Joint report on the Common Documentation of Initial Surveys, Baseline Monitoring report, and Annual Monitoring Report 1

Deliverable A.2 + Deliverable D.1 + Deliverable D.2

Table of contents

Motivation of the Report

Based on the discussion during the TMO visit we merged these different deliverables into 1 report. The baseline monitoring and initial surveys show a lot of overlap. The monitoring reports will include monitoring our impacts of restoration, after the first works are carried out. Now only the current situation is assessed and future activities are harmonized and planned.

Geomorphological setting and hydrology

Digital elevation model

Belgium: Valley of the Grote Beek

In Flanders there is a DEM available with a resolution of 0.25m. This DEM was used to do an initial mapping of the Valley of the Grote Beek. The DEM shows the wet areas and the exact transmission zones towards the dry flanks, but also ditches, ponds and anthropogenic elevations become visible. We mapped these ditches, pools and elevations to get an idea of drainage and we will check and measure these in the field in order to strengthen the ecohydrological study. Based on the combination of this DEM, the peat mapping and the ownership of the ground, we selected some target zones on which we will focus the rewetting works in Belgium. The rewetting works will mainly consist of closing these ditches and ponds and removing artificial elevation on the peatland. The analysis of the digital elevation model is the very basis of the upcoming restoration and this tool is used almost daily to better understand the small very local differences found in the field. Below the results of this DEM mapping can be found within each of the selected zones.

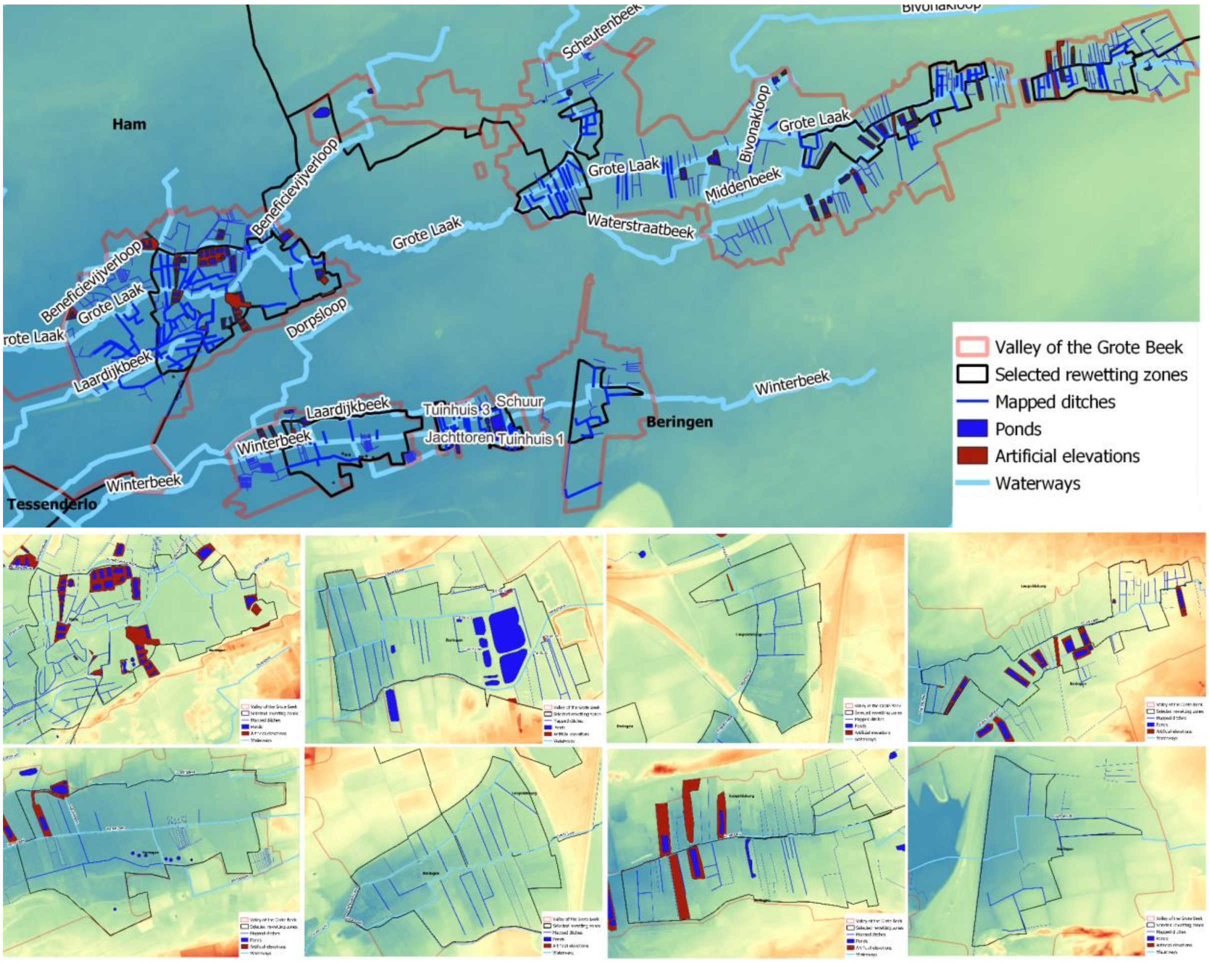


Figure 1.1: Results of the DEM analysis in Belgium.

Germany: Häsener Luch

For an initial mapping of the Project Site in Germany we used a digital elevation model (DEM) with a spatial resolution of 1 x 1 meter, generated in 2011 and after post-processing published in 2020. The DEM illustrates well the current relief situation of the Häsener Luch, which is a part of a former glacial channel system surrounded by ground moraine plates composed of till and loamy substrates. It also reveals the location and course of the drainage systems, former dams and local depressions, that forms the base for further rewetting activities.

In general, the project site can be distinguished roughly in three main units: (1) the flat north-north-western part, (2) the “rough” central part and (3) the inclined south-southeast edges.

The north-/north-western part, especially close to the main drainage channel *Welsegraben*, is characterized by an almost homogeneous relief with low differences in heights and a very low slope. Exceptions are a former small peat digging pit and a small linear bump, which crosses the northern areas and could indicate a former drainage pipe (see Figure 1.2).

The central part of the Häsener Luch, especially the southern part is characterized by alternating dams and larger pits originating from peat extraction reportedly conducted at the end of the 19th and beginning of the 20th century. (See Figure 1.2). The height differences amount in general to 0.3 to 0.5 m between dams and pits and show a low to moderate slope. All of these former peat pits run from east to west into another small ditch, which in turn drains into the *Welsegraben*. The height differences within the peat pits are very low. The following most southern and south-eastern areas of the central part are disconnected from these peat pits by a 0.3 m high dam and run off in the southern ditches. All drainage ditches surrounding the peatland have a moderate to high slope and indicate the peat subsidence resulting from intensive drainage.

The last parts are the south-south-eastern edges, which are characterized by higher relief differences, especially the south-eastern areas, where we could find height differences of up to 3 meters. There are double slopes originating from the eastern mineral plates and flank the whole eastern peatland edge.

Figure 1.2: Overview of the DEM of Häsener Luch; Lower Panel shows details of the northern and southern part of Häsener Luch in a shading style

Ireland: Connemara

The project area in Connemara consists of two sites: Doire Fhada, which is the northernmost site, and Fionnán which is the southernmost site. DEM for the area is only available at 25m resolution with the most recent version generated in 2017.

Elevation at Doire Fhada decreases from south to north with an elevation change of approximately 200m within the site. The site is situated at an elevation of approximately 100m to 300m. There is no evidence of peat harvesting within the site, however, ground works in preparation for tree planting have taken place in the past. This can be seen in the photo below which show furrows along areas of blanket bog. Some sections of the site have been planted with conifer trees, however the majority of the site has not.

There is very little elevation change within Fionnán, which is located at a lower elevation ranging from approximately 100-110m.

Figure 1.3.1: Photos from within Doire Fhada, which shows the steeply sloping ground onsite

Figure 1.3.2: Past ground works within Doire Fhada in preparation for planting tree planting

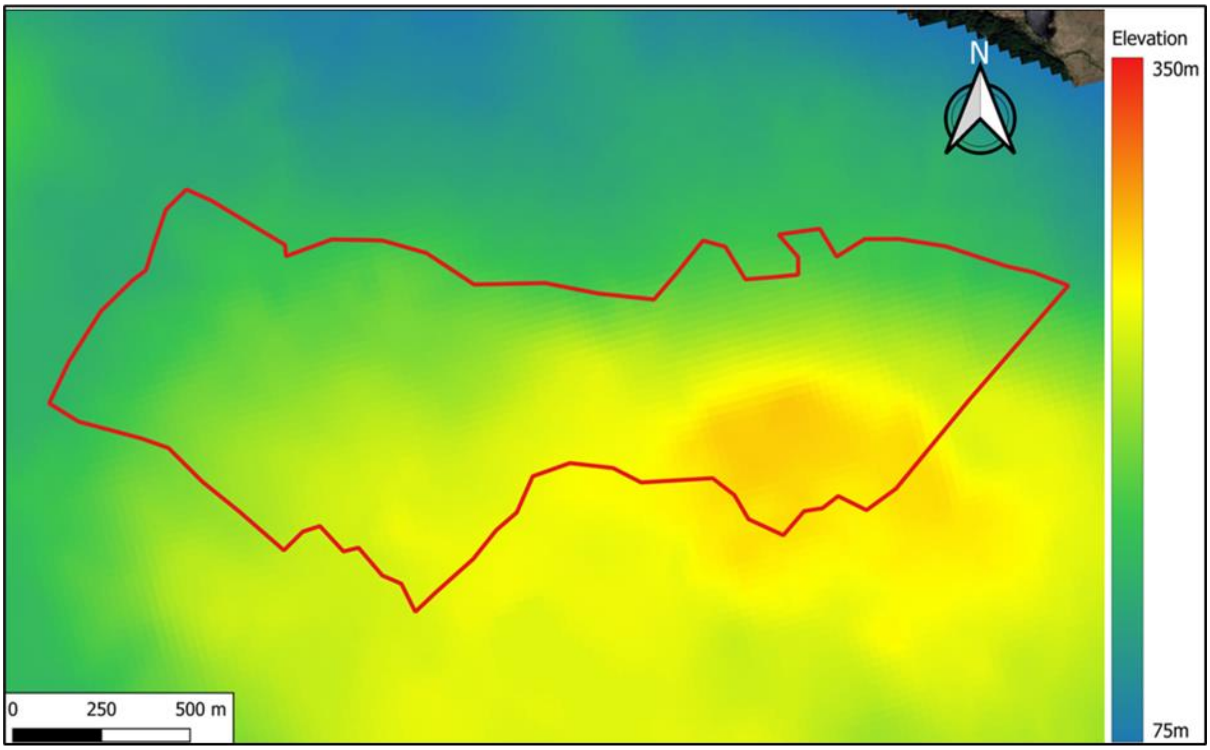
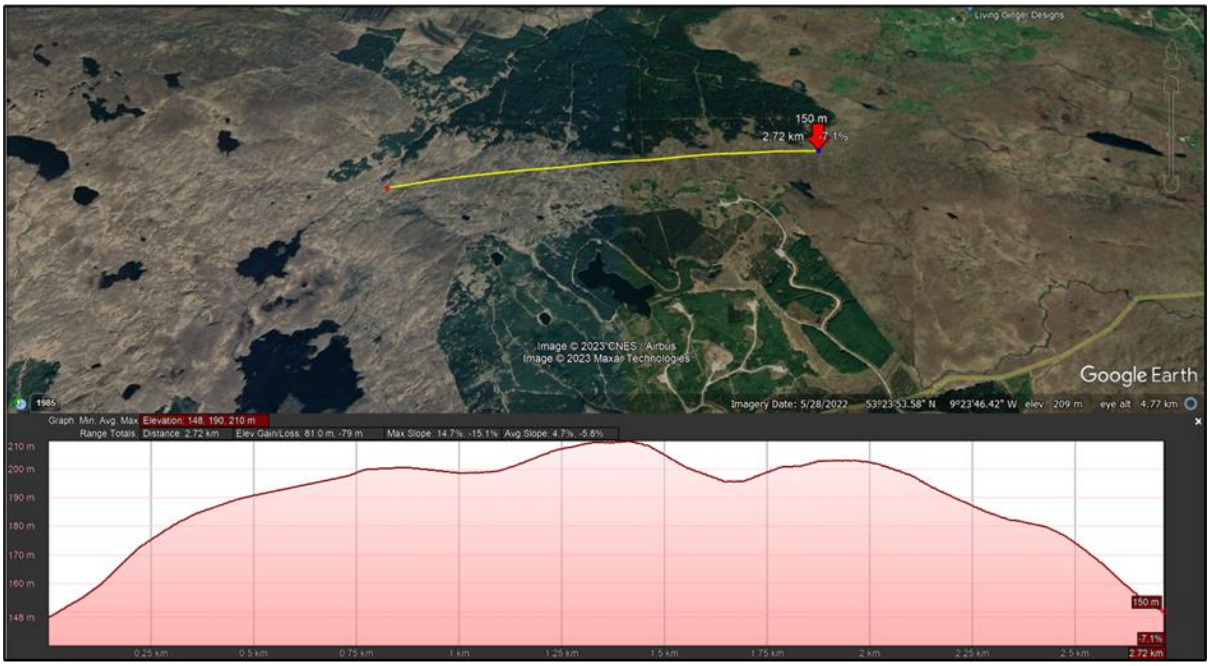


Figure 1.3.3: Elevation in metres at Doire Fhada, the northern site


Graph: Min, Avg, Max Elevation: 148, 190, 210 m
Range Totals: Distance: 2.72 km Elev Gain/Loss: 81.0 m, -79 m Max Slope: 14.7%, -15.1% Avg Slope: 4.7%, -5.8%

Imagery Date: 5/28/2022 53°23'53.58" N 9°23'46.42" W elev 209 m eye alt 4.77 km

Figure 1.3.4: Elevation profile of Doire Fhada from west to east generated on Google Earth Pro showing an elevation range of 148m to 210m

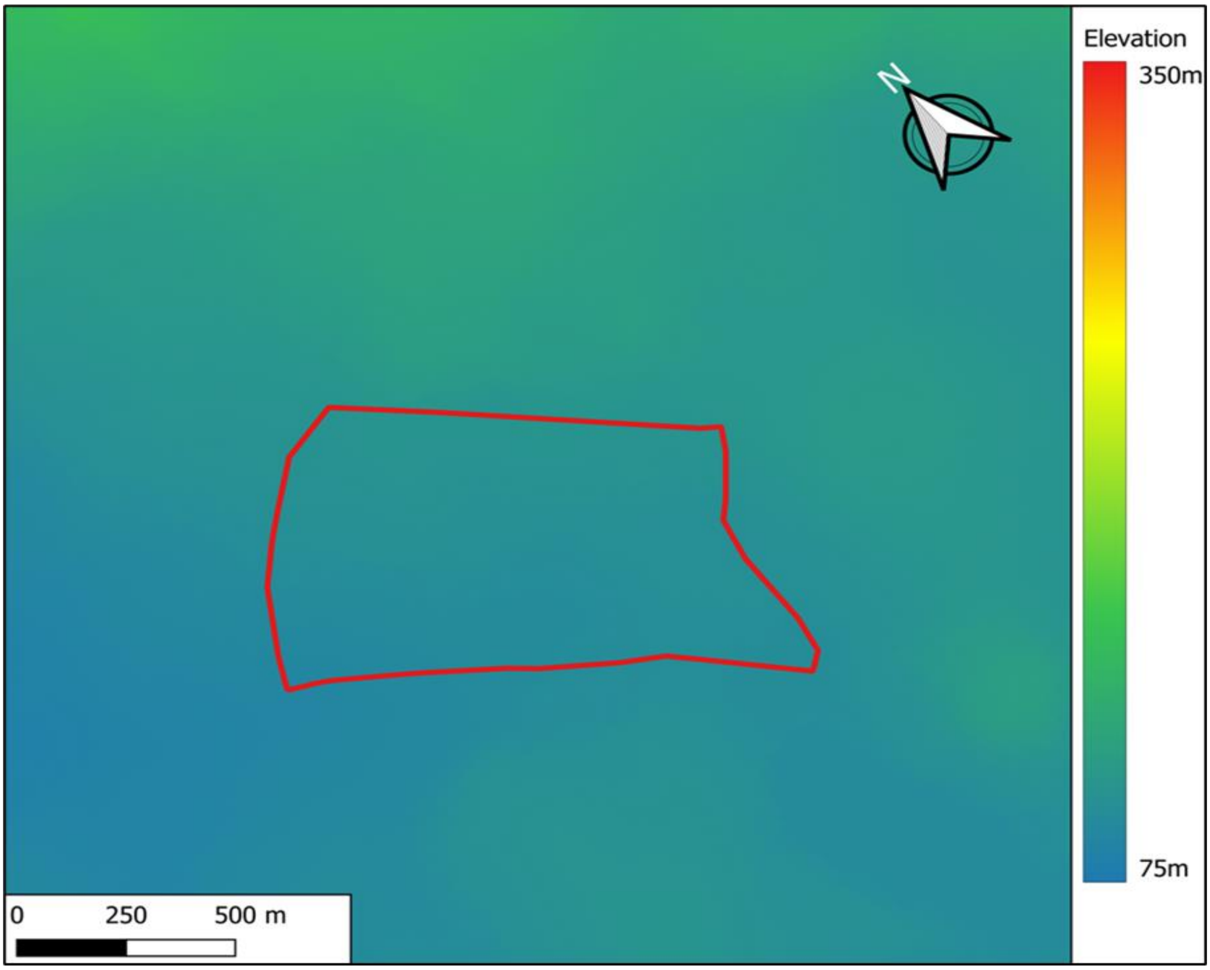


Figure 1.3.5: Elevation at Fionnán, the southern site within the project area.

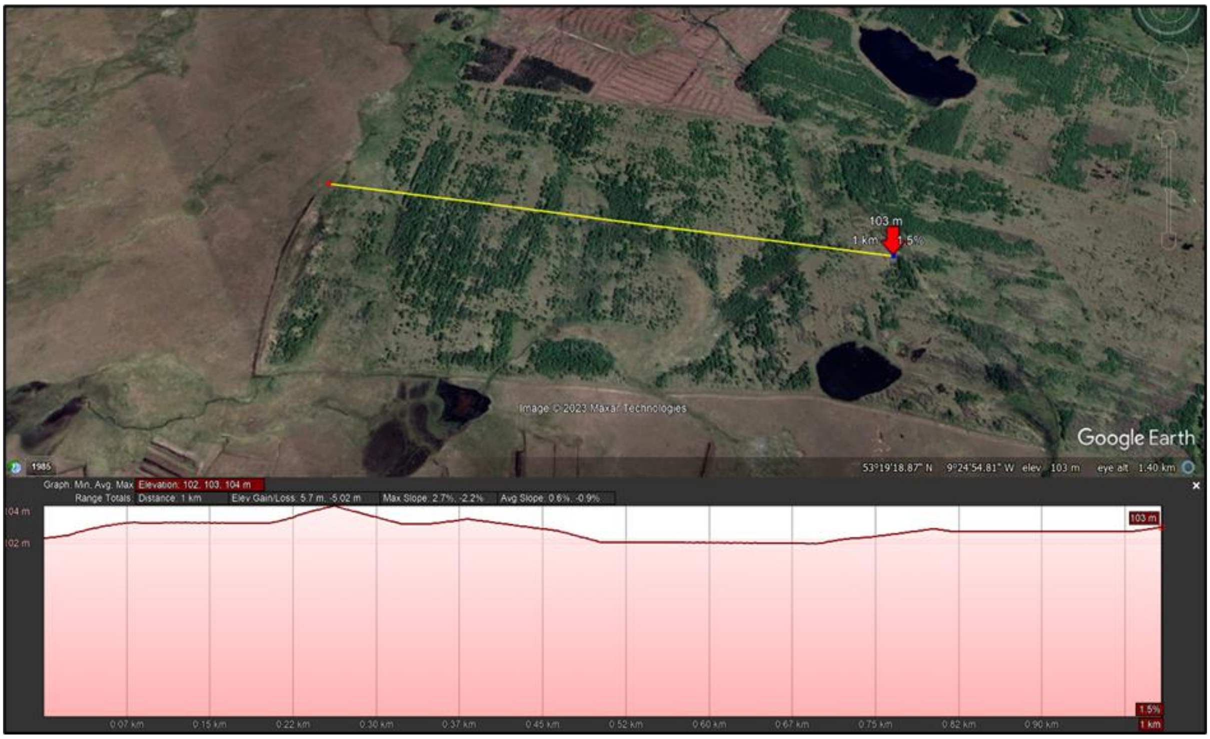


Figure 1.3.6: Elevation Profile of Fionnán from northwest to southeast showing an elevation range from 102m to 104m

Poland: Orawa

The Baligówka bog, part of the Orawa-Nowy Targ bog complex in Poland, is a cupola-shape raised bog, developed by paludification process on a clay layer in the flat area of Orawa-Nowy Targ basin. Together with other bogs in a region this is a unique example of big raised bogs in Carpathians. The Orawa-Nowy Targ bog complex, hosting unique habitats and biodiversity, is designated as Natura 2000 site Torfowiska Orawsko-Nowotarskie. PLC120003

