Urban Sprawl Metrics (USM) Toolset – User Manual for ArcMap

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Naghmeh Nazarnia[a], Christian Schwick[b,c], Parnian Pourtaherian[a], Miroslav Kopecky[d], Tomas Soukup[d], Erika Orlitova[d], Felix Kienast[c], Jochen A.G. Jaeger[a,e]
[a] Concordia University Montreal, Department of Geography, Planning and Environment, 1455 De Maisonneuve Blvd. West, Suite H1255, Montreal, QC, H3G 1M8, Canada
[b] Die Geographen schwick+spichtig, Turbinenstrasse 60, CH-8005 Zurich, Switzerland
[c] Swiss Federal Research Institute WSL, Zürcherstrasse 111, CH-8903 Birmensdorf, Switzerland
[d] GISAT and European Topic Centre on Urban, Land and Soil Systems (ETC-ULS) of the European Environment Agency, Prague, Czech Republic
[e] Primary contact, jochen.jaeger@concordia.ca

The Urban Sprawl Metrics (USM) Toolset is a geographic information system (GIS) toolset and was developed using Python and C+ languages. This tool is freely available under the Creative Commons Licence[1] and can be downloaded from the Swiss Federal Institute of Forest, Snow and Landscape Research (WSL) homepage (www.wsl.ch/zersiedelung) as well as from Spectrum, Concordia University's open access research repository (spectrum.library.concordia.ca).

Fig. 1: Example of a landscape from Switzerland that includes built-up areas (close to Zurich). The USM Toolset can be used to measure the degree of urban sprawl of this landscape (photo: J. Jaeger, 2015).

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1. Introduction

The USM Toolset was developed to facilitate the calculation of Weighted Urban Proliferation (*WUP*) and all components of urban sprawl for landscapes that include built-up areas (e.g., dispersion (*DIS*), land uptake per person (*LUP*); Fig. 1). The Toolset is straightforward to use. The language of the user interface is English. The Toolset requires three input data:

(1) the binary map of built-up areas (settlements areas and/or solitary buildings), in the ESRI raster format;
(2) the map of reporting unit(s) (e.g., municipalities, districts, or a grid of a certain cell size) in geodatabase feature class or shapefile format; and
(3) the number of inhabitants and jobs for the reporting unit(s) (this information has to be saved by the user in the attribute table of the reporting unit(s) shapefile).

2. Important background information

A variety of definitions have been proposed in the literature in the last hundred years (Fig. 2). However, no agreement about the main components has been achieved so far. Most importantly, the conceptual diversity is caused by some attempts to define urban sprawl using its causes and consequences and including them in the definition. However, it is advisable to differentiate the causes and consequences of urban sprawl from the main phenomenon (Schwick et al. 2012).

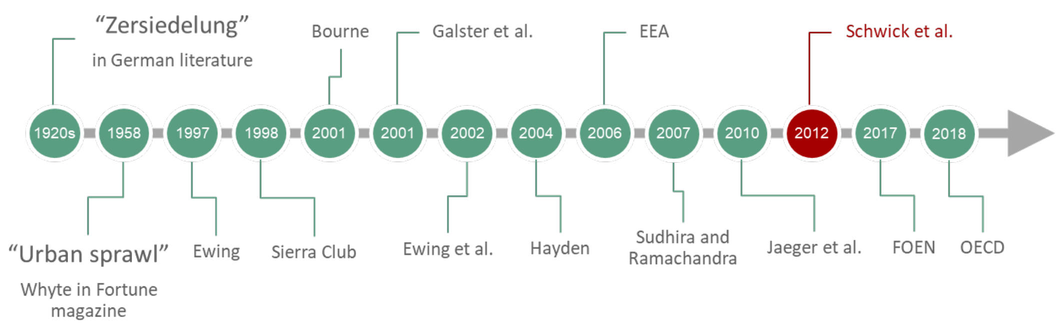


Fig. 2: Timeline of most common definitions of urban sprawl.

The metrics of Weighted Urban Proliferation (*WUP*) and Weighted Sprawl per Capita (*WSPC*) have three components: *PBA*, *DIS* and *LUP* (or *UD*) (Fig. 3).

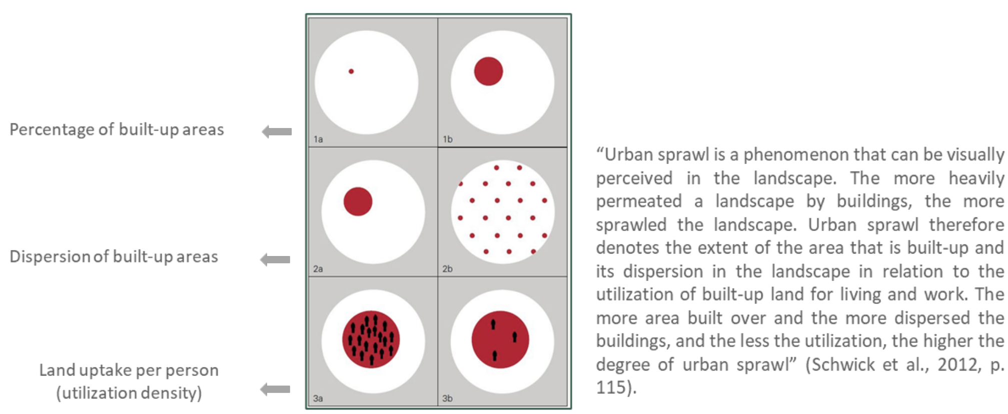


Fig. 3: The three components of urban sprawl *PBA*, *DIS*, and *LUP* (Schwick et al. 2012).

The relationships between the metrics of Weighted Urban Proliferation (*WUP*) and Weighted Sprawl per Capita (*WSPC*) and their three components: *PBA*, *DIS* and *LUP* (or *UD*) are illustrated in Fig. 4.

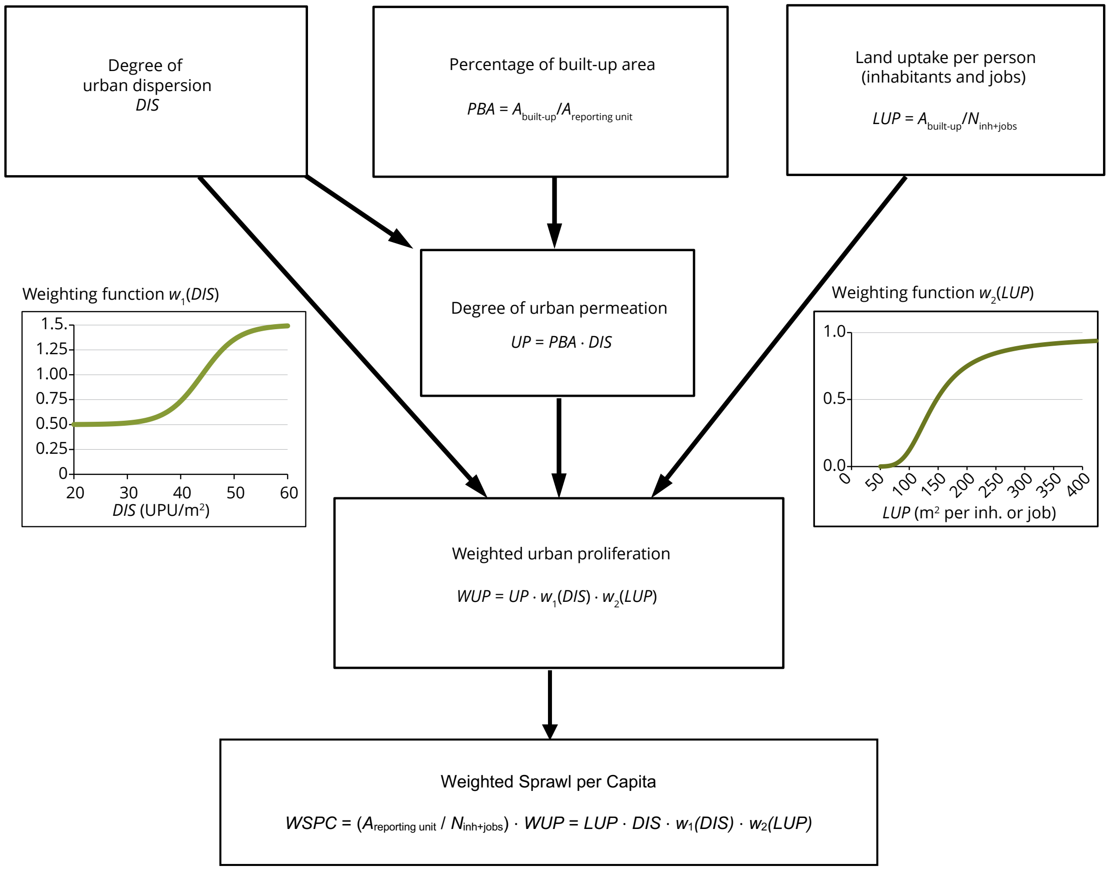


Fig. 4: The relationships between the *WUP* metric and the *WSPC* metric and their components *DIS*, *PBA*, and *LUP* (EEA & FOEN 2016: 39). The *DIS*, *PBA* and *UD* (= 1/*LUP*) metrics are intensive metrics. $A_{\text{reporting unit}}$ = area of the reporting unit (the landscape studied); $A_{\text{built-up}}$ = size of built-up area in the reporting unit; $N_{\text{inh+jobs}}$ = number of inhabitants and jobs in the built-up area of the reporting unit. The shapes of the weighting functions are shown in the boxes as indicated.

Users who already have sufficient knowledge of the definition of built-up areas and the metrics of urban sprawl can continue reading in section 3 (installation of the USM Toolset). However, if the users do not yet have adequate background knowledge, we highly recommend that they read this section carefully or the paper by Jaeger and Schwick (2014) or the first part (sections 2.1 and 2.2) of Chapter 2 "Measurement of urban sprawl, base data, and hypotheses about potential drivers" in the report "Urban sprawl in Europe" (EEA & FOEN 2016) for more detailed information(Fig. 5), e.g., about the meaning of the values of *WUP* and *DIS*.

2.1 Definition of built-up areas

Built-up areas "may include various types of settlement and buildings, ranging from places with urban character to villages to separate single buildings in the open landscape. Generally, a built-up area is defined as a surface covered by man-made structures. Roads and railways outside towns and cities are not included in this definition, since they are not perceived to be part of urban sprawl (but rather contribute to landscape fragmentation)" (EEA and FOEN, 2016, p. 47).

For the purpose of comparisons between different regions (or for one region between different points in time), the definition of the built-up areas must be chosen in a precise and consistent way. For smaller regions, usually there are more detailed datasets on 'built-up areas' available (e.g., data on the elements of urban surface such as building footprints). However, for large areas, data on built-up areas do not usually include such details of the urban surface. It should be noted that for a meaningful comparison between different points in time, it is necessary to use the same delineation criteria of built-up area. Examples are given in Nazarnia et al. (2016).

(a) (b) (c)

Fig. 5: Chapter 2 of the report "Urban sprawl in Europe" (EEA and FOEN 2016) is highly recommended reading before using the USM Toolset (a). A book about the *WUP* method and results for Switzerland is available in English and French (Schwick et al. 2012) and German (Schwick et al. 2010) (b). A Practitioner's Introduction to the *WUP* method is available in German (Schwick et al. 2011a) and French (Schwick et al. 2011b) as a PDF online at http://www.wsl.ch/info/fokus/zersiedelung/index_FR (c).

2.2 Metrics of urban sprawl

Weighted Urban Proliferation (*WUP*) has three components: *PBA*, *DIS* and *LUP* (or *UD*) (Fig. 4). In addition, the two metrics of *TS* and *UP* are defined here.

The proportion of built-up areas (*PBA*) is the proportion of the size of built-up areas to the size of the landscape (reporting unit): *PBA* = Area of built-up area / Area of reporting unit.

Degree of urban dispersion (*DIS*) measures the dispersion of built-up areas based on the distances between any two points within the built-up areas (Jaeger et al. 2010b). *DIS* is expressed in urban permeation units per square meter of built-up area (UPU/m^2). The more dispersed the built-up areas, the larger the value of *DIS*. Therefore, more compact built-up areas have lower values of *DIS* than more dispersed built-up areas.

$w_1(DIS)$ is a weighting function for *DIS* which assumes values between 0.5 and 1.5 to give higher weights to the more dispersed built-up areas and lower weights to less dispersed areas (Jaeger and Schwick 2014).

Total Sprawl (*TS*) is defined as the average sum of the weighted distances between all points in the urban area and randomly chosen second points where each second point is not farther away from the first point than the horizon of perception (*HP*). The value of *TS* is the product of *DIS* and the total amount of built-up area (*TS* = *DIS* * Area of built-up area). To learn more about *TS*, see Jaeger et al. (2010b).

Utilization Density (*UD*) measures the number of people living and working per km^2 of built-up area. The more people and jobs are located in a built-up area, the higher the land utilization as measured by utilization density (*UD*). This metric is expressed in inhabitants and jobs per square kilometer of built-up areas (inhabitants+jobs / km^2).

$w_2(UD)$ is a weighting function for *UD* which assumes values between 0 and 1 to give lower weights to more intensively utilized urban areas, i.e., those that have more inhabitants and jobs. The value of $w_2(UD)$ is close to 1 when there are less than 40, and close to 0 when there are more than 100 inhabitants and jobs per hectare of built-up area (Jaeger and Schwick 2014).

Land Uptake per person (*LUP*) is the area of land that is used per inhabitant or job within the built-up areas and expressed in square meters per inhabitant or job (m^2/(inh. or job)) (*LUP* = Area of built-up areas/Number of inhabitants and jobs). High *LUP* values indicate that more space is used per inhabitant or workplace compared to areas where *LUP* values are lower. *LUP* is in fact the reciprocal of *UD*: $LUP = 1/UD$.

Urban Permeation (*UP*) is a measure of the permeation of a landscape by built-up areas. It accounts for the *DIS* and *PBA* and is expressed in urban permeation units per m^2 of landscape (UPU/m^2): $UP = PBA \cdot DIS$.

Weighted Urban Proliferation (*WUP*) is the main metric used to quantify urban sprawl. It is the product of the Urban Permeation (*UP*), the weighting of *DIS* ($w_1(DIS)$) and the weighting of the *UD* ($w_2(UD)$). *WUP* is expressed in urban permeation units per square meter of landscape (UPU/m^2): $WUP = UP \cdot w_1(DIS) \cdot w_2(LUP)$. More detailed information about these metrics of urban sprawl can be found in Jaeger and Schwick (2014), and in Jaeger et al. (2010b, p. 431, Fig. 4) regarding the cross-boundary connections (CBC) procedure.

Weighted Urban Proliferation of the settleable part of the study area (WUP_b): Urban sprawl can be measured with and without the inclusion of those areas that are not suitable for the construction of buildings (called the "unsettleable" or "irreclaimable areas") of the study area. Examples of such types of areas considered as not feasible for the construction of buildings are glaciers and perpetual snow, watercourses, lakes and other water bodies, coastal lagoons, estuaries, inland marshes, and peat bogs. Areas in which the construction of buildings is not permitted, could also be excluded, e.g., protected areas in Switzerland. Excluding the areas not suitable for construction from the reporting units results in larger *WUP* values. WUP_b can be calculated as

$$WUP_b = (A_{\text{reporting unit}} / A_{\text{settleable}}) \cdot (PBA \cdot DIS) \cdot w_1(DIS) \cdot w_2(LUP) = (A_{\text{reporting unit}} / A_{\text{settleable}}) \cdot WUP.$$

WUP_b is expressed in urban permeation units per square meter of landscape (UPU/m^2). More detailed information can be found in Hennig et al. (2015: 492-494).

Weighted Sprawl per Capita (*WSPC*) measures the contribution of each inhabitant or job to urban sprawl in the reporting unit and is expressed in urban permeation units per inhabitant or job (UPU / (inh. or job)): *WSPC* = (Area of reporting unit / Number of inhabitants and jobs) · *WUP* (Behnisch et al., 2022; Pourtaherian & Jaeger, 2022).

While Shannon's entropy has been widely used for measuring urban sprawl in earlier studies, Nazarnia et al. (2019) proved that it is not a suitable method for the assessment of urban sprawl since it does not comply with the 13 suitability criteria introduced by Jaeger et al. (2010b). The number of studies using the *WUP* method and the USM toolset for the measurement and analysis of urban sprawl has increased since. Pourtaherian and Jaeger (2022) used this method to analyze the degree to which greenbelts are effective at mitigating urban sprawl, and Behnisch et al. (2022) measured urban sprawl globally to reveal trends in urban sprawl since 1990.

Tab. 1: Metrics for the measurement of urban sprawl and their associated equations and units

Acronym	Name of the metric	Equation	Unit	Mathematical homogeneity
WUP	Weighted Urban Proliferation	$(PBA \cdot DIS) \cdot w_1(DIS) \cdot w_2(LUP)$	UPU per m^2 of landscape	Intensive
WUP_b	Weighted Urban Proliferation for the settleable part of the study area	$(A_{\text{reporting unit}} / A_{\text{settleable}}) \cdot (PBA \cdot DIS) \cdot w_1(DIS) \cdot w_2(LUP) = (A_{\text{reporting unit}} / A_{\text{settleable}}) \cdot WUP$	UPU per m^2 of landscape	Intensive
PBA	Percentage of Built-up Area	$A_{\text{built-up}}/A_{\text{reporting unit}}$	%	Intensive
DIS	Dispersion	–	UPU per m^2 of built-up area	Intensive
LUP	Land Uptake per Person (per inhabitant or job)	$A_{\text{built-up}}/N_{\text{inh+job}}$	m^2 per inhabitant or job	Intensive
UD	Utilization Density	$N_{\text{inh+job}}/A_{\text{built-up}}$	Inhabitants or jobs per km^2 of built-up area	Intensive
UP	Urban Permeation	$PBA \cdot DIS$	UPU per m^2 of landscape	Intensive
TS	Total Sprawl	$DIS \cdot A_{\text{built-up}}$	MUPU	Extensive
WTS	Weighted Total Sprawl	$w_1(DIS) \cdot w_2(LUP) \cdot TS$	MUPU	Extensive
SPC	Sprawl per Capita	$TS/N_{\text{inh+job}}$	UPU per inhabitant or job	Intensive
WSPC	Weighted Sprawl per Capita	$w_1(DIS) \cdot w_2(LUP) \cdot SPC = (A_{\text{reporting unit}}/N_{\text{inh+job}}) \cdot WUP = WTS/N_{\text{inh+job}}$	UPU per inhabitant or job	Intensive

2.3 Choice of the Horizon of Perception

Calculation of the dispersion of built-up areas (*DIS*) and Weighted Urban proliferation (*WUP*) requires a defined scale of analysis, which is specified by the Horizon of Perception (*HP*). The user can choose the size of the *HP* between 0.2 and 10 km. However, the default value of *HP* in the USM Toolset is 2 km, and the weighting function for the computation of weighted Dispersion ($w_1(DIS)$) operates properly only when 2 km is selected. The reason is that the weighting of *DIS* as a component of *WUP* was chosen for this scale of analysis of urban sprawl based on expert opinion (see Jaeger and Schwick 2014 for details). If users are interested in using a different value of *HP* they may need to consider modifying the weighting function equation accordingly in the sivalues.exe tool (see section 3.1). However, working on the logic of suitable weighting functions for *HP*s other than 2 km should be done in a cautious way and this remains future work.

2.4 Job data full-time equivalents

When it is possible to distinguish between part-time and full-time jobs, converting part-time jobs into full-time equivalents would lead to more accurate urban sprawl metrics results. This can be done using the average number of weekly hours worked for each type of employment in a given country. By calculating a conversion factor based on this data, part-time jobs can be converted into full-time equivalents, which can then be added to the number of full-time jobs to obtain the total number. In cases where part-time and full-time jobs are not provided separately, it may still be possible to estimate them using the percentage of part-time employment as a percentage of total employment, as seen in App. D in Pourtaherian and Jaeger (2022) (Fig. 6).

