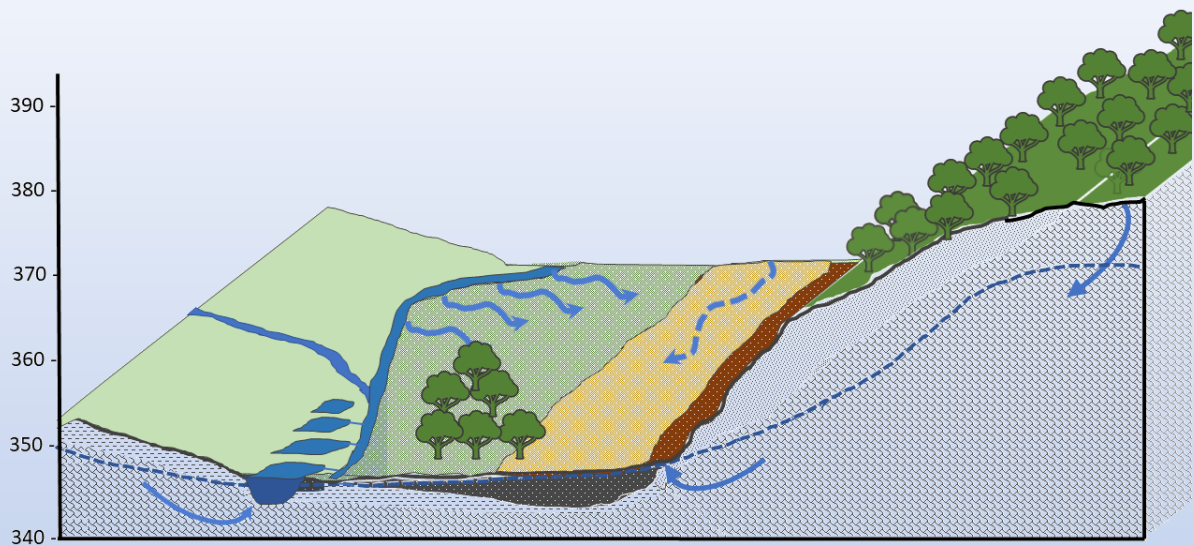




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ECOHYDROLOGICAL ANALYSIS OF MARAIS DE HEINSCH IN THE CONTEXT OF LIFE+ “ANTHROPOFENS” LIFE18 NAT/FR/000906



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**Ecohydrological analysis of Marais de Heinsch in the
context of LIFE+ “Anthropofens”**

LIFE18 NAT/FR/000906

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**University
of Antwerp**

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1 Introduction

Mires and other wetlands provide important ecosystem services. They possess a unique biodiversity of specialised species adapted to this extreme environment and to a certain degree they can store and later release excess water and thus buffer water table fluctuations. Mires provide an additional important service in that they sequester and store huge quantities of carbon in the soil, thus mitigating Greenhouse gas emissions. Peatlands are the most effective storage systems of terrestrial carbon that exist on earth. Yet, peatlands are threatened all over the world and in western Europe especially. Peatlands and especially groundwater-fed fens are therefore highly valued and some of them are even priority habitats in the European Habitat directive. The Walloon Nature Conservation Organization *Natagora* manages important groundwater-fed peatlands in the Gaume region in southern Belgium in the valley of the river Semois. The region is internationally important especially because of the occurrence of smaller and larger surfaces of the Habitattypes 7140 ('Transition mires and quaking bogs') en 7230 ('Alkaline fens'). At the regional level of Wallonia they are also important because they contain significant surfaces of Reed beds ('Phragmition'), large sedge marshes ('Magnocarion') and wet meadows ('Calthion'). One of the peatlands in the upper Semois catchment is the *Marais de Heinsch*.

Marais de Heinsch has been recognized as a natural reserve since 1971 and is one of 17 'NATURA 2000' zones located partially or totally on top of the RWM092 groundwater body. It has a surface of 67,75 ha, most of which consists of reed beds, greater tussock sedge vegetation, willow forest, alkaline or acidic peatlands, and moor birch forests. The site is situated in the municipalities of Arlon and Attert. The valley has a triangular form, that widens at the confluence of the Semois and the two tributaries: the Kripsbach and the Bierbach.

Although the overall vegetation zonation corresponds well to the typical zonation of natural and semi-natural brook valleys (Grootjans 1980; Grootjans et al. 2006) and seems to have hardly changed since 1977 (Van Rossum et al. 2012), the characteristic and rare species of H7140 and H7230 in particular are highly threatened. Many have regionally disappeared and are also internationally highly endangered (<http://biodiversite.wallonie.be/fr/125-marais-de-heinsch>). The analysis of Van Rossum et al. (2012) shows that despite the management conducted, there is an increase in nitrophilic species. They explain this by increased flooding with nutrient-rich surface water from the streams along the Marais. Moreover, the abandonment of former agricultural activities also resulted in large vegetational changes such as spontaneous afforestation and the disappearance of light-demanding species typical of low productive vegetation.

To counter these negative developments, Natagora decided to participate in the French LIFE+ project Anthropofens (LIFE18 NAT/FR/000906). In Belgian Lorraine this project focusses on the Natura 2000 sites along the Semois which still contain several of the typical species of alkaline fens. The objective is to restore and improve the conservation status of more than 45 ha of habitats of community interest. An important part of the LIFE project consists of hydrological restoration, including the filling of at least 2500 m of drainage ditches, and planting of seedlings of the here rare or disappeared species *Carex davalliana*, *Carex pulicaris*, *Liparis loeselii*, *Schoenus nigricans*, *Thelypteris palustris* and *Juncus subnodulosus*. The aim of the latter action is to establish a minimum population of at least 200-500 individuals, spread over several smaller subpopulations.

The present study concerns an ecohydrological analysis of the Marais de Heinsch at two different levels. It has the following objectives:

1. To analyse the functioning of the system at the regional scale. Without a clear understanding of the functioning of an ecosystem within its landscape context, and the bottlenecks therein, well-founded choices of management and restoration strategies cannot be made. Comparing the present functioning to that under natural conditions enables an assessment of the distance-to-target (DTT). It also helps to identify the effects of changes *outside* the area on the ecosystem functioning *inside* the reserve. Effects of interferences at the regional scale can only be reversed or mitigated by measures outside the reserve. Examples of such measures include changes in land use to decrease nutrient runoff or diminish groundwater abstraction close to a nature reserve in order to strengthen groundwater flow to such area.
2. To analyse the functioning of the system at the local scale. While interferences at the regional scale generally require the cooperation of many different stakeholders and are therefore often very time-consuming, measures *inside* a reserve are often less complicated. Managers of nature reserves can relatively quickly take actions to optimise conditions inside a reserve even when optimisation processes outside the reserve are still under discussion. For instance they can try to optimise water levels by blocking ditches inside the reserve or to sodcut to enhance success of reintroduced seedlings of endangered plant species.

The present study is structured along these lines (Figure 1) and consists of two main tasks:

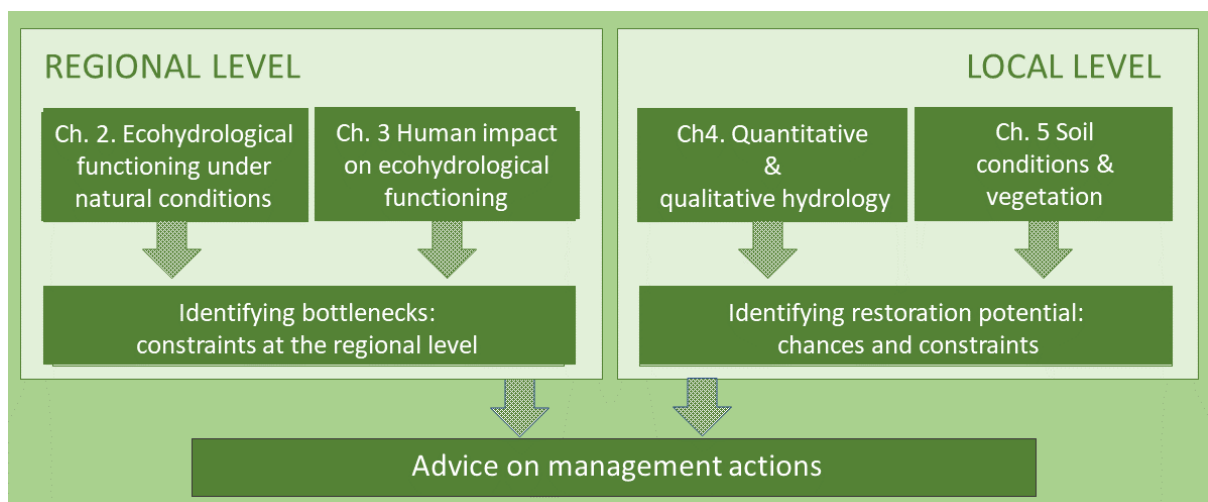


Figure 1. Conceptual framework of the present study

- Task 1 (Chapters 2 and 3) consists of a spatial analysis at regional level focusing on (I) describing the subsoil that steers the hydrological functioning of the system, (II) identification of the groundwater system and the positioning of infiltration and seepage areas, (III) delineation of the catchment of the surface water system, (IV) describing the natural vegetation zonation and (V) analysing changes in the regional functioning by human interferences and assessing which constraints this imposes upon restoration prospects of degraded sites.
- Task 2 (Chapters 4 and 5) consists of a one-time eco-hydrological assessment at local level, aimed especially at assessing the restoration potential for the endangered Habitattypes 7140 ('Transition mires and quaking bogs') and 7230 ('Alkaline fens'). The analysis focusses on (I) local water regime and chemical composition of the water (II) peat soil biogeochemistry and nutrient dynamics, and (III) vegetation dynamics and the indication this yields of (changes in) abiotic site conditions.

2 Regional level: ecohydrological functioning with little human impact

2.1 Geology and soil

The project area is situated in the south of the province of Luxembourg. This is the only Belgian region whose outcropping geological layers date from the Jurassic period. It is part of the Paris basin, which was covered by a vast inland sea. From the Triassic period (-250 million years BP) the sea began to fill in with the deposition of sediments resulting from the erosion of the massifs, resting on the southern edge of the primary Ardennes base. This filling in occurred in several phases with withdrawals from the sea that were followed again by several returns. Consequently, layers of hard strata, like sandstone or limestone, alternate with more loose strata, like clay, marls, shale or sand. Over time, erosion has sculptured a remarkable landscape, with a peculiar relief consisting of several asymmetrical cuestas (Figure 2).

In the Gaume region three separate cuestas can be distinguished, the Sinemurian, Domerian, and the Bajocian cuesta. The project area is situated along the Sinemurian cuesta, along the river Semois. The river is dug into an inclined layer of soft marl, deposited 200 million years ago (Hettangian stage) which was covered between 199 and 190 million years ago by a layer of harder calcareous sandstone (Sinémurien). That layer has been only eroded slightly. The crest of the cuesta can reach altitudes of 400 m above sea level. The depression formed by the Semois and this sandstone ridge forms a steep front, which gently slopes downward to the south. To the North, there is a smaller outcrop of a sandstone layer from the Rhetian, which is underneath the Hettangian layer of marl on which the site itself is situated.

These same layers are visible around Marais de Heinsch (Figure 3), going from Keuperian marl layers and Rhetian sandstone layers in the North to Hettangian marl layers, Sinemurian limestone layers and eventually Virtonian schist layers more to the south. The site itself consists of alluvial deposits and peat on top of a Hettangian marl layer (Marl from Jamoigne). The area West of the Arlon-Wolfrange fault is characterized by Sinemurian deposits, with alternating sandy limestone and marl layers.

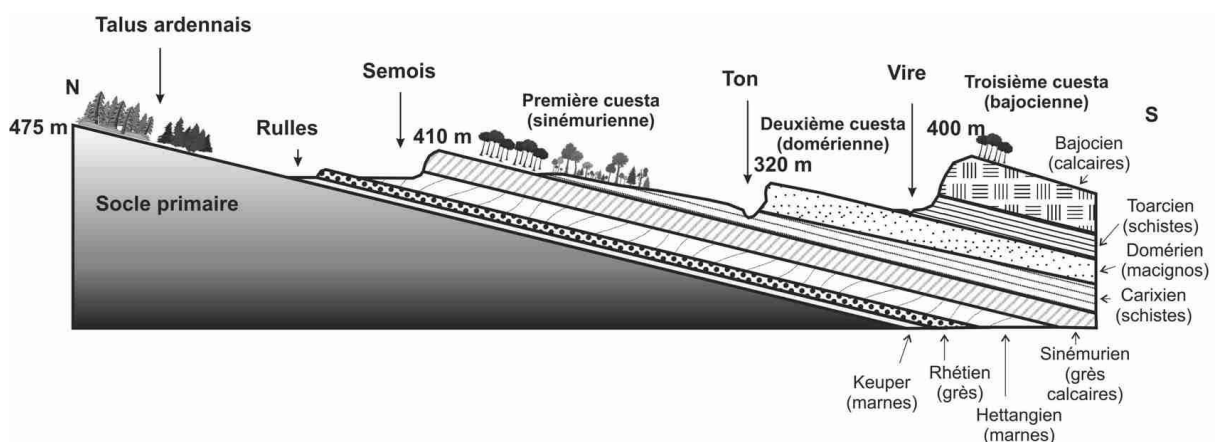


Figure 2. Geological cross section of the different geological strata in the Gaume region. Marais de Heinsch is situated along the Semois directly adjacent the Sinemurian cuesta. <https://cheminsdecampagne.be/s-english.php>

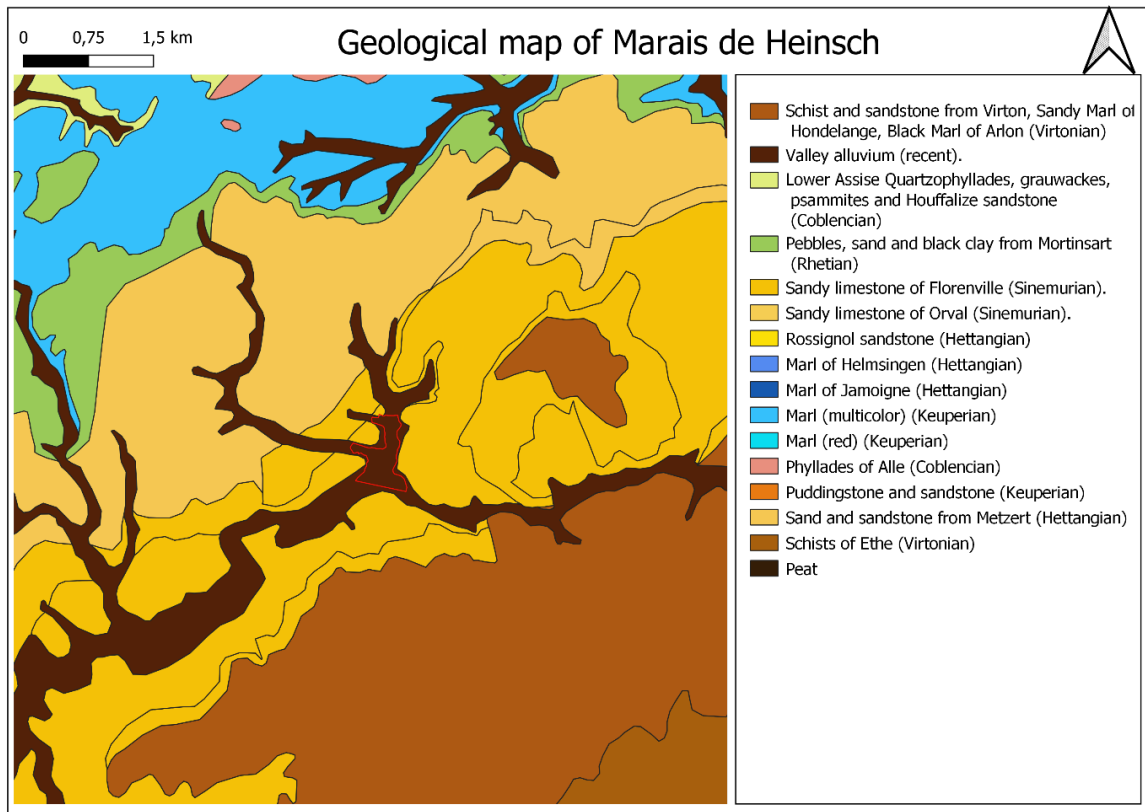


Figure 3. Geological map of Marais de Heinsch, showing the distinct geological layers around the Sinemurian cuesta. The Marl layers from the Hettangian (Marl of Warcq and of Strassen) have been excluded to show the sandy limestone layer of Florenville underneath. © Géoportail Wallonie

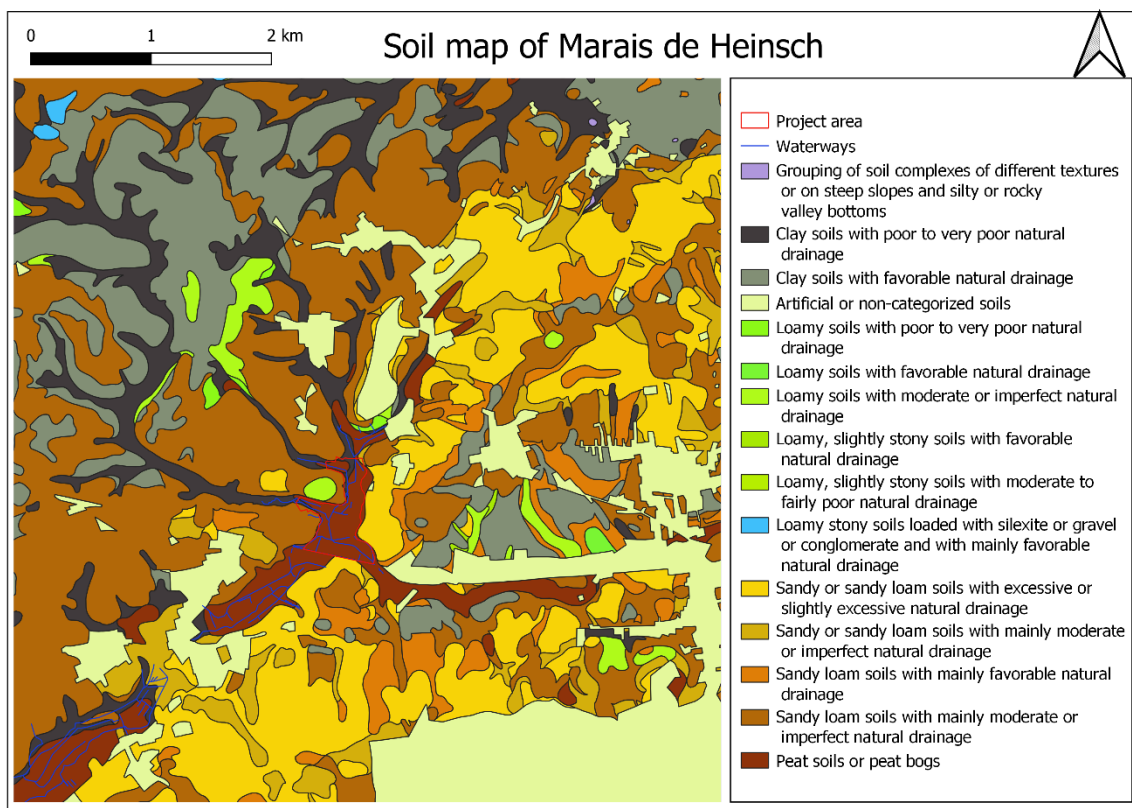


Figure 4. Soil map of Marais de Heinsch, showing the distinct change from sandy soil to more loamy soil in the Sinemurian cuesta, along which marais de Heinsch is situated. Source: Géoportail Wallonie

On either side of the project area, only the sandy limestone layers from Orval and Florenville are present, covering the marl layers from Strassen and Warcq respectively. In the field the steep Sinemurian limestone ridge is visible on the eastern side of the area.