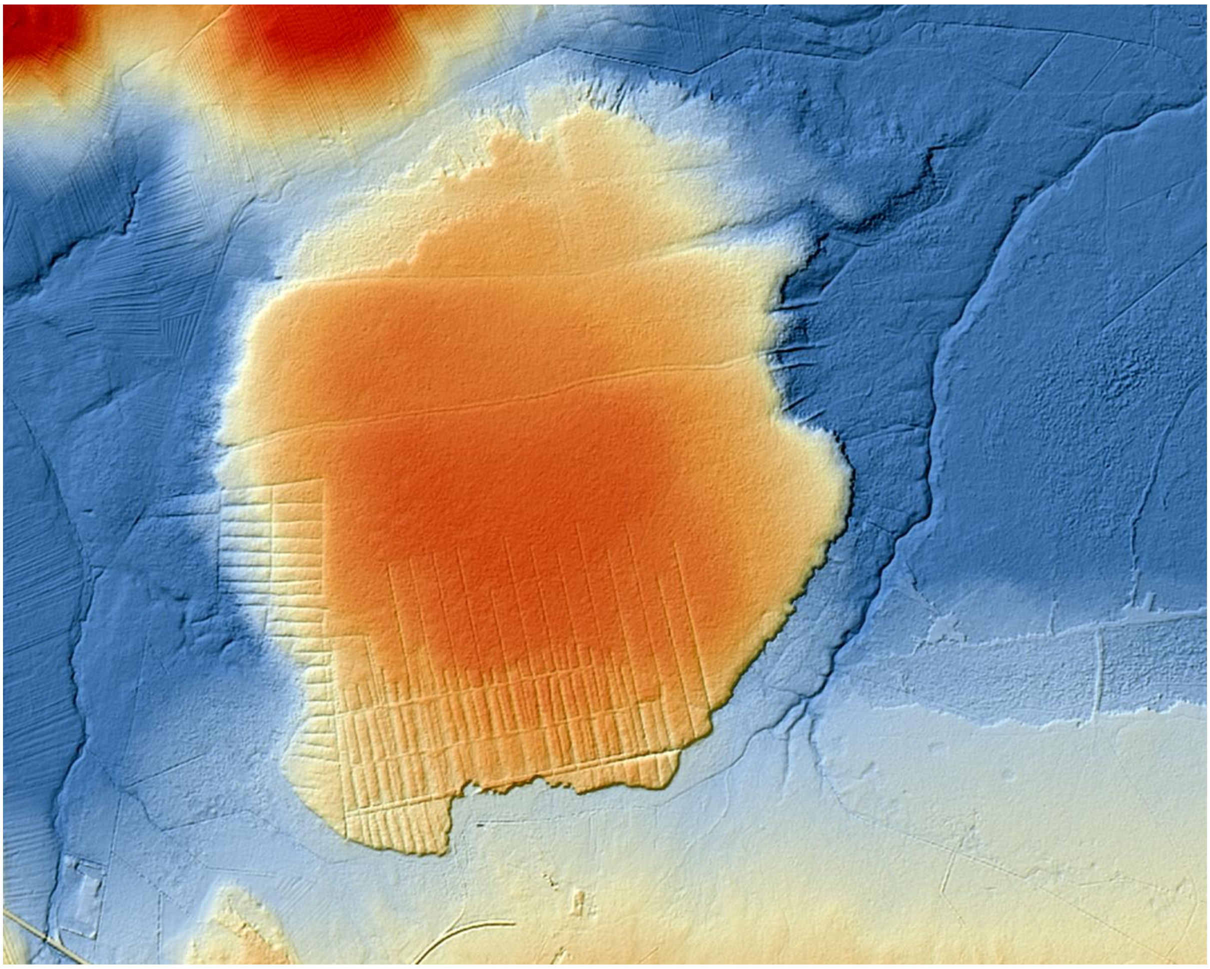
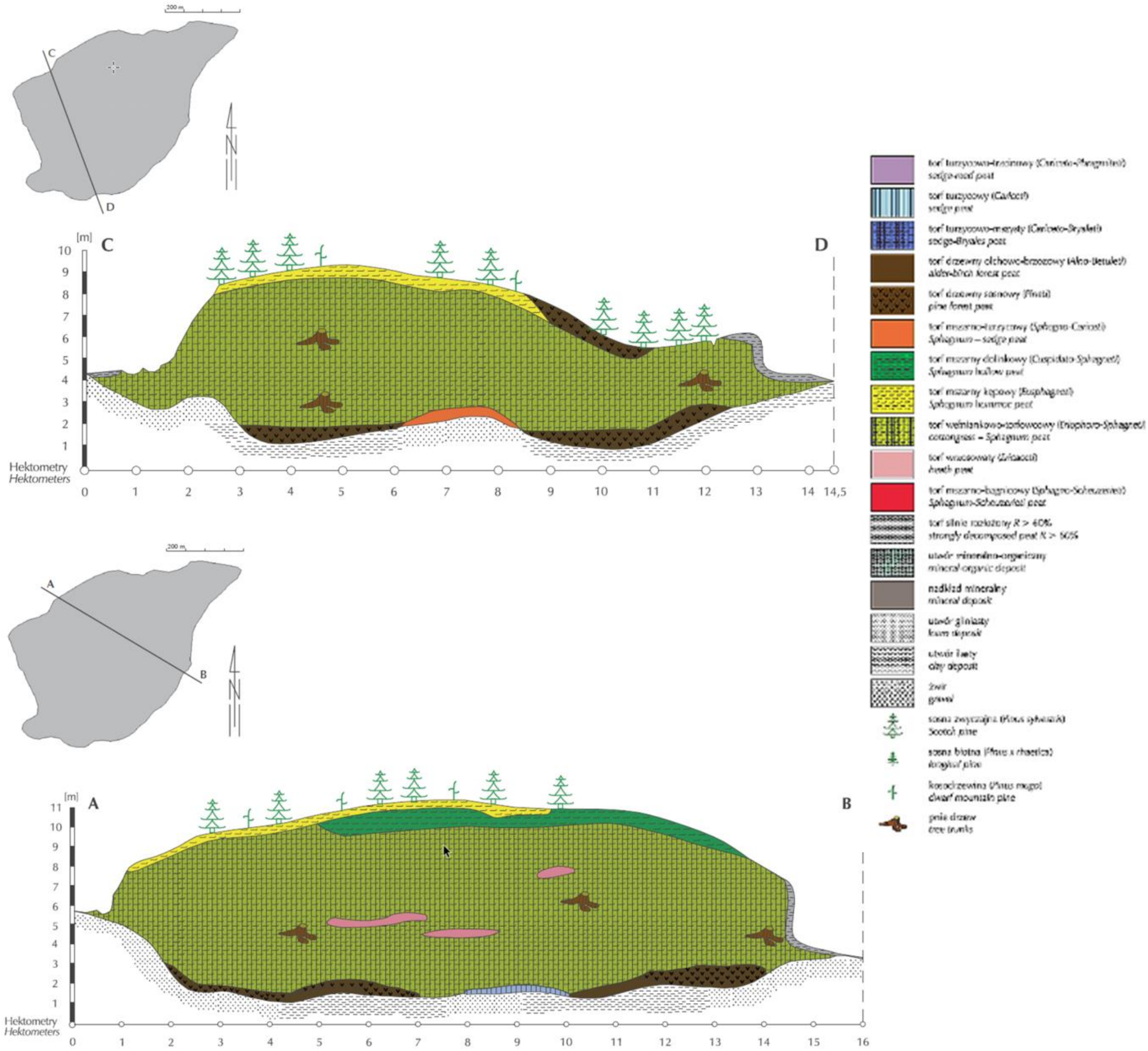


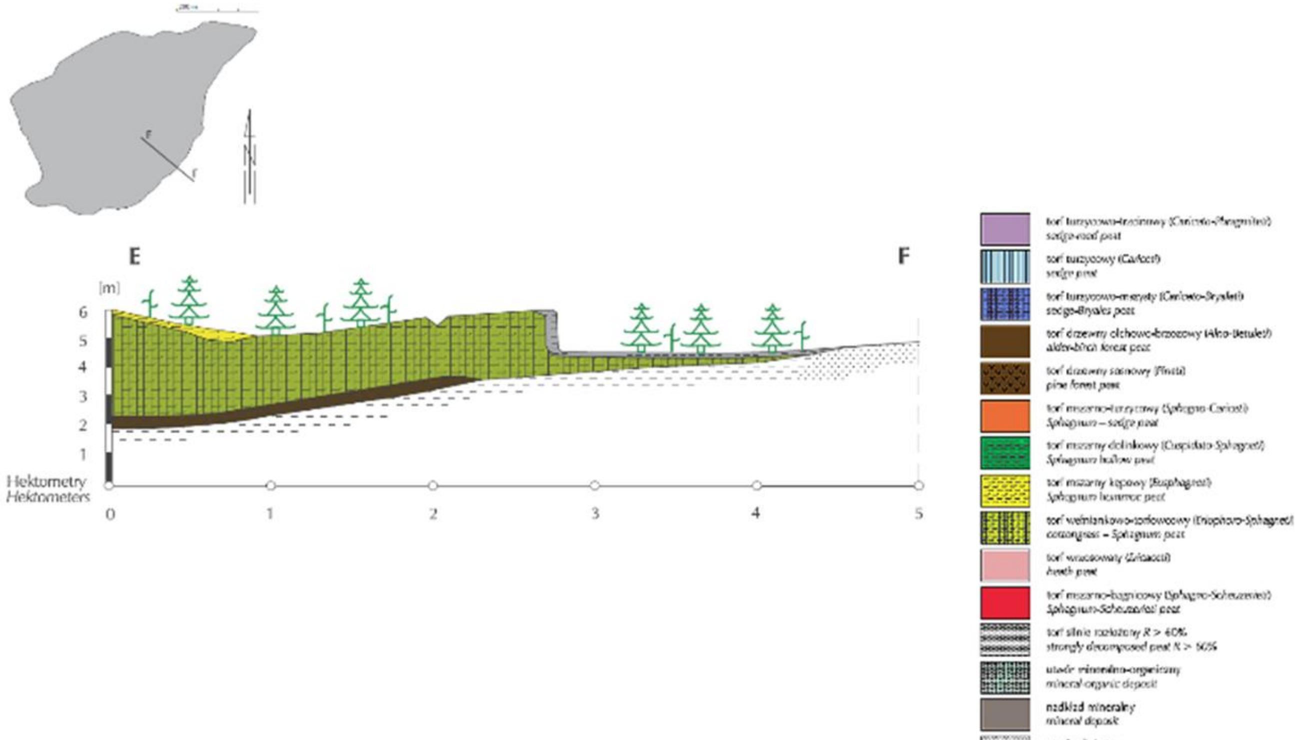
Figure 1.4.1: Baligówka bog - digital elevation model of land surface

The bog was originally much bigger, as presented on the map from the XIX century. Nevertheless, the eastern part was totally destroyed by peat digging. Baligówka, the western part, is the last remnant of the original bog. Although the peat was also dug here, it will not be followed by total destruction. but only by some transformation of habitats.

Figure 1.4.2: Historical map and contemporary aerial photo of Baligówka Bog (western part) and Puścizna Rękowiańska bog (eastern part, totally destroyed by peat digging, now covered by birch-pine forest)

The peat layer is up to 8 m and is built mainly by *Eriophoro-Sphagneti* peat. Detail profiles are shown below:


200 m
C
D
[m]
10
9
8
7
6
5
4
3
2
1
Hektometry
Hektometers
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
14,5
200 m
A
B
[m]
11
10
9
8
7
6
5
4
3
2
1
Hektometry
Hektometers
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
torf turzycowo-trzcinowy (Cariceto-Phragmiteti)
sedge-reed peat
torf turzycowy (Caricei)
sedge peat
torf turzycowo-mszysty (Cariceto-Bryaleti)
sedge-Bryales peat
torf drzewny olchowo-brzozowy (Alno-Betuleti)
alder-birch forest peat
torf drzewny sosnowy (Pineti)
pine forest peat
torf mszarno-turzycowy (Sphagno-Caricei)
Sphagnum – sedge peat
torf mszarny dolinkowy (Cuspidato-Sphagneti)
Sphagnum hollow peat
torf mszarny kępowy (Eusphagneti)
Sphagnum hummock peat
torf wełniankowo-torfowcowy (Eriophoro-Sphagneti)
cottongrass – Sphagnum peat
torf wrzosowaty (Ericaceti)
heath peat
torf mszarno-bagnicowy (Sphagno-Scheuzerieti)
Sphagnum-Scheuzerieti peat
torf silnie rozłożony R > 40%
strongly decomposed peat R > 50%
utwór mineralno-organiczny
mineral-organic deposit
nadkład mineralny
mineral deposit
utwór gliniasty
loam deposit
utwór ilasty
clay deposit
żwir
gravel
sosna zwyczajna (Pinus sylvestris)
Scotch pine
sosna błotna (Pinus x rhaetica)
bog pine
kosodrzewina (Pinus mugo)
dwarf mountain pine
pnie drzew
tree trunks


200 m
E
F
[m]
6
5
4
3
2
1
Hektometry
Hektometers
0
1
2
3
4
5
torf turzycowo-trzcinowy (Cariceto-Phragmiteti)
sedge-reed peat
torf turzycowy (Caricei)
sedge peat
torf turzycowo-mszysty (Cariceto-Bryaleti)
sedge-Bryales peat
torf drzewny olchowo-brzozowy (Alno-Betuleti)
alder-birch forest peat
torf drzewny sosnowy (Pineti)
pine forest peat
torf mszarno-turzycowy (Sphagno-Caricei)
Sphagnum – sedge peat
torf mszarny dolinkowy (Cuspidato-Sphagneti)
Sphagnum hollow peat
torf mszarny kępowy (Eusphagneti)
Sphagnum hummock peat
torf wełniankowo-torfowcowy (Eriophoro-Sphagneti)
cottongrass – Sphagnum peat
torf wrzosowaty (Ericaceti)
heath peat
torf mszarno-bagnicowy (Sphagno-Scheuzerieti)
Sphagnum-Scheuzerieti peat
torf silnie rozłożony R > 40%
strongly decomposed peat R > 50%
utwór mineralno-organiczny
mineral-organic deposit
nadkład mineralny
mineral deposit

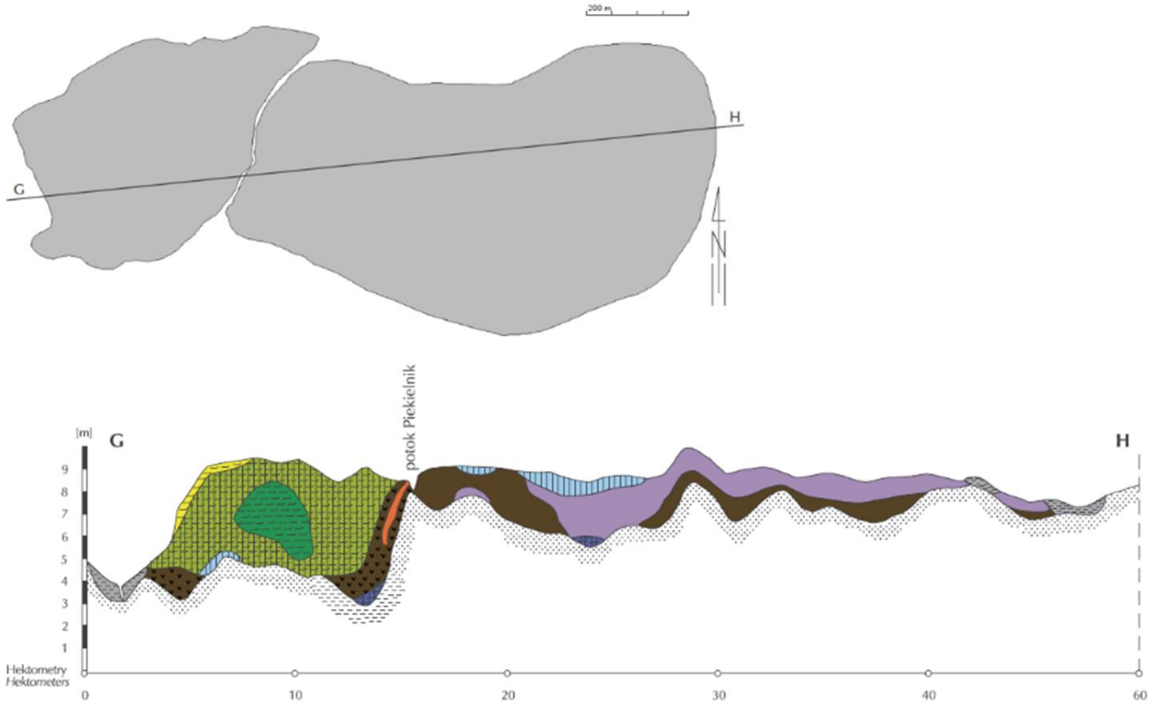


Figure 1.4.3: Peat stratigraphy of Baligówka bog, by Lipka & Zając

The Netherlands: Witte Veen

In the preparation of the project an extensive eco-hydrological system analysis has been established. This analysis describes the geology, geomorphology, hydrology etcetera. In the present initial survey, we will only give a short summary. Full details are available in Dutch.

The Witte Veen is a Natura2000 reserve in the east of The Netherlands at the border with Germany. See figure 1.5.1. The area is located between two main brooks: the Hege Beek in the north and the Buurser Beek in the south. The main study site in the Witte Veen is the peat bog in the northeast. This peat bog was formed in a lower area in a late Pleistocene sand dune landscape on top of clay loams which originate from the glacial period. During the Holocene the peat bog grew and spread over the landscape. However, since Medieval times human influence started and after drainage, peat cutting and exploitation only a small remnant was left.

The geomorphological setting and the upper geological layers are illustrated in the cross section in figure 1.5.2. In the above mentioned eco-hydrological analysis several of these cross sections are available.

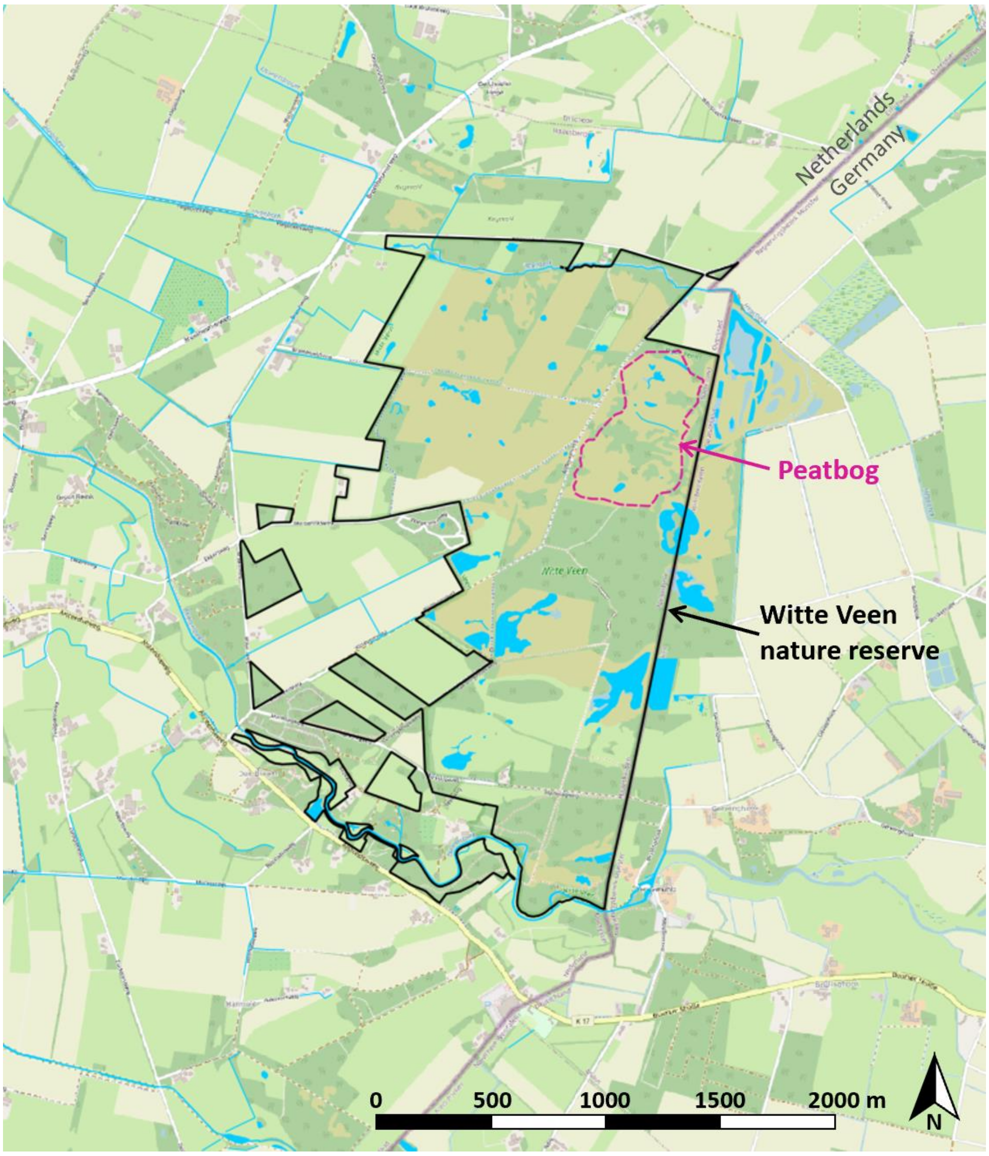


Figure 1.5.1: The Witte Veen nature reserve and the location of the peat bog.

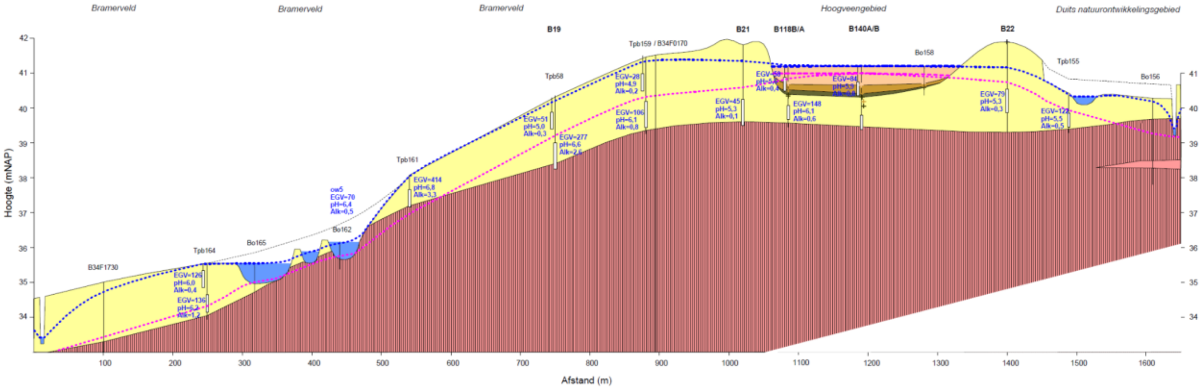


Figure 1.5.2: West-east cross section illustrating the geomorphological setting.

In the Netherlands a nation-wide DEM is available on both a 0.5 meter and 5 meter resolution. By the end of 2022 the most recent version of that DEM has become available for the Witte Veen (AHN version 4). On the German side of the border we do not have a recent DEM on a fine resolution. Since the project is carried out in The Netherlands the German DEM is only needed for visualisation purposes and does not require a high level of accuracy.

The DEM for the Witte Veen and its surroundings is shown in figure 1.5.3. The elevation decreases from east to west. The peat bog - depicted with the dotted white line - is located on the higher part of the nature area. The valley of the Buurser Beek in the south is clearly visible. In figure 1.5.4 the DEM of the peat bog is shown in more detail. The late Pleistocene sand dunes are visible as higher parts in the landscape, surrounding the somewhat lower peat bog.

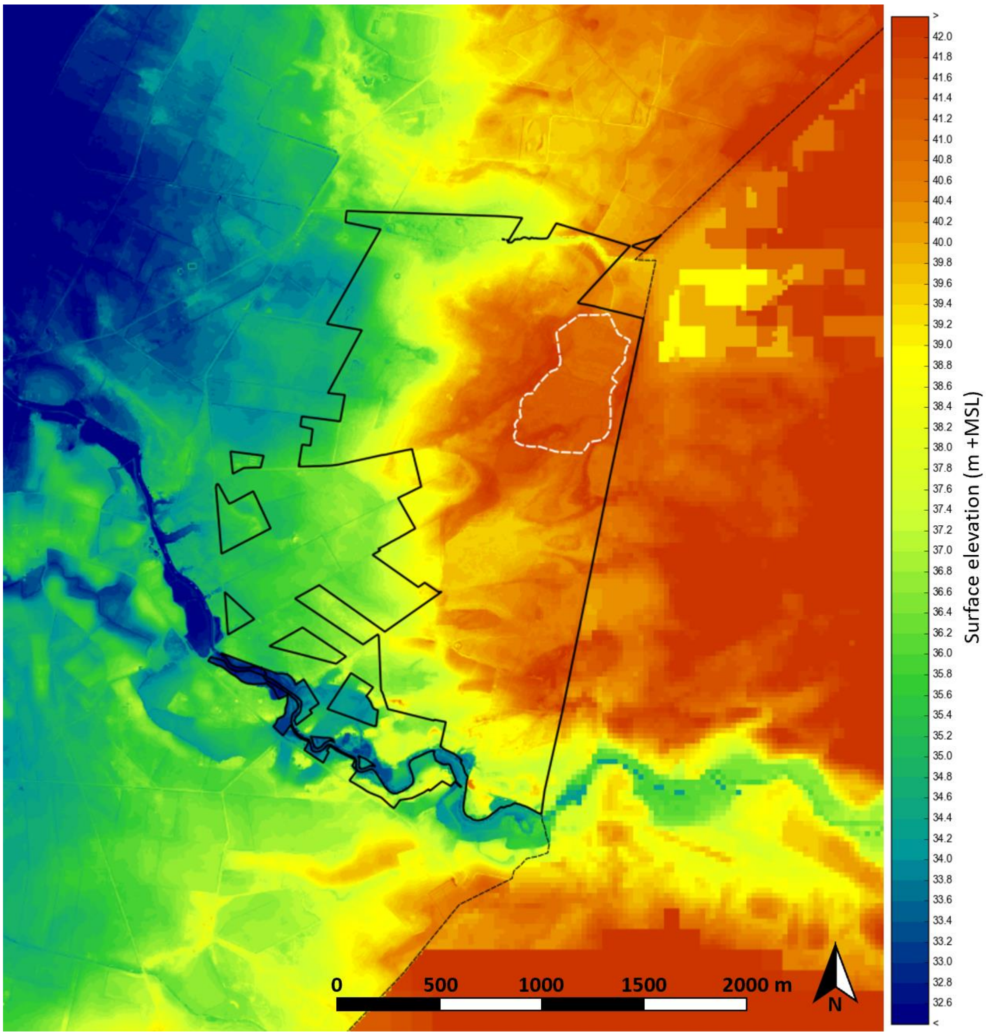


Figure 1.5.3: DEM (5x5 meter resolution) of the Witte Veen and its surroundings.

