



RITSUMEIKAN UNIVERSITY



SCHOOL OF GEOGRAPHY



**Lecture 6:**  
**Integrated Assessment:**  
**The Tyndall Models for Greater London:**  
Topical Issues of Climate Change and Energy Predictions in Models



Centre for Advanced Spatial Analysis



# Outline

- Strict Requirements & Motivations for the Model
- Structure of the ***SIMULACRA*** Suite of Models
- The Residential Location Model
- Visual Analytics and Modelling Processes
- The Economic-Energy Focus
- Energy Changes: Rising Costs of Transport
- Integrated Assessment using Sketch Simulation
- Next Steps

# Strict Requirements & Motivations for the Model

## 1. Predictions:

Very long time horizons suggests that dynamics is less, not more important? Climate change wrt to sea level rise is relevant for 50 to 100 year forecast periods

Very short time horizons suggests the same: rapid changes in energy costs due to gasoline prices rises

*Equilibrium models* are useful to predicting responses where we simply do not know how the system will adapt

Such models address directly “What If” types of scenario

Predictions are to inform the debate, they cannot produce magical results

## 2. Stakeholder Involvement:

The need for *simple immediate models* that can be used over and over again to focus debate on “What If?” questions formulated as a dialogue

The need to explain model inputs, processes and outputs visually using maps etc as well as *visual analytics*. It is as important for stakeholders to understand the data as the model

## 3. Complex Problems over Many Scales and Fields:

Integrated assessment – wrt to climate and energy change – melding physical with social and economic – the need for visual analytics to communicate with scientists from different fields and to identify potential errors in extensive data sets

The need for simple fast models in all of this

#### 4. Flexibility in Model Design and Extension:

The need for developing new but related models quickly retaining with powerful visualisation

The need to tailor models to questions and data which can be defined by stakeholders quickly and often casually

The need to evolve and build more dynamic model types

#### 5. The Need to Embrace Organisational Constraints:

To build models understood by all members of the Consortia, stakeholders and scientists alike, where the process is dominated by resource constraints, different expertise in different locations, and by stakeholders directly defining the problems and absorbing the predictions. *All this implies, fast, simple, visual, and accessible models*

*Let me address these issues by way of telling you what we have and are doing before I get into the land use transport models we are developing*

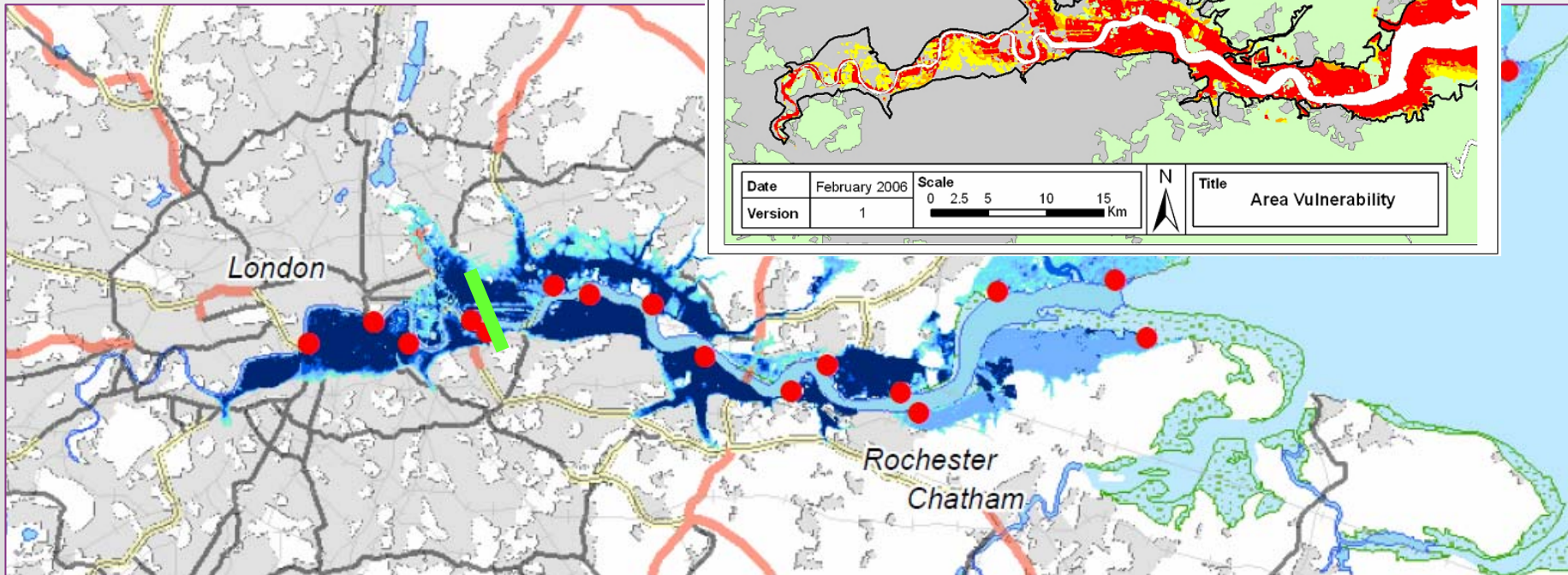
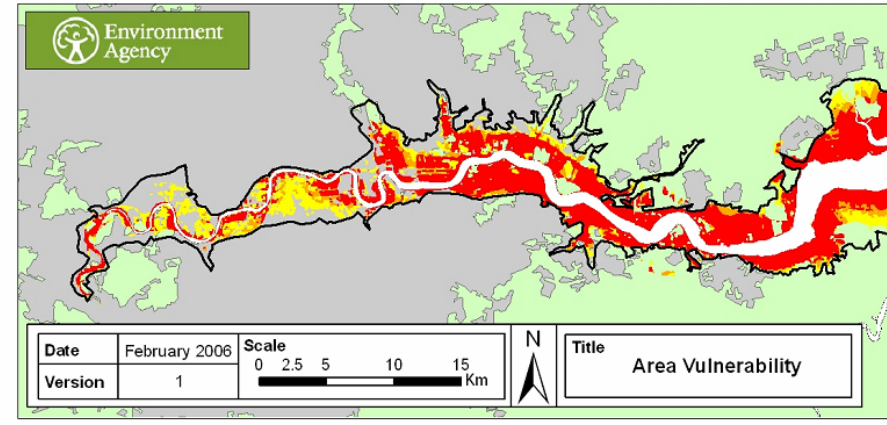
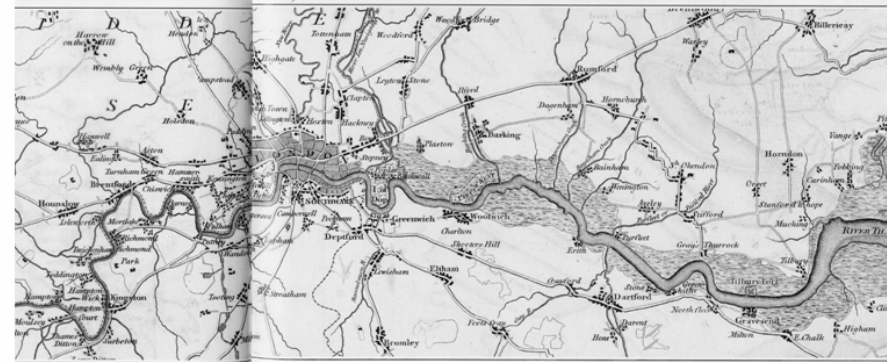
First climate change and then energy change. In London we already have a major response to climate change which was put in place in the early 1980s in response to major flooding in the early 1950s – this is the Thames barrage. It wasn't seen as being part of climate change then.

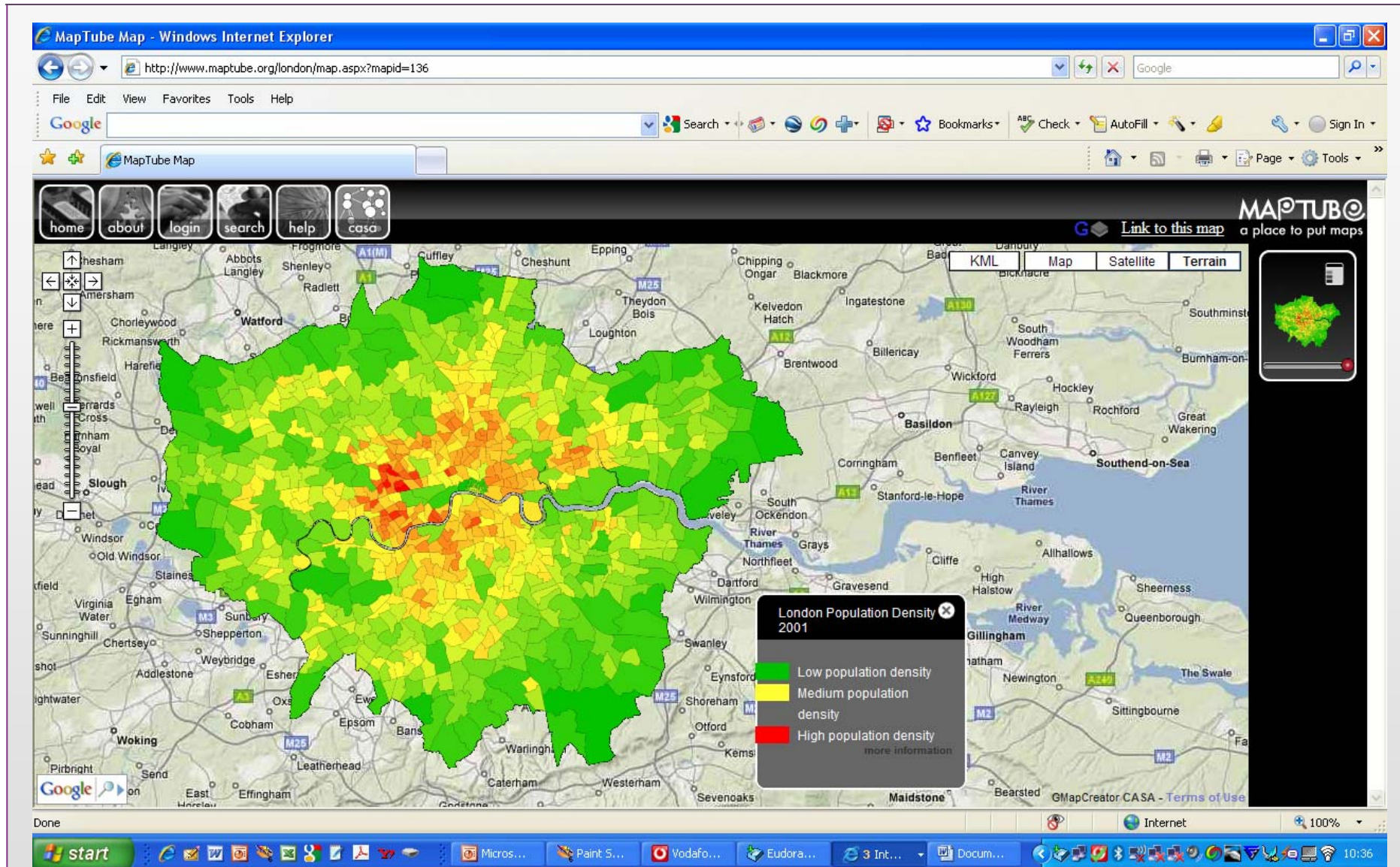
We also have in place congestion charging with road pricing a distinct possibility in the near future, to save money due to extensive current gridlock, for strategic reduction of gasoline usage (fossil fuel depletion and rising costs) and because of a growing awareness of 'green issues'



The Thames Barrier built 1978 to 1984 in operation, likely to be ineffective by 2040? due to new predictions of sea level rise forecast at 1-2 metres by 2100 – somewhat debatable, but ....







