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Geomorphic change and its impact on floodplain vegetation in a lowland river system (River Ingrebourne, Ingrebourne Marshes SSSI)

Mots clés : Marais - fen,

Marécages - marshes,

Gestion de l'eau - water management,

***Phragmites australis*, roseau - reed,**

Photographie en vue aérienne – UAV pictures

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Summary

The Ingrebourne marshes is a lowland fen, flooded by the Ingrebourne River that flows in the middle. In 1989, it was classified as Site of Special Scientific Interest by Natural England for its wildlife and extensive area of reeds. The variety of habitat includes extensive area of Common reed *Phragmites australis* and Reed sweet grass *Glyceria maxima* swamps, wet neutral grassland and tall fen. It is the home of lot of breeding birds and macroinvertebrates.

In 2009, Natural England highlighted shared issues such as Himalayan Basalm presence, build-up of litter, in some places, a particular dense section had high cover of nettles, and the reed provided a low structural diversity for invertebrates due to their uniform age. In some area, *Typha* and *Phragmites* are invading the *Glyceria* bed. The cause of these issues was mainly agriculture, with inappropriate mowing and cutting, and freshwater invasive species near to a pond.

To understand the reason for this change in the plant dynamics, we used UAV pictures that were merged, so as to form an orthomosaic. The orthomosaic were classified in Arcgis so as to be able to identify each vegetation community, and to obtain a relative percentage cover of each. We would like to observe the gradient of vegetation in the reed bed from the river channel to the trees; and also to see the gradient of vegetation from upstream to downstream into the fen habitat. We also would like to see if, since the 2009 assessment, the vegetation has continued to evolve, and toward what… A better or a worse condition for the fen habitat?

This vegetation study is followed by a hydrologic study, as a fen habitat is conditioned by the water level in the ground, and by the river floods. Finally, the geomorphology of the river has been studied since 1960, with the hypothesis that a narrowing of the channel has increased the water level in the channel and impacts the marshes around.

Preamble

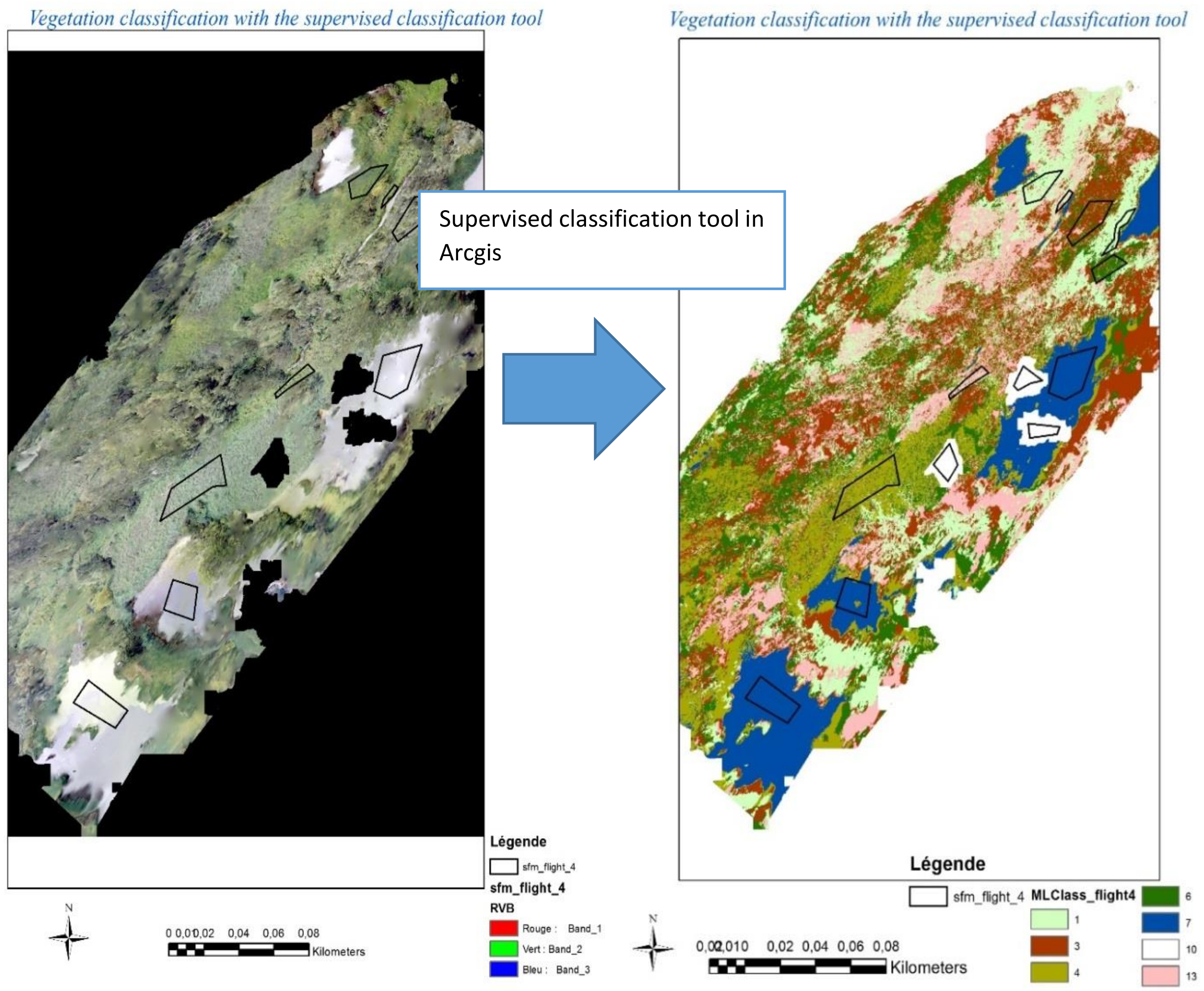
The Ingrebourne Marshes is a Site of Special Scientific Importance (SSSI), located to the east of London, UK, which is protected for its freshwater marsh vegetation assemblage. Whilst the majority of the SSSI is in favourable condition, large sections of the marshes that adjoin the Ingrebourne River were reclassified to unfavourable condition in 2009/10, primarily because of an expansion of common reed, *Phragmites australis*, and a transition to wetland carr habitat. At the same time, concern has been raised about the ecological status of the Ingrebourne River under the Water Framework Directive, with excess fine sediment cited as a significant negative pressure on the formerly gravel-bed river.

The aim of the study is to quantify any changes to the vegetation community, any change in the hydrology of the river and changes in the long profile of the river (e.g. aggradation of the bed due to fine sediment deposition)

This project will be built on the work conducted in last year's group project. It will assess the current and historical vegetation community using field surveys and 2014 UAV pictures for the current, and 2009 assessment by Natural England for the historical data. This project is followed with active involvement from the Environment Agency and Natural England.

In order to use the 2014 UAV pictures, a new method was developed: they were merged by a specialised software that create orthophoto with different aerial photo taken with different angles. A decade of pictures can create one orthophoto, geolocalised. The deformation is due to the difference of angle and distance between the different photos. After, the orthophoto was classified by identifying each patch of the same vegetation community with a tool in Arcgis.

Merged with Agisoft to create one orthophoto



Then, each class was linked to a surface area by multiplying the number of pixel of a class by the pixel size. The relative percentage cover were calculated for each class by dividing the surface of one class by the sum of the others. Thanks to this, comparisons between maps are possible. When studying all the vegetation data, we were able to find that the marshes vegetation is in decline since the 2009 assessment.

A hydrologic study was also done in the river Ingrebourne, the river flowing into the marshes. We found an anthropic hydrologic alteration leading to a dryer period for the river. This may be a reason for the vegetation change in the marshes.

At the same time, a study of the geomorphology of the river was run to observe the changes in the channel morphology since 1960. A narrowing and cut-off meanders were observed, probably linked with the excessive sedimentation in the river. This change in the morphology may impact the fen habitat around, as the water level in the channel has increased, modifying the vegetation community dynamics. Moreover, we found out that the marshes is probably a sediment deposit place, and this fine particle may impacts the vegetation ecology.

This study is principally desk-based and a more field-based work would be needed for a better understanding of the environment. This study does not claim to be exhaustive, it is not a full diagnostic of the fen habitat.

Summary

Introduction

This project is supported by the Cranfield Water Science Institute at Cranfield University, in partnership with the Environment Agency and Natural England. The Cranfield Water Science is recognised for its research and teaching in the science, engineering and management of water in the municipal, industrial and natural environments. My supervisor, Robert Grabowski is a professor and gives lectures on catchment science, working in fluvial geomorphology research.

Ecology of a fen habitat

The Ingrebourne Marshes was designated as a Site of Special Scientific Interest (SSSI) in 1988, it contains the largest continuous area of freshwater reedbed in London, and one of the largest in the country. This base rich fen mosaic covers more than 50 ha. The variety of habitat includes extensive area of Common reed *Phragmites australis* and Reed sweet grass *Glyceria maxima* swamps, wet neutral grassland and tall fen.

The ecology of a fen rely on its ability to capture nutrients from groundwater, rainfall and surface water. In the case of the Ingrebourne marshes, which is a topogenous floodplain fen, water movement is mainly vertical and overland flows from the river, resulting in water ponding in depressions such as valleys, basins and floodplains. But this fen classification is not set, as it may vary during the year, groundwater seepage might be important in spring when the groundwater tables are high, whilst the same fen might predominantly receive input from surface water via ditches in the summer. (*Understanding fen hydrology*, 2014)

High soil water level is necessary for the functioning of a fenland, therefore, a basin topography and a groundwater or surface water reliable supply is mandatory. High frequency and low magnitude flood events are important for the sediment supply and the plant ecology.

Reedbeds are dynamic ecosystems, the temporal and spatial variation are significant for the fauna and flora diversity of the fen habitat. Traditional management practices that maintain a range of successional stages is the best for their conservation. (Graham, Self and Blyth, 2014) A glossary of management practises is presented in appendices 1. The water regime is also crucial to the management of a reedbed.

To manage the marshes, Natural England divided the SSSI into 10 units, rated in how they achieve their specifications. Since 2009, Natural England has found 4 areas judged “unfavourable” due to the presence of negative indicator species (competition between *Phragmites* and *Glyceria*, presence of nettles within the beds); the presence of *Himalayan Basalm*; a dense litter cover and the scrubs and wood encroachment.

In the table below, we can see the reasons for "unfavourable" designation for each unit and the associated map of the units:

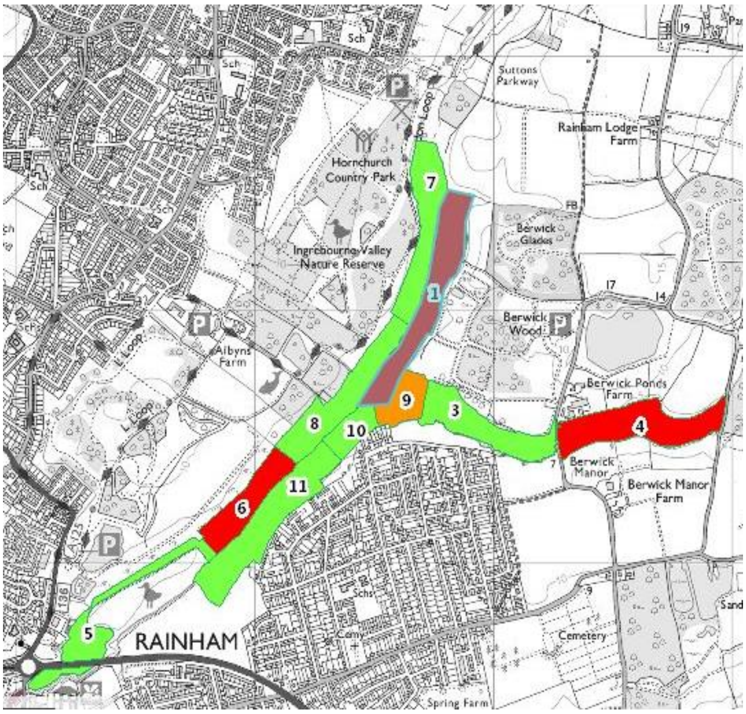


Figure 1: map and table of the SSSI designation- Natural England

Unit 1	The *Glyceria maxima* beds are unfavourable due to: - dense litter cover -presence of *Himalayan basalm* - presence of negative indicator species - woody species covering more than 10% of area
Unit 4	-*Himalayan Basalm* -build-up of litter
Unit 6	Reedbed are unfavourable due to: - Dense litter cover - high cover of undesirable species (nettles within reedbed) - a lack of structural diversity within the unit (i.e. dense reeds of similar age with no structural variation).
Unit 9	The Glyceria maxima beds and Reedbeds are unfavourable due to: - dense litter cover - presence of Himalayan balsam; presence of negative indicator species - *Typha and Phragmites* are invading the *Glyceria bed and Typha* is invading areas of reed. There are also areas of nettle within the *Glyceria* bed.

It is important to understand the macrophyte ecology to adapt the management and restoration practises.

Vegetation competition

Lowland vegetation can be in water level competition, in fact, *G. maxima* grows well on wet area with water up to 75 cm deep and satisfactorily even at depths of 1.5 m. *G.maxima* is a year-round deep water plant. The best conditions for the extensive reed sweet-grass development is when winter flooding and silt deposition are most regular, and when the ground stays wet during the summer.