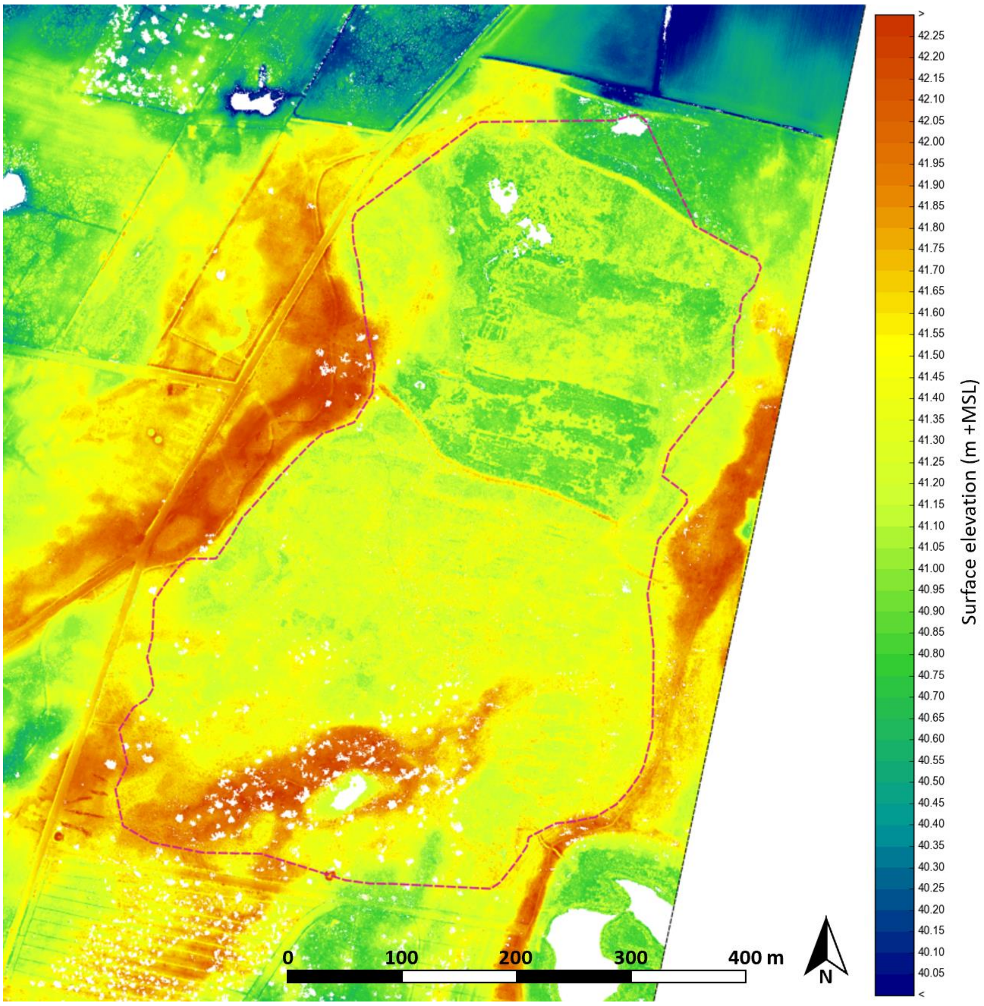


Figure 1.5.4: DEM (0.5x0.5 meter resolution) of the peat bog within Witte Veen.

Hydrology

Belgium: Valley of the Grote Beek

In order to get a better understanding of the hydrology of the valley, we installed 45 piezometers throughout the area. These piezometers were placed in rows perpendicular to the main waterways, because this gives most insight into the movement of water. Piezometers were chosen because these do not only measure the groundwater level, but also the seep pressure. Seeps are very important in keeping the area wet. Each site selected for greenhouse gas measurement also has a piezometer installed. 2 of these sites are situated alongside a row of piezometers, but 1 site needed an extra 46th piezometer. The piezometers are of the type RUGGED TROLL 100 of Koenders instruments. The piezometers were all working from September 2022 and will collect data hourly throughout the project. First data on the baseline groundwater level will only be available after the exact height of piezometers is measured using an RTK-GPS and 3 manual measurements are done spread over time to correct the data. We expect to have these first results mid-April.

The valley is drained severely by a huge network of small ditches connected to larger waterways. The impact of these ditches and waterways will be assessed in a hydrological study. Results of this study will be available at the end of 2023 and will be reported later. In preparation for this study, a mapping of all small ditches is currently being undertaken. The ditches are selected using the DEM (see there), but these will also be checked in the field and depth, drainage and seep indications will be noted. The results of this thorough ditch mapping will be provided in the next annual monitoring report.

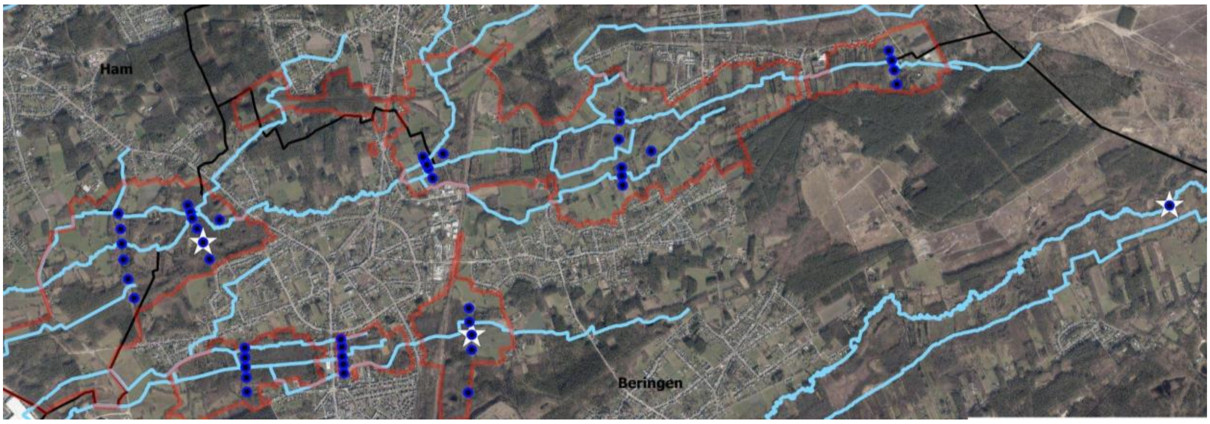


Figure 2.1.1: Map of the piezometers installed in the Valley of the Grote Beek. The stars indicate the GHG plots, blue lines are the major waterways, black lines are city borders and the red lines are the outline of the nature reserve.

Figure 2.1.2: Installed piezometers: Left: placed in the peat soil. Middle: a datalogger. Right: placed on the bottom of the waterway

Germany: Häsener Luch

Based on our analysis of the DEM we could identify the main pathways of the water within the drainage system. Fig 2.2.1 shows the location of the ditches in the whole project area and also the former barrage constructions, which are currently not working. The most water from the area run off into the *Welsegraben*, the main drainage ditch, which forms the western border of our project area. The flow direction within this ditch runs from south-west to north. The water storage basin in the north-eastern part was reportedly constructed to allow for regulating water levels in the peatland. Currently it has an unregulated outflow (of the same barrage construction type) connecting to the drainage system.

For better understanding the groundwater level dynamics we installed five pipes in autumn 2022 close to the ditches and equipped them each with a HYDROS-21 Water level sensor (METER). It is planned to repair three of the former barrage constructions in 2023 to carry out a test filling of the adjacent fen grassland parts in order to learn about the potential rewetting areas and also to raise awareness and trust with the local farmers and stakeholders.

In this context we will also install further staff gauges in the *Welsegraben* and sensors at the barrage constructions to observe the water movement throughout the measures.

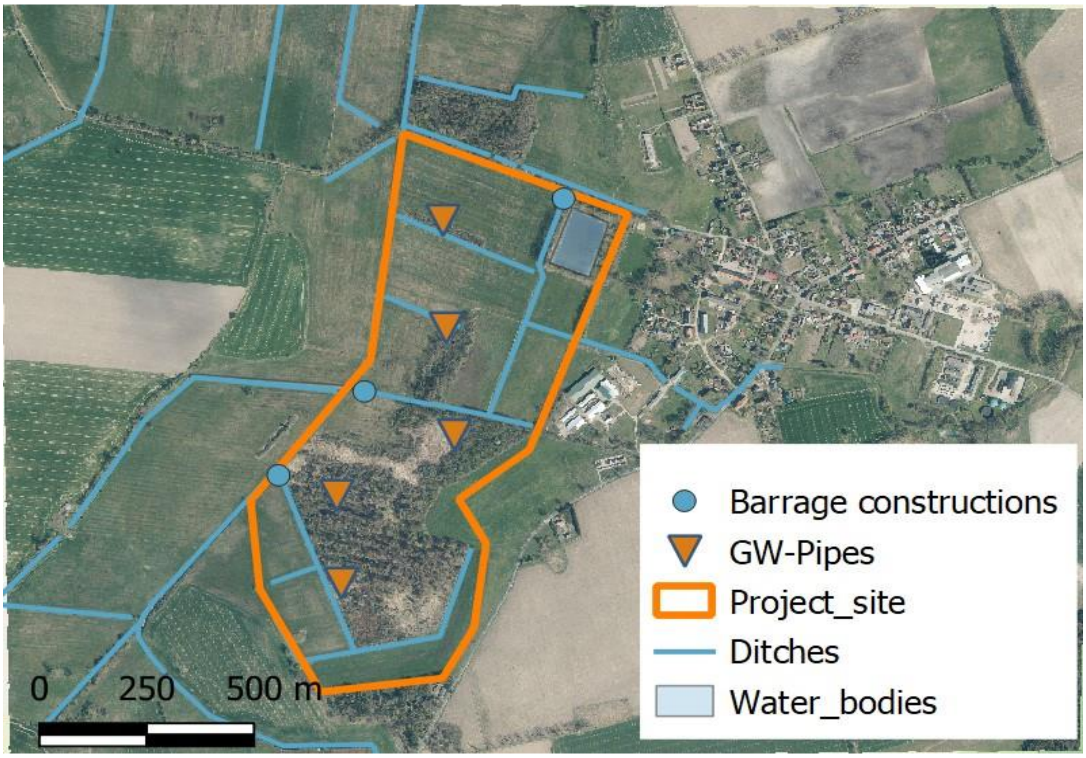


Figure 2.2.1: Map of the Groundwater Pipes installed in the Häsener Luch. The circles indicate the barrage constructions, so called “Schachtstaue”

Figure 2.2.2: a) Main drainage channel “Welse-Graben”; b) Installed GW-Pipe on a grassland site; c) Barrage construction exterior and d) interior view

Ireland: Connemara

Doire Fhada is located within the Corrib Catchment area. It is drained by 6 natural watercourses which flow from south to north. These water courses flow both aboveground and underground. This is clearly visible in the westernmost stream mapped in Figure 2.3.2 below, which is shown in 3 segments. The gaps in the mapped stream show where the stream disappeared underground. The easternmost stream mapped in Doire Fhada has its source at the lake located along the eastern boundary of the site, and flows southwards through Doire Fhada. Given the steep landscape within the site, water flow is fast within these streams.

Fionnán is located within the Galway Bay North catchment area, it has fewer watercourses, and similarly has sections of streams above and below ground, with thick Molinia and scattered *Phragmites australis* growing on the banks of the stream. Streams flowing within the site follow a westerly direction, eventually joining together just outside the north west corner of the site. Given the more even topography at Fionnán, stream flow is slower than at Doire Fhada.

Figure 2.3.1: A & B: Watercourse within Doire Fhada flowing from south to north. C: Watercourse exiting the western boundary of Fionnán. D: Lake towards the southern boundary of Fionnán

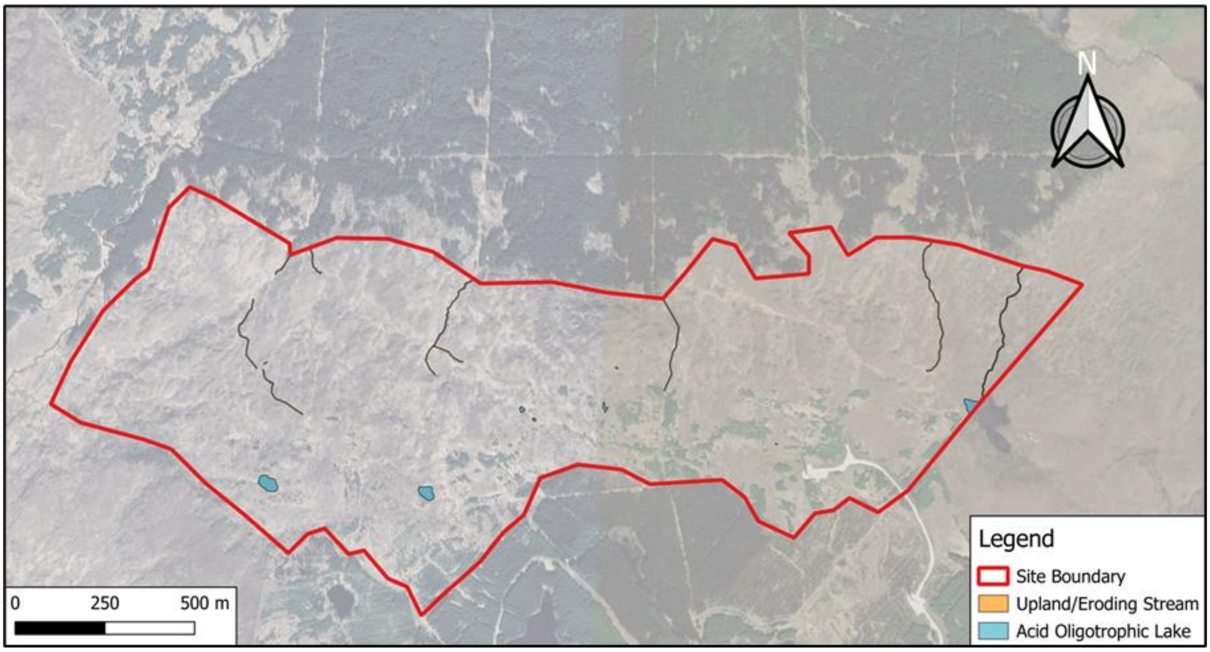


Figure 2.3.2: Streams and lakes within Doire Fhada. Stream flow is from a south to north direction

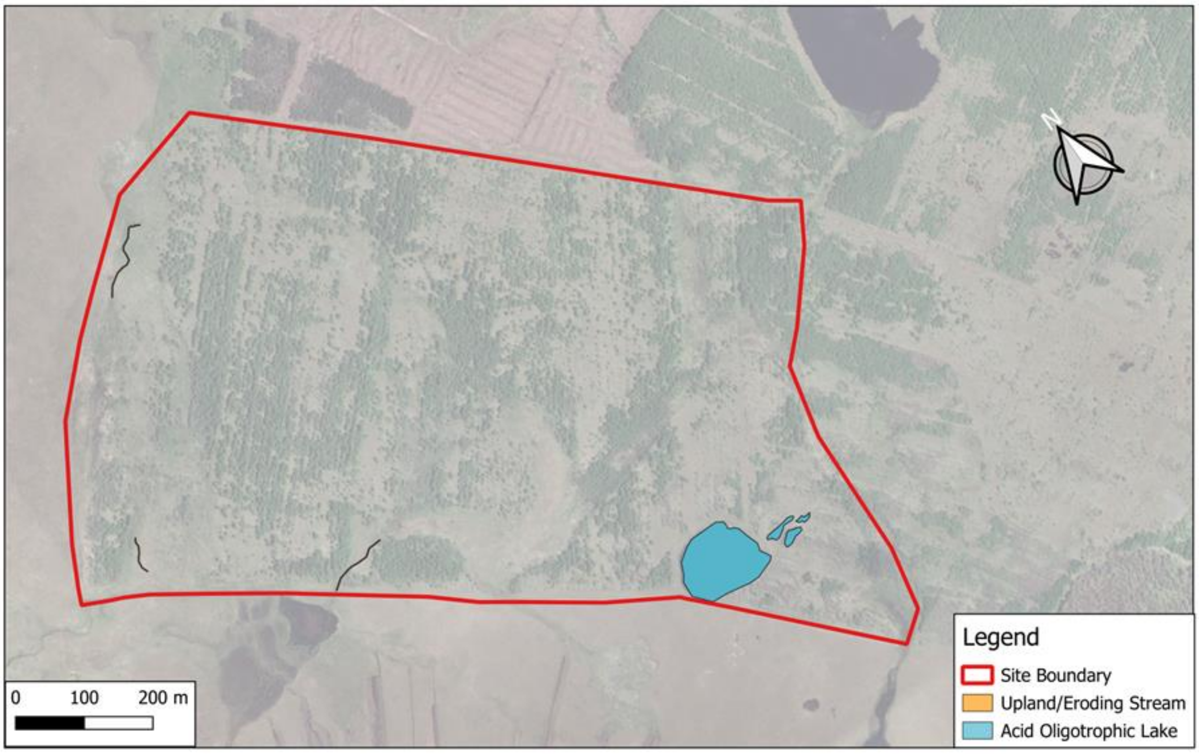


Figure 2.3.3: Streams and lakes within Fionnán, with stream flow in a westerly direction

Poland: Orawa

The Baligówka bog is located near the watershed between river catchments of Dunajec (Vistula basin, Baltic Sea) and Czarna Orawa (Vah basin, Black Sea), nevertheless is drained mostly towards Piekielnik stream on the eastern edge. There are no natural watercourses on the bog cupola, but there are a lot of remnants of artificial ditches, connected also with the longitudinal post-excavation holes. The ditches are strongly overgrown by vegetation and sometimes hardly visible, nevertheless still drain the bog and transport water, in particular in the springtime.

Monitoring of water level in the peat is foreseen. Location of piezometers is proposed. Nevertheless, the attempt to install piezometers in 2022 failed, due to lack of potential contractors. Monitoring is expected to be started in spring 2023.

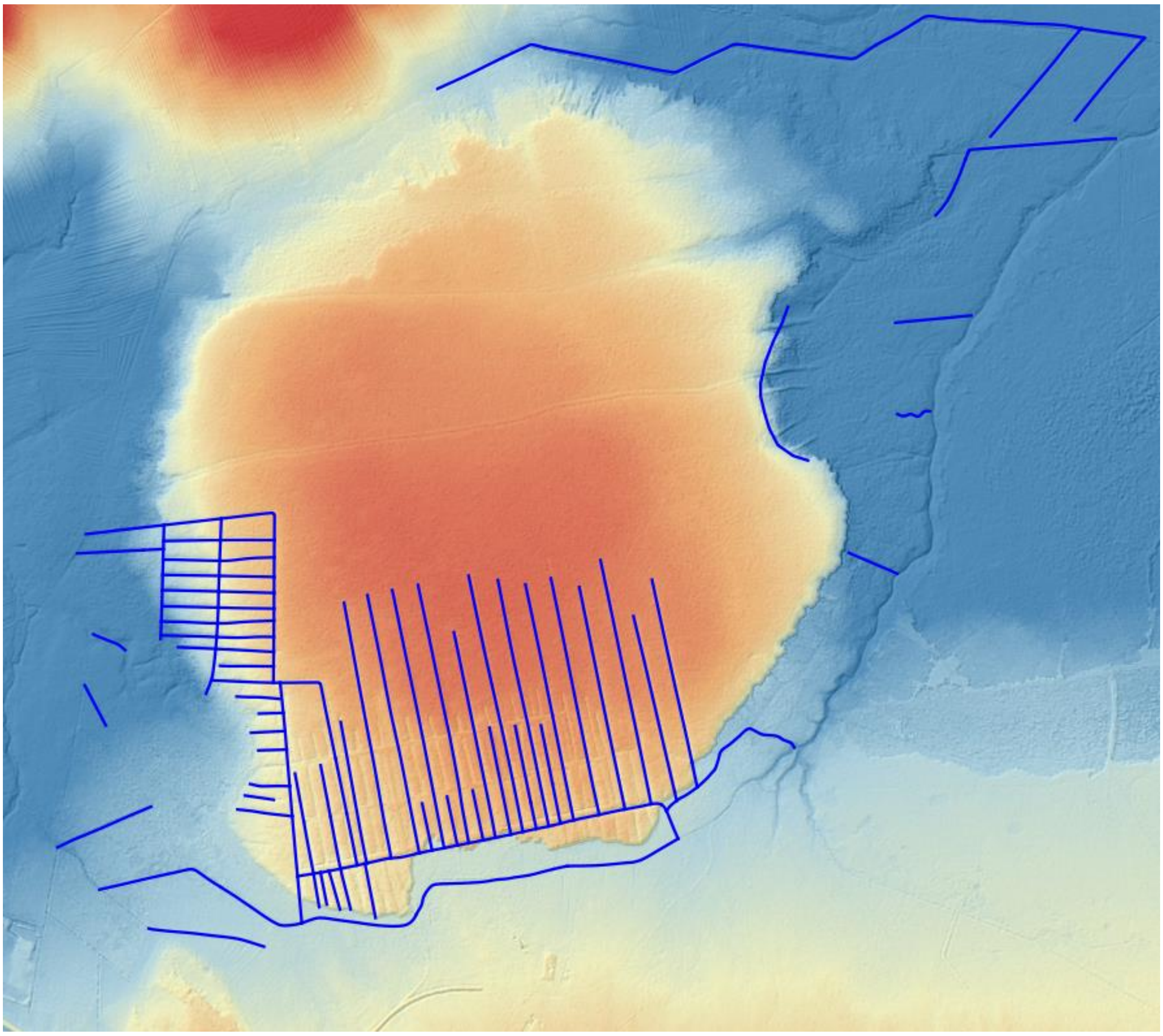


Figure 2.4.1: ditches draining the Baligówka bog

Figure 2.4.2: Remnant of ditch on Baligówka bog; overgrown by vegetation but still draining the bog and transporting water, in particular in spring.

