



Megacities, Vulnerability and Global Climate Change:
FAPESP: City of São Paulo, July 20th – 22nd 2009

Integrated Modelling of the Spatial Impacts of Climate Change In Greater London

Michael Batty
University College London

m.batty@ucl.ac.uk
www.casa.ucl.ac.uk



Outline

The Context: *Climate Change London*

Requirements for Modelling: *Simplicity, Communicating Simulation & Prediction, Robustness*

The Integrated Assessment: *Strings of Models*

The Land Use Transport Model

A Demo of the Model

Climate Change in London: *Integrated Assessment*

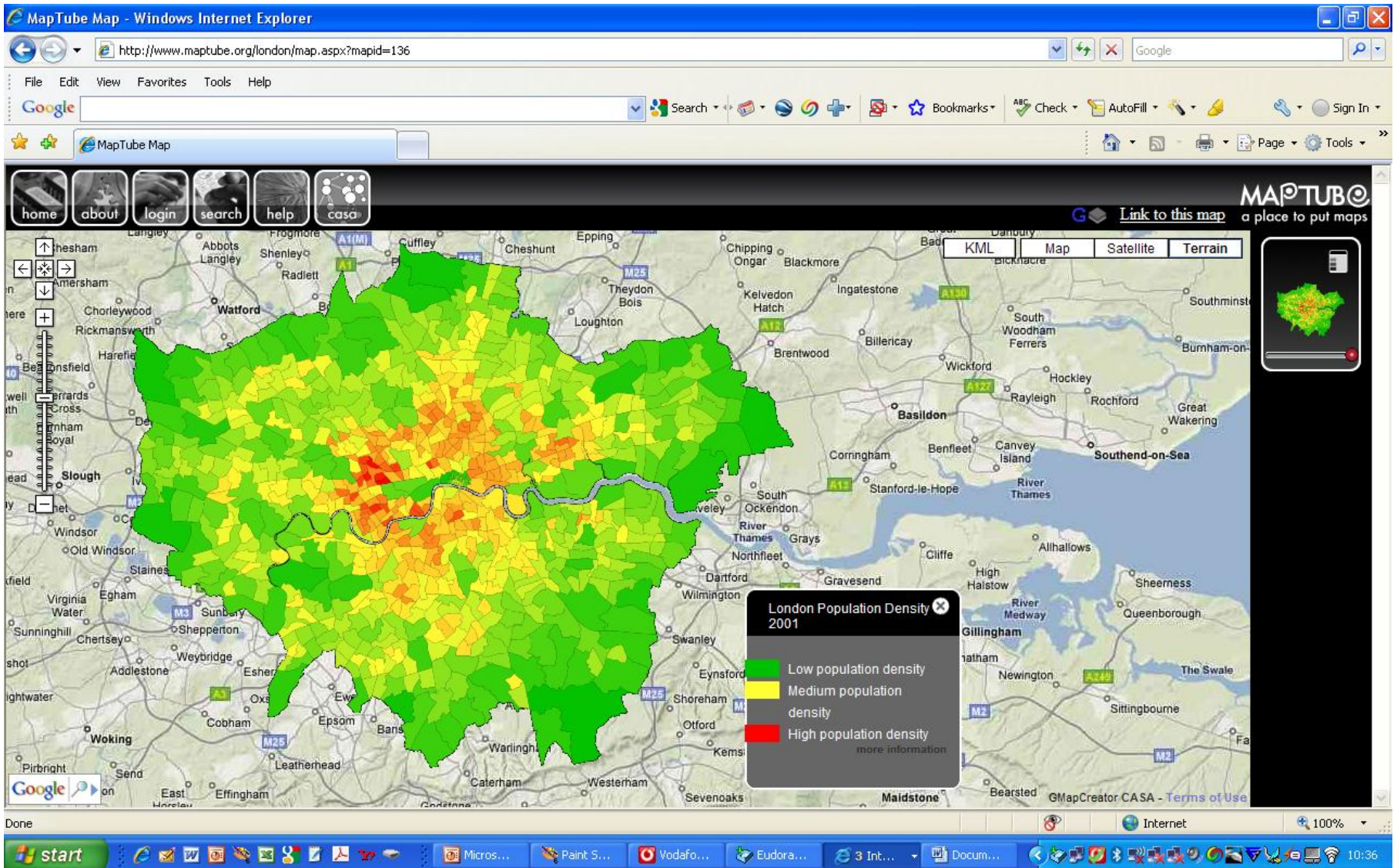
Next Steps

Location in Europe and the UK:

South East England is the wider megalopolis, Greater London is the 33 boroughs with about 7.7million population

Our study so far focuses on Greater London but will be extended to the wider region in the next phase





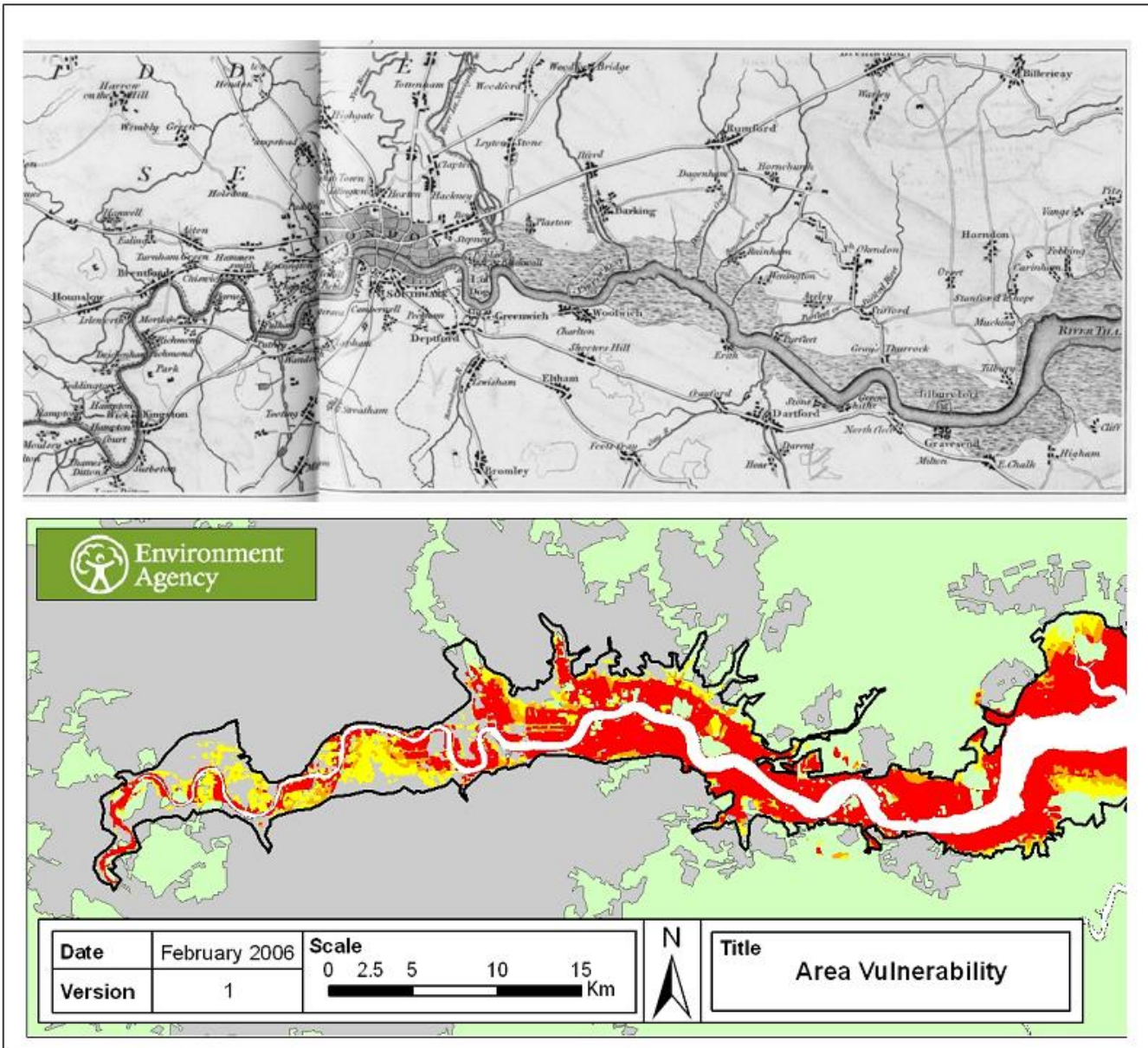
The Greater London Region consisting of 33 boroughs and 7.7million population

*The Context: Climate Change in London: Flooding & Pollution
Mainly along the River Thames and Its Estuary*



The Thames Barrier built from 1978 to 1984 in operation, likely to be ineffective now by 2040? due to new predictions of sea level rise but this is highly debatable ...





