PROWATER Impact Assessment Tool

Manual

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1. Introduction

This document acts as user manual for the QGIS Prowater-plugin. This tool can be used to quantify the effect of a number of Ecosystem-based adaptations on the delivery of Ecosystem Services in the 2 Seas region. This tool was developed in the Interreg 2 seas PROWATER project.

2. Installation procedure

The installation procedure is straightforward, however installation rights are required to install QGIS on a computer. The tool works correctly in Windows 7, 10 and 11, but has not been tested for other operating systems.

2.1. Installation QGIS

The plugin works correctly in QGIS3 and has been tested for QGIS 3.22. QGIS is Free and Open Source Software (FOSS) and can be downloaded from www.qgis.org.

2.2. Installation plugin

The tool consists of 2 parts, plugin and database, which must be installed separately on the computer (Figure 1). Because the database is quite large, it was decided to disconnect it from the plugin. This gives the user the flexibility to place each part where it suits him/her best. Due to size constraints, different layers of the database can be downloaded separately and be placed in their correct position in the database afterwards.
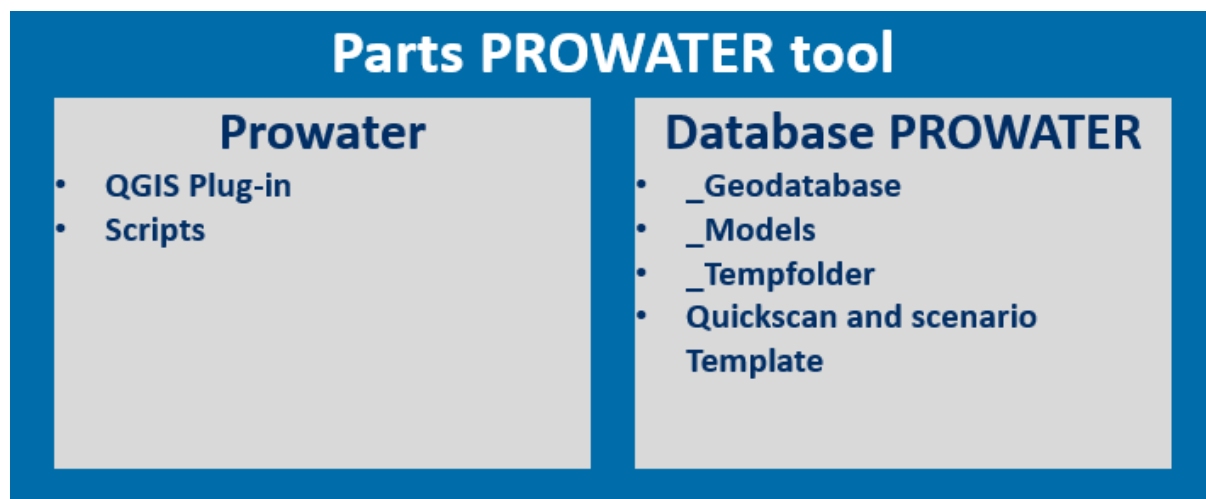

Figure 1: Structure of the Prowater-tool.

1. The first part, the QGIS Plugin, contains the scripts which builds the interface of the plugin in QGIS. This folder "prowater" must be placed in a specific user-related folder. This can be found in QGIS via:

   `Settings -> User profiles -> Open Active Profile folder.`

   In this folder the folder `python/plugins` can be found.

   If the folder 'plugins' is not present in the folder 'python', it can also be created manually.

   After installation and when restarting QGIS, the plugin will appear in the list of installed plugins. The plugin then needs to be activated in the list of plugins, which can be found in the menu bar under *Plugins*.

   > Select *Manage and Install Plugins*
   > Go to *Installed*
   > Activate 'Prowater' by checking the box.

   The PROWATER tool will then become available directly under *Plugins* in the menu bar.

2. The 2nd part, the database, contains several folders needed to run the different models as well as a folder to store intermediate results. This 2nd part can be placed anywhere on the computer but requires a considerable amount of memory. In this part the analyzes are performed and possibly saved. This part contains 4 folders that are name sensitive. This naming should not be changed, or the plugin will not work correctly. It is also best to keep the names of the layers in the model consistent with what is shown below.
   - _Geodatabase = Database with a land cover map and maps with the mean highest and lowest groundwater for a subpart of the 2 seas region.
     - Landcover.tif
     - MHG.tif
     - MLG.tif
   - _Models = Contains data used for the different calculations of the ecosystem services.
     - Model_drainage
     - Model_health
       - population_ha.tif
     - Model_infiltration
       - texture.tif
     - Model_soil_c
       - clay.tif
       - sand.tif
       - podzol.tif
     - Model_soil_np
   - _TempFolder = Contains temporary data that is placed inside this folder during calculations. This data gets automatically deleted afterwards.
   - _Legends = qml files

Some layers of the database have been split up in parts. For the tool to work correctly, these parts either have to be renamed (remove the regional part of the file name so it is equal to the one in the overview above) or the different parts have to be merged together. This is the case for the layers land cover, MHG and MLG.

The land cover layer has been split into 2 parts: landcover_FL_NL and landcover_UK. Both the MHG and MLG layer have been split into 4 parts: 1 part for Flanders and the Netherlands (MHG_FL_NL and MLG_FL_NL) and the other parts compromising parts of the UK: Southwest, Southeast and Anglia (Figure 2).
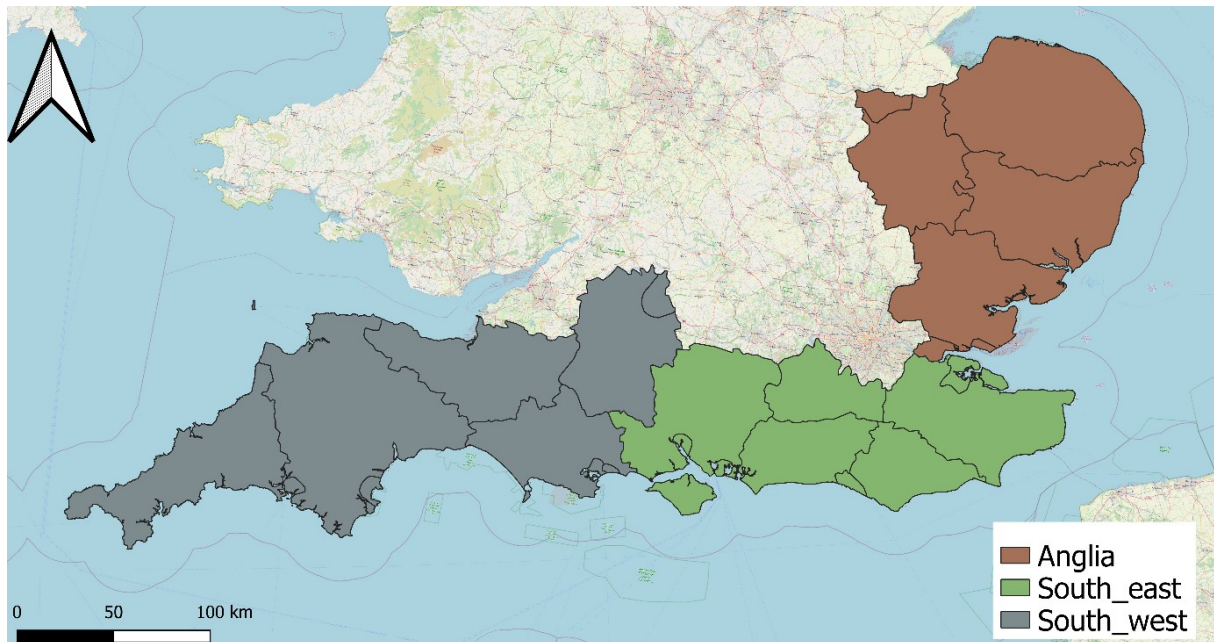
Figure 2: Part of the regional map of the UK relevant to the 2Seas region.

How to merge the different parts into 1 layer?

1. Open the different parts in QGIS.
2. Go to Raster -> Miscellaneous -> Merge
3. Input layers: Select the different subparts of the layer you want to merge. Don't tick any of the boxes.
4. Output data type: The data type depends on the layer. For MLG and MHG it should be Int16, for land cover UInt16.
5. Save to file: Here you should provide the save location and name. You can save the merged layer under database_PROWATER/_Geodatabase/ and give it the name landcover/MHG/MLG .tif.

3. Geodatabase

3.1. Land cover

A tool only works with correct input data. To facilitate the use of the tool, we have provided a geodatabase with all the maps that are needed to make the tool work. This geodatabase is based on EU-wide datasets on land cover, soil and topography. Downside of these datasets is that they have a poor thematic and spatial resolution and may be outdated. Our suggestion is to use local, more accurate datasets instead of the data layers in the geodatabase. The data layers in the GDB can be replaced if they use exactly the same categories, projection and resolution. The GDB allows the user to explore the tool without investing too much time in the development of a local, more accurate dataset.

Land cover data is retrieved from multiple sources. All data sources are remote sensing based, which has several drawbacks. The RS-based methods rely on multiple images that cover a time span of multiple years. This implies that dynamic land cover – often seen on agricultural fields – is not well captured. Crop rotations will result in a single class, namely arable. It would be of value to capture typical rotations in agricultural crops (e.g. grassland – maize – potatoes), especially because some rotations are more soil and infiltration friendly than others. RS-based land cover mapping also performs very poor for natural vegetation. The RS-signal is a mixture of many species and has a spatial resolution of 5-10 meters.

⇨ We built the PROWATER LC map using detailed and accurate datasets where available and resorting to less accurate datasets where needed. The pan-European High Resolution Layers (HRL) provide information on specific land cover characteristics, and are complementary to land cover / land use mapping such as in the CORINE land cover (CLC) or S2GLC 2017 datasets. The HRLs are produced from satellite imagery through a combination of automatic processing and interactive rule based classification. Since the 2015 reference year, the production is increasingly based on time series of satellite images from a number of different sensors, including the combination of optical and radar data. The main sources are now (since the 2018 reference year) the Sentinel Satellites (in particular Sentinel-2 and Sentinel-1). Since 2018, the products have increased in resolution to 10 meters, thus following the source resolution of the Sentinel-2 imagery.

⇨ Five themes have been identified so far, corresponding with the main themes from CLC, i.e. the level of sealed soil (imperviousness), tree cover density and forest type, grasslands, wetness and water, and small woody features. We use three of these themes to develop the PROWATER LC-map. The wetness and water and the grassland layer have been less consistent over time (2015-2018).

  o The VHR Imperviousness layer maps the % of soil sealing at 10 m resolution. The layers allows to specify the % of imperviousness at pixel level. If a pixel is mapped as 20% imperviousness, we assume the remainder to be grassland.

  o The VHR Forests layer maps the tree cover density (%) and the dominant leaf type (broadleaved versus coniferous).

  o The HRL Small Woody Features (SWF) maps types of linear or patchy structures of woody/scrubby/bushy vegetation . It is a Copernicus Land mapping product, which provides harmonized information on linear structures such as hedgerows, as well as patches of woody features across the EEA38+UK countries.

⇨ The second basis of the PROWATER LC-map is the S2GLC map. The S2GLC 2017 dataset is delivered with 10 m spatial resolution with thematic legend composed of 13 land cover classes. The Sentinel-2 Global Land Cover (S2GLC) project was founded by the European Space Agency (ESA) through its Scientific Exploitation of Operational Missions (SEOM) element. This map has a poor thematic resolution.

⇨ The third basis of the PROWATER LC-map is CORINE Land Cover. CLC datasets are based on the classification of satellite images produced by the national teams of the participating countries - the EEA members and cooperating countries (EEA39). National CLC inventories are then further integrated into a seamless land cover map of Europe. The resulting European database relies on standard methodology and nomenclature with following base parameters: 44 classes in the hierarchical 3-level CLC nomenclature. All features in original vector database are delineated and classified on satellite images according to CLC specifications i.e. with better than 100 m positional accuracy and 25 ha minimum mapping unit.