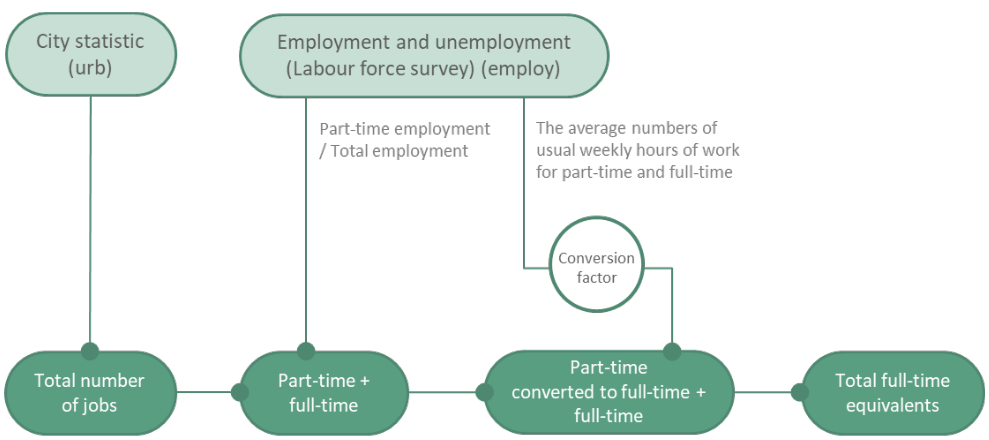


Fig. 6: Job data preparation in the case part-time and full-time jobs can be distinguished: An example of a data source (urb and employ are European open-source databases provided by Eurostat - European Commission).

2.5 City boundaries adjustment for comparison of cities of differing sizes (optional)

Because *WUP* is an intensive metric, it can be applied to, and compared between, landscapes irrespective of their sizes. However, in some cases (e.g., Uppsala), the boundary of the city is located far from the built-up areas, whereas in other cases (e.g., Glasgow), the boundary runs closely along the built-up areas. Such differences convolute a fair comparison of the cities, because even when the population sizes and the amounts and spatial arrangements of the built-up areas of two cities are the same, the *PBA* of the two cities differs. In such a situation in which the sizes and patterns of built-up areas are similar in two cities, but their boundaries and area sizes differ, the value of *WUP* will be lower for the landscape of the city whose boundary is located farther away as a result of its lower *PBA*. Therefore, the boundaries can be rescaled to make the cities comparable on an equal footing. In contrast, *WSPC* relates to the number of inhabitants and jobs rather than the landscape and is not affected by changes in the boundaries.

For this purpose, Pourtaherian and Jaeger (2022) used the relationship between population size and the city size (log-transformed) by applying a linear regression to determine average city size as a function of population size, which they called "adjusted city size" (Fig. 7). In the cases in which the adjusted city size was greater than the original area, this step corresponds to adding some empty space with no built-up areas and no population in it. Hence, the only component adjusted is *PBA*, while *DIS* and *LUP* remain the same. The adjusted city size was larger than the size of the built-up areas in all 60 European cities they studied. Consequently, none of the cities for which the area shrank due to the adjustment lost any built-up areas, i.e., its boundaries were simply drawn somewhat closer around the built-up areas, and population stayed the same as well. The corresponding values of the metrics are referred to as adjusted *PBA* and adjusted *WUP*. This adjustment is an interesting option for the comparison of cities.

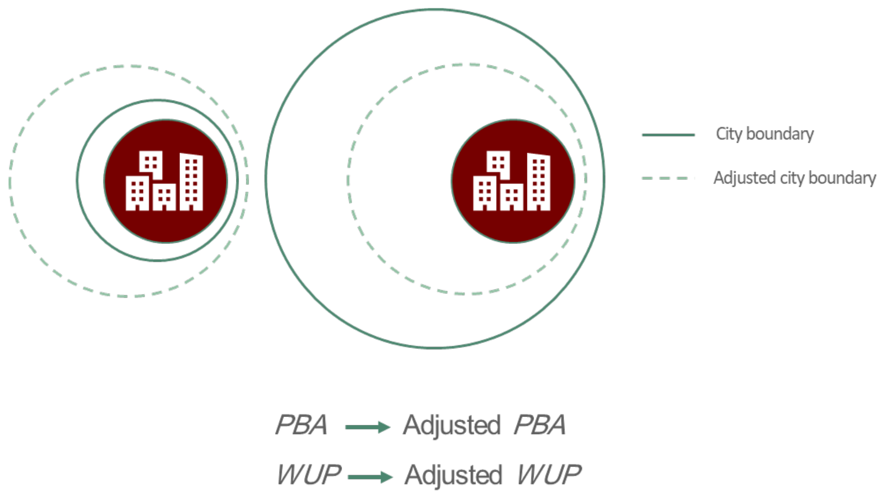


Fig. 7: Illustration of city size adjustment. In case that the population size of the two cities is the same, their adjusted city size will be the same.

3. Installation of the Urban Sprawl Metrics (USM) Toolset

The Urban Sprawl Metrics Toolset works with ArcGIS version 10.1 (ESRI, 2010) or higher. Only an ArcInfo license of the ArcGIS software is required for the installation of this Toolset (no additional ArcGIS extensions are needed). Minimum requirements for the system (PC/laptop) on which the Toolset will be installed are:

(1) 4 GB or more Random Access Memory (RAM),
(2) 10 GB or more free space on the disc where ArcGIS temporary directory and ArcGIS "Default.gdb" geodatabase are stored,
(3) 10 GB or more free space on the disc where working directories (see section 4 for explanation on working directories) will be stored.

03.1 Urban Sprawl Metrics Toolset archive

The USM Toolset is distributed as a "zip" archive called "USM_Toolset.zip". The toolset can be installed from http://www.wsl.ch/info/fokus/zersiedelung/index_DE.
The USM Toolset archive contains five files:

(1) "USM_toolset.tbx" which is the tool that installs in ArcGIS,
(2) "1_Si_value.py" which is the Python script for the computation of Si values (see section 4.1 for explanation of Si values),
(3) "2_metrics.py" which is the Python script for computation of the urban sprawl metrics (e.g., *DIS*, *UP*, *WUP*) (see section 2.2 for information about urban sprawl metrics),
(4) "3_cleaning.py" which is the Python script for performing directory clean-ups, and finally
(5) "sivalues.exe" which is a tool that is being used along with 1_Si_valye.py script for the computation of Si values.

3.2 Step by step installation guide

Step 1: Download the "USM_toolset.zip" archive from http://www.wsl.ch/info/fokus/zersiedelung/index_DE.

Step 2: Extract (unzip) the "USM_Toolset.zip" archive" into a folder where the tools will be installed. (Note that you need 10 GB or more free space on the disc where you locate this folder.)

Step 3: Open the ArcMap window (you need to have the updated license of this component of ArcGIS suite).

Step 4: Open the ArcToolbox window (Fig. 8).

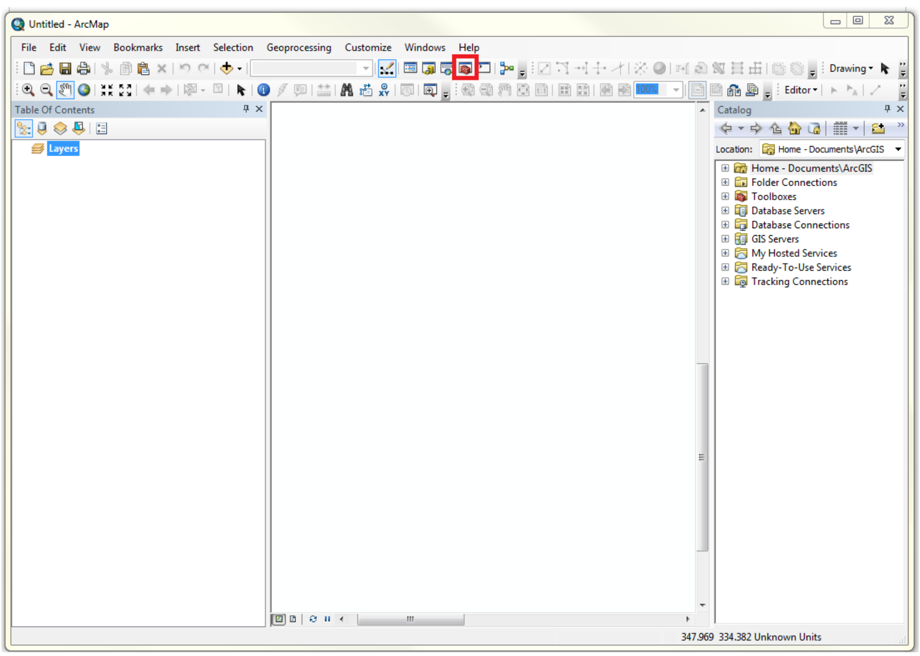


Fig. 8: ArcToolbox in Arcmap.

Step 5: Right-click (use right button of the mouse) on the ArcToolbox icon and select "Add Toolbox" from the popup menu (Fig. 9).

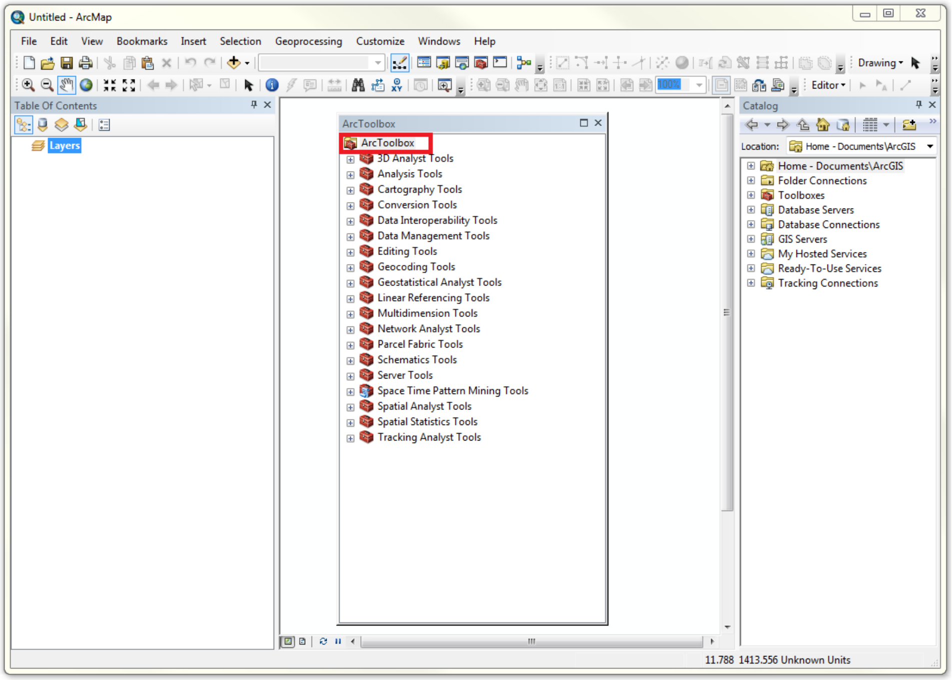


Fig. 9: ArcToolbox-Add toolbox.

Step 6: From the newly opened window, skip to the folder where the "USM_Toolset.zip" was stored and unzipped. Select USM_toolbox.tbx file and click "Open" (Fig. 10).

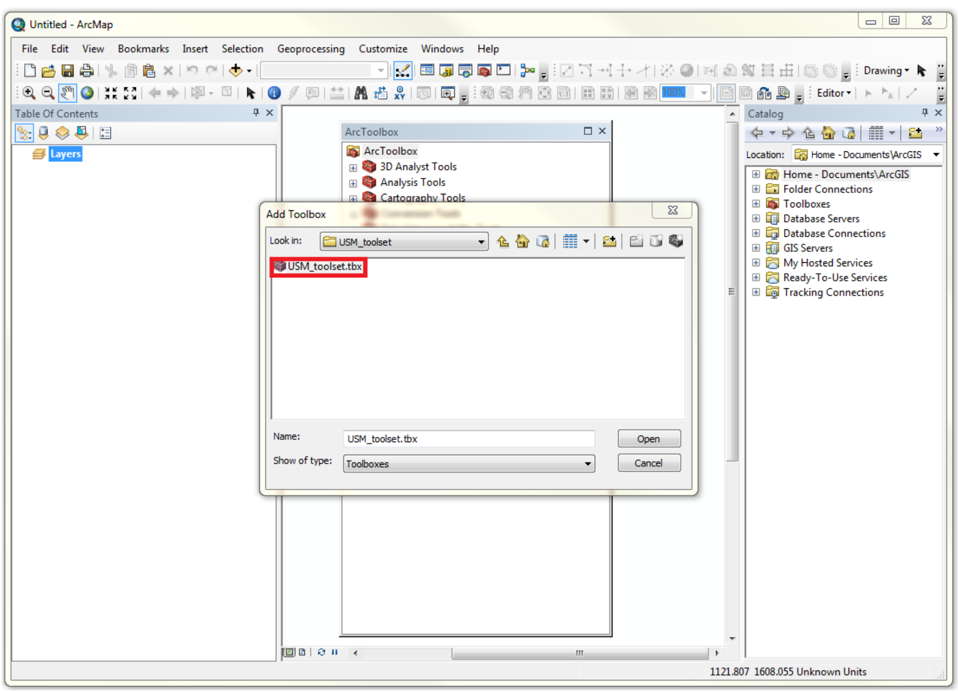


Fig. 10: Add toolbox-USM_toolset.tbx.

After completing step 6, a new toolset called “USM Toolset” is added to the ArcToolbox window. This toolset contains three tools: “1-Si values calculation”, “2-Metrics calculation” and “3-Cleaning” (Fig. 11).

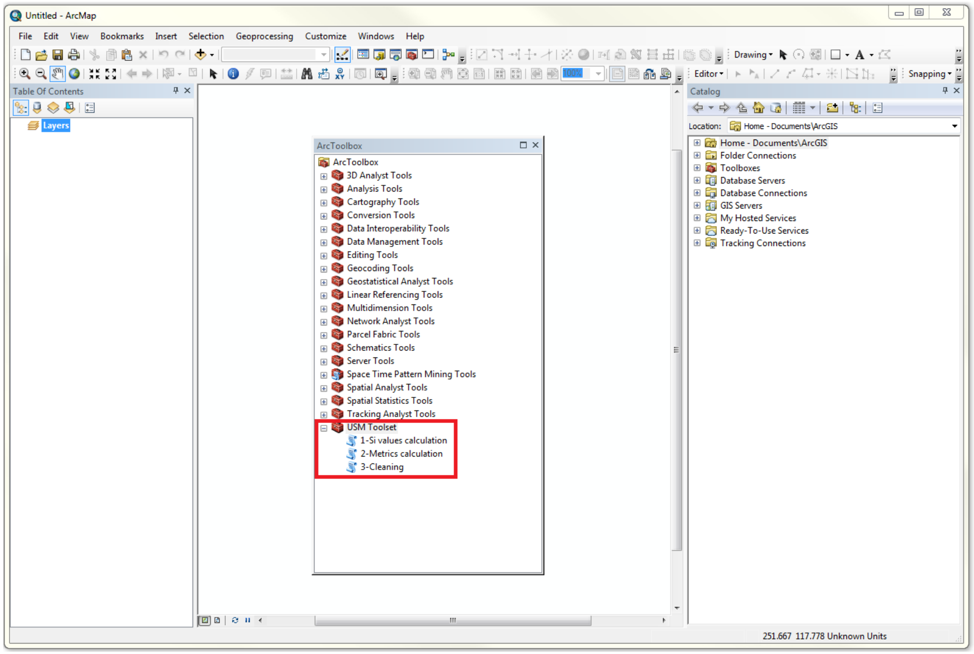


Fig. 11: USM Toolset added to the ArcToolbox.

Step 7: Right-click (use right button of the mouse) on the “1-Si values calculation” icon and select properties from the popup menu.
Step 8: From the newly opened window, go to the “Source” tab and then from the “Script File” bar skip to the folder where the USM_Toolset archive is stored and select “1_Si_value.py” and click on the ‘OK’ button (Fig. 12). Keep all the default properties as is and do not make any changes.

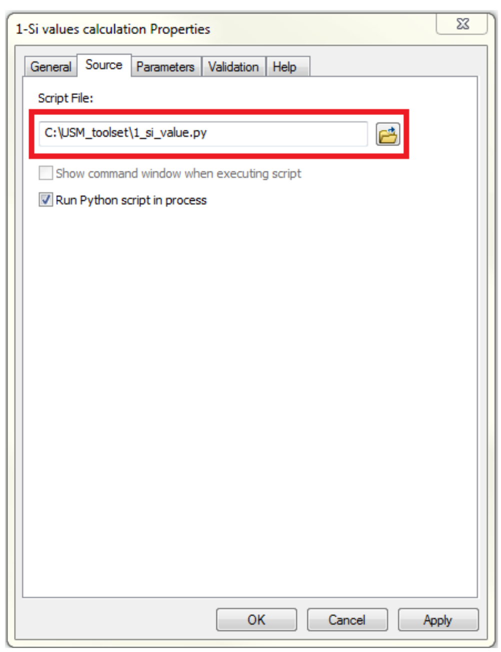


Fig. 12: 1-Si values calculation properties window.

Step 9: Repeat steps 7 and 8 for the next tool (2-Metrics calculation). Right-click (use right button of the mouse) on the “2-Matrics calculation” icon and select properties from the popup menu. From the newly opened window go to the “Source” tab and then from the “Script File” bar skip to the folder where the USM_Toolset archive is stored, select “2_metrics.py”, and click on the ‘OK’ button.

Step 10: Repeat steps 7 and 8 for the third tool (3-Cleaning). Right-click (use right button of the mouse) on the “3-Cleaning” icon and select properties from the popup menu. From the newly opened window go to the “Source” tab and then from the “Script File” bar skip to the folder where the USM_Toolset archive is stored, select “3_cleaning.py”, and click on ‘the OK’ button.

In order to avoid the need for repeating the implementation of above-mentioned steps, the user should save the ArcMap project after completing the final step (step 10). The USM Toolset will be automatically available whenever the saved ArcMap project is being used.

4. How to use the Urban Sprawl Metrics Toolset

In the following sections, a step-by-step guide to use the USM Toolset is described. Users should consider preparing their input data and working directories before using the USM Toolset.
Users need to have two working folders: (1) a ‘Directory’ folder and (2) an ‘Output’ folder. In the directory folder users should store their input data along with the sivalues.exe Tool. The three components of the directory folder should be (1) the binary map of built-up areas2, (2) geodatabase feature class or Shapefile of the reporting unit(s)/area of study, and (3) sivalues.exe file. Users should keep the Output folder empty because the outputs of the calculations will be sorted in this folder automatically.

4.1 Si values calculation tool

The purpose of this tool is to calculate the Si values for each pixel of urban area. The metrics of urban sprawl characterize sprawl in a geometric perspective, and their calculation is based on all distances between any two points within the urban area. The so-called Si values are in fact the mean of the weighted distances between any pixel of urban area and all other urban pixels within the horizon of perception.
The input of the tool is the binary map of built-up areas (settlements areas and/or solitary buildings) in ESRI raster format. The binary raster has two values (0 values for non-built-up areas and 1 value for built-up areas). At this stage, the user should choose a value for the horizon of perception. The default *HP* of the USM Toolset is 2 km and the calculation of metrics of urban sprawl is based on weighting functions that are appropriate for a horizon of perception of 2 km. So it is highly recommended that users keep the default value (*HP* = 2000 m).

