

# Integration and unification of land use 2007-2015 change layer with LU geodatabase 2015-2018 for Luxembourg

Version 1.0

10 February 2021

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**Title:**

Integration and unification of land use 2007-2015 change layer with LU geodatabase 2015-2018 for Luxembourg

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**Place and date:**

Niederanven, 10.02.2021

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## LIST OF ABBREVIATIONS

Term	Abbreviation
<i>Land Information System Luxembourg</i>	LIS-L
<i>Land Use</i>	LU
<i>Land Cover</i>	LC
<i>Land Use map of 2018</i>	LU 2018
<i>Minimum Mapping Unit</i>	MMU
<i>Occupation Biophysique du Sol</i>	OBS
<i>space4environment</i>	s4e

## **1 INTRODUCTION**

### **1.1 LU 2007-2015 change layer**

The Land Information System Luxembourg (LIS-L) project performed by space4environment (s4e) aimed to develop an approach for the development of land cover (LC) and land use (LU) maps of the Grand Duchy of Luxembourg updated for the reference year 2015. The LU update was carried out on the basis of the 2007 Occupation Biophysique du Sol map (OBS). The original OBS nomenclature had been reclassified to the new LU nomenclature. Based on the OBS, an updated LU for 2015 (hereinafter referred to as the LU 2015 Version 1) and a new version of OBS 2007 with a new nomenclature were generated. Additionally, a change layer 2007-2015 (hereinafter referred to as the LU 2007-2015 change layer) was created with polygons containing the range of changes and LU classes in 2007 and 2015.

### **1.2 LU 2015-2018 database**

The Land Use 2018 (LU 2018) project performed by s4e includes the land use map of the Grand Duchy of Luxembourg updated for 2018 (hereinafter referred to as the LU 2018) with minimum mapping unit (MMU) of 100 m<sup>2</sup> for settlement classes (S.1.1-S.1.5), standing waters (W. 2.1-W.2.2) and transport (T.1.1-T.1.2) and 500 m<sup>2</sup> for all other classes. It also includes an improved version of the land use map for 2015 (hereinafter referred to as the LU 2015 Version 2) created in the context of the Land Information System Luxembourg (LIS-L) project and generated a change layer for the 2015-2018 timestamp. The project was a continuation of the LIS-L project to map the land cover and land use in Luxembourg for 2015.

### **1.3 Objectives**

This document presents the methodological approach to implement the integration and unification of the 2007-2015 change layer with the land use database of the Grand Duchy of Luxembourg for 2015 and 2018. The proposed methodology was developed using automatic GIS data processing to update objects geometry and semi-automatic improvement of LU classes.

### **1.4 Document content**

The document is divided into six main sections. Section 1 covers the content of this document and the main goals of the project. Section 2 introduces the technical specifications of the input data set, while section 3 provides a general description of the LU nomenclature. Section 4 presents a methodological approach for integrating the dataset. The remaining sections 5 and 6 provides detailed information on the results and suggestions for future update, respectively.

## 2 TECHNICAL DESCRIPTION OF LU 2007-2015 CHANGE LAYER DATA SET AND LU 2018 DATABASE

### 2.1 Overall information about LU 2007-2015 change layer data set

According to INSPIRE definition (Directive 2007/2/EC) a Land Use is a “territory characterised according to its current and future planned functional dimension or socio-economic purpose (e.g. residential, industrial, commercial, agricultural, forestry, recreational)”. In the LIS-L project we use an OBS map of 2007 as an input source to produce a land use map of 2015 (LU 2015 Version 1).

The LU 2015 Version 1 and a change layer generated for 2007-2015 consists the LU classes listed in Table 2-1. Objects classified as 140 have been directly inherited from OBS 2007 and have not been corrected when performing the update, while objects classified 141, 142, 143 and 144 are new objects that were updated when generating LU 2015 Version 1.

**Table 2-1 LU nomenclature of LIS-L LU 2015 Version 1 datasets and a change layer 2007-2015**

Thematic block	Land use class	Class name	Class code
Settlement (S)	Settlement (S.1)	Settlement type - 5	Types - 5
		Residential (S.1.1)	111
		Agriculture facilities (S.1.2)	112
		Industry & Commerce (S.1.3)	113
		Unused urban areas, brownfields (S.1.4)	114
		Social, cultural, and other (S.1.5)	115
	Estate (S.2)	Types – 5	Types – 5
		Residential (S.2.1)	121
		Agriculture facilities (S.2.2)	122
		Industry & Commerce (S.2.3)	123
		Unused urban areas, brownfields (S.2.4)	124
		Social, cultural, and other (S.2.5)	125
	Public facilities (S.3)	Types - 4	Types - 4
		Cemetery (S.3.1)	131
		Square (S.3.2)	132
		Park (S.3.3)	133
		Other (S.3.4)	134
	Sports and leisure (S.4)	Types - 1	140
		Types - 4	Types - 4
		Golf course (S.4.1)	141
		Camp ground (S.4.2)	142
		Other sport facilities (S.4.3)	143
		Other recreation facilities (S.4.4)	144
Technical infrastructure (S.5)	Types - 2	Types - 2	
	Utility (production, disposal facilities) (S.5.1)	151	

Thematic block	Land use class	Class name	Class code	
		Mining / extraction <b>(S.5.2)</b>	152	
	Construction site <b>(S.6)</b>	Types - 1	160	
Transport <b>(T)</b>	Roads <b>(T.1)</b>	Types - 2	Types - 2	
		Rural roads <b>(T.1.1)</b>	611	
		Main roads <b>(T.1.2)</b>	612	
	Railways <b>(T.2)</b>	Types - 1	620	
	Air traffic <b>(T.3)</b>		Types - 2	Types - 2
			Commercial <b>(T.3.1)</b>	631
			Sport & Leisure <b>(T.3.2)</b>	632
	Water traffic <b>(T.4)</b>	Types - 1	640	
Parking <b>(T.5)</b>	Types - 1	650		
Agriculture <b>(A)</b>	Arable land <b>(A.1)</b>	Types - 1	210	
	Grassland <b>(A.2)</b>	Types - 1	220	
	Special cultures <b>(A.3)</b>		Types - 4	Types - 4
			Wine <b>(A.3.1)</b>	231
			Fruit trees <b>(A.3.2)</b>	232
			Orchard <b>(A.3.3)</b>	233
			Other <b>(A.3.4)</b>	234
Forest <b>(F)</b>	Forest block <b>(F.1)</b>	Forest type - 3	Forest type - 3	
		Coniferous <b>(F.1.1)</b>	311	
		Mixed <b>(F.1.2)</b>	312	
		Deciduous <b>(F.1.3)</b>	313	
		Young forest <b>(F.1.4)</b>	314	
	Clearing <b>(F.2)</b>		Cause type - 3	Cause type - 3
			Burnt area <b>(F.2.1)</b>	321
			Storm damage <b>(F.2.2)</b>	322
		Clear cuts & Other <b>(F.2.3)</b>	323	
Natural surfaces <b>(N)</b>	Gravel <b>(N.1)</b>	Types - 1	410	
	Rocks <b>(N.2)</b>	Types - 1	420	
	Natural grassland <b>(N.3)</b>	Types - 1	430	
	Heathland <b>(N.4)</b>	Types - 1	440	
	Bushes <b>(N.5)</b>	Types - 1	450	
	Wetland <b>(N.6)</b>	Types - 1	460	
Water <b>(W)</b>	Running water <b>(W.1)</b>	Types - 2	Types - 2	
		Natural <b>(W.1.1)</b>	511	
		Artificial <b>(W.1.2)</b>	512	
	Standing water <b>(W.2)</b>	Types - 2	Types - 2	
		Natural <b>(W.2.1)</b>	521	
		Artificial <b>(W.2.2)</b>	522	