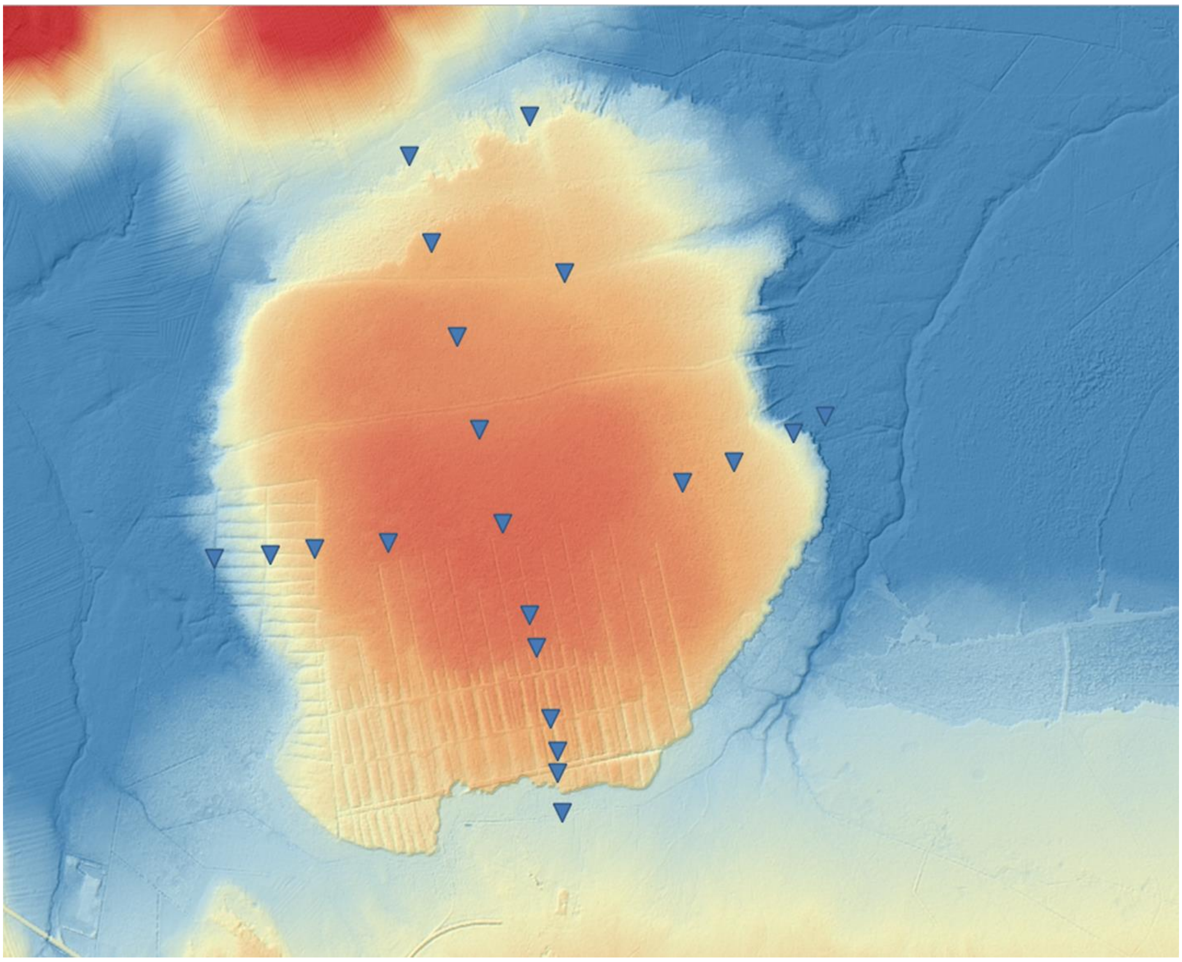


Figure 2.4.3: Foreseen water level monitoring (piezometers) on Baligówka bog

The Netherlands: Witte Veen

Within the peat bog there are no ditches or other streams present. Surface (runoff) and sub-surface water flow from south to north within the peat bog, leaving the bog through a ditch just outside the nature reserve. Water from this ditch flows to the west and north towards the Hege Beek brook in the north. In the nature area outside the bog several (shallow) ditches are present, transporting water to the surroundings in several - mainly westward - directions. These ditches cause water losses from the peat bog area and will therefore be removed in the project. The regional groundwater flow is oriented from the higher parts towards the west.

Several piezometers are already available for the monitoring of groundwater and surface water levels on a daily basis. See figure 2.5.2. The data from these piezometers formed a crucial source of information in the preparation phase and the design of the project.
An example of the groundwater levels is shown in figure 2.5.1. This graph shows that the annual fluctuation in the peat is about 50 cm, but just below the peat even more (up to 90 cm). A more stable water level with less drawdown in summer is desired. In summer time the lower head below the peat is causing downward leakage from the peat. In winter time the heads are recovered and limited seepage occurs. Full recovery was however not possible after the last dry summers: the highest winter levels show a negative trend. This vulnerability to drought is one of the issues we aim to resolve within the project.

New piezometers will be installed at the GHG measurement locations. The existing piezometers give us the opportunity to correlate the new piezometer to and extrapolate back in time.

Figure 2.5.1: Example of measured groundwater level in the Witte Veen. B118B (green) is positioned in the peat layer, B118A (red) below the peat.

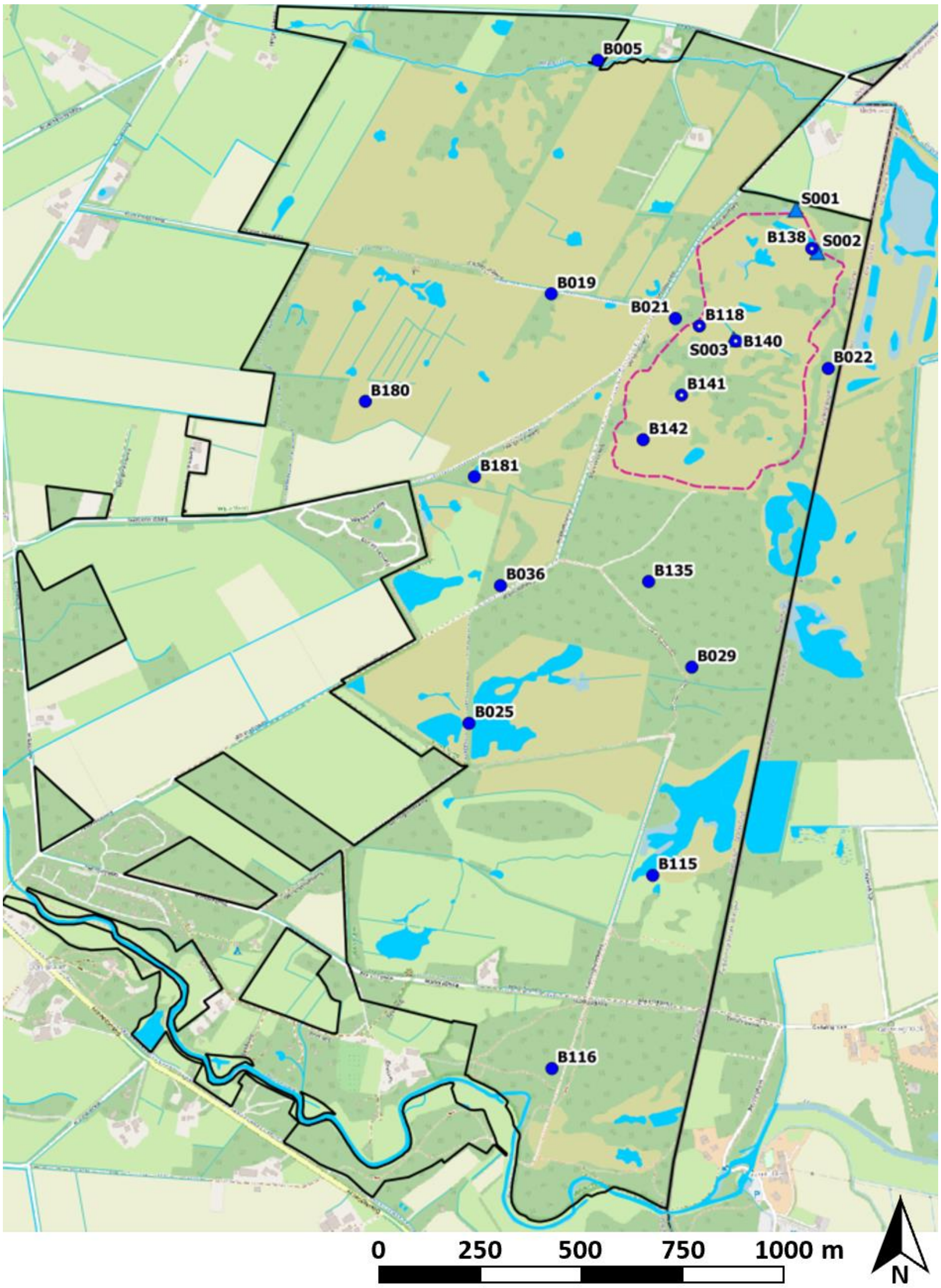


Figure 2.5.2: Location of the existing piezometers in the Witte Veen.

Vegetation surveys

Vegetation maps

Belgium: Valley of the Grote Beek

The vegetation within the Valley of the Grote Beek has been mapped completely over the last 20 years in the so-called “biological valuation map”. These vegetation mappings are quite old for some parcels. Therefore, these are being renewed in order to follow up the vegetation development within the Multi Peat project. We expect to have the initial vegetation maps mid-April. Vegetations are classified using abbreviations commonly used in Belgium, which are very similar to the vegetation associations commonly used throughout Europe. This vegetation map is then again divided into classes of nature value running from worthless (labelled as “m” and marked as completely blank) to biologically very valuable (labelled as “z” and marked as completely green).

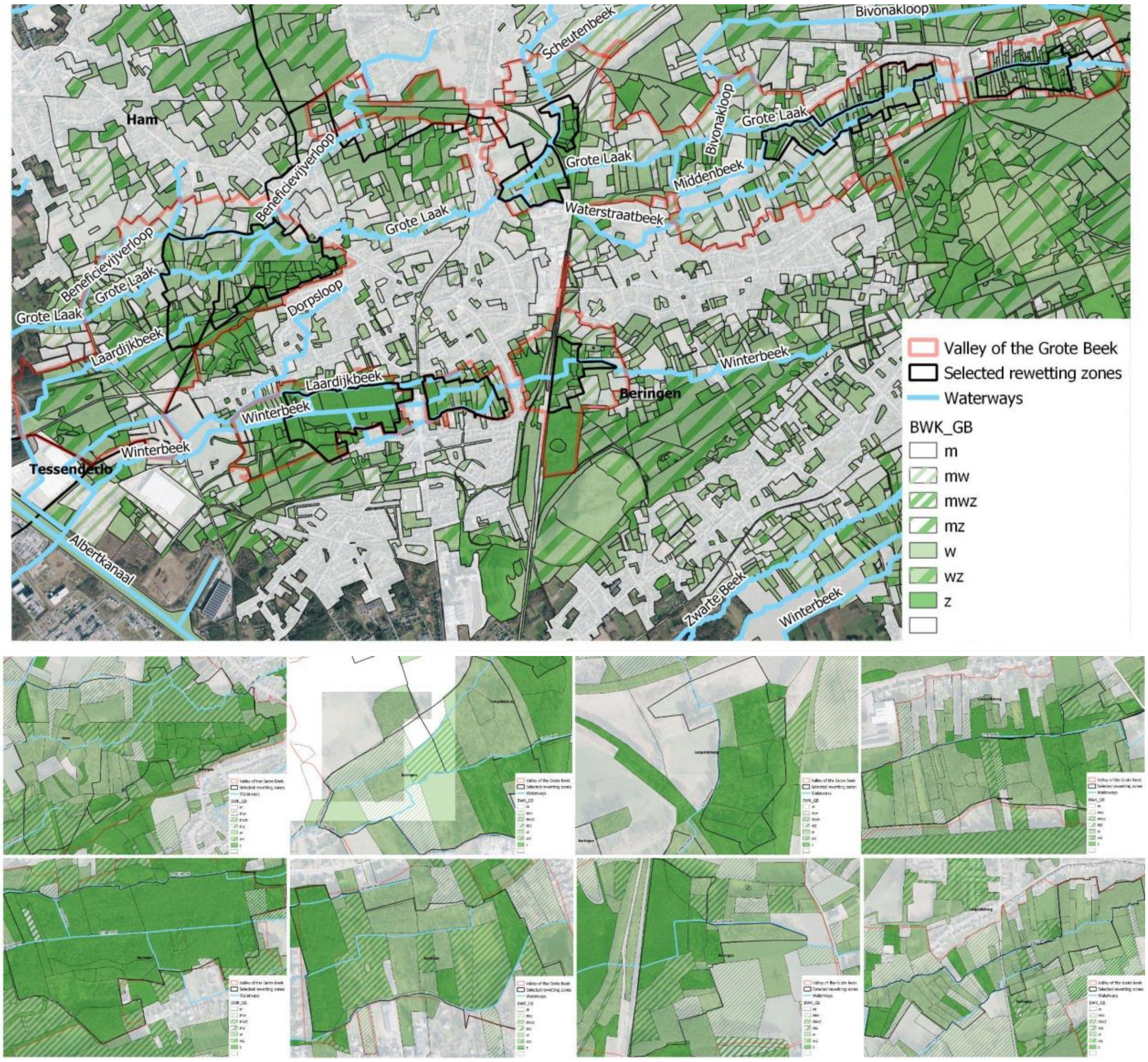


Figure 3.1: Biological valuation map in the Valley of the Grote Beek

Germany: Häsener Luch

The vegetation mapping of the project site was performed in summer 2022 during the phenological season. We included only vegetation units, which were almost homogeneous in relation to physiognomic-structural aspects, ecological site conditions as well as floristic features and which could be clearly distinguishable from the surrounding area.

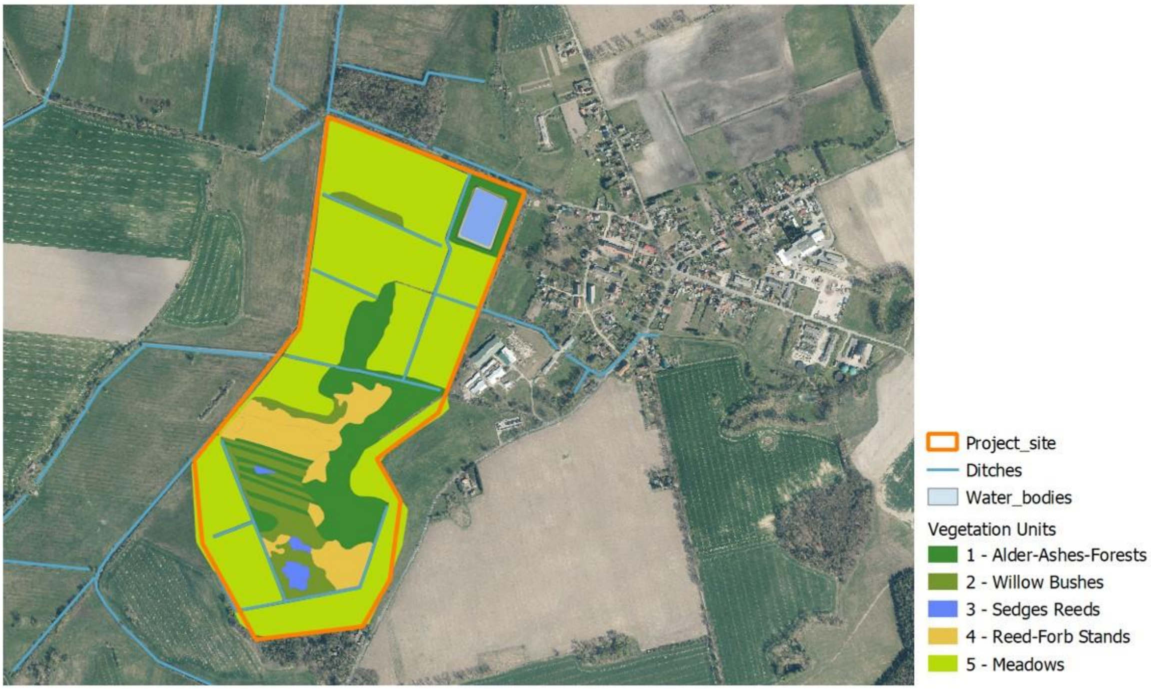


Figure 3.2: Summarising field map of the vegetation units in the Häsener Luch site

It is planned to verify the spatial extent of the different vegetation units by UAV flights in spring 2023.

Within each vegetation unit all occurring species were listed including the coverage rate. Because of mowing activities on the grassland sites some species could be not included here.

Ireland: Connemara

The project area is located within the Galway Wind Park and borders the Connemara Bog Complex SAC, which is designated for the presence of several habitats and species. The Connemara Bog Complex SAC is a large site encompassing the majority of the south Connemara lowlands in Co. Galway. The site is bounded to the north by the Galway–Clifden road and stretches as far east as the Moycullen–Spiddal road. It is characterized by areas of deep peat surrounded by rocky granite outcrops covered by heath vegetation. However, the main habitat within this site is lowland Atlantic blanket bog, as most of the area is covered by blanket peat greater than 1 m in depth. A mosaic of different communities exists in association with the blanket bog, including hummock/hollow systems, interconnecting bog pools, flushes, transition and quaking mires, freshwater marshes, lakeshore, lake and river systems. (NPWS, 2015).

The project area is a good representation of the Connemara Bog Complex on a smaller scale, although some areas of former blanket bog habitat have since been planted with Conifer Plantations.

Doire Fhada is the northernmost site in the Galway Wind Park and a habitat map of the site is shown above in Figure 3.3.1. The majority of the site is upland blanket bog which is characterized by Deergrass *(Trichophorum caespitosum)*, Cottongrasses *(Eriophorum vaginitum, C. angustifolium)* and dwarf shrubs such as Ling (*Calluna vulgaris*), Cross-leaved Heath (*Erica tetralix*) and occasional Bilberry (*Vaccinium myrtillus*). Purple Moor-grass *(Molinia caerulea)* is present throughout the site and dominates on particularly wet patches of ground near streams, or near conifer plantations. Conifer Plantations consist almost entirely of Sitka Spruce *(Picea sitchensis)*, with occasional Lodgepole Pine *(Pinus contorta)*, and the ground within this habitat is significantly drier than outside. Upland/eroding streams flow from north to south within the site. Wet heath and dry siliceous heath occur in areas of shallower peat and consist largely of ling. The site drains from south to north through a number of streams.

The majority of Fionnán consists of Conifer Plantation, which is dominated by Sitka Spruce. The conifer plantation is underlain by wet, peat soils. Pockets of degraded blanket bog, dominated by *Molinia, are* found within the site as well as an acid, oligotrophic lake towards the southern corner of the site. A small stream along the south western boundary of the site drains into a lake just outside the project area.

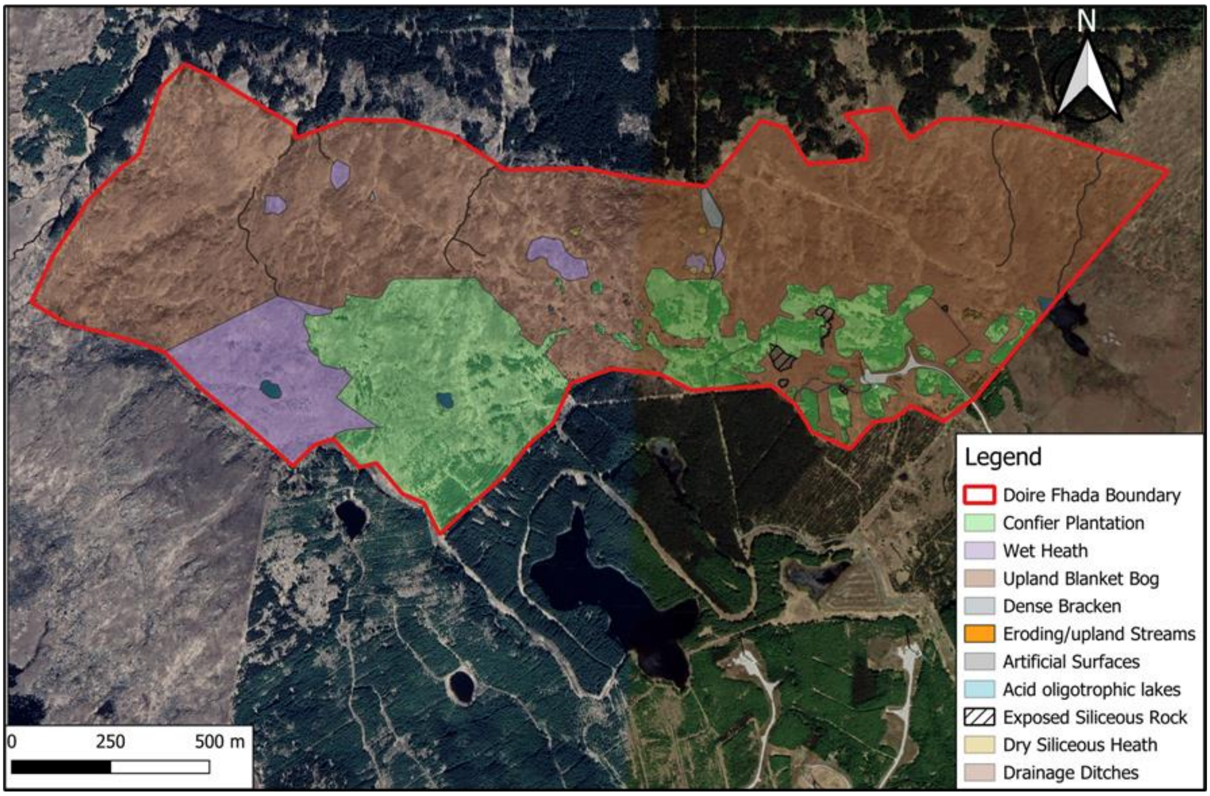


Figure 3.3.1: Habitat Map of Doire Fhada, the northern site within the Connemara project area

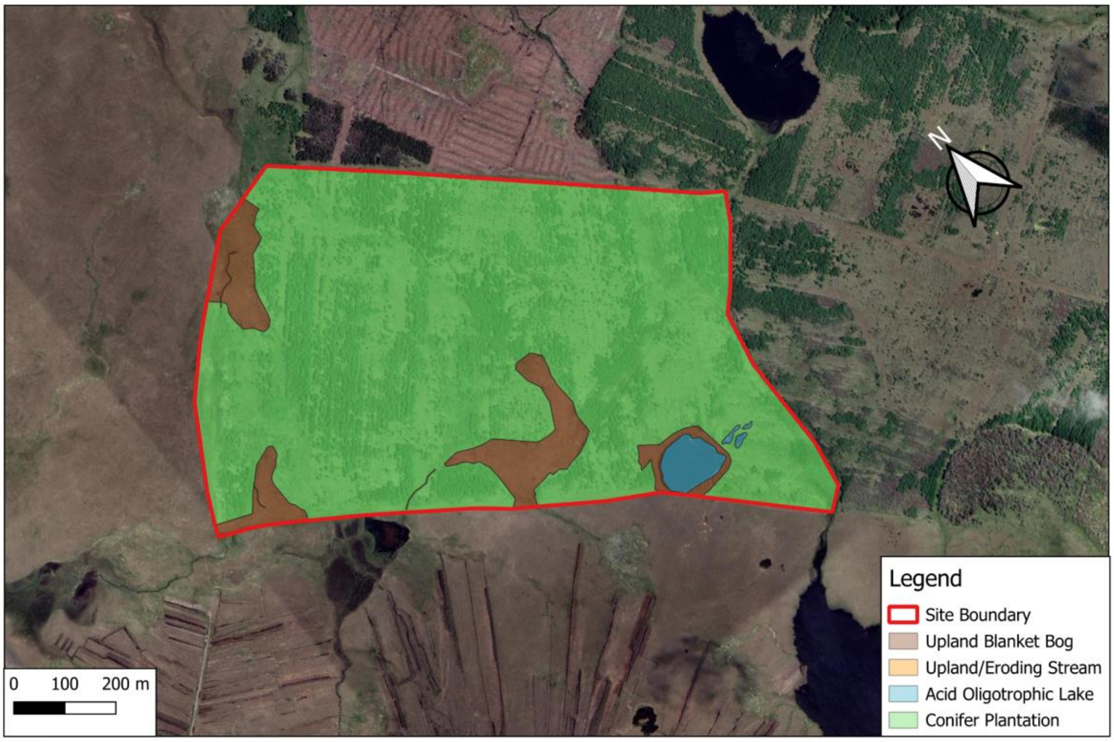


Figure 3.3.2: Habitat Map of Fionnán, the southern site within the Connemara project area

	Hectares		
Habitat	**Doire Fhada - North**	**Fionnán - South**	**Total**
Total Site area	178.68	70.33	249.01
Upland Blanket Bog	122.91	6.08	128.98
Conifer Plantation	40.71	63.08	103.79
Eroding Upland Stream	0.43	0.02	0.45
Acid Oligotrophic Lakes	0.43	1.15	1.58
Wet Heath	12.69	-	12.69
Artificial Surface	0.53	-	0.53
Exposed siliceous rocks	0.55	-	0.55
Dry siliceous heath	0.17	-	0.17

Table 3.3: The area covered by each habitat within Doire Fhada and Fionnán

Poland: Orawa

Vegetation of Baligówka bog was mapped in 2022. The bog is dominated by the pine bog forest *Vaccinio uliginosi-Pinetum*, nevertheless the central part is still open, covered by *Eriophoro vaginati-Sphagnetum,* with only single tree islands and thickets of *Pinus mugo* and *Pinus rhaetica*. The post-excavation holes are filled with *Sphagnum* carpets with *Eriophorum angustifolium* and *Rhynchospora alba.* In the northern and southern part of the bog, the driest parts are covered with heather, *Calluna vulgaris.* The vegetation is expected to change due to implementation of conservation measures by conservation authority in January and February 2023 (not in the scope of the LIFE Multi Peat project): some trees will be removed and the area of bog forest will probably be reduced. Thus, the vegetarian will be re-mapped in 2023, to document the baseline for implementation of LIFE-Multi Peat measures.

