PROPOLIS

Planning and Research of Policies
for
Land Use and Transport for Increasing Urban Sustainability

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Deliverable D 4

The PROPOLIS Raster Module

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17 November, 2003

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Work Package 4: GIS-based Raster Module

Deliverable D4
The PROPOLIS Raster Module

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1. INTRODUCTION

The major objective of the PROPOLIS project is a systematically evaluation of policies with respect to their long term sustainability impacts. For that purpose a modelling system was designed in which different models and tools are integrated.

Land use transport models are the driving engines of the system. The land use transport models simulate the effects of the policies in terms of changing zonal activities such as population or employment and changing mobility pattern resulting in different modal splits and different link loads. All land use transport models used are fully GIS integrated and their GIS databases contain spatial data on zonal boundaries, road and public transport networks, land use categories etc.

A range of indicator modules post-process the output of the land use transport models to calculate raw values of sustainability indicators. This includes a Raster Module for environmental and social indicators requiring a high spatial resolution, an Economic Indicator Module for an economic evaluation and a Justice Indicator Module addressing equity issues.

The sustainability indicator values are further processed in a sustainability evaluation module by using multicriteria evaluation. Finally, presentation tools show results in standard form for each policy and have options to make comparisons between policies and cities.

The Deliverable D4 is devoted to the Raster Module of this suite of models and tools. The Deliverable D4 integrates the originally planned Deliverables D4.1 "Specification and implementation report of the module" and D4.2 "Operational Raster Module" into one report. Chapter 2 will present the basic rationale of the module and its specification. Chapter 3 will demonstrate the operational tool with examples from the seven PROPOLIS case study regions.

2. SPECIFICATION OF THE RASTER MODULE

Urban models have always been spatially aggregate with zones of varying size such as boroughs or statistical districts as units of spatial reference. As the internal distribution of activities and land uses within a zone is not known, a homogenous distribution across the area of the zones has to be assumed. Even though the number of zones of some models has increased substantially in recent years, the spatial resolution of zone-based models is much too coarse to represent other environmental phenomena than total resource use, energy consumption or CO_2 emissions (see for an overview, Wegener, 1998). Many environmental processes and their social impacts at the urban scale can not be treated by those kind of models, i.e. significant indicators for urban sustainability cannot be calculated.

A combination of raster and vector representation of spatial elements as it is possible in GIS might lead to spatially disaggregate models that are able to overcome the disadvantages of zonal models (Spiekermann and Wegener, 1998). Creating a GIS database and using spatial interpolation techniques, zonal data can be disaggregated from polygons to pixel to allow the calculation of micro-scale indicators meaningful for urban sustainability such as land coverage, biodiversity, air pollution or exposure to air pollution and noise (Wegener and Spiekermann, 1997)

In order to calculate such indicators in PROPOLIS the so-called Raster Module has been developed of which the methodology will be introduced in this chapter. The Raster Module maintains the zonal organisation of the land use transport models and adds a disaggregate raster-based representation of space for some specific environmental and social impact submodels.

As the Raster Module is based on the output of aggregate urban models, several steps have to be undertaken to arrive from the polygon-vector representation of zones and networks to small-scale environmental and social impacts and to a re-aggregation to indicators for assessing sustainability.

Figure 1 shows the basic structure of the *Raster Module*.

There are two main sources of input for the Raster Module. On the one hand there is a spatial database containing zone boundaries and land use categories as polygons and the network coded as vectors. On the other hand there are the policy-dependent forecasts by the land-use transport models for the location of households by socio-economic group, employment and floorspace in the zones and and the traffic flows on the links of the network.

This information is converted to raster cells. The main assumption concerning the disaggregation of activity locations is that population and employment are not equally distributed over the territory of a zone but that there are differentiations in density. The assumption of intra-zonal differentiation is reflected by weights assigned to the raster cells based on typical densities of land use categories (e.g. Bosserhof, 2000). These weights are converted to probabilities by dividing them by the zonal total of weights. This gives a probability distribution of households in a zone. Cumulating the weights over the cells of a zone one gets a range of numbers associated with each cell. Using a random number generator for each household a cell is selected as the household's location. The allocation of households takes account of different weighting schemes for three socio-economic groups. The disaggregation of employment follows the same procedure but with different weights (Spiekermann and Wegener, 1998).

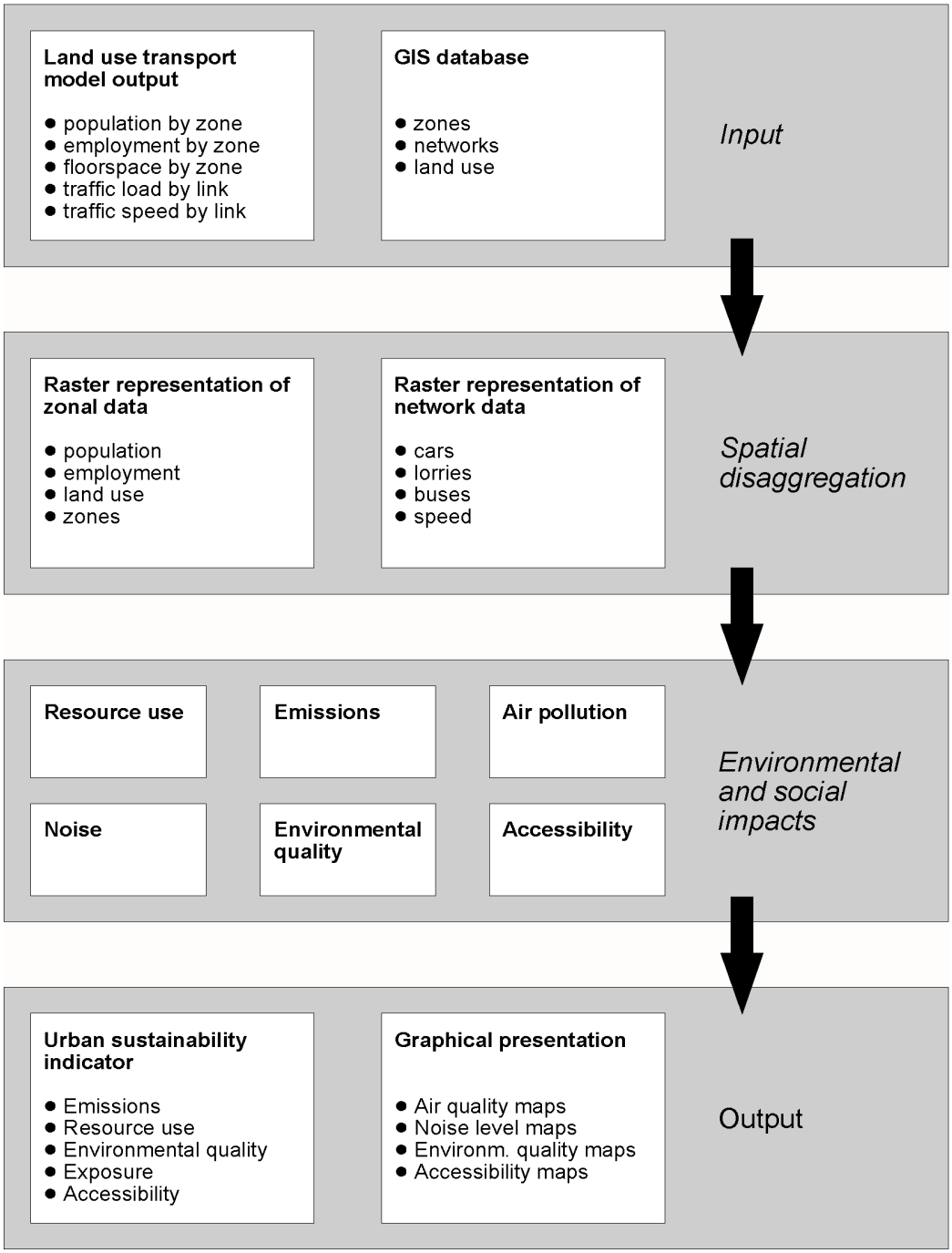


Figure 1. The structure of the Raster Module.

The result of the population and employment disaggregation are artificial micro data that are controlled by zonal totals and of which the intrazonal allocation follows empirical observed patterns and additional information, e.g. from land use planning. The raster representation of three socio-economic household groups and the employment has several functions in the subsequent parts of the *Raster Module*. It is used for the localisation of intrazonal and access trips and the calculation of land coverage. In addition, the raster representation serves as a proxy for barriers in the dispersion models, where households are considered as recipients of pollutants and noise.

Raster disaggregation is also applied to network data. The transport flows forecast by the transport models (number of cars, trucks and buses, speed by link) is related to the information in the GIS database. The GIS database contains the alignment of each link. Because the transport models consider network links as straight lines between nodes, the alignment is required to localise the emission points for subsequent environmental modelling more precisely. The rasterisation of the networks is straightforward: The raster grid overlaid over the network. Each raster cell traversed by a network link receives the information assigned to the link, i.e. number of cars, trucks and buses and speed. The result of the network disaggregation are five raster layers representing urban traffic: three of them contain the number of cars, trucks and buses, the other contain the dominant link type and the average speed for each raster cell. In the environmental models described below the raster cells are considered as point sources of emission.

Using this information, environmental and social impact submodels are used to assess emissions, air quality for several pollutants and noise levels, population exposure, environmental quality and accessibility in each raster cell:

- The *emission submodel* relates the information on traffic flows with up-to date emission functions (Hickman et al., 1999, Journad, 1999). The emission functions used distingues more disaggregate vehicle types than provided by the transport models. Future technological developments and foreseeable environmental regulations are taken into account by changing the vehicle fleet composition over time. The emission submodel calculates also the consumption of mineral oil products by transport (based on Ntziachristos and Samaras, 2000).

- The *air pollution and exposure submodel* has been set up in such a way that it models the chain from emissions to exposure for the whole study areas by applying a Gaussian air dispersion model to the emissions and by relating the resulting concentration to the living places of population. The raster cells are considered point sources of emission. The air dispersion model is applied sequentially to all emission cells. The concentrations in a receptor raster cell from emission raster cells are summed up and related to population subject to European guideline values for air quality.

- The *noise submode*l models the sequence from noise generation via noise propagation to noise levels for all raster cells of the study areas. It is based on the German guidelines for noise protection measures along roads, the so-called RLS-90 (BMV, 1990). For the implementation of this model in a raster framework some modifications and simplifications had to be made with respect to road surface, slope, meteorological conditions and intersections (Lee, 1998). The result is a raster layer that contains for each cell the traffic noise level in dB(A) which is then related to the population living in those cells.

- The *environmental quality submodel* calculates land coverage and two indicators related to open space. Open space is defined as raster cells without transport links and settlements. A fragmentation index is calculated as the average size of contiguous open space areas. For assessing the quality of open space, the noise level is taken into account. High-quality open space is calculated as the area not disturbed by traffic noise, i.e. having a noise level of less than 45 dB(A).
- The *accessibility to open space submodel* assesses the living environment in terms of open space usable by the inhabitants. For this a potential indicator was developed in which the attraction term is open space and the impedance is walking distance.

The output of the *Raster Module* consists of eleven of the PROPOLIS sustainability indicators:

- Greenhouse gases from transport (tons per 1000 inhabitants per year),
- Acidifying gases from transport (Acid equivalents per 1000 inhabitants per year),
- Volatile organic compounds from transport (tons per 1000 inhabitants per year),
- Consumption of mineral oil products from transport (tons per 1000 inhabitants per year),
- Land coverage (percent of study area),
- Fragmentation of open space (index related to base year),
- Quality of open space (index related to base year),
- Exposure to PM in the living environment (% of population above guideline values),
- Exposure to NO2 in the living environment (% of population above guideline values),
- Exposure to traffic noise (% of population annoyed),
- Accessibility to open space (index related to base year).

In addition, the Raster Module generates graphical presentations in form of maps showing air quality, noise levels, environmental quality and accessibility. The Raster Module provides also data input for the Economic Indicator Module and the Justice Indicator Module.

3. OPERATIONAL RASTER MODULE

The Raster Module has been implemented according to the specification presented in the previous chapter. Raster Module is fully integrated in the PROPOLIS modelling system. It will be directly performed after the land-use transport models and the model specific indicator and GIS tools have been executed. The Raster Module has been developed in such a way that no user input is required, i.e. the module can be fully integrated in an automatic process in form of a batch run or a Windows script.

To do a Raster Module run in a case city, the Raster Module requires input from different sources.

- *Land-use transport model output*. The most important input for the Raster Module is the output of the land-use transport models because these data varies from policy to policy. For a smooth data transfer between the different parts of the modelling system a PROPOLIS Common Data Format (CDF) has been defined. The Raster Module accepts requires two CDF input files: one contains the zonal forecasts, the other the traffic flows by link.
- *GIS data*. The Raster Module requires data held in a GIS. Data categories include zone boundaries, network alignment and land use (see Annex 1 for a specification of data requirements and accepted GIS formats.
- *Case city specific parameter*. In addition, the Raster Module requires case city specific parameters. Besides meteorological information required by the air dispersion models, the most important information is data about the current composition of the vehicle fleet and its evolution into the future.

The Raster Module has been implemented and used in the PROPOLIS case cities, i.e. in Bilbao, Brussels, Dortmund, Helsinki, Inverness, Naples and Vicenza. The remaining parts of this chapter demonstrate the operational Raster Module for the seven urban regions. For each case study regions a set of figures is presented which show the spatial distribution at the raster cell level of key indicators calculated by the tool. Displayed are the spatial distribution of population and employment disaggregated to raster cells, the noise level and air quality as well as the quality of open space and the accessibility to open space. The figures are presented for the base scenario. The outcome of the Raster Module for the different policies is reported in the PROPOLIS Final Report.

