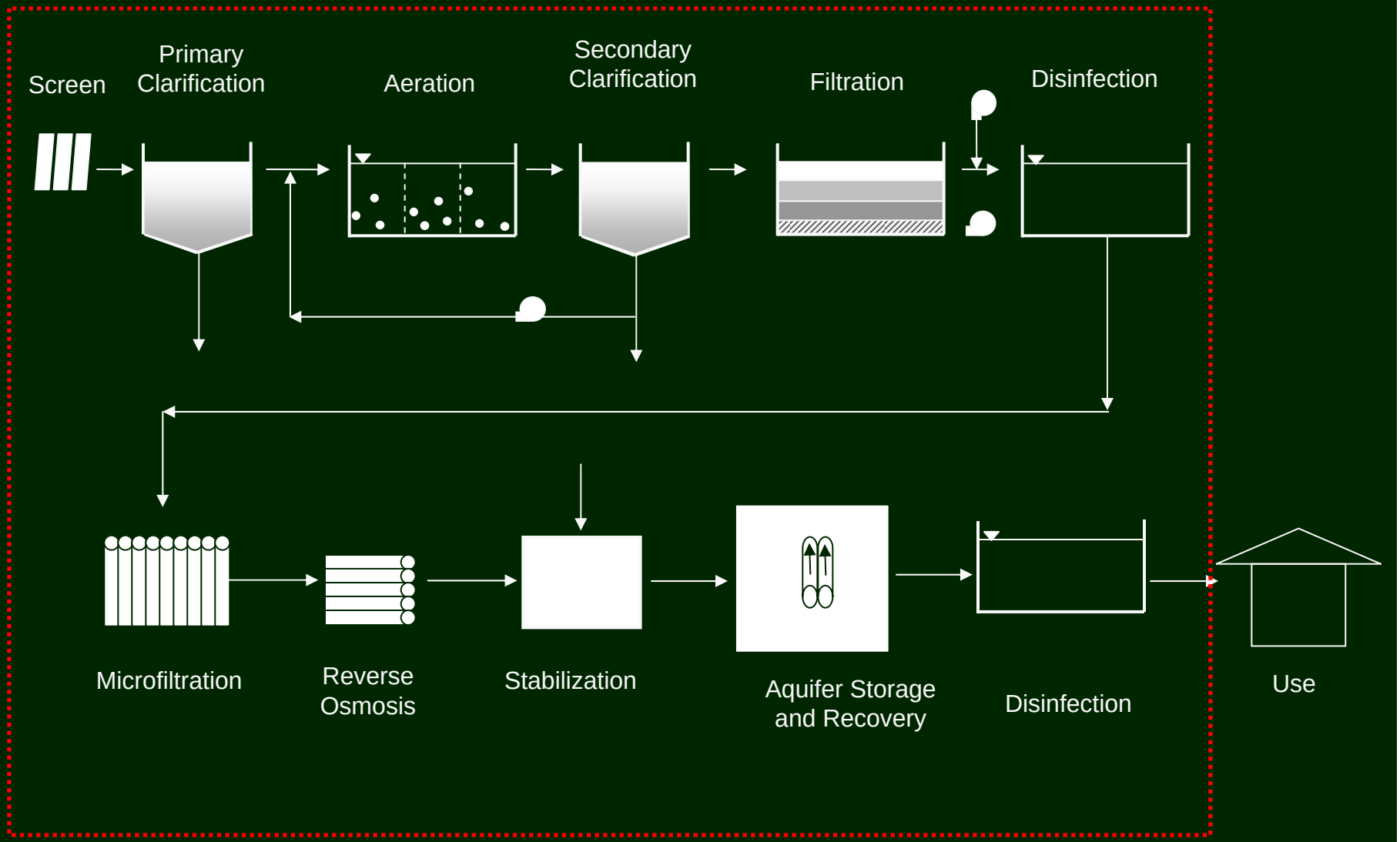
Importation - CAP Plant Inputs – 50 Year Plant Life

	Per 1000 gallons of water
Concrete (yd^3)	0.000065
Steel (lbs)	0.0067
Energy (kWh)	5.4
PAC (g)	38
$KMnO_4$ (g)	3.1
Cationic Polymer (g)	3.1
Alum (g)	115
Chlorine (g)	19

Reclamation Plant

- Source – Reclaimed effluent
- Treatment Processes
  - Wastewater treatment
  - Advanced water treatment
  - Groundwater recharge and recovery
- Assume 70% wastewater capture
- Supplement with groundwater

Reclamation Plant - System Diagram



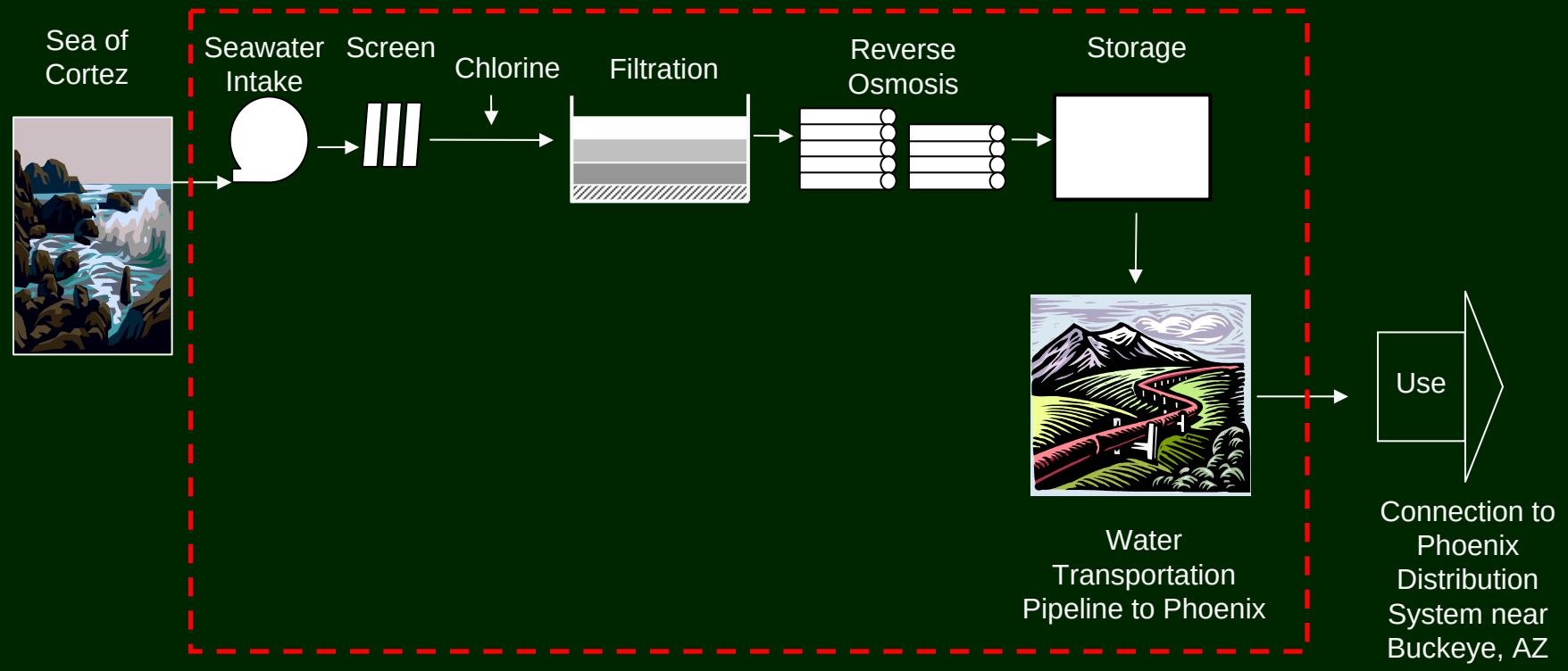
Reclamation Plant Inputs – 50 year Plant Life

	Per 1000 gallons of water
Concrete (yd^3)	0.0000273
Steel (lbs)	0.00272
Energy (kWh)	3.62
Chlorine (g)	47.5
Sulfuric acid (g)	653
Anti-scalant (g)	18.7
Lime (g)	993

Desalination Plant

- Source – seawater from the Sea of Cortez
- Treatment Processes
  - Filtration
  - Reverse Osmosis
- Steel pipeline conveying water from the Sea of Cortez to Phoenix, AZ

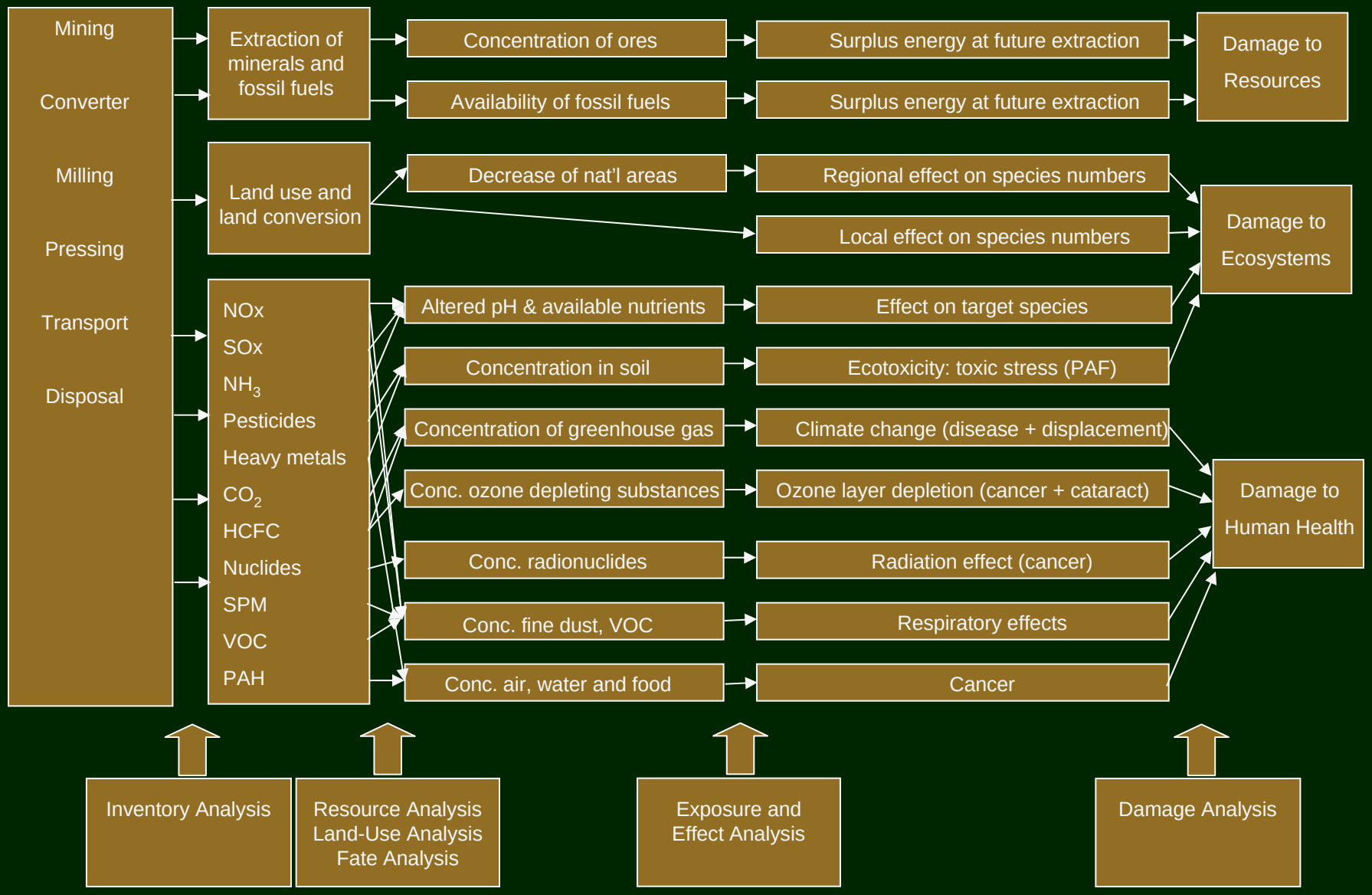
Desalination Plant - System Diagram



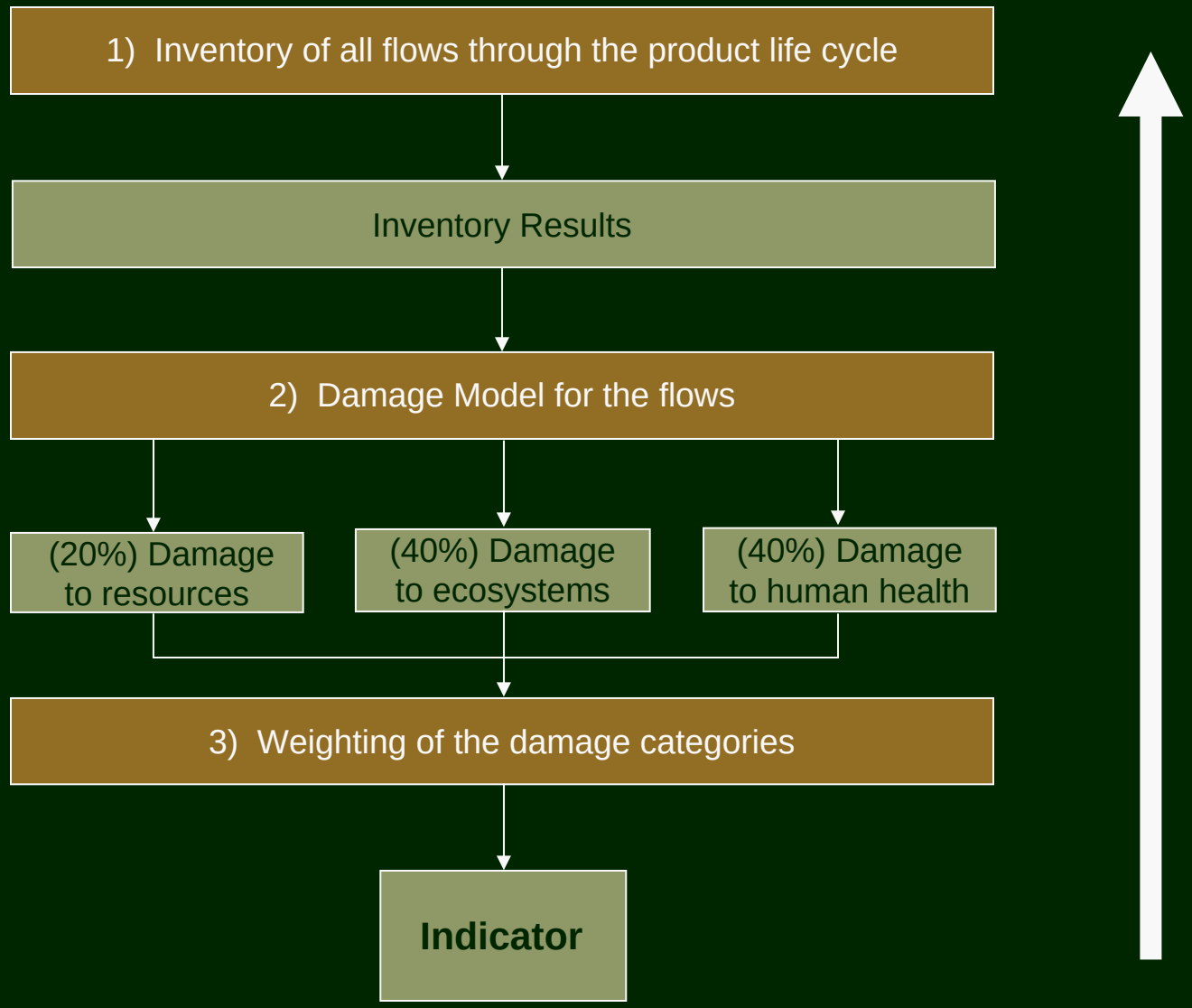
Desalination Plant Inputs – 50 Year Plant Life

	Per 1000 gallons of water
Concrete (yd^3)	0.00000511
Steel (lbs)	0.35
Energy (kWh)	21.9
Chlorine (g)	1.9
Sulfuric acid (g)	77.2
Sand (g)	3.2
Anthracite (g)	9.6
Lime (g)	771.6

Eco-Indicator 99 Calculations



Eco-Indicator 99 Calculations



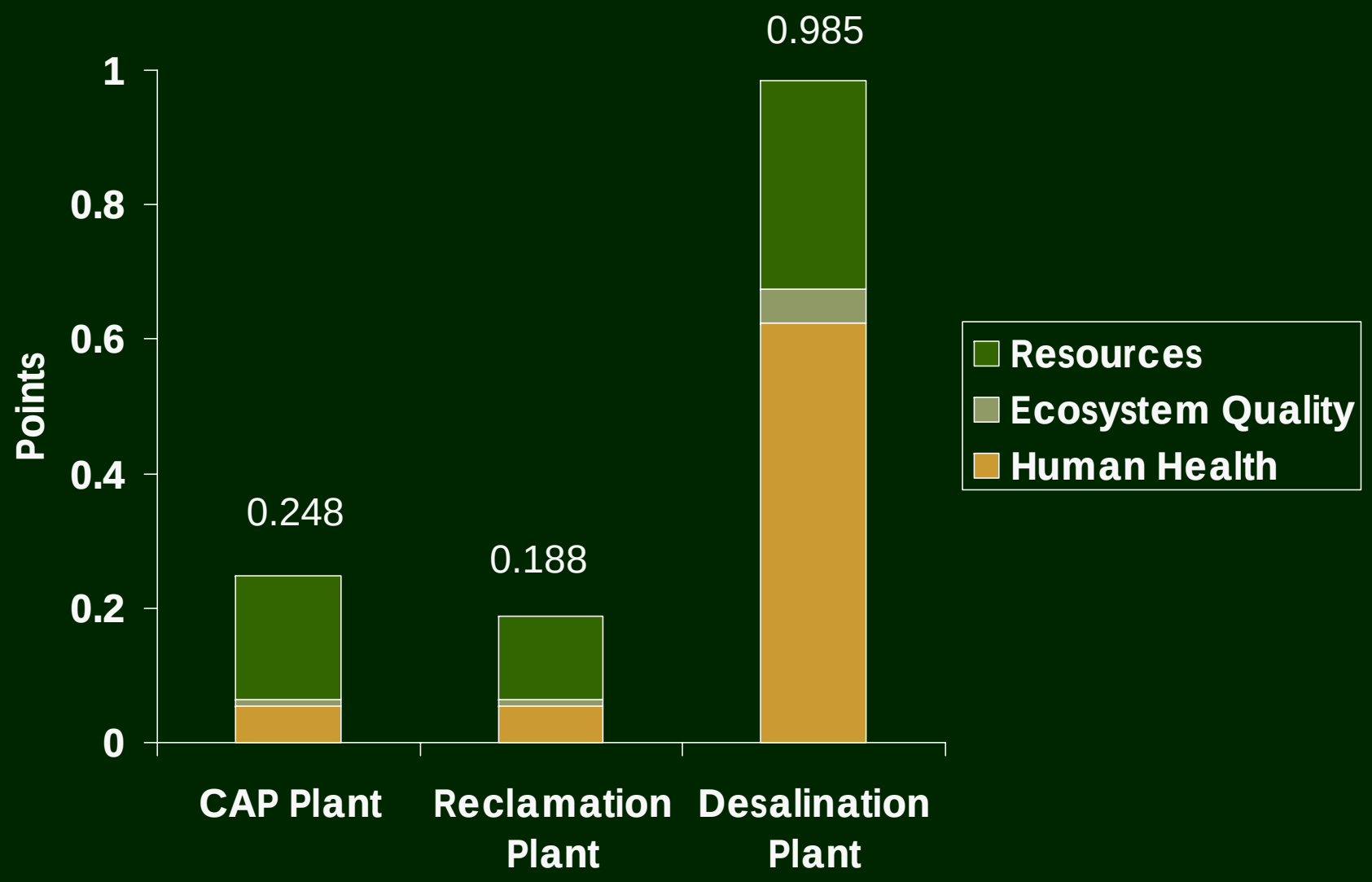
Eco-Indicator 99 Units

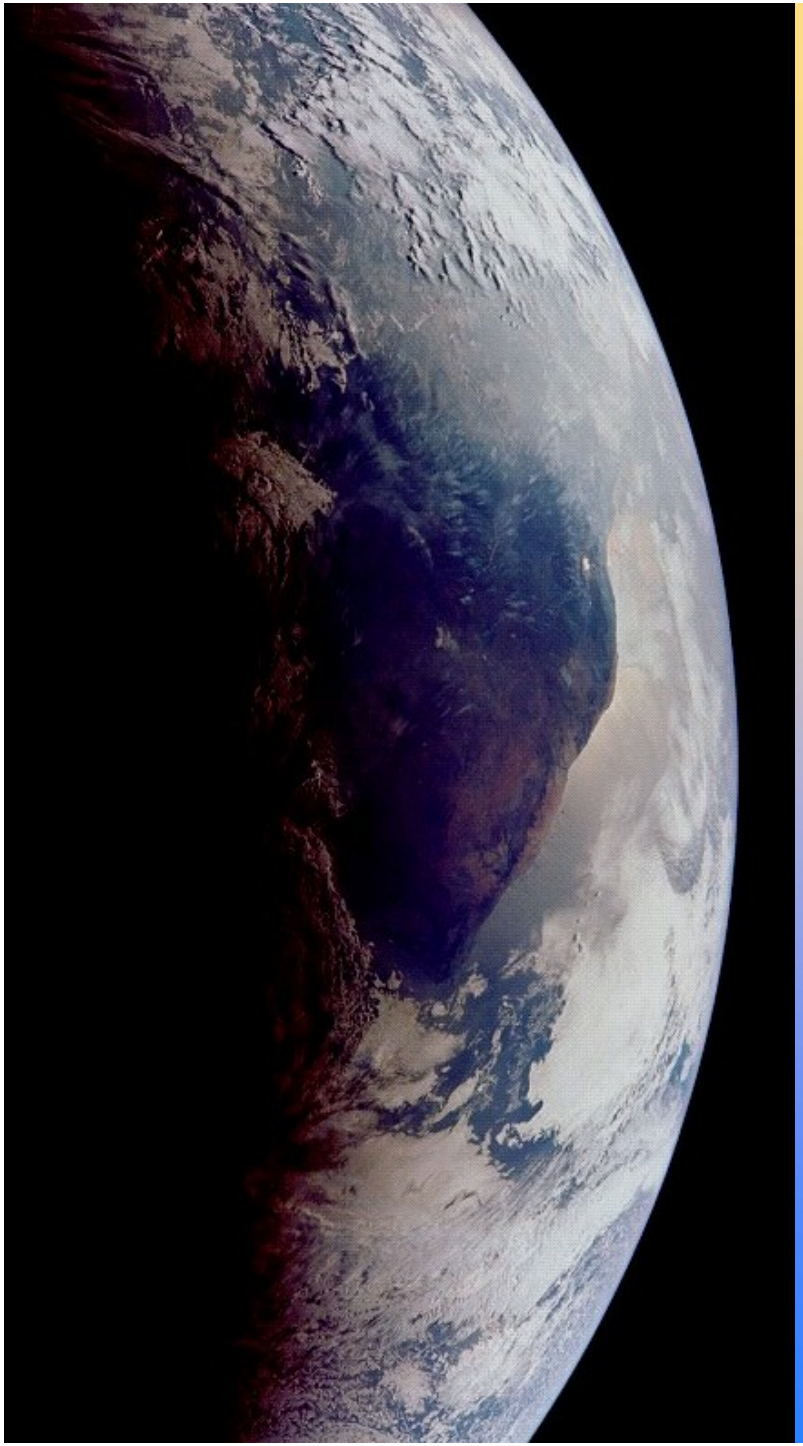
- (40 %) Disability-Adjusted Life Years (DALYs)
- (40 %) Potentially disappeared fraction *area*year (PDF*m2*yr)
- (20 %) MJ Surplus Energy

- Points
  - 1 Point represents 1/1000 annual environmental load of an average European

$$= \frac{\text{total environmental load}}{\text{population}} * 1000$$

Comparison

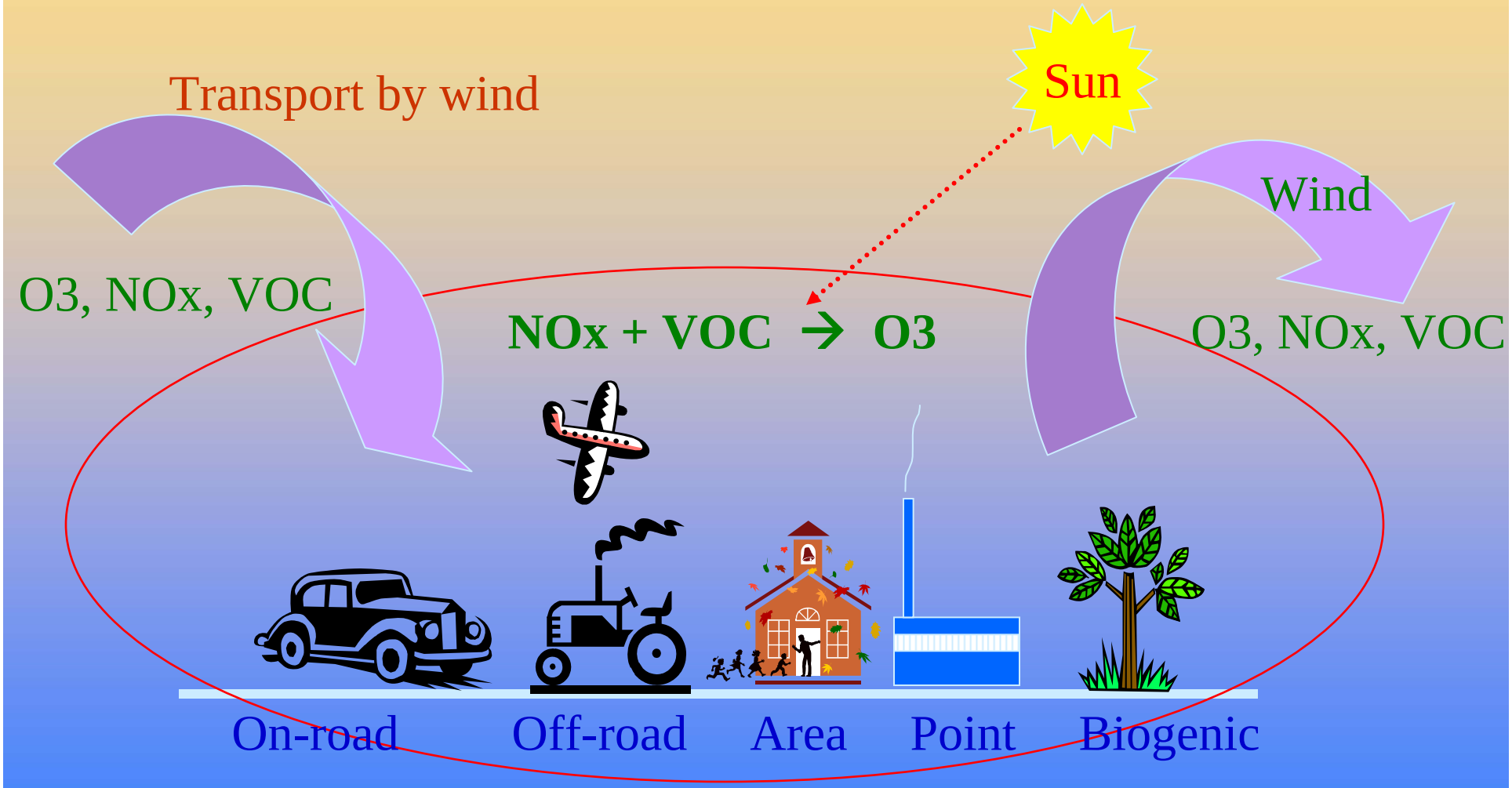

0.985
1
0.8
0.6
0.4
0.2
0
Points
0.248
0.188
Resources
Ecosystem Quality
Human Health
CAP Plant
Reclamation Plant
Desalination Plant



Outline

- What is Sustainability ?
- Background and Vision
- Urban Development Simulation
- Material Flow Analysis
- Air Quality and Heat Island Simulations
- Conclusions

Ozone accumulation
(Local production + Transport)



Local production

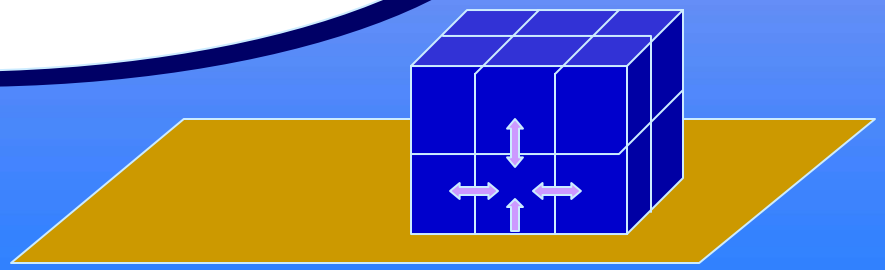
(Courtesy of Choi)

Main components of 3D photochemical air quality modeling system

Meteorology
(MM5 by Penn. State. U.)
(Temp., Wind, Humid., Press..)

