Patch-level Land Use Simulation model V1.0 (PLUS) User's Manual

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Consultation

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Abstract

The cellular automata (CA) model is developed to improve the representation of complex land-use and land-cover (LULC) systems. Previous studies focus on the improvement of technical modeling procedures, and little researches has pay attention to promote the understanding of the nonlinear relationships underlying LULC. Lacking of model ability to reflect patch-level landscape evolution also limits the applicablepotential of CAs for policy development. This study presents a patch-level land use simulation (PLUS) model that integrates a rule -mining framework based on Land Expansion Analysis Strategy (LEAS), and a CA model based on multi-type Random Seeds (CARS), which can illustrate drivers of land expansion and project landscape dynamics. The PLUS model can obtain higher simulation accuracy and a more similar landscape pattern than other models. The LEAS can help researchers investigate discovery and policy-making processes, which can provide vital information formultiply users (e.g., researchers, planners and policy makers).

PLUS was developed purely in the C++ language. The parallel technology of PLUS software is from High-performance Spatial Computational Intelligence Lab @ China University of Geosciences (Wuhan) (<u>https://github.com/HPSCIL</u>). The Random forest technique in our model is from a powerful open -source library called Alglib 3.9.2 (http://www.alglib.net/). The UI of the software is built using a famous open -source library Qt 5.13 (https://www.qt.io/download/). This UI provides a real-time display of dynamic changes of land use in the simulation process. Moreover, the using of open source library GDAL 2.0.2 (http://www.gdal.org/) allows our model to directly read and write raster data (.tif, .img, .txt files) that includes geographical coordinate information.

This user's manual intends to provide users a "quick start" on how to use the PLUS software. All of the necessary data and files for the tutorial have been provided and can be used as templates forpractices.

1. Download and start PLUS

The latest version of PLUS software and the user's manual are provided at a download link (<u>https://github.com/HPSCIL/Patch-level_Land_Use_Simulation_Model</u>). Click the executable files "**PLUS VX.0.exe**" to start the software.

Patch-level Land Use Simulation (PLUS) Model V1.0
Data Processing PLUS Validation Demand Prediction Analysis About PLUS

Fig. 1. The main interface of the PLUS model.

The main interface is a brief image browser that provides dynamic display function for the simulation process.

2. Some critical notes before applying the PLUS model

- 1) The input land use data must be in an 'unsigned char' format.
- 2) The LEAS do not require the input image data have the same number of rows and columns. An integral alignment mechanism is available. However, the coordinate or projection system of these images must be supported by GDAL. We recommend the World Geodetic System (WGS 84).
- 3) If a module of the PLUS software needs multiple land use maps as its inputs, these land use maps should have the same number of rows and columns.
- 4) In the step of simulating dynamics of land use change (CARS), the input image data need to have the same number of rows and columns, including the land use pattern, restricted area, and change probability data.
- 6) Cancel the dynamic display by unchecking the 'Dynamic Display' checkbox can make the model faster and more stable.
- 5) We strongly recommend the users do not include a non-English character or sign in the file paths of the PLUS model, **including the spaces**. The file names and folder names must begin with a letter, not a number.

3. Example data description

Category	Data	Filename	Description		
		wh2003_refy.tif	1: Grass, 2: Deciduous forest, 3: Cropland,		
Land use data	Land use data		4: Urban land, 5: Bare land, 6: Water area,		
		wh2013_refy.tif	7: Evergreen forest		
Constraint data	Land use constraint	wh_open_water13.tif			
	Population	wh_Pop.tif	http://www.geodoi.ac.cn/WebCn/Default.as		
	GDP	gdp2010.tif	рх		
	Proximity to the highway	wh_dist_highway.tif			
Socioeconomic data	Proximity to the arterial road	wh_dist_trunk.tif			
	Proximity to the primary road	wh_dist_primary.tif	OpenStreetMap		
	Proximity to the secondary road	wh_dist_secondary.tif	(https://www.openstreetmap.org/)		
	Proximity to the tertiary road	wh_dist_teriary.tif			
	Proximity to railway	wh_dist_railway			
	Proximity to high-speed	wh_dist_highspdstatio			
	railway stations	n.tif	http://lbsyun.baidu.com/		
	Proximity to governments	wh_dist_gov.tif			
			HWSD v 1.2		
	Soil type	wh_soiltype.tif	(http://westdc.westgis.ac.cn/data/844010ba- d359_4020_bf76_2b58806f0205)		
Climatic and			u <i>357-</i> 4020-0170-203000017203)		
environmental	Annual Mean	wh df tem tif			
data	Temperature	wn_ur_crittur	WorldClim v2.0		
	Annual Precipitation	wh_df_pre.tif	(nttp://www.worldclim.org/)		
	DEM	wh _df_dem.tif	NASA SRTM1 v3.0		

Tab. 1 List of test data

Slope	wh_df_slope.tif
Proximity to water	wh_dist_openwater

The test dataset can be found in the *TestData* folder. Use this dataset to run an example model or compared it with your simulation results. In practical, more human and natural environment effects can be taken into consideration. The study region in this example is Wuhan city, located in Hubei province, central China.