## 2.2 Overall information about LU 2018 database

The main aim of the LU 2018 project was to produce an updated land use map for the entire Grand Duchy of Luxembourg for 2018. In the LU 2018 project we use a LIS-L map of 2015 (LU 2015 Version 1) as an input source to produce a land use map of 2018 and to update a land use map of 2015 (LU 2015 Version 2).

The nomenclature of the LU classes of the new database for 2018 was set-up based on the LIS-L nomenclature with few changes which includes merging the classes of 'estate' (classes 121, 122, 123, 124 and 125) with the classes of 'settlement' and removing the class of 'sport and leisure' (class 140). The LU 2018 and LU 2015 Version 2 consists the LU classes listed in Table 2-2 and described in Annex I.

**Table 2-2 LU nomenclature of LU 2018 and LU 2015 Version 2 datasets. Detailed description of LU classes is available in Annex I.**

Thematic block	Land use class	Class name	Class code
Settlement (S)	Settlement & Estate (S.1)	Settlement & Estate type - 5	Types - 5
		Residential (S.1.1)	111
		Agriculture facilities (S.1.2)	112
		Industry & Commerce (S.1.3)	113
		Unused urban areas, brownfields (S.1.4)	114
		Social, cultural, and other (S.1.5)	115
	Public facilities (S.3)	Types - 4	Types - 4
		Cemetery (S.3.1)	131
		Square (S.3.2)	132
		Park (S.3.3)	133
		Other (S.3.4)	134
	Sports and leisure (S.4)	Types - 4	Types - 4
		Golf course (S.4.1)	141
		Camp ground (S.4.2)	142
		Other sport facilities (S.4.3)	143
		Other recreation facilities (S.4.4)	144
	Technical infrastructure (S.5)	Types - 2	Types - 2
		Utility (production, disposal facilities) (S.5.1)	151
		Mining / extraction (S.5.2)	152
	Construction site (S.6)	Types - 1	160
Transport (T)	Roads (T.1)	Types - 2	Types - 2
		Rural roads (T.1.1)	611
		Main roads (T.1.2)	612
	Railways (T.2)	Types - 1	620
	Air traffic (T.3)	Types - 2	Types - 2
		Commercial (T.3.1)	631
		Sport & Leisure (T.3.2)	632

Thematic block	Land use class	Class name	Class code	
	Water traffic <b>(T.4)</b>	Types - 1	640	
	Parking <b>(T.5)</b>	Types - 1	650	
Agriculture <b>(A)</b>	Arable land <b>(A.1)</b>	Types - 1	210	
	Grassland <b>(A.2)</b>	Types - 1	220	
	Special cultures <b>(A.3)</b>		Types - 4	Types - 4
		Wine <b>(A.3.1)</b>		231
		Fruit trees <b>(A.3.2)</b>		232
		Orchard <b>(A.3.3)</b>		233
		Other <b>(A.3.4)</b>		234
Forest <b>(F)</b>	Forest block <b>(F.1)</b>	Forest type - 3	Forest type - 3	
		Coniferous <b>(F.1.1)</b>	311	
		Mixed <b>(F.1.2)</b>	312	
		Deciduous <b>(F.1.3)</b>	313	
		Young forest <b>(F.1.4)</b>	314	
	Clearing <b>(F.2)</b>	Cause type - 3	Cause type - 3	
		Burnt area <b>(F.2.1)</b>	321	
		Storm damage <b>(F.2.2)</b>	322	
		Clear cuts & Other <b>(F.2.3)</b>	323	
Natural surfaces <b>(N)</b>	Gravel <b>(N.1)</b>	Types - 1	410	
	Rocks <b>(N.2)</b>	Types - 1	420	
	Natural grassland <b>(N.3)</b>	Types - 1	430	
	Heathland <b>(N.4)</b>	Types - 1	440	
	Bushes <b>(N.5)</b>	Types - 1	450	
	Wetland <b>(N.6)</b>	Types - 1	460	
Water <b>(W)</b>	Running water <b>(W.1)</b>	Types - 2	Types - 2	
		Natural <b>(W.1.1)</b>	511	
		Artificial <b>(W.1.2)</b>	512	
	Standing water <b>(W.2)</b>	Types - 2	Types - 2	
		Natural <b>(W.2.1)</b>	521	
		Artificial <b>(W.2.2)</b>	522	

### **3 LU NOMENCLATURE AND PROPOSED RECLASSIFICATION OF EXISTING LU DATA SET TABLES FOR THE LU 2018 CATEGORY**

#### **3.1 LU 2018 database nomenclature**

The LU 2018 database consists of LU for the entire Grand Duchy of Luxembourg for 2015 and 2018. The database was created as a 2018 LU update based on LIS-L data for 2015 (LU 2015 Version 1). Instead of creating a standalone LU database for 2018, the LIS-L data for 2015 has been implemented to allow for easy analysis and statistics of changes in 2015-2018.

While performing the project it was decided to remove the 'estate' class as being redundant and reclassify all objects belonging to this class into the appropriate 'settlement' classes. There was no need to maintain the 'estate' class because this class contained the same LU information as the 'settlement' class, but for a facility located a certain distance from more densely built-up areas.

In addition, the polygons belonging to class 140 were reclassified into classes 141, 142, 143, and 144 based on the LU objects they represent. This step was carried out because class 140 was a remnant of the old OBS nomenclature which had not been revised and adapted to the new nomenclature in the LIS-L project distinguishing different types of sport and leisure facilities in the use of land.

Moreover, the objects incorrectly classified in 2015 were updated. This is due to the fact that the LIS-L data for 2015 was used as input data to generate the new LU version for 2018. In case the operator found that the object class was not compatible with the reference orthophotomap from 2018, the class was changed to the appropriate class in 2018 and it was checked whether it was different in 2015 and whether it was a change, or whether the facility was incorrectly classified in 2015. Some geometries of objects have also been improved as needed. Therefore, the 2015 LU map (LU 2015 Version 2) generated in this project differs from that generated in the LIS-L project (LU 2015 Version 1).

In the current project, the 2015-2018 LU database nomenclature has been recognized as the final nomenclature (see Annex I) to which the 2007-2015 land use change layer should be adapted and standardized.