Soils develop on the basis of the prevailing geological strata and the soil map of the region (Figure 4) therefore shows also a distinct change in soil types between the eastern and western side of Marais de Heinsch, with sandy soil on the eastern side of the Marais and a more loamy soil to the western side.

2.2 Groundwater system

2.2.1 Hydrogeology

Marais de Heinsch is situated on top of 2 large aquifers, which overlap to a certain extent, an aquifer from the Upper Trias (Rhetian conglomerates) (RWM091) and an aquifer from the Lower Lias – Sinemurian (Meuse district) (RWM092). The RWM092 water body covers an area of 524 km², of which

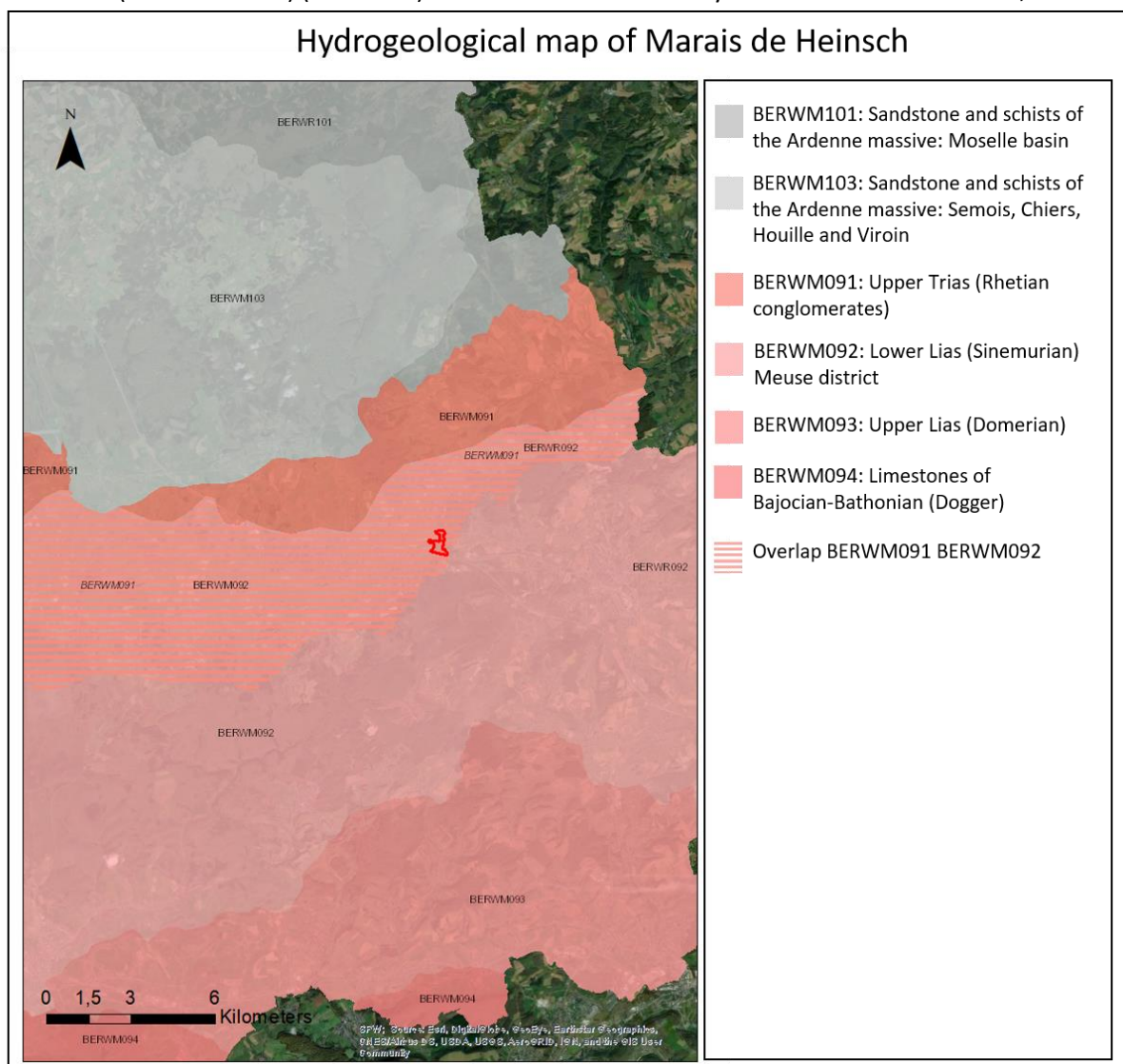


Figure 5. Hydrogeological map of marais de Heinsch, showing the different (overlapping) groundwater bodies on which marais de Heinsch is situated. Source: Géoportail Wallonie

94 km² are superimposed on the RWM091 water body. The RWM092 water body borders with France and is linked to the French groundwater body FRB1G018.

The groundwater body RWM092 belongs to the Sinemurian. It is made up of monoclinals with a shallow South/South-eastern dip (1-5°) and is mainly composed of Liasic deposits (Lower Jurassic – Lower Lias – Sinemurian & Hettangien). The Jamoigne Formation, of Hettangian age mainly consists of marls with interbedded clay limestones and sandstone. This layer is covered by Sinemurian deposits comprising two very distinct contemporary formations on either side of the Arlon-Wolkrange fault, with the sandy and sandstone-limestone facies of the Luxembourg Formation to the west, and the marly facies of the Arlon Formation to the East. In the centre, there is a transition zone with the presence of intercalations. It consists of 3 different layers, from bottom to top: The Strassen layer composed of peaty clay, the Posterie layer made up of calcareous clay, and the Hondelange aquitard, made up of calcareous sandstone, sandstone limestone, and sandy clay. Marais de Heinsch is located on top of the Luxembourg Formation, very close to the transition zone (Figure 5). While the Arlon Formation does not border the Marais de Heinsch directly, the marl layer from Strassen (calcareous clay) does surround the area (Figure 3) and the Marais itself is covered by a peat layer from the Quaternary.

The Luxembourg Formation constitutes the main water resource of the water body. The thickness of the Luxembourg Formation (70-100 m) increases towards the South and towards the West. It is divided into three different aquifers by the presence of marly intercalations of the Formation from Arlon. These aquifers are difficult to distinguish from a lithological perspective, since they are characterized by alternations of limestone sandstone beds, sandy sandstone and yellow to red sands. From top to bottom the layers are: aquifer of Virton, aquifer of Orval and aquifer of Florenville. These aquifers are separated by two aquicludes from Arlon, marl from Posterie and marl from Strassen, which occur between the aquifer of Virton and Orval and between the aquifer of Orval and Florenville respectively (Table 1).

The lateral variation of the different facies and the discontinuous character of these formations make the hydrogeological pattern of the water body quite complex. In addition, the region is characterized by a network of faults oriented mainly NNE-SSW and NE-SW, which can be seen both West and East of the Marais (Figure 7). Some of these faults reach have significant releases, such as the Arlon-Wolkrange fault, oriented approximately N-S, the discharge of which is estimated at about 80 m (Anonymous, 2016)

All of the previously mentioned layers can be seen on the hydrogeological map around Marais de Heinsch (Figure 7). The sandstone layers of Virton and Orval are present to the south and southeast of the Marais, but do not border the site directly. Only the aquifer of Florenville can be seen on either side of the Marais, which is covered by the aquiclude of Arlon (marl from Strassen) to the south/southeast, separating the aquifer of Florenville from the aquifer of Orval. Piezometric data around Bellefontaine show that these two aquifers are independent (Bouezmarni & Debbaut 2006). However, some communication between the two aquifers cannot be excluded, which may take place locally at faults (Bouezmarni & Debbaut 2006). While there are several faults near and around the Marais, only the one southeast of the Marais cuts through the aquifer of Orval. However the direction of groundwater flow at the fault is not towards the Marais so the effect of the connection is presumably small.

Table 1: Table showing the vertical and horizontal distribution of different aquifers. RWM092 outlined in red, RWM091 outlined in blue, and relevant layers for Marais de Heinsch outlined in green. Source: Service public de Wallonie 2016.

							Faille d'Arion-Wotränge	
							W	E
Ere	Système	Série	Etage	Formation	Membre	Abréviation	Hydrogéologie	Hydrogéologie
Quaternaire						AMO	Aquifère des alluvions	Aquifère des alluvions
Mésozoïque	Jurassique	Dogger	Bajocien	Longwy		LWY	Aquifère de Longwy et Mont-Saint-Martin	Aquifère de Longwy et Mont-Saint-Martin
			Aalénien	Mont-Saint-Martin		MSM		
			Toarcién	Grandcourt		GRT	Aquiclude	Aquiclude
		Pliensbachien	Domérien	Aubange		AUB	Aquifère de Aubange et Messancy	Aquifère de Aubange et Messancy
			Messancy		MES			
			Carixien	Ethe		ETH	Aquiclude des schistes d'Ethe	Aquiclude des schistes d'Ethe
			Lias	Sinémurien	Arlon	Hondelange	HON	Aquifère des grès sableux de Virton et des sables de Hondelange
		Luxembourg			Virton	VIT	Aquiclude des marnes de la Posterie	Aquifère de Florenville (Formation de Luxembourg)
		Arlon			Posterie	POS		
		Luxembourg			Orval	ORV	Aquifère des grès sableux d'Orval	Aquiclude des marnes de Jamoigne (localement aquifère)
Arlon	Strassen	STR			Aquiclude des marnes de Strassen			
Luxembourg	Florenville	FLO		Aquifère des grès calcaires de Florenville				
Hettangien	Jamoigne		JAM	Aquiclude des marnes de Jamoigne (localement aquifère)	Aquiclude des marnes de Jamoigne (localement aquifère)			
Trias	Supérieur	Keuper	Rhétien	Mortinsart		MOR	Aquifère des sables de Mortinsart	Aquifère des sables de Mortinsart
			Norien	Attart		ATT	Aquiclude	Aquiclude
			Carnien	Habay		HAB	Aquifère des sables de Habay	Aquifère des sables de Habay

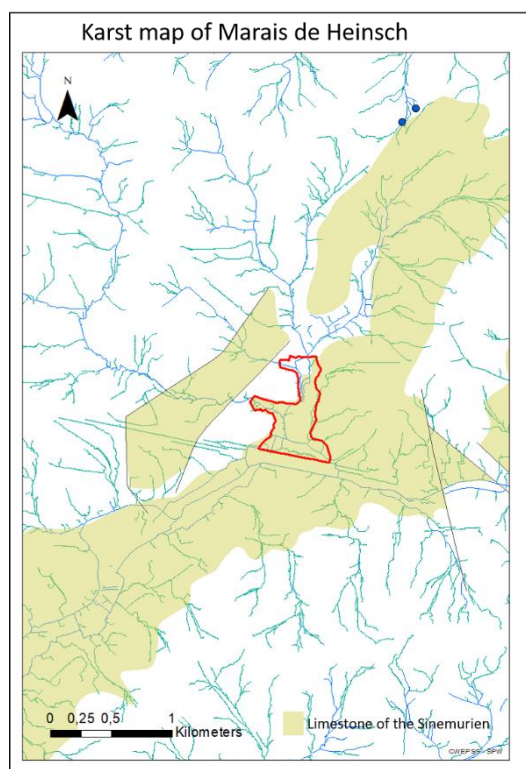


Figure 6. Distribution of Karst phenomena. Source: Géoportail Wallonie

The map with Karst phenomena of the region shows a similar distribution to the sandy limestone of Florenville (Figure 6), suggesting that the Karst most likely originates from the Florenville aquifer. Except for the most north-eastern part, it is present all throughout the Marais. The aquifer of Florenville can therefore be considered the primary aquifer contributing to the Marais. Figure 8 (Petit et al. 2017) shows a simplified hydrogeological cross section of the Semois and its surroundings, which resembles the situation in Marais de Heinsch quite closely. The Florenville aquifer is about fifty meters thick and it constitutes the most important aquifer in all of Belgian Lorraine and the Grand Duchy of Luxembourg. The supply zone of the aquifer of Florenville is located on the reverse side of the Sinemurian. It is mostly a wooded area, largely covered by the forests of Orval and Whiting. At the height of Heinsch, however, the infiltration zone consists mainly of intensively used agricultural fields. It is possible that the Florenville aquifer is also recharged, to the east and west of the map, by drainage from the upper aquifers, given the sedimentary discontinuities of the marl facies of the Arlon formation.

Hydrogeological map of Marais de Heinsch

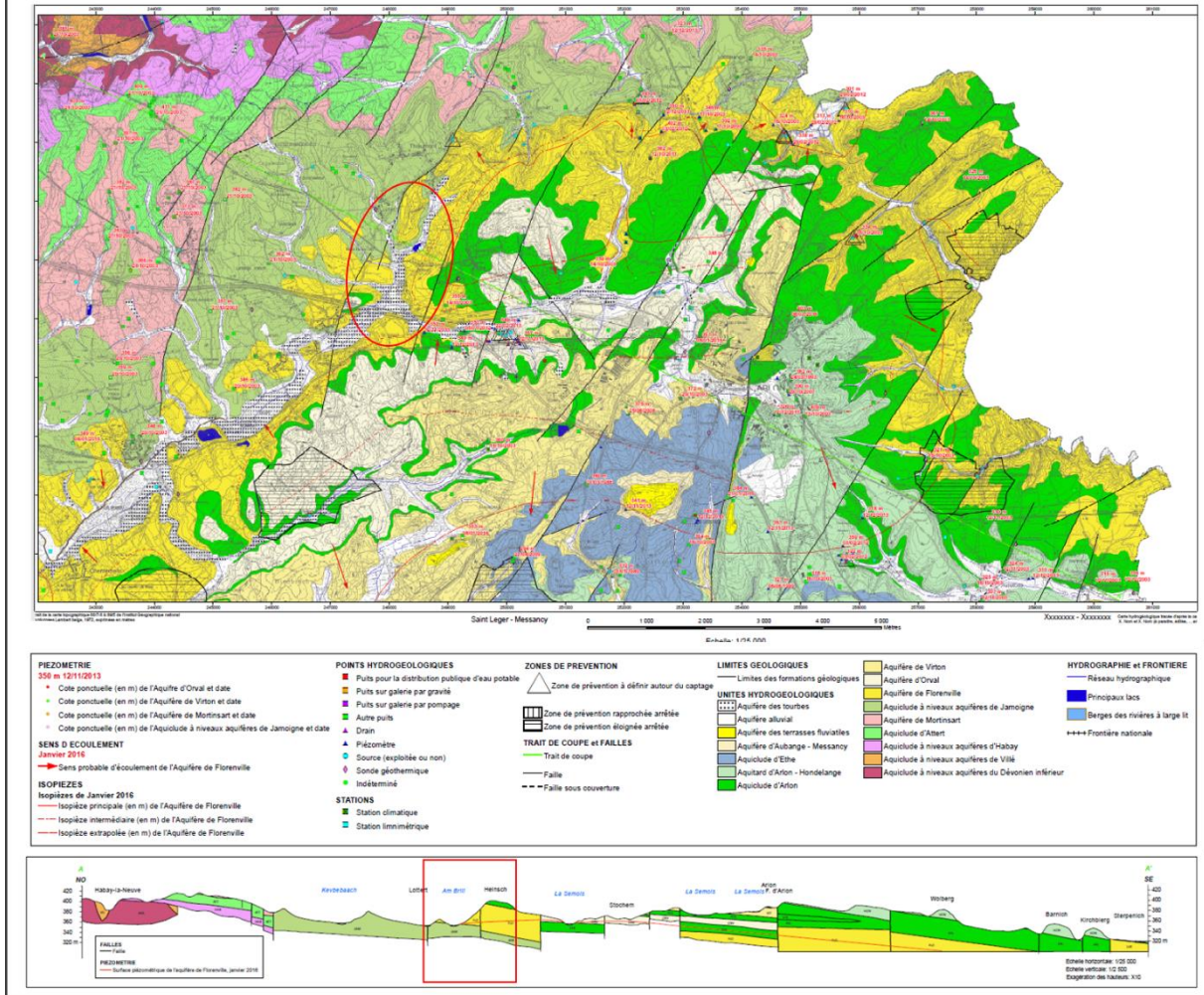


Figure 7. Hydrogeological map of the marais, showing the Florenville aquifer around the alluvial aquifer

On the western side of the Marais the hydrogeological situation is different. The small rivers along the western and southern sides of the Marais run for the largest part on top of the marl of Jamoigne that has a low permeability. Much groundwater supply into the rivers from the western side is therefore unlikely. However, one of these brooks originates on top of the Mortinsart aquifer. In addition, both brooks encounter faults along their course, which might lead to some inflow of water from the Mortinsart aquifer into the brooks. Closer to the Marais the brooks are surrounded by the Florenville aquifer. The surface water in these rivers therefore likely consists mainly of superficial runoff from the marl of Jamoigne, with probably locally some influence of groundwater from both the Mortinsart and the Florenville aquifer.