Emissions
(SMOKE by U.North Carolina)
(bio. and anth. emissions)

Chemistry & Transport
(CMAQ by U. S. EPA)
(chemical reactions, advection, diffusion, deposition..)
Calculate concentrations of pollutants



(Courtesy of Choi)

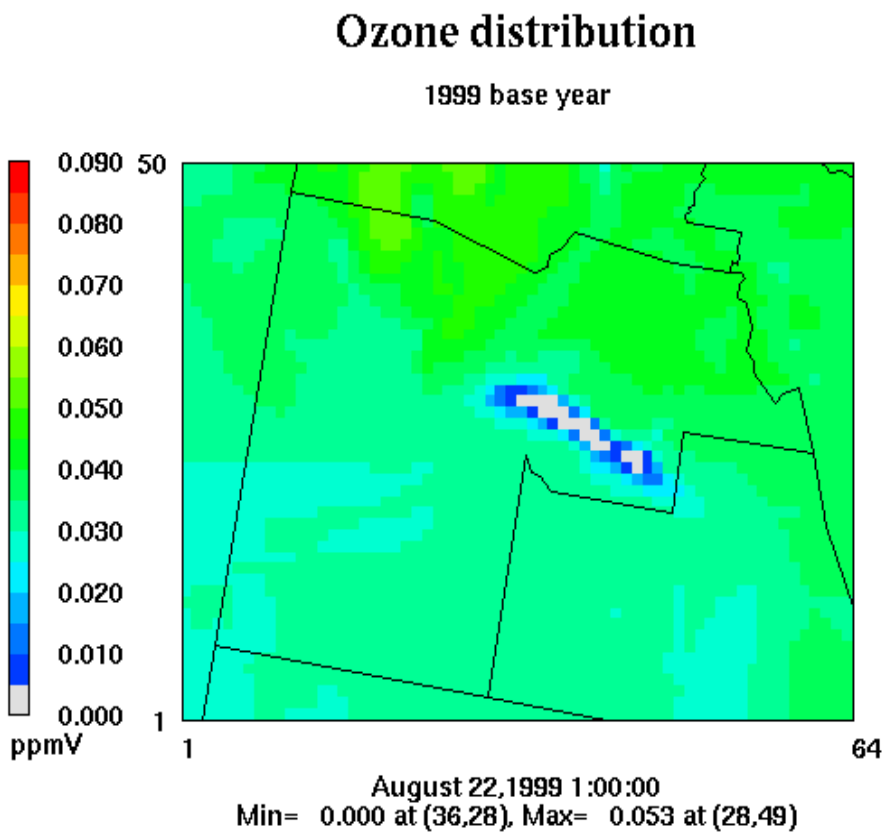
Ozone precursors from residential building construction and other sources

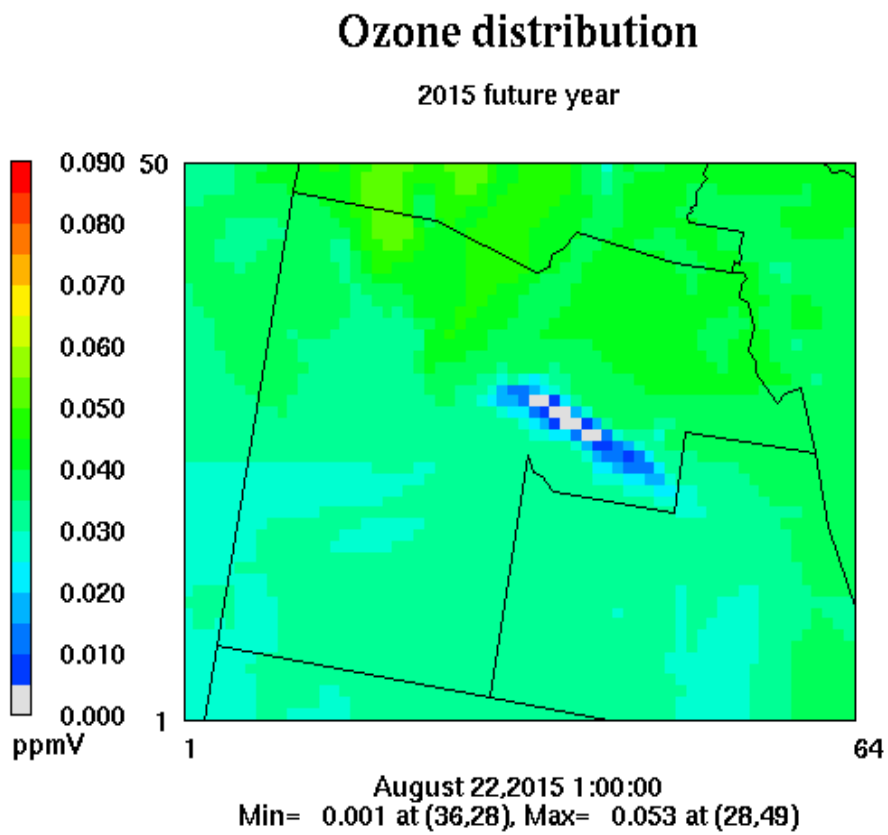
		NO_x	VOC	CO	SO_x
Other sources (tons)	1999	113,341	121,029	597,634	3,793
	2015	59,833	111,465	390,240	2,570
Construction in 2015 (tons)	One-story scenario	304	23	148	237
	Two-story scenario	245	15	117	276

* Emissions from construction = the number of newly-built residential houses in 2015 projected by UrbanSim × emission factor from life-cycle analysis

The construction of one-story and two-story residential buildings generate similar amount of ozone precursors. But their contributions to the collective ozone precursor emissions in the Phoenix area are negligible.

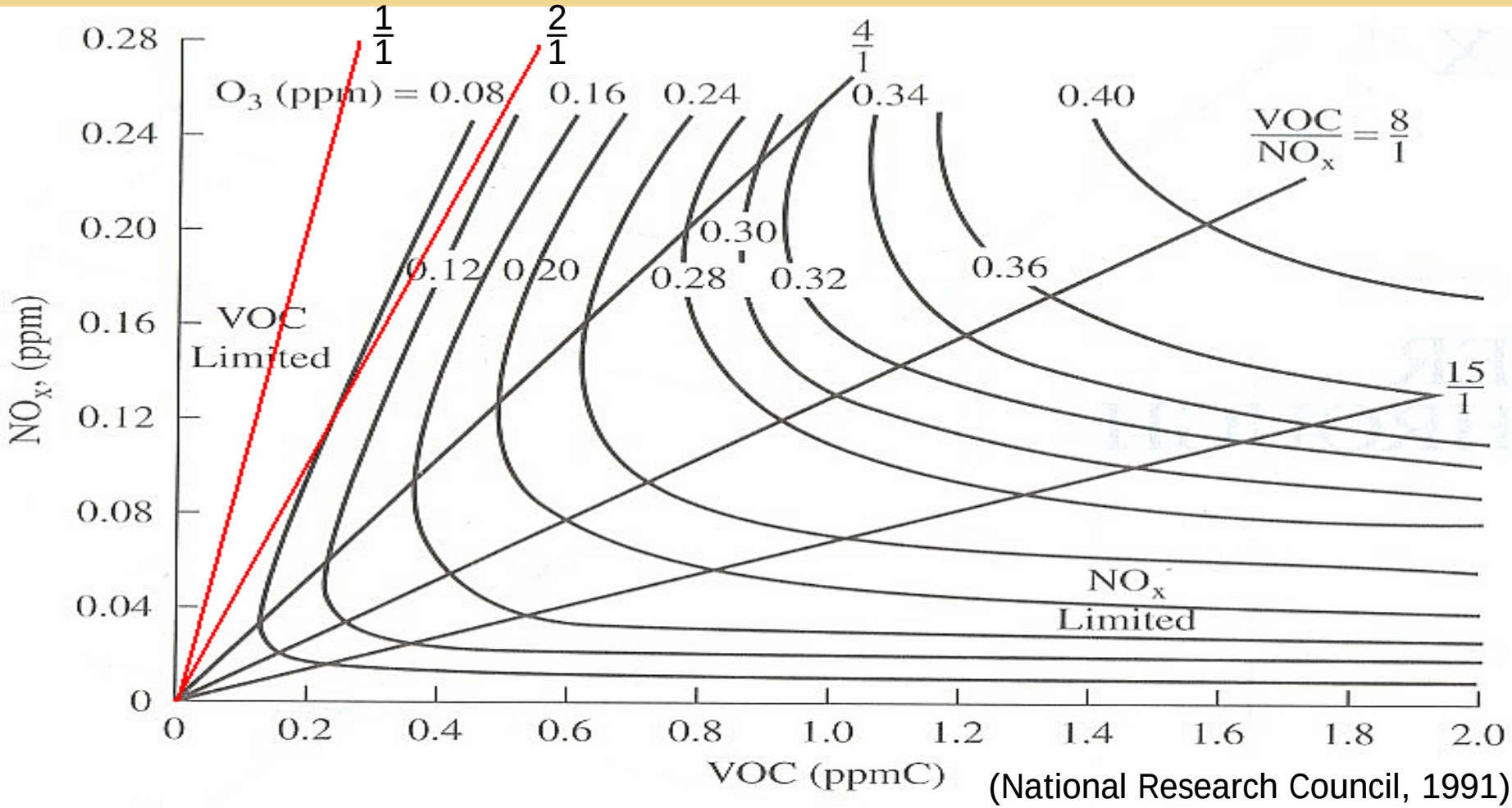
Ground-level ozone distribution
1999 VS. 2015





The animation shows a shortened ozone distribution in 2015 compared to 1999.

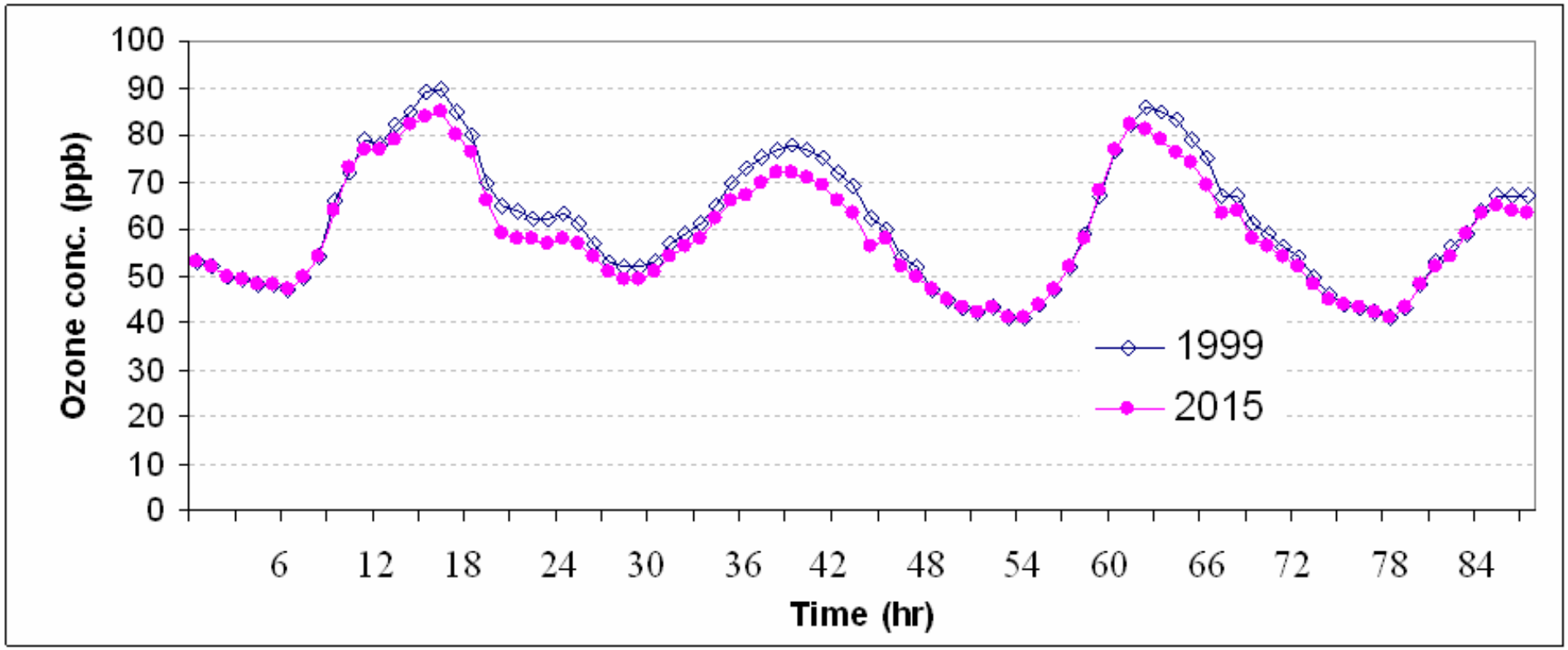
Ozone formation and NOx, VOC concentration



(National Research Council, 1991)

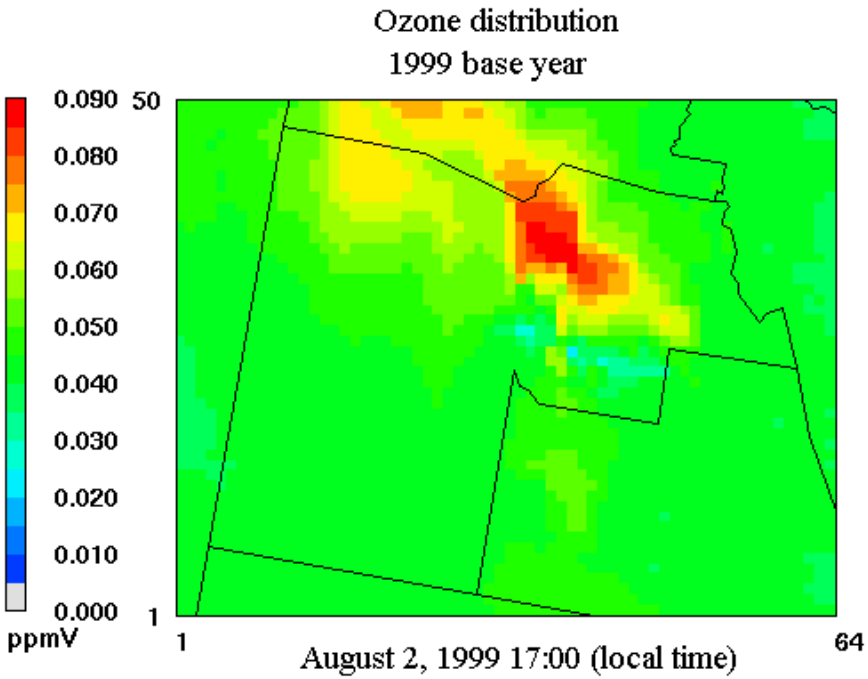
The Phoenix area is VOC-limited area and located between two red lines.

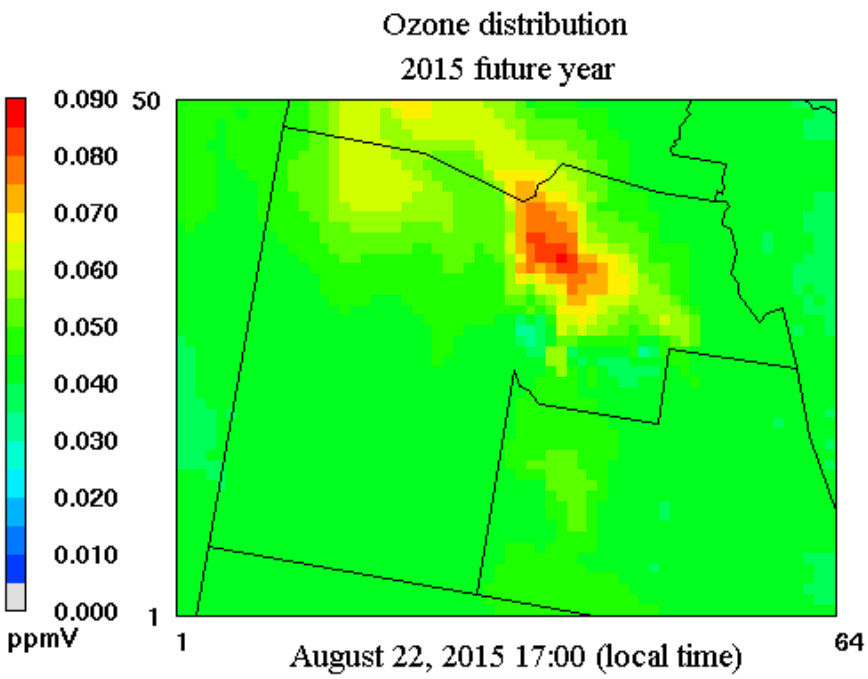
Maximum ozone concentration 1999 VS. 2015



The figure shows a decrease in maximum ozone concentration in 2015 compared to 1999.

Ground-level ozone distribution at a peak ozone time

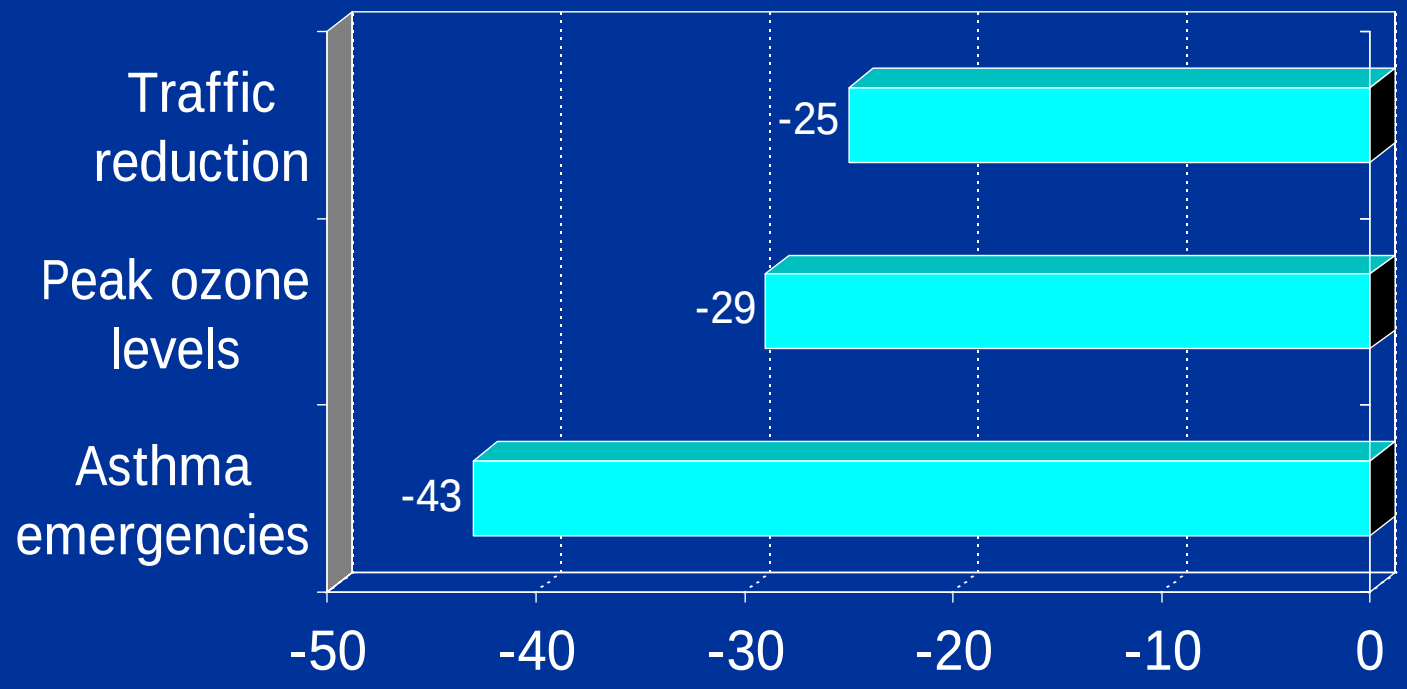




Ozone Distribution at a Peak Ozone Time for the Base and the Future Year

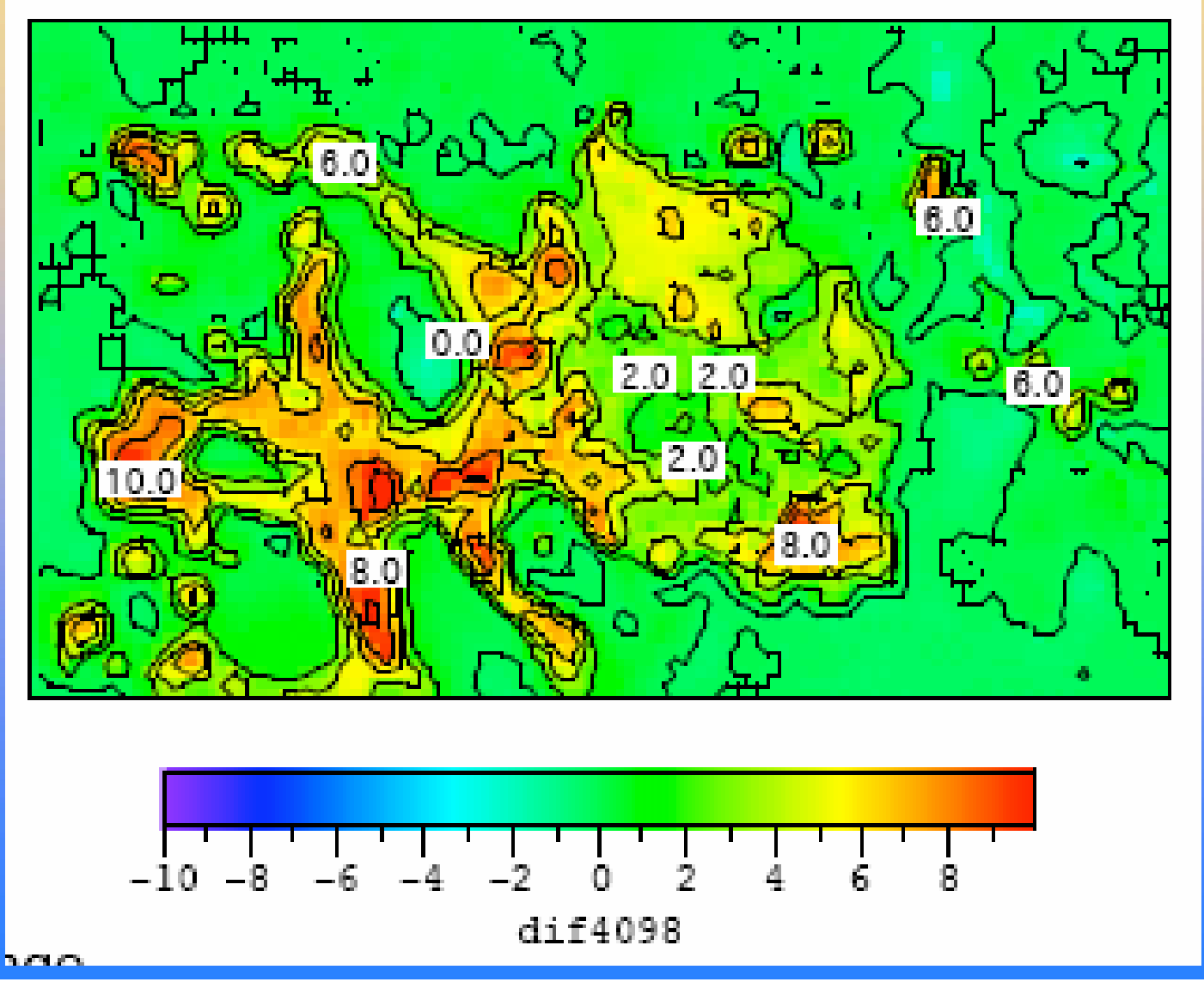
(showing a decrease in 2015 compared to 1999)

