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Central Bedfordshire Development Strategy

Ecosystem Services Report

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Spatial Evidence Base to improve Regulating Ecosystem Services in Central Bedfordshire

Cranfield UNIVERSITY

Central Bedfordshire

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Disclaimer

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List of acronyms

AES: Agri-Environment Scheme

AS: Active substance

BAP: Biodiversity Action Plan

CAP: Common Agricultural Policy

CBC: Central Bedfordshire Council

CEH: Centre for Ecology and Hydrology

CLC: Corine Land Cover

CN: Curve number

EA: Environment Agency

FEH: Flood Estimation Handbook

GAEC: Good Agricultural and Environmental Condition

HSG: Hydrologic Soil Group

HVZ: High Vulnerability Zone

LA: Local Authority

MMF: Morgan Morgan Finney, a soil loss model

NSRI: National Soil Resources Institute

OM: Organic Matter

P: Phosphate

SMRs: Statutory Management Requirements

SOC: Soil Organic Carbon

SOM: Soil Organic Matter

USLE: Universal Soil Loss Equation

WFD: Water Framework Directive

Executive Summary

This report prepared for Central Bedfordshire Council (CBC) describes a 10 week project, undertaken between 14 February and 23 April 2012, to deliver spatial information relating to regulating ecosystem services (with a particular focus on soil carbon storage and sequestration, water runoff, and water quality), which will improve the evidence for habitat/land use decisions in the Central Bedfordshire area.

The project involved the collation of spatial databases for the Central Bedfordshire area regarding existing soil type, land use, and potential land use changes. Soil data was derived from the LandIS databases provided by the National Soil Resources Institute at Cranfield University. Land use data was obtained from CORINE 2006, available from the European Environment Agency. A geographical information system (ArcGIS) was used to map how current and proposed future land use affects carbon storage, sequestration, soil erosion, and runoff and water quality.

Scenarios were identified to explain and identify the spatial priorities in relation to 1) urban development, 2) agricultural management, and 3) the Biodiversity Action Plan (BAP) which would minimise negative and maximise positive impacts on the studied ecosystem services. The application of the approach was also illustrated with three case study sites focused on 1) urban development north of Luton, 2) agricultural management for a farm in the Flit Valley, and 3) woodland creation near Biggleswade. The results obtained for each regulating ecosystem service is outlined below.

Soil Carbon

- Globally soils are a more important store of carbon than vegetation and the atmosphere, and hence a key priority in climate change mitigation initiatives.
- Total soil carbon stock (to a depth of 1.5 m) in Central Bedfordshire is estimated to be nine million tonnes. This is divided between arable soils (7.4 million tonnes), pasture (1.5 million tonnes), woodland (0.5 million tonnes) and urban areas (63 thousand tonnes). (see Section 2.4.2)
- Soil texture has a direct influence on soil organic carbon (SOC). Soils with high clay content have a higher SOC content than those with a high sand content. In Central Bedfordshire, soil classified as "seasonally wet deep peat to loam soils" showed exceptionally high contents to 1.5 m depth (600- 700 t ha^{-1}) compared to all other soil types (100-300 t ha^{-1}).
- Over 55% of SOC in the top 1.5 m of soil is found in the top 30 cm. In Central Bedfordshire, the SOC between 100 and 150 cm depth is predicted to be similar for all land use types and soil types with the exception of the peat land north of Biggleswade and those alongside rivers.
- 78% of SOC (0-150cm depth) is found under arable land use, which makes up 70% of CB land cover. The smallest mean carbon stock is found under urban areas (67 t ha^{-1}) , and the highest mean SOC densities are located under woodlands (187 t ha^{-1}), followed by pastures (171 t ha^{-1}).

- Above-ground carbon stored in vegetation makes a relatively small contribution to carbon stock of an area. Woodland can store between 30 to 40 tC ha^{-1}, but pastures and arable land only 1 to 3 tC ha^{-1}.

Modelling land use changes and their impacts on SOC gave the following results:

- Urban developments in any part of the county inevitably result in losses of SOC. Some areas showed significantly higher losses than others, depending on the land use and the soil type. Arable areas were estimated to lose 20-90 t ha^{-1}, whilst woodlands lose 50-110 t ha^{-1} for all soil types except peat which loses significantly more at 110-160 t ha^{-1}.
- Proposed development areas which showed relatively low SOC losses (less than 75 t ha^{-1}) include Lidlington, North West of Dunstable, North and East of Luton, North of Silsoe, and North of Broom. Proposed developments which showed relatively high SOC losses (greater than 75 t ha^{-1}) include: North and East of Sandy, South and East of Potton, North of Shefford, around Leighton Buzzard, West and South East of Biggleswade and all sites falling within river valleys and the peat lands.
- Urban development on the case study area of the North Luton SSSA (227 ha) is predicted to cause a maximum predicted soil carbon loss equivalent to 66 t ha^{-1}, a total of 14,982 t of SOC.
- Implementation of the proposed Biodiversity Action Plan (including woodland, neutral grassland and hedgerows) is predicted to result in a net gain in SOC, with the majority of sites gaining 50-100 t ha^{-1}. The greatest gains (over 100 t ha^{-1}) are predicted on arable areas North-East of Milton Bryan and close to the A5 junction with Sheep Lane. Other areas outside the BAP which could potentially give high SOC gains when forested include: the area between Cranfield and Marston Vale, Cockayne Hatley, and South of Linsade.
- The case study site of Jubilee woodland (20 ha) conversion from arable to woodland gave a predicted gain of 52 t $ha^{-1}$of SOC, a total of 1040 t of SOC.
- The analysis showed no detectable difference between the SOC of sites currently registered under the Entry level Agri-environment Scheme (AES) and those with no scheme. This is expected as the current requirements of the AES are focused on biodiversity rather than soil carbon enhancement. Management practices to improve SOC include minimum tillage on arable land, and maintenance of continuous ground cover, and organic mature application.

Soil Erosion and Runoff

Reducing runoff and erosion will generally have a positive effect on soil organic carbon (discussed above) and water quality (discussed below). Runoff can cause soil particle detachment, including organic matter and pollutants, leaving such particles in water bodies whose properties are altered by the nature of the eroded particles.

The greatest runoff rates were associated to urban areas, followed by arable land, while woodland registered the smallest runoff predictions. Depending on the soil type, average predicted values of runoff in urban areas of the county ranged between 4 and 30 mm day^{-1} for the maximum 1 in 10 year rainfall event. Predicted average runoff from arable land and pasture land, for the same rainfall event, were 1.4-17 mm day^{-1} and 0.3-15 mm day^{-1} respectively. Finally, average runoff estimated in woodland areas for such a precipitation event ranged between 0.6 and 10 mm day^{-1}

For a given land use, the Hydrological Soil Group largely determines runoff generation: whilst the Greensand Ridge has a high potential for infiltration, a significant area of Central Bedfordshire (North-West and South-East on either side of the Greensand Ridge) comprises soils with impeded drainage where sealing will have the most limited impact. The hydrological model also showed that development areas should be carefully chosen according to the potential upstream land use change that could provoke flooding downstream. The model showed that implementation of good land management practices could significantly reduce runoff.