Types of Prediction and Types of Models

The time horizon – short term to long term; obvious uncertainties

In general the longer the time horizon for prediction, the greater the uncertainty that detail in the model is required.

Longer time horizons, simpler models

More robust models – an overused word – hardly every defined – but little point in developing very detailed and intricate models which require huge data resources for very long term forecasting when detailed data inputs are needed to forecast independently

Requirements: Simplicity, Accessibility, Robustness

The model we will demonstrate here is for very long time horizons – for 50 or 100 years when there are quite well established predictions of physical change – climate change, in our case rising sea levels.

Thus the model is comparative static – to forecast small area population change that we assume adjusts over 50 or 100 years. Contestable of course.

The model also needs to be intelligible to a wide variety of professionals and experts as well as informed stakeholders. These stakeholders are uncertain, who are they and how do they interact with the models?

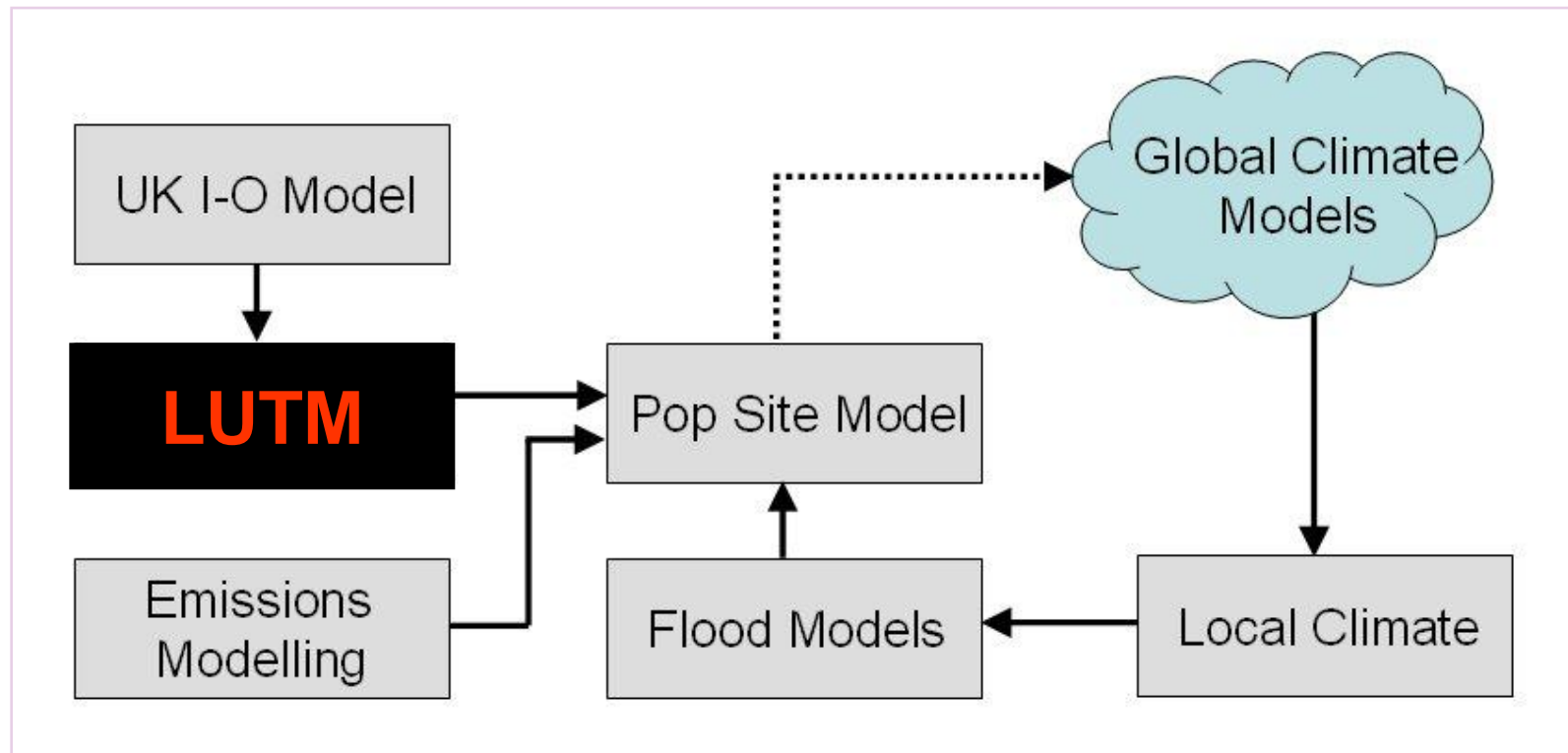
The Integrated Assessment:

Our part in the integrated assessment is a land use transport model to forecast small area population change in Greater London as part of a series or sequence of models designed to explore how more global economic change translates into change in population and how this is affected by rising sea levels.

The land use transport model sits between the aggregate economic modelling and more detailed flood modelling at the local scale.