The Greater London Region consists of 33 Boroughs, 7.8 million population & 4.4 million jobs

# TIMES ONLINE

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JEREMY CLARKSON | NEW CAR REVIEWS | USED CAR REVIEWS | NEWS | FEATURES | VIDEOS |

Where am I? > Home > Driving > News

From **The Times**

July 28, 2008

## Pedal power challenges car culture as cyclists seize Los Angeles freeways



Chris Ayres in Los Angeles

✓ RECOMMEND?

Los Angeles, meet the bicycle.

### ARCHIVE

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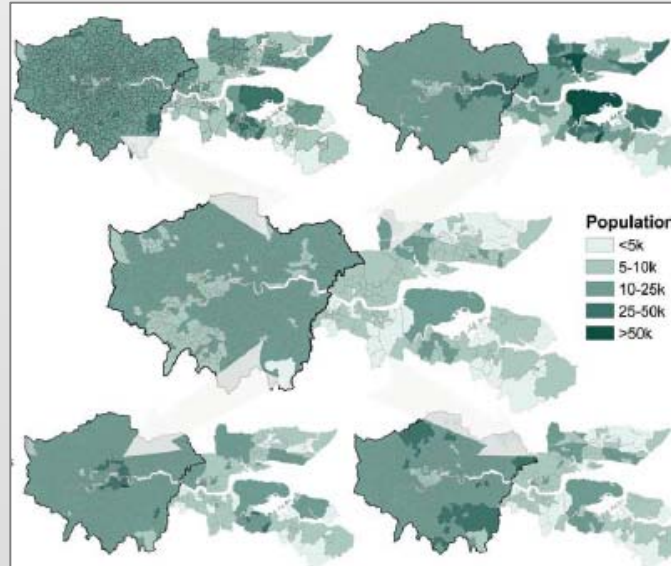
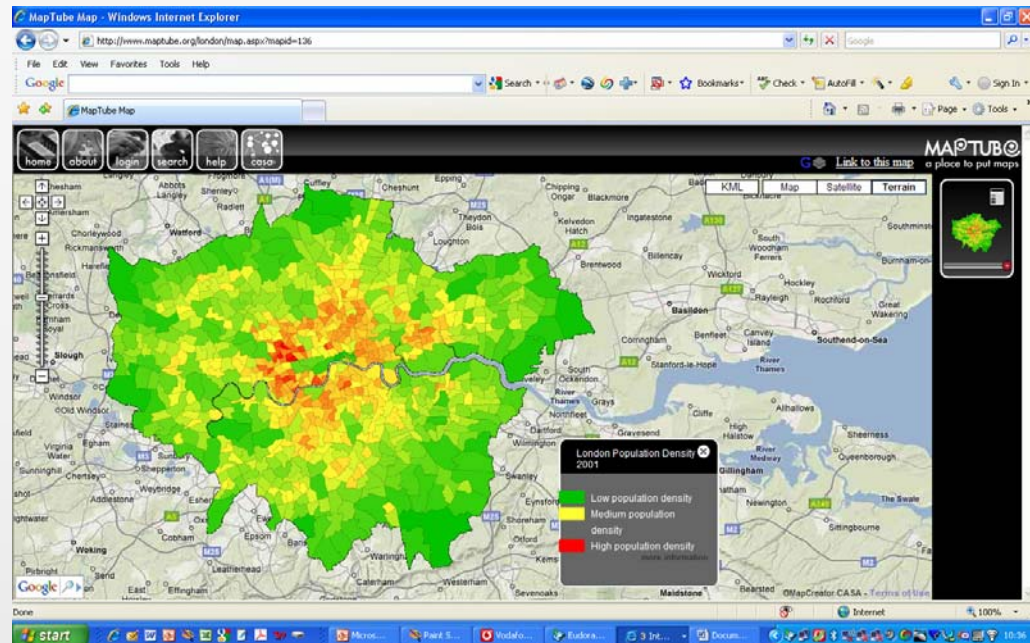


“ Fun-suckers from

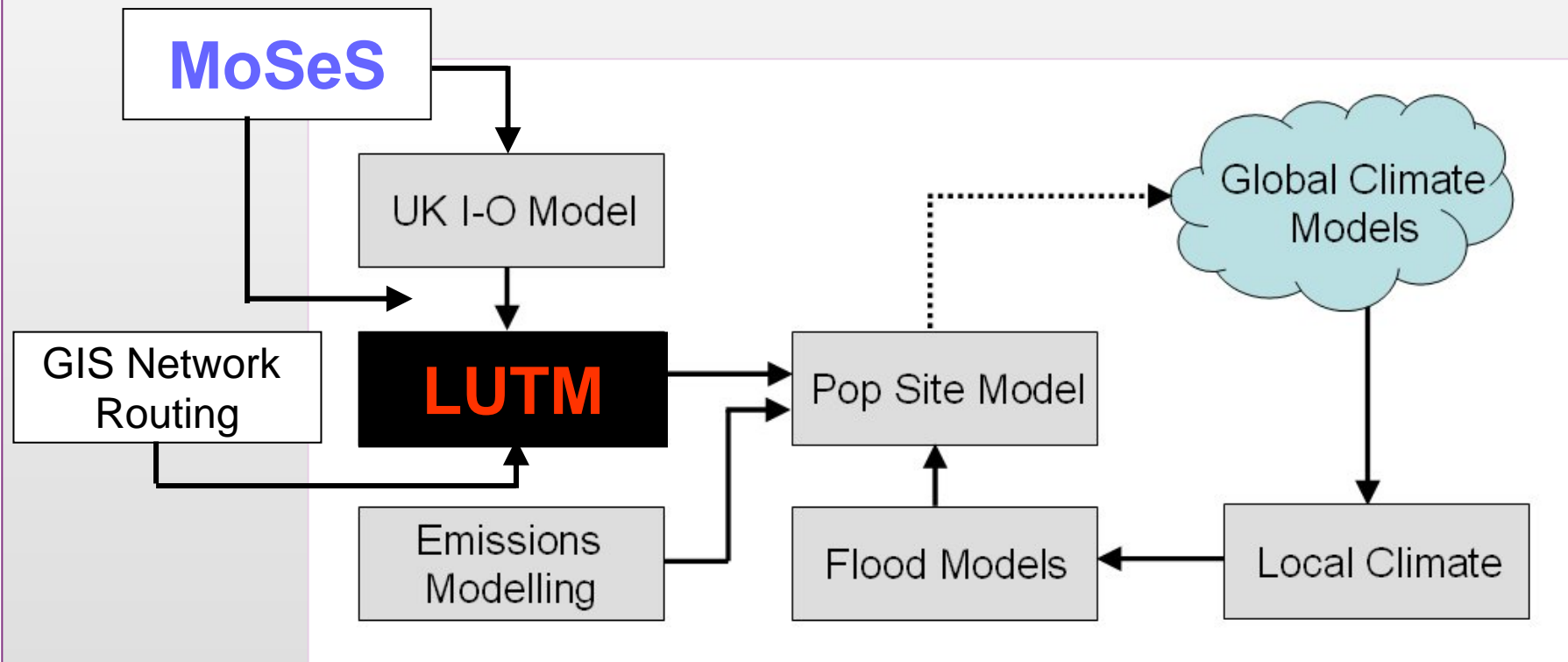
**Engineering Cities:**  
How can cities grow  
whilst reducing  
emissions and  
vulnerability?

**Tyndall°Centre**  
for Climate Change Research

The IPCC forecasts moderated by UKCiP suggest North Sea will rise 2m by 2010, hence serious flooding of Central and East London



The model sits lies at the core of a process of chaining models together built by different groups and coming from different traditions



## Structure of the ***SIMULACRA*** Suite of Models

Our models begin with those like TRANUS, MEPLAN, to an extent IRPUD and so on – they are potentially quite detailed in terms of disaggregation – the current one is 5 employment types and 5 population types, 4 transport modes and so on – although the one that we will show is the most aggregative

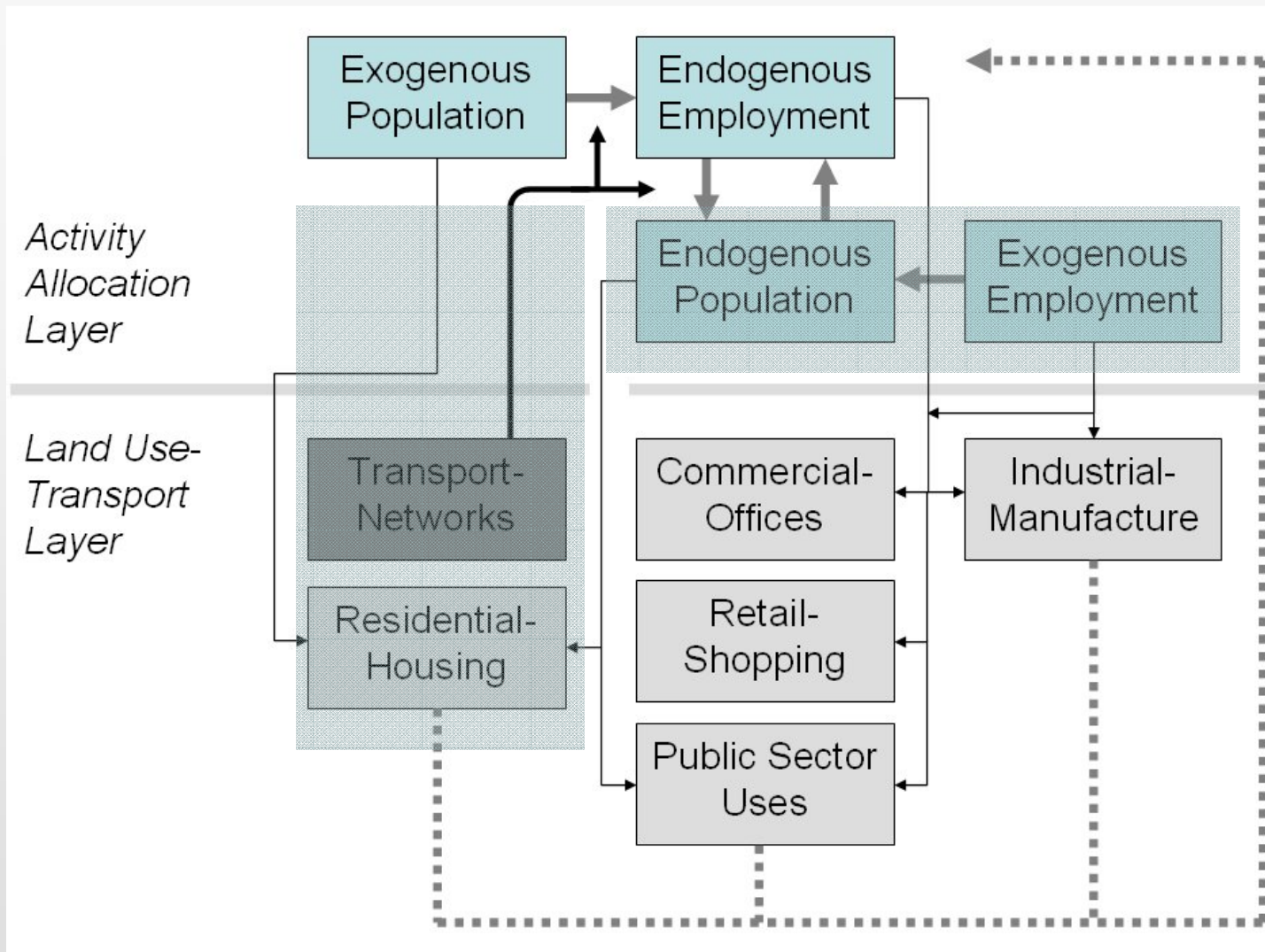
They are essentially input output structures but with the flows being between conventional quantities such as types of population, employment, other sectors such as education, shopping and so on