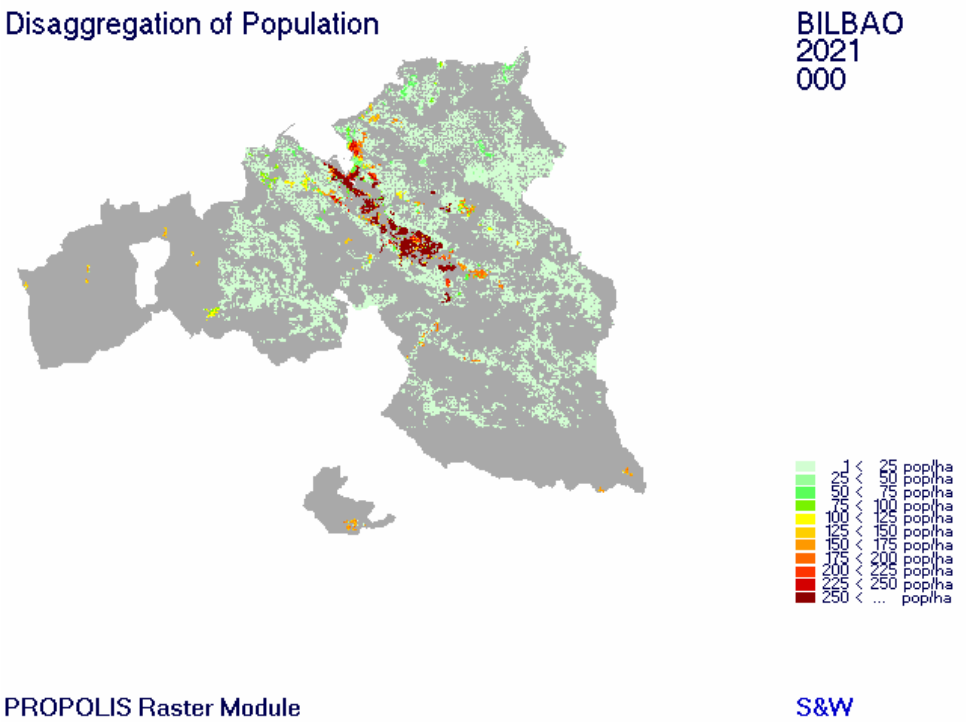


Figure 2. Bilbao, population density.

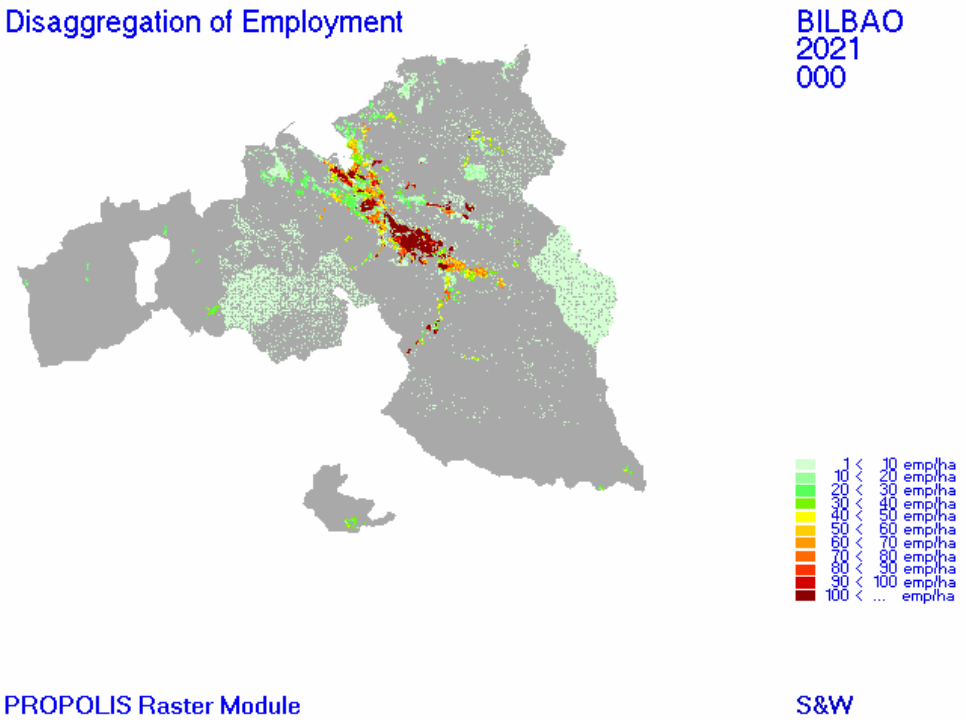


Figure 3. Bilbao, employment density.

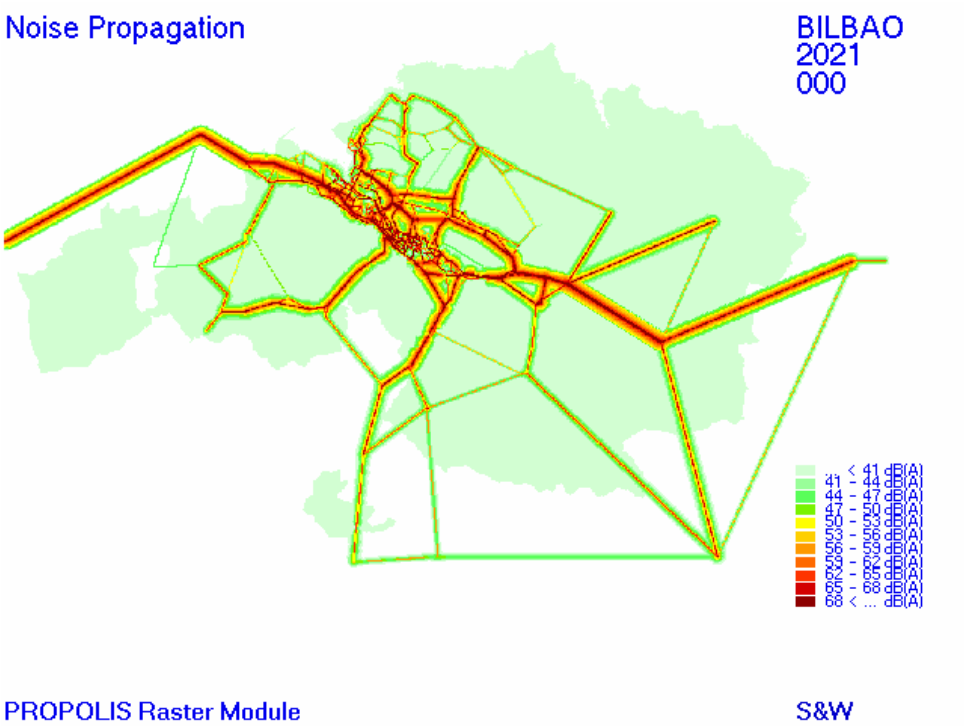


Figure 4. Bilbao, traffic noise

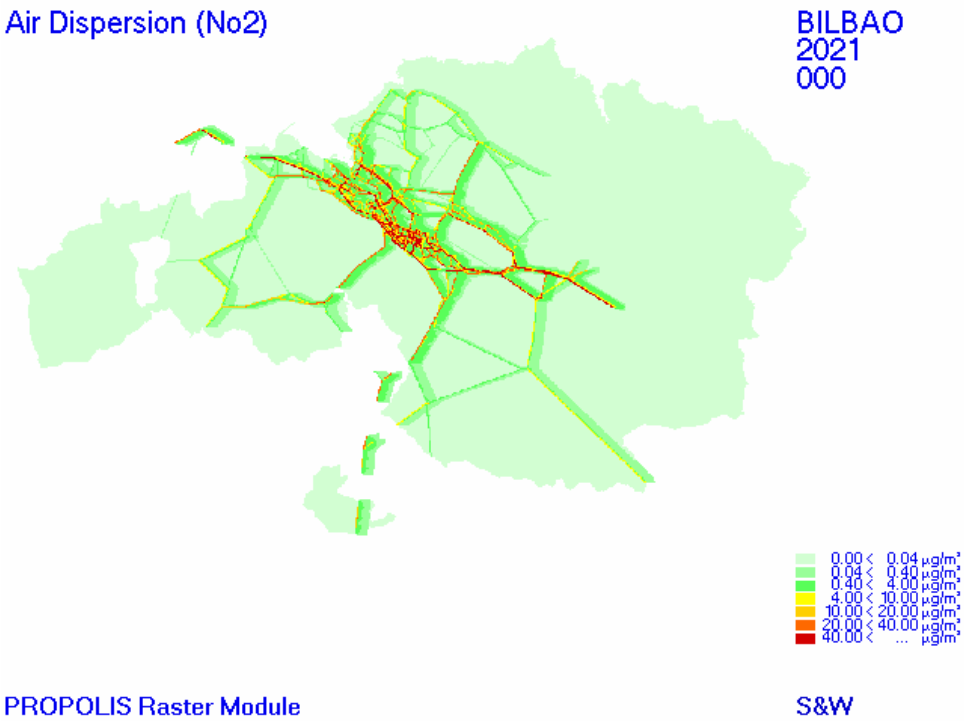


Figure 5. Bilbao, air quality

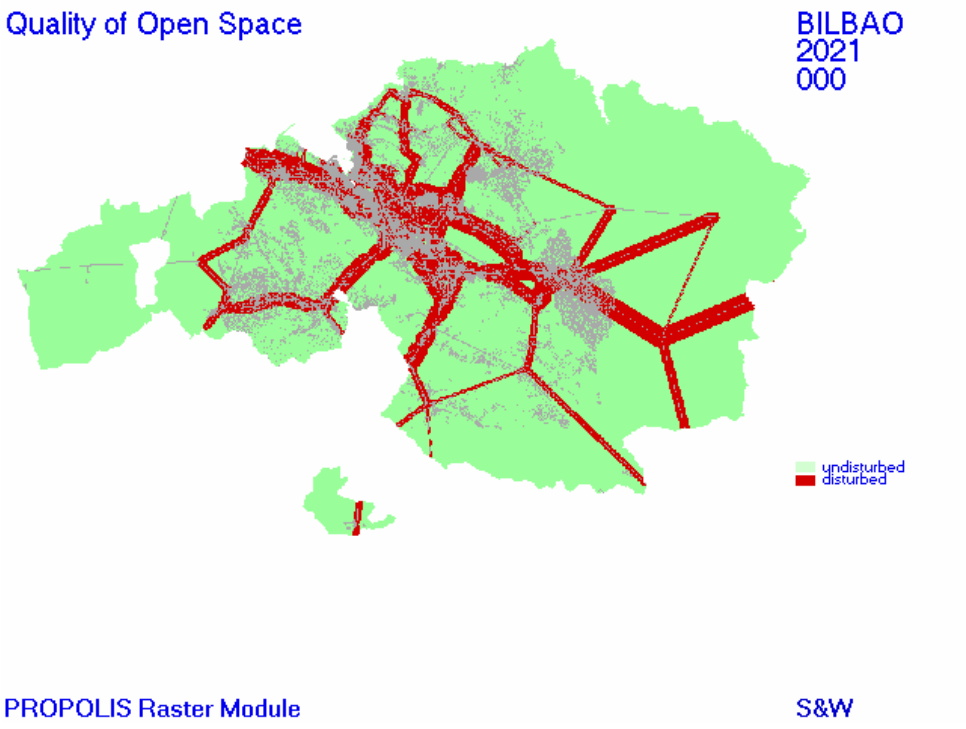


Figure 6. Bilbao, Quality of open space.

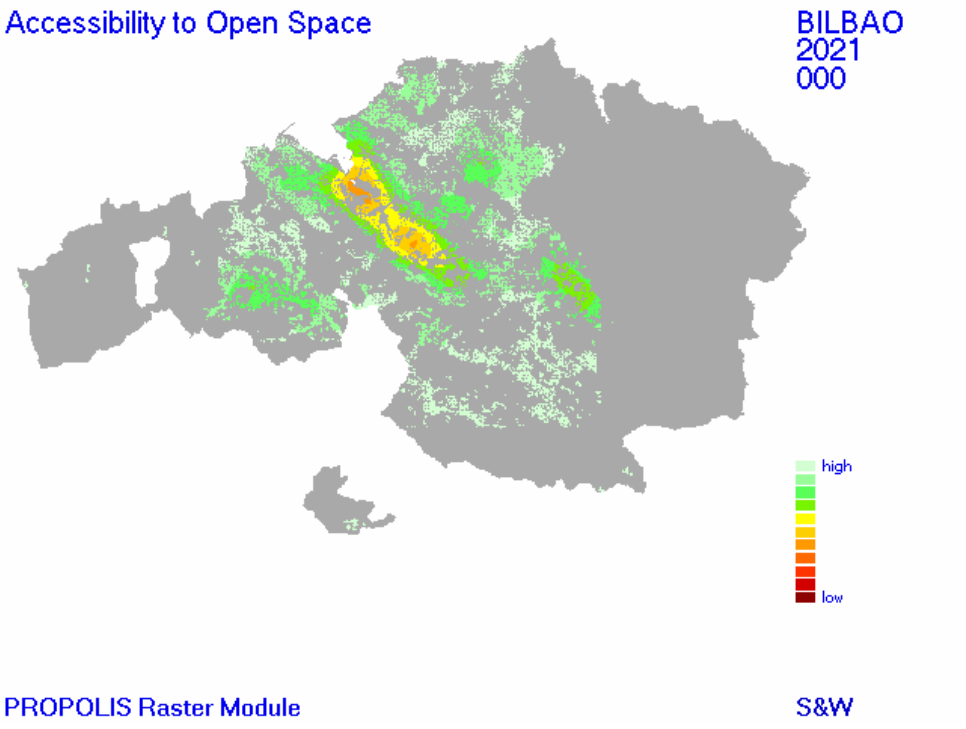


Figure 7. Bilbao, Accessibiltiy to open space.