OID	Value_1	Count_1	Legend	Source		OID	Value_1	Count_1	Legend	Source
0	0	14975717	NoData			30	3101	2221635	Natural grasland	CORINE
1	2100	1889649	Broadleaf forest of unknown density	VHRL		31	3201	13409108	Agricultural grasland	CORINE
2	2110	60718	Broadleaf forest 10-20 % canopy density	VHRL		32	4000	1,32E+08	Moors and heathland	S2GLC
3	2120	281874	Broadleaf forest 20-30 % canopy density	VHRL		33	5200	532704	Dunes and beaches	CORINE
4	2130	1253816	Broadleaf forest 30-40 % canopy density	VHRL		34	6000	3.09E+08	Cropland (probably)	S2GLC only
5	2140	4721931	Broadleaf forest 40-50 % canopy density	VHRL		35	6112	16533858	Cropland (certain)	S2GLG + CORINE
6	2150	12724644	Broadleaf forest 50-60 % canopy density	VHRL		36	6204	217803	Orchards	CORINE
7	2160	23428552	Broadleaf forest 60-70 % canopy density	VHRL		37	6300	227948	Vineyards	CORINE
8	2170	30831736	Broadleaf forest 70-80 % canopy density	VHRL		38	7000	7806734	Swamp	S2GLC
9	2180	25161594	Broadleaf forest 80-90 % canopy density	VHRL		39	7101	6533888	Marshland	S2GLC
10	2190	10247369	Broadleaf forest 90-100 % canopy density	VHRL		40	8101	203951	Tidal mudflats	CORINE
11	2200	250101	Coniferous forest of unknown density	VHRL		41	8201	109384	Tidal marshes	CORINE
12	2210	725	Coniferous forest 10-20 % canopy density	VHRL		42	9010	6812082	Urban 10-20 %paved	VHRL
13	2220	3206	Coniferous forest 20-30 % canopy density	VHRL		43	9020	14269300	Urban 20-30 % paved	VHRL
14	2230	21425	Coniferous forest 30-40 % canopy density	VHRL		44	9030	18524130	Urban 30-40 % paved	VHRL
15	2240	118924	Coniferous forest 40-50 % canopy density	VHRL		45	9040	17939820	Urban 40-50 % paved	VHRL
16	2250	686165	Coniferous forest 50-60 % canopy density	VHRL		46	9050	15606911	Urban 50-60 % paved	VHRL
17	2260	3291823	Coniferous forest 60-70 % canopy density	VHRL		47	9060	12733981	Urban 60-70 % paved	VHRL
18	2270	9476250	Coniferous forest 70-80 % canopy density	VHRL		48	9070	10381692	Urban 70-80 % paved	VHRL
19	2280	7355626	Coniferous forest 80-90 % canopy density	VHRL		49	9080	8690502	Urban 80-90 % paved	VHRL
20	2290	1427250	Coniferous forest 90-100 % canopy density	VHRL		50	9090	26441575	Urban 90-100 % paved	VHRL
21	2310	97405	Undefined forest 10-20 % canopy density	VHRL		51	10000	23501445	Water	S2GLC
22	2320	401806	Undefined forest 20-30 % canopy density	VHRL		52	10200	26551	Tidal water	CORINE
23	2330	1427423	Undefined forest 30-40 % canopy density	VHRL		53	10204	86271	Rivers and canals	CORINE
24	2340	3581723	Undefined forest 40-50 % canopy density	VHRL		54	10300	95461	Sea	CORINE
25	2350	5361158	Undefined forest 50-60 % canopy density	VHRL		55	11000	16516	Bare rocks	CORINE
26	2360	4604041	Undefined forest 60-70 % canopy density	VHRL						
27	2370	2502592	Undefined forest 70-80 % canopy density	VHRL						
28	2380	1006515	Undefined forest 80-90 % canopy density	VHRL						
29	2390	290343	Undefined forest 90-100 % canopy density	VHRL						

Figure 3: Overview of the Prowater Land cover Map and data sources for each category

3.2. Mean highest (MHG) and lowest (MLG) groundwater level

The mean high groundwater (MHG) gives an indication of the average groundwater table at the end of the winter season. The mean lowest groundwater level (MLG) gives an indication of the average groundwater table at the end of the growing season over a longer period.

The depth at which the soil is water saturated varies a lot and depends on the preceding weather conditions. Preferably such data is locally available and can be used to replace the datasets in the GDB. Unfortunately, data on soil water levels is very difficult to obtain and is generally an output of hydrological models. A lot of the scenarios involve the reduction of drainage and the manipulation of water levels to increase water retention in the soil. MHG and MLG may also be deducted from vegetation and local measurements.

To allow the exploration of the Output 2 tool, we developed these MHG and MLG maps for the GDB. It is however very unlikely that they reflect a real local situation.

The original MHG/MLG map of Flanders is an interpolation of the drainage classes from the digital soil map of the Flemish region (1970) (AGIV,2006), with topographic corrections based on the DTM for Flanders (AGIV, 2014). The basis of the original soil map of Flanders are soil samples taken anno 1960-1970. Through the rusty mottles or the oxidation-reduction front in the soil samples, the drainage class of a soil can be determined. Based on a combination of the drainage and texture class an indicative designation of the depth of groundwater relative to the topography was developed (Stuurman et al., 2002). These estimates of groundwater depth are the mean for each polygon of the soil map. Inside polygons with identical texture and drainage, significant topographic variations can be identified. The indication of the depth of groundwater should therefore be seen as the mean state of a larger zone. The availability of the DTM in a higher resolution (DHM Flanders II) enabled the selection of only the topographic mean locations. These could then be used for interpolation to obtain an even more detailed groundwater table layer. Similar to the way the MHG layer was developed, MLG can be deducted from soil samples, more specifically the reduction front in soil samples. This can also be linked to drainage classes. Based on a combination of the drainage and texture class an indicative designation of the depth of groundwater relative to the topography was developed (Stuurman et al., 2002). However in dry soil classes there was insufficient differentiation. The relationship between drainage classes and the difference between MHG and MLG was then further extrapolated using the water system map.

This high resolution Flemish dataset has been used to extrapolate a MHG and MLG for the other parts of the 2 Seas region, by using a regression model. A regression model provides a function that describes the relationship between one or more independent variables and a response, dependent, or target variable. So we used the water system map (output 3) to predict the MHG and MLG, based on the data available for the Flemish Region. Evidently, the performance of this function is not very high and even questionable outside the Flemish Region. However, this was the best available method to develop such a map for the 2 Seas Region.

3.3. Other layers

The models of the ecosystem services sometimes contain other layers that will be shortly presented here. These layers are provided with the database, but can be replaced by others if more accurate (local) data is present.

3.3.1. Texture

The map of texture is used in the calculations of the ecosystem service of infiltration/evapotranspiration/runoff and is derived from data from LUCAS (Ballabio et al., 2016). This dataset recognizes 4 different textures: Sand, loam, sandy loam and clay. As the original data is very coarse (500x500m) and binary, we opted to increase the resolution and make the changes more gradual by selecting the middle of a pixel and using these datapoints to interpolate between values. This creates then a map with 4 bands, one for each soil texture. Band 1 corresponds with loam, band 2 with sand, band 3 with clay and band 4 with sandy loam.

3.3.2. Sand/Clay/Podzol

These maps are used in the calculation of the ecosystem service soil carbon. The clay and sand content maps are based on data from LUCAS (Ballabio et al., 2016). These maps have a pixel size of 500x500m. For this reasons again the pixel size was artificially raised to 10x10m by choosing the middle of the original pixels and interpolating between these.

Podzols are soil types with a spodic horizon, which has a large soil organic carbon content. For this reason, these soils are part of the calculation of soil carbon.

3.3.3. Population

The map with the population density per ha is used in the calculation of the ecosystem service health. The layer has a resolution of 100x100m.

4. Plugin

4.1. Scenario development

4.1.1. Extract case study

Description

Module 1.1 retrieves the GIS data for the research area from the _Geodatabase. In this way calculations in the other modules can be limited to the area of interest. The datasets produced can then be used further in the plugin.

Method

Module 1.1 extracts parts from the different geodatabase layers based on a study site shapefile, created by the user. These partial datasets can then be used further in the other modules. The module only requires an output folder and defines the result names. The provided shapefile must be in coordinate system EPSG 3035.

Required information in the module			
		Type	Description
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select the case study area	Shapefile	Select the shapefile which delineates the study site
3	Give a location to save the results.	Folder	Select a folder where the results can be saved.

4.1.2. Develop LC scenario

Description

Module 1.2 gives the user the possibility to set up scenarios with an adapted land cover. The original land cover map from the geodatabase or, if available, a more precise local land cover map can be used as input to then be adjusted through this module. The module offers the possibility to define sub-areas within which one or more changes take place. Module 1.2 uses user-defined shapefiles and defined conversion rules for this, which are assigned to the different shapefiles. The module will then combine both and integrate them into one map.

The advantage of this module is that elements that need to be preserved are simply taken over from the original maps. Streets, houses, waterways, etc. can thus be kept the same as they are currently. In addition, scenarios can be easily modified by adding, modifying, or removing conversion rules or changing the shape of the shapefiles. The result is a system that gives the user maximum flexibility. The naming of the output map can be determined by the user himself.

Method

In this module, the user must create several files: a txt-file that contains the necessary customization rules and a number of shapefiles to indicate the zones in which certain changes take place.

These shapefiles delineate the areas to which the changes will be applied. Within a zone, forest can be moved to grassland, while the forest remains outside. One shapefile can be used for processing several conversions. Settings must be correct when the shapefiles are created:

- The shapefile must have the same name as in the Excel and txt-file.
- Shapefiles must be in the correct coordinate system: EPSG 3035.
- One shapefile can contain more than one polygon. During the analysis these polygons will be considered as one zone for which the same conversion rules apply.
- Shapefiles can overlap, allowing for different conversion rules for specific subzones.

The different shapefiles must be placed together in one folder. It is the location of this folder that must be entered in the module. The module will find the correct shapefile from the txt-file with the conversion rules.

The txt-file that is required can be created in the Excel document 'Scenario_Template' that is supplied with the database. With this Excel file, the user can set up a series of conversion rules that allow the development of alternative scenarios and indicate what needs to be changed within each shapefile. Each line is associated with a shapefile, whereby according to the coding it is indicated which current land cover classes should be replaced by an alternative. The user can create as many rules as he/she wants. Using the "Scenario Table" tab, it is easy to set up the scenarios by means of drop-down selections (Figure 4). An overview of the codes of the land cover map can be found in the same Excel and in appendix 1. The list must then be copied, without a header, to the txt-file. Cut and paste the excel selection in e.g. notepad and save this file. The columns must be delineated with tabs. This txt-file must be defined via the user interface of the QGIS scenario module. It is possible to check the txt-file by going to the tab 'Conversion rules'. Extra rules can also be added here after which the updated text can be saved.

Figure 4: Screenshot of Scenario_Template with drop-down menu

The conversion rules must comply with several rules to apply the correctly:

- The naming of the shapefiles is largely free (numbers and/or letters). However special punctuation marks such as ^ and ¨ can cause problems.

- Different rules can be drawn up for one shapefile. In the same area (of one shapefile), for example, forest can be converted to a swamp type in a first line and grassland to an arable type in a second line.
- The letter X acts as a wildcard. Using 'X' instead of a more specific code in the "Current State" ensures that all more specific codes (under the 'X') are included in the conversion. For example, entering '21XX' will select all areas with codes 2100, 2110, 2120, etc. for conversion by the module. With 'XXXX' the entire area is included within the delimitation of the shapefile, regardless of the current coding.
- For the "Future State" land cover must always be specified to the highest level of detail. For example, it is not possible to enter 21XX as new land cover.
- The list of conversion rules is run from top to bottom. If a pixel is converted by several lines, the last conversion line takes precedence. It is therefore best to place large land cover changes at the top and the more detailed changes at the bottom.
- If the desired type of land cover is not available or cannot be defined, 65535 can always be entered as a no data area.

	Required information in the module		
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map which needs to be adapted
3	Give location and name of the updated land cover (Tiff)	Tiff	Give the location and name for the new land cover map. This file will be created or overwritten if it already exists.
4	Select the txt-file with conversion rules (txt)	Txt	Select the txt-file with the different conversion rules.
5	Select the folder with the different areas (folder)	Folder	Give the folder which contains the shapefiles that are given in the txt-file with conversion rules.

4.1.3. Adapting groundwater levels

Part of the scenario is also adapting the groundwater levels to a new status quo. The next module drainage will take into account some effects of new land cover, however apart from land cover changes certain measures will have a more profound effect on groundwater levels. Examples are the installation of leaky dams (rewetting larger areas around it), the creation of floodplains or the filling up off ditches. These adaptations will require the user to manually adapt the MHG/MLG values.

How to adapt MHG/MLG in QGIS:

If the complete area of the case study should be adapted with a flat rate, this can be easily done through the raster calculator (under the raster tab). However if more complex changes need to be made things become more difficult.

In our calculations of study sites, certain rules of thumb were used. Around measures such as leaky dams, wetland scrapes or the filling up of ditches we chose to create a buffer of 50 meter combined with a rewetting of 10 cm inside (both for MHG and MLG). If site data is available , it is always better to use that information.

An example is the demonstration site of Walkhampton, where 8 leaky dams were installed. The leaky dams will slow down run-off, causing more infiltration, which can cause the MLG and MHG to increase locally around these dams.

First buffers should be made around the newly installed leaky dams. Take a shapefile with only the leaky dams and add a buffer through "Vector -> Geoprocessing Tools > Buffer", where a distance for the buffer can be specified e.g. 50 meter. If specific local data is present this can be used to determine an exact buffer distance.

It is also possible to define your own polygon if you don't expect the same effect on both sides of the measure. This can be done through "Layer -> Create Layer -> New Shapefile Layer". Provide a name, select geometry type polygon and select coordinate system EPSG 3035. Right click the new layer, toggle editing and then click on "Add polygon feature" which can be found under the tab "Edit" or in the Digitizing Toolbar. You can now make a polygon by clicking on the map and finalise it by right clicking.

In a next step the buffer should be joined with the original shapefile of the area (in case the buffers extend beyond the original) through "Vector -> Data Management Tools > Merge Vector Layers". This new shapefile can then be used in the first step of the ES-tool to extract MHG, MLG and land cover.

A simple way to adapt the groundwater in the buffer only with a flat rate can be done in the following way:

1. Create a new column in the (multi)polygon with only the buffers, where you put the number of the change needed in the groundwater level. For this opten the attribute table of the polygon click on the pencil at the top left and then either click on 'open field calculator'. Give an output field name and add the number of the change in groundwater level. Save the edit (click on the pencil again).
2. Save the edit
3. Raster -> Conversion -> Rasterize. Select the polygon and column you just adapted, choose as output raster size units georeferenced units of 10 by 10. Select as output extent a layer that selects the whole site. Don't choose 0 as NoData value but choose something as 65535.
4. Go to raster tools, select Fill No Data cells and fill it with 0.
5. Now you can adapt the original groundwaterlevels obtained through the 'extract case study' of the plugin with raster calculator by adding or subtracting the change. (Rewetting means subtracting from the original values.