They differ from all these models in that they contain exogenous totals that can be exogenous in space and time, thus enabling the model system to distinguish between movers and stayers

This suite of possible models – the suite is called SIMULACRA – I won't unpack the acronym – it does unpack in more than one way – is given as follows and a more detailed specification is given in:

*M. Batty (1986) Technical Issues in Urban Model Development : A Review of Linear and Non-Linear Model Structures, in B. G. Hutchinson and M. Batty (Editors) **Advances in Urban Systems Modelling**, North Holland Publishing Company, Amsterdam, 133-162.*

The model structure that we have under construction essentially has two sectors – population and employment – and it is structured as a spatial I-O model with the flows being modelled using mode split spatial interaction submodels



The exogenous inputs are both from previous time periods and from external forecasts

## The Residential Location Model

- is formulated as a four mode residential location model, origin constrained but subject to capacity constraints, with competition between locations and modes of travel determined respectively by land availability and travel costs.
- Land availability enables the model to consistently account for dimension trips so that there are consistent with their density
- The capacity constraints are introduced exogenously and can be formulated as policy levers but this as in all such model application introduces a degree of arbitrariness.
- The modes are road, bus, heavy rail and light rail (Tube and DLR)

The model can be written in conventional form as

Interaction:	$T_{ij}^m = E_i \frac{A_j \exp(-\lambda^m c_{ij}^m)}{\sum_j A_j \sum_m \exp(-\lambda^m c_{ij}^m)}$
Mode split on each link:	$\frac{T_{ij}^{m=1}}{T_{ij}^{m=2}} = \frac{\exp(-\lambda^{m=1} c_{ij}^{m=1})}{\exp(-\lambda^{m=2} c_{ij}^{m=2})}$
Total Mode Split:	$\frac{T^{m=1}}{T^{m=2}} = \frac{\sum_{ij} T_{ij}^{m=1}}{\sum_{ij} T_{ij}^{m=2}} = \frac{\sum_{ij} \exp(-\lambda^{m=1} c_{ij}^{m=1})}{\sum_{ij} \exp(-\lambda^{m=2} c_{ij}^{m=2})}$
Residential Location:	$P_j = \sum_{im} T_{ij}^m$

And it is calibrated by solving the associated maximum likelihood equations which you can find in my book

Urban Modelling: Algorithms, Calibrations, Predictions Cambridge Urban and Architectural Studie - Windows Internet Explorer

http://www.amazon.co.uk/Urban-Modelling-Calibrations-Predictions-Architectural/dp/0521134366/ref=sr\_1\_11?ie=UTF8&s=books&qid=1271234928&sr=1-11

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Michael Batty

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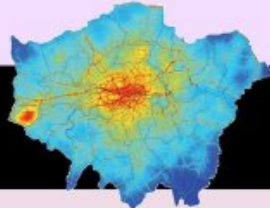
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Internet 100% 09:49


- There is an option which will be implemented in the version to be used to look at energy changes for equilibrating the transport flows with respect to capacities
- The model package is structured as a sequence of:
  1. Data exploration
  2. Model calibration and validation, and thence
  3. Prediction
- At each stage, the user can engage in extensive analysis of data, calibrated outputs, or predicted outputs
- This version model is calibrated to mean trip costs
- The entire process is visually driven and I will first show some screen shots before running the model

# Visual Analytics and Modelling Processes

London and the Thames Gateway Land Use Transportation Model



**Cities Research Programme**  
**Tyndall Centre**  
for Climate Change Research



This program is a rudimentary land-use transportation model built along classical lines which allocates population and employment to small zones of the urban system. It uses spatial interaction principles which bind the population sector (residential or housing) to employment sector (work or industrial and commercial) through the journey to work (work trips) and the demand from services (which loosely translate into trips made to the retail and commercial sector).

The model is being built for Greater London and the Thames Gateway at ward level - 633 in all - so that it can be used in a wider process of integrated assessment focussed on assessing the impact of climate change on small areas in this metropolitan region. In particular rises in sea level and pollution are key issues, and as such the model sits between aggregate assessments of environmental changes associated with global and regional climate change models and environmental input output models, and much more disaggregate models related to the detailed hydrological implication of long term climate change.

The programme enables the user to read in the data and explore it spatially, to calibrate the parameters of the model and explore its outputs spatially and to engage in various predictions ranging from the typical 'business as usual scenarios' to much more radical changes posed limits on spatial behaviour which either result from climate change and/or mandated by government. The predictions and scenarios are intended to go out to 2100 and thus the model is largely designed as a sketch planning tool.

These various stages of the model contained in a master tool bar which is activated when the GO! button is pressed on this screen. The master tool bar enables the users to proceed through the various stages indicated and to display outputs in map and statistical form at any stage.

with **GLAECONOMICS LONDON**

**GO!** Program Manual

Master Tool Bar

Input Data >> Explore Data >> Calibration >> Explore Outputs >> Prediction >> Explore Predictions **Reset Tool Bar** Quit

Reading in Data

### Population, Employment and Floorspace Data

Employment Origin Zones 633

Population Destination Zones 633

OK 6 86962.9

OK 7 10217

OK Floorspace Data

### Physical Line and Area Data

Centroids OK Zones X-Centroid Y-Centroid

Coordinates OK Polygon X-Coordinate Y-Coordinate

Zone Zone Area

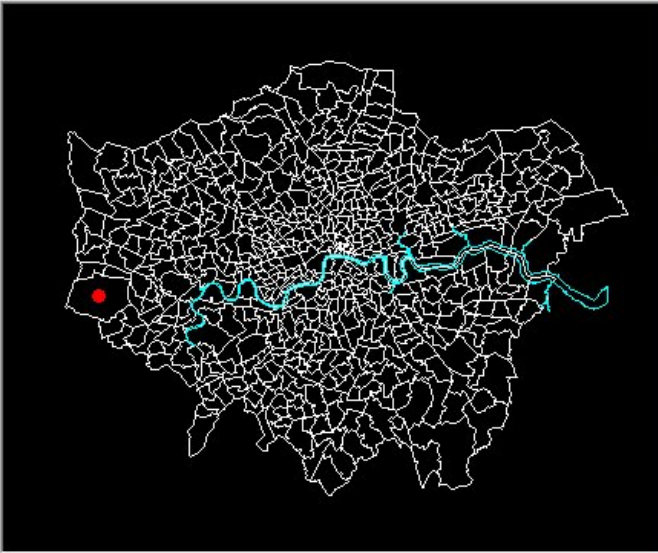
### Travel Data

OK Zone i to j Observed Trips

OK Zone i to j Distance-Cost

Mean Trip Length 22.40

### Displaying the Physical Map



Zones: 633 Wards in 2001

6 Heathrow Villages Hillingdon

**Reading in Data**

Population, Employment and Floorspace Data

READ Employment Origin Zones 633 Click Here to Complete the Input of Data Directly

READ Population Destination Zones 633

Read Employment Data OK Zone Employment Data

Read Population Data OK Zone Population Data

Read Floorspace Data OK Zone Floorspace Data

Physical Line and Area Data

Read Map Data Centroids OK Zones X-Centroid Y-Centroid

Area Data Coordinates OK Polygon X-Coordinate Y-Coordinate

Zone Area

Travel Data

Mean Modal Trip Cost

Mode	Mean Cost
Road	32.82082
Bus	16.67022
Heavy Rail	99.76682
Light Rail	31.98717
All Trips	57.97092

Zones: 633 Wards in 2001

6 Heathrow Villages Hillingdon

Locate Zone

Clear Zone Nodes

Data Input Has Been Completed

**Modes**

- Road
- Bus
- Heavy Rail
- Light Rail
- All Trips

Road: 38%; Bus: 12%; Heavy Rail: 12%; Light Rail 19%; Other (Walk, Bike, Fly): 19%

Master Tool Bar

Input Data >> Explore Data >> Calibration >> Explore Outputs >> Prediction >> Explore Predictions Reset Tool Bar Quit

Data

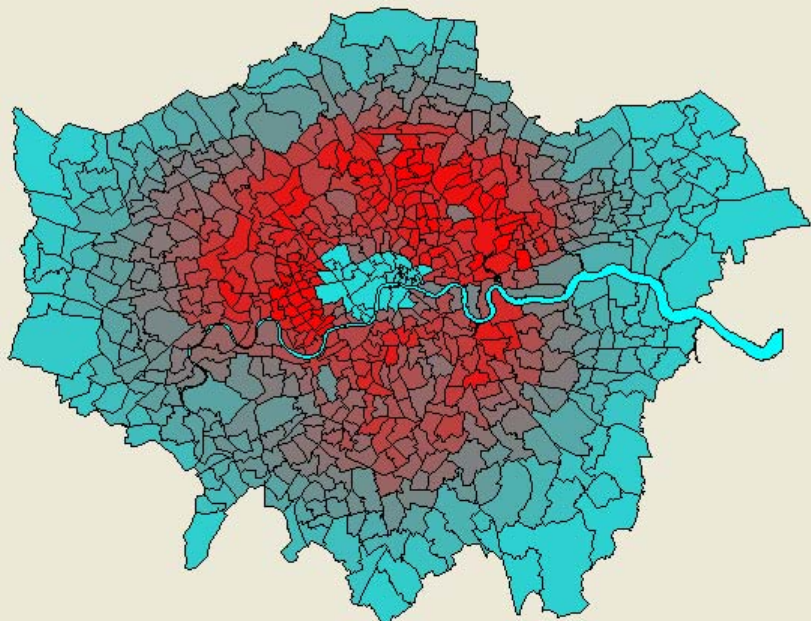
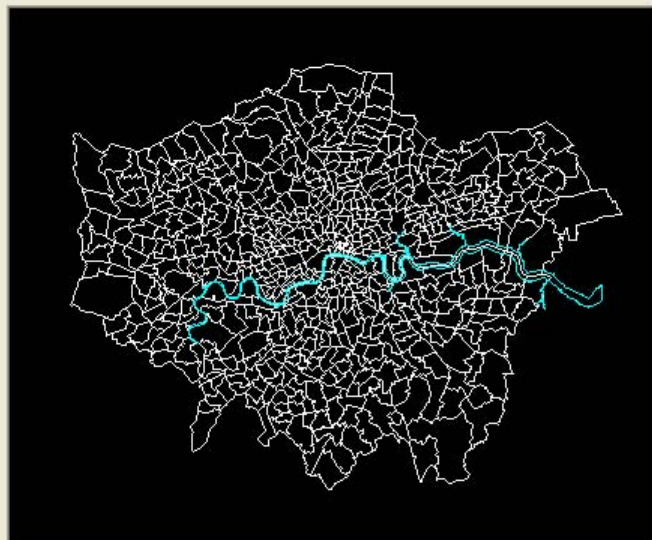
Map Raw Data  
Map Derived Data  
Plot Trip Data  
Accessibility Maps  
Accessibility Surfaces

