LAMASUS
Land Management for Sustainability

D2.2 Protocol for Updating the Land Use Management (LUM) Geodatabase

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101060423. The information and views set out in this deliverable are those of the author(s) and do not necessarily reflect the official opinion of the European Union. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein.

Funded by the European Union

Grant Agreement	101060423
Call identifier	HORIZON-CL6-2021-GOVERNANCE-01
Project full title	Land use and management modelling for sustainable governance
Work package	WP 2
Due date	31/01/2026
Deliverable lead	IIASA
Authors	Linda See, Zoriana Romanchuk, Orysia Yashchun

Abstract

This is a supplementary document to the LAMASUS policy brief Integrating Pan-European Data Sets Improves Spatial and Temporal Characterisation of Land Use Management. Here, we describe the protocol for updating the Land Use Management (LUM) geodatabase in the future, focusing on updates to 2024. This includes high-level step-by-step instructions to update the LUM geodatabase with the current methodology. It also provides a comprehensive overview of new data sets that have become available since the release of the LUM geodatabase, which could be used to improve the characterization of LUM across Europe but would also require updates to the methodology (and potentially modifications to the management classes). The penultimate section considers an outlook to the future in terms of technological developments, i.e., Artificial Intelligence (AI) and the availability of new hyperspectral satellites, both of which could substantially impact our ability to map land use management in the future. Finally, the protocol addresses the issue of dynamic land cover mapping, which is currently provided by companies such as Google and ESRI, and how this relates to the dynamic updating of land use management.

Keywords

Land use management, geodatabase, forest, cropland, grassland, updating protocol

Internal Technical Auditor	Name (Beneficiary short name)	Date of approval
Task leader	Linda See	09/02/2026
WP leader	Linda See	27/01/2026
Coordinator	Tamas Krisztin (IIASA)	27/01/2026
Project Management Office (PMO)	Eleonora Tan (IIASA)	09/02/2026

Dissemination level

PU	Public, will be published on CORDIS	✓

SEN	Sensitive. Confidential information, only for members of the Consortium (including the EC services)	
Nature of the deliverable		*R*

Table of Contents

List of Tables

Abbreviations

CAPRI	Common Agricultural Policy Regional Impact
CLC	Corine Land Cover
EEA	European Environment Agency
EC	European Commission
ESRI	Environmental Systems Research Institute
EWM	European Wetland Map
JRC	Joint Research Centre of the European Commission
LUCAS	Land Use/Cover Area Frame Survey
LUM	Land Use Management
MLLM	Multi-modal Large Language Model
NDVI	Normalized Difference Vegetation Index
VLCC	Vegetated Land Cover Characteristics

1. Updating the LUM Geodatabase with the Current Methodology

This section provides high-level step-by-step instructions to update the LUM geodatabase with the current methodology. Note that the approach can also be used to update the LUM geodatabase after each six-year cycle of the production of Corine Land Cover by the Copernicus Land Monitoring Service (where the European component is led by the European Environment Agency - EEA) under the assumption that Corine Land Cover in this format will continue.

Step 1: Obtain a new Corine Land Cover (CLC) product

Once the Copernicus Corine Land Cover (CLC) legacy product is released for 2024, it needs to be downloaded along with the change layer that is produced by individual countries. This change layer captures actual changes in land cover and land use between 2024 and 2018 (i.e., the last release) rather than changes detected by the remote sensing classification algorithm. Ideally, a 2024 accounting version would be released by the European Environment Agency, but if this is not available, the change layer will be used.

Step 2: Create annual time series

This step is only necessary if an annual time series of CLC (covering the individual years 2019 to 2023) is required, e.g., to create a LUM layer for an intermediate year such as 2020. Changes in land cover and land use that occurred between 2018 and 2024 are known because they are provided in the change layer. However, the year in which the change took place is not known. Therefore, the year of change must be determined and then assigned to the corresponding year in the time series. Changes can be determined using the following methods:

- Use the annual Corine time series up until 2020 from OpenGeoHub (Witjes et al., 2022) to look for changes that occurred between 2018 and 2020.
- Use the BFAST algorithm to detect changes across the whole time series (Masiliūnas et al., 2021).
- Use the Sentinel-2 time series processed by the Joint Research Centre (JRC) of the European Commission (EC), which consists of monthly composites classified into major land cover types that may capture the date of change.
- Use visual interpretation to examine Sentinel-2 imagery, vegetation profiles (of NDVI – Normalized Difference Vegetation Index) and very high resolution time series from Google Earth to look for the year of change.

The first three approaches are automatic/semi-automatic while the final manual approach would only be used at those locations where automated/semi-automated methods did not detect the year of change. Finally, if no method reveals the date of change, the year of change will be chosen randomly.

