Preliminary Study of the Doe Lea Catchment for the Doe Lea Project

Irantzu Lexartza-Artza, David Lerner, Nataliya Tkachenko

Catchment Science Centre

The University of Sheffield
August 2009

A report created for

THE NATIONAL TRUST
Hardwick Hall
Chesterfield
S44 5QJ
United Kingdom

Catchment Science Centre

ISBN 978-0-9561379-4-4

Supported by the Environment Agency and the Yorkshire Regional Flood Defence Committee

EXECUTIVE SUMMARY

This report presents a preliminary assessment of the Doe Lea Catchment, Derbyshire, to provide a tool for the understanding of the catchment for the planning phase of the Doe Lea Project. The Doe Lea Project aims to implement a land management approach to address the pressures that are leading to poor flow and water quality in the catchment. A data compilation has been carried using a variety of sources, including the partner institutions and organisations of the Project. The information gathered has been used to provide a description of the different catchment elements and the pressures that contribute to poor water quality and flood risk in the catchment.

The Doe Lea Catchment is predominantly rural, although some urban areas can be found within it and it is crossed by the M1 motorway. The main geological units in the catchment are the Carboniferous Coal Measures and the Permian Magnesian Limestone, the latter restricted to a narrow area in the east. The change in geology creates steeper slopes in the east of the catchment. The soils associated with each geological unit are permeable calcareous soils on top of the limestone and slowly permeable and seasonally waterlogged soils in the rest of the catchment. The main agricultural use is arable, which is found throughout the catchment, followed by improved grassland, neutral grassland and woodland. The catchment is mostly underdrained, and different management options can be found, for example when some arable fields are ploughed while others are not, and some grassland is used for grazing and grassland elsewhere is used for silage, although the specific spatial distribution of each has not been specified.

The Doe Lea Project has identified water quality, poor ecology and excess flow issues in the catchment, linked to runoff related diffuse pollution and suspended sediments. These problems have been reflected by the poor status identified by the monitoring carried by the Environment Agency, including Water Framework Directive monitoring in the five water bodies in which the catchment is divided. Runoff, diffuse pollution and diffuse sediments have also been reflected by colour issues and poor ecology in National Trust land and flooding problems mainly downstream in the River Rother. Some Environmental Stewardship options that can potentially contribute to reduce the pressures are currently being applied in many holdings of the catchment.

The knowledge of the different elements of the catchment has been used to create a conceptual model of the interaction of different factors in the catchment, including topography, geology, soil type, land use and management, to influence properties and processes that can lead to runoff generation, suspended sediments and diffuse pollution. These properties consist of infiltration, soil compaction, soil moisture, soil erosion and the presence of nutrient and pollutants. Thus, for instance, gentle slopes and soils on limestone are identified as favouring infiltration, arable land and improved grassland are identified as the main potential sources of nutrients and pollutants from agriculture in the catchment, and seasonal reduction in land-cover on arable land and steep slopes favour soil erosion under intense rainfall events.

This understanding of catchment processes has been used to design a GIS-based model to characterise the catchment spatially in terms of the existing pressures. Risk maps have been produced for diffuse pollution, suspended sediments and runoff, to identify high-risk areas for each pressure. From the results obtained a combined map has been produced to link high-risk areas for diffuse pollution and suspended sediments with areas with high risk of runoff generation and good connectivity to water bodies. The highest risk subcatchments have thus been identified, and are located mostly in the east and the southwest of the catchment.

Finally, an approach to design a monitoring strategy is proposed. Clear and measurable objectives need to be set when choosing the actions, so their success can be measured by looking at specific parameters. Also, a baseline understanding needs to be set, and focusing in high-risk areas if necessary is suggested. Potential gaps in baseline knowledge have been identified for some of the high-risk catchments, in local-scale settings and for time-dependent processes. A qualitative field surveying has been suggested as a tool to gather some specific knowledge. Monitoring approaches used to set the baseline should be maintained over time, so the results can be compared against the objectives and the performance of the interventions can be evaluated.

A large part of the data used to create this report has been provided by Natural England and The Environment Agency.

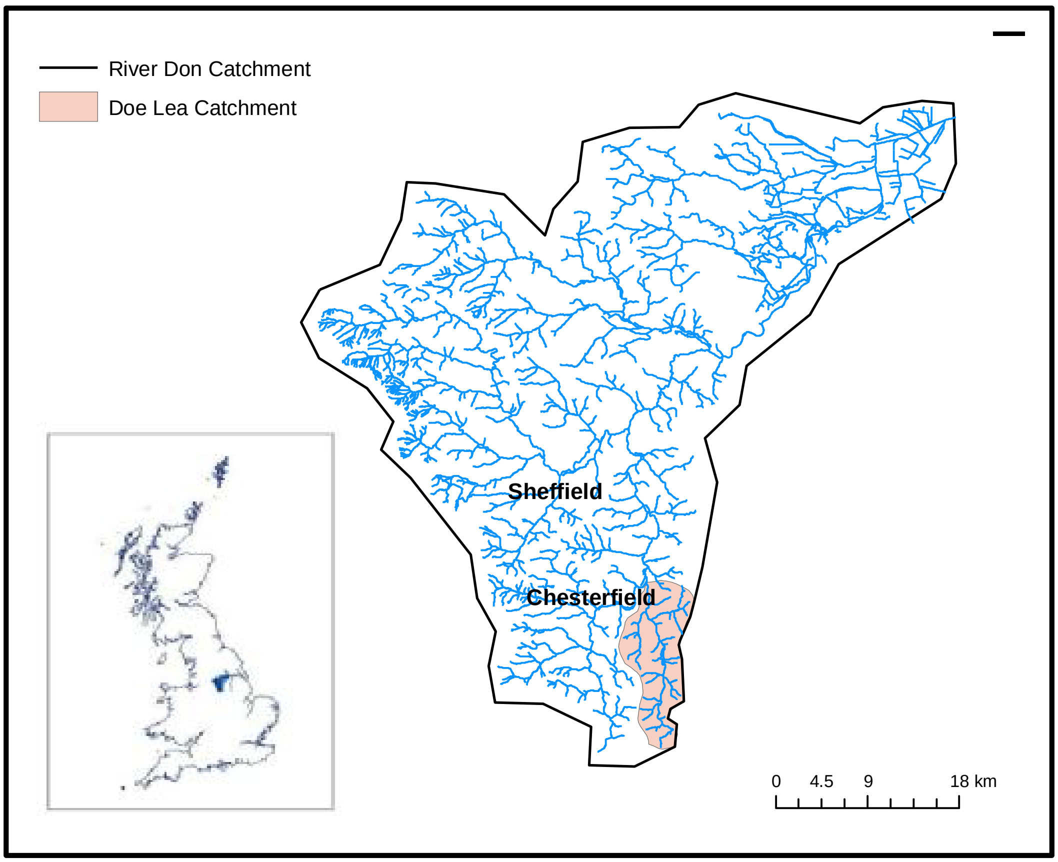
Table of contents

List of Figures

List of Tables

INTRODUCTION AND BACKGROUND

The Doe Lea Catchment, in Derbyshire, is located in the south of the River Don Catchment (fig.1) and is part of the Humber River Basin District. The Doe Lea is a major tributary of the River Rother and its catchment has an area of around 67.9 km^2. The main stream runs mostly in a S-N direction for just over 18 km, from its source at an altitude of 215 m, to the River Rother at about 50m above sea level. There are several tributaries both east and west of the Doe Lea, and various reservoirs and lakes along its course. The catchment, predominantly rural, is crossed by a motorway (M1). The main urban area is Bolsover. (fig.2).



“River data © NERC".

Figure 1. Location of the Doe Lea Catchment in the River Don Catchment.

The Doe Lea Project has identified excess flow issues and poor ecological quality in the Doe Lea Catchment. On this context, the Doe Lea Project aims to adopt actions that will enhance the ecological status of the water bodies and the surrounding landscape and the reduce flood risk at different levels and scales.

Land management has the potential to influence diffuse pollution, runoff discharge and suspended sediments from agriculture by, for instance, adopting measures to increase infiltration, reduce overland flow and increase water retention (e.g. Allan *et al.*, 1997, Foster *et al.*, 2003, DEFRA, 2005). Thus, one of the alternatives considered by the Doe Lea Project is to develop an integrated catchment wide approach in which landscape management can be used to reduce the pressures in the catchment.

This report presents a preliminary study to contribute to the understanding of the catchment for land management approach, and is composed of the following:

- A description of the catchment and its conditions based on the available existing data
- An assessment of the existing pressures leading to the problems of poor water quality and excess flow.
- A conceptual model of the interactions of the different components of the catchment in relation to the pressures.
- A characterisation of the catchment in terms of risk.
- Suggestions and considerations for monitoring.

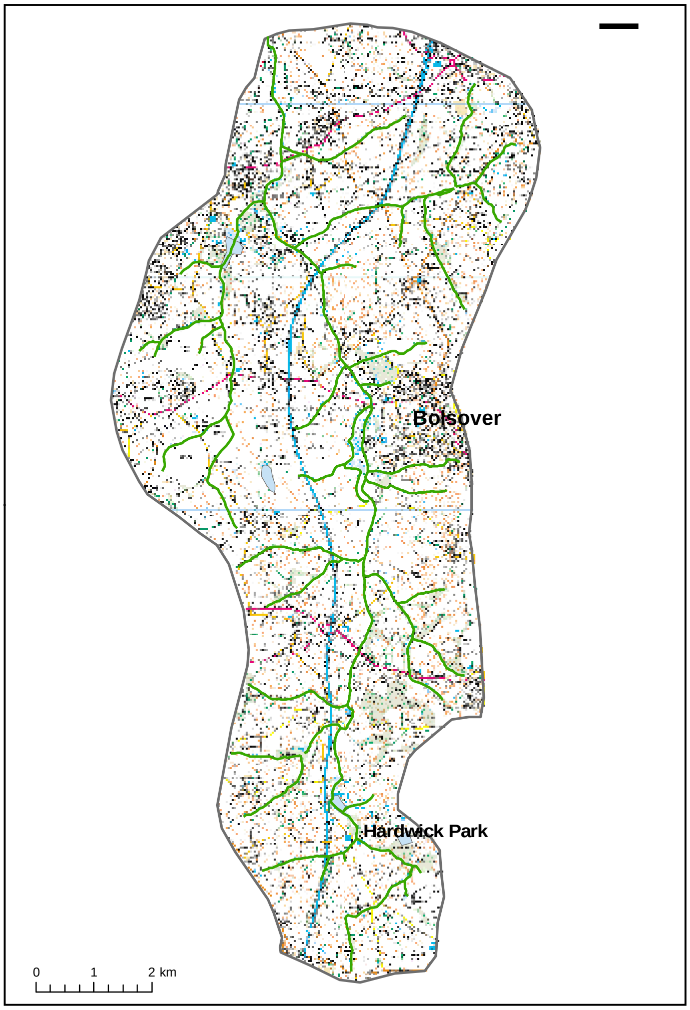
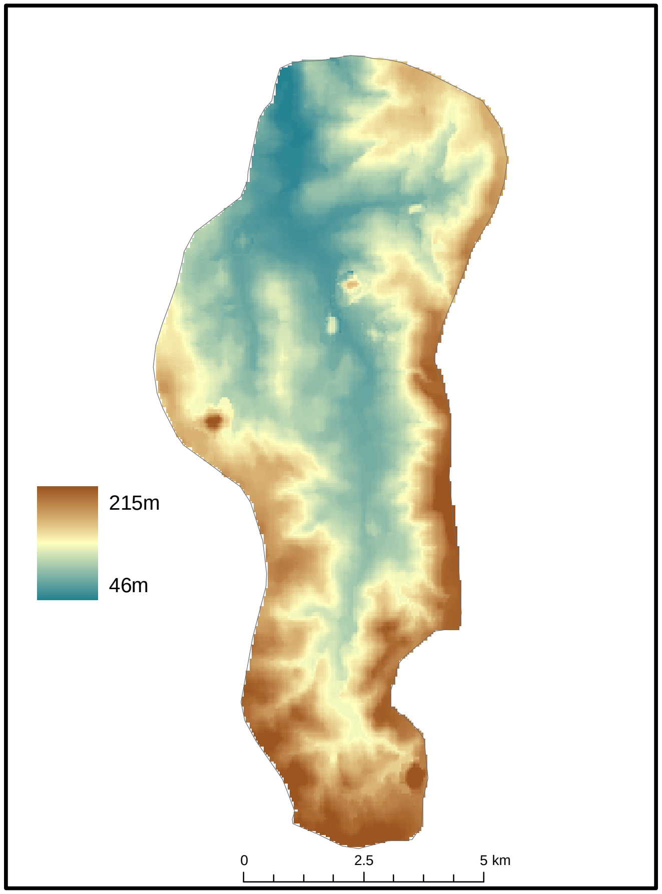


Figure 2. Doe Lea Catchment.

CATCHMENT DESCRIPTION

The Doe Lea and its tributaries drain the catchment over a height difference of just about 150m (fig.3). Slopes are mostly gentle, although they get steeper at places, especially in the eastern side of the catchment because of the scarp created by the underlying limestone geology (fig.4). The motorway runs almost parallel to the Doe Lea for about three quarters of its length, and opencast mining areas can be found among the agricultural land across the catchment. Some former opencast locations have been restored to agricultural land in recent decades. A number of these sites are identified as such in OS maps, but it is thought that not all of them are included.