Reading in Data

Accessibility Indicators

EmpPop Origin Access Dest Access

Dummy Road Orig Access Area Map Dest Accessibility

Zones: 633 Wards in 2001

Zone Ward Borough

Locate Zone  
Clear Zone Nodes

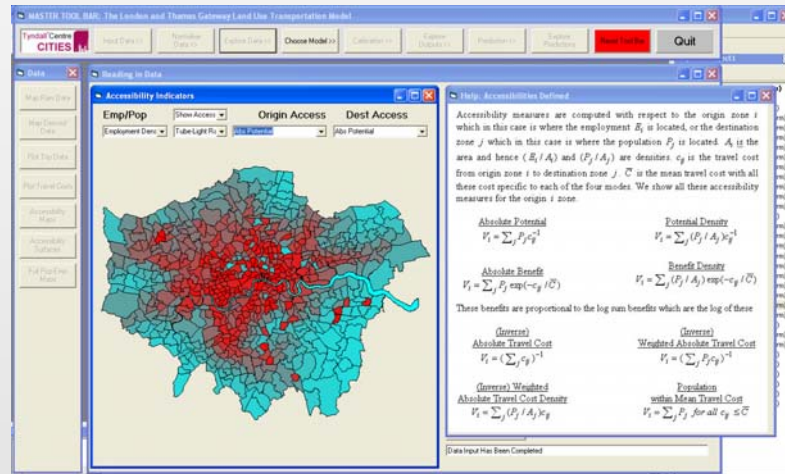
Data Input Has Been Completed

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# Accessibility from the LUTM model

Many different accessibility measures, 8 in all



**Help: Accessibilities Defined**

Accessibility measures are computed with respect to the origin zone  $i$  which in this case is where the employment  $E_i$  is located, or the destination zone  $j$  which in this case is where the population  $P_j$  is located.  $A_i$  is the area and hence  $(E_i / A_i)$  and  $(P_j / A_j)$  are densities.  $c_{ij}$  is the travel cost from origin zone  $i$  to destination zone  $j$ .  $\bar{C}$  is the mean travel cost with all these cost specific to each of the four modes. We show all these accessibility measures for the origin  $i$  zone.

<p><u>Absolute Potential</u></p> $V_i = \sum_j P_j c_{ij}^{-1}$	<p><u>Potential Density</u></p> $V_i = \sum_j (P_j / A_j) c_{ij}^{-1}$
<p><u>Absolute Benefit</u></p> $V_i = \sum_j P_j \exp(-c_{ij} / \bar{C})$	<p><u>Benefit Density</u></p> $V_i = \sum_j (P_j / A_j) \exp(-c_{ij} / \bar{C})$
<p><u>(Inverse) Absolute Travel Cost</u></p> $V_i = (\sum_j c_{ij})^{-1}$	<p><u>(Inverse) Weighted Absolute Travel Cost</u></p> $V_i = (\sum_j P_j c_{ij})^{-1}$
<p><u>(Inverse) Weighted Absolute Travel Cost Density</u></p> $V_i = \sum_j (P_j / A_j) c_{ij}$	<p><u>Population within Mean Travel Cost</u></p> $V_i = \sum_j P_j \text{ for all } c_{ij} \leq \bar{C}$

Master Tool Bar

Input Data >> Explore Data >> Calibration >> Explore Outputs >> Prediction >> Explore Predictions **Reset Tool Bar** Quit

**Predict** Reading in Data

**Input Scenario Data**

Scenario from File

**Employment Changes**

Floorspace Changes

Distance Changes

**Run Scenario Model**

Run Model

**More Scenario Runs ...**

Expansion .....

Expansion .....

Expansion .....

**Prediction Routines**

### Long Term Scenarios Based on the Impact of Changes in Employment, Residential Floorspace, and Transport Costs

Predictions with the model involve forecasting the location of small area populations and the trip patterns associated with the four modes used to distribute employment as population to these small (residential) areas. This involves changing the input variables - employment and residential floorspace by small area, and the travel costs associated with each mode of transport, which in turn imply changes to the transport infrastructure. The user also has control over the parameter values on the friction of Travel Cost or travel cost associated with each mode. This can be changed in value to reflect changes in the average Travel Cost or cost travelled on each mode.

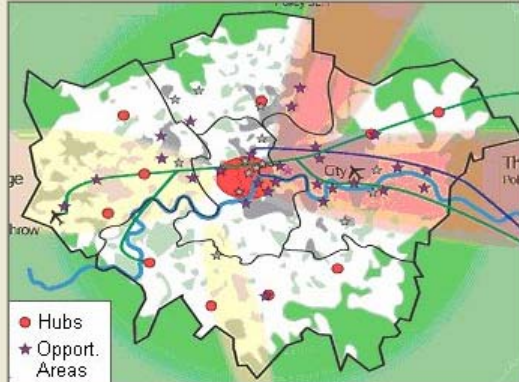
Users have a choice of inputting a preset scenario in which all these variables are changed exogenously or a process of changing these variables interactively, on screen. The interactive process can involve many thousands of changes and is probably best used to input data which reflects 'what-if' scenarios which require a small number of rather simple changes in the inputs reflecting substantial or radical change.

By clicking the 'Scenario from File' button in the toolbar to the left, a preset scenario is loaded and the user is then taken to the point where the model must be run. Alternatively if the user clicks the Employment Changes button, the user activates a screen where each employment zone can be identified by pointing the mouse at it and clicking. Then the user can use a slider bar to increase the value of employment in that zone by up to 100 percent or decrease it by up to 100 percent. As many zones as required can be changed using this method. When the user is satisfied with the employment scenario which has been developed, a button accepting these changes can be clicked. The same can then be done for floorspace activated by clicking the relevant button from the toolbar to the left.

Finally the travel cost on any link by any mode from one zone to another can be changed using the same method. An origin and then a destination zone need to be clicked and then reduced or increased travel cost (by up to 100 percent) made using the slider bar. The user must choose the mode each time and the program then recomputes all the shortest routes implied by these changes once the changes are accepted.

The user then proceeds to run the model as for the 'Scenario from File' option and once this is done, the outputs can be visualised using the same system for exploring the data and calibration results.

### Key Elements of the London Plan to 2025 Shown Below.



● Hubs  
★ Opport. Areas

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**Predict** X

**Input Scenario Data**

Scenario from File

Employment Changes

Floorspace Changes

Distance Changes

**Run Scenario Model**

Run Model

**More Scenario Runs ...**

Expansion .....

Expansion .....

Expansion .....

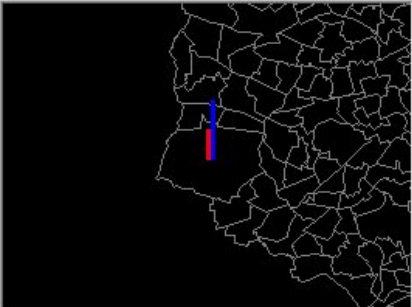
**Prediction Routines** \_ □ X

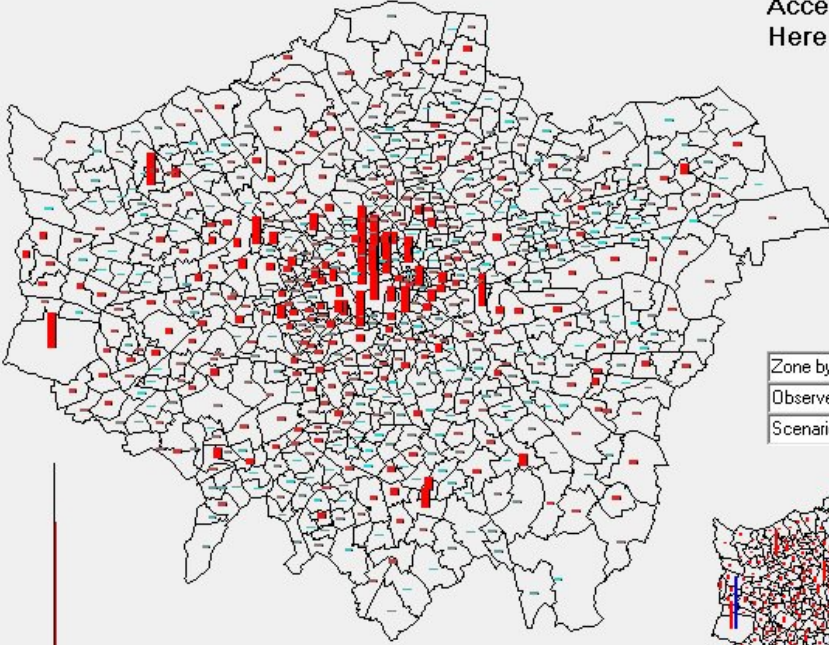
**Interactive Input of Changes to Employment-Origin Zone Data**

Point Your Mouse at the Zone You Wish to Change and Click

Use Slider to Input Percentage Change for Zone 6 6

Old Employment in 6 is 86962  
New Employment is 173925






Click Button to Accept Changes Here

**Click**

Zone by Borough Name

Observed Employment

Scenario Employment



**Updated Employment So Far**

**Input Scenario Data**

Scenario from File

Employment Changes

Floorspace Changes

Distance Changes

**Run Scenario Model**

Run Model

**More Scenario Runs ...**

Expansion .....

Expansion .....

Expansion .....