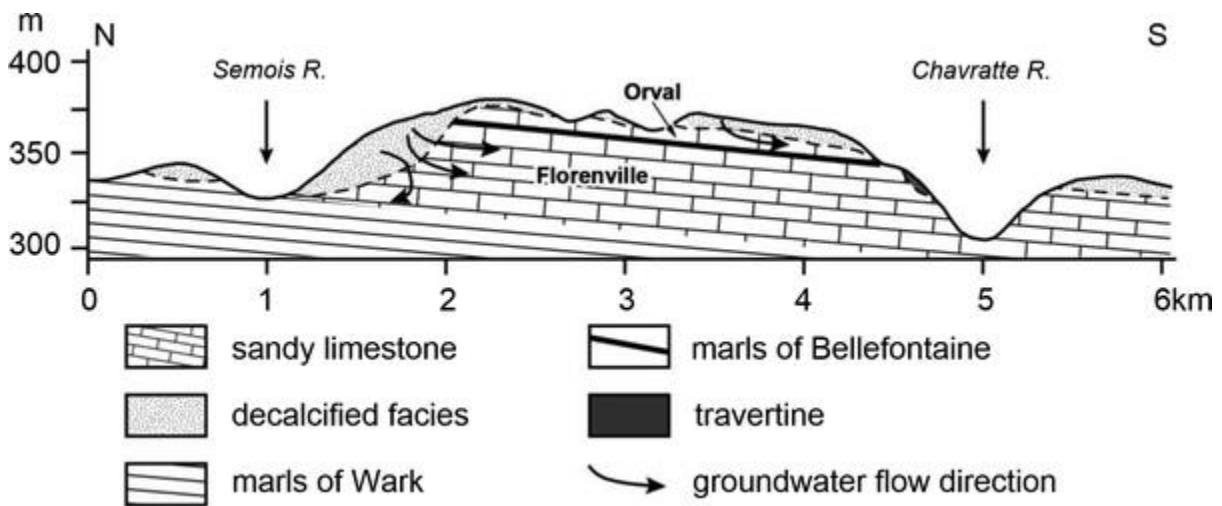


Figure 8. Geological cross section showing the different aquifers and aquitards around the Semois (Petit et al., 2017)

2.2.2 Potential groundwater seepage areas

The PROWATER spatial prioritisation tool (<https://www.interreg2seas.eu/nl/PROWATER>) models the wetness of sites on the basis of the digital elevation model. The analysis reveals areas which are wet

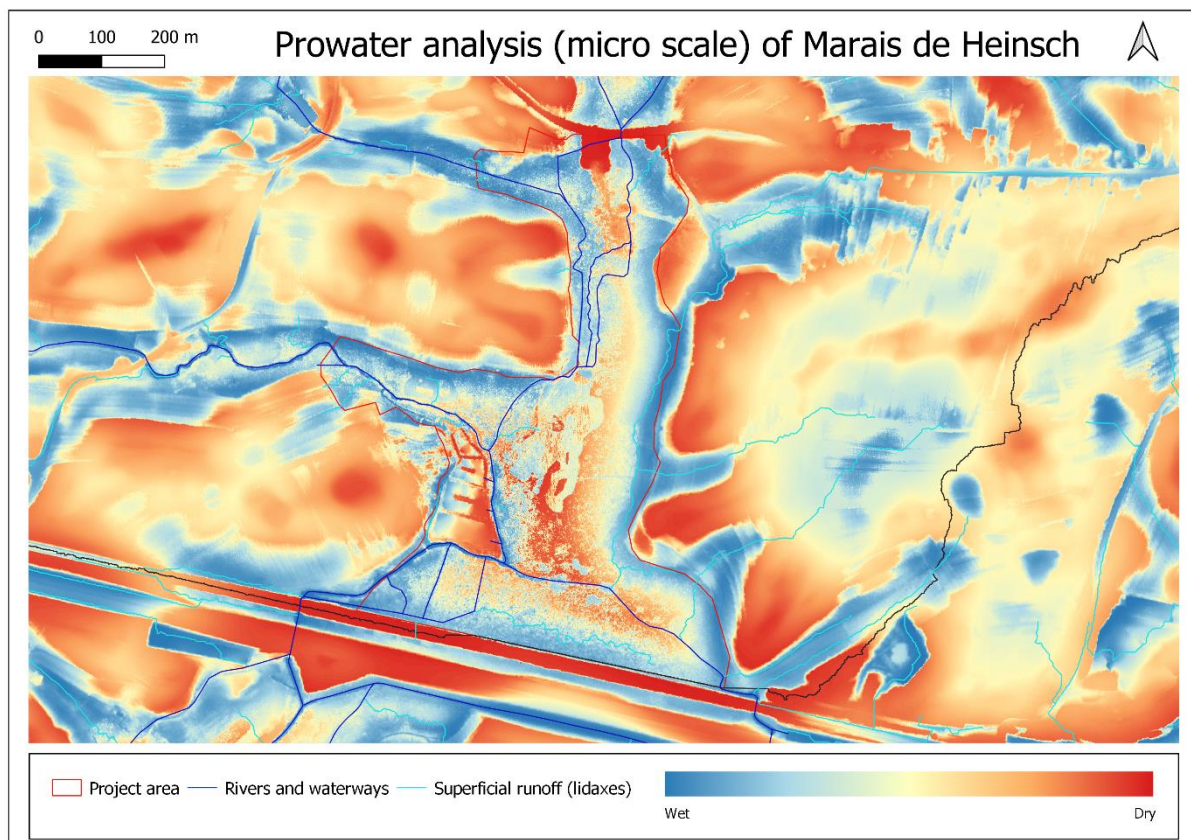


Figure 9. PROWATER analysis on the basis of the digital elevation model. Constantly wet sites are coloured blue, constantly dry sites are red. Sites with intermediate or fluctuating wetness have colours in between.

throughout the year (blue), where upward groundwater movement is likely to occur and dry areas (red) where water movement is predominantly downward. The approach cannot discriminate between groundwater originating from very local origins such as an adjacent field and water from deeper layers and therefore always needs to be combined with hydrogeological knowledge.

The analysis indicates distinct patterns inside and around the Marais (Figure 9). Along the eastern and the western edge of the Marais there are wet zones with a drier ridge in the middle separating them. The *cuesta* is constantly dry and functions as infiltration area. The eastern edge of the Marais at the feet of the *cuesta* is constantly wet, indicating a large supply of water. Undoubtedly part of this water consists of surface runoff from the *cuesta* but the fact that this zone is constantly wet also in dry periods shows this is not the only water source. It is highly likely that this side of the Marais receives upwelling groundwater both from locally infiltrated groundwater in the adjacent part of the *cuesta* and from non-captive aquifers, in this case the aquifer of Florenville. With the existing data it is not possible to determine the relative importance of the different watersources but, given the stability of the water levels and the observation that upwelling groundwater can be witnessed here throughout the year (par. 2.3.2), a considerable inflow of groundwater is clearly present.

2.3 The surface water system

Marais de Heinsch is situated in the Meuse district in the upper Semois-Chiers basin. The main waterway in the basin is the Semois, which flows from east/north-east to west/south-west. Marais de Heinsch is situated at the confluence of the Semois and two of its right bank tributaries: the Kripsbach

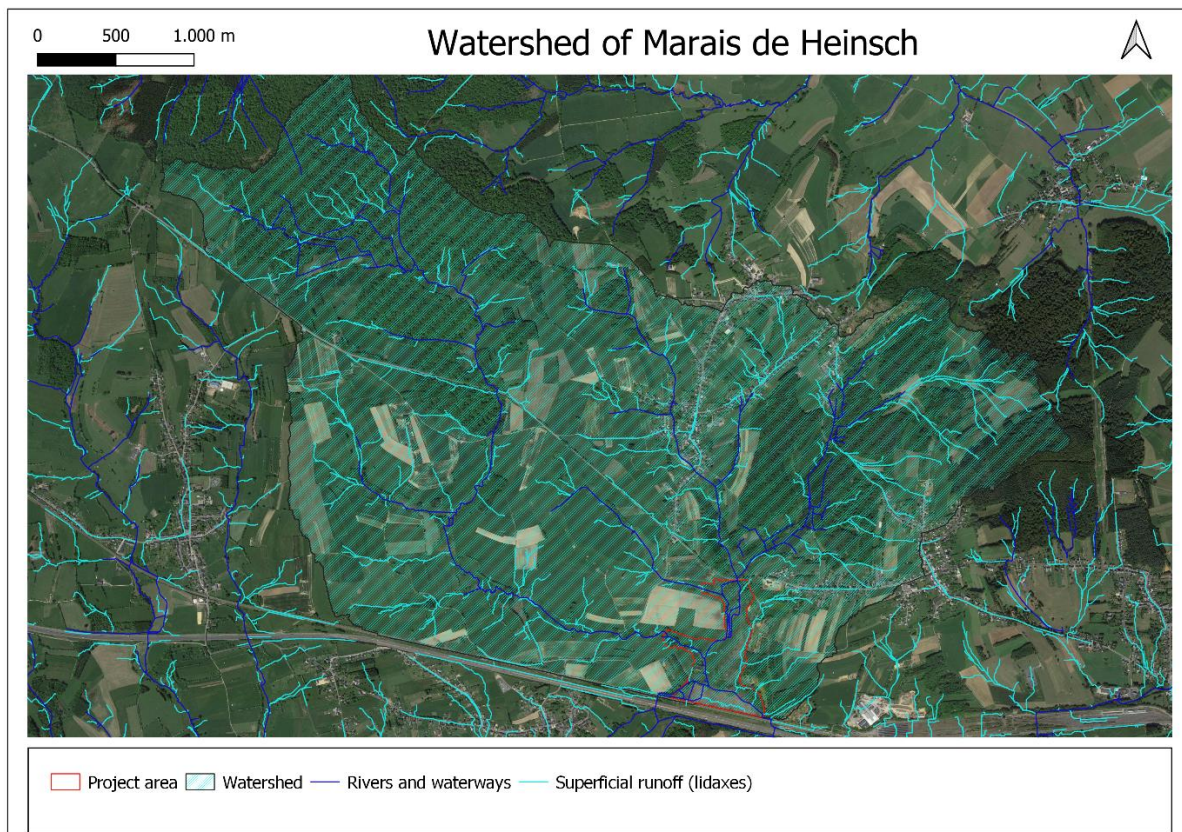


Figure 10. Catchment analysis showing the area that affects the Marais hydrologically.

and the Bierbach. After the passage of Marais de Heinsch the Semois follows a north-east to south-west orientation.

2.3.1 The catchment

The catchment analysis (Figure 10) shows the area that potentially affects the Marais by superficial runoff and shallow groundwater flow. The figure also depicts permanent streams (rivers and waterways) and ephemeral flow paths (lidaxes) caused by differences in topography. Figure 10 clearly shows that the catchment of the Marais is rather large. At the same time it is highly asymmetric with a very large part covering the area west of the Marais whereas the catchment extends much less towards the east. The main causes for this remarkable difference are the asymmetric (hydro)geology (par. 2.2.1) and associated infiltration capacity of the soil. The western part of the catchment is relatively flat and consists mainly of sandy loam – clay soils with a relatively low infiltration capacity. Groundwater recharge in this area is low and in periods with a precipitation excess almost all water is discharged superficially into the streams. As a consequence the Kripsbach and especially the Bierbach have a dynamic water regime with a low base flow in dry periods and a high peak flow in wet periods. The eastern side of the Marais is subject to a different type of catchment. It consists of the Sinemurian cuesta which is covered mainly by sandy soils with a much higher infiltration capacity. The fraction of the precipitation that infiltrates in wet periods is therefore much higher than in the western part of the catchment. Consequently water levels in the eastern part of the Marais are likely sustained by upward (ground)waterflow, also in drier periods, and fluctuate therefore much less than in the western part where supply from the surface water system is dominant.

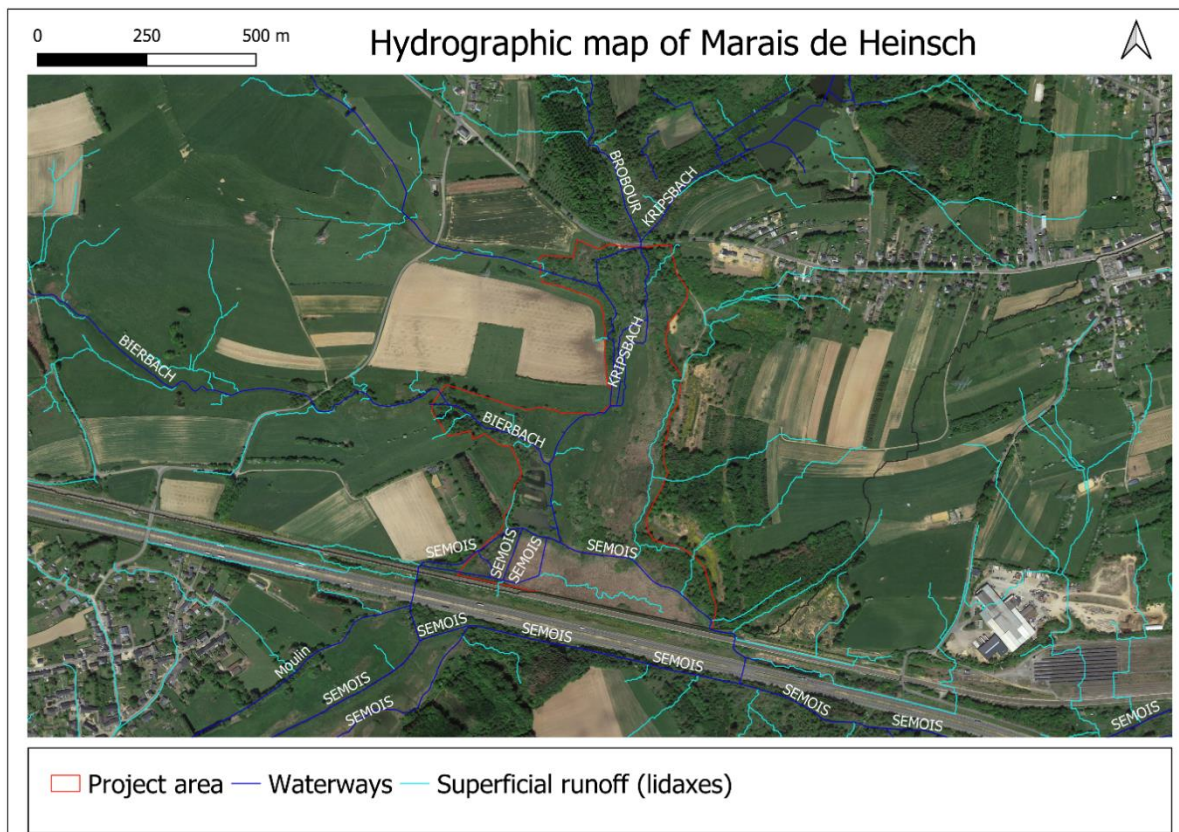


Figure 11. Hydrographic map including superficial runoff streams (lidaxes).

2.3.2 Hydrography

Marais de Heinsch is situated along a sidearm of the Semois and two of its tributaries, the Kripsbach and the Bierbach. The Kripsbach enters the area from the north and flows to the south along the western side of the Marais. Just north of the Marais the Kripsbach is joined by the Brobour from the northwest. The Bierbach enters the area from the west, where it joins the Kripsbach, and continues as Bierbach further south.

While today Bierbach and Kripsbach flow through the westernmost part of the Marais this was likely not the case in the natural situation. The map of Ferraris (Figure 12) originates from the 1770's and depicts a more or less natural hydrography. Contrary to the present situation it shows the Kripsbach flowing more or less north-south through the eastern part of the Marais and connecting to the south with the Semois.



Figure 12. Ferraris map (1777). Source: Géoportail Wallonie

Even in the early 20th century this hydrography has hardly changed (Figure 13), though, admittedly, the course of the Kripsbach seems to have been clearly straightened. The map of 1904 shows some east-west connections between Kripsbach and Bierbach. Whether these are natural connections is unclear but it should be noted that turf ponds have appeared on the 1904 map. These east-west water courses therefore could well have been dug to facilitate drainage for peat digging. At the moment it looks most likely that Kripsbach and Bierbach were not connected and ran parallel in the southern part of the area where both joined the Semois.

Also the course of the Semois itself has been altered substantially in recent times, resulting in the main flow of the Semois now running along the highway in the south. On the Ferraris map and the 1904

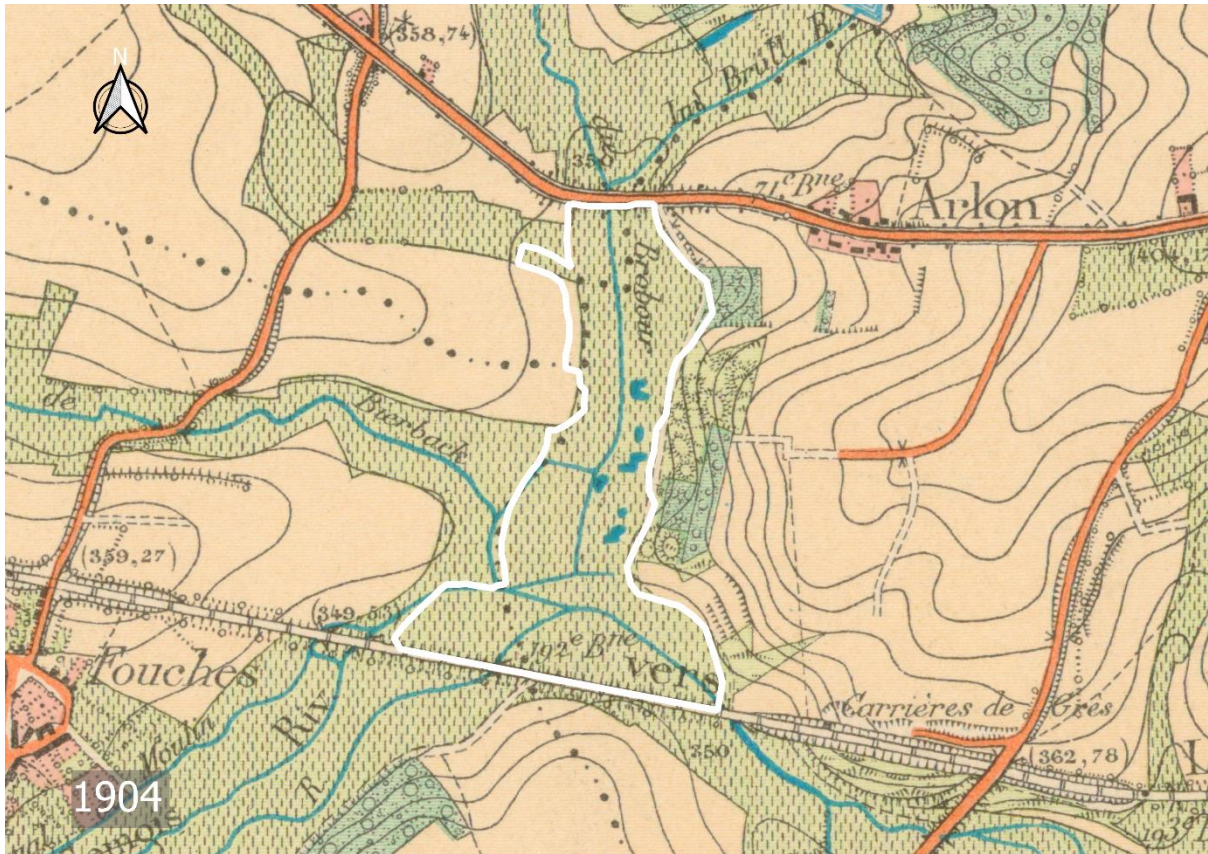


Figure 13. Topographic map of 1904. Source: Géoportail de Wallonie

map the Semois runs through the southern part of the Marais, separating this from the central part. In that period the Kripsbach connected to this 'old' Semois in the southeastern corner of the Marais. Today these streams have been shifted to the west where they join the old Semois and run jointly to a connection with the new Semois just on the other side of the motorway. Right before the old and new Semois join, an old mill stream "the Canal du Moulin" splits off from the old Semois. This mill stream is fed by the old Semois, which is probably why the old Semois still exists.

Hydrographically there are clear differences between the eastern and western part of the Marais. The courses of Bierbach and Kripsbach now run both along the western edge of the area while there is no open waterway or clear stream present in the eastern part. However the map shows an ephemeral superficial runoff stream (*lidaxes*) on the old course of the Kripsbach along the eastern edge of the Marais (Figure 11). In contrast to most *lidaxes* that are only present in wet periods, this stream could be observed in the field throughout the year with slowly flowing water in southerly directions. It is likely fed by upwelling groundwater (par. 2.2.2) in combination with runoff from the eastern catchment. The analysis suggest also other runoff streams from the cuesta into this main stream, however these could not be observed in the field. Most likely they appear only during periods of high precipitation. This 'former Kripsbach' drains into the old Semois on the southeastern side of the Marais.

2.4 Peat depth and stratigraphy

In november 2020 we made 11 peat corings from the top to the mineral layer underneath the peat to determine both peat depth and peat stratigraphy (Figure 15). To get a more detailed map on peat depth we measured many additional points by inserting an iron rod in the peat until it reached the underlying mineral soil. We combined the results with additional data taken by Wout Opdekamp (Natagora) in december 2021 who used the same technique to further increase the detail of this map (Figure 14). With this method it is not always possible to distinguish between peat and water-saturated soft clay so the interpretation should be done carefully. Nevertheless, it is clear that peat depth is largest in the eastern part of the area (Figure 14). Peat layers in the western part are shallower.

Not only peat depth, also the composition of the peat differs between the different parts of the area (Figure 15). Again three sub-areas appear. The corings along the eastern edge (points 8, 13 and 19) contain mainly peat that consists of the remnants of Brown mosses, often mixed with remnants of small sedges and occasionally also with large sedges and/or reed. The occurrence of brown-moss



Figure 14. Peat depth in centimetres below topsoil

vegetation is limited to sites with nutrient-poor and base-rich conditions with water levels close to or on the soil/peat surface. These water levels are very stable and fluctuate only minimal, typically less than 10-15 cm/year (Ilomets et al. 2010; Johansen et al. 2018). In some points these layers alternate with layers with Alder peat. Alder woodland requires (much) more nutrient-rich conditions and also larger fluctuations in the water table. Alder peat therefore indicates more dynamic conditions, typically after (natural or artificial) drainage, for instance caused by diversion of rivers or damming by beavers. In the western and the southern part of the Marais the corings (points 10, 17, 20, 21, 22) reveal mainly either reed- and/or large sedge peat or loamy clay layers, the latter sometimes mixed with reed and large sedges. Large sedge and reed vegetation is characteristic for eutrophic and dynamic conditions with larger water table fluctuations. Such peat is typically found in floodplain mires that are situated along

water courses and are flooded with surface water during wet periods. In dry periods water tables drop and dead organic material is partly mineralized, thus increasing nutrient availability. Loamy clay, finally, is deposited in areas with very dynamic conditions where surface water flow is so strong that peat growth is not possible.