The rivers generally respond rapidly to rainfall events. A great part of the channel has experienced some kind of modification and hard flood defences can be found along the stream. According to the Catchment Abstraction Management Strategies (EA, 2003), relatively small quantities are abstracted from or discharged to the Doe Lea. Abstractions are made upstream for coal washing. A variety of discharge points are distributed across the catchment. Point and diffuse sources of water and associated sediments and pollutants have been identified, including licensed discharges, land and mining drainage and overland flow.



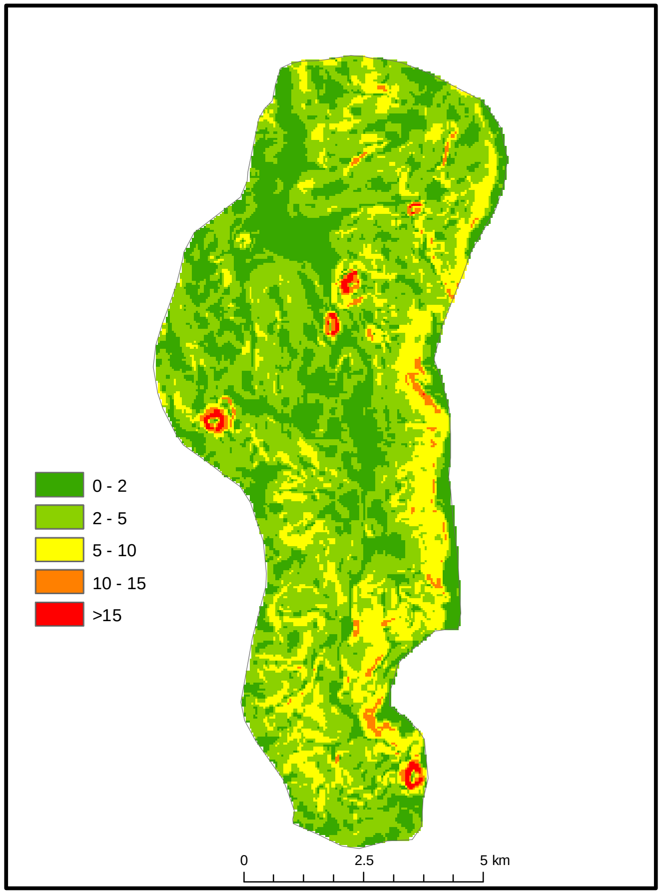


Figure 3. Topography of the Doe Lea Catchment. Highest ground is located in the east and south of the catchment (Source: CEH).

Figure 4. Slope distribution in the Doe Lea Catchment. Steepest slopes are found in the east, with a plateau/gentle slope on higher ground.

Geology

The catchment is composed of two main geological units, the Carboniferous Coal Measures (Middle and Lower) and the Permian Magnesian Limestone (fig. 5):

- Carboniferous Coal Measures- The dominant unit in the catchment. It is formed mostly of shales and sandstones, which creates different levels of permeability depending of the spatial distribution of this composition. The unit has two subdivisions:
  - Middle Coal Measures. They compose most of the catchment, and are mostly shales with some sandstone.
  - Lower Coal Measures. Found mainly in the western part of the catchment, and composed of undifferentiated argillaceous (formed from clay sediments) rocks.
- Permian Limestone. This unit is found in the eastern edge of the catchment, forming a scarp. It is formed mostly of porous dolomites, which are highly permeable, with strata dipping eastwards. The main fault lines are also oriented towards the E, which suggest that most water that infiltrates will leave the catchment towards the aquifer in that direction.

Soil

The catchment is composed by several main soil types (fig.6), including:

- Loams over limestone in the east - Aberford Series.
- Seasonally wet deep clays over shales - Dale Series.
- Restored opencast areas, also seasonally wet.
- Seasonally wet loam to clay over shales - Barsdey Series.

The hydrological behaviour of soils is a key element necessary to understand flow estimation and susceptibility to pollution. The HOST (Hydrology of Soil Types) classification is a hydrologically based system which gives hydrologically important properties, including soil hydrogeology, permeability, depth to the aquifer or groundwater, presence of a peaty topsoil, depth to a slowly permeable layer, depth to the gleyed layer and integrated air capacity (Boorman et al, 1995).

Only two HOST types are found. The Aberford series belongs to the HOST class 2, which is characterised by well drained permeable soils on permeable rock. Lateral movement is confined to the saturated zone, as the dominant movement is vertical to an aquifer, in this case through relatively shallow soils made of well drained calcareous fine loams. If nutrients and pollutants are present on the soil, the dominant transfer into the aquifer can have important effects on groundwater quality. Although in this case, as mentioned above, the effect will be more significant outside the catchment due to the geological structure, measures to reduce pollutant inputs would have to be taken in the catchment.

All the other soil series, on the Coal Measures, are classified as HOST class 24, dominated by slowly permeable and seasonally waterlogged soils, more compact with much more lateral movement and not so well drained. The characteristics of these soils suggest that they can favour runoff generation and under steep topographies runoff transfer. Artificial land drainage has been incorporated in many agricultural areas with the drains often discharging directly into the water bodies. Land drainage is thought to be especially efficient in some old mining sites newly restored for agriculture (NT, personal communication). A more detailed understanding of these restored sites would be useful to assess the effect of this improved drainage, and also to know whether they pose an increased erosion risk due to unprotected/poorly structured soil conditions as can be the case in some restored areas (Cranfield University, 2004).

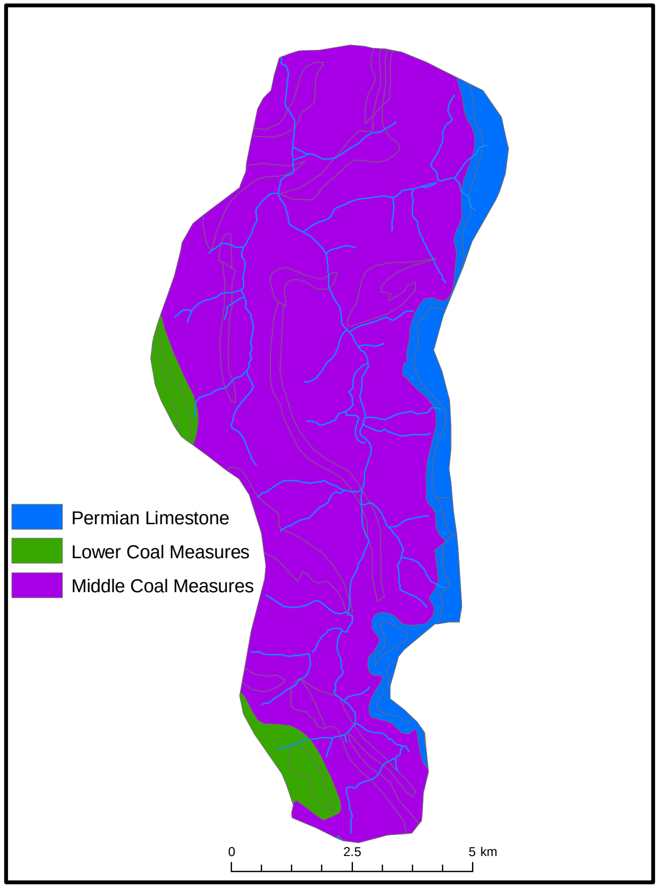


Figure 5. Solid Geology of the Doe Lea Catchment. (Source: BGS)

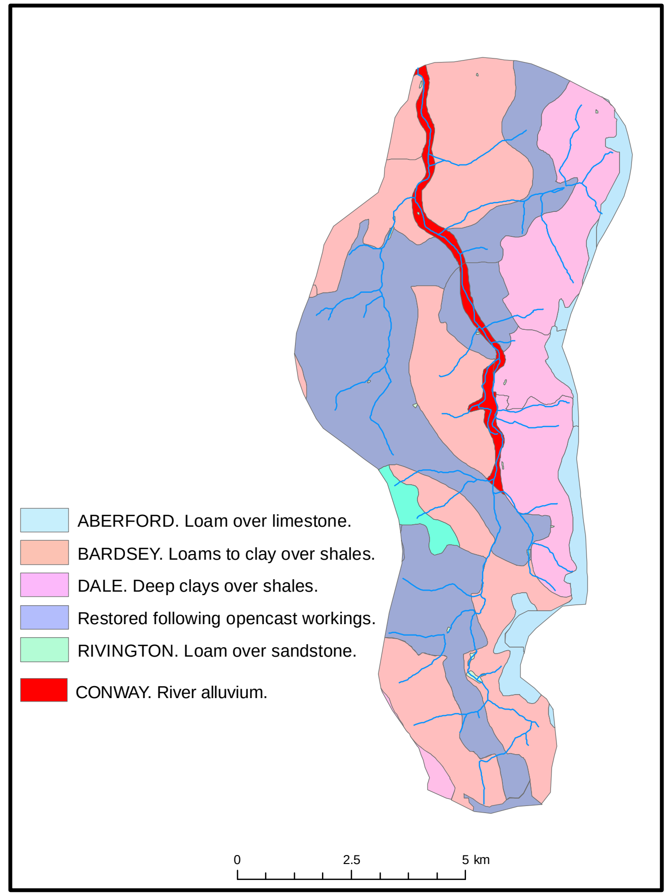


Figure 6. Distribution of soil types in the Doe Lea Catchment. All soils are HOST class 24 (low permeability) except Aberford Series (class 2, permeable). (Source Cranfield University).

Land use

The data used for this analysis shows the land-cover distribution in 2000, so it has to be taken into considerations that some changes might have taken place since then. The data is derived from satellite imagery, and occasionally classes may differ from the real land use (which will usually be similar) in higher resolution mapping, although general structural patterns are usually similar (Fuller *et al*., 2001). In the original land-cover map (fig.7a), arable uses are divided into cereal and horticulture, with horticulture being dominant, which in this case has been considered a misinterpretation, as that is not the case in reality. All agricultural land is considered as one land-use unit for further analysis (fig.7b). About two thirds of the non-improved grassland have been identified as calcareous grassland, although for further analysis purposes it has been considered as neutral grassland (fig.7b) (calcareous grassland is not found on soils like those underlying those areas in the catchment and it is therefore considered that it has been wrongly identified).

The land cover map (fig.7a and 7b) shows that a variety of land uses and covers are found within the catchment. The main land use is agriculture, and arable land is the dominant use throughout. The approximate distribution of the land use according to the modified land-cover map is as follows:

- Arable, 44%.
- Improved grassland, 14%.
- Neutral grassland, 12%.
- Broad-leaved woodland, 7%.
- Urban and suburban, 20%.
- Other (bracken, coniferous woodland, bare ground) 3%

Although some of the land uses are found at different locations throughout the catchment, the management practices are not necessarily the same for all sites. For instance, although some grassland is used for grazing, other grass fields are used solely for the production of fodder. Grazing by cattle can cause compaction and in turn reduce infiltration and favour the production of runoff. The use of heavy machinery can cause a similar effect of soil compaction, and also create effective transfer pathways in wheelings. Different management is found in places for arable fields in different types of soils. Very clayey soils, for instance, will in cases not be ploughed, as other soils will be, thus limiting the increase of soil erosion and reduction of infiltration that ploughing can favour. Also, the conditions and efficiency of land drainage can vary spatially, which will be reflected by the amount of water discharged into the water bodies via this pathway with efficient drainage acting as a direct pathway for water and related nutrients, pollutants and sediments.

Urban land is not considered in detail here, although it can be significant in terms of pollution (e.g. heavy metals and hydrocarbons) and runoff generation and transfer, as it is dominated by impervious surfaces (e.g. Ellis *et al.*, 1987, Wu *et al.*, 1998).