4. User interfaces of PLUS model

4.1. Data processing

First of all, data processing is critical! The PLUS model only supports the 'unsigned char' format land use/land cover (LULC) data, with encoded land use category as consecutive integers start from 1 (e,g., 1, 2, 3, 4, 5, 6,.....). Also, the PLUS model only supports the 'unsigned char' land use constraint data, which is a binary value image that ranges from 0 to 1.

If the users use ArcGIS software to reclassify the LULC data, the ArcGIS usually convert the original 'unsigned char' LULC data to 'int' or 'unsigned int' format, which is not allowed in the PLUS model. Thus we provide a conversion tool. It can convert LULC data and constraint data (in all formats) to 'unsigned char' format. If you are not sure theformat in your LULC or constraint data, just apply the conversion tool to generate the 'unsigned char' data that are suitable for the PLUS model. This tool is very fast and convenient to use.

Unfold the "**Data Processing**" menu and click the "**Convert LULCs to Unsigned Char Format**" to start the module that has the same name as the item. Click the button to input theland use or constraint data: 'wh2003_refy.tif' and 'wh2013_refy.tif' in the pop-up dialog. Then the users can specify the output folder and click the **Convert** button to convert the data format. The new LULC files 'wh2003_refy_uc.tif' and 'wh2013_refy_uc.tif' will be exported by the conversion tools. Note that the format of all the test data is suitablefor the PLUS software, this tutorial just provide a guide for how to use the PLUS software. What is more, all the LULC images need to have the same number of rows and columns.

Convert LULCs Data to Unsigned Char Format –		\times
Original LULCs		
1 C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2003_refy.tif		
2 C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2013_refy.tif		
Finish! Finish! Finish! Output Folder		
C:/Users/liang/Desktop/PLUS_test_data/LULCs/		
=== Please wait === Output path: C:/Users/liang/Desktop/PLUS_test_data/LULCs/ wh2003_refy_uc.tif Output path: C:/Users/liang/Desktop/PLUS_test_data/LULCs/ wh2013_refy_uc.tif	Conver	t

Fig. 2. The UI of the data conversion tool.

4.2. Extract Land expansion

The PLUS consists of three main parts, 1) Extract Land expansion, 2) Land expansion analysis strategy (LEAS), and 3) CA based on multiple random seeds (CARS). Users are allowed to start the corresponding module by selecting the option from the "PLUS" button's pull-down menu on the main menu.

Patch-level Land Use Simulation (PLUS) Model V1.0

Data Processing	PLUS	Validation	Demand Prediction	Analysis	About PLUS
1	Ex	tract Land Ex	<pre>cpansion</pre>		
	La	nd Expansio			
	CA	A based on M			

Fig. 3. Starting the 'Extract Land Expansion' module.

Click the _____ button and select theland use or constraint data: 'wh2003_refy.tif' and 'wh2013_refy.tif' in the pop-up dialog. Then the users can specify the output file path and click the _____ button to extract the land expansion map from 2013 to 2013.





Fig. 4. Extracting land expansion from two periods of land use data.

4.3. Land expansion analysis strategy (LEAS)

4.3.1. Start the module

Click the "Land Expansion Analysis Strategy (LEAS)" item to start the module.

LEAS	-	×
1	Input Raster	
	Land expansion map	
	T1>T2	
	Folder of driving factors	
	File list in the folder	-
	Balance?	
	Number of regression tree 20 Sampling rate 0.01 mTry 5	
	Output Raster	
	Development potential	
	Operating Parameters	
	Thread 1 -	
		Start

Fig. 5. UI of the 'Land expansion analysis strategy' module.

4.3.2. Input land expansion data

Click the button of the "Land expansion map" text box and select the land

expansion map "landexpansion03_13_landuse_1to2.tif" outputted in the previous step in the pop-up dialog.

Input	Raster				
Land	expansion	map	1	C:/Users/liang/Desktop/PLUS_test_data/LULCs/landexpansion03_13_landuse_1to2.tif	
	T1>T2				

Fig. 6. Select the land expansion map outputted in the last step.

4.3.3. Input driving factors

Click the button in the "Folder of driving factors" group box and select the folder of driving factors in the pop-up dialog. The PLUS software would automatically

load the "tiff" File in the folder. We provide 16 driving factorsimplementing the simulation.

C:/	/Users/liang/Desktop/PLUS_test_data/dringfactor/		
1	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_Pop.tif	^	
2	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_dem.tif		
3	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_pre.tif		
4	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_slope.tif		-
5	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_tem.tif		
6	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_dist_gov.tif	,	
	C:, 1 2 3 4 5 6	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/ 1 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_Pop.tif 2 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_dem.tif 3 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_pre.tif 4 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_slope.tif 5 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_tem.tif 6 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_dist_gov.tif	C:/Users/liang/Desktop/PLUS_test_data/dringfactor/ 1 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_Pop.tif 2 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_dem.tif 3 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_pre.tif 4 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_slope.tif 5 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_tem.tif 6 C:/Users/liang/Desktop/PLUS_test_data/dringfactor/wh_df_tem.tif

Fig. 7. Chose a folder and the software will automatically input all the driving factors within the folder..