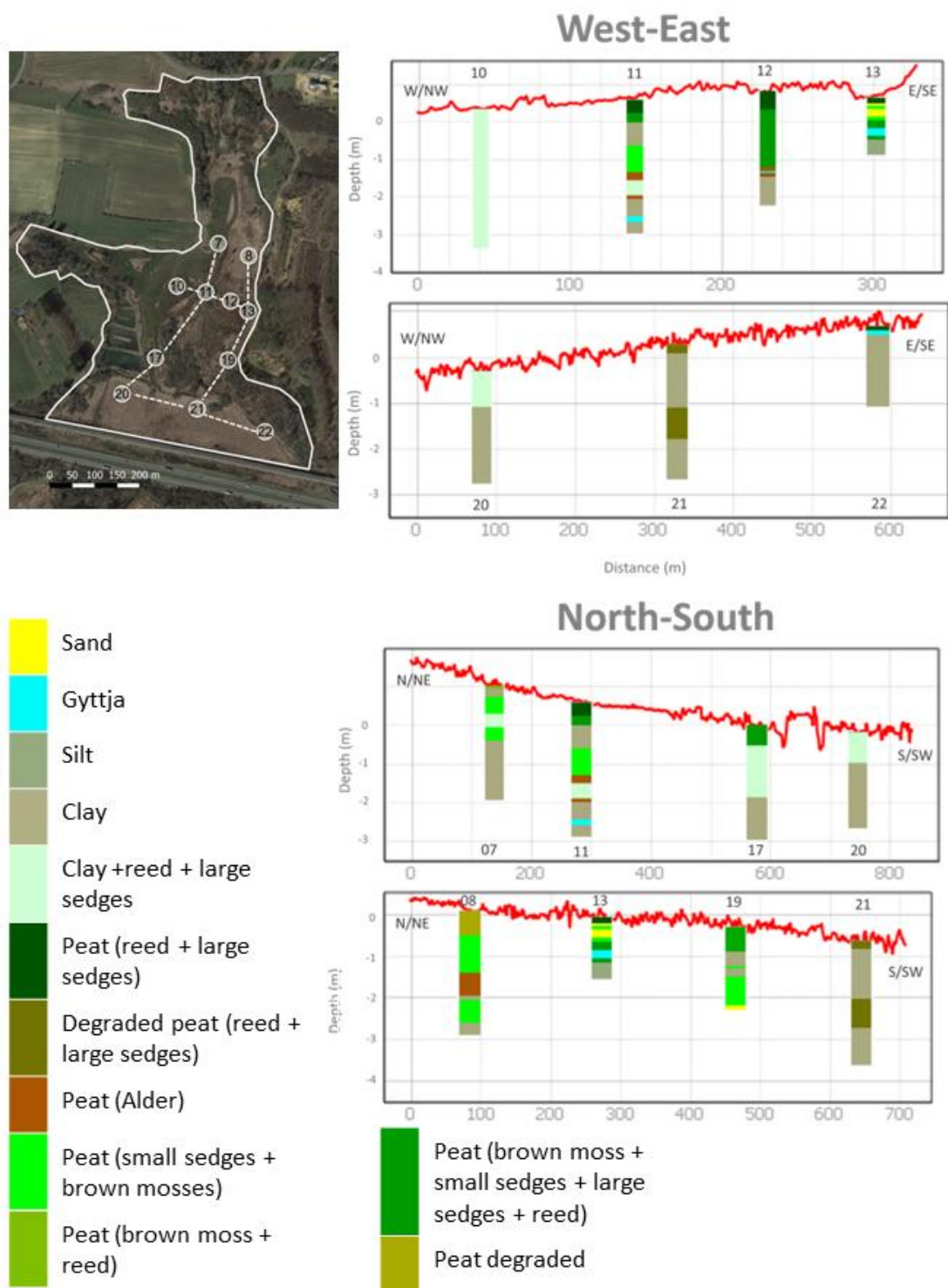


Figure 15. Peat stratigraphy as measured in november 2020. The red line is the surface as derived from the Digital Terrain Model (Source: Géoportail de la Wallonie)

Currently alkaline fens only occur in small patches along the eastern edge of the Marais (points 13, 16, 19) but the presence of layers with brown-moss peat shows they were historically also present at more central parts of the Marais (points 7, 11). In these central parts brown-moss peat layers are now covered by peats that point to nutrient-rich and dynamic conditions or even by loamy clay. All in all this indicates that the area with flooding has increased at the cost of areas with intensive groundwater inflow.

2.5 Interpretation

Combining all information gives an idea of the hydro-ecological functioning of the Marais under natural conditions without much human impact (Figure 16). The higher areas east and west of the valley were covered with forests and functioned as infiltration area, especially the area along the eastern edge. Not only because the cuesta is much higher than the relative flat western area, it consists also of highly permeable chalk-sand aquifers of Florenville. Much of the infiltrated precipitation flows through the calcareous subsoil, partly in the direction of the Marais where it wells up along the lower edge of the Cuesta. Waterlevels here were stable and alkaline fens could develop. However, because all geological strata lie under an angle most infiltrated water moves in a south-easterly direction and only a small part flows towards the Marais. The width of these alkaline fens was therefore limited also under undisturbed conditions. The peat corings show it covered the eastern half of the valley and was broader in the northern half. Further towards the south it became increasingly narrower and was not present at all in the southernmost corings.

The western part of the peatland functions in a different way. The subsoil here consists mainly of marls with a high hydraulic resistance, i.e. a low infiltration capacity. Precipitation surpluses are mainly transported away via the surface water system. The western part of the catchment is much larger than the eastern part, meaning that in wet periods large amounts of water flow towards the Marais. The peat corings indeed show a broad floodplain, especially south of entrance of the Bierbach in the area. Moreover, the presence of thick layers of loamy clay suggests the floodings were intensive. Whether this occurred in a natural situation or has developed later is not known. Intensive flooding can occur close to river courses but most likely it has also at least partly a human origin. As early as paleolithic times, but certainly in the Middle ages, people cleared most of the forests on the infiltration areas, thus sharply increasing the erosion in this hilly environment and with that the sediment load of the water courses rose sharply (but see also par. 3.2.1).

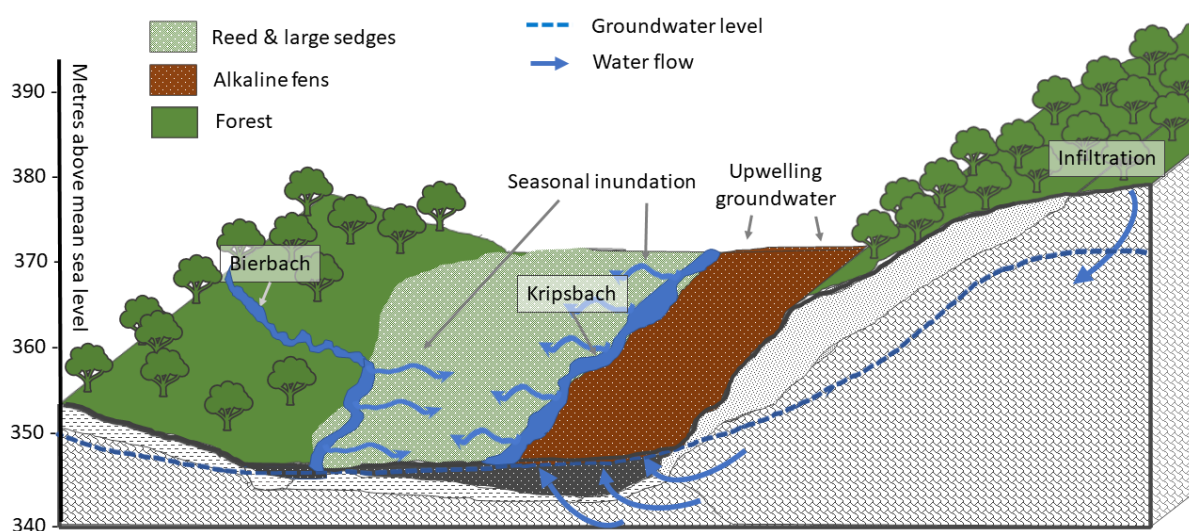


Figure 16. Interpretation of the hydro-ecological functioning of the Marais de Heinsch under natural conditions

2.6 Conclusions ecohydrological functioning under natural conditions

Marais de Heinsch is situated on top of a geological fault and is affected by two different geological constellations:

- The western half of the peatland is supplied with surface water from a large area west of the Marais that runs over rather impermeable layers of marl. Water levels are highly dynamic in this part and go up and down with precipitation. The western half of the Marais is relatively productive and under (almost) natural conditions covered by reed beds and large sedge vegetation;
- The eastern half is fed by upwelling groundwater from the Florenville aquifer which consists of calcareous sandstone. Water levels are very stable and the upwelling water is rich in calcium. This results in a very low productivity in the eastern half of the peatland. Under natural conditions the eastern part of the Marais consists of transition mires and alkaline fens.

3 Regional level: human impact on the ecohydrological functioning

3.1 Changes in the groundwater system

The amount of groundwater extracted in the direct vicinity of the Marais is small (Figure 17) and this suggests that this impact is negligible. However, as pointed out earlier (par 2.2.1), the Florenville aquifer that supplies the Marais with upwelling groundwater is sloping down towards the southeast. In other words, the majority of the groundwater flows to the southeast, away from the Marais, and the latter is only supplied with 'spill over'. A limited change in the water pressure inside the aquifer could therefore potentially have a large impact on the amount of spill-over. Most likely the infiltration area that does supply the groundwater to the eastern side of the Marais is relatively small, at maximum 100-150 ha and possibly even much smaller. Assuming the (irrealistic) situation that the complete yearly precipitation surplus of about 300 mm infiltrates into the aquifer this would imply that the yearly supply to this part of the aquifer would maximally amount between 300 000 and 450 000 m³. Because a significant part of the precipitation is lost via run-off this value will be much lower in reality

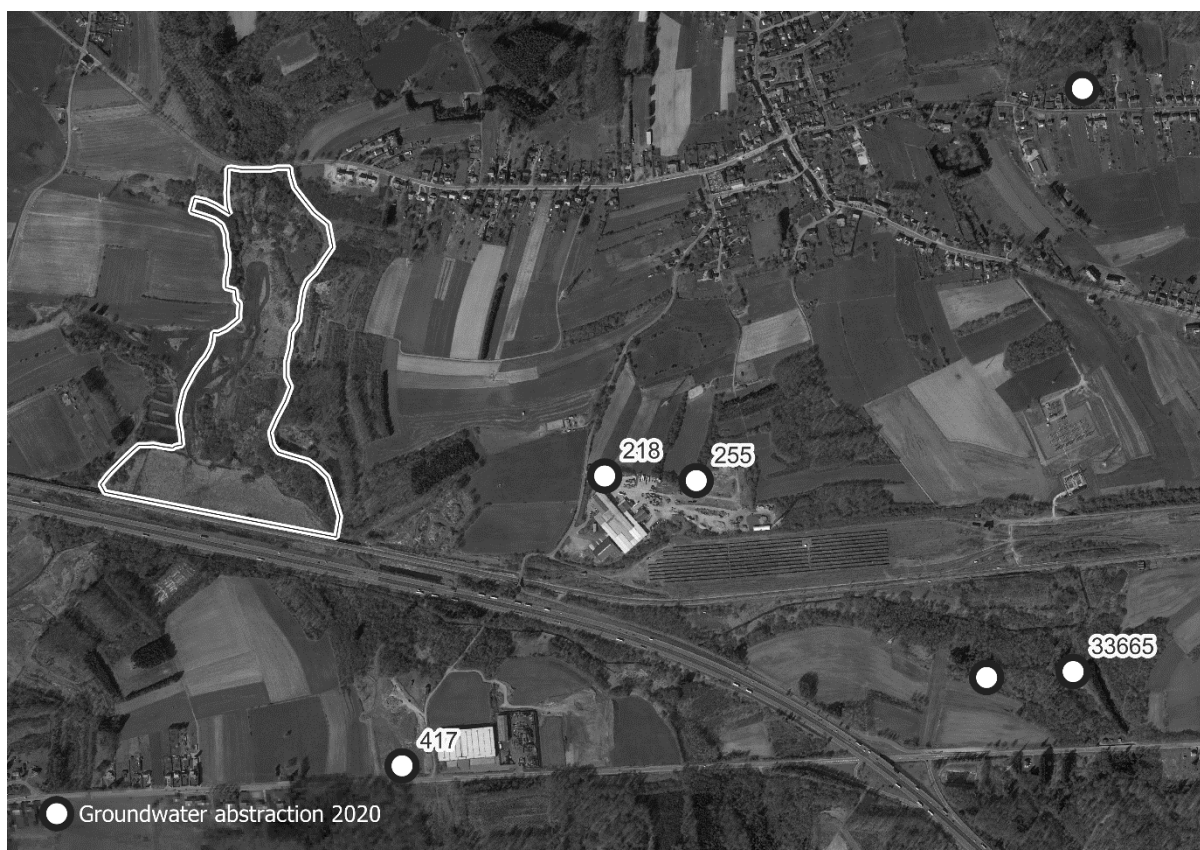


Figure 17. Groundwater abstraction wells in 2020. Where known the abstracted quantities are indicated in m³ per year. Only wells that pump water out of the Florenville aquifer are shown.

3.2 Changes in the surface water system

3.2.1 Changes in the hydrography

The hydrography of the area has changed substantially since the 18th century. Historically, the Kripsbach, that currently flows along the western edge of the area, followed a more central path, along the edge between peat and clay (Figure 18). The Ferraris map (Figure 12) suggests the Kripsbach ran more or less along the foot of the Cuesta in the 1770's, where groundwater seepage intensity is highest (par 2.5). However, given the inaccuracy of the map and the fact that it is unlikely for a river to flow through the middle of a groundwater-fed fen, it is more likely that the Kripsbach also then flowed along the transition zone between peat and clay, as depicted for example in the 1904 map (Figure 18). All topographic maps between 1777 (Ferraris Map) and 1939 show an east-west connection between Bierbach and Kripsbach. In some maps this is the only watercourse present, in others there is also a Kripsbach running further south where it finally connects to the Semois. The latter situation is also present on the topographic map of 1939. It is likely that there were two parallel watercourses along each side of the Marais until the second World War. While the Ferraris map still shows 'untouched' peatland, this is no longer the case on maps of the period between 1873 and 1939. They all show peat extraction pits in the seepage zone along the foot of the Cuesta that are not present on the Ferraris map. Small-scale peat extraction was carried out here in the beginning of the 19th century (Wathelet, 1982). The emphasis in the 1837 Depot de Guerre map on the redirection of the Kripsbach to the west suggest that this was the main water course during that period, functioning as drainage channel for the peat diggings.

This situation changed after WW II. The topographic map from 1969 (Figure 18) shows a situation identical to the present, where the Kripsbach has shifted to the western edge of the peatland. At the same time the stream is very deep for such a small river. Most likely this deepening happened in the same period because in 1971 the area became protected as a nature reserve and enlarging the drainage system was no longer allowed. However, the stream was also not made shallower after 1971. This implies that the drainage of the peatland has been highly increased in comparison to the period before WW II..

Another significant hydrographical change concerns the course of the Semois itself. In both historical maps the Semois is pictured in the Southern part of the Marais. This situation still existed in 1904 (Figure 18) but currently this is no longer the case. Parts of this stream still exist, but most parts contain more or less stagnant water throughout the year and function as a drainage channel only during very wet periods. The main part of the Semois was straightened and redirected along the railroad and later shifted further south along the highway (Figure 19).

This is not the only hydrographical change in the course of the Semois. The first known straightening of this river was carried out around 1710-1712 in Villers-sur-Semois. Since then large parts have been straightened to counteract losses of arable fields and pastures by flooding of the river (<https://cheminsdecampagne.be/Semois-english.php>). Most of the works to improve river discharge were carried out between 1890 and 1930 but were taken up again in 1948. Rocky plugs, which had impeded the flow, were removed and some meanders were straightened. In addition stone walls were placed in locations with layers of quicksand to stop the erosion there and clogging up of the river. All in all, the Semois has lost more than 4 km length over its entire course due to these straightenings.

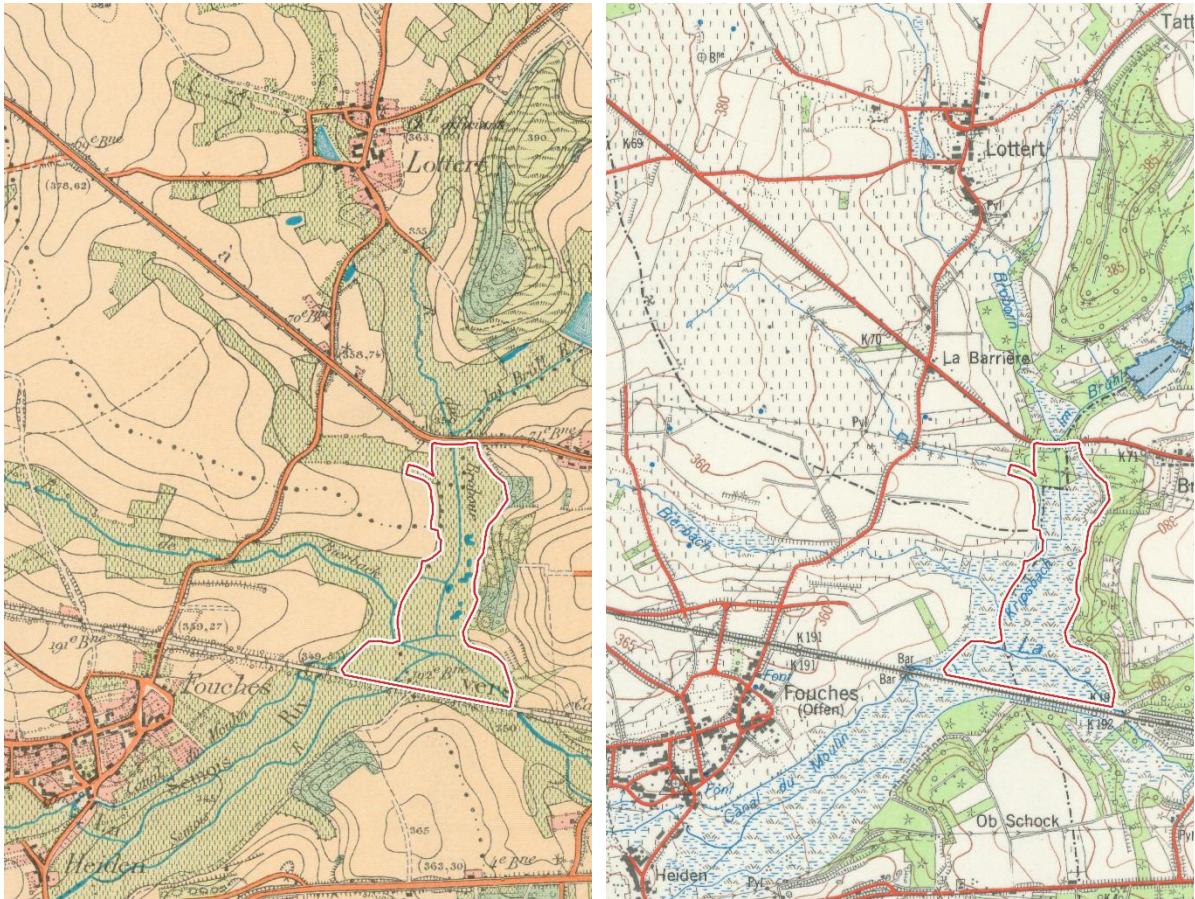


Figure 18. Historical maps of Marais de Heinsch, left the 1904 topographic map and right the 1969 map.