Another way of doing it is:

1. In order to change the MHG and MLG inside the buffers around the leaky dams but not in the rest of the site, start by extracting data from the original groundwater rasters with the buffer shapefile as mask (Raster -> Extraction -> Clip Raster By Mask Layer). Turn off the option 'Match the extent of the clipped raster to the extent of the mask layer'
2. Adapt this new raster through the raster calculator.
3. Open the raster calculator again and create a mask by dividing the adapted layer by itself. This will create a raster with 1's where the buffers are located and NoData cells outside of it.

Note: if a value of 0 is present in the raster, adapt the raster by adding a constant number to both sides in order to avoid dividing zero by zero.

4. Search in the Processing Toolbox for the raster tool 'Fill NoData Cells' and use a value of zero to fill the NoData cells in the mask (to create a 'Filled mask'). This creates a binary raster with zeroes and ones.

5. Open the raster calculator and use 'original layer * (1- Filled mask)' in order to create a raster with the original values that need to be kept. It is possible to do calculations with this layer as well.

6. Use the Fill No Data Cells on the layer with the adapted values inside the buffer and fill the no data with 0.

7. This layer can then be summed together with the layer with the values outside the buffer in order to have a complete layer, with adapted MHG or MLG values.

Important: MHG and MLG values are positive when underneath the ground level. In order to raise the groundwater level it is thus necessary to subtract a number from the original values. A raise of the MHG with 20 cm equals "MHG – 20" in the raster calculator.

4.2. Ecosystem services

In this part of the tool different maps with a quantification of different ecosystem services will be calculated. This makes it possible to examine in detail in which part of the sites the potential delivery of ecosystem services is the highest.

4.2.1. Drainage

Description

To make land uses such as agriculture, urban developments or forestry possible, ground water tables need to be stable and remain under certain ground water depths. These depths vary between land uses as trees require different levels compared to crops. Drainage systems, such as ditches, remove excess rainwater fast and reduce ground water tables to these specific levels. But lowering ground water tables influences a range of ecosystem services, from ground water recharge up to carbon storage in the soil. To estimate the impact of drainage on these services, changes in land cover need to be translated into groundwater table changes. This module calculates new mean high and low groundwater table maps and estimates the losses in groundwater in the upper soil layer compared to the natural situation. The effect of these changes can then be evaluated in the ES modules by implementing these new mean high and low groundwater table maps.

Method

The module compares the mean low and high ground water levels from the tiff-files with a table with maximum ground water levels. For each land use type a high and low estimate of the maximum ground water level is given above which the land use can become compromised (e.g. reduced crop production). The user can change these ground water levels to the local situation. The values from the table are combined with the land cover map and MHG map, to assess which areas have to be drained to make the land use possible. The differences between the MHG map and land use targets are aggregated to give an high and low estimate of the ground water volume that needs to be drained to keep the ground water during the wet season below the target levels.

The module also creates new MHG and MLG maps where the ground water levels are decreased to the mean value of the high and low target levels. These maps can then be used to calculate the effect of the drainage on the other ecosystem services. The module only takes into account the effects from drainage, a reduction in groundwater levels. Measurements to artificially increase the ground water level are not considered.

Important: In case of rewetting of an area, it might be necessary to add the rewetting after running the drainage module. This is because the tool has a low and high target of groundwater level. If the area is rewetted, it might simply be reduced to the same level as before, not reflecting the original situation. However it is important to realise that in such cases for example crop or forest growth will be impacted.

Required information in the module			
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Select mean high groundwater (Tiff)	Tiff	Select the mean high ground water map of the study site. This map will be adapted by the
4	Select mean low groundwater (Tiff)	Tiff	Select the mean low ground water map of the study site. This map will be adapted by the
5	Give location and name for the output minimum drainage losses file (Tiff)	Tiff	Give location and name of the map with the new ES minimum drainage loss. This file will be created or overwritten if it already exists.
6	Give location and name for the output maximum drainage losses file (Tiff)	Tiff	Give location and name of the map with the new ES maximum drainage loss. This file will be created or overwritten if it already exists.
7	Give location and name for the new MHG file (Tiff)	Tiff	Give location and name of the map with the new MHG. This file will be created or overwritten if it already exists.
8	Give location and name for the new MLG file (Tiff)	Tiff	Give location and name of the map with the new MHG. This file will be created or overwritten if it already exists.
	Optional	**Type**	**Description**
9	LC - Drainage	Txt	Table with low and high drainage estimates. Can be adapted for each land cover. Provided in

4.2.2. Soil carbon

Description

The ecosystem service soil carbon storage results from the storage of non-mineralized carbon from dead organisms in the soil, where it is stored in the long term. The more atmospheric CO_2 is captured in the soil, the less it can contribute to global warming. The benefits of this service are on the one hand the preservation of existing carbon stocks and on the other hand the storage of extra carbon in the soil. This module calculates the total carbon storage in the soil (ton C / ha).

Method

The module uses 4 different regression equations that were originally developed for Flanders (Ottoy, Beckers et al. 2015; Ottoy, Elsen et al. 2016; Ottoy, De Vos et al. 2017; Ottoy, Van Meerbeek et al. 2017) and now adapted to better fit the wider region. Together, these equations allow to calculate the carbon storage in the soil for most land cover types down to a depth of 1 meter. The regression equations are based on the most reliable databases available for Flanders.

From these equations and the available data within the module, the carbon storage in the soil can then be calculated to a depth of 1 meter (ton C/ha). To calculate the storage per year in the quick scan it is assumed that it takes 100 years to convert a carbon stock to a new equilibrium state (Foereid and Høgh-Jensen 2004; Freibauer, Rounsevell et al. 2004). If extra field data is available with the percentage of soil organic carbon, sand or clay in the upper soil layer, these data can be added under the optional tab of the module.

	Required information in the module		
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Select mean high groundwater (Tiff)	Tiff	Select the mean high ground water map of the study site.
4	Select mean low groundwater (Tiff)	Tiff	Select the mean low ground water map of the study site.
5	Give location and name for the carbon output file (Tiff)	Tiff	Give location and name of the map with the new ES soil carbon. This file will be created or overwritten if it already exists.
	Optional	**Type**	**Description**
6	Select areas with increases in SOC (%) (Shp)	Shp	Provide a shapefile with the areas in which there is an increase in Soil Organic Carbon. The amount should be added as a column in the attribute table.
7	Select field (%)	Field in Shp	Select the field of the attribute table of the above shapefile with the % of Soil Organic carbon.
8	Select amount of sand in the upper soil layer (%) (Tiff)	Tiff	Select a map with the percentage of sand in the upper soil layer. The coordinate system should be EPSG 3035.
9	Select amount of clay in the upper soil layer (%) (Tiff)	Tiff	Select a map with the percentage of clay in the upper soil layer. The coordinate system should be EPSG 3035.

4.2.3. Nitrogen and phosphorus in the soil

Description

Ecosystems can filter nutrients from soil and surface water and incorporate them into the organic matter (living, litter, humus and organic matter). These nutrients end up in litter, after which mineralization and decomposition processes make it available again for plants. This process will also ensure that soils are enriched with organic material. This organic material also contains some nutrients (N/P). In this way they can remove N and P from the groundwater and surface water for a long time, improve the quality of both and provide numerous direct (e.g. pure water) and indirect benefits (e.g. water recreation). This module calculates the total N and P storage (tons N/ha and tons P/ha) in the soil.

Method

The storage of nitrogen and phosphorus in soils is directly linked to the storage of carbon in soils. For the different soil cover classes, C/N and N/P ratios were taken from the report "benefits of the NATURA2000 network" (Broekx et al., 2013). These ratios are then used to calculate the storage of N and P in the soil from the carbon map from module 2.2.

	Required information in the module		
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Select soil carbon (Tiff)	Tiff	Select the soil carbon map of the study site.
4	Give location and name for the output nitrogen file (Tiff)	Tiff	Give location and name of the map with the new ES soil nitrogen. This file will be created or overwritten if it already exists.
5	Give location and name for the output phosphorus file (Tiff)	Tiff	Give location and name of the map with the new ES soil phosphorus. This file will be created or overwritten if it already exists.

4.2.4. Infiltration – evapotranspiration – runoff

Description

The infiltration or seepage of rainwater into the soil is an important supporting ecosystem function. Infiltration assures us of sufficient ground and surface water of good quality. Once deeply infiltrated into the soil, the water will slowly continue its way to deeper groundwater layers over a long period of time. The long residence times of groundwater mean that pollutants and nutrients are removed by adsorption, soil chemical processes and microbial processes. Groundwater will largely return to the surface in seepage zones and thus contribute to a stable and clean basic flow of our waterways. The module calculates the amount of water that infiltrates locally annually (m³/ha*year).

Method

Water infiltration is partly determined by the physical system and partly by soil cover and use. Several physical factors together determine a maximum potential infiltration. This potential is then reduced by the land cover to the actual infiltration. The module combines the spatial information from the study site with yearly estimates for evapotranspiration, runoff and infiltration from a database considering the physical system, land use and land management options for five rainfall scenarios. These estimates were calculated using an hourly stepwise 2-D model which contains both land cover and the upper soil layer. A general overview of the model is given in Figure 5.

The model simulates both above and below ground physical and biological processes and can be applied on a number of natural vegetation types, grassland, crop types as well as different types of impervious land cover types on different soil types (sand, loam, sandy loam and clay).
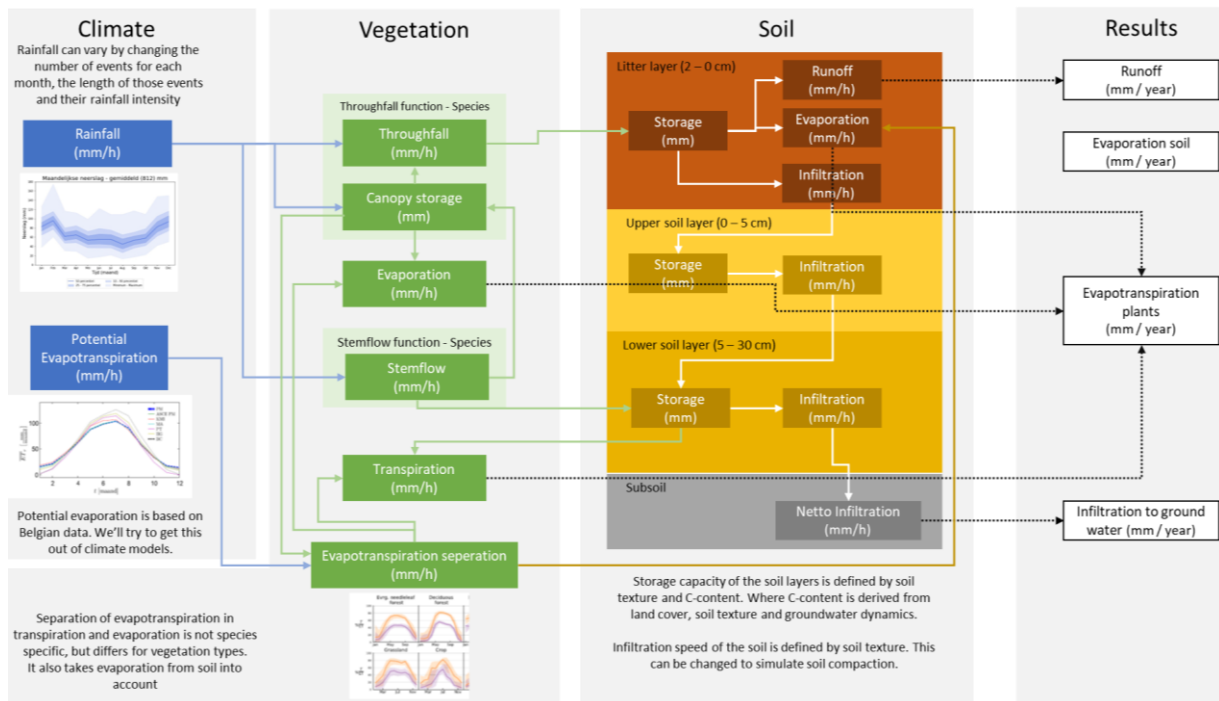

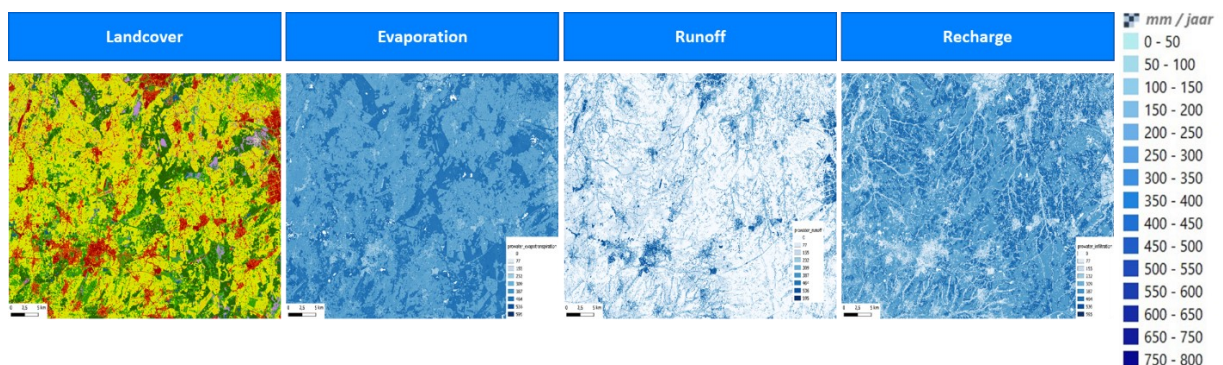*Figure 5: General overview of the infiltration model.*