During the 1996 Olympics in Atlanta, city officials reduced vehicle traffic by 22.5% and asthmas related emergencies decreased 41.6%



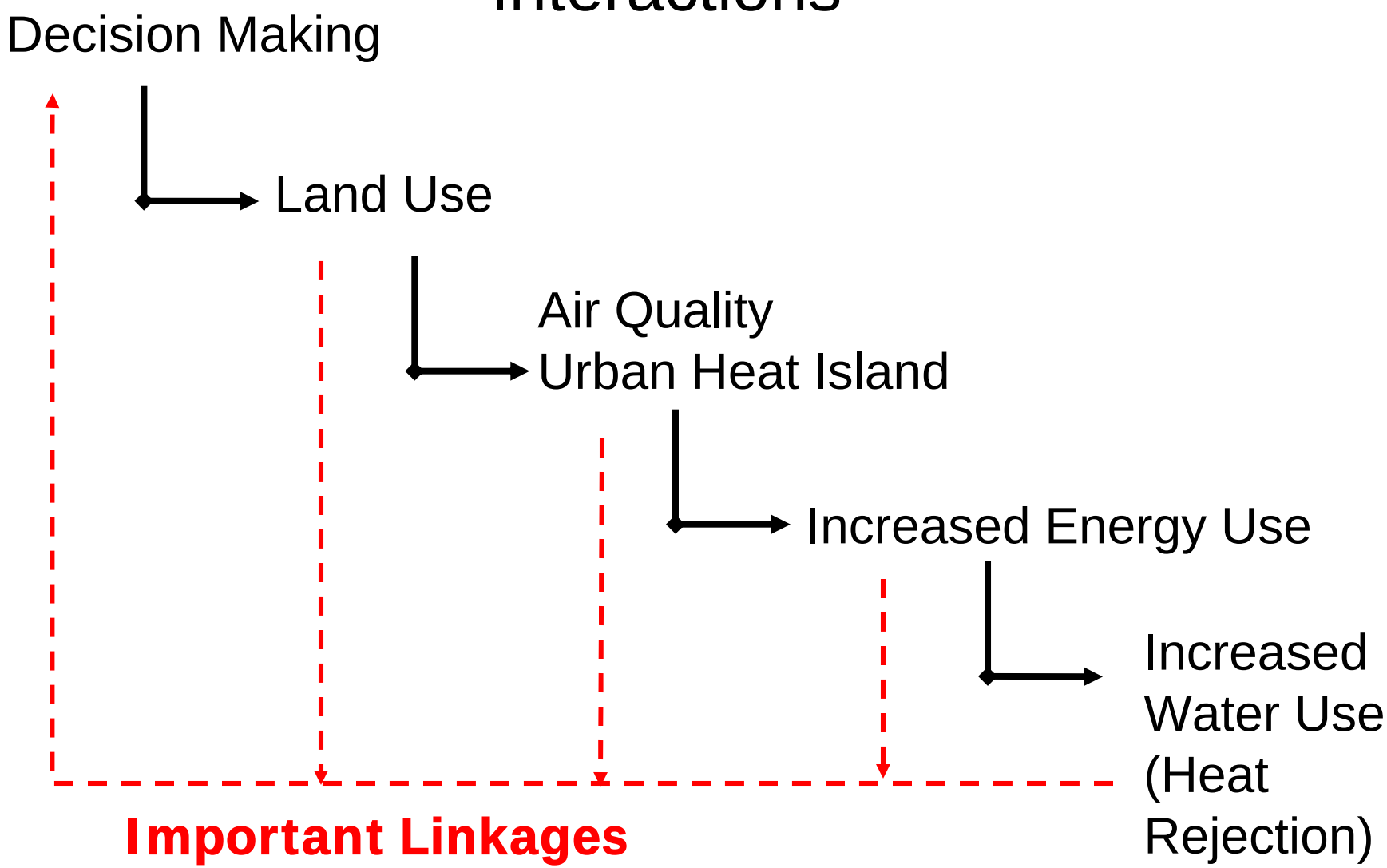
Source: Friedman et al., 2001 (CDC/*JAMA*)

Difference in Temperature Contour in 1998 and 2040 (Predicted by UrbanSim)

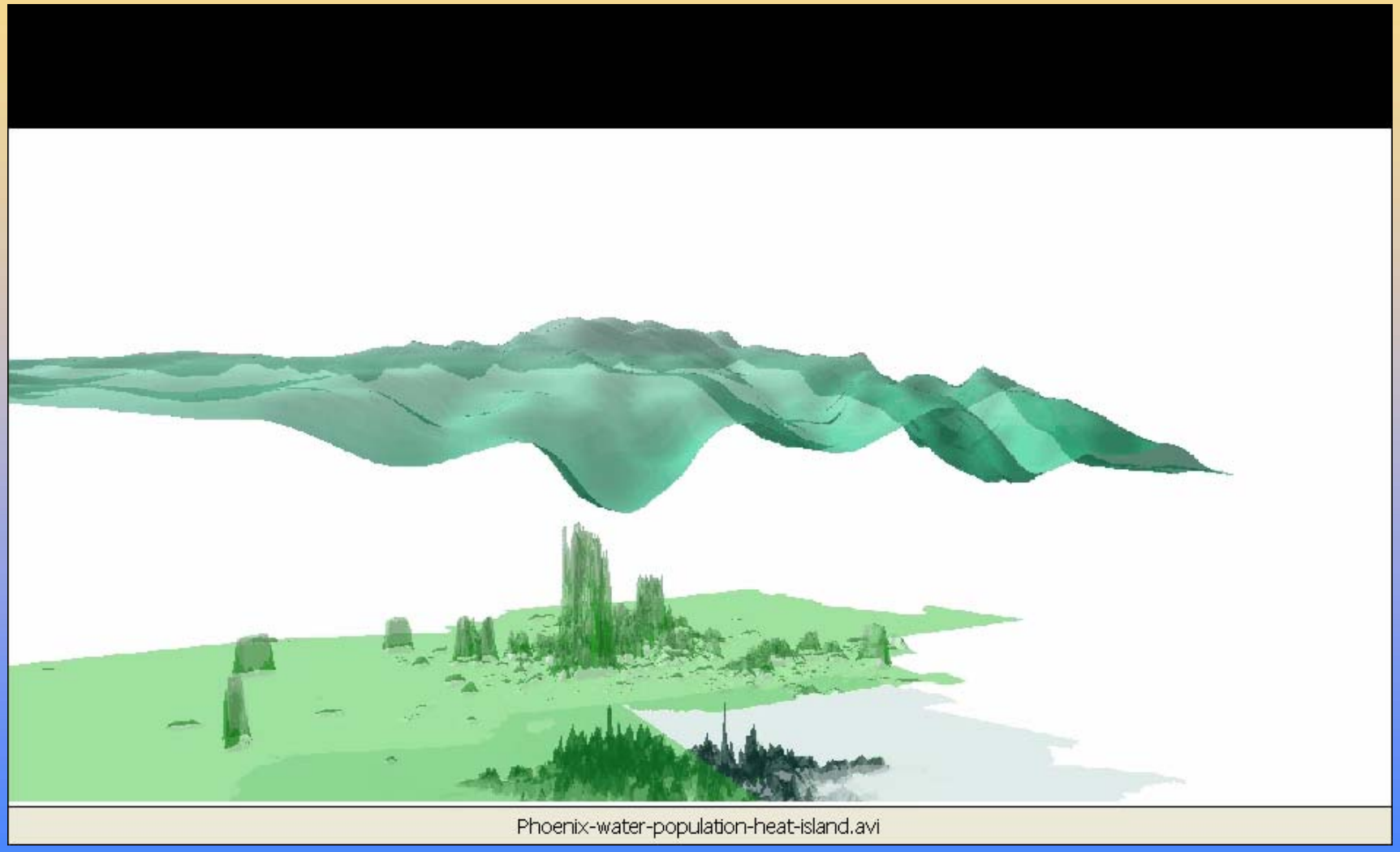


Zehnder, Clarke, Guhathakurta, Li Crittenden

Importance of Considering the Big Picture and Informed Decision Making- System of Systems Interactions

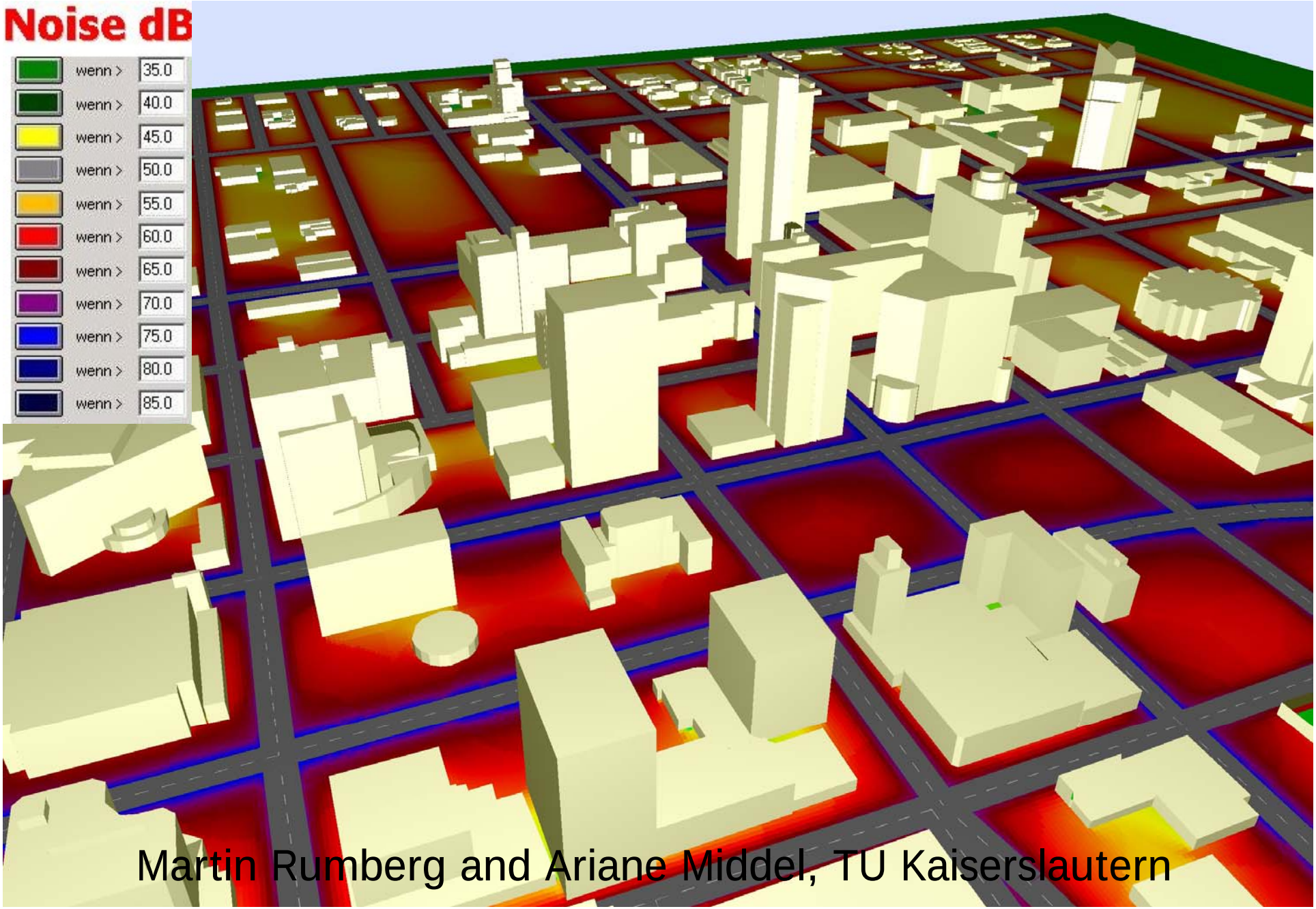


Heat Island, Water Use and Population



(Torrens)

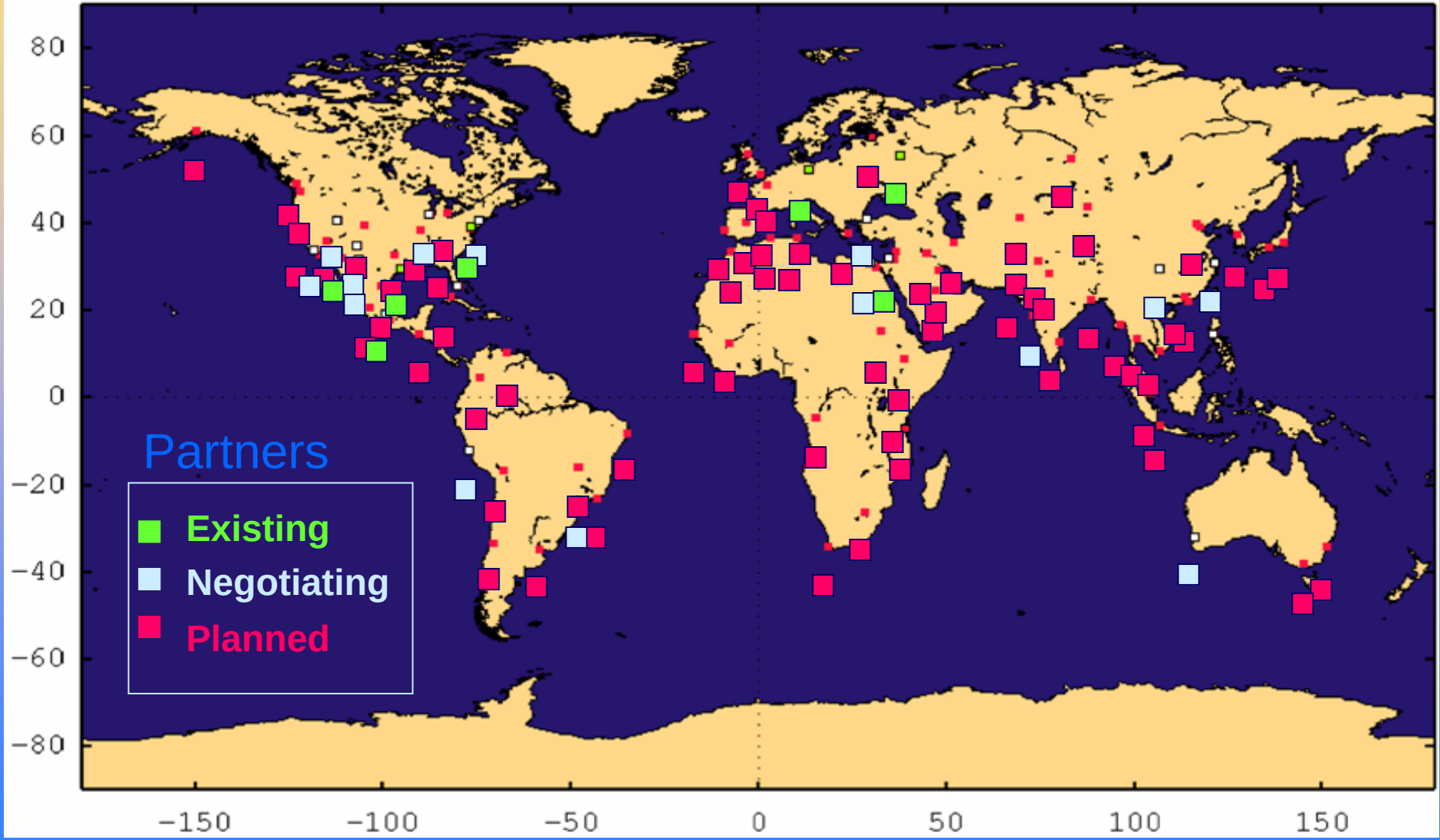
Noise – Predicted from Development Patterns and Traffic Patterns



Martin Rumberg and Ariane Middel, TU Kaiserslautern

100 Cities Project:

Standardized, repeated urban remote sensing



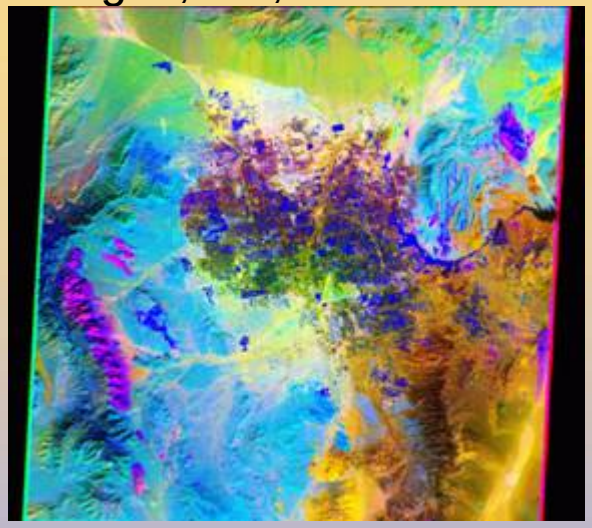
Different sensors = different information

Las Vegas, NV, 17-Oct-2000

Visible to near-infrared
15 m/pixel

Major land cover classes

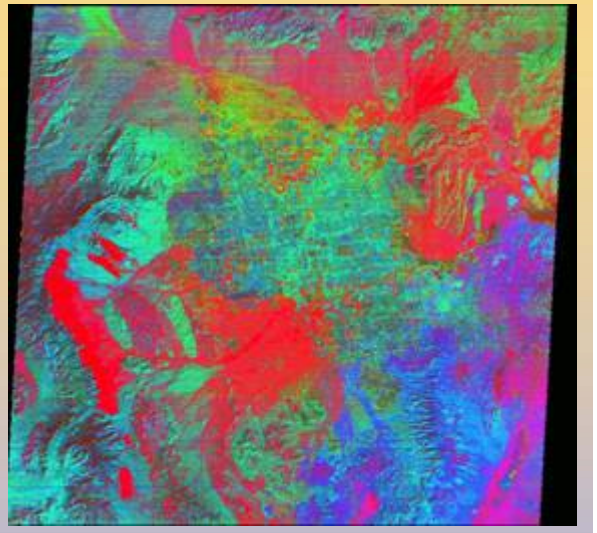
- Vegetation health
- Soil properties
- Soil contamination



Shortwave infrared
30 m/pixel

Urban surface materials

- Rooftop materials
- Energy use
- Fugitive dust production
- Metal contamination
- Ecological communities

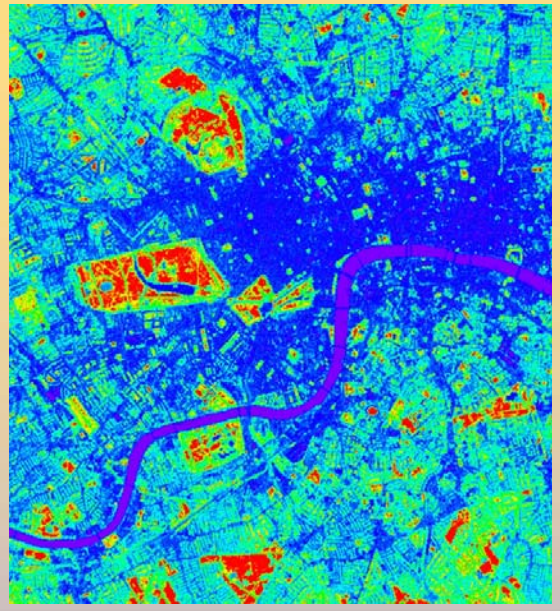


Thermal infrared bands
90 m/pixel

Surface energy balances

- Regional climate models
- Anthropogenic heat sources
- Heat island development

100 Cities Project:



- Annual day and night images collected for each
- Goal is to partner with local groups in all 100 cities
- Can we develop a taxonomy of growing cities?
- How can cities minimize their environmental impact?
- How can urban security threats be minimized?
- How can technologies promote sustainability?

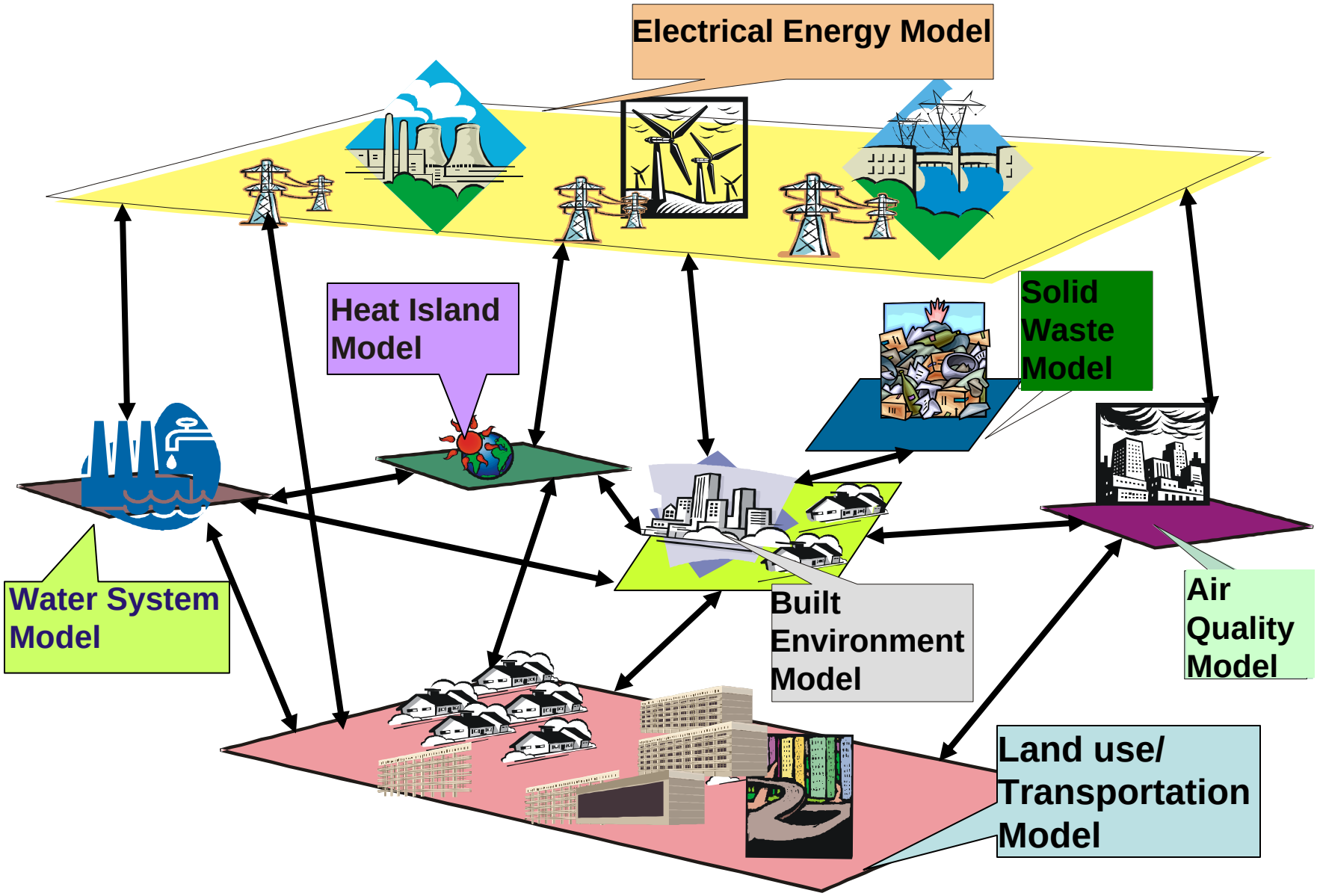
Cyber Infrastructure

- Tremendous Opportunity to Influence it for Urban Sustainability
- NAE Definition
  - Human
  - Hardware
  - Software
- Wireless Communication
- Sensors (Remote and Embedded)
- Modeling
- Data Mining and Fusion
- Visualization

Cyber Infrastructure

An NSF blue-ribbon advisory panel on cyberinfrastructure stated this in a recent report (Atkins et. al., 2003):

"The emergence of ubiquitous wireless networks offers another big opportunity. Billions of internet connected cell phones, embedded processors, hand-held devices, sensors, and actuators will lead to radical new applications in biomedicine, transportation, environmental monitoring, and interpersonal communication and collaboration. The combination of wireless LANs, the third generation of cellular phones, satellites, and the increasing use of unlicensed wireless bands will cover the world with connectivity enabling both scientific research and emergency preparedness to utilize a wide variety of 'sensornets.' Building on advances in micro-electronic mechanical systems (MEMS) and nanotechnology, smart sensors can be deployed widely, will be capable of multiple types of detection, and can survive for long periods of time. The integration of real-time multisensor data with data mining across large distributed data archives opens further avenues for adaptive monitoring/observation, situational awareness, and emergency response."