4.3.4. Setting the training parameters and output path

Users can set the parameters of **Random Forest Regression** (**RFR**). The sampling rate is set to 0.01 by defaultwhich means about one percent of pixels is selected for training. The number of regression trees is set to 20 in this experiment. mTry means the feature number used to train the RFR model. The max feature number is 16 in this experiment, equal to the number of driving factors. If the checkbox $\[tau]$ Uniform sampling is

checked, the sampling points for each land use type will be the same. If not, the

sampling points will randomly scatter across the study area. Then, click the

button in the "**Output Raster**" group box and select the change probability in the pop-up dialog. In the test data, the generated development potential of each land use type is named "devPotential.tif". Users can increase the number of parallel internal threads to accelerate the running speed.

🗹 Uniform sampling	
Random Forest Regression	(RFR)
Number of regression tree	20 Sampling rate 0.01 mTry 16
Output Raster	
Development potential	C:/Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential.tif
Operating Parameters	
Thread	1 -

Fig. 8. Determining the training parameters and output path of the RFC.

4.3.5. Running program and examine the result

Once the setting-ups complet, click the button for running the module. A message box will come out as below when the model process run isfinished.

Finish!	×
i Fir	nish!
ОК	

Fig. 9. A message that shows the program run successfully.

The text panel at the left of the interface will output the training accuracies of the RFCs for each land use component. The RFC outputs two accuracy indicators: RMSE and OOB-RMSE for each land use type.



Fig. 10. Accuracy for each land use type.

What is more, the contribution of all the driving factors for the expansion of each land use type can be exported by the RFC, which is very important for researchers to understand the underlying causes of land use change. The contribution of the driving factors for all land use types are saved in CSV files in the 'Parameterfile' folder .





Fig. 11. Contribution of each driving factor to he expansion of grassland.

For example, the file 'contribution0.csv' recorded the contribution of various driving factors on the expansion of grassland. We find that the proximity to governments has the most influence on the growth of grass. This result indicates that the grass is most likely to grow in the place with less human activities because the surrounding areas ofgovernments are generally the most active places of the human being.

After the training process, we obtained 7 RF classifiers corresponding to 7 land use types. These classifiers are applied to predict the development potential of each land use type on each cell. Finally, the PLUS model output 7 development potential maps.



and_1.tif













and_6.tif



DevPotential_b and_2.tif

DevPotential b and_3.tif

DevPotential b and_4.tif

DevPotential_b and_5.tif

DevPotential_b and_7.tif



4.4. Simulating patch-level land use change

4.4.1. Start the module

Click the "CA -based on multiple random seeds (CARS)" item to start the simulation module.

Patch-level Land Use Simulation (PLUS) Model V1.0								
Data Processing	PLUS	Validation	Demand Prediction	Analysis	About PLUS			
1	Ex	tract Land Ex	pansion					
	La	nd Expansio	n Analysis Strategy (LE	EAS)				
	C/	A based on N	Iultiple Random Seed	ls (CARS)				

CARS				- 🗆	×
	Data Preparation				
	Land use pattern				
	Development potential				
	Conversion constrains				
	Output Path				
	Neighborhood Size 3 Hidden Parameters Thread 1 + How ma	Patch generate 0.5 ny year? 1 ♀ Predict block Size	Expansion coefficient 0.3	1	
	Color Dynamic	Display	Para	meters Ru	n

Fig. 13. The UI of the 'CARS' module.

4.4.2. Input initial land use data

Click the button in the "Land use pattern" text line and select the land use data of the start year "wh2003_refy.tif" in the pop-up dialog.

			1	C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2003_refy.tif	
Land	use	pattern			

Fig. 14. Select the land use structure data at the start year.

4.4.3. Input development potential maps

Input the development potential file generated from the 'LEAS' module in the "Development Potential" group box.

	1	$eq:c:/Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential_band_1.tif$	^	
	2	$eq:c:Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential_band_2.tif$		
Development potential	3	$eq:c:Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential_band_3.tif$		
	4	$eq:c:Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential_band_4.tif$		
	5	$eq:c:Users/liang/Desktop/PLUS_test_data/DevelopmentPotential/DevPotential_band_5.tif$	~	

Fig. 15. Select the potential development maps generated by the LEAS module.

4.4.4. The constraint of open water (Spatial policies)

Some policies restrict all types of land change in designated areas, such as open water and some nature conserved areas. Users should prepare a binary image of restricted area that only contains value of 0 or 1. The value 0 means no conversion while the value 1 meansconvertible. In this case, we assume that open water (a sub-category of waterbody) is not allowed to be converted to other land use components.



Fig. 16. Select the change probability data.