Step 3: Update the forest management component of the LUM geodatabase

The first and second versions of the forest management map were produced by the LAMASUS project partner Free University of Amsterdam (VUA) (Oostdijk et al., 2023; Scherpenhuijzen et al., 2025), which includes the publication of their code. Using updated layers on forest cover from Global Forest Watch and forest extent maps from the newly released Copernicus Vegetated Land Cover Characteristics (VLCC) layers, the forest management component can be updated to 2024. However, forest management is a long-term approach so any changes would most likely be related to changes in forest extent rather than forest management practices.

Step 4: Update the cropland management component of the LUM geodatabase

The simplest approach to updating the cropland management component of the LUM geodatabase for 2024 would involve applying the five energy classes from the CAPRI (Common Agricultural Policy Regional Impact) energy layer for 2010 (Rega et al., 2020) to produce 5 classes of cropland management intensity from very low to very high. Although the layer is out of date, there are no plans by the JRC to update this layer to 2020 or later. Moreover, this layer represents the only product that captures different aspects of cropland management intensity (i.e., mineral fertilizers and manure, planting/seeding, irrigation, pesticides, energy used to produce seeds, use of machine and direct consumption of electricity for building maintenance). Hence, the update would mainly be based on changes in cropland extent rather than real changes in cropland management intensity. An advantage of this approach is that there would be spatial and temporal consistency across the years in the LUM geodatabase. See the section below for the other approaches to mapping cropland management intensity, now possible with the emergence of new spatially explicit data sets for Europe.

Step 5: Update the grassland management component of the LUM geodatabase

The method for determining grassland management relies on livestock data. One approach would be to collect more recent livestock statistics from each country in the EU, similar to the approach taken by Malek et al. (2024b). Another approach would be to use an alternative source of livestock data to calculate livestock densities, e.g., gridded livestock data from the agricultural census for 2020 and the agricultural survey for 2023, produced using the method outlined in Skøien et al. (2025) or gridded livestock data for 2020 produced by Parente et al. (2024). The grazing, non-grazing and semi-natural grazing layers would then be updated using the maximum entropy approach outlined in Malek et al. (2024a) using LUCAS (Land Use/Cover Area Frame Survey) data from 2022. The rules outlined in D2.1 The LUM Geodatabase and Area Estimates of Land Use Change to 2018 would then be applied to the relevant CLC classes to allocate these to the 12 grassland management classes.

Step 6: Update urban intensities in the LUM geodatabase

The urban intensities are a straightforward mapping directly from the CLC urban classes in combination with the Copernicus Impervious Density layer for low, medium and high urban intensities, the infrastructure class and the other urban class. A new 10m product was released for 2021. The Copernicus Urban Atlas product is currently being updated for 2021 and 2024, but these are not yet available. Once released, these products can also be used directly in mapping the urban CLC classes to urban intensities.

Step 7: Update wetland classes with data from the ALFAWetlands project

The ALFAWetlands project has produced the European Wetland Map (EWM) (Tegetmeyer et al., 2025), with the latest information on European wetlands and floodplains. This product will be used to correct the wetland class in the Corine 2024 layer, which will then be transferred to the LUM geodatabase to improve information on the location of wetlands.

Step 8: Combine the components into a single layer for each year and aggregate

In this step, the land use management classes for the forest, cropland, grassland and urban components will be combined into a single layer for 2020 and 2024. Any areas that remain will retain their original CLC land cover classes, including the improved wetland information. The layers will then be aggregated to the 1 km grid (to match the grid used by the EPIC crop model) and NUTS2 administrative layers, where each zone contains the shares of land use management classes.

Step 9: Fit LUM layers to official statistics and aggregate

In this step, the layers used to calculate the forest, cropland and grassland probability layers would be updated. The new Copernicus high-resolution Vegetated Land Cover Characteristics (VLCC) layers would be used as one input to update these probability layers in addition to other new or updated global products (e.g., Hansen's stable forest layer, JRC's forest map, the global grassland time series from OpenGeoHub (Parente et al., 2024), etc.). Using the probability layers, the LUM geodatabase for 2024 and 2020 would be modified to reallocate the forest, cropland and grassland management classes to match official area statistics from FAO and Eurostat. The layers would also be aggregated to a 1 km grid and NUTS 2 regions as shares.

Step 10: Calculate areas of transition with uncertainty estimates

The transition matrix between 2018 and 2024 will be calculated based on the change layer for all CLC classes or for aggregate classes, e.g., changes to and from cropland. However, robust area estimates with uncertainties require a probability-based sample approach (Olofsson et al., 2013, 2014). This sampling approach was used previously to calculate the transition areas between 2000 and 2018, as outlined in D2.1 The LUM Geodatabase and Area Estimates of Land Use Change to 2018. The following steps would be required to repeat this exercise for 2018 to 2024:

1. Create a sample of locations with change and no change from the CLC/change layer, covering as many types of change as possible.