4.1.1 How to use the Si values calculation tool

1. Open the saved ArcMap project in which the USM Toolset has been installed. From Arctoolbox, select USM toolset and click on the first tool (1-Si values calculation) (Fig. 13).
2. From the ‘Path to the sivalues.exe Tool’ bar, skip to the ‘Directory’ folder and click on the ‘Add’ button.
3. From the ‘Input Raster of the Built-up Areas’ bar, skip to the directory folder, select the binary map of built-up areas and click on the ‘Add’ button.
4. In the ‘Horizon of Perception’ bar, keep the default value of 2000 m.
5. Finally from the ‘Output Directory’ bar, skip to the ‘Output’ directory/folder in which you want the output files be stored, select the folder, and click on the ‘Add’ button.

[2] If the data about built-up areas is in vector format, in order to convert the data to raster binary format, users should first convert the feature class or Shapefile to a raster. Users can use the tool 'Polygon to Raster' in ArcGIS version 10.3.1 to create the raster data. The second step is to reclassify the output raster file to a binary file. For this purpose, users can use the tool 'Reclassify' in ArcGIS version 10.3.1 and change the old values of the raster file to 1 for all built-up area pixels and to 0 for No Data values.

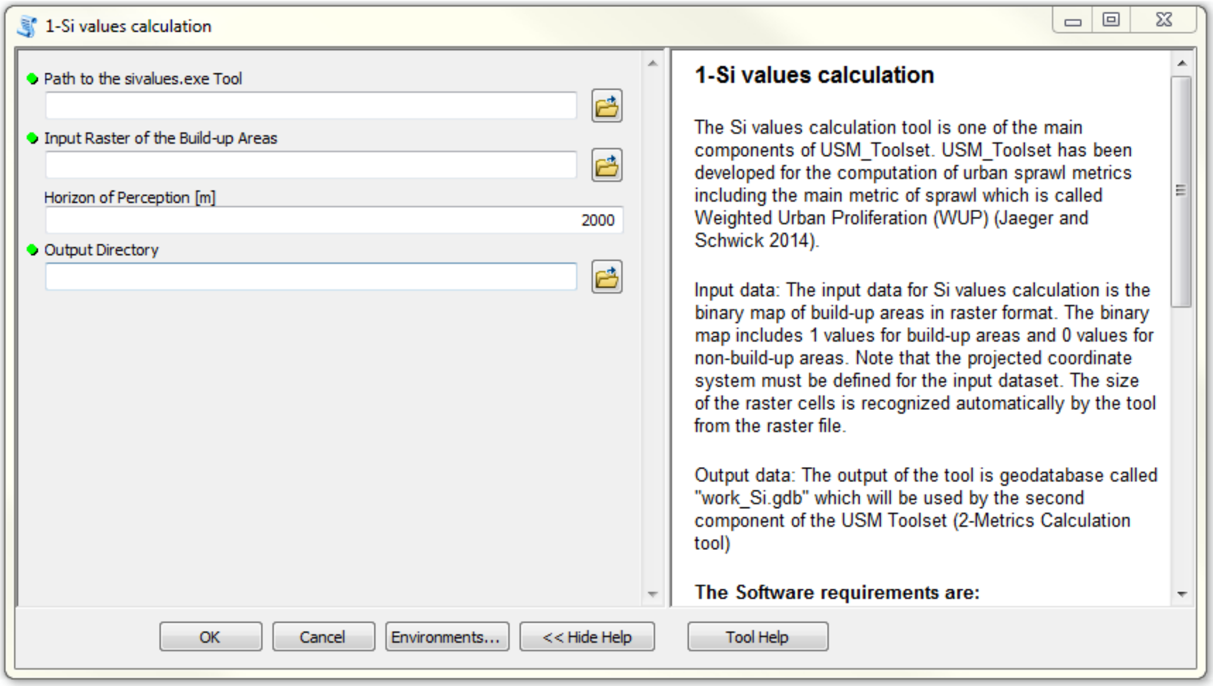


Fig. 13: Si values calculation tool.

When all the empty bars are filled correctly, click on the 'OK' button. Si values calculation tool calls the sivalues.exe tool and computes the Si value for each pixel of built-up area. During this process, a summary report file (step1_working_report.txt) will be created and stored in the Output folder. The output of this process will be stored in the 'work_SI.gdb' geodatabase located in the Output folder. This geodatabase will be called by the next tool (Metrics tool) for computation of Dispersion and other metrics of urban sprawl.

4.2 Metrics calculation tool

The purpose of this tool is to calculate the suite of metrics of urban sprawl (e.g., *DIS*, *UP*, *UD*, *WUP*). The input data for the Metrics calculation tool are:

(1) the binary map of built-up areas in raster format (the same raster file that was used in the Si values calculation tool),
(2) the geodatabase feature class or the shapefile of the reporting unit(s) which includes two fields in its attribute table: reporting unit(s) identifier and number of inhabitants and jobs, and
(3) the output of the first tool (work_SI.gdb) for computation of Dispersion and the other metrics of sprawl (the tool calls this file automatically as long as it is stored properly in the correct directory).

The output of the tool is a shapefile (similar to the shapefile of the reporting unit(s)) that includes all the values of the urban sprawl metrics in its attribute table (see examples in section 5).

4.2.1 How to use Metrics Calculation tool

1. Open the saved ArcMap project in which the USM Toolset has been installed. From Arctoolbox select USM Toolset and click on the second tool (2-Metrics calculation) (Fig. 14).
2. From the 'Input Raster' bar skip to the directory folder, select the binary map of built-up areas, and click on the 'Add' button.
3. From the 'Reporting Unit(s) Layer Field' bar, skip to the directory folder, select the shapefile of reporting unit, and click on the 'Add' button.

4. From the ‘Reporting Unit(s) Identifier Field’ drop down menu, select the field in which the ids of the reporting unit(s) is/are stored.
5. From the ‘Number of Inhabitants and Jobs Field’, drop down menu select the field in which the number(s) of inhabitants and jobs is/are stored for the reporting unit(s).
6. From the ‘Output Directory’ bar, skip to the ‘Output’ folder (in which the results will be stored, select the Output folder, and click on the ‘Add’ Button.
7. Finally, from the ‘Output File’ bar skip to the Output folder, type the name of the result file in the ‘Name’ bar (e.g., Results, FinalOutput), select ‘Shapefile’ in the ‘Save as type’ bar, and click on the ‘Save’ button.

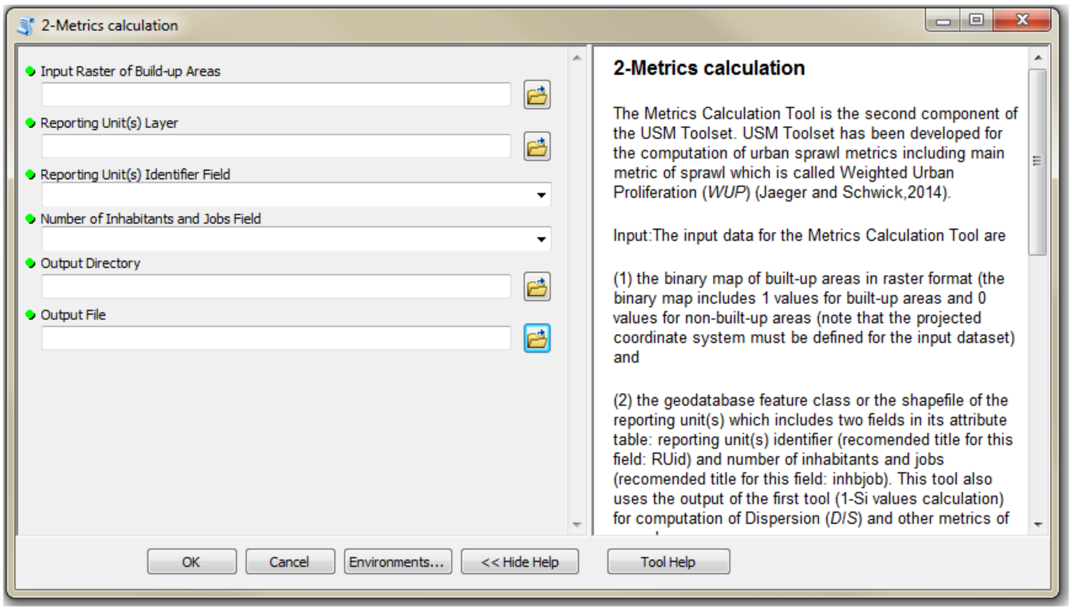


Fig. 14: Metrics calculation tool.

When all the empty bars are filled correctly, click on the ‘OK’ button. The metrics calculation tool uses the input that you have entered to the tool and also the output of the Si values calculation tool and computes the metrics of urban sprawl for the reporting unit(s). During this process, a summary report file (step2_working_report.txt) will be created and stored in the Output folder.

Potential issue with running the Metrics Calculation tool:
In step 4, using the default ‘FID’ field as the identifier will lead to empty or incorrect output. To avoid wrong results, the ids must always be stored in a new field, which has to be created manually.

If the output folder is in a simple path, it usually works better: Try to save your "Output" folder in a simple path (like your desktop).

4.3 Cleaning tool

The purpose of this tool is to remove all the unnecessary files that have been produced by the Si values and Metrics calculation tools.[3] The only input of the tool is the working directory (i.e., Output folder). The users can decide if they want to delete the ‘work_SI.gdb’ or not. The default option of the tool is ‘No’, i.e., not to delete the geodatabase. If the ‘work_SI.gdb’ has been removed, the calculation of Si values should be repeated for future computations using different reporting unit(s)).

[3] This step is optional and its implementation does not make any difference in the final results.

4.3.1 How to use the Cleaning tool

1. Open the saved ArcMap project in which the USM Toolset has been installed. From Arctoolbox, select USM Toolset and click on the third tool (3-Cleaning) (Fig. 15).
2. From the 'Working directory' bar, skip to the Output folder (or the folder that you want it to be cleaned-up), select the folder and click on the 'Add' button.
3. Keep the default option of 'No' in 'Delete Si value geodatabase?' bar if you want to keep the Si values geodatabase, or select 'Yes' if you want to delete this geodatabase along with other files.

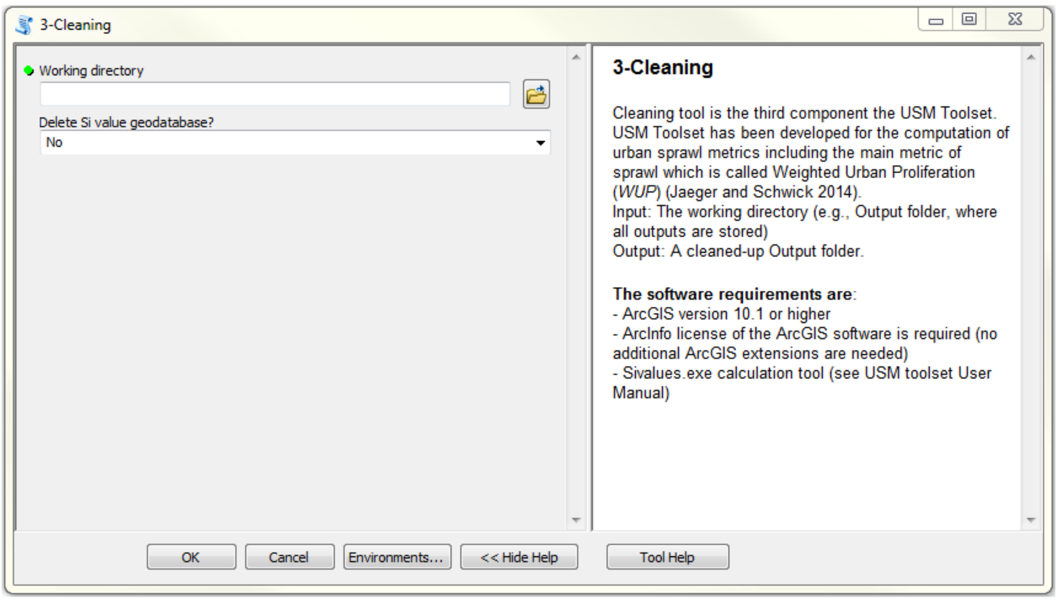


Fig. 15: Cleaning tool.

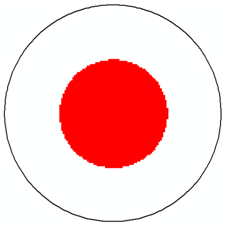
When the two empty bars are filled correctly click on the 'OK' button. While using this tool, similar to the other two tools of the USM Toolset, a report file (step3_working_report.txt) will be created and stored in the Output folder. The files that exist in the Output folder after running the Cleaning tool (and when keeping the default value for 'Delete Si value geodatabase?') include 'work_Si.gdb', 'step1_working_report.txt', 'step2_working_report.txt', 'step3_working_report.txt' and the final results shapefile. To see the final results, the user should open the shapefile in an ArcMap window, right-click on the shapefile in the 'Table Of Contents' panel, and click on the 'Open Attribute Table' tab. A table will open in ArcMap that includes all the metrics of urban sprawl for the landscape studied.

5. Examples of using the USM Toolset

In this section, you find six simple model and seven real landscapes and the results of applying the USM Toolset to these landscapes. The files of all examples are available with this tool (on Concordia University's Spectrum website) for users to practice. For each example, users should create two folders: (1) a directory folder (e.g., Directory_ex1) and (2) an Output folder (e.g., Output_ex1). Copy and paste the relevant raster file and shapefile of each example (e.g., example 1) along with the 'sivalues.exe' tool into the directory folder. Then follow the steps described in section 4. Note that when using the second tool (Metrics Calculation Tool), from the 'Reporting Unit(s) Identifier Field" drop down menu, select the 'RU_id' (in the field in which the id of the reporting unit is stored) and from the 'Number of Inhabitants and Jobs Field', drop down menu, select 'inhbjob' (the field in which the number of inhabitants and jobs is stored). Continue with step 3 and you will get the final results that are presented in this user manual.

5.1 Six simple hypothetical model landscapes

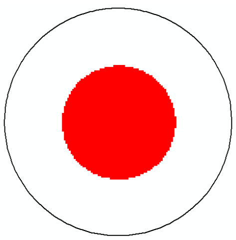
Example 1: Area of built-up areas = 785,000 m^2 (circle with a radius of 500 m), Area of the reporting unit = 3.14 km^2, Number of inhabitants and jobs = 2,600 people and jobs.



FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	2600	1	785700	3141176.98082	0.25013	28.13074	0.50926	22102322.4	7.03632	3309.2	0.89379	302.2	3.20275

The value of Weighted Urban Proliferation for a landscape of size 3.14 km^2 and with 785,000 m^2 of built-up areas and 2,600 inhabitants and jobs is 3.2 UPU/m^2. The value of *WSPC* is 3869.39 UPU/(inhb. or job). Increasing the number of inhabitants and jobs for the same theoretic landscape will decrease the *WUP* value. See the next example for details.

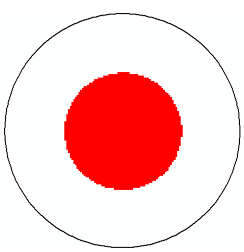
Example 2: Area of the built-up areas = 785,000 m^2 (circle with a radius of 500 m), Area of the reporting unit = 3.14 km^2, Number of inhabitants and jobs = 12,000 people and jobs.



FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	12000	1	785700	3141176.98082	0.25013	28.13074	0.50926	22102322.4	7.03632	1527	0.00546	65.5	0.01956

The only difference between the theoretic landscape shown in this example and example 1 is the number of inhabitants and jobs (12,000 versus 2,600 people and jobs). In this example, the higher number of inhabitants and jobs resulted in a higher value of Utilization Density, and therefore, in a lower value of *WUP* (0.02 UPU/m^2). The value of *WSPC* is 5.12 UPU/(inhb. or job).

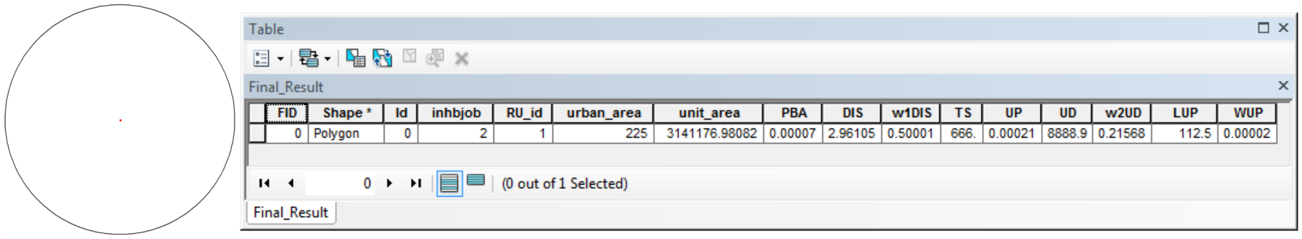
Example 3: Area of built-up areas = 785,000 m^2 (circle with a radius of 500 m), Area of the reporting unit = 3.14 km^2, Number of inhabitants and jobs = 0 people and jobs.



FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	0	1	785700	3141176.98082	0.25013	28.13074	0.50926	22102322.4	7.03632	0	0.98462	-1	3.52822

In this example, the number if inhabitants and jobs is zero and therefore the value of *UD* is zero indicating that the built-up area is not utilized at all. The value of -1 for *LUP* indicates an undefined value, because *LUP* is the result of a division of the area of built-up areas by the number of inhabitants, which is infinity when there are no inhabitants and no jobs. The value of *WSPC* also is infinity.

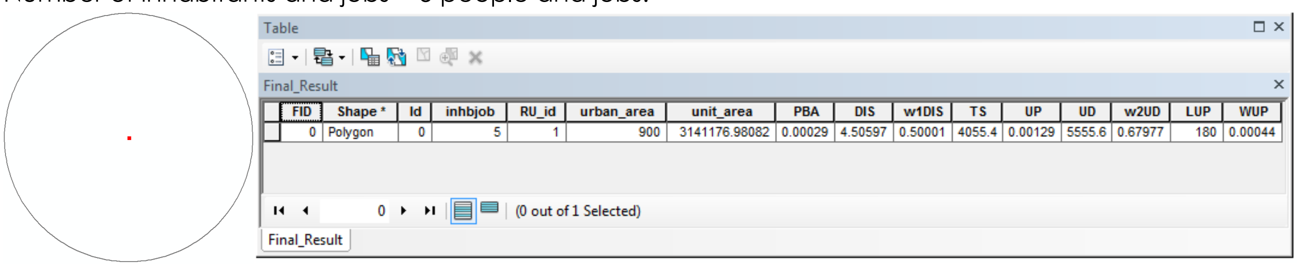
Example 4: Area of built-up areas = 225 m² (1 pixel size of 15 m x 15 m), Area of reporting unit = 3.14 km², Number of inhabitants and jobs = 2 people and jobs.



FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	2	1	225	3141176.98082	0.00007	2.96105	0.50001	666.	0.00021	8888.9	0.21568	112.5	0.00002

The smallest possible built-up area at any given resolution is one pixel. This will result in very low values of *DIS* and *WUP*. The example shown here is for a pixel size of 15 m x 15 m. The value of *WSPC* is 31.41 (UPU/inhb. or job).