The *Phragmites* reeds acclimatize to grow in a wide range of water depths, which varies from –0.6 to about 1.0 m (Liu, 2009). Reeds are found in seasonally flooded zones in which water level does not exceed 0,5m. Moreover, neglected reed communities often have a build up litter which might choke young shoots and will eventually dry out the marsh. [..] Restoration is most easily achieved by a controlled of the standing vegetation followed by a rake and burn of any residual litter. (Haslam, 2010)

With *Typha. latifolia*, controlled experiments showed decreased rhizome production at water levels above 30 cm (Weller, 1975). *T. latifolia* died in water depths over 95 cm and density was greatest at 22 cm depths in experimental ponds in Arkansas (Grace, James and Harrison, 1985). *T. latifolia* has been found to tolerate drying of wetlands over several months (Fickbohm and Zhu, 2006)), but perish if water was drained for a period of 2 years (Nelson and Dietz, 1966).

Phalaris arundinacea grows in saturated soils, or nearly so, for most of the growing season, but where standing water does not persist for extended periods. It tolerates extended periods of inundation. (Stace, 1997)

In the case of the nettles, Greig Smith reported in 1984 the Great Britain growth of *U. dioica* on almost all soil types, but noted its absence from waterlogged soils. The nettles are, in the succession reed bed diagram, in the dry area near to the willow.

Typha is more dry-tolerant than *Phragmites*, and even more than *Glyceria*, so it may invade the *Glyceria* and *Phragmites* reed beds. *Phalaris* does not tolerate standing water for extended period, however, it is present throughout the reed bed, so it may be a sign of drying. The presence of *Himalayan Basalm,* which grows on fresh to wet soils, could show dryer conditions.

Fluvial geomorphology

The river flowing in the middle of the fen habitat impacts the ecology of the system. (Figure 2)

Figure 2: picture of the Ingrebourne river into the fen habitat, wikimedia

For example a change in the morphology of the river, because of excessive sedimentation or a channel choked with plants, increases the water level in the channel, and impacts the habitat.

Aim and objectives of the study

The aim of the project is, on the one hand, to provide for a better understanding of the ecology of a lowland floodplain habitat. We will identify the main vegetation communities. Vegetation communities in this type of habitat are linked with other factors like the water level, the water quality, changes in the channel, sediment interaction, nutrients supply, management and practices in the area (grazing, cutting, dredging), urbanization…

Moreover, we will investigate the factors responsible for changes in vegetation communities in a lowland floodplain fen, the Ingrebourne Marshes (Essex, UK). The study uses a range of data to document changes in vegetation and the hydrological and anthropogenic factors driving a shift towards a drying of the fen habitat.

The hypothesis is that an imbalance in flows in the river channel, in particular a decrease in water level, could have led to a modification of the vegetation community dynamics along the river, in the fen habitat.

On the first hand, the vegetation dynamics will be studied, with a fieldwork map and 2014 UAV pictures. After, we will focus on the hydrologic aspect of the river, and the hydrology of the fen habitat. Thirdly, the geomorphology of the river will be studied with the digitalization of the 1960 channel and 2015 channel.

1. Material and methods

1. Site description

The Ingrebourne catchment includes the cities of Brentwood in Essex and Harold Hill, Hornchurch, Upminster and Rainham in the London Borough of Havering. (Figure 3)

Figure 3: Ingrebourne river catchment and marshes location (Despinasse et al.*, 2016)*

The Ingrebourne River is a 43.3 km length river, tributary of the Thames, in the London Borough of Havering (Nord East London). The lower part of the Ingrebourne catchment (between Upminster and Rainham) is a protected floodplain wetland named the Ingrebourne marshes. This type of environment is important for many reasons: it prevents flooding by a buffer effect, and thereby helps keep the river levels normal. Wetlands are also a niche for biodiversity: it releases plant matter into the channel which helps feeding fish, animals like amphibian and birds take shelter into wetlands during their migration and reproduction. However, this ecosystem involves controlling erosion; emergent plants have the capability to slow the water flow by increasing the roughness and permits to counter the erosive forces. Wetlands also clean the water by their ability to recycle nutrients, filtering out sedimentation, and decomposing vegetative matter. (Eau France, 2017)

Nowadays, the interactions between the sediment layer, the water quality, the management practises, the vegetation in the marshes, the flow regime are not very known to well understand this type of wetland.

2. Vegetation community dynamics

It is an uncommon mix of freshwater marshland habitat, which supports an assemblage of invertebrates and breeding birds. Reedbed are among the most important habitat for breeding birds. The site hosts a large diversity of birds including kingfishers *Alcedo atthis*, redshank *Tringa totanus*, lapwing *Vanellus vanellus*, yellow wagtail *Motacilla flava,* tufted duck *Aythya fuligula*… For invertebrates, the marshes includes 16 nationally scarce fly, beetle, dragonfly and cricket species. It is also the home of water voles. (Essex wildlife trust, 2014)

Reed swamps have 20 cm or more water level during the summer, composed in majority of *Glyceria maxima*. Some other plant species are present such as the occasional water dock *Rumex hydrolapatham*, purple loosestrife *Lythrum salicaria* and cerely leaved buttercup *Ranunculus sceleratus…* The two large reed beds are located on the western flood plain of the River Ingrebourne, and the other within a reservoir named Berwick Pond.

In the shallow standing waters can be found tall fen communities. Reed sweet-grass is abundant, but the coverage is lower than in swamps and allows a greater diversity of other plants. There are yellow flag *Iris pseudacorus*, nodding bur-marigold *Bidens cernua*, hairy willowherb *Epilobium hirsutum*, tufted forget-me-not *Myosotis caespitosa*, amphibious bistort *Polygonum amphibium*, water pepper *P. hydropiper* and greater reed-mace *Typha latifolia*. (London Borough of Havering, 1988)

Reedbeds are dynamic ecosystems, the temporal and spatial variation are significant for the fauna and flora diversity of the marshes. There is a gradient associated with the distance from the river channel: near to the channel, the predominant habitat is the reed swamp, where the reeds are permanently wet. With the distance of the channel, reeds are drier and drier, until the old reeds with litter, which are dry in summer. The border of reedbed is usually scrubs and trees.

Traditional management practices that maintain a range of successional stages are the best for their conservation. (Graham, Self and Blyth, 2014) The water regime is crucial to the management of a reedbed.

3. Methods

a) Vegetation community dynamics

This study will focus on the water level effect on wet plant communities. First of all, we will use historical data such as the 2014 UAV pictures and the 1989 and 2009 Natural England data. A field survey has been done in June 2017 with the quadrat method. We use different books to identify the British water plants. (Haslam, Sinker and Woseley, 1979); (Spencer-Jones and Wade, 1986) and (Sterry, 2006). We were able to go in a small area because a big extent of the marshes is inaccessible by foot. (Fences, ditches, cattle grazing)

In the vegetation survey, the goal was to take a look at the current plant communities in this area, to use quadrats method to identify each plant, and to walk in the area with a GPS to map the vegetation community boundaries. After, an Arcgis map was drawn.

With the 2014's UAV pictures, the software used to process the data was Agisoft, which is a software of Structure from motion (SFM). It performs photogrammetric processing of images and generate 3D spatial data. The UAV pictures were merged, and an orthomosaic was created. We manage to create 4 orthophoto that represents 4 different marshes localities.

Using supervised image classification tool in the Spatial analyst extension in the orthomosaic allows us to have the area of each plant community. The supervised classification uses the spectral signatures obtained when you select a training sample that represents the class you want to extract. After, a Maximum likelihood classification was made from the Image classification toolbar. It assigns each pixel to one of the different classes based on the means and variances of the class signatures. We obtain colored area for each plant community. Same type of work was released in another scientific paper. (Lück-Vogel and Mbolambi, 2016)

The Figure 4 below shows the location of the 2014 UAV pictures classified (Area 1 to 4) and the location of the vegetation survey (fieldwork vegetation sampling in green).

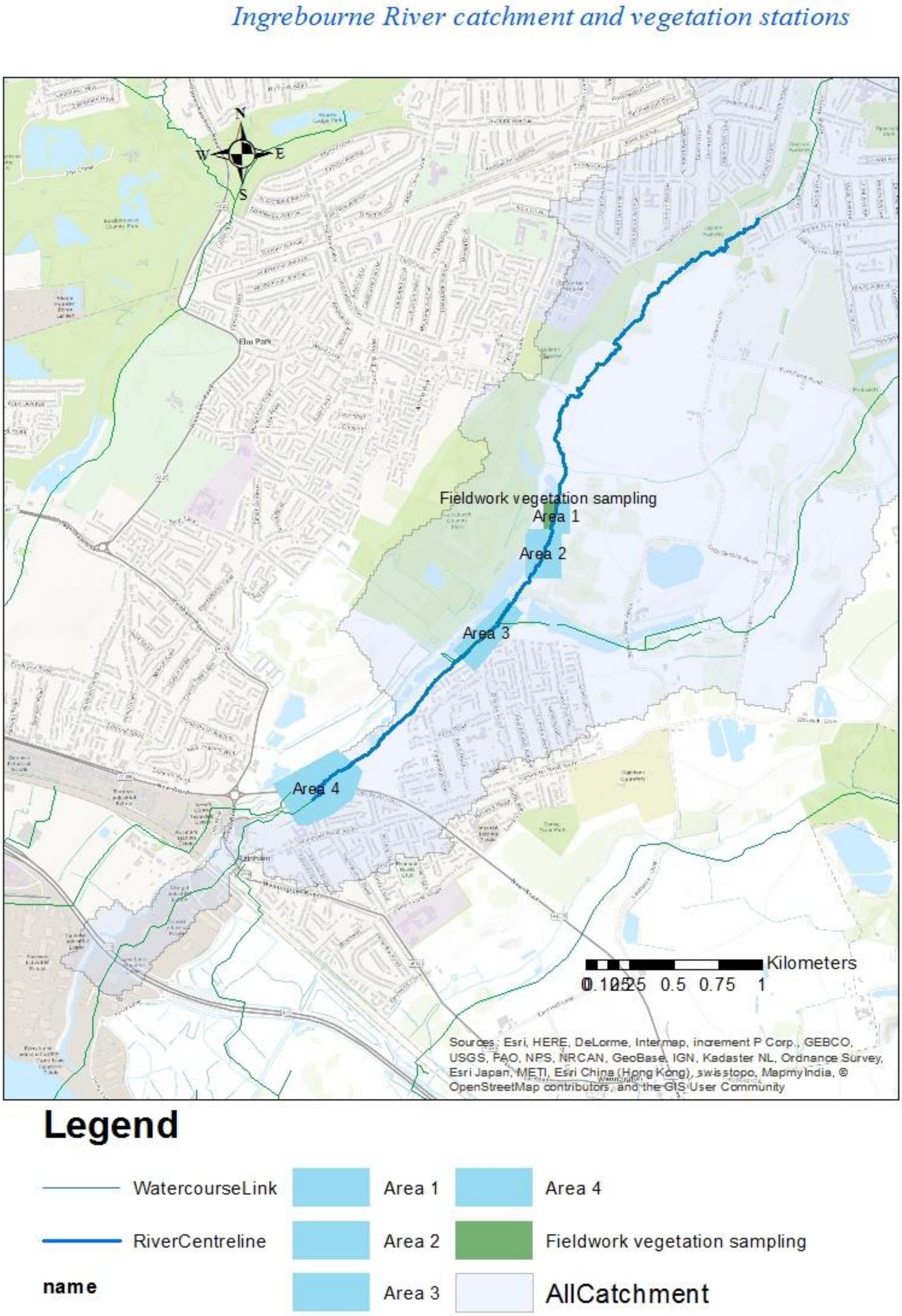


Figure 4: Vegetation stations location in the Ingrebourne Marshes

With Excel, a relative percentage cover of each vegetation type was calculated for the orthomosaic and for the vegetation map. The 2 diagrams created allow us to compare the vegetation communities. We also have tested the reliability of the method with a confusion metrics method by comparing the vegetation map obtained with fieldwork and the same classified area obtain with UAV photo.

To test the image classification method, an idea was to compare 3 different orthophoto of the same area, in order to see if the classification tool is reliable if we change the picture quality. The first attempt was constituted of 10 photos, with 6 aligned by the software. The second attempt was with 20 photos, with 18 aligned. The third attempt was 27 photos and 26 aligned. The second and third attempt was composed of the same flight pictures (approximately same angle and distance UAV photos).

b) Hydrological changes over time

Then, we studied the hydrologic evolution since 1970 for the Ingrebourne River at the Gayne Park Gauging Station (The more upstream point in Figure 5).

Water level data was acquired from the Environment Agency for two locations in the marshes (in the Hornchurch Country Park, in the middle and in the New road station, downstream of the marshes in the figure beside).

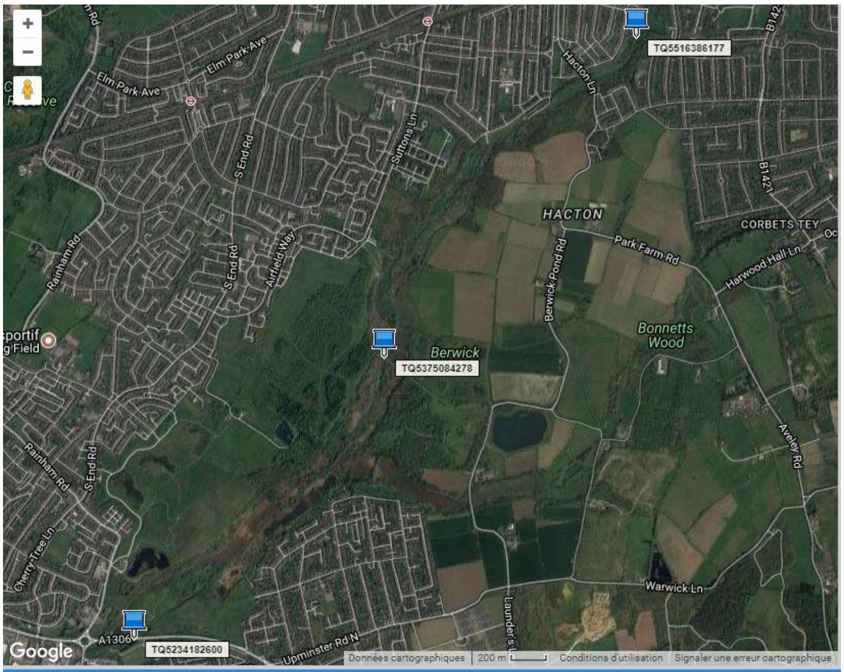


Figure 5: location of the gauging station

The data was analysed to prove an interaction between water levels in the marshes and plant shift with the hypothesis that a decrease or an imbalance in water level have brought new species.