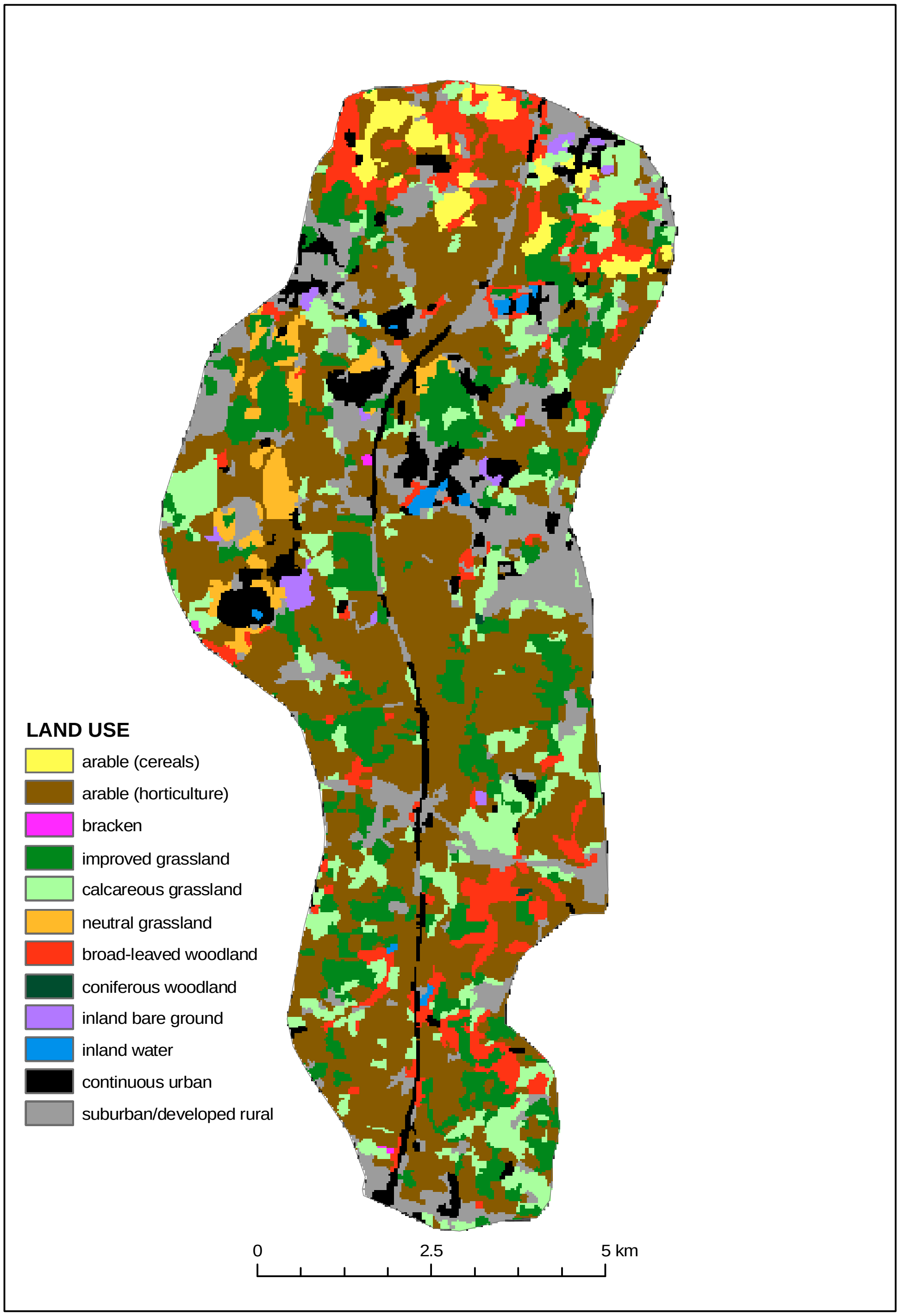


Figure 7a. Land-cover map of the Doe Lea Catchment, showing dominance of arable uses. (Source: CEH, 2000 data).

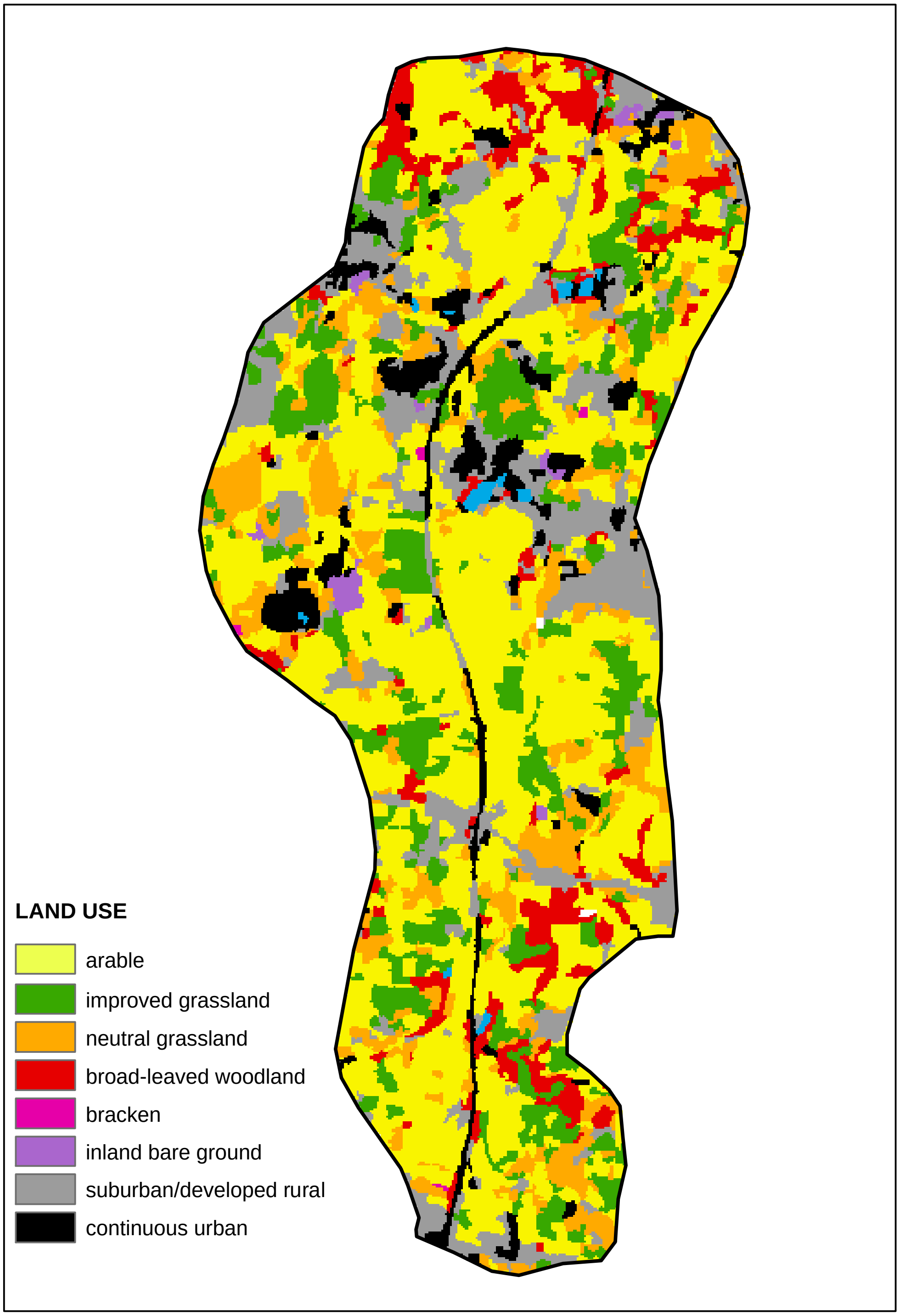
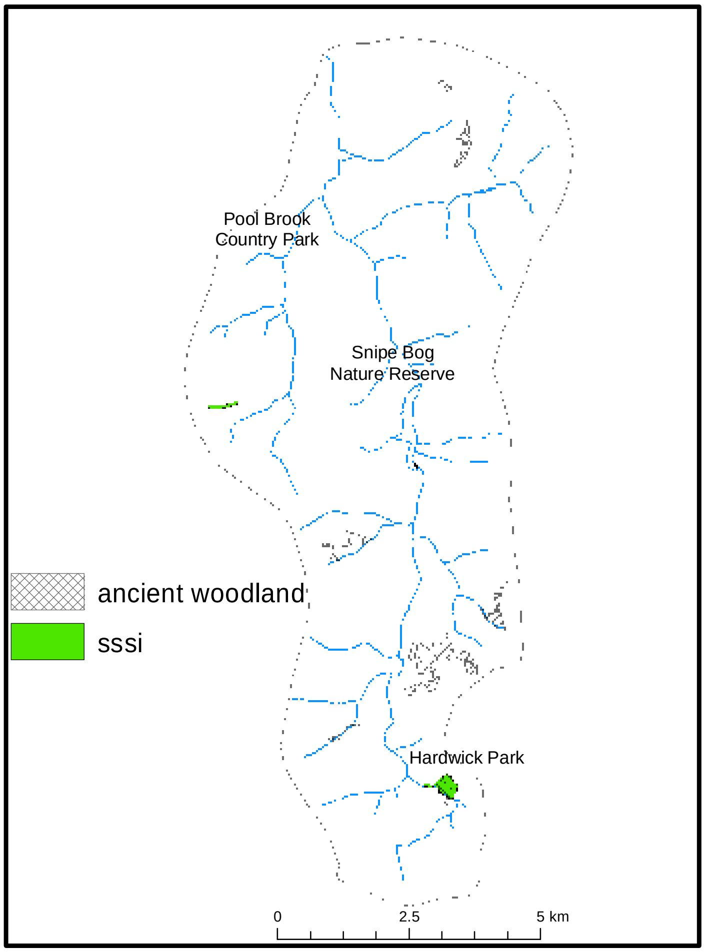


Figure 7b. Modified land-cover map of the Doe Lea Catchment. Areas originally identified as calcareous grassland have been reclassified as neutral grassland, and all arable land is shown under a single classification (Modified from CEH, 2000 data).

Designations

There are three Sites of Special Scientific Interest in the catchment (fig.8), only one of which, Dovedale Wood, relates to the land cover of the area (the other two are geological, Duckmanton Railway Cutting and Doe Lea Stream Section). Dovedale Wood is also designed as an Ancient Woodland, as are several other woods in the catchment. There are also two major parks (Pools Brook Country Park and Hardwick Hall Country Park) and a Nature Reserve (Snipe Bog Nature Reserve, DCWT), with other minor parks and recreational areas.



"© Natural England [2010], reproduced with the permission of Natural England, http://www.naturalengland.org.uk/copyright."

Figure 8. Location of designated Sites of Scientific Interest , Ancient Woodlands, Parks and Nature Reserves in the Doe Lea Catchment. (Source: NE and NT).

CATCHMENT PRESSURES

Monitoring

Water flow and quality issues have been identified in the Doe Lea catchment as mentioned. A series of point monitoring takes place in the catchment to provide quality data (fig. 9). There is a flow gauge at Staveley, near the confluence with the River Rother, which provides high resolution flow data for the Doe Lea. A rain gauge in Wingerworth, Chesterfield, provides surrogate high resolution rainfall data, with average values in the area of about 800 mm per year (Met Office, 2010). The general quality assessment (GQA) scheme has evaluated the quality of river water in terms of its biology, nutrients and chemistry. An extensive network of GQA points is found in the Doe Lea catchment, mostly in the main stream but also in some of the major tributaries.

The River Habitat Survey (RHS) is a system designed to assess the habitat quality of rivers and streams based on their physical structure. It characterises the river according to a variety of parameters such as the physical characteristics of the stream and the riparian zone, the vegetation cover and the flow type. There are three RHS points in the Doe Lea.

The European Water Framework Directive (WFD) demands that good ecological status is achieved in water bodies (European Commission, 2000). To be able to respond to the demands of the WFD, a series of monitoring points have been established, which look at different measures of ecological status, including biology and elements such as phosphorous and pH, and chemical status. Many of the WFD monitoring points in the Doe Lea Catchment have replaced GQA points, although they are more numerous.

Status

Under the implementation of the WFD, the Doe Lea is part of the Humber River Basin District (HRBD). The Doe Lea catchment has five river water bodies (table 1). The ecological status of these five river water bodies is classified as either poor or bad for most of the cases (Environment Agency, 2009). The main Doe Lea stream is expected to reach good ecological status by 2027 rather than by the 2015 target required by the WFD, as it is considered technically unfeasible or disproportionately expensive to achieve otherwise. Some tributaries are expected to reach good status by 2015. However, it is worth noting that although the objective is to achieve Good ecological status by 2015 in Hawke Brook, it is actually the only water body in the catchment for which a Bad current status has been given.

Table 1. Water bodies of the Doe Lea Catchment, from upstream to downstream. Current overall status given by the River Basin Management plan and prediction for the achievement of the WFD objective of good ecological status by 2015 is shown. Where status is not given, current overall potential is given in brackets instead. (Source, EA, 2009).

Water Body	Reference no.	GR	Status	Good Ecological Status by 2015?
Doe Lea, source to Hawke Brook	GB104027057290	SK 46068 70830	Poor	No (2027)
Hawke Brook, source to Doe Lea	GB104027057320	SK 45801 74180	Bad	Yes
Doe Lea, Hawke Brook to Pools Br	GB104027057300	SK 44409 73862	Poor	No (2027)
Pools Brook, source to Doe Lea	GB104027057310	SK 43614 71845	(Good)	Yes
Doe Lea, Pools Brook to Rother	GB104027057690	SK 44555 75737	(Moderate)	No (2027)

Supporting physico-chemical conditions used for the classification perform differently in the different water bodies (table 2). Phosphate conditions are poor in three of the catchment for which a classification has been given. The other elements considered show generally a good status, except for the further downstream water body where the status of ammonia is also poor. No values for nitrate are given, although it is known that it has been monitored in the catchment, so it would be useful to obtain the results of that monitoring.

Biological quality is recorded generally as poor or bad (table 3), although not all elements have been considered for all water bodies. On the other hand, however, quality and morphology of flow are considered generally good (table 4). Some ecological potential and mitigation measures have been implemented, mostly related vegetation control and channel management. Other potential measures considered, which include for instance improvements of floodplain connectivity, have not been implemented.

Table 2. Supporting physico-chemical elements. Only some of the elements considered are given as a sample. Those elements not shown (temperature, copper and zinc) all show good status when they have been given. Blank cells show that results were not given/available. (Source, EA, 2009).