Figure 6: Spatial output of the model. Through different pathways in the model, precipitation totals are divided between evapotranspiration, runoff and recharge (deep infiltration). Runoff requires interpretation because secondary/delayed infiltration/evaporation can occur.
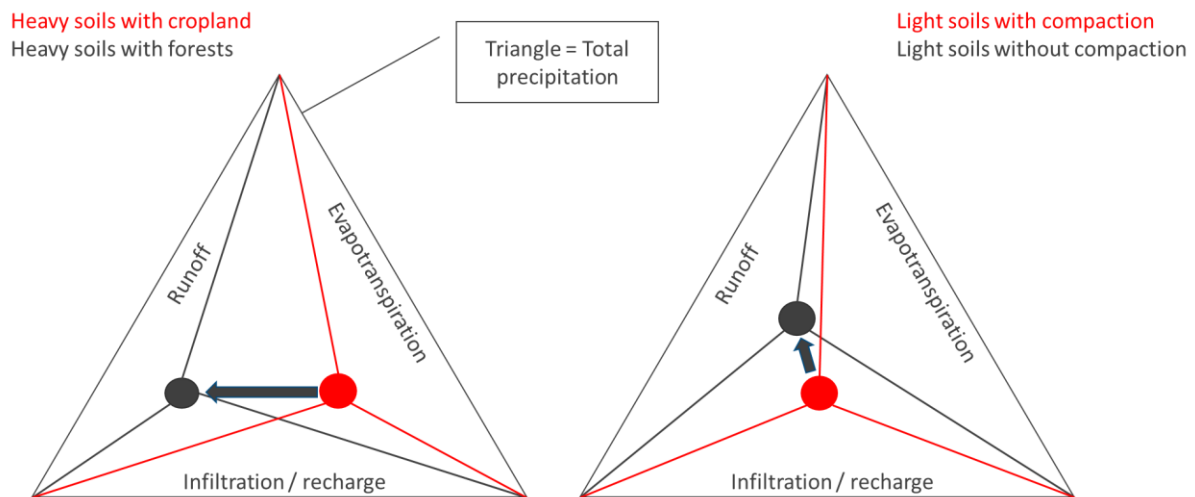
Figure 7: Conceptual representation of how precipitation is divided between Runoff, Evapotranspiration and Infiltration/recharge. The red/black dot shows a potential shift after implementation of resp. afforestation (left) and soil decompaction (right).

To develop the database the model was applied under a wide range of conditions, as a result the following options are integrated in the database and module:

- **Rainfall scenarios**

Five rainfall scenarios were derived from rainfall measurements in Flanders over the last 10 years. These scenarios were developed as monthly rainfall-length-intensity probability distributions. From these distributions 500 rainfall series were simulated which were run in the model to get average yearly values for evapotranspiration, runoff and infiltration:

- o Average precipitation (803 mm / year)
- o Low precipitation (635 mm / year)
- o High precipitation (1150 mm / year)
- o Average precipitation - dry summer/wet winter (794 mm / year)
- o Average precipitation - Wet summer/dry winter (817 mm / year)

The user should compare these scenarios with rainfall distributions within the research area to assess potential differences in outcome and their impact on evapotranspiration, runoff and infiltration.

- **Changes in land cover**

Changing the land cover map will allow the user to assess the impact of land cover conversion. The available land cover classes allow the user to evaluate a wide range of land cover types as well as mixed land covers such as open forest and heath land with dunes.

- **Changes in drainage**

Infiltration capacity is affected by the depth of the ground water level. Areas with high ground water levels such as wetlands have limited capacity to store rainwater during rain events and high runoff values. To take this effect into account mean high and low ground water maps are used to limit the amount of infiltration in areas with high ground water levels and increase runoff.

- **Soil carbon content**

Soil carbon content has an impact on the water holding capacity of the soil and effects as such the infiltration capacity of the soil. Therefore, the soil carbon map from the soil carbon module is required to calculate the infiltration correctly. Improvements in soil carbon content can increase the amount of water which can be retained in the soil layers. By changing the soil carbon content within an area in this map manually, the impact of management some options can be evaluated.

- **Soil compaction**

The use of heavy equipment on agriculture and forestry can lead to compaction of the soil. Especially on arable land the effect can be found as a plow pan directly beneath plow depth. In the module a shapefile can be given with areas where soil compaction is present. The module can evaluate four different conditions:

- 0 – No compaction = natural infiltration rate
- 1 – Low compaction = reduction of infiltration rate by 27% beneath the lower soil layer.
- 2 – Medium compaction = reduction of infiltration rate by 65% beneath the lower soil layer.
- 3 – High compaction = reduction of infiltration rate by 82% beneath the lower soil layer.

The values 0 – 4 need to be given in a column in the compaction shapefile to define the level of compaction for each polygon.

- **Soil texture**

Soil texture is currently coded as a percentage adding up to 100. This map should have 4 bands. Band 1 = loam, Band 2= Sand; band 3 = Clay; band 4 = sandy loam, each band between 0 and 100.

	Required information in the module		
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Select mean high groundwater (Tiff)	Tiff	Select the mean high ground water map of the study site.
4	Select mean low groundwater (Tiff)	Tiff	Select the mean low ground water map of the study site.
5	Select soil carbon (Tiff)	Tiff	Select the soil carbon of the study site (created in 2.1)
6	Select climate scenario		Select 1 of the 5 climate scenarios.
7	Give location and name for the output infiltration file (Tiff)	Tiff	Give location and name of the map with the new ES infiltration. This file will be created or overwritten if it already exists.
8	Give location and name for the output evapotranspiration file (Tiff)	Tiff	Give location and name of the map with the new ES evapotranspiration. This file will be created or overwritten if it already exists.
9	Give location and name for the runoff infiltration file (Tiff)	Tiff	Give location and name of the map with the new ES runoff. This file will be created or overwritten if it already exists.

	Optional	Type	Description
10	Select areas with compaction (code) (Shp)	Shp	Provide a shapefile with the areas in which there is soil compaction. The amount should be added as a column in the attribute table.
11	Select field (code)	Field in shp	Select the field of the attribute table of the above shapefile with the code of Soil Compaction (0-3).
12	Give texture (Tiff)	Tiff	Select a map with the soil texture (as a percentage). This map does not have to be clipped on the study site (as long as it is in EPSG 3035)

4.2.5. Water retention

Description

Water retention in shallow groundwater involves the (temporary) retention of rainwater which is an important regulating function. Water retention has positive effects on peak drainage (increased storage) and in periods of drought (water retention, sponge effect). Water retention as a supporting function strongly determines ecosystem services such as denitrification, carbon storage in soils and the associated nutrient retention. Water retention is influenced by soil characteristics, drainage and land use (desired drainage). On the one hand, the module calculates the possible buffering of precipitation surplus between seasons (difference between the average highest and lowest groundwater level) and, on the other hand, the water buffer that is still available in the event of a prolonged drought (m³ of water present in the first meter below ground level).

Method

Water retention is determined based on the differences between the MHG and MLG maps. An indicator is given of the seasonal retention (variations between winter and summer levels) and permanent retention available during prolonged drought up to 1 meter below ground level. Both maps give values in m³ per hectare.

Permanent retention refers to the intrinsic capacity to deliver water to surface water in the event of extreme drought. This is reflected by the total amount of water that is present up to 1 meter below ground level in the situation of the average lowest groundwater level. This limit to 1 meter below ground level is under the assumption 1 meter is a permanent drainage depth. The permanent retention is thus especially high for areas that are extremely and/or permanently wet. It is the capacity for water-supply capacity to surface water in the event of extreme low water and NOT in function of flood prevention. If permanent retention is high, there is often a very low capacity to receive extreme precipitation.

- Formula for permanent retention: (100-MLG)/2) *100

Seasonal retention refers to the capacity to buffer soil water between periods of high and low rainfall. It is determined by the difference between the average highest and the average lowest groundwater level. Here too this is limited to a maximum of 1 meter below ground level. Areas that combine a high winter/spring groundwater level with a low summer groundwater level have a high seasonal retention. These are often temporary wet areas in upstream depressions in the landscape. In such areas, shallow groundwater flows and runoff water converge, causing such zones to react quickly to precipitation surpluses and precipitation shortages. They contribute strongly to flood prevention and groundwater replenishment.

- Formula seasonal retention:
  If MLG > 100 and MHG <100: (100-MHG)/2 *100
  IF MLG AND MHG <100: ((100-MHG)-(100-MLG))/2) *100

Required information in the module			
	Module	Type	Description
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Select mean high groundwater (Tiff)	Tiff	Select the mean high ground water map of the study site.
4	Select mean low groundwater (Tiff)	Tiff	Select the mean low ground water map of the study site.
5	Give location and name for the output seasonal retention file (Tiff)	Tiff	Give location and name of the map with the new ES seasonal retention . This file will be created or overwritten if it already exists.
6	Give location and name for the output maximum retention file (Tiff)	Tiff	Give location and name of the map with the new ES maximum retention. This file will be created or overwritten if it already exists.

4.2.6. Health benefits

Description

There is a lot of scientific evidence that greenery contributes to improving the physical and mental health of residents and the people who visit these areas. There are several mechanisms at play here:

- View of and contact with nature have positive effects on mental health (stress, depression).
- Proximity to greenery stimulates outdoor recreation and exercise, with direct positive effects on health.
- Contact with greenery improves the cognitive, physical, and social development of children.
- Proximity to greenery reduces the risk of overweight and obesity.
- Nature provides a specific framework of importance for care tourism.

Method

The method in this module has been adopted from Broekx et al. (2013) and is based on the results of a scientific multi-year program in the Netherlands (Vitamin G - Maas, 2008). This study shows that there is a positive relationship between the amount of green area within a 1 km radius of the home and the reduction of 18 out of a total of 24 specifically studied disease states. The study has been adjusted for indirect demographic and socio-economic characteristics of the respondents and for the degree of urbanization. Among other things, a positive effect has been found on heart disease, neck and back complaints, depression, anxiety disorders, upper respiratory tract infections, asthma, infectious diseases of the gastrointestinal tract, urinary tract infections and diabetes. The relationship is greatest for mental illness. For other important diseases such as stroke or cancer, no associations with the presence of greenery have been found (but with traffic-related air pollution, for example). The relationship was strongest for population groups that are expected to spend a lot of time in the vicinity of their own home, such as children and groups with a lower socio-economic status.

To estimate the relative importance of these health effects, how often they occur has to be investigated. Their occurrence is based on Dutch prevalence figures, which indicate how often a disease or condition occurs on average in 1,000 people (Hoeymans et al., 2007). To be able to compare and add up very different health effects, these effects are expressed in DALYs. DALYs or disability adjusted life years is an indicator for comparing different health effects. The indicator considers the severity and duration of the condition and is expressed in the number of healthy life years lost. All the disorders on which greenery has a positive effect together represent 40% of the total disease burden in the Netherlands or 74 healthy life years lost (per 1,000 Dutch people in 2007 (Hoeymans et al., 2007). Green has a relatively large effect on some important health problems such as mental problems (anxiety and depression), coronary heart disease, COPD and diabetes.

According to the study of Maas (2008), 10% extra green space within a radius of 1 km leads to a total health gain of 2.46 healthy life years per 1,000 inhabitants. Green within the module includes a wide range of green space such as park, nature, forest and agriculture. In addition, the study by Maas also provides a relationship for the share of green space within a radius of 3 km around the place of residence and effects on mental health. Both relations are combined in the module.

The following methodology is then applied in the module:

1. Converting land cover to "Green" – "No Green".
2. Calculate % green within a 1km buffer around each cell.
3. Calculate % green within a buffer of 1 to 3km around each cell.
4. Calculate health effect of greenery within 1km:
   - ➔ DALYs = number of inhabitants x %green1km x 0.000246
5. Calculate health effect of greenery between 1km and 3km:
   - ➔ DALYs = number of inhabitants x %green1 to 3km x 0.000078
6. The health effects (total DALYs) are assigned to the surrounding green. The DALY value of each cell is divided by the area surrounding green. This value is subsequently assigned to each green cell and the results of dividing all cells are added together:
   - ➔ Health effect of green = sum ((Health effect 1km / area green 1km) + (Health effect 1to3km / area green 1to3km))

Required information in the module			
	Module	**Type**	**Description**
1	Select the location of the PROWATER database	Folder	Select the geodatabase
2	Select land cover (Tiff)	Tiff	Select the land cover map of the study site.
3	Give location and name for the health effects file (Tiff)	Tiff	Give location and name of the map with the new ES health . This file will be created or overwritten if it already exists.
	Optional	**Type**	**Description**
4	Select population density – inh/ha (10m resolution)		Table with low and high drainage estimates. Can be adapted for each land cover.

4.3. Evaluation

4.3.1. QuickScan

The quick scan module has been developed to aggregate the results of the ecosystem services calculations (map layers) in a simple way and makes a comparison between scenarios possible. This gives the user the opportunity to contextualize and interpret the calculated results. The tables make it possible to report and communicate the results in an understandable and systematic way.