Erosion depends on several factors. Some are inherent to the location (slope, rainfall erosivity, soil texture), but others can be controlled by management (soil structure and organic matter, vegetation, and land management practices). It is especially important to control erosion through these methods, where local slope and soil types would otherwise result in significant soil loss.

Based on the findings of this study, the following are recommended to tackle runoff issues:

- Urban development should aim to maintain runoff patterns prior to development, causing as little change as possible. In this context, runoff increases are minimised by focusing urban development on soil areas with low permeability.
- The potential urban development sites which appear to offer the least negative impacts on runoff (as determined by our methodology) include those close to Cranfield, and those in the Western area of Flitwick and Ampthill, in the North-East of Sandy, and in the North-West area of the county. Conversely the sites that appear to create the largest negative impact on runoff include those north of Luton and in the south-west corner of Central Bedfordshire, that in the East of Ampthill, and the large development located North-East of Shefford.
- Undesirable effects of urban land use on runoff can be reduced by including good structural controls at the design stage.
- Sealing in a catchment can be mitigated by woodland establishment. Grassland establishment seems to be less effective.

Some key solutions to minimise soil erosion are:

- Areas with steep slopes should be covered with woodland or permanent grassland.
- Implementation of realistically implementable good land management practices, some of which are proposed in the Entry Level Stewardship Scheme (e.g. buffer strips, green corners, cover crops), whereas some other are not (e.g. contouring).
- Temporary measures (e.g. geotextiles, sediment traps) should be implemented on construction sites, as they are particularly sensitive to erosion.
- Permanent bare land areas (landfills and mines) should prioritised for covering with vegetation.

- Erosion on site in a catchment is not usually a great concern in urban locations. However, runoff from new developed areas should be controlled to prevent indirect erosion problems out of the towns.

Water Quality

The Environment Agency (2007) has identified diffuse pollution as a 'bigger threat to river water quality than point source pollution'. Hence this is the focus of this study. The primary pollutants were modelled within a source-pathway-receptor framework. Two key flow paths were:

- Overland flow/soil erosion to surface water bodies involving sediments, phosphates, pesticides and nitrates.
- Leaching to surface and groundwater bodies involving other pesticides and nitrates primarily.

The level of risk, taking into account soil type and land use from these two pathways was assessed. Risk was categorised in levels ranging from 0 to 5, with 5 indicating the highest risk.

- Factors which influence soil erosion, such as soil texture, also influence the risk of the transport of sediment, and the associated adsorption of phosphate and pesticides. Soils with a fine texture are particularly susceptible to soil erosion.
- Surface runoff can also transport dissolved nitrates and pesticides. Factors driving runoff are explained extensively within the runoff section of this report. Silty soils over chalk were associated with highest overland flow risk.
- Soil type is also important in terms of affecting surface and groundwater pollution through leaching. Clay soils, with low permeability and a high water holding capacity, generally show a lower leaching risk than coarse textured soils such as sand. Impermeable bedrock geology will also increase the risk of groundwater pollution compared to permeable aquifers. Examples of areas at risk of pollutants transported through leaching in Central Bedfordshire include Woburn Sands and the Lower and Middle Chalk areas.

Land use also affects the availability of a source for pollutants transported by overland flow and leaching. Woodlands may act as a source of sediment for overland flow, but generally are not a source of nitrates or phosphates (the main pollutants transported through leaching). Other land uses, including urban, pasture and particularly arable, provide greater sources of the four pollutants.

An urban development scenario was overlaid on the two risk models. The leaching model indicated that urban development generally increased water pollution risk compared to other land uses for most soil types.

The urban development scenario for overland flow risk suggested the least favourable place for development would be on woodland with deep clay, deep loam, and seasonally wet deep clay. These areas experienced 2 level losses of risk categorisation. Conversely the least detrimental place in terms of overland flow risk pollution was predicted to be arable land on shallow silty and silty soils over chalk. These soil types are prone to overland flow risk and urbanisation can help reduce potential losses.

The report indicates that river status can be improved by:

- Changing arable and pasture land cover to woodland where possible. The greatest benefits are predicted from converting arable land on seasonally wet deep clay, seasonally wet deep peat to loam and deep silty to clay soils.
- A decreased risk of pollution through leaching is predicted when pasture is changed to semi-natural vegetation and woodland, or arable land is changed to pasture. A decreased risk of pollution through overland flow is also predicted when pasture is changed to woodland (especially deep loam over gravel, deep silty to clay and seasonally wet deep clay), or from arable to pasture (especially on seasonally wet deep clays).

The best place to prioritise urban development in the context of water quality is on arable land. Development on permeable soils can help reduce overland flow risk and development of impermeable soils can reduce leaching risk. In terms of water quality, woodlands are the least suitable place for development with increased leaching and overland flow risk. The most suitable areas for urban development in terms of water quality are discussed in Section 6.2.4.

The project represents one of the first attempts to bring together soil and land use information for a unitary authority area, with the aim of describing the effects of land use and management options on soil carbon, runoff, soil erosion and soil carbon. As such it serves as a useful spatial evidence base to identify the effect of proposed land use land management changes on some key regulating ecosystem services.

1. Introduction

1.1 Background

Central Bedfordshire Council (CBC) is one of three unitary authorities in Bedfordshire, created from an integration of the area covered by Mid-Bedfordshire District Council and South-Bedfordshire District Council. The area covered by the council extends from Dunstable and Houghton Regis in the South, to Leighton Buzzard in the West, Cranfield in the North-West, and to Biggleswade in the East, and is home to around 255,000 people (2010 mid-year estimate), with the largest communities being Leighton-Linslade (37,000), Dunstable (35,100), Houghton Regis (16,700) and Biggleswade (16,400) (Central Bedfordshire Council 2011). The area covered by the council is 716 km^2, with a mean population density is 3.6 people per hectare, and is classified as "predominantly rural".