Water Body	Ammonia	Dissolved O	Phosphate	pH
Doe Lea, source to Hawke Brook	Good	Good	Fail	Good
Hawke Brook, source to Doe Lea				
Doe Lea, Hawke Brook to Pools Brook	Good	Good	Fail	Good
Pools Brook, source to Doe Lea	Good	Good	Good	Good
Doe Lea, Pools Brook to Rother	Fail	Good	Fail	Good

Table 3. Biological Elements. Only some of the elements have been considered in most of the water bodies. No values for diatoms are given. Blank cells show that results were not given/available. (Source, EA, 2009).

Water Body	Fish	Invertebrates	Phytobenthos
Doe Lea, source to Hawke Brook	Poor	Good	Poor
Hawke Brook, source to Doe Lea		Bad	
Doe Lea, Hawke Brook to Pools Brook	Poor		
Pools Brook, source to Doe Lea		Moderate	
Doe Lea, Pools Brook to Rother	Poor		

Table 4. Supporting hydrological and morphological conditions. Conditions are good in all the water bodies. Blank cells show that results were not given/available. (Source, EA, 2009).

Water Body	Quantity and dynamics of flow	Morphology
Doe Lea, source to Hawke Brook	Good	Good
Hawke Brook, source to Doe Lea	Good	Good
Doe Lea, Hawke Brook to Pools Brook	Good	Good
Pools Brook, source to Doe Lea	Good	
Doe Lea, Pools Brook to Rother	Good	

Thus, the river does not perform well in terms of quality indicators. The best status is found in the west of the catchment, in the Pools Brook subcatchment, but there is only one monitoring point in this catchment (fig.9), and some parameters that might be important such as suspended sediments are not measured. The water bodies upstream, covering all the southern and eastern part of the catchment and the northeast, where the majority of the sampling points are located, have a poor status and perform badly in terms of ecology and phosphate. The water body located furthest downstream, up to the confluence with the River Rother, is classified as having a moderate potential (rather than status), but still performs badly in terms of fish, phosphate and ammonia.

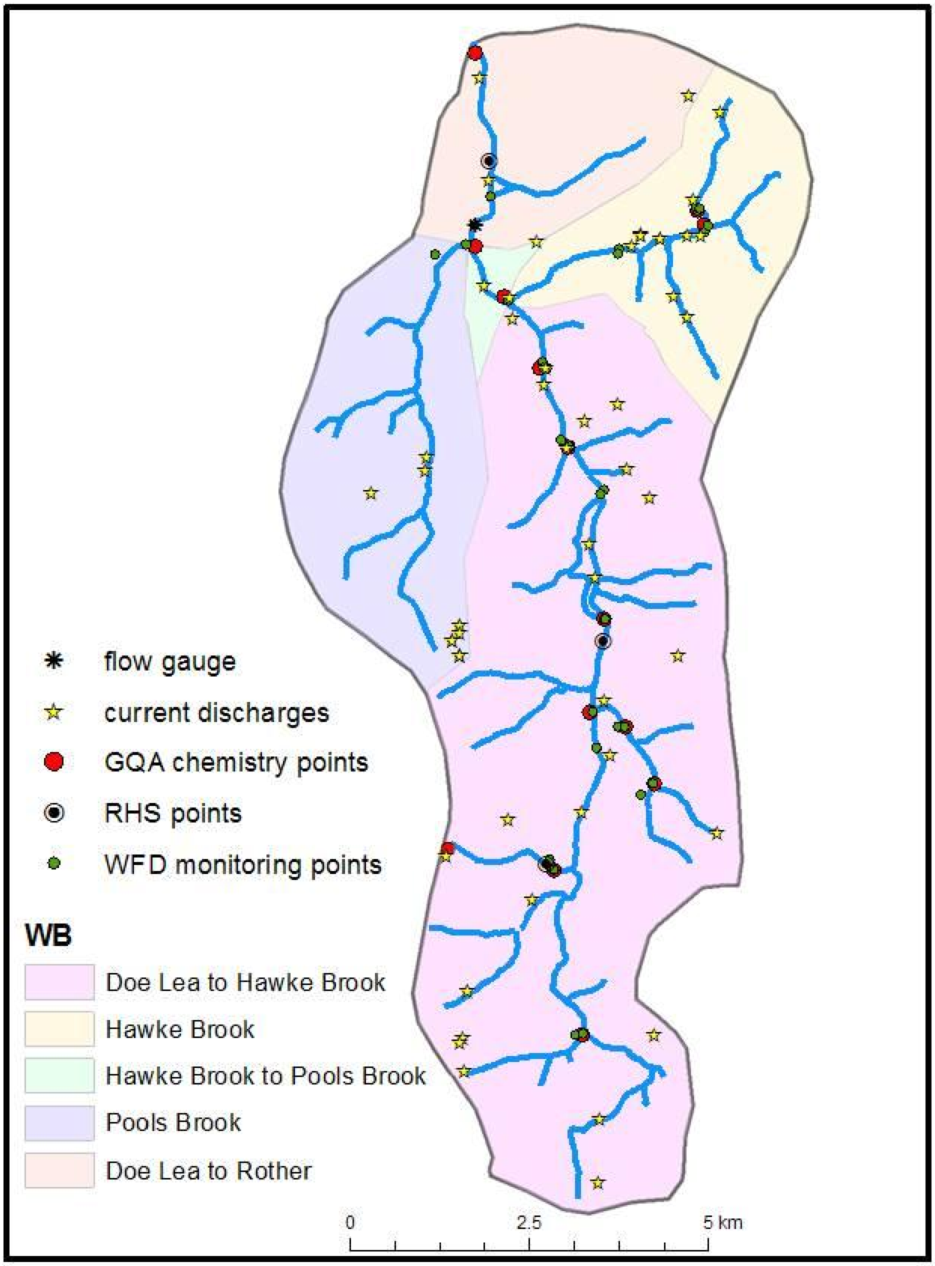


Figure 9. Monitoring points in the five water bodies of Doe Lea Catchment. See Appendix 1 for details of points and monitoring. (Source: EA).

The Doe Lea Project has identified three main pressures leading to this poor status, which are all related to the movement of water across the catchment: runoff generation and transfer, diffuse pollution and diffuse sediment transfer.

Diffuse pollution

Diffuse agricultural sources are considered a major contributor to elevated nutrient and pollutant concentrations in surface waters (e.g. Foster *et al*., 2003). The poor results shown by the monitoring of the Doe Lea and its tributaries in terms of the biological conditions of the catchment are an indicator of the adverse impact of diffuse pollution from agriculture and other sources upon the water bodies in the catchment.

The whole catchment has a protected area designation under the Nitrates Directive, which aims to reduce water pollution by nitrate from agricultural sources and to prevent such pollution occurring in the future (ADAS, 2004). In the water bodies in which supporting element have been considered in the WFD monitoring bad phosphate conditions (table 2) have been found, which may be linked to agriculture and point source inputs. Nitrate data, if obtained, could also reflect diffuse pollution.

Suspended sediments

Soil erosion and transport of sediment and sediment-associated substances might affect land and water quality (Freeman *et al*., 2007). Problems of diffuse sediment sources have been identified in the south and west of the Doe Lea catchment, leading to poor water quality.

For example, significant colour and siltation issues have been observed in the ponds in Hardwick Park. Besides increased turbidity, such diffuse sediment issues can contribute also to diffuse pollution problems as sediment-associated nutrients and pollutants are transported to the water bodies and added to the dissolved fraction. No specific measurement of suspended sediment is available, other that those mentioned in the pond above, as this aspect is not covered in the water-body monitoring at present.

Runoff

Excess flow from runoff and land drainage can lead to flooding issues both in the catchment and further downstream in the River Rother catchment. The Flood Map (fig.10) shows areas of the catchment of different risks or likelihoods of flooding occurring, with higher risk in flood zone 3 than in flood zone 2.

The risk seems to be concentrated in the lower part of the river. For example, the area around the confluence with Pools Brook is considered to be at risk from the Doe Lea in a 100-year event. This area is protected by an embankment, but it has been known to be overtopped under severe events (Chesterfield Borough Council, 2009).

Nine flood warnings have been issued by the Environment Agency along the Doe Lea since 2000, seven of them only in the last three years. Of these, only once has a flooding occurrence been reported (in June 2007), although in the majority of the remaining cases it is not known whether flooding occurred or not. However, other instances of recent flooding have been reported by users of the catchment, including a perception of increased occurrences in recent years (e.g. NT).

Maintenance programmed by the Environment Agency considers the system low risk in this aspect. There are no works planned in the capital programme, and inspections are carried on a yearly basis.

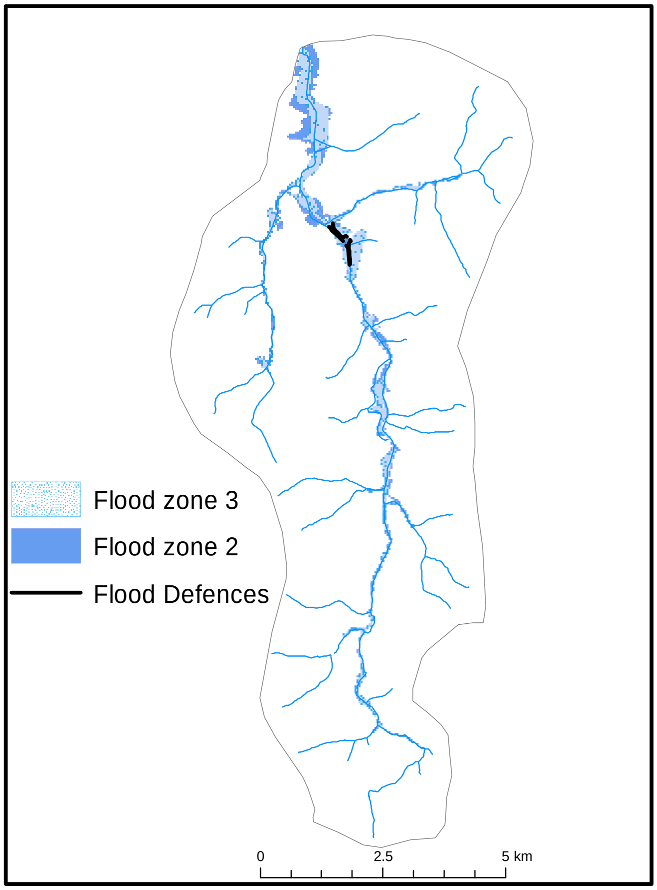


Figure 10. Location of hard flood defences maintained by the EA and flood zones. Flood zone 3 shows areas with higher likelihood of flooding (1 in 100 or greater annual probability of river flooding), whereas flood zone 2 show areas susceptible to flooding under more extreme rare events (between 1 in 100 and 1 in 1000 annual probability of river flooding). (Source: EA).

Catchment initiatives

A series of Countryside Stewardship Schemes (CSS) and Environmental Stewardship (ES) options have been implemented in the catchment and are still active (fig.11).

Most of the CSS current agreements started in 2002-2003 and will end in 2011-2012. Some of the options that have been implemented include the restoration of hedgerow and the regeneration of natural grassland.

Most current ES Schemes in the catchment are entry level, with some entry level plus higher level and two higher level schemes (both in the same holding in the east of the catchment) and the schemes started between the years 2005 and 2010. There is a wide variety of options (fig.12), including among others management of ditches, creation and management of hedges, management of field edges and buffer zones, maintenance or creation of ponds/wetlands, and restoration/management of natural grassland and related habitats and features. To these options it has to be added the implementation of the soil management plan, manure management plan and nutrient management plan.

Point data is available to plot the options in the map of the catchment, but the exact location of the implementation of an action relative to other elements in a field is not known, making therefore more difficult to assess the effectiveness of each option in reducing the pressures of concern without a direct survey. However, some of the options have the potential to influence directly runoff production and the risk of diffuse pollution and sediments.