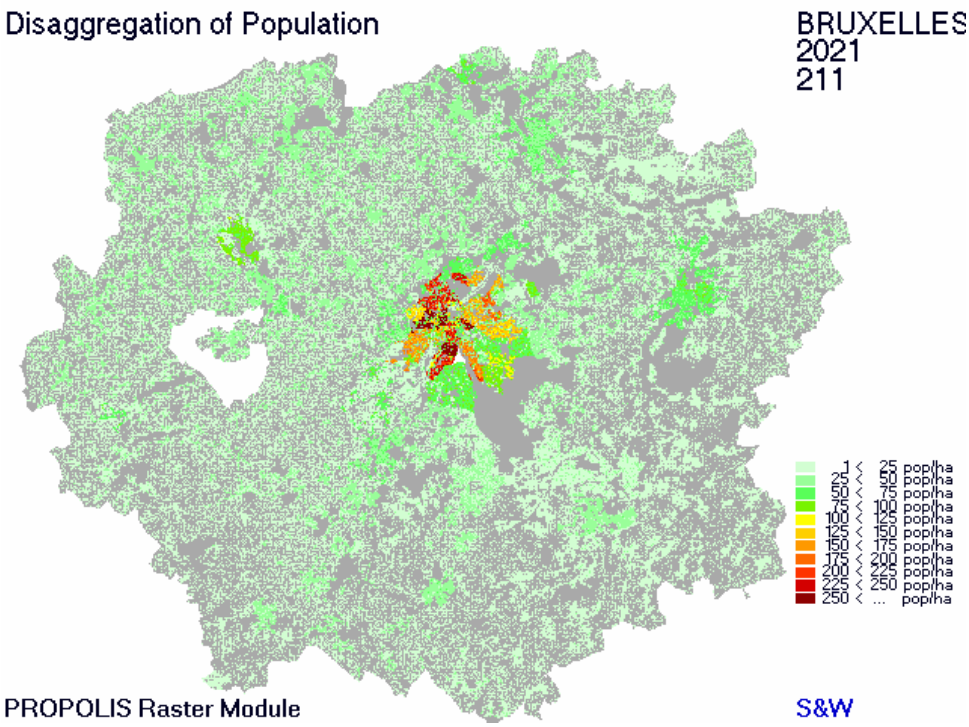
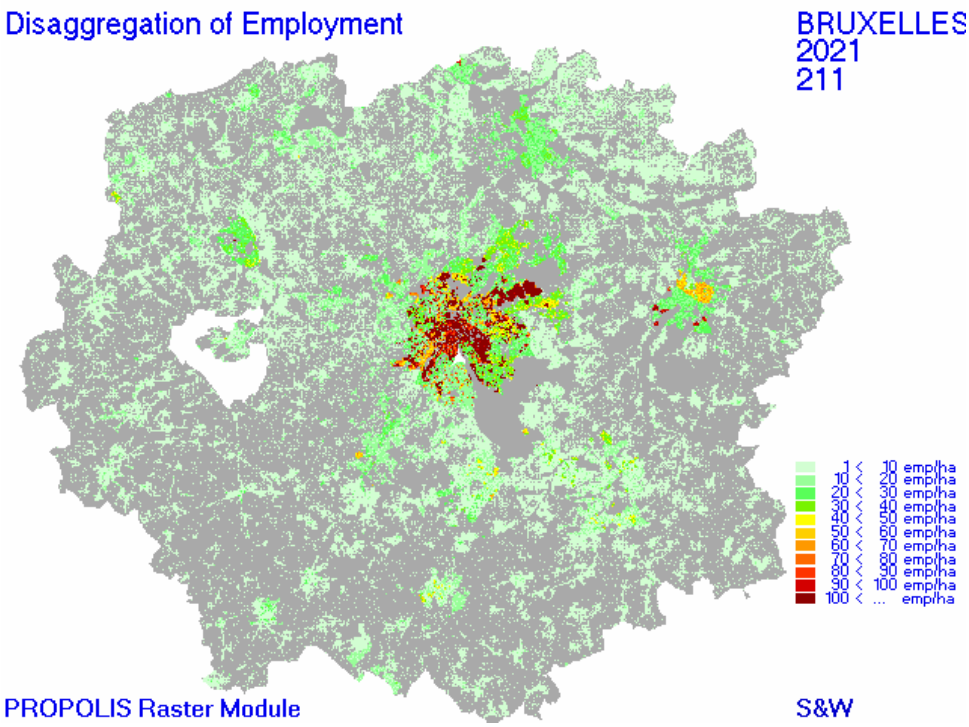


Figure 8. Brussels, population density.



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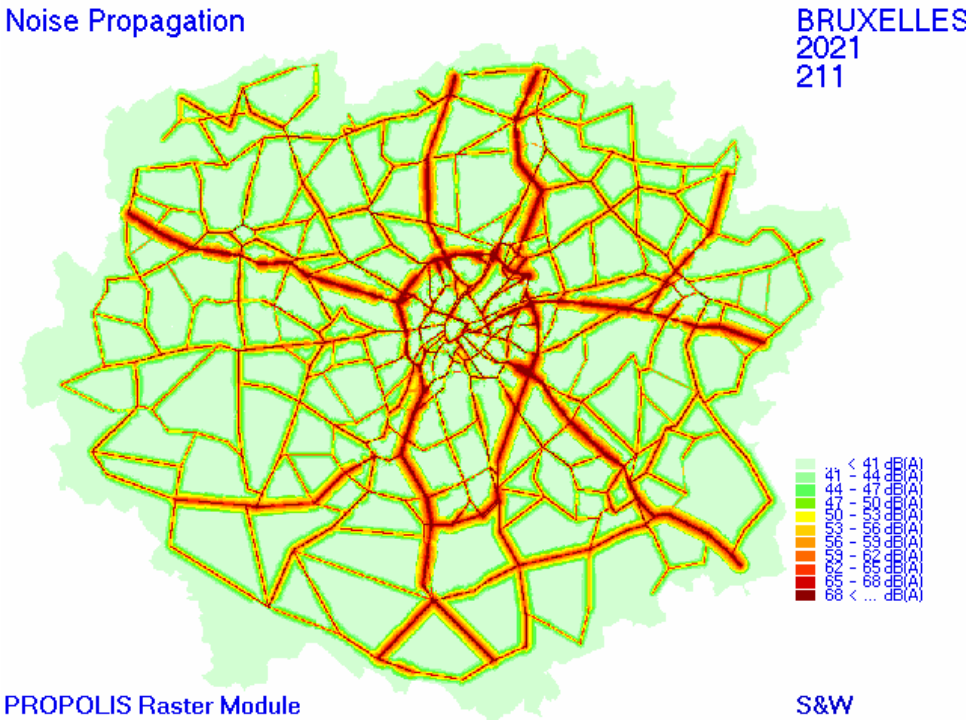


Figure 10. Brussels, traffic noise

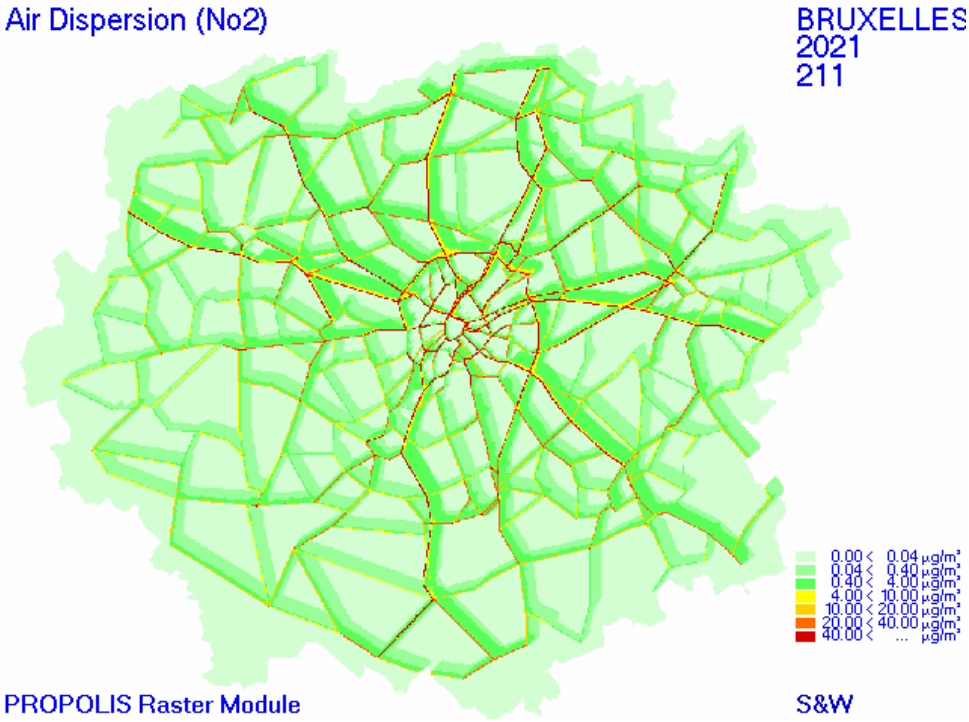
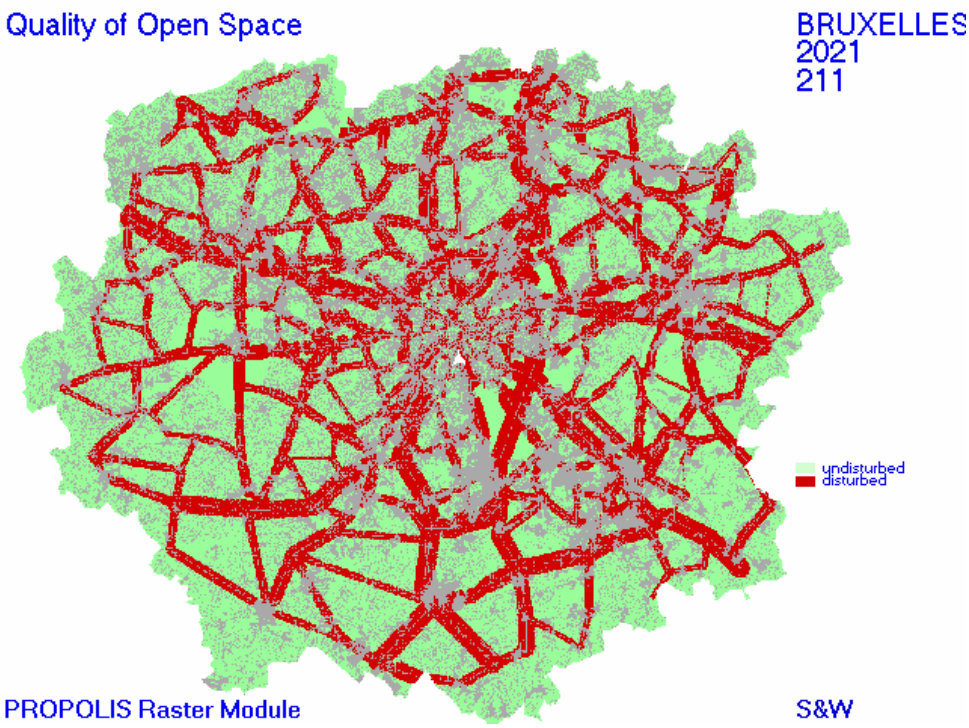


Figure 11. Brussels, air quality.



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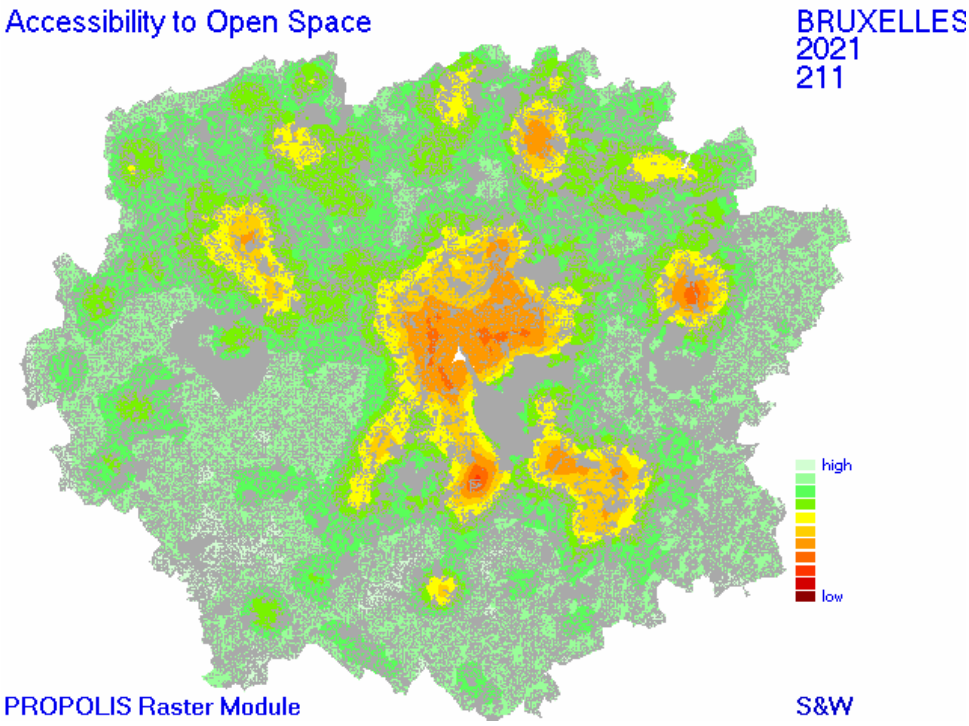


Figure 13. Brussels, Accessibiltiy to open space.

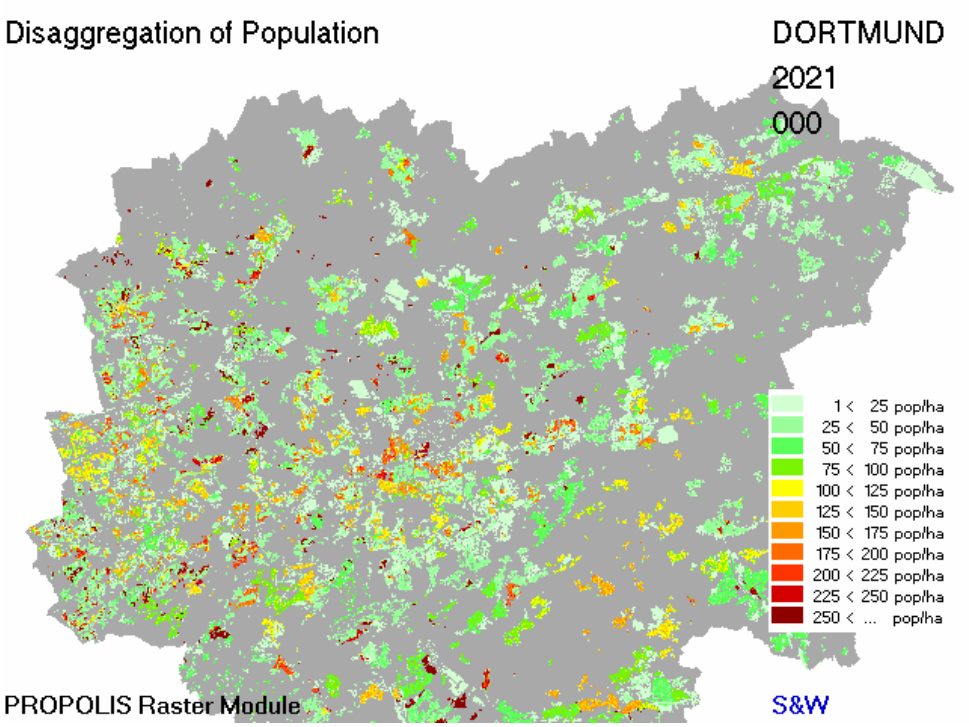
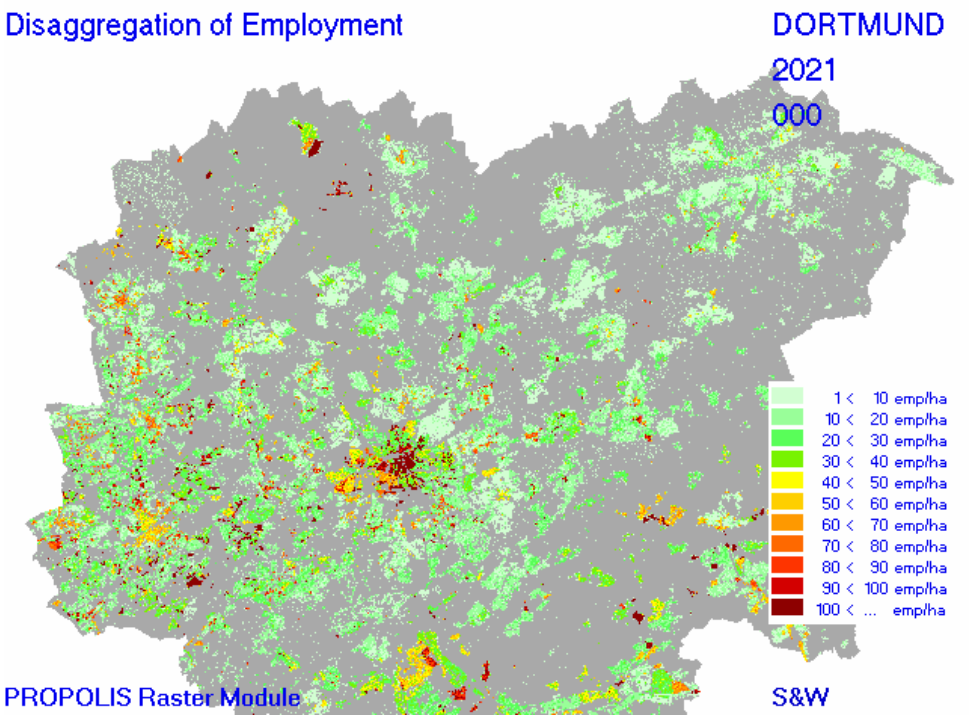


Figure 14. Dortmund, population density.