Ecosystem service assessment

The Millennium Ecosystem Assessment report (MEA 2005) defines an ecosystem as a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. Ecosystem Services are simply "the benefits people derive from Ecosystems", (MEA 2005). Ecosystem services have been classified into four general categories: Supporting, Provisioning, Regulating and Cultural (MEA 2005) that determine human wellbeing (Figure 1.1)

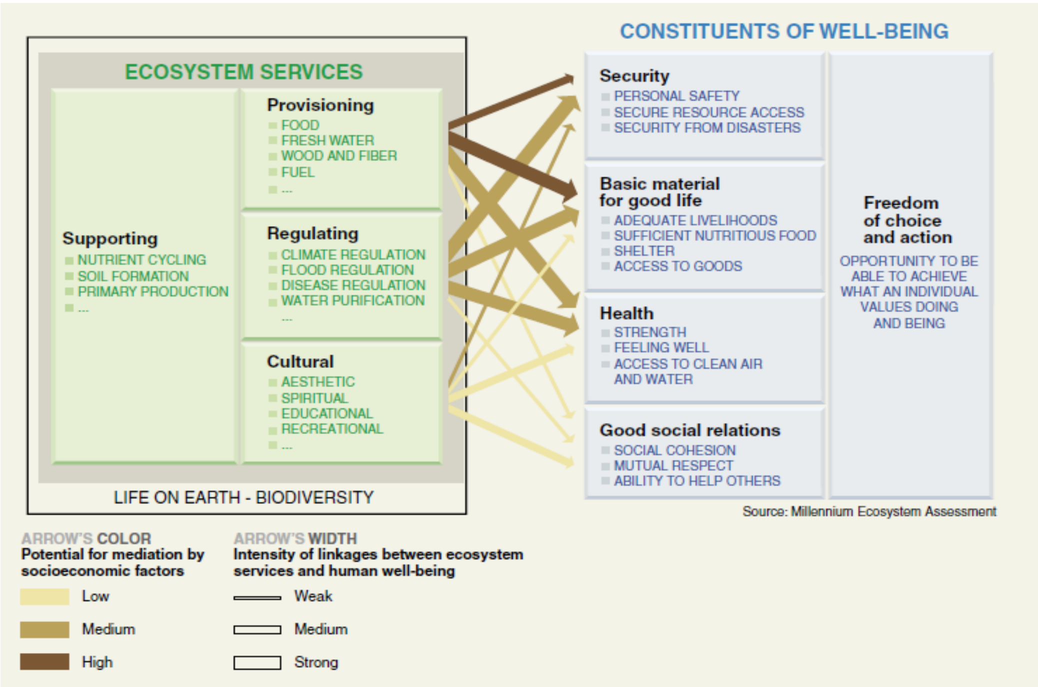

Figure 1.1 Ecosystem services and their interactions with human wellbeing (Millennium Ecosystem Assessment 2005)

The UK National Ecosystem Assessment Report (UKNEA 2011) noted that over the past 60 years, ecosystems and ecosystem services and the way people benefit from them, have changed markedly. Whereas the provisioning service for food from agriculture increased, regulation ecosystem services particularly related to air water and soil quality declined. The drivers attributed to these trends are diverse. The UK population has grown by 25%, which means increased demands. Great advances made in the field of technology enabled faster rates of exploitation of natural resources. All this influenced people's lifestyle patterns and behaviours, with significant repercussions for ecosystems and ecosystem services. Future predictions show that UK population is set to increase by 10 million in the next 20 years (Office for National Statistics 2012). Coupled with predicted changes in climate, the result is an increased threat to the future sustainability of ecosystem services.

Policy drivers

The Department for Environment, Food and Rural Affairs (DEFRA 2007) indicated that the Ecosystem Services Framework should be integrated in all planning and land use decisions.

DEFRA emphasised the need for the consequences of development on ecosystem services to be understood, both for current and future generations. Applying robust techniques that estimate the current value of ecosystem services, and applying models that depict changes to these services under plausible future scenarios, can serve to better inform decision makers. This allows necessary tradeoffs to be understood and agreed upon when making choices.

Within the UK, local authorities have the responsibility of tackling and mitigating climate change through reducing carbon emissions from operations, services and local communities. This can be achieved by providing scientific information, supporting decision making with maps, developing a strategy and recommendations related to carbon sequestration and carbon management (Local Government Innovation and Development 2012).

The Water Framework Directive UK (EC 2000): aims to ensure that all aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands meet 'good status' by 2015. In particular it aims to deal with diffuse pollution. The European Union passed the WFD in 2000, and it was put into UK law in 2003. The Environment Agency is the leading body tasked to implement this framework. Its objectives include among others:

- To reduce pollution of water, especially by 'priority' and 'priority hazardous' substances.
- To ensure progressive reduction of groundwater pollution.

The WFD establishes a strategic framework for managing the water environment through the development of River Basin Management Plans (Appendix A1). The plans are based on a detailed analysis of the impacts of human activity on the water environment and incorporate a programme of measures to improve water bodies where required.

The Flood and Water Management Act (2010) provides for better, more comprehensive management of flood risk for people, homes and businesses, helps safeguard community groups from unaffordable rises in surface water drainage charges and protects water supplies to the consumer.

The Environment Agency (EA) has a strategic overview role, while local authorities have a new leadership role, in local flood risk management (Local Government Association 2010). Local flood risk covers flooding from an ordinary watercourse, surface runoff and groundwater. This local management role is given to County and unitary local authorities (LAs) which lead and are accountable for ensuring effective management of these local flood risks. The National Flood and Coastal Erosion Risk Management Strategy for England 2011 provides a national framework for local communities to develop local partnerships and solutions to the flood and coastal erosion risks they face.

This new role for local authorities is encompassed within the strategy for Local Government Improvement and Development 2010, which charges Local Governments to take active steps towards strengthening the resilience of their services and local communities to a changing climate. Key among these steps is regulating the net greenhouse gas emissions by improving carbon sequestration and storage.

The above changes demonstrate that Central Bedfordshire Council, like all local authorities, is increasingly responsible for the delivery of measures regarding climate change mitigation, water runoff, and water quality. It is therefore apparent that local authorities require clear information on how spatial differences in soil type and land use could affect the potential rate of infiltration and runoff, nitrate and pesticide leaching, and soil erosion.

1.2 Aims

The aim of this project is to create robust results on the basis of a literature review, to describe the links and processes between habitat/land use, soil type, and topography, on regulating ecosystem services with particular focus on carbon storage and sequestration, runoff and soil and water quality to improve the evidence base for land use decisions in the Central Bedfordshire area.

1.3 Structure of the report

The report is structured in 7 sections, starting with this introduction. The second section is a literature review of existing knowledge about the Central Bedfordshire area and the interactions between land and soil carbon, runoff and soil erosion, and water quality. Section three describes the methodology for developing the spatial information. Section four, five and six describe and discuss the results for each of the regulating ecosystem services considered: soil carbon storage and sequestration, runoff and flood risk, and water quality. Section 7 describes the conclusions of the work.

2. Literature Review

The literature review is presented in seven sections. The first three sections describe the climate of the area, current land use, and soil types. The next three sections review the three ecosystem services considered in this project, and the final section is focused on land use options.

2.1 Climate

2.1.1 Solar radiation and temperature

The climate in any area is primarily driven by the solar radiation. As with any northern latitude location, solar radiation reaches a maximum between June and August, with minimum values between December and January. Mean air temperatures follow this seasonal pattern with the mean monthly mean maximum temperatures reaching 21.5°C in July and August, and monthly mean minimum temperatures reaching 0.6-0.8°C in January and February (Figure 2.1a). The maximum difference between the daily maximum and minimum temperature occurs during the summer. The mean number of air frost days per year at Bedford is 51 (Figure 2.1b).

