LUCI Help Documentation

The LUCI team

April 16, 2019

Contents

1 Purpose of this document

The document combines the information from the *LUCI v0.4 help documentation* and the *LUCI 2017 release version Help text-aligned with in the tool help* that was included in LUCItools and the updated help text within the LUCItools ArcMap interface. This document is written for the version of LUCI on SourceTree on the *develop* branch as of 30/01/2019. More information on LUCI including our team and research projects can be found at http://lucitools.org.

2 Overview

The LUCI (Land Utilisation and Capability Indicator) model, is a second-generation extension and software implementation of the Polyscape framework, as described in (Jackson et al., 2013). LUCI explores the capability of a landscape to provide a variety of ecosystem services, such as agricultural production, erosion control, carbon sequestration, flood mitigation, habitat provision etc. It compares the services provided by the current utilisation of the landscape to estimates of its potential capability, and uses this information to identify areas where change might be beneficial, and where maintenance of the status quo might be desirable.

The ecosystem services that LUCI models include:

- Agricultural production
- Erosion risk and sediment delivery
- Carbon sequestration
- Flood mitigation
- Habitat provision
- Water quality – Nitrogen and Phosphorus

2.1 Background

Ecosystem service condition is assigned based on nationally-available datasets (enhanced with local data where available), on topography (raster DEM), stream network (vector polyline format), precipitation and evapotranspiration (raster format), land cover and soil type (vector polygon format). These are linked to lookup tables and processed within the model, with simulation of connectivity through cost distance approaches for habitat and topographic routing for hydrological and associated services. The topographic routing approach enables explicit simulation of movement of water and diffuse pollution over the landscape, as well as identification of features which help to mitigate risk of flash flood and in-stream pollution. The model runs at catchment scale with a fine resolution, enabling assessment of the impact of farm scale interventions at catchment scale. The model also identifies opportunities to improve ecosystem service condition, and these output maps can be used for decision support. Tradeoffs and synergies between individual service provisions are modelled explicitly to support such decision making. The LUCI framework is designed to follow the following principles:

2.2 Availability and requirements for application

LUCI is an evolving tool; the current release version includes the original Polyscape functionality along with additional water quality, data analysis and reporting functions. It requires ESRI's ArcGIS 10.1 or above to run. Documentation and help are included within this document, and additionally embedded within the LUCI software.

LUCI requires three datasets to run and can be enhanced with local data if available:

Table 1: Principles of the LUCI framework.

Practical	**Conceptual**
Can be run using nationally available data; i.e. available everywhere so *relevant to national spatial planning*	Operates at a spatial scale *relevant for field and sub-field level management decisions*
Modular – can embed other models and aspects can be embedded in other models (LUCI is a *framework*)	"Values" features and potential interventions by area affected, not just area directly modified
Fast running to enable "real time" scenario exploration	Addresses trade-offs and searches for "win-win" solutions

1. **Digital elevation model (DEM):** To represent landscape topography and ideally has a grid size of 5x5m to 10x10m, although any resolution data can be used as input. The finer the resolution the more detailed the output

2. **Land cover information:** To represent impacts of different types of vegetation and management on ecosystem services. The land cover information must first be correlated to the existing database of land cover types already supported by LUCI

3. **Soil information:** To represent the effect of soil types on ecosystem services. The soil information must first be correlated to one of the existing soil classification schemes already supported by LUCI

Other optional information that can be used as input include a stream network, rainfall, and evapotranspiration. These are not necessary to LUCI, but their addition improves the accuracy and reliability of LUCI output.

The DEM and stream network (if available) generates a hydrologically and topographically consistent DEM to correct for potential artefacts, allowing LUCI to more accurately simulate the flow of water through the landscape. Together with the land cover and soil information, LUCI generates a baseline scenario that feeds into determining the spatial distribution, supply, and opportunities of the individual ecosystem services. The land cover information can be amended to explore potential scenarios where the land use or management have changed.

Because of its efficient numerical implementation, LUCI is fast-running and runs at multiple spatial scales, from sub-field to catchment to national planning. LUCI generates a series of ecosystem services maps that show areas of good provision and areas that would benefit from changes in management intervention. Multiple ecosystem services can be compared to identify where trade-offs or synergies in ecosystem services exist.

A number of national datasets are supported for United Kingdom and New Zealand applications; for other countries it is currently necessary to match land cover and soil information into the supported classification systems. Support for a broader range of datasets will be added in the future. Suggested/default parameters are provided with LUCI; see the individual tool documentation for more detail.

Table 2: Services, description, and method of the ES modelled by LUCI.

Service	**Description**	**Method**
Agricultural productivity	Evaluates the potential, current, and optimal agricultural productivity	Based on slope, fertility, drainage, aspect, climate
Carbon stocks and fluxes	Calculates carbon levels at a steady state, potential to increase storage, emissions, and sequestration	IPCC Tier 1 compatible. Based on soil, vegetation, stocking rate, fertiliser

Erosion and sediment	Estimates soil loss from gullies and rill/inter-rill erosion	Uses CTI and RUSLE. Based on slope, curvature, contributing area, land use and soil type
Flood mitigation	Maps locations that are sinks for overland and surface flow, where flow may accumulate, and average flow to all points of the stream and lake network	Topographical routing of water accounting for storage and infiltration capacity as function of soil & land use
Habitat connectivity and suitability	Identifies suitable areas for habitat expansion and protection based on connectivity and characteristics	Cost-distance approach: dispersal, fragmentation, connectivity; Identification of priority habitat by biophysical requirements; Measures of habitat richness, evenness, patch size etc.
Nitrogen and Phosphorus	Maps the terrestrial load of different land cover and soil, accumulation of nutrients through the landscape, pathway to streams, and instream nutrient concentrations	Export coefficients (land cover, farm type, regional fertiliser, stocking rate) combined with water and sediment delivery models
Coast/floodplain inundation risk	Creates an indicative map of areas that could potentially be inundated by storm surge or long term rise	Based on topography and input height of storm surge/long term rise etc: surface and groundwater impacts estimated
Trade-offs/synergy identification	Identifies areas where management interventions may enhance or degrade multiple services	Various layering options with categorised service maps; e.g. Boolean, conservative, weighted arithmetic, distribution plots

2.3 Summary of included tools

- Preprocessing tools
  - Generate Baseline
- Individual Ecosystem Services
  - Agricultural Productivity
  - Carbon Stocks and Fluxes
  - Erosion and Sediment
  - Flood mitigation
  - Habitat connectivity
  - Habitat suitability
  - Nitrogen
  - Phosphorus
  - RUSLE
- Batch run and tradeoffs
  - Batch run ecosystem services
  - Load Outputs for Multiple Services

- Tradeoff maps

- Aggregation and disaggregation tools
  - Report aggregate habitat metrics
  - Report aggregate input statistics
  - Report aggregate single service statistics
  - Report aggregate soil metrics
  - Report aggregate tradeoff statistics

- Miscellaneous
  - Calculate stream and study area statistics
  - Change user settings
  - Clean geodatabase
  - Clip and buffer raster
  - Clip data in folder
  - Clip LUCI Subset Output
  - Create Polygon Grid
  - Floodplain inundation
  - Recondition DEM
  - Sea level inundation
  - Show terrestrial flow

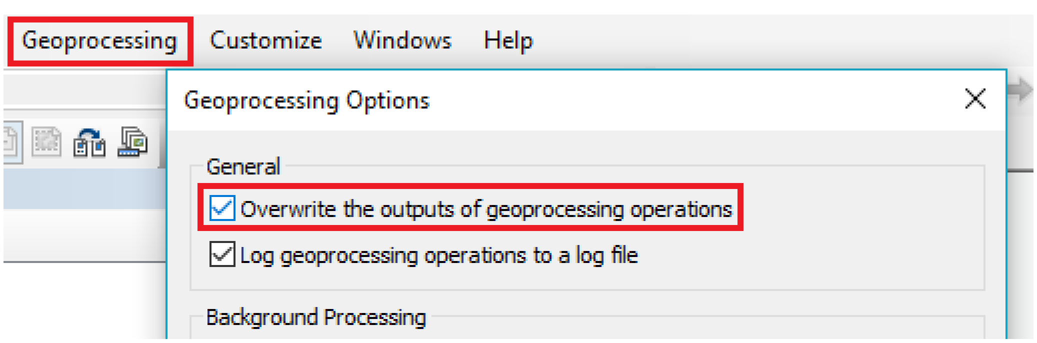
3 Quick Start Guide

LUCI requires ArcGIS 10.4 or higher and the Spatial Analyst license to run. Generally any computer that is able to run ArcMap is able to run LUCI. Installing and using LUCI is done through GitHub, and instructions will be provided upon enquiry. Testing of server-based and web-based LUCI is currently ongoing.

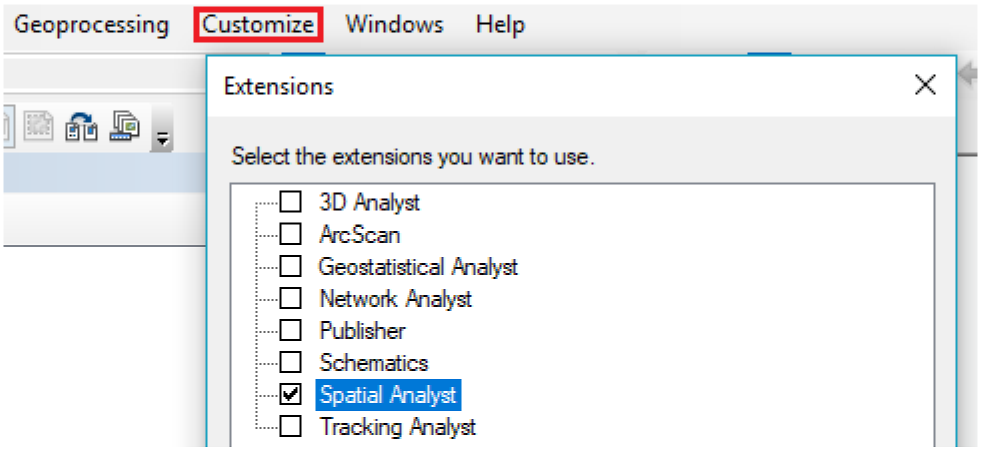
It is recommended to keep the LUCI files within their own folder on a drive where you have write permissions, and ensure that the folder structure is intact. The files must not be placed on in a OneDrive folder and the path to the files must not have any spaces. LUCI is likely to run much slower if it is put on a network drive, or is writing output to a network drive. We suggest using a local drive on your computer (e.g. the C drive). There are also significant speed increases when writing to solid state drives and to machines with ample memory.

3.1 Setting up LUCI on ArcMap

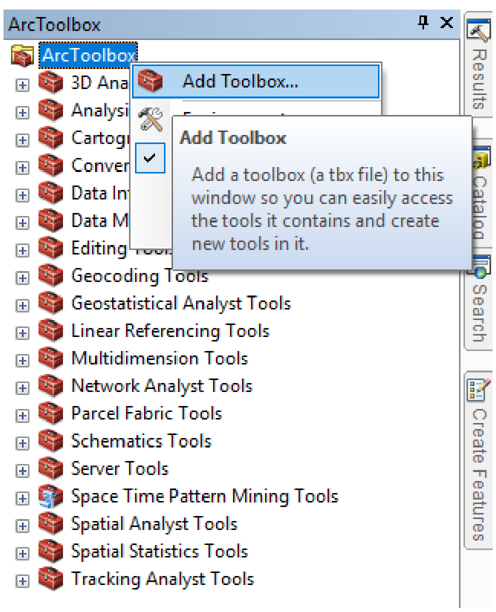
1. **Ensure geoprocessing results are set so they can be overwritten:** Go to *Geoprocessing* > *Geoprocessing Options...*. Check "Overwrite the outputs of geoprocessing operations".