The software Indication of Hydrologic Alteration (IHA) (Swanson, 2002) was used to study daily data flow in Gaynes Park Gauging station, just upstream of the marshes. This software is a suite of 33 hydrologic parameters that are ecologically meaningful and serves as indicators of anthropogenic effects on riverine systems.

c) Geomorphological change

We use 2 maps, done by a previous researcher, one in 1960 “National Grid” 1:2500 and one in 2015 “OS mastermap topography Layer” 1:1000, where the river channel was digitalised to allow us to compare the differences over time. With the “Symmetrical change” Arcgis tool, we calculate the shape differences.

The goal is to find if there has been a change in the channel shape, with the hypothesis that the channel has narrowed, and so the water level has increase in the channel and can disturb the ecology of the riparian vegetation.

2. Results

1. Vegetation community dynamics

We dispose of 2014 UAV photo taken by a previous group project. The 2014 UAV photos were merged into Agisoft, we obtain 4 orthophotos.

Normally, we should map all the marshes zones but the UAV photos have different angles, distance, localisation… and it was impossible to create orthophoto for all the marshes area. An example of an orthophoto obtained is presented beside (Figure 6):

Figure 6: orthophoto of the first area of the marshes

Next, we would like to be able to run a supervised classification in these photos. (Figure 7 to 11) First, the method was to go on the field and identify single species stand. These identified stands allow to calibrate the classification.

Figure 7: a glyceria maxima stand taken in a vertical photo

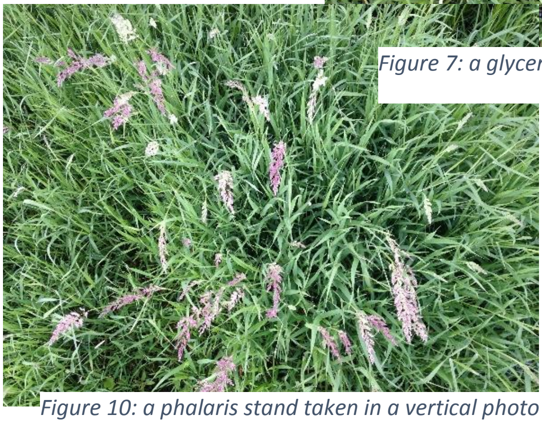


Figure 10: a phalaris stand taken in a vertical photo

Figure 11: a phalaris stand taken in a vertical photo

Figure 9: a young phragmites stand taken in a vertical photo

Figure 8: an old phragmites stand taken in a vertical photo

We observe that *Phalaris* stand can have purple spike or yellow-white spike. We observe also that there are two types of *Phragmites* stands: young that are green blade and old that are browner.

Then, a field map was designated in Arcgis (Figure 12) to have a reference and be able to compare the plant on the field and the plant seen in the UAV photos. We use the quadrat method in transect and we localise plant stands with the GPS.

Vegetation map in an area of the Ingrebourne Marshes

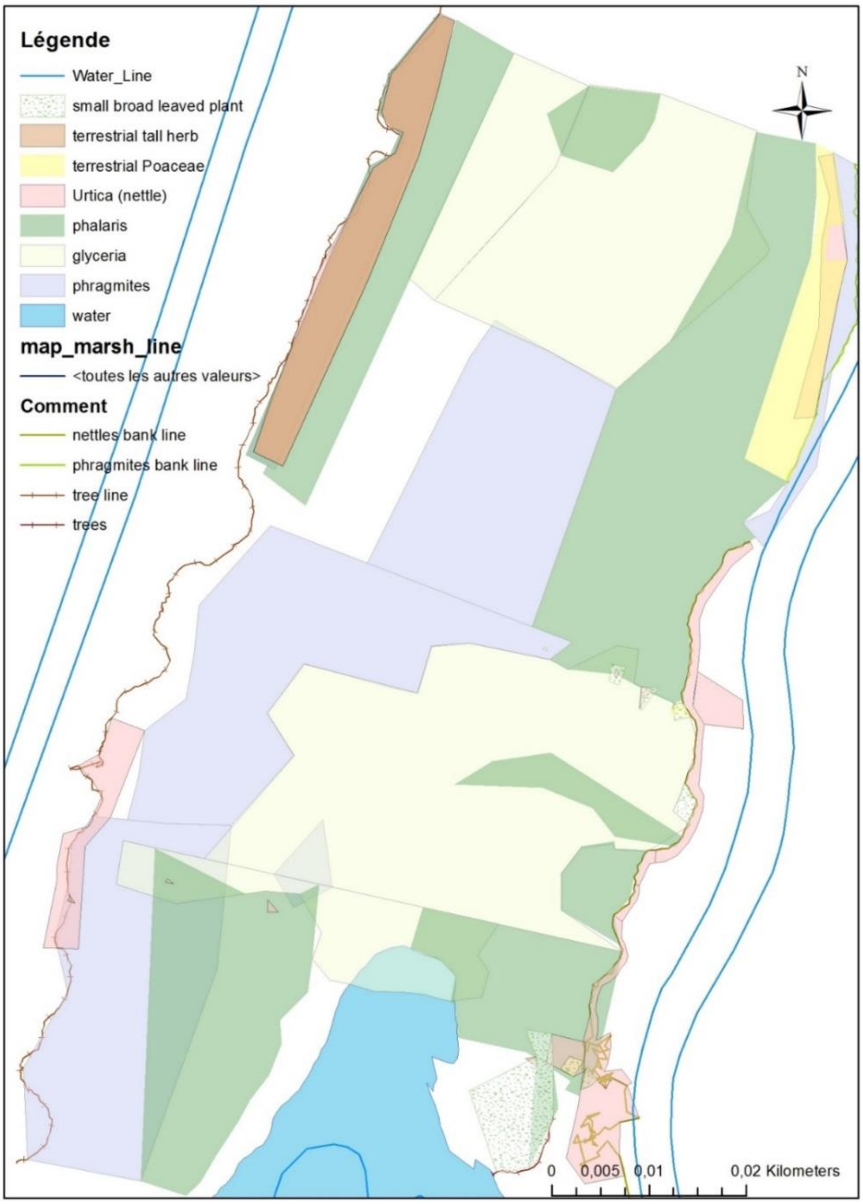


Figure 12: Vegetation map of an area of the marshes using quadrats and GPS method

The river is located in the east of the map, along the vegetation. We can see a gradient from East to West, with distance from the river. Along the river, we have nettles or *Phragmites*. In the northeast, there are terrestrial *Poaceae* which forms a meadow habitat. After, we have patches of *Glyceria* or *Phalaris*. Then, big patches of *Phragmites* are found. At the Northwest, there are patches of terrestrial tall herb mixed with nettles, *Phragmites and Phalaris*. At the extreme west, we have tree lines, mainly composed of *Salix*. There is a gradient associated with the distance from the river channel: near to the channel, the predominant species are the permanently wet reeds. With the distance of the channel, reeds are drier and drier, until the old reeds with litter, which are dry in summer. The border of a reed bed is usually scrubs and trees.

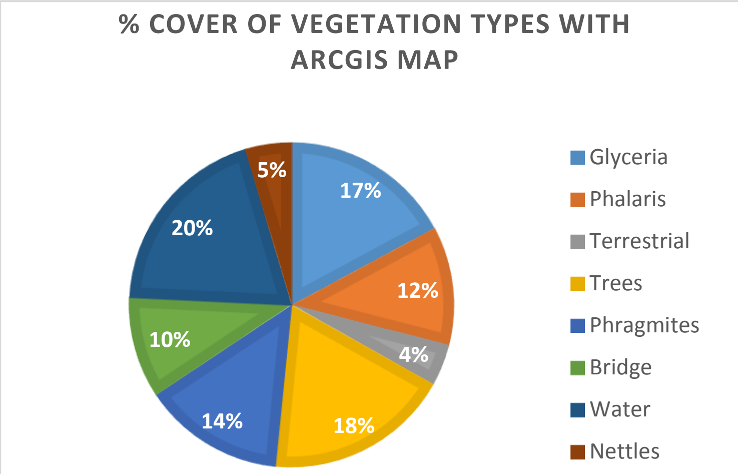


Figure 13: percentage cover of the Argis map designated with fieldwork

We can calculate the percentage cover of each vegetation type with Arcgis and do a pie chart. (Figure 13) The most represented vegetation plants in this area are the trees, after *Glyceria maxima*, *Phragmites autralis*, and *Phalaris arundinaceae*.

Nettles and terrestrial plant (like *Agrotis stolonifera*) are present, which are link to grazing in this area.

Finally, we launch the image classification tool in Arcgis in the 2014 UAV pictures, we obtained a vegetation classification like this (this Figure 14 displays 2 areas on the 4): The green colours are for the reed bed plant, the pink for the terrestrial, brown for the trees, and blue for the water.

Representation of the supervised vegetation classification for 2 areas in the Ingrebourne Marshes

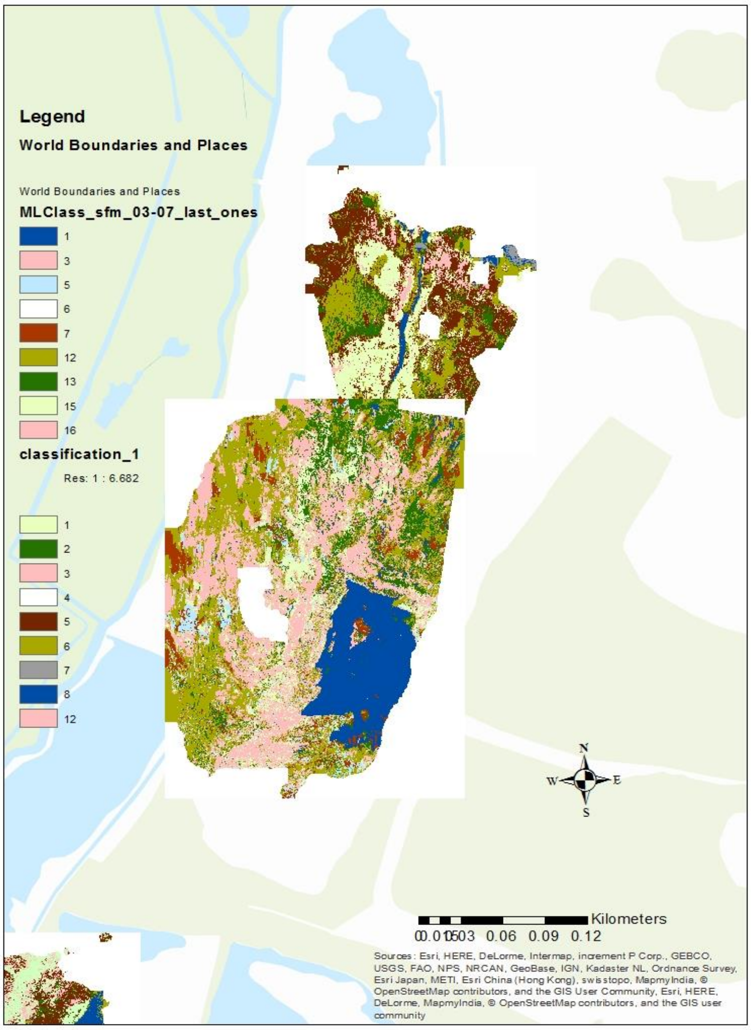


Figure 14: Representation of the vegetation classification for 2 areas of the marshes

We can see that patches of terrestrial (nettles, *Agrostis stolonifera*) are present in the reed bed.

To test the reliability of the method, we use a confusion metrics, which compares the result given by the model and the real result on field. In the field, we did 4 quadrats (Q1 - Q4) in 2 transects (Transect 1 and 2) from the river to the tree line (East to West) (Figure 15). The figure 15 contains also GPS information that helps to draw the field vegetation cover map seen on top (Figure 12). The field sheet is presented in appendices 2.