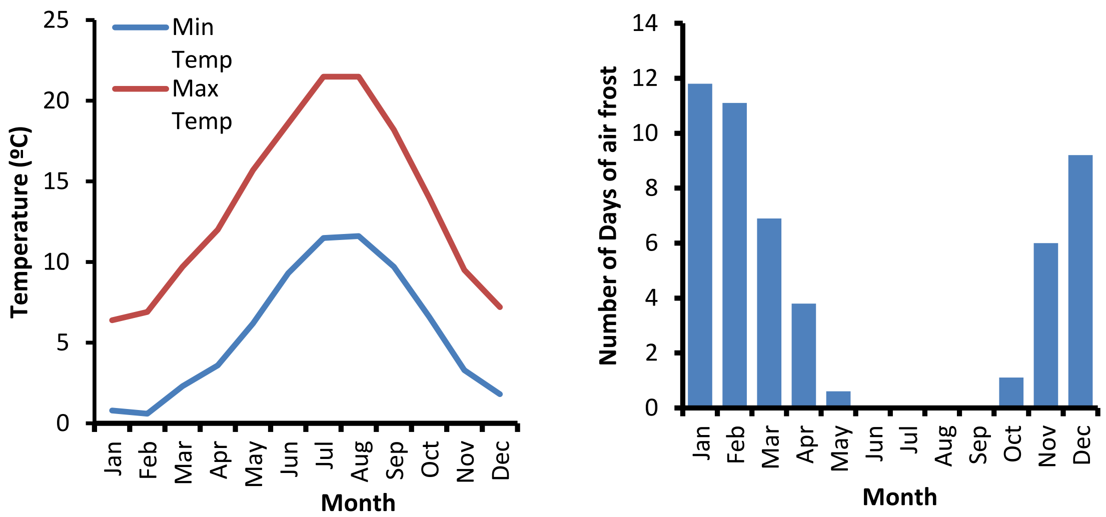

Figure 2.1 a) Mean daily maximum and minimum temperatures (1971-2000) and b) average number of days of air frost (1971 – 2000) at Bedford (85m amsl) (Met Office 2012).

2.1.2 Precipitation and wind speed

The mean annual precipitation (1971-2000) in Bedford is 584 mm. On average, rainfall is relatively evenly distributed throughout the year. There are usually more than 29 days of rainfall greater than 1 mm between December and February, and 23 days between June and August (Figure 2.2a).

Central Bedfordshire is one of the least windy areas of the UK. The strongest winds usually occur in winter and they are associated with large depressions or storms (Figure 2.2b). The increase in temperature during the day causes air convection and consequently wind is usually stronger at this time of the day. As a result of frequent Atlantic depressions, wind normally originates from the South-West of the UK. When the depression moves away, the wind usually flows from the North-West. The formation of high pressure weather systems in Scandinavia can cause strong North-East winds during the spring. In Eastern England, there is not normally more than 2 days of gales (more than 34 knots during at least 10 minutes) per year (Met Office 2012).

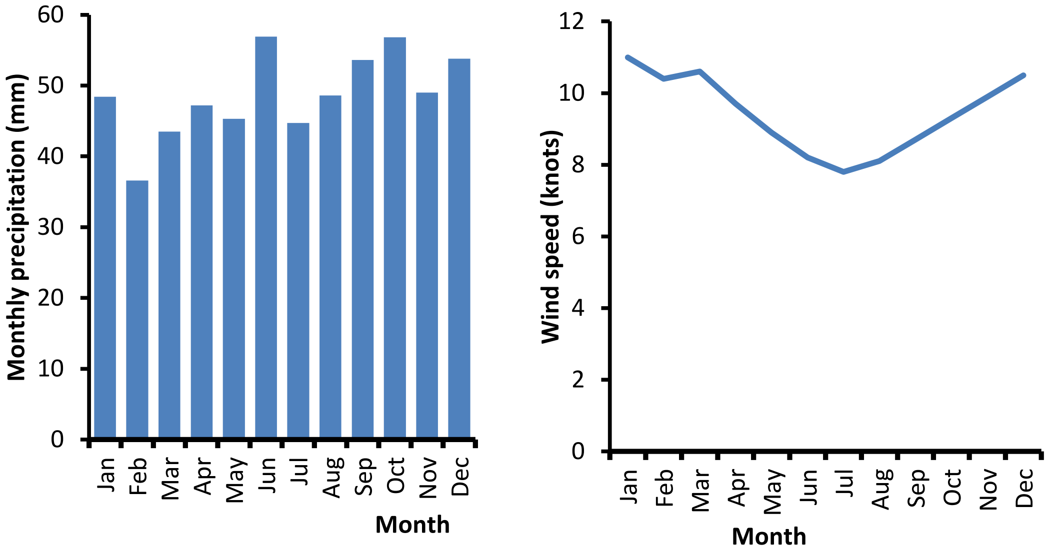

Figure 2.2 a) Mean monthly precipitation (1971-2000) at Bedford (85 m amsl) (Met Office 2012) and b) mean monthly wind speed.

2.2 Current land use

Central Bedfordshire covers 71,600 ha and can be broadly classified as an agricultural area. According the 2006 Corine land cover dataset, the majority (69.6%) is classified as arable land (49802 ha), the proportion covered with pasture is 12.6% (9037 ha) and 3.9% is covered with woodland vegetation (2762 ha). Urban areas cover 13.3% (9495 ha); this can be sub-divided into open spaces (3.6%; 2590 ha) commercial (1.5%; 1057 ha), residential (6.7%; 4796 ha), and impervious (1.5%; 1052 ha). Water bodies include lakes which cover 0.7% (470 ha). Rivers are classified as linear features and are not included in the area values (see Figure 2.3, EIONET 2006, NSRI 2008a, b, c & 2009). There are also other land use classifications which will result in different categorisations and totals for specific land uses.

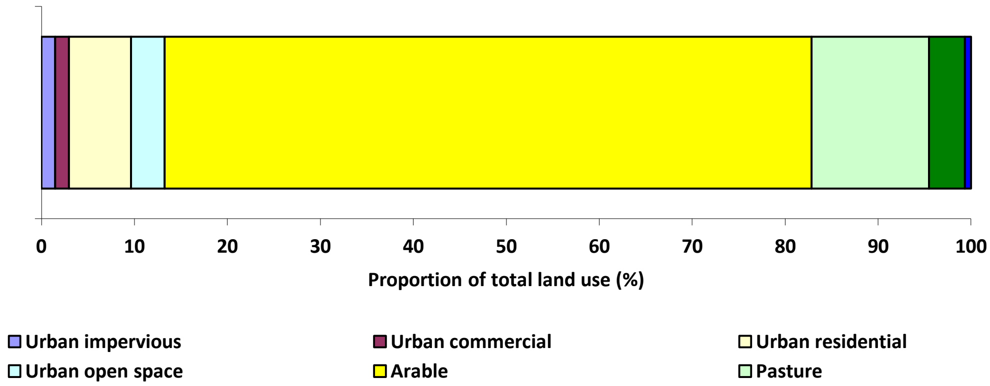

Figure 2.3 Land use in Central Bedfordshire according to EIONET (2006)

The largest residential areas are Dunstable, Leighton Buzzard, Linslade, Ampthill, Flitwick, Sandy, and Biggleswade. Large commercial areas include Millbrook Proving Ground, the south of Leighton Buzzard, and the centre of Dunstable. Large open spaces include Woburn Safari Park, Woburn Abbey Park, Cranfield airport, Whipsnade Park Golf Club, and John O'Gaunt Golf Club. Areas classified as "urban impervious" include Leighton Buzzard silica sand quarry, Brogborough landfill, Stewartby brickfields, and a chalk pit South of Dunstable. Woodland vegetated areas and pasture are scattered throughout the county and relatively small in size.