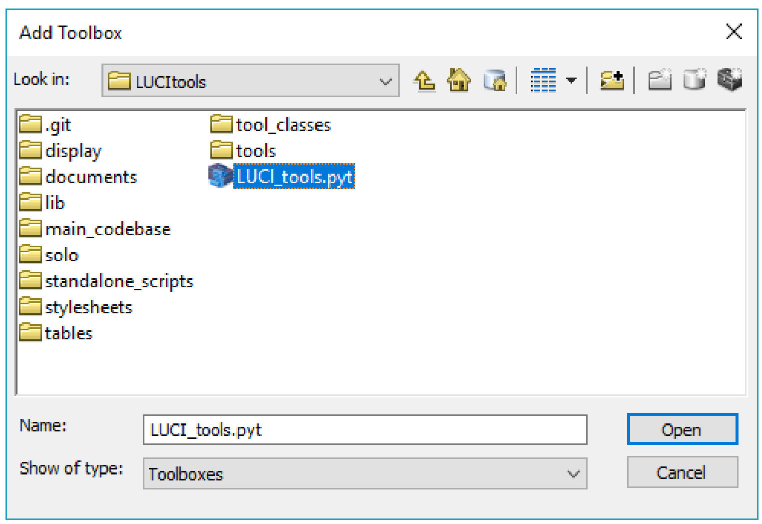


2. **Ensure spatial analyst license is enabled:** Go to *Customize >Extensions...*. Check "Spatial Analyst."



3. **Load LUCI for use within ArcMap:** Through the ArcToolbox window, right-click on *ArcToolbox* and select *Add Toolbox...*. Navigate to where you have stored the LUCI files and under the *LUCItools* folder, select the *LUCI_tools.pyt* file and click *Open*. A toolbox called *LUCI General Release Tools v0_8* will be added to your ArcToolbox window. If you would like LUCI to be automatically loaded into all future sections, right-click on *ArcToolbox* again once LUCI has loaded in, select *Save Settings* and *To Default*. If you do not do this, each time you use LUCI you will need to load the toolbox to your ArcMap session first.





LUCI is now ready to run. Here are a few technical guideliness for running LUCI:

- Please note there are a number of ArcGIS bugs that intermittently interrupt LUCI operations that are beyond our control: please exit ArcMap and start again if you have any error messages that do not give any guidance on what might have gone wrong, or relate to not being able to write or overwrite a file to a location.
- At the end of almost every tool is the **Rerun** parameter, which will continue the previous run from the point where any errors occurred.

- If restarting a second or third time does not fix the problem, please detail the error message to info@lucitools.org including a screenshot of the error and the data used if possible.
- The most common issues are caused by ArcGIS either switching its default location for writing intermediate files to a system directory without write permission part way through calculations, or failing to release a "hold" on files so that they cannot be overwritten, or become corrupted and cannot be properly deleted.
- If you are running ArcGIS using a network license, you also risk crashes or "hanging" if your network is not always working or there are problems with your network license. ArcGIS checks this license regularly and will stop geoprocessing anytime it cannot verify the license.
- You should also regularly clean out your default geodatabase which holds temporary ArcMap calculations, using ArcCatalog. Within ArcMap, this can be found by clicking *File >Map Document Properties...* and looking at the location in the resulting dialogue box. This should be pointing to a local drive if at all possible.

3.2 Order of tools to run

Some of the LUCI operations require tools and algorithms to be carried out in a particular order, as defined below:

1. **Preprocessing:** First, use the *Generate Baseline* tool to generate the hydrological, climate, land use, and soil information LUCI requires to run the other tools. The resulting files define the topography and routing pathways for water, sediment, nutrients, etc. along with various site-specific parameters. This needs to be rerun each time a new land management scenario is being considered. This first step is the most computationally intensive, and should be carried out before field engagement.
2. **Run ecosystem services:** Any of the tools under *Individual Ecosystem Services* can now be run in any order. Alternatively, the *Batch run ecosystem services* tool can be run to generate the outputs for multiple services. The output from the batch run tool is also used as input to the tradeoffs tool.
3. **Identify tradeoffs:** Use the *Tradeoff maps* tool to generate maps that identify tradeoffs or synergies.
4. **View outputs:** All tools produce a PDF with the main output maps and summary tables produced by the tool. This PDF is found under the output folder with the same name as the tool. At the end of almost every tool is the **Generate PNG maps and graphs** option. When ticked, the tool will produce maps and graphs of the output that can be found under the *Images* folder inside the output folder

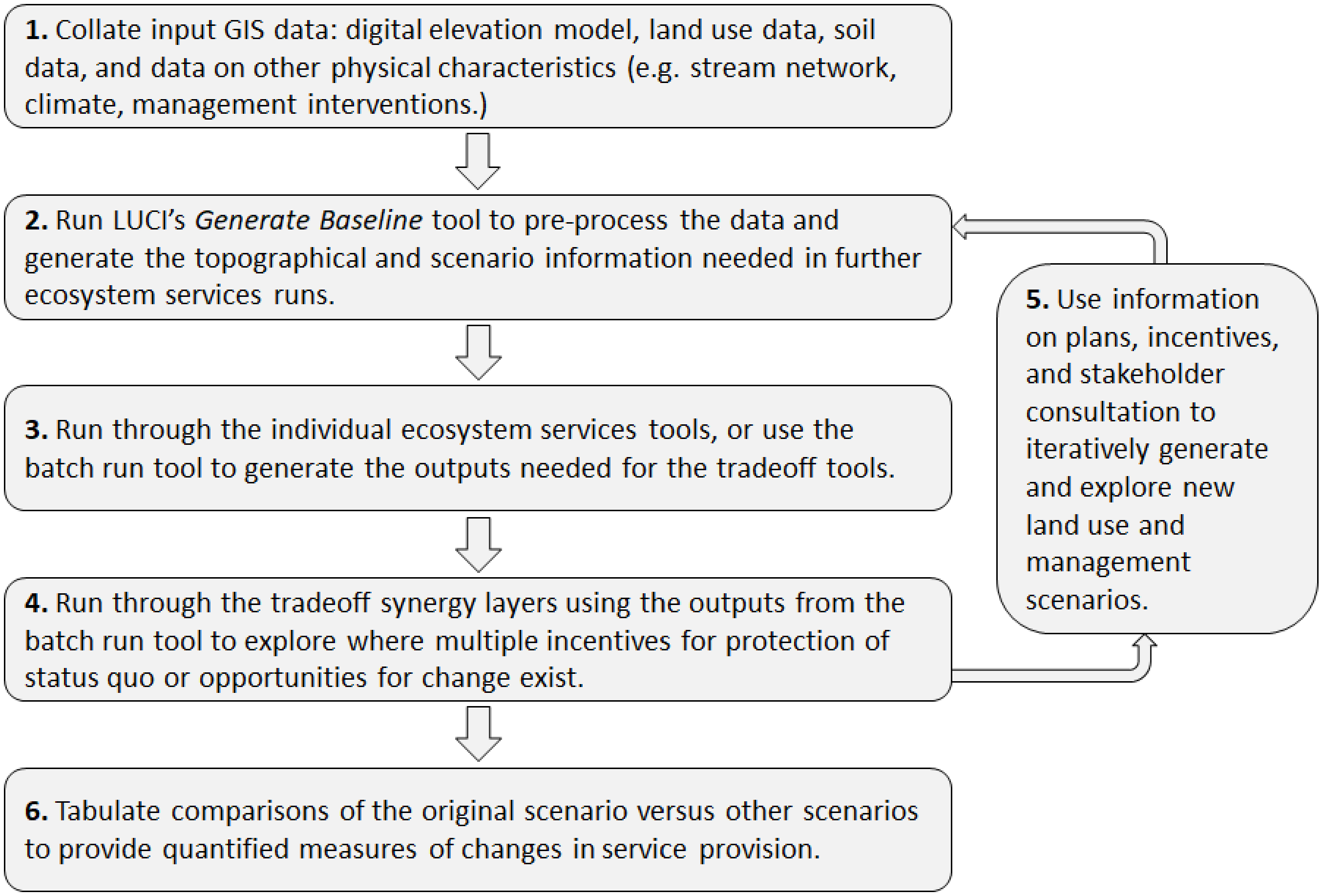


Figure 1: Sample workflow for LUCI applications.

3.3 Exploring different scenarios

There are two options for running land cover or management change scenarios through LUCI. Ensure that the land cover classification of the new or amended land cover is aligned with the original land cover file used to generate the first scenario. For example, if the original land cover has a field called "CLASS_2012," then the new land cover must also have this field and the corresponding land cover values in the attribute table.

1. **Using new land cover information for the entire study area:** For large-scale changes or future land use management plans, the new land cover shapefiles can be used as input to the *Generate Baseline* tool as long as they have full coverage for the application region.

2. **Using new land cover information that partially covers the study area:** If only small areas within the study area are being changed, a shapefile containing partial coverage can be used as input. Within the *Generate Baseline* tool and under *7 More land cover parameters*, input this shapefile into the *Detailed or corrected land cover (optional)* parameter. This overwrites the original land cover and reruns the scenario generation.

4 Preprocessing Tools Guide

4.1 Summary

The only preprocessing tool within LUCI is the *Generate Baseline* tool which must be run before any ecosystem services tools, and rerun to produce new land cover scenarios. The purpose of the preprocessing is two-fold:

- Generate the hydrological and topographical information by reconditioning the input DEM by filling depressions and using an approach based on the AGREE method to burn river networks into the elevation data.
- Generate the land management scenario using the soil and land cover provided by the user and comparing the classes to lookup tables that have the information required by LUCI's ecosystem services

4.2 Input

- **Output folder for LUCI Baseline:** Specify the path and folder name where output from this tool should be stored.
- **Digital elevation model (DEM):** The DEM should be in GRID format and the recommended spatial resolution for use in LUCI is 5 to 10 m. The choice of resolution is very important. LUCI produces quantification and classification of ecosystem performance at the grid square scale i.e. for every grid square. If the DEM data is coarse, but vegetation, soil or other input data is of fine resolution, it is recommended that the DEM be resampled to a finer resolution. This is necessary to ensure the effect of, for example, small area vegetation or mangement interventions are accounted for. Resampling will not change topographical routing capabilities though and this will still be limited by the resolution of the original dataset.
- **Study area mask:** This shapefile sets the boundaries or extent for LUCI processing. All other inputs are clipped to the same extent.
- **Include uphill / upstream contributing area?:** Choose from the dropdown options below:
  - *No; calculate farm in isolation:* This option will only consider the farm area and will not consider any area uphill or upstream of the farm, even if it contributes overland, near-surface or stream run-off to the farm.
  - *Yes; include uphill contributing areas:* This option considers the farm plus a surrounding area. The surrounding area includes hillslopes which route overland and near-surface flow of water and diffuse pollution into the farm. **Note:** If using this option, the land use and soil shapefiles are recommended to have the same coverage of the DEM.
  - *Yes; include uphill areas plus upstream watersheds:* This option considers the farm plus a surrounding area. The surrounding area includes hillslopes which route overland and near-surface flow of water and diffuse pollutants into the study area, as well as watersheds draining streams that enter the farm. **Note:** If using this option, the land use and soil shapefiles are recommended to have the same coverage of the DEM.
- **Land cover dataset, land cover data source, and land cover linking code:** These three parameters relate to the input land cover dataset, which must be in polygon format. The land cover data source is specified in the table below. The land cover linking code is the main identifier field in the input land cover attribute table and is associated with the land cover classification of that data source. The land cover shapefile **must** have a field with the name of the *Land cover linking code* below and the correct classification. For example, if the user is using the product Land Cover Database 4 (LCDB4), the attribute table of the shapefile must contain the **CLASS_2012** field.