Anthropogenic influences are also visible just south of the Marais. Here the Semois is split into three separate streams, the northernmost of which is a mill brook, created for a mill in Fouches. During the time of Maria Theresa of Austria (1717-1780), this mill was improved and perfected in order to grind cereals for the Austrian army. It was probably at this time that this 'Canal du Moulin' was dug, receiving waters of Bierbach, Kripsbach, the Brobour stream and the Semois itself. Walter & Merritts (2008) hypothesize that many wetlands in NW Europe are the result of the damming of small rivers to create artificial ponds for the year-round provision of water for milling. Such ponds function as sediment traps and become filled over time with fine sediments, thus creating thick layers of fine sediments. They ascribe the afore-mentioned mid- to late medieval deposition of thick clay layers (par 2.5) and burial of organic-rich soils in many river valleys in Northern Europe as a result of mill damming. While inconclusive, the reed bed in the south of the area might constitute such a pond. The high levels of clay in the soil profile in this area might be a result of this practice. Conversely, it might also be the result of frequent flooding of the old Semois and the current Bierbach.

3.2.2 Drainage

The largest source of drainage within the Semois-Chiers basin, is the Semois itself. Especially the aforementioned straightening and removal of rocky plugs increased its drainage capacity. Within the watershed of the Marais itself, a collection of smaller streams influence the hydrology. The Kripsbach and the Bierbach along the western side of the Marais – while providing water during periods of

inundation - also constitute the main drainage system for the western side of the Marais. In combination with the faster discharge of the Semois this implies that also the discharge of these local water courses has increased. The duration of flooding has likely decreased but, more important, base flow in dry periods is likely also higher. In other words, drainage intensity in the Marais during the dry season has likely increased.

In the southwest of the Marais there are four large ponds that are connected to the Bierbach through underground drains (Figure 19). As long as such large open water bodies remain connected to the surface water system they function as intensive drainage structures.

Additionally there is a tight network of former ditches inside the whole western half of the Marais which is still partially functioning (Figure 19, category 'secondary watercourses'). These ditches are the last witnesses of the former use of this part of the Marais for low intensity agriculture, in particular hay-making and grazing on the drier patches (<http://biodiversite.wallonie.be/fr/125-marais-de-heinsch>). In the 20th century agricultural activities were increasingly abandoned here and completely stopped after the establishment of a nature reserve in 1971. The drainage channels slowly got filled with sediments and debris, their drainage capacity decreased and the area got wetter over time.

The eastern part of the Marais is currently less affected by drainage than the western part. Historically, the change in the course of the Kripsbach and the Bierbach has reduced the input of floodwater to the eastern side. Due to its low position in the landscape, directly adjacent to a relatively steep and permeable sandy limestone cuesta, it still receives a substantial input of groundwater from the Florenville aquifer. At present this water flows in a broad front over the surface of the Marais to the

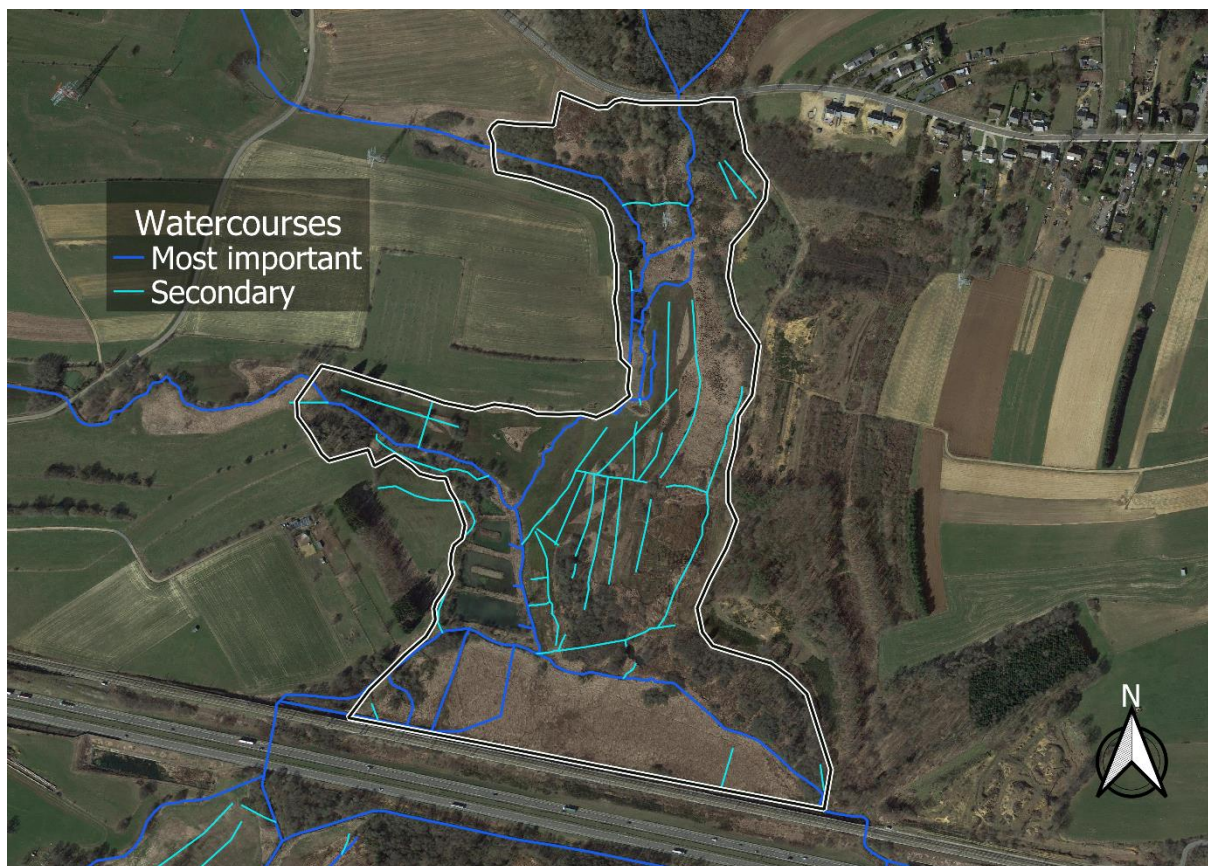


Figure 19. Drainage map of marais de Heinsch.

south. This zone is about 20 metres wide in the North and increases to at least 70 metres more south. This zone is situated more or less along the eastern edge of the peatland and finally enters the old east-west drainage channel between Kripsbach and Bierbach that is already visible on all old maps.

3.3 Land use changes

The older maps (Figure 12, Figure 18) and more recent photographs (Figure 21) show that landuse has been remarkably stable in the area around the Marais, with only little changes between the 18th century and early 1970's. During that period the Marais was mainly surrounded by arable fields while meadows and pastures were restricted to the lower lying wetter areas along Kripsbach and Bierbach. Forests were uncommon and the landscape was rather open.

This picture has substantially changed during the last decades of the 20th and the first ones of the 21st century. Not only has the cover of woodland and shrubs increased, also the average size of agricultural

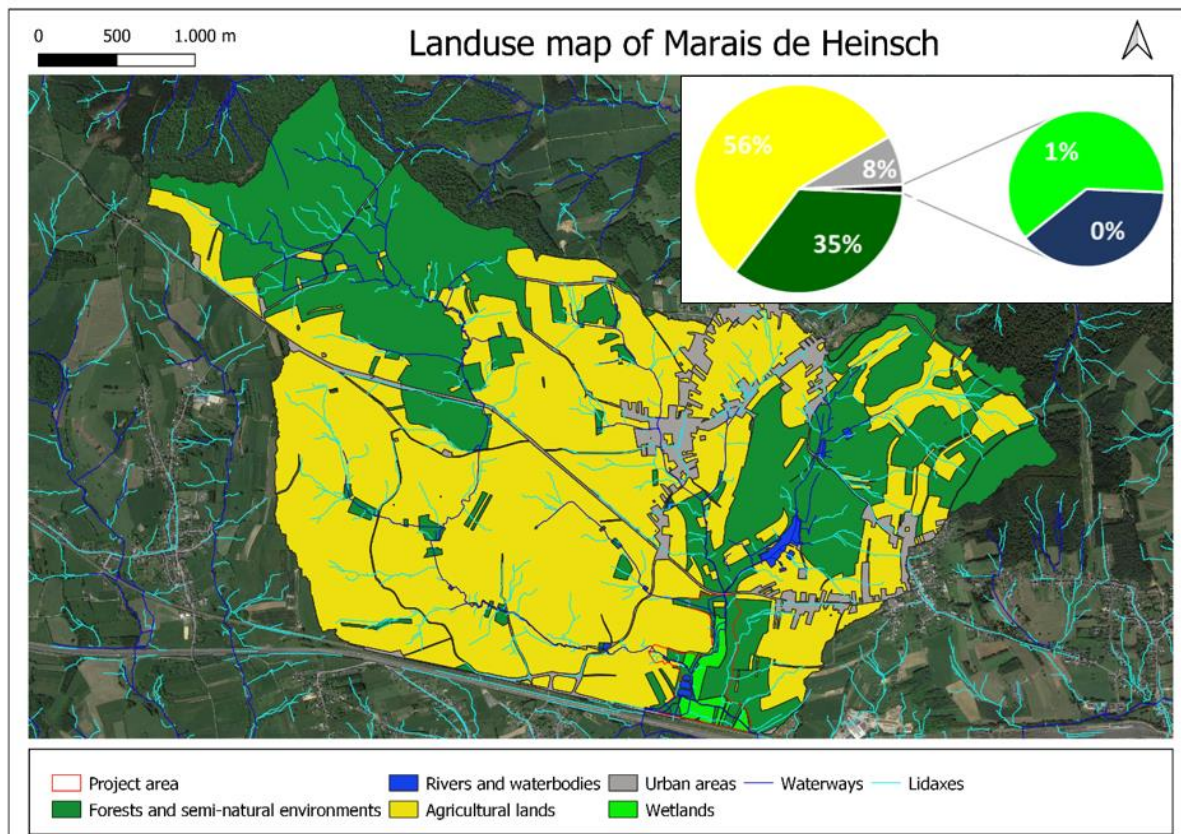


Figure 20. Present-day landuse in the catchment of marais de Heinsch, with cover percentages per landuse type. Source: Géoportail Wallonie.

parcels has grown considerably, particularly in the area west of the Marais. Moreover, the map of 2019 shows that meadows are no longer restricted to the wet areas along the river courses but have expanded also to the drier sites. All in all the aerial photographs present clear evidence for agricultural intensification in the western part of the catchment and increased forest development along the eastern edge. Such intensification of agriculture goes hand in hand with an increased use of fertiliser and it is very likely that the nutrient load of the water courses has significantly increased since 1970. Unfortunately we are not aware of chemical analyses of the composition of the surface water in

Bierbach and Kripsbach/Brabour. In periods with low surface water levels such water directly drains into the Semois without affecting the Marais. However, during flooding events in wet periods the Marais is inundated with water from the creeks and the nutrients in that water do affect the Marais. Especially nutrients bound to sediment particles that are deposited can have long-lasting effects. Given the regular flooding of the western half of the Marais it must be assumed that the nutrient load of this zone has increased during the last decades.

The situation in the eastern zone of the reserve is quite different. Woodland has developed along the whole eastern edge of the reserve and this buffers against nutrient-rich run-off from agricultural fields in periods with high precipitation. Moreover, the cuesta consists mainly of relatively permeable sands with a high infiltration capacity, causing the incoming precipitation to infiltrate more easily. This water is then partly cleaned by soil processes. Phosphates are immediately bound to the limestone particles in the sand and most of the nitrates disappear via denitrification processes. This implies that it is not very likely that the nutrient load of the groundwater in the eastern part of the Marais has increased because of agricultural intensification on the cuesta.

3.4 Waste water and landfill

Nutrient availability not only increased because of intensification of agriculture, also the urbanification of the region has increased. This made the building of a waste water treatment facility necessary which is situated to the northwest of the Marais. Its outlet is connected to a small, unnamed stream that runs via the Marais to the Kripsbach. Undoubtedly this further increases the nutrient load of the Kripsbach and enhances nutrient deposition in the flooded parts of the reserve during wet periods. There is, however, also a more direct impact of the sewage on the Marais. The sewage originates from the neighbouring villages of Heinsch and Lottert and the water from Heinsch runs via an underground pipe to the sewage treatment facility. This pipe runs underneath the Marais and has an overflow close to the eastern edge of the Marais. The function of this overflow is to transport excess water to the Kripsbach in periods with intensive precipitation (Figure 22). Unfortunately this pipe seems broken, which leads to the situation that in wet periods part of the sewage directly enters the Marais and is transported along its eastern edge with the southward stream of upwelling groundwater (par 3.2.1). This has serious consequences on nutrient availability there.

Not only sewage enters the peatland, there is also another additional source of pollution inside the reserve. After the abandonment of agriculture in the 1960s the northeastern part of the Marais was used by the municipality of Heinsch to dump garbage. Declaring the area a nature reserve made it possible to stop this activity, although clandestine deposits still exist. This landfill is now covered with sand but not sealed. It is highly likely that run-off and superficially infiltrating groundwater leaves this garbage dump and is transported further south with the already mentioned stream of upwelling groundwater along the eastern edge. Also this source is likely to enhance the nutrient load further in the eastern part of the reserve.

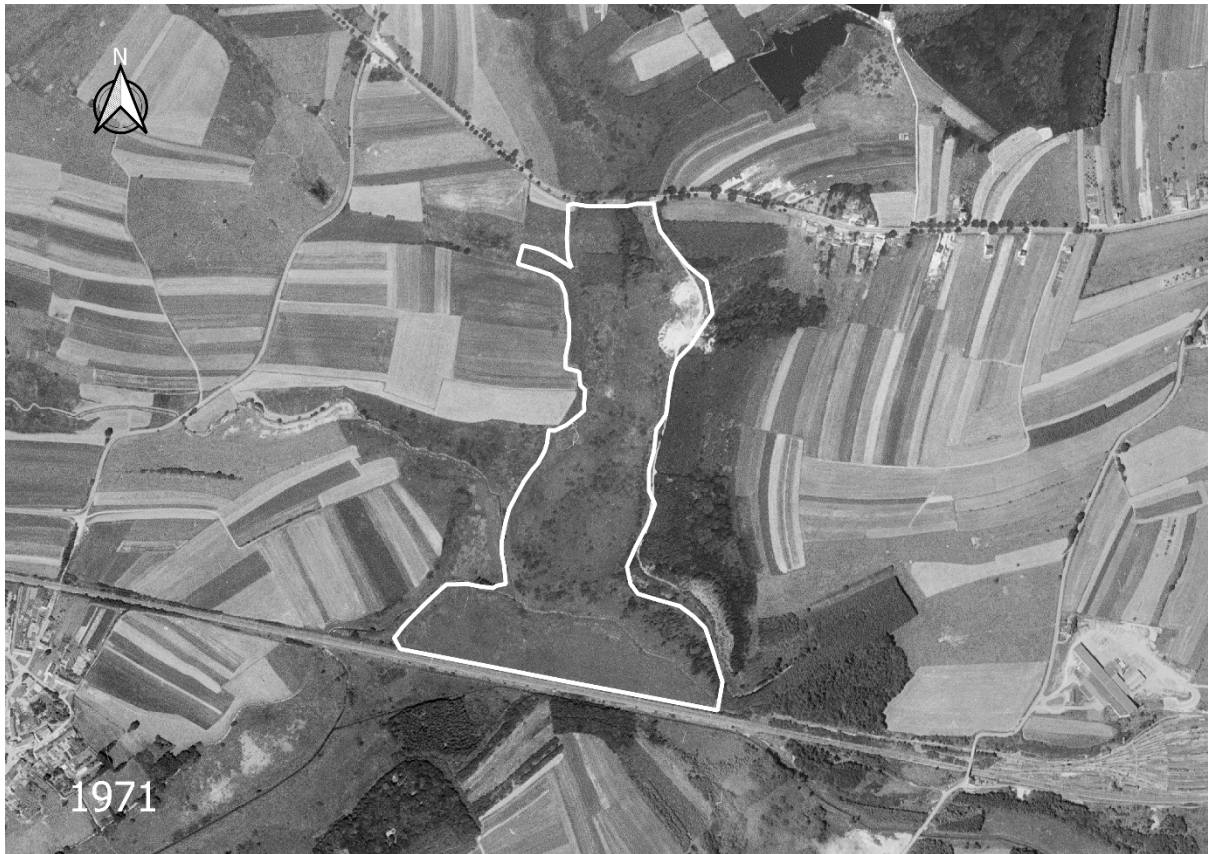


Figure 21. Aerial photos of the Marais and its surroundings in 1971 and 2019. Source: Geoportail Wallonie



Figure 22. Sewer and threshold before (left) and after (right) rainfall.

3.5 Interpretation

The present hydro-ecological functioning of the Marais (Figure 23) differs significantly from the natural situation as depicted in Figure 16. To begin with the hydrography has changed considerably. In the natural situation the Kripsbach was situated in the center of the Marais where it transported much of the upwelling groundwater away. In the present situation the Kripsbach has been shifted to the western edge and there is no longer a water course more to the centre. Instead there is a relatively broad stretch where surface water flows superficially to the south. Based on the present vegetation composition the zone with upwelling groundwater seems much narrower than under natural conditions. Partly the alkaline fen vegetation is now replaced by very productive vegetation that is nourished by polluted surface water originating from the waste dump and the leaky sewage pipe. Whether the hydraulic potential in the Florenville aquifer has also decreased is not known but it could

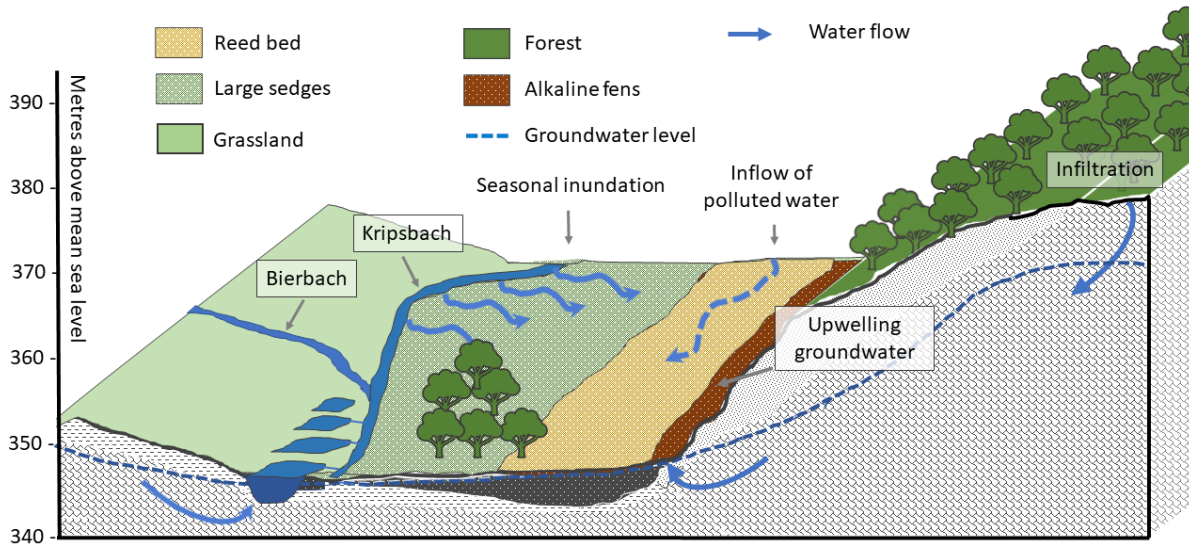


Figure 23. Interpretation of the functioning of the Marais de Heinsch under present conditions

be the case. Several groundwater abstraction points have been constructed in the last few decades (see par. 3.1). Also the enhanced drainage capacity of the whole Semois river basin, including Kripsbach and Bierbach, does increase groundwater removal rate. The water tables in both rivulets were very low in the dry summers of the first years of the 2020's and certainly drained the Marais, removing much of the upwelling groundwater via the still partly functioning former ditch network. Nevertheless groundwater levels in the eastern part remained high in the dry summers, suggesting that, despite the increased drainage, groundwater supply remained high here.