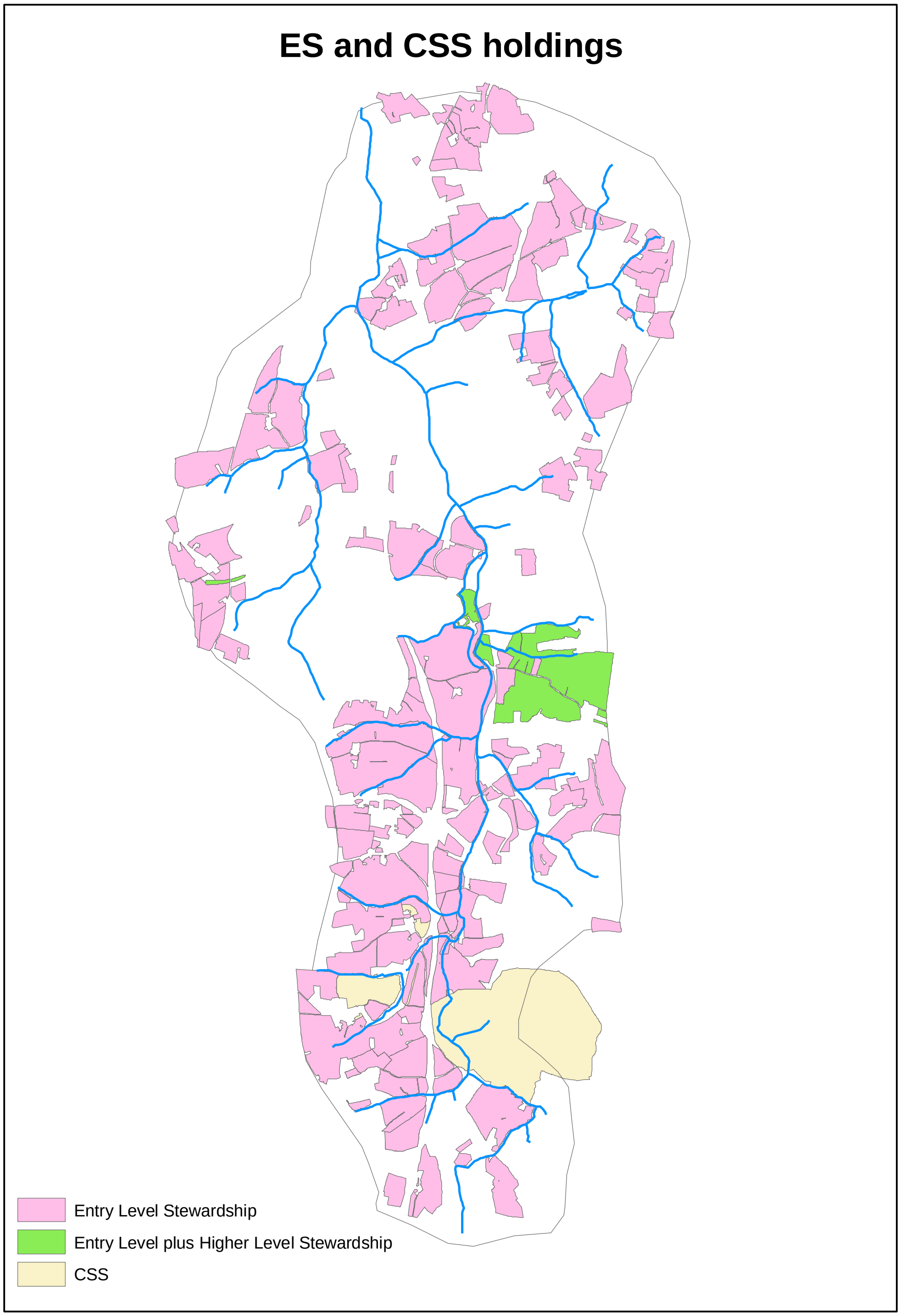


Figure 11. ES and CSS holdings in the Doe Lea Catchment, showing scheme and level. (Source: NE).

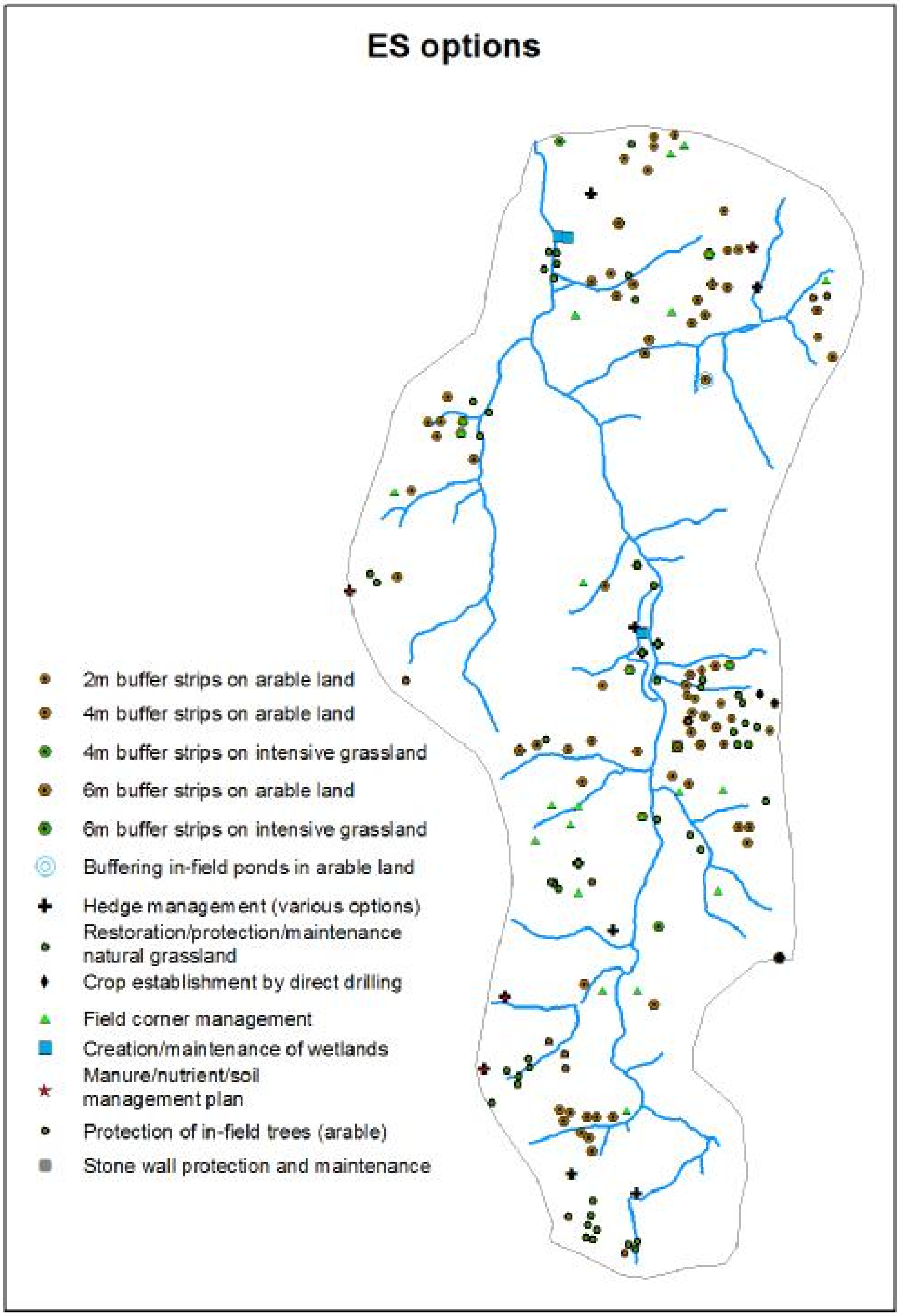


Figure 12. ES options with potential for runoff and diffuse pollution mitigation currently in place in the Doe Lea Catchment. (Source: NE).

CONCEPTUAL MODEL OF THE SYSTEM

The understanding of the catchment needs to consider all the relevant elements of the system and their relation to each other in terms of the identified pressures. The physical characteristics and the structure of the catchment, the processes taking place and the land-use and management practices are all driving factors of diffuse pollution (e.g. Heathwaite *et al.*, 2005).

Some of the factors contributing to overland flow and its related transfer of water, sediments and pollutants, for example precipitation, are external to the system, on which they have an influence but are not in turn directly affected by the other drivers at this scale. On the other hand, feedbacks will exist among the different internal components of the system, so they will determine its behaviour in a combined and dynamic fashion. Structural aspects of the Doe Lea catchment to be considered are geology, topography, soil type and vegetation and land cover. Management factors such as land-use practices and management (e.g. type of crop, use of chemicals, till practices) will interact with those elements under the effect of climate. It will be the combination of these factors (fig. 13 and 14) that will determine the conditions that will be more or less favourable to contribute to the pressures of concern.

For these pressures to affect water bodies in the catchment adversely there must be sources for sediments and pollutants, but also pathways that connect those source areas to the water bodies (Haygarth *et al.*, 2005). Often in agricultural systems more nutrients are applied than are removed from the system in produce (Beaton *et al.*, 1995). This results in nutrient surpluses which can then be removed when significant rainfall events occur, creating thus a fundamental source of diffuse pollution from agriculture. Effects on water quality and ecology suggest that this is the case in the Doe Lea catchment, where agricultural land to which additional nutrients and chemicals are added will contribute to the risk of diffuse pollution as a source. Although the presence of pollutants does not in itself increase the risk of runoff or soil erosion, if heavy machinery is used for the application of substances it might lead to soil compaction and also to the creation of preferential pathways that might increase the surface connectivity. Similarly, other management decisions may also influence landscape responses. Grazing, for instance, can case the same effect on the soil as the use of heavy machinery. On the other hand, tillage can increase the risk of erosion and runoff, and the introduction of artificial drainage can provide very effective pathways for the transfer of water, sediments and pollutants into water bodies (Foster *et al*., 2003). The spatial division of the land will also have an effect in the connectivity of the landscape and the transfer effectiveness of the surface pathways.

Some land uses are generally considered more susceptible to increased risks. Thus normally, risk from arable land is considered higher, as ploughing is more common, as is a greater use of fertilizers and pesticides and heavy machinery. Also, the seasonal variation in vegetation cover in arable land leaves the soil at times without a protective layer that also contributes to water retention. However, some arable land in the catchment (with very clayey soils) is not widely ploughed, and other land uses can also pose potential risk, such as improved grassland which can also contribute to pollution, and in the cases in which fields are used for grazing the effects described above may be seen. Urban areas, on the other hand, are mostly covered by impervious surfaces that might contribute to pollution and favours runoff generation and transmission. A particularly significant impervious surface in the catchment in terms of pollutants and runoff transmission is the M1 that runs across it. Some land covers, conversely, can have a role on reducing risk, as it is for the example the case of woodland, or the wet grasslands found in the catchment that can provide storage for water that might otherwise reach watercourses.

Topography influences the saturation conditions of the soil and the generation of runoff (Lane *et al*. 2004) and whether it will be connected to water bodies. Soils on steeper areas are more susceptible to erosion, and the risk of nutrients being washed away also increases as slopes get steeper. The steepest slopes in the catchment are found in the eastern part, but there are some less extensive ones in other the south and west too.

The related soil types have to be considered together with the above factor, as the vulnerability of areas of similar uses will vary if the soils are different. Well drained soils, found in the east of the catchment, show less risk for overland flow, although they can lead to a negative effect on water through subsurface pathways and on aquifers through the infiltration of polluted water with leached substances. On the other hand, the non-permeable soils found elsewhere are more susceptible to waterlogging and therefore overland flow. These characteristics are linked to the underlying geology, which can influence the effects of infiltration. In this case, the relatively permeable limestones favour this infiltration, but the structure of the rocks suggests that water that reaches this level is carried out of the catchment.

Although these elements and their interactions contribute to the pressures of concern, all three pressures do not necessarily occur simultaneously. Generally, runoff occurs when effective rainfall events take place, and the spatial distribution of overland flow will be related to the factors discussed above. However, not every time runoff is generated will lead to the same amount (or any at all) of soil and nutrient transfer, as there are temporal variables related for instance to seasonal land cover variation, timing of fertilizer applications, characteristics of previous events, etc., which make the availability of sediment and pollutant availability to vary both temporally and spatially.

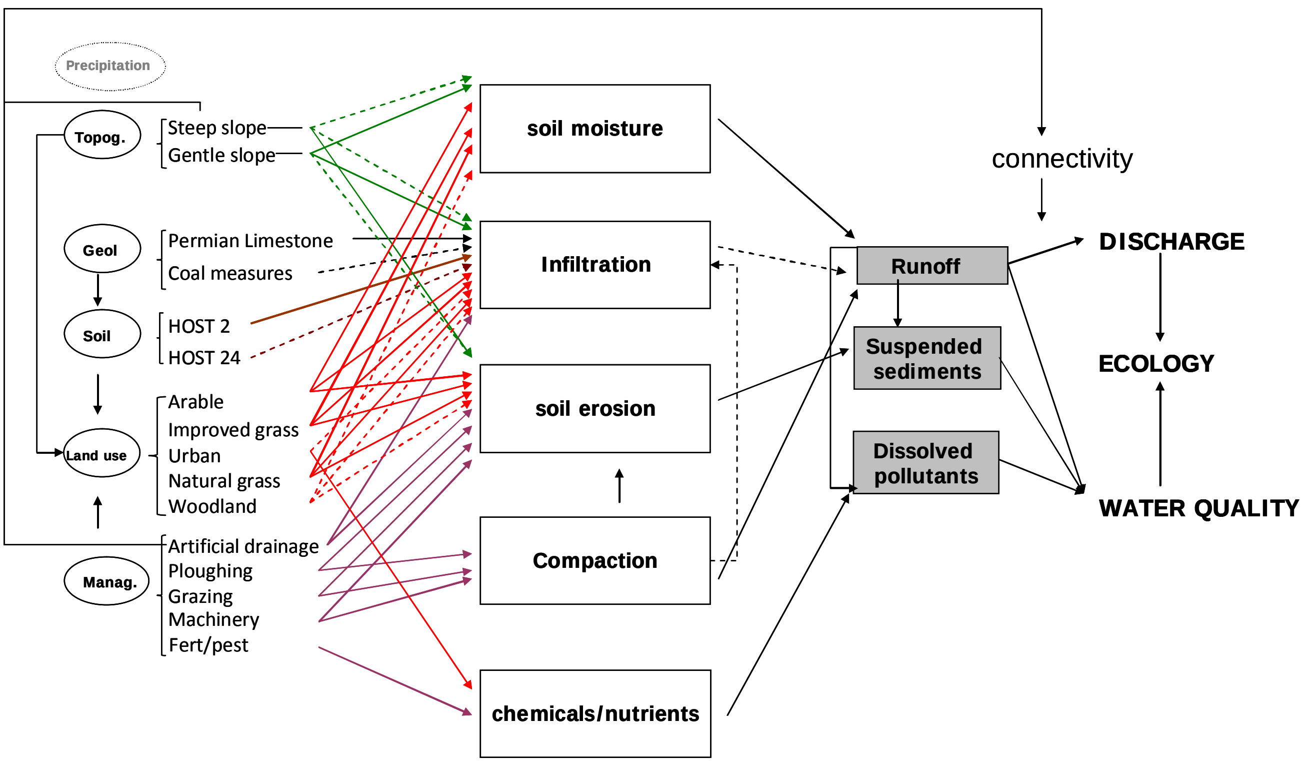


Figure 13. Conceptual model of the drivers and factors interacting in the Doe Lea Catchment and leading to the resulting issues on flow and water quality. The different factors in the left affect catchment properties (in the boxes) that may influence the pressures. Solid lines show favouring of the properties (with thicker lines showing stronger influence) whereas dashed lined show less favourable conditions.