  This input data will feed through into many of the ecosystem service model outputs, so it is important to be aware of errors and uncertainties. These may be due to land use change occurring since the dataset was created, or mis-classification of land cover, due to the way in which remotely sensed data have been processed.

To use another landcover data product, you would need to create a new column in your dataset that correlates to an equivalent value in one of the supported data products; all model output would then be subject to additional error in terms of the differences between real and assigned landcover, in terms of how the model has been parameterised for the supported landcover product.

If you have detailed information about your landcover product to be used within LUCI, you may use user-defined landcover which requires a landcover shapefile and a land cover linking table. This linking table should contain the relevant fields and information to be used by LUCI. This will be used in the parameter *Land cover linking table* below.

Table 3: Land cover products supported by LUCI.

Land cover product	**Land cover linking code**	**Provider**
Land Cover Map 2007 (LCM2007)	INTCODE	Centre for Ecology and Hydrology, United Kingdom
Land Cover Map 2007 BH (LCM2007 BH)	FIELDCODE	Centre for Ecology and Hydrology, United Kingdom
Terrestrial Phase 1 Habitat Survey (CCW Phase I)	CODE	Natural Resources Wales
Land Cover Database 1 (LCDB1)	LCDBCLASS	Landcare, New Zealand
Land Cover Database 2 (LCDB2)	LCDB2CLASS	Landcare, New Zealand
Land Cover Database 3 (LCDB3)	LCDB3CLASS	Landcare, New Zealand
Land Cover Database 4 (LCDB4)	CLASS_2012	Landcare, New Zealand
CORINE Land Cover (CORINE)	GRID_CODE	European Environment Agency
National Land Cover Database 2011 (NLCD 2011)	VALUE	Multi-Resolution Land Characteristics, United States of America

- **Soil dataset, soil data source, and soil linking code:** These three parameters relate to the input soil dataset, which must be in polygon format. The soil data source is specified in the table below. The soil linking code is the main identifier field in the input soil attribute table and is associated with the soil classification of that data source. The soil shapefile **must** have a field with the name of the *Soil linking code* below and the correct classification. For example, if the user is using the product Soilscapes, the attribute table of the shapefile must contain the **SS_ID** field.

  This input data will feed through into many of the ecosystem service model outputs, so it is important to be aware of errors and uncertainties. Soil mapping is often based on a limited number of samples, and the use of other datasets on geology and topography.

  To use another soil data product, you would need to create a new column in your dataset that correlates to an equivalent value in one of the supported data products; all model output would then be subject to additional error in terms of the differences between real and assigned soil, in terms of how the model has been parameterised for the supported soil product.

  If you have detailed information about your soil product to be used within LUCI, you may use user-defined soil which requires a soil shapefile and a soil linking table. This linking table should contain the relevant fields and information to be used by LUCI. This will be used in the parameter *Soil linking table* below.

Table 4: Soil products supported by LUCI.

Soil product	**Soil linking code**	**Provider**
Soilscapes	SS_ID	Cranfield, United Kingdom
NATMAP	MUSID	Cranfield, United Kingdom
Fundamental Soils Layer (FSL)	SOIORDER	Landcare, New Zealand
S-Map	smapSib1	Landcare, New Zealand

- **Gridded annual rainfall (mm):** This gridded raster should contain rainfall values in millimetres (mm) per year. Gridded rainfall is used in conjunction with evapotranspiration data to calculate effective rainfall for input to flow and diffuse pollution routing calculations. If this gridded raster layer is provided, accumulation of water, sediment and chemicals in the landscape will adjust to respect the overall spatial pattern in evapotranspiration, where appropriate. Lower resolution than DEM is permitted, since data are unlikely to be available at such fine resolution.

  For New Zealand, a 500m gridded data product is available for download with the tool and can be accessed by running the **Initialise LUCI** tool. This provides a good resolution to represent spatial pattern of rainfall, which will increase confidence in model output. This dataset will be used unless user input data on rainfall are provided (e.g. for climate scenarios).

- **Annual rainfall value (mm):** Specify the annual rainfall amount received by the study area in millimetres (mm) per year.

- **Gridded annual evaporation (mm):** This gridded raster should contain evapotranspiration values in millimetres (mm) per year. Gridded evapotranspiration data is used in conjunction with rainfall data to calculate effective rainfall for input to flow and diffuse pollution routing calculations.

  For New Zealand, a 500m gridded data product is available for download with the tool and can be accessed by running the **Initialise LUCI** tool.

- **Annual evaporation value (mm):** Specify the annual evaporation value of the study area in millimeters (mm) per year.

- **Stream network option and Stream network:** These parameter influences where LUCI places streams in the study area. Choose from the dropdown options for *Stream network option*:

  - *Generate river network directly from DEM:* This option uses the DEM topography to determine where streams should be burned.
  - *Burn in user-defined stream:* This option allows users to define their own stream network. The stream network must be a polyline shapefile. The path to and file name of the stream network must be specified in the Stream network parameter

- **Accumulation threshold for stream initiation, major rivers, and ephemeral streams:** These three parameters influence where LUCI models streams based on the flow accumulation of that cell. Default values are provided for generally temperate environments and hilly topography. For areas with flatter topography, it is recommended to raise the default values by a factor of 5 to 10. It is recommended to iterate through and test which values would produce a stream network closer to reality.

- **Point water additions/subtractions:** This input should contain a point shapefile of locations associated with additions (e.g. springs) or subtractions (e.g. irrigation takes) of water to or from the stream network.

  The data must include an attribute table column, headed 'CUMECS', giving an annual average addition or subtraction in m3/s. Values must be positive for additions and negative for subtractions.

  Including this data will increase accuracy of annual average flow calculations. If the data are not available, possible additions or subtractions should be considered when using stream flow output generated by the model.

- **Force water additions/subtractions to stream network?:** This option should be marked true unless there are known additions or subtractions which are not directly connected to the stream network.

- **Stream smooth drop buffer distance (m), stream smooth drop (m), and stream drop (m):** These three parameters influence the stream reconditioning as seen below:

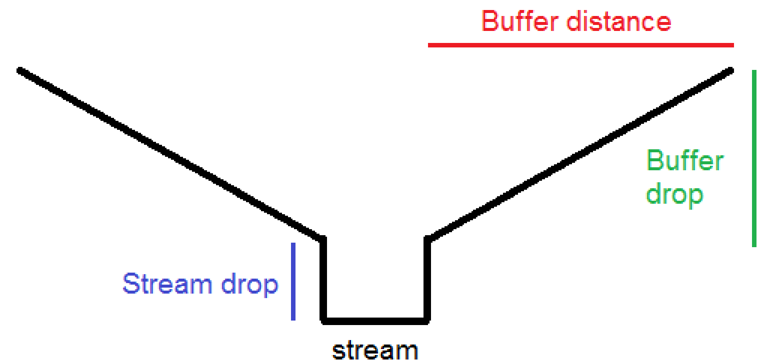


Figure 2: Diagram of the stream reconditioning parameters at the stream cross-section.

- **Minimum lake area threshold (ha):** Specify the minimum area threshold in hectares (ha) for a water body to be considered a lake and for output from that water body to be generated.

- **Determine stream entry and exit points and watersheds:** Check this option to create the point shapefile of entry/exit points and the polygon shapefile of the watersheds.

- **Elevation modifications:** This input should contain a polygon or polyline shapefile of locations where elevation is different to that shown in the DEM. For example, where elevated flood stopbanks are located.

  The data must include an attribute table column, headed 'metres_chg', giving the elevation of the feature in metres. Be wary of putting in small or narrow modifications as LUCI will modify whole DEM grid squares that intersect with each polyline or polygon.

- **Are elevation modifications relative (box ticked) or absolute (box unticked)?:** If this option is ticked/true, input modifications to the elevation are added (for a decrease in height, put a negative number). If it is not ticked/false, the input elevation modifications will be assumed to be absolute, and relative to sea level.

- **Detailed or corrected land cover:** This input should be a polygon with changes to land cover. See the subsection *Exploring different scenarios* above for more information about how to construct this polygon shapefile.

- **Land cover linking table:** For applications that use a land cover classification not already supported within LUCI, the land cover linking table must contain the unique idenfier field of the land cover (e.g. FIELDCODE) and fields that are used within LUCI. To use this, be sure to select *User-defined* in the parameter *Land cover data source* above and to fill in the identifier field in *Land cover linking code*. This option is for users who know the fields used by the LUCI algorithms and are familiar with their classification.

- **Detailed or corrected soil data:** Similar to corrected land cover, this input allows corrections to be made to the default or national soil dataset if more specific information is available.

- **Soil linking table:** For applications that use a land cover classification not already supported within LUCI, the land cover linking table must contain the unique idenfier field of the land cover (e.g. FIELDCODE) and fields that are used within LUCI. To use this, be sure to select *User-defined* in the parameter *Soil data source* above and to fill in the identifier field in *Soil linking code*. This option is for users who know the fields used by the LUCI algorithms and are familiar with their classification.

- **Soil data disaggregation:** Specify the integer code to indicate if England and Wales carbon model will be run, and if so what level of disaggregation to apply. If modelling outside England and Wales, or not planning to model carbon, this should be set to 0.

For England and/or Wales, if planning to run for fully disaggregated England and Wales carbon, this should be set to 15. An updated or scenario land cover layer can then be supplied if desired, or the model can be applied to calculate potential for sequestration under maximum soil carbon storage scenario.

The model can also be run according to values applied by the UK carbon LULUCF inventory level. To do this, soil disaggregation should be set to 14. This method uses the UK LULUCF inventory values to estimate carbon for land cover change, hence it will be necessary to also supply an updated or scenario land cover layer so that the model can apply inventory values for landcover change.

- **Soil sibling handling option:** This is specific for applications using the Smap dataset in New Zealand. Smap links a number of soil types or 'siblings' to each soil polygon. This option identifies which soil sibling or combination of siblings to consider.
  - *Use dominant soil sibling:* This option considers only the main or dominant soil sibling.
  - *Use weighted average of soil siblings:* This option considers all soil siblings, weighted according to their prevalence within each polygon.
  - *Choose random soil sibling according to probability of coverage:* This option considers one soil sibling, which is chosen according to the probability of coverage.
- **New land cover or Scenario:** This polygon shapefile is a required input if you plan to run the England and Wales carbon model for the LULUCF level of soil aggregation (code 14). It is an optional input for the fully disaggregated carbon model (code 15). This layer must have the same "land cover linking code", i.e. main identifier code, as the input land cover.