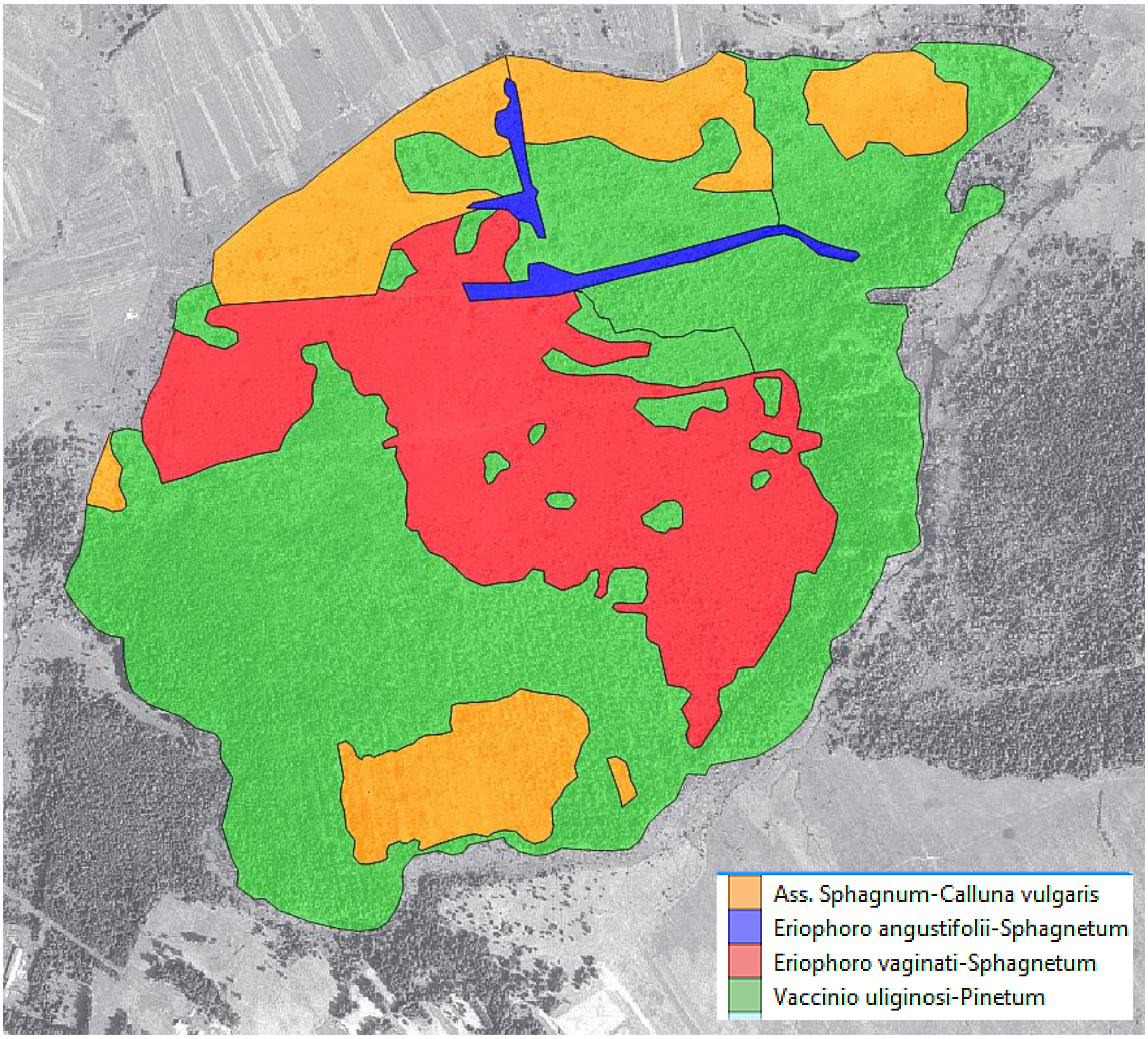


Figure 3.4.1: Vegetation of Baligówka bog in 2022.

For more precise documentation of vegetation, 43 circle permanent plots, 100m^2 each, were established. 20 of 43 plots were re-established in points where vegetation was formerly recorded in 2001, 23 are the new ones. Phytosociological relevees, as well as trees measurements were collected in 2022.

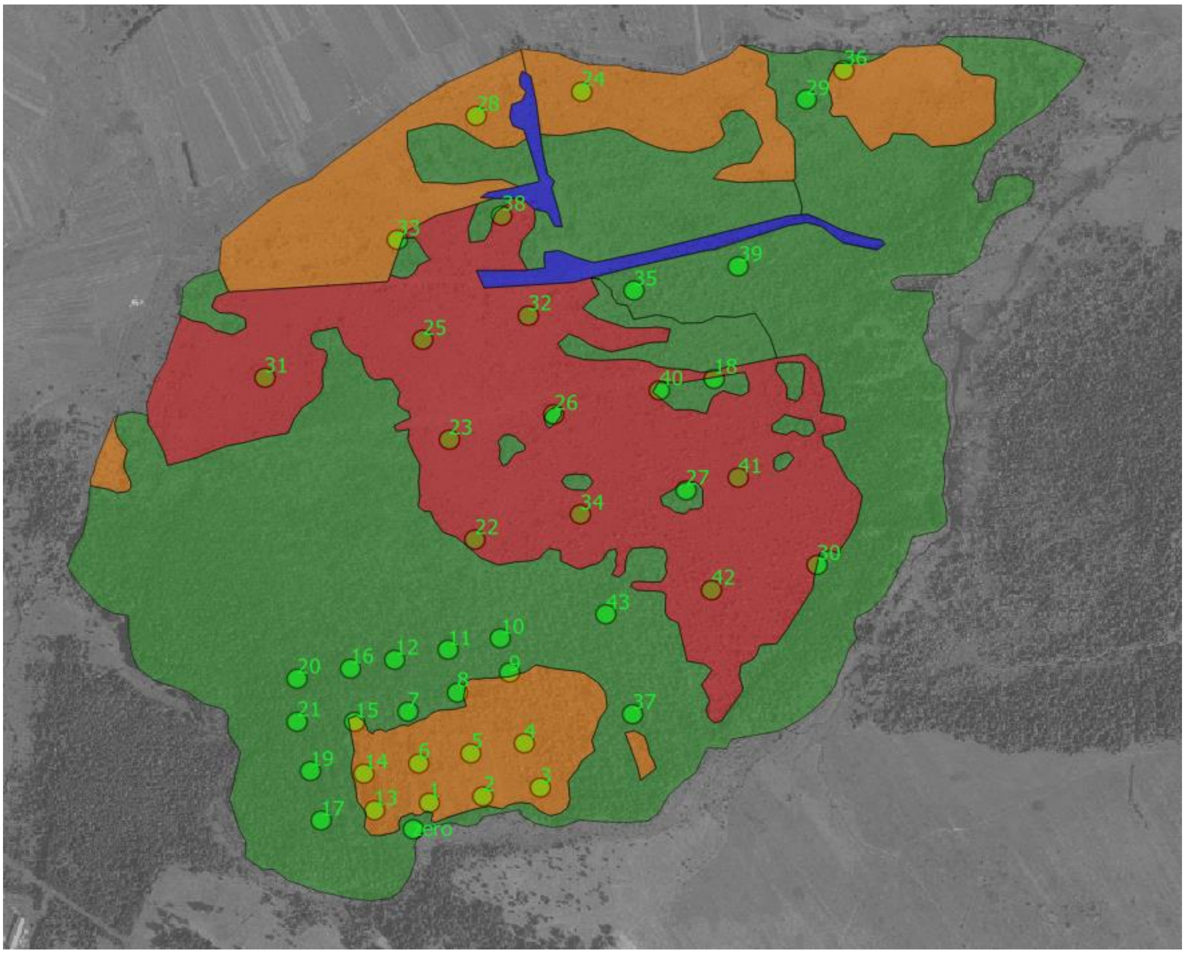


Figure 3.4.2: Location of vegetation monitoring plots on Baligowka bog

Figure 3.4.3: Open part of the Baligówka bog (Eriophoro vaginati-Sphagnetum)

Figure 3.4.4: Bog pine forest (Vaccinio uliginosi-Pinetum)

The Netherlands: Witte Veen

Vegetation was mapped in 2021 just prior to the start of the project. The vegetation map - shown in figure 3.5.1 - did not cover the whole of the Natura2000 area, but included the peat bog. A more detailed picture of the vegetation map for the peat bog is given in figure 3.5.2. The Dutch vegetation classification has not yet been translated in English, but this will be done later in the project. In addition to the 'normal' vegetation mapping the distribution and abundance of Sphagnum species was mapped, specifically with the LIFE project goals in mind.

In the last year of the LIFE project the vegetation will be mapped again to evaluate the effect of the rewetting measures.

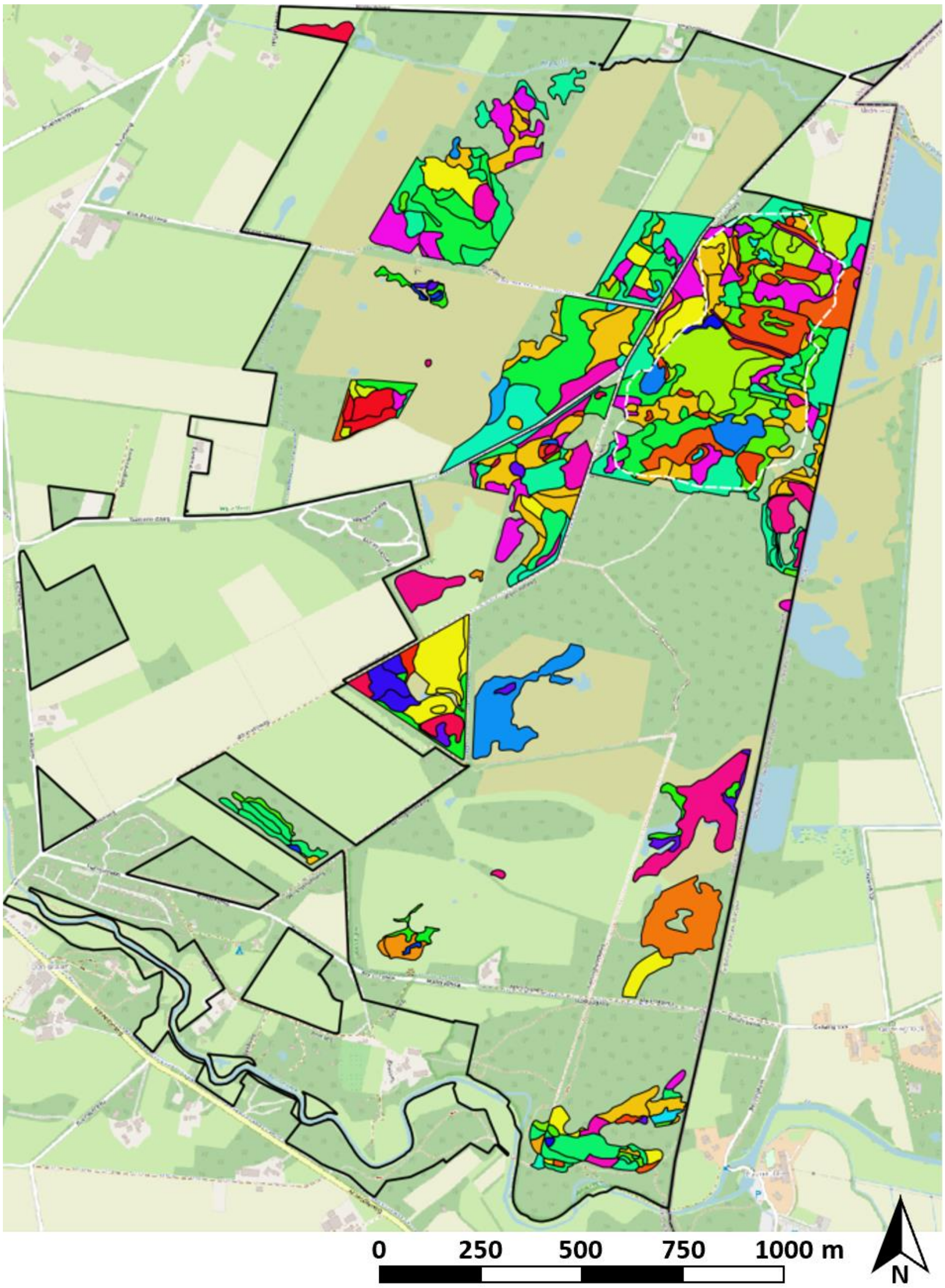


Figure 3.5.1: Vegetation mapped in 2021 in the Witte Veen.

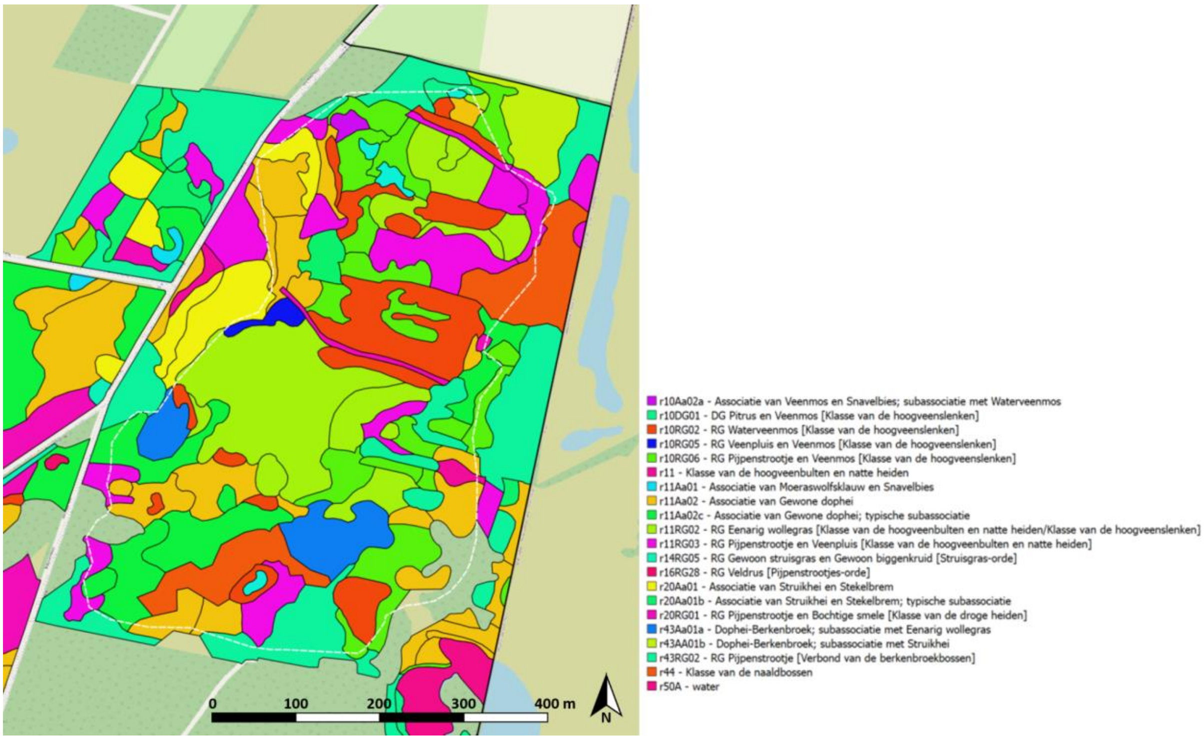


Figure 3.5.2: Vegetation map (2021), zoomed in on the peat bog in the Witte Veen.

UAV approach/ satellite analyses

Sentinel 2 satellites are used for earth observation. These satellites pass over each pilot site area each 3 or 4 days. This allows us to monitor changes in vegetation properties through time and compare before and after the project on a large scale. These images are freely available and can be used to calculate a variety of different so-called “indices”. The indices we used are described below. The resolution of these images is 10*10 meters. Which is rather rough, but this is more than enough to map on an ecosystem scale. For small areas drone data will be much more efficient in monitoring these changes.
With these satellite images, we calculate different indices related to water and vegetation using the program QGIS.

- NDVI: Normalized Difference Vegetation Index (plant activity)
  - (NIR-RED)/(NIR+RED)
  - NDVI is a measure of the state of plant health based on how the plant reflects light at certain frequencies (some waves are absorbed and others are reflected). Chlorophyll (a health indicator) strongly absorbs visible light, and the cellular structure of the leaves strongly reflects near-infrared light. When the plant becomes dehydrated, sick, afflicted with disease, etc., the spongy layer deteriorates, and the plant absorbs more of the near-infrared light, rather than reflecting it. Thus, observing how NIR changes compared to red light provides an accurate indication of the presence of chlorophyll, which correlates with plant health.
- NDMI: Normalized Difference Moisture Index (plant water stress)
  - (SWIR1610 – NIR)/(SWIR1610 + NIR)
  - Highlights differences in water content of leaves.
- NDWI: Normalized Difference Water Index (locates changes in water content of water bodies)
  - (Green - NIR)/(Green + NIR)
  - Used to highlight open water features in a satellite image, allowing a water body to “stand out” against the soil and vegetation. The NDWI index effectively measures moisture content, and allows to detect subtle changes in water content of the water bodies.
- MNDWI: Modified Normalized Difference Water Index (searches water bodies, useful to see waterlogging, presence/absence of surface water)
  - (Green - SWIR1610) / (Green + SWIR1610)
  - Used to enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise. MNDWI is more suitable for enhancing and extracting water information for a water region with a background dominated by built-up land areas.
- NMDI: Normalized multi-band drought index (locates water content within plants)
  - (NIR - (SWIR1610 - SWIR2190))/(NIR + (SWIR1610 - SWIR2190))
  - Used for monitoring soil and vegetation moisture.

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

Figure 4: Different bands on the Sentinel 2 satellites, with their respective wavelength and resolution. Bands with 20m resolution are resampled to 10 m using the bilinear method. To calculate the indices, we use bands 2,3,4,8,11 and 12 from the sentinel 2 satellites.

Belgium: Valley of the Grote Beek

In the Valley of the Grote Beek there are some problems regarding drone images. The nearby military zone claims the airspace most of the time, making the possibilities for drone images limited. But since the war in Ukraine this temporary no-fly zone changed into a permanent no-fly zone. This makes us unable to launch drones on the whole project site. We don't expect this to change anytime soon, so in Belgium we won’t use drones for remote sensing, but we will use satellite imagery. The satellite images have the advantage that we can cover the complete valley and have pictures for each month to follow up the vegetation and water during the project on a large scale.

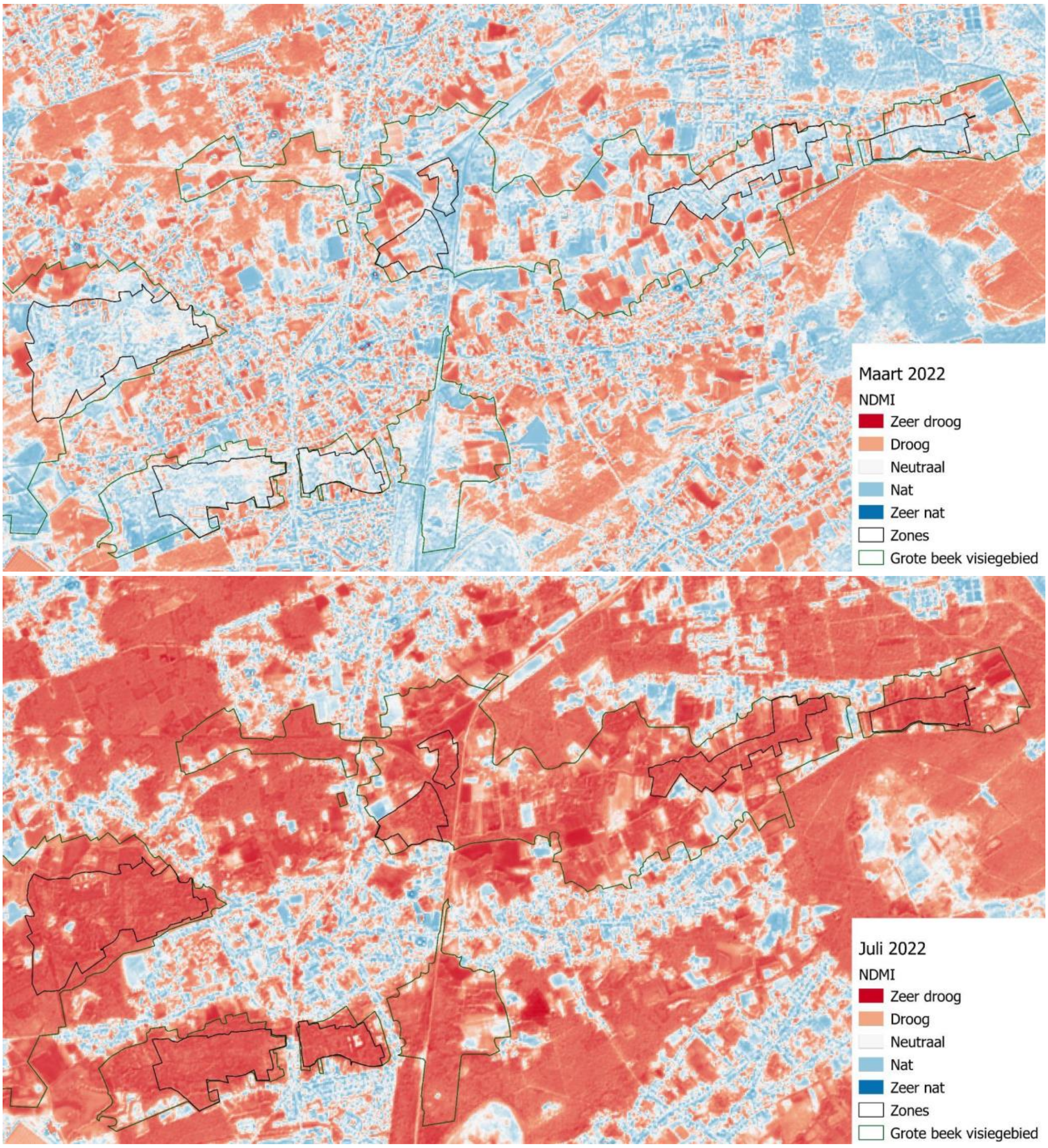


Figure 4.1: 2 Examples of satellite analysis during 2022 in the Valley of the Grote Beek. Here we can see the NDMI. Mind that only vegetated areas can be interpreted.