#### **3.2 LU 2007-2015 change layer nomenclature**

The 2007-2015 change layer nomenclature differs from the 2015-2018 LU database nomenclature. Therefore, a synchronization was performed to standardize the classes in both data sets. The 2007-2015 change layer contains few more classes than the 2015-2018 LU database that should be synchronized. The classes that should be reclassified are included in the nomenclature of the 2007-2015 patch layer 140 – 'sports and leisure' and 121, 122, 123, 124 and 125 – 'estate'. We have automatically reclassified the estate (see Figure 3-1), assigning the appropriate settlement class to each class as follows:

- 121 was reclassified to 111;
- 122 was reclassified to 112;
- 123 was reclassified to 113;
- 124 was reclassified to 114;
- 125 was reclassified to 115.

In total, we reclassified 331 polygons from the 'estate' class to the 'settlement' class.

Reclassification of class 140 was performed semi-automatically, by visual verification of each polygon and assignment to the appropriate class 141, 142, 143 and 144 (see Figure 3-1). The

process was semi-automatic as classes 141-144 are a subtype of the main class 140 and therefore we had no information about the specific class of the subtype LU to assign it automatically. In total, we have visually verified and reclassified 63 polygons.



**Figure 3-1** Examples of polygons in the classes 'sport and leisure', and 'estate' in 2007 of the LU 2007-2015 change layer that were reclassified and synchronised into the LU 2015-2018 nomenclature.

## 4 INTEGRATION AND UNIFICATION OF LU 2007-2015 CHANGE LAYER WITH LU 2018 DATABASE

The national LU data sets for Luxembourg were mainly generated from previous LU versions with the support of ancillary data. For example, OBS 2007 was based on the OBS 1999 dataset, LU 2015 Version 1 based on OBS 2007, and LU 2018 based on LU 2015 Version 1. In case of detecting a wrong delineation of the polygon border in the input dataset, such error was corrected in the new database, but not necessarily in the input dataset (except LU Version 2 for 2015 and 2018 which are one integral dataset, see Figure 4-1). Also the LU nomenclature between the updates changed. This caused the data sets to have different geometries, and LU classes, making it difficult to compare and extract correct land use changes, mainly due to sliver polygons. Therefore, the option to overcome this issue is to standardise the nomenclatures and combine the dataset to one integral geo-database to compare LU changes between data sets.

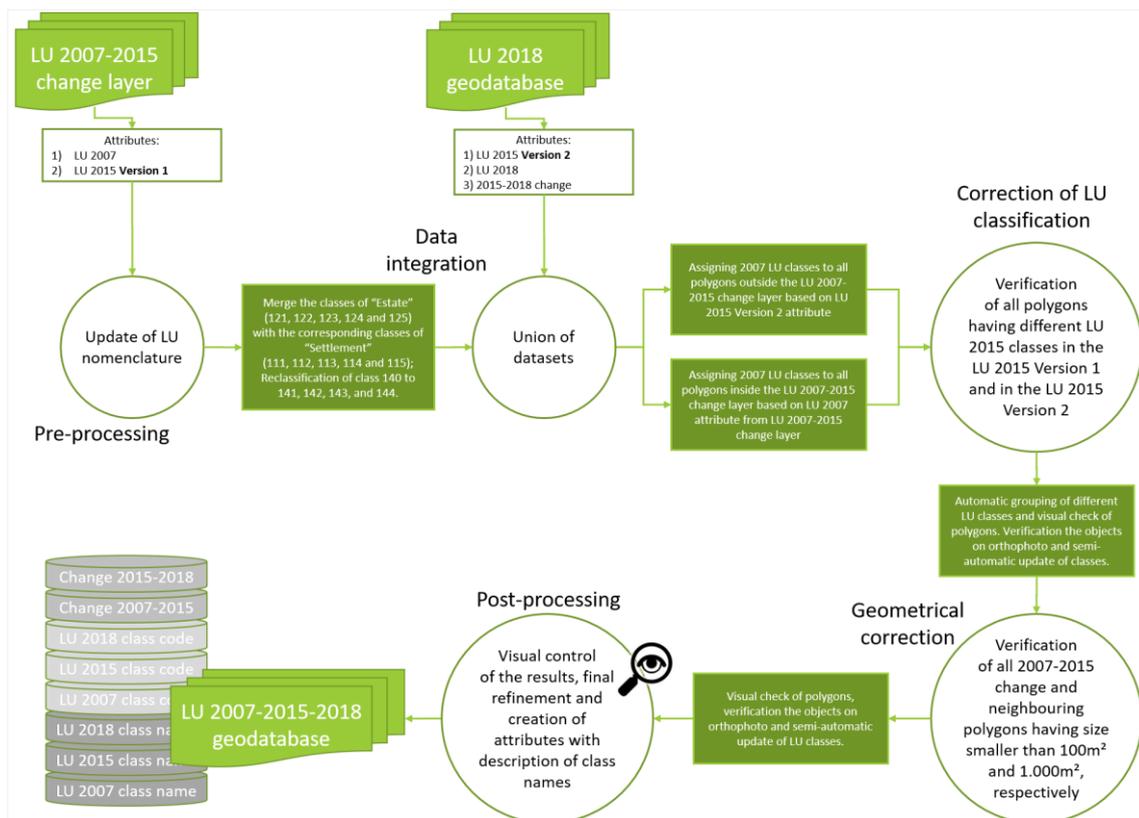


Figure 4-1 Flow diagram of proposed methodology for integrating 2007-2015 LIS-L change layer with LU 2018 geodatabase.

### 4.1 Combining LU 2007-2015 change layer with LU 2018 database

We performed a union of the layer of changes LU 2007-2015 with the LU 2018 database. Then we created new attributes for LU codes in 2007, 2015 and 2018 and changes for 2007-2015 and 2015-2018. We filled out the new attributes with information about the land use and changes with the following rules:

- New LU 2018 class code attribute was overwritten based on LU 2018;
- New LU 2015 class code attribute was overwritten based on LU 2015 Version 2;
- New LU 2007 class code attribute was overwritten based on:

- LU 2015 Version 2 for polygons not being assigned as change polygon in change layer 2007-2015;
- LU 2007 for polygons being assigned as change polygon in change layer 2007-2015;
- New change 2007-2015 attribute was overwritten based on change layer 2007-2015;
- New change 2015-2018 attribute was overwritten based on change attribute 2015-2018.

#### 4.2 Verification and correction of different codes in LU 2015 Version 1 and LU 2015 Version 2

The LU codes of Version 1 in 2015 differ from the codes in Version 2, because while generating an update in 2018 some polygons were updated with regards to their geometry and the LU class. Therefore, we selected all polygons having different classes in our database – 4.593 polygons in total, which we visually checked to verify which class is the correct one. We grouped different class combinations between Version 1 and Version 2 to allow for smooth and faster visual control. We noticed that in most of the changes the class of Version 2 was correct, for some random points the class was wrong in both versions, so we corrected the class accordingly. Figure 4-2 shows an example of checked polygons, in many cases this was a misclassification within intensively managed forests – see Figure 4-2 "forest management". Another example of differences is that in Version 1 some objects representing different classes in the settlement were classified as 111. Also, in Version 1 the polygons of the changes were drawn in a simplified manner and were not divided according to the appropriate class – see Figure 4-2 "agriculture to settlement" where the change polygon was reclassified to class 111, despite the fact that the new building was built on only one small plot, and the other was unused urban area.