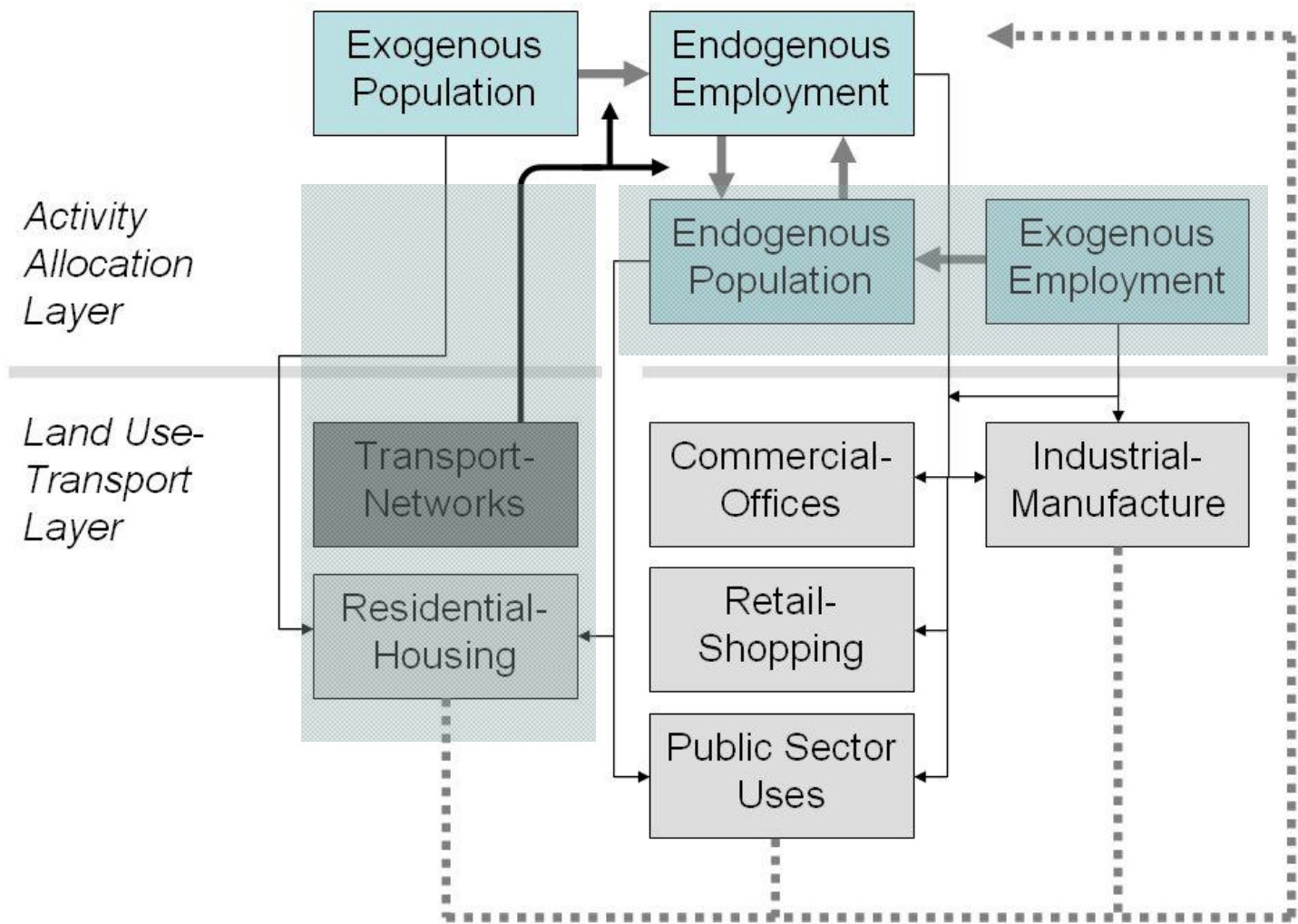
Here is the sequence of models and we will return to this sequence once I have outlined the LUTM & demoed it

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



The LUTM is in two layers – activity allocation and physical location

The Land Use Transport Model



The model is simple, highly visual – so that any informed expert can use it or at least it can be demoed easily.

It is strongly coupled into GIS as mapping is central to the visualisation – in fact all the GIS is purpose built

It is accessible, immediate and capable of being demoed quickly

It is quite different from many of the current large scale LUTM models like UrbanSim, more aggregate

This doesn't mean it is better, far from it. It is different and designed for a very different purpose. It is designed to give structure to the process of **very** long term forecasting and scenario setting

The easiest way is to demo it

To give a flavour of the model, I will show some screen shots first

London and the Thames Gateway Land Use Transportation Model

Cities Research Programme
Tyndall Centre
for Climate Change Research

CASA@UCL **Newcastle** **CE9**

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

Reading in Data

Population, Employment and Floorspace Data

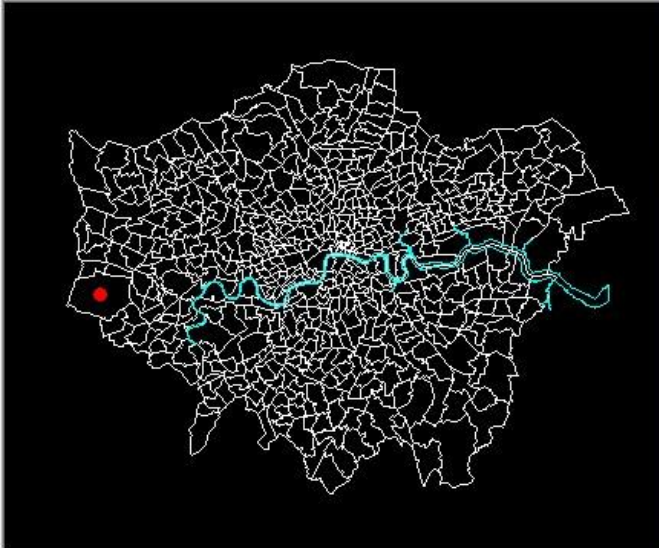
Employment Origin Zones

Population Destination Zones

Physical Line and Area Data

Travel Data

Displaying the Physical Map



Zones: 633 Wards in 2001

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

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

Travel Data

Mean Modal Trip Cost Observed Trips

Mean Cost by Mode Distance-Cost

32.82082
16.67022
99.76682
31.98717
57.97092

Click to Display Map Now

Click Here If You Wish to Close This Interface

Modes

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

Zones: 633 Wards in 2001

6 Heathrow Villages Hillingdon

Locate Zone

Clear Zone Nodes

Data Input Has Been Completed

Project1 - Form1 (Project2.vbp)

- Forms
- Form1 (Form1.frm)
- Form10 (Form10.frm)
- Form11 (Form11.frm)
- Form12 (Form12.frm)
- Form13 (Form13.frm)
- Form14 (Form14.frm)
- Form15 (Form15.frm)
- Form16 (Form16.frm)
- Form17 (Form17.frm)
- Form18 (Form18.frm)
- Form19 (Form19.frm)
- Form2 (Form2.frm)
- Form20 (Form20.frm)
- Form21 (Form21.frm)
- Form22 (Form22.frm)
- Form23 (Form23.frm)
- Form24 (Form24.frm)
- Form25 (Form25.frm)
- Form26 (Form26.frm)
- Form27 (Form27.frm)
- Form3 (Form3.frm)
- Form4 (Form4.frm)
- Form5 (Form5.frm)
- Form6 (Form6.frm)
- Form7 (Form7.frm)
- Form8 (Form8.frm)
- Form9 (Form9.frm)

Modules

start Paint Shop Pro Project1 - Mic... Master Tool Bar Reading in Data 07:10

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

(Project2.vbp)
(Form1.frm)
(Form10.frm)
(Form11.frm)
(Form12.frm)
(Form13.frm)
(Form14.frm)
(Form15.frm)
(Form16.frm)
(Form17.frm)
(Form18.frm)
(Form19.frm)
(Form2.frm)
(Form20.frm)
(Form21.frm)
(Form22.frm)
(Form23.frm)
(Form24.frm)
(Form25.frm)
(Form26.frm)
(Form27.frm)
(Form28.frm)
(Form3.frm)
(Form4.frm)
(Form5.frm)
(Form6.frm)
(Form7.frm)
(Form8.frm)
(Form9.frm)
1 (Module1.bas)

start

Eud... Proj... Mas... Rea... Data Acc...

08:57

Master Tool Bar

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

Predict

Reading in Data

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.

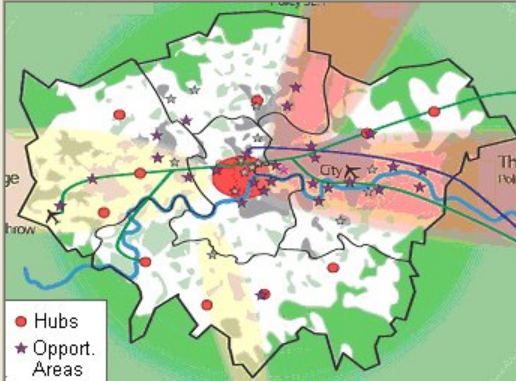
Users have a choice of inputting a preset scenario in which all these variables are changed exogenously or a process of changing these variables interactively, on screen. The interactive process can involve many thousands of changes and is probably best used to input data which reflects 'what-if' scenarios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



(Project2.vbp)
 (Form1.frm)
 (Form10.frm)
 (Form11.frm)
 (Form12.frm)
 (Form13.frm)
 (Form14.frm)
 (Form15.frm)
 (Form16.frm)
 (Form17.frm)
 (Form18.frm)
 (Form19.frm)
 (Form2.frm)
 (Form20.frm)
 (Form21.frm)
 (Form22.frm)
 (Form23.frm)
 (Form24.frm)
 (Form25.frm)
 (Form26.frm)
 (Form27.frm)
 (Form28.frm)
 (Form3.frm)
 (Form4.frm)
 (Form5.frm)
 (Form6.frm)
 (Form7.frm)
 (Form8.frm)
 (Form9.frm)
 1 (Module1.bas)

start

E... P... M... R... P... Pr... Pr...