**Prediction Routines**

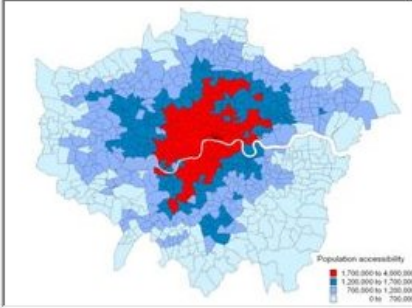
**Interactive Input of Changes to Origin-Destination Crow-Fly Distances**

Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click

Use Slider to Input Percentage Change for Zone 6 to 219

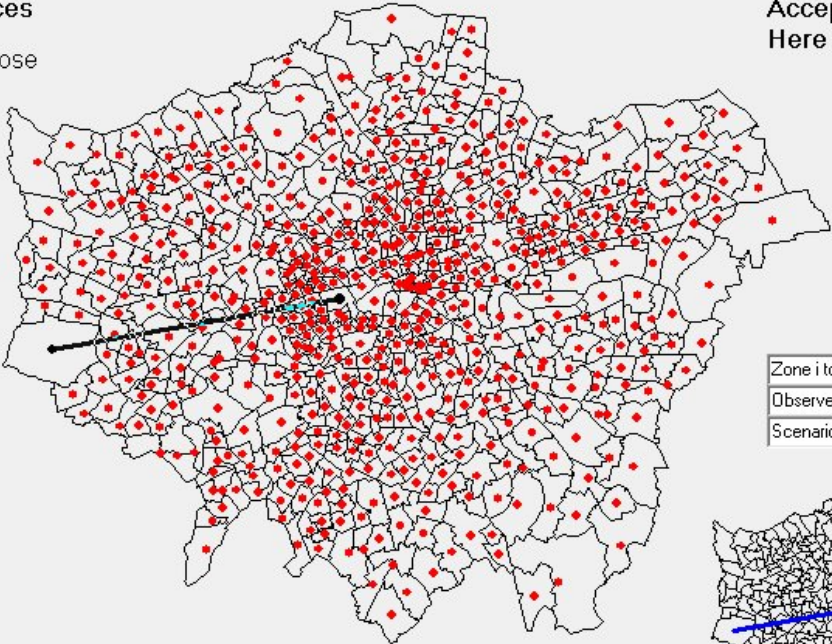
Old Distance from 6 to 219 is 35

New Distance is 7



Population accessibility

- 4 700 000 to 4 900 000
- 3 200 000 to 3 700 000
- 1 700 000 to 2 200 000
- 0 to 1 700 000




Click Button to Accept Changes Here

Zone i to Zone j

Observed Distance

Scenario Distance



Updated Distances So Far

Let us run the model... I need to go to my folder...>>

**Run**

For a movie of all this go to our web site – this is 3 years old so it has changed a lot since then but it suffices  
<http://www.casa.ucl.ac.uk/transportmodel/transportmodel.asp>



And now a little bit more about the model .....looking at the version we are currently building

## The Economic-Energy Focus

- We have replaced the simple travel cost function with one that relates to wages, travel cost and housing cost
- In essence, we compute the proportion of a wage in any origin (employment zone) which is available for a) travel and b) housing, and we separate housing and travel costs into energy and non-energy related components
- Monies for travel are then compared to the actual travel cost on any link and those closest to the cost have a greater probability of determining a trip
- Monies for housing at origin  $i$  are then compared to the actual house price at location  $j$  and those closest to the housing price have a greater probability of determining the trip

- The model is built around variances between monies available for travel and housing and the actual costs of these as

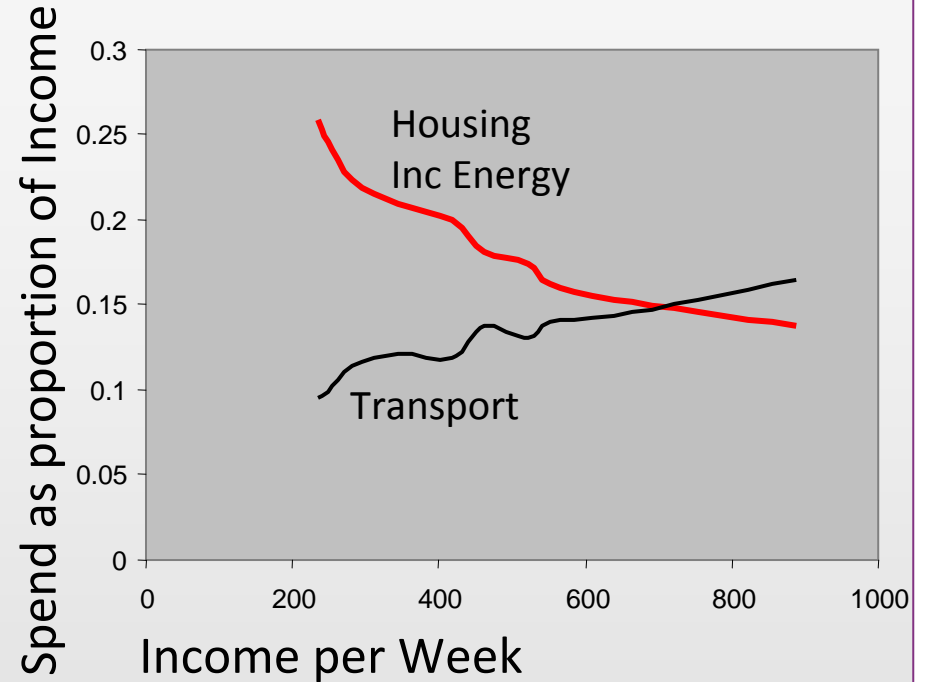
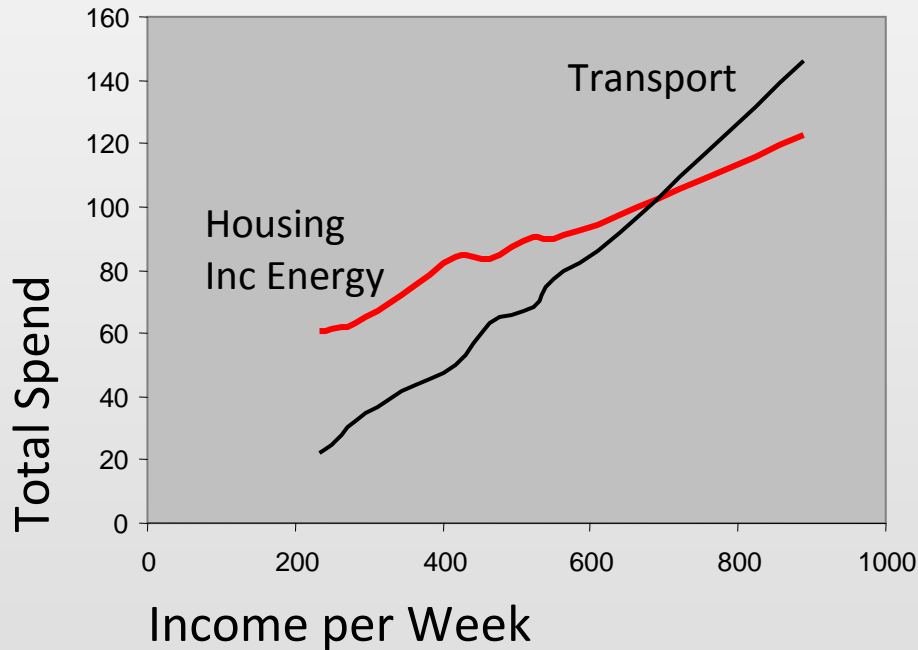
Interaction:

$$T_{ij}^m = E_i \frac{A_j \exp(\alpha p_j) \exp(-\lambda^m c_{ij}^m) \exp(-\beta(p_i(w) - p_j)^2) \exp(-\beta(c_i(w) - c_{ij}^m)^2)}{\sum_j A_j \exp(\alpha p_j) \exp(-\beta(p_i(w) - p_j)^2) \sum_m \exp(-\lambda^m c_{ij}^m) \exp(-\beta(c_i(w) - c_{ij}^m)^2)}$$

- Again we solve the model from its maximum likelihood equations
- There are several variants of all these models which can be chosen in real time by the user based on different patterns and combinations of moments and related constraints
- We need to look at the data which is aggregate as we have wages at the origin end and income at the destination end

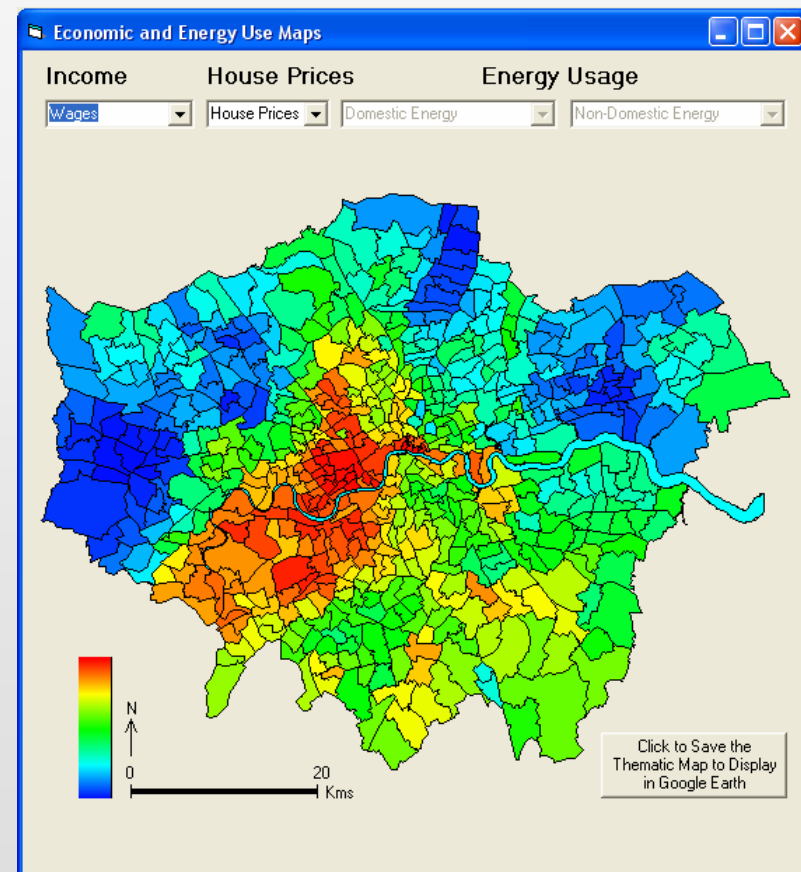
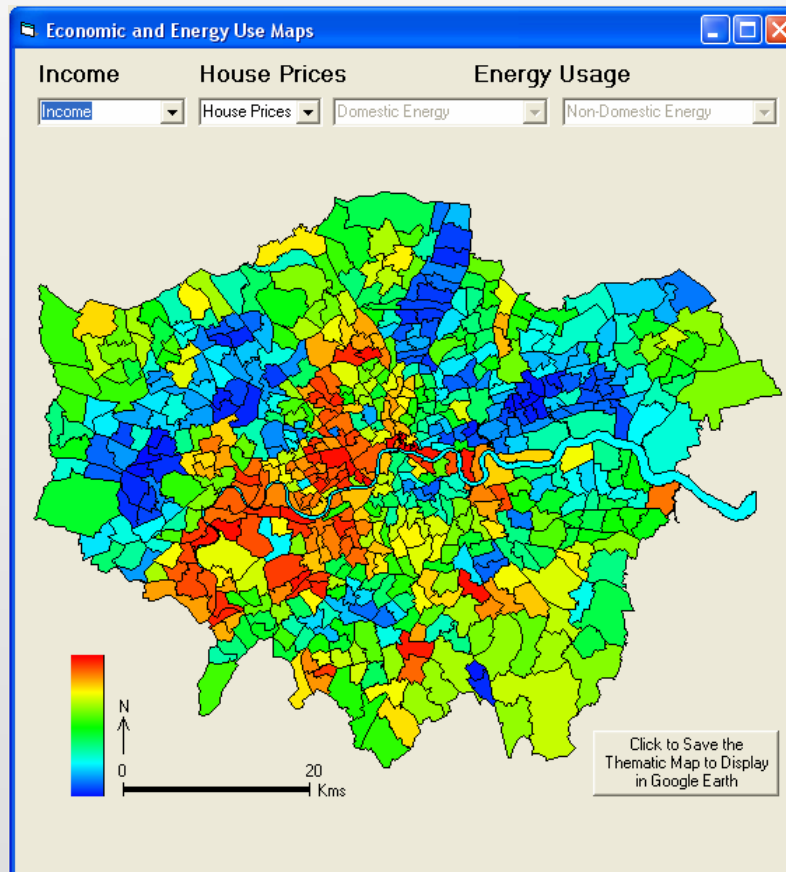
# Transport & Housing Costs from the '09 Spending Survey