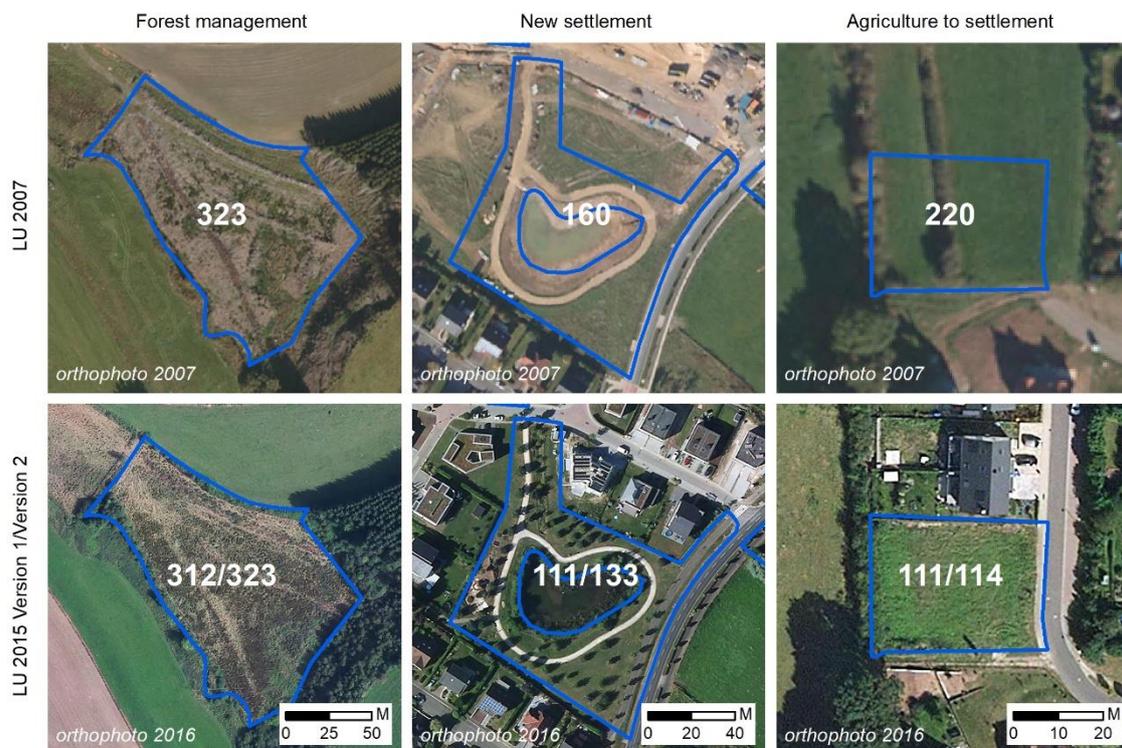
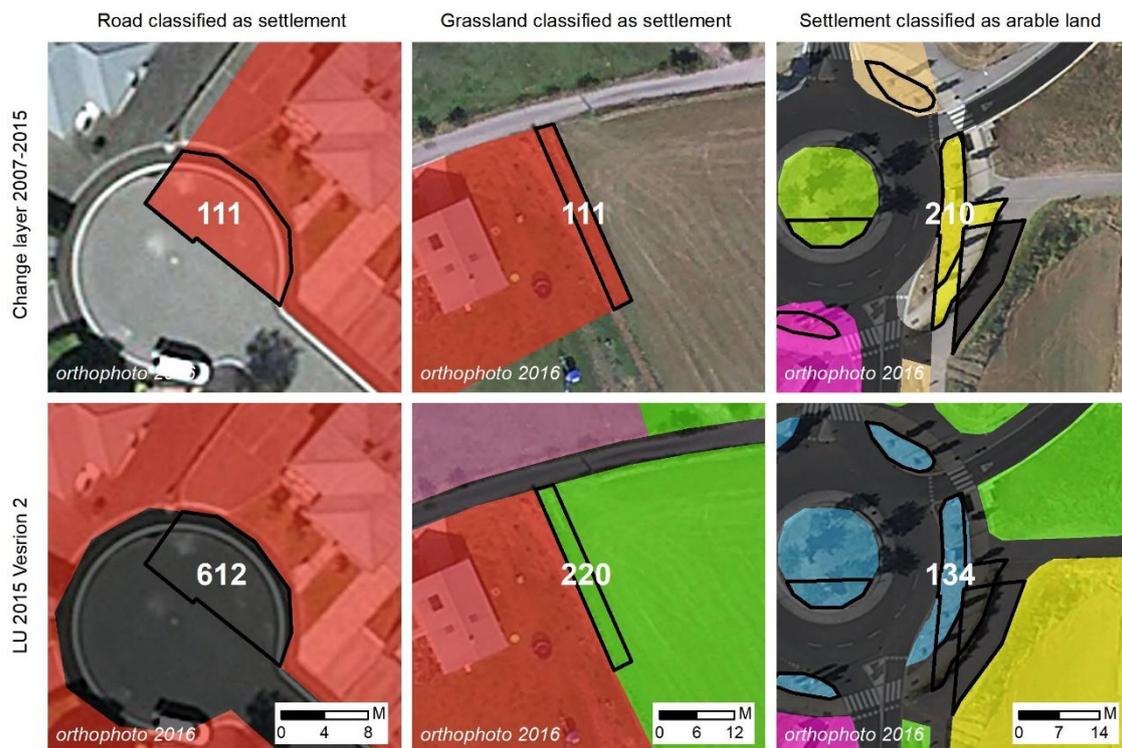


Figure 4-2 Examples of difference in LU classes for 2015 between the LIS-L change layer 2007-2015 (LU 2015 Version 1) and LU 2018 (LU 2015 Version 2) and LU classes for 2007. The numbers in white present the LU class code corresponding to the year displayed on the left.

### 4.3 Geometrical correction

We verified the accuracy of classification of small change polygons to remove the slivers representing the differences between the polygon geometry between LU 2007-2015 change layer and LU 2018 database. We selected all polygons assigned as change polygons between 2007 and 2015 and having the area smaller than 100m<sup>2</sup>.

In total, we verified and corrected 1.333 polygons with change and area smaller than 100m<sup>2</sup>. Some of them represented correct changes. However, the majority represented differences in the geometry between two datasets, for example: a road network improved when generating LU 2018 (see Figure 4-3 "road classified as settlement"); an updated border of a settlement (see Figure 4-3 "grassland classified as settlement"); or an updated LU classification of areas being part of a construction of a new road between 2007 and 2015 (see Figure 4-3 "settlement classified as arable land").