The module in QGIS aggregates all data coming from the different ecosystem services modules to total values for the study area. These are then presented in an understandable way in tables and graphs in an included Excel document. In the Excel file, the results of different scenarios for the same area can be brought together and compared with each other.

To calculate the quick scan and place the results in the Excel file, the following actions must be taken:

1. Using module 3.1 in QGIS, the data from the different data layers is aggregated into total values for the area. This creates 2 different txt-files. The first file the 'Ecosystem services.txt' contains the results of the ecosystem services calculations. The 2nd file the 'Land cover.txt' contains an overview of the land cover classes and is used to calculate certain averages (e.g. per ha non-urban). If certain ecosystem services have not been calculated and are therefore not available in the results folder, a zero value is automatically entered in 'Ecosystem services.txt'.
2. The scenario name and both files must then be copied to the correct places in the Excel file.
   - The scenario name entered in the module must be placed at the bottom of the list in the "Scenarios" tab
   - The results from ecosystem services txt must be copied to the 'Ecosystem services' tab. The results should be placed at the bottom of the existing list.
   - The results from the land cover tab must also be copied here to the 'land cover' tab and placed at the bottom of the existing list.

After the scenario name has been entered in the correct tab, it automatically becomes available in the drop-down windows for selecting the study and reference area in the tab 'Overview'. If all tabs are filled in correctly, the results are automatically adjusted in the rest of the tables.

Calculate net gain or loss of water

The quickscan module offers the difference in delivered ecosystem services in the case of 2 scenarios, often the current situation and a future scenario with EbA-measures implemented. If the goal is to calculate the total net gain or loss of water in the study site as a result of the EbA-measures, there are three calculations that can be done depending on site characteristics. These calculations need to be done with the results from the table 'changes in ecosystem services' (unless otherwise specified).

Retention + Infiltration – Avg. drainage

This equation assumes that runoff is lost to the area. However if this is not the case and runoff will remain in the site and infiltrate at a later time , the equation changes to:

Retention + Infiltration + Runoff (change) – Avg. drainage

This equation assumes that no water that initially runoffs evaporates before it infiltrate. It might be more realistic to add a coefficient before assuming all runoff will eventually infiltrate. This equation assumes that only the extra runoff will remain in the study site, however these EbA-measures will also influence the original runoff that already occurred.

Retention + Infiltration + All Runoff – Avg. drainage

In this equation the total runoff in the scenario with EbA-measures is added, instead of only the difference between the updated and original scenario.

4.3.2   Case studies

General remarks

The tool has been tested on every demonstration site of the PROWATER project. Some tips and tricks will be given with how to best use the tool and interpret some of the results.

- After extracting the case study area, it is important to check if the resulting values are realistic. This means checking the land cover map (the land cover map in the database is based on remote sensing) and also the MLG and MHG. If there is surface water during parts of the year, this should be reflected in the MHG which should be smaller than or equal to zero (as negative values mean water above the surface).
- Develop scenario: It is highly likely that the land cover extracted from the database is not completely correct when comparing to the situation on the site. That is why it is useful to develop first a scenario with the correct original situation and later an adapted version to be able to compare the ecosystem services before and after the ecosystem based adaptations are in place.
- Before the ecosystem services are calculated it can be necessary to adapt the groundwater levels, as these have an influence on the delivery of the ES. Choosing realistic values can be difficult, so having site information is recommended. Certain measures will influence a larger area around the implementation site with regards to the groundwater level which then needs to be adapted. An example is the installation of leaky dams, causing an elevation of the groundwater around it. However, adapting groundwater levels can be hard, especially if you want to do more complex calculations. Estimations will also need to be made about the area affected by the change.

- Regarding the ecosystem service runoff: The tool will often find that in wet areas only a small amount of water will infiltrate, causing larger amounts of runoff. However, as long as the pool wherein this water is stored is closed off and the water does not get drained away by ditches or removed by a sloped landscape, this amount of water will not be lost to the ecosystem. The tool only provides numbers for what initially happens, so the initial runoff can still infiltrate at a later time. Furthermore the amount of water in the infiltration part of the water system will extend a pressure which will reach those part of the water system where seepage of water can be observed.

4.3.2.1 Flanders: Den Rooy

In Den Rooy, a site in the Campine region with sandy soil in Flanders, a degraded bog relict was restored. Before any measures were in place, this bog was drained by various ditches. This bog is located in the north part of the site, which lies more in the wet part of the water system. Other parts of the site lie in the permanently dry part of the water system. This part contained pine plantations, which were partly removed and replaced by heathland in order to increase infiltration (Figure 8).
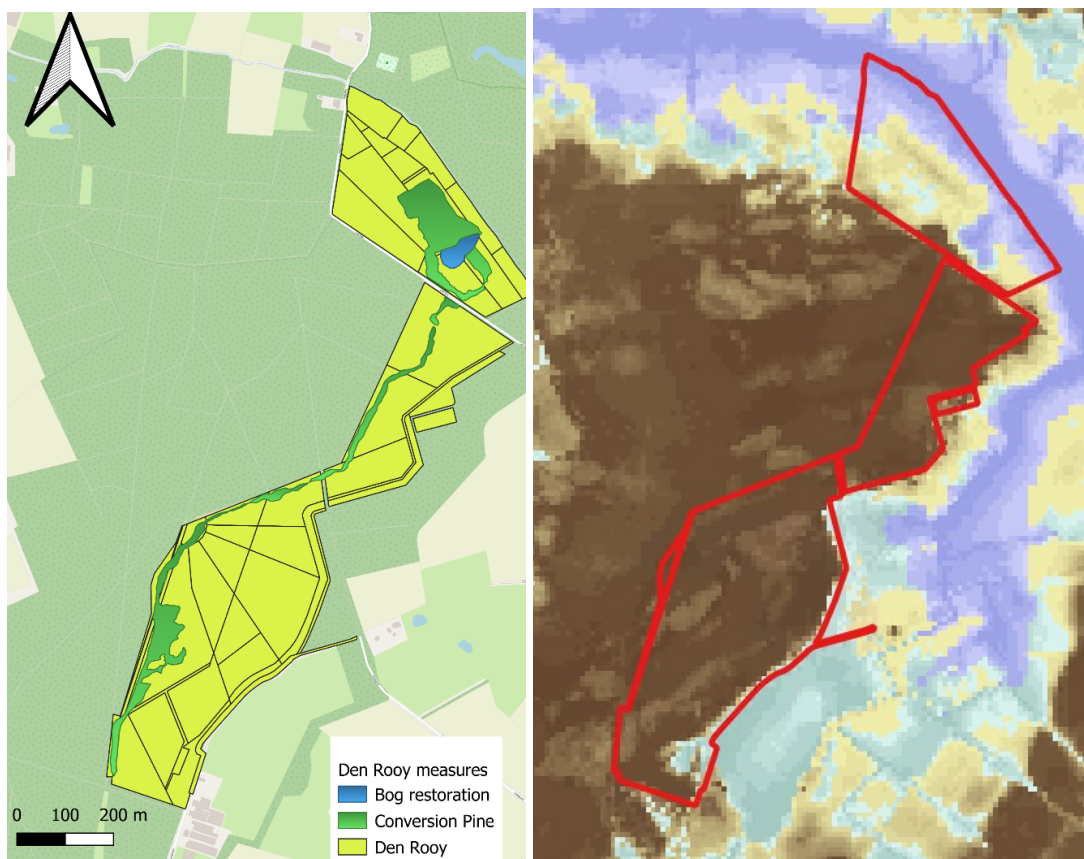
Figure 8: Overview of the measures taken on the site in Den Rooy and its location on the watersystem map where brown-yellow = infiltration area and blue= floodplain.

In a first step the before situation is calculated. As the remote sensing data is not always correct or specific enough it is often better to correct the land cover for the site. In the example for Den Rooy this means changing the land cover where the bog will be restored to heathland (code 4070) and setting the initial land cover of the pine forest to a more dense variant (code 2280) per data provided by the site partner. The resulting txt-file, loaded into the QGIS-tool can be seen in Figure 9.
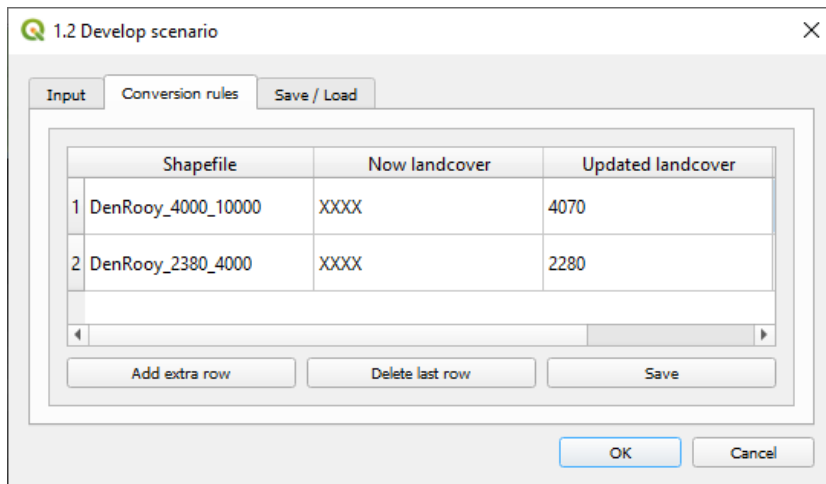
Figure 9: Example original scenario txt-file for the site of Den Rooy.

The next step is the calculation of the ecosystem services. In the first module of drainage the groundwater levels will change depending on the land cover. It is important to keep using these 'corrected' groundwater levels for the other ES-modules (Figure 10).
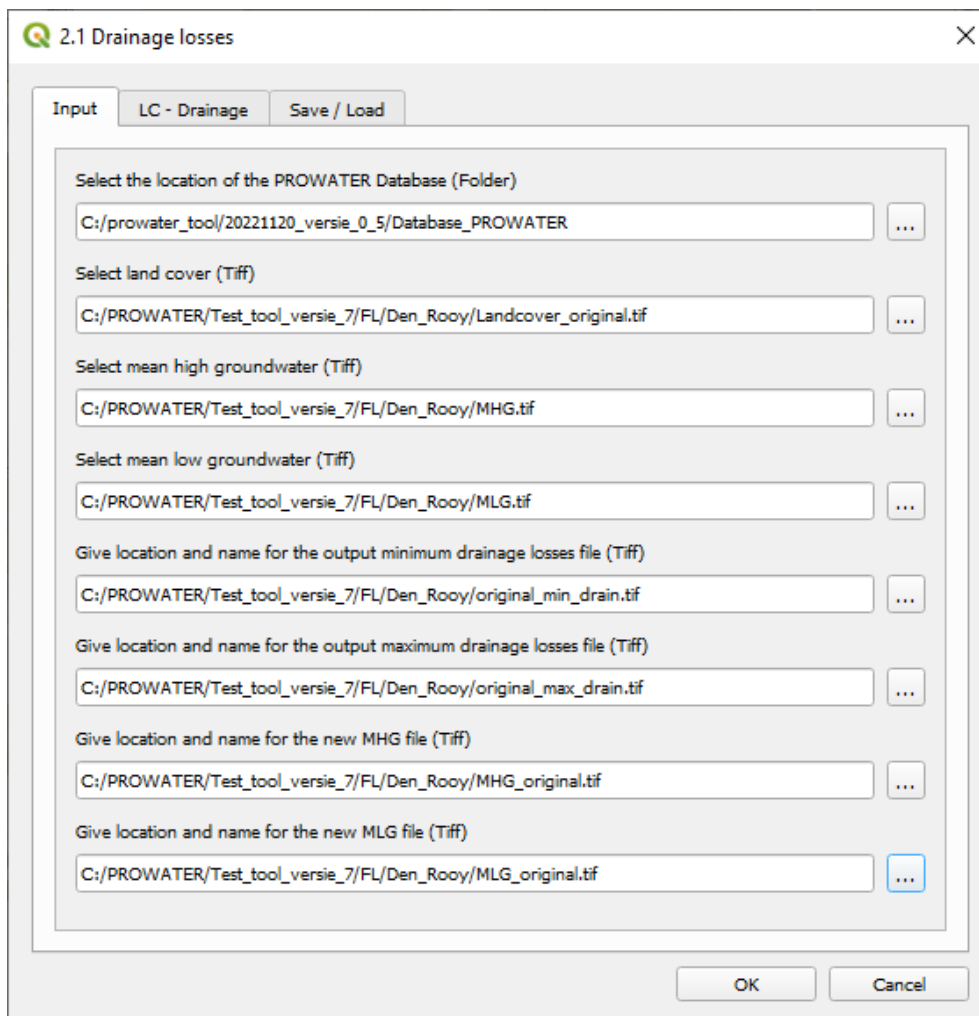

Figure 10: Example of the drainage module for the site of Den Rooy.

For the scenario after the ecosystem based adaptations are in place, it is important to change the MHG and MLG in the upper part as different ditches are filled up with bentonite, causing a diminished drainage and more retention of water in this part. In order to simulate this in the tool, values in the upper part were decreased with 20 (as the groundwater values are under ground level). However this value is not based on site measurements, but rather an estimation.