Here are the absolute costs



The above the relative costs to income

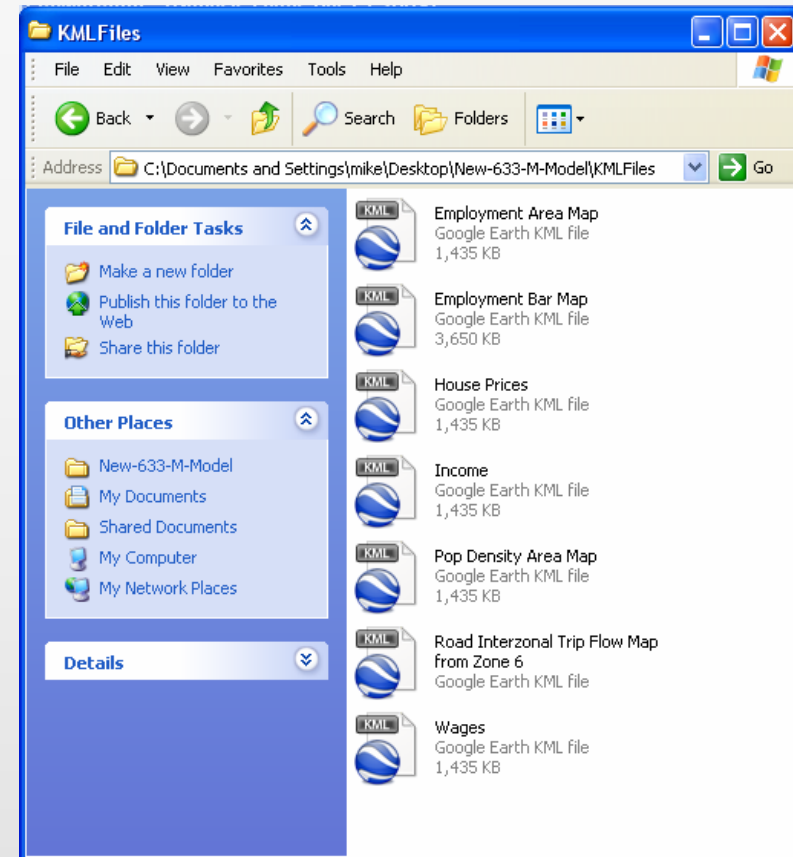
- Let us look at incomes where people live and wages where people work



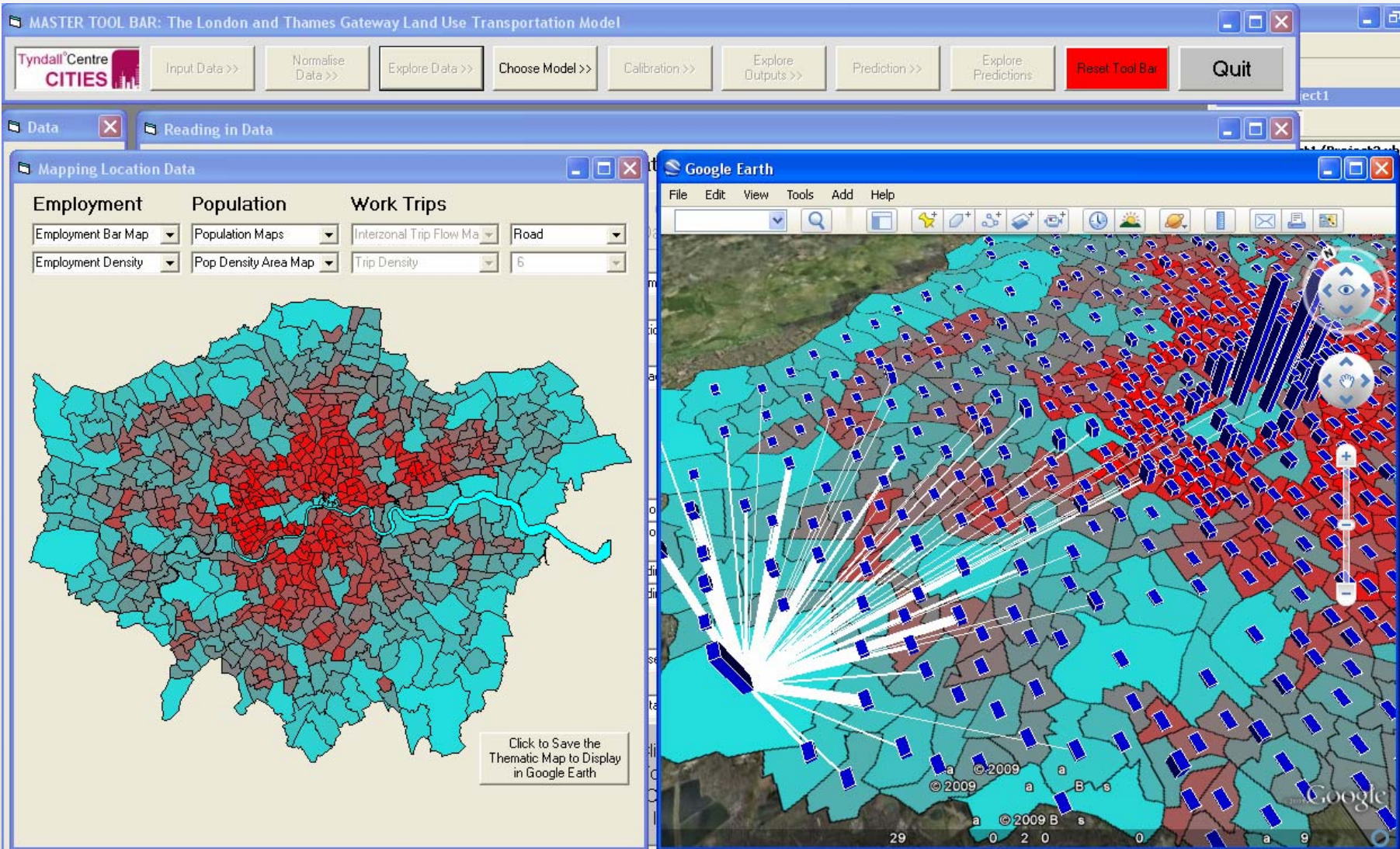
## Extending the Software

- Currently we do not have good zoom, pan, overlay facilities in the model due to difficulties of such programming in VB. I suspect these could be developed but we also need to share the data and the predictions and a quick possibility is to use a non-proprietary open map visualisation system to link on the fly to the model: this should be web-based
- The best way forward at present is to generate KML files in the program and then feed them to Google Earth where we have overlay, 3D, and external data facilities. You have seen this.

- In this way, we can extend massively our ability to visualise as well as providing a storage facility for the model input and output data
- What is impressive about this is that the speed of doing all this is not slower than the interactive program in VB



*It is based on pragmatic use of available software but it generates familiarity. It also lets us store data in a convenient fashion and add other external data as KML files – particularly physical data which is hard to store in the customised software*



- Energy Changes: Rising Costs of Transport
- I now want now to show you how we are using the model to handle energy costs in terms of rising costs of transport
- What we can do is increase the cost of gasoline for road users relative to other modes and see what the effect is
- If we double the cost of gas we then can see how users shift mode of travel and also how location of the population changes. The key issue is to assess this kind of shift in terms of interaction and location
- We will show some screen shots of the model doing this

MASTER TOOL BAR: The London and Thames Gateway Land Use Transportation Model

Tyndall Centre CITIES

Input Data >> Normalise Data >> Explore Data >> Choose Model >> Calibration >> Explore Outputs >> Prediction >> Explore Predictions