4.4.5. Set the path of saving simulation result

Select the save path of the simulation result in the "Output path" group box.

Fig. 17. Select the output path.

4.4.6. Simulation parameters

Simulation parameters include the land use demand, transition matrix, and neighborhood weights. The land use demand is an vital parameter of the PLUS modelthat needs to be firstly set according to the actual situation of the study region. We suggest users to apply external models to determine the land use demand for future scenarios. In the testing, the time span for the land use change simulation is from 2003 to 2013, so we set the land use demand equal to the land use map of 2013. We also provide TWO simple tools for predicting future land demand (section 3.4). We will introduce the two modules in the following section.

The PLUS model will automatically stop when the allocated area equals to the demanded area for all land use types. In the tab widget, users can input the future land use demand of each land use type in the second row "Future Amounts" of the "Land Demand" page is. The "Start Amounts" will automatically load. Users can also input the future cell amount of each land use type in predicted year as figure 18 shows.

Land Demands	Transtion Matrix	Neighborhood	Weights				
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Start Amounts	0	0	0	0	0	0	0
Future Amounts 1	43394	231113	2477678	929417	39413	1453586	150790

Fig. 18. Input the future land use demand.

In addition, the neighborhood effect of PLUS is similar to the traditional CA model. Here the default value of the **neighborhood effect** is 3. The **patch generation** is a decay threshold for generating new patches, ranging from 0 and 1. A higher decay threshold means a more conservative transition strategy, which makesthe cells with lower overall probability are less likely to to change. The **expansion coefficient** is a parameter adjust the ability of model to generate new land use patches, ranging from 0 to 1. A higher expansion coefficient means a higher ability to generate new patches.

Neighborhood Size	3	🗧 Thread	5
Patch generation 0.9)	Expansion coefficient	0.1

Fig. 19. The simulation parameters of the PLUS model.

Then, switch the tab widget to the "**Transition Matrix**" page. The columns of this matrix indicate the current land use types, and the rows indicate the future land use types. A value of 1 means the conversion is allowed, while a value of 0 indicates that

the conversion is not possible. A **Transition Matrix** is a collection of a series of prior knowledge of the expertise about the study area. An example of the transition matrix is shown below:

Land D	emands T:	ranstion Matrix	Neighborhood Wei	ghts			
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Type 1	1	1	1	1	1	1	1
Type 2	0	1	0	0	0	0	0
Type 3	1	1	1	1	1	1	1
Type 4	0	0	0	1	0	0	0
Type 5	1	1	1	1	1	1	1
Type 6	1	1	1	1	1	1	1
Type 7	0	0	1	0	0	0	1

Fig. 20. Transition Matrix.

In the "**Neighborhood weights**" page, users need to set the neighborhood weights of different land use types. The neighborhood effects may be different for different land use types in a unique study region. The value of the neighborhood weight for each land use type can be determined according to expert knowledge and a series of model tests, ranging from 0-1. Or the users can also determine the neighborhood weight of each land-use type by calculating the ratio of the expansion areas of a land-use type accounting for the total land expansion based on the land expansion map (the map outputted in section 4.2). The users can still modify them according to the expert knowledge. According to the land expansion map, we set the parameter as below:

Weights	Transtion Ma	trix Land Dem	ands				
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Weights	0.033354448	0.072010689	0.214762891	0.449313208	0.027947715	0.130501503	0.072109546

Fig. 21. Neighborhood weight for each land use type.

4.4.7. Setting the colors of all land use types for dynamic display

<	>
Color 🗸 Dynamic Display	Parameters Run

Fig. 22. The position of the 'Color' button on the UI.

. o	perties of Land	olors and values to Use Type	r each Landuse Type	9	
T.	Land Use Code	Land Use Type	Color Selection	Color	
	1		Set Color		
2	2		Set Color		
:	3		Set Color		
ŀ	4		Set Color		
;	5		Set Color		
5	6		Set Color		
,	7		Set Color		

Click the "Color" button to activate the 'Set Color Display' module.

Fig. 23. The 'Set Color Display' interface.

Click the "Set Color" button of each row in the list box to set an RGB value (such as rgb(150,200,50)) for all land use types. Then, input the name of each land use type in the 'Land Use Type' column. Finally, click the "**Accept**" button, confirm the above settings.

Select Color	×	I S	et Color Display				
Basic colors		Setu Pr	p Corresponding C operties of Land	olors and Values fo I Use Type	r each Landuse Type	•	
			Land Use Code	Land Use Type	Color Selection	Color	
		1	1	glass	Set Color		
		2	2	deciduous	Set Color		
		3	3	cropland	Set Color		
Pick Screen Color		4	4	urban	Set Color		
	Hue: 0 🗣 Red: 255 🖨	5	5	bareland	Set Color		
Custom colors	Sat: 0 🗘 Green: 255 🗘	6	6	water	Set Color		
	Val: 255 🗘 Blue: 255 🖨	7	7	evergreen	Set Color		
Add to Custom Colors	HTML: #ffffff						
	OK Cancel						Accep

Fig. 24. Setting color for all land use types.