The understanding of the system interactions has been used to characterise the catchment spatially according to the risk of overland flow and diffuse pollution and sediments. Thus, the conceptual model has been used as a basis to construct a GIS-based model to represent the risk for each area of the catchment to contribute to diffuse pollution, overland flow and suspended sediments. Different properties of the geology, topography, soil types, land use and management have been ranked according to their relative influence on each of the pressures (fig. 14) and then built together on a GIS framework to show the spatial distribution of the aggregated risk (see Appendix 2 for a more detailed methodology). As discussed above, some of the driving factors contributing to these pressures are the same, so it can be expected that the risk maps for each of the pressures show many similarities. However, some structural conditions and land-use practices will have a more direct effect on some pressures than on others, so therefore different scores have been for each map given.

The diffuse pollution risk map (fig.15) is based on the combination of a slope, land use, soil, geology, and land use, and shows the relative risk from low to high. Highest risks are observed in the central part and northeast of the catchment. Figure 16 shows the motorway and urban areas superimposed on the diffuse pollution risk map which might be significant for runoff generation and transmission and for the input of road-related pollutants.

The diffuse sediments risk map (fig.17) is based on the same parameters adjusted to this pressure (fig. 14). The effects of grazing and the use of heavy machinery have not been included as no high-resolution data regarding this aspect is available. The highest risk areas are located in the central-east and the southeast of the catchment.

The runoff risk map (fig.18) considers flow accumulation and direction based on a topographic index, showing potential of runoff producing areas to connect to water bodies. The model does not take into account that there might be features or structures in the landscape that may limit connectivity (e.g., dense hedges, walls, etc.), although information could added to the model if known. The highest risk is observed in the east and in the southwest of the catchment.

Figure 19 shows the aggregated risk after combining the elements of all three pressures, and showing areas that have a high potential of being nutrient and sediment sources and have at the same time good conditions for runoff generation and are well connected to water bodies. The highest risk areas seem to be concentrated in the east and the southwest of the catchment. Some of the issues posed in those areas might already be targeted to some extent by the implementation of schemes, as can be seen in figure 20. The subcatchments with the highest risk potential have been highlighted in figure 21, showing in this case those subcatchments in which more than half of the area is covered by over 70% risk values.

The risk posed by subsurface land drainage has not been included in the modelling, as high resolution data is not available. It must be taken into consideration, however, that this drainage can be a very important pathway for the delivery of water, pollutants and sediments into the water bodies.

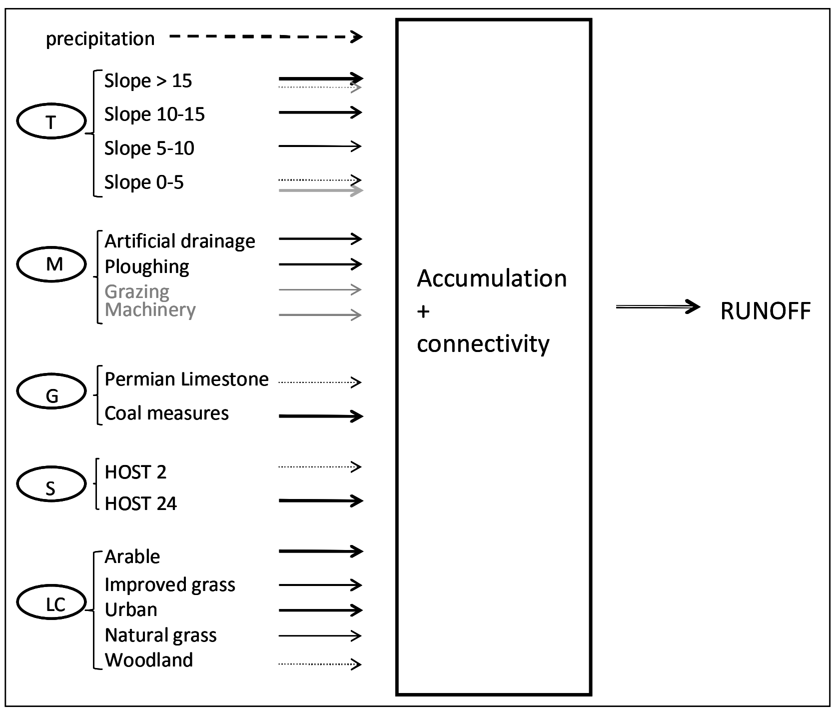


Figure 14. Example of the conceptual approach used for risk modelling (all details for each pressure can be seen in Appendix 2). The different arrow thickness shows the relation between the different values given to each factor (e.g. thickest=highest score).

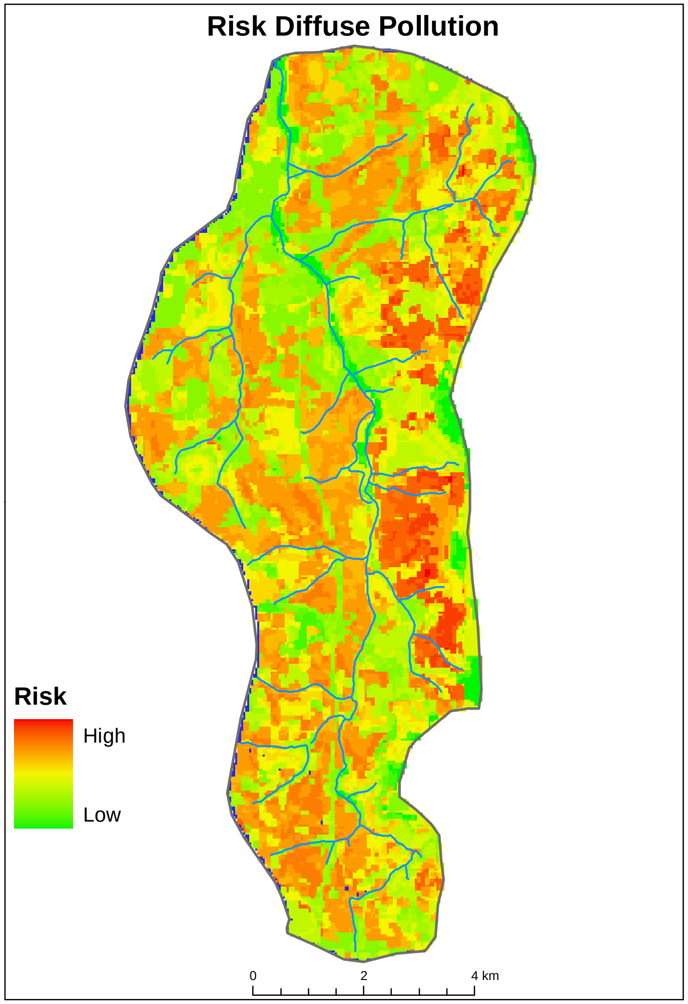


Figure 15. Risk map of diffuse pollution from agriculture, showing relative risk to be sources of nutrients and pollutants.

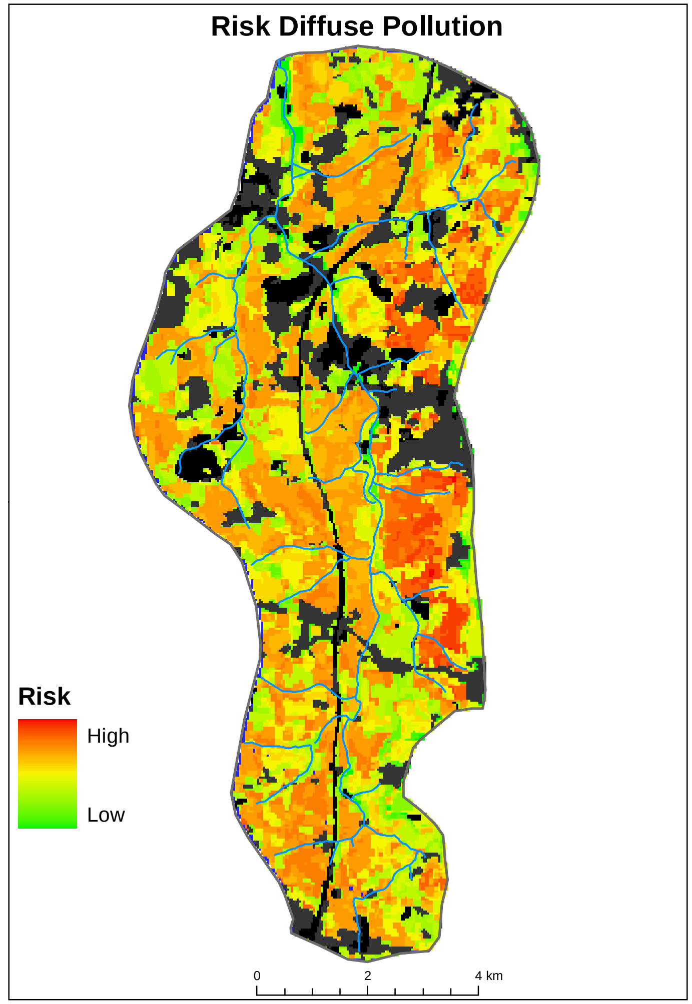
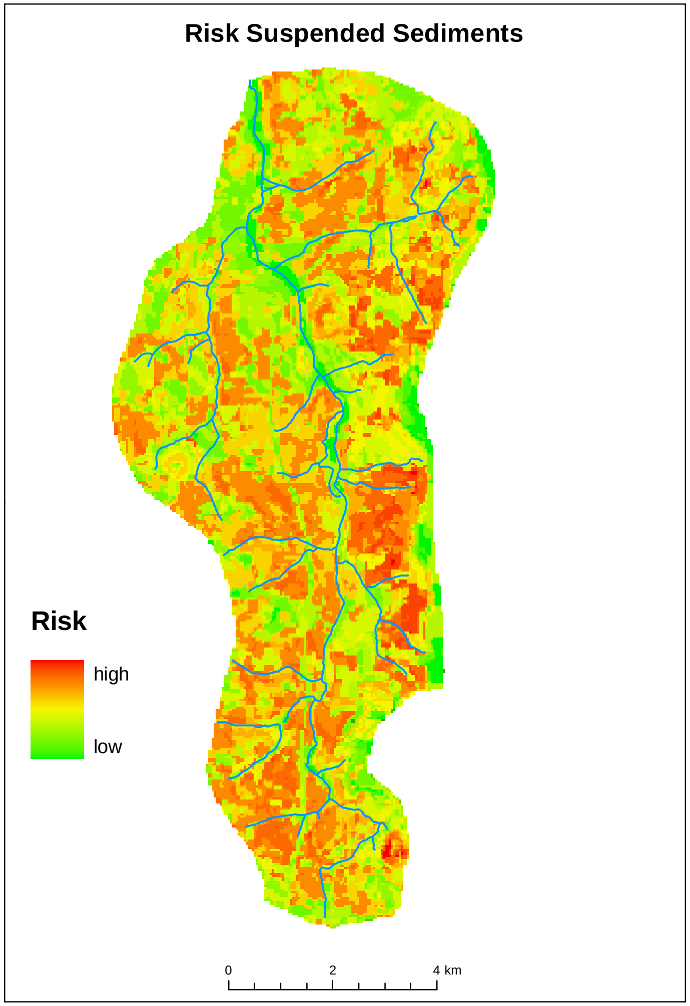


Figure 16. Risk map for diffuse pollution with urban areas and bare ground in black These areas are dominated by impervious surfaces that can be transport pathways and potential sources of pollution.