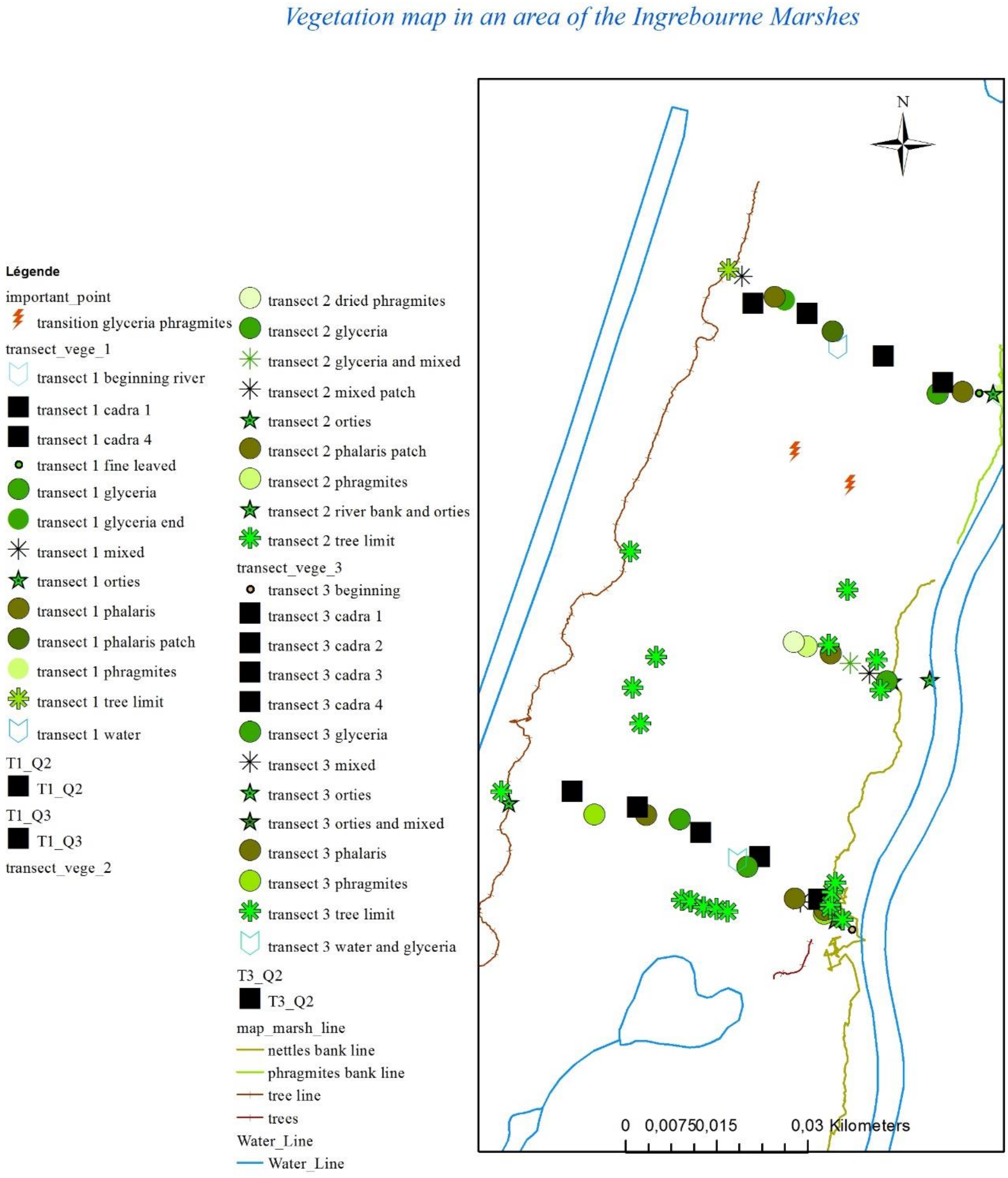


Figure 15: map of the 2 transect and quadrats location

Then, we compare the quadrat location and the image classification with the confusion metrics. (Table 1) P is for presence, A for absence. If the model predicted the presence of a species, and that in the field it was present, then the method is reliable.

Transect 1							
Phalaris species				*Glyceria* species			
	field				field		
model		P	A	model		P	A
	P				P	Q2 Q3	
	A	Q1 Q4			A		
Transect 2							
Phalaris species				*Glyceria* species			
	field				field		
model		P	A	model		P	A
	P				P	Q1 Q3	
	A	Q1 Q2			A		

Table 1 : confusion metrics

The *Glyceria* species seems better recognised by the classification software than the *Phalaris* species. We compared the percentage cover of each plant for the 2 methods, classified image and fieldwork-based map. (Figure 16)

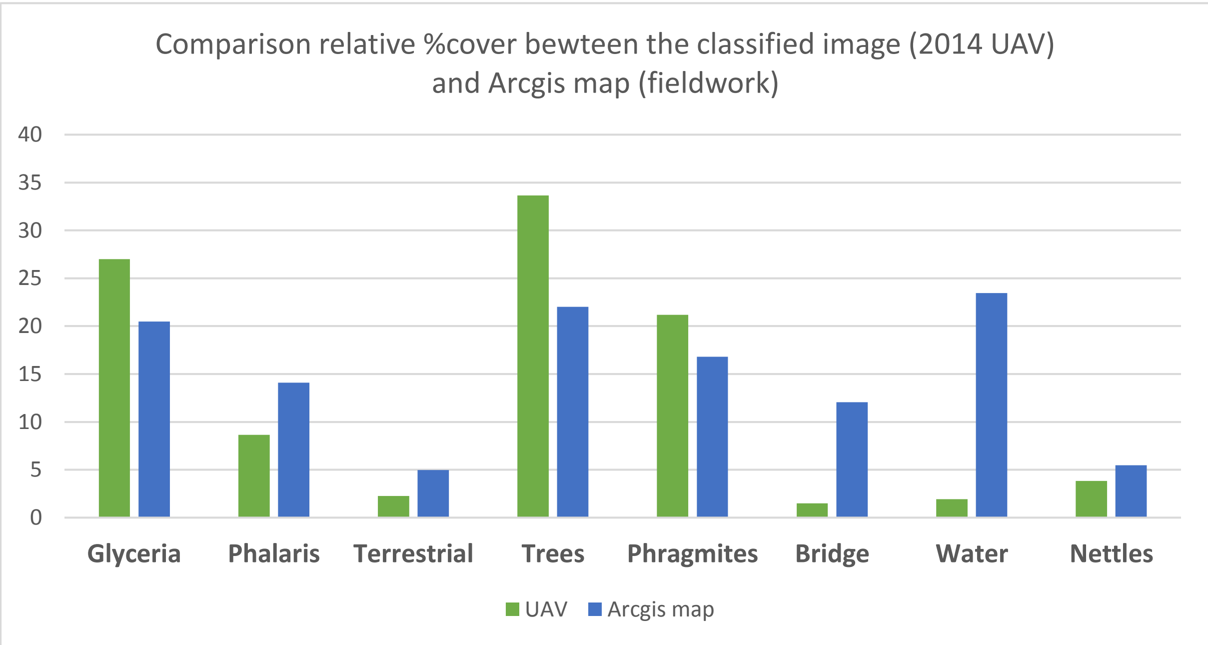


Figure 16 : comparison between the arcgis map %cover and the image classification

The plants seem well recognised, but there is a high difference for the recognition of the water and the bridge. It could be linked to the fact that the orthophoto shows a deformed view.

The classification image method was tested by using 3 different orthophotos of the same area, to see if the classification tool is reliable with the picture quality changing (Figure 17).

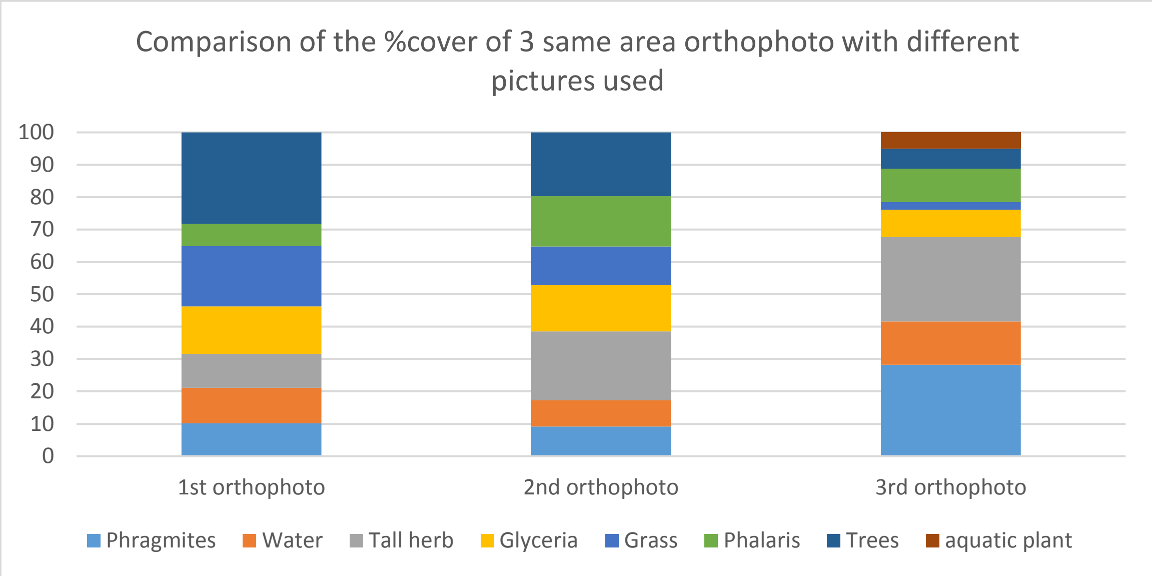


Figure 17: comparison of the %cover of 3 same area orthophoto with different pictures used

We can see that another class appears with the 3rd orthophoto that was more accurate (more picture used to create the orthophoto). This is this classified picture that we will be used in order to understand our vegetation evolution.

With these four 2014 UAV pictures which were classified, we can observe an evolution along the river channel of the vegetation types (Figure 18). The area 1 is the more upstream, and the 4 the more downstream in the marshes. A map shows the repartition of the different relative land cover (see appendices 3).

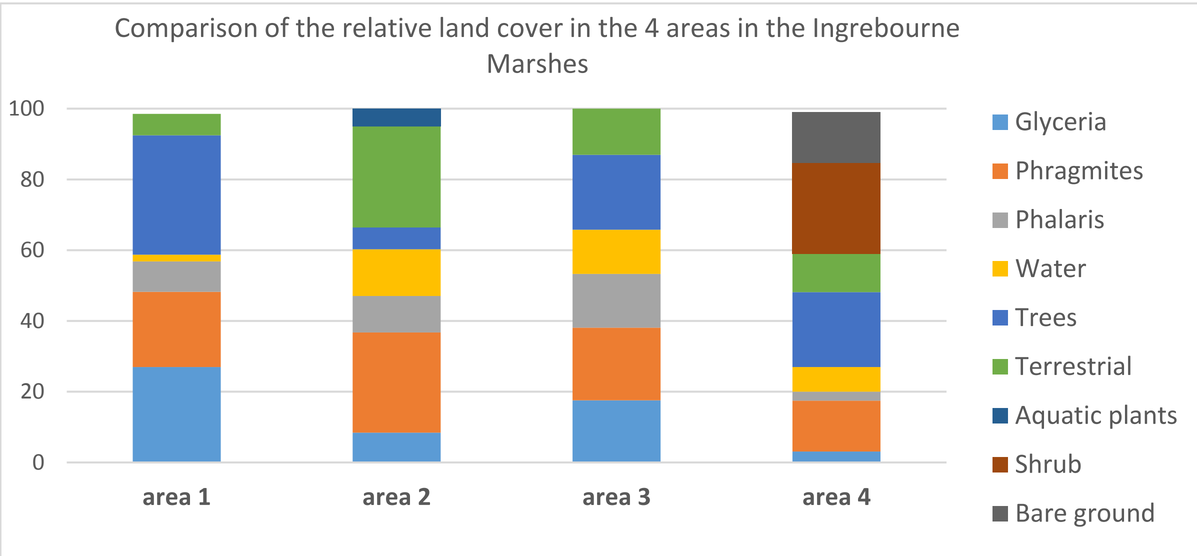


Figure 18: Comparison of the relative land cover in the 4 areas in the Ingrebourne Marshes

The vegetation in the marshes is evolving from upstream to downstream of the river, with more trees, shrubs and bare ground in upstream.

In the end, we obtain 4 supervised classification maps. We were able to superpose them with the SSSI units of England (Figure 19). Each classified map matches with a unit area. The map 1 and 2 form the unit 1 and 7.