Note that the PLUS model allowed the users to not activated the dynamic display function by unchecking the 'Dynamic Display' checkbox. Because the display function can cause software crashes in some situations. Running the PLUS model without a dynamic display can also make the model run faster.

Color	🗌 Dynamic Display

Fig. 25. Cancel the dynamic display by unchecking the 'Dynamic Display' checkbox.

4.4.8. Running the CARS

Finally, click the button to start the simulation. The information of each iteration is shown on the left of the interface of 'Simulating dynamics of land use structures' module. Also, the PLUS model can present the process of land use change dynamically, including the land cover spatial change, value change and change curve of each land use type on the main interface.

The visualization panel allows the users to zoom in and observe the land use dynamics processes of study regions. The horizontal axis of the dynamic chart represents the number of iteration, and the vertical axis represents the amount of cell.

The model will stop and save the simulation result when the allocated area equals to the demanded area for all land use types. The PLUS software will save all the parameters to two configuration files: "CARSparameters.tmp" in the 'Parameterfile' folder. The module will load the parameters that are recorded in the configuration files

when clicking the ^{Parameters} button, which is convenient for the user to use to repeat their experiments.

CARS								-		×
28925 222326 2477678 929417 58995 1458121 150790	Data Preparation									
/ ***********************************/ Error: 47373 , Derror: 2578 All time for one epoch: 13 494a	Land use patte	n 1 C:/Users	s/liang/Desktop/	PLUS_test_data/LUI	LCs/wh2003_refy.	tif				
Count Fixel: 33 29292 22278 4477678 929417 58830 1457467 150790 / Error: 45755, Derror: 1638 411 the for one epoch: 13.2975 Count Fixel: 34 29509 222074 2477678 929417	Development potenti	1 C:/Users 2 C:/Users 3 C:/Users 4 C:/Users 5 C:/Users	s/liang/Desktop/ s/liang/Desktop/ s/liang/Desktop/ s/liang/Desktop/ s/liang/Desktop/	PLUS_test_data/Dev PLUS_test_data/Dev PLUS_test_data/Dev PLUS_test_data/Dev PLUS_test_data/Dev	velopmentPotent velopmentPotent velopmentPotent velopmentPotent velopmentPotent	tial/新建文件夹/De tial/新建文件夹/De tial/新建文件夹/De tial/新建文件夹/De tial/新建文件夹/De	vPotential_band_1 vPotential_band_2 vPotential_band_3 vPotential_band_4 vPotential_band_5	Ltif		
58731 1457053 150790 // Error: 44709, Derror: 1020 All time for one epoch: 13.344 Count Fixel: 35 29638 223231 2477678 929417 58699 1456799 150790	Conversion constrait Output Path Neighborhood Size	C:/Users/)	s/liang/Desktop/Pl liang/Desktop/Pl	PLUS_test_data/wat	ter/wh_open_wat ulation/simulati	er13.tif on_wh_2013Simula	ttion.tif			
/ ************************************	Patch generate 0.9				Expansion cos	efficient 0.1				
Error: 44137 , Derror: 572 All time for one enoch:	Weights Transtio	n Matrix L	and Demands							
13.375s Count Pixel: 36 29704 223319 2477678 929417 58697 1456647 150790	Start Amounts	Type 1 12742	Type 2 169912	Type 3 3005564	Type 4 362518	Type 5 132649	Type 6 1506974	Type 7 135893	7 3	
/ Hittittittittittittittittittitti Error: 43829 , Derror: 308 All time for one epoch: 13.2198 Count Pixel: 37 30312 223962 2477678 929417 58492 1455601 150790 //	Future Amounts 1	43394	231113	2477678	929417	39413	1453586	150790)	
**************************************	Color Dynami	c Display						Parameters	Ru	л



Fig. 26. The dynamic information of each iteration is shown on the left.

Fig. 27. The dynamic display of the simulation process on the main interface.

45. 0 Iteration

4.5. Accuracy validation of simulation

The PLUS software provides a kappa statistic tool and an FoM statistic tool for evaluating the agreement between simulation results and actual land use patterns.

Patch-level Lan	nd Use S	Simulation (P	LUS) Model V1.0		
Data Processing	PLUS	Validation	Demand Prediction	Analysis	About PLUS
:		Confus	ion Matrix and Fom		

Fig. 28. Start the validation module.

4.5.1. Kappa statistic tool

Click the Validation \rightarrow Confusion Matrix and Fom item on the main menu to start the kappa statistic tool.

Validation(Confus	ion Matrix & Fom) —			×
Data Preparation				
Ground Turth				
Simulation result				
Confusion Matrix	(CM)			
Sampling rate	0.05		Caculat	е
-Figure of merit ()	Fon)	_		_
Initial Map			 Caculat	e

Fig. 29. UI of the validation module.

4.5.1.1. Load data and set the sampling rate

Click the _____ button in the "Ground Truth" row, to input the actual land use data"wh2013_refy.tif". Then click the _____ button in the "Simulation Result" row to input the simulated land useresults. In this case, we set the sampling rate to 10%.