08:59

Predict

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

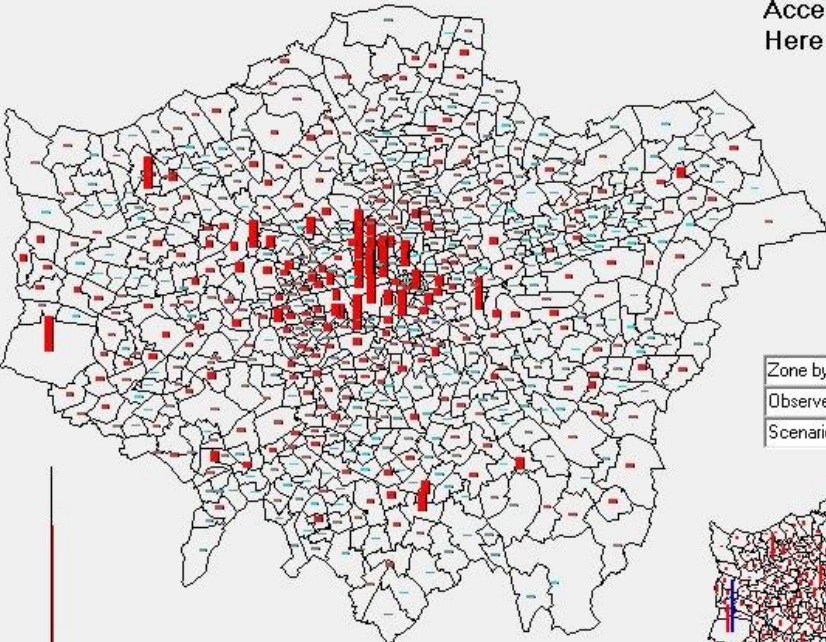
Interactive Input of Changes to Employment-Origin Zone Data

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

Use Slider to Input Percentage Change for Zone 6 6

Click Button to Accept Changes Here


Old Employment in 6 is 86962
New Employment is 173925



Zone by Borough Name

Observed Employment

Scenario Employment



Updated Employment So Far

Predict

Input Scenario Data

Scenario from File

Employment Changes

Floorspace Changes

Distance Changes

Run Scenario Model

Run Model

More Scenario Runs ...

Expansion

Expansion

Expansion

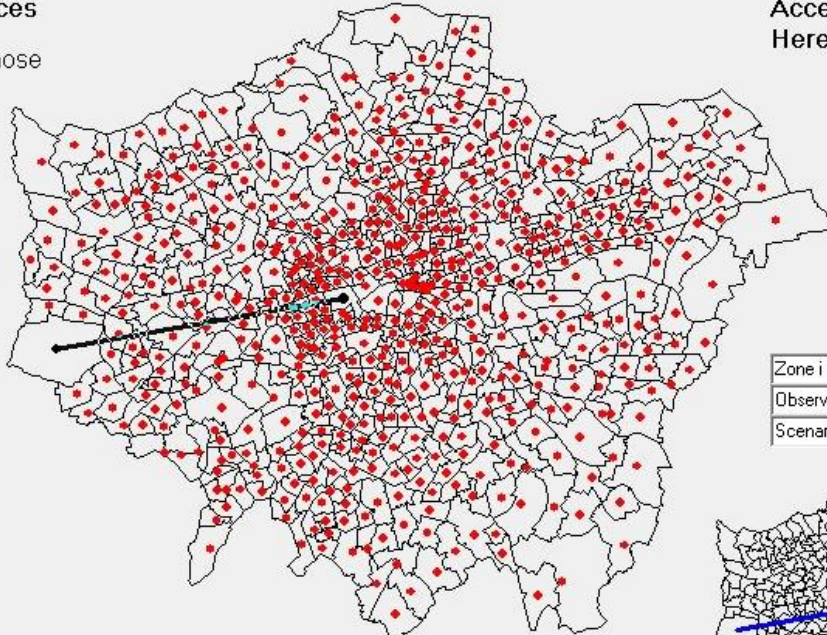
Prediction Routines

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

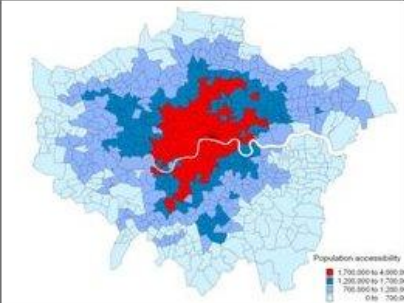
Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click

Use Slider to Input Percentage Change for Zone 6 to 219

Click Button to Accept Changes Here




Old Distance from 6 to 219 is 35
New Distance is 7



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...

For a movie of all this go to our web site

<http://www.casa.ucl.ac.uk/transportmodel/transportmodel.asp>

UCL CENTRE FOR ADVANCED SPATIAL ANALYSIS
A LAND USE TRANSPORT MODEL FOR LONDON

Search CASA's site

Research Programme 6: Cities
Newcastle, Leeds, UCL, Loughborough, Cambridge, Manchester

↓

Environmental Input-Output

↓

Scenario Generator

↓

Transport Network Generator

↓

Land Use Transport Model

↓

Urban Development Allocator

↓

Flood Models

Tyndall Centre

A LAND USE TRANSPORT MODEL FOR LONDON

We are building a land use transport model as part of the **Tyndall Centre for Climate Change Cities Project**. This model sits in a sequence of models that are listed in the attached panel on the right. This begins with an econometric model – an environmental input-output model which generates employment totals (as well as many other economic indicators for Greater London and other large regions in western Europe) and these are then input into our land use transport model through a scenario generator. Our own model simulates the location of the residential population as a function of this employment, floorspace and generalised travel cost. The model is currently, in the jargon, a partially constrained spatial interaction/residential location model disaggregated by four modes of transport – road, heavy rail, light rail (tube and DLR) and bus, with walk-cycle-other the fifth residual mode.

The model is highly visual as we are motivated to make the entire modelling process as transparent as possible. Moreover to verify the data and to interpret the spatial structure of the metropolitan area, we need as much visual synthesis through maps and graphs as possible.

If you click on the button below, then this will launch a movie which takes you through the sequence of stages from input data to calibrating the model to using it for predictions. When you load the movie, occasionally you may need to resize your window to see the full extent, as the movie was made for 1280 by 800 screen size.

[Click Here to Launch the Movie](#)

At each stage – input, calibration, prediction – the user can explore the data in map and graph form and at the prediction stage, the user can alter the data on the fly – adding new levels of employment and floorspace and adding or changing the generalised costs of different transport links (for any of the four modes). We have not written any papers on this as yet so the movie of how the model works is the best you are going to get at this stage. There is a general paper on the process of integrated assessment that you can in fact download by clicking [here](#)

In fact what we hope to do is to add to this movie, with movies of the scenario generator, the trip and generalised cost computations

start | C:\Document... | UNC-Demons... | stakeholders... | UCL Centre f... | 12:40



You can find more about the Tyndall Cities Project on the Tyndall Web site

<http://www.tyndall.ac.uk/research/programme6/>



The screenshot shows a website page with a blue header. On the left is a logo for 'Cities' featuring a stylized city skyline. On the right is the 'Tyndall°Centre™ for Climate Change Research' logo. Below the header is a navigation menu with links: 'Homepage', 'About Us', 'People', 'Research', 'Publications', 'Events', 'News', 'Partnerships', 'Contact', and 'Search'. The main content area is titled 'Engineering Cities' and contains the following text:

... how can cities grow while reducing vulnerability and emissions?