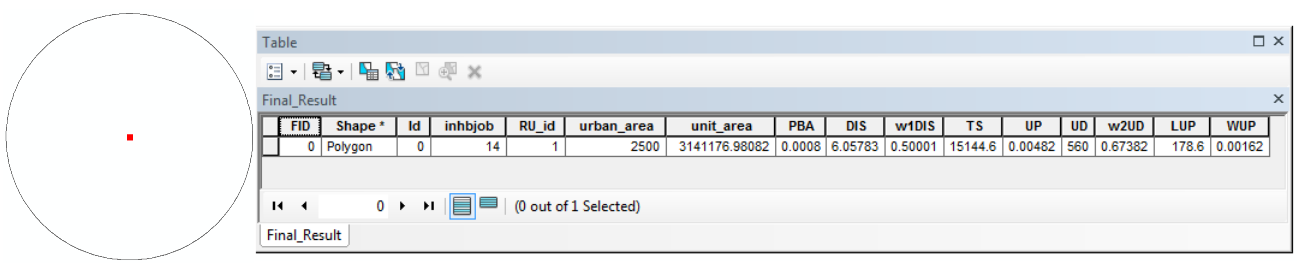
Example 5: Area of built-up areas = 900 m² (1 pixel size of 30 m x 30 m), Area of reporting unit = 3.14 km², Number of inhabitants and jobs = 5 people and jobs.



FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	5	1	900	3141176.98082	0.00029	4.50597	0.50001	4055.4	0.00129	5555.6	0.67977	180	0.00044

Increasing the size of the built-up area results in a higher value of *UP* and *DIS* and accordingly, in a higher value of sprawl (0.00044 UPU/m² in this example compared to 0.00002 UPU/m² in example 4). The value of *WSPC* is 276.42 UPU/(inhb. or job).

Example 6: Area of built-up areas = 2,500 m² (1 pixel size of 50 m x 50 m), Area of reporting unit = 3.14 km², Number of inhabitants and jobs = 14 people and jobs.

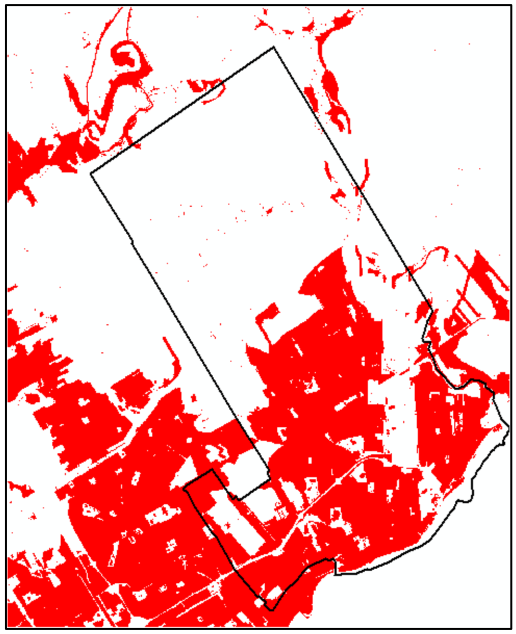


FID	Shape *	Id	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	0	14	1	2500	3141176.98082	0.0008	6.05783	0.50001	15144.6	0.00482	560	0.67382	178.6	0.00162

Similar to example 5, this example shows that a higher amount of built-up areas results in higher degree of urban sprawl. In this example, the number of inhabitants and jobs was selected proportional to the size of the built-up area to be comparable to example 5 (*LUP* values in the two examples are very close). The value of *WSPC* is 363.48 UPU/(inhb. or job).

5.2 One example of an urban landscape from Canada

Example 7: Area of built-up areas = 27,506,925 m^2 (in 2011), Area of reporting unit = 74 km^2 (borough of Beauport in Quebec City, Quebec, Canada, 2011), Number of inhabitants and jobs = 91,569 people and jobs; pixel size is 15 m x 15 m (see detailed information in Nazarnia et al. 2016).



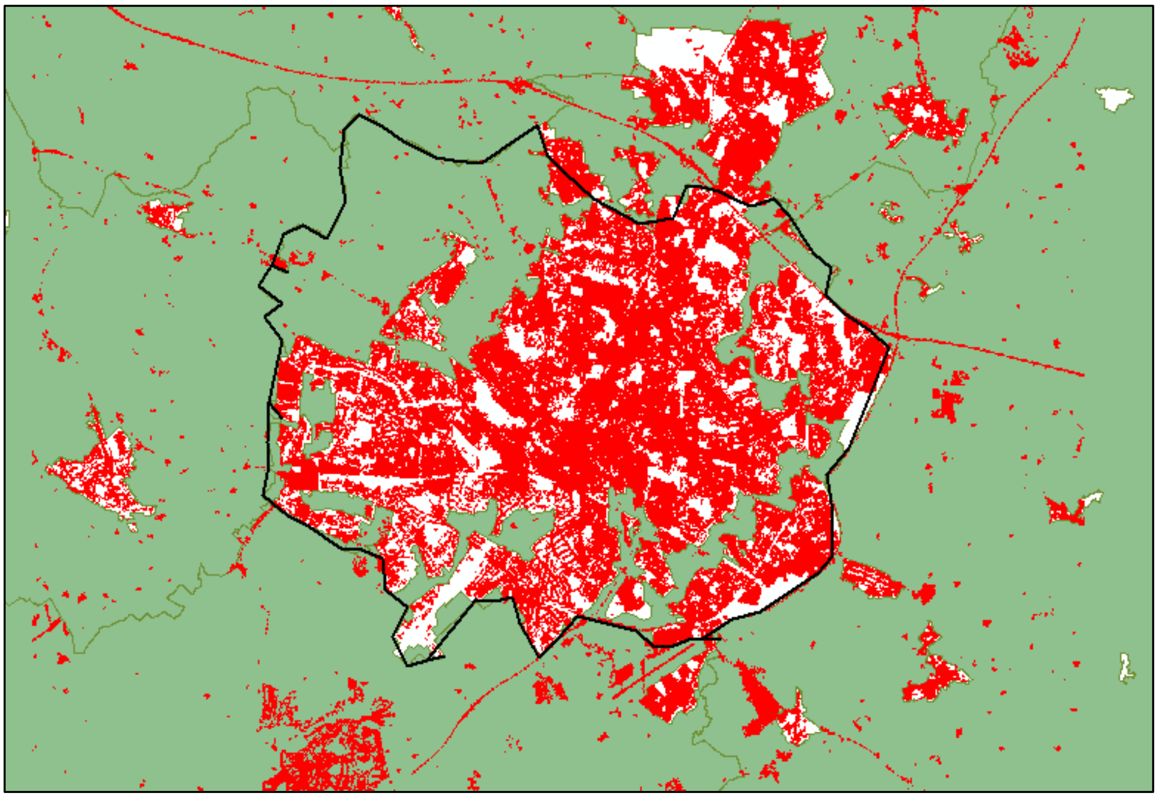
FID	Shape *	Borough_nu	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	91569	27506925	74246512.6824	0.37048	48.32345	1.28125	1329229514.9	17.90292	3328.9	0.89264	300.4	20.47543

Beauport is a northeastern suburb of Quebec City and is one of the oldest European-founded communities in Canada. Between highly sprawled boroughs of Quebec City, the borough of Beauport is the third-least sprawled area with *WUP* value of 20.47 UPU/m^2 and *WSPC* value of 16,602.01 UPU/(inhb. or job).

5.3 Six European cities with and without greenbelts

The examples presented below are taken from the research conducted by Pourtaherian and Jaeger (2022). These examples show the impact of greenbelts on urban sprawl, as measured by the USM toolset. The study evaluates 60 European cities with and without greenbelts to understand the extent of urban sprawl and the effectiveness of greenbelts at mitigating it. For more detailed information on the study and its findings, readers are encouraged to refer to Pourtaherian and Jaeger's research paper and appendices.

Example 8, Coventry: Area of built-up areas = 48 km^2 (in 2015), Area of reporting unit = 99 km^2 (City of Coventry), Number of inhabitants and jobs = 475,614 people and jobs; pixel size is 20 m x 20 m.



Table

Final_Result

FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Coventry	UK	1	475614	48382800	98740617.256	0.49	48.7801	1.3033	2360121209.	23.9022	9830.	0.1337	101.	4.1669

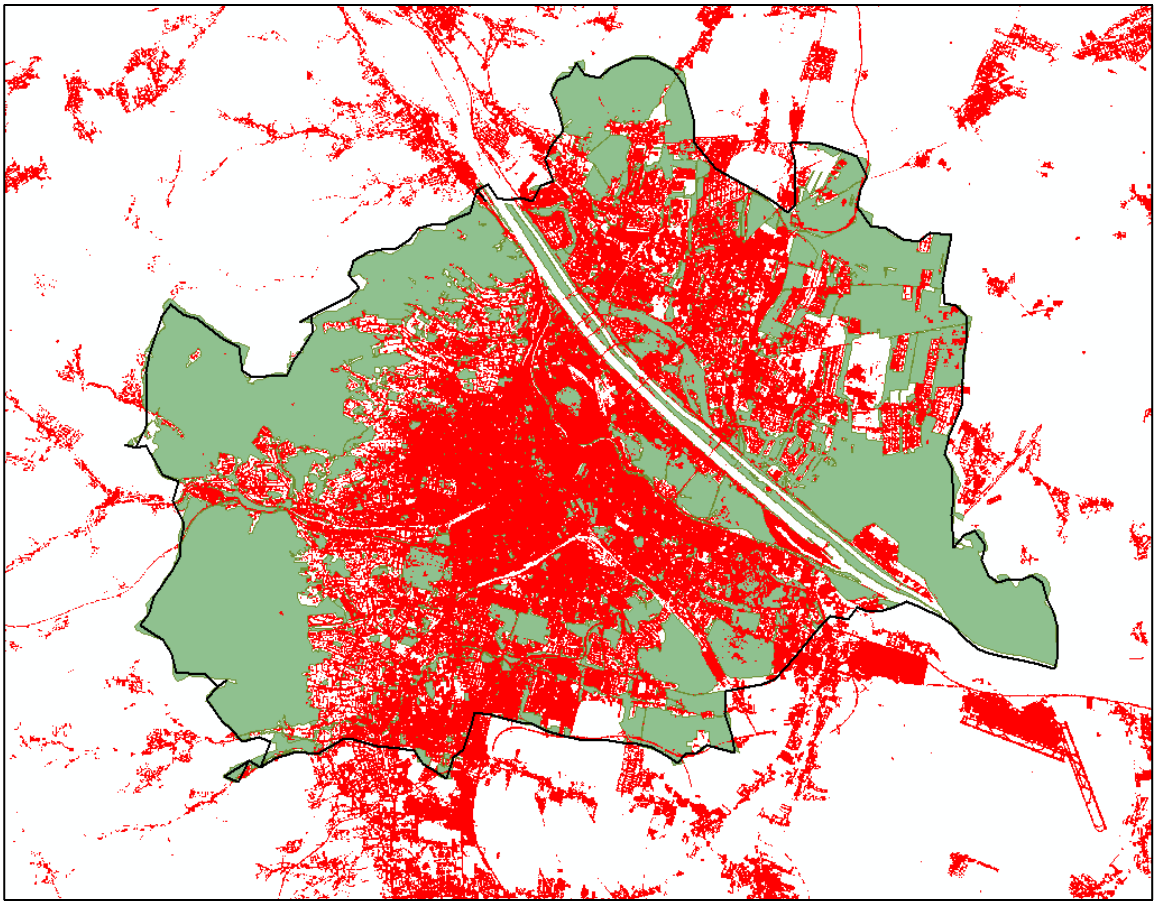
0 (0 out of 1 Selected)

Final_Result

The greenbelt of Coventry is part of the West Midlands greenbelt and has been in place since 1982. In 2001, three small areas were detached from the greenbelt to accommodate population growth, but the overall extent of the greenbelt has remained untouched since then and accommodating housing needs while keeping the greenbelt area intact has been effective in controlling urban sprawl.

WUP = 4.17 UPU/m^2; *WSPC* = 865.11 UPU/(inhb. or job)

Example 9, Vienna: Area of built-up areas = 170 km² (in 2015), Area of reporting unit = 413 km² (City of Vienna), Number of inhabitants and jobs = 2,590,493 people and jobs; pixel size is 20 m x 20 m.



Table

Final_Result

FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Vienna	AT	1	2590493	169934400	413266520.89	0.411	48.99	1.3131	832593592	20.1466	15244.	0.0055	65.6	0.1469

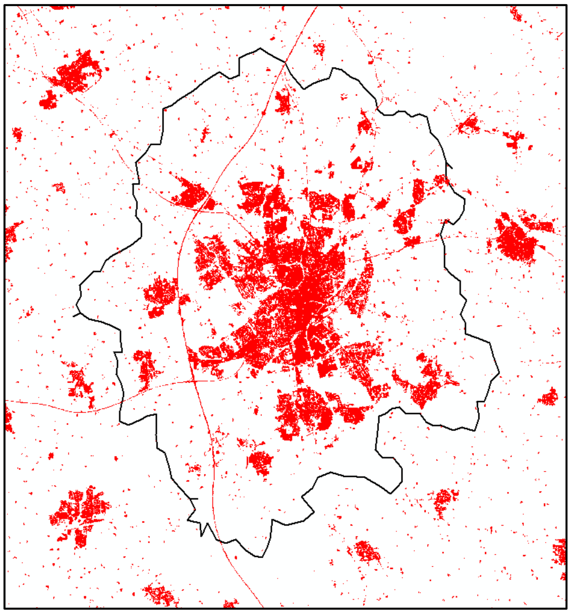
0 (0 out of 1 Selected)

Final_Result

In 1995, the Vienna Greenbelt Masterplan was officially adopted, marking a pivotal moment in the city's efforts to expand green space. The city took decisive steps towards achieving this goal, and today, over 50% of the city's area is covered by greenery. As a result of this initiative, Vienna has a very low *WUP* value, making it a model of sustainable urban development.

WUP = 0.15 UPU/m²; *WSPC* = 23.42 UPU/(inhb. or job)

Example 10, Munster: Area of built-up areas = 58 km² (in 2015), Area of reporting unit = 304 km² (City of Munster), Number of inhabitants and jobs = 430,844 people and jobs; pixel size is 20 m x 20 m.



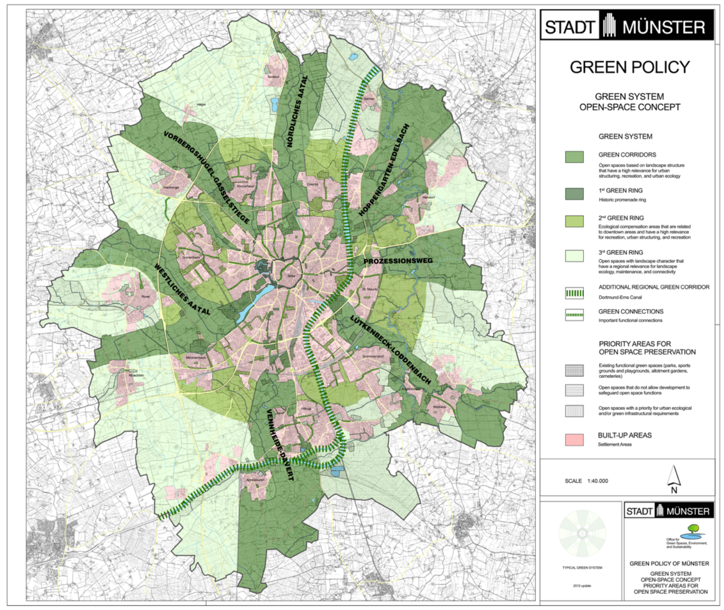


Fig. 16: Map of the "Green Policy Munster" ("Grünordnung Münster"). Source: Stadt Münster, n.d.; translated from German by Pourtaherian and Jaeger (2022).

Table

Final_Result

FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Munster	DE	1	430844	57992400	303678353.83	0.1909	47.2178	1.2206	2738278184.	9.0170	7429.	0.4022	134.	4.4272

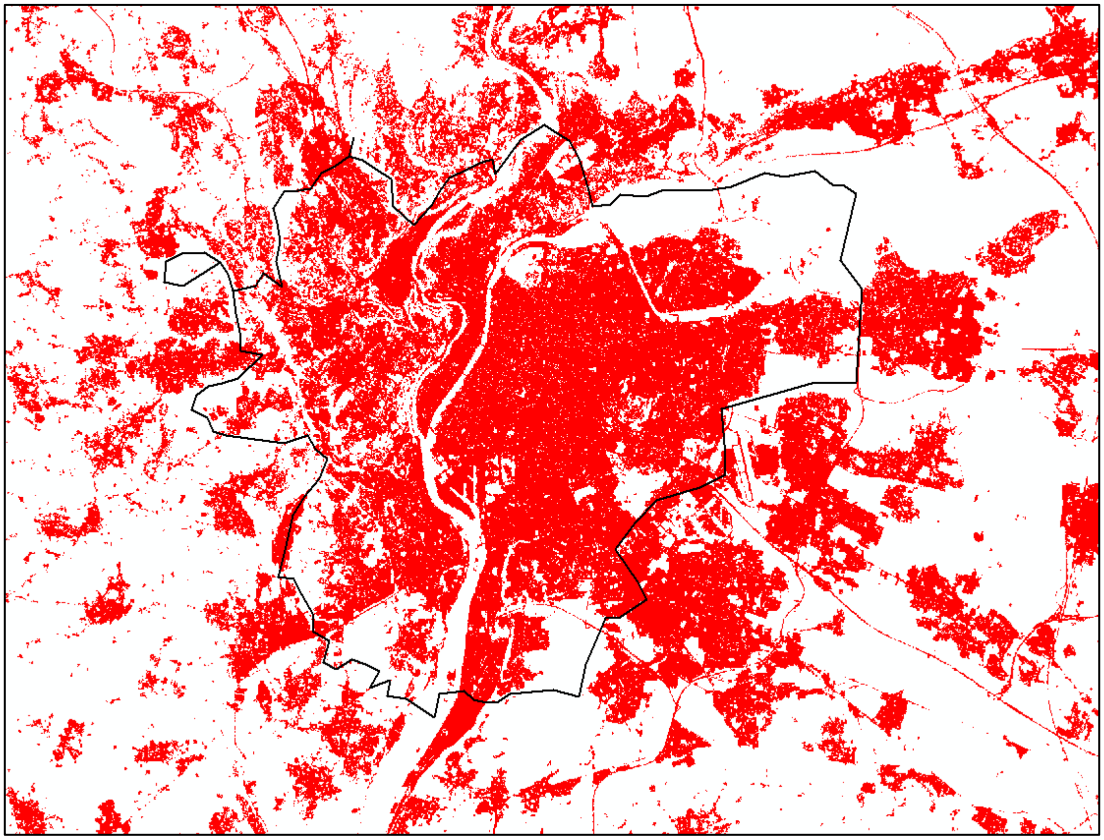
0 (0 out of 1 Selected)

Final_Result

Munster has a Green Policy consisting of three green rings and seven green corridors that act as a greenbelt for the city (Fig. 16). The Green Policy protects open spaces, leading to more compact forms of urban development and limiting urban sprawl.

WUP = 4.43 UPU/m²; *WSPC* = 3,120.52 UPU/(inhb. or job)

Example 11, Lyon: Area of built-up areas = 134 km^2 (in 2015), Area of reporting unit = 220 km^2 (City of Lyon), Number of inhabitants and jobs = 1,546,701 people and jobs; pixel size is 20 m x 20 m. Lyon does not have a greenbelt.