Catchment Science Centre



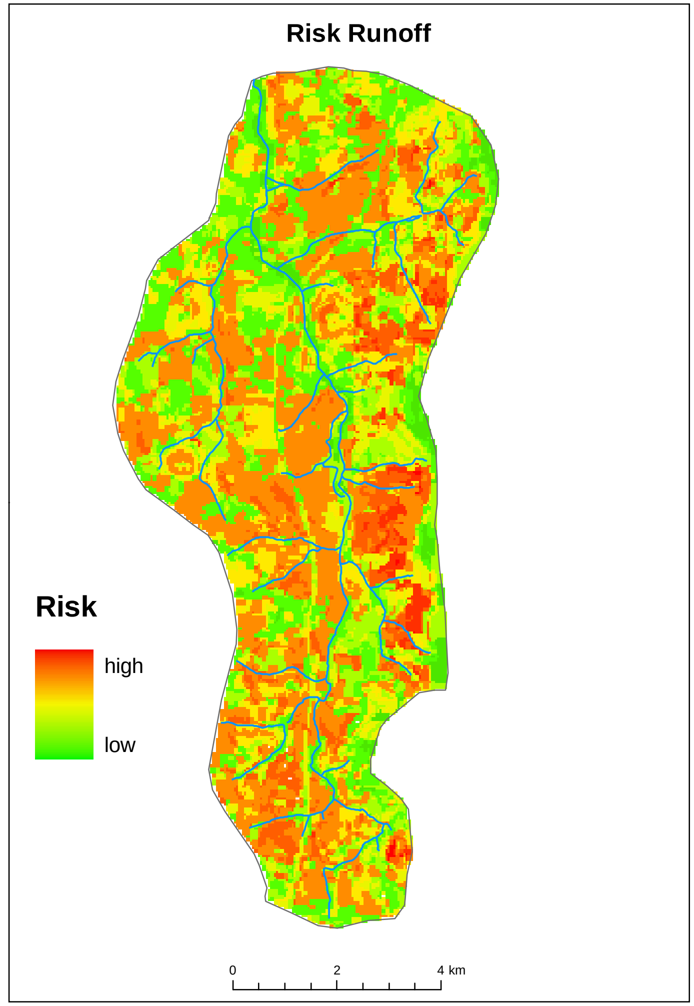


Figure 17. Risk map for diffuse sediments, showing relative risk of areas to be susceptible to soil erosion and become suspended sediment sources.

Figure 18. Risk map for runoff. It considers risk based on flow accumulation areas and effective connectivity (potential of accumulation areas to be connected to water bodies).

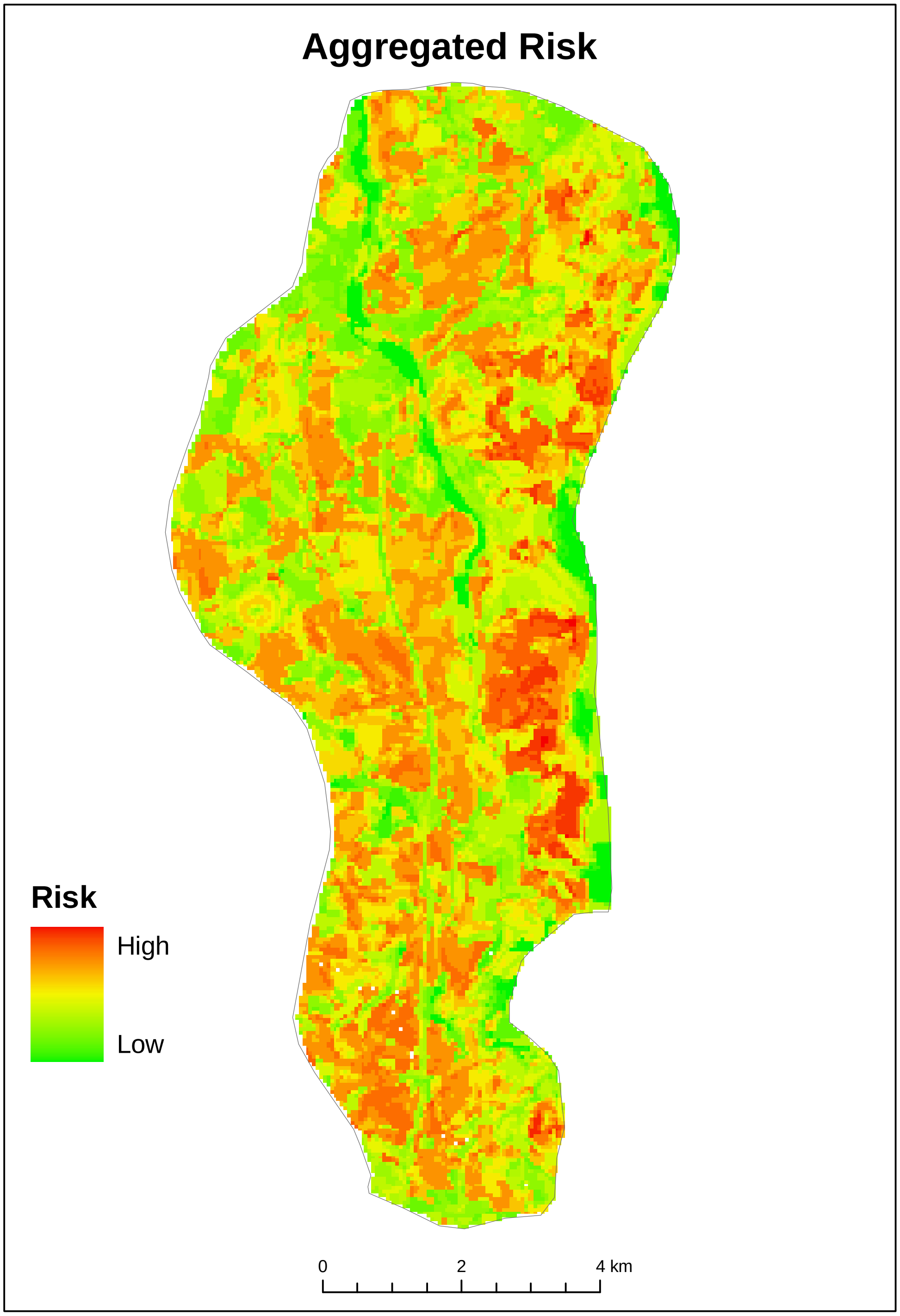


Figure 19. Aggregated risk map for the Doe Lea Catchment. It combines potential sources of nutrients and sediments with areas of runoff generation likely to be connected to water bodies.

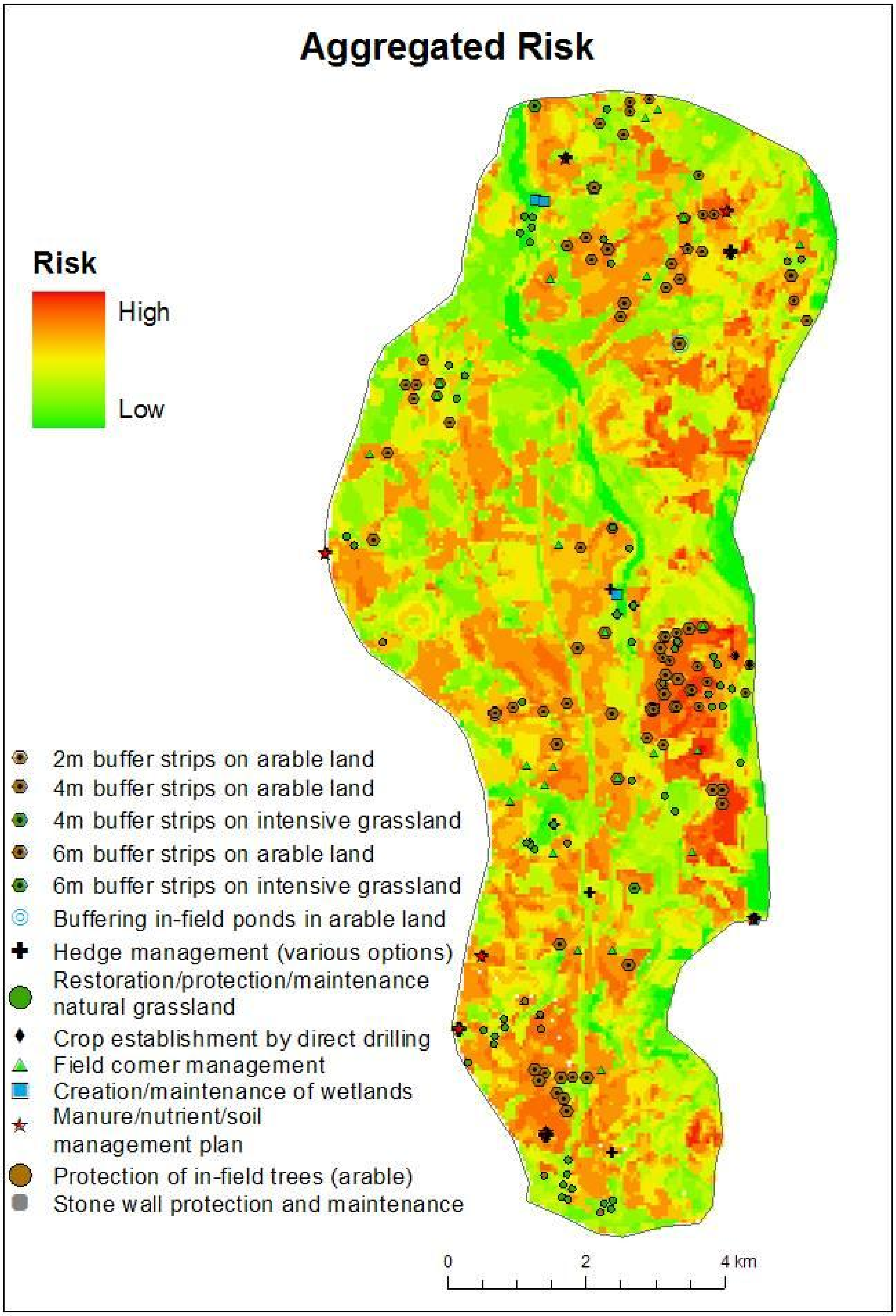


Figure 20. Aggregated risk map with superimposed location of ES options. It might be useful to assess on the ground the options being implemented in high risk areas.

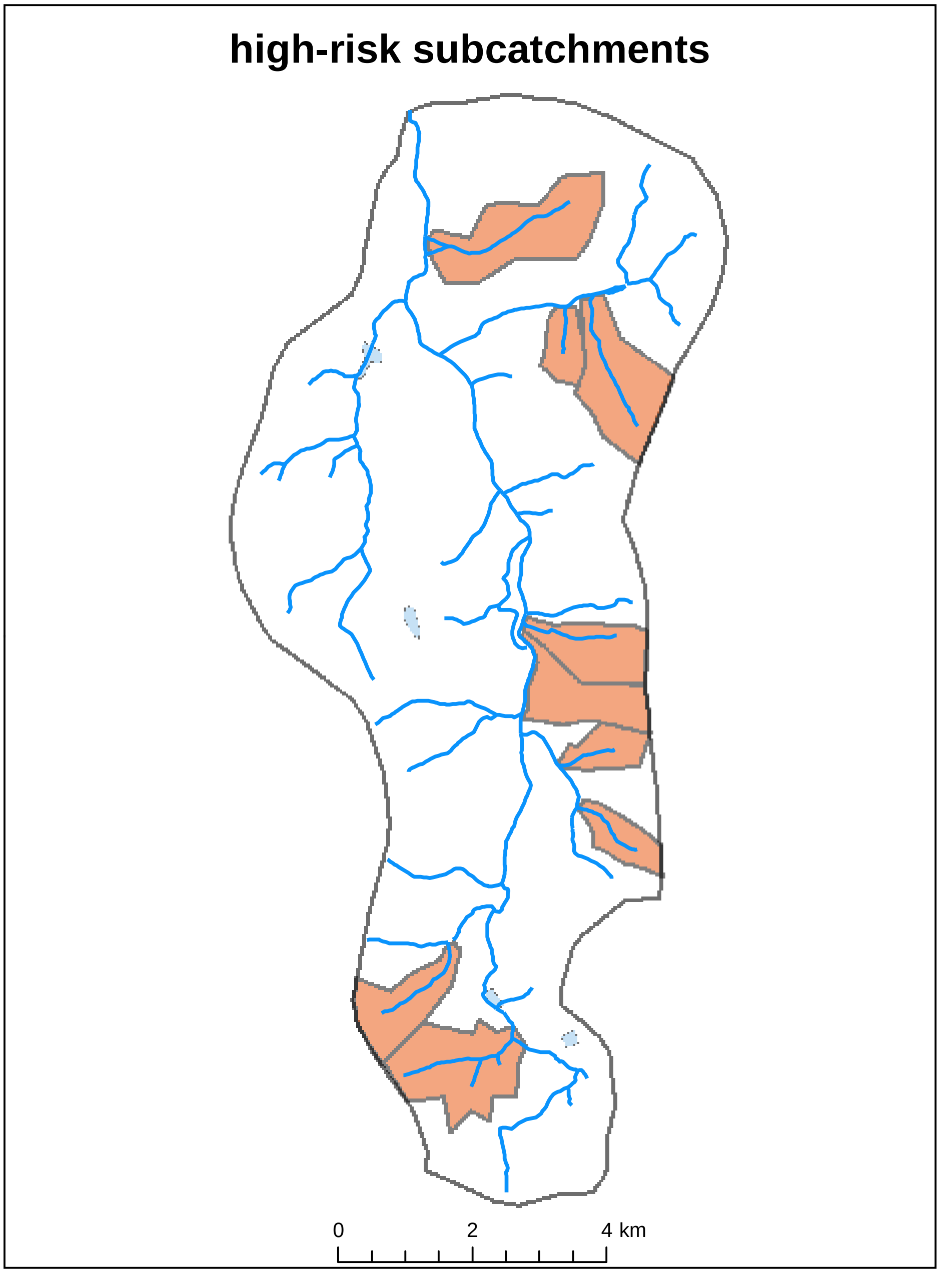


Figure 21. High-risk subcatchments. Subcatchments with the highest potential to be nutrient and sediments sources and for highest runoff production and connectivity are highlighted.