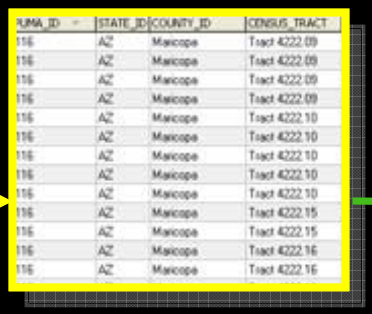
Urban Landscape System of Systems
Interaction of System Models

Digital Phoenix:

Long Term Outlook

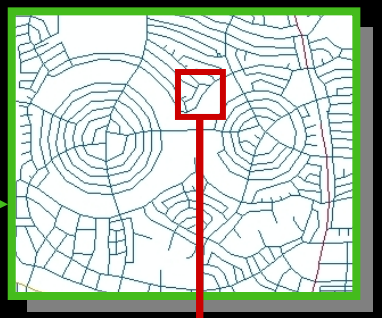
Definition of urban area

Definition of input data

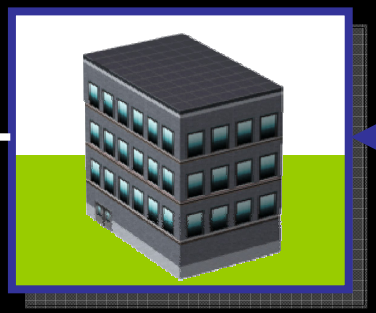


PUMA_ID	STATE_ID	COUNTY_ID	CENSUS_TRACT
116	AZ	Maricopa	Tract 4222.09
116	AZ	Maricopa	Tract 4222.09
116	AZ	Maricopa	Tract 4222.09
116	AZ	Maricopa	Tract 4222.09
116	AZ	Maricopa	Tract 4222.10
116	AZ	Maricopa	Tract 4222.10
116	AZ	Maricopa	Tract 4222.10
116	AZ	Maricopa	Tract 4222.10
116	AZ	Maricopa	Tract 4222.10
116	AZ	Maricopa	Tract 4222.15
116	AZ	Maricopa	Tract 4222.15
116	AZ	Maricopa	Tract 4222.16
116	AZ	Maricopa	Tract 4222.16

Street network generation



subdivision into allotments



modeling of buildings

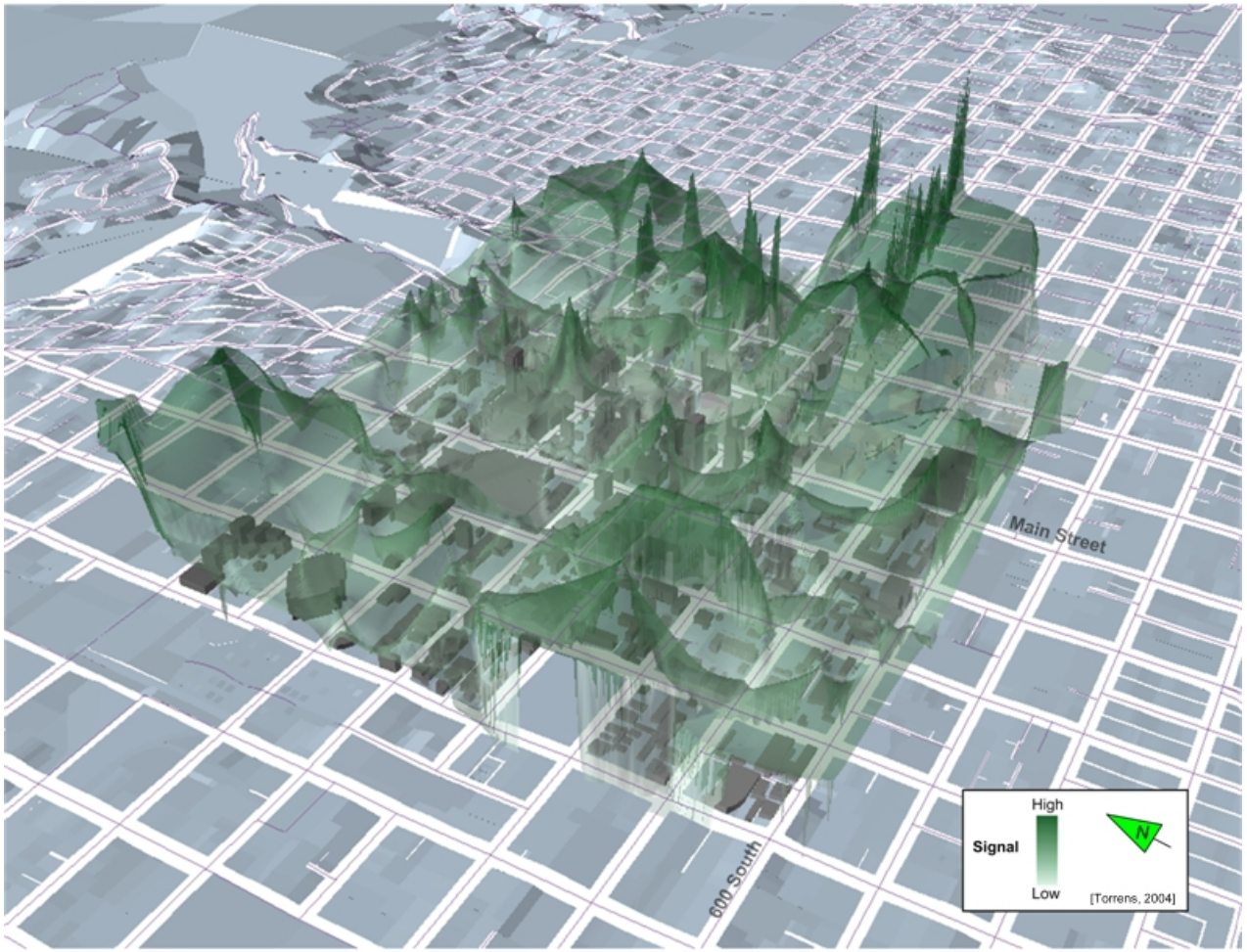
Adding furniture

Courtesy: Ariane Middel

Computable tags for material flow

Radio Frequency Induced Device Indentification tag could be used for material flow analysis and include environmental, social and economic performance information

Mapping urban data clouds

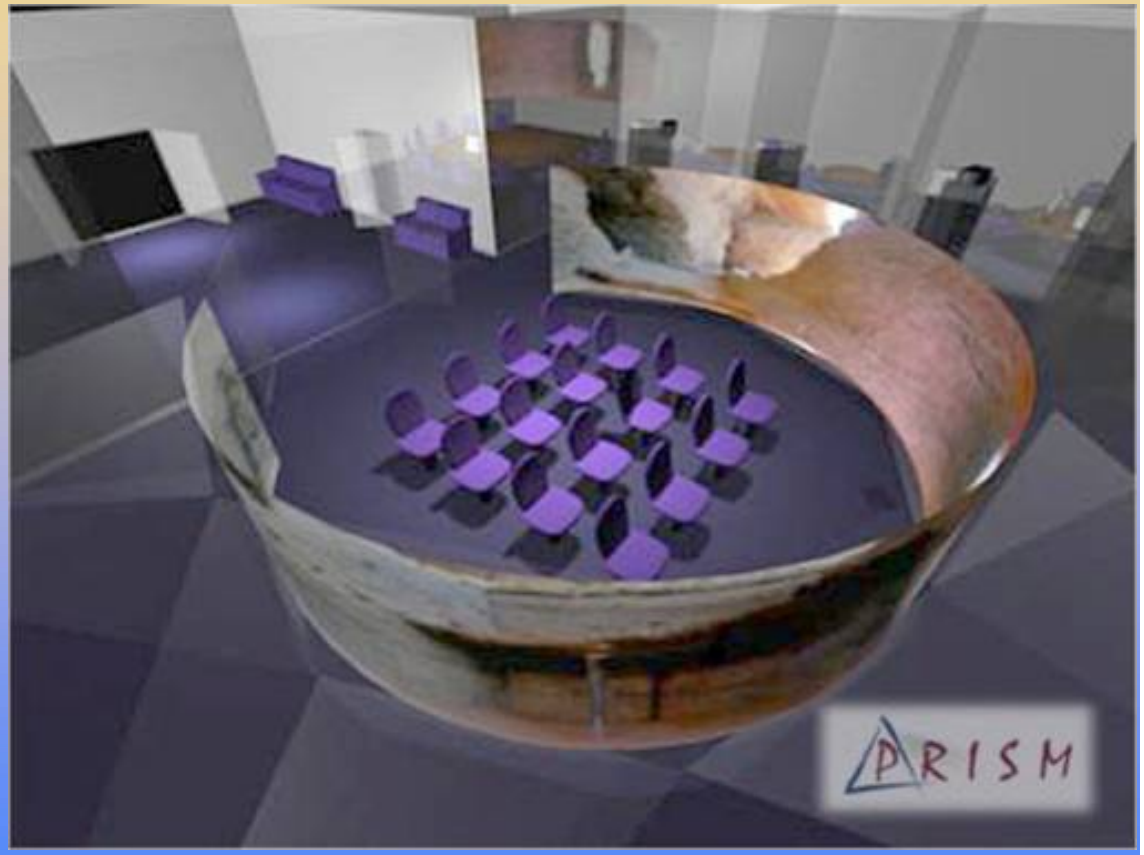


- Paul Torrens work…
- All signals, central Salt Lake City, UT

Greater Phoenix 2100

Visualization tools

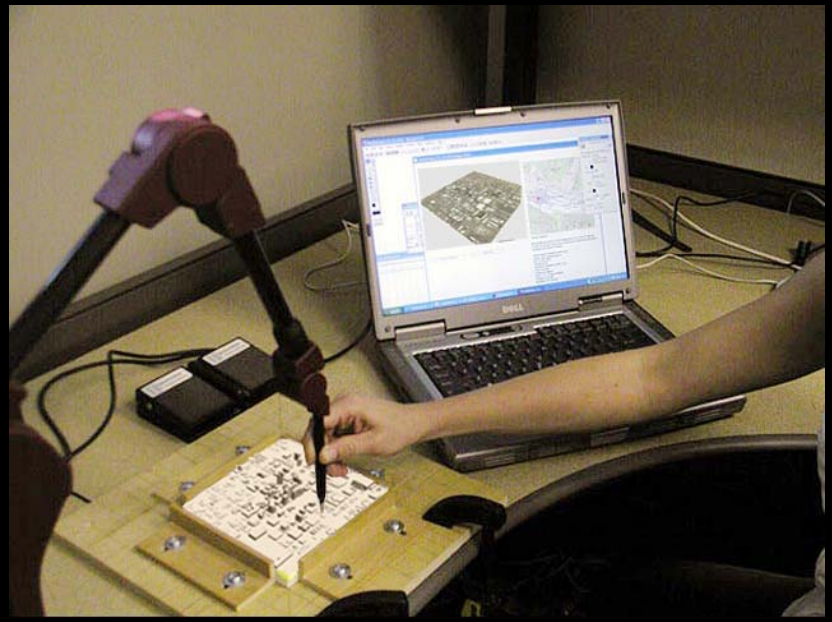
- Regional e-Atlas
- SIM Phoenix
- Decision Theater for a Future Arizona
- Urban-SAT(s)

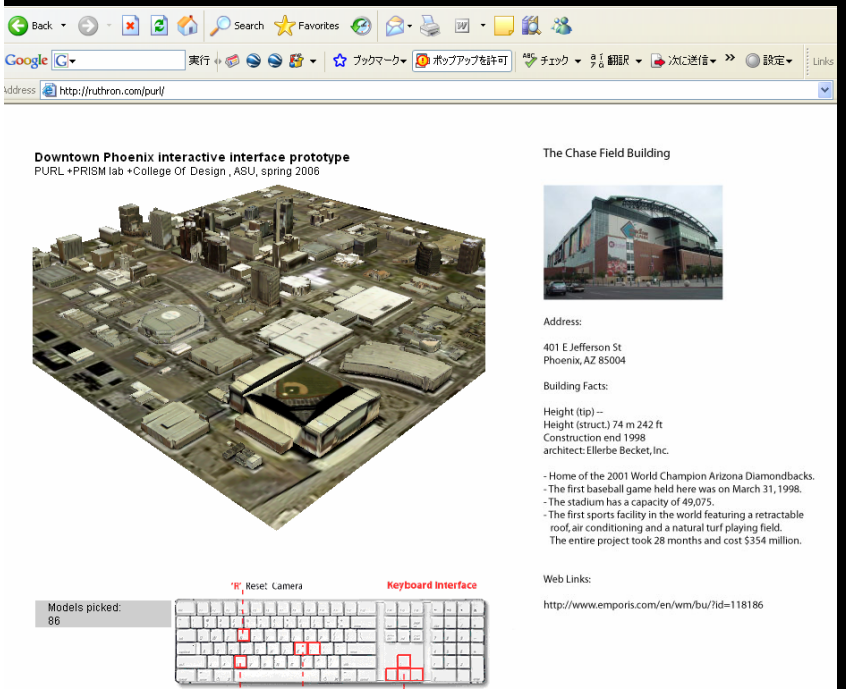


Digital Phoenix:

3D modeling…

Digital Phoenix:





Conclusions

- We have successfully validated and calibrated UrbanSim for the Greater Phoenix area using historical data obtained from Maricopa Association of Governments (MAG).
- Material flow analysis has been carried on to analyze the environmental impact of construction materials for residences.
- Ground level ozone concentration in the Phoenix area has been predicted based on the urban development simulation and material consumption.
- The holistic approach allows us to predict the impacts of individual and social decisions on urban growth, environmental quality, resource use, and waste generation at a spatially disaggregated level.

Conclusions

- Our research and its products (tools to envision alternate future scenarios) thus will have the practical, broader impact at the regional scale of aiding planning and material selection (concrete, lumber, roof tiles, paints, and so on) that can reduce environmental impact.
- Decision support tools may be used by local governments to examine the impact of urban-growth scenarios on environment quality and its disproportionate effect on disadvantaged populations.

Questions

(Yes this is a real fish)

Future Work

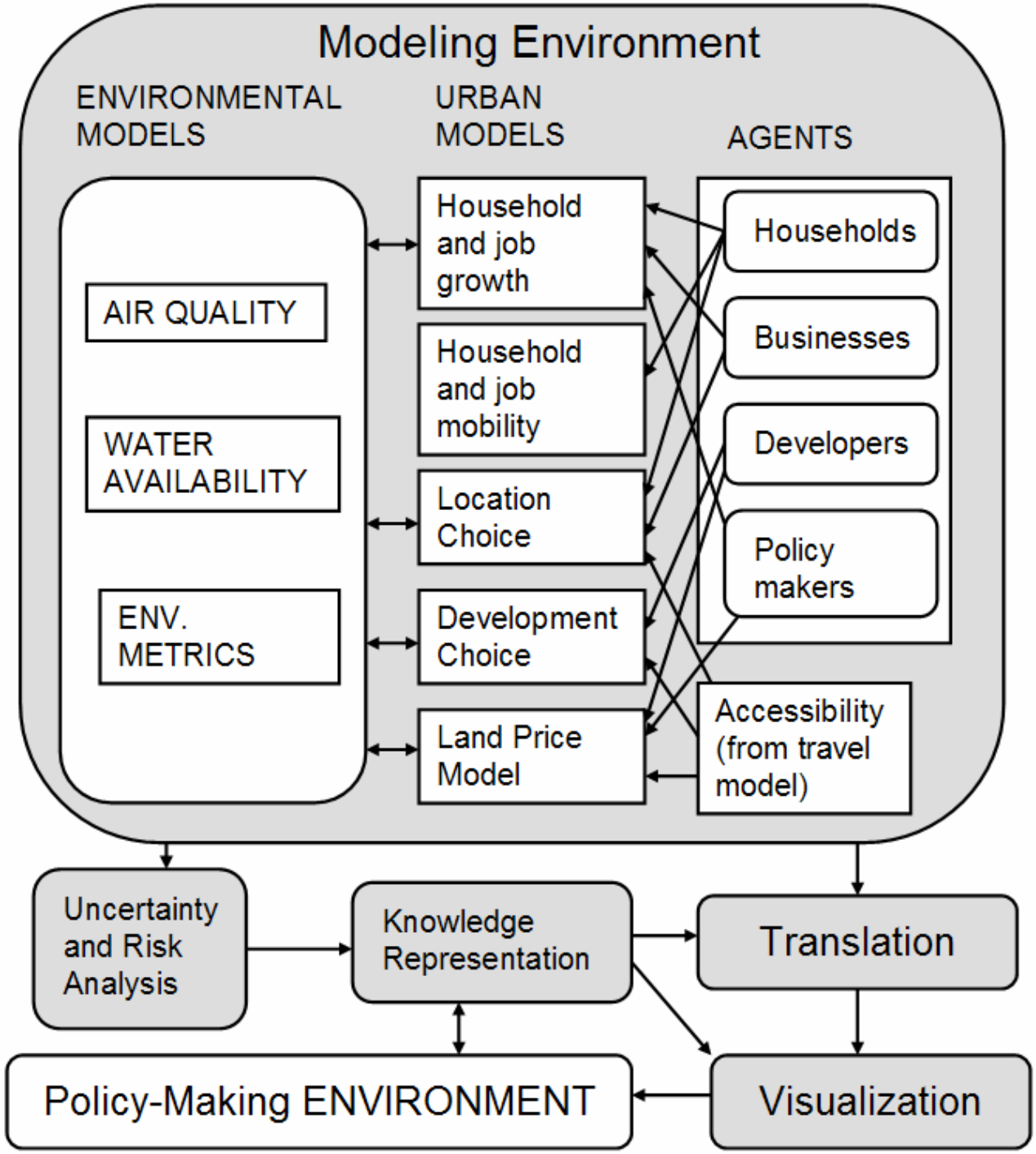
- Include other built infrastructure (commercial buildings, ground transportation)
- Examine scenarios between these two extremes scenario storylines (IPCC, 2001):
  - (1) ***Tech World*** - economic growth is extremely high, natural resources availability is assumed to be unconstrained, new technology yields new products and uses new materials, and the environment is not a priority;
  - (2) ***Green World*** - strong economic focus on green products, practices and processes, sustainability becomes a major ideological driver for society, rapid technological change focuses on lower material intensities, and industrial ecology is widely practiced and regions internalize environmental externalities.
- Include other urban systems such as energy, water, etc...

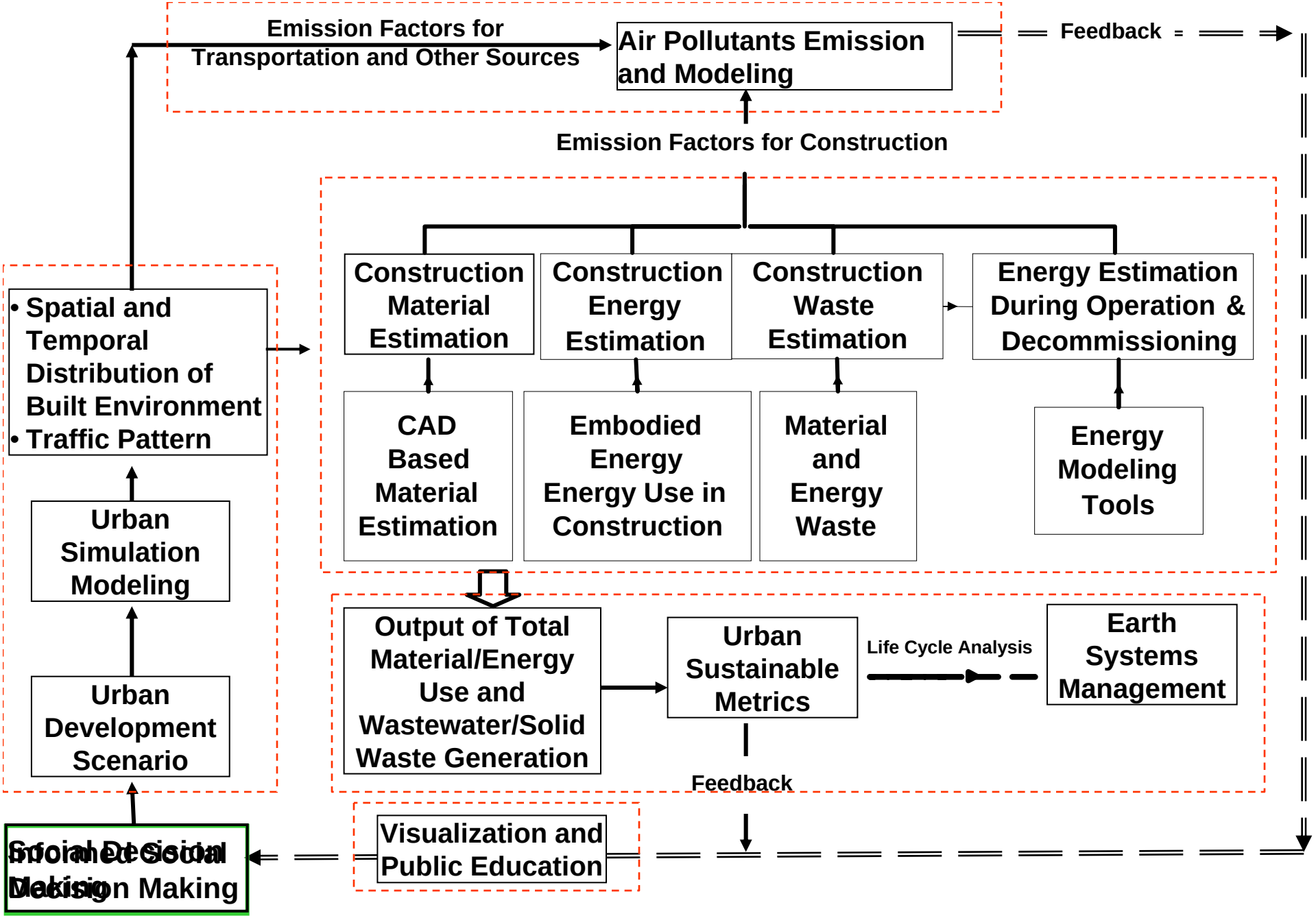
Conclusions - Land Use Scenarios

- Three General Plan Scenario (slow growth, General Plan growth, fast growth)
- Dispersed Polynucleated City
- Strong Central City
- Resort Mecca
- Transportation Influenced
- General Plan Scenarios, buildout population constant, buildout year varies
- Maricopa County population totals constant, Phoenix totals allowed to vary

Workflow showing the interface between the models and policy-making environment

(2 Million lines of code for Land Use Simulation)





Skeleton of the Information Flow for MUSES

Exiting Tools – Agent Modeling and Geospatial Modeling

- The past decade has witnessed a significant increase in the quality and quantity of geospatial information from various sources. Consequently, the quest for knowledge from the massive geospatial information for scientific, commercial and decision-making activities has posed new challenges for the geospatial research community. While conventional spatial statistics methods remain their power and popularity in numerous studies, many new techniques and approaches have appeared in response to the newly available geospatial data, which is essentially massive, complex, incomplete and uncertain. A variety of analysis and modeling approaches have been brought into geospatial domain such as cellular automata, agent-based modeling, and qualitative and fuzzy reasoning. These techniques are efficient and effective in discovering hidden structures, patterns and associations within geospatial data. On the other hand, emerging visualization and interaction technologies provide a powerful tool for obtaining additional insights into geospatial information for spatial analysis and modeling process. There has been an increasing convergence of the analytical reasoning and visualization towards creation and discovery of geospatial knowledge for real world applications.

Object tags

- Tagging of objects—Ford VIN

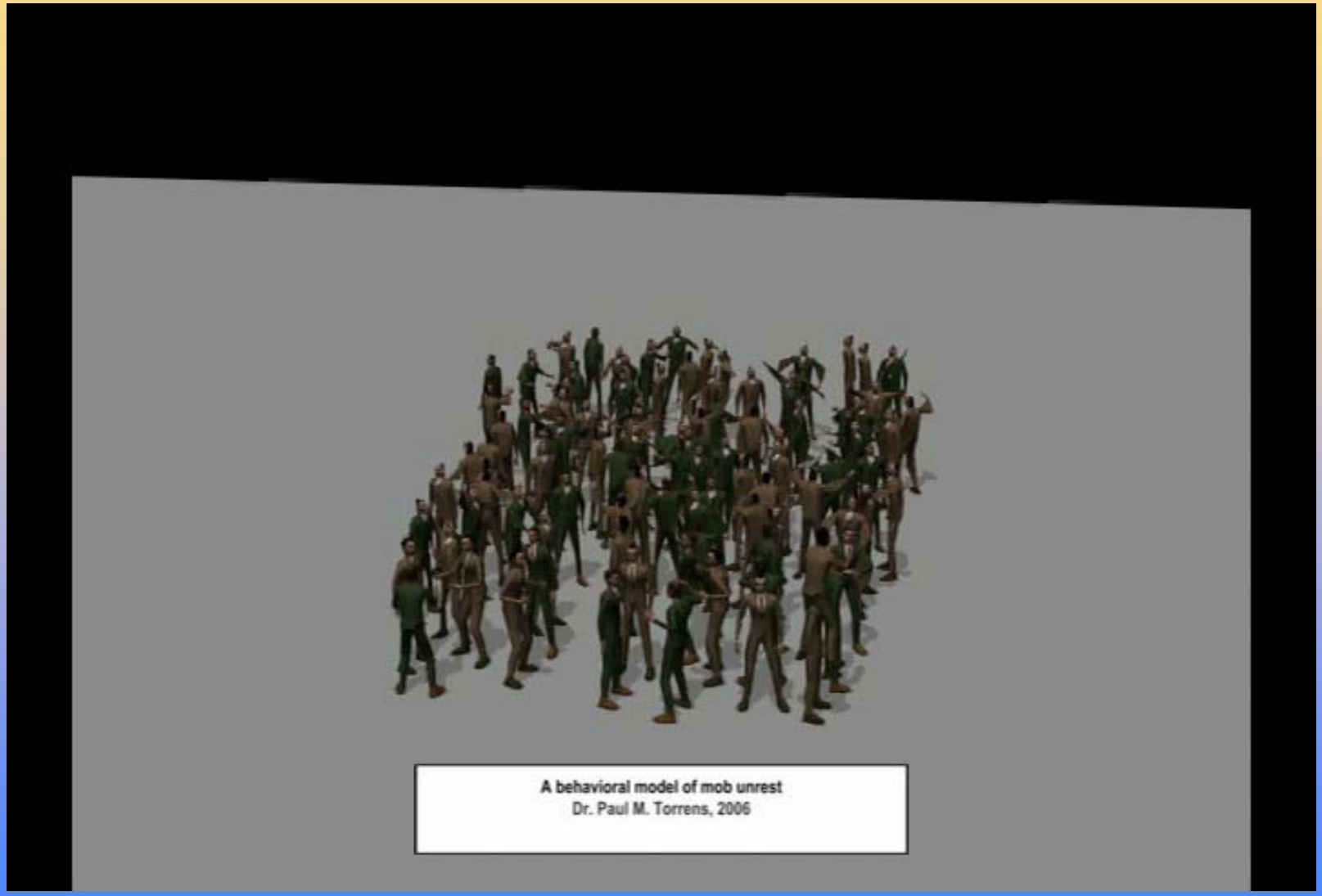
Object tags

- Tagging of objects—UPC bar-code

Pedestrian activity spaces

Agent-agent- Panic (Torrens)

Pedestrian activity spaces



Agent-agent- Mob rule (texture-, shadow-mapping)

Cities

John C. Crittenden

Hong Kong, China

43 buildings over 200 meters tall.