In terms of landscape fragmentation, it is valuable to compare the mean patch area for each land use. Arable areas can be found in the largest patches with a mean area of 63.4 ha. The recorded urban impervious areas (mineral extraction sites, dumpsites and construction sites) have a mean patch size of 24.5 ha, and the recorded open areas (airports, green urban areas, sport and leisure facilities) have a mean area of 22.9 ha. The land use type with the smallest patch area are water features (3.2 ha).

Table 2.1 Mean patch area of land use types

Land use		**Mean patch area (ha)**
Urban	Impervious	24.5
	Commercial	16.0
	Residential	19.0
	Open space	22.9
Arable		63.4
Pasture		14.7
Woodland		11.7
Water		3.2

Spatial distribution of Agri-Environment Schemes

According to DEFRA (2009b), the largest proportions of arable land are occupied by wheat (53%), oilseed rape (17%) and barley (10%). Beans and salad vegetables are also present. The proportion classified as discontinuous urban fabric (6.7%) includes buildings and roads, and housing estates. It is estimated that 3.3% of the land area is occupied by sport and leisure facilities. Around 1.5% of the land is used as mineral extraction sites and waste facilities. Industrial and commercial units also use 1.5% of the available space. The rest of the urban area is used for green areas, airports and construction sites (EIONET 2006). The proportion of the area covered by broad-leaved forest (2.7%), coniferous forest (1%) and mixed forest (0.1%) are substantially lower than mean woodland cover in the UK (EIONET 2006; Forestry Commission 2011).

Agri-Environment schemes are only applicable to pasture and arable areas. The majority (54.5%) of pasture and arable land in Central Bedfordshire is not under any scheme. The most popular Agri-Environment measure is the “Entry Level Scheme” (34.5%). About 9.1% of the agricultural area is under an “Entry Level plus Higher Level Scheme”. The areas under organic (0.2%), and organic high level (0.9%) and just high level (0.7%) are small. There appears to be no distinct pattern in the uptake of the schemes.

2.3 Soil Type

The dominant soil type found in Central Bedfordshire is deep clay, which covers the majority of the county’s area. Other soil types which cover significant areas of Central Bedfordshire include deep loam over clay, loam over red sandstone, deep sandy soil, and seasonally wet deep clay, which follows the river valleys and floodplains. A clear banded pattern can be seen in the soil map (see figure 2.6) which closely follows the geology. Soil type can greatly impact on ecosystem services such as carbon sequestration and risk of erosion and leaching, as well as the effects of land use change or development on these ecosystem services.

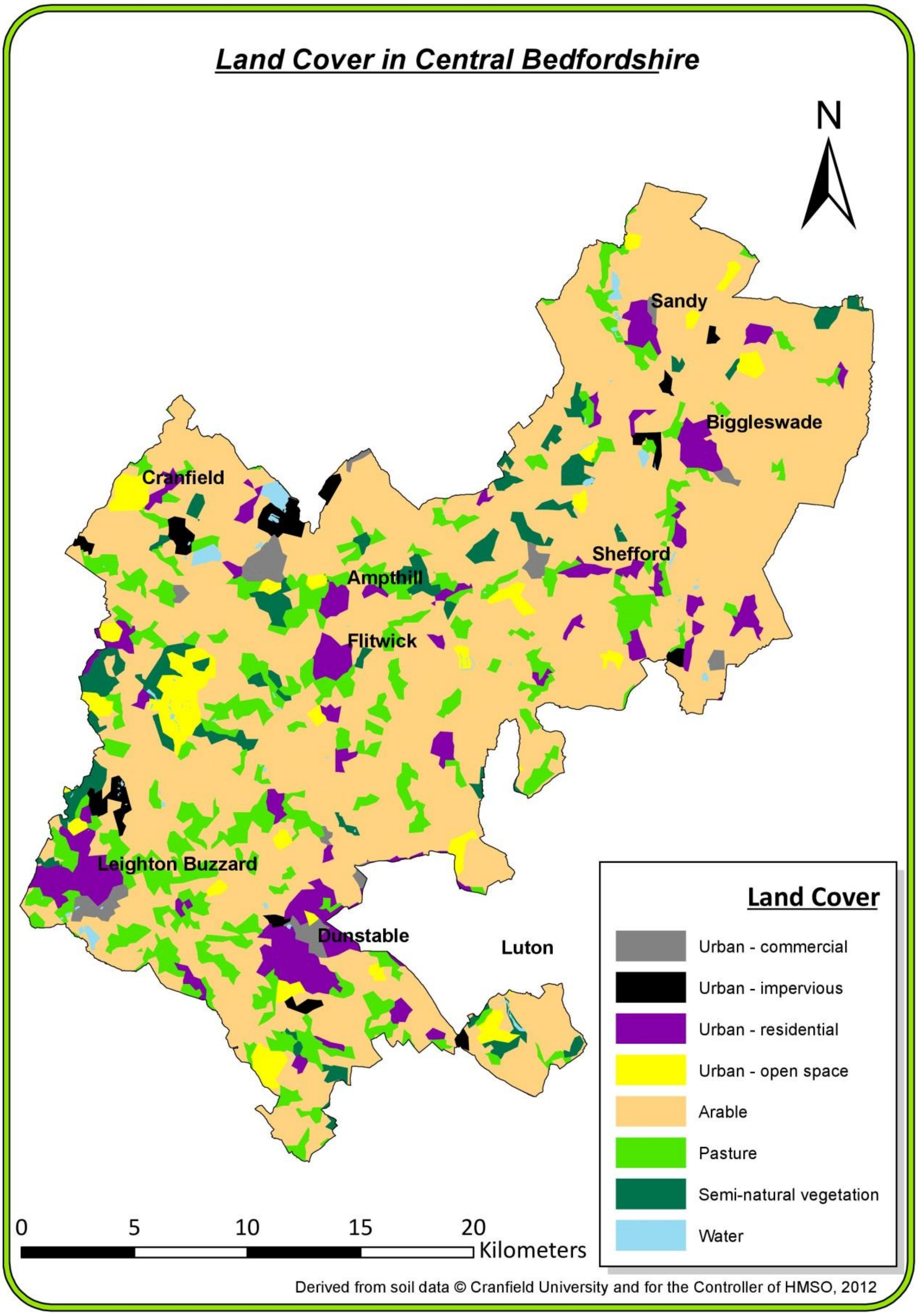

Figure 2.4. Broad land cover types found in Central Bedfordshire (data from EIONET 2006 and NSRI 2008a, b, c & 2009).