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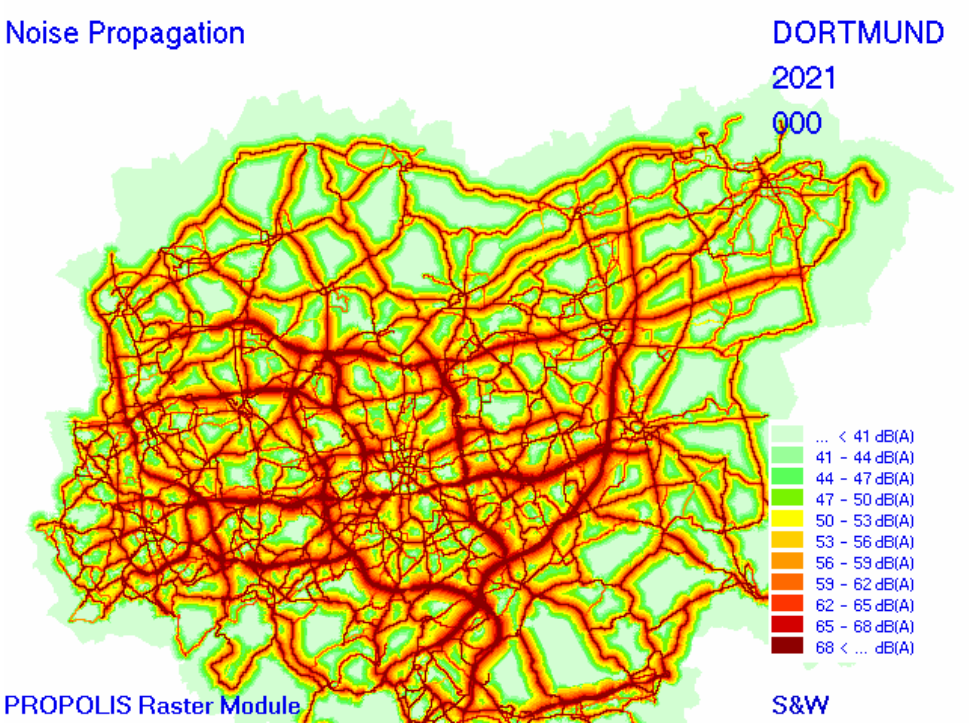


Figure 16. Dortmund, traffic noise

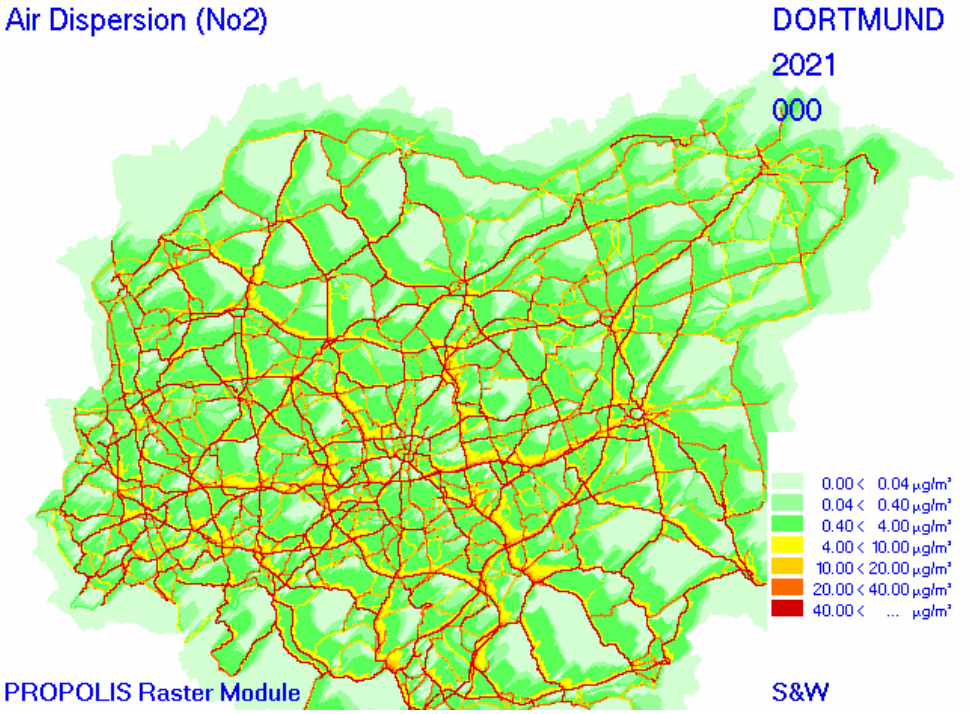


Figure 17. Dortmund, air quality.

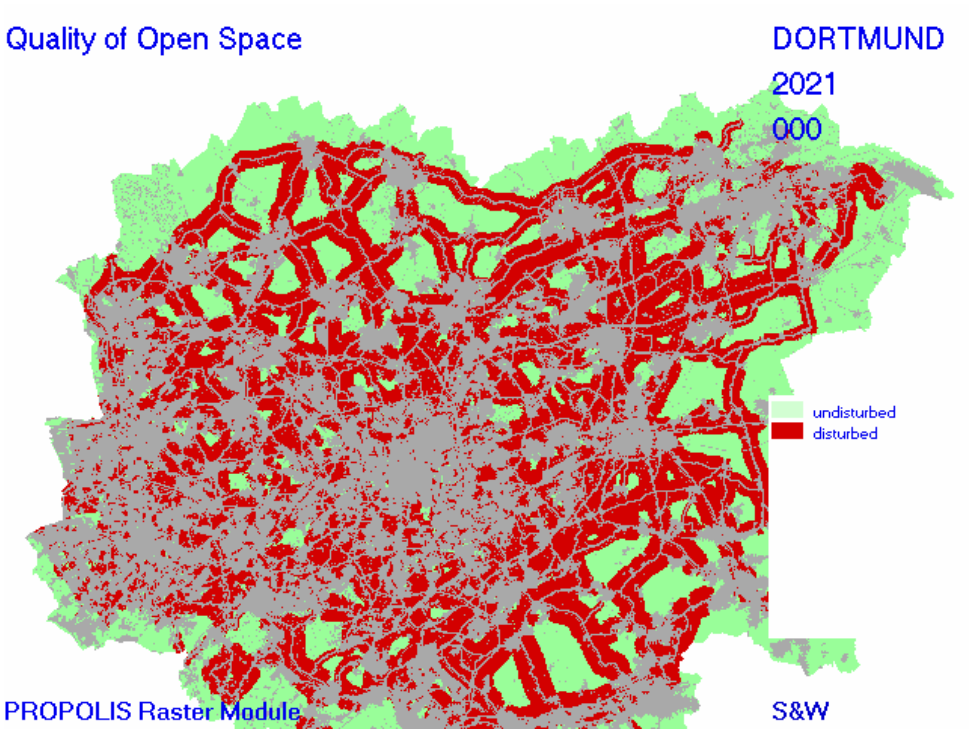
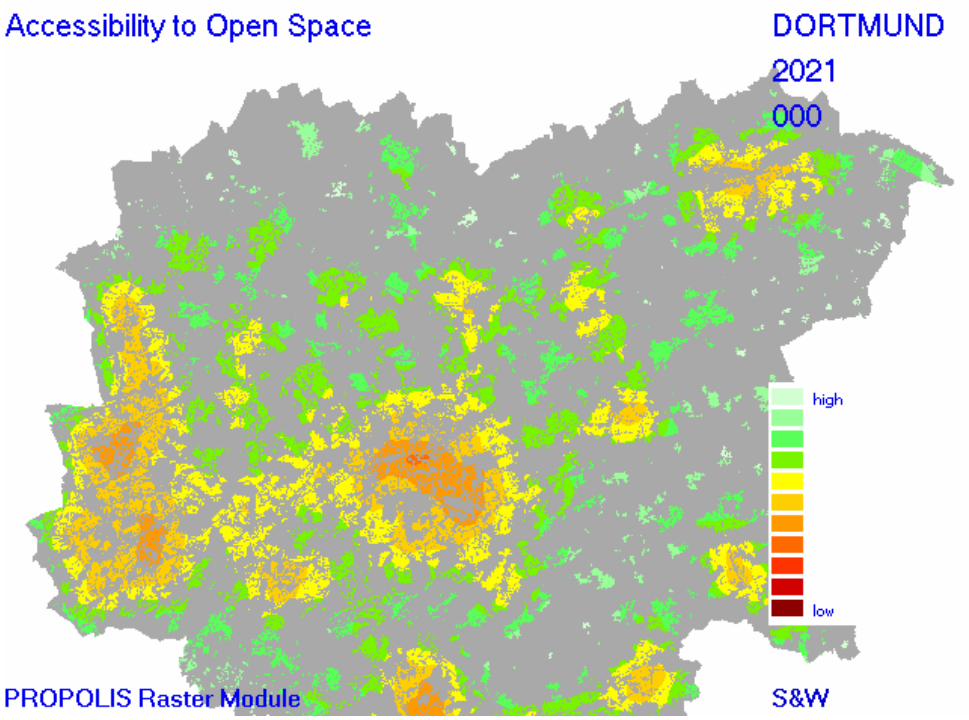


Figure 18. Dortmund, quality of open space.



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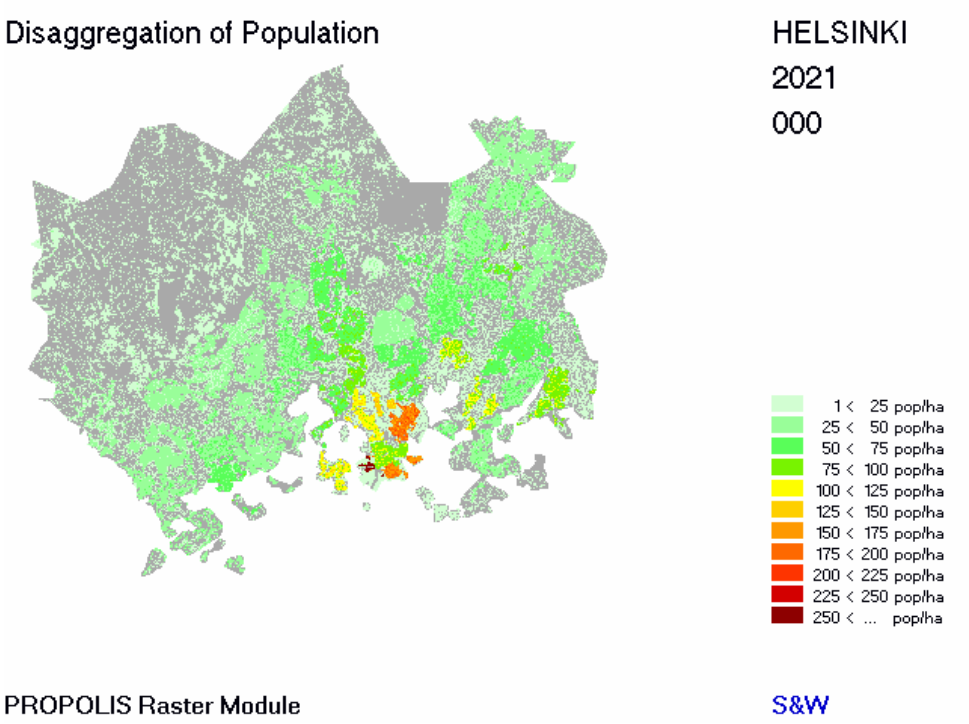


Figure 20. Helsinki, population density.