Table

Final_Result

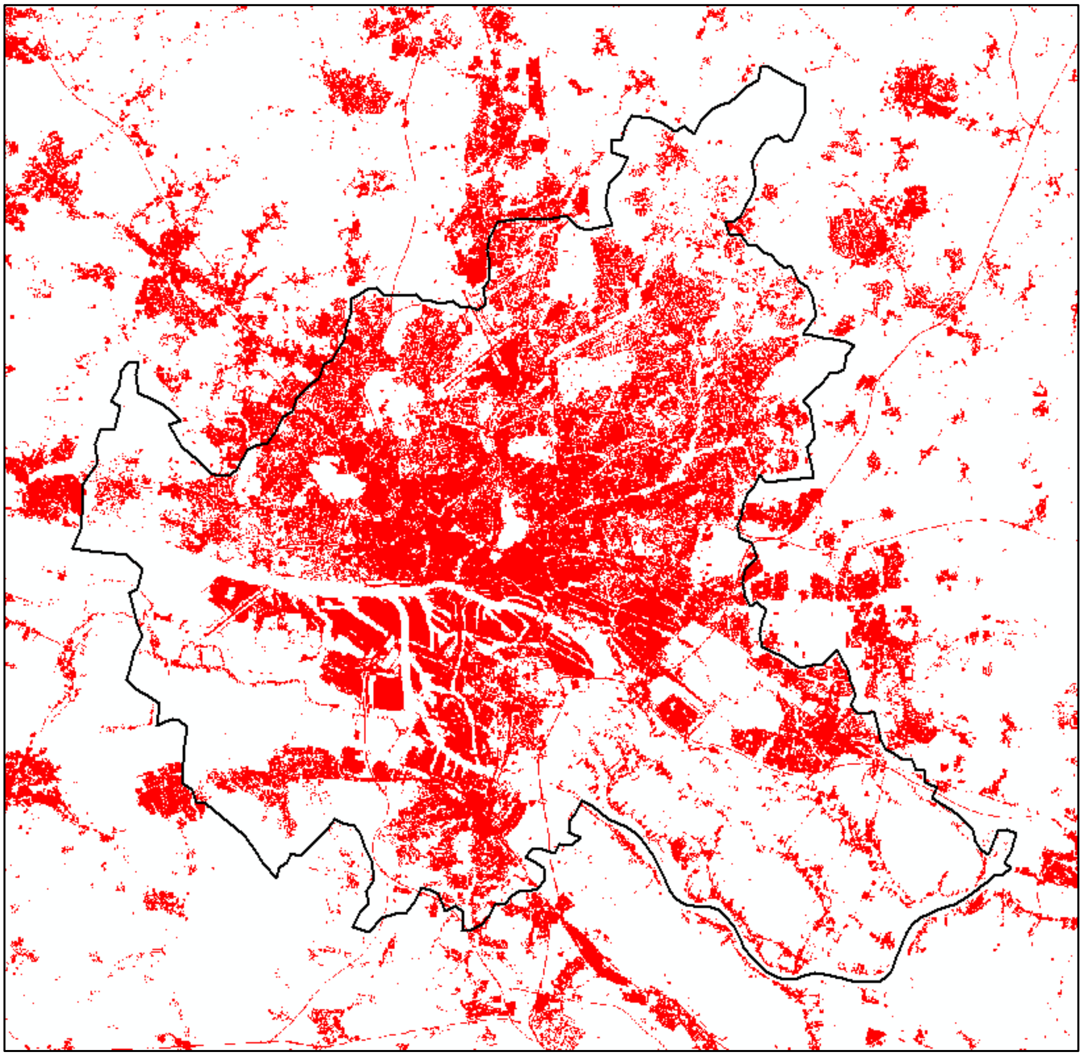
FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Lyon	FR	1	1546701	133645600	219778032.07	0.6080	49.1612	1.3204	6570190098.	29.8946	11573.	0.0503	86.4	1.9881

0 (0 out of 1 Selected)

Final_Result

WUP = 1.99 UPU/m^2; *WSPC* = 282.48 UPU/(inhb. or job)

Example 12, Hamburg: Area of built-up areas = 283 km² (in 2015), Area of reporting unit = 747 km² (City of Hamburg), Number of inhabitants and jobs = 2,561,708 people and jobs; pixel size is 20 m x 20 m. Hamburg does not have a greenbelt.



Table

Final_Result

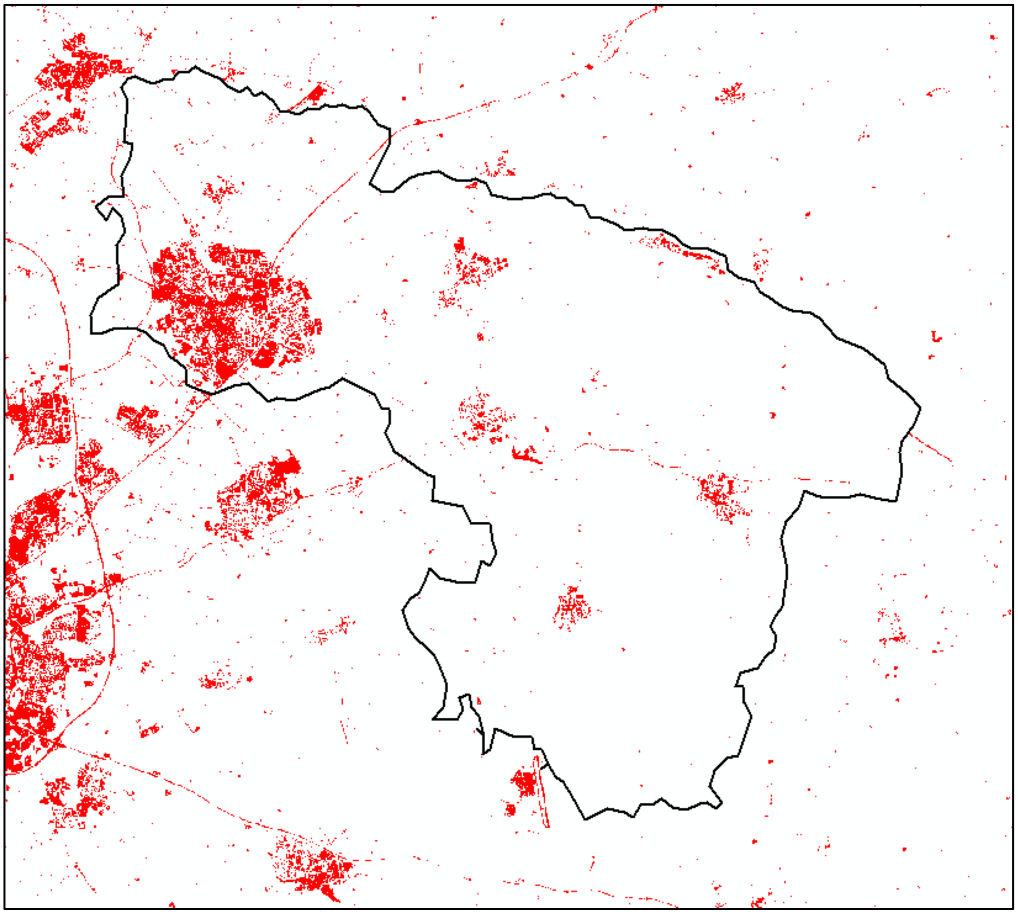
FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Hamburg	DE	1	2561708	283387200	747130046.3	0.379	48.7160	1.3003	13805505004.	18.4780	9039.	0.2004	110.	4.8167

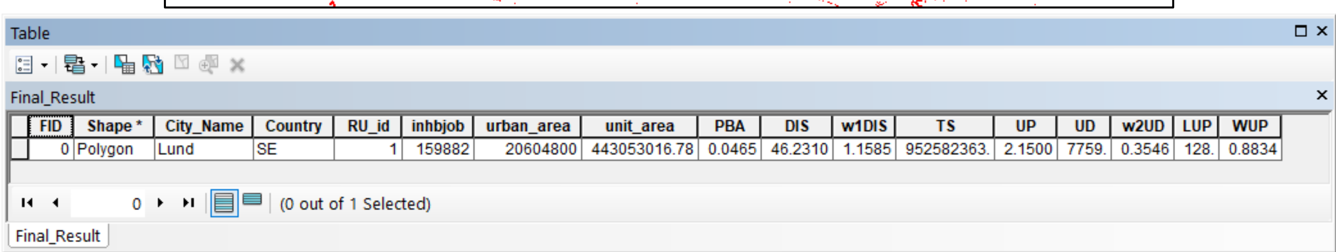
0 (0 out of 1 Selected)

Final_Result

WUP = 4.82 UPU/m²; *WSPC* = 1,404.8 UPU/(inhb. or job)

Example 13, Lund: Area of built-up areas = 21 km^2 (in 2015), Area of reporting unit = 443 km^2 (City of Lund), Number of inhabitants and jobs = 159,882 people and jobs; pixel size is 20 m x 20 m. Lund does not have a greenbelt.





Table

Final_Result

FID	Shape *	City_Name	Country	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	Lund	SE	1	159882	20604800	443053016.78	0.0465	46.2310	1.1585	952582363.	2.1500	7759.	0.3546	128.	0.8834

(0 out of 1 Selected)

Final_Result

WUP = 0.88 UPU/m^2; *WSPC* = 2,448.285 UPU/(inhb. or job)

Comparing a sample of 30 cities with greenbelt with 30 cities without greenbelt, Pourtaherian and Jaeger (2022) revealed that greenbelts were highly effective in mitigating urban sprawl. The proportion of cities in which sprawl decreased was significantly higher in the group of cities with greenbelts, with 90% of these cities experiencing a decrease, more than twice the proportion of cities without greenbelts. While some cities without greenbelts also saw a decrease in urban sprawl, the average relative decrease was much stronger in cities with greenbelts.

It is worth noting that the examples included in this User Manual do not capture the aforementioned difference between cities with and without greenbelts, since (a) a single point in time is presented here, and (b) only a few examples are provided that are not representative of cities with and without greenbelts more broadly.

6. Examples of using the USM Toolset for different planning scenarios

In this section, you find some theoretic as well as some realistic examples of landscapes in different urban design/planning scenarios and the results of applying the USM Toolset to these landscapes. While the data layers for the following examples are not provided with the tool, they serve as a demonstration of the versatility of the USM toolset in analyzing a wide range of scenarios.

Example 6.1: Area of built-up areas = 1.44 km² in scenarios a and b, 0.18 km² in scenario c. Area of reporting unit in scenarios a, b and c = 16 km² (a square of 4 km x 4 km). Pixel size is 15 m x 15 m.

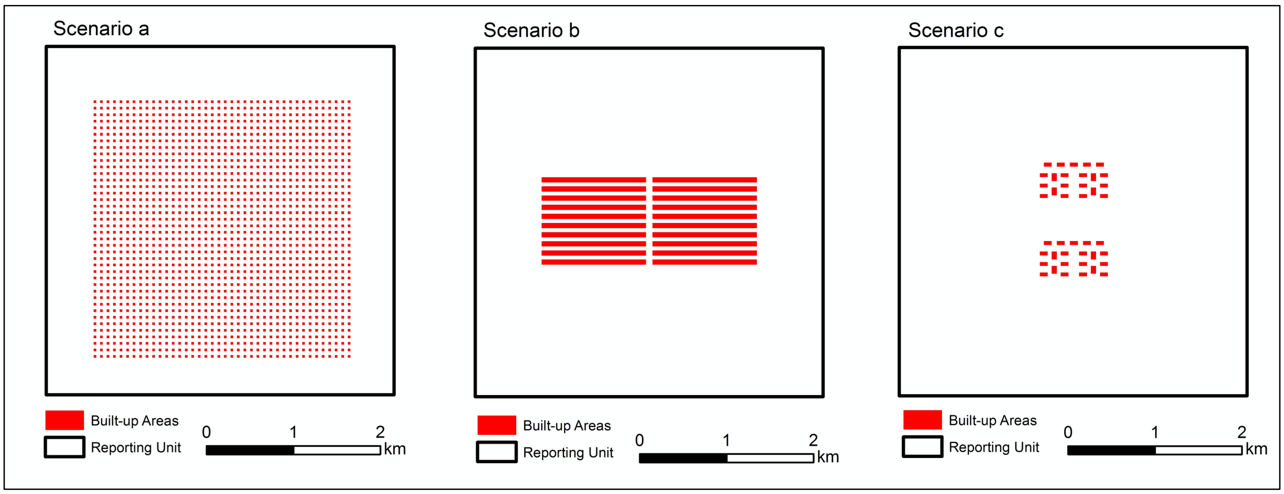


Fig. 17: Scenario a) single family houses, scenario b) attached row-houses and scenario c) condominium buildings.

In this example a landscape with the size of 16 km² is presented in three different configurations: scenario a) 1.44 km² of built-up areas (surface area) in the form of single family houses that represents 'dispersed development' (Fig. 17-a and Fig. 18-a), scenario b) 1.44 km² of built-up areas (surface area) in the form of attached row-houses (halfway between a condo and a single family detached home) that represents 'semi-compact development (Fig. 17-b and Fig. 18-b) and scenario c) 0.18 km² of built-up areas (surface area) in the form of multiple storey condominiums that represents 'compact development' (Fig. 17-c and Fig. 18-c).

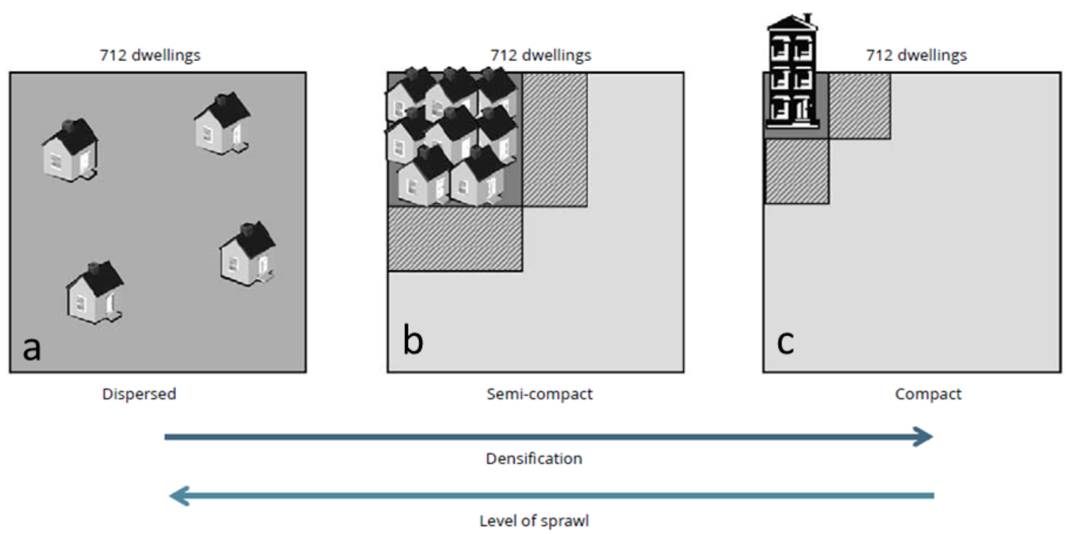


Fig. 18: a) single family houses (dispersed development), b) attached row-houses (semi-compact development) and c) condominium residential buildings (compact-development). Source: Modified from Gagné and Fahrig (2010).

Scenario a represents a dispersed landscape that includes 1600 dwellings in the form of single-family houses. In this scenario the size of each house is 900 m^2 (surface area) and the distance between houses from all sides is 45 meters. With *DIS* value of 46.46 UPU/m^2, *PBA* value of 0.09 and 300 meter of land uptake per person the *WUP* is 4.38 UPU/m^2 for this scenario (Tab. 2). The value of *WSPC* is 14,593.97 UPU/(inhb. or job).

Tab. 2: Metrics of sprawl for example 6.1, scenario a.

Table

Scenario_a

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	4800	1440000	16000000	0.09	46.4576	1.1734	6689894	4.18118	3333.3	0.89238	300	4.37819

1 (0 out of 1 Selected)

Scenario_a

Scenario b represents a semi-compact landscape which includes 1600 dwellings in the form of attached row-houses. In this scenario the size of each house is 900 m^2 (surface area). With dispersion value of 40.06 UPU/$m^{2,}$ *PBA* value of 0.09 and 300 meter of land uptake per person the *WUP* is 2.38 UPU/m^2 for this scenario (Tab. 3) and *WSPC* is 7923.7 UPU/(inhb. or job).

Tab. 3: Metrics of sprawl for example 6.1, scenario b.

Table

Scenario_b

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	4800	1440000	16000000	0.09	40.06248	0.73879	57689971.2	3.60562	3333.3	0.89238	300	2.37711

0 (0 out of 1 Selected)

Scenario_b

Scenario c represents a compact landscape that includes 1600 dwellings in the form of three storey condominiums. In this scenario there are 42 buildings. Each building includes 38 residential units with the average size of 370 m^2 (including public spaces) that are distributed on three floors. The minimum distance between buildings is 45 meters. With *DIS* value of 33.37 UPU/m^2, *PBA* value of 0.01and 37.7 meter of land uptake per person the *WUP* value is 0 UPU/m^2 and *WSPC* is 0 UPU/(inhb. or job) as well (indicating no sprawl) for this scenario (Tab. 4).

Tab. 4: Metrics of sprawl for example 6.1, scenario c.

Table

Scenario_c

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	4800	180900	16000000	0.01131	33.36615	0.54185	6035936.5	0.37725	2653	0.00001	37.7	0

0 (0 out of 1 Selected)

Scenario_c

This example shows how dispersion of built-up areas, density of inhabitants and proportion of built-up areas affect the value of sprawl in a landscape. The only difference between scenario a and b is the value of dispersion (46.46 UPU/m^2 in scenario a versus 40.06 UPU/m^2 in scenario b). This decrease of dispersion happened when attached row-houses in scenari0o b replaced single family houses in scenario a which in consequence resulted in decrease of urban sprawl by 46% (2.38 UPU/m^2 in scenario b versus 4.38 UPU/m^2 in scenario a).

Scenario c represents the least dispersed landscape that has the highest density/lowest value of land uptake per person and the smallest proportion of built-up areas (*PBA*). In this scenario, the three dimensions of sprawl: dispersion, proportion of built-up areas and land uptake per person were amended in a way that the value of urban sprawl decreased to 0 UPU/m^2 indicating that there is no sprawl in scenario c.

Example 6.2: Area of built-up areas = 23.04 km^2 in scenarios a, 11.52 km^2 in scenario b, and 15.36 km^2 in scenario c. Area of reporting unit in scenarios a, b and c = 36 km^2 (a square of 6 km x 6 km). Pixel size is 10 m x 10 m.

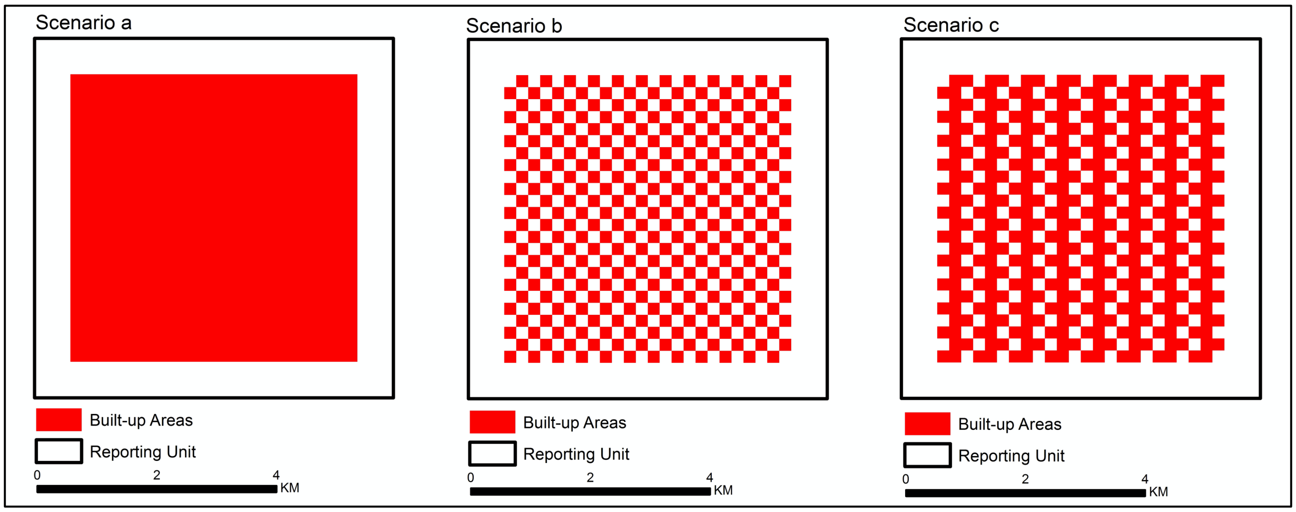


Fig. 19: Scenario a) landscape that includes one big patch of built-up area with the size of 23.04 km^2, scenario b) landscape that includes patches of built-up area with the total size of 11.52 km^2, and scenario c) landscape that includes patches of built-up areas with the otal size of 15.36 km^2.