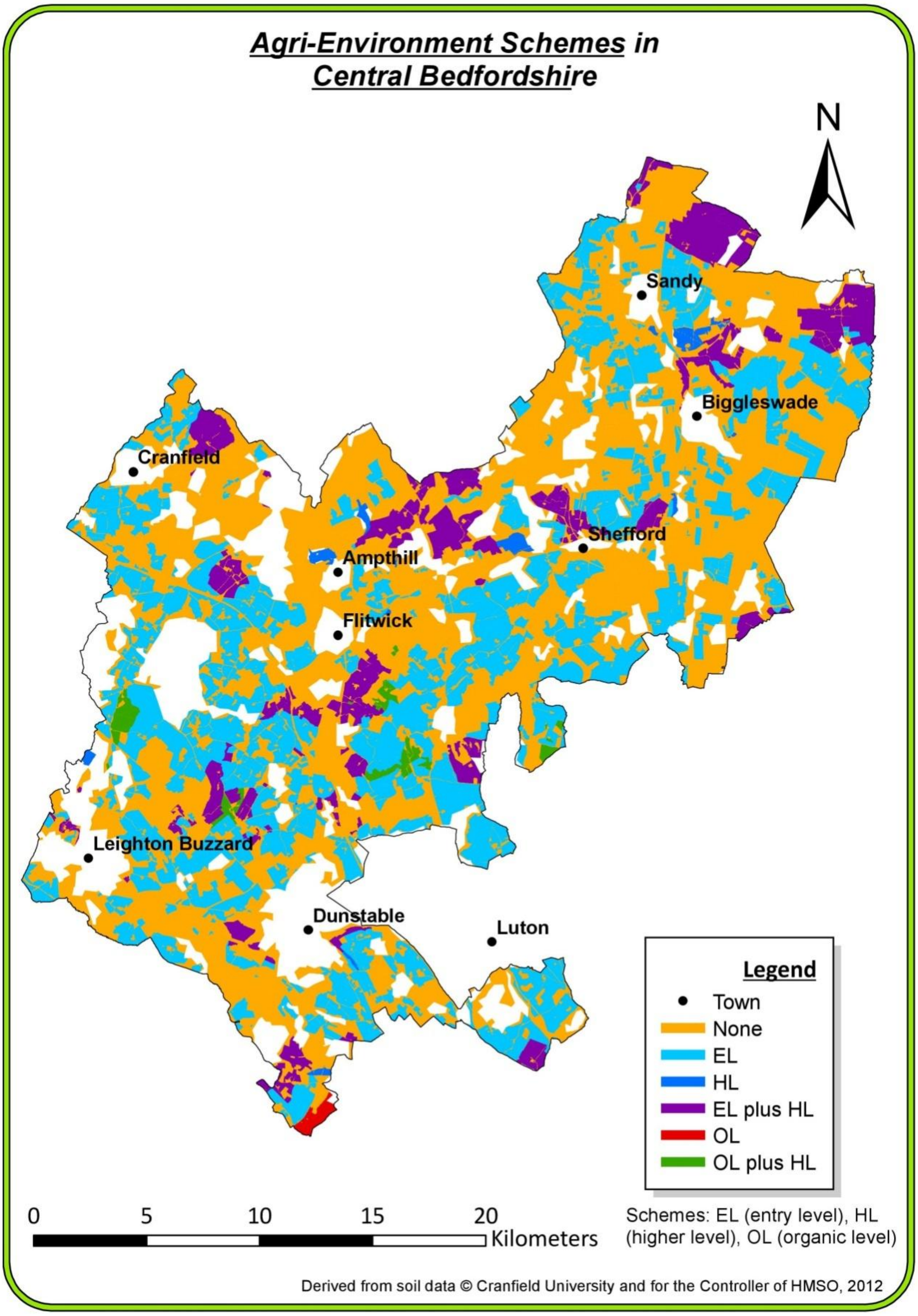

Figure 2.5. Spatial distribution of pasture and arable land in Central Bedfordshire under Agri-Environmental schemes: Entry-level (EL), Higher-level (HL), and Organic Level (OL) Environmental Stewardship. Urban areas, water bodies and areas of woodland vegetation have been omitted from the map