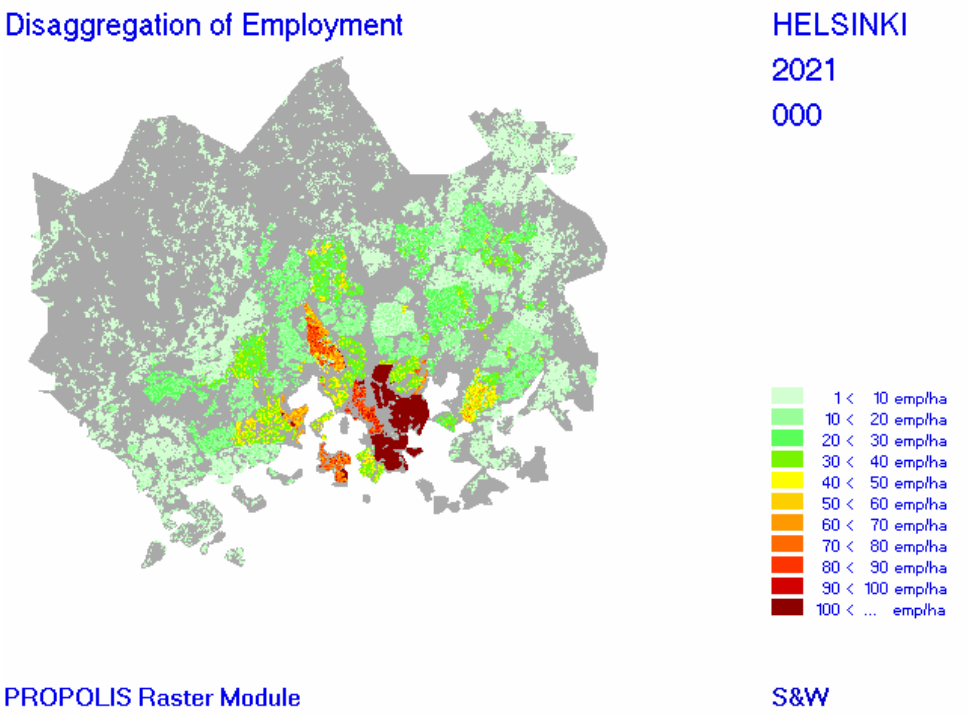


Figure 21. Helsinki, employment density

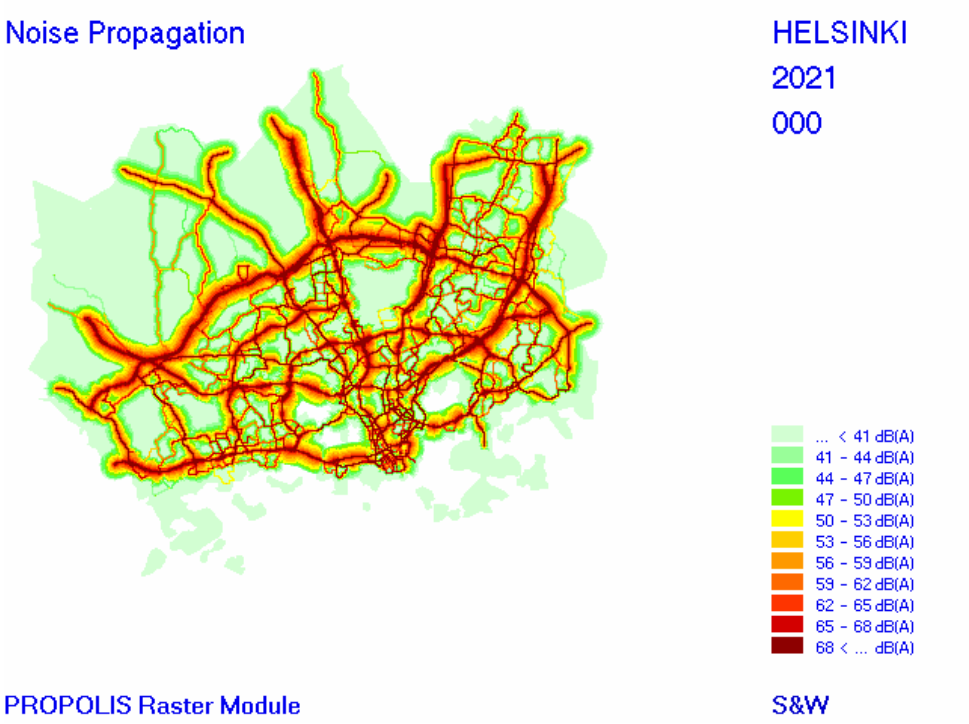


Figure 22. Helsinki, traffic noise

Figure 23. Helsinki, air quality.

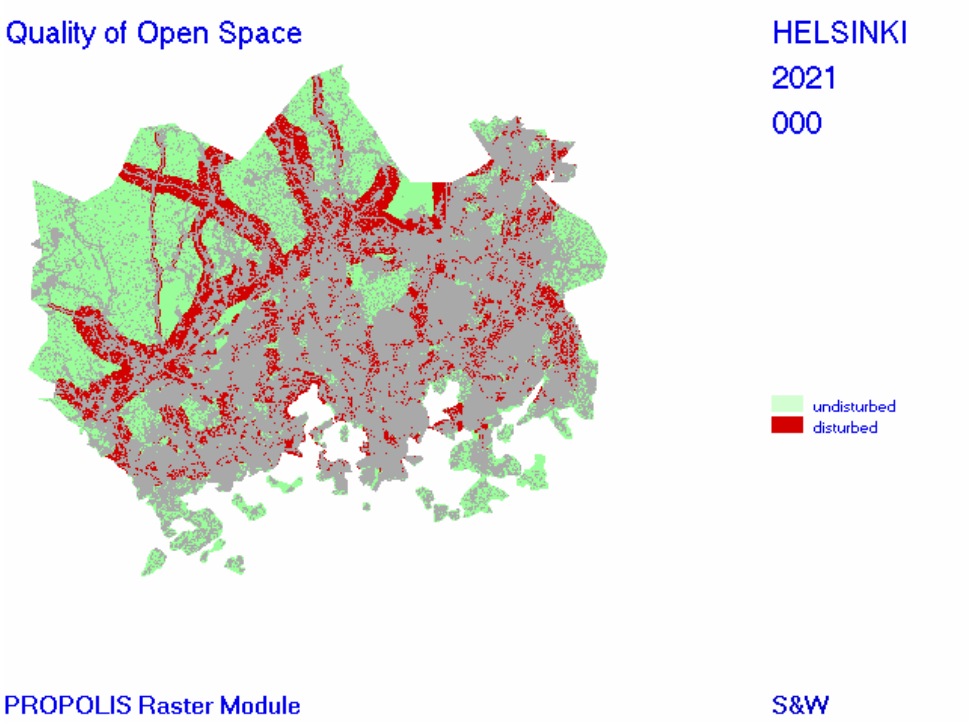


Figure 24. Helsinki, quality of open space.

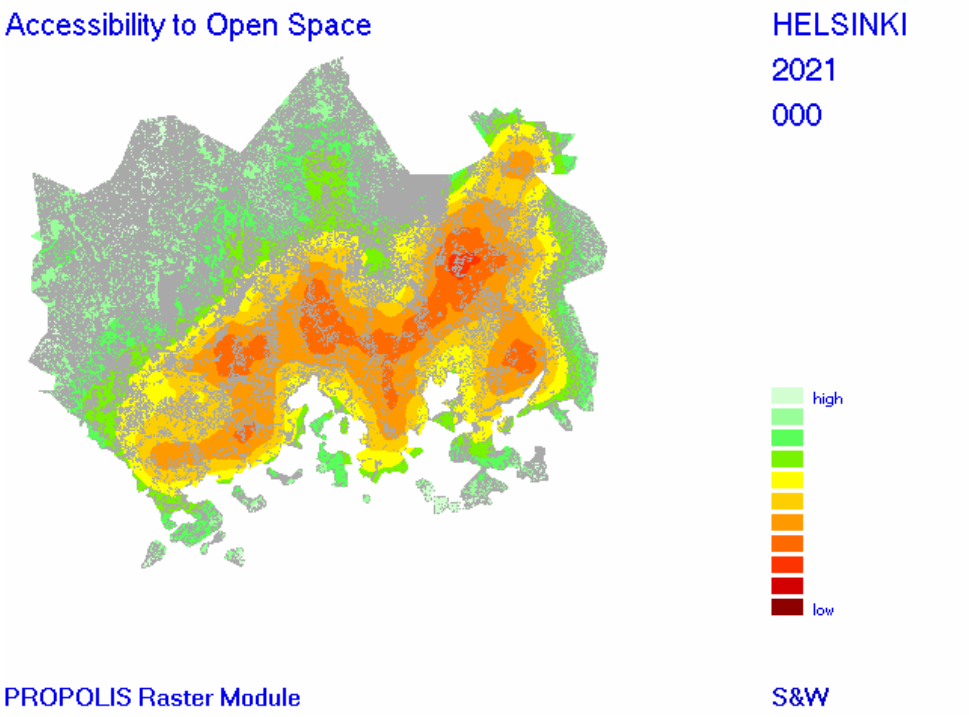


Figure 25. Helsinki, accessibiltiy to open space.

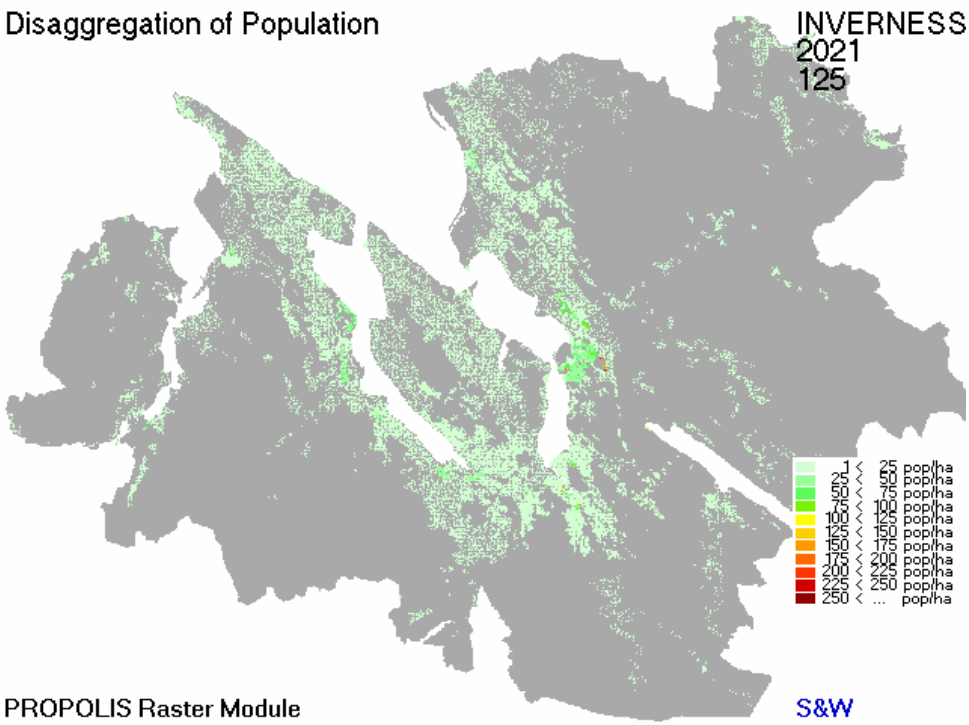


Figure 26. Inverness, population density.

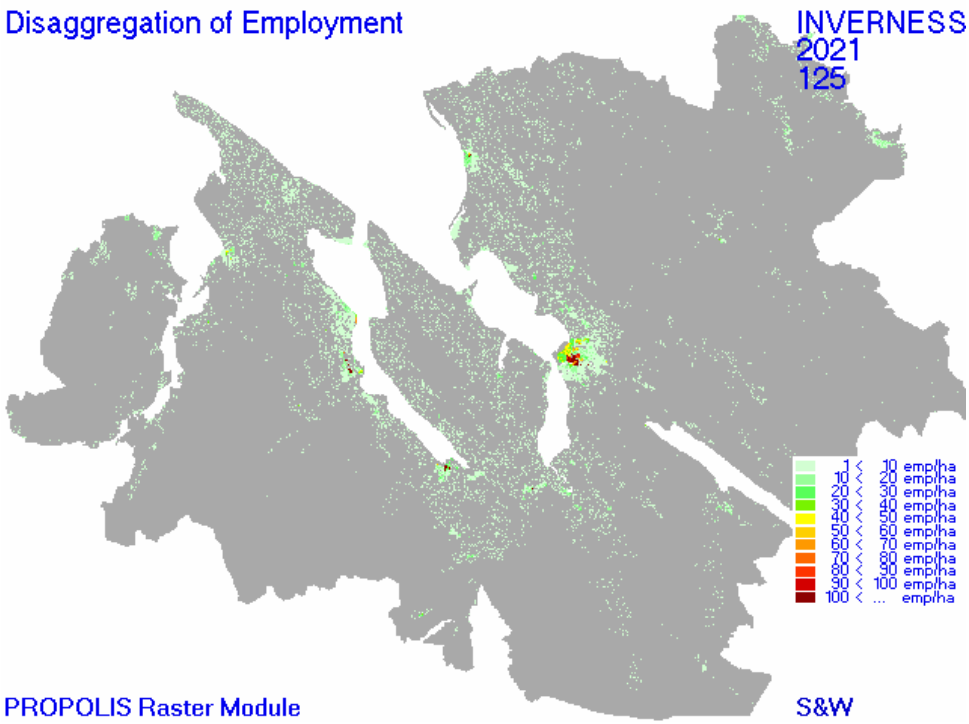
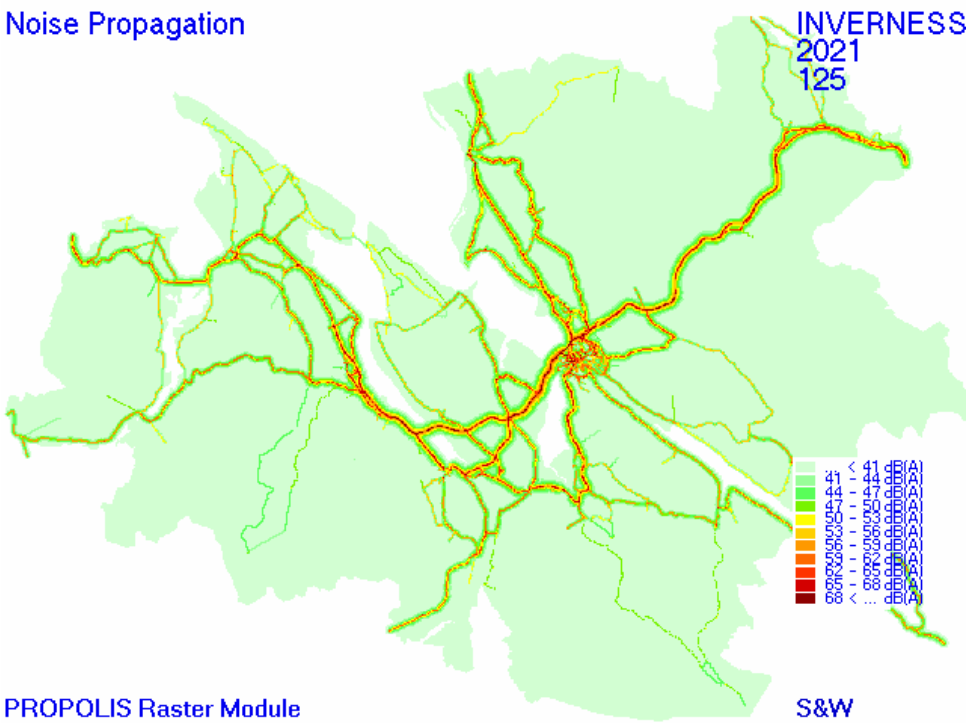


Figure 27. Inverness, employment density.