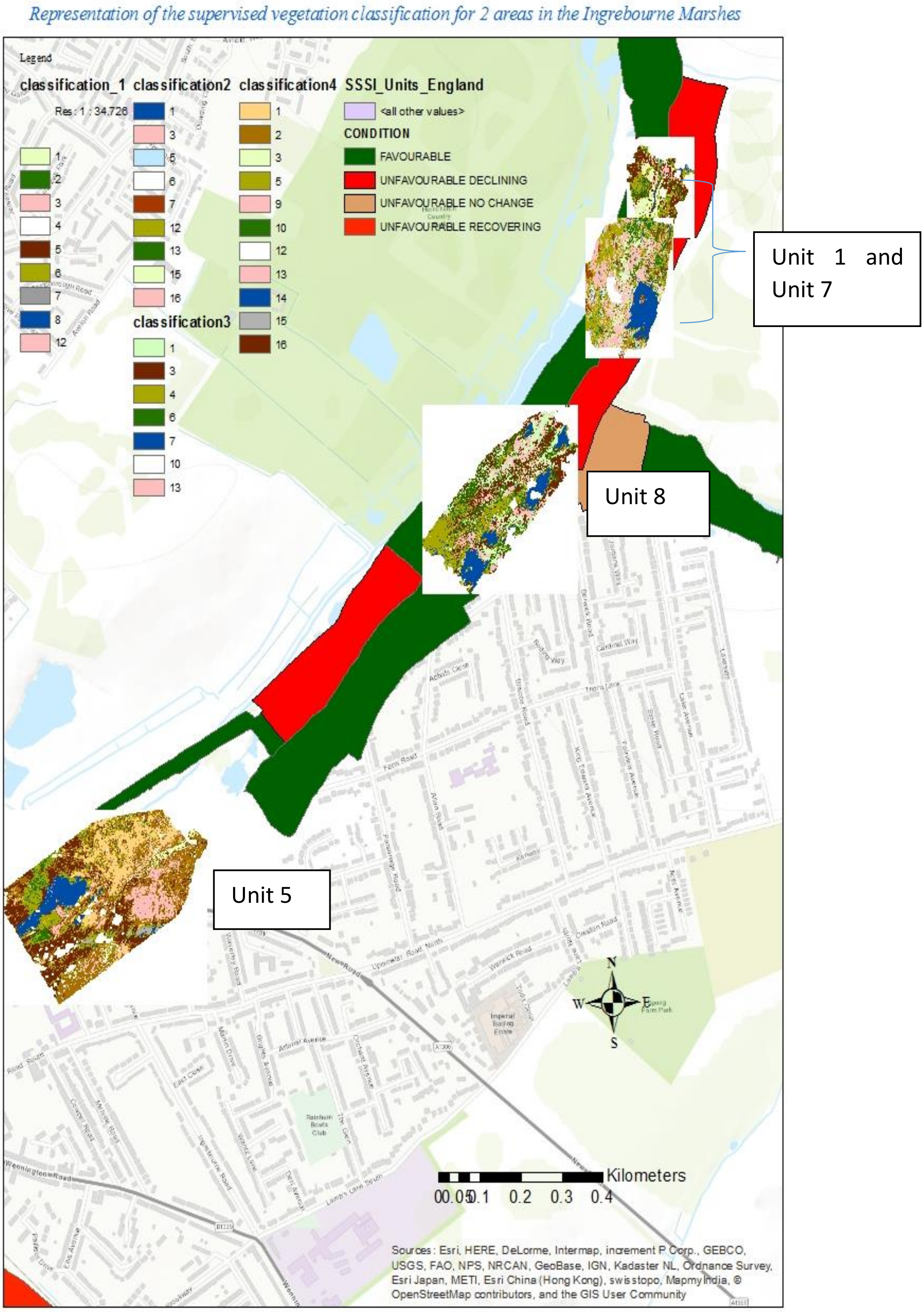


Figure 19: SSSI units and classified map

A summary table (Table 2: summary of changes between 2009 and current study) was set up to see the changes for each area between 2009 assessment by Natural England and the current study. If blank in the box, there was no change.

Table 2: summary of changes between 2009 and current study

	2009 assessment (Natural England)	**2014 UAV pictures/ fieldwork**
UNIT 1// UNFAVOURABLE	*Phragmites australis* and *Glyceria maxima* present	
	Indicators of negative change : the *Glyceria maxima* beds are unfavourable due to :- dense litter cover- presence of *Himalayan balsam*- presence of *Urtica dioica* in the reedbed	
	Woody species covering >10% of area	
Unit 7 // FAVOURABLE	*Phragmites australis* and *Glyceria maxima* present	
	Positive indicators *: Phragmites* in dense stand >90% cover // *Glyceria* constant	
		Indicators of negative change : *Urtica dioica* in the reedbed and *Gallium Aparine* present
		Indicators of negative change : woody species **>10%**
	Comment: Area south of the footpath is slightly overgrazed	Overgrazing mark with 4% of terrestrial tall herb south of the footpath
Unit 8 //FAVOURABLE	no apparent reduction in extent of wetland	
	litter cover <10% at edge of open water // exposed substrate <5%	
	Phragmites and *Glyceria* present	
	Positive indicators : *Phragmites* in dense stand >90% cover // *Glyceria* constant	
Unit 5// FAVOURABLE	no apparent reduction in extent of wetland	
	litter cover <10% at edge of open water // exposed substrate <5%	Exposed substrate **>5%**
	Phragmites and *Glyceria* present	
	Positive indicators : *Phragmites* in dense stand >90% cover // *Glyceria* constant with associated species: *Lemna minor* present, *Solanum dulcamara* not present, other positive indicator species : *Alisma Plantago aquatica* and *Lycopus europaeus*	
	Indicators of negative change: *Crassula hemsii* present in water body, isolated and not impacting in features of interest, Falonica japonica close but outside SSSI// few patches of Typha and Phalaris in the areas of S5, around water bodies, distincts stands from Glyceria, not impacting on features of interest	
	Indicators of negative change - woody species : Salix species present but in discrete stands, and not within fen areas	Trees and shrubs **>10%**

Between 2009 and 2014, changes appear in Unit 5 and 7. These units were “favourable” in 2009, and are now in decline, which is to say that, the condition in this fen habitat going worse and worse. The areas that were “unfavourable” have not been subject to modification.

Secondly, we will focus on the hydrologic study to see if this deterioration may be relevant with the water table.

2. Hydrology

The water level in the Marshes was measured by the Environment Agency from the 28/01/2016 to the 04/05/2017, every 15 min, in the Hornchurch country park, just in the begin of the marshes and in New road, downstream of the marshes. (Figure 20)

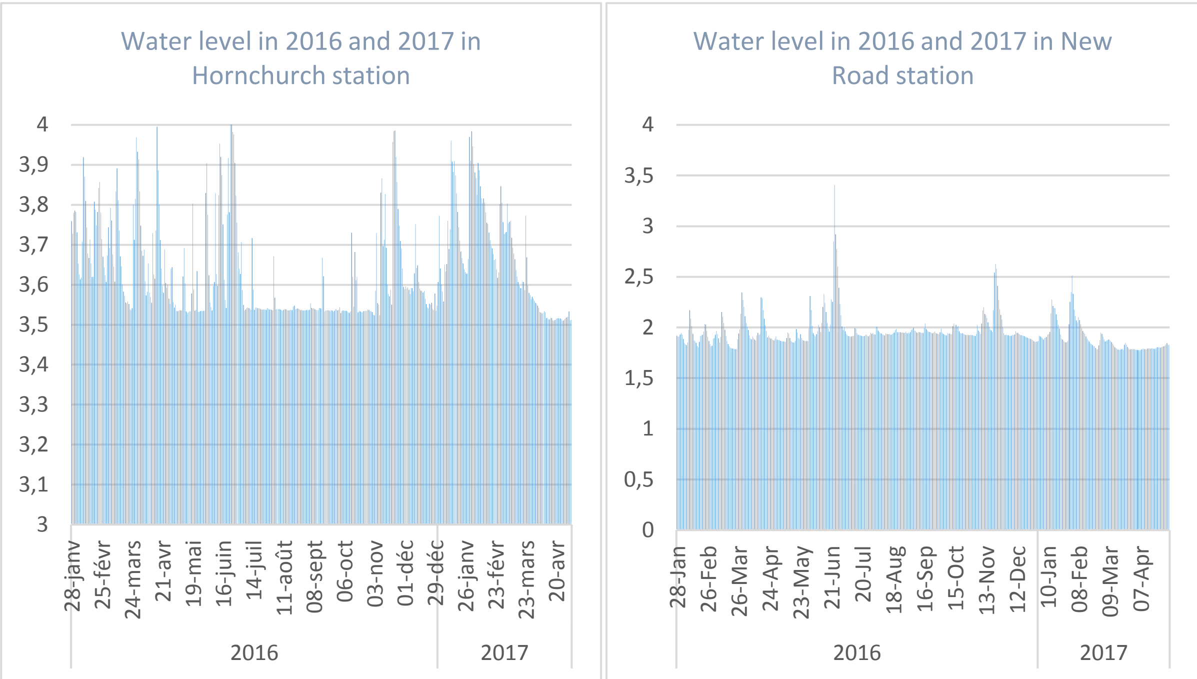


Figure 20: water level in 2016 and 2017 in Hornchurch station and new road station, upstream and downstream of the fen habitat

The average water level is 3,76m in the Hornchurch Country Park and 1,91m In New Road. The reason for this difference is a weir in the middle. We can see that in the Hornchurch country park, the water level varies from above 3,50m to 4m. The high levels are more frequent from January to June and from November to March. From July to November, the water level is stable at 3,50m.

The discharge of the river and the water level in the marshes were compared (Figure 21):

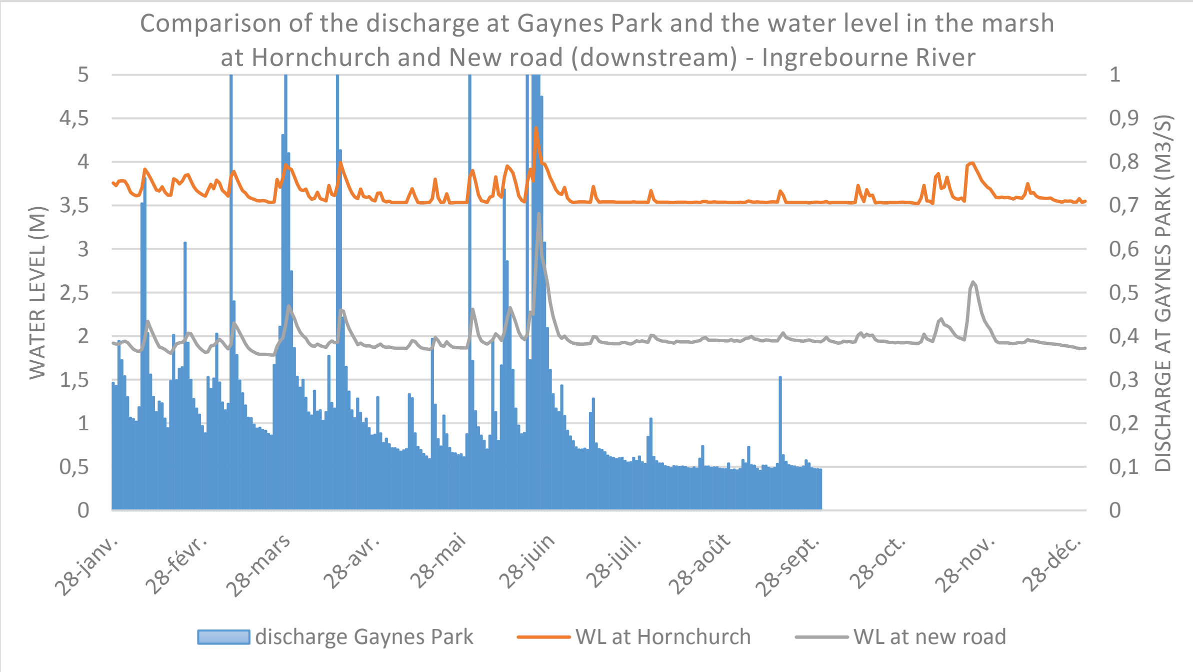


Figure 21: Comparison of the discharge at Gaynes Park and the water level in the marsh at Hornchurch (upstream) and New road (downstream) - Ingrebourne River

Water level in the marshes and discharge more upstream are linked for the 2 water level recorder stations.

With the IHA software, by using the daily flows in Gaynes Park since 1971, we were able to see long-term trend flows (Figure 22, Figure 23, and Figure 24):