Reset Tool Bar Quit

Predict

Reading in Data

Prediction Routines

Interactive Input of Changes to Origin-Destination Crow-Fly Travel Costs

First You Must Choose the Mode from the Drop Down Menu

Choose Mode

Now Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click

Use Slider to Input Percentage Change for the Link #-#

Click Right Button to Move On ... Click

Update the Overall Cost Changes

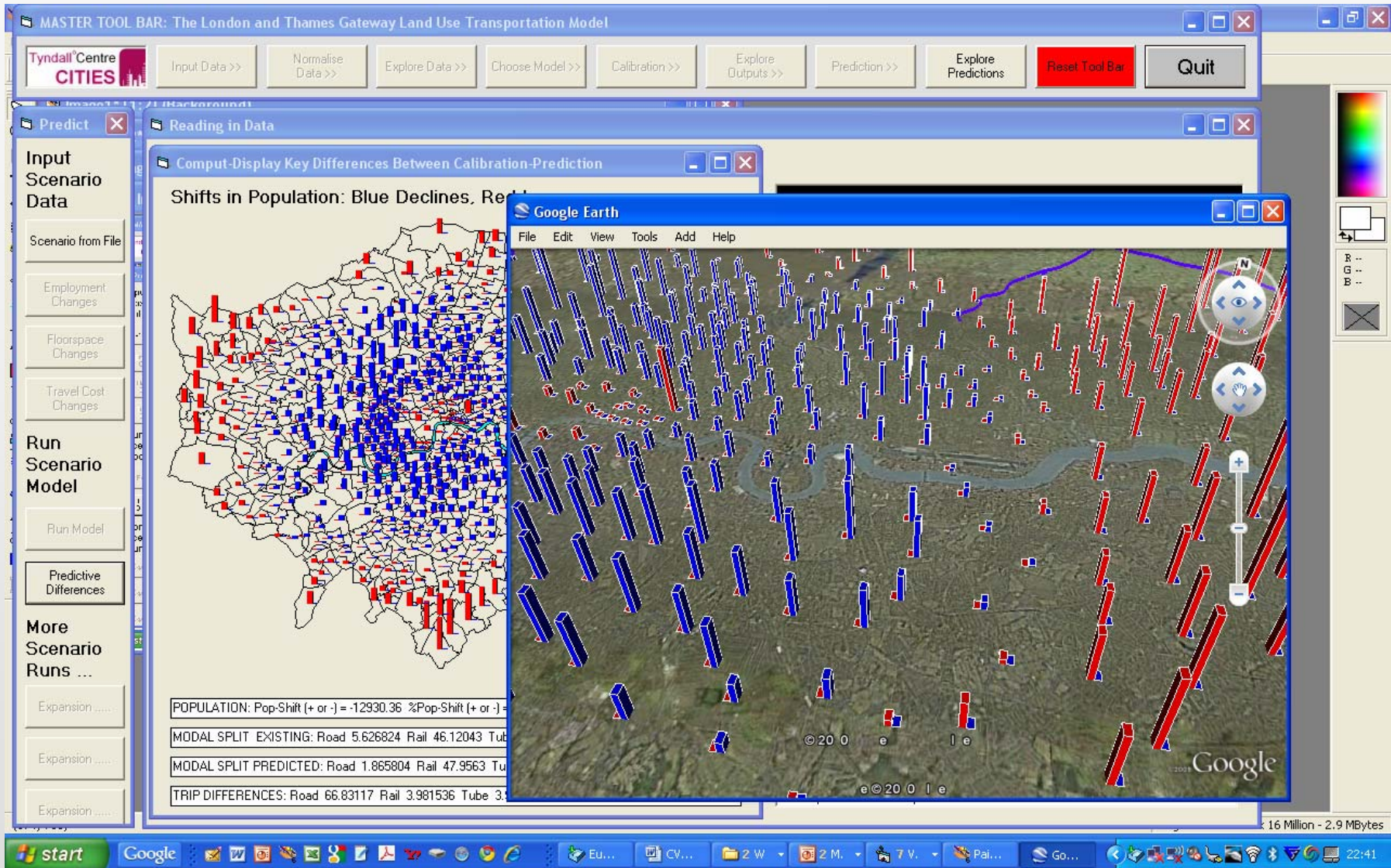
Road 100  
Rail 165  
Tube 170  
Bus 175

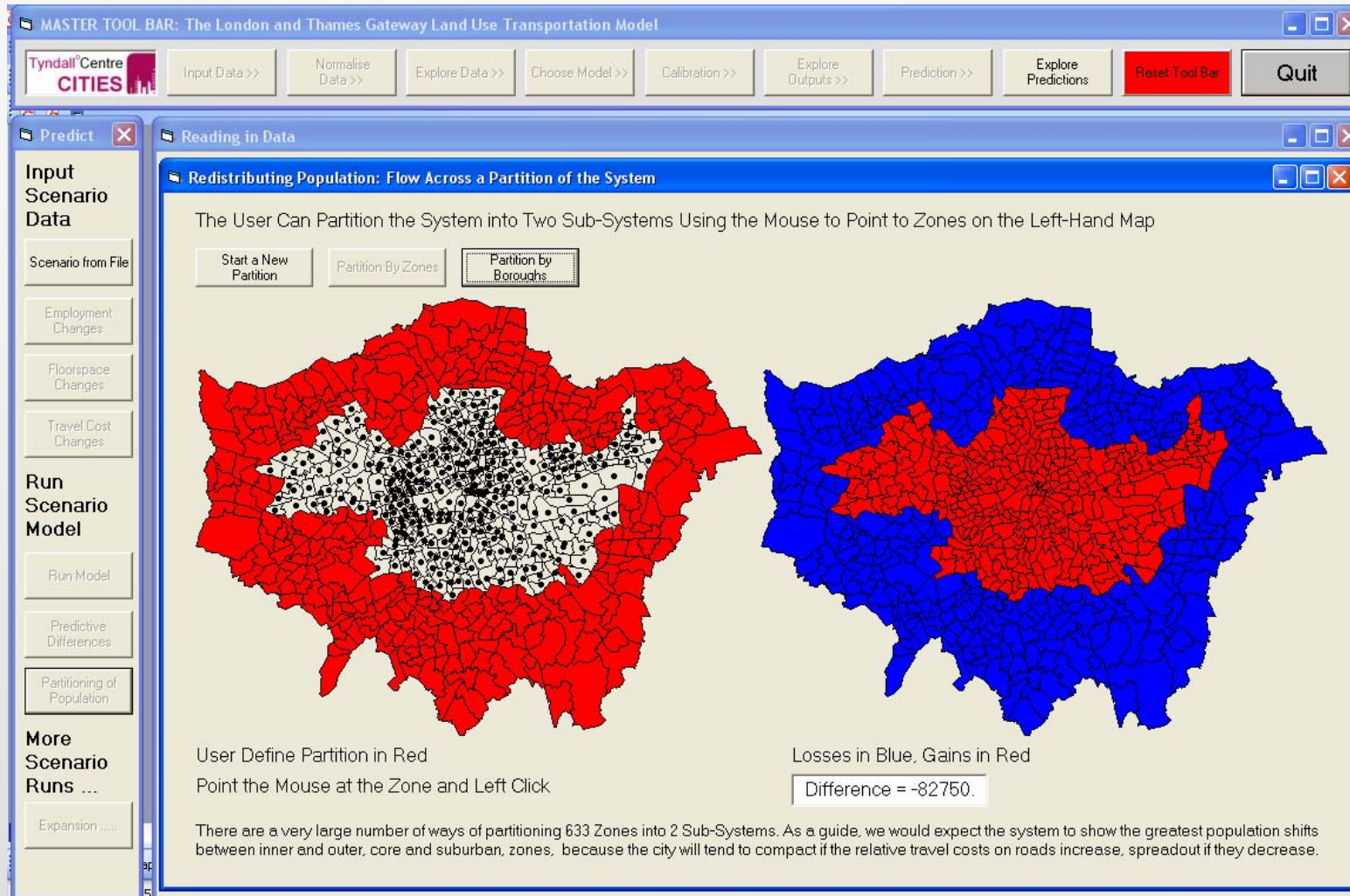
Form1 (Form1.frm)  
Form10 (Form10.frm)  
Form11 (Form11.frm)  
Form12 (Form12.frm)  
Form13 (Form13.frm)  
Form14 (Form14.frm)  
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Form6 (Form6.frm)  
Form7 (Form7.frm)  
Form8 (Form8.frm)  
Form9 (Form9.frm)

Population accessibility

If You Wish to Alter the Entire Distribution, Select the Mode on the Right  
Use the Boxes to Increase or Decrease the Cost of Travel from 100% Up or Down  
You Can Do This for Any or Every Mode and when Finished, Click the Update Box

start Google Eudora - ... CV and T... 2 Wind... 2 Micro... 5 Visual... 22:30





Loss of Population from the Suburbs to central City – i.e. Big increases in travel costs on the road lead to compacting