The changes in the western part of the Marais are less clearly visible. Improvements in the catchment drainage have most likely resulted in more extreme water table fluctuations than under natural conditions. This was clearly visible in the dry summer of 2022 when groundwater levels dropped to the same low levels as in the Kripsbach (unpubl. Data Wout Opdekamp). Flooding intensity and the deposition of sediments almost certainly has increased. Agricultural intensification has led to higher nutrient contents of sediment particles in the brooks and in the water itself, thus increasing the nutrient loads of the flooded areas. Remarkably, this is hardly visible in the vegetation. An important reason is probably that these additional nutrients are to a large part removed by the reinstalled mowing management.

3.6 Conclusions human impact on ecohydrological functioning

Human impact on the Marais de Heinsch has been significant and diverse:

- The already mentioned difference between the eastern and western part of the Marais has been enhanced in Medieval times by clearcutting of forests on the slopes of the catchment area and possible the digging of ponds to safeguard the water supply for water mills. These activities have led to increased sediment deposition and associated nutrient enrichment in the western part of the area;
- The natural drainage system inside both sides of the Marais has been changed and greatly enlarged, resulting in stronger drainage, larger water table fluctuations and further eutropication of the area;
- The hydrology of the eastern half is further affected by peat extraction in the beginning of the 19th century. The resulting peat ponds were connected to surface water system, thus draining this part of the Marais;
- Agricultural intensification of the western part of the catchment has increased the nutrient content of the surface water and thus enhanced the nutrient loading in the flooded zones in the western side of the Marais;
- The eastern side of the Marais is severely affected by a large nutrient input from the area around the former garbage dump. Most likely this is caused by leakage from an overflow of the sewage pipe from Heinsch and Lottert to the treatment facility. Possibly there is also direct run off of nutrients from the garbage dump;
- The zone with upwelling groundwater has become narrower than in the natural situation. Possibly this is caused by groundwater extraction from the Florenville aquifer system. Because this zone is the core area for attempts to restore degraded and disappeared transition mires and alkaline fens this is highly worrying.

4 Local level: hydrological conditions

4.1 Quantitative hydrology

4.1.1 2017/2018

Waterlevels were measured by hand between 25 april 2017 and 24 april 2018 at 12 points in the centre of the Marais (Figure 24). Six of these points consisted of pairs of piezometers with filters in the top layer (approximately 50 cm below soil surface) and in a deeper layer (approximately 250 cm below soil surface). Additionally five points consisted of only a shallow piezometre and one point was a surface water measurement point.

Maximum water levels during the research period were relatively similar in all piezometers, regardless of piezometre depth and were close to the surface. In the 2.50 m deep piezometres also average and lowest levels did not change that much (Figure 26) but the picture in the 50 cm tubes was much more differentiated. In some piezometres water levels were remarkably stable whereas in some others the water tables dropped almost 30 cm's. There was a good correlation between lowest water level and degree of fluctuation (Figure 25), implying that the lowest level can be used to assess the size of fluctuation.



Figure 24. Piezometers 2017 2018

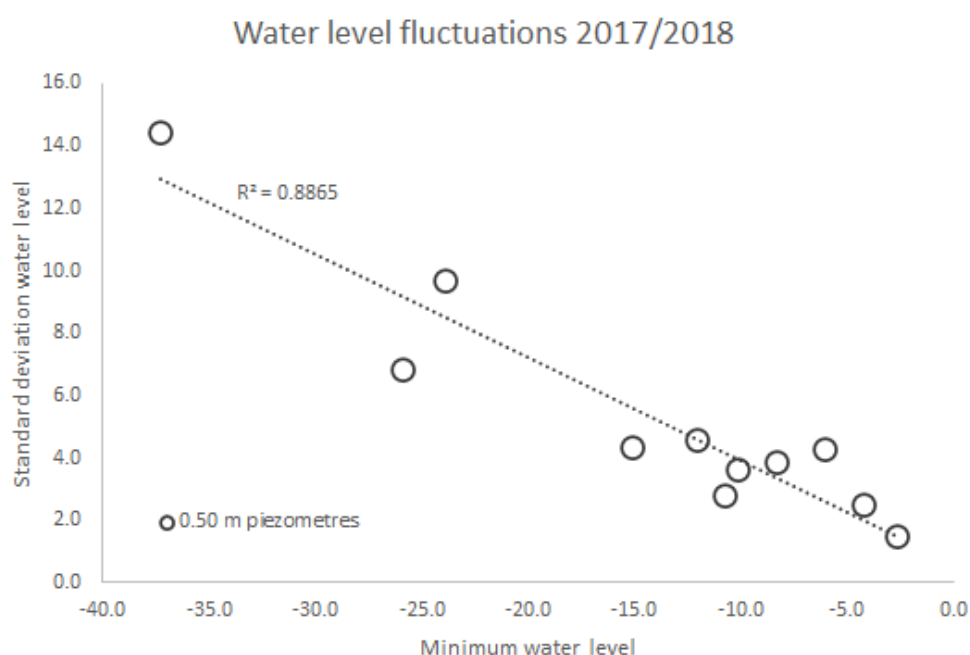


Figure 25. Average water level fluctuations in relation to minimum water level in shallow piezometres



Figure 26. Lowest water level in shallow (left) and deeper (right) piezometers between april 2017 and april 2018

Plotting the lowest water level in the 50 cm piezometres in a spatial map shows a clear pattern with stable water levels along the eastern edge and in the centre of the area (Figure 26).

These results suggest that groundwater wells up in the centre of the Marais and along the eastern edge. To check whether this was indeed the case we analysed the five piezometre couples and calculated whether the hydrological potential in the deeper piezometre was higher than in the shallow one. If this is the case groundwater flows upward while it moves downward when the water level in the shallow piezometre is higher. Figure 27 shows the results for all couples of piezometres. The figure shows that only in the most northern couple 111-112 the potential in the deeper tube was always higher than in the shallow one, i.e. here there is upward groundwater movement during most of the year. The groundwater movement in couple 108-109 is rather erratic but most measurements suggest downward movement. All other piezometres show upward groundwater movement in the drier summer period and downward movement in the winter. Figure 27 shows that in all three points upward movement is approximately in equilibrium with downward movement. In other words, in these points there is no clear net upward groundwater movement, anyway not in the study period. This implies that it is unlikely that large amounts of dissolved substances are supplied to the Marais via the groundwater.

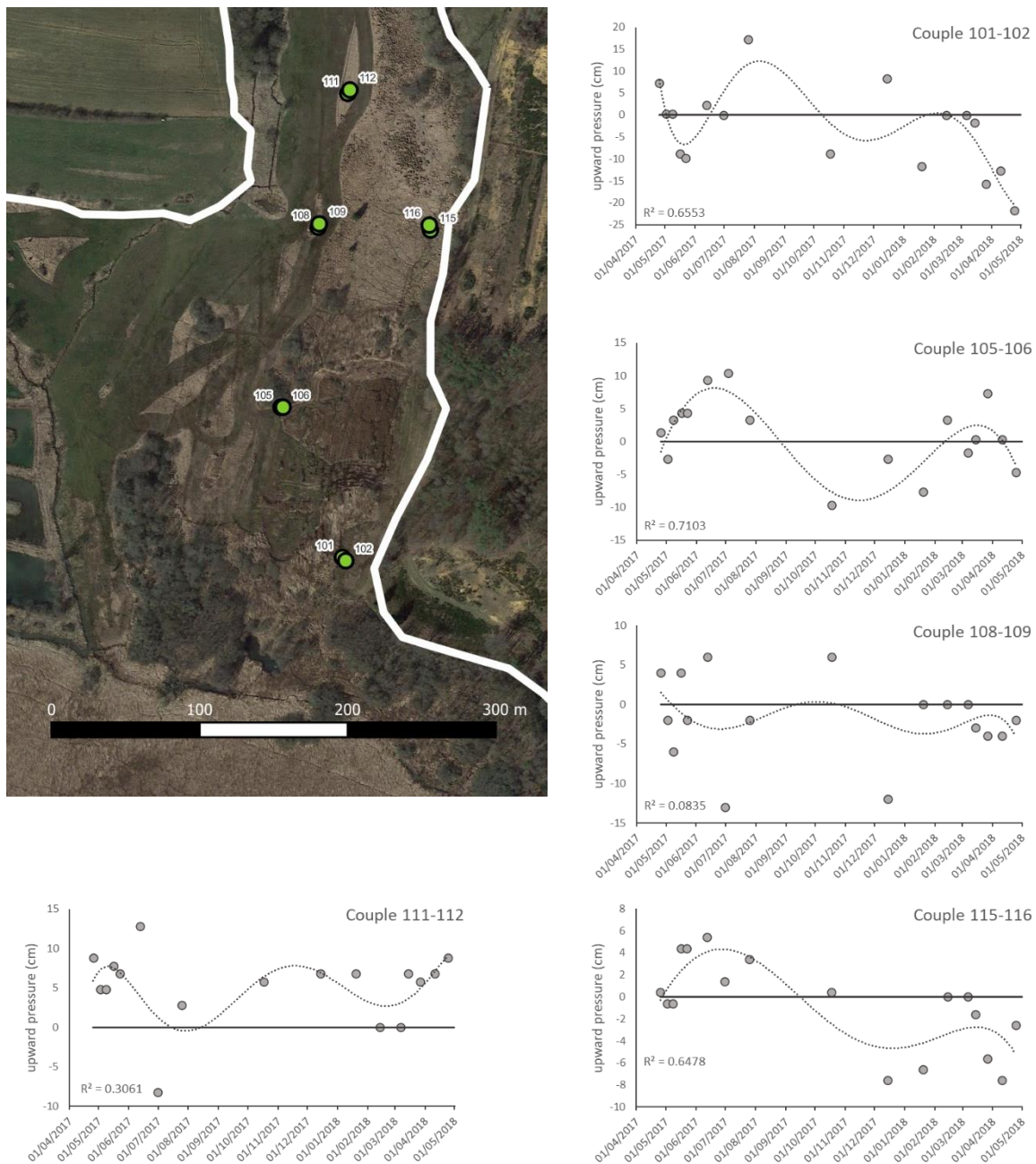


Figure 27. Comparison of waterlevels in shallow (50 cm) and deeper (250 cm) piezometres between 25 april 2017 and 24 april 2018. If values are positive above the horizontal line water movement is upward, if values are negative water movement is downward

4.1.2 2021-2023

In november 2020 a pair of piezometres was installed in the southeastern corner of the area. This pair consisted of a phreatic piezometre (T3.1, see Figure 28) placed in the peat layer and a deeper one (T3.2) placed in the underlying sand layer. In spring 2022 7 other piezometres were installed in the Marais to replace the ones from the 2017/2018 study. Two of these formed also a couple of a phreatic and deeper tube (T1.1 and T1.2, see Figure 28). All piezometres were equipped with electronic loggers that registered groundwater level at least every 6 hours.

The results confirm the outcomes from the 2017/2018 measurement campaign to a high degree. Fluctuations in the shallow piezometres were highly related to lowest water levels ($r^2 = 0.95$, $n = 7$, data not shown here) and increased in westernly and southernly direction. Fluctuations in the

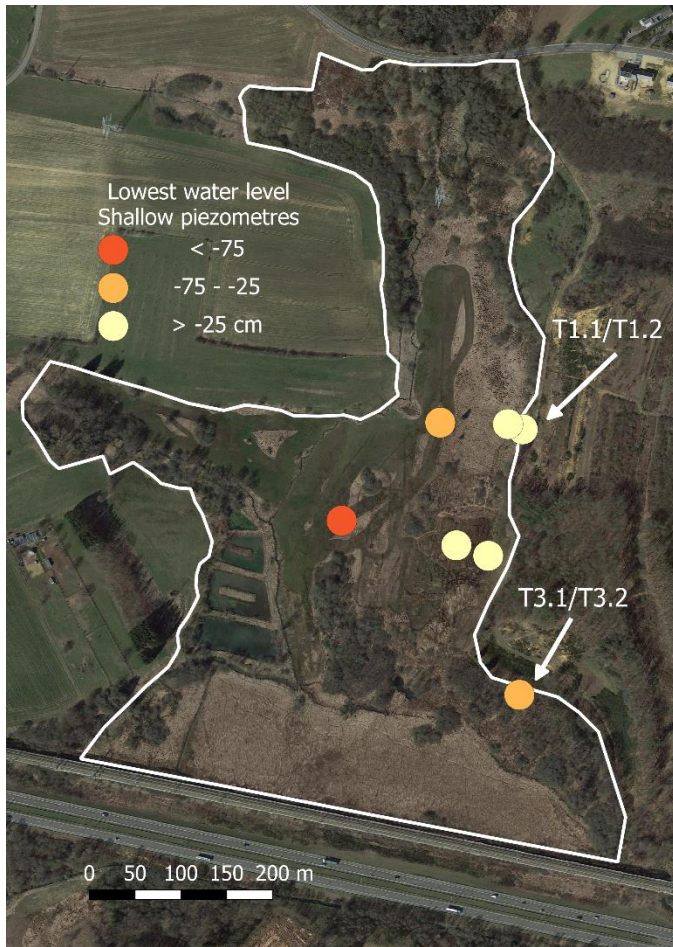


Figure 28. Lowest waterlevel in phreatic piezometres placed in 2020 or 2022. Couples consisting of 1 phreatic piezometre placed in the peat layer and one placed in the underlying sand layer are indicated with arrows.

piezometre couple T1.1/T1.2 along the middle part of the eastern edge were very small: despite the extremely dry summer of 2022 waterlevels in the peat layer fluctuated only 7 cm between 12 May 2022 and 19 September 2022. The fluctuations in the underlying sand layer were slightly larger: the waterlevels there fluctuated about 13 cm in the same period. Such stable values point to a steady supply of (ground)water.

This was not the case in the couple T3.1/T3.2 in the south-eastern corner of the Marais. Here waterlevels fluctuated 56 cm in the phreatic peat and 50 cm in the underlying sand. Waterlevels were not stable either in the more western piezometres closer to the Kripsbach. The lowest waterlevels in the two phreatic piezometres there dropped to respectively 57 cm and almost 1 m in summer, whereas both had highest waterlevels at or even slightly above soil surface in wet periods.

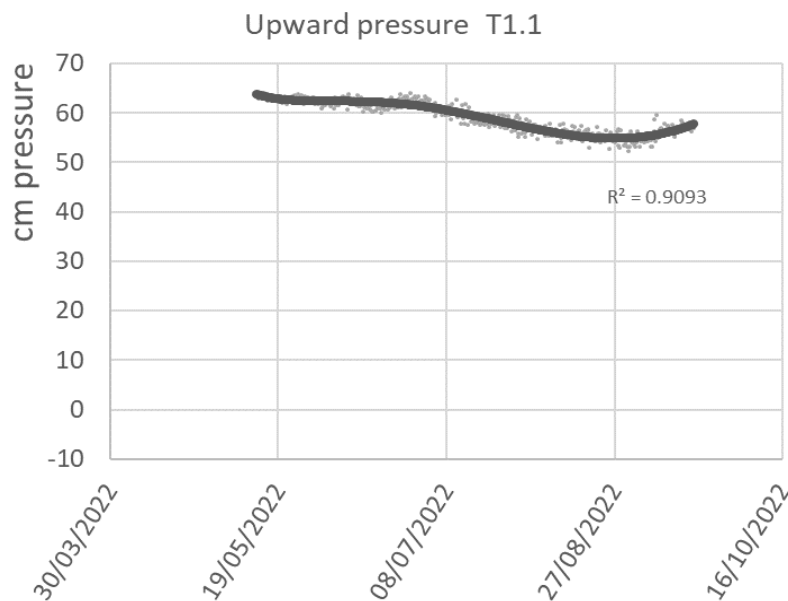


Figure 29. Difference in hydraulic head between deep piezometre T1.1 in the sand layer and phreatic piezometre T1.2 in the peat layer

Not only were waterlevels very stable in the couple T1.1/T1.2, also the difference in hydraulic head was considerable: the water pressure in the deeper piezometre T1.1 was constantly between 50 and 60 cm higher than in the phreatic piezometre T1.2 (Figure 28). This points to a constant supply of groundwater in this site.

This was not the case with the couple T3.1/T3.2. Hydraulic heads in these both piezometres were approximately similar with only slight differences of maximal a few cm's (Figure 30). Such small differences in combination with considerable fluctuations in both piezometres shows that groundwater supply is minimal in this site

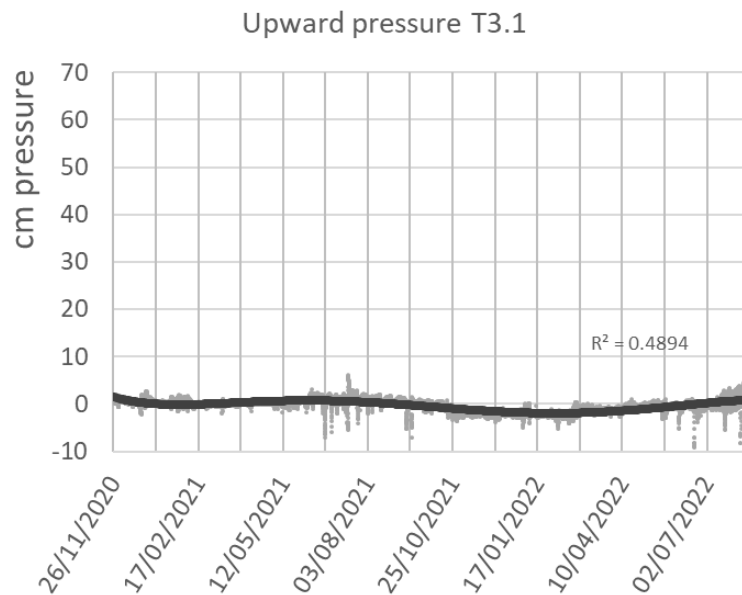


Figure 30. Difference in hydraulic head between deep piezometre T3.1 in the sand layer and phreatic piezometre T3.2 in the peat layer

4.2 Hydrochemistry

4.2.1 pH and conductivity

In 2017 and 2018 pH and Electrical Conductivity were measured in the piezometres. pH only differed minimally between the sites and is not shown here. It varied around 6.5. Conductivity on the other hand differs considerably between the sites and shows a negative relationship with water table fluctuations (Figure 32). In other words, the sites with the most stable water levels, i.e. the sites supposed to be fed at least during part of the year with upwelling groundwater (par. 4.1.1), have a high average conductivity. The average value of around 700 $\mu\text{S}/\text{cm}$ exceeds the values between 250 and 390 $\mu\text{S}/\text{cm}$ as measured in the aquifer of Florenville in 1985 and 1999-2005 (Bouezmarni and Debbaut, 2006) by far. Recent values from this aquifer near the Marais de Heinsch are not known but such high values could either be caused by upwelling groundwater that has now become polluted or by inflow from a quantitatively important second source of water with high EC. A further analysis shows that the relation between the EC of shallow and deeper groundwater fluctuates around 1 (grey line in Figure 31) suggesting that the chemical composition of groundwater at both depths is fairly