Almost 50 per cent of the world's population live in cities, increasing to 60 per cent by 2030. As a result of this, urban emissions will be an increasing driver of global warming. At the same time, urban areas, particularly in coastal regions in the developing world, are vulnerable to climate change and its impacts. In turn, these impacts induce energy-intensive adaptations such as air conditioning, pumped drainage or desalination. The mitigation of these impacts and sustainable options for adaptation in vulnerable cities require integrated strategies involving key stakeholders. Ultimately, we want to understand more about the effects of climate change on cities, the causes of greenhouse gas emissions from urban areas and assess the effectiveness of alternative approaches to mitigation and adaptation.

Our research combines generic developments intended to be widely applicable with place-specific studies to provide convincing demonstrations and to engage with stakeholders. We are working with stakeholders in London and cities elsewhere to define policy questions not addressed by other initiatives, to provide a vision of future urban strategies for mitigation and adaptation, to understand decision-making processes, and to access datasets and collaborate with researchers from other climate-related initiatives.

Together, these tasks will mean that stakeholders and researchers will understand more about the systemic effects of climate change on cities, will have new insights into greenhouse gas emissions from urban areas, and will be able to conduct model-based assessment of the effectiveness of alternative strategic approaches to mitigation and adaptation.

Programme Leader: Professor Jim Hall, University of Newcastle-upon-Tyne

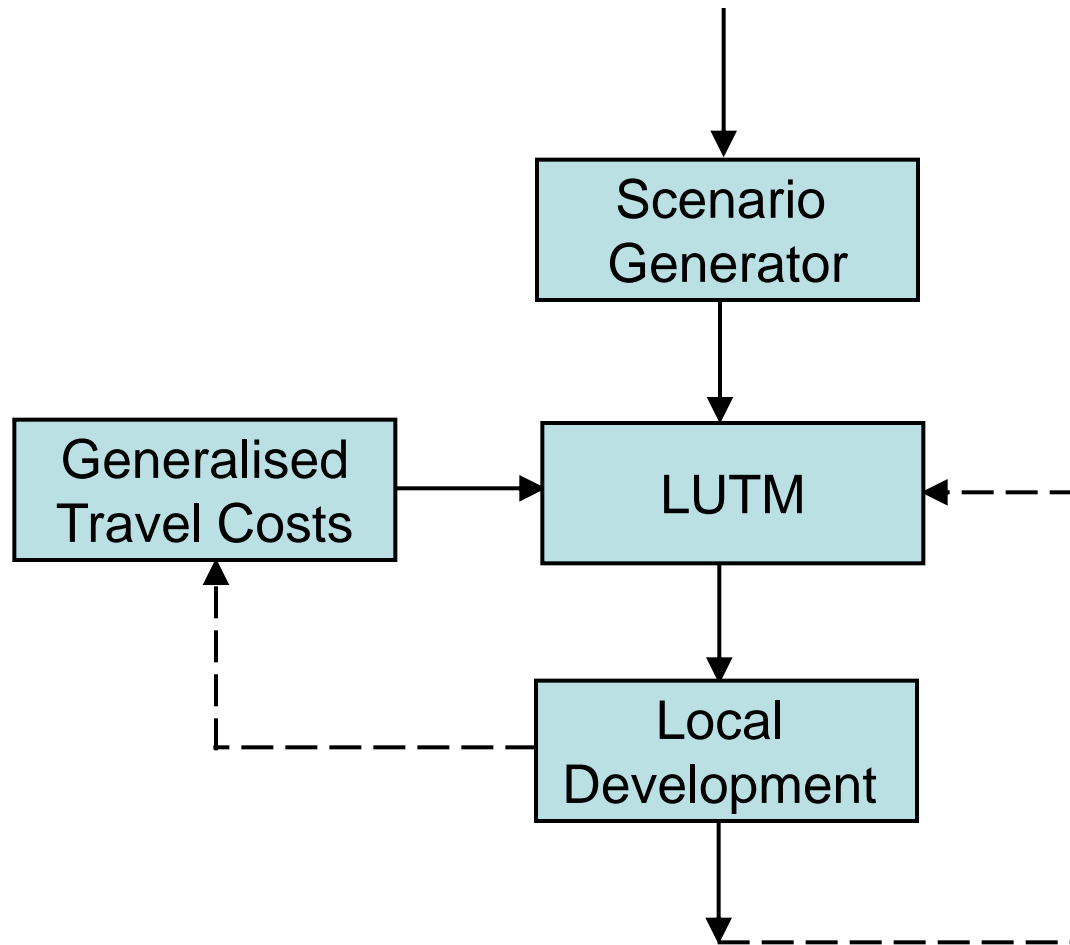
But there is a launch event in London October 16th 2009
at the GLA

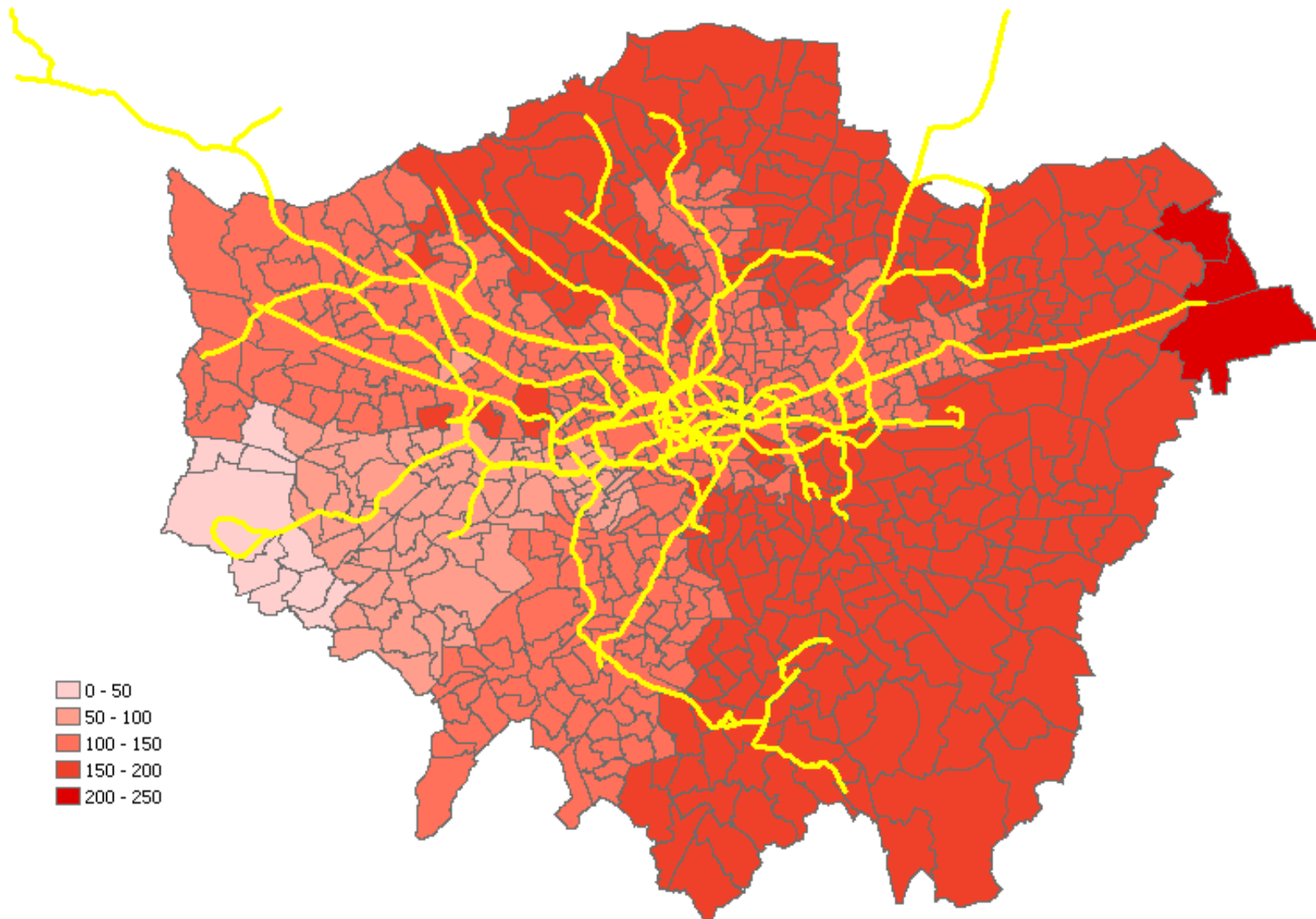
Ok let me step back and tell you more about the integrated assessment:

- The Aggregate Economic Forecasting
- The Scenario Generator
- The Transport Network Analysis Module
- The LUTM
- The Local Development Model
- The Flooding Models
- The Aggregate Emissions Models

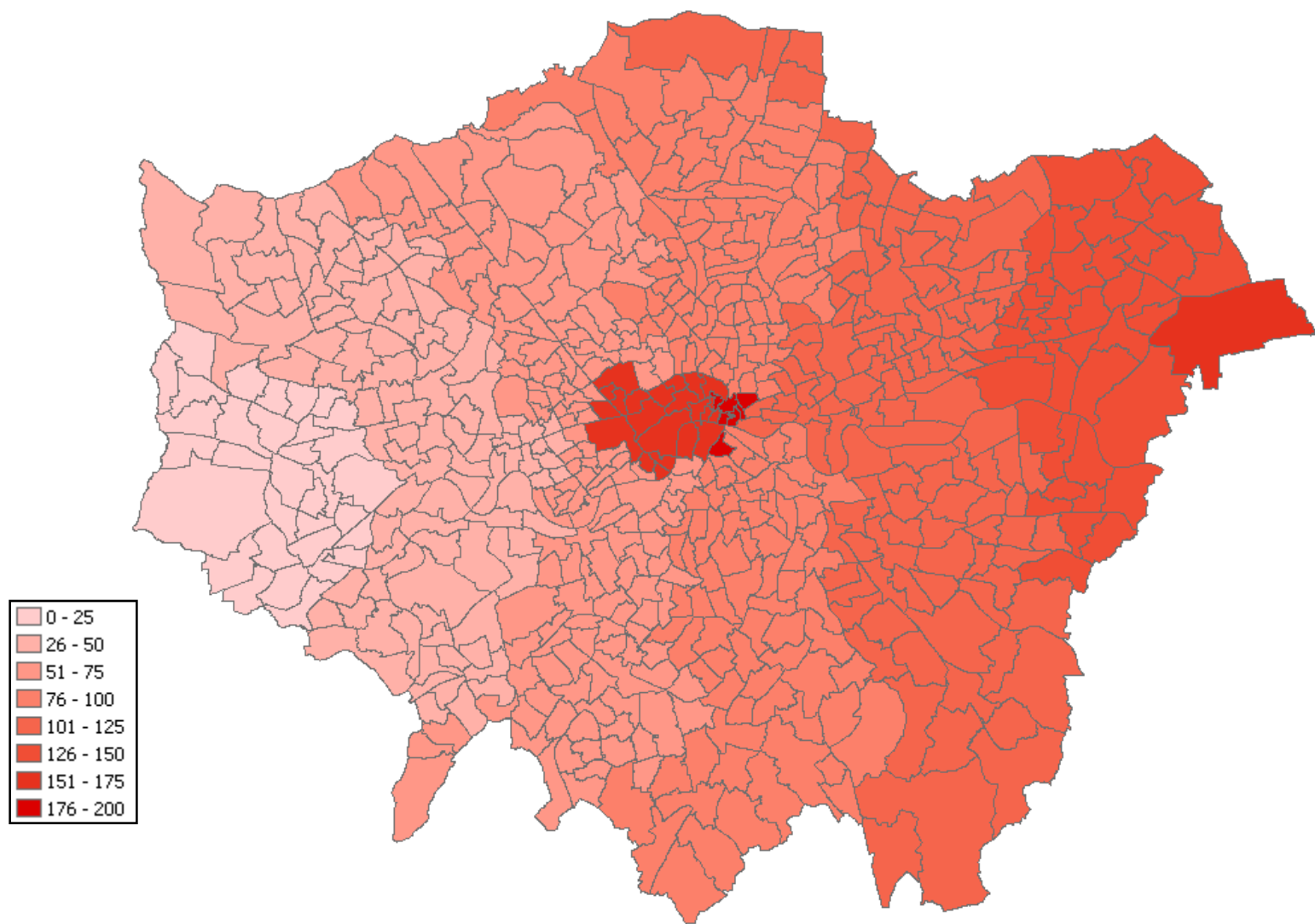
I am going to sketch just two of these models to give a sense of how they are integrated

Let us unpack the LUTM process as there are really four types of models/analytical tools here





Light Rail Generalised Costs from Heathrow Ward (minutes)



2001 Road Generalised Cost from Heathrow Ward (minutes)

The ArcGIS Interface

- Reflect the cost of travel including:
 - Monetary costs
 - Time
- Differing calculations for public and private transport
- Includes policy drivers:
 - Cost of fuel
 - Road user/congestion charging
 - Ticket costs
 - Service frequencies
- Allows modelling of both geographical and economic costs

Road Generalised Cost Calculation

OD Time Layer: OD_ITN_Time

Congestion Charge: OD_ConC_ITN

OD Distance Layer: OD_ITN_Dist

Number of Zones: 633

OD Origin Field: OriginID

OD Dest. Field: Destinatio

OD Cost Field: Total_Time

Con Charge Field: Total_Con_

Distance Field: Total_Dist

Generalised Cost Parameters

Value of Time (£/h): 5.04 OD Matrix

Walking Time to car (m): 1.5 OD Pairs

Walking Weight: 1.6

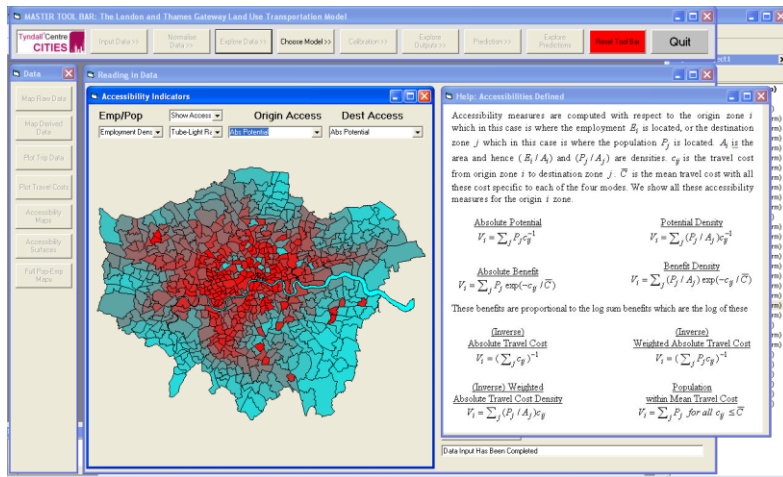
Operating Cost (£/km): 1.6

Number of Occupants: 1.16

OK Cancel

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.