# The Impact of Fares-Free Public Transport Upon Urban Residential Location

by M. Batty, P. G. Hall and D. N. M. Starkie

TRANSPORTATION RESEARCH FORUM

Volume XV • Number 1 1974 347-353

### IMPACT OF RELOCATING POPULACE



FLOW OF RELOCATING POPULATION  
0 50 '000'S OF PERSONS

CENTRAL BIRMINGHAM: INNER BIRMINGHAM



FLOW OF RELOCATING POPULATION  
0 50 '000'S OF PERSONS

WOLVERHAMPTON CENTRE: EAST-WEST PARTITION

FIGURE 3

### ISOMETRICS OF SPATIAL IMPACT

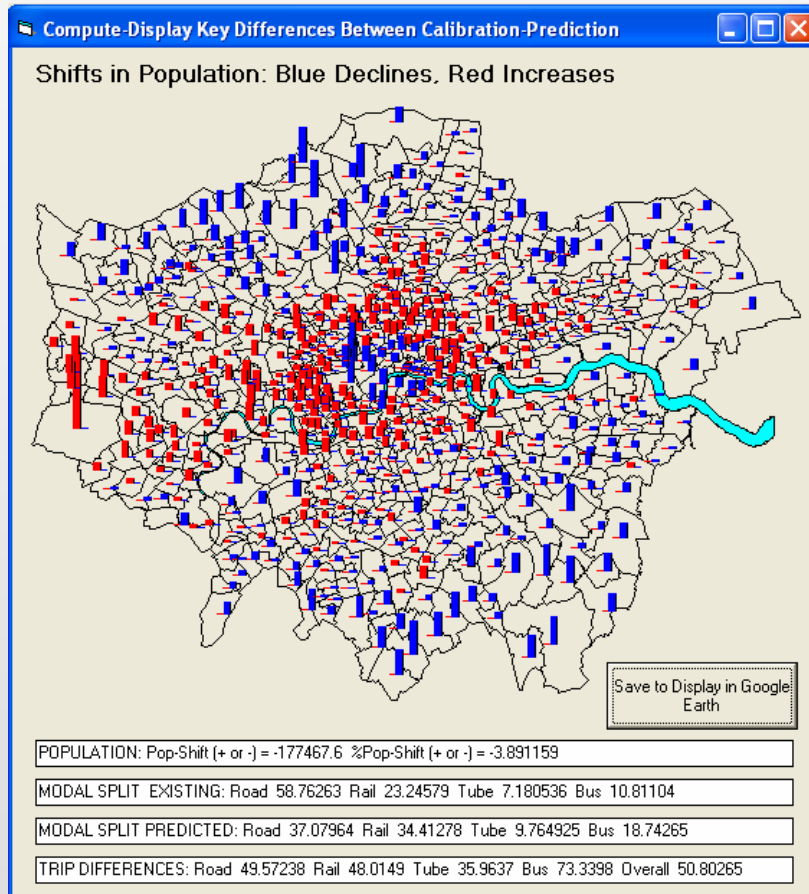


0 5 '000'S OF POPULATION  
LOSSES FROM THE CORE



0 5 '000'S OF POPULATION  
Gains on the Periphery  
FIGURE 4

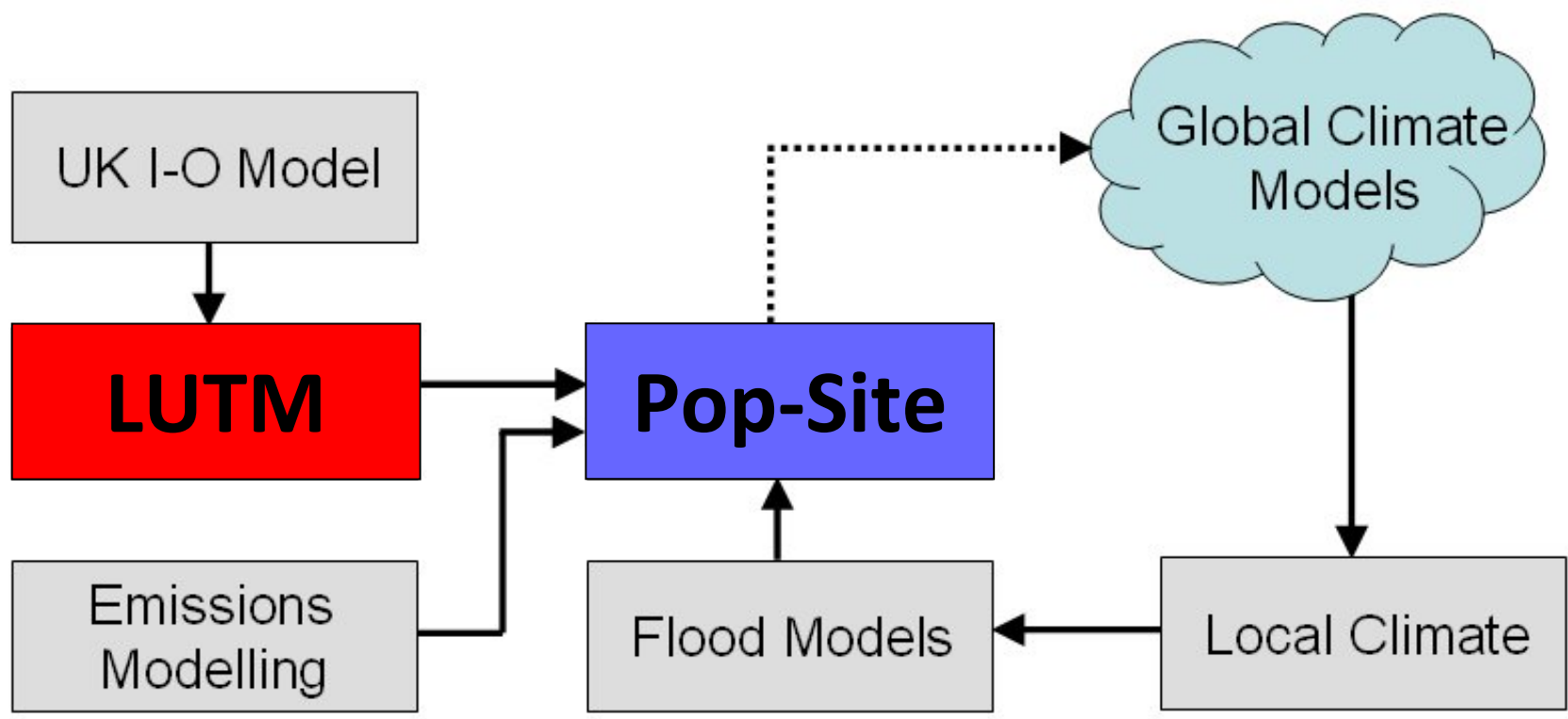
- The following figures show what happens if gas costs rise by 100% i.e. double



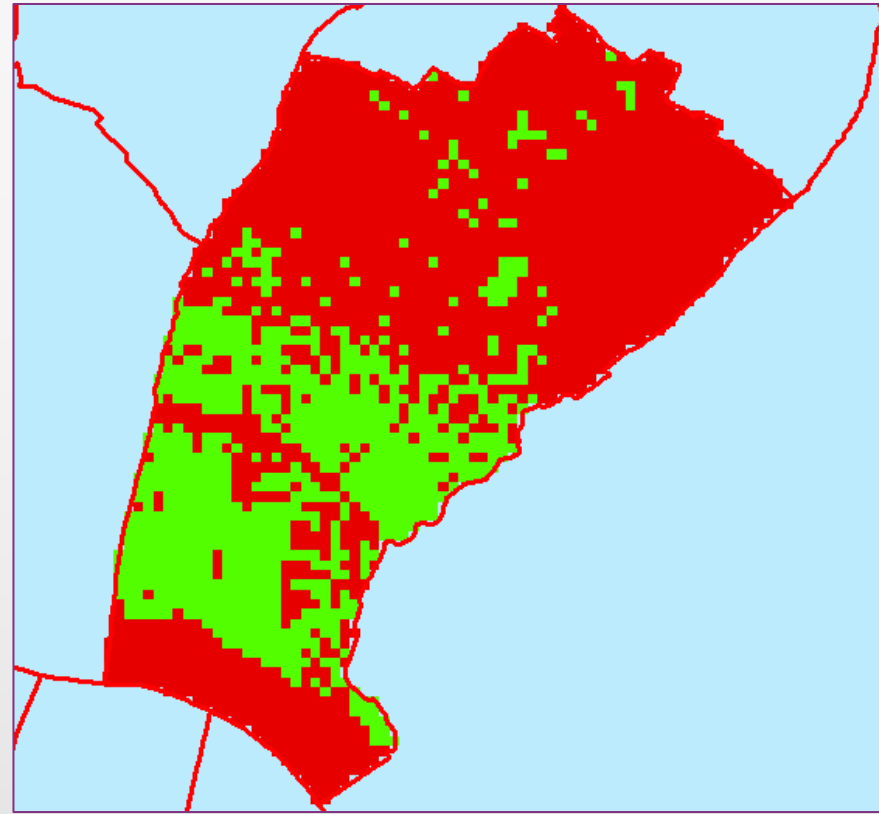
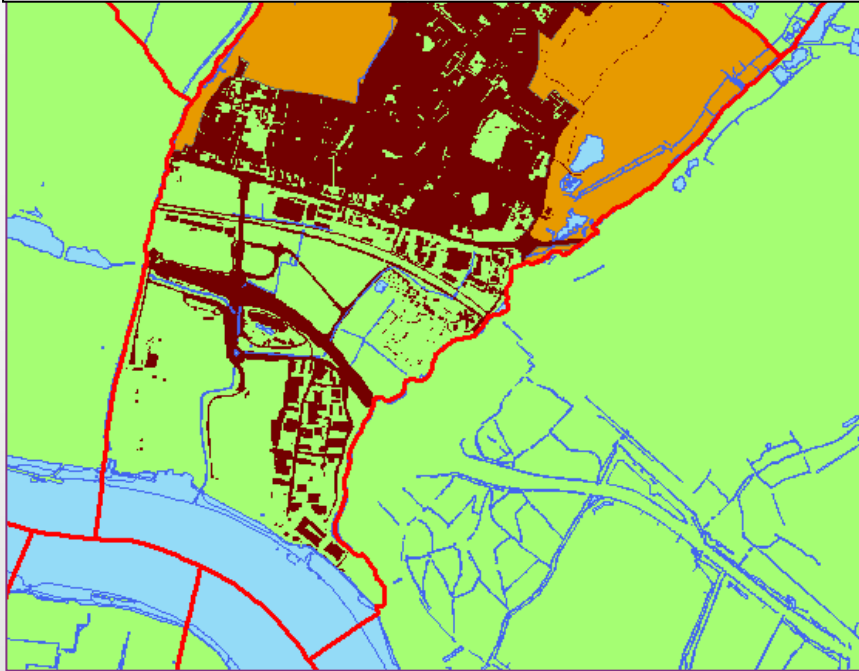
<i>Mode</i>	<i>Observed</i>	<i>Percent Shift</i>
<b>Road</b>	39%	-50%
<b>Rail</b>	12%	+48%
<b>Tube</b>	33%	+36%
<b>Bus</b>	16%	+73%
<b>Population Shift</b>		4%

# Integrated Assessment using Sketch Simulation

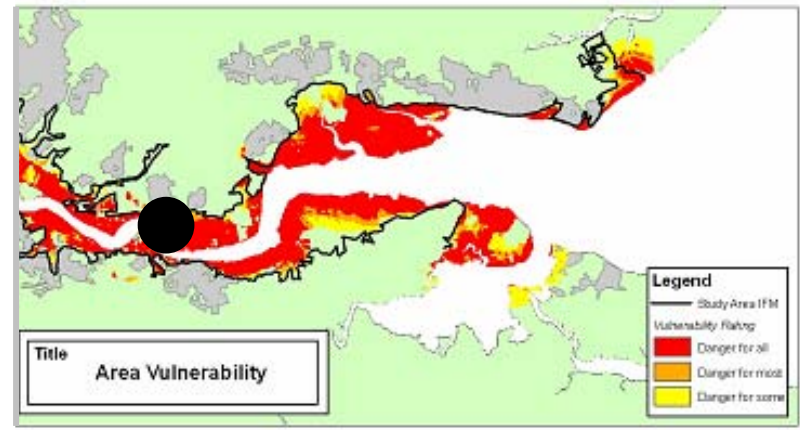
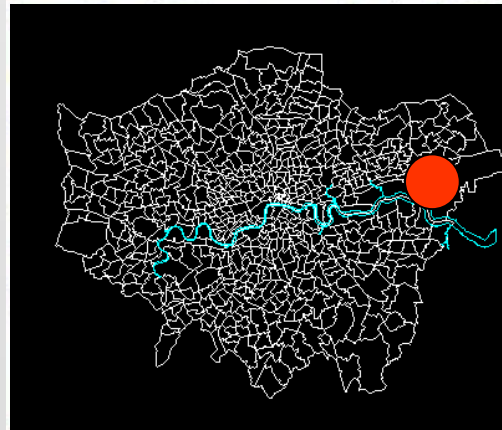
- I have said nothing at all about how this model is embedded in the integrated assessment – the string of models that are used to scale national regional forecasts to very small scale. I cannot show you all these models but let me just talk briefly about the next stage down – how we go from 633 zones in London to 50 metre grid squares and this sort of hooks up to another style of modelling
- In GIS ..... Here is the integrated assessment block diagram again



# The local development model GIS layers at 50 metre resolution



- Current Water
- Currently Developed
- Planning Constrained Land



This particular version of the model is being extended in a second phase of Tyndall under the ARCADIA project

<http://www.ukcip-arcc.org.uk/>



The screenshot shows the ARCC website interface. At the top left is the 'arcc' logo. To the right are login fields for 'User:' and 'Password:' with a 'Login' button and a 'Lost Password?' link. Below this is a navigation menu with links for 'Home', 'ARCC', 'News & events', 'Project Summaries', 'Get involved', and 'Coordination Network'. A search bar on the right contains the text 'search this site...'. The main content area features a section titled 'Project: ARCADIA' in orange. Underneath, there is a list of project summaries on the left and a detailed description for ARCADIA on the right. The detailed description includes the project title, the lead professor, and the project's aim.

arcc

User:  Password:   [Lost Password?](#)

Home ARCC News & events Project Summaries Get involved Coordination Network

**Project: ARCADIA**

Project summaries

- ARCADIA
- ARCC-Water
- BIOPICCC
- COPSE

**ARCADIA: Adaptation and Resilience in Cities: Analysis and Decision making using Integrated Assessment**

Prof. Jim Hall, Newcastle University

**AIM:** To provide system-scale understanding of the inter-relationships between climate impacts, the urban economy, land use, transport and the built environment and to use this understanding to design cities that are more resilient and adaptable.

## Next Steps

- Extending the area to 2000 or so zones – wider south east region
- Building the extended set of sectoral models
- Building in market clearing and some simple dynamics
- Extending the energy use to locational factors
- Disaggregating the model into more population and employment types relative to data
- Specifying movers and stayers through the exogenous inputs and tying these to past model outputs

# Questions?