-Data Preparation-		
Ground Turth	1 C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2013_refy.tif	
Simulation result	1 C:/Users/liang/Desktop/PLUS_test_data/Simulation/simulation_wh_2013Simulation_1.tif	

Fig. 30. Input the ground truth and simulation result.

4.5.1.2. Start calculating and save the result

Click the Caculate button to start calculating the Kappa coefficient. A message box will pop up when the program completes the calculation.

E Finish! ×					
	Finish!				
(ОК				

Fig. 31. The message box indicates that the calculation has finished.

The results include the Kappa coefficient, overall accuracy and confusion matrix, which will be saved in a file named "Kappa.csv" in the 'Parameterfile' folder.

Validation(Confusion Matrix & Fom)		<
Data Preparation		
Ground Turth]
Simulation result 1 C:/Users/liang/Desktop/PLUS_test_data/Simulation/simulation_wh_2013Simulation_1.tif]
Confusion Matrix (CM)		
Sampling rate 0.1	Caculate	
Figure of merit (Fom)		
Initial Map		
	Caculate	
type7, 84, 26, 5393, 1683, 135, 1285, 6419, 15025		^
total, 4399, 23191, 248131, 93148, 3983, 144615, 14775, 532242. 000000		
[Kappa Coefficient] Kappa, 0. 688292		
[Overall Accuracy] Overall, 0. 789445		~

Fig. 32. Kappa coefficient and overall accuracy of the simulation result.

4.5.2. FoM statistic tool

Then click the **use** button in the "**Initial Map**" row, to input the start land use

data "wh2003_refy.tif" in 2003. Click the Caculate button to start calculating the FoM coefficient. A message box will pop up when the program completes the calculation.



Fig. 29. The message box indicates that the calculation has finished.

The results include FoM statistics and producer's accuracy, which will be saved in a file named "FoM.csv" in the 'Parameterfile' folder.

Validation(Confusion Matrix & Fom)		<
Data Preparation		
Ground Turth 1 C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2013_refy.tif]	
Simulation result		
Confusion Matrix (CM)		
Sampling rate 0.1	Caculate	
Figure of merit (Fom)		
Initial Map C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2003_refy_uc.tif]	
	Caculate	
C=, 55924		^
D=, 270225		
[Figure of Merit]=B/(A+B+C+D)		
FoM=, 0. 290793		
[Producer's Accuracy]=B/(A+B+C)		
Producer's Accuracy=, 0.350523		
[User's Accuracy]=B/(B+C+D)		
User's Accuracy=, 0.585729		*

Fig. 33. The figure of merit of the simulation result.

4.6. Projecting future land use demand

Future land use demand can be determined by many methods, such as expert experience, linear regression, Markov chains, the system dynamics model, or an integrated assessment model. The PLUS provides a linear regression method and Markov chain method. This experiment projects future land use demand based on historical data.

4.6.1. Linear regression method

Click the "Linear regression" item to start the prediction module.

Patch-level Lar	nd Use S	Simulation (P	VLUS) Model V1.0				
Data Processing	PLUS	Validation	Demand Prediction	Analysis	About PLUS		
1			Linear Regressio	n 🔚			
			Markov Chain				

Fig. 34. Activating the land use demand projection module.

4.6.1.1. Input historical land use data

Click the button, select the historical land use data. In this case we picked the data in the year of 2003, 2005, 2010, and 2013.



Fig. 35. Select the historical land use data.

The program can automatically read the year on the filename. The uses can also manually input the year to the 'Year' column on the chart of data. We set the predict year amount to 20 and the module will predict the future land use demand from 2013 to 2033 (2013+20).

Project Future Land demand with Linear Regression			-		\times
Predict Year anou	int	20			
Data List Y	ear				
C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2003_refy.tif		2003			
C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2005_refy.tif		2005			
C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2010_refy.tif		2010			
C:/Users/liang/Desktop/PLUS_test_data/LULCs/wh2013_refy.tif		2013			
				R	un

Fig. 36. Inputting the historical land use data to the Demand projection module.

4.6.1.2. Running linear regression and predicting future demands

Click the Run button to start calculating future land use demand. A message box will pop up when the program completes the calculation. The results will be showed on the interface and saved in a file named "PredictDemand.csv" in the folder 'Parameterfile'.The formulas of linear regression can also be shown.



Fig. 37. Running the linear regression and predicting future land use demands.

4.6.2. Markov chain method

4.6.2.1. Input historical land use data

Click the "Markov chain" item to start the prediction module.

Markov Cha	in	_		×
Start year ima End year image	ge			
Start year End year Predict year			Ru	n

Fig. 38. The interface for the Markov chain.

Click the button in the "Start year image" row to input the land use data of
start year "wh2003_refy.tif". Then click the button in the "End year
image" row to input the land use data of end year "wh2013_refy.tif". Then click the
text plain below and activated the "Predict year" pull-down menus. Users can choose
the future year they want to predictsuch as 2033 year.