Absolute Potential

$$V_i = \sum_j P_j c_{ij}^{-1}$$

Potential Density

$$V_i = \sum_j (P_j / A_j) c_{ij}^{-1}$$

Absolute Benefit

$$V_i = \sum_j P_j \exp(-c_{ij} / \bar{C})$$

Benefit Density

$$V_i = \sum_j (P_j / A_j) \exp(-c_{ij} / \bar{C})$$

These benefits are proportional to the log sum benefits which are the log of these

(Inverse)

Absolute Travel Cost

$$V_i = (\sum_j c_{ij})^{-1}$$

(Inverse)

Weighted Absolute Travel Cost

$$V_i = (\sum_j P_j c_{ij})^{-1}$$

(Inverse) Weighted

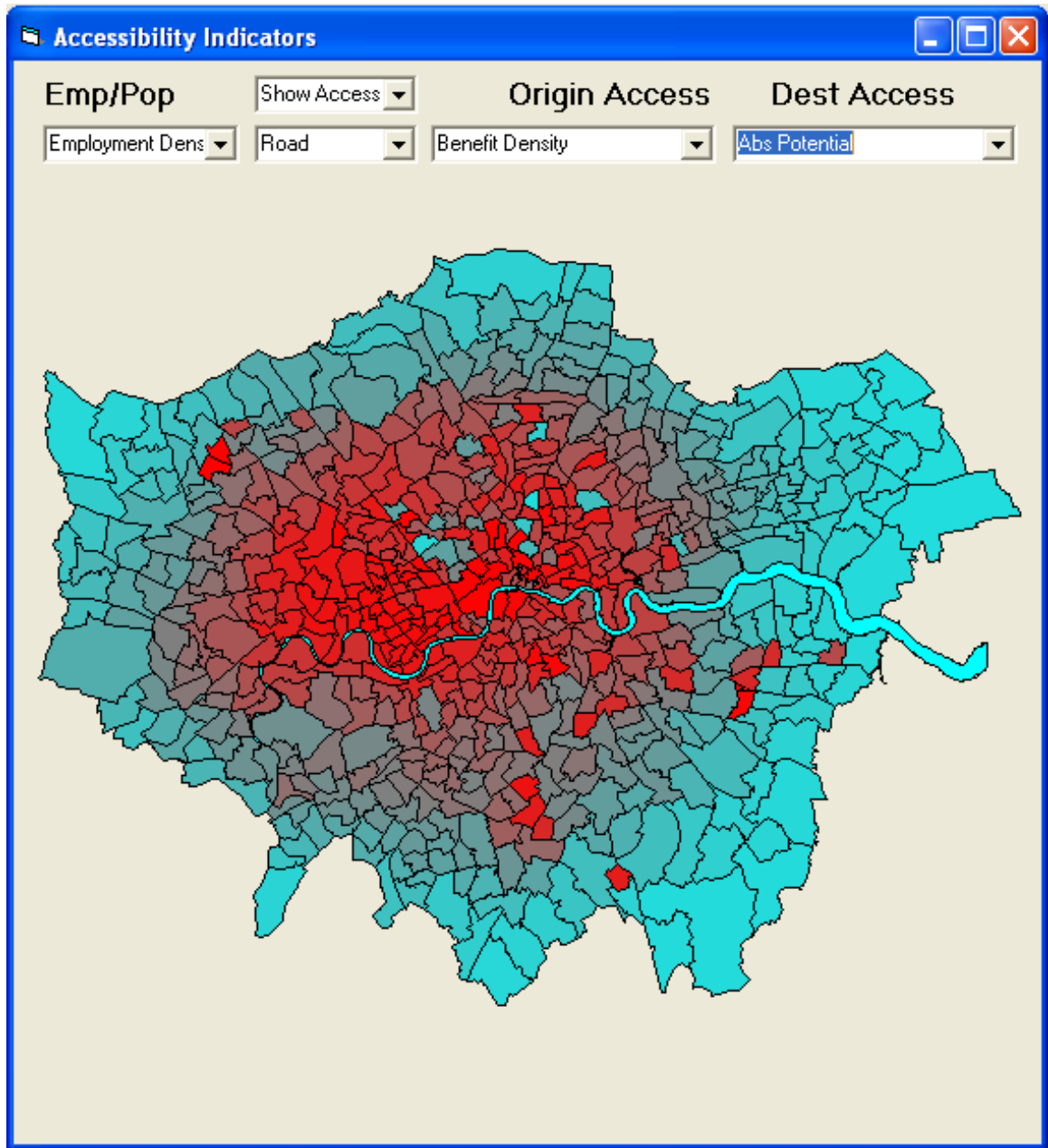
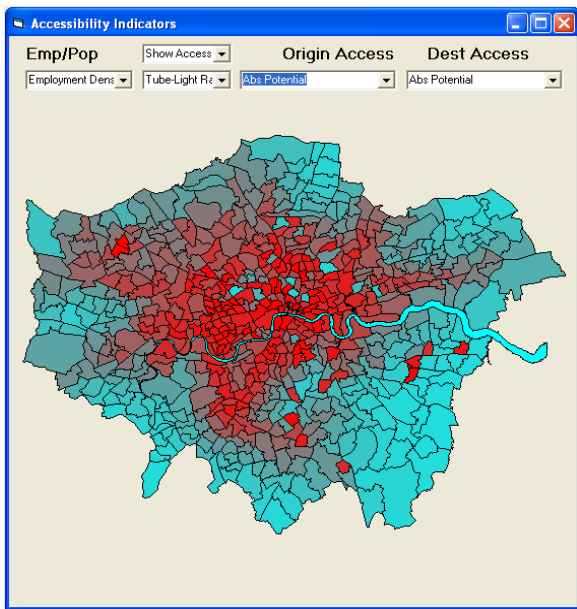
Absolute Travel Cost Density