Metro/Urban Population: 6.9 million.

Chicago, USA

Birthplace of the modern skyscraper.

19 buildings over 200 meters tall.

Metro/Urban Population: 9.5 million.

Shanghai, China

China's biggest and most advanced city.

25 structures that are over 200 meters tall (468m downtown Oriental Pearl TV Tower).

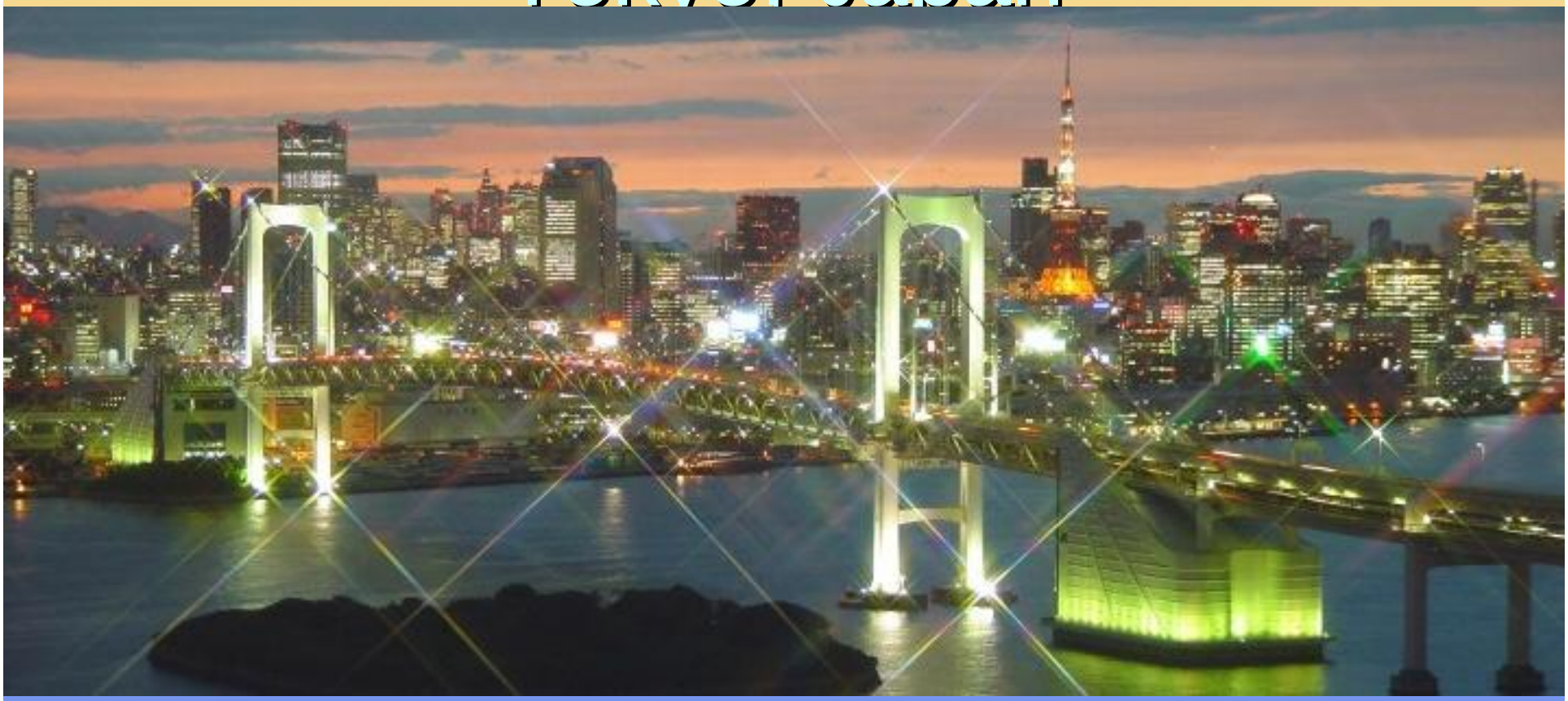
Metro/Urban Population: 13.1 million.

New York City, USA

47 buildings over 200 meters.

Metro/Urban Population: 21.0 million.

Tokyo, Japan



Tokyo is the world's most populated city.

Metro/Urban Population: 32.0 million.

World's largest fleet of helicopters.

15 structures at over 200 meters tall.

Singapore

One of the best (urban) planned and cleanliest metropolitan cities in the world.

8 over 200 meters.

Metro/Urban Population: 3.8 million.

Toronto, Canada

7 structures in its skyline that stand at over 200 meters.

Metro/Urban Population: 5.1 million.

Kuala Lumpur, Malaysia

Metro/Urban Population: 1.5 million.

Three of the 25 tallest buildings worldwide, Petronas Towers.

Shenzhen, China

13 buildings at over 200 meters tall.

Metro/Urban Population: 4.2 million.

Seoul, South Korea

10 buildings over 200 meters tall.

Metro/Urban Population: 20.8 million.

Sao Paolo, Brazil

Only one over 200 meters tall.

Fleet of over 500 helicopters, the second largest helicopter fleet in the world.

Metro/Urban Population: 18.3 million.

Sydney, Australia

Metro/Urban Population: 4.2 million.

8 buildings over 200 meters tall.

Frankfurt, Germany

Five structures that are over 200 meters tall.

Metro/Urban Population: 4.1 million.

Dubai, United Arab Emirates

Seven structures in this city at over 200 meters.

Metro/Urban Population: 1.6 million.

Seattle, USA

4 buildings over 200 meters.

Metro/Urban Population: 3.6 million.

Pittsburgh, USA

Metro/Urban Population: 2.4 million.
Two buildings over 200 meters tall.

Guangzhou, China

Metro/Urban Population: 4.1 million.

Six structures at over 200 meters tall.

Dallas, USA

7 buildings over 200 meters.

Metro/Urban Population: 5.2 million .

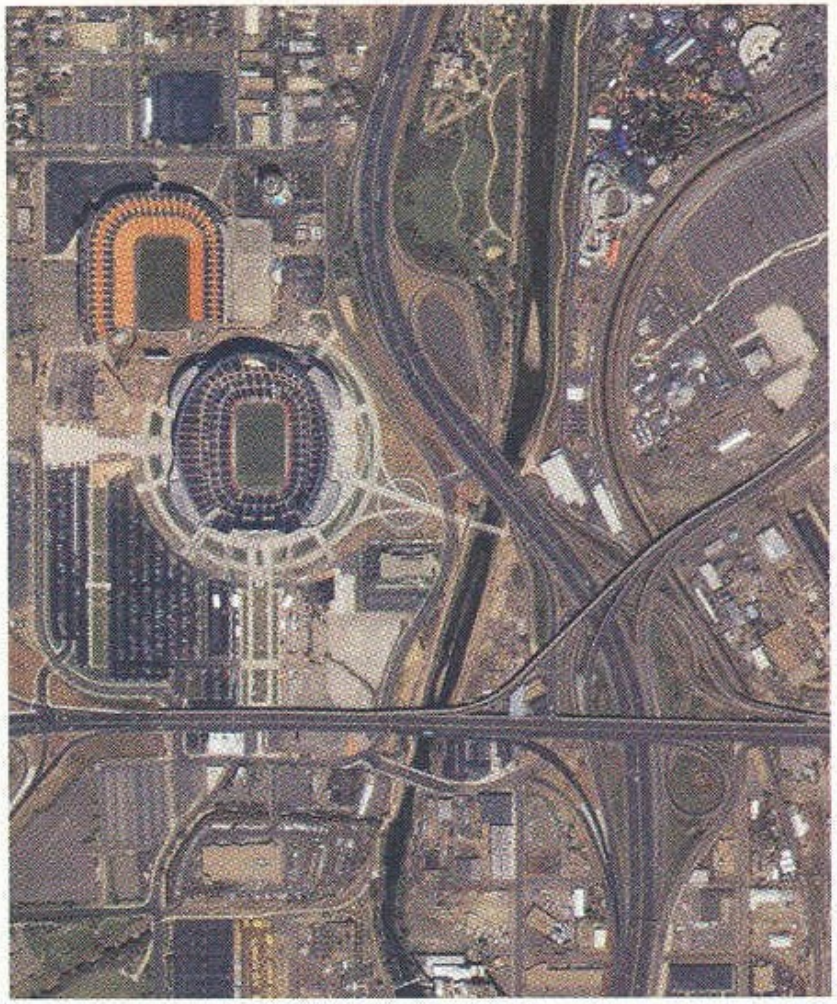
Reference

- http://www.diserio.com/top15-skylines.html

Engineering Complex Systems

The emergent properties of complex systems are far removed from the traditional preoccupation of engineers with designing technology around a purpose.

Urban systems are complex adaptive systems. They are more than the sum of its parts. They are constantly evolving. (e.g., Transportation is really access to function. Relationship of Teleworking, air quality, Ultrabroadband)



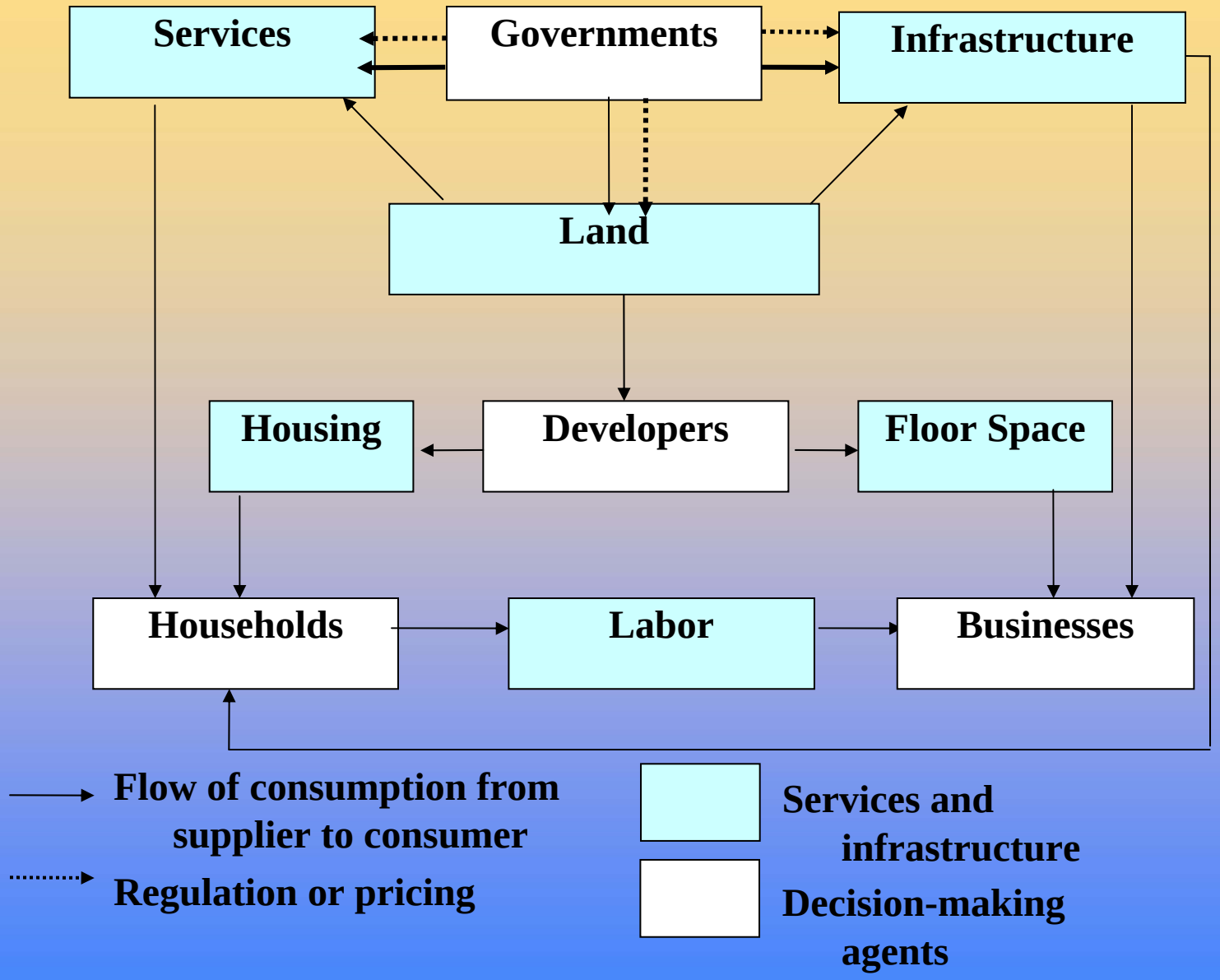
More than the sum of its parts: complex systems, such as highways, are constantly evolving.

Engineering Complex Systems

Urban systems are complex adaptive systems. Complex adaptive systems are networks that consist of many nonlinearly interacting elements and these elements can adapt their dynamic behavior to external influences. For example, the character of the built environment, the type of transportation systems, among others, determine urban-rural temperature differences (e.g., urban heat island), which in turn, affect water use, waste generation, noise, energy demand, micro-climate, air quality (ozone and carbon dioxide concentrations), and the quality of life of urban habitants (e.g., socioeconomic conditions).

Brown Revolution

- 3/4 of Earth Surface is transformed by Humans
- Current Epoch is now called Anthropocene period after Holocene which was the most recent geologic age and includes all the time since the last glaciation about 12,000 years ago (Geologic time scale, e.g., Creatacious or Jurrasic)


Services
Governments
Infrastructure
Land
Housing
Developers
Floor Space
Households
Labor
Businesses
Flow of consumption from supplier to consumer
Regulation or pricing
Services and infrastructure
Decision-making agents

Computable tags

- RFID tag

Computable tags

- RFID tag

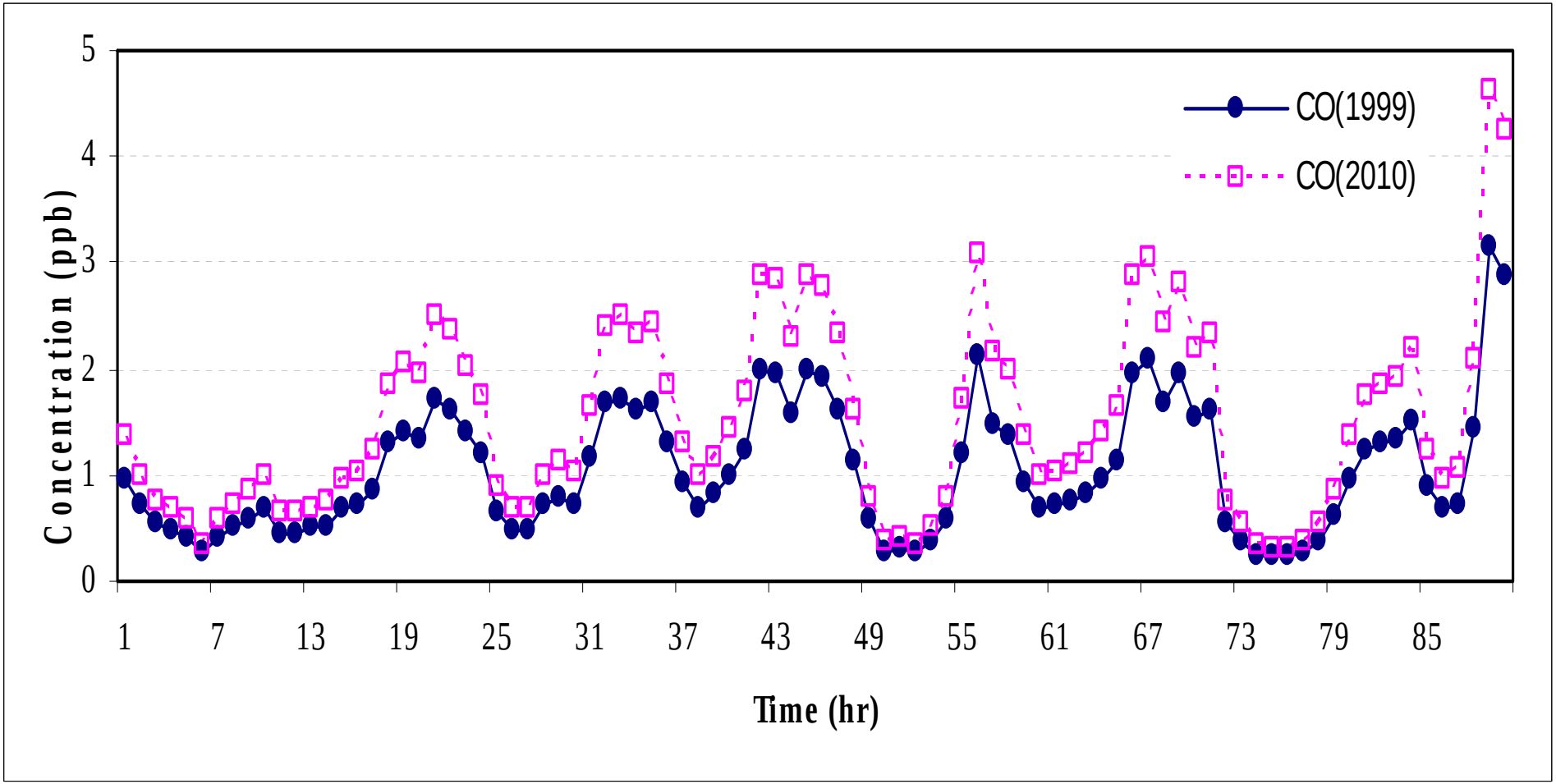
Urban tags

- Tagging is already ubiquitous in urban environments

Urban mark-up language

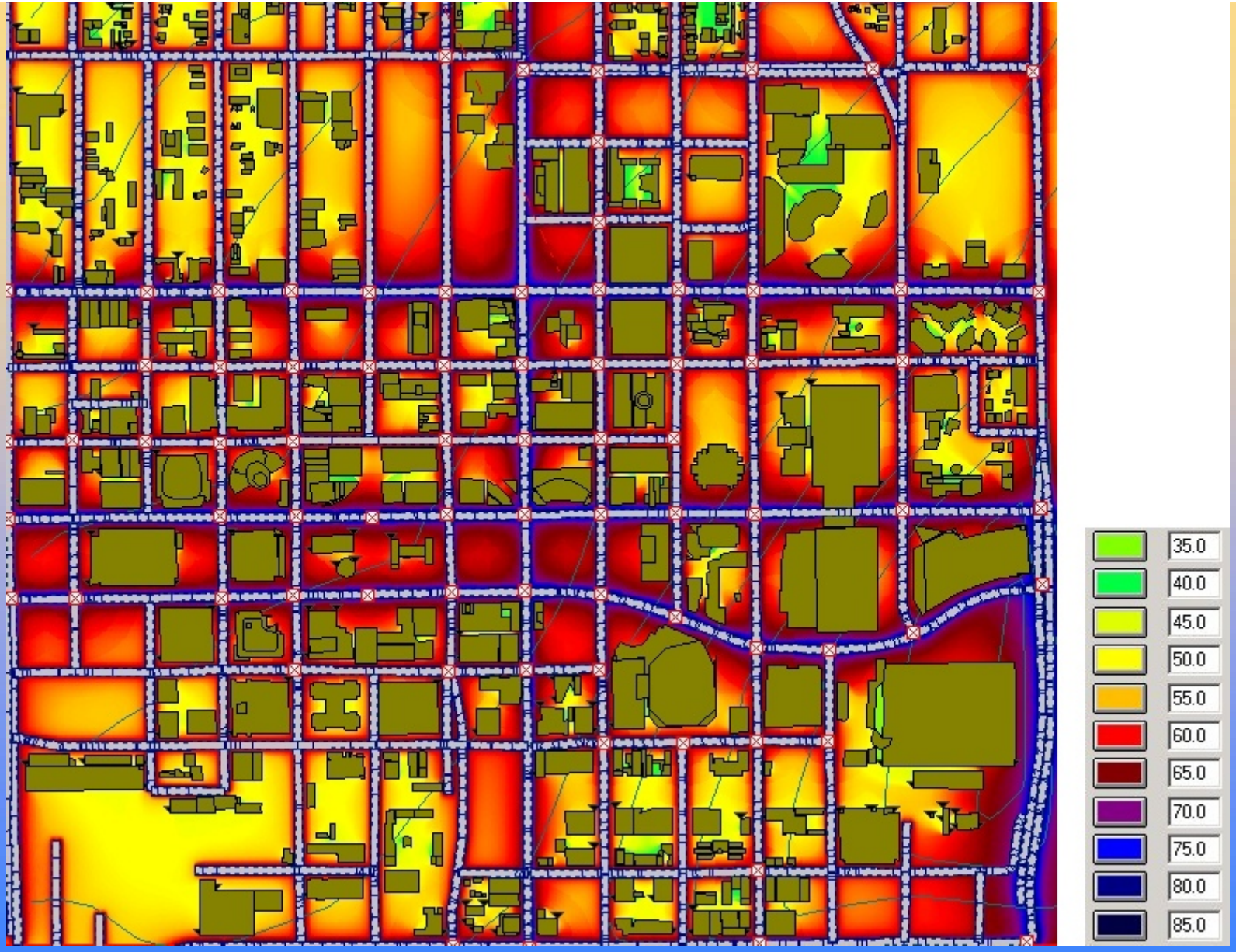
- Tagging is already ubiquitous in urban environments

Difference of maximum CO in entire domain between base & future years



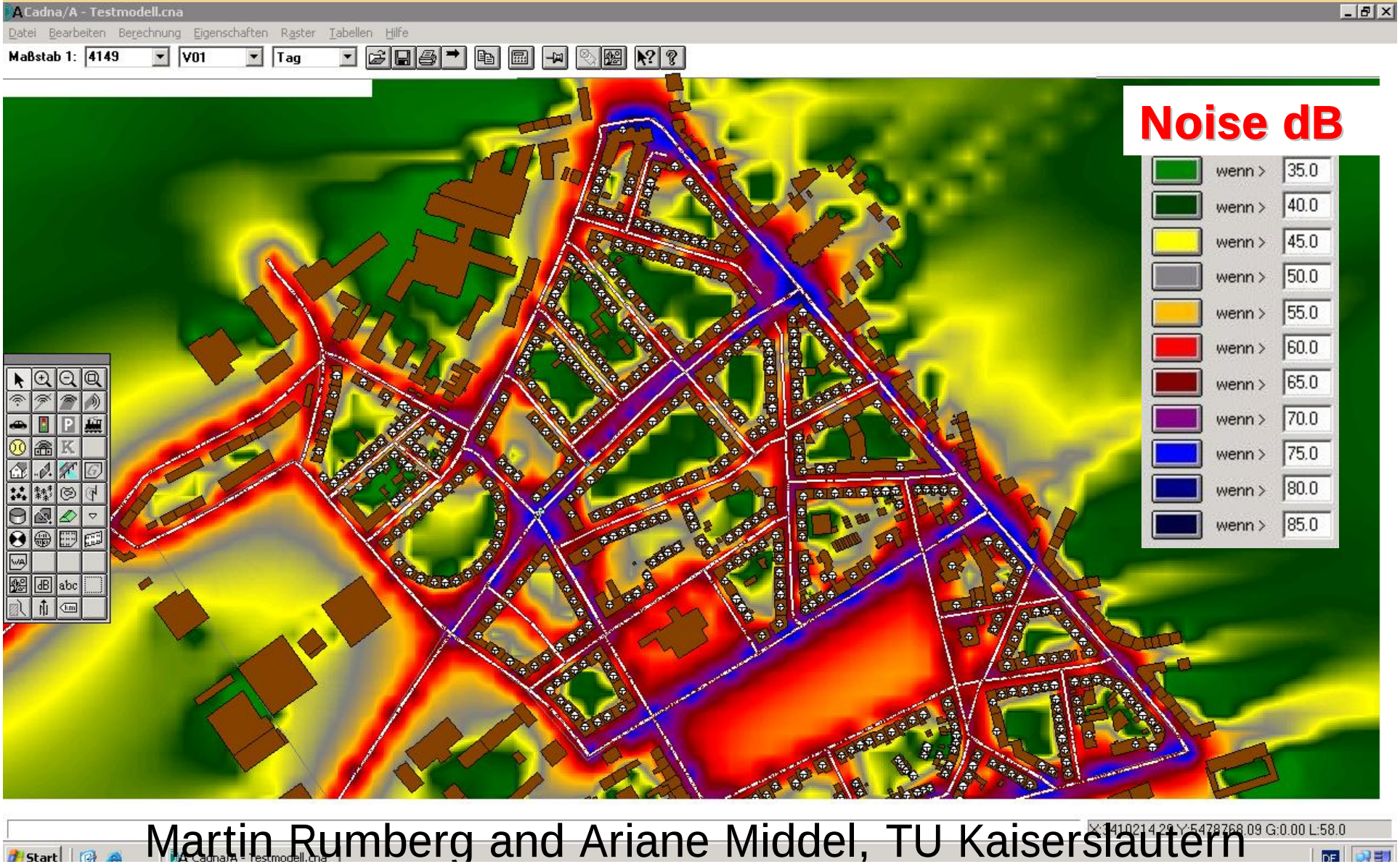
(Fernando, Choi, Li, Crittenden, Gerrity, Peng)

Noise – Predicted from Development Patterns and Traffic Patterns



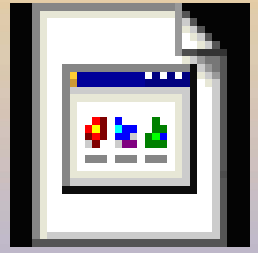
Martin Rumberg and Ariane Middel, TU Kaiserslautern

Noise – Predicted from Development Patterns and Traffic Patterns



Martin Rumberg and Ariane Middel, TU Kaiserslautern

Groundwater Overdraft



dt_wateranimation.mov

Comparison of two systems for producing potable water.