**Figure 4-3** Examples of polygons (marked in black) representing difference in polygon geometry for 2015 between the LIS-L change layer 2007-2015 (LU 2015 Version 1) and LU 2018 (LU 2015 Version 2). The colour composition of the data presents the LU 2015 classes (Version 1 – upper panel; Version 2 – bottom panel). The numbers in white present the LU code in 2015.

Additionally, we also verified small polygons that neighbour to change layer 2007-2015, because they may represent real changes, but were not included due to geometrical differences of datasets. Such differences represent omissions in the change layer 2007-2015. In total, we verified 3.193 polygons with the size smaller than 1.000m<sup>2</sup>.

The red polygons in Figure 4-4 show some examples of omissions. Most of them represented very small polygons that were slivers along polygons classified as forest or construction site, the shape of which was corrected in LU 2015 Version 2. However, some represent omissions of the entire parcels that were not included in the change layer 2007-2015. Many of the selected polygons did not represent omissions - see a few examples of the polygons outlined in blue in the bottom panel in Figure 4-4, and their classification has not been corrected.



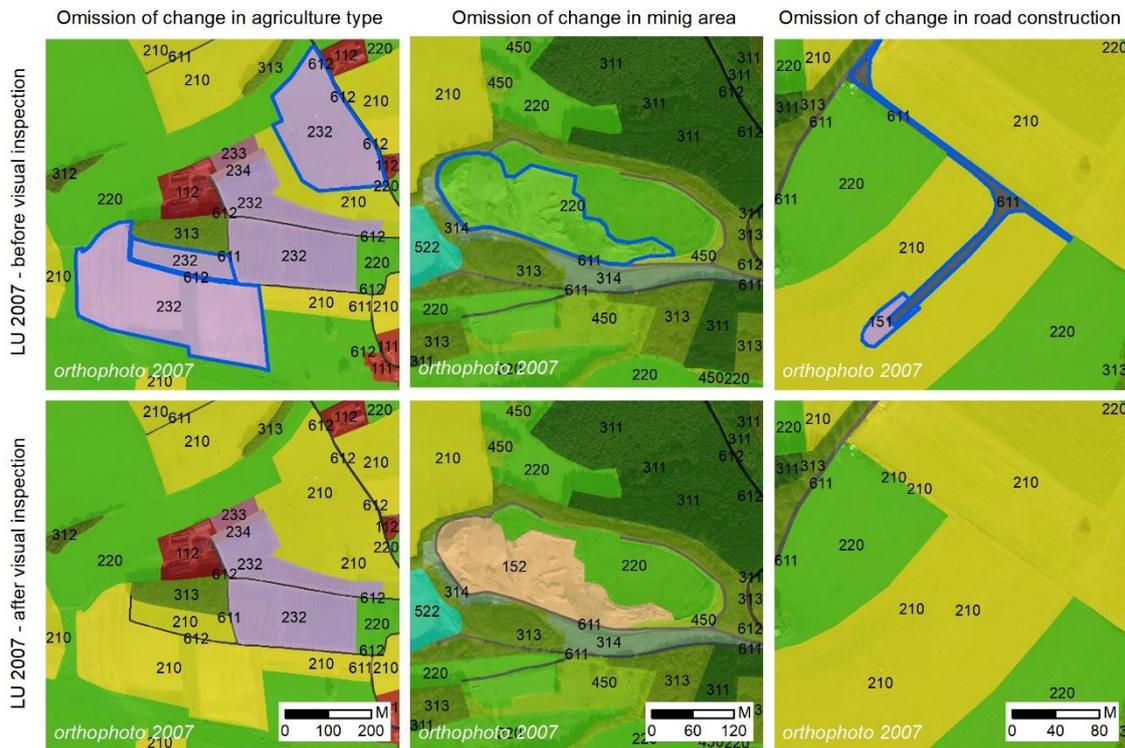
**Figure 4-4** Examples of geometrical errors improved in the polygons that neighbour with LU 2007-2015 change layer. The colour composition of the data presents the LU 2007 classes. The numbers in white present the LU code in 2015 (upper panel) and LU code in 2007 (lower panel).

#### 4.4 Post-processing

After performing the semi-automatic improvement of change polygons we verified quality of the final dataset. We performed the union to verify whether any gap in the dataset has been created and whether geometrical errors occurs. We also dissolved the data to reduce the number of small polygons neighbouring each other and representing the same LU class codes that we generated by performing union in Section 4.1. Dissolve we performed for all LU class codes except the classes in the transport thematic block (classes 611-650) as they represent for example the road network and dissolving them would create one large polygon with complex shape for the entire area of Luxembourg and making difficult to open the data and visualise them in a GIS software. The road and railway networks are split into 1×1km tiles across the country.

We performed a visual inspection of generated database by displaying the classification of LU 2007 and orthophoto for 2007 in a background. The visual check we performed in scale 1:5.000 by verifying 1km<sup>2</sup> tiles across entire country. Only errors clearly visible at scale 1:5.000 were corrected. The manual check showed that there were omissions in LU 2007-2015 change layer, especially in change from coniferous forest (class 311) in 2007 to clear cut (class 323) in 2015 which resulted in overwriting the class of clear-cut to year 2007 in the automatic process described in Section 4.1, despite the forest has been cut down after 2007. Such omissions could not be found by applying the improvement described in Sections 4.2 and 4.3 as they did not represent a change polygon in the change layer 2007-2015. Other errors that were improved contain for example: omissions in change of the agriculture type between 2007 and 2015, omissions of natural succession of vegetation in mining areas; and omissions in facility for the

production and provision of water, electricity, gas or heat and the roads constructed between 2007 and 2015 (see Figure 4-5).



**Figure 4-5 Examples of omission errors (marked in blue) in LU 2007-2015 change database and its improvement while performing a visual check of dataset for 2007 at scale 1:5.000. The colour composition of the data presents the LU 2007 class codes. The numbers in black present the LU class code in 2007.**

#### 4.5 Quality check and generation of final LU 2007-2015-2018 database

In further step, we verified the correctness of LU class codes in attributes for 2007, 2015 and 2018 with regards to the attributes generated for the changes between 2007-2015 and 2015-2018. We did this by creating an additional temporary attribute named QA in which we assigned unique values for each combinations representing changes, based on assumptions which were:

- If LU2007 = LU2015 = LU2018 and the change attributes are equal 0 then give 1;
- If LU2007 ≠ LU2015 = LU2018 and the change attribute for 2007-2015 is equal 1 and the change attribute for 2015-2018 is equal 0 then give 2;
- If LU2007 = LU2015 ≠ LU2018 and the change attribute for 2007-2015 is equal 0 and the change attribute for 2015-2018 is equal 1 then give 3;
- If LU2007 ≠ LU2015 ≠ LU2018 and the change attributes are equal 1 then give 4;
- If there is any other combination than those described above then give 999 (assign this as an error).