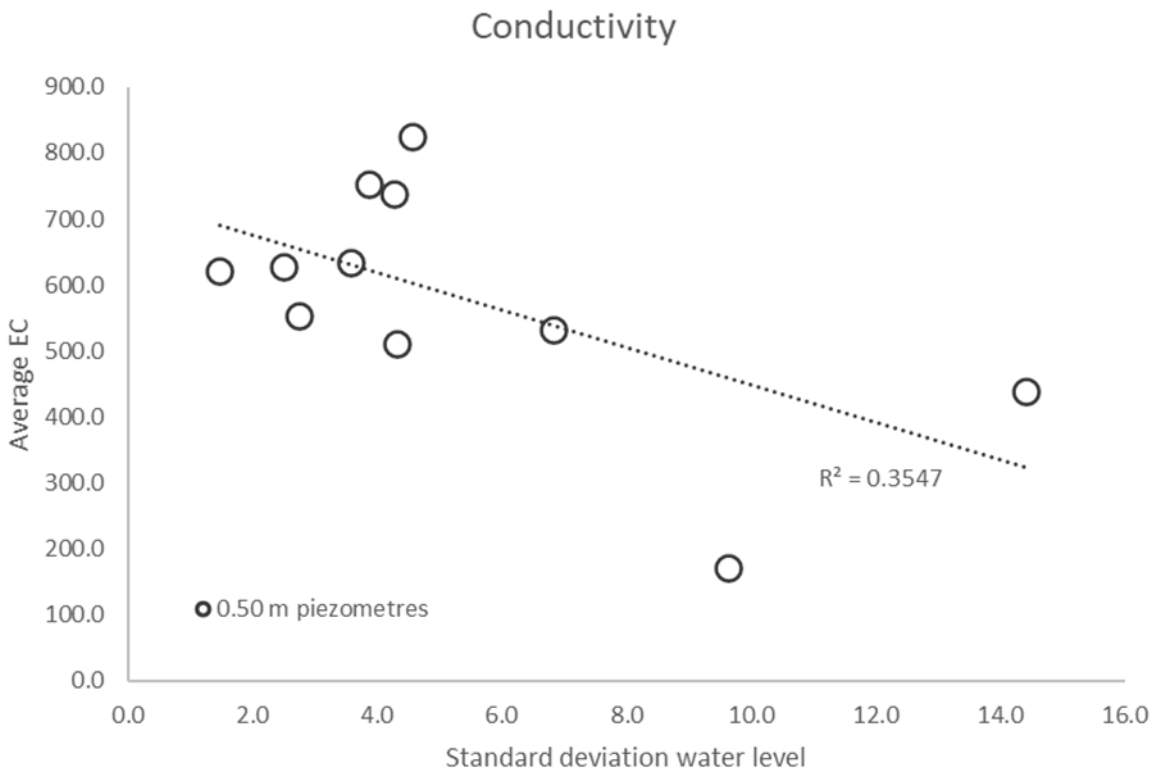


Figure 32. Average conductivity of groundwater in phreatic piezometres in 2017-2018 in relation to water level fluctuation

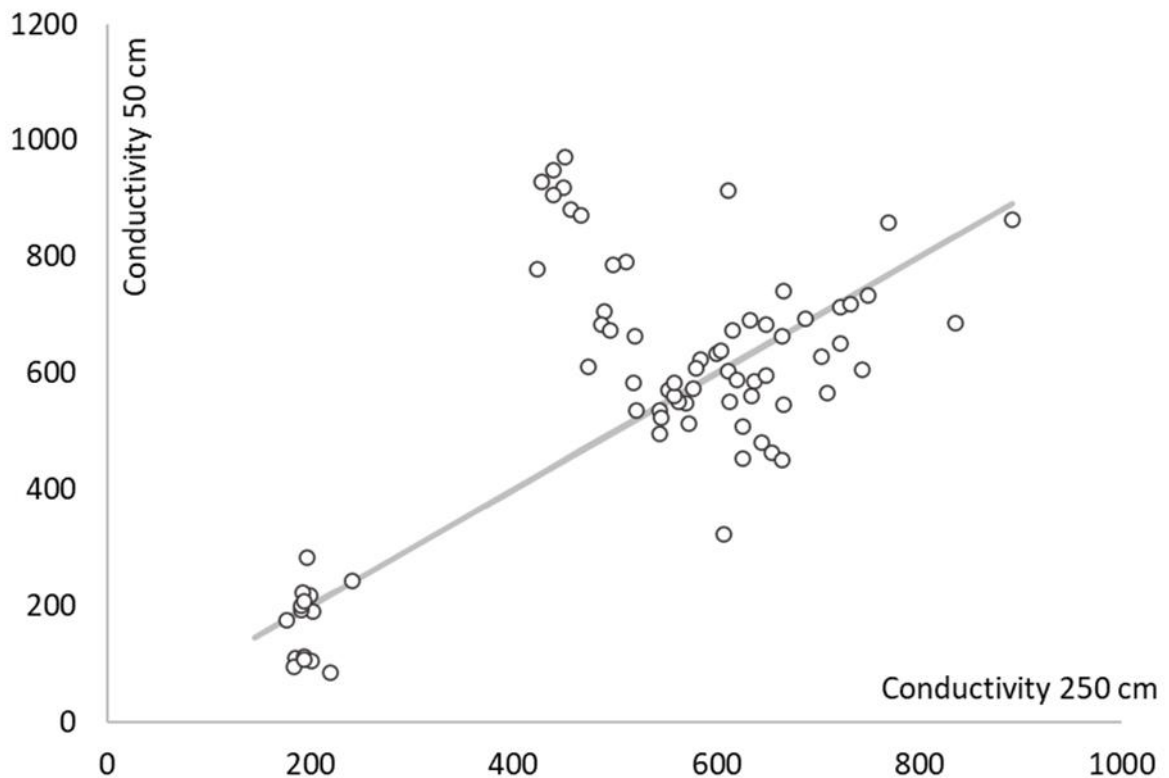


Figure 31. Conductivity in the top layer in relation to that at 250 cm depth. The diagonal line depicts the values where EC in shallow and deeper piezometres are identical

equal. In itself such observation is not conclusive on the origin of the water but when combined with

the interpretation that upward groundwater movement is limited or even absent in most of the area (par 4.1.1) this suggests that the contribution of water with a high EC by discharge from a polluted aquifer is limited. The hypothesis that most of the pollution is coming from above (par 3.4) seems therefore likely. Which of the hypotheses are true cannot be concluded with certainty without more in-depth research. Both are, however, very worrying because such conditions highly reduce the chances of a successful restoration of alkaline fens.

4.2.2 Groundwater composition

Samples of ground- and surfacewater were taken in June 2020, April 2022 and September 2022 and analysed in the laboratory soon thereafter.

As expected in such calcareous landscape the main variation in the chemical composition is related to differences in concentrations of Ca^{2+} and HCO_3^- and both are strongly correlated ($R^2 = 0.94$). Differences in the amount of chalk dissolved therefore is the main factor structuring water chemical differences in the Marais. Indeed, the combined concentrations of Ca^{2+} and Mg^{2+} are well correlated to those of TIC (Total Inorganic Carbon; $R^2 = 0.95$) and are on average 1% higher than those of TIC. Because the values for Ca^{2+} and HCO_3^- are well correlated to electrical conductivity EC_{25} ($R^2 = 0.84$ and 0.67 respectively) measurements of EC can also be used to estimate the base-richness of the water. Figure 32 therefore suggests that the base-richness of the water is highest in the sites with most stable water levels, close to the edge of the cuesta where upward groundwater movement is strongest (par. 4.1.2)

What is remarkable, though, and deviates from the general picture as described above, is that Ca contents and especially TIC are clearly higher in the shallow piezometres than in the deep ones. Further away from the zone with upward seepage the concentrations are also higher, especially in April. In other words, part of the enhanced values of Ca^{2+} and HCO_3^- are not likely caused by upwelling of calcareous groundwater but the result of other, more local processes (Schot & Wassen 1993). The most likely process under such wet conditions is anaerobic decomposition of peat, thus releasing minerals trapped in the peat (Aggenbach et al. 2013) and producing TIC. Such process requires an electron acceptor, notably NO_3^- , Fe^{3+} or SO_4^{2-} (Appelo & Postma 2013) and results in decomposition of part of the existing peat layer. The higher values of both NO_3^- and SO_4^{2-} in the deeper piezometres as compared to the more shallow ones both in April and September suggests that the same process occurs here. Also the pollution tracer Cl^- is higher in deeper layers.

5 Local level: Soil conditions and vegetation

5.1.1 Soil pH

The pH of the top soil was measured in situ in June 2020 and again in November 2020 (Figure 33) with portable instruments (<https://Hannainstruments.be>). In each point we made five individual measurements and calculated the average of these. In summer the highest pH values are found in the reed beds in the southern part of the Marais, and in the north eastern corner. Soils in the eastern part of the Marais have higher pH than the western part. In late autumn the differences between east and

west are also clearly pronounced, with the eastern part having higher soil pH. The somewhat lower pH in the western part, especially during summer, is caused by acidification, either as a result of increased decomposition in dry periods, and/or by infiltrating (acid) rain water in periods when the groundwatern table is low. In the western part the soil is not buffered by upwelling Ca-rich groundwater and therefore much more susceptible to acidification. The higher pH in the eastern part is likely due to upwelling groundwater from the adjacent limestone hills. However, the fact that in most of the eastern part the intensity of upward groundwater movement is nowadays at a yearly base much lower than in the past (see par 4.1.1) implies that this soil buffering stems in large parts of this zone from the past and is now very limited. Most likely these buffers are now gradually being leached out, i.e. such pH is not sustainable. In the long run these sites are likely to acidify if upward groundwater flow is not restored.

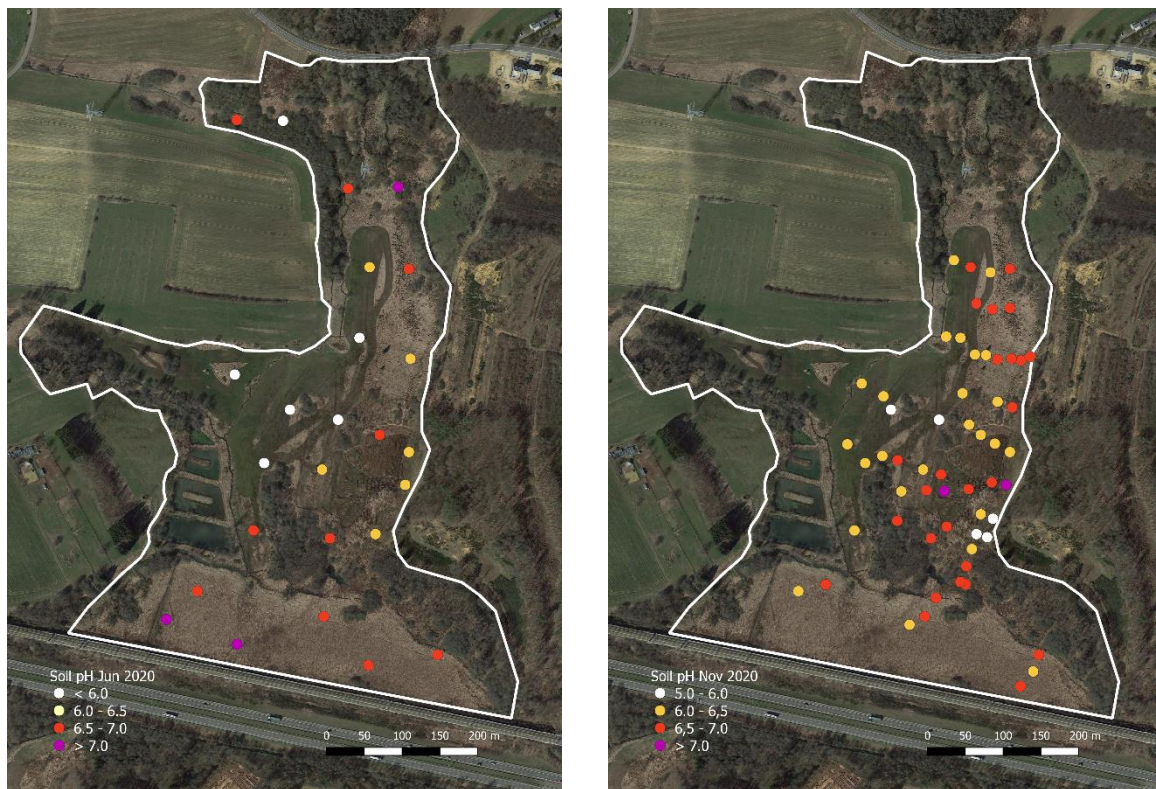


Figure 33. Soil pH measured in situ in June 2020 (left) and November 2020 (right)

5.1.2 Soil nutrient conditions

In conditions with calcareous soil such as in Heinsch one would expect very low soil P-availability because calcium binds phosphorous strongly, thus rendering P unavailable for the vegetation. Soil analyses, however, do not confirm that picture: Figure 35 shows that the soil in most sample points is eutrophic with respect to P. C/P ratios are low which implies that mineralisation of organic matter yield significant amounts of P. Only a few points show C/P values that are characteristic for P-mesotrophy, all of them in the layer that lies 20-30 cm deep below the surface.

The availability of N shows a more differentiated picture. Approximately half of the samples have C/N ratio's that indicate a high (eutrophic) or very high (hypertrophic) soil N-status. However, the other half of the samples point to a low (meso-/oligotrophic) or even extremely low N-status. Though also

here this is mainly the case in the deeper layers there are also a few points in the top layer that are meso- or oligotrophic for N.

Figure 34 shows that the N-status in the top layer is very high in the eastern half of the Marais. The majority of points there are classified as 'hypertrophic', even some sites that have a relatively low vegetation. Remarkably some of the western and southern sites that also have a quite high vegetation (and presumably a high productivity) have a much lower N-status. Two points in the southern reedbed are even classified as "oligo- and ombrotrophic".

In the deepest layer of 20-30 cm (layer 10-20 cm not shown, values lie in between the two other layers) the N-status is generally much lower, except for three points in the centre of the area. Values along the eastern edge point to meso- and oligotrophic conditions. The nitrogen status in the southern reedbed is even lower than in the upper layers.



Figure 34. Soil N-status at 10 cm depth (left) and 30 cm depth (right)

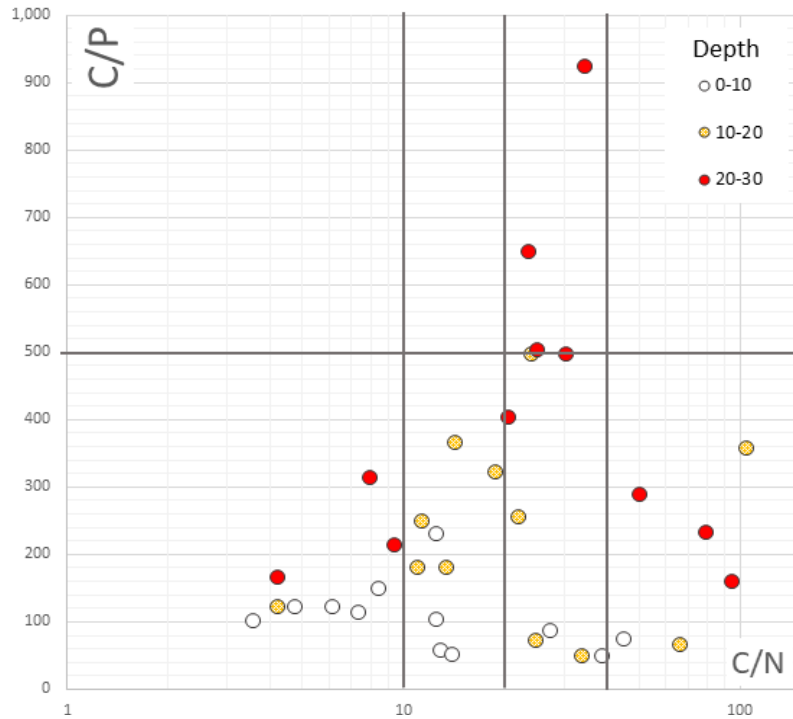


Figure 35. Soil phosphorous status C/P in relation to soil nitrogen status C/N. Lines separate soils of different trophic status. C/N < 10: N-hypertrophic; C/N 10- 20: N-eutrophic; C/N 20- 40: N-mesotrophic & N-oligotrophic; C/N > 40: N-ombrotrophic; C/P < 500: P-eutrophic; C/P > 500: P-mesotrophic

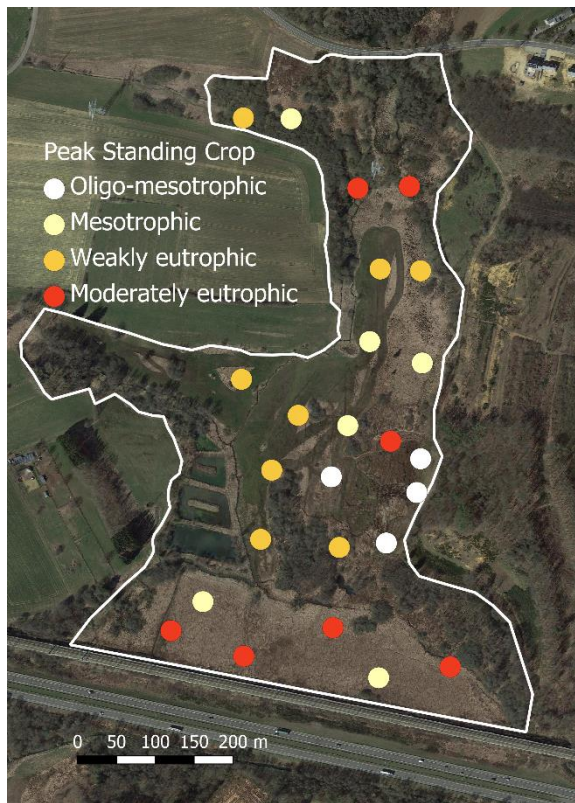


Figure 36. Peak standing crop based on the average of two samples (June 2020)

5.1.3 Biomass productivity and nutrient limitation

The afore-mentioned differences in nutrient status lead to differences in the productivity of the herb layer as indicated by peak standing crop (Figure 36). The lowest values are found in the species-rich plots along the eastern edge while the highest values occur in the northeastern corner and in the reedbed in the southernmost part. However, even the most productive sites are not extremely eutrophic. All sites in the centre of the area are mesotrophic to meso-eutrophic, certainly not hypertrophic. This is remarkable given the very high nutrient status in this part of the Marais (Figure 34). It should be realised that soil nutrient status points to *potential* nutrient availability, namely the nutrients that become available when the organic matter is decomposed. As long as the soil remains saturated with water N-availability remains low but in very dry periods increased decomposition will produce a ‘nutrient bomb’, most likely also an ‘acid bomb’. Peat soils loaded with nitrogen typically contain also large

amounts of sulfate that get oxidised when oxygen enters the soil and produce strong acids then. The origin of these enhanced N-levels are not entirely clear. A possibility is N-deposition from the nearby motorway but then one would expect very high levels close to the motorway and lower levels further away and that is not the case. The most likely option is transport from the sewage pipe overflow with the surface water. Whatever the origin, the fact that there are such large amounts of easily available nutrients present is very worrying from a conservation perspective and again stresses the need to keep watertables high so that these nutrients are not released.

We analysed nutrient limitation by measuring foliar content of N, P and K in all sites indicated in Figure 36. We calculated the N/P, N/K and P/K ratio's cf. Olde Venterink et al. 2003 to assess which nutrient is limiting biomass productivity (data not shown). Without exception all N/P ratio's were below the critical threshold of 14-16, showing that biomass productivity is only limited by Nitrogen availability. The three sites along the eastern edge that show very low productivity in Figure 36 (the points 13, 16 and 19) are closest to the threshold value of N/P and show ratio's of 13.2, 12.0 and 12.6 respectively. All other sites have considerably lower N/P ratio's. This implies that an increase in N-availability because of enhanced mineralisation due to low watertables, N-deposition, agricultural runoff or polluted surface water, will immediately lead to an increase in biomass productivity and a decrease in nature conservation value.