4.3 Output

None of the files produced by this tool are considered to be fundamental LUCI output, rather they are intermediate files for use by the single services functions described later. The output folder contains a variety of rasters and shapefiles used by LUCI to generate various single services calculation.

5 Individual Ecosystem Services tools

All of the individual ecosystem services tools requires the output from the **Generate Baseline** tool. Each tool generates files and several are loaded to the screen with the correct symbology and the legend. The key outputs are written to a PDF file that can be found within the output folder. If desired, the key maps and tables can be generated in PNG format by ticking the *Generate PNG maps and graphs* parameter. These maps and tables can be found under the *Images* folder of the output folder.

If a tool fails, the user can re-run the tool through the Results window and tick the *Rerun tool (will continue previous run from the point where any errors occurred* option. This only works if the relevant files such as intermediate and temporary files are still within the scratch folder and have not been erased.

5.1 Agricultural Productivity

5.1.1 Summary

This tool evaluates potential agricultural productivity of the land according to simple criteria (slope, fertility, aspect and drainage). The model calculates predicted optimal agricultural utilisation based on soil type, using assigned values of fertility and waterlogging (yes, no or seasonal) and topographic data, using calculated values for aspect slope and elevation. If desired you can weight this calculation to increase soil fertility values to account for farmer effort and management which may be applied due to low production potential in the region containing your study area. Current agricultural utilisation will be mapped according to the land cover data, ranking land use from highest productivity to lowest: Arable; Improved grassland; Unimproved grassland; Woodland and heath; Bog sand and rock. An output for relative utilisation is calculated from comparison of current and potential utilisation.

As input, this tool requires the outputs from the **Generate Baseline** tool. Output from this tool can be used to assess where land may be under or over utilised. The tool can also be used to identify areas of more productive land, where farmers may be less willing to make changes, and areas of less productive land,which could be targeted for re-wilding or afforestation.

5.1.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Slope threshold (degrees) for very productive land:** Maximum slope (in degrees) of very highly productive agricultural land. This can be changed to respect regional agricultural practice. If an adjusted value is applied, this should be considered when interpreting model output, in terms of additional management efforts required to enable agricultural production of steeper slopes. When setting this threshold DEM resolution should be considered. For example, use of an overly coarse DEM may mean that smaller areas of steep slope are not detected. *(Default value is 5.)*
- **Slope threshold (degrees) for somewhat productive land:** Maximum slope (in degrees) of somewhat productive agricultural land. This can be changed to respect regional agricultural practice. If an adjusted value is applied, this should be considered when interpreting model output, in terms of additional management efforts required to enable agricultural production of steeper slopes. When setting this threshold DEM resolution should be considered. For example, use of an overly coarse DEM may mean that smaller areas of steep slope are not detected. *(Default value is 15.)*
- **Elevation threshold (metres) for improved agriculture:** Maximum threshold in metres above sealevel (m asl) of productive agricultural land. This can be changed to respect regional agricultural practice. If an adjusted value is applied, this should be considered when interpreting model output, in terms of additional management efforts required to enable agricultural production at higher elevations. *(Default value is 350m asl.)*
- **Elevation threshold (metres) for all agriculture:** Maximum threshold in metres above sealevel (m asl) of all agricultural land. This can be changed to respect regional agricultural practice. If an adjusted value is applied, this should be considered when interpreting model output, in terms of additional management efforts required to enable agricultural production at higher elevations. *(Default value is 3000m asl.)*
- **Fertility relative to national standard:** This parameter allows fertility to be adjusted for regional variation to account for the study area being in a low or very low fertility region.
  - *1: standard*
  - *2: low fertility*
  - *3: very low fertility*
- **Save intermediate calculations?:** If this is selected, the intermediate categorisations for agricultural productivity, based on single indicators only (i.e. slope, waterlogging etc.), are saved for user inspection. This will enable consideration of how the component factors affect productivity potential. Saving this data is recommended if slope and elevtaion thresholds are adjusted or soil fertility reweighted because exploration of intermediary data will enable the influence of these user choices to be better understood when interpreting model output.
- **Consider slope in overall valuation?:** Select to consider slope in evaluation of agricultural productivity. This should be applied in areas where slope is a factor in agricultural productivity. If not selected in areas with slopes over relevant thresholds, this may reduce accuracy of output on predicted agricultural productivity.

- **Consider elevation in overall valuation?:** Select to consider elevation in evaluation of agricultural productivity. This should be applied in areas where elevation is a factor in agricultural productivity. If not selected in areas with elevations over relevant thresholds, this may reduce accuracy of output on predicted agricultural productivity.
- **Consider waterlogging in overall valuation?:** Select to consider waterlogging in evaluation of agricultural productivity. This should be applied in areas where waterlogging is a factor in agricultural productivity. If not selected in areas with waterlogging, this will reduce accuracy of output on predicted agricultural potential. Conversely, in areas where all soils are prone to waterlogging and have been artificially drained, it may be more accurate not to apply this variable, and this option should be de-selected.
- **Consider soil fertility in overall valuation?:** Select to consider soil fertility in evaluation of agricultural productivity. If not selected in areas where soil fertility is important this will reduce accuracy of output on predicted agricultural potential. Where management activities aim to overcome issues with soil fertility, it may still be appropriate to select this option, in combination with a soil fertility adjustment of 2 or 3 in "Fertility relative to national standard" above.
- **Consider aspect in overall valuation?:** Consideration of aspect can be adjusted. Choose adjustment desired from dropdown options:
  - *0: no*
  - *1: yes, direct face only*
  - *2: yes, direct face + face-E and face-W*

5.1.3 Output

- **Current agricultural utilisation (util_curr):** This map predicts the current agricultural utilisation from the input land cover product (or land cover scenario), and is therefore reliant on its accuracy. Arable and improved grassland are considered to be highly productive, for example, while bare ground and wetlands are considered to provide no agricultural utilisation. The output is discrete; five categories of production are considered, from very high production (or production capacity) to no production (or production capacity).
- **Predicted optimal agricultural utilisation (util_pred):** This map ignores the input land cover, and instead predicts a near-optimal utilisation based on soil water holding characteristics, fertility, slope and aspect. Flat, well-draining and fertile areas are predicted to have high potential for agricultural production for example, more waterlogged areas or steeper areas have less potential. This model output is dependent on accuracy of user set thresholds and weightings, as well as the soil data layer supplied as input to the scenario pre-processing tool. Uncertainty may also be introduced through model processing, since values for soil fertility and waterlogging are based on estimates or national averages for the soil type, and may not reflect site conditions accurately.
- **Relative agricultural utilisation (util_rel):** This map compares the previous two outputs, and flags where land appears to be over or under-utilised. If both current and predicted utilisation are within one category of each other, land is considered to be appropriately utilised. If they differ by more than one category, LUCI flags where current production appears to be over utilising the land (so may be inefficient farming, or not sustainable), and also where opportunities to increase agricultural production may be present. Any errors in model output for current and predicted agricultural utilisation will propagate through to this data layer.
- **Agricultural utilisation status (util_stat):** This map combines the current and "predicted optimal" output in a different way to the relative utilisation described previously. Rather than being concerned with direction of change (under or over utilisation), it considers whether the current agricultural utilisation may be worthy of preservation or change. Land in appropriate utilisation is considered worthy of protection, areas where land is over or under-utilised are flagged for consideration of change to management. This output is a fundamental input to the trade-off and synergy mapping algorithms within LUCI. Again, errors in model output for current and predicted agricultural utilisation will propagate through to this data layer.

5.2 Carbon Stocks and Fluxes

5.2.1 Summary

For England and Wales: The model first calculates carbon levels at steady state i.e. assuming that land cover is fully established and soil and biomass carbon are no longer in flux. Values are assigned based on the soil and land cover combination, according to assumptions that a) the England and Wales mean for a given soil and landcover combination is broadly representative of the steady state soil carbon where that combination occurs and b) the England and Wales mean biomass carbon for a landcover is broadly representative of the steady state mean value. Values calculated for use in the model are based on the IPCC tier 1 protocols on Climate Change (IPCC); separating carbon into above ground biomass, below ground biomass, deadwood, litter, and soil carbon. The total values for biomass carbon and soil carbon are then fed into the model, to avoid modelling time spent on unnecessary processing.

The model then calculates potential to increase carbon storage over the landscape, by comparing a value of potential carbon stock at equilibrium under a different landcover with the current carbon stock. The model applies a "space for time" substitution to calculate potential for emissions or sequestration, in assuming that any change in carbon storage in soils following landuse change can be estimated based on comparison with data from other sites with the same soils where the new land use is already established. In the case of a supplied landcover change scenario, the second valuation layer is indicative of emissions, whilst in the case of a baseline run, the second valuation layer is indicative of potential for sequestration of carbon, as detailed below.

The values for carbon and land use combinations were based on Bradley et al. (2005), Milne and Brown (1997), and Morison et al. (2012).Values for some soil/land use combinations may be based on expert opinion where data were absent. These calcluations will also be affected by spatial uncertainty in land use and soil layers combined in stage 1.

For New Zealand: The model first calculates carbon levels at steady state i.e. assuming that land cover is fully established and soil and biomass carbon are no longer in flux. Values are assigned based on the land cover, according to assumptions that a) the average value for that landcoveris broadly representative of the steady state soil carbon where that coveroccurs and b) the average carbon for a landcover is broadly representative of the steady state mean value. Values calculated for use in the model are based on the IPCC tier 1 protocols on Climate Change (IPCC); separating carbon into above ground biomass, below ground biomass, deadwood, litter, and soil carbon.

The model then calculates potential to increase carbon storage over the landscape, by comparing a value of potential carbon stock at equilibrium for that soil type with the current carbon stockassociated with the landcover. The model applies a "space for time"substitution to calculate emissions or sequestration, in assuming that any change in carbon storage in soils following landuse change can be estimated based on comparison with data from other sites with the relevant soil or landcover.

5.2.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Very high stock threshold:** Threshold for stocks to be classified as very high that feeds into classification for mapping and tradeoffs. *Default value is 90.*
- **High stock threshold:** Threshold for stocks to be classified as high that feeds into classification for mapping and tradeoffs. *Default value is 50.*
- **Moderate stock threshold:** Threshold for stocks to be classified as moderate that feeds into classification for mapping and tradeoffs. *Default value is 27.*
- **Low stock threshold:** Threshold for stocks to be classified as low that feeds into classification for mapping and tradeoffs. *Default value is 21.*

5.2.3 Output

- **Carbon stock (cstock) and Carbon stock to 30 (CSto30):** This map shows the estimated total carbon storage in the biomass and either top 1m or top 30cm of soil in tonnes/ha. Values are calculated based on soil carbon data for soil type and land-use combinations, and average biomass carbon for each land-cover type. The dataset used depends on the level of aggregation selected in the pre-processing tool; fully disaggregated (*Soil disaggregation value is 15*) uses published soil series level national data from Bradley et al. (2005); Milne and Brown (1997), whereas LULUCF inventory level (*Soil disaggregation value is 14*) uses values taken from the more aggregated inventory approach described in Dyson et al. (2009); Morison et al. (2012).

  Potential sources of error and uncertainty include inaccuracies in user input spatial land use and soil data; in particular, peats are not well accounted for spatially in soil or land use datasets. Accounting will have significant uncertainty, due to use of inventory values of average C for the relevant land use on the relevant soil type; these are often estimated, or based on limited sampling. Actual carbon storage will be strongly affected by site variation from national average conditions.