The changes in land cover before and after the adaptations are present can be observed in Figure 11. Original heathland was changed into a pond, while coniferous forest is converted to heathland. For forest and heathland, it is important to make an estimation of the canopy density in order to assign the correct code. This should not be the current density, but the expected future density.
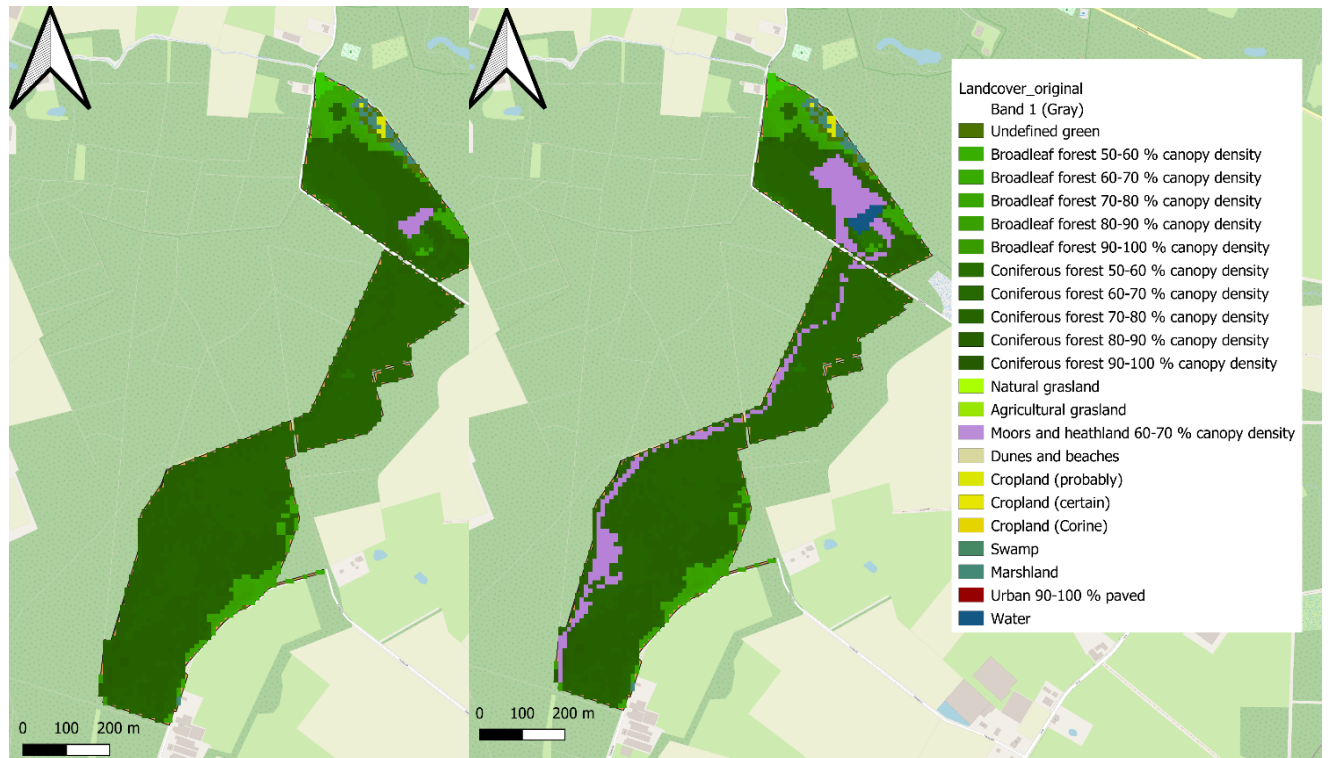
Figure 11: Land cover before (left) and after(right) EbA-measures are in place for the site of Den Rooy.

The new land cover and groundwater levels can then be used to predict the adjusted ecosystem services after the EbA-measures are implemented. The changes in delivered ecosystem services are shown in Table 1.

Table 1: Changes between ES delivery for the site of Den Rooy in the scenario after the adaptations are in place.

	Ecosystem services	%	Total	Unit
	Original runoff		326,52	m³ / year
Supporting and regulating	Runoff (change)	83,65	273,15	m³ / year
	Soil carbon	-5,83	-339,93	ton C
	Soil nitrogen	-6,28	-15,57	ton N
	Soil phosphorus	-6,28	-1,04	ton P
	Health effects	0	0	DALY / year
	Evapotranspiration	-0,49	-75,22	m³ / year
	Minimum drainage losses	166,4	52,25	m³ / year
	Maximum drainage losses	67,85	97,43	m³ / year
Provisioning	Infiltration	-1,7	-197,48	m³ / year
	Seasonal retention	15,85	1946,75	m³ / year
	Maximum retention	74,75	2762,25	m³ / year
Net gain or loss of water* *Retention + Infiltration – Avg. drainage*			+ 4436,68	m³ / year
Net gain or loss of water* If runoff> 0, remains in situ and can slowly infiltrate *Retention + Infiltration + Runoff (if >0) – Avg. drainage*			+ 4709,83	m³ / year
Net gain or loss of water* If all runoff (original + change) remains in situ and can slowly infiltrate *Retention + Infiltration + All Runoff – Avg. drainage*			+ 5036,35	m³ / year

The impact assessment tool predicts an increase of the seasonal and maximum retention. This is a predictable ecosystem service resulting of the bog restoration. In the upper part of the site around the bog drainage ditches were closed and filled up with bentonite, resulting in the increased retention of water.

Given that more water can reach the ground (after converting high interception pines to lower interception heathland), while at the same time the groundwater table in the part around the bog will rise, an increase in water runoff can be expected. This emphasises the importance of understanding where runoff in the landscape converges to. Ideally it ends up in the bog where it can infiltrate towards the groundwater from there at a later time (i.e. delayed infiltration), rather than being drained away. However we also see an increase in drain losses. This is to be expected as there is still a large ditch, called the 'Heerlese loop', to the northside of the area of Den Rooy, while simultaneously the groundwater table is elevated.

The results with regards to the other ecosystem services are not completely in line with the expectations. An effect of the raised groundwater table however is that the tool predicts a lower infiltration, which is not fully compensated by the cutting down of forest in the lower part and replacing it with heathland for the corridor.

The tool further predicts a decrease in soil carbon as a result of the cutting down of forest. In the model of the tool. This is not compensated by the restored bog and new heathland. The restored bog was in the calculations of the tool seen as a pond, but if over time the full pond is converted to a real bog the carbon captured by it will increase more than currently estimated.

4.3.2.2 The Netherlands: Vloeiweide

In the 'Vloeiweide' site, situated in the Mark basin along the brook Bijloop a more natural water landscape was restored. This was done by adding sand and woody debris to give structure to the water flow, restoring a meander and raising of the riverbed to decrease drainage. This also increases the water retention in nearby flood meadows. An overview of the measures and the location on the watersystem map can be seen in Figure 12.
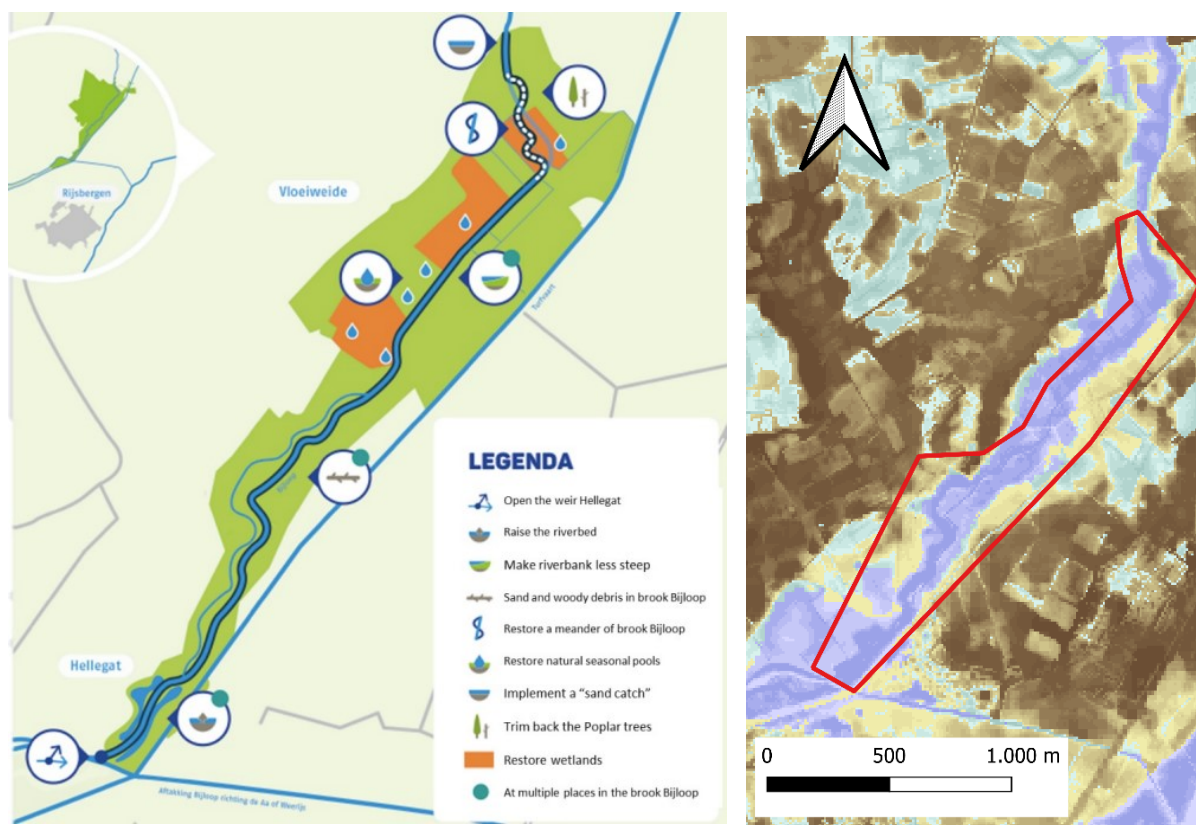

Figure 12: Restoration measures in the Vloeiweide and its location on the watersystem map where brown-yellow = infiltration area and blue= floodplain.

The first step in doing the analysis is checking if the original land cover and groundwater levels are correct. Using data of the site partner quite some changes in the land cover were made. They can be seen in figure 13. The various forest is replaced by a single category (dark green), areas wrongly categorized as cropland (yellow) are changed to agricultural and natural grassland (yellow-green and light green). Blue-green represents alluvial forest and red is built-up area. In order to do these corrections the original shapefile is split up in various smaller polygons, named after their future land cover value
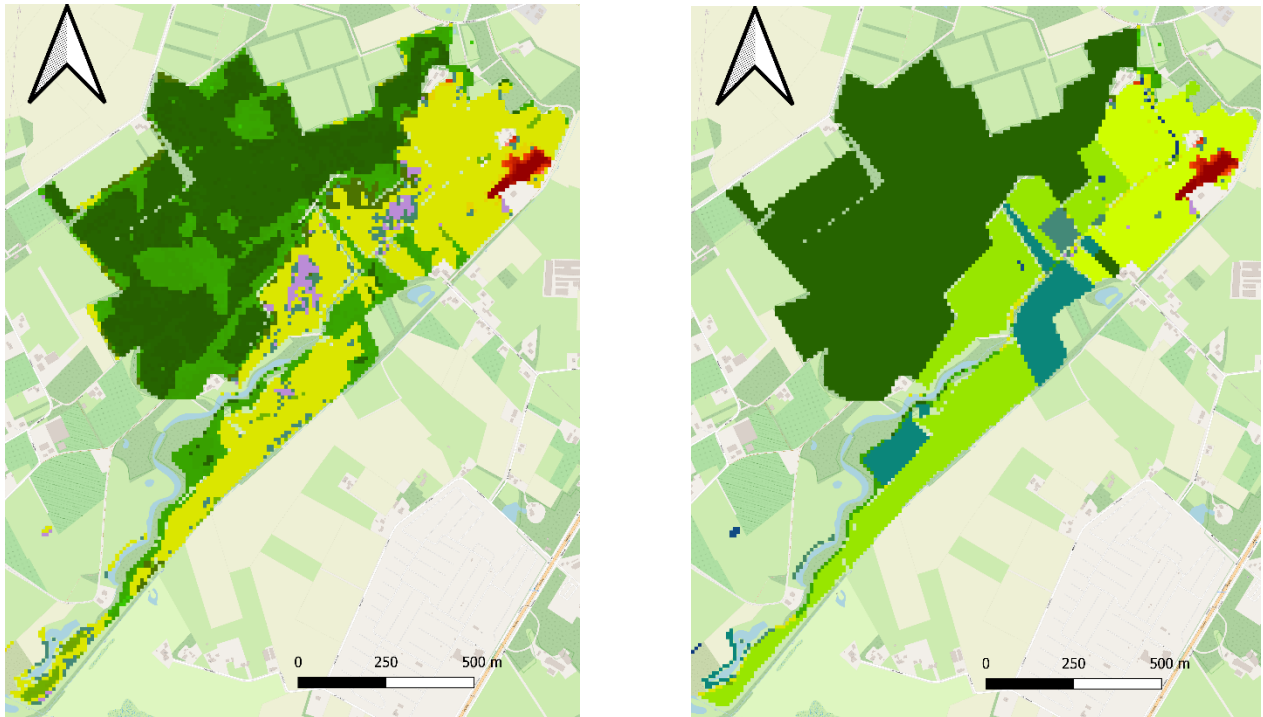
Figure 13: Land cover based on original geodatabase (left) and after corrections were made based on site data (right)

Figure 14: Example original scenario txt-file for the site of the Vloeiweide.

The further calculations of the ecosystem services is straightforward and can be done with the help of this manual and the video.