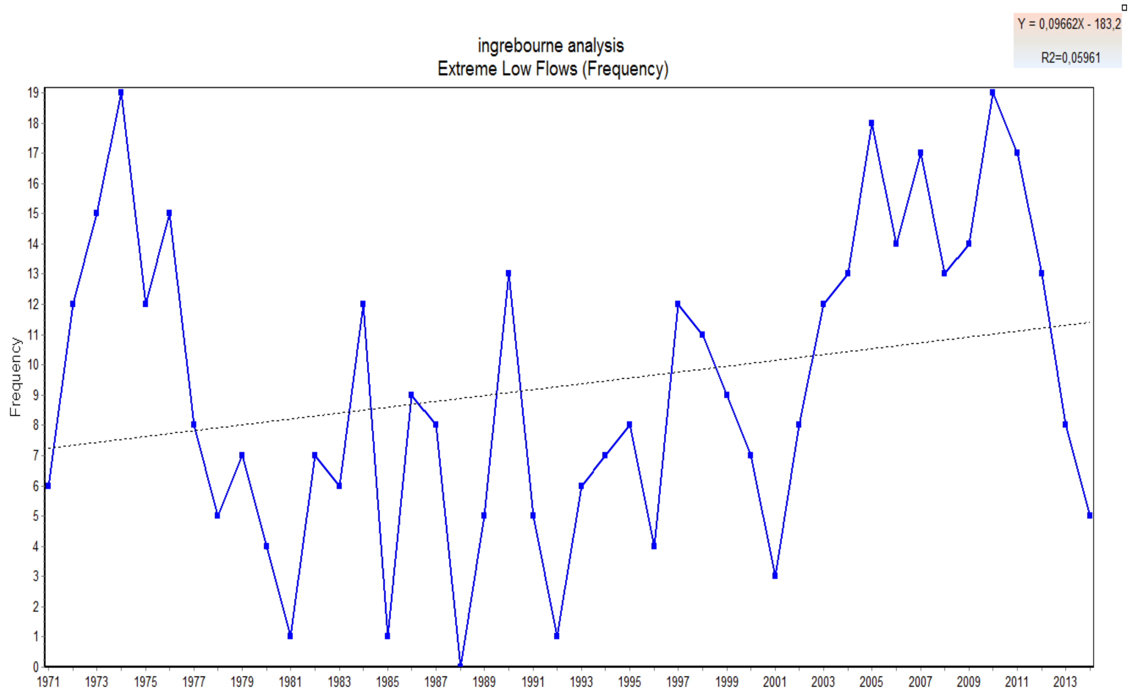


Figure 22: extreme low flows for Ingrebourne river since 1971

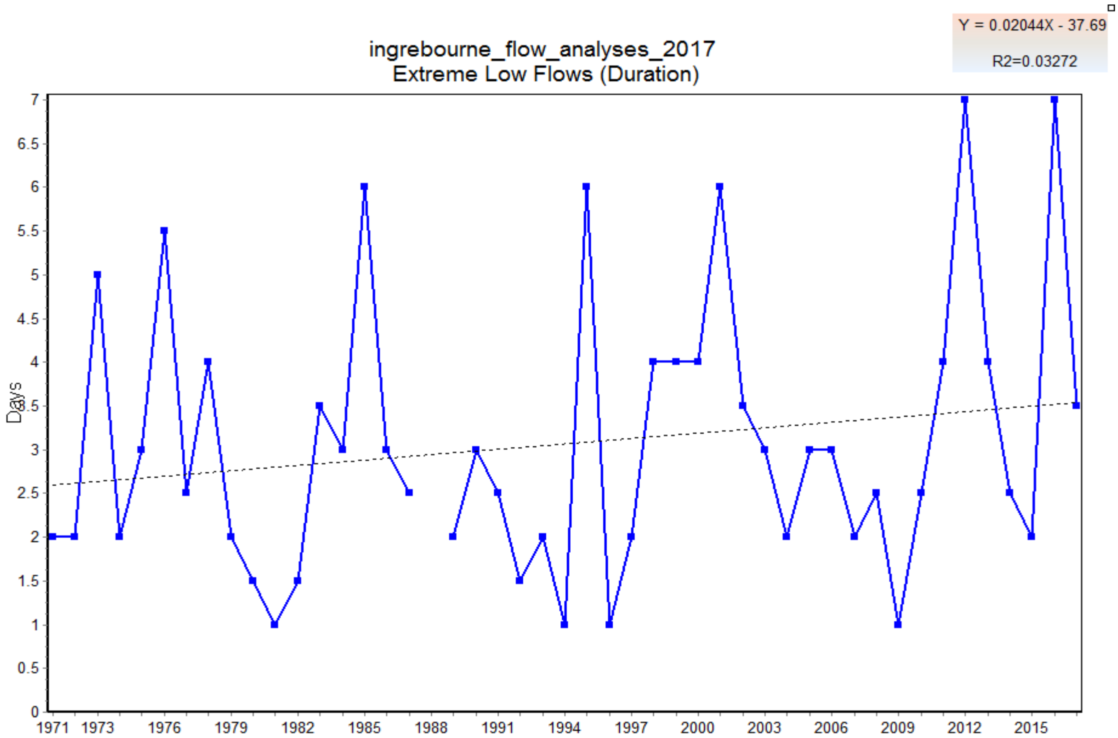


Figure 23: extreme low flows duration since 1971 (days)

These diagrams show an increase in the frequency from 7 to 12 time a year and duration (from 2.5 to 5 days in 2017) of extreme low flows since 1971. Next, this curve shows monthly low flows in May (Figure 24):

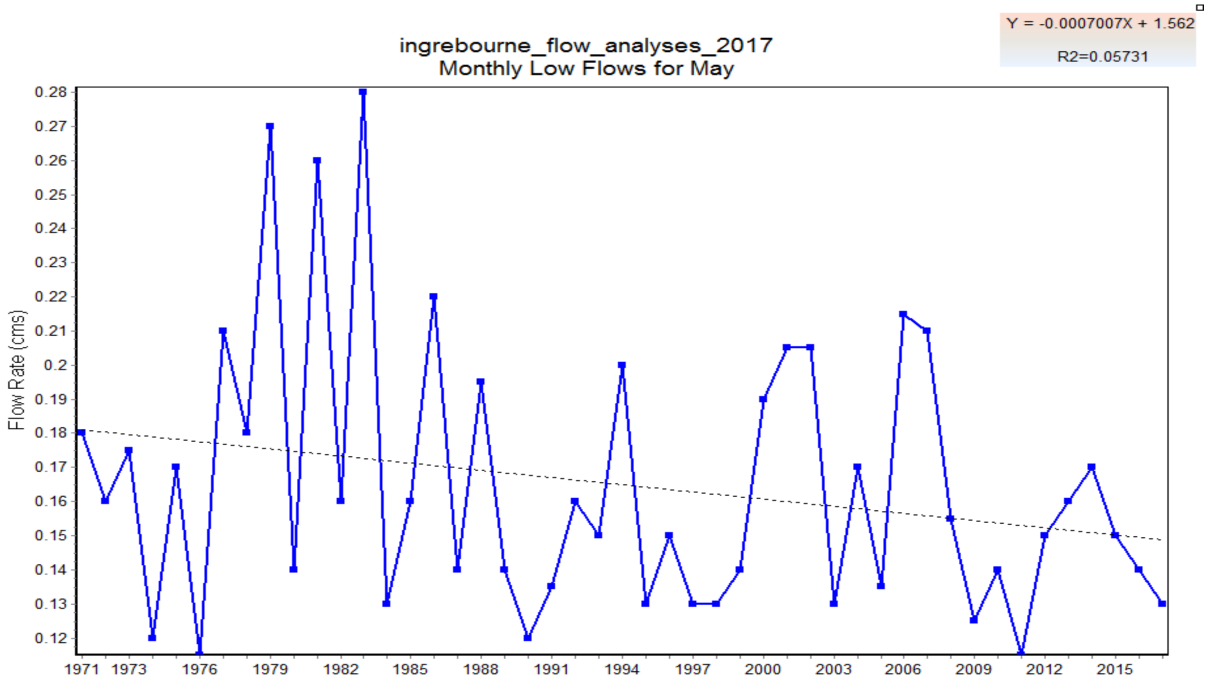


Figure 24: monthly flows for May, Ingrebourne River

This diagram shows that the monthly low flows for May are decreasing. However, May is the growing season for vegetation.

With the next diagram, we run the same analysis but with a separation between two periods: from 1971 to 1995 and from 1995 to 2017. The year 1995 corresponds to a perturbation with the installation of the weir downstream of the marshes, which may have perturbed the system. We can see in Figure 25 a break in the curve of the monthly flows for May since 1995 weir installation:

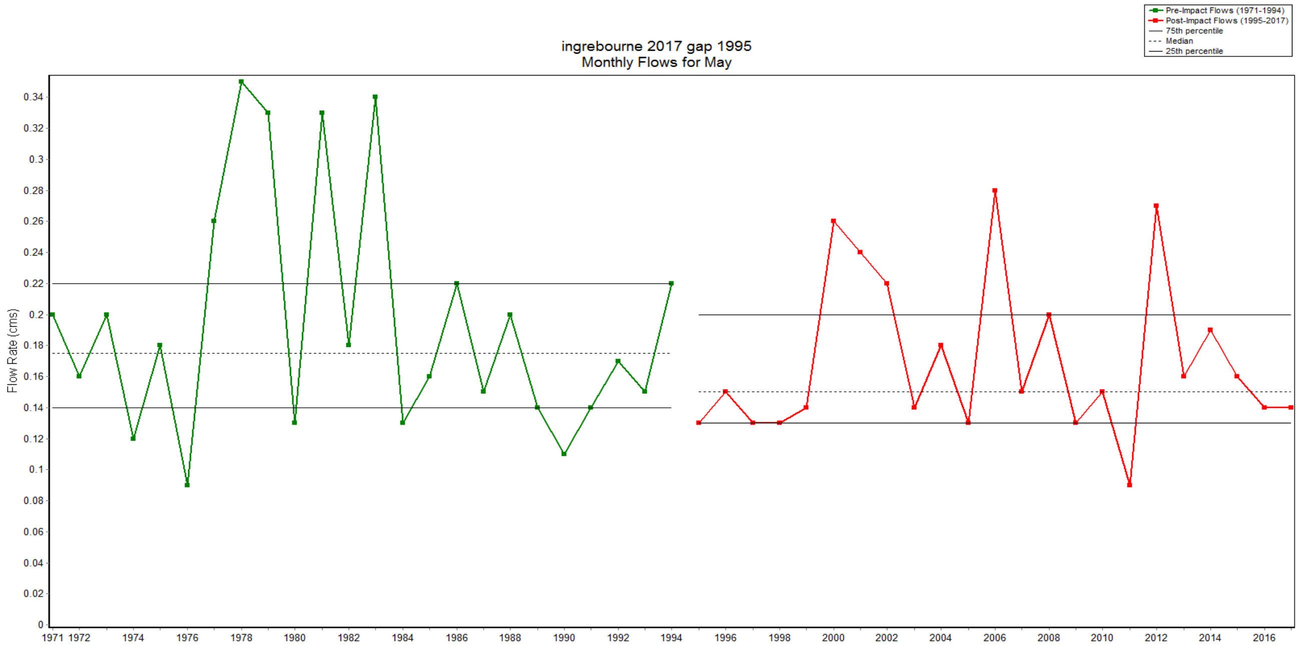


Figure 25: monthly flows for may, pre and post impact

The monthly flow for May is lower after 1995, with the median at 0.15 instead of 0.18 cms. It is a dryer period. The base flow is useful to analyse in this situation (Figure 26):

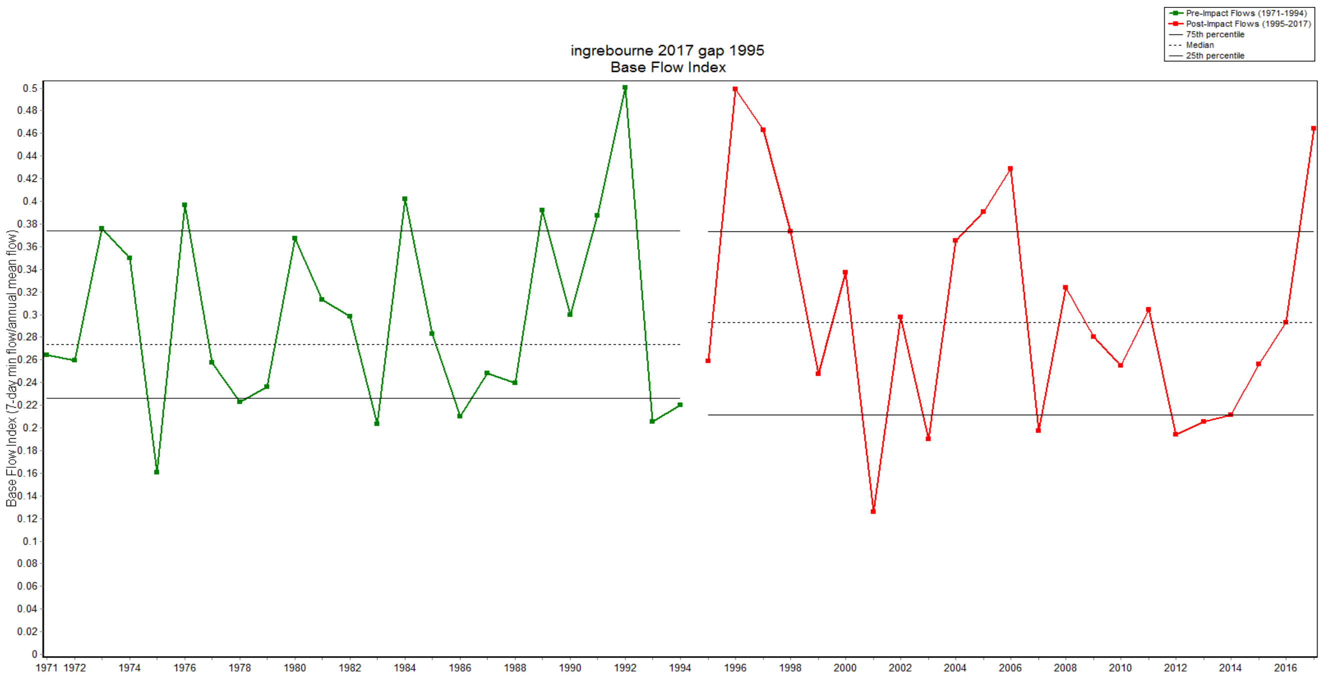


Figure 26: pre and post impact - base flow index

An increase in the base flow index (7-day minimum flow/ mean flow for year) after 1995 means that it is a dryer period. However, the flows and the geomorphology of the river are closely linked.

3. Geomorphology

Concern has been raised about the ecological status of the Ingrebourne River under the Water Framework Directive, with excess fine sediment defined as a significant negative pressure on the formerly gravel-bed river. This imbalance in the system must be visible in the morphology of the river.

With the digitalization of the 1960 and 2015's channel from 5 km before the fen habitat to the confluence with the Tamise, we want to identify a morphologic change. (See appendices 4)

We found out that the area of the 1960 channel was 46794 m² for a length of 21.6 km and those of the 2015's channel was 45372 m² for a length of 21.3 km.