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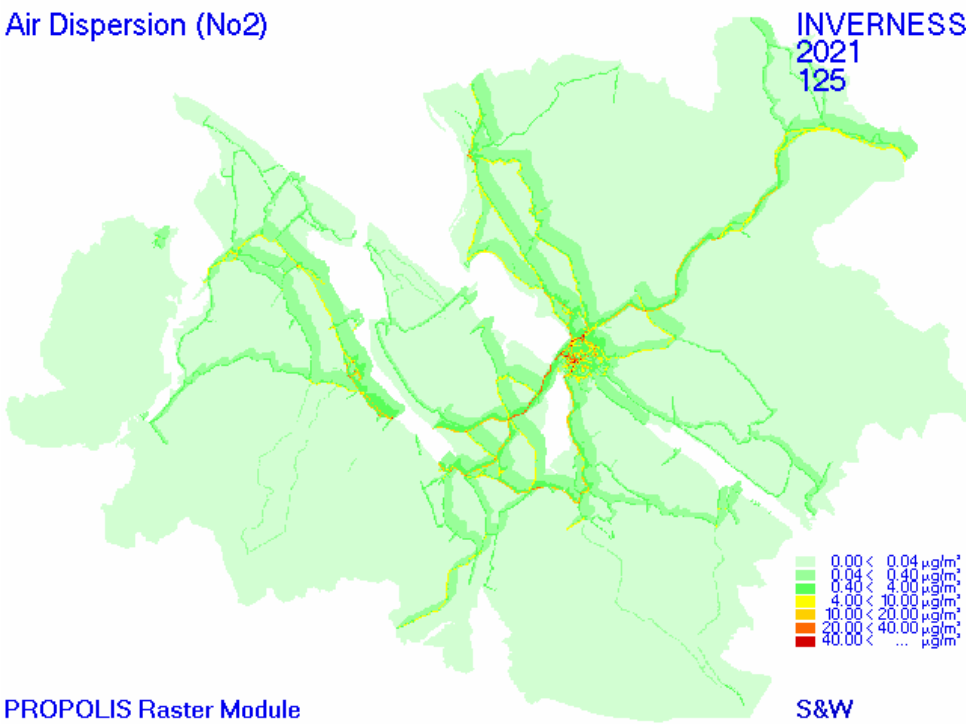


Figure 29. Inverness, air quality.

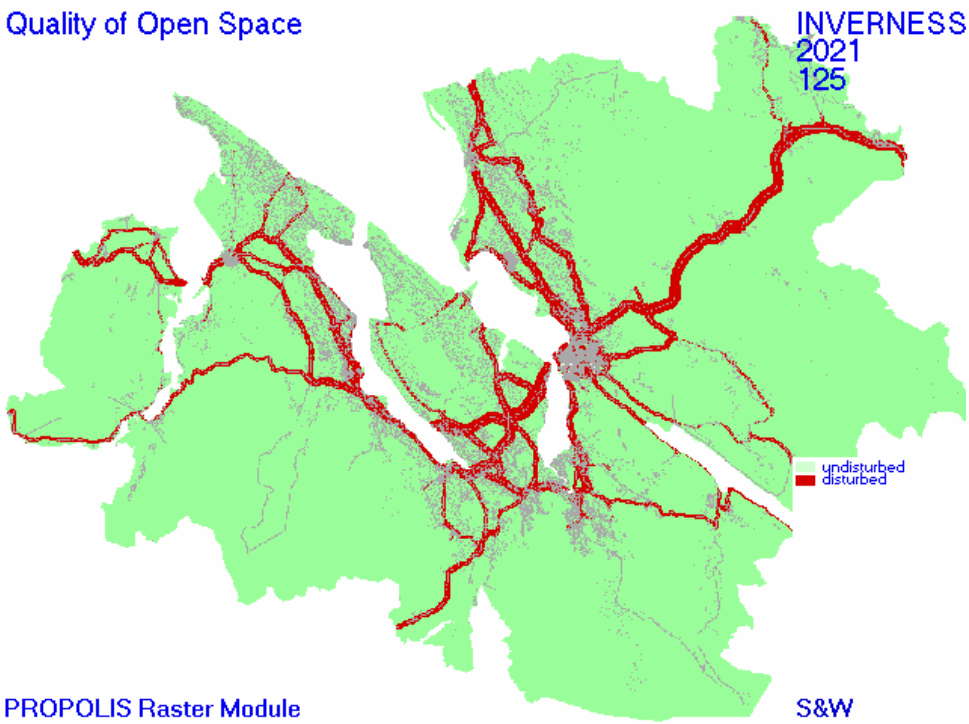
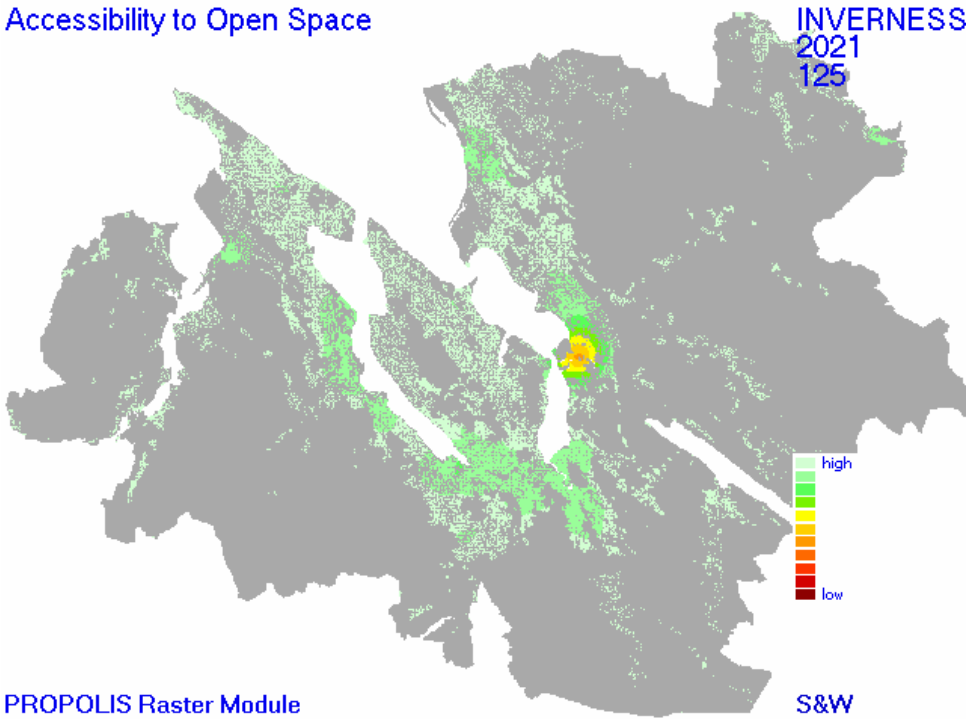


Figure 30. Inverness, quality of open space.



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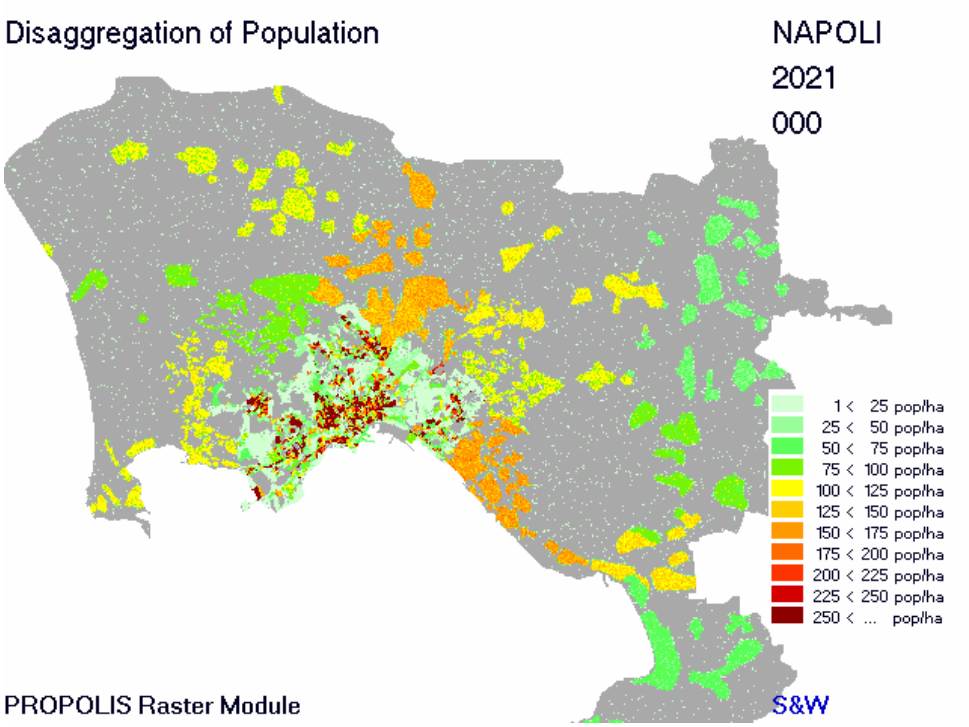

Figure 32. Naples, population density.

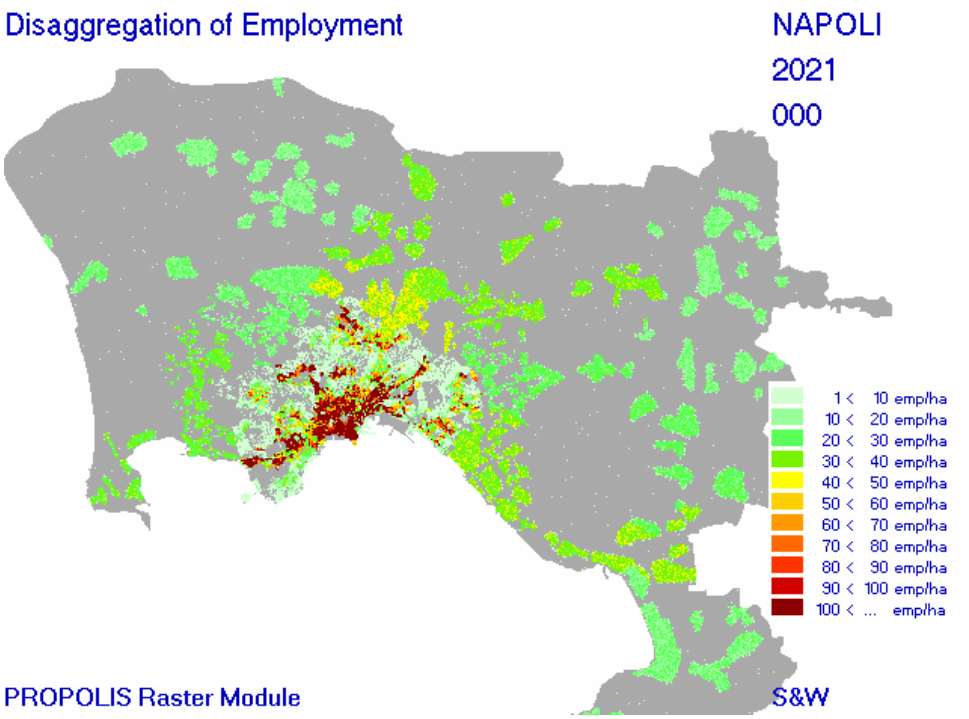

Figure 33. Naples, employment density.

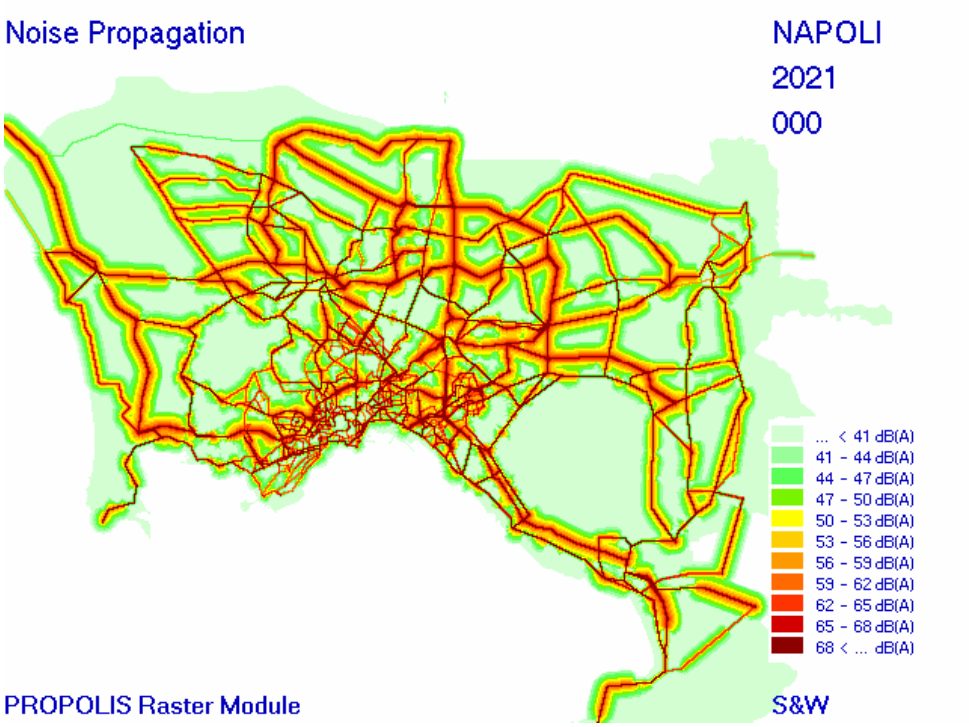

Figure 34. Naples, traffic noise

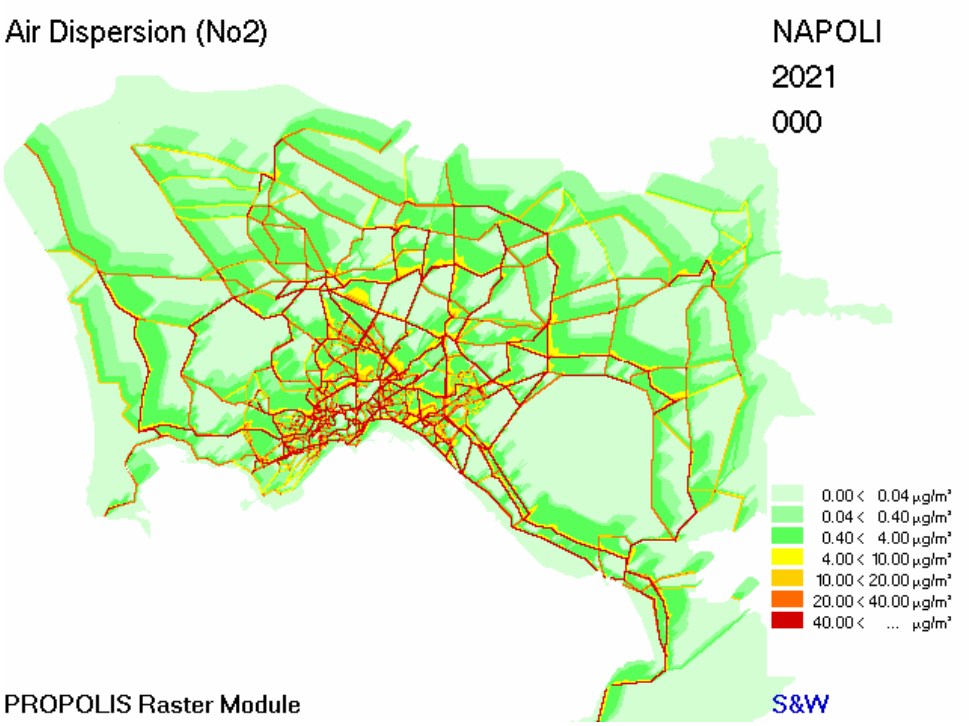

Figure 35. Naples, air quality.