Upper: We see that the valley is still very wet in March.

Lower: We see that the valley is completely dried out in July during our extremely dry summer. Only bare earth colours blue (not interpretable) And some agricultural terrain that is irrigated.

Germany: Häsener Luch

As a low-budget alternative of drone flights for identification of different vegetation units, vitality and moisture parameters we first applied freely available satellite images from scihub (Copernicus). We downloaded the images for our project sites and also calculated the NDVI and all other indices, but unfortunately the resolution was quite unsatisfactory for our small project site (see Figure 4.2), so that we decided to return to the originally intended UAV-approach. We plan to implement a drone flight in May 2023, which will cover the whole project site in a higher resolution (cm scale) and allow us to calculate the NDVI and NDMI more precisely than the satellite images.

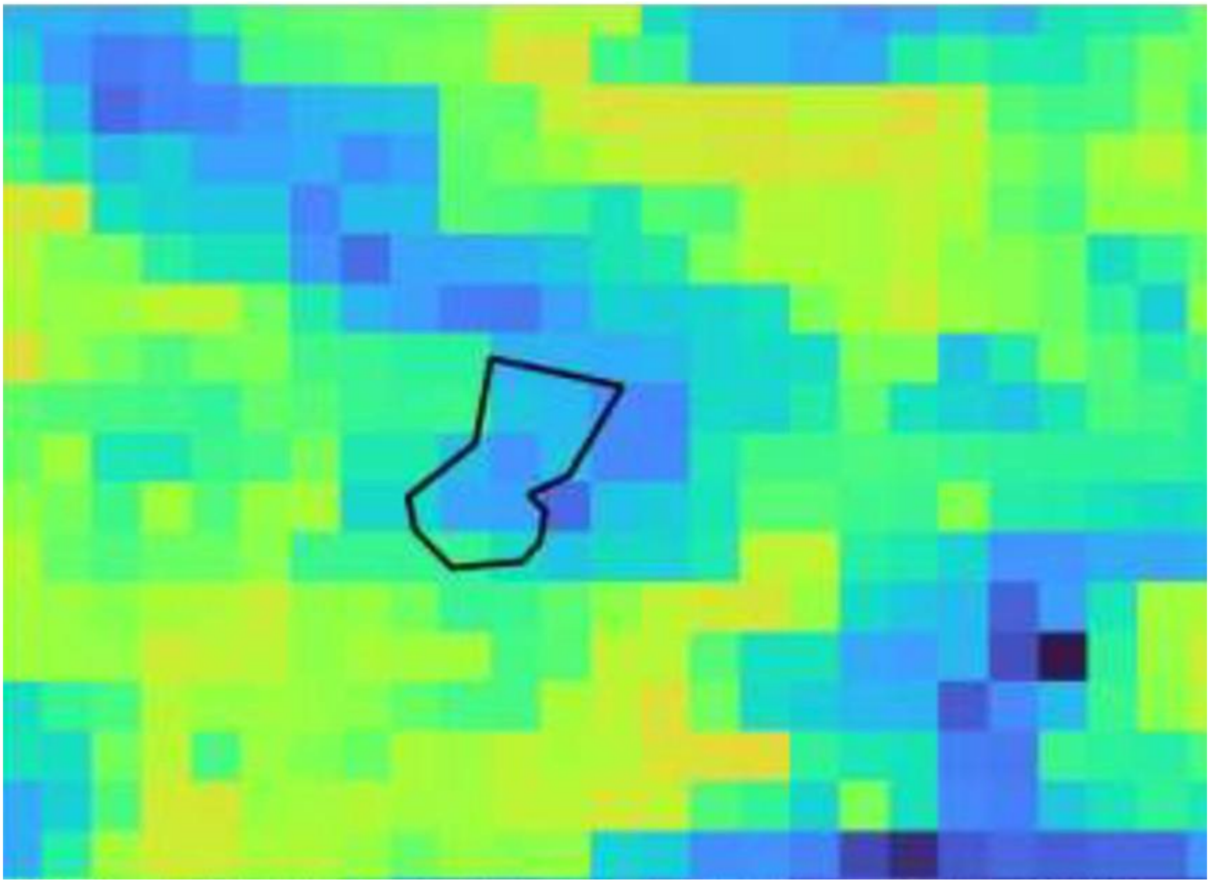


Figure 4.2: Illustration of the calculated NDVI; the resolution based on the available satellite image data for the Häsener Luch site (black line)

Ireland: Connemara

The two sites in Connemara will use both UAV/Drone surveys and use of satellite Sentinel-2 (S-2) data to assess vegetation cover pre-and post-project. UAV flights are scheduled for summer 2023. S-2 data is included below. Data bands were processed using bands 2,3,4,8,11 and 12 from the sentinel 2 satellites. Bands 2,3,4, and 8 have a resolution of 10m. Bands 11 and 12 had a resolution of 20m, but were resampled using the bilinear method to give a resolution of 10m.

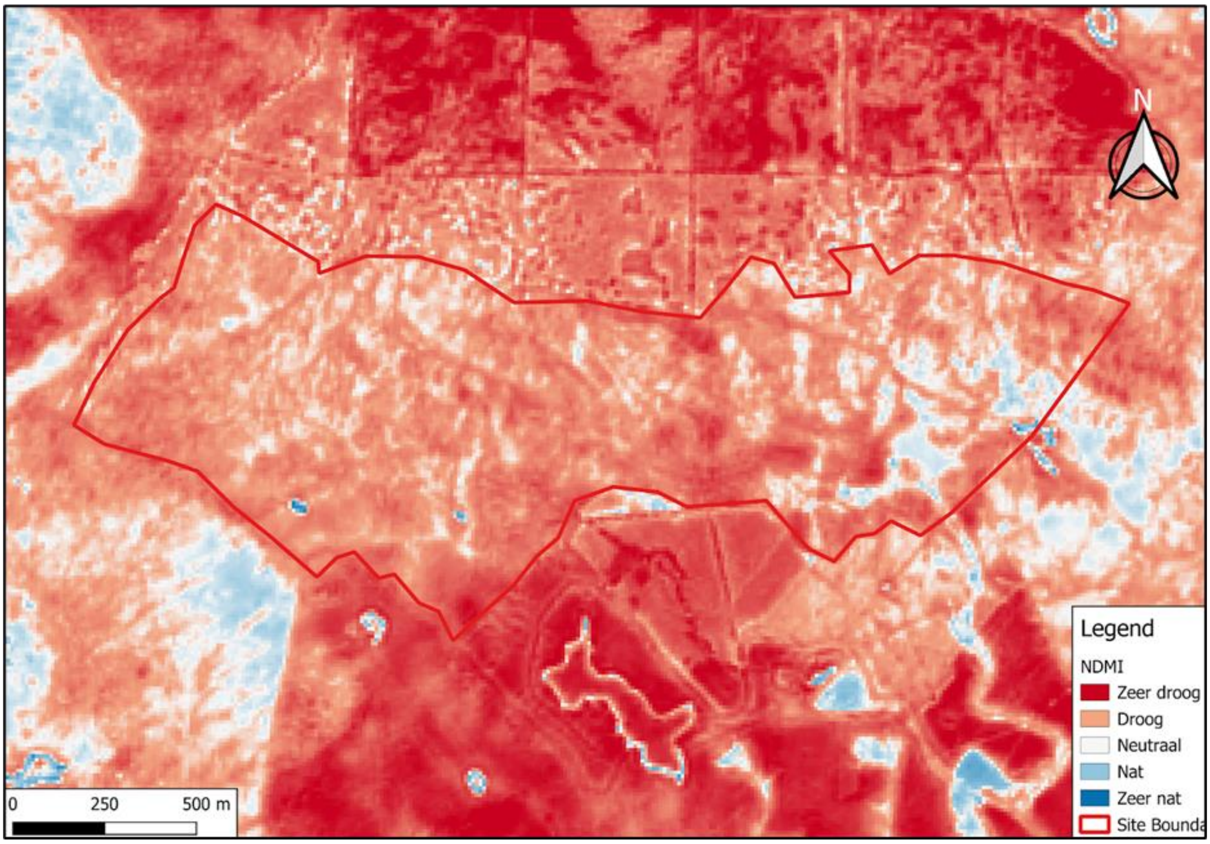


Figure 4.3.1: NDMI for Doire Fhada, the northernmost site within the project area

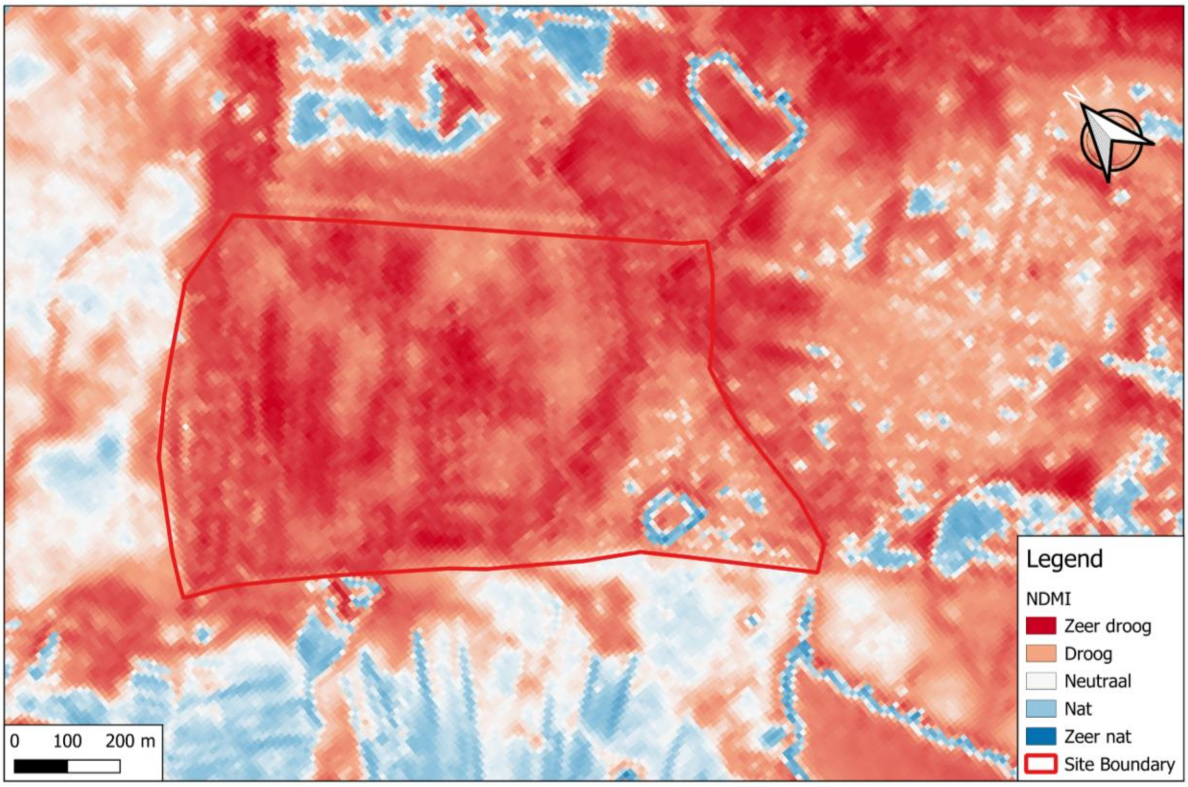


Figure 4.3.2: NDMI for Fionnán, the southernmost site within the project area

Poland: Orawa

For Orawa bogs, satellite Sentinel-2 (S-2) data will be used to assess vegetation cover. In 2022 some test analyses were implemented. Samples of S-2 data were acquired for the project site and some standard visualizations were produced:

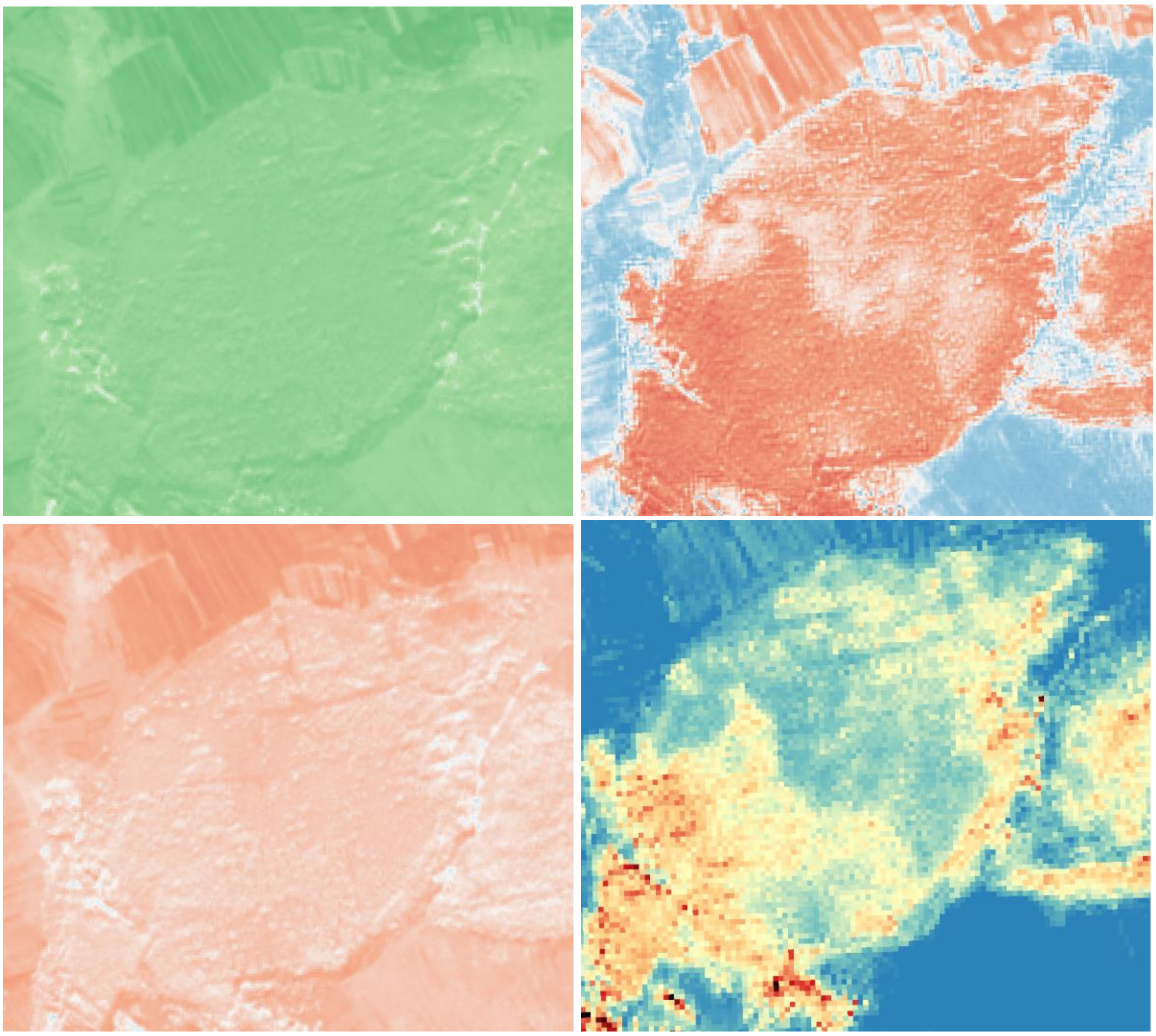


Figure 4.4: NDVI, NDMI, NDWI, NDMI - test samples for Baligówka bog, S-2 from November 2022.

GEST

To assess the total GHG emissions of all project sites in the beginning of our MULTI PEAT project we used the GEST-approach based on the methodology published by COUWENBERG et al. 2008, 2011) and also approved by the Verified Carbon Standard (VCS) as a method to estimate the Global Warming Potential (GWP) of temperate peatlands (EMMER & COUWENBERG 2017) The fundamental points are:

- Greenhouse gas emissions are significantly related to mean annual water level
- Water levels can be described by presence or absence of special groups of plant species
- Classification in more or less homogeneous Greenhouse-Gas-Emission-Site-Types (GEST) by referring of published GHG data of similar sites

The crucial point for application and identification of GESTs is a full coverage in vegetation descriptions/mapping, that must be done before. For determination of a GEST a compilation of so-called vegetation forms according to KOSKA (2001) is required. The vegetation forms are characterized - depending on the site parameters - by ecological-sociological species groups and their common physiognomy and indicate certain site conditions like moisture, trophy state or acidity (like ELLENBERG (1992)). The vegetation forms are composed of several species' groups. A more detailed description of the approach is written in the Handbook for Assessment of Greenhouse Gas Emissions from Peatlands within the LIFE Project Peat Restore (https://life-peat-restore.eu/en/publications/).

Nr.	**GEST**	**SMC (exceptions)**	**CH_4 (kg / ha / a)**	**CO_2 (t / ha / a)**	**Total (t CO_2-eq. / ha / a)**
	Grassland				
G1	Dry to moderately moist grassland	2+, 2-	-0.28	25.2	25
G1v	Grassland very dry in summer, (very) moist in winter	2~	-0.28	48.6	48
G2	Moist grassland	3+, 3+/2+	-0.08	19.6	19.5
G3	Moist to very moist grassland	4+/3+	8.12	14.1	14.5
G3f	Periodically flooded grasslands	4~, 3~	-1.95	14.1	14
G3s	Moist to very moist grassland with shunts (Juncus)	4+/3+, 3~, (3+, 3+/2+)	26.7	14.1	15
G3m	Moist to very moist acidic Molinia meadows	4+/3+	173.2	14.1	19
G4	Very moist grassland	4+, 4~	14.5	4.66	5

G4s	Very moist grassland with shunts	4+	89.5	4.66	7.0
G5	Wet grassland	5+/4+	1.27	-3.99	-3.5
G5s	Wet grassland with shunts (Juncus)	5+, 5+/4+, (4~)	101.8	-3.99	-1
	Cropland				
A1	Dry to moderately moist arable land	2+, 2-	3.30	37.4	37.5
A2	Moist arable land	3+, 3+/2+	4.82	21.5	21.5
	Unmanaged				
U1	Moist bare peat	3~, 3+	1.05	8.99	9
U2	Moist bog heath	3+	9.63	12.3	12.5
U3	Very moist bog heath	(5+/4+), 4+	32.8	2.99	4
U4	Very moist forbs and sedges	(5+/4+), 4+, (4+/3+)	42.9	14.4	16
U5	Very moist Sphagnum lawn	(5+, 4+), 4+	55.5	-4.41	-3
U6	Very moist tall sedges	(5+/4+), 4~, 4+, (4+/3+)	57.9	12.6	14.0
U7	Wet bare peat	5+/4+	7.87	1.34	1.5
U8	Wet meadows and forbs	5+	262.8	0	7.5
U9	Wet small sedges with moss layer	5+ (4+)	179.3	-1.92	3.0
U10	Wet sphagnum lawn	5+, (5+/4+)	110.8	-3.44	-0.5
U11	Wet tall reeds	(5~), 5+, (5+/4+)	230.9	0.20	6.5
U12	Wet tall sedges	5~, 5+, (5+/4+)	203.5	1.30	7.0
U13	Wet to very wet Sphagnum hollows	6+, (5+)	298.6	-4.84	4.0
U14	Very wet tall	6+, 6+/5+	243.3	-1.08	5.5

	sedges and Typha				
U15	Very wet Phragmites and Phalaris reeds	6+, (6+/5+, 5~)	427.6	-7.23	5
U16	Flooded tall reeds (>20 cm above surface)	6+	1010.4	-32.7	-4.5
	Special GESTs				
S1	Dry to moderately moist grassland on peaty soils	2-, 2+/2-, 2+	-1.75	45.0	45
S2	Moist grassland on peaty soils	3+/2+, 3+, 3~	0.46	26.7	27
S3	Very moist grassland on peaty soils	4+	205.0	17.1	23
S4	Dry to moderately moist arable land on peaty soils	2+, 2-	1.98	40.9	41
S5	Moist arable land on peaty soils	3+	-3.86	20	20
S6	Grassland (3+/2+) flooded in summer (wet year)	(5+), 5+/4+, (4+)	802.5	1.73	24
S7	Cropland (2+) flooded in summer (wet year)	3+	278.0	8.54	16.5
S8	“Rewetted” grassland dry in summer, wet in winter	4~	542.8	19.2	34.5
S9	Simulated harvest (Paludiculture Phragmites/Typha)	(5+), 5+/4+	386.2	7.82	18.5
S10	Wet tall reeds (dry year)	(5+/4+), 4~, 4+, (3~)	24.8	2.77	3.5
S11	Wet aberrant bog sites	5+, 5+/4+	1125.1	3.80	35
S12	Very wet reeds with lateral import of organic matter	6+, 6+/5+, (5~, 5+)	1509.6	1.87	44

S13	Ditches	6+	873.1	26.4	51
	Forests				
Fo1	Dry Forests and Shrubberies	2	0	26	26
Fo2	Moderately Moist Forests and Shrubberies	2+	-0.3	25.2	25.2
Fo3	Moist Forests and Shrubberies	3+	9.63	12.3	12.5
Fo4	Very Moist Forests and Shrubberies	4+	32.8	2.99	4
Fme1	Dry Forests and Shrubberies	2-	0	43.4	43.4
Fme2	Moderately Moist Forests and Shrubberies	2+	-0.28	25.2	25
Fme3	Moist Forests and Shrubberies	3+	-0.08	19.6	19.5
Fme4	Very Moist Forests and Shrubberies	4+	42.9	14.4	16
Fme5	Wet Forests and Shrubberies	5+	179.3	-1.92	3

Table 5.1: GEST table used to estimate the carbon emissions (or storage) of the pilot sites. This table is based on the latest updated list from COUWENBERG et al. (2022) (in prep.) and indicates the GESTs with the related soil moisture classes and summarized emission factors for methane, carbon dioxide and the total global warming potential.

Nature reserve	**Peat Surface (ha)**	**CH_4 (tCO_2eq/y)**	**CO_2 (tCO_2/y)**	**GWP ($tCO_2eq/ha/y$)**	**Total GWP (tCO_2eq/y)**
Belgium: Valley of the Grote Beek	121.8	303	1425	14.4	1755
Germany: Häsener Luch	62.6	4	1208	20.6	1290
Ireland: Connemara	245.6	135	1641	7.5	1848
Poland: Orawa	199.7	200	1599	9	1799
The Netherlands: Witte Veen	22.7	61	130	8.4	191
Total	**652.4**	**703**	**6003**	**59.9**	**6883**

Table 5.2: Global Warming Potential estimates of the pilot sites.