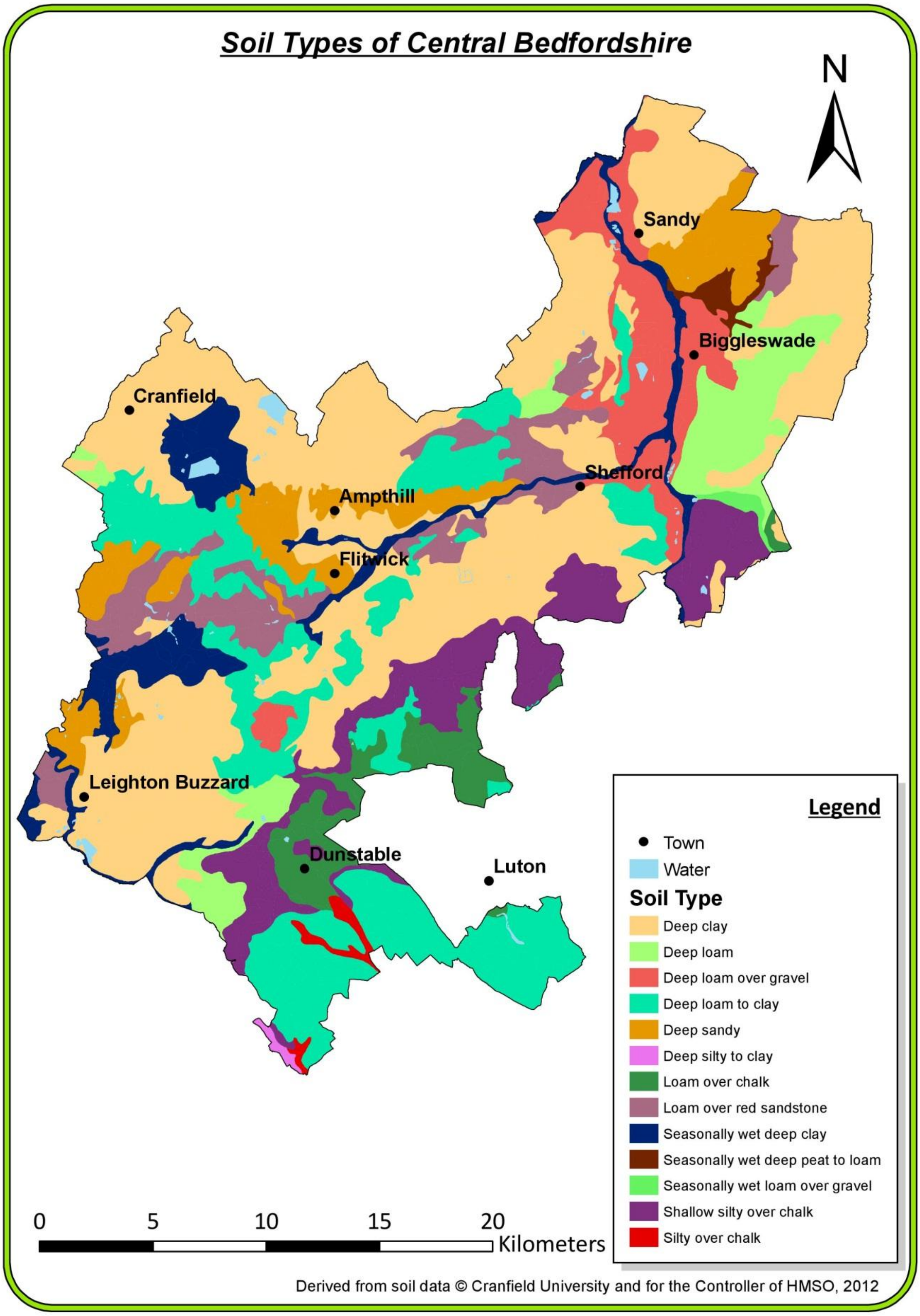

Figure 2.6 Broad soil types found in Central Bedfordshire (data from NSRI 2008a, b, c & 2009).

2.4 Carbon storage and sequestration

This section reviews current knowledge on the regulating ecosystem service of carbon sequestration and storage. The main driver for prioritisation of carbon sequestration and storage in policy and regulation is to take excess carbon dioxide (CO_2) out of the atmosphere. Between 1750 and 1994, total atmospheric carbon levels have increased by 165 Gigatonnes of Carbon (GtC), while average global temperatures increased by 0.75°C between 1906 and 2005 (IPCC 2007). According to Bonan (2010) the level of CO_2 in the atmosphere has increased from 278ppm in 1750 to 379ppm in 2005.

2.4.1 Role of carbon sequestration and storage in climate change mitigation

Between 1980 and 2000, the rate of CO_2 emissions from burning of fossil fuels increased by 40% (Wofsy 2001; Lal, 2008). The increase in net CO_2 in the atmosphere was moderated in part through capture by carbon sinks like oceans, soils and forests. (Battle et al. 2000). This process of capture and locking away of atmospheric CO_2 into other stable carbon sinks that would have otherwise accumulated in the atmosphere is what is referred to as carbon sequestration. Because of the complexities related to ownership and use rights of oceans, focus on enhancing the capacity of soil as a carbon sink is considered a more feasible approach (UNFCC 1998).

2.4.2 Why soil carbon is important

The Royal Society (2001) highlighted the role that enhancing atmospheric carbon capture by the biotic pool through photosynthesis (through land cover and land use change), maximising the transfer of carbon from the biotic pool to the soil pool, and minimising carbon losses from the soil to the atmosphere would effectively lower the net atmospheric carbon.
Soils and vegetation store three times the amount of carbon present in the Earth's atmosphere, with soils storing approximately 1660 Gt, vegetation 550 Gt, and the atmosphere 750 Gt. Soils are also estimated to sequester 33% of the annual increase in carbon emissions (Baloch et al. 2008). Therefore, soil is an extremely important carbon sink, with important implications for climate change.

Within Europe, climate change could have several consequences on soil carbon. In warmer and wetter conditions the soil respiration will increase (assuming the soil is not waterlogged) and lower the levels of soil carbon. Drier conditions will cause vegetation stress and reduced organic matter input into soil (SOER 2010). There is a potential in mitigating climate change through soil and land management. This is a readily available method and a low cost option based on proven technologies (SOER 2010). This will also be in line with Central Bedfordshire's aspiration to achieve 35% reduction in its net carbon emissions by 2015 (from 33,700 t CO_2 to 23,520 t CO_2) and 60% by 2020 (down to 13,480 t CO_2) compared to the 2008/2009 figures of 33,700 tonnes of carbon dioxide (Central Bedfordshire 2010).

Soil Organic Carbon (SOC) is a major component of soil organic matter (SOM). SOM is derived from inputs of leaf, stem and root tissues to the soils that decompose over tens, hundreds and, in the case of peatlands, thousands of years. It can improve soil structure by binding soil particles into more stable aggregates (Jones et al. 2004; Hunter 2009). Soil organic matter also provides improvements in infiltration rates, water storage capacity, and pH buffering capacity, as well as providing an energy source for soil microorganisms (Jones et al. 2004). A decrease in organic matter is an indicator of a reduction of quality in most soils (Jones et al. 2004).

2.4.3 Factors affecting the soil's ability to sequester and store carbon

Because the vast majority of soil carbon is found within the SOM, any factor that influences the status of SOM, will also be related to the soil's ability to sequester and store carbon (Brady and Weil 2008) Both *natural* factors such as climate, soil parent material, land cover and/or vegetation present and topography, as well as *human-induced* factors such as land use, management and degradation influence the organic matter content of soils (Jones et al. 2004, FAO 2000). These factors can be classified as:

Natural soil properties

Whilst climate and vegetation tend to affect soil carbon over broad geographic areas, soil texture and drainage are often responsible for marked differences in SOM within a local landscape (Brady and Weil 1996). The inherent physicochemical properties of a soil, including texture, bulk density, potash content, and pH, have a large impact on the amount of carbon stored and sequestered (Baloch et al. 2008). A sandy soil usually contains less OM than a soil of finer texture. Finer textured soils accumulate more OM because they can produce more plant biomass as they are more fertile, they lose less OM because they are less well-aerated, and more of the OM is protected from decomposition as it is bound in clay-humus complexes or within aggregates (Brady and Weil 1996).

Climatic properties

Temperature and moisture content, which are related to climate, precipitation, temperature variation and elevation, can affect the rate of decomposition of organic matter in the soil (Baloch et al. 2008). Therefore, in cooler, wetter climates, if the rate of accumulation exceeds the rate of deposition, SOM can accumulate as peat). Within belts of uniform moisture conditions and comparable vegetation, the mean total SOM content increases 2 to 3 times for each 10°C fall in temperature. In general, under comparable conditions, OM increases as the effective moisture becomes greater, therefore, soils with good drainage usually have less OM (Jones et al. 2004).

Vegetation

The greater plant productivity encouraged by a well-watered environment leads to greater additions to the pool of SOM. With grassland vegetation, a relatively high proportion of the plant residues consist of root matter, and this can decompose more slowly and contribute more efficiently to soil humus formation than forest leaf litter (Brady and Weil 1996). Woody vegetation is better for above ground carbon storage than herbaceous vegetation, as carbon in wood has a longer turnover time than carbon in leaves, flowers, fruit and fine roots (Bashkin 2002).