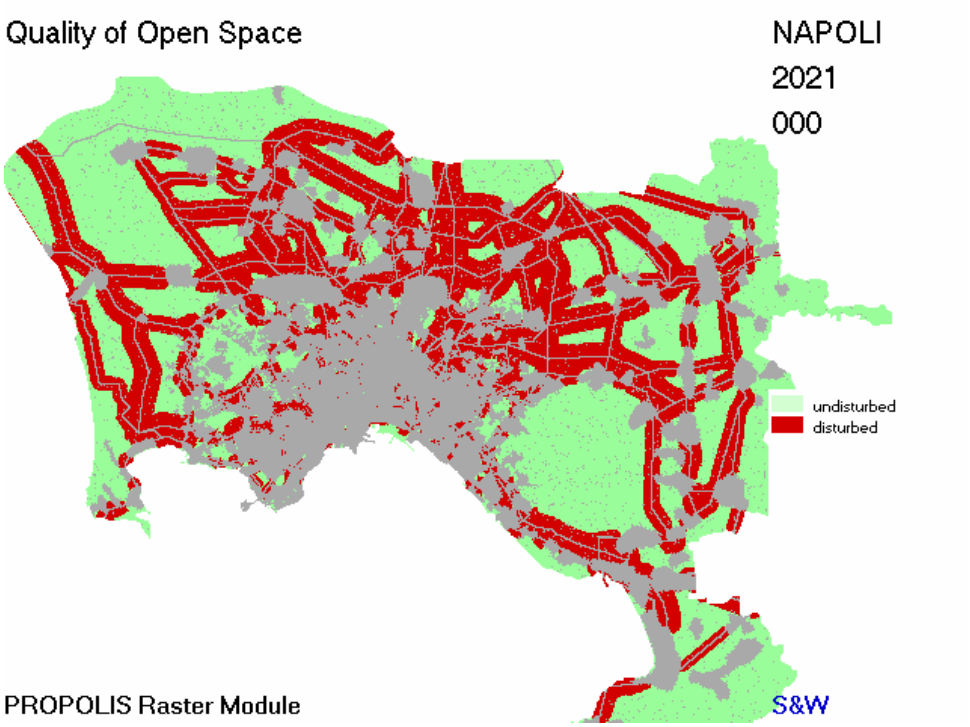

Figure 36. Naples, quality of open space.

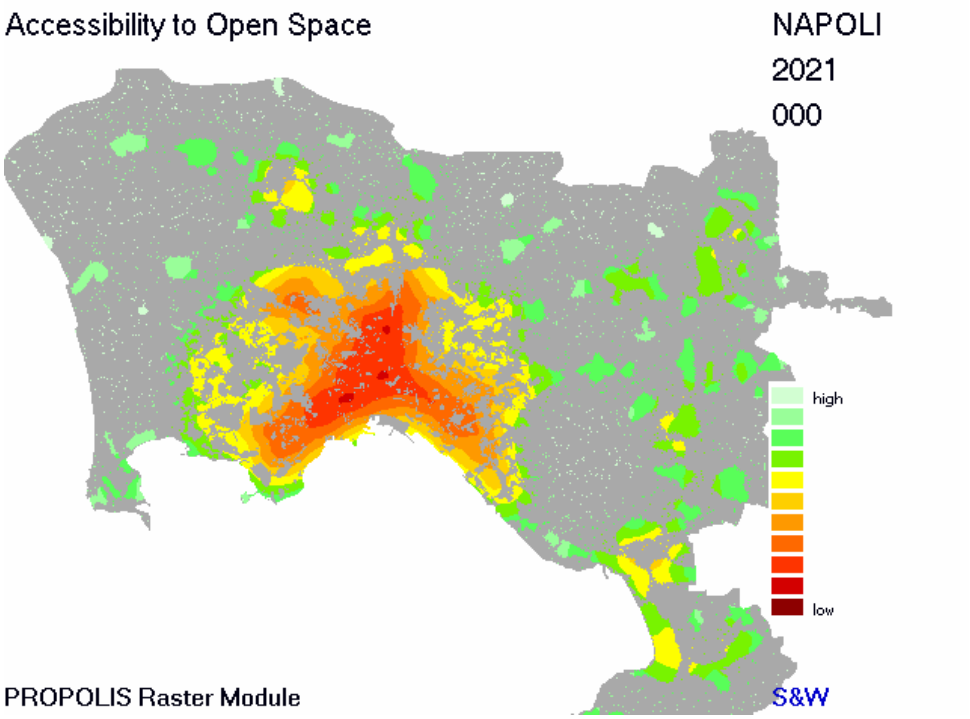

Figure 37. Naples, accessibiltiy to open space.

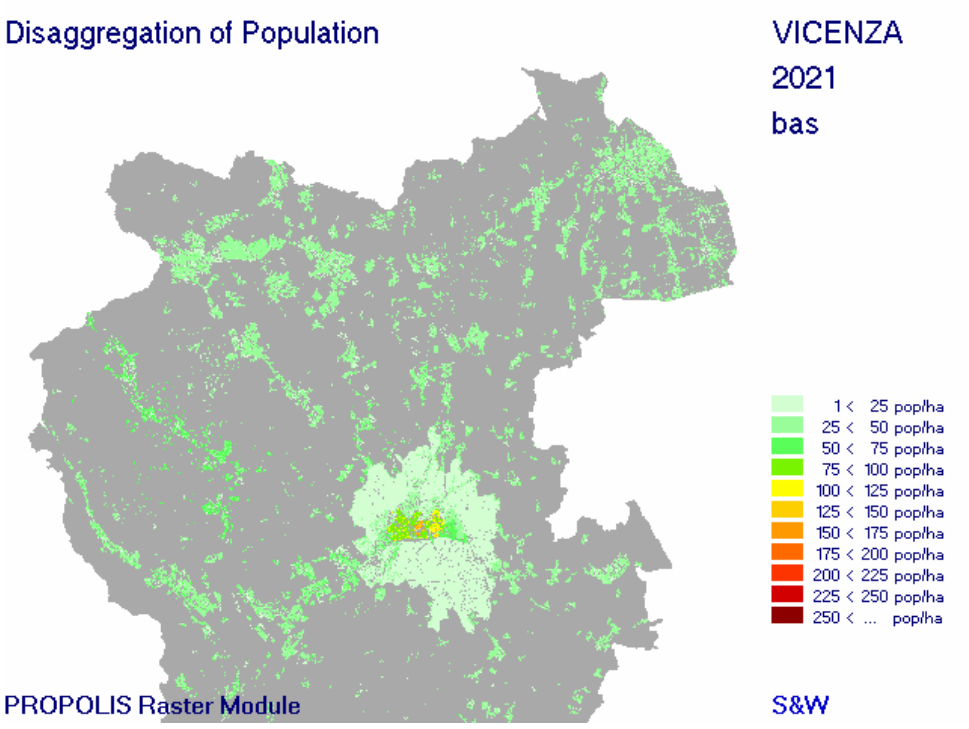

Figure 38. Vicenza, population density.

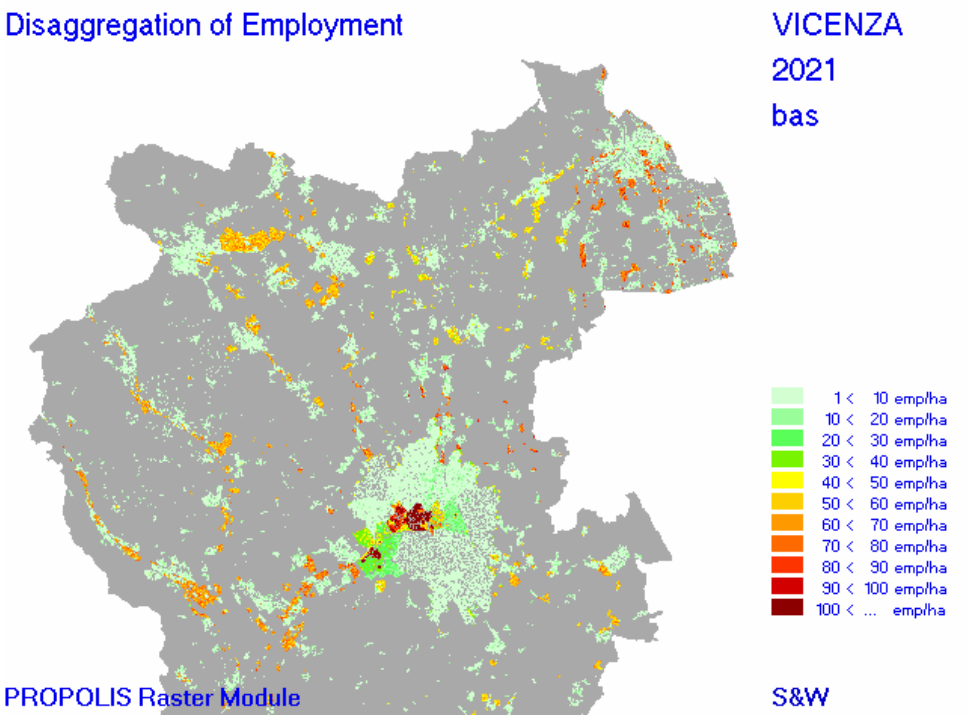

Figure 39. Vizenca, employment density.

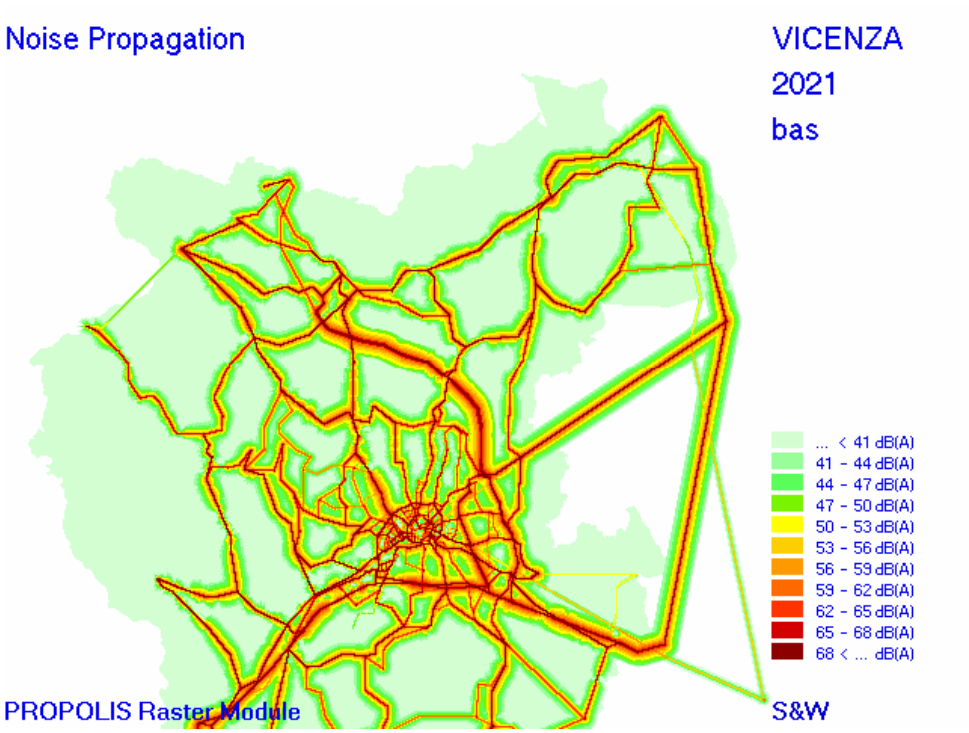

Figure 40. Vicenza, traffic noise

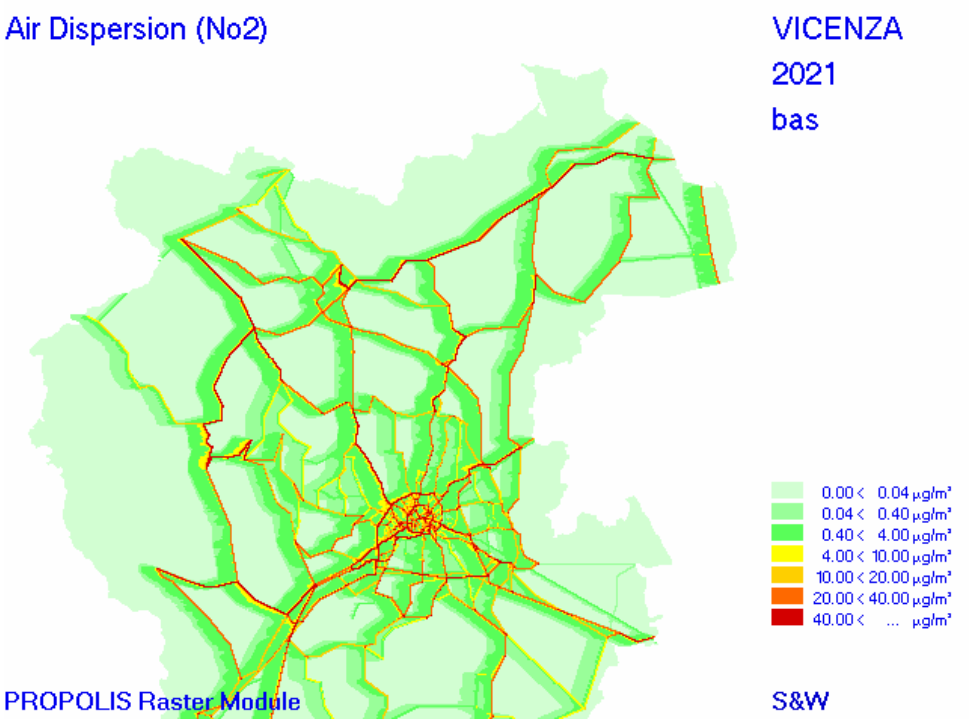

Figure 41. Vizenca, air quality.