2. Put the sample into the Geo-Wiki application for the validation of the change using very high resolution time series, Sentinel images and vegetation profiles.

3. Run a campaign with experts and/or citizen scientists to validate the sample with multiple validations at each location for quality assurance purposes.

Calculate the areas of transition and the uncertainty estimates based on the methodology of (Olofsson et al., 2013, 2014), as undertaken previously in D2.1 The LUM Geodatabase and Area Estimates of Land Use Change to 2018.

2. Updating with Changes in Methodology and/or Data Sets

Since the delivery of the LUM geodatabase at the end of August 2024, new data sets of relevance to land use management have appeared (and will continue to appear in the future). These are listed in Table 1. New products on tree height and species can be used to better differentiate wood production from other types of forest management. Cropland management could be defined using new products derived from the Copernicus VLCC layers and gridded agricultural census and survey data from Eurostat. Grassland management can also benefit from the new VLCC layers, in particular the layer on the number of mowing events and the dates of these mowing events, as well as 2022 LUCAS data from the grassland module.

However, incorporating these layers would also require some methodological changes, which could impact the land use management intensity classes (e.g., addition of new classes or modification of class definitions) and would mean some potential incompatibilities with older layers in the LUM geodatabase. This would require careful consideration, and it would need to be discussed with users regarding how these layers would be used. It would also require reprocessing of historical layers.

Table 1: New spatially explicit data sets that could be used to define land use management intensity classes.

Domain	Data Set
Forest	JRC forest cover map for 2020 (https://forobs.jrc.ec.europa.eu/GFC)
	Global data set of tree heights produced by Meta (https://dataforgood.facebook.com/dfg/tools/canopy-height-maps)
	Tree height and tree species maps from PlantNet (to be released in the future)
Cropland	Gridded agricultural census data from 2020 provided by Eurostat on organic farming and size of farm holding (area and economic size)

Domain	Data Set
	Gridded agricultural survey data from 2023 on type of tillage and irrigated area
	Crop rotations and crop diversity based on 7 years of Copernicus VLCC data on crop types
	Presence of cover crops/bare soil from VLCC (based on second crop)
	Temporary grassland from Copernicus VLCC data (combining cropland and grassland layers)
	Pesticide data from JRC (Galimberti et al., 2025)
Grassland	Gridded livestock data from the 2020 agricultural census and number of months of outdoor grazing from the 2023 agricultural survey
	New downscaled livestock products (Parente et al. (2025) for 2020; Du et al. (2025) for 2020 and 2021) available at 1 km resolution
	2022 LUCAS data on grassland and from the dedicated grassland module, which has information on intensive and extensively managed grasslands
	Copernicus VLCC on grassland extent, number of mowing events (up to 3) and the start date of these mowing events
	Managed and semi-natural grassland for 2020 (Parente et al., 2024)

Source: LAMASUS WP 2

3. Other Future Improvements

Since the start of the LAMASUS project in 2022, there have been considerable advances in generative AI with the release of Multi-modal Large Language Models (MLLMs) such as ChatGPT, Gemini and DeepSeek, among others (Patil and Gudivada, 2024). Another major advance has been the release of embeddings, which are vectors of multiple features processed for satellite imagery, which are being used for classification purposes (Google, 2025). An example of their use in cropland mapping can be found in Zvonkov et al. (2025) and is only the beginning of an era that will see many new applications with relevance to mapping land use management. Finally, hyperspectral satellites are being launched, including by Copernicus and the European Space Agency, which could also benefit the detection of land use management-related features.

4. Dynamic Updating of LUM Information

There are new dynamic global land cover maps being generated, e.g., ESRI's (Environmental Systems Research Institute) annual land cover time series available until 2024 (Sentinel-2 Land Cover Explorer) and Google's Dynamic World, updated in near-real time as satellite images become available. However, they only contain a limited number of land cover classes and do not cover land use management. Using the Copernicus VLCC annual product, it would be possible to update the LUM geodatabase annually, although there is often a delay in the release, e.g., 2022 and 2023 have only just been released. Hence, dynamic updating with short lead times is not currently possible, but the use of AI in combination with hyperspectral satellite imagery or satellite embeddings could potentially produce more timely high-resolution land use management products in the future.