In this example a landscape with the size of 36 km^2 is presented in three different configurations: scenario a) 23.04 km^2 of built-up areas in the form of a big patch of urban area with no open space or green area (Fig. 19-a), scenario b) 11.52 km^2 of built-up areas (Fig. 19-b) which includes one block of open space as for one block of built-up areas (half of the built-up areas in scenario a is now open space in scenario b) and scenario c) 15.36 km^2 of built-up areas (Fig. 19-c) which includes one block of open space as for two blocks of built-up areas (one-third of the built-up areas in scenario a is now open space in scenario c).

Scenario a represents a landscape that includes one big patch of built-up areas with the size of 23.04 km^2 that is in fact composed of a grid of 576 squares of 200 m * 200 m. The landscape in scenario a does not have any green areas or open spaces within the built-up areas (built-up areas only include network of local streets and big family houses). With 55,000 inhabitants and jobs, *DIS* value of 47.77 UPU/m^{2,} *PBA* value of 0.64 and 418.19 meter of land uptake per person the *WUP* is 35.9 UPU/m^2 in this scenario (Tab. 5).and the value of *WSPC* is 23,479.29 UPU/(inhb. or job).

Tab. 5: Metrics of sprawl for example 6.2, scenario a.

Scenario_a

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	55000	23040000	35999999.2676	0.64	47.77481	1.2524	1100731622.4	30.57588	2387.2	0.93675	418.9	35.87114

(0 out of 1 Selected)

In scenario b, the density increased by 50% (compare to scenario a). In fact, half of the built-up areas in scenario a turned into green open spaces/community gardens in scenario b, (inhabitants and jobs in scenario a and b = 55,000 people and jobs). In scenario b, there are 11.52 km^2 of built-up areas that are composed of 288 squares of 200 m * 200 m. With *DIS* value of 47.75 UPU/m^2, *PBA* value of 0.32 and 209.5 meter of land uptake per person the *WUP* is 14.8 UPU/m^2 for this scenario (Tab. 6). The value of *WSPC* is 9,686.32 UPU/(inhb. or job).

Tab. 6: Metrics of sprawl for example 6.2, scenario b.

Scenario_b

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	55000	11520000	35999999.2676	0.32	47.75054	1.25106	550086220.8	15.28017	4774.3	0.77413	209.5	14.79854

(0 out of 1 Selected)

In scenario c, the density increased by 33.3% (compare to scenario a). In fact, one-third of built-up areas in scenario a turned into green open spaces/community gardens in scenario c, (inhabitants and jobs in scenario a, b and c = 55,000 people and jobs). In scenario c, there are 15.26 km^2 of built-up areas that are composed of 384 squares of 200 m * 200 m. With the dispersion value of 47.76 UPU/m^2, *PBA* value of 0.43 and 279.3 meter of land uptake per person the *WUP* is 22.36 UPU/m^2 and the value of *WSPC* is 14,637.61 UPU/(inhb. or job) for this scenario (Tab. 7).

Tab. 7: Metrics of sprawl for example 6.2, scenario c.

Scenario_c

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	55000	15360000	35999999.2676	0.42667	47.75849	1.2515	733570406.4	20.37696	3580.7	0.87692	279.3	22.36301

(0 out of 1 Selected)

This example shows how density of inhabitants and jobs and proportion of built-up areas affect the value of sprawl in a landscape. Scenario b shows increasing the density of inhabitants and jobs and decreasing the proportion of built-up areas by 50% (compared to scenario a) results in decrease of sprawl by 59% (14.8 UPU/m^2 in scenario b versus 35.9 UPU/m^2 in scenario a). In scenario c, a more moderate increase of density occurred. With 33.3 % increase of density and 33% decrease of proportion of built-up areas, urban sprawl decreased by 38% (compare to scenario a).

Example 6.3: Area of built-up areas = 2.5 km^2 (in current scenario and scenario a) and 2.6 km^2 (in scenario b). Area of reporting unit = 3.8 km^2 (Nuns' Island, Montreal, Canada). Number of inhabitants and jobs = 22,373 people and jobs (in current scenario) and 23,373 people and jobs (in scenario a and b). Pixel size is 15 m x 15 m.

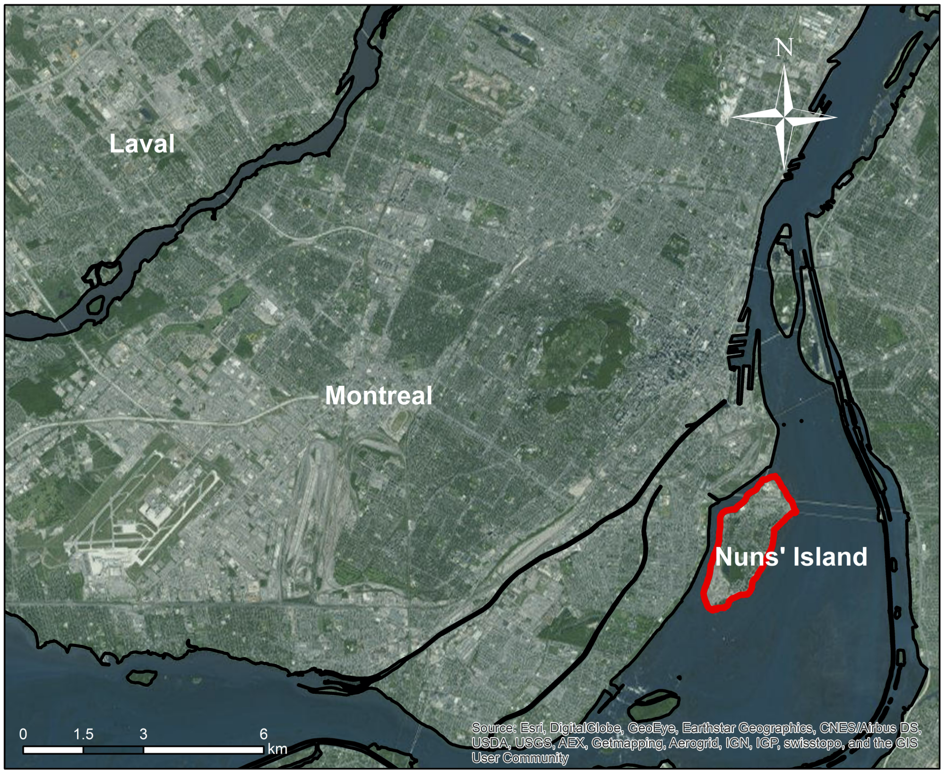


Fig. 20: Area of interest: Nuns' Island neighborhood, Montreal, Quebec, Canada.

This example compares the metrics of urban sprawl for the current scenario (actual physical situation) and two different future scenarios of urban development on Nuns' Island (Île des Sœurs in French) neighborhood located in the Saint Lawrence River, southeast of the Island of Montreal that forms a part of the city of Montreal in Quebec, Canada (Fig. 20). Nuns' island is part of the borough of Verdun and is primarily composed of residential apartments, condos, row houses and single family houses. This neighborhood is renowned for its parks and scenery including Domaine Saint-Paul natural woodland in the southern part of the island. This woodland is an important nesting area for different species of birds and is one of the last remaining natural woodlands in southern Montreal (Ville de Montréal, 2016).

In the current scenario there are 2.5 km^2 of built-up areas and 22,373 inhabitants and jobs in a landscape with the size of 3.8 km^2 (Nuns' Island neighborhood) (Fig. 21). With dispersion value of 46.87 UPU/m^2, *PBA* value of 0.65 and 110.6 meter of land uptake per person, the *WUP* is 7.34 UPU/m^2 and *WSPC* is 1,244.66 UPU/(inhb. or job) for the current scenario (Tab. 8).

Tab. 8: Metrics of sprawl for example 6.3, current scenario.

Table

Scenario_Current

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	22373	2474100	3793661.37136	0.65217	46.87395	1.19977	115970839.7	30.56963	9042.9	0.20014	110.6	7.34037

0 (0 out of 1 Selected)

Scenario_Current

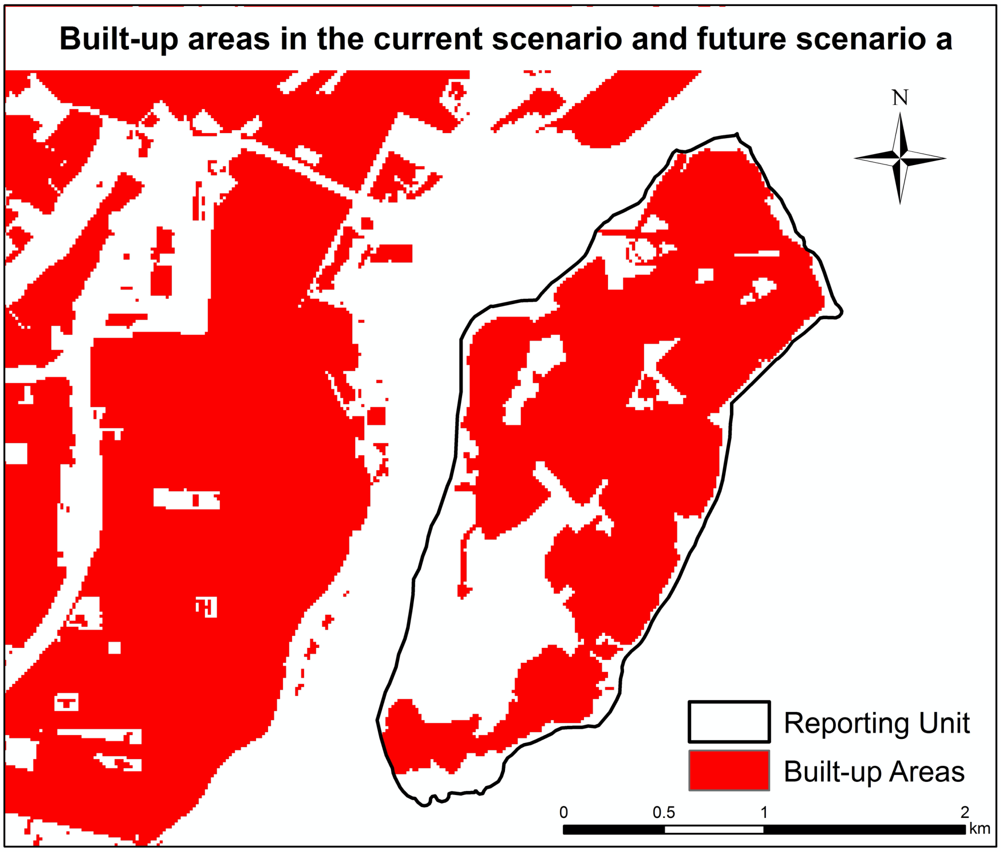


Fig. 21: Built-up areas in the current scenario and future scenario a.

In future scenario a, there are 2.5 km^2 of built-up areas and 23,373 inhabitants and jobs in a landscape with the size of 3.8 km^2 (Nuns' Island neighborhood) (Fig. 21). In this scenario, it is assumed that number of inhabitants and jobs increased to 23,373 (1000 more inhabitants and jobs compare to current situation) while the total amount of built-up areas remained the same (2.5 km^2). In fact, densification in this scenario occurred through infilling of the already built/developed areas by using the wasted lands and open parking lots. With *DIS* value of 46.87 UPU/m^2, *PBA* value of 0.65 and 105.9 meter of land uptake per person the *WUP* value for future scenario a is 5.99 UPU/m^2 (Tab. 9). The value of *WSPC* is 1,016.1 UPU/(inhb. or job).

Tab. 9: Metrics of sprawl for example 6.3, future scenario a.

Table

Scenario_a

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	23373	2474100	3793661.37136	0.65217	46.87395	1.19977	115970839.7	30.56963	9447.1	0.16339	105.9	5.99239

(0 out of 1 Selected)

Scenario_a

In future scenario b, there are 2.6 km^2 of built-up areas and 23,373 inhabitants and jobs in a landscape with the size of 3.8 km^2 (Nuns' Island neighborhood) (Fig. 22). In this scenario, it is assumed that number of inhabitants and jobs increased to 23,373 (1000 more inhabitants and jobs compare to current situation) while a total of 150,000 m^2 of built-up areas were added to the current/already existing built-up areas. In fact, in future scenario b, instead of infilling, new inhabitants and jobs are located in the newly developed lands. With *DIS* value of 47.02 UPU/m^2, *PBA* value of 0.69 and 112.3 meter of land uptake per person the *WUP* value for future scenario b is 8.41 UPU/m^2 (Tab. 10) and the *WSPC* value is 1,425.35 UPU/(inhb. or job).

Tab. 10: Metrics of sprawl for example 6.3, future scenario b.

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	23373	2624175	3793661.37136	0.69173	47.01912	1.20867	123386399.2	32.52436	8906.8	0.21383	112.3	8.40598

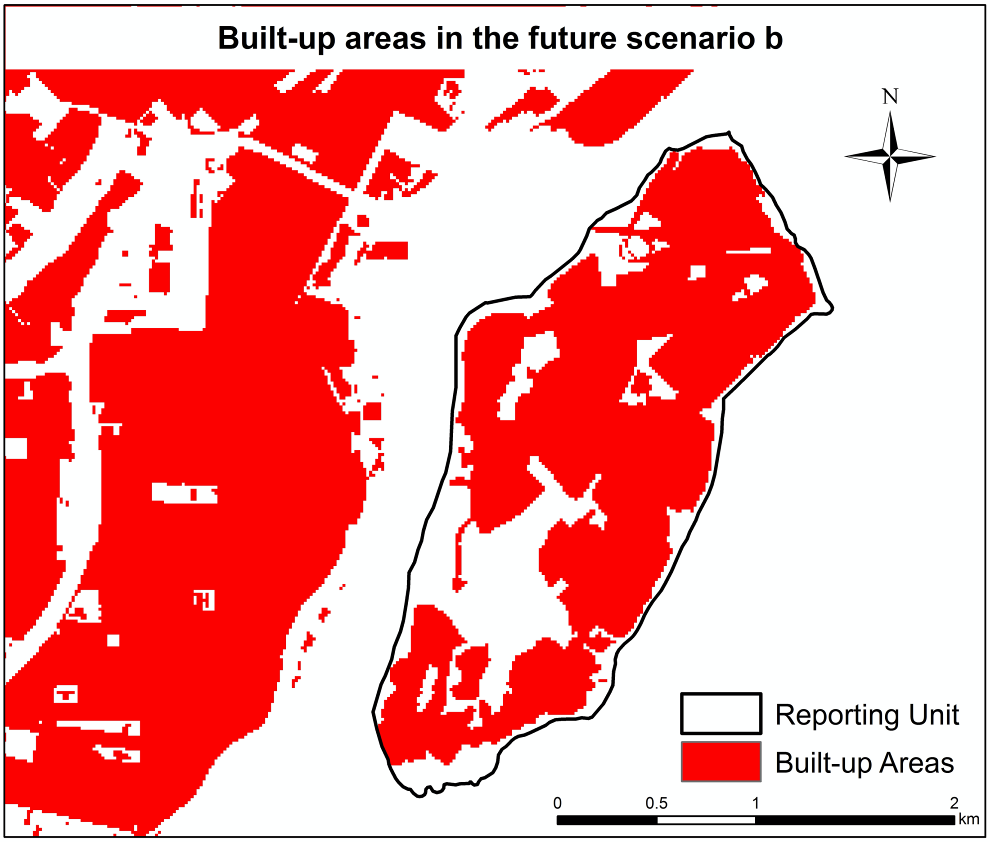


Fig. 22: Built-up areas in the future scenario b.

This example shows how increasing the density through infilling the *already existing* urbanised areas can positively affect decreasing the value of sprawl in a landscape. In future scenario a, number of inhabitants and jobs increased by 1000 more people and jobs while no new built-up area were added to current situation. For this reason, in the future scenario a; urban sprawl decreased by 18% (5.99 UPU/m^2 in future scenario a versus 7.34 UPU/m^2 in the current scenario). In contrast, proportion of built-up areas, dispersion and land uptake per person were all increased in future scenario b. In consequence, level of urban sprawl increased by 15% (8.41 UPU/m^2 in future scenario b versus 7.34 UPU/m^2 in current situation).

Example 6.4: Area of built-up areas = 29.7 km² (both in the current and future scenarios). Area of reporting unit = 48.1 km² (municipality of Brossard, Montreal Census Metropolitan Area, Canada). Number of inhabitants and jobs = 102,561 people and jobs (in the current scenario) and 127,561 people and jobs (in the future scenario). Pixel size is 15 m x 15 m.

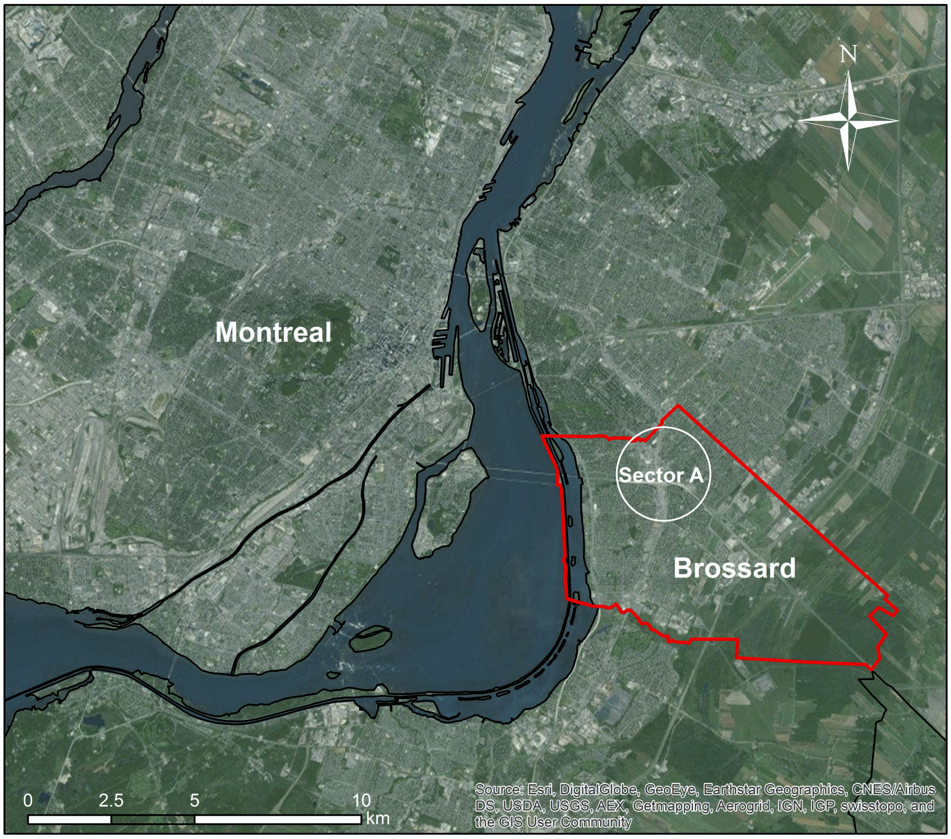


Fig. 23: Area of interest: municipality of Brossard, Montreal Census Metropolitan Area, Quebec, Canada.