  Although average and estimated values are not expected to provide an accurate measure of change for individual sites, there is an assumption that errors will balance out at scales relevant for most assessments, particularly for national level inventories. Likely site variation around the mean value applied is strongly affected by the option selected for soil disaggregation; there is much greater variance within the lumped soil types applied in the LULUCF compatible approach. Values for some soil/land use combinations in the fully disaggregated approach may be based on expert opinion where data were absent, increasing uncertainty.

- **Classified carbon stock (cstockclass):** This map is a classified version of carbon stock created both for display purposes and for calculation of inputs to trade-off mapping. Only provided for 1m of soil depth plus biomass, and subject to same sources of error as the non-classified version, in addition to influence from the user-set thresholds. The user provided values for low, moderate, high and very high storage should therefore reflect levels requiring improvements for agricultural purposes or worth protecting to avoid CO_2 emissions.

- **Carbon emission estimation (cemit):** This map predicts the rate of emissions or sequestration of C in tonnes/ha/year. Output will be subject to the same sources of error as the carbon stock maps, in addition to error associated with the space for time substitution approach, since soils may never reach the expected carbon value. There is an assumption that soils will take 150 years to reach the expected value, and output is provided as annual average sequestration or emissions, however soil carbon change tends to follow an exponential curve, and much of the change would occur during the first few years. This approach also fails to account for any initial losses due to soil disturbance etc., which will be strongly affected by land management approaches and timing of activities. Using the fully disaggregated approach, new soil carbon is calculated for the "effective depth" occupied by the same quantity of soil, to give a value for change in carbon that accounts for change in soil density.

  For scenario: In the case of a supplied landcover change scenario, the second valuation layer is indicative of emissions in kg $m^{-2\ yr^{-1}}$, calculated as:

  $$\frac{\text{Scenario total C storage} - \text{ Current total C storage}}{150} \tag{1}$$

  For current land cover: In the case of a baseline run, the second valuation layer is indicative of potential for sequestration of carbon in soils. The scenario with most soil carbon is identified from the average under each land use on the relevant soil type, and sequestration potential thus calculated as:

  $$\frac{\text{Maximum potential soil C storage} + \text{ Associated biomass carbon} - \text{ Current total C storage}}{150} \tag{2}$$

Positive values mapped for carbon change indicate potential to store more carbon in soils and biomass if landcover is changed. Where values are negative for a baseline run, this shows that soils are able to store more carbon under a different landuse, but that reduction in biomass carbon may offset any benefits.

- **Classified carbon emission estimation (cemitclass):** This map is a classified version of carbon emission created both for display purposes and for calculation of inputs to trade-off mapping. Only provided for 1m of soil depth plus biomass, and subject to same sources of error as the non-classified version, in addition to influence from the pre-set thresholds.

  For scenario: If the carbon stock per unit area is reducing under the applied scenario, opportunity to reverse this is flagged. Conversely, where carbon stocks are expected to increase, protection is suggested, and where they are expected to remain static, LUCI will indicate preservation of the carbon stock "status quo".

  For current land cover: If the total carbon stock per unit area has potential to increase under a maximum soil carbon stock scenario, opportunity for interventions to sequester carbon is flagged. Where the current landcover has maximum soil carbon stock, LUCI will indicate preservation of the carbon stock "status quo". Conversely, where total carbon stocks would decrease due to biomass carbon loss under a scenario of land use change to increase soil carbon, LUCI flags these areas as probably unsuitable for change.

  For example, many woodland areas have moderate to high carbon stocks and hence are considered as of moderate to high value according to the carbon stock calculation, and preservation may have been considered. However, if the woodland has been planted onto peat, for example, a reduction in stored carbon (and associated net CO_2 emission) might be anticipated, so interventions to prevent this or revert land use might be appropriate.

- **Carbon status (cstatus):** This map is an assessment of provision of carbon storage and sequestration service which feeds in to the LUCI trade off calculations. It is calculated by combination of classified stock and classified emission layers, and therefore subject to any errors and uncertainties in the creation of these layers. The output maps as good performance anything with high carbon and no loss, as well as areas sequestering or without potential for further carbon storage. Areas with low carbon and no sequestration are mapped as moderate, whilst anything losing carbon, or with potential to gain, or else steady state low carbon is mapped as bad.

- **High SOC (HighSOC):** This map highlights locations which are likely to have significant carbon in total soils and biomass; for example landcover associated with deep peats. The classification is applied where either soil or landcover indicates possibility of large stores, and this helps to account for greater inaccuracies in soil mapping due to the difficulty of gathering data. Potential sources of error include inaccuracies in land use and soil input data, or LUCI classification of land cover as associated with high carbon stores; these are based on general trends and may not be representative of the area mapped. The map is intended to highlight areas which may warrant protection.

5.3 Erosion and Sediment

5.3.1 Summary

This tool identifies areas at risk of erosion and also areas at risk of contributing significant sediment loading into water bodies. Areas of land that are vulnerable to erosion are identified in LUCI using the Compound Topographic Index (CTI) Thorne and Zevenbergen (1990). The CTI represents the erosive potential of overland flow by combining three important factors in this form of soil erosion: water flow magnitude and concentration, slope, and landscape convexity/concavity. Appropriate CTI values can be calibrated to particular landscapes/regions by identifying existing erosion scars and setting threshold values accordingly. Areas of land which are vulnerable to severe soil erosion and at risk of being linked to proximate watercourses by uninterrupted overland flow are identified by combining the erosion information with information on their connectivity to streams (derived from topographical information and soil hydraulic properties); this allows users to identify and prioritise areas of land for sediment delivery mitigation efforts (e.g. buffer zone creation).

5.3.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **CTI threshold for moderate erosion risk:** Specify the Compound Topographic Index (CTI) threshold for moderate erosion risk. *Default value is 50.*
- **CTI threshold for high erosion risk:** Specify the Compound Topographic Index (CTI) threshold for high erosion risk. *Default value is 1000.*

5.3.3 Output

- **Erosion vulnerability (erosion):** This map shows areas at risk from soil erosion. Areas of "opportunity for change" have CTI values exceeding min threshold, while areas of "high opportunity for change" have CTI values exceeding max threshold.
- **Sediment delivery mitigation (seddel):** This map shows areas of land that would benefit from or be suitable for sediment delivery mitigation efforts. Areas of "opportunity" have CTI values that exceed min threshold and have an unmitigated flow connection to a watercourse, while areas of "high opportunity" have CTI values that exceed max threshold and have an unmitigated flow connection to a watercourse. Areas of "high existing value" provide protection by breaking connections of sediment sources to the stream and "marginal" areas are either at negligible risk of contributing substantial sediment or already benefit from features (land use and soil type) that intercept and hence limit sediment delivery.

5.4 Flood mitigation

5.4.1 Summary

This tool maps areas where overland and near surface flow may accumulate as well as "Mitigating features" with the capacity to help mitigate floodsand high stream flow which may follow high intensity precipitation events. Areas with high water storage capacity and/or high infiltration capacity can help to mitigate downstream flood risk by acting as a sink for fast moving overland flow and near-surface subsurface flow; either storing this or routing the water more slowly through subsurface routes. This tool takes information about high storage and/or permeability regions from land use data and corrects flow accumulation using a bespoke algorithm - any flow that accumulates into these mitigating areas is removed from the flow accumulation data and treated as of low priority (mitigation already exists). The tool also calculates the average flow delivery to all points in the river and lake networks, to estimate water supply services.All land use or types that provide flood mitigation are treated as having high existing values; these include woodland, wetland, bog, marsh, scrub and similar natural cover. Areas where a large amount of unmitigated flow mayoccur are treated as priority areas for change. Parameters to define where flow exceeds a threshold for priority can be specified, with default parameters provided.

As input, this tool requires stream network data, a hydrologically consistent digital elevation model (consistent with the stream network and with local depressions removed) and land use data. These inputs are accessed from the folder generated by the **Generate Baseline** tool.

5.4.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Lower threshold for flood mitigation opportunity (relative upstream area caught):** Water accumulation threshold value for land to be considered a significant pathway for transporting water to the stream network. The threshold is specified as a multiplier of the area e.g. if a value of 5 is provided, all land cells that do not have significant mitigation potential (i.e. high permeability and water storage capacity) and that accumulate flow more than 5 times their area from uphill contributions, are considered significant pathways and targets for potential mitigation.

  These thresholds are used to generate classified maps, to identify areas to target with mitigating interventions, and to evaluate improvement opportunities for synergy and trade-off analysis. *Default value is 5.*
- **Lower threshold for very high flood mitigation opportunity (relative upstream area caught):** Water accumulation threshold value for land to be considered a very significant pathway for transporting water to the stream network. The threshold is specified as a multiplier of the area and works in the same way as the previous threshold, but checks for more significant pathways. These are considered highly important target areas for potential mitigation. *Default value is 20.*

5.4.3 Output

- **Flood mitigation classification (mitclass):** This map shows the mitigation classification of the current soil/landuse. Areas that are providing mitigation of flow (e.g., trees, ponds, deep permeable soils or other flow sinks) are shown as pale green, areas that receive mitigation (i.e. water and other mass originating there later flow through mitigated areas before reaching a stream, lake or river) are shown as orange, and areas with low permeability and/or storage that do NOT flow through a mitigated area are shown as red. Potential sources of error include inaccuracies in land use input data or LUCI classification of land cover as mitigating or not-mitigating, as well as failure to account for soil permeability.
- **Flood interception classification (scenflood):** This map shows the flood mitigation layer. High priority areas for targeting modifications are those where unmitigated flood generating land concentrates flow accumulation, and there is potential to make modifications that significantly improve water holding capacity, infiltration capacity, etc. red areas show areas of high flow concentration (large contributing area with no mitigation) and where landscape could benefit from mitigation; areas with negligible flow concentration are shown as orange and areas that are providing mitigation of flow (e.g., trees, ponds, deep permeable soils or other flow sinks) are shown as green. Potential sources of error include inaccuracies in land use input data or LUCI classification of land cover as mitigating or not-mitigating. Failure to account for storage capacity of deep soils in non-wetland areas, or faster runoff in urban areas with paved surface may reduce accuracy of mapping of areas of high and low flood concentration.
- **Classified average water flow (avgflow_class):** Classified version of average water flow created for display purposes (feature class). Subject to same sources of error as the non-classified version. Accuracy is dependent on the use of representative precipitation data, and the approach used to calculate estimated potential evapotranspiration. Changes in land use which will affect evapotranspiration must be considered. Routing is modelled based on topography and river maps, so any inaccuracies in these may also be important.

5.5 Habitat Connectivity (BEETLE)

5.5.1 Summary

The habitat connectivity tool can be applied for identification of suitable areas for habitat expansion and protection. The tool follows a cost-distance approach to evaluating habitat connectivity, following the approach outlined by

Forest Research's BEETLE project (Biological and Environmental Evaluation Tools for Landscape Ecology). LUCI automates this approach, and uses Forest Research's parameters for selected habitats of interest; see Watts et al. (2010), Eycott et al. (2007a), Eycott et al. (2007b) for further information on the approach and its parameterisation.

It is currently only available for UK applications. The approach can be applied for both "generic focal" and actual species of interest, according to the data available and parameters implemented. The application here is for generic focal woodland species; output is therefore reliant on the parameterisation for these species, as well as the accuracy of user-input landcover data.