5. References

Du, Z., Yu, L., Zhao, Y., Li, Xinyue, Liu, X., Li, Xiyu, Hao, P., Chen, Z., Guo, Z., You, L., Ma, X., Wang, H., 2025. Annual global grided livestock mapping from 1961 to 2021. Earth Syst. Sci. Data 17, 5543–5556. https://doi.org/10.5194/essd-17-5543-2025

Galimberti, F., Bopp, S.K., Carletti, A., Catarino, R., Claverie, M., Florio, P., Ippolito, A., Jones, A., Marchetto, F., Olvedy, M., Pistocchi, A., Verhegghen, A., Van Der Velde, M., Vieira, D., d'Andrimont, R., 2025. Development of a spatial risk indicator for monitoring residential pesticide exposure in agricultural areas. Sci. Rep. 15, 16785. https://doi.org/10.1038/s41598-025-96928-1

Google, 2025. AI-powered pixels: Introducing Google's Satellite Embedding dataset [WWW Document]. URL https://medium.com/google-earth/ai-powered-pixels-introducing-googles-satellite-embedding-dataset-31744c1f4650 (accessed 12.3.25).

Malek, Ž., Romanchuk, Z., Yaschun, O., Jones, G., Petersen, J.-E., Fritz, S., See, L., 2024a. Improving the representation of cattle grazing patterns in the European Union. Environ. Res. Lett. 19, 114077. https://doi.org/10.1088/1748-9326/ad858a

Malek, Ž., Romanchuk, Z., Yashchun, O., See, L., 2024b. A harmonized data set of ruminant livestock presence and grazing data for the European Union and neighbouring countries. Sci. Data 11, 1136. https://doi.org/10.1038/s41597-024-03983-w

Masiliūnas, D., Tsendbazar, N.-E., Herold, M., Verbesselt, J., 2021. BFAST Lite: A lightweight break detection method for time series analysis. Remote Sens. 13, 3308. https://doi.org/10.3390/rs13163308

Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E., Wulder, M.A., 2014. Good practices for estimating area and assessing accuracy of land change. Remote Sens. Environ. 148, 42–57. https://doi.org/10.1016/j.rse.2014.02.015

Olofsson, P., Foody, G.M., Stehman, S.V., Woodcock, C.E., 2013. Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. Remote Sens. Environ. 129, 122–131. https://doi.org/10.1016/j.rse.2012.10.031

Oostdijk, S., Debonne, N., See, L., Scherpenhuijzen, N., Verburg, P., 2023. A forest management map for Europe. https://doi.org/10.34894/HQIJN5

Parente, L., Sloat, L., Mesquita, V., Consoli, D., Stanimirova, R., Hengl, T., Bonannella, C., Teles, N., Wheeler, I., Hunter, M., Ehrmann, S., Ferreira, L., Mattos, A.P., Oliveira, B., Meyer, C., Şahin, M., Witjes, M., Fritz, S., Malek, Z., Stolle, F., 2024. Annual 30-m maps of global grassland class and1 extent (2000–2022) based on spatiotemporal Machine Learning. Submitted.

Patil, R., Gudivada, V., 2024. A Review of Current Trends, Techniques, and Challenges in Large Language Models (LLMs). Appl. Sci. 14, 2074. https://doi.org/10.3390/app14052074

Rega, C., Short, C., Pérez-Soba, M., Luisa Paracchini, M., 2020. A classification of European agricultural land using an energy-based intensity indicator and detailed crop

description. Landsc. Urban Plan. 198, 103793. https://doi.org/10.1016/j.landurbplan.2020.103793
Scherpenhuijzen, N., West, T.A.P., Debonne, N., Oostdijk, S., Adame, P., Astrup, R., Verburg, P.H., 2025. Mapping forest management regimes in Europe. For. Ecol. Manag. 594, 122940. https://doi.org/10.1016/j.foreco.2025.122940
Skøien, J.O., Lampach, N., Ramos, H., Seljak, R., Koeble, R., See, L., van der Velde, M., 2025. A flexible approach for statistical disclosure control in geospatial data. J. Geogr. Syst. 27, 341–367. https://doi.org/10.1007/s10109-025-00472-5
Tegetmeyer, C., Kaiser, M., Barthelmes, A., 2025. The European Wetland Map ('EWM'). https://doi.org/10.5281/ZENODO.15302184
Witjes, M., Parente, L., Van Diemen, C.J., Hengl, T., Landa, M., Brodský, L., Halounova, L., Križan, J., Antonić, L., Ilie, C.M., Craciunescu, V., Kilibarda, M., Antonijević, O., Glušica, L., 2022. A spatiotemporal ensemble machine learning framework for generating land use/land cover time-series maps for Europe (2000–2019) based on LUCAS, CORINE and GLAD Landsat. PeerJ 10, e13573. https://doi.org/10.7717/peerj.13573
Zvonkov, I., Tseng, G., Becker-Reshef, I., Kerner, H., 2025. Cropland Mapping using Geospatial Embeddings. https://doi.org/10.48550/arXiv.2511.02923