Belgium: Valley of the Grote Beek

Greenhouse gasses were estimated with the GEST method within the selected parts of the valley for restoration. This selection is based on the presence of peat in the soil and on the ownership of the grounds. Only parts where larger parts are owned by Natuurpunt can be restored. Only ground with a peat soil are considered in the GEST analysis. As a result, we found that for a peatland area of 122 hectares, about 2640 tons CO_2eq. are emitted per year.

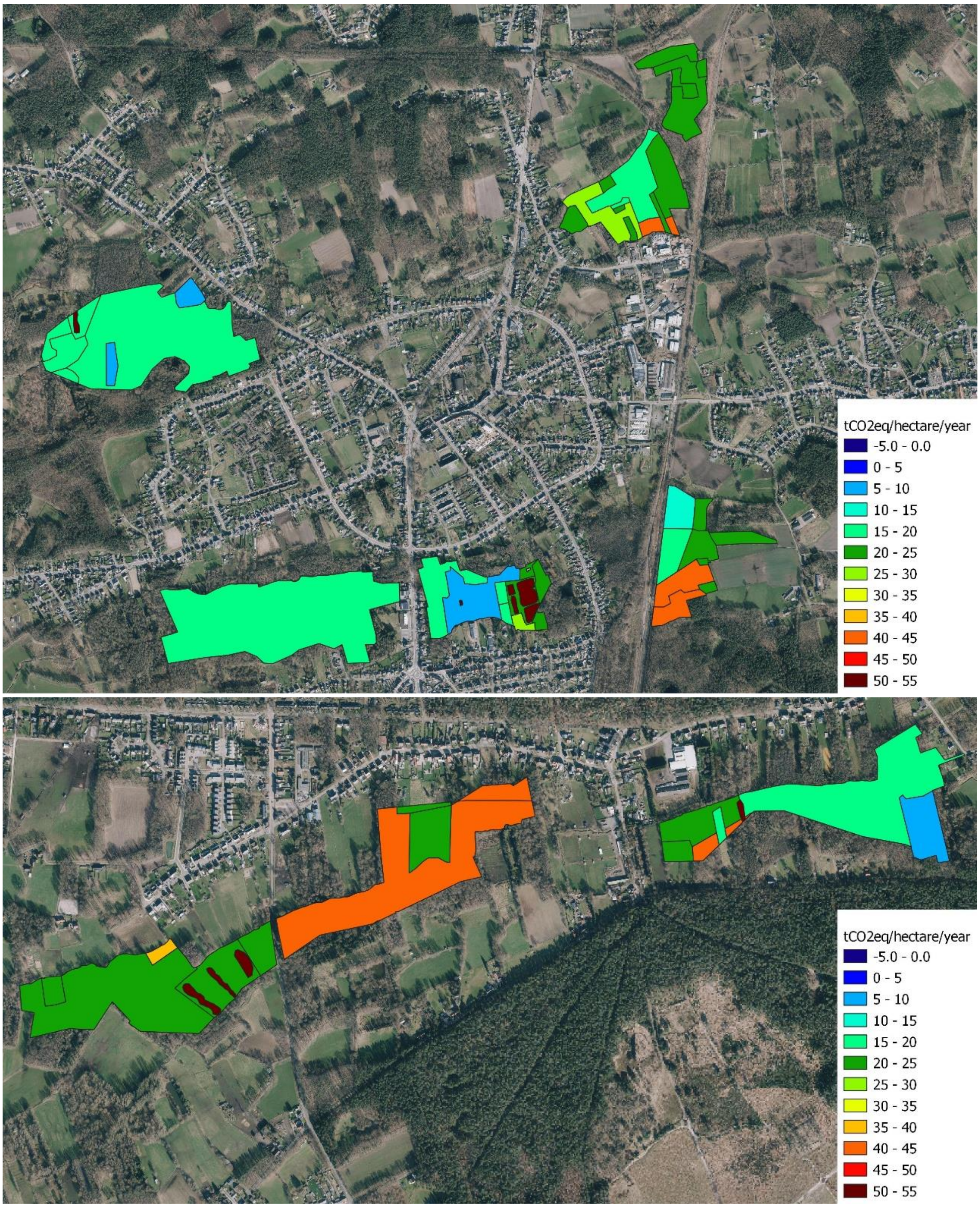


Figure 5.1: GEST Global warming potential in the Valley of the Grote Beek. Above: western part of the valley, Below: eastern part of the valley. The valley mainly consists of alder swamp forest.

Germany: Häsener Luch

The current greenhouse gas emissions were estimated by the GEST approach. Based on the areas of the sites covered with organic soils, which amounts to 62 ha we estimated the total global warming potential of 1290.45 t CO_2eq. per year. The highest emissions originate from the ditches, which also amounts to around 3 ha. Results are summarised in the table below.

Figure 5.2.1: Summarised Map of GESTs in the Project area

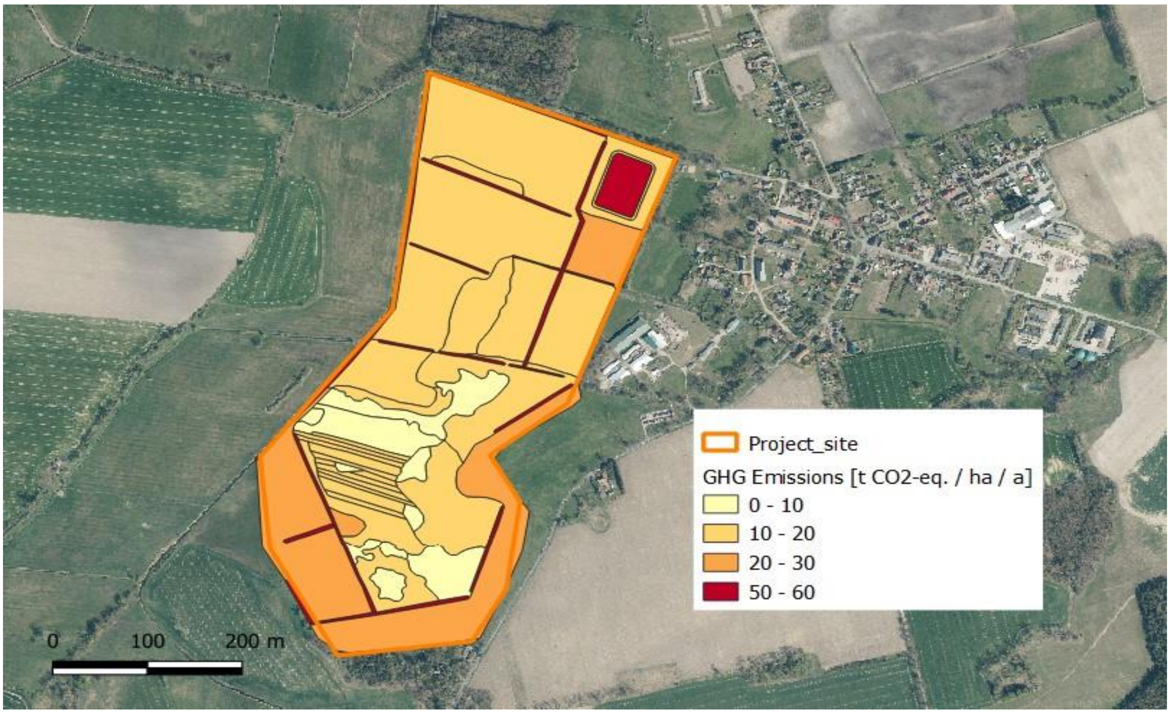


Figure 5.2.2: Global Warming Potential of the Häsener Luch Site

Ireland: Connemara

Greenhouse gasses were estimated with the GEST methodology. Surveyed habitats were correlated with the GEST equivalent. The estimation is based on areas of the site which are underlain by peat soils, which amounts to 245.6ha. Results are summarised in the table below.

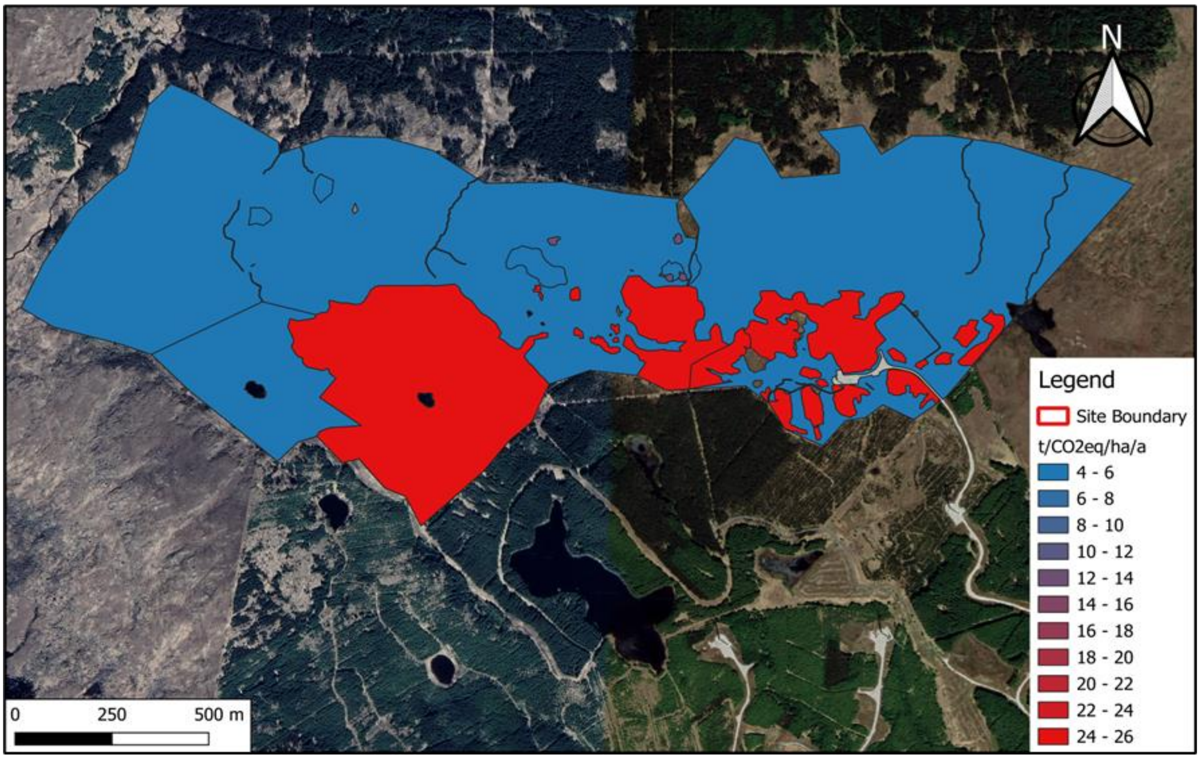


Figure 5.3.1: GEST GWP of Doire Fhada, the northern site within the project area

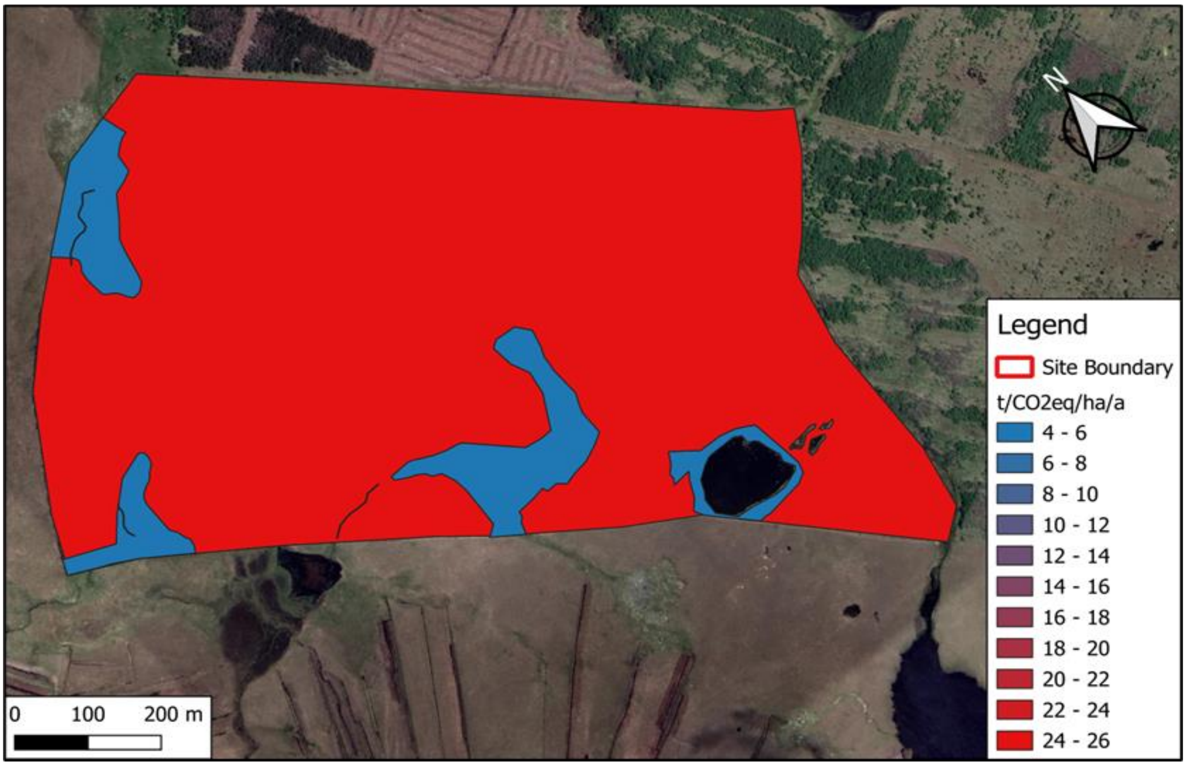


Figure 5.3.2: GEST GWP of Fionnán, the southern site within the project area

Poland: Orawa

The GEST map was prepared by transformation of the vegetation map. U2,. U10, U13 and Fo3 GEST units were mapped.

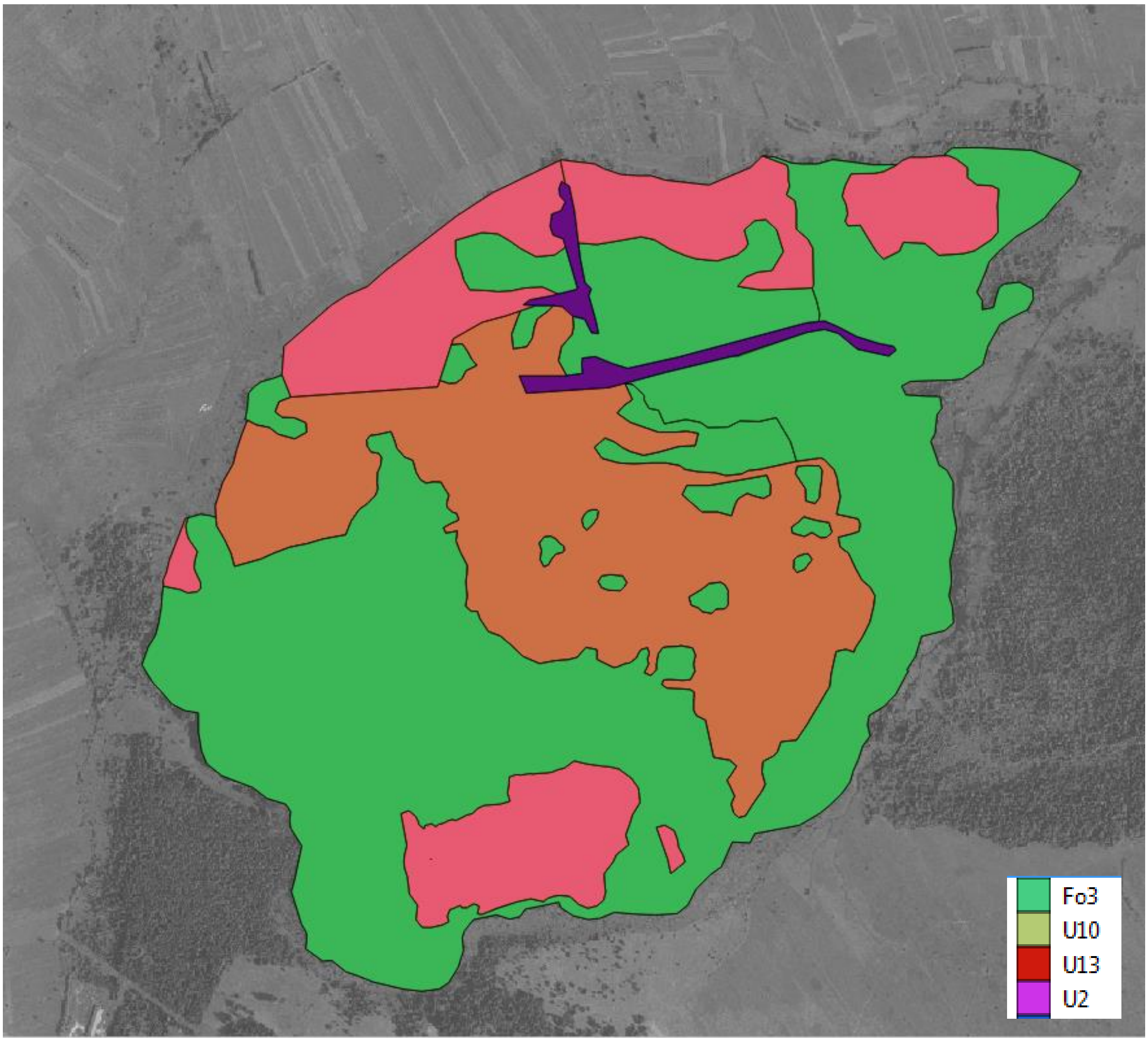


Figure 5.4.1: Summarised Map of GESTs in the Project area

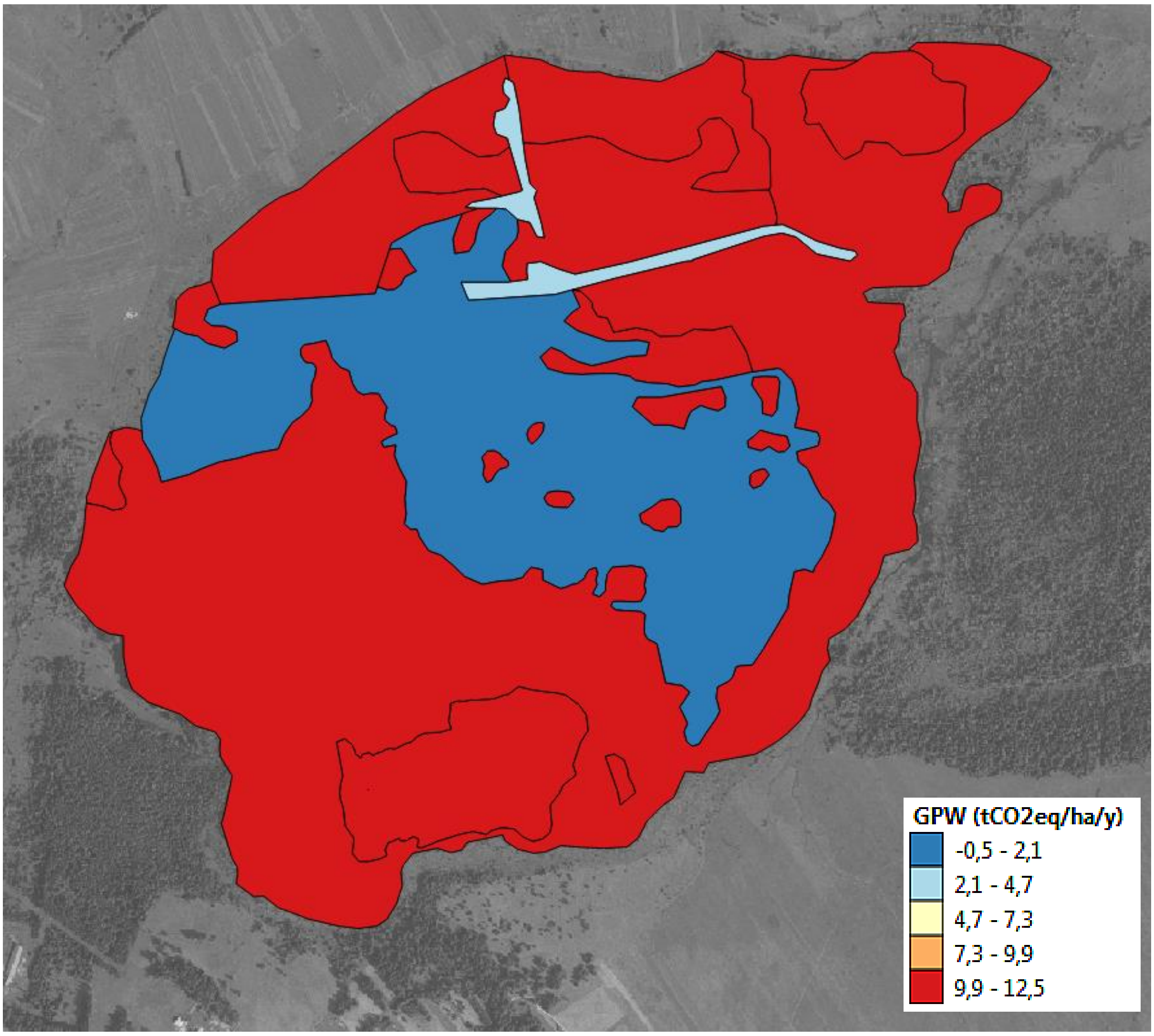


Figure 5.4.2: Global Warming Potential of the Orawa site

The Netherlands: Witte Veen

Based on the vegetation map the GWP was calculated for the peat bog with the GEST method (see figure 5.5). The translation from the Dutch vegetation classification to the GEST types (and taking the water table classes into account) is not yet fully established at this moment. Thus, the calculated GWP should be regarded as a first estimate which might be improved at a later stage.

The average GWP is ~8.4 ton CO_2eq/ha/year. In total the annual GHG emission is ~191 ton CO_2eq/year.