4.6.2.2. Predicting future land demands with Markov chain

Click the Run button to start calculating future land use demand. A message box will pop up when the program completes the calculation. The results will be showed on the interface and saved in a file named "MakovChain.csv" in the folder 'Parameterfile'.

🔳 Markov Cha	in	_		\times	
Start year ima End year image	Markov Chain — tart year image ang/Desktop/PLUS_test_data/LULCs/wh2003_refy.t nd year image ang/Desktop/PLUS_test_data/LULCs/wh2013_refy.t tart year 2003 nd year 2013 redict year 2033 year, type1, type2, type3, type4, type5, type6, type7 2013, 44392, 231101, 2477186, 929369, 39411, 1453499, 150767 2023, 38637, 266154, 2118925, 1338791, 35737, 1384590, 142892				
Start year	2003				
End year	2013		Run	1	
Predict year	2033	\sim			
year, type1, ty	pe2, type3, type4, type5, type6, type7			^	
2013, 44392, 23	1101, 2477186, 929369, 39411, 1453499, 150767				
Start year image ang/Desktop/PLUS_test_data/LULCs/wh2003_refy.tif End year image ang/Desktop/PLUS_test_data/LULCs/wh2013_refy.tif Start year 2003 Start year 2013 Run Predict year 2033 year, type1, type2, type3, type4, type5, type6, type7 2013, 44392, 231101, 2477186, 929369, 39411, 1453499, 150767 2023, 38637, 266154, 2118925, 1338791, 35737, 1384590, 142892 2033, 33844, 283078, 1871356, 1663837, 33839, 1309333, 130439					
2033, 33844, 28 	3078, 1871356, 1663837, 33839, 1309333, 130439			~	

Fig. 39. Predict future land use amount with Markov chain.

4.6.3. Simulating future land use from 2013 to 2033

Click the button in the "Land use pattern" text line and select the land use data of start year "wh2013_refy.tif" in the pop-up dialog. Then input the development potential file from 2003 to 2013 generated by the 'LEAS' module in the "**Development Potential**" group box. Input the open water map in 2013 "wh_open_water13.tif" as land use constraints, and define an output path for the simulation result.

Other simulation parameters (Neighborhood size, Patch generating factor, Expansion coefficient, Neighborhood weights, and Transition matrix) remain the same as the validation process (section 3.4.6). Then users need to import the predicted land use demand in the year of 2033. We analyzed two future scenarios in this tutorial: 1) Linear regression scenario and 2) the Markov chain scenario with separately running the PLUS model. Note that the final land use amount will approximate but may not exactly equal to the land use demands. Because the final land use amounts not only determined by the land use demands from "top-down" scale but also determined by the local geographical conditions from the "bottom-up" scale. The final land use amounts are final results of the interactions between "top-down" and "bottom-up" effects.

CARS							-	_		×
1962432 39707 1355776 98729 Start Count Pixel: 0 - 44394 231113 2477356 929417	Data Preparation	1 C:/U	sers/liang/Desktop)/PLUS_test_data/Ll	JLCs/wh2013_refy.	tif				
39413 1438380 15079 Year: 0 Error: 2463111 , Derror: -2463111 All time for one epoch: 12.5472 (Count Fixel: 1 45751 23571 2404104 1000609 39678 143420 150790 // Error: 2308287, Derror: 154824 All time for one epoch: 13.5155 Count Fixel: 2 46000 239763 2308376 1029145	Land use patter Development potentia Conversion constrair	n 1 C:/U 2 C:/U 1 3 C:/U 4 C:/U 5 C:/U s 1 C:/U	sers/liang/Desktop sers/liang/Desktop sers/liang/Desktop sers/liang/Desktop sers/liang/Desktop	/PLUS_test_data/D /PLUS_test_data/D /PLUS_test_data/D /PLUS_test_data/D /PLUS_test_data/D /PLUS_test_data/W	evelopmentPotent evelopmentPotent evelopmentPotent evelopmentPotent evelopmentPotent ater/wh_open_wat	ial/DevPotential ial/DevPotential ial/DevPotential ial/DevPotential ial/DevPotential ial/DevPotential	band_1.tif band_2.tif band_3.tif band_4.tif band_5.tif			
30202 1403204 103019 / ***********************************	Output Path	Output Path C:/Users/liang/Desktop/PLUS_test_data/Simulation_simulation_wh_2033_linearRegresion								
CARS 1962432 39707 1355776 98729 111111111111111 Count Fixel: 0 44394 23113 2477356 929417 39413 1453586 15079 Year: 0 Error: 2463111, Derror: -246311 All time for one epoch: 12.5478 Count Fixel: 1 49751 235711 2404104 1000609 39678 1449426 150790 /************************************	Neighborhood Size Patch generation 0.9		3	×	Thread 5 Expansion coefficient 0.1					-
40874 242496 2357019 1034355 36255 1454716 154354 / ***********************************	Start Amounts	Type 1 44394	Land Demands Type 2 231113	Type 3 2477356	Type 4 929417	Type 5 39413	Туре б 1453586		Type 7 150790	
Error: 2231825 , Derror: 17020 All time for one epoch: 13.734s Count Pixel: 4 47302 244192 2352631 1035375 36288 1455432 154849 /	Future Amounts 1	147705	308025	1377648	1962432	39707	1355776		98729	
Error: 2225471 , Derror: 6354 All time for one epoch:	Color Dynamic	: Display					Paran	əters	Ru	n



Fig. 40. Parameter setting and simulation result from for the year 2033 under the Linear regression scenario.