By dividing the area by the channel length, we can have an approximate width of the channel. For 1960, the channel width was 2.17m and for 2015, 2.13m, so the channel has narrowed. We can see that the channel is narrowing in some places, such as at 1.5 km upstream of the marshes, at Hacton (Figure 27):

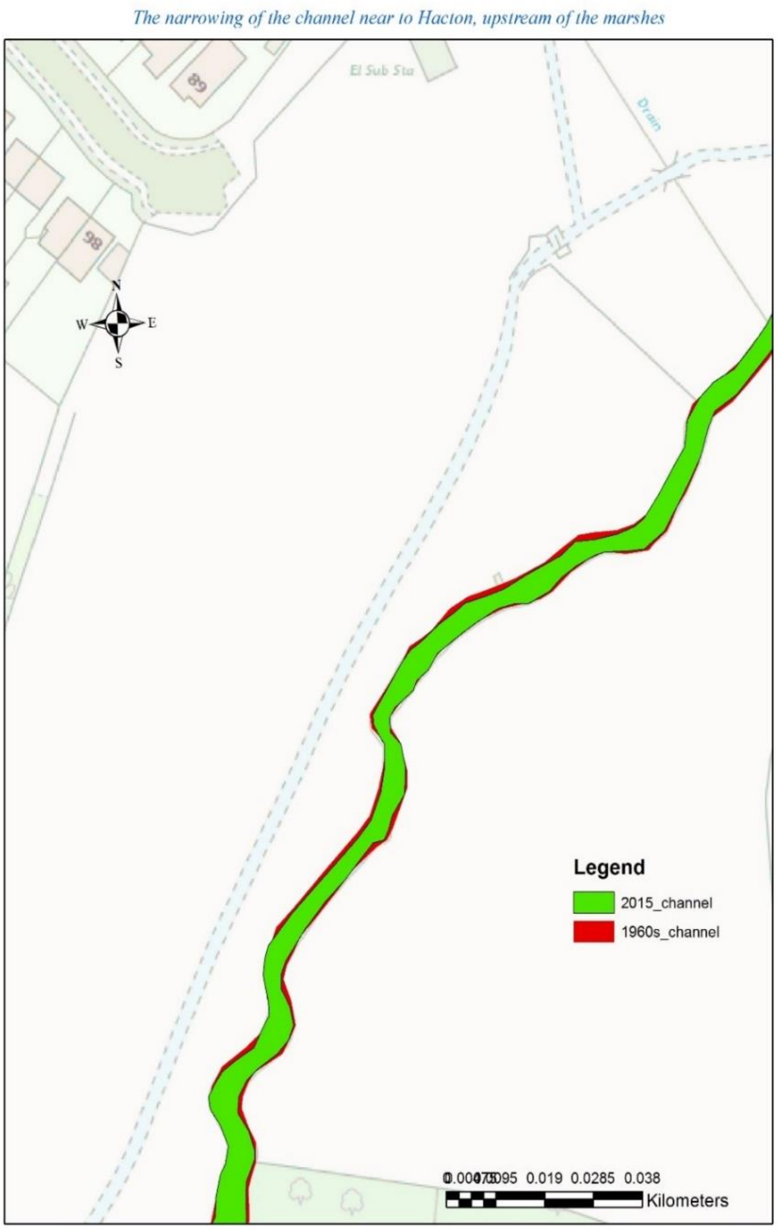


Figure 27: the narrowing of the channel represented with the 1960 and 2015 channel morphology in Hacton - basemap : 2015 Mastermap 1_1000

In some area, the channel shape has changed significantly, as we can see in the below Figure 28 in Upminster, 5km upstream of the marshes.

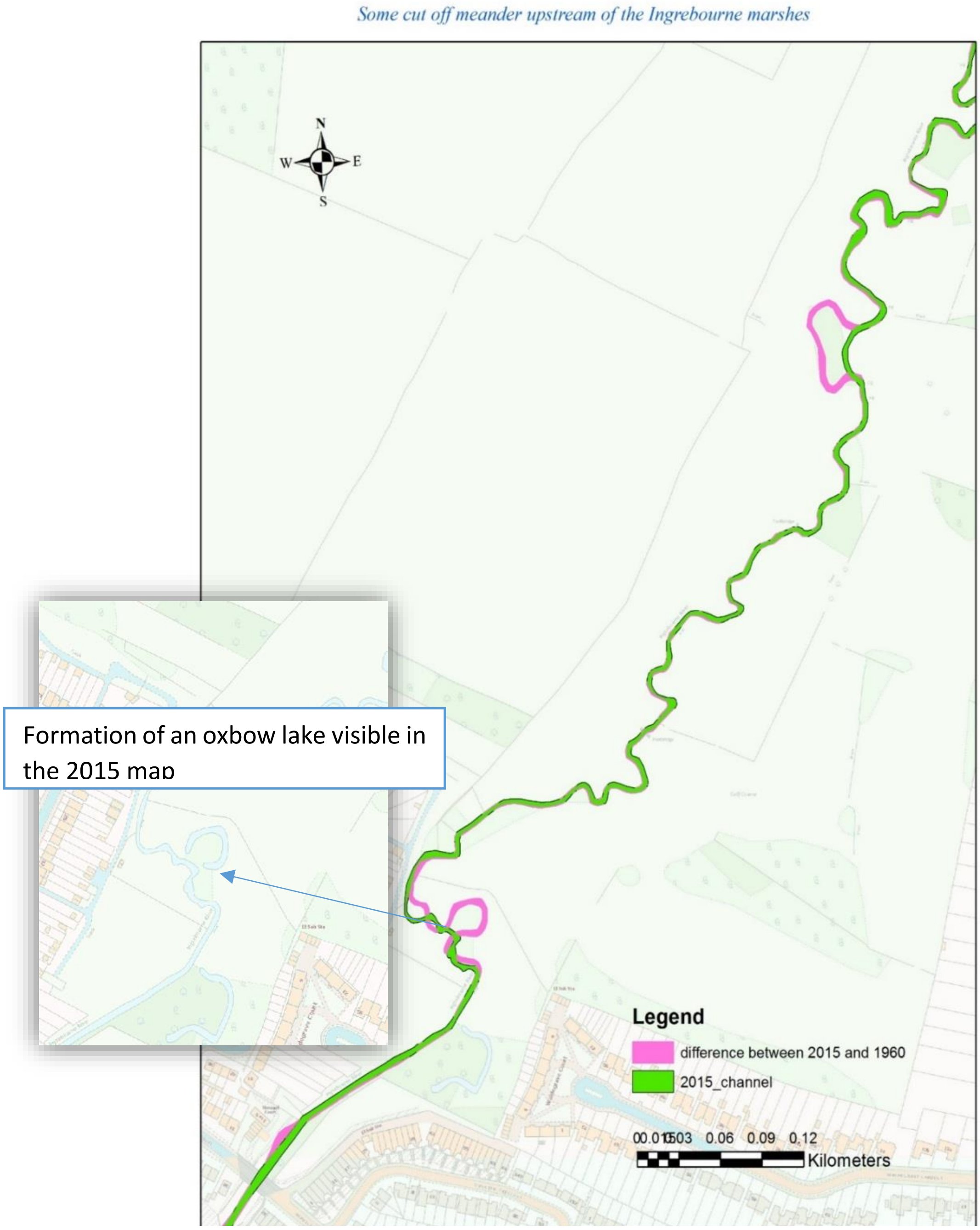


Figure 28: map of the cut off meanders upstream of the marshes and a zoom in the oxbow lake, basemap : 2015 Mastermap 1_1000

This type of readjustment is happening when the river has more sediment discharge (Qs) than water discharge (Q), therefore the system is unbalanced. Sediment are deposed and plugs are created. The river overflows at the beginning of the meander. The meander is cut with the formation of another arm, with a bigger slope, that connect the outset and the exit of the meander. This lead to the formation of an oxbow lake, the 2 ends of the former arm will be obstructed by the sediment deposition. This is a sign that management practises in the catchment have change the river dynamic, and could have consequences in the fen habitat itself.

3. Conclusion- discussion

Vegetation communities

With our method, we were able to map area in the fen habitat and to compare it with the 2009 study to see the ecological state of the marshes. We found out several results:

First, with the fieldwork map, a reedbed gradient with distance from the river to the trees was highlighted, with more and more litter and dry conditions. The plants growing in dry conditions are nettles and terrestrial tall herb. (*Agrostis stolonifera* for instance) But we also found these types of plants inside the reedbed, where the conditions are supposed to be wetter. In 1997, combine surface outfall moved by Environment agency to enable flooding of land owned by the Council (unit 7 and 8) in favour of creating additional shallow wetland habitat. The water level is controlled to a depth of maximum 0.1m from October to May by structures, and fenced off to allow grazing from the end of June (Andrews Ward Associates, 2002). The structures are extensive drainage ditches. Their project was to diverted surface run-off into the marshes. However, the grazing reduces the cover of reed sweet-grass in favour of wet neutral grassland.

Then, with the 2014 UAV pictures classified, we found that the vegetation throughout the fen habitat evolves from upstream to downstream of the river. There is no clear tendency, except more scrubs and trees in the downstream. When superimposing with the SSSI units map, we discover that 2009 favourable area were, after 2014, in decline. The main problems seem to be the overgrazing that bring nettles and terrestrial tall herb in the unit 7 and the exposed substrate and scrub and tree encroachment in the unit 5.

To improve the method, it would be useful to have a drone that take an orthophoto directly, and do a vegetation classification afterwards in Arcgis with the same method. A 10 year follow-up will be interesting to see the changes in the habitat. Moreover, if we had 5cm-accurate remote sensing images for example from the Sentinel-2 satellite, we could do the same operation.

In a fen habitat, water level and vegetation communities are closely linked, and the impact of the water level is not negligible.

Hydrology

The water level analyses show that the high levels are more frequent from January to June, and from November to March. From July to November, the water level is stable at 3,50m. In winter, during period of high flows when much sediment are suspended and transported, high sediment deposition may occur into the marshes. After July, with lower water level, the soil may be dryer, and the sediment depositions of winter increase the soil drying up.

Moreover, during the dieback, reeds can produce large quantities of leaf litter which often cause litter accumulation, resulting in the reedbed drying out. (Cowie.N.R, 1992) In very dry condition, this litter does not decompose well, and if this dry period is then followed by a high flow period, flooded the marshes, the sediment may by trapped into the litter structure and it increases the sediment deposition. (Bedford, 2005)

When interesting in the impact of sediment deposition in reed, we found out that where deposition rates are high and deposited material largely inert and unstable (sands) the impacts are

obvious and plant loss a common feature. The evidence available indicates that changes in the macrophytes community as a consequence of enhanced deposition of fine sediment derived from human activities in the catchment closely parallel those that are typically associated with increased dissolved nutrient loads (i.e. reduced light penetration to the bed, loss of low-stature slow-growing species, increases in competitively dominant rank species). (Jones *et al.*, 2011)

In addition, some evidence of man-induced reduction in natural fluctuation of the water level has been found. In 1995, a weir was installed in the river downstream of the marshes. It may have modified the flows.

With the IHA software, we were able to identify an anthropologic hydrologic alteration. The analyses run tends to show that the river knows a dry period, this affect the water level in the marshes. *Glyceria maxima* swamp needs a ground that stay wet in summer, however, in some area, the soil is no longer wet. It can explain why trees, scrubs and terrestrial plant, such as nettles colonize the fen habitat.

To validate the hypothesis, we would need a water level recorder inside the reed bed to know if the *Glyceria maxima* swamp has enough water in summer, and if it is well supplied in winter, as it needs to be flooded regularly.

Another idea was to use hydrologic data to assess geomorphologic change. We have the current water level in the river of the marshes (h2017), which is linked to a certain discharge of the river (Q2017), and precipitation (P2017) as shown on Figure 29.

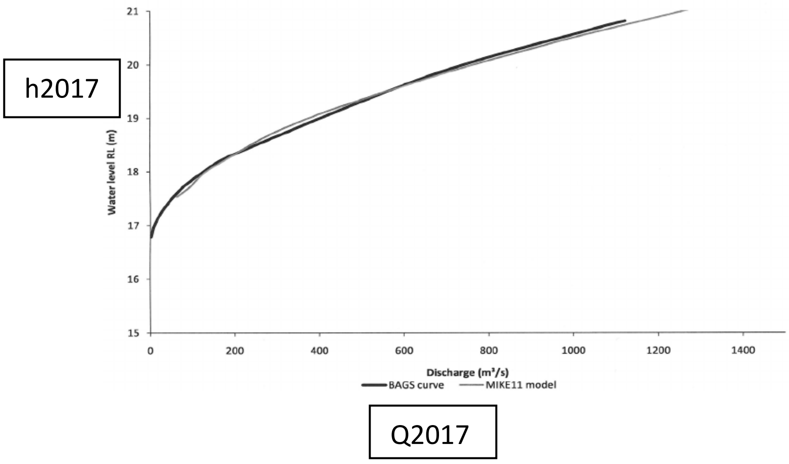


Figure 29 water level and discharge example of rating curve

If assuming that it is not the hydrology that changed over time but the morphology of the channel, we have: h2017 → Q2017→ P2017

P1990 → Q1990 → h1990?

$$h1995 = \frac{h2017}{Q2017} \times Q1995 \; and \; h1995 = \frac{h2017}{P2017} \times P1995$$

It is possible to find the former water level (h1995) into the channel, and if it has increased, the channel has narrowed. Studying directly the former morphology of the river is possible by digitalizing maps.

Geomorphology

A previous study, Hydro-Geomorphological assessment of the Ingrebourne River and SSSI Marshes (Despinasse *et al.*, 2016), has analysed the sedimentation in the marshes and concluded in an excessive sedimentation. This might be a threat for the SSSI designation.

This has shown many results: First, the source of the sediment inputs is the increase in urban areas between 2007 and 2012 which generate high rate of sediment. Moreover, other inputs exist such as the increase in the drainage network, dredging in the upper catchment, or the bank erosion. If we assume that all the sediment that reaches the streams is transported directly to the downstream of the catchment, and is being deposited within the marshes, it can explain why the SSSI designation is threatened.

During high flow periods, in the marshes area, the floodplain is flooded leading to decrease velocity, as the cross sectional area of the river is increased. This will induce sediment deposition into the marshes.