5.2 Vegetation

In the summer of 2020 vegetation relevés of the herb and moss layer were made in all 25 sampling points (Figure 38). All relevés were situated outside shrubs and woodland. An NMDS ordination on

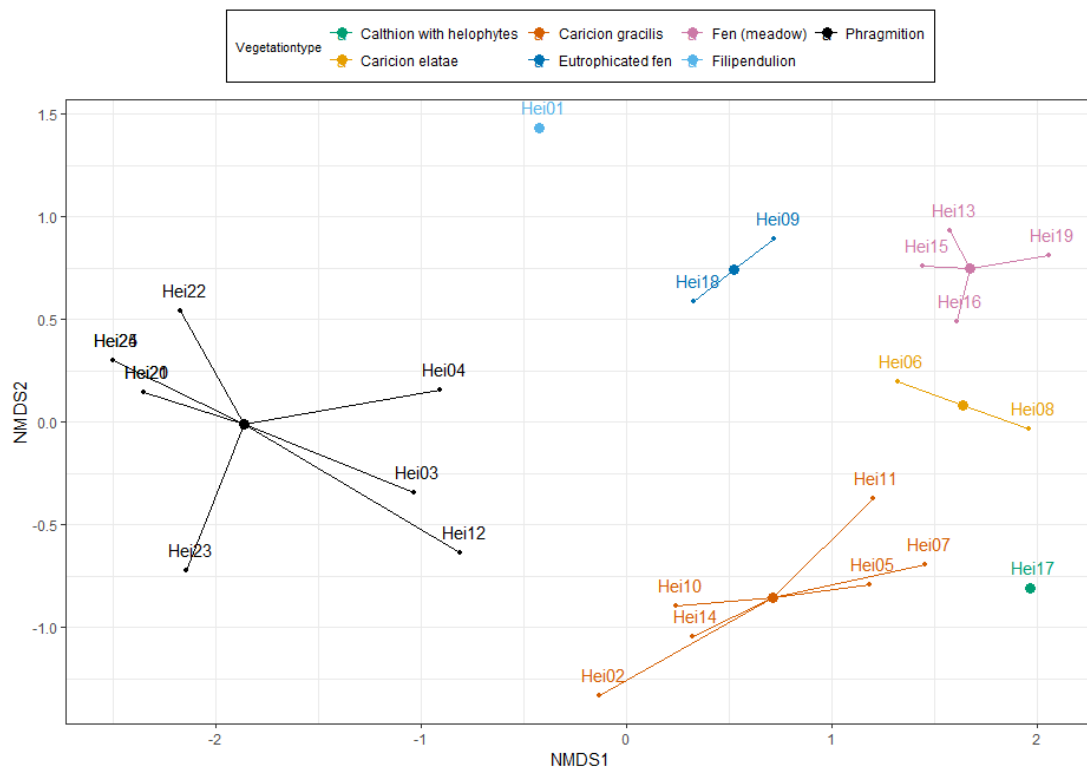


Figure 37. NMDS ordination and classification of 25 vegetation relevés made in Marais de Heinsch in 2020

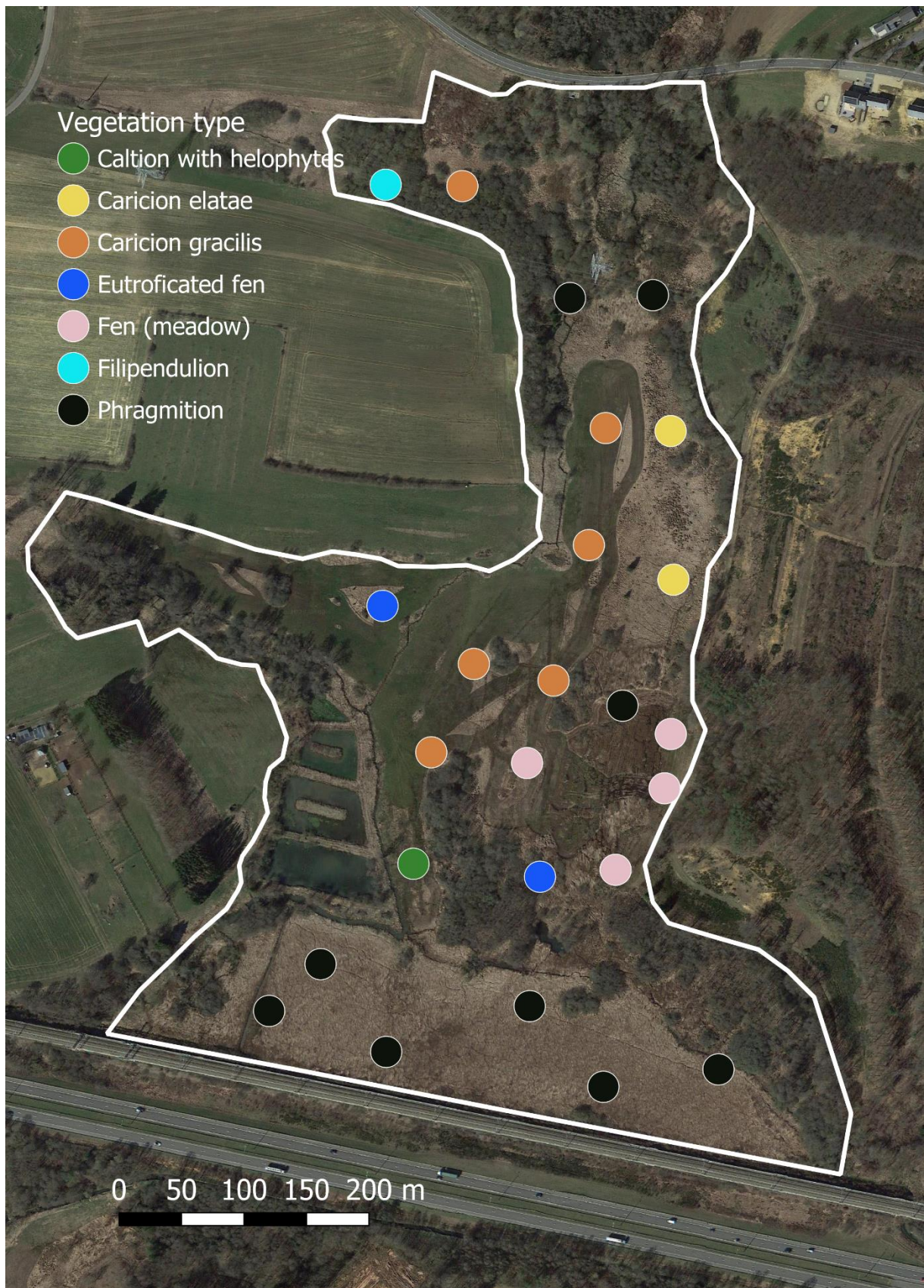


Figure 38. Vegetation relevées taken in 2020. Vegetation types are indicated with colours

the basis of the complete vegetation composition showed a clear distinction in 7 different groups, ranging from low-productive fen vegetation via fen meadows, large sedge communities to rough

pastures, eutropic marshes and productive reed beds (Figure 37).

Also in 1977 and 2010 relevées were made in the Marais but only in the central part of it (Overall 1977; Van Rossum et al. 2012; see Figure 38). Based on the composition of the vegetation classification Van Rossum et al. (2012) concluded that the vegetation had hardly changed between 1977 and 2010 and ascribed this stability to the mowing management that had been carried out.

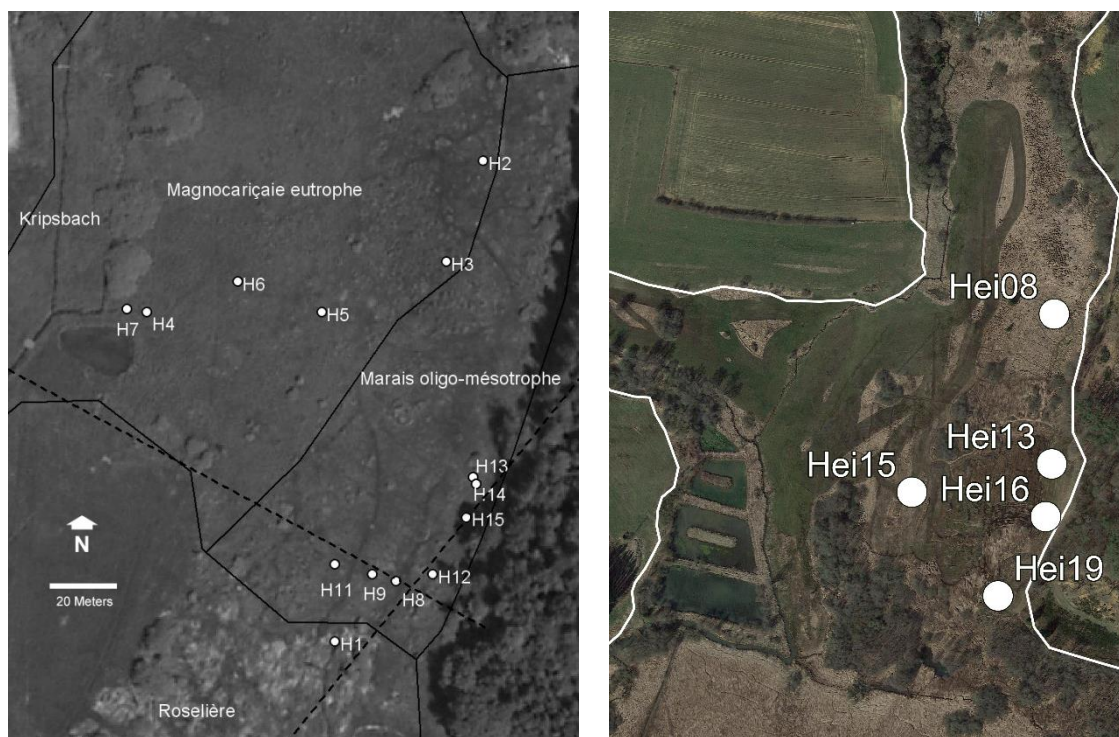


Figure 39. Left: position of relevées made in 1977 along two transects (dotted lines) and 2010 (dots with a code starting with "H"); Right: position of relevées made in 2020.

When the relevées of 1977, 2010 and 2020 of this area are combined and re-analysed with an NMDS ordination (Figure 40) the picture changes. Indeed the relevées of 1977 and 2010 lie very closely together and overlap to a large degree, showing that there has hardly been any shift in vegetation composition during that period. This is, however, not the case for the relevées of 2020 which are clearly separated from the two other groups (Figure 40).

Table 2. Average Ellenberg indicator values in the alkaline fen area along the eastern edge in different years

Year	Light	Moisture	Reactivity	Nutrients
1977	7.3	8.7	6.2	4.4
2010	7.2	8.5	6.2	4.1
2020	7.1	8.0	5.5	4.1

Vegetation indication values cf. (Ellenberg et al. 2001) show clear changes, especially for the parameters 'Reactivity' (=acidity) and moisture (Table 2). Both parameters have decreased, showing a shift from wet alkaline conditions in 1977 towards less wet, less alkaline conditions in 2020. In other words, these indicator values strongly suggest that the influence of alkaline groundwater has

diminished. Indication values for nutrient availability and the closely associated values for light/productivity have changed much less.

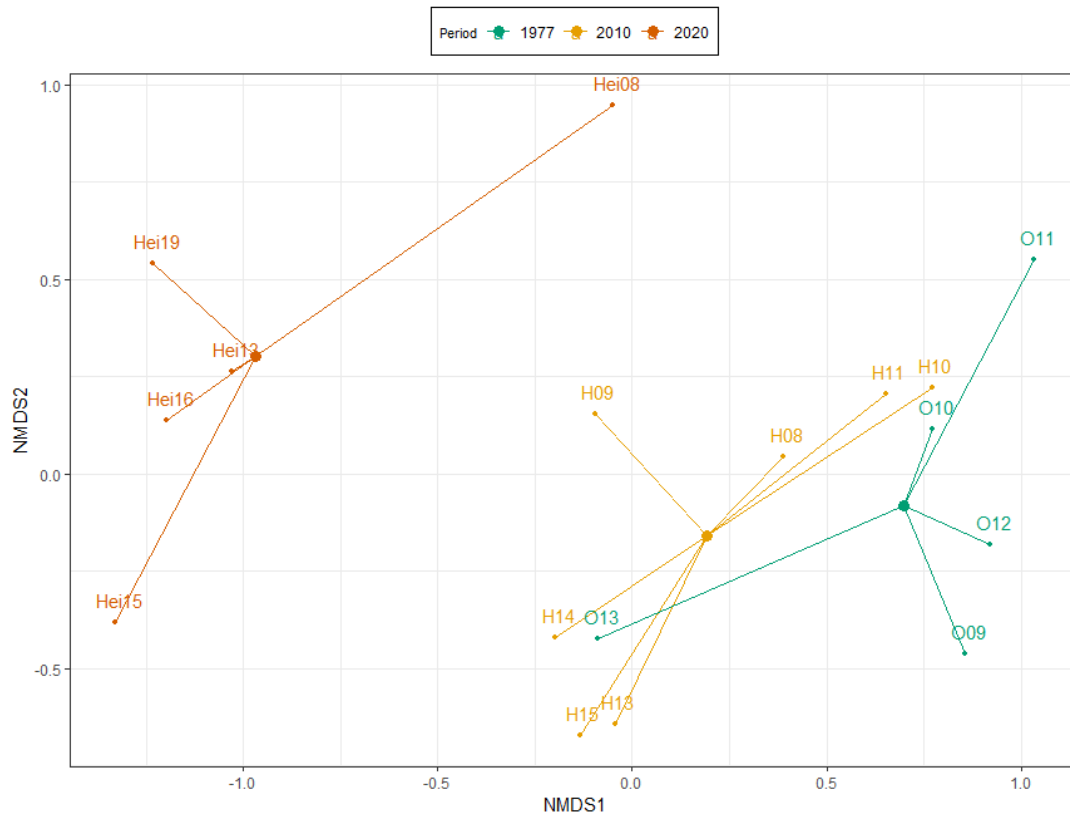


Figure 40. NMDS ordination of relevés of the alkaline fen vegetation along the eastern edge from 1977, 2010 and 2020

5.3 Interpretation of local functioning

The more detailed analyses confirm the conclusions of previous chapters that in the central and western part of the Marais de Heinsch there is no upward groundwater movement but instead the groundwater moves downward. Combined with a still existing and still partly functioning drainage network this implies that water table fluctuations have increased, leading to a slow but continuous decomposition of the existing peat layers. On the one hand this increases nutrient availability and thus biomass productivity, on the other hand this releases Ca and other base cations that are contained in the peat. In the short run this results in eutrophic and base-rich conditions, in the longer run this leads to acidification. Without detailed measurements on decalcification rates a determination of the length of the period with stable and high pH is not possible but most likely it will take at least several decades before acidification will occur over large surfaces. However, the first signs of acidification are already visible in the soil pH. At present most of the area is suited for eutrophic vegetation. Depending on the management type it will develop into woodland (no mowing), large sedge or wet meadow vegetation (mowing in summer) or reed beds (mowing in winter). In this part of the Marais the occurrence of alkaline fen vegetation is extremely unlikely.

The analysis also points to the existence of a zone with upwelling groundwater along the eastern edge of the Marais. This zone is, however, narrow and small and has most likely decreased in size in the last

centuries. An important reason for this decrease are the remnants of the former drainage network that still function and drain away much of the groundwater. In such way lowering the influence of groundwater over larger surfaces creates 'space' so that polluted water coming from the north can enter this zone. This results in largely enhanced nutrient availability and leads to a shift in vegetation composition from low productive fen vegetation to high productive marsh vegetation with species like *Typha* and *Phragmites*. As a consequence the sites with the highest botanic value that are now covered with a vegetation that is related to alkaline fen vegetation are not in the center but on the edge of the part with the strongest upwelling of groundwater. The more south one goes along the eastern edge of the Marais, the smaller the influence of groundwater is and the larger the effect of rainwater. In the most southern part of this zone the soil is already acid and the fen vegetation here consists, despite continuous mowing, not of alkaline fen vegetation but of poor fen vegetation. Also in the site where there is now still a vegetation type that is similar to alkaline fen vegetation the development of Ellenberg indicator values from 1977 to 2020 clearly show a shift towards acidification.

5.4 Conclusions on local functioning

Conditions inside the Marais de Heinsch are diverse but increasingly less suitable for the conservation of alkaline fens:

- Groundwater inflow occurs only in a narrow zone along the eastern edge;
- Ca-richness in the rest of the marais most likely results at least partly from anaerobic decomposition of alkaline peat instead of from groundwater inflow only;
- A major reason for the anaerobic decomposition are enhanced nitrate and sulphate-levels, mainly caused by the inflow of polluted ground- and surface water;
- Biomass productivity in the area is limited everywhere by Nitrogen availability;
- Soil N-availability of the top layer is very high almost everywhere throughout the area. Deeper layers (20-30 cm) are often N-meso or N-oligotrophic;
- Phosphorous availability is high throughout the area except for deeper layers (20-30 cm) in a few sites;
- Vegetation development points to a decreasing influence of alkaline nutrient-poor groundwater, even in the sites that are now covered with alkaline fen vegetation.

6 Recommendations for management

Based on the local and regional functioning of the area as described in the previous chapters we come to the following management recommendations to maximise chances for alkaline fens:

- The decrease of external nutrient input has the highest priority. At this moment conditions for alkaline fens are only suitable in a few small spots and even there the trend is negative, thus decreasing future conservation and restoration prospects. As long as biomass productivity is limited by nitrogen instead of by phosphorus the focus must lie on lowering nitrogen input via atmospheric deposition and inflow of nitrogen-loaded ground- and surface water. An assessment of the relative impact of the different nitrogen sources is beyond the scope of the present study but some general recommendations can nevertheless be made. (1) Nitrogen emissions from the nearby motorway are released close to the ground and therefore the reserve can to some degree be shielded from them by trees. We advise to isolate the motorway as much as possible from the reserve by planting buffering trees. (2) The input of polluted surface water from the overflow of the sewage pipe and the landfill into the peatland can be prevented by hydrological construction works. (3) Nitrogen input via the groundwater can be lowered by (more) strict regulations regarding fertiliser use in the infiltration area.
- Decreasing internal drainage is a second priority. Presently there are a large number of smaller and larger ditches that still function partly and drain a significant part of the peatland. In parts that are not supplied with upwelling groundwater -predominantly the western half of the reserve- this enhances water level fluctuations and stimulates mineralisation, thus increasing nitrogen availability. It also leads to acidification by infiltrating rainwater, the least in the zone along the eastern edge where calcareous groundwater wells up but even there there are locally signs of acidification. Keeping buffered ground- and surface water longer in the area lowers the acidification rate and can in areas with a strong upward groundwater flow even increase pH. However, as long as the nutrient load of ground- and surface water has not decreased, lowering drainage will also keep nutrients longer in the system, thus increasing eutrophication risk. Lowering drainage intensity should therefore be carried out in small steps and adapted whenever negative effects occur. The effects of rewetting are especially beneficial when the external nutrient load has diminished significantly.
- Locally top soil removal and species introduction may be considered. Top soil chemistry in most of the area lies far outside the tolerance of alkaline vegetation and even in sites where such vegetation is present at the moment the conditions are only marginally suitable. The removal of degraded topsoil to a depth where conditions are better suited is a technique that can considerably improve restoration prospects via seedling establishment. In the Marais de Heinsch suitable C/N and C/P ratios are measured at a depth of c. 30 cm in a few places along the eastern edge. In practice such restoration would therefore imply topsoil removal of c. 30 cm, more shallow removal would temporarily lower competition with existing vegetation but not structurally lead to better soil conditions. Moreover, for low productive alkaline fens such technique makes only sense when the external nutrient input has been minimised, otherwise conditions will again deteriorate rapidly. Top soil removal and species introduction therefore should be carried out only when the other restoration measures mentioned have been carried out.

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