The aggregated risk map shows that the highest risk areas are mostly within the water bodies classified as having a poor or bad status. One high-risk area is found in a subcatchment downstream where potential was considered moderate but showed poor ecology and chemistry. However, there are no monitoring points in this specific subcatchment. No high-risk subcatchments are found in the Pools Brook water body, the only one with good potential, and the risk for most of the catchment is low to moderate, although high-risk pockets can be found. It is worth considering, however, that there are areas outside the high-risk catchments where the risk is high or moderately high, but are not highlighted here because they do not occupy more than half of the subcatchment where they are located. Different filters could be used to address specific questions and identify other areas of interest. Most of the highlighted subcatchments are in the main water body (DL to HB), which is the largest in extension. Figure 20 shows that many ES options concentrate in some of the high-risk catchments in the east, which suggests that the risk potential might have been already reduced, but the effectiveness of those options needs to be checked in the ground to evaluate whether or not it will be necessary to concentrate in those areas for intervention.

Monitoring points are found in one of the high-risk subcatchments in the southwest and one in the east (figure 22), whereas no sampling points are found in the others, although their effect seems to be captured in the points downstream. In the water body in the northeast (HB), there are no monitoring points in the identified high-risk subcatchment, but there are points downstream and the water body has the worse status in the catchment, so the problems arising in this upstream area can be reflected in that status classification. The output risk map of the modelling provides a tool to address and plan land management measures in a targeted manner.

MONITORING

Detailed monitoring will not be defined until specific actions for the Doe Lea project are decided and planned and specific measurable objectives are set. The following, however, presents some ideas and considerations that need to be taken into account. An effective monitoring strategy should fulfil the following conditions.

- Have an adequate understanding of baseline conditions.
- Be sustainable long-term.
- Be easy to implement.
- Be relevant to the project objectives.
- Involve stakeholders (if possible).

Having those conditions in mind, we can look at the three steps of the monitoring:

1. Set baseline
2. Monitoring program
3. Assessment of results and evaluation of measures.

1. Baseline.

Useful monitoring will depend on the adequate understanding of baseline conditions (which will be used as a reference). At present, this baseline is provided by some monitoring and by the knowledge being gathered by the project manager. It is necessary to assess if this knowledge is sufficient or if further understanding is needed before the implementation of measures.

1.1. Existing baseline data.

There are two existing sustained monitoring/data collections in the Doe Lea Catchment:

NT turbidity monitoring.

EA water monitoring.

The NT turbidity monitoring is site specific, and based at Hardwick, but might be extended to monitor suspended sediments in other areas if related problems have been identified and measures are to be implemented. The water quality monitoring takes place at several sites across the catchment (fig.22). Higher resolution data or a different spatial distribution will be necessary, however, depending on the measures.

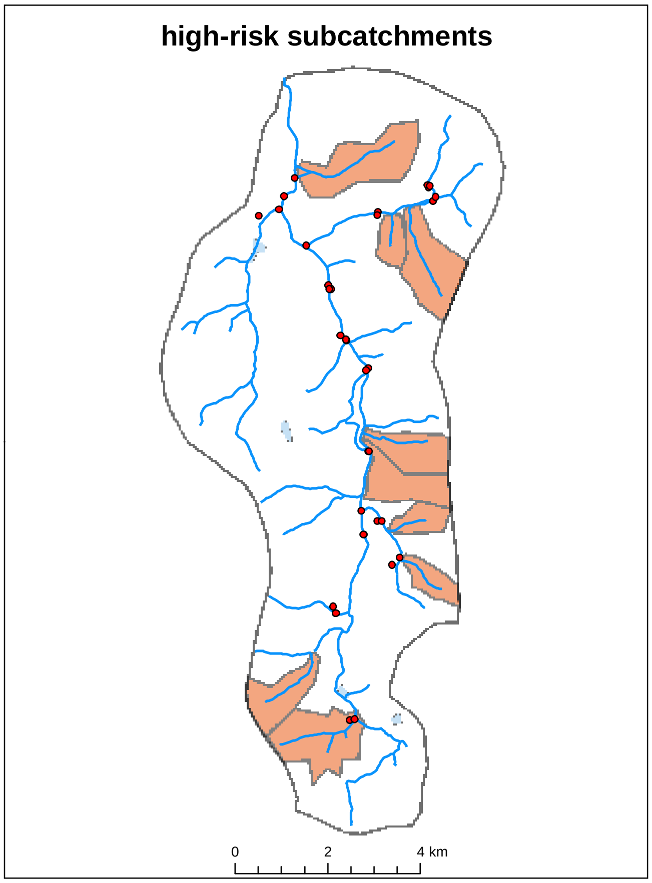


Figure 22. High-risk subcatchments and location of monitoring points. (Source: EA)

1.2. Potential data gaps.

Some of the subcatchments the risk modelling has identified as high risk are not directly monitored. It these catchments are chosen for intervention it will be necessary to assess:

a) whether the data from downstream points is enough to assess changes. The usefulness of downstream data might be complicated if several subcatchments are contributing to the monitoring point, so it is hard to say what measures from what area are having an effect.

b) whether higher temporal resolution is needed, as some of the processes are highly time dependent (for example seasonal changes or timing of management practices).

Other data needs will depend on the approach to measures. The existing datasets are likely to be very coarse if small scale targets are to be considered.

At present there is no data on runoff discharges or drainage discharges into stream or water bodies.

The trial sites will offer the opportunity to gather more information and to work on setting the baseline in other areas while trials are being carried.

1.3. Filling the gaps.

The management plan will have to concentrate on specific areas in the catchment, for example the high-risk areas highlighted by the modelling. The project will need to assess if it is possible and/or desirable to extend the current monitoring network. For parameter for which there is no data currently, it will be necessary to establish how they will be measured or whether proxies can be used.

A possible approach to contribute to local-scale baseline knowledge could be to run initial qualitative reconnaissance surveys and record the response to rainfall events of different landscape units. This is a relatively human-resource intensive task, but one that the Doe Lea project might be able to carry due to its partnership nature. It is a relatively inexpensive and effective method to gather information, which can also be used during the monitoring process. This approach can also be a tool to favour stakeholder involvement. A possible idea would be to identify, map and assess the location and characteristics of initiatives and features that might have an effect on any of the pressures, followed by recording any signs of runoff production and transmission and soil erosion in response to precipitation (see a simplified example in table 5). This approach could also contribute to ground truthing the results of the modelling and assess the location and performance of existing initiatives.

2. Monitoring program.

As already discussed by the Doe Lea Project, existing turbidity and water monitoring will be used. Once other needs for the baseline are set, the same approaches should be used for monitoring as the new results must be compared against the initial (and further) reference(s). Spatial and temporal scales also should be maintained throughout the monitoring program.

Ideally a combination of qualitative and quantitative approaches should be used. If the surveying/mapping approach is taken for initial reconnaissance, it should be maintained for monitoring. For example, it could be used to record field observations of runoff events after runoff limiting measures have been implemented, or measures to limit connectivity between the land and the water bodies have been adopted.

3. Assessment.

The data assessment and evaluation of the implemented measures will be an iterative process. The success of the measures will be evaluated (and reassessed if needed) by this means, although it will be necessary to consider that different actions will have different response times. The evaluation process will have to consider the following.

- Objective. What we wanted to achieve.
- Subcatchment. What area of the catchment.
- Location. Where specifically.
- Measure. What action or measure has been implemented.
- Monitoring. What parameter has been measured and how.
- Evaluation in relation to the objectives. Has the objective been achieved partly/fully?

Table 5. Example of simple land surveying form, including photographs and maps for reference and comparison.

FIELD SURVEY (diffuse pollution)

Record and describe the location.
Identify and describe features that may either accelerate or delay the transfer of pollutants to water.

Enhancing features	
Wheelings	
Roads / tracks	
Hardstandings	
Soil damage	
Erosion	
Field drainage	
Ditches	
Other	

Limiting features	
Ponds	
Woodland	
Field boundaries	
Other	

Waterlogging and poaching of soil in proximity to the main channel.

CONCLUSIONS

The Doe Lea Project aims to implement a land-management approach to address the pressures that are leading to poor flow and water quality in the catchment. These pressures have been identified by the project as runoff and runoff related diffuse pollution and suspended sediments.

A compilation of existing data has been used to develop a description of the catchment and to identify factors and characteristics in the catchment that influence the pressures. A conceptual model has mapped the interactions between those catchment components and their effect on soil erosion, diffuse pollution and runoff generation and transfer.

This conceptual understanding has been used to create a GIS-based risk characterisation of the catchment. Risk maps of diffuse pollution, suspended sediment and runoff have been produced, and their combination has highlighted subcatchments in the east and southwest of the catchment as showing the highest risk of diffuse pollution, suspended sediments and runoff connected to water bodies.

Clear and measurable objectives need to be set when choosing the land-management measures for the Doe Lea Catchment, so they can be measured against a baseline. Focusing interventions in high-risk areas is an option to optimise efforts and resources. The need to fill data gaps has to be assessed, and mechanisms implemented. Existing and new monitoring mechanisms need to be maintained over time so the results can be used to assess the success of the land-management interventions.

REFERENCES

ADAS, 2003. Nitrate Vulnerable Zones, 2003 Re-survey report. DEFRA, London.

Allan, J.D., Erickson, D. L., Fay, J., 1997. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology*, 37(1): 149-161.

Beaton J.D., Roberts T.L., Halstead E.H., and Cowell L.E.. (1995), Global transfer of P in fertilizer materials and agricultural commodities, in Tiessen, H., ed.. *Phosphorus in the Global Environment - Transfers, Cycles and Management*. John Wiley, New York , pp 7-26.

Boorman, D.B., Hollis, J.M., Lilly, A., 1995. Hydrological soil types: A hydrologically-based classification of the soils of the United Kingdom. Institute of Hydrology, Report No. 126.

Chesterfield Borough Council, 2009. Chesterfield, Bolsover and North East Derbyshire Strategic Flood Risk Assessment: Causes of Flooding.

Cuttle, S.P., Macleod, C.J.A., Chadwick, D.R., Scholefield, D., Haygarth, P.M., Newell-Price, P., Harris, D., Shepherd, M.A., Chambers, B.J., Humphrey, R., 2007. An Inventory of Methods to Control Diffuse Water Pollution from Agriculture (DWPA): User manual ES0203. DEFRA, London.

DEFRA, 2005. Controlling soil erosion: A manual for the assessment and management of agricultural land at risk of water erosion in lowland England.

Ellis, J.B., Revitt, D.J., Harrop, D.O. and Beckwith, P.R., 1987. The contribution of highway surfaces to urban stormwater sediments and metal loadings. *Science of the Total Environment*, 59(C): 339-349.

Environment Agency, 2003. The Don and Rother Catchment Abstraction Management Strategy. Leeds.

Environment Agency, 2009. River Basin Management Plan Humber River Basin District Annex B: Water body status objectives.

European Commission. 2000. *Directive 2000/60/EC of the European Parliament and of the Council of 23rd October, 2000: establishing a framework for Community action in the field of water policy*. Official Journal of the European Communities: Brussels; 22.12.2000, L327, 1–72.

Foster, I.D.L. et al., 2003. Changing suspended sediment and particulate phosphorus loads and pathways in underdrained lowland agricultural catchments; Herefordshire and Worcestershire, U.K. *Hydrobiologia*, 494: 119-126.

Freeman, M.C., Pringle, C., Jackson, M. and Rhett, C., 2007. Hydrologic connectivity and the contribution of stream headwaters to ecological integrity at regional scales1. *Journal of the American Water Resources Association*, 43(1): 5-14.

Fuller, R.M., Smith,G.M., Sanderson, J.M., Hill, R.A., & Thomson, A.G. 2001. The UK Land Cover Map 2000: construction of a parcel-based vector map from satellite images. *Cartographic Journal.*

Haygarth, P.M., Wood, F. L., Heathwaite, A. L., Butler, P. J., 2005. Phosphorus dynamics observed through increasing scales in a nested headwater-to-river channel study. *Science of the Total Environment*, 344(1-3 SPEC. ISS.): 83-106.

Heathwaite, A.L., Quinn, P. F., Hewett, C. J. M., 2005. Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation. *Journal of Hydrology*, 304(1-4): 446-461.

Lane, S.N., Brookes, C.J., Kirkby, M.J. and Holden, J., 2004. A network-index-based version of TOPMODEL for use with high-resolution digital topographic data. *Hydrological Processes*, 18(1): 191-201.

Met Office. UK Climate Summaries. Accessed at http://www.metoffice.gov.uk/climate/uk/ in January 2010.

Wu, J.S., Allan, C.J., Saunders, W.L. and Evett, J.B., 1998. Characterization and pollutant loading estimation for highway runoff. *Journal of Environmental Engineering*, 124(7): 584-592.