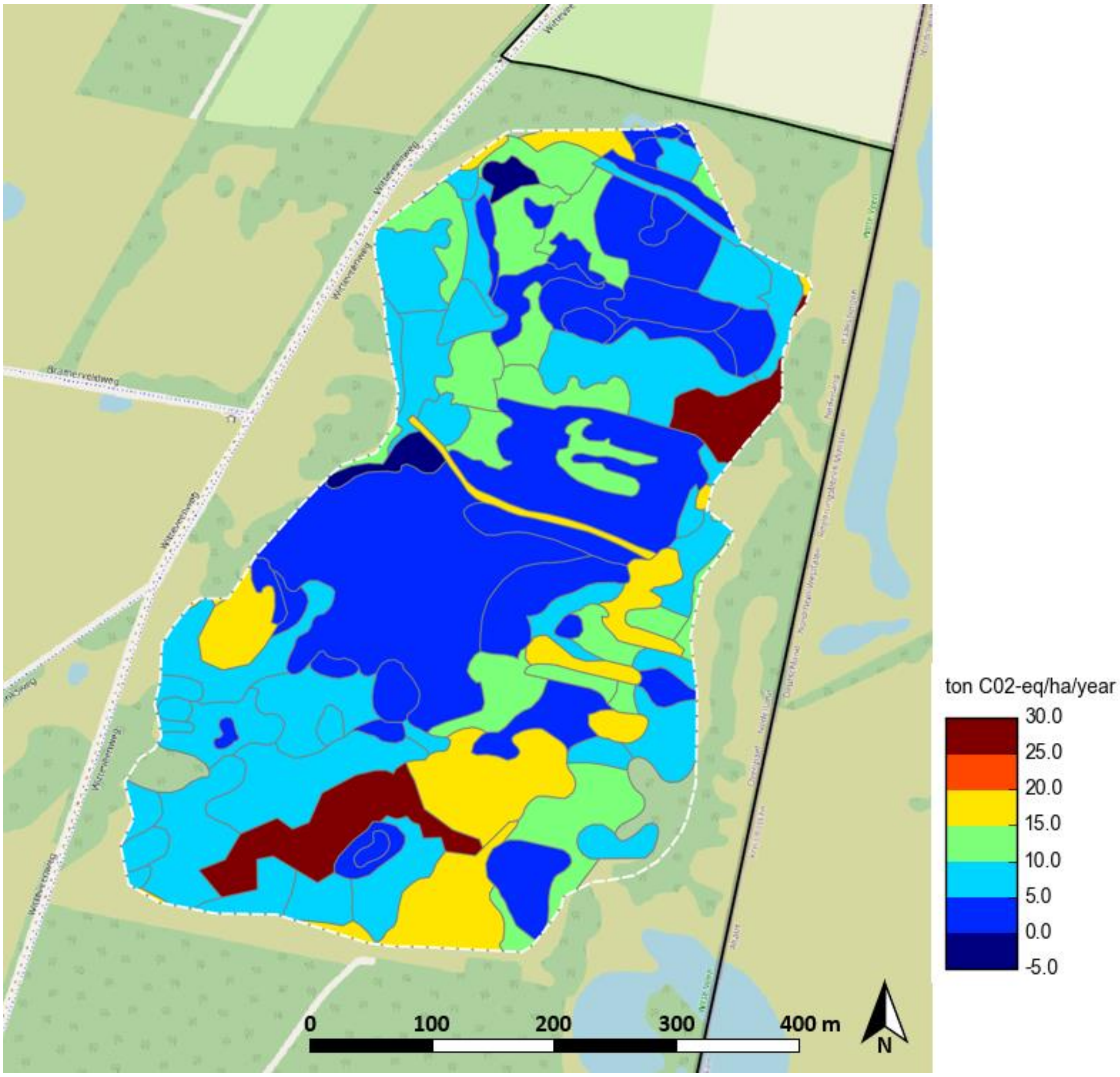


Figure 5.5: GWP of the peat bog in Witte Veen based on GEST.

Carbon stocks

Below-ground carbon stock

The calculation of the below-ground carbon stocks refers only to the peat layer and not to the mineral ground layer or any other mineral top layer. In general we used the following equation:

$$C_t = \left(\sum_{i=1}^{n} Corg_i * BD_i * PD_i\right) * Area$$

whereas:

Ct = total soil organic carbon stock in tons per hectare
i = number of the individually peat soil horizon
Corg = soil organic carbon content in %
BD = bulk density in t/m³
PD = depth of the peat horizon in m
Area = area of the selected peat depth class

For calculation of the total soil organic carbon stock we differentiated between the more degraded and higher decomposed top soil horizon and the lower decomposed peat subsoil. For that we used mean values of carbon content and bulk density of given peat substrates (Table 6) and multiplied it with the depth of the peat horizon and summed up all parts of the given soil profile. Finally, we multiplied this stock by the area of the peat soil depth class.

Peat Type	**Carbon Content [%]**	**Bulk density [t/m³]**
amorphous peat highly decomposed	34.8	0.32
cotton grass peat	48.9	0.12
moss peat	46.7	0.11
alder wood peat	40.4	0.21
reed peat	41.3	0.16
sedges peat	41.9	0.15

Table 6: Common Values of organic carbon content and bulk density for most important peat substrates based on over 10.000 soil profiles in the Peatland archives of the Humboldt-Universität zu Berlin

Belgium: Valley of the Grote Beek

The below ground carbon stocks in Belgium were measured using a soil corer and an iron stick. The whole valley was mapped by measuring the peat depth in rows perpendicular to the valley. The point measurements were linked to each other and extrapolated using QGIS. As a result, we now have a peat map of the valley of the Grote Beek in depth classes per 50cm. The points measurements have a 10 cm resolution. The valley consisted almost largely out of Alder peat. Literature study shows that alder peat has a bulk density of about 0.21 t/m^3 and the carbon content estimated as 40.4% of the total organic matter. In the Valley of the Grote Beek we estimated to have 1.07 million m^3 of peat, or recalculated with the numbers mentioned before this gives us 90682 t carbon stored in the peat soil, this is equal to 332500 t CO_2eq. This is still only a rough estimation of the carbon content, since the peat type has a big influence on these estimates. Peat types will be assessed this year and the below-ground carbon stocks will be updated according to these more accurate parameters. The fine-tuned results will be reported in the next monitoring report (October 2023).

Figure 6.1.1: result of the peat mapping in the Valley of the Grote Beek

Figure 6.1.2: Peat mapping. Left to right: taking a peat core with our internee, intact alder wood in the peat soil, peat core in permanently wet conditions with glauconite sand, earthified peat core with less clear transition to oxidized sand.

Germany: Häsener Luch

The peat depth of the Häsener Luch based in general on the peatland soil map of Germany referred to the situation in 2013 (LBGR 2022). For updating and improving the given map we repeated the soil mapping at some points by additional drillings. We could also use the archive of the Humboldt-Universität zu Berlin, where we found more than 60 old soil profiles for the project site recorded in 1969 at a distance of 100 x 100 m. These old profiles give us a good search grid for our reference drillings. In total we could record 21 soil profiles mostly close to the historical drillings.

The peat depth varied from 0.00 m to 2.50 m with an average depth of 0.78 m. The depth of the degraded topsoil of the peatland was in the range of 10 to 35 cm. The peat depths were classified into 4 groups and mapped.

For calculation of the soil carbon stock of our project sites, we differentiated between the degraded topsoil with an average soil carbon content of 34.8 % and a bulk density of 0.32 g/cm³ (see table 6). The subsoil was characterized almost by moderately decomposed reed peat with some alder wood. For carbon stock calculation we used the average values for reed peat.

The estimated carbon stock amounts in total 42271.46 tonnes of carbon, which corresponds to 155136.24 tonnes of carbon dioxide stored in the peatland soils in the Häsener Luch.

Ireland: Connemara

Peat depth was measured throughout both sites, using a peat probe at 100m intervals along transects spaced at 100m intervals. Depths have been mapped below for both sites (see figures 6.3.1 and 6.3.2 below). Peat depth varied from 0.00m to 7.02m, with an average depth of 1.05m. The total volume of peat on both sites amounts to 2617185m³ – or 1438031m³ at Doire Fhada and 1179154m³ at Fionnán. At the time of writing, bulk density has not been measured onsite. However, an estimate of carbon stock has been based on values taken from Koehler et al (2011) – a study on from a similar Atlantic blanket bog. With a bulk density of 0.045t/m³, soil organic carbon at 50% and organic matter at 96%, the estimated carbon stock is at 31061.46 tonnes of carbon. Site specific data will be calculated this summer and more accurate figures will be reported in the next monitoring report.

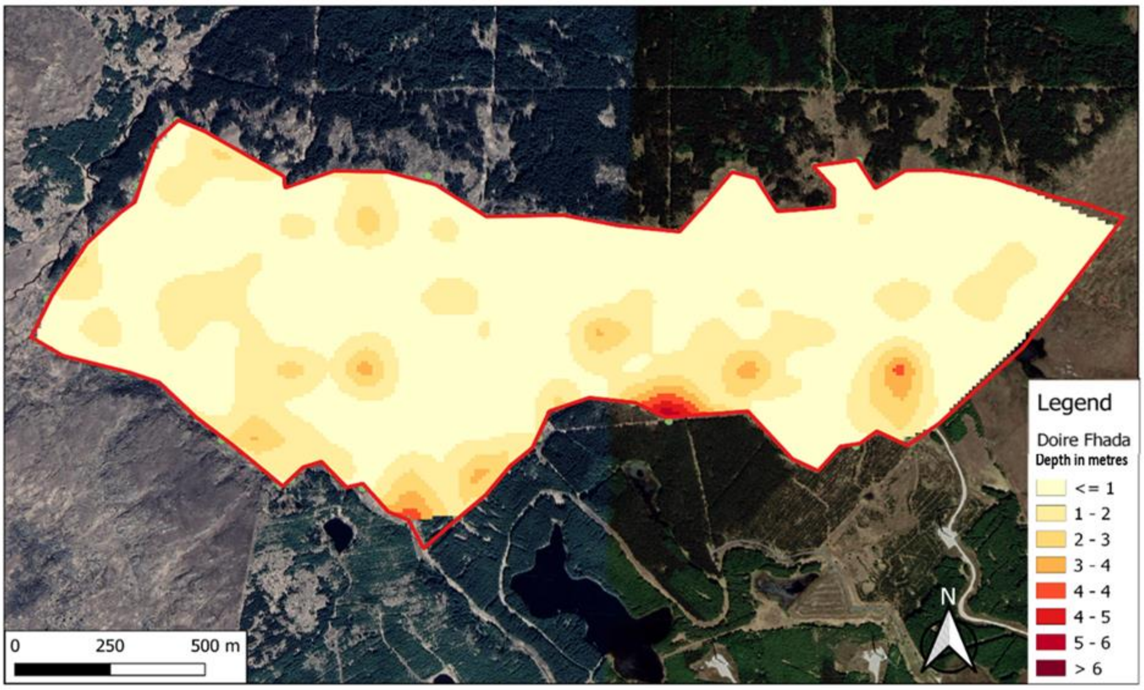


Figure 6.3.1: Peat depths at Doire Fhada, Connemara, Co. Galway

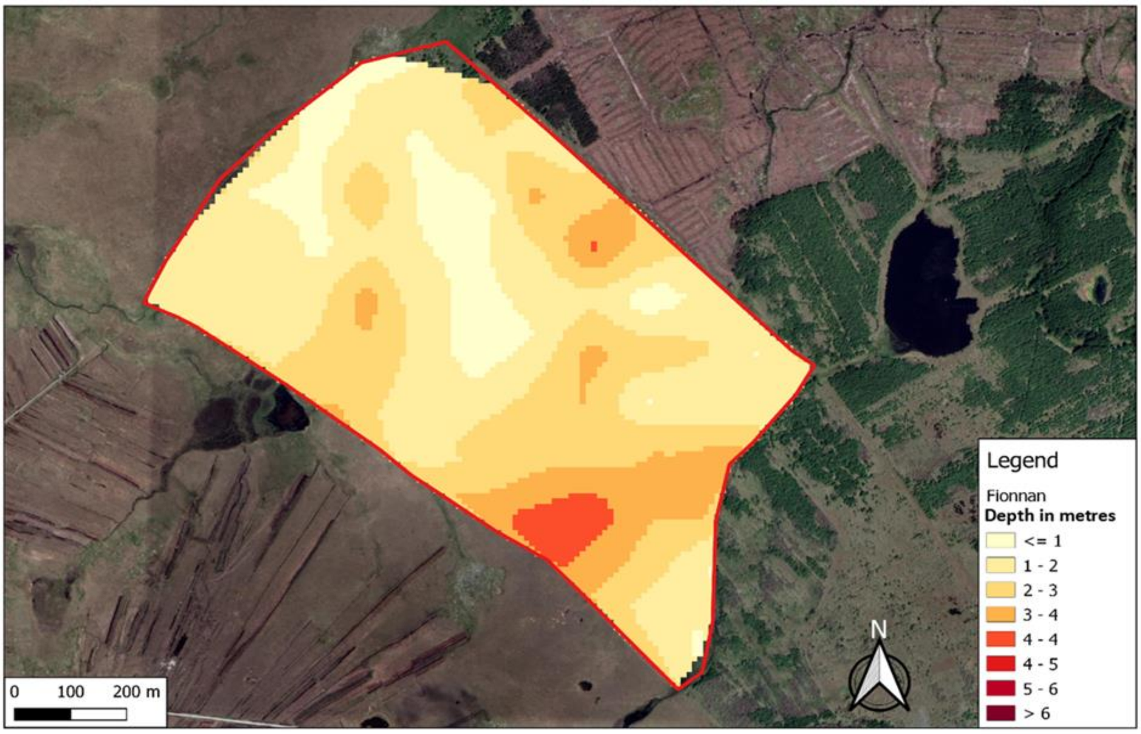


Figure 6.3.2: Peat depths at Fionnán, Connemara, Co. Galway

Poland: Orawa

The peat deposit is thick (ca 5.5m average) and the thickness was not yet mapped precisely. The stratigraphy of the peat deposit is shown in the previous chapter. The volume of the peat is roughly estimated, on the basis of average thickness in sampling points, as 10.945 million m^3, with domination of cotton-grass peat. It is the equivalent of 644 500 tons of carbon.

The Netherlands: Witte Veen

Peat formation is assumed to have started around … in open water in which a gyttja layer formed. A terrestrialisation process started and after the first peat layers were formed the area was overgrown by forest. Most likely the peatland was in that phase not yet fully ombrotrophic. Reed is found in the lower peat layers. Eventually peat mosses became dominant. Nowadays, after human exploitation and drainage of the peat bog, the peat is partly degraded and decomposed.

The peat is not yet sampled and classified in detail. From a few corings we expect that the present peat body is mainly a mixture of alder wood peat, reed peat, moss peat and (highly) decomposed peat.

The peat thickness is measured on transects across the peat bog with an iron stick. The peat thickness on the point locations was linearly interpolated to obtain a spatial coverage of the peat thickness. The resulting map (see figure 6.5) is considered the best estimate of the peat depth we have at the moment and suitable enough for overall estimation of peat and carbon stocks.

The peat thickness varies from 10 to 90 cm (maximum of 96 cm), with an average of 32 cm. Although the peat thickness is quite limited in a part of the area it is relevant for GHG fluxes and peat bog development and enhancement.

The total volume of peat is approximately 69500 m^3. The bulk density has not yet been measured in the Witte Veen (that will be done in a later stage in conjunction with the GHG measurements). However, from the literature values in table 6 and the expected composition of the peat we could roughly estimate the carbon stock. With a mean bulk density of 0.20 ton/m^3, an organic matter content of 90.7% (Loisel *et al.*, 2014) and a carbon content of 40.8% the estimated carbon stock in peat is 5144 ton C (=18865 ton CO_2eq).

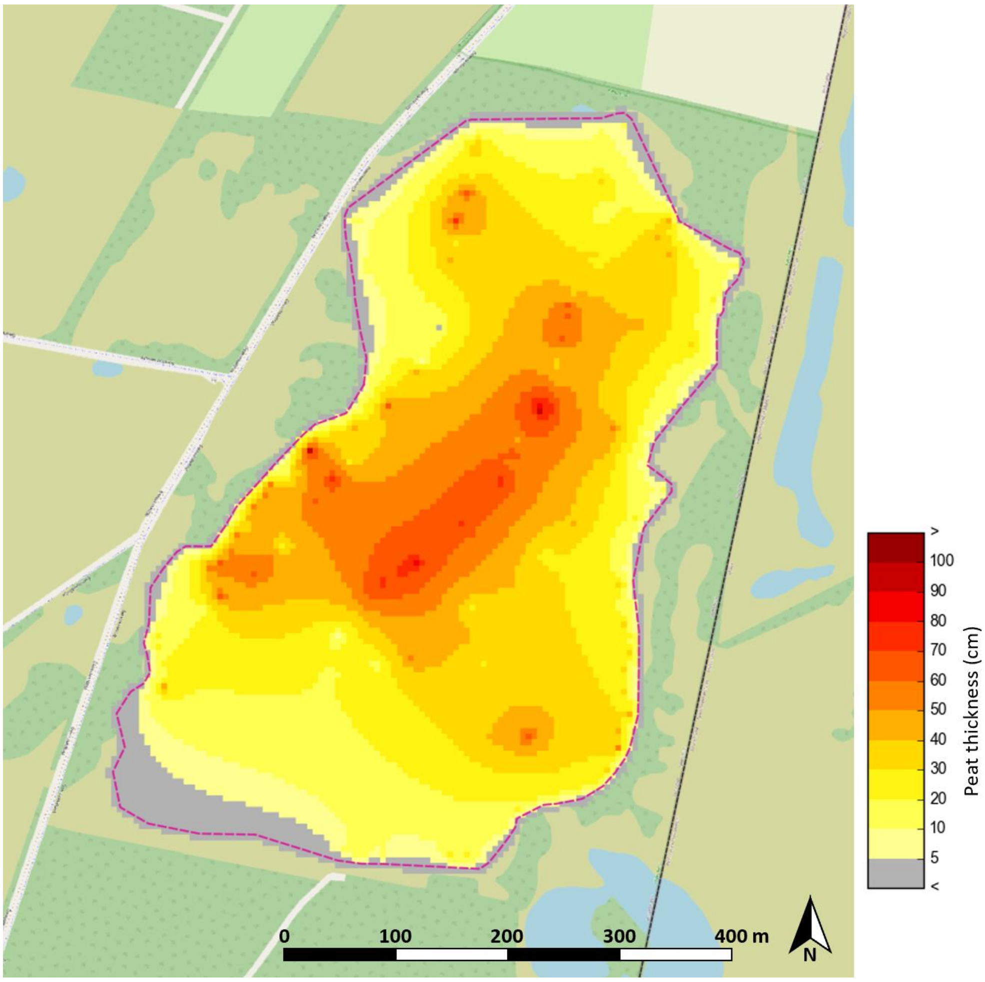


Figure 6.5: Estimated peat thickness in the Witte Veen.

Above-ground carbon stocks

Carbon is stored above ground for a semi-long period within trees. About half of the dry mass is carbon. This above-ground carbon can be an important part of the carbon stored within the nature reserve. And nature restoration might have a short, but big impact on this when these trees are removed for peatland restoration. It is thus important to take this tree-carbon into account. In order to do this, representative plots of 10 by 10 meters were sampled. Within these plots all trees were measured. with 3 parameters (tree height, tree stem circumference at breast height and tree species), the amount of carbon was calculated. This calculation is based on the formula used in the LIFE peat restore project. First the stem volume is calculated from the circumference and height as if it would be a cylinder. These stem volumes are summed for the whole plot per tree species and multiplied by 100 to have estimations per hectare. For each tree species, wood densities were found in literature as a biomass expansion factor and a root/shoot ratio. These ratios were multiplied by the volume/ha of that species Giving the dry mass of the tree species per hectare. Knowing that half of this dry biomass is carbon, dividing by 2 gives us the actual above-ground carbon. In the end a simple sum of all species gives us the above-ground carbon stock per hectare.

Belgium: Valley of the Grote Beek

The above-ground carbon stock will be estimated within 30 plots spread throughout the valley. To make these plots, the valley was divided into parts with a similar vegetation type. Then depending on the size of these parts, a number of representative plots are chosen randomly by computer software. Only parts of the valley where trees or shrubs are present are considered. Within these plots everything will be measured with the aid of an internee. Tree height will be estimated using a handheld laser device using triangulation to calculate heights. The results of this above ground carbon mapping will be discussed in the next monitoring report (October 2023)

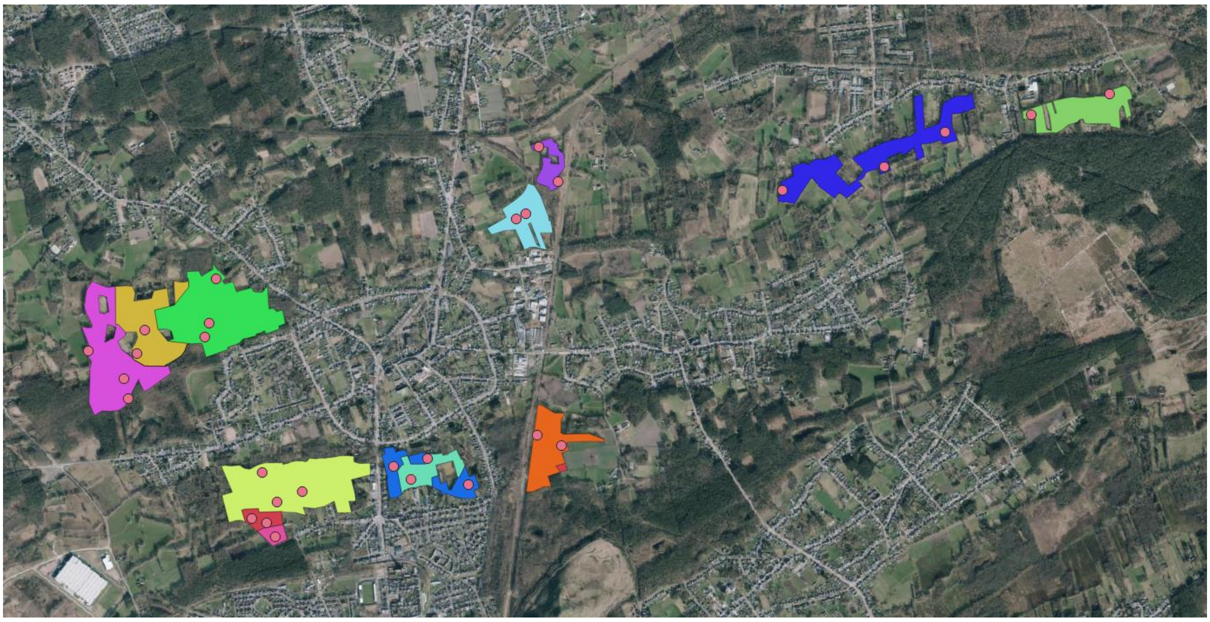


Figure 7.1: Parts of the valley with similar vegetation types and the randomly selected plots within each vegetation area.

Germany: Häsener Luch

The central part of the project site is covered mostly by alder, ashes and birches. To estimate the above ground carbon stock of these forests we measured the DBH, height and stand density within a 10 x 10 m plot in a 200 x 200 m raster. Due to higher ground water level and partly inaccessibility of some stands we must postpone our samplings and will present the calculations in the next monitoring report (October 2023).

Ireland: Connemara

A significant portion of the sites in Connemara consist of conifer plantation on peatlands.

Plantations consist almost entirely of Sitka spruce with occasional lodgepole pine. 10x10m plots were sampled within the sites. Plots of different densities were chosen for sampling, and results were upscaled based on aerial imagery and ground surveys.

Within each plot DBH, height and stand density were measured. Stem volume was then calculated as if it were a cylinder. Wood density per species was taken from relevant Irish literature (Green et al., 2017). Wood density was multiplied by volume/hectare of the stand of which 50% is carbon.

The total estimate of above ground carbon stock for the forestry plantations within the site is therefore: 212873t. These results can be refined after UAV flights later in the year.

Poland: Orawa

The above ground carbon stock was estimated on the basis of tree measurements made on permanent vegetation plots (see above). The total volume of the trees was estimated as 7041 m^3, which is (taking 50% of carbon, 0.75g/cm^3 bulk density) the equivalent of 2640 C tons - the figure is negligible in comparison to below-ground carbon.

In the beginning of 2023, conservation measures of removing trees were implemented by conservation authority, regional Directorate of Environment Protection (outside the scope of LIFE Multi Peat project), thus trees volume must be recalculated in 2023, to provide real Multi Peat project baseline.

The Netherlands: Witte Veen

The above ground carbon stock has not yet been estimated in the Witte Veen. This is done during the restoration works by the sub-contractor. Numbers will come available in the course of the project, expected by the end of 2023.