This example compares the metrics of urban sprawl for the current scenario (actual physical situation) and a future scenario which is a Transit Oriented Development (TOD) in the sector A of municipality of Brossard located in the South Shore of Montreal, Quebec, Canada (Fig. 23). Brossard is known for being a car-oriented suburb. However, the high-profile construction of a major transit infrastructure on the South Shore has the potential to encourage inhabitants of Brossard to choose public transit over their cars.

In current scenario there are 29.7 km² of built-up areas and 102,561 inhabitants and jobs in a landscape with the size of 48.1 km² (municipality of Brossard) (Fig. 24). With *DIS* value of 49.07 UPU/m², *PBA* value of 0.62 and 289.2 meter of land uptake per person the *WUP* is 35.26 UPU/m² for the current scenario (Tab. 11) and the value of *WSPC* is 16,531.23 UPU/(inhb. or job).

Tab. 11: Metrics of sprawl for example 6.4, current scenario.

Table

Scenario_Current

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	102561	29657250	48082875.6153	0.61679	49.07326	1.31664	1455377940.1	30.26811	3458.2	0.8848	289.2	35.26119

0 (0 out of 1 Selected)

Scenario_Current

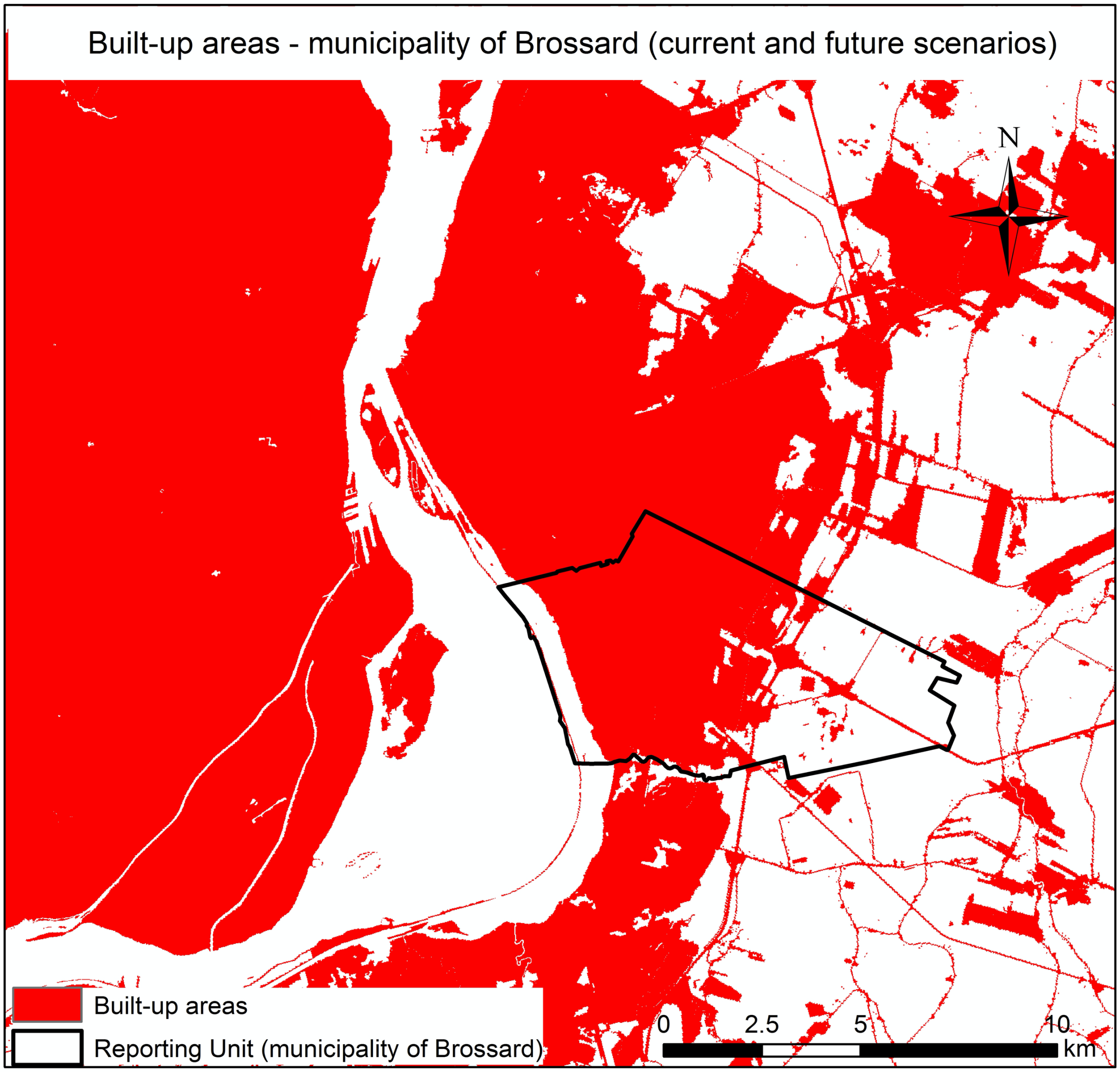


Fig. 24: Built-up areas in current and future scenarios, municipality of Brossard, Quebec, Canada. Source: Statistics Canada, built-up areas, Montréal census metropolitan area (CMA), 2011.

In the current scenario, most of the land in Sector A is covered by a big shopping mall and multiple big parking lots and vast concrete surfaces which cause heat island effect (Fig. 25 and 26-a). Currently, sector A is undergoing a transformation that involves the densification of an old neighborhood due to its accessibility to transit and low housing prices. This transformation will inevitably accelerate with long-awaited Light Rail Transit (LRT) line that will connect Sector A to Downtown Montreal.

Future scenario is a proposed densification in the form of Transit Oriented Development in Brossard's Sector A. The proposed urban development in this scenario sees Sector A as the City Center for Brossard with different entertainment and commercial amenities in a dense urban setting (Fig. 26-b). The future scenario, proposes 9000 new residential units, 133,000 m^2 institutional area and 424,000 m^2 commercial area. Therefore, it is estimated that the new proposed plan can accommodate 25,000 new inhabitants and jobs (9000 * 2.5 (average household size) = 22,500 people + 2,500 new jobs). This proposed plan was developed by Nadia El Dabee, Brett Hudson, Yue Yue Zou and Ashley Prudencio Macaraeg (the students of advanced urban design laboratory) under supervision of Dr. Pierre Gauthier at Concordia University.

Fig. 25: Current situation of built-up areas in the selected TOD site. Source: Google Earth, imagery date: 2013.

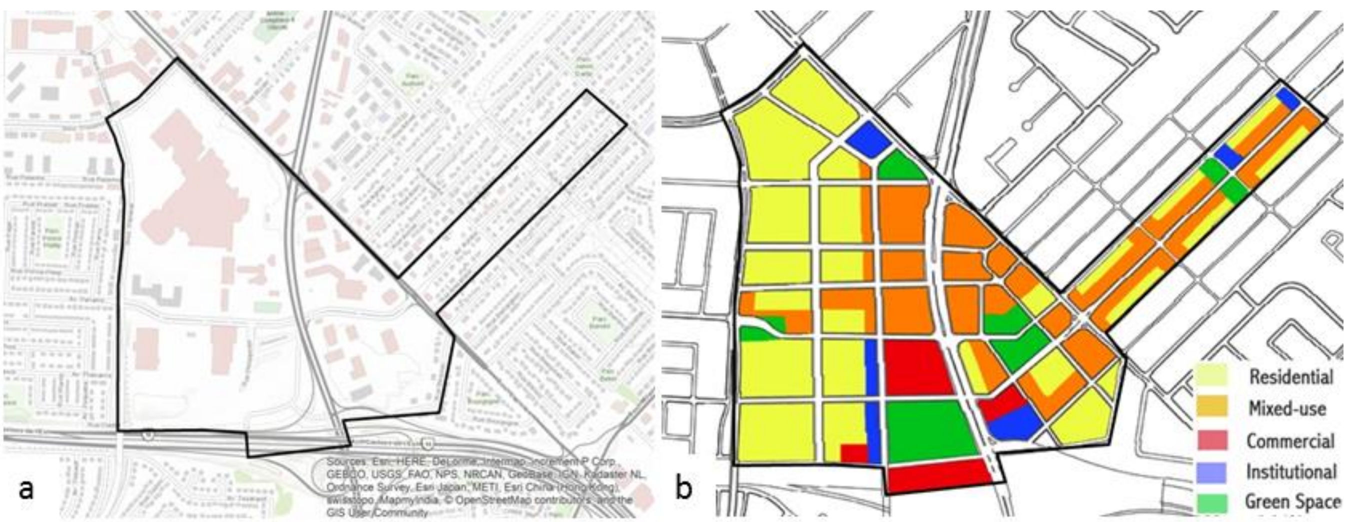


Fig. 26: a) current situation of built-up areas in the selected TOD site (current scenario); b) proposed plan for densification in the selected TOD site (future scenario). Source: a) own map based on ESRI, ArcGIS Online Basemap; b) El Dabee et al. (2015).

In future scenario, there are 29.7 km^2 of built-up areas (same as current scenario), 127,561 inhabitants and jobs (25,000 more people and jobs compare to current scenario) in a landscape with the size of 48.1 km^2 (municipality of Brossard) (Fig. 24). With *DIS* value of 49.07 UPU/m^2, *PBA* value of 0.62 and 232.5 meter of land uptake per person the *WUP* value for future scenario is 32.71 UPU/m^2 (Tab. 12). The value of *WSPC* is 12,330.1 UPU/(inhb. or job).

Tab. 12: Metrics of sprawl for example 6.4, future scenario.

Table

Scenario_Future

FID	Shape *	RU_id	InhbJob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	127561	29657250	48082875.6153	0.61679	49.07326	1.31664	1455377940.1	30.26811	4301.2	0.82081	232.5	32.71095

(0 out of 1 Selected)

Scenario_Future

Similar to example 6.3, future scenario a, this example shows how increasing the density through infilling the *already existing* urbanised areas can positively affect decreasing the value of urban sprawl in a landscape. In the proposed densified scenario, number of inhabitants and jobs increased to 127,561 people and jobs while adding new built-up areas to the current situation was avoided. This resulted in decrease of urban sprawl by 7% (32.71 UPU/m^2 in future scenario versus 35.26 UPU/m^2 in current scenario) in the municipality of Brossard with the size of 48.1 km^2.

Example 6.5: Area of built-up areas = 1.7 km^2 (both in the current and future scenarios). Area of reporting unit = 1.7 km^2 (Cartierville neighborhood, Montreal, Canada). Number of inhabitants and jobs = 8,370 people and jobs (in the current scenario) and 11,250 people and jobs (in future scenario). Pixel size is 15 m x 15 m.

Fig. 27: Area of interest: Cartierville neighborhood, Montreal, Quebec, Canada.

This example compares the metrics of urban sprawl for the current scenario (actual physical situation) and a future scenario for the redevelopment of disinvested sector in the neighborhood of Cartierville located in the borough of Ahuntsic-Cartierville on the Island of Montreal (Fig. 27). Developed around late 20th century, Cartierville has many underused spaces. In this example, the future scenario, proposes series of linked interventions surrounded by residential, commercial, and mixed-use developments which at the same time helps reducing the level of urban sprawl in the Cartierville neighborhood.

In the current scenario, there are 1.7 km^2 of built-up areas (Fig. 28) and 8,370 inhabitants and jobs. With dispersion value of 49.17 UPU/m^2, proportion of built-up areas of 1 (100% of the reporting unit is covered by built-up areas) and 139.2 meter of land uptake per person the *WUP* value for the current scenario is 28.49 UPU/m^2 (Tab. 13) and the value of *WSPC* is 3,967.27 UPU/(inhb. or job).

Tab. 13: Metrics of sprawl for example 6.5-current scenario.

Table

Scenario_Current

FID	Shape *	Est_InhbJo	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	8370	1	1165050	1165501.94767	0.99961	49.16971	1.32085	57285170.6	49.15064	7184.2	0.43885	139.2	28.49076

(0 out of 1 Selected)

Scenario_Current

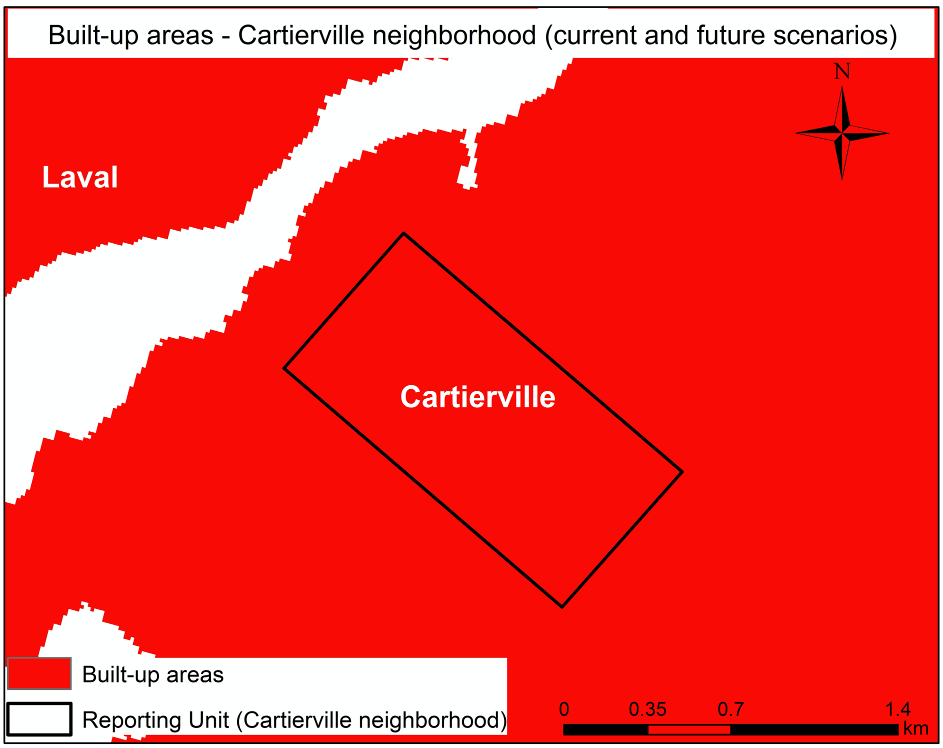


Fig. 28: Built-up areas in current and future scenarios, Cartierville neighborhood, Montreal, Quebec, Canada. Source: Statistics Canada, built-up areas, Montréal census metropolitan area (CMA), 2011.

The selected site is located along the corridor of Boulevard Laurentien (National Route 117), which is the main thoroughfare in the neighbourhood and major artery connecting the islands of Montréal and Laval (largest suburb of Montreal) (Fig. 29 and 30-a).

Future scenario is a proposed densification in the Western part of the Cartierville neighborhood that includes medium and high density residential, commercial, and mixed-use developments. This proposed plan was initially developed by Mary Sprague, Sarah Chinerman and Patrick Aouad (the students of urban design laboratory) under supervision of Dr. Pierre Gauthier at Concordia University (Fig. 30-b).

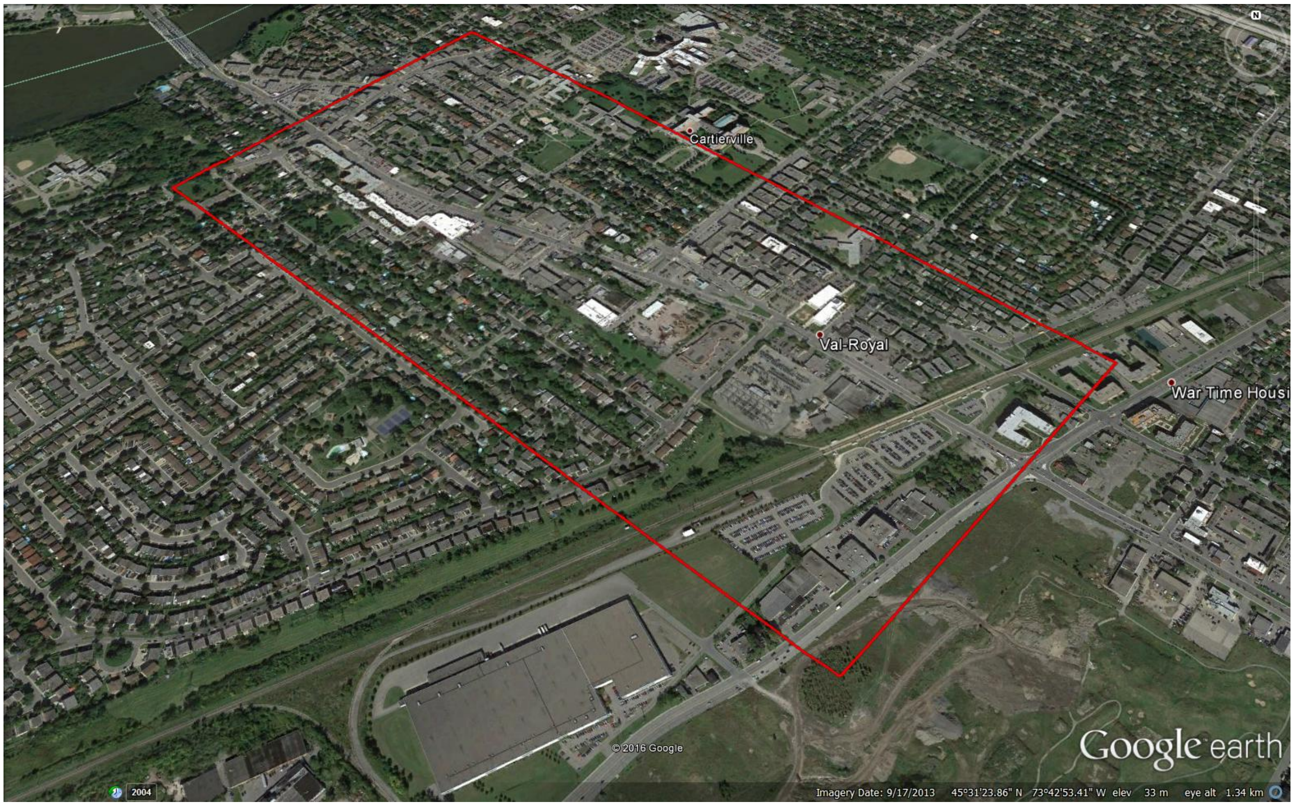


Fig. 29: Current situation of built-up areas in the selected site. Source: Google Earth, imagery date: 2013.