CARS								-		×
11480 ^	Data Preparation									
15.203s Count Pixel: 75 70734 283078 1871356 1472725 33839 1401173 193164	Land use patterr	1 C:/U	sers/liang/Desktop/P	LUS_test_data/LU	ILCs/wh2013_refy.	tif				
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Development potential	1 C:/U 2 C:/U 3 C:/U 4 C:/U 5 C:/U	sers/liang/Desktop/P sers/liang/Desktop/P sers/liang/Desktop/P sers/liang/Desktop/P sers/liang/Desktop/P	LUS_test_data/De LUS_test_data/De LUS_test_data/De LUS_test_data/De LUS_test_data/De	evelopmentPotent evelopmentPotent evelopmentPotent evelopmentPotent evelopmentPotent	ial/DevPotential ial/DevPotential ial/DevPotential ial/DevPotential ial/DevPotential	band_1.tif band_2.tif band_3.tif band_4.tif band_5.tif			
15.422s Count Pixel: 77 60792 283078 1871356 1478590 33839 1396066 193348 / ***********************************	Conversion constrains Output Path	1 C:/U: C:/User	sers/liang/Desktop/P	LUS_test_data/wa JS_test_data/Sim	ater/wh_open_wat ulation/simulati	er13.tif on_wh_2033_mark@	ovChain.tif			
<pre>1 L4NS 11480 All time for one epoch: 15.203s Count Pixel: 75 70734 283078 1871356 1472725 38389 140173 193164 ************************************</pre>	Neighborhood Size Patch generation 0.9	3			Thread S Expansion coefficient 0.1					-
33839 1394517 193415 / ####################################	94517 193415 Weights Transition 107155 Derror: 3082 Start Amounts Future Amounts 1xel: 79 93078 1871356 1481732 193419 Heights Transition		Land Denands Type 2 231113 283078	Type 3 2477356 1871356	Type 4 929417 1663837	Type 5 39413 33839	Type 6 1453586 1309333		Type 7 150790 130439	
Error: 304553 , Derror: 2602 All time for one epoch: 15.281s Count Pixel: 80 60196 283078 1871356 1481732	Color 🗸 Dynamic	Display					Par	aneter:	s Ru	n







Fig. 41. Parameter setting and simulation result for the year 2033 under the Markov chain scenario.

The PLUS software will save all parameters to two configuration files: "CARSparameters.tmp" in the 'Parameterfile' folder. The module will load the parameters that are recorded in the configuration files when clicking the Parameters buttom, which is convenient for the user to use to repeat their experiments.

4.7. Calculation of scenario diversity

Scenario diversity describes the different of pixels between various scenarios. Areas show more variations between scenarios are more sensitive to the scenario with unique regional environment, while the area likely to remain unchanged regardless of scenario is less sensitive. Areas that change between scenarios (3 scenarios or more) also represent the hotspots of variability in the study regions. This, the PLUS software provides a tool for calculating the scenario diversity.

- Fatch level La	iu ose .	Simulation (F						
Data Processing	PLUS	Validation	Demand Prediction	Analysis	About PLUS			
				Scen	ario Diversity	H		
-								
🛯 Scenario Diverisity						_		×
Mutiple scenarios								
Output								
							Run	

Fig. 42. Activating the 'Scenario Diversity' module.

4.7.1. Input multiple simulation results under different scenarios

Click the button in the "**Multiple scenarios**" row, select the simulation result in 2033 under the two mentioned above scenario in the pop-up dialog. Then click the button in the"**Output**" row to set the output path of the diversity image.

Scenario Diverisity	-		×
Mutiple scenarios			
1 C:/Users/liang/Desktop/PLUS_test_data/Simulation/simulation_wh_2033_linear	rRegressionSimulation_1.tif		
2 C:/Users/liang/Desktop/PLUS_test_data/Simulation/simulation_wh_2033_mark	covChainSimulation_1.tif		
C:/Users/liang/Desktop/PLUS_test_data/Simulation/diversityMap.tif			
		Run	

Fig. 43. Set the input and output paths for the 'Scenario Diversity' module.

4.7.2. Calculating the land use mixture of each cell

Click the button to generate the scenario diversity map in 2033. Note that the 'Scenario Diversity' module supports multiple scenarios. This tutorial only provides a simple case study with 2 scenarios.



Fig. 44. Generating the scenario diversity map in 2033.