The scenario after the adaptations are in place needs to be done more carefully. Not only does the land cover change (Figure 15), but also groundwater levels and the ground level itself change. This is because certain parts are either lowered or raised. However this can't be added directly, but can only be added in reference to the water level. This means that if 5 cm of topsoil is removed, this can be translated as a raise of 5 cm of the groundwater level means subtracting 5 of the current level (as the value of groundwater level is cm under ground level). In figure 16 you can see that the groundwater becomes deeper where the Bijloop used to flow, while the groundwater level rises in other parts of the catchment.
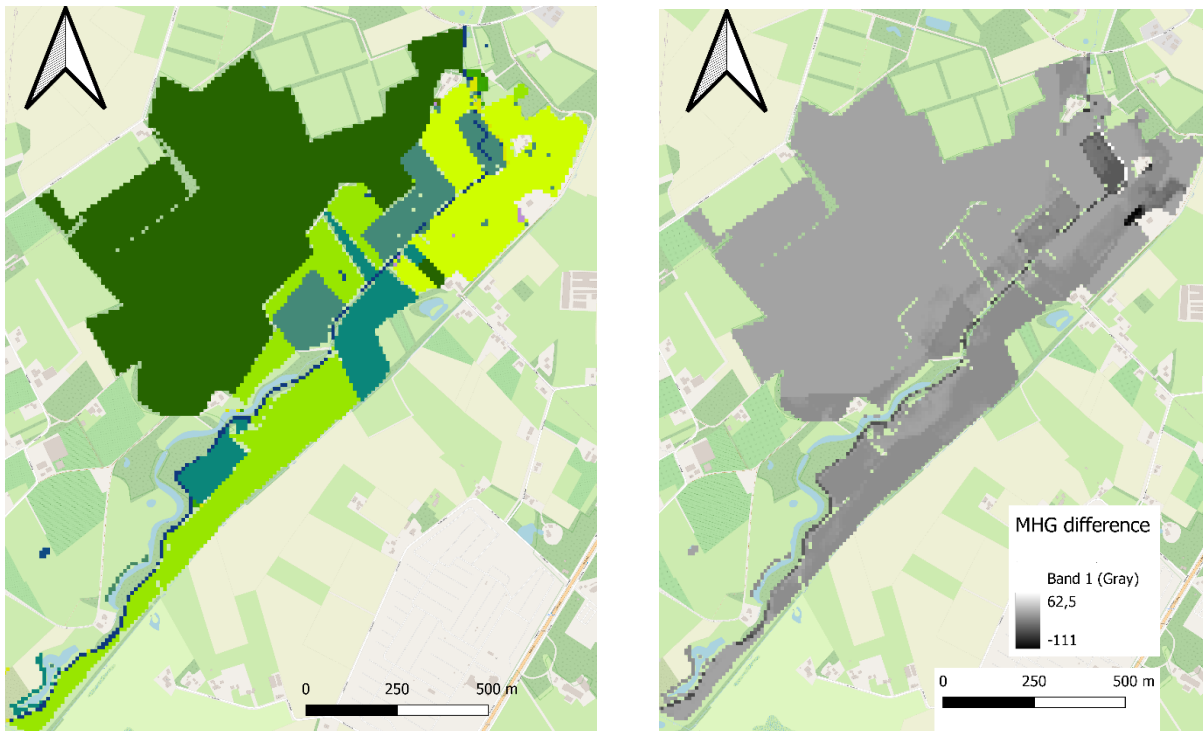

Figure 15: Land covers after the restoration measures are in place.   *Figure 16: Change in MHG values.*

When all the ecosystem services are calculated with the tool, the overall change can be seen in table 2. In the table a large increase in the maximum retention of the site is clear. However the exact number depends on the chosen groundwater table in the tool and can be further adjusted in the tool if more site information is available in order to do more accurate predictions. Changes in weir management are not possible to incorporate into the tool, but will also have an effect on water retention in the area.

The (permanent) heightening of the groundwater table by various measures taken in the Vloeiweide will also have an effect on other ecosystem services. One such effect is that there is less room for immediate infiltration of water. Therefore, the tool expects infiltration to decrease slightly. Coupled with this, an increase in water runoff can be expected. This emphasises the importance of understanding where runoff in the landscape converges to. In the Vloeiweide, ditches are present who will lead the water deeper into the floodplain combined with weir management in order to make sure this runoff will not be lost but spread out over the site if the weirs are closed. As such we can expect this initial runoff to slowly infiltrate over time towards deeper groundwater bodies (i.e. delayed infiltration). This is not modelled by the tool.

At first glance the result from drainage seems contradictory with the raised riverbed, as drainage increases. However this result takes into account the increased groundwater level after the ecosystem based adaptations are in place. For this the water level was manually raised. If this is not done, the drainage will actually decrease. As such the increased drainage is an effect of the increased water retention in the Vloeiweide.

Table 2: Changes between ES delivery for the site of the Vloeiweide in the scenario after the adaptations are in place.

	Ecosystem services	%	Total	Unit
	Original runoff		6459,62	m³ / year
Supporting and regulating	Runoff (change)	29,13	1881,42	m³ / year
	Soil carbon	0,99	147,04	ton C
	Soil nitrogen	-4,36	-32,88	ton N
	Soil phosphorus	-4,36	-2,19	ton P
	Health effects	1,53	2605,71	DALY / year
	Evapotranspiration	0,02	8,12	m³ / year
	Minimum drainage losses	35,44	85,09	m³ / year
	Maximum drainage losses	4,79	28,84	m³ / year
Provisioning	Infiltration	-6,47	-1887,23	m³ / year
	Seasonal retention	-15,54	-12750,4	m³ / year
	Maximum retention	90,99	34653,84	m³ / year
Net gain or loss of water* ** Retention + Infiltration – Avg. drainage*			+ 19959,24	m³ / year
Net gain or loss of water* If runoff> 0, remains in situ and can slowly infiltrate ** Retention + Infiltration + Runoff (if >0) – Avg. drainage*			+ 21840,66	m³ / year
Net gain or loss of water* If all runoff (original + change) remains in situ and can slowly infiltrate ** Retention + Infiltration + All Runoff – Avg. drainage*			+ 28300,28	m³ / year

4.3.2.3 United Kingdom: Moat Farm

In the subsite of Moat Farm, part of the Beult catchment in the United Kingdom, two temporal wetlands were restored by filling up 2 ditches. Moat Farm lies at the top of the catchment (in Shadoxhurst) in the 'seasonally wet' zone of the watersystem map. Local runoff gives rise to a number of streams that form part of the headwaters of the river Beult. The first ditch was located in woodland, the other in agricultural land.

A small catchment area used to feed a seasonally dry, over-deep woodland channel. During flow periods, this drained water quickly out of a potential wetland, carrying sediment from a byway upstream and contributing to high flows downstream. To restore the retention function, trees were cleared around the channel to bring light in and make woody material available; 200m of the channel were filled in using clay from the site; a pond was dug and large woody debris was placed across the flow path of water. This has wetted up the woodland area, spilling water into the floodplain and transforming it into a wet water retaining woodland habitat with dense vegetation.
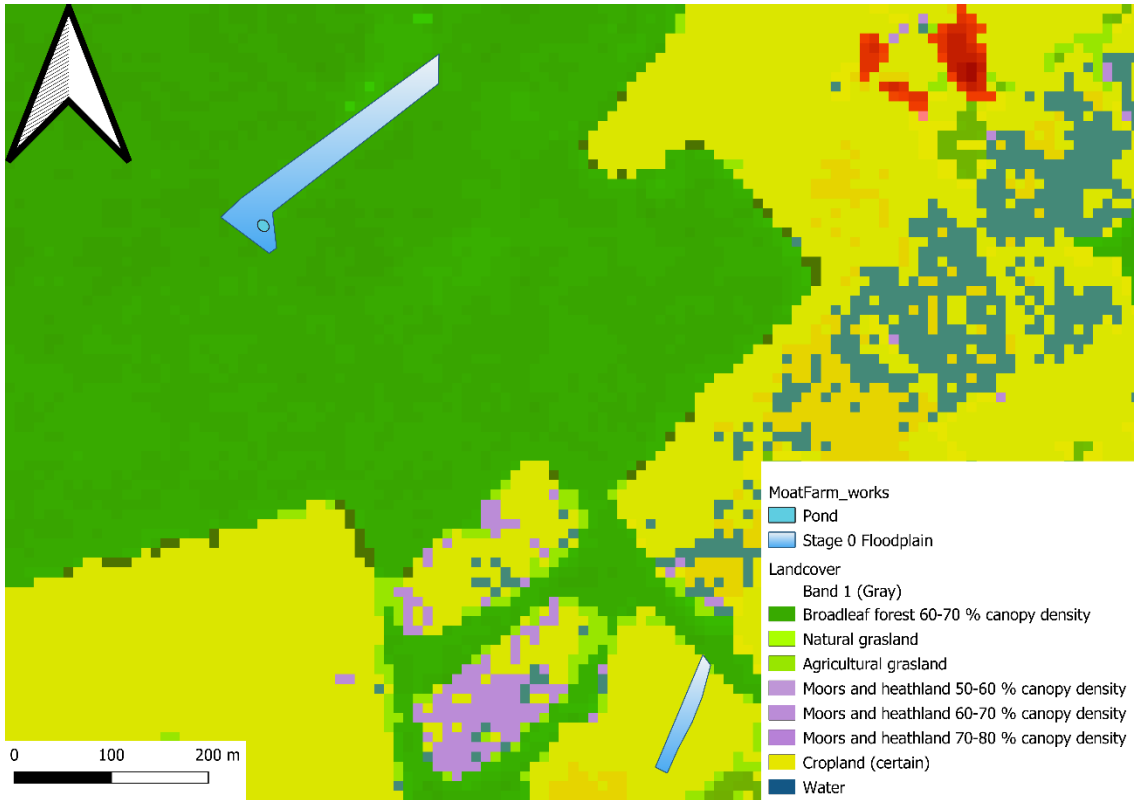
Figure 17: Overview of the measures taken on the site of Moat Farm with the land cover of the geodatabase.
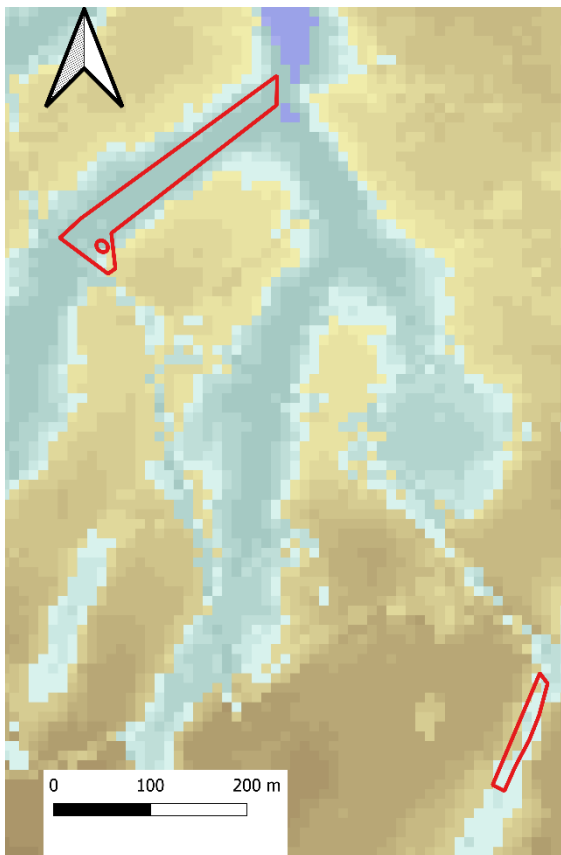

Figure 18: Moat Farm location on the watersystem map where brown- yellow = infiltration area and light-blue= temporary wet.

In this case it is important to not only change the land cover in the area where the ditch is filled up, but also use a buffer around it, as this area will receive the effects of rewetting. The exact value of the buffer depends on site condition, but in this case there was opted for a buffer of 50 meters. Figure 19 shows the original land cover inside the buffer after it was changed according to the provided site data. Figure 20 shows the land cover after the adaptations. This means changing the woodland to alluvial forest and the agricultural grassland to marshland.
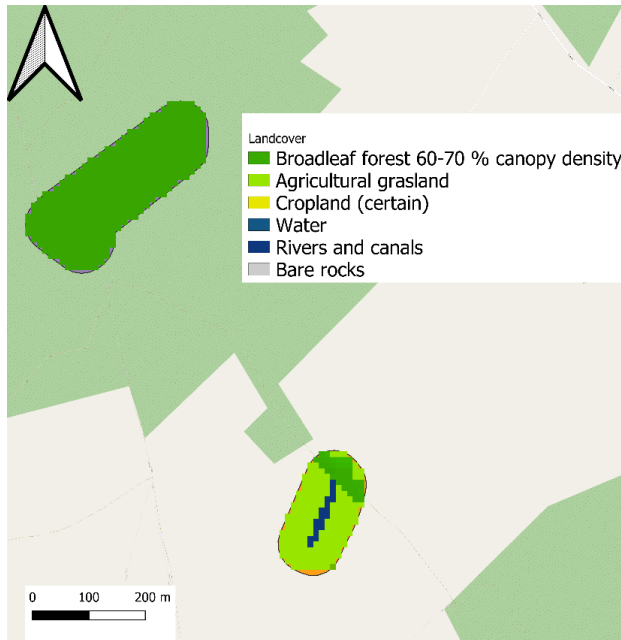

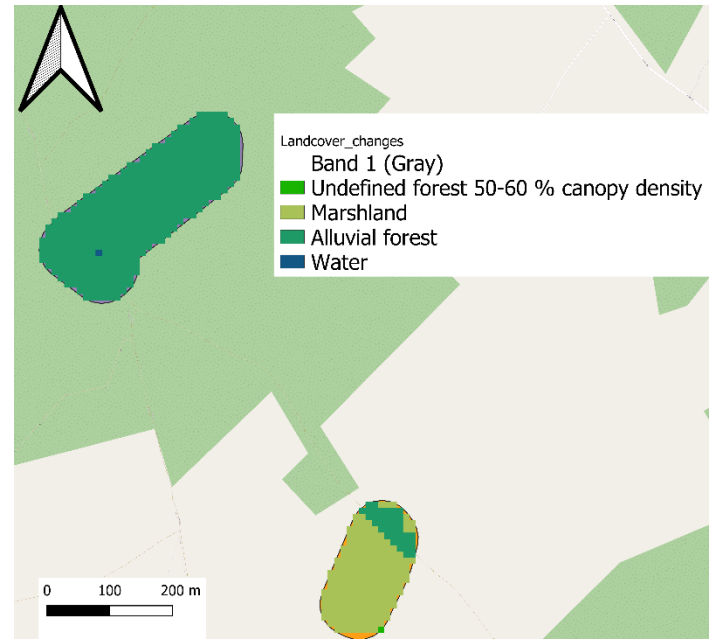*Figure 20: Land cover, after it was adapted to site data and a buffer of 50 m was applied.*

Figure 19: Land cover after the EbA-measures are in place in the Moat Farm site.