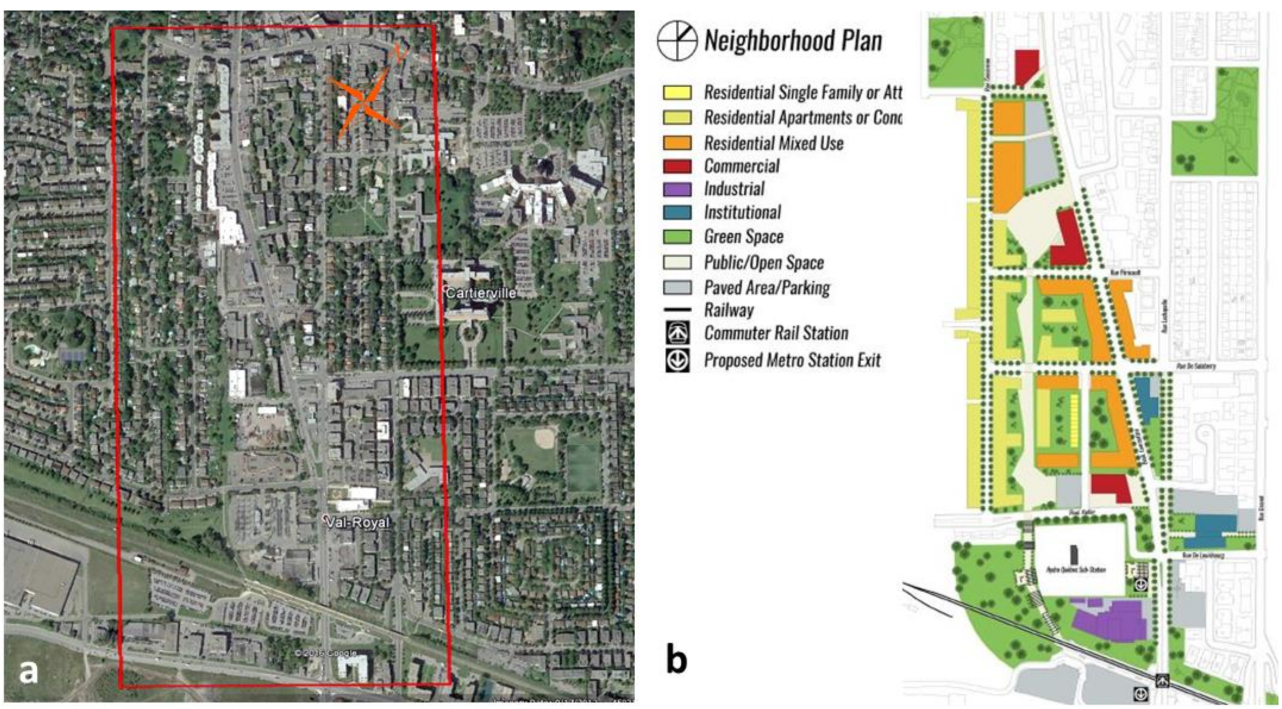


Fig. 30: a) current situation of built-up areas in the selected site (current scenario). b) proposed plan for densification in the selected site (future scenario). Source: a) own map-based Google Earth (imagery date: 2013), b) Sprauge et al. (2016)

In the future scenario, there are 1.7 km^2 of built-up areas (same as current scenario) (Fig. 28) and 11,250 inhabitants and jobs (2,880 more people and jobs compare to current scenario). With *DIS* value of 49.17 UPU/m^2, *PBA* value of 1 (100% of the reporting unit is covered by built-up areas) and 103.6 meter of land uptake per person the *WUP* value for future scenario is 9.52 UPU/m^2 (Tab. 14). The value of *WSPC* is 986.05 UPU/(inhb. or job).

Tab. 14: Metrics of sprawl for example 6.5, future scenario.

FID	Shape *	Est_InhbJo	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	11250	1	1165050	1165501.94767	0.99961	49.16971	1.32085	57285170.6	49.15064	9656.2	0.14661	103.6	9.51789

Similar to examples shown above, this example shows how land utilization affects the degree of urban sprawl in a landscape. In this example in the proposed densified scenario, number of inhabitants and jobs increased by only 2,880 more people and jobs (compared to current scenario). This resulted in decrease of urban sprawl by 67% (28.49 UPU/m^2 in future scenario versus 9.52 UPU/m^2 in current situation) in the selected site in the neighborhood of Cartierville with the size of 1.7 km^2.

We wish you good success with your own urban sprawl analysis!

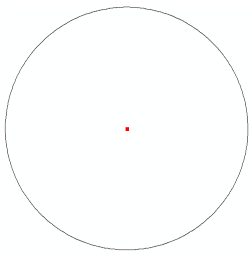
Acknowledgements

We thank Michael Wenzlaff and Beat Trachsler for their generous programming support. Michael Wenzlaff programmed the original URSMEC tool (that was used and explained in Jaeger et al. 2008). We also cordially thank Dr. Zachary Patterson for his help with job data and Dr. Pierre Gauthier for his great help in the selection of the examples of densification in Canada. We thank the Swiss Federal Office for the Environment (FOEN, contract no. 06.0111.PZ/M132-2143) and the European Environment Agency (EEA) for their financial support for our project "Urban sprawl in Europe" (Hennig et al. 2015; EEA & FOEN 2016). The development of the USM Toolset has also partly been supported through the project “Controlling urban sprawl – limiting soil consumption” in the context of the Swiss National Research Programme NRP 68 “Soil as a Resource”. In addition, some earlier parts of the work leading to the USM Toolset were funded by the following institutions and foundations: Swiss Federal Institute for Forest, Snow and Landscape Research WSL (Birmensdorf, Switzerland), Paul Schiller Foundation (Lachen, Switzerland), Sophie and Carl Binding Foundation (Basel, Switzerland) and the Bristol Foundation - Ruth und Herbert Uhl-Forschungsstelle für Natur- und Umweltschutz (Schaan, Principality of Liechtenstein).

Appendix A: A few more examples

The following examples serve as additional illustrations of the use of the USM toolset and the interpretation of the results. They include three simple hypothetical model landscapes (A.1a – A.1c) and two real urban landscapes (A.2 and A.3).

Example A.1a: Area of built-up areas = 900 m^2 (4 pixels size of 15 m x 15 m), Area of reporting unit = 3.14 km^2, Number of inhabitants and jobs = 5 people and jobs.



Table

Final_Result

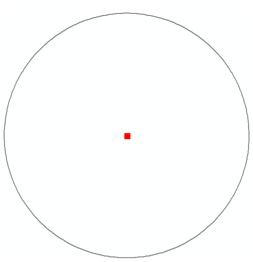
FID	Shape *	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	5	1	900	3141176.98082	0.00029	4.42161	0.50001	3979.4	0.00127	5555.6	0.67977	180	0.00043

0 (0 out of 1 Selected)

Final_Result

This example is very similar to example 5 in the main text above with the exception of the number of pixels. In example 5, one patch of built-up area with the area of 900 m^2 is represented by one pixel size of 30 m x 30 m. However, in this example, the same amount of built-up area is represented in a raster file that consists of 4 pixels size of 15 m x 15 m. When the size of the pixels is smaller, the value of Dispersion is slightly smaller because the value of *DIS* is approximated by the distances between the four pixels (using the distances between the centres of the pixels rather than the distances between all possible pairs of points within each pixel, whereas for each pixel the within-pixel value was calculated for the integral using Mathematica, see Jaeger et al. (2010: Tab. 1), which results in a slightly lower value of *WUP*.

Example A.1b: Area of built-up areas = 2500 m^2 (4 pixels size of 25 m x 25 m), Area of reporting unit = 3.14 km^2, Number of inhabitants and jobs = 5 people and jobs.



Table

Final_Result

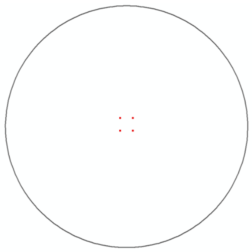
FID	Shape *	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	14	1	2500	3141176.98082	0.0008	5.94874	0.50001	14871.9	0.00473	560	0.67382	178.6	0.00159

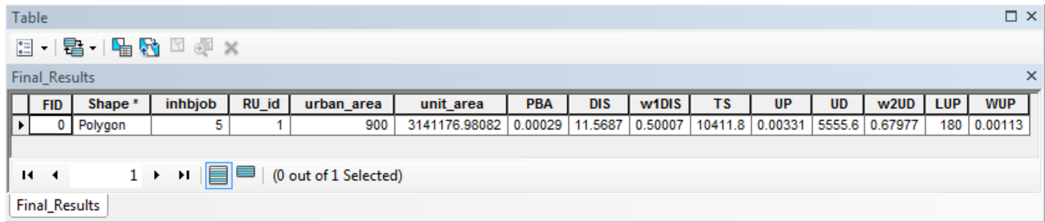
0 (0 out of 1 Selected)

Final_Result

This example is very similar to example 6 in the main text above with the exception of the number of pixels. In example 6, 2500 m^2 of built-up areas were presented by one pixel of 50 m x 50 m. However, in this example the same amount of built-up area is presented in a raster file that consists of 4 pixels size of 25 m x 25 m. When the size of the pixels are smaller the value of Dispersion is slightly smaller for the same reason as mentioned above.

Example A.1c: Area of built-up areas = 900 m² (4 pixels size of 15 m x 15 m), Area of reporting unit = 3.14 km², Number of inhabitants and jobs = 5 people and jobs.





Table

Final_Results

FID	Shape *	inhbjob	RU_id	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	5	1	900	3141176.98082	0.00029	11.5687	0.50007	10411.8	0.00331	5555.6	0.67977	180	0.00113

1 (0 out of 1 Selected)

Final_Results

This example should be compared with example A.1a. In example A.1a, 900 m² of built-up area are presented in 4 pixels size of 15 m x 15 m that are distributed in the most compact way (side by side without any distance/empty space between them) in the landscape. In contrast, in this example, the four pixels (size of 15 m x 15 m) are located at a certain distance between them (90 m from edge to edge, or 105 m between the centers of the pixels). This theoretic example shows that the metric of Dispersion depends very much on the relative spatial arrangement of the built-up areas in the landscape. The value of *DIS* in this example is 11.57 UPU/m², whereas in example A.1a, the *DIS* value is 4.42 UPU/m². Accordingly, *WUP* in this example is 0.00113 UPU/m², which is also higher than *WUP* in example A.1a.

It is very useful to compare this value with a calculation done by hand because this procedure illustrates the use of the formulas by the tool. The most convenient way of calculating *DIS* is based on the S_i values (for each cell i, i = 1, 2, 3, ... to n), according to the following formulas (Jaeger et al. 2010b: 429-431 and 437-438):

$$S_i = \frac{1}{n_i}\left(\sum_{k=1}^{n_i}\left(\sqrt{\frac{2 \cdot d_{ik}}{1\,\text{m}} + 1} - 1\right) + WCC(b)\right),$$

where n_i is the number of built-up cells within the *HP* of cell i, including the cell i itself, d_{ik} is the distance between (the centers of) cell i and cell j, and $WCC(b)$ is the within-cell contribution to the value of *DIS* (and to the other metrics), and b is the cell width (in m). For example, when there is only cell i and no other cell within its *HP*, then $n_i = 1$ and $S_i = WCC(b)$ (since $d_{ik} = 0$). For any chosen reporting unit, *DIS* can then be calculated based on the Si values of the cells located within the reporting unit:

$$DIS(b) = \frac{1}{n}\sum_{i=1}^{n} S_i \frac{\text{UPU}}{\text{m}^2},$$

where n is the total number of built-up cells in the reporting unit. In example A.1c, this results in:

$n_i = 4$ and $n = 4$,

WCC(for 15 m x 15 m cell) = 2.961,

$S_i = 0.25 \cdot (2 \cdot (\sqrt{(2 \cdot 105 + 1)} - 1) + (\sqrt{(2 \cdot \sqrt{2} \cdot 105 + 1)} - 1) + 2.961)$

$= 0.25 \cdot (2 \cdot 13.5258 + 16.2622 + 2.961)$

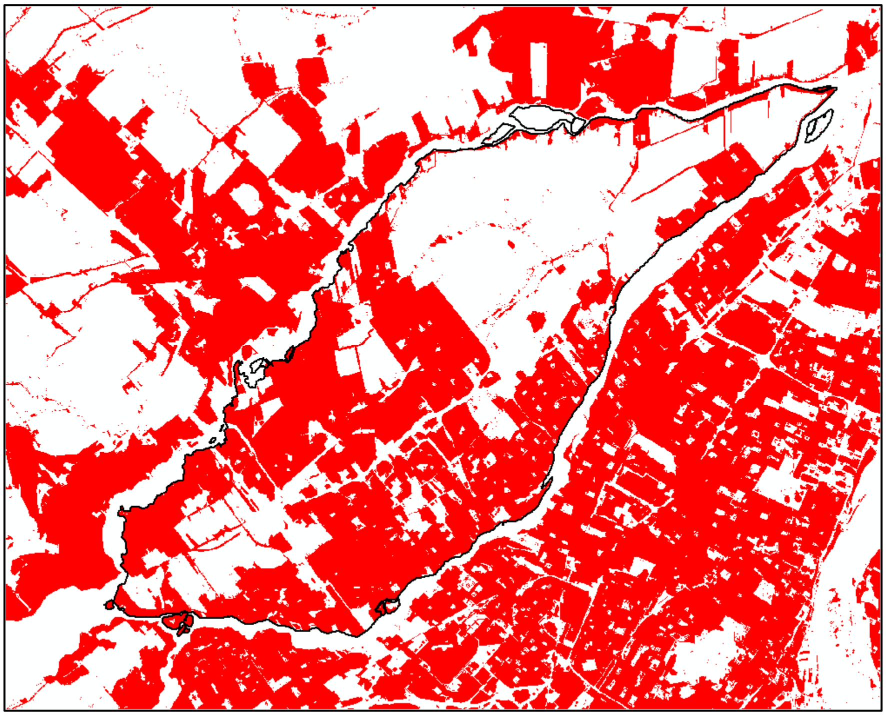
$= 0.25 \cdot 46.275 = 11.5687$, and

$DIS = 0.25 \cdot (4 \cdot 11.5687)$ UPU/m² = 11.5687 UPU/m².

Accordingly, $UP = PBA \cdot DIS$ = 0.0002865 · 11.5687 UPU/m² = 0.00331 UPU/m². This corresponds to the values of *DIS* and *UP* provided by the USM Toolset.

A similar calculation can be done for example A.1a, using a distance of 15 m between the centers of the cells.

Example A.2: Area of built-up areas = 123,911,325 m² (in 2011), Area of reporting unit = 246.6 km² (City of Laval, Quebec, Canada), Number of inhabitants and jobs = 510,319 people and jobs; pixel size is 15 m x 15 m (see detailed information in Nazarnia et al. 2016).



Table

Final_Result

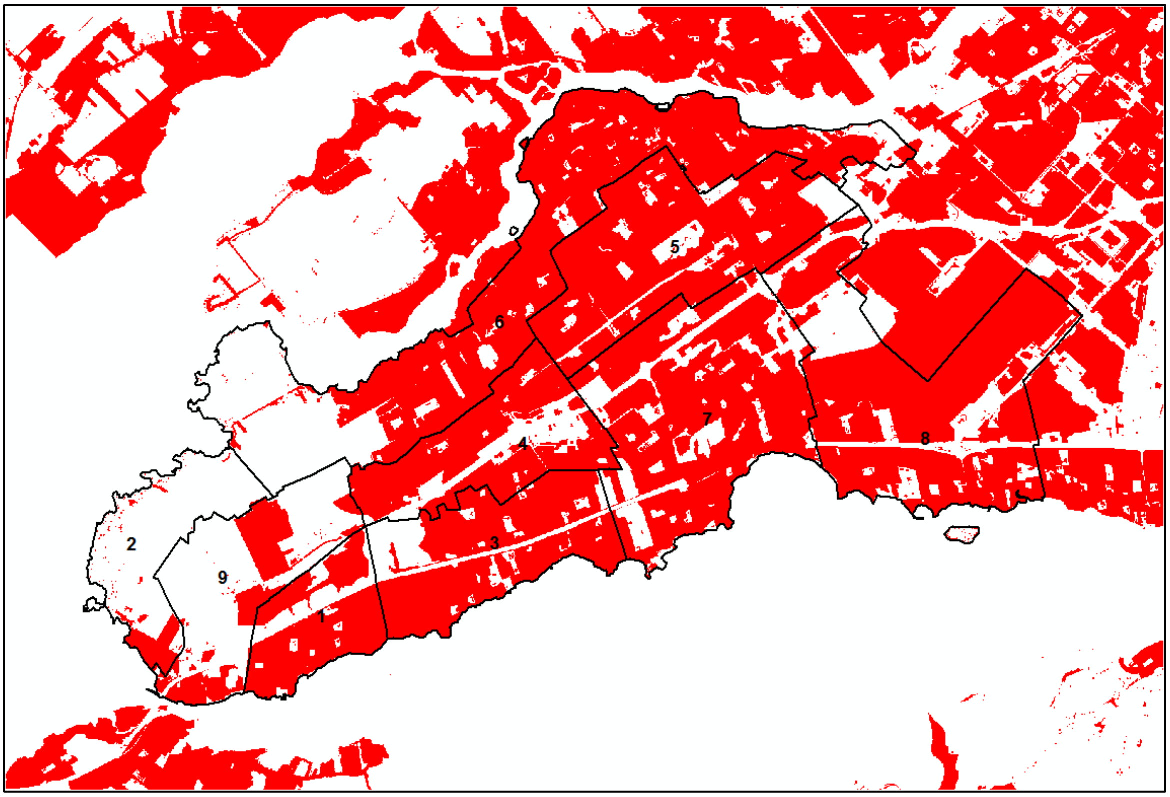
FID	Shape *	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	13	510319	123911325	246576180.353	0.50253	48.93506	1.31047	6063608123.6	24.59122	4118.4	0.8367	242.8	26.96361

0 (0 out of 1 Selected)

Final_Result

Laval is the third largest municipality in the province of Quebec in Canada and the largest suburb of Montreal and one of the highly sprawled urban areas in the Montreal Census Metropolitan Area. This city is geographically separated from the Island of Montreal by the Prairies River. Most of the built-up areas in Laval are located in the centre of the island and along the shore. The value of *WSPC* is 13,028.29 UPU/(inhb. or job).

Example A.3: Municipalities located in the west of the Urban Agglomeration of Montreal, Quebec, Canada (western tip of the Island of Montreal). For details on the size of the built-up areas, size of the reporting units, and the number of inhabitants and jobs for each reporting unit, please refer to the table of results (and to Nazarnia et al. 2016). Pixel size is 15 m x 15 m.



Table

Final_Result

FID	Shape *	RU_id	inhbjob	urban_area	unit_area	PBA	DIS	w1DIS	TS	UP	UD	w2UD	LUP	WUP
0	Polygon	1	7830	4691475	6023310.02257	0.77889	47.64633	1.24528	223531566	37.11108	1669	0.95834	599.2	44.28855
1	Polygon	2	2624	859050	7479575.71446	0.11485	46.97876	1.20621	40357103.8	5.39564	3054.5	0.90773	327.4	5.90775
2	Polygon	3	22468	8658225	11003211.1413	0.78688	48.08244	1.26888	416308584.1	37.83519	2595	0.92877	385.4	44.58873
3	Polygon	4	29528	7415100	9640900.83134	0.76913	49.45066	1.3327	366681589	38.03396	3982.1	0.8478	251.1	42.97321
4	Polygon	5	58406	12785175	15198595.1734	0.84121	49.24913	1.32427	629658745.6	41.42875	4568.3	0.79544	218.9	43.64021
5	Polygon	6	75835	18109800	27104583.7548	0.66815	49.1503	1.32001	890102102.9	32.83954	4187.5	0.83083	238.8	36.01539
6	Polygon	7	54877	14276925	18871894.0814	0.75652	49.01281	1.31396	699752212.4	37.07907	3843.8	0.85843	260.2	41.82278
7	Polygon	8	54672	15813675	21064123.4904	0.75074	48.89375	1.30859	773189872	36.70648	3457.3	0.88486	289.2	42.503
8	Polygon	9	8402	2997900	10572643.6966	0.28355	47.95963	1.26239	143778174.8	13.59908	2802.6	0.91988	356.8	15.79187

0 (0 out of 9 Selected)

Final_Result

The table below provides *WSPC* values for each reporting unit, calculated using the area of the reporting unit, number of inhabitants and jobs, and *WUP*.

Tab. 15: *WSPC* values in municipalities located in the west of the Urban Agglomeration of Montreal, Quebec

Reporting unit	***WSPC*** (UPU/(inhb. or job))
0	34069.43
1	16839.73
2	21836.35
3	14030.77
4	11356.19
5	12872.45
6	14382.62
7	16375.63
8	19871.68

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