We verified all polygons marked as errors visually and amend changes accordingly.

In the next step, we standardised the naming of final attributes and created attributes representing a textual description of LU classes for 2007, 2015 and 2018. We exported the data to a new geodatabase and created a template colour composition to visualise the LU in a standardised manner for all time stamps.

#### 4.6 Statistics of datasets in LU 2007-2015-2018 geodatabase

The final database consists of attributes for LU 2007, LU 2015 and LU 2018, textual description of LU classes for each time stamp and also attributes for changes between 2007-2015 and 2015-2018 (Figure 4-6). Additionally, each polygon in the database has assigned an attribute of its area, to allow computation of statistics within all LU classes. Table 4-1 provides a general overview of the statistics for all LU classes for 2007, 2015 and 2018 and the area changes of each LU class during this period.

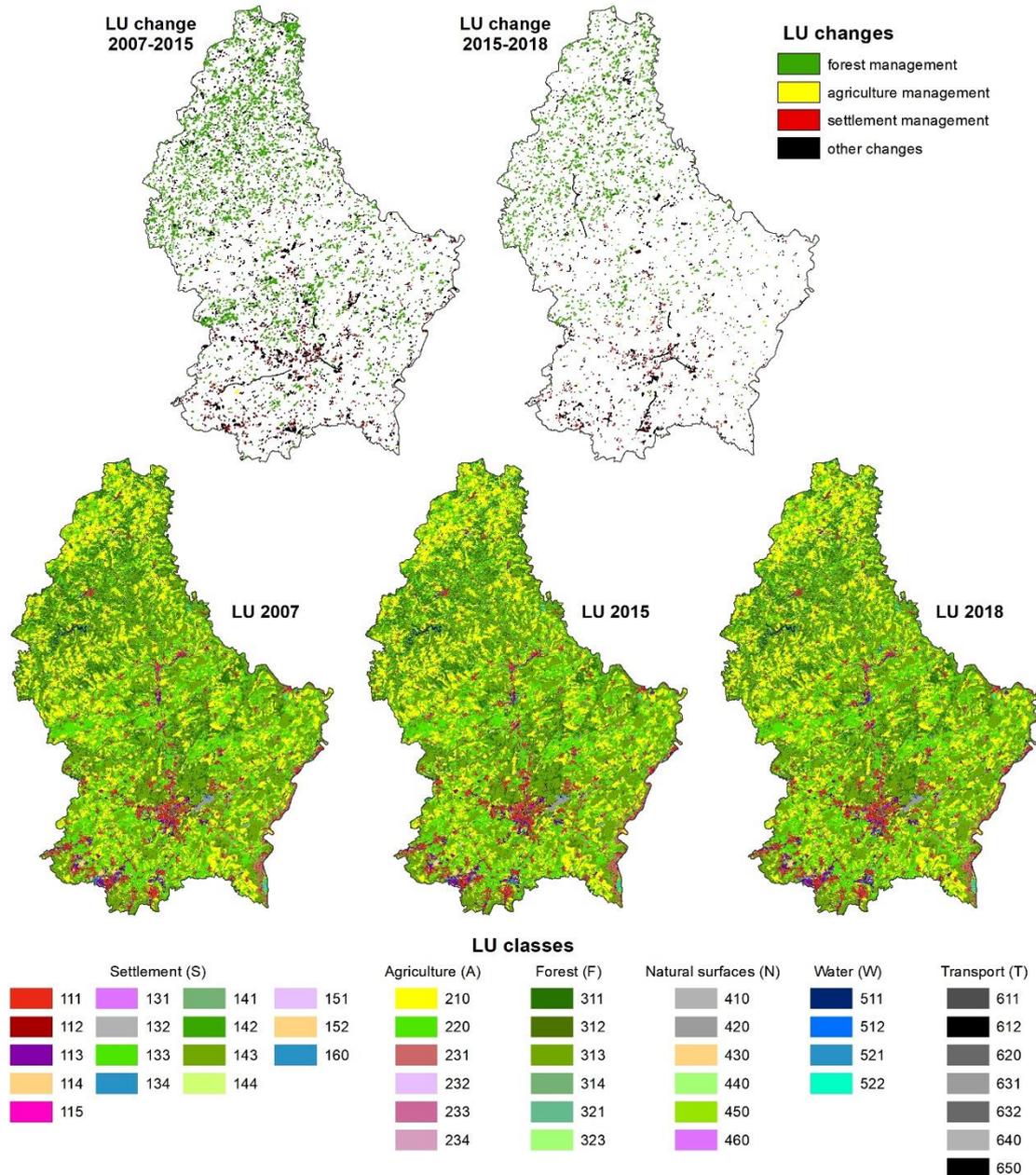


Figure 4-6 Visualisation of LU 2007-2015-2018 database with respect to attributes of: LU 2007; LU 2015; LU 2018; changes between 2007 and 2015; and changes between 2015 and 2018 in the Grand Duchy of Luxembourg.

**Table 4-1 LU class statistics for 2007, 2015 and 2018 and area differences in hectares between LU classes in 2007-2015 and 2015-2018**

LU class	Area in [ha]			Area difference [ha]	
	2007	2015	2018	2007-2015	2015-2018
111	11361.3	11997.7	12159.2	636.5	161.5
112	1316.7	1535.5	1585.5	218.8	50.0
113	2710.5	2982.2	3111.5	271.7	129.3
114	633.0	437.8	343.3	-195.2	-94.4
115	1102.6	1279.0	1299.0	176.4	19.9
131	156.3	156.4	156.3	0.1	-0.1
132	6.7	6.7	6.2	0.1	-0.5
133	754.2	751.3	748.6	-2.9	-2.7
134	541.0	559.8	548.8	18.9	-11.0
141	290.8	290.4	290.4	-0.4	0.0
142	297.0	297.6	297.1	0.5	-0.5
143	389.3	392.5	389.6	3.2	-2.9
144	208.4	206.5	205.3	-1.9	-1.2
151	216.8	234.5	240.3	17.7	5.8
152	426.4	474.9	469.0	48.5	-5.9
160	547.5	522.2	772.5	-25.3	250.4
210	57920.4	57622.5	57447.2	-297.8	-175.4
220	68045.3	67277.3	66938.0	-768.0	-339.4
231	1309.0	1330.5	1330.1	21.5	-0.4
232	93.3	108.3	108.0	15.0	-0.3
233	2647.5	2595.2	2596.0	-52.3	0.8
234	195.4	167.3	176.1	-28.0	8.8
311	23568.7	21370.4	20592.3	-2198.3	-778.1
312	5325.7	3441.4	3421.6	-1884.4	-19.8
313	61982.9	63382.7	63174.6	1399.8	-208.1
314	376.1	955.0	2338.7	578.9	1383.6
321	0.0	0.0	5.3	0.0	5.3
323	1374.1	3348.0	2902.1	1973.9	-446.0
410	21.8	20.9	20.9	-0.9	0.0
420	2.4	2.7	2.7	0.3	0.0
430	310.6	308.0	314.5	-2.5	6.5
440	122.9	22.7	22.1	-100.2	-0.6
450	4194.9	4251.5	4233.4	56.6	-18.2
460	230.3	230.3	230.9	0.0	0.6
511	709.7	709.3	709.3	-0.4	0.0
512	90.5	90.4	90.0	0.0	-0.4
521	19.8	20.1	20.1	0.3	0.0
522	338.2	337.4	340.5	-0.7	3.1
611	2989.8	2997.4	3001.6	7.6	4.1