5.5.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Species of interest:** Specify the species whose habitat connectivity is being modelled. Currently this model defaults to 11 for broadleaved woodland generic focal species. Parameterisation for further species will take place according to LUCI project needs. *Default value is 11.*
- **Minimum area for focal network (ha):** Minimum area (in hectares) for a feature to be considered large enough to provide significant habitat for species of interest. *Default value set to 2ha.*
- **Maximum cost distance through hostile terrain (km):** Maximum cost distance that can be travelled through hostile terrain, in km. This cost distance is a function of distance and permeability of hostile habitats to species of interest. Default was based on work with stakeholders in Pontbren, comparing mapped output for values between 1 and 5. *Default value set to 2.5km.*

5.5.3 Output

- **Habitat connectivity for the species of interest (habconn):** This map shows in dark green the areas of existing habitat of interest. Pale green shows other priority areas of other habitat which is not the habitat of interest being considered but are a priority to conserve. Orange areas show where habitat establishment is possible but exceed the maximum cost-distance travelled. Habitat established here would not be connected to existing habitat of interest. Red areas show areas currently accessible to the species of interest; establishing new habitat in this area would act to extend the existing habitat. It is not saying that the entire red area needs to be established with the habitat of interest; rather it is showing the maximal extent within which new habitat would be connected to existing habitat. Establishing habitat at this edge of this extent will improve connectivity because the distance travelled across 'hostile' terrain to get to this patch is within the maximum cost-distance through hostile terrain threshold. Outside of this extent, too much hostile terrain would need to be travelled and therefore would not improve connectivity. Patches of existing habitat of interest which are below the minimum area for focal network are not considered large enough to be a priority to improve habitat connectivity.

5.6 Habitat Suitability

5.6.1 Summary

The habitat suitability tool uses information on soil type, including soil water holding capabilities, water accumulation potential, geology, estimated water table level, slope and climate as appropriate to evaluate suitable areas for habitat extension or creation according to specific habitat requirements. It is currently only available for UK applications.

5.6.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Habitat of interest:** Specify the habitat of interest.
  - *1: calcaerous grassland*
  - *2: wet grassland/wetland establishment*

5.6.3 Output

- **Habitat suitability (habsuit):** This map shows areas which are suitable for habitat extension/habitat based on catchment physical properties.

5.7 Nitrogen

5.7.1 Summary

The fate of nitrogen in LUCI is currently modelled using an export coefficient approach. The tool combined topographic routing and effective precipitation to calculate the accumulation of water flow over the landscape and delivery to all points in the river and lake networks. The cumulative N export is also computed for every point in the landscape, based on the export associated with the land cover and/or land management classification for each grid cell. The ratio of the estimates of cumulative total nitrogen (TN) export and cumulative flow are then calculated to provide an estimate of the annual average accumulated TN concentration.

The current export coefficients included in LUCI databases are estimates of export of total N, rather than dissolved N. Hence the proportion of assumed particulate vs dissolved needs to be entered as a parameter in this approach. Note that the export coefficients do not account for point sources such as from sewage treatment works and septic tanks. These sources are not presently included in the LUCI water quality layer, so model output may be considered indicative of agricultural contribution to water quality issues. Any additional contribution from urban areas and point sources must be taken into account when the model is applied for predictive assessment of water quality against, for example, water framework directive criteria.

The export coefficients were originally calculated at small-catchment scale. At a finer scale, for example looking at an individual 5m square with no surface drainage, the simulated concentrations cannot reliably be taken as an indication of TN concentrations in soil water. However, once hillslope scale aggregation within LUCI is achieved (as has happened by the time loadings reach water bodies), the scale is consistent with the N loading data.

5.7.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Proportion dissolved vs particulate:** Specify the proportion of N expected to be in dissolved rather than particulate form. *Default value is 0.8.*
- **N concentration threshold 1 (mg/l):** Specify the threshold in milligrams per litre (mg/L) below which accumulated N concentration is to be considered of no concern. In the absence of site-specific information and requirements, 5mg/L is suggested, based on World Health Organisation recommendation of maximum concentration of 11.3mg/L for drinking water. *Default value is 5mg/L.*

- **N concentration threshold 2 (mg/l):** Specify the threshold in milligrams per litre (mg/L) above which accumulated N concentration is to be considered of significant concern. In the absence of site specific information and requirements, 10mg/L is suggested based on World Health Organisation recommendation of maximum concentration of 11.3mg/L N for drinking water. *Default value is 10mg/L.*

- **N critical load threshold 1 (kg/yr):** Specify the threshold in kilograms N per year (kg/yr) below which accumulated N load is considered of no concern. In the absence of site specific information or requirements, 0.1kg/yr is suggested. *Default value is 0.1kg/yr.*

- **N critical load threshold 2 (kg/yr):** Specify the threshold in kilograms N per year (kg/yr) above which accumulated N load is considered of significant concern. In the absence of site specific information or requirements, 1kg/yr is suggested. *Default value is 1kg/yr.*

- **Root zone to stream attenuation factor:** Specify the proportion of accumulated N remaining in the water that is routed to the stream. This parameter reflects N loss from attenuation in the rooting zone. Values from 0 to 1 are appropriate. The value should be set to reflect the proportion of accumulated N remaining in the water routed to the stream. **Note:** Not currently being used in the UK version. *Default value is 0.5.*

- **In-stream attenuation factor:** Specify the proportion of in-stream N which remains in the water i.e. it is not consumed by in-stream processes. This parameter allows consideration of N loss from attenuation in the river network. The default value for New Zealand is based on values extracted from the OVERSEER tool Trodahl et al. (2016). *Default value is 0.5.*

- **Calculate stream statistics (load, concentration and flow accumulation - average and at exit points):** Check box to ensure in-stream statisitcs are calculated.

- **Only generate load (i.e. stop tool once load has been generated):** Check to generate load only. Note: very few users will wish to take this option. *Default is unchecked.*

5.7.3 Output

Within the output folder are additional output files showing instream nutrient concentration, input to lakes, and concentrations at the lake outlet.

- **Nitrogen load (N_load):** This map shows the total nitrogen load (in kg/ha/yr) generated at any point within the landscape. Accuracy reflects that of the input data on land use and the relevant LUCI export coefficient.

- **Nitrogen accumulated load (N_AccLoad):** This map shows the accumulated total N load (in kg/yr), considering the load not just at a point, but also that contributed from "uphill" sources. High values are prime targets for mitigation / interception opportunities. Again, accuracy reflects that of the input data on land use and the relevant LUCI export coefficient, as well as the DEM and topographic routing approach used to model accumulation.

- **Nitrogen accumulated load (classified) (N_CL_AccLoad):** This map combines the predictions of accumulated N load with user specified thresholds, to categorise the N loading into very low to very high categories.

- **Nitrogen in-stream concetration (N_StrConc):** This map shows total N concentration (in mg/L) at all points in-stream. High values suggest catchment of this point should be targeted for mitigation/interception opportunities. This map is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial N concentration.

- **Classified nitrogen concentration in water (N_StrConcClass):** This map combines the predictions of N stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.

- **Nitrogen input to lakes (N_LakeStats):** This polygon feature class shows estimates of annual average loading and concentration entering lakes from land management only. No sewage etc currently considered. This output subject to the same sources of error as the in-stream value.
- **Nitrogen at lake outlet (N_LakeOutlet):** This point feature class is the same as N_LakeStats but presents information at lake outlet only.
- **Stream entry and exit points (entryexitpoints):** This map shows the streams and where they enter/exit the study area.
- **Stream watersheds (watersheds):** For each of the streams in the study area, this map shows the contributing watershed to that stream.

5.8 Phosphorus

5.8.1 Summary

The fate of phosphorus in LUCI is currently modelled using an export coefficient approach. The tool combined topographic routing and effective precipitation to calculate the accumulation of water flow over the landscape and delivery to all points in the river and lake networks. The cumulative P export is also computed for every point in the landscape, based on the export associated with the land cover and/or land management classification for each grid cell. The ratio of the estimates of cumulative total phosphorus (TP) export and cumulative flow are then calculated to provide an estimate of the annual average accumulated TP concentration.

The current export coefficients included in LUCI databases are estimates of export of total P, rather than dissolved P. Hence the proportion of assumed particulate vs dissolved needs to be entered as a parameter in this approach. Note that the export coefficients do not account for point sources such as from sewage treatment works and septic tanks. These sources are not presently included in the LUCI water quality layer, so model output may be considered indicative of agricultural contribution to water quality issues. Any additional contribution from urban areas and point sources must be taken into account when the model is applied for predictive assessment of water quality against, for example, water framework directive criteria.

The export coefficients were originally calculated at small-catchment scale. At a finer scale, for example looking at an individual 5m square with no surface drainage, the simulated concentrations cannot reliably be taken as an indication of TP concentrations in soil water. However, once hillslope scale aggregation within LUCI is achieved (as has happened by the time loadings reach water bodies), the scale is consistent with the P loading data.

5.8.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Proportion dissolved vs particulate:** Specify the proportion of P expected to be in dissolved rather than particulate form. *Default value is 0.3.*
- **P critical accumulation threshold 1 (mg/l):** Specify the threshold in milligrams per litre (mg/L) below which accumulated P concentration is to be considered of no concern (oligotrophic). In the absence of site-specific information and requirements, 0.025mg/L is suggested, based on guidance from Dodds et al. (1998). *Default value is 0.025mg/L.*
- **P critical accumulation threshold 2 (mg/l):** Specify the threshold in milligrams per litre (mg/L) above which accumulated P concentration is to be considered of no more than moderate concern (mesotrophic). In the absence of site-specific information and requirements, 0.075mg/L is suggested, based on guidance from Dodds et al. (1998). *Default value is 0.075mg/L.*

- **P critical load threshold 1 (kg/yr):** Specify the threshold in kilograms P per year (kg/yr) below which accumulated P load is considered of no concern. In the absence of site-specific information or requirements, 0.01kg/yr is suggested. *Default value is 0.01kg/yr.*
- **P critical load threshold 2 (kg/yr):** Specify the threshold in kilograms P per year (kg/yr) above which accumulated P load is considered of significant concern. In the absence of site-specific information or requirements, 0.1kg/yr is suggested. *Default value is 0.1kg/yr.*
- **Root zone to stream attenuation factor:** Specify the proportion of accumulated P remaining in the water that is routed to the stream. This parameter reflects P loss from attenuation in the rooting zone. Values from 0 to 1 are appropriate. The value should be set to reflect the proportion of accumulated P remaining in the water routed to the stream. **Note:** Not currently being used in the UK version. *Default value is 0.5.*
- **In-stream attenuation factor:** Specify the proportion of in-stream P which remains in the water i.e. it is not consumed by in-stream processes. This parameter allows consideration of P loss from attenuation in the river network. For New Zealand, a value of 0.7 is suggested based on local calibration Trodahl et al. (2016). *Default value is 0.5.*
- **Calculate stream statistics (load, concentration and flow accumulation - average and at exit points):** Check box to ensure in-stream statisitcs are calculated.
- **Only generate load (i.e. stop tool once load has been generated):** Check to generate load only. Note: very few users will wish to take this option. *Default is unchecked.*

5.8.3 Output

Within the output folder are additional output files showing instream nutrient concentration, input to lakes, and concentrations at the lake outlet.