In the next step it is important to adapt the groundwater values to the new situation. Due to the filling up of the canal, the area will be significantly rewetted. The original groundwater levels (Figure 21) strongly vary between the sites and are strongly affected by the canals. When the groundwater level was raised this was done gradually so higher values (deeper groundwater) were diminished more than the lower values (groundwater closer to ground level). This adaptations result in the groundwater values in Figure 22.
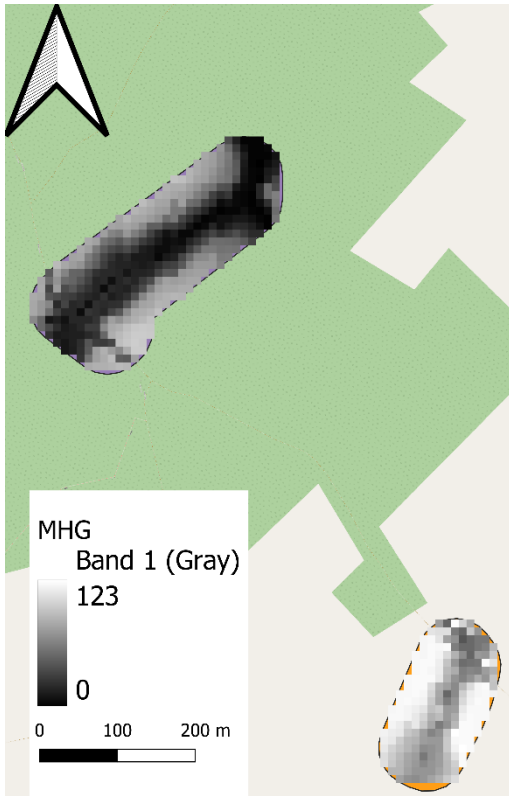
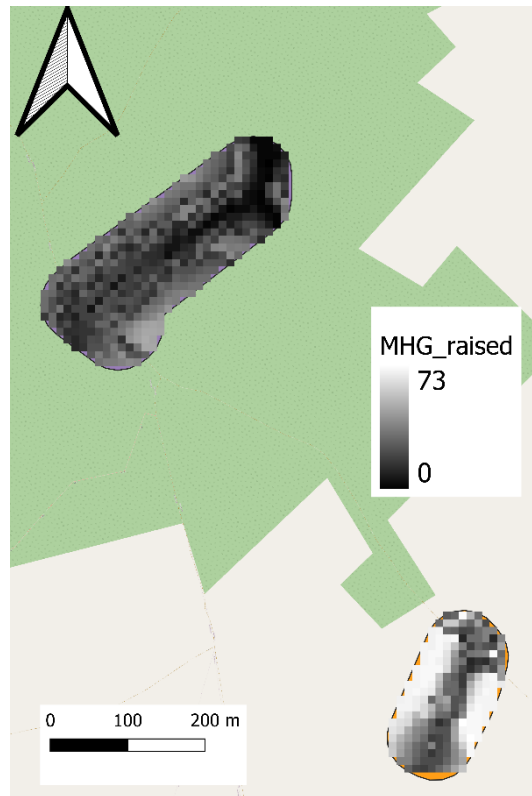*Figure 21: Original groundwater levels for the site of Moat Farm.*

Figure 22: Adapted groundwater levels for the site of Moat Farm.

The difference in delivered ecosystem services before and after the EbA-measures are in place can be seen in Table 3. An increase in the water retention of the site is a result of the temporal wetland restoration measure of which the increase in seasonal retention is the highest, while the maximum retention almost remains constant.

Due to the rewetting of the area, higher groundwater tables are present. This decreases the potential infiltration as the tool sees this as less room to infiltrate and the tool predicts a slight decrease. Due to the rewetting, we also expect more evapotranspiration to take place as former forest and (agricultural grassland is changed to alluvial forest and marshland. We expect a small decrease in runoff. It is however important to also look at the original runoff and where in the landscape it converges to. In this case at the end of the filled up channel a pond is created from which it will not be drained away through ditches or other means. As such we can expect this initial runoff water to slowly infiltrate over time towards deeper groundwater bodies (i.e. delayed infiltration).

The creation of the wet forest area and the conversion of grassland to wet nature will increase the carbon captured in the area. Soil nitrogen and phosphorus are also expected to increase. Drainage losses will almost completely disappear as an effect of the rewetting of the area.

Table 3: Changes between ES delivery for the site of Moat farm in the scenario after the adaptations are in place.

	Ecosystem services	%	Total	Unit
	Original runoff		941,67	m³ / year
Supporting and regulating	Runoff (change)	-7,31	-68,88	m³ / year
	Soil carbon	33,44	556,31	ton C
	Soil nitrogen	20,54	17,49	ton N
	Soil phosphorus	20,54	1,17	ton P
	Health effects	0,00	0,00	DALY / year
	Evapotranspiration	3,10	97,08	m³ / year
	Minimum drainage losses	-100,00	-41,29	m³ / year
	Maximum drainage losses	-99,67	-107,34	m³ / year
Provisioning	Infiltration	-1,53	-24,75	m³ / year
	Seasonal retention	20,95	1705,75	m³ / year
	Maximum retention	43,61	1241,50	m³ / year
Net gain or loss of water* ** Retention + Infiltration – Avg. drainage*			+ 2996,82	m³ / year
Net gain or loss of water* If runoff> 0, remains in situ and can slowly infiltrate ** Retention + Infiltration + Runoff (if >0) – Avg. drainage*			+ 2996,82	m³ / year
Net gain or loss of water* If all runoff (original + change) remains in situ and can slowly infiltrate ** Retention + Infiltration + All Runoff – Avg. drainage*			+ 3869,61	m³ / year

References

AGIV. (2006). Digitale bodemkaart van het Vlaams Gewest. Gent, België, AGIV.
AGIV. (2014). Digitaal Hoogtemodel Vlaanderen II, DTM, raster, 5 m. Gent, België, AGIV.

Ballabio C., Panagos P., Montanarella L. Mapping topsoil physical properties at European scale using the LUCAS database (2016) Geoderma, 261 , pp. 110-123.

Batelaan, Okke & Smedt, F.. (2007). GIS-based recharge estimation by coupling surface-subsurface water balances. Journal of Hydrology. 337. 337-355. 10.1016/j.jhydrol.2007.02.001.

Broekx, Steven & Poelmans, Inge & Staes, Jan & Van der Biest, Katrien & Meire, Patrick & Verheyen, Kris & Liekens, Inge & De Nocker, Leo. (2013). Raming van de baten geleverd door het Vlaamse NATURA 2000-netwerk. 10.13140/2.1.3890.9765.

Foereid, Bente & Jensen, Henning. (2004). Carbon sequestration potential of organic agriculture in northern Europe – A modelling approach. Nutrient Cycling in Agroecosystems. 68. 13-24. 10.1023/B:FRES.0000012231.89516.80.

Freibauer, Annette & Rounsevell, Mark & Smith, Pete & Verhagen, Jan. (2004). Carbon sequestration in the agricultural soils of Europe. Geoderma, v.122, 1-23 (2004). 122. 10.1016/j.geoderma.2004.01.021.

Hoeymans, N. & Gommer A.M. & Poos, M.J.J.C. (2007). Sterfte, ziekte en ziektelast voor 56 geselecteerde aandoeningen. In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid. Bilthoven: RIVM, online via http://www.rivm.nl/

Maas, Jolanda. (2009). Vitamin G : Green environments - Healthy environments.

Ottoy, Sam & Beckers, Veronique & Jacxsens, Paul & Hermy, Martin & Orshoven, Jos. (2015). Multi-level statistical soil profiles for assessing regional soil organic carbon stocks. Geoderma. 253. 10.1016/j.geoderma.2015.04.001.

Ottoy, Sam & Elsen, Annemie & Van De Vreken, Philippe & Gobin, Anne & Merckx, Roel & Hermy, Martin & Orshoven, Jos. (2016). An exponential change decline function to estimate soil organic carbon stocks and their changes from topsoil measurements. European Journal of Soil Science. 67. 816-826. 10.1111/ejss.12394.

Ottoy, Sam & De Vos, Bruno & Sindayihebura, Anicet & Hermy, Martin & Orshoven, Jos. (2017). Assessing soil organic carbon stocks under current and potential forest cover using digital soil mapping and spatial generalisation. Ecological Indicators. 77. 139 - 150. 10.1016/j.ecolind.2017.02.010.

Ottoy, Sam & Meerbeek, Koenraad & Sindayihebura, Anicet & Hermy, Martin & Orshoven, Jos. (2017). Assessing top- and subsoil organic carbon stocks of Low-Input High-Diversity systems using soil and vegetation characteristics. Science of The Total Environment. 589. 153-164. 10.1016/j.scitotenv.2017.02.116.

Stuurman, R., Dierckx, J., & Runhaar, H. (2002). Uitwerking van de methodiek voor de bepaling van de gewenste grondwatersituatie voor natuur in potentieel natte gebieden in Vlaanderen. Projectnummer 005.51027 TNO-rapport.

Appendix 1: List of possible land covers

Possible Land covers

1100 - Undefined green
2100 - Broadleaf forest of unknown density
2110 - Broadleaf forest 10-20 % canopy density
2120 - Broadleaf forest 20-30 % canopy density
2130 - Broadleaf forest 30-40 % canopy density
2140 - Broadleaf forest 40-50 % canopy density
2150 - Broadleaf forest 50-60 % canopy density
2160 - Broadleaf forest 60-70 % canopy density
2170 - Broadleaf forest 70-80 % canopy density
2180 - Broadleaf forest 80-90 % canopy density
2190 - Broadleaf forest 90-100 % canopy density
2200 - Coniferous forest of unknown density
2210 - Coniferous forest 10-20 % canopy density
2220 - Coniferous forest 20-30 % canopy density
2230 - Coniferous forest 30-40 % canopy density
2240 - Coniferous forest 40-50 % canopy density
2250 - Coniferous forest 50-60 % canopy density
2260 - Coniferous forest 60-70 % canopy density
2270 - Coniferous forest 70-80 % canopy density
2280 - Coniferous forest 80-90 % canopy density
2290 - Coniferous forest 90-100 % canopy density
2310 - Undefined forest 10-20 % canopy density
2320 - Undefined forest 20-30 % canopy density
2330 - Undefined forest 30-40 % canopy density
2340 - Undefined forest 40-50 % canopy density
2350 - Undefined forest 50-60 % canopy density
2360 - Undefined forest 60-70 % canopy density
2370 - Undefined forest 70-80 % canopy density
2380 - Undefined forest 80-90 % canopy density
2390 - Undefined forest 90-100 % canopy density
3100 - Grassland
3200 - Natural grassland
3300 - Agricultural grassland
4010 - Moors and heathland 10-20 % canopy density
4020 - Moors and heathland 20-30 % canopy density
4030 - Moors and heathland 30-40 % canopy density
4040 - Moors and heathland 40-50 % canopy density
4050 - Moors and heathland 50-60 % canopy density
4060 - Moors and heathland 60-70 % canopy density
4070 - Moors and heathland 70-80 % canopy density
4080 - Moors and heathland 80-90 % canopy density
4090 - Moors and heathland 90-100 % canopy density
4000 - Moors and heathland
5100 - Dunes and beaches
6100 - Cropland (probably)
6101 - Cropland (certain)

6102 - Cropland (Corine)
6200 - Orchards
6300 - Vineyards
7100 - Swamp
7200 - Marshland
7300 - Alluvial Forest
8100 - Tidal mudflats
8200 - Tidal marshes
9010 - Urban 10-20 %paved
9020 - Urban 20-30 % paved
9030 - Urban 30-40 % paved
9040 - Urban 40-50 % paved
9050 - Urban 50-60 % paved
9060 - Urban 60-70 % paved
9070 - Urban 70-80 % paved
9080 - Urban 80-90 % paved
9090 - Urban 90-100 % paved
10000 - Water
10100 - Surface water
10200 - Tidal water
10300 - Rivers and canals
10400 - Sea
11000 - Bare rocks
65535 - No data