LU class	Area in [ha]			Area difference [ha]	
	2007	2015	2018	2007-2015	2015-2018
612	5286.1	5365.9	5410.2	79.8	44.3
620	473.3	470.9	488.9	-2.4	18.1
631	366.9	374.5	380.9	7.6	6.4
632	14.5	14.5	14.5	0.0	0.0
640	20.9	22.0	22.0	1.1	0.0
650	317.1	344.2	351.5	27.0	7.3
<b>Grand Total</b>	<b>259306.5</b>	<b>259306.5</b>	<b>259306.5</b>	<b>0.0</b>	<b>0.0</b>

## 5 DELIVERY

The LU 2007-2015-2018 geodatabase contains three attributes with LU information for: 2007, 2015 and 2018, as well as textual description of LU classes. Additionally, it contains two attributes with information about the change in LU between 2007 and 2015, and between 2015 and 2018 saved as 0/1 numbers, where 1 means a change and 0 means no change. We also provide a layer with a standardized colour composition to visualize the data in the same way for each timestamp. The data is not dissolved for the transport thematic block, which means that two polygons representing the same class may be adjacent. This is to allow smooth visualisation of datasets and its faster processing.

## 6 CONCLUSIONS AND OUTLOOK

The aim of the present study was to develop a consistent approach for integrating the LU 2007-2015 change layer with LU database for 2015-2018 in Luxembourg.

In this report, we present a GIS approach for integrating two dataset into one geodatabase that we performed for the entire area of the Grand Duchy of Luxembourg. This approach is based on automatic GIS processing and semi-automatic improvement of the results. The accuracy of the GIS approach is high, which indicates its potential to be used in future LU updates for the entire country of Luxembourg.

A common database is a key when updating the LU in the future, we recommend adding a new attribute to the geodatabase and using the classification for 2018 as input datasets. This allows you to update the map and also correct errors in the input LU. If a technical error is found which was omitted in this project, the LU class can easily be updated backwards for all timestamps existing in the geodatabase. Also technical errors in delineating boundaries can be updated for all time stamps in one step. After each update, we suggest to perform a quality check as described in bullets in Section 4.5 to ensure avoiding random errors in the database.

### 6.1 Suggestions for future update – unifying inconsistencies in LU classes

The LU classes in the LU 2007-2015-2018 database are consistent with respect to the LU nomenclature presented in Annex I. However, some classes or objects that are assigned into specific classes are not specified in detail, and therefore some polygons representing similar objects are assigned into two or more different LU thematic blocks. In the future update, we suggest to define in more detail specific issues that should be unified; especially should be discussed:

- Strict rule in assigning classes 450 and 134 inside urbanised areas;
- Detailed specification of the class 650 – e.g. what kind of parking lot should be assigned into this class, and based on what ancillary data the update could be performed;
- Definition of the class 114 – there are polygons that are classified as 114 in all timestamps and there has never been urban activity in the past, and the polygons are assigned as 114 because they were part of a large change polygon;
- Definition of the class 160 – e.g. whether a construction taking place in a small part of polygon classified as for example 113 is considered as construction and should be split from the former polygon.

## 7 ANNEX I

### Detailed description of 2007, 2015 and 2018 land use classes

The land use classes have been divided into six main thematic blocks:

- Settlement
- Traffic
- Agriculture
- Forest
- Natural and semi-natural surfaces
- Water

#### S – SETTLEMENT

Settlements are built-up surfaces including buildings and their functionally associated surfaces, such as roads, driveways, gardens and other vegetated areas, storage and manipulation/handling places.

Roads for the “inner development” of settlements and traffic lines between settlements are to be included in the “traffic” class. Therefore, settlement patches smaller than the pre-defined minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

#### S.1 – Settlement & Estate

The delineation of settlements can be derived from the orthophoto/satellite image or can be based on the ownership information in the cadastral map.

Based on their use, five settlement types are defined:

**S.1.1 (Class code = 111) – Residential** (>50% of the surface dedicated to residential use);

**S.1.2 (Class code = 112) – Agricultural facilities** (>50% of the surface dedicated to agriculture);

**S.1.3 (Class code = 113) – Industry & commerce** (>50% of the surface dedicated to industry / commerce / trade);

**S.1.4 (Class code = 114) – Unused urban areas or industrial brownfields** (>50% of the surface includes open urban spaces without managed vegetation and that are not currently in use (e.g. are occupied by ruderal vegetation), as well as residential and industrial wastelands, whether contaminated or not);

**S.1.5 (Class code = 115) – Social, Cultural and Other** (>50% of the surface includes cultural and spiritual buildings, health, education, military, train station, administration and public services, indoor sports halls).

A minimum mapping unit of 100m<sup>2</sup> applies to individual objects of settlement types.

The separated LIS-L land cover map can be used to assess the density of the settlement classes (4<sup>th</sup> level). The LIS-L land cover layer has a spatial resolution of 1m<sup>2</sup> and can be used to attribute density to existing land use objects.

### S.3 – Public facilities

- >50% of the surface includes cemeteries (**S.3.1; Class code = 131**), town squares (**S.3.2; Class code = 132**), parks and playground (**S.3.3; Class code = 133**) or other public facilities (**S.3.4; Class code = 134**; e.g. includes urban areas unused for recreational activities that are covered by significant green vegetation (e.g. green roundabout) and cannot be merged to the road network). A minimum mapping unit of 500m<sup>2</sup> applies.

### S.4 – Sport and leisure

- >50% of the surface includes golf courses (**S.4.1; Class code = 141**), campgrounds (**S.4.2; Class code = 142**) or other sports facilities (**S.4.3; Class code = 143**; e.g. football, tennis, indoor/outdoor swimming-pools). A minimum mapping unit of 500m<sup>2</sup> applies.
- Includes other recreation facilities (**S.4.4; Class code = 144**) like allotment gardens and picnic areas. A minimum mapping unit of 500m<sup>2</sup> applies.

### S.5 – Technical infrastructure

- Facility for the production and provision of water, electricity, gas or heat as well as for the evacuation, disposal or recycling of waste material or wastewater (**S.5.1; Class code = 151**). A minimum mapping unit of 500m<sup>2</sup> applies.
- Mining and extraction areas (**S.5.2; Class code = 152**). A minimum mapping unit of 500m<sup>2</sup> applies.

**S.6 (Class code = 160) – Construction sites** (Areas that are characterized as a construction site at the time of aerial survey, regardless of future use, e.g. street, commercial, housing). A minimum mapping unit of 500m<sup>2</sup> applies.