- **Phosphorus load (P_load):** This map shows the total P load (in g/ha/yr) generated at any point within the landscape.
- **Phosphorus accumulated load (P_AccLoad):** This map shows the accumulated total P load (in g/yr), considering the load not just at a point, but also that contributed from "uphill" sources. High values are prime targets for mitigation / interception opportunities.
- **Phosphorus accumulated load (classified) (P_CL_AccLoad):** This map combines the predictions of accumulated P load with user specified thresholds, to categorise the N loading into very low to very high categories.
- **Phosphorus in-stream concetration (P_StrConc):** This map shows total P concentration (in mg/L) at all points in-stream. High values suggest catchment of this point should be targeted for mitigation/interception opportunities. This map is subject to errors in the input (or modelled intermediate) spatial data layer for the river network, in addition to any sources of inaccuracy in the modelled accumulated terrestrial P concentration.
- **Phosphorus concentration in water (P_StrConcClass):** This map combines the predictions of P stream concentration with the user specified thresholds, to categorise the concentration into very low to very high categories.
- **Phosphorus input to lakes (P_LakeStats):** This polygon feature class shows estimates of annual average loading and concentration entering lakes from land management only. No sewage etc currently considered. This output subject to the same sources of error as the in-stream value.
- **Phosphorus at lake outlet (P_LakeOutlet):** This point feature class is the same as P_LakeStats but presents information at lake outlet only.
- **Stream entry and exit points (entryexitpoints):** This map shows the streams and where they enter/exit the study area.
- **Stream watersheds (watersheds):** For each of the streams in the study area, this map shows the contributing watershed to that stream.

5.9 RUSLE

5.9.1 Summary

This tool estimates the annual soil loss (tons/km2/yr) using the Revised Universal Soil Loss Equation (RUSLE) approach, and sediment delivery vulnerability depending on whether the soil loss is occurring on non-mitigated land. There are multiple approaches to calculating the rainfall erosivity and the slope length-steepness factor.

5.9.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Lower threshold for medium erosion risk (tonnes/km2):** Specify in tonnes/km2/yr the lower threshold of medium soil erosion. *Default is 250.*
- **Lower threshold for high erosion risk (tonnes/km2):** Specify in tonnes/km2/yr the lower threshold of high soil erosion. The default value is based on the unsustainable value of soil loss defined by **?**. *Default is 500.*
- **Lower threshold for extreme erosion risk (tonnes/km2):** Specify in tonnes/km2/yr the lower threshold of extreme soil erosion. *Default is 1000.*
- **R-factor: Choose method:** Two options are used to estimate rainfall erosivity:
  - (Klik et al., 2015) is formulated for New Zealand applications and uses different values for a-constant and b-constant depending on the study area's region within NZ. Please specify the values for the a-constant and b-constant below.
  - (**?**) produced a global R-factor layer that can be freely downloaded. Please clip and reproject this layer to the study area for input in the parameter below.
- **R-factor: a constant and b constant:** These constants can be taken from Klik et al. (2015).
- **R-factor layer from Panagos et al. (2017):** Specify the path and filename of the rainfall erosivity raster that has been clipped and reprojected for the study area.
- **LS-factor: Choose method:** Two options are used to estimate slope length and steepness:
  - *Calculate based on slope and length only:* This method only accounts for slope length and steepness as specified by (**?**).
  - *Include upslope contributing area:* This method includes slope length, steepness, and upslope contributing area as specified by (**?**) and (**?**).
- **LS-factor: Cutoff slope angle (degrees):** Specify the cutoff angle for calculating the LS-factor. Beyond this slope angle, only rock is expected to be found with no soil on the surface. The value of 26.6 degrees or 50% was suggested by Panagos et al. (2015). *Default value is 26.6.*

5.9.3 Output

- **Soil loss (tons/km2/yr):** This map shows soil loss from zero to the maximum loss.
- **Soil loss risk:** This map shows soil loss risk based on the user-defined thresholds set in the inputs.
  - Low erosion risk
  - Medium erosion risk
  - High erosion risk

  - Extreme erosion risk
  - Water body

- **Sediment delivery:** This map shows which areas are vulnerable to sediment delivery based on their location on non-mitigated land. The classification used is:
  - Mitigating features
  - Negligible delivery to stream
  - Moderate delivery to stream
  - Water body

6 Batch Run / Tradeoffs

6.1 Batch run ecosystem services

6.1.1 Summary

This tool allows a selection (or all) of the multiple ecosystem function models available in LUCI to be run in "batch process" mode, saving their various outputs into a user-specified folder. A complementary tool then allows these output to be loaded into the current ArcMap session for inspection.

6.1.2 Input

- **Ecosystem services output folder:** Specify the path and folder where output from this tool should be stored.
- **Input: Study area baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Tickboxes to run the individual ecosystem services:** Select the ecosystem services of interest.
- The succeeding parameters are the same as those in the single service ecosystem services tools.

6.1.3 Output

Within the output folder are separate folders for each of the ecosystem services with all the output files and PDFs.

- **agprod:** Agricultural productivity
- **carbon:** Carbon
- **erosed:** Erosion and sediment
- **flood:** Flood mitigation
- **habconn:** Habitat connectivity
- **habsuit:** Habitat suitability
- **nitrogen:** Nitrogen
- **phosphorus:** Phosphorus

6.2 Load Outputs for Multiple Services

6.2.1 Summary

This tool takes the already generated output from the **Batch run ecosystem services** tool and loads the results from the single ecosystem service models to the current ArcMap session.

6.2.2 Input

- **Output folder:** Specify the path and folder where the outputs from the **Batch run ecosystem services** tool are stored.
- **Tickboxes to load the outputs from the individual ecosystem services:** Select the ecosystem services of interest.

6.2.3 Output

This tool will automatically load the outputs to the ArcMap session.

6.3 Tradeoff maps

6.3.1 Summary

LUCI Trade-off maps identify where opportunities exist to improve delivery of services whilst protecting areas which currently delivery a high level of service. LUCI's individual service calculations include an output for each service where each cell in the terrestrial landscape is categorised into one of five provisioning categories from high to low, and this categorisation is further reduced into three categories for trade-off analysis, as indicated in the table below.

Categories for LUCI individual service categories	**Categories for LUCI tradeoffs**
a) Very high existing service b) High existing service	High existing good
c) Moderate or marginal service	Negligible existing good but negligible opportunity to improve significantly
a) Small or degrading service b) Very small or rapidly degrading service	Bad or negligible existing good with potential to improve

LUCI then layers those categorised services to identify parts of the landscape where trade-offs versus win-win situations exist, and where management interventions could enhance or protect multiple services. Areas with multiple "high existing good" and no "bad" or "potential to significantly improve" areas are flagged as win-win situations where status quo should be preserved. Similarly, areas where multiple "bad" or "potential to significantly improve" classifications exist are flagged as "win-win" situations for implementation of change. Areas where trade-offs exist – where significant improvements of some services would likely go in tandem with degradation of other services- are separately categorised, as are areas where there are not obvious advantages in either preserving status quo or implementing management change.

For trade-off analysis, this categorisation is further reduced into "high existing good", "bad or negligible existing good with potential to improve", or "negligible existing good but negligible opportunity to improve significantly". LUCI then layers those categorised services to identify parts of the landscape where trade-offs versus win-win situations exist, and where management interventions could enhance or protect multiple services. Areas with multiple "high existing good" and no "bad" or "potential to significantly improve" areas are flagged as win-win situations where status quo should be preserved. Similarly, areas where multiple "bad" or "potential to significantly improve" classifications exist are flagged as "win-win" situations for implementation of change. Areas where trade-offs exist – where significant improvements of some services would likely go in tandem with degradation of other services- are separately categorised, as are areas where there are not obvious advantages in either preserving status quo or implementing management change.

6.3.2 Input

- **Output folder for tradeoffs:** Specify the path and folder where output from this tool should be stored.
- **Folder containing ecosystem services output:** Specify the path and folder where files are stored from running the **Batch run ecosystem services** tool.
- **Tradeoff options:** Five options are possible in the tradeoff mapping tool.
  - *Equal arithmetic:* counts the number of "wins", "losses" and "negligible impact" predicted under change, and identifies those areas where more wins or more losses are expected overall. It treats all services as being of equal importance, and is a special / simple case of the "weighted arithmetic" option.
  - *Conservative:* seeks to avoid negative change in any service. This option is not available when more than four service are being traded off against each other (where conservation is particularly important for a subset of services, see the mixed conservative/arithmetic option).
  - *Standard:* considers concepts from both, considering both the overall "sum" from the tradeoff analysis and the balances of "wins" and "losses". In some way it can be seen as a middle ground between the arithmetic and conservative approach; seeking to maximise wins with minimal losses. Although all output is produced through objective/deterministic functions the choices made to categorise this third "standard" option are somewhat subjective. This option is only supported for up to four single services.
  - *Weighted arithmetic:* counts the number of "wins", "losses" and "negligible impact" predicted under change, and identifies those areas where more wins or more losses are expected.
  - *Mixed conservative/weighted additive:* allows up to three services to treated conservatively, and treats the rest through the weighted additive approach. This allows a small number of services identified as vital to be prioritised, while also enabling consideration of a wider range of services.
- **Reporting option:** Four reporting options are possible.
  - *Limited:* produces an aggregated "overall" tradeoff/synergy map.
  - *Summary:* generates the Limited map, and stores additional information at each pixel so the total number of "wins", "losses", and "negligible impacts" can be investigated.
  - *Individual:* stores individual service information on "wins", "losses" etc so these numbers can be interrogated along with the summary output at each pixel.
  - *Full (summary + individual):* stores all this information within all output tradeoff rasters. Users should balance their needs for fuller reporting/analysis with storage and computational demands.
- **Lowest level of calculation:** This sets the lowest level of tradeoff calculations that will be carried out. E.g. a value of two (lowest possible value) will carry out two way calculations, then three way, up to the maximum level of tradeoffs input. Conversely, a value set at the maximum level (ie. 4 with 4 services being analysed) will only carry out the highest level analysis.The highest level of analysis is the quickest option, and does offer some capability to explore which services contribute to wins and losses through the raster attribute table.
- **Tickboxes to select which ecosystem services to consider:** Tick the boxes of the services that will be considered for the tradeoffs.
- **Weight for each of the ecosystem services:** The weighting for the services can be specified. Weighting that will be given to this service. For the mixed weighted arithmetic/conservative approach a weight of -1 will cause this service to be treated as conservative. In all other cases, the number must be greater than zero. Its proportional weighting in the tradeoff calculation is the contribution this makes to the overall sum of weights. *Default value is 1.*
- **Habitant being considered for what species?:** Specify the species for which habitat connectivity was modelled. Currently this model defaults to 11 for broadleaved woodland generic focal species Parameterisation for further species will take place according to LUCI project needs. *Default value is 11.*

6.3.3 Output

The tool produces rasters showing the spatial distribution of tradeoffs and synergies. The corresponding tables summarise the proportion of the study area that have the following characteristics:

- Excellent service provision
- Moderate service provision
- Negligible service or tradeoffs
- Opportunity to improve service
- Excellent opportunity to improve service

The rasters and tables are named with combinations of abbreviations of the services being considered for that tradeoff:

- **Agp:** Agricultural productivity
- **Car:** Carbon
- **Ero:** Erosion and sediment
- **Flo:** Flood mitigation
- **Hab:** Habitat connectivity and suitablity
- **Nit:** Nitrogen
- **Pho:** Phosphorus

7 Aggregation and disaggregation tools

These tools summarise the land cover, soil, ecosystem services output, and tradeoffs output metrics based on user-defined aggregation units. The tool **Create data aggregation grid** can be used to create a shapefile of aggregation units in the shape of regular squares that cover the study area with user-defined thresholds and size. Alternatively, the user can supply their own shapefile of aggregation units such as sub-watersheds or using administrative boundaries.