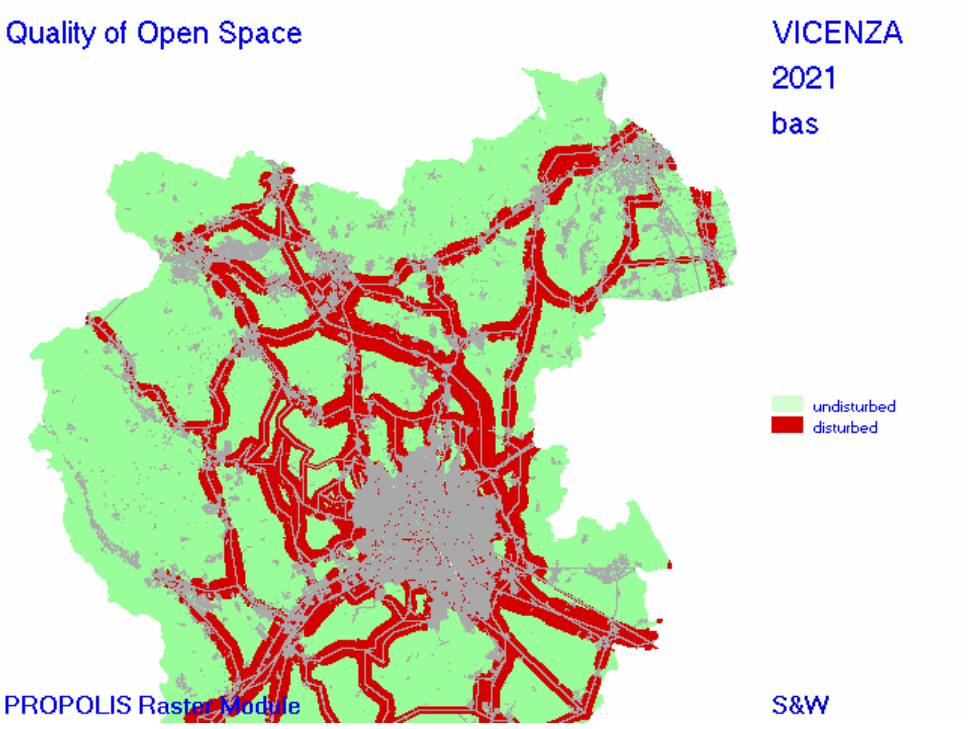

Figure 42. Vicenza, quality of open space.

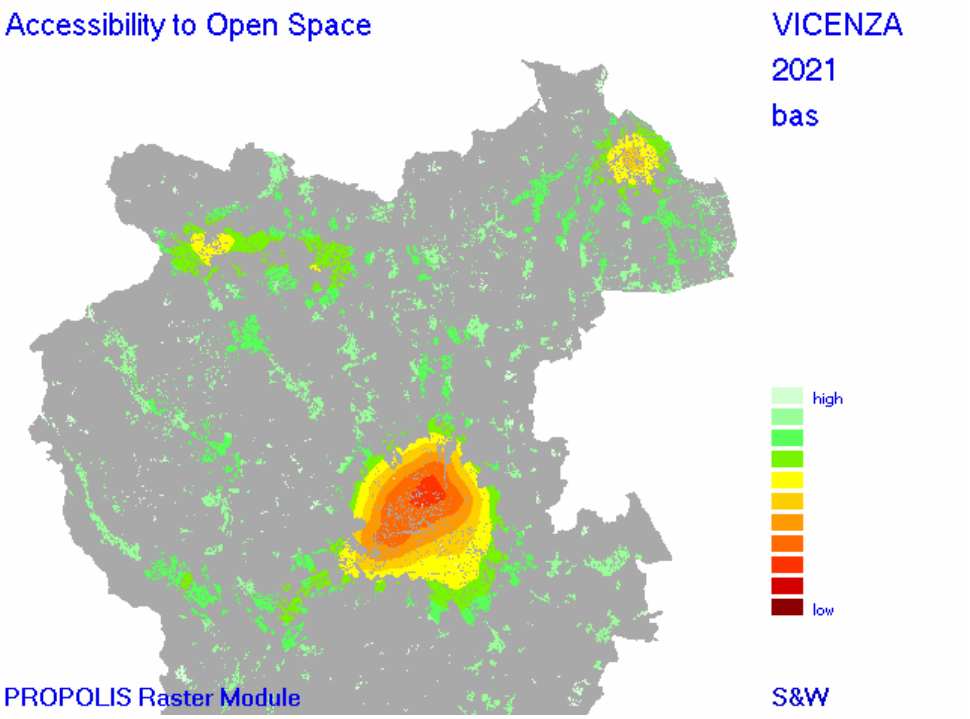

Figure 43. Vicenza, accessibiltiy to open space.

4. CONCLUSIONS

The PROPOLIS project is one of the first attempts to make urban models more disaggregate in spatial terms in order to enrich the indicators for assessing sustainability of land use and transport policies. The methodology developed for this purpose is based on raster-based models that post-process the zone and link-based output of the urban model. The so-called Raster Module disaggregates the aggregate model output, employs several raster-based submodels and provides several indicators for emissions, resource use, quality of open space, for the exposure of population to different air pollutants and noise from transport.

One of the preconditions for use of the Raster Module is that the land-use transport models have to be integrated with geographic information systems. All model zones and networks links need to have a direct correspondence in a GIS:

The implementation of the Raster Module has been demonstrated in the report through a number of maps showing sample results of the tool for the seven case study regions. The results of the Raster Module in the PROPOLIS policy testing and evaluation will be reported in the final report of the project.

With the incorporation of the Raster Module, the PROPOLIS model system is also one of the first attempts to address the issue of urban sustainability in a comprehensive long-term forecasting framework. The model system moves from two-way land-use transport modelling (LT) towards three-way land use transport environment modelling (LTE). The Raster Module is helpful here in overcoming the formerly separate modelling traditions.

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ANNEX I GIS DATA REQUIREMENTS OF THE RASTER MODULE

GIS data requirements

For each case city, the Raster Module combines results from the land use transport models with geometric information held in a GIS. The basic difference between the two data groups to be linked is that the model output varies between policies whereas the GIS data has to be produced only once. However, the GIS data has to be so comprehensive that all data for all years and all possible policies have to be stored in the database. Because the zones will not change over time, this is mainly relevant for data on transport infrastructure. That means, even a link that is used only in one policy scenario has to be stored in the database. It is the task of the Raster Module to select the relevant links of a policy for further modelling.

Zonal data

For each land use zone the boundaries have to be provided as polygons. For models that work also with transport zones the boundaries of the transport zones have to be provided as well. There are two attributes required for each zone:

- a unique zone number for identification, i.e. that number that is used in the land use transport model output files,
- a zone name (optional); this could be the name of the statistical district or of a municipality.

In addition the boundaries of the superzones have to be provided as polygons. Again, there are two attributes required for each superzone:

- the superzone classification number (see Table 1),
- a zone name (optional).

Network data

The network should be represented in the GIS as a set of network nodes and network links.

Network nodes should be stored in the GIS as points. The only attribute required is the unique node number which is used by the land use transport model.

The Raster Module requires for the exact location of emission sources the alignment of the network links. Each link should be represented in the GIS as a polyline, i.e. a series of x and y coordinates. This is the main difference from the link representation in the land use transport model, in which a straight line between the network nodes is implicitly assumed(see Figure A1).

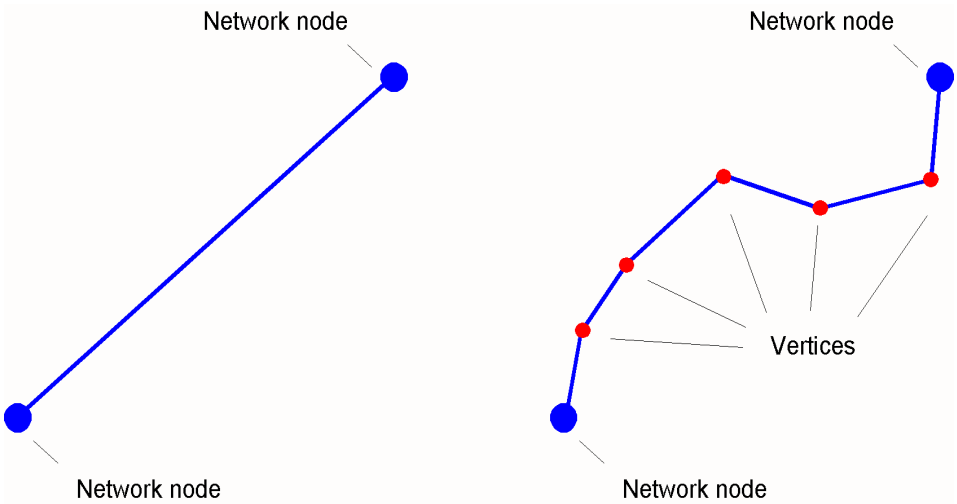

Figure A1. Link representation in land-use transport models (left) and required by the Raster Module (right).

The attribute data consists of link identification and a couple of further items:

- Unique from-node-id
- Unique to-node-id
- Unique link number (if used in the land use transport model output file)
- PROPOLIS link type for forecast year (see Table 1)
- Length
- Capacity
- Link name (optional)

Land use data

The Raster Module requires for the disaggregation of zonal data information on land use. The city modellers are free to specify the number of land use categories. The minimum requirement is two land use categories: settlement area and open space. However, the disaggregation process will work more precisely if more detailed land use data is available. Most useful are further differentiations of residential areas, e.g. low, medium, high density areas, and industrial areas, e.g. heavy industries, manufacturing, science park. Possible is also the categorisation of residential areas according to social status or income, e.g. working class neighbourhood, living area of the better-offs.

Land use has to be provided as polygons. The land use data has to cover the complete study area. The only attribute required is a land use type identification number. This number will be related in a parameter file of the Raster Module to land use specific weights indicating the probability that an activity takes place on a certain land use type.

Land use data is required at least for the base year, but different land use data might also be provided for the forecast year. If land use data is available only for the base year, the Raster Module will use its built-in rules for an extension of the settlement area within a zone if the zonal forecast sees an increase in certain activities.

Table A1 summarises the different GIS data requiremts of the Raster Module.

Table A1. GIS Data required for Raster Module

Category	**Data type**	**Attributes**
Land Use Zones	Polygons	1) Unique zone number 2) Zone name (optional)
Transport Zones*	Polygons	1) Unique zone number 2) Zone name (optional)
Superzones	Polygons	1) Superzone classification number: 1 (for city centre) 2 (for inner urban) 3 (for outer urban) 4 (for rest of metropolitan) 5 (for rest of region, urbanised) 6 (for rest of region, rural) 2) Zone name (optional)

Network nodes	Points	1) Unique node number
Network links	Polylines	1) Unique from-node number 2) Unique to-node number 3) Unique link number or '0' if unique link number not exists 4) PROPOLIS aggregate link type 1 (for motorway) 2 (for major urban road) 3 (for other road) 4 (for railway / metro) 5 (for bus and tram) 8 (for ferry service) The link types 6 (car park / access), 7 (train and bus access / wait), 9 (walk) and 10 (intrazonal) are not expected to be represented in the GIS 5) Link length (in m) 6) Link capacity 7) Link name (optional)
Land use	Polygons	1) Land use type identification number (individually defined for each case city)

GIS Data formats

The Raster Module is able to process ASCII export files from two different commercial GIS systems: ArcGIS Generate Format and MapInfo Data Interchange Format. Note, that the APT requires from ArcGIS user the provision of shapefiles instead of ASCII export files, but will process the same export files of MapInfo users as described below.

ArcInfo Generate Format

There are two operations necessary to export geometric information and attribute data from ArcInfo to ASCII export files: the *ungenerate* command to produce a file containing the coordinates, the so-called Generate Format and the *unload* command to produce a file containing attribute data. The relation between both files is established via User-IDs, i.e. unique numbers that link geometric and attribute data.

The coordinates should have meters as unit. The data in the attribute file should be comma separated. All other file specific information is presented in Table A2. The categories listes are the same as in Table A1. The file names are compulsory. The graphical object column indicates which type of coordinate data is expected. The attribute data column lists the information per record to be stored in the attribute data file.

Table A2. ArcGis export files for the Raster Module

Category	**File names**	**Graphical object**	**Data in attribute data file**
Land Use Zones	**LZ<cc>.pol** **LZ<cc>.dat**	Polygon	User-ID Zone number (integer) or User-ID Zone number (integer) Zone name (character *50)

Transport Zones*	**TZ<cc>.pol** **TZ<cc>.dat**	Polygon	User-ID Zone number (integer) or User-ID Zone number (integer) Zone name (character *50)
Superzones	**SZ<cc>.pol** **SZ<cc>.dat**	Polygon	User-ID Zone number (integer) or User-ID Zone number (integer) Zone name (character *50)
Network nodes	**NN<cc>.pts** **NN<cc>.dat**	Point	User-ID Node number (integer or decimal)
Network links	**NL<cc>.lin** **NL<cc>.dat**	Line	User-ID From-node-number (integer or decimal) To-node-number (integer or decimal) Link number (integer) Link type (integer) Link length (integer) Link capacity (integer) Link name (character *50) or User-ID (as above, but without link name)
Land use	**LU<cc><nn>.pol** **LU<cc><nn>.dat**	Polygons	User-ID Land use id

<cc> case city abbreviation, <nn> land use coverage number, if more than one exists

MapInfo Data Interchange Format

MapInfo exports GIS data in two files, the geometric data is stored in a .MIF file, attribute data in a .MID file.

The .MIF file consists of a file header and a geometric data section. The .MID file contains one record of data per row, delimited by a character specified in the delimiter statement in the .MIF file header. There is no User-ID to link geometric with attribute data as it is the case in ArcInfo export files; there is a direct correspondence between data rows in .MID and objects in .MIF, i.e. first row to first object, second row to second object etc.

For all export files the following parameters have to be set in the .MIF file header:

- DELIMITER ","
- in CoordSys, the unitname should be "m"

All other file specific information is presented in Table A3. The categories are the same as in Table A1. The file names are compulsory. The column .MIF header columns gives the valid entries for this part of the MIF header, i.e. it defines the number of attributes and the variable type and contents of the .MID file. Variable names might be changed. The graphical object defines the type of geometric data; region corresponds to polygon.

Table A3. MapInfo export files for the Raster Module

Category	**File names**	**.MIF header: Columns**	**Graphical object**
Land Use Zones	**LZ<cc>.mif** **LZ<cc>.mid**	COLUMNS 1 Zonenumber integer or COLUMNS 2 Zonenumber integer Zonename char (50)	Region
Transport Zones*	**TZ<cc>.mif** **TZ<cc>.mid**	COLUMNS 1 Zonenumber integer or COLUMNS 2 Zonenumber integer Zonename char (50)	Region

Category	File names	.MIF header: Columns	Graphical object
Superzones	**SZ<cc>.mif** **SZ<cc>.mid**	COLUMNS 1 Zonenumber integer or COLUMNS 2 Zonenumber integer Zonename char (50)	Region
Network nodes	**NN<cc>.mif** **NN<cc>.mid**	COLUMNS 1 Nodenumber integer (or decimal (width,decimals))	Point
Network links	**NL<cc>.mif** **NL<cc>.mid**	CO:LUMNS 7 from-node-number integer (or decimal) to-node-number integer (or decimal (width,decimals)) linknumber integer linktype integer linklength integer linkcapacity integer linkname char(50) or COLUMNS 6 (as above, but without linkname)	Polyline
Land use	**LU<cc><nn>.mif** **LU<cc><nn>.mid**	COLUMNS 1 landuseid	Polygons

<cc> case city abbreviation, <nn> land use coverage number, if more than one exists