## T – TRANSPORT

Transport includes all connecting roads between settlements (**T.1.1 – Rural roads; Class code = 611; T.1.2; Class code = 612 – Main roads**), railway facilities (**T.2; Class code = 620**), airports (**T.3.1; Class code = 631 – commercial; T.3.2; Class code = 632 – sports & leisure**), harbours (**T.4; Class code = 640**), parking lots (**T.5; Class code = 650**). A minimum mapping unit of 100m<sup>2</sup> applies to T.1.1 and T.1.2; a minimum mapping unit of 500m<sup>2</sup> applies to the other subclasses. Still, patches smaller than 500m<sup>2</sup> can be found in the final map when resulting from contiguous parcels split by the road network.

Traffic does NOT include single buildings. Only functionally associated buildings (e.g. service areas, gas stations, road maintenance depot) are included here.

Sub-classes are not foreseen, except for roads and air traffic.

## A – AGRICULTURE

The classification of agricultural areas differentiates between three main land use categories: arable land, grassland and special crops.

Similar to “settlements”, which include individual buildings and their surroundings (e.g. urban gardens), individual fields are grouped into agricultural blocks which are delineated by roads, water courses or hedgerows.

A minimum mapping unit of 500m<sup>2</sup> applies. Patches smaller than the minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

### **A.1 (Class code = 210) – Arable land**

Arable land can encompass various land cover classes, such as bare soil (fallow land), herbaceous (crops) and even woody (coppice < 30 years) vegetation.

A differentiation by crop type is not foreseen.

### **A.2 (Class code = 220) – Grassland**

Contrary to “arable land” the grassland class is characterised by the lack of bare soil during the year (i.e. no ploughing). Nevertheless, woody vegetation can occur (orchards or surface overgrown by bushes).

The frequency of mowing can be included as a sub-type indicator of the management intensity, but it needs multi-temporal or other ancillary data to be distinguished.

### **A.3 – Special crops**

Special crops include wine, fruits, orchards and other special crops (e.g. hop):

- Wine (sub-type **A.3.1; Class code = 231**) includes surfaces in flat as well as hilly terrain, with or without vegetation in between the rows.
- Fruits trees (sub-type **A.3.2; Class code = 232**) – contrary to orchards (sub-type **A.3.3; Class code = 233**) – are characterised by the linear arrangement of the plants.
- Other (sub-type **A.3.4; Class code = 234**) includes agricultural surfaces not included in the previous sub-types, such as greenhouses.

## **F – FOREST**

The thematic block “forest” is mostly composed of the land cover class “woody vegetation”. A “forest” is composed of woody vegetation of surfaces > 500m<sup>2</sup>, although also multiple smaller patches can be classified as forest if overall they achieve a tree cover density of > 10% and a total surface of > 500m<sup>2</sup>.

Analogue to the class “settlement” and “agriculture”, forest classes are delineated by “connecting” roads and water courses. Therefore, patches of forest classes smaller than 500m<sup>2</sup> can be found in the final map when resulting from contiguous forest parcels split by the road network.

### **F.1 – Forest block**

The following forest types are mapped:

**F.1.1 (Class code = 311) – Coniferous** (>75% coniferous)

**F.1.2 (Class code = 312) – Mixed** (25% < coniferous < 75%)

**F.1.3 (Class code = 313) – Deciduous** (>75% deciduous)

**F.1.4 (Class code = 314) – Young Forest** (It represents forest regeneration / recolonization or natural succession with the mean vegetation height between 0.5 and 3 meters above the ground surface, such as young plants of broad-leaved and coniferous species, with herbaceous

vegetation and dispersed solitary adult trees. If young trees cannot be identified in the plot, then it should be classified into class F.2 – clearing.

### **F.2 – Clearing**

Area inside the “forest” temporarily without woody vegetation cover. Normally a clearing was wooded before and will be wooded again. Temporarily clearings can contain one or more land cover classes (e.g. bare soil or grassland < 500m<sup>2</sup>).

Clearings are mostly caused by normal forestry related activities (sub-type **F.2.3; Class code = 323** = “other”), but can also have specific origins (i.e. forest fire (**F.2.1; Class code = 321**), and storm damages (**F.2.2; Class code = 322**)).

## **N – NATURAL AND SEMI-NATURAL AREAS**

Natural and semi-natural areas are mostly defined and monitored by specific inventories like the “Biotopkataster” and the “Grünlandkartierung”. The delineation of these sites is a-priori defined by these specific inventories and EO are subsequently used to detect changes within these boundaries.

A minimum mapping unit of 500m<sup>2</sup> applies. Patches of natural and semi-natural elements that are smaller than the pre-defined minimum mapping unit can be found in the final map when resulting from contiguous parcels split by the road network.

### **N.1 (Class code = 410) – Gravel**

Surfaces covered > 50% by land cover class “gravel”.

### **N.2 (Class code = 420) – Rocks**

Surfaces covered > 50% by the land cover class “rocks”.

### **N.3 (Class code = 430) – Natural grasslands**

Surfaces covered > 50% by the land cover class “grassland” that are also in the Biotopkataster mapped as natural or dry grasslands. The key characteristic of dry grasslands is that they have low-growing plants, causing the area to be quite open, and soils that are relatively dry and nutrient-poor.

### **N.4 (Class code = 440) - Heathland**

Surfaces covered >50% by open, low growing woody vegetation (e.g. heath).

### **N.5 (Class code = 450) – Bushes**

Surfaces covered > 50% by the land cover class “bushes”. These areas are often found at the outer perimeter of forests or they represent a succession state from former agricultural use to a forest vegetation, e.g. former vineyards that have been abandoned and left to natural succession.

### **N.6 (Class code = 460) – Wetland**

A wetland is a land area that is saturated with water, either permanently or seasonally. The delineation should be based on specific ancillary data, nonetheless evidence should also be present in the EO data.

## **W – WATER**

The land use block Water includes permanently water covered surfaces, including adjacent, functionally associated areas such as slopes, riparian vegetation and foot paths.

### **W.1 – Running water**

Permanently flowing water. Delineated is the water course itself plus the immediately adjacent water influenced area, e.g. 30-year flood return period. A minimum mapping unit of 500m<sup>2</sup> applies.

#### **W.1.1 (Class code = 511) –Natural**

Water course of natural origin (e.g. river, creek).

#### **W.1.2 (Class code = 512) –Artificial**

Man-made water course (e.g. channel).

### **W.2 – Standing water**

Spatial information about the distribution of lakes and reservoirs is essential for the effective management of competing uses, such as flood and fire control, drought mitigation, agricultural irrigation, recreation, etc. Therefore, for this class, a minimum mapping unit of 100m<sup>2</sup> applies.

#### **W.2.1 (Class code = 521) –Natural**

Water body of natural origin (e.g. lake).

#### **W.2.2 (Class code = 522) –Artificial**

Man-made water body (e.g. reservoir).