One system uses water from a natural source which is transported into an area and a conventional treatment system;

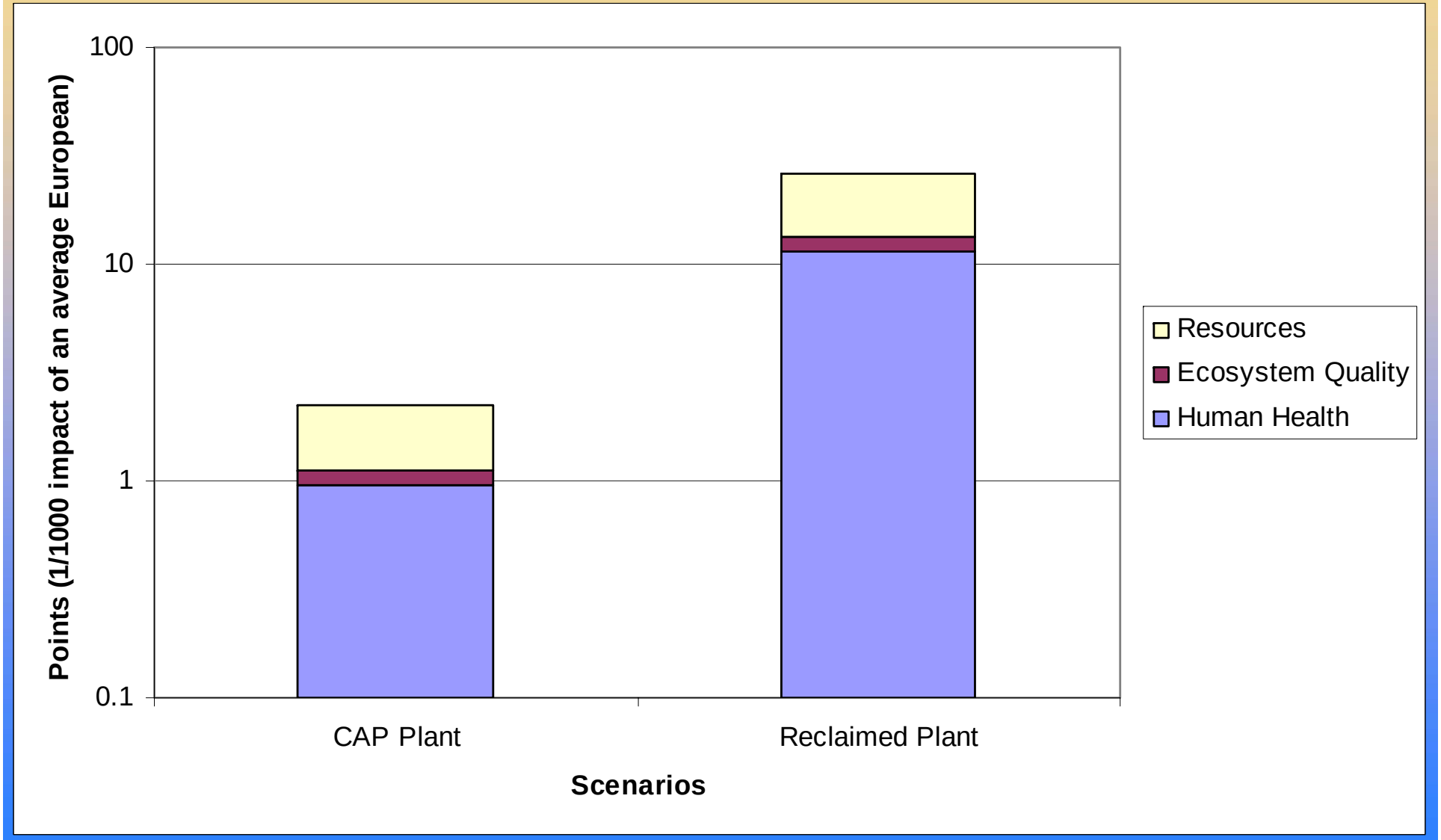
The other system uses reclaimed water and advanced water treatment systems.

Energy accounts for more that 99% of the impacts.

*DALY = disability adjusted life years; which combines the number of years of life lost and the numbers of years of life lived disabled. (World Bank)

Endpoint	Impact Category Indicators (units)
Resources	Depletion of fossil fuel (MJ surplus energy)
	Depletion of minerals (MJ surplus energy)
Ecosystem Quality	Land use (PDF*m^2*yr)
	Acidification/eutrophication (PDF*m^2*yr)
	Ecotoxicity (PDF*m^2*yr)
Human Health	Climate change (DALY)*
	Ozone layer depletion (DALY)
	Carcinogenic substances (DALY)
	Respiratory effects (organic) (DALY)
	Respiratory effects (inorganic) (DALY)
	Ionising radiation (DALY)

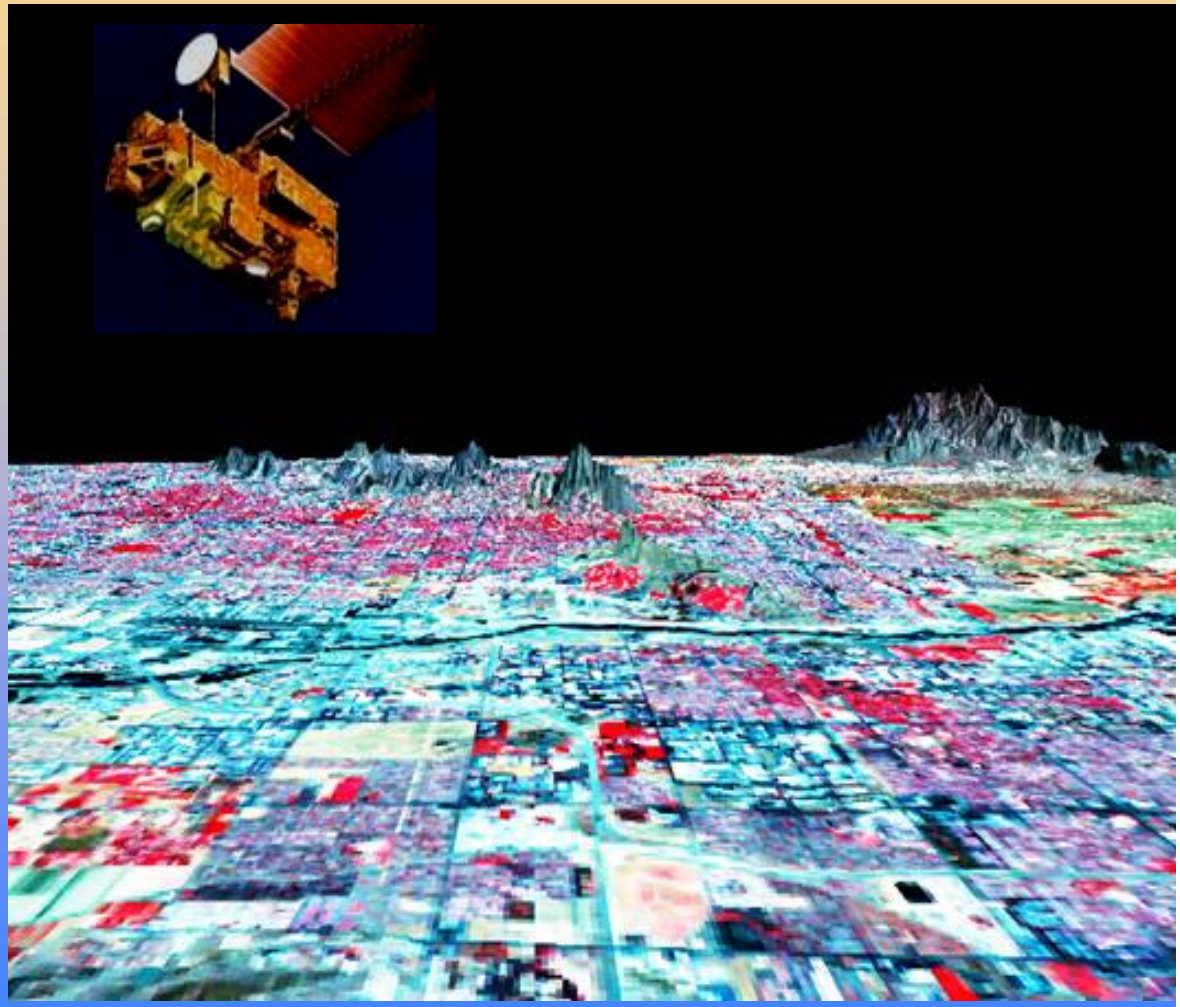
- The unit is referred to as an Eco-indicator point (Pt) and represents one thousandth of the yearly environmental load of an average European inhabitant.

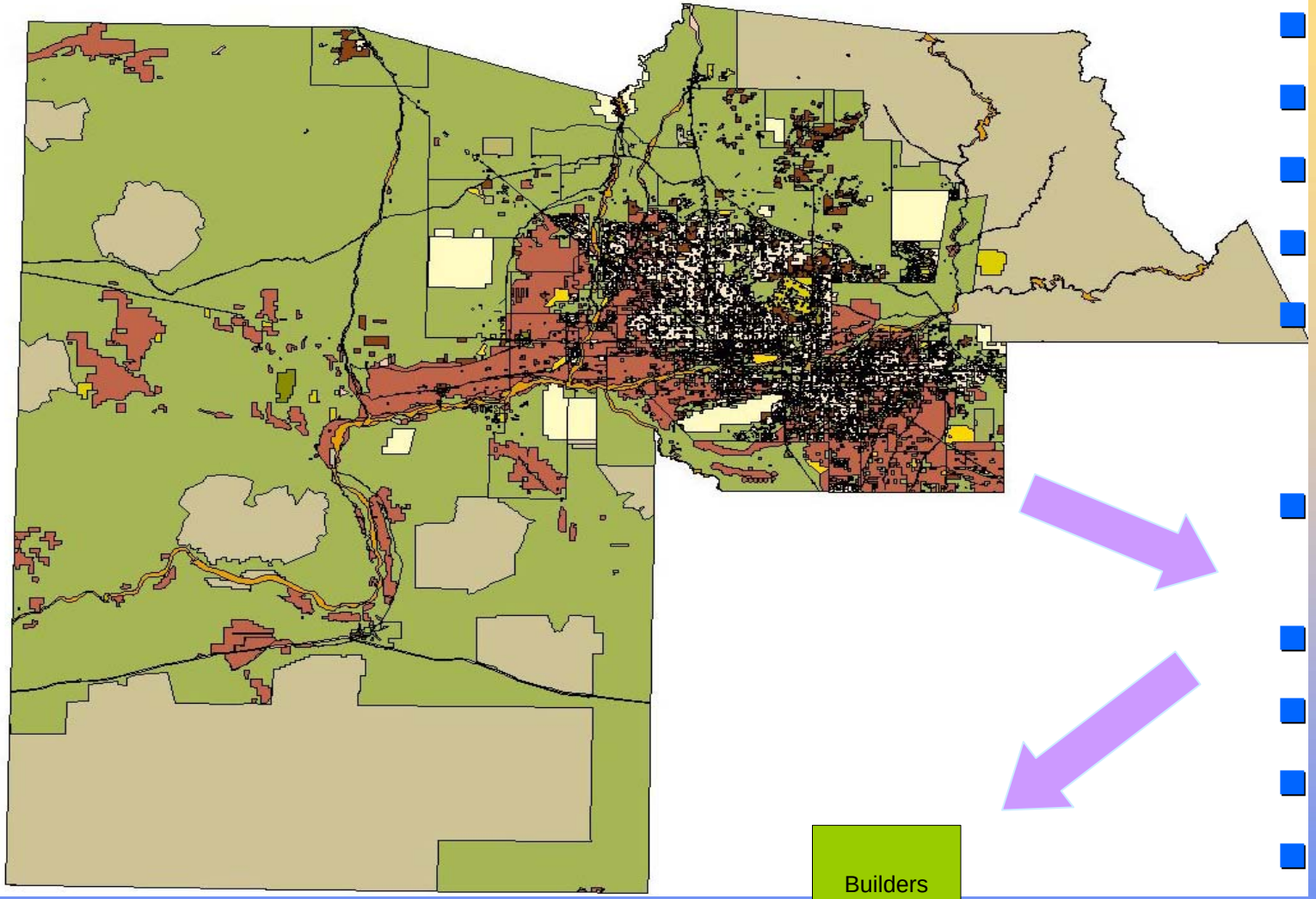


Greater Phoenix 2100 – Not Just about Rich Phoenix

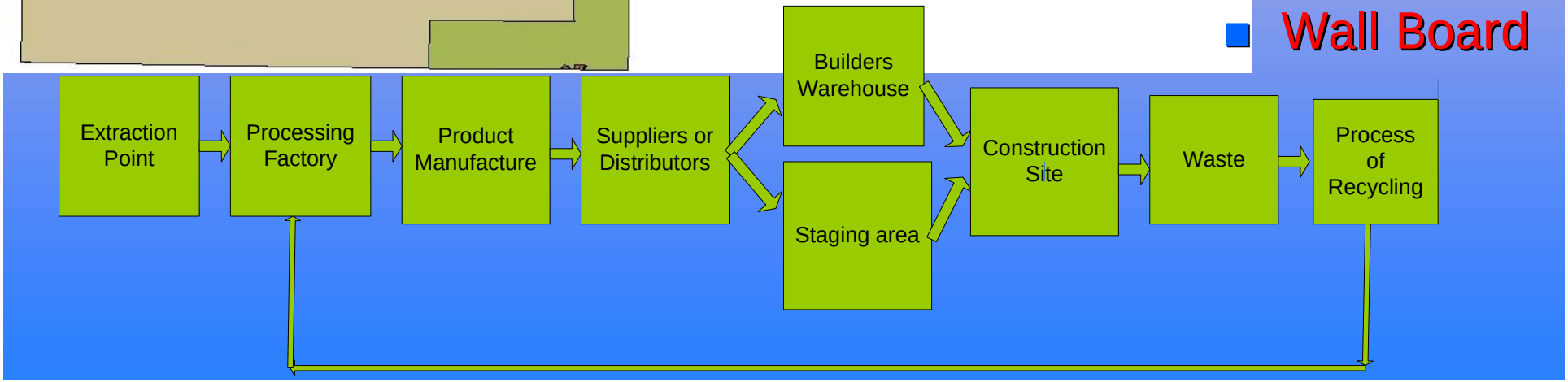
Visualization tools

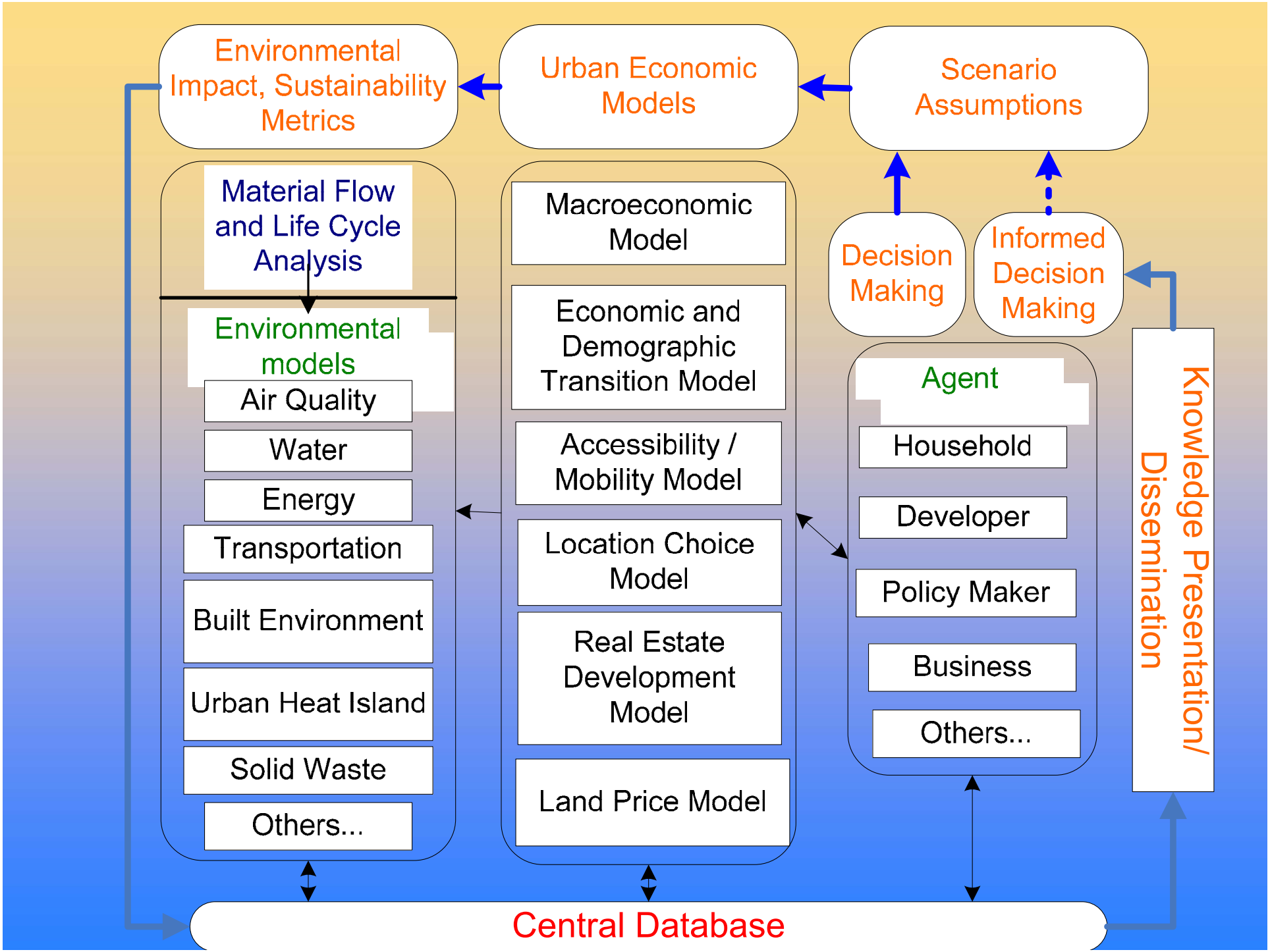
- Regional e-Atlas
- SIM Phoenix
- Decision Theater
- Urban-SAT(s)





- Energy Use
- Lumber
- Concrete
- Roof tiles
- Flooring (carpet, tile)
- Glass – (windows)
- Paint
- Steel
- Insulation
- Wall Board

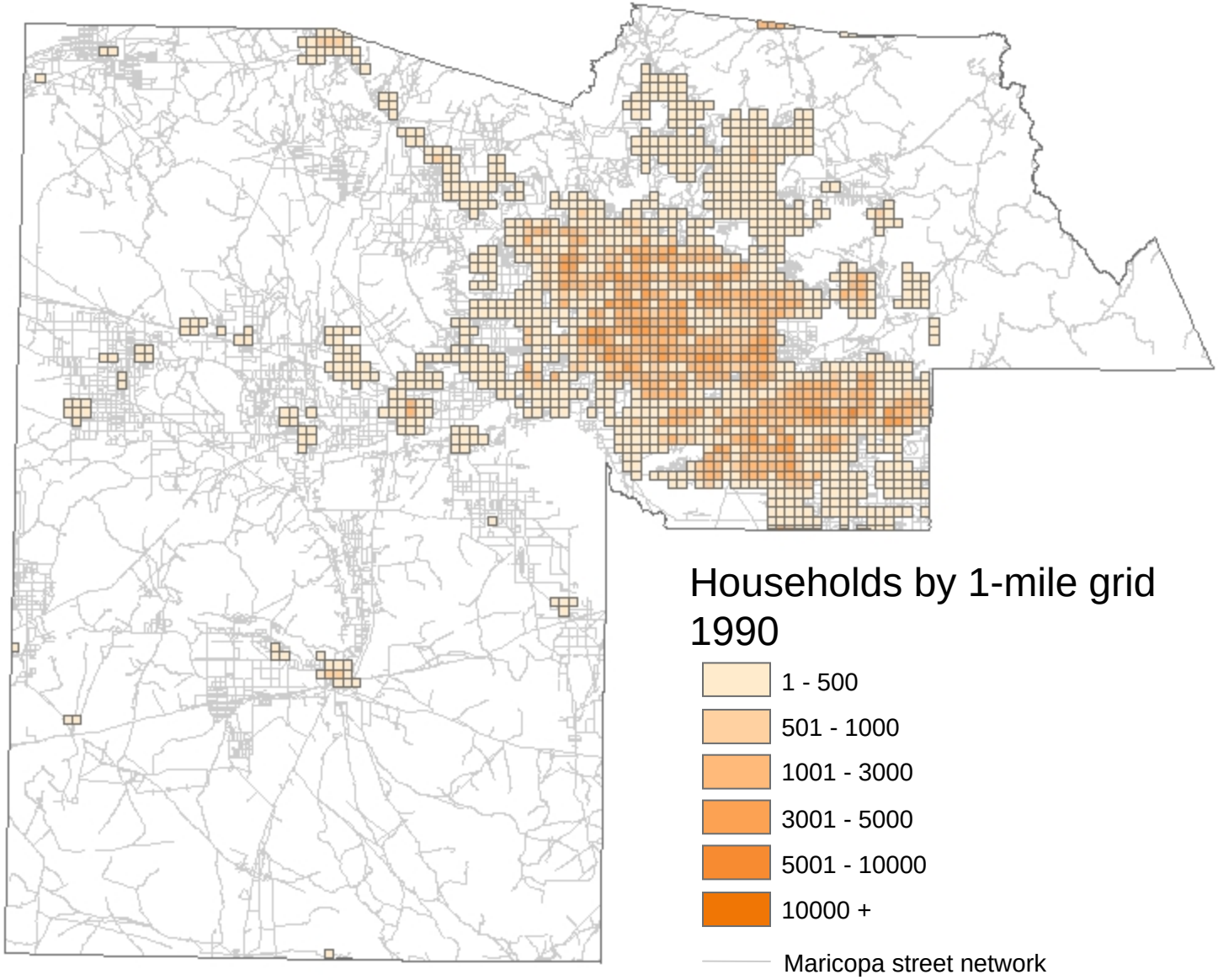



Environmental Impact, Sustainability Metrics
Urban Economic Models
Scenario Assumptions
Material Flow and Life Cycle Analysis
Environmental models
Air Quality
Water
Energy
Transportation
Built Environment
Urban Heat Island
Solid Waste
Others...
Macroeconomic Model
Economic and Demographic Transition Model
Accessibility / Mobility Model
Location Choice Model
Real Estate Development Model
Land Price Model
Decision Making
Informed Decision Making
Agent
Household
Developer
Policy Maker
Business
Others...
Knowledge Presentation/ Dissemination
Central Database