Land cover conversion and changes in land management

Land cover conversion and changes in land management are the major direct human causes of carbon disequilibrium, and include deforestation and forest degradation, changes in agricultural practices, reforestation and afforestation, and changes in ecosystem and fire management. Carbon dioxide is released through both the direct burning of vegetation and the subsequent decomposition of biomass (the organic matter associated with living organisms) and soil organic matter (Vesteral et al. 2011).

Within mature natural soil systems, the release of carbon by SOM oxidation is cancelled out by the input of carbon from plant residues (Brady & Weil 1996). However, human-induced land use conversion results in a loss of SOC, particularly the conversion of forests to agricultural land, and agricultural land to urban development (Baloch et al. 2008). The conversion of agricultural land to urban development can result in significant soil carbon losses during the construction phase, and a decrease in potential carbon sequestration due to the creation of impervious surfaces, sealing the soil (Baloch et al. 2008). Deep ploughing of arable soils can also cause rapid mineralisation of the labile components of SOM (Jones et al. 2004). Land management methods which can encourage carbon sequestration in soils include increasing organic inputs and returning clippings to the soil, encouraging perennial vegetation growth, minimising soil disturbance, particularly through reducing tillage, minimising the use of nitrogen-rich fertilisers, raising water tables on farmed peat lands, and reducing or minimising impervious areas during development, for example through the use of permeable paving and green roofs (Baloch et al. 2008).

A lot of research has been done in assessing soil carbon in different soil types under various land covers and land uses over a wide range of scales. Jones et al. (2004) mapped SOC of topsoils at the European scale. They used a revised pedo-transfer rule to associate sampled carbon stocks in different soil textures under various climate (temperature) and land cover types. Based on the observed patterns, extrapolated carbon stocks for the whole of Europe were derived. Inputs for soil were derived from the European Soil Database provided by the European Soil Bureau, and land cover information was provided by Corine. The carbon content was classified into five categories and the output displayed in ArcGIS. The modelled output was validated against ground data, where values for each spatial unit were calculated by averaging values from all point samples within the spatial unit.

Baloch et al. (2008) estimated carbon content in the Milton Keynes area within Buckinghamshire. National Soil Inventory database figures were used to calculate the carbon content in soils of different textures under agricultural, woodland and other rural land use. Land cover data was derived from aerial photography interpretation. This data and other research findings were extrapolated to determine carbon stores in various urban (green) landscapes. A ‘Carbon Calculator’ was then devised using Microsoft Excel to model pre- and post-development carbon levels for a planned urban site at Fairfield in Milton Keynes. Carbon levels were calculated based on percentage of typological units within each mapping unit.

Hunter (2009) focused on the Flit river catchment in Bedfordshire, modelling the relationship between arable soils management under different Agri-Environment Schemes and ecosystem service provision, including carbon sequestration and storage. These papers heavily influenced the methodology applied to mapping of carbon sequestration and storage in Central Bedfordshire.

2.5 Runoff and soil erosion

The study area spans the Upper and Bedford Ouse catchment within the Anglian River Basin District (EA 2009) and the Upper Lee Catchment of the Thames River Basin District (EA 2009b). Naturally, a considerable amount of water that falls as precipitation soaks into the ground, and is carried out by rivers. However, roads and other structures in urban areas have hard, impervious surfaces, which increase the amount and rate at which precipitation becomes runoff (DEFRA 2008). Run-off and erosion are growing concerns in the UK; with the government typically investing between £600 and £800 million pounds per year (DEFRA 2008).

2.5.1 Land Use

Several factors have induced changes in water runoff generation and delivery to channel network, such as drainage efficiency and pathway connectivity. A main factor is the effect of soil structure degradation on runoff generation, as a result of soil compaction. Inappropriate land management considerably impacts on local surface runoff generation. For instance, managerial practices that lead to the formation of a crust at the soil surface, or soil compaction, impede the infiltration capacity of the soil and cause infiltration-excess runoff. It is considered that there has been an increase in runoff generation and discharge from farm land in recent years (Posthumus et al. 2008).

Compaction of soil due to the movement of vehicles, livestock poaching and reduction of organic content affect the infiltration capacity of the soil, hence result in water runoff (Cuttle et al. 2007, DEFRA 2004). Land management of a catchment has to be handled on a case-by-case basis. Drainage on a sandy soil is susceptible to leaching of soluble pollutants, while retarded drainage on clay soil leads to runoff during a rainfall event. Soil type has an important influence on erosion risk, sediment pollution, transfer of phosphates and hydrophobic chemicals (Hunter 2009).

2.5.2 Soil Erosion

The rate of soil loss from arable land close to watercourses can be in the range of 0.1-20 tonnes per hectare per year (DEFRA 2004). Sandy soils are the most vulnerable to gully and rill erosion, and heavy soils are vulnerable to loss through drainage and subsurface runoff (DEFRA 2004). Hydrological studies show that water runoff process at a catchment scale happens due to the interaction of climate, soil hydraulic properties, vegetation and topography, which is affected by small scale heterogeneity (Jolley et al. 1993).

Soil erosion is a growing concern on agricultural land because it is a threat to soil quality and capability of the soil to provide ecosystem services. The notable impacts of water runoff and erosion are mainly eutrophication of water bodies, sedimentation of river beds, reduction in reservoir capacity, and the flooding of roads and other facilities (Boardman et al. 2009). Soil erosion of arable land is of particular concern (EIONET 2006, Quinton et al. 2005). This is because of the low extent of crop cover before the crop is established (Oost et al. 2009; Boardman 2002).

The factors affecting soil erosion include the erosive nature of the rainfall, soil erodibility (how easily the soil is eroded), land slope, land management practices, and the type of plant cover (Posthumus et al. 2010). Erosion risk is high with crops such as potatoes, winter cereals, maize and grazed turnips (Boardman et al. 2009). It is also high when the soil surface is compacted, because such soil surface enhances the speed of runoff.

Two categories of rainfall event include intense short-lived duration storms where the soil infiltration rate is superseded, and the more prolonged rainfall duration that keeps the soil saturated. In the first type of rainfall, loose materials are eroded by water runoff, leaving little for the other coming storms. Therefore, rainfall erosion is mainly caused by intense short lived duration storms (Al-Kaisi 2002, Morgan 2005). This erosion could be in the form of water runoff carrying fine soil particles, or more seriously it cuts rills or gullies in the slope (DEFRA 2005).

Erosion of soil is a physical process that needs energy; hence it needs some measures to dissipate the energy. Therefore, to control soil erosion, it is advisable to maintain a permanent surface cover on the surface of soil for instance grass or meadow (Al-Kaisi 2000). Management of plant residues is an alternative way to reduce erosion, because they give good