The aggregate metrics are reported in:

- Inverse Simpson diversity index
- Shannon diversity index
- Classifications per aggregation units
- Mean patch size

The documentation for these tools is in-progress as the tools are being revised to run with the latest version of LUCI.

7.1 Aggregate data

7.1.1 Summary

This tool takes any feature class data and reports aggregate metrics according to the metrics specified above.

7.1.2 Input

- **Output folder:** Specify the path and folder where the output of this tool will be stored.
- **Data to aggregate:** Specify the path and filename of the feature class with the data to aggregate.
- **Classification column:** Specify the column within the target feature class to be used as the basis for the aggregation analysis.
- **Aggregation units:** Specify the path and filename of the feature class containing the aggregation units.
- **Only consider aggregation units which fully lie within the study area:** If ticked, the tool will only calculate the aggregation metrics for units that lie fully within the study area.

7.1.3 Output

The outputs are grid squares reporting the aggregation in the above metrics.

7.2 Aggregate LUCI input data

7.2.1 Summary

This tool takes the folder generated by the **Generate Baseline** tool and calculates the above metrics for the land cover and soil data of the study area.

7.2.2 Input

- **Output folder:** Specify the path to the folder where the ouputs from this tool will be saved.
- **LUCI Baseline folder:** Specify the path and folder to the outputs from the **Generate Baseline** tool.
- **Aggregation units:** Specify the path and filename of the feature class containing the aggregation units.
- **Only consider aggregation units which fully lie within the study area:** If ticked, the tool will only calculate the aggregation metrics for units that lie fully within the study area.
- **Calculate landcover statistics?** Tick this box to calculate statistics for the land cover data.
- **Calculate soil statistics?** Tick this box to calculate statistics for the soil data.
- **Soil hierarchical level for analysis (NATMAP only):** If the soil data is NATMAP, specify the soil hierarchical level for the aggregation analysis.

7.2.3 Output

The outputs are grid squares reporting the aggregation in the above metrics.

7.3 Create aggregation grid

7.3.1 Summary

This tool creates a grid of squares over the input study area with a user-defined size and coverage.

7.3.2 Input

- **Boundary feature class:** Specify the path and filename to the feature class of the study area.
- **Output grid feature class:** Specify the path and filename of the output grid file.
- **Cell size in projection units:** Specify in the size of the grid squares in map projection units. If the desired cell size is a proportion of the study area's total rectangular extent (e.g. 10% of the extent), set this parameter to 0 and modify the *Proportion of total rectangular extent area for each cell* parameter below.
- **Proportion of total rectangular extent area for each cell:** Specify the desired cell size as a proportion (between 0 to 1) of the total rectangular extent. For example, if the desired cell size is 10% of the extent, then this parameter should be 0.1.
- **Grid coverage:** Specify the extent of the output grid:
  - *Rectangular, covering full extent of boundary feature class:* The output grid will be rectangular in shape and cover the full height and width of the boundary.
  - *Grid covers area bounded by boundary feature class only:* The output grid will follow the boundary of the feature class.
- **Percentage area for grid cells on boundary:** If the second option is chosen above, specify the percentage area of the grid cells on the boundary that will be included in the aggregation grid.
- **Buffer radius (in projection units):** Specify the size of the optional buffer in map projection units.
- **Align to grid:** If True, sets the grid to integer extent values, and aligns to appropriate coordinates, rounding min xy values down, and max xy up, depending on the distance between the shortest polygon extent side.
- **Significant figures:** Number of significant figures to align the coordinates to. This refers to the difference between the shortest length, so for coordinates of 123411 and 123511, where the difference is 100, and a sig_figs value of 2, the output would be 123410 and 123510. *Default is 3.*

7.3.3 Output

This tool produces a grid of regular squares according to the size, coverage, and thresholds specified by the user.

7.4 Report aggregate habitat metrics

7.4.1 Summary

This tool reports habitat diversity metrics for aggregated regions. It includes Shannon's index, Simpson's index, mean patch size and total number of habitats.

7.4.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Aggregation Units:** Specify the polygon shapefile that outlines your aggregate units. Outputs will be reported at each individual polygon within this class. The mask could be a collation of political regions, a collection of catchments or subcatchments, a grid (e.g. for reporting by 1 km^2), etc.
- **LUCI Baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.

7.4.3 Output

This tool outputs summary statistics to a copy of the spatial data layer used for aggregation. The statistics calculated are: number of habitats, Shannon index and Simpsons index. The results are dependent on accuracy of the spatial input data layer for landcover, as well as the level of disaggregation by type applied (broad habitat subclass or aggregated). Both Shannon and Simpson indexes are indicative of probability of occurrence, according to the equation:

$$\text{Shannon} = -\sum(\text{Probability of occurrence}) * \log(\text{Probability of occurrence}) \tag{3}$$

$$\text{Simpsons} = \sum(\text{Probability of occurrence}^2) \tag{4}$$

7.5 Report aggregate input statistics

7.5.1 Summary

This tool reports aggregated statistics on land cover, soil, and/or topographical/climate information.

7.5.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Aggregation Units:** Specify the polygon shapefile that outlines your aggregate units. Outputs will be reported at each individual polygon within this class. The mask could be a collation of political regions, a collection of catchments or subcatchments, a grid (e.g. for reporting by 1 km^2), etc.
- **LUCI Baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Calculate landcover stats? and Landcover reporting option:** Tick the box to calculate land cover statistics. The available land cover reporting options are:
  - *1:* calculates all land cover present
  - *2:* divides the land cover into broad classes
  - *3:* divides land cover into "water", improved, other grass, bogs, conifers, etc.
- **Calculate soil statistics? and Soil reporting option:** Tick the box to calculate soil statistics. The available soil reporting options are:
  - *1:* full soils reporting
  - *2:* simplified soils reporting
  - *3:* very simplified soils reporting
- **Calculate topographical and climate statistics?:** Tick this box to calculate topographical/climate statistics.

7.5.3 Output

- In-progress

7.6 Report aggregate single services metrics

7.6.1 Summary

This tool reports aggregated statistics from a range of LUCI single service outputs.

7.6.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Aggregation Units:** Specify the polygon shapefile that outlines your aggregate units. Outputs will be reported at each individual polygon within this class. The mask could be a collation of political regions, a collection of catchments or subcatchments, a grid (e.g. for reporting by 1 km^2), etc.
- **LUCI Baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **LUCI Single Services Folder:** Specify the path to the folder containt the LUCI ecosystem service output.
- **Report service?:** Tick the succeeding tickboxes to report statistics from different services.

7.6.3 Output

- In-progress

7.7 Report aggregate soil metrics

7.7.1 Summary

This tool reports aggregated soil metrics for NATMAP soils.

7.7.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Aggregation Units:** Specify the polygon shapefile that outlines your aggregate units. Outputs will be reported at each individual polygon within this class. The mask could be a collation of political regions, a collection of catchments or subcatchments, a grid (e.g. for reporting by 1 km^2), etc.
- **LUCI Baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **Soil hierarchical level for analysis:** Specify the hierarchical level within NATMAP for analysis:
  - *1:* top level
  - *2:* SOIL_LEVU1
  - *3:* SOIL_LEVU2
  - *4:* SOIL_LEVU3

7.7.3 Output

- In-progress

7.8 Report aggregate tradeoff metrics

7.8.1 Summary

This tool reports aggregated statistics from LUCI tradeoffs.

7.8.2 Input

- **Output folder:** Specify the path and folder where output from this tool should be stored.
- **Aggregation Units:** Specify the polygon shapefile that outlines your aggregate units. Outputs will be reported at each individual polygon within this class. The mask could be a collation of political regions, a collection of catchments or subcatchments, a grid (e.g. for reporting by 1 km^2), etc.
- **LUCI Baseline folder:** Specify the path and folder where files are stored from running the **Generate Baseline** tool.
- **LUCI Tradeoff Folder:** Specify the path to the folder generated by the **Tradeoff maps** tool.
- **Report service combinations?:** Tick the succeeding tickboxes to report statistics from tradeoffs with that service.

7.8.3 Output

- In-progress

8 Miscellaneous

This section contains standalone tools and functions, and are described briefly.

8.1 Calculate stream and study area statistics

8.1.1 Summary

For either Nitrogen or Phosphorus, this function calculates the statistics of nutrient loads and concentrations in the study area and in the streams.

8.2 Change user settings

8.2.1 Summary

This tool allows the user to configure some aspects of LUCI:

- **Scratch path:** Sets the location of the scratch geodatabases that hold the intermediate files during a LUCI run.
- **Basemap:** Choose the basemap shown when LUCI loads output into ArcMap.
- **Use developer mode?:** If making code changes, setting this to true will mean that any modules imported will be refresh before they are used. This removes the extra step of manually refreshing the toolbox after a code change.
- **Reset all settings to their default values:** Resets the user settings to default values.

8.3 Clean geodatabase

8.3.1 Summary

This tool manually clears a geodatabase, and the scratch geodatabase is commonly used as input to remove any intermediate files still left from a previous run.

8.4 Clip and buffer raster

8.4.1 Summary

This tool takes a raster and shapefile, buffers the shapefile by a user-defined width, and clips the raster down to the extent of the buffered shapefile.

8.5 Clip data in folder

8.5.1 Summary

This tool runs a batch operation to clip all the rasters and shapefiles within the input folder to the extent of a user-defined shapefile.

8.6 Clip LUCI Subset Output

8.6.1 Summary

This tool runs a batch operation to clip all the rasters and shapefiles, and to update the maps within the PDF of LUCI output from the baseline tool, the single services tools, or from the tradeoff tool.

8.7 Create Polygon Grid

8.7.1 Summary

This tool generates a grid of square-shaped cells of a specified size, from an input polygon extent. The grid extent can optionally be aligned to suitable coordinates e.g. 123456 to 123000, and have a buffer applied. If a desired cell size is not known, set to zero.

The output grid will overlap the input extent completely, and as such, if the extent is not exactly divisible by the chosen cell size, the extent of the output will be slightly larger than that of the input.

8.8 Floodplain inundation

8.8.1 Summary

This tool uses the flatwater inundation approach described in Ballinger et al. (2011) and Benavidez (2018) to generate flooding extent. Note: This tool is currently being tested for the Lower Hutt catchment, New Zealand and is still in-development.

8.9 Recondition DEM

8.9.1 Summary

This tool implements the AGREE method (Hellweger, 1997) to burn streams into a digital elevation raster.

8.10 Sea level inundation

8.10.1 Summary

This tool calculates the land area covered by user-defined sea level rise and the height of the flood water for the inundated area.

8.11 Show terrestrial flow

8.11.1 Summary

This tool uses the flow direction information to identify where flow is exiting or entering the study area, or where there are ridgelines at the boundary.

9 On-going and future developments

This section lists the tools and improvements to the LUCI framework that are on-going development or are priorities for future development.

- Further application of LUCI to more study areas and climate regions
- Global application of LUCI

10 Contact us

For any questions, please feel free to contact us at info@lucitools.org.

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