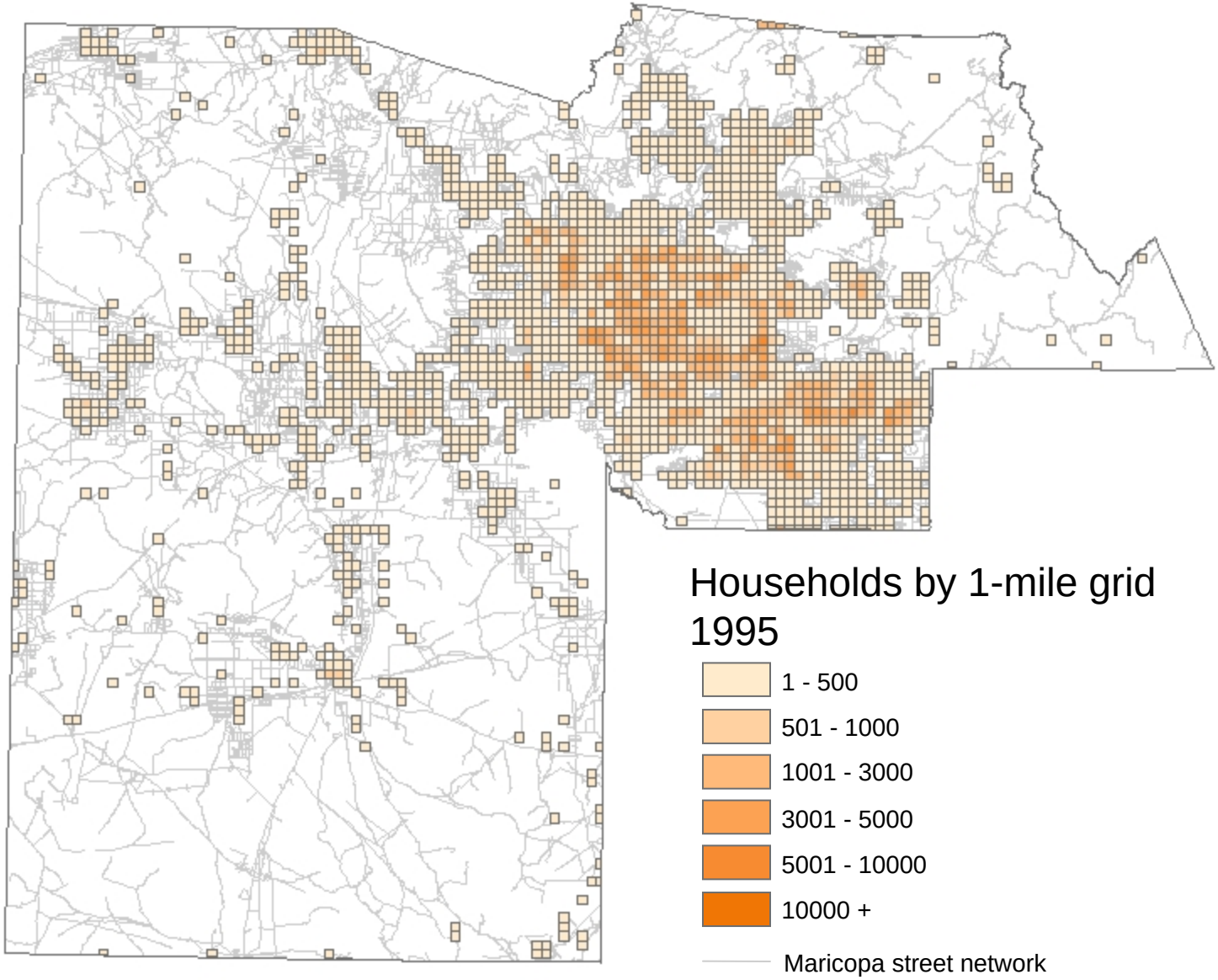
Simulating Household Location from **1990 to 2015** In Maricopa County

Business as usual scenario
(Guhathakurta, Konjevod, Li, Crittenden, Joshi, Elangovan*)*

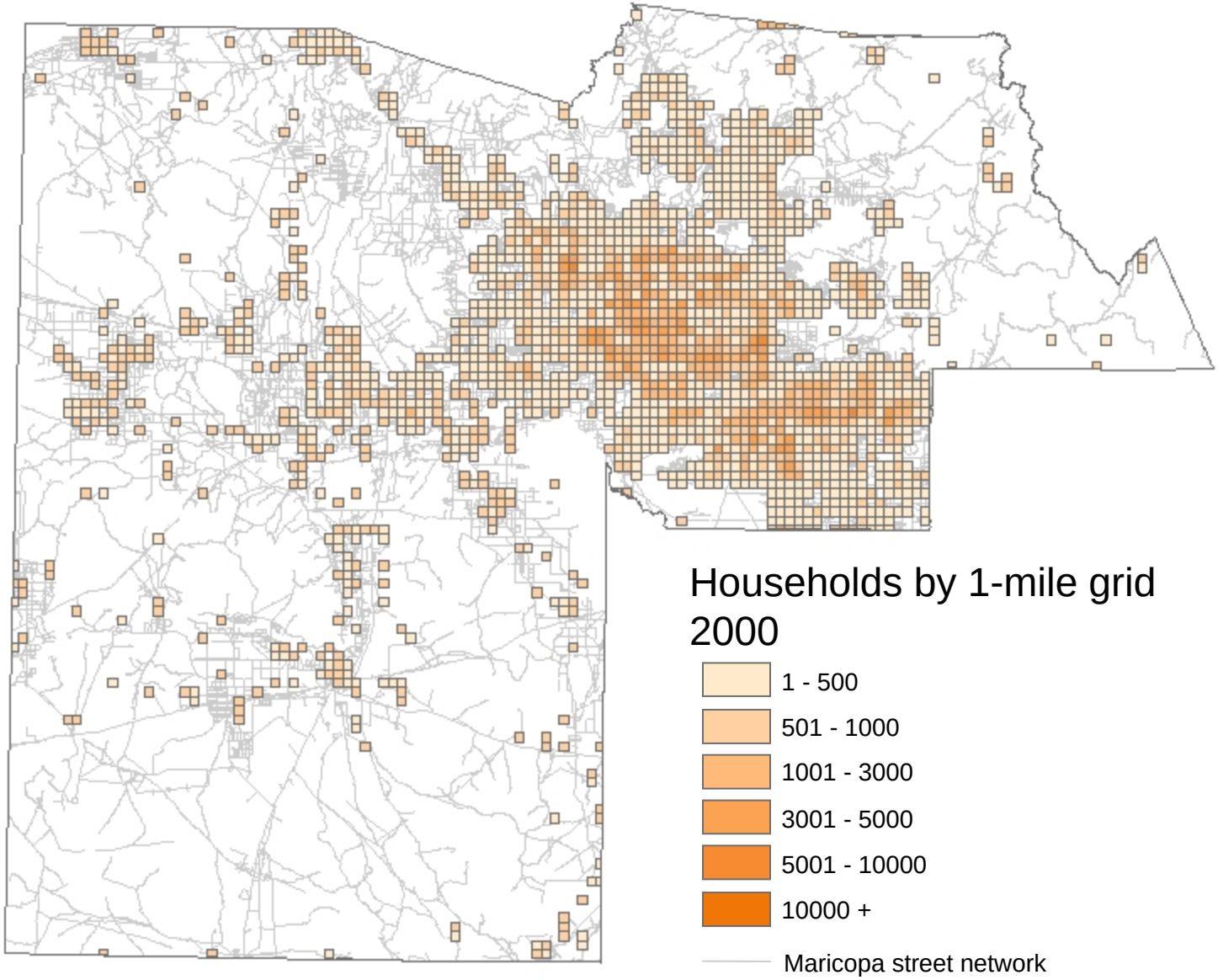
Change of household distribution between 1990 and 2015



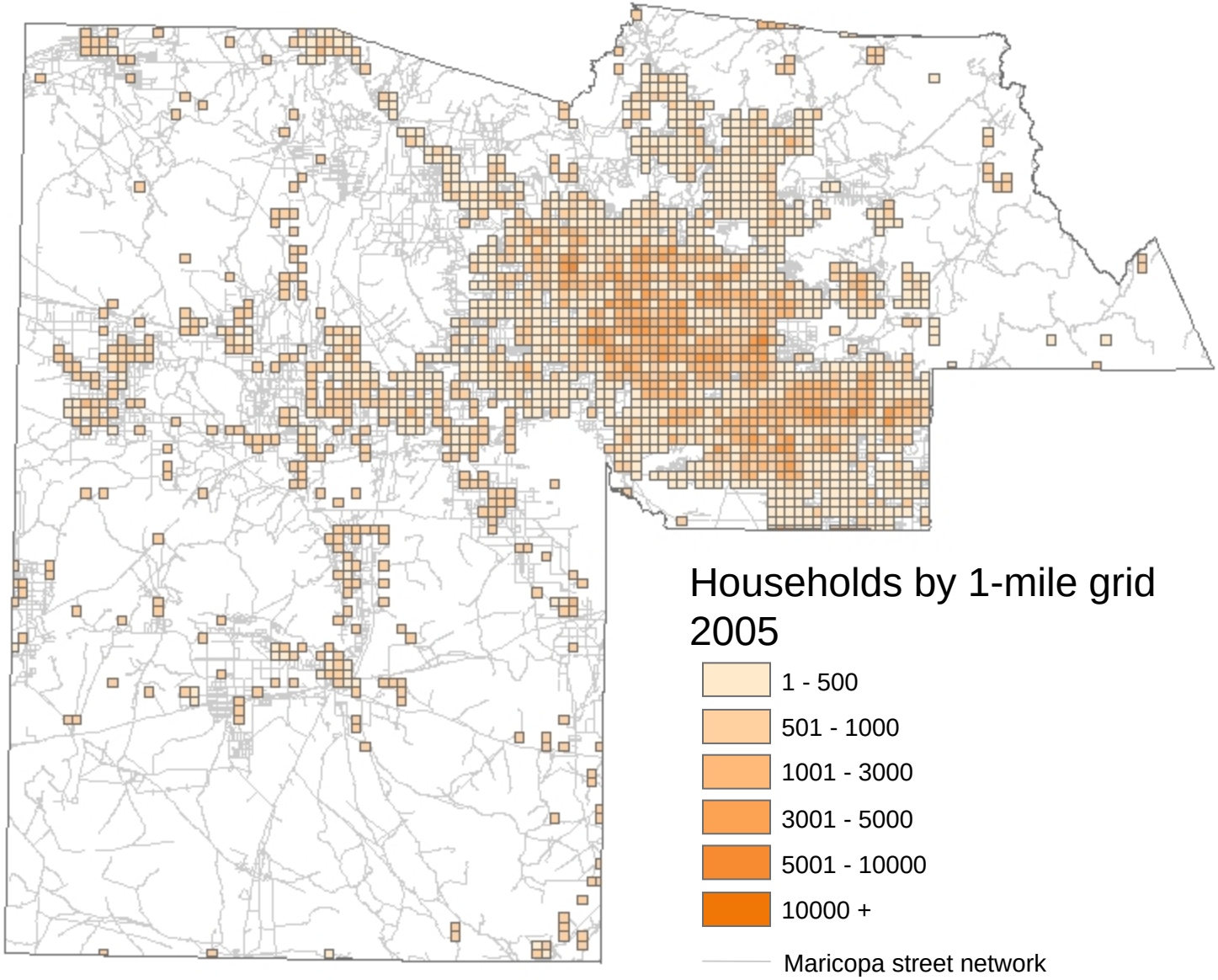
Change of household distribution between 1990 and 2015



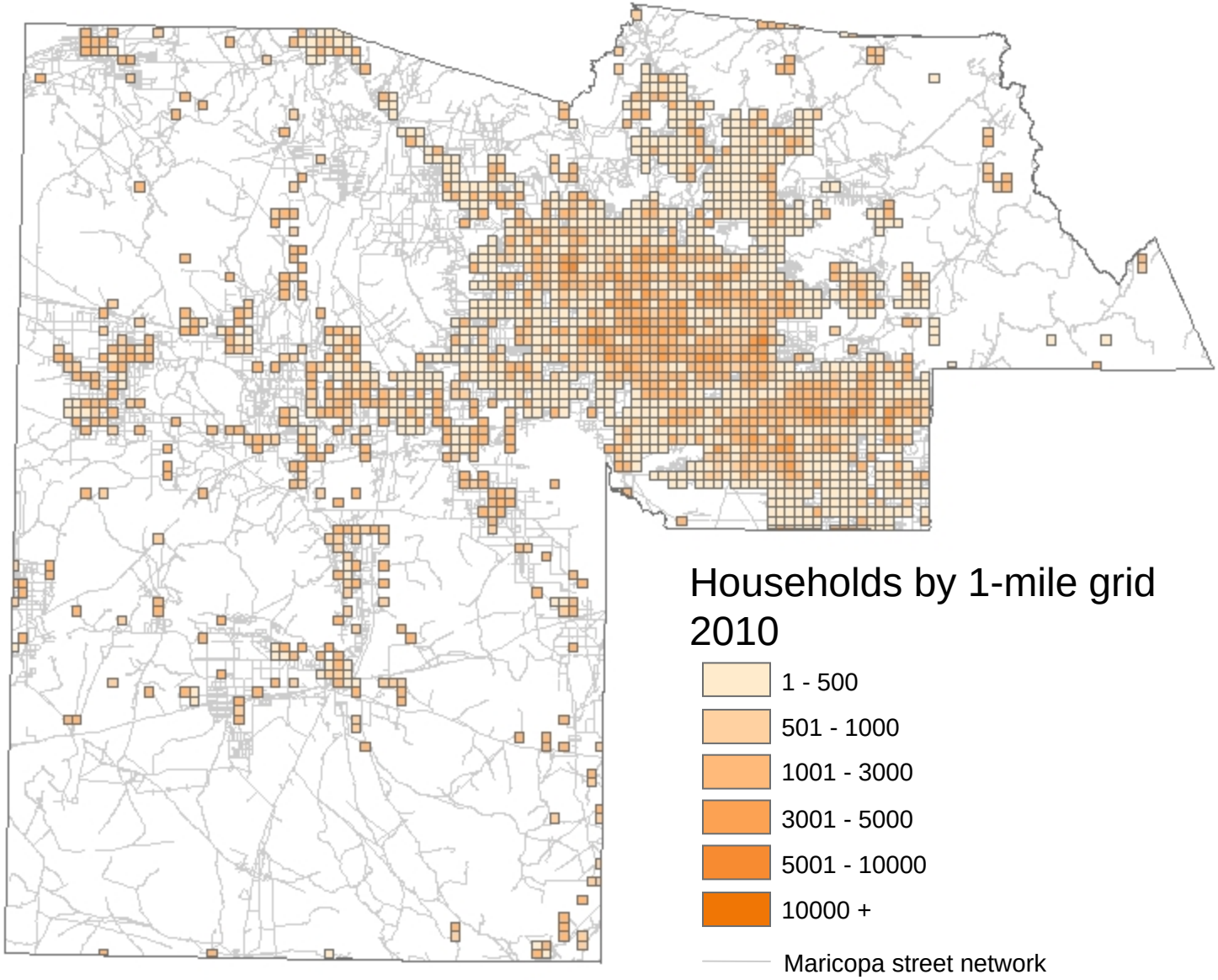
Change of household distribution between 1990 and 2015



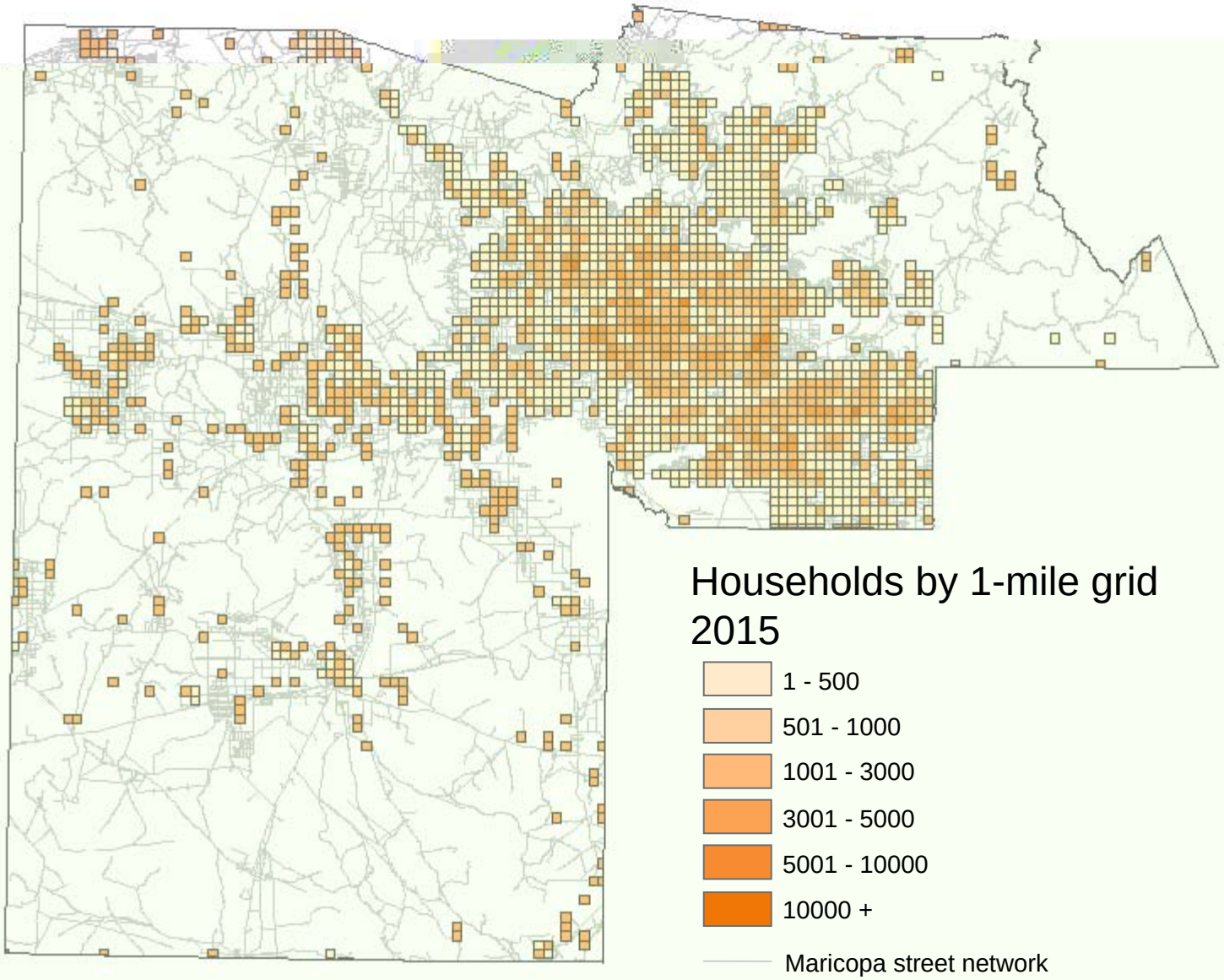
Change of household distribution between 1990 and 2015



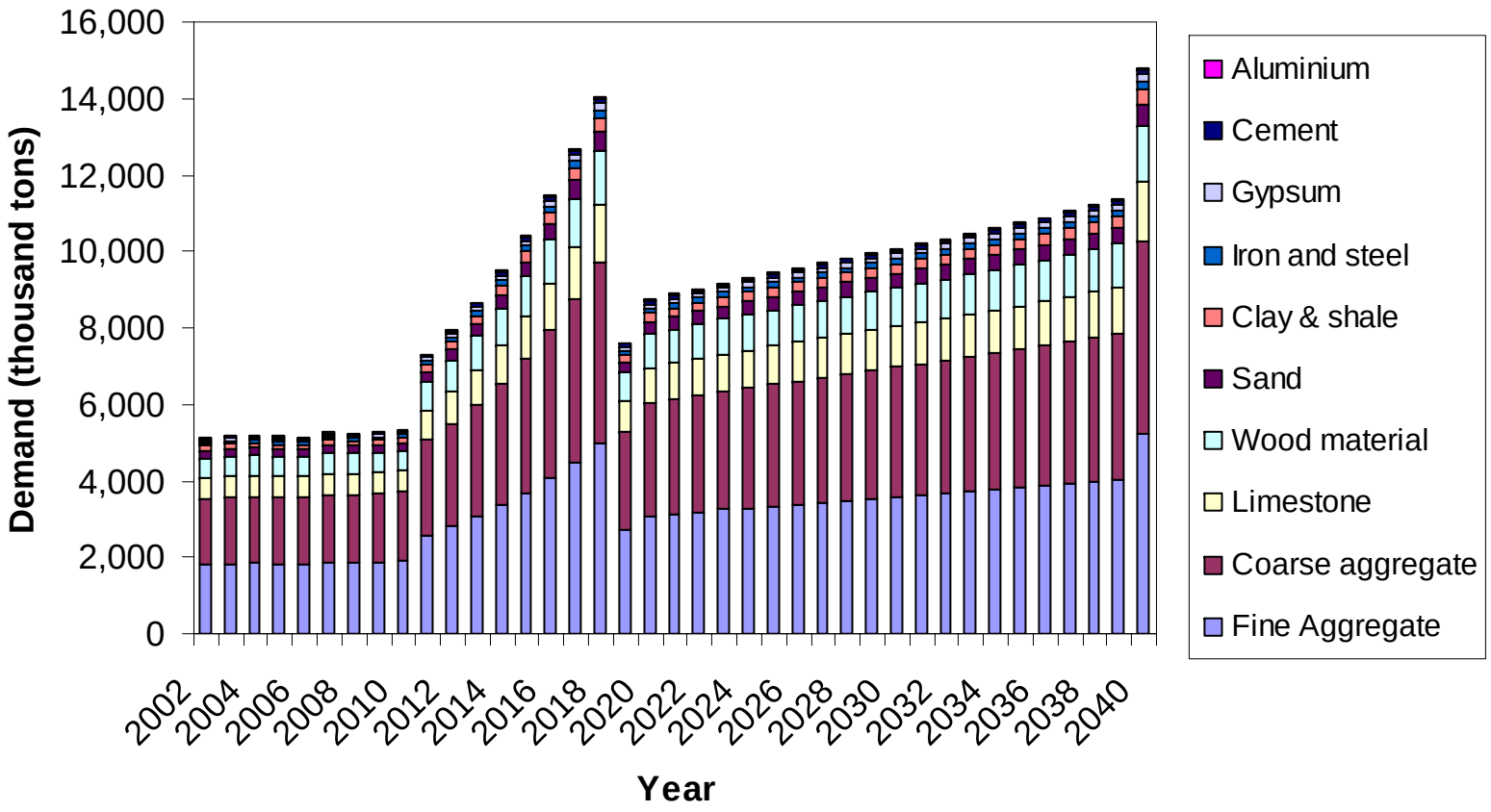
Change of household distribution between 1990 and 2015



Change of household distribution between 1990 and 2015



Annual Construction Material Demands From 2002 to 2040



Consortium of Rapidly Developing Regions

- Develop visualization tools to help policy-makers better understand implications of their decisions
- Make science and engineering results more accessible
- Promote regional and long-term perspectives
- Partner with businesses and state agencies

International Institute for Sustainability: Consortium Of Rapidly Developing Regions

URBAN SUSTAINABLE ENGINEERING AND SCIENCE

John C. Crittenden, Ph.D., N.A.E., P.E.

Director of Consortium

Of Rapidly Developing Regions

Richard Snell Presidential Chair of Civil and Environmental Engineering,
ASU Main Campus
Ira A. Fulton School of Engineering
Department of Civil and Environmental Engineering

Email: j.crittenden@asu.edu

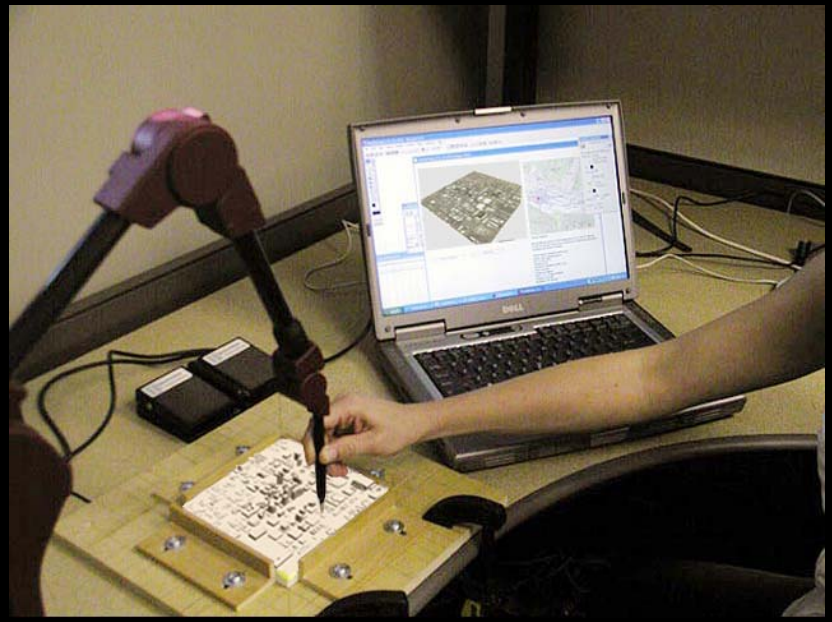
http://sustainability.asu.edu/iishome/index.jsp

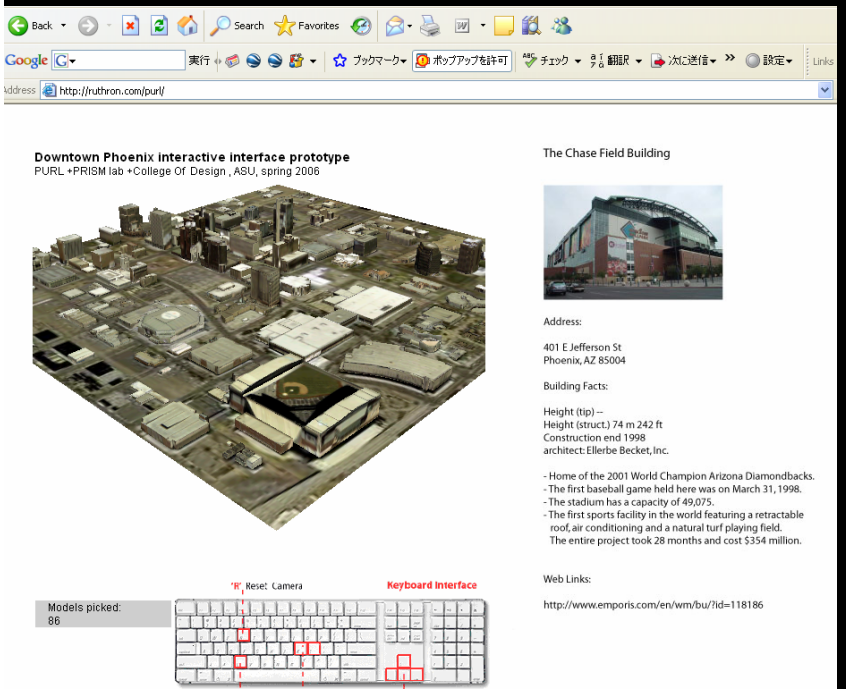
ARIZONA STATE UNIVERSITY

Digital Phoenix:

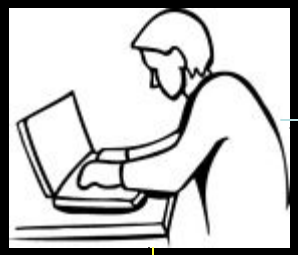
3D modeling…

Digital Phoenix:





Digital Phoenix:



SQL Queries

Rerun of Exported Data

Travel Model

Generating Scenarios of Future Growth

SR Tool

my.scenario
(XML file)

MySQL Output DB
(model results)

MySQL Input DB
(estimates, forecasts, plans, constraints)
Sample DB: Eugene_1980_ baseyear

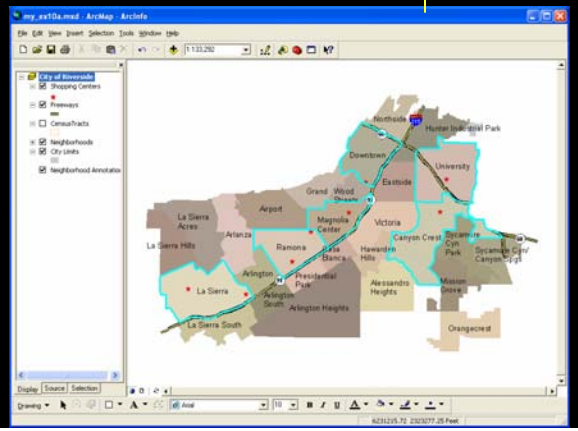
Connection & queries

JDBC

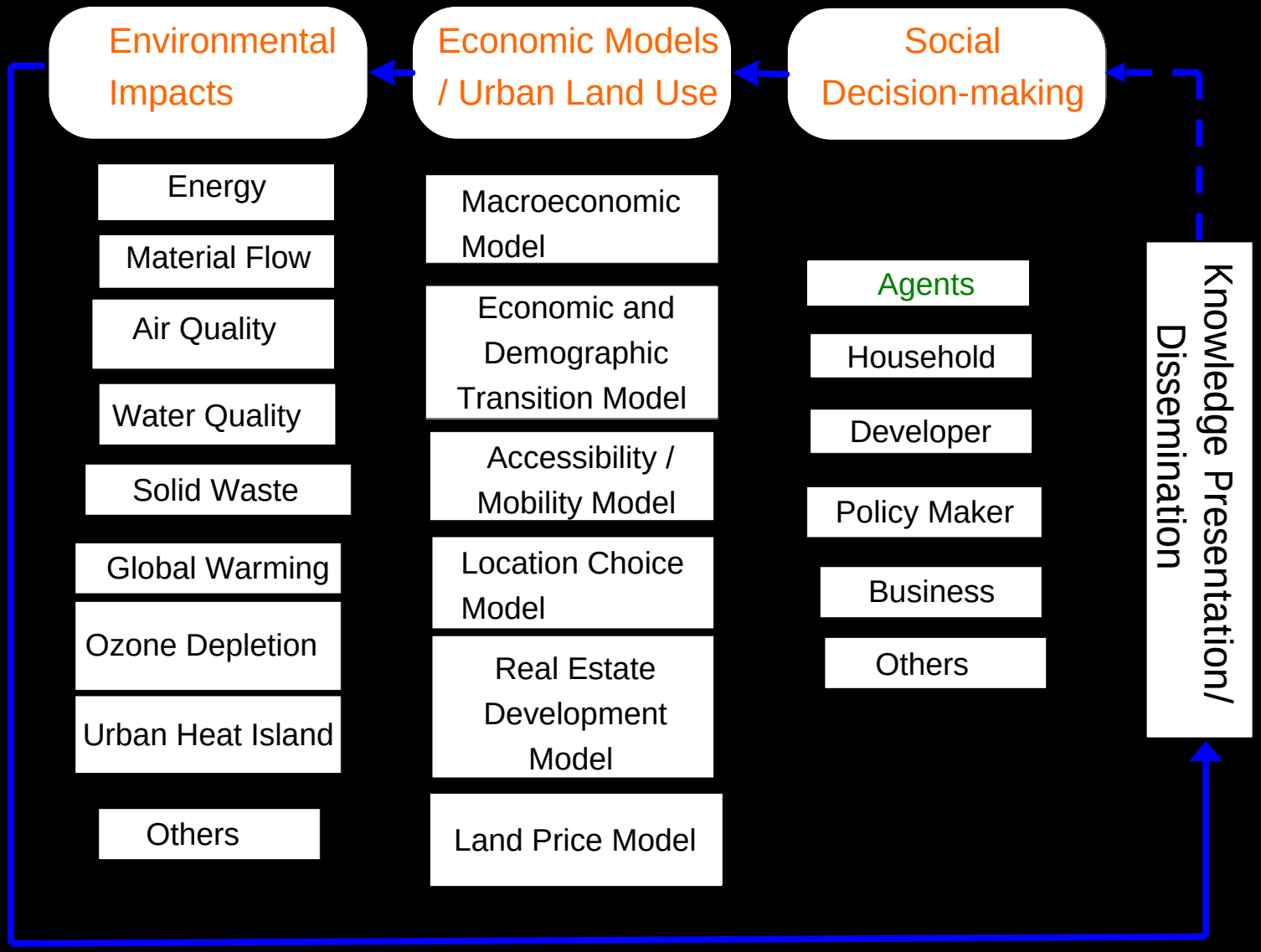
Query Results

UrbanSim
(urbansim.bat my.scenario)

SQL; JDBC



Framework of simulation models

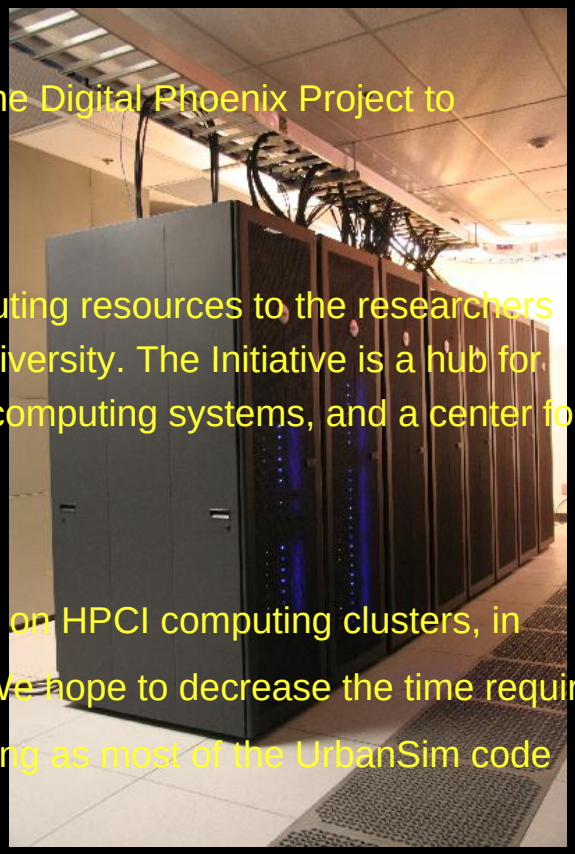


Digital Phoenix:

Parallel UrbanSim

Steffen Eikenberry, Student, Fulton HPCI

The Fulton High Performance Computing Initiative (HPCI) is working with the Digital Phoenix Project to accelerate the performance of UrbanSim through parallel processing.



Overview of the HPCI

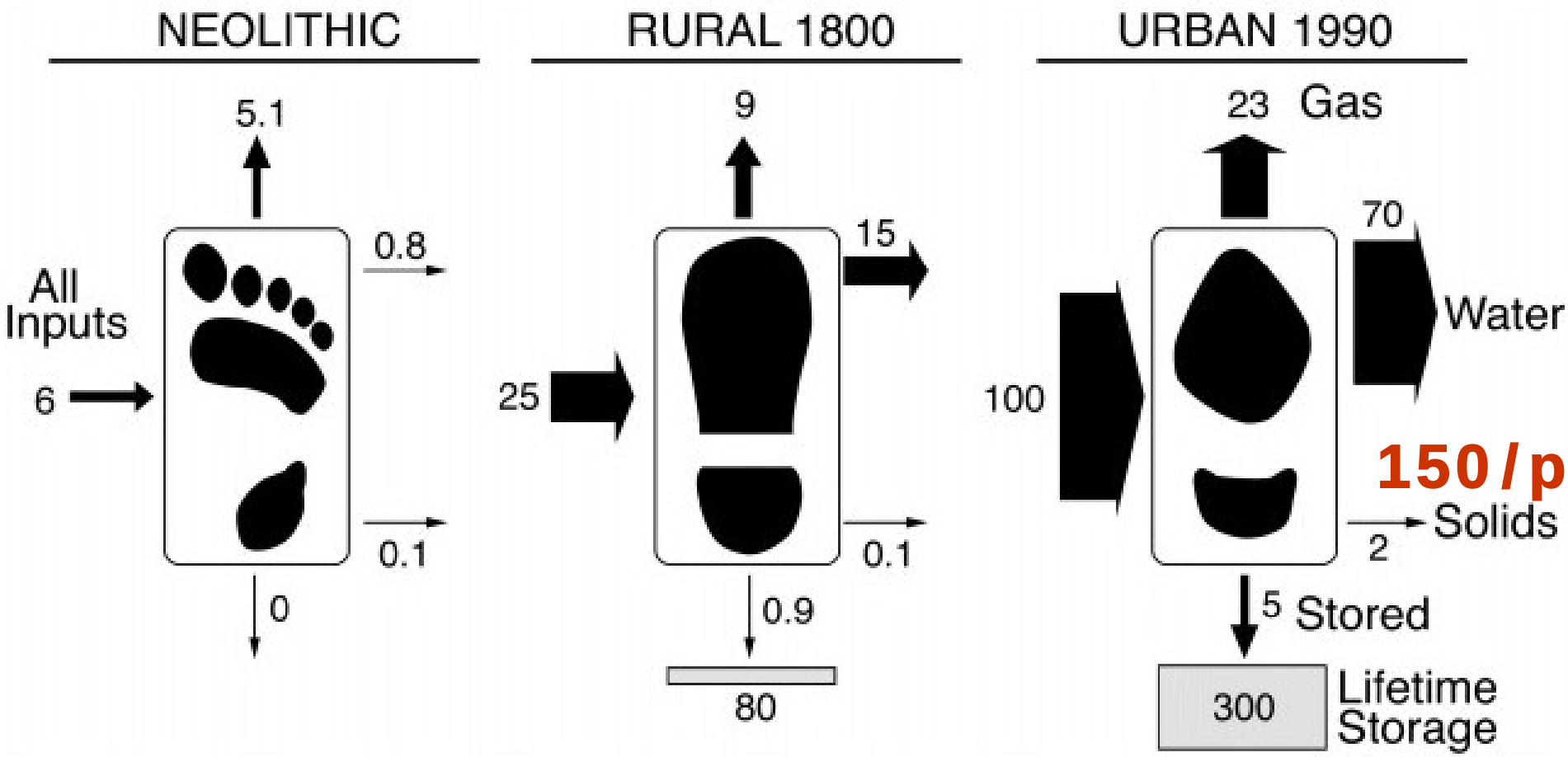
The Fulton High Performance Computing Initiative offers world class computing resources to the researchers and students in the Ira A. Fulton School of Engineering at Arizona State University. The Initiative is a hub for research in computing, collaborative research in the application of parallel computing systems, and a center for education in high performance computing systems.

HPCI and Digital Phoenix

Our goal is to modify the UrbanSim program so that it can be run in parallel on HPCI computing clusters, in order to enable real-time visualization and accelerate research progress. We hope to decrease the time required to run UrbanSim by at least an order of magnitude.Early results are promising as most of the UrbanSim code has been parallelized, resulting in a significant decrease in runtime.

ASU Ira A. Fulton school of engineering
ARIZONA STATE UNIVERSITY
High Performance Computing Initiative

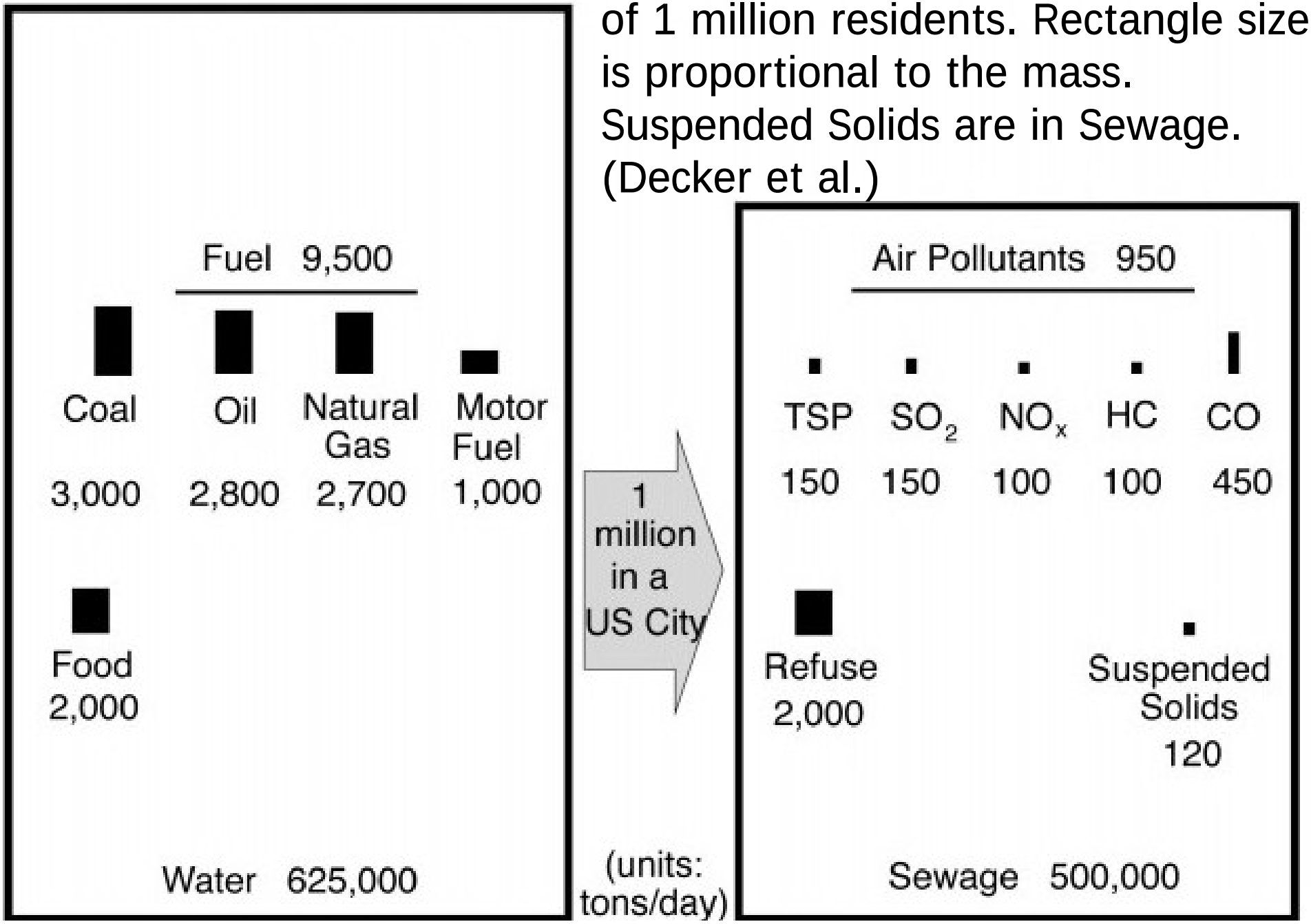
Regional/ Global Impacts: Urban Metabolism – Energy and Materials are Transformed into Durable Infrastructure and Waste



All units are tons per year per individual. Life time storage includes infrastructure and artifacts. (Decker et al.) Still increasing inputs by 2.5%/ year.

Urban Metabolism

All units are tons per day for a city of 1 million residents. Rectangle size is proportional to the mass. Suspended Solids are in Sewage. (Decker et al.)



Evolution of Environmental Issues

End-of-Pipe Treatment → Pollution Prevention → Environmentally Responsible Manufacturing → Sustainable Development

End-of-Pipe Treatment

- Reactive
- Reliance on abatement
- Driven by regulations
  - Manufacture
  - Product use
  - Disposal
- No regard for resource consumption
- Limited accountability

Pollution Prevention

- Reduce
- Reuse
- Recycle

Environmentally Responsible Manufacturing

- Proactive
- Beyond compliance
- Life cycle analyses
- Design for waste minimization, disassembly, material and energy conservation, etc.

Sustainable Development

- Triple bottom line
  - Economic
  - Environmental
  - Social
- Good individual and corporate citizens and Government
- Multifaceted accountability for the both Public and Private Sectors

Credit: Jerry Rogers, GM, Cliff Davidson, CMU

Evolution of EES Education

- Conventional and Toxic Pollution Transport, Impact, Mitigation and Risk Reduction
- We need is to focus on systems level activities.
- This includes: Industrial Ecology, Earth Systems Engineering, Engineering the Anthrosphere to Live within the Means of Nature (or our alteration of it).
- Start by examining material and energy flow and its consequences in urban systems (e.g., toxic releases, conservation, environmental disturbances, etc.)

New Pedagogy

System Boundaries (Design Decision Layers)			
Environ. Responsible Manufacturing (Gate to Gate)	**Life Cycle Analysis (Cradle to Grave)**	**Industrial Ecology (Industry/Industry Interactions)**	**National/ International Resource Use**
Example: Chemical Selection	**Example: Electric vs. gasoline**	**Example: Road construction**	**Example: International Economic Analysis**
Tool Option: OPPT P2 Framework	**Tool Option: Life Cycle Assessment**	**Tool Option: Input/Output Analysis**	**Tool Option: Material Flow Analysis**

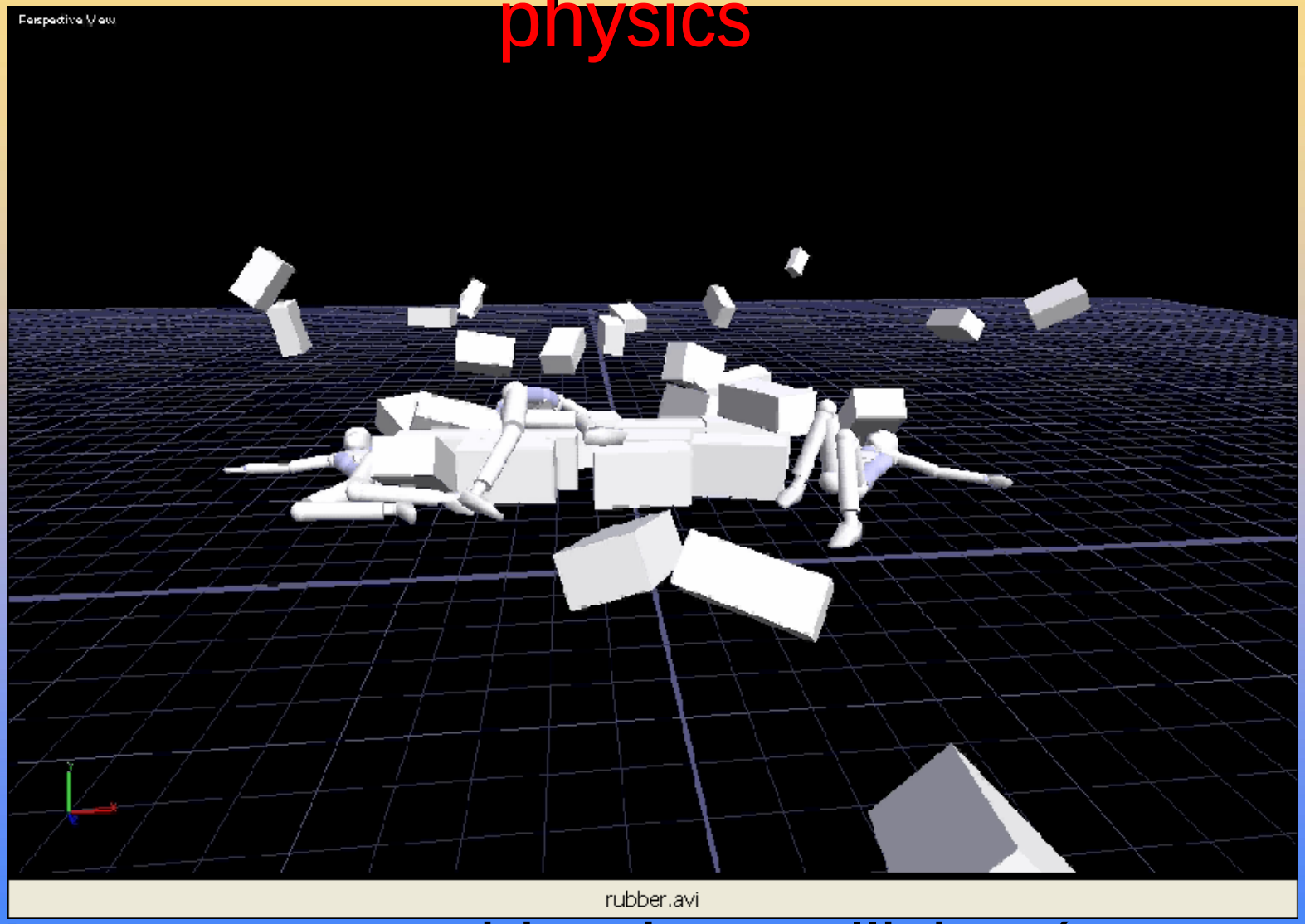
Center for Sustainable Engineering

- Consortium between CMU (Lead for Education Module Development), UT(Lead for Benchmarking), ASU
- Course Module Development and Bookbuild Web Site – NSF: Vetting, Distribution and Achiving of Course Materials
- Benchmarking What Is Being Taught in Engineering in the US (~1500 Universities in the US)
- Workshops July 17 – 20, 2007 and Winter 2008
- See http://www.csengin.org/ or #1 hit on Google
- Author Guidelines will be up soon.

Advances in Urban Geocomputation – Agent Modeling and Geospatial Modeling

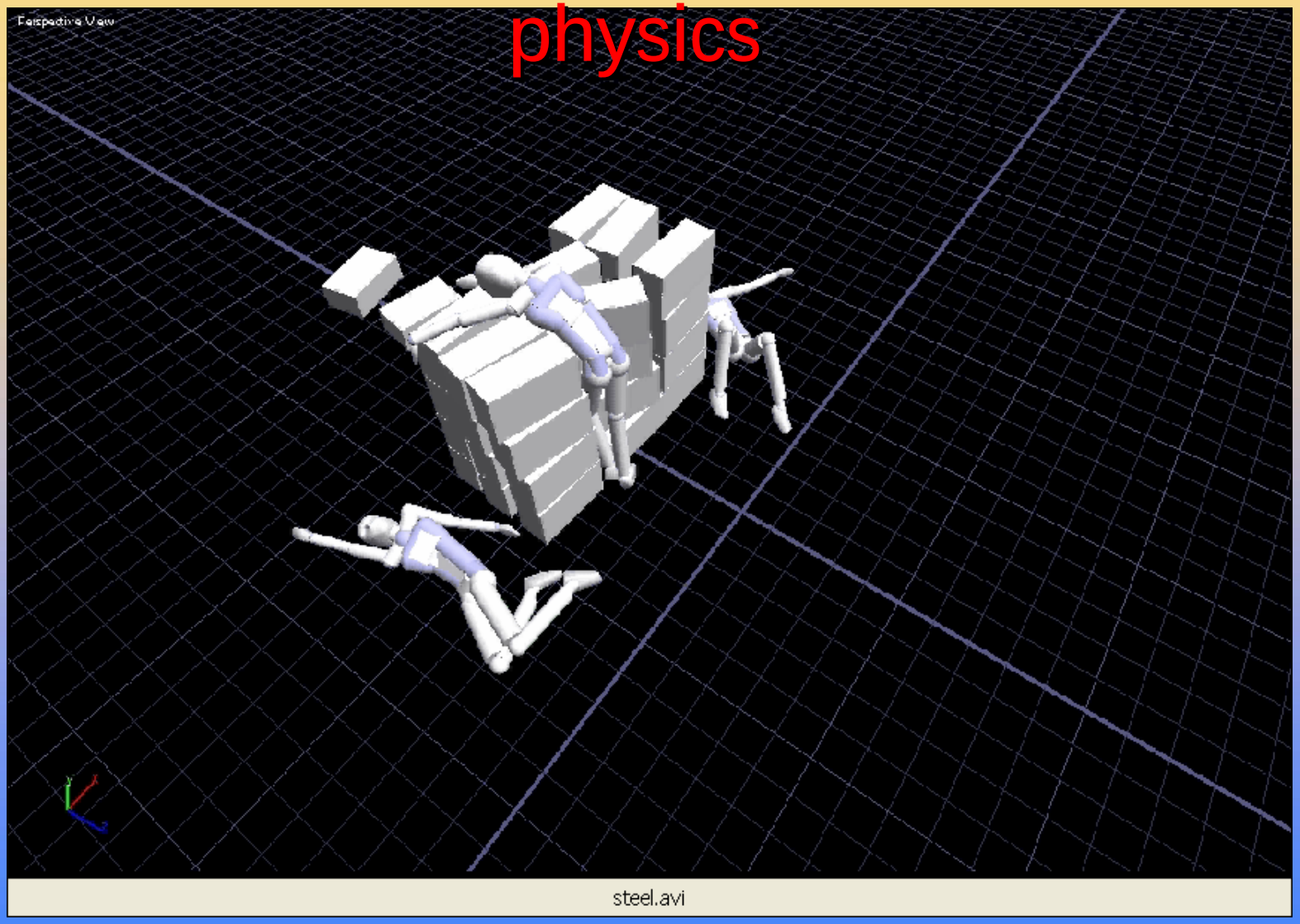
- Complexity modeling
  - Not interested details but the macroscopic properties, e.g., resource use, (e.g., contrast the movement of individual molecules versus the pressure)
  - Social Decision Making
  - Socioeconomic Decision Making
  - Homeland security

Pedestrian activity spaces – obey laws of physics



Agent-agent- rubber box collision (mocap, physics) (Torrens)

Pedestrian activity spaces – obey laws of physics



Agent-agent- steel box collision (mocap, physics) (Torrens)