$$V_i = \sum_j (P_j / A_j) c_{ij}$$

Population

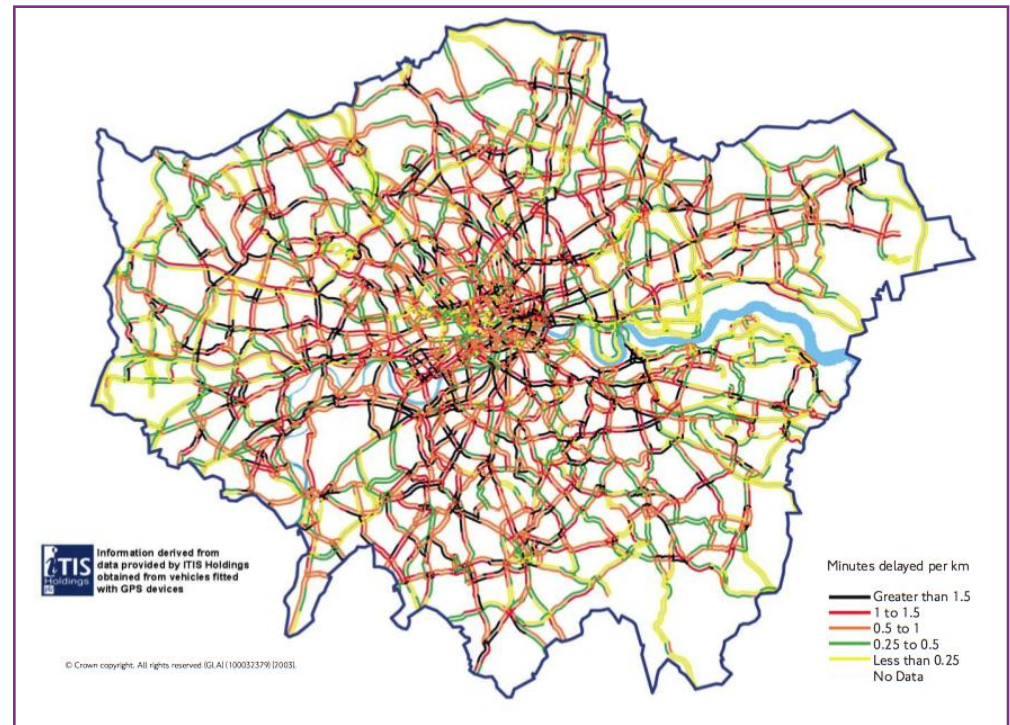
within Mean Travel Cost

$$V_i = \sum_j P_j \text{ for all } c_{ij} \leq \bar{C}$$



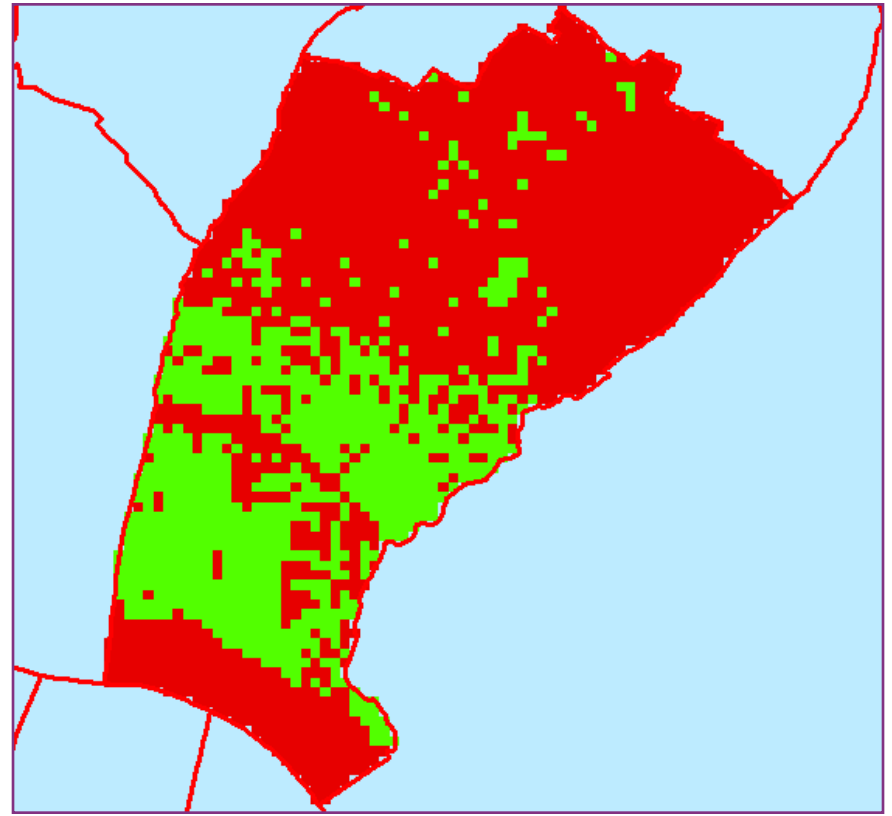
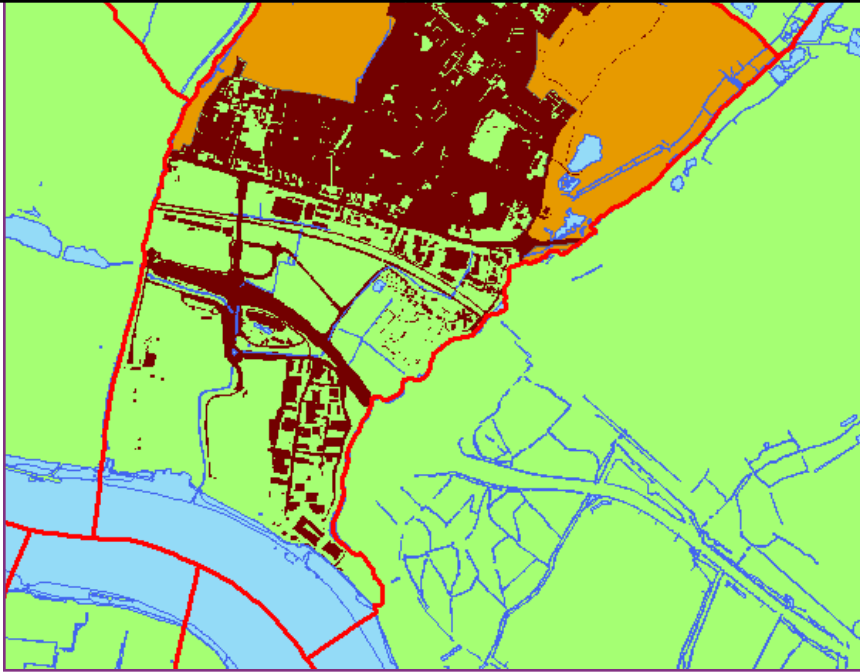
Further work on networks

From our London database project which Andrew Crooks and Duncan Smith talked about this morning



Bring the data in-house
Currently we have the
Road system in good
Detail with speeds etc
From TfL

The local development model GIS layers at 50 metre resolution



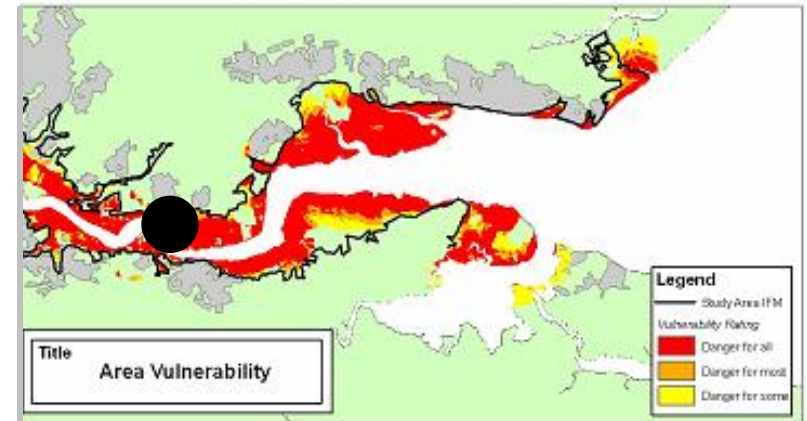
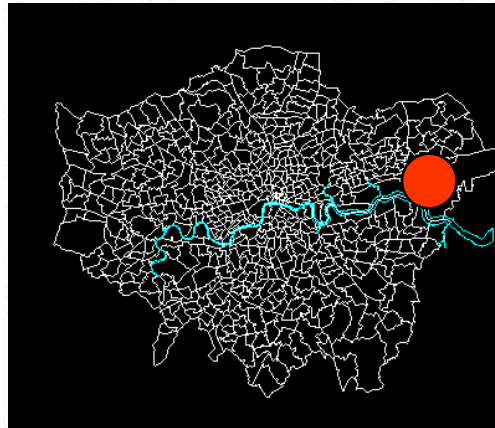
Current Water



Currently Developed



Planning Constrained Land



Title
Area Vulnerability

Legend

- Study Area IFM
- Vulnerability Rating
 - Danger for all
 - Danger for most
 - Danger for some

Extending the formal project

The roll out of all these models will be accomplished in a second phase of Tyndall which in fact is financed not by NERC but by EPSRC 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 input fields for 'User:' and 'Password:', a 'Login' button, and a 'Lost Password?' link. Below this is a navigation menu with links: 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 is titled 'Project: ARCADIA' in orange. Under 'Project summaries', there is a list of projects: ARCADIA, ARCC-Water, BIOPICCC, and COPSE. The 'ARCADIA' entry is expanded, showing the title 'ARCADIA: Adaptation and Resilience in Cities: Analysis and Decision making using Integrated Assessment', the lead 'Prof. Jim Hall, Newcastle University', and the '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

Extensions to the Gateway

Extending the model to generate employment

Disaggregating the Model to five population and five employment groups

Developing the Land Use Constraints

Developing feedbacks from transport to land use

Extending the transport costs and travel time to incorporate explicit energy use

Extending the location models to incorporate energy use in work and home

Thanks, Any Questions?

Look at

<http://www.casa.ucl.ac.uk/transportmodel/transportmodelmovie.html>