Moreover, the channel morphology study shows that the channel has narrowed since 1960, this may be the development of reed along the channel that have trapped sediment and narrowed the channel step by step. The cut-off meanders show that the energy of the river has changed. It happens when the sediment discharge is superior to the water discharge, the sediments are deposed in the channel and create a plug, and then the river finds a channel with a higher slope by cutting the meander. This high sediment discharge is due to increase in urban area, bank erosion as seen previously.

Conclusion

We have observed a shift in vegetation communities toward a meadow habitat. This is the evidence of an imbalance in the system.

The river flows analyses show a dryer hydrologic period which may change vegetation species.

Then, the high sediment discharge in the river in recent years has two consequences, the river channel narrowing, and the sediment deposition in the downstream of the river, in the marshes.

On the one hand, the water level in the river is increased, and changes the riparian vegetation.

On the other hand, with high sediment deposition in the marshes, the marshes is drying out, clogged and may lose its “sponge” effect. The river flood is less absorbed by the marshes during significant rainfall event. This causes more frequent inundation of the marshes and around, flooding the tourist paths. This is a threat for the habitat such as in the spring for the breeding-birds (like the redshank) that nests at the foot of reeds.

To maintain the fen habitat, appropriate cutting and mowing are necessary, cattle grazing has to be regulated.

Resource page

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Table of Figures and tables

Figures :

Tables :

Appendices

1. Management practices

In the valley, the management practices have changed over years. Berwick Woods area was an agricultural land in 1947.

1985-2005: Marshes at downstream area changed from predominantly river washland vegetation (land adjacent to rivers which are deliberately flooded to avoid flooding in important agricultural or residential areas) to common reed vegetation. It is possibly due to the high water levels. (Atkins, 2002)

1990: Water level plan was investigated because the right bank and the southern extent becomes much wetter, in particular the south of Abbey Wood. Common reed becomes predominant. (Andrews Ward Associates, 2002)

Around 1995, a submerged weir was installed in the Ingrebourne downstream of the marshes. It allows for water levels to be maintained within the marshes. In 1995, the Ingrebourne Valley Management Plan was produced and confirmed that most of the site was no longer under active agricultural management, and that a significant part of the site was unmanaged.

In 1997, combine surface outfall moved by Environment agency to enable flooding of land owned by the Council (unit 7 and 8) in favour of creating additional shallow wetland habitat. The water level is controlled to a depth of maximum 0.1m from October to may by structures, and fenced off to allow grazing from the end of June (Andrews Ward Associates, 2002). The structures are extensive drainage ditches.

In 2002, a water management plan report concluded that the drainage ditch system in place to manage the grassland within the marshes had not been managed for a long time. This, and a lack of grazing have promoted flooding for several weeks because of high water levels in the marshes.

In 2004-2005, a sluice was installed at the northern part of the SSSI to control the water level regime of winter flooding. Grass cutting and scrub management was carried out. Ditches are silted up due to lack of maintenance and allowing colonisation by emergent vegetation.

In 2007, the right bank, middle part of the marshes became difficult to access due to the overgrowing of weeds in the drainage ditch. Land on the right bank at the start of the Marshes and opposite the Visitors centre is seasonally flooded grassland with a strip of open water where reed colonisation is developing. On the left bank at this point, a large open water body is present. (EECOS, 2007).

2011, unauthorized dredging occurred between Hacton Bridge and the Marshes (Jacob, 2011)

In recent times, additional wetland areas and drains have been created (Andrews, 2002).

2. Quadrats method

<u>Site and vegetation description</u>
Sketchmap:

Sample N°	author
altitude	Slope Soil depth
Stand area	Sample area
Layers mean height	
Layers cover	
Site management	
Soil feature (litter, moisture)	
Bank distance	

Invasive species	
Crassula helmsii	
Acorus calamus	
Mimulus spp	
Impatiens glandulifera	
Fallopia japonica	
Heracleum mantegazzianum	

Undesirable species	
Urtica dioica	
Gallium aparine	
Pteridium aquilinum	
Rubus fruticosus	
Epilobium hirsutum	
Bryophytes	

Canopy layer		**cov**
Betula Salix Rhododendron Pinus- other gymnosperms		

Emergent narrow leaved plant			**cov**	**Emergent broad leaved**			**cov**	**Terrestrial plants**			**cov**
Grasses	**Phragmite**			Simple/ alternate	Polygonum			spiked flower	Lythrum		
	Glyceria				Myosotis			Grassland plant	Agrostis		
	Phalaris				Rumex			tufted hair grass	Elocharis		
									Cladium		
				Simple/ opposite/ square stem	Caltha			flowering plants	Bidens		
Sedges	**Carex**				Mentha				Epilobium		
					Lytrhum				Cardamine		
Rushes	Juncus				Lycopus				Ranunculus		
	Eleocharis				Scrophularia				Symphytum		
	Scirpus			*/ round stem	Veronica			Umbellifers	**Angelica**		
Other monocot y	Acorus			Compound / cresses	Rorippa				**Filipendula**		
	Iris			Compound /umbellifer s	Berula				**Thysselinium (Peucedanum)**		
	Typha				Apium				**Eupatorium**		
	Sparganium				Oneanthe						
	Butomus			Trifolliate	Menyanthes						
	Hippuris										

% cover	scale
<1%	+
1-5%	1
6-25%	2
26-50%	3
51-75%	4
76-100%	5

Braun-Blanquet scale

Date	Place	<u>GPS coordinates :</u> Grid reference code

3. Vegetation evolution from upstream to downstream

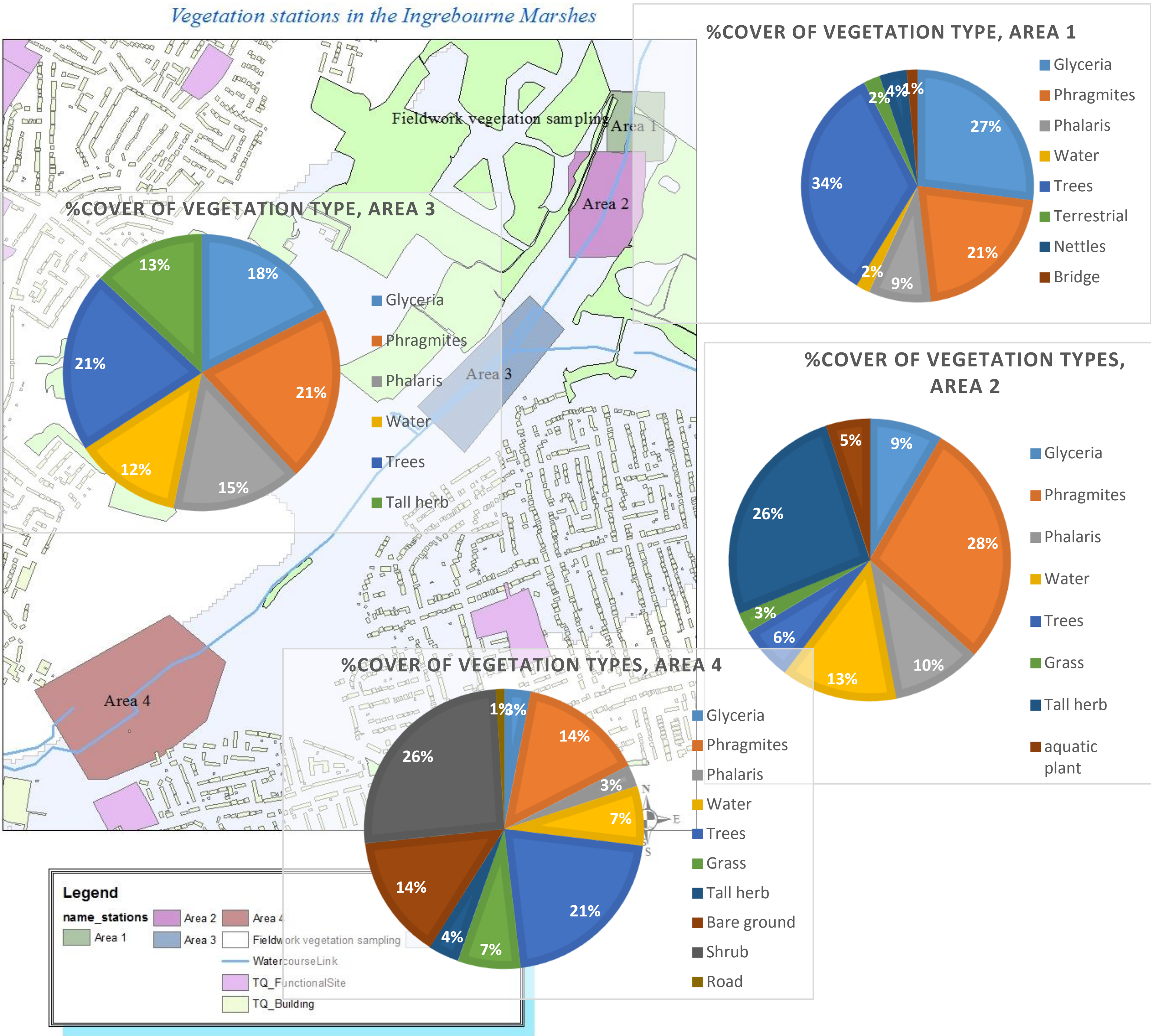

Figure: Map of the 4 classified areas with their %cover associated-base map: Ordnance survey, IGN

4. Evolution of the morphology

The map below shows the differences between the 1960's channel morphology and the 2016 one. We can see that the river has moved with the pink features in the map. The area that represents the difference between the two channels is 9593m².

Difference between the 1960s channel and the 2015 in the Ingrebourne Marshes using Symmetrical Change tool

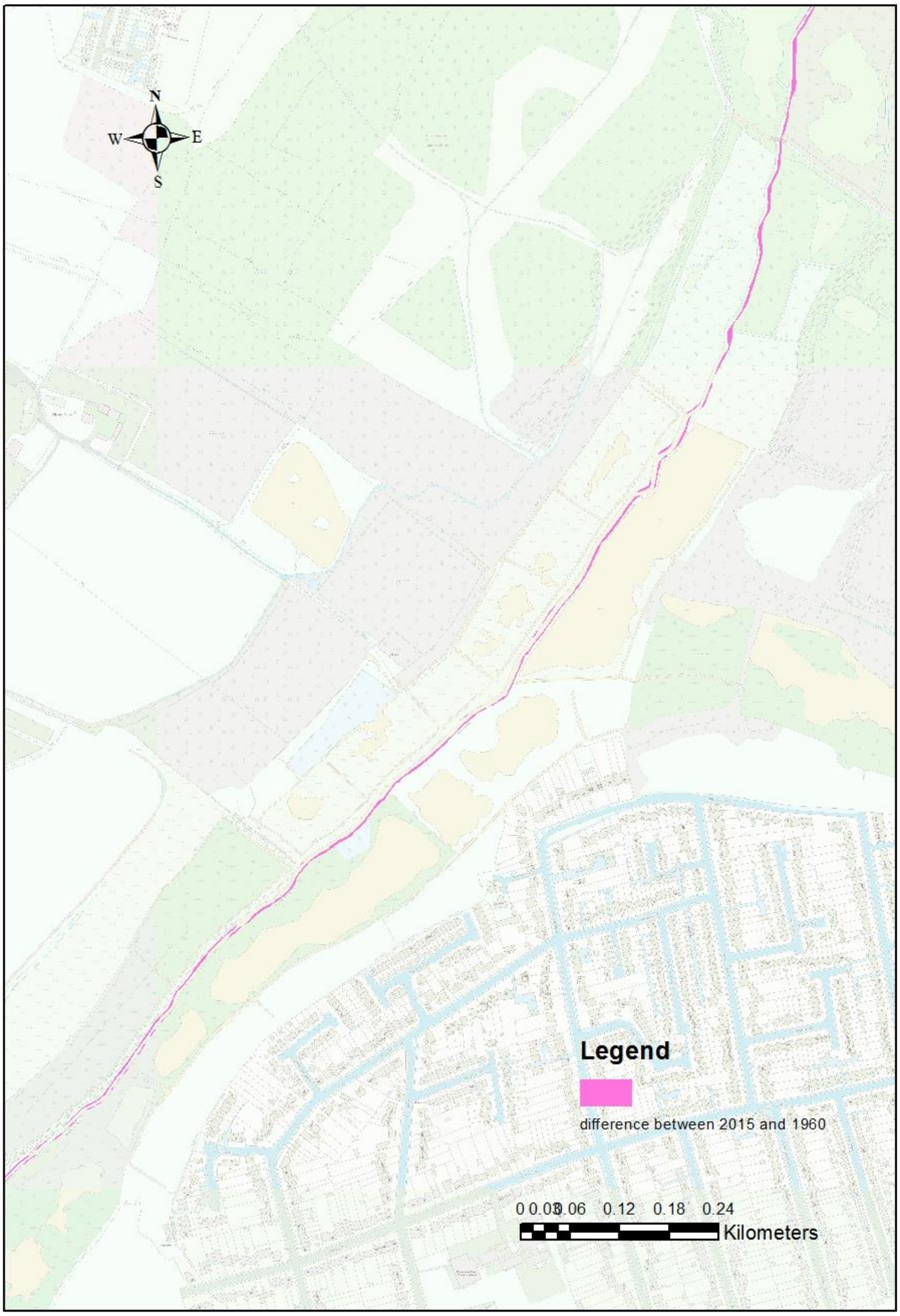

Figure: Map: Differences between 1960 and 2015 channel morphology using Symmetrical change tool, basemap : 2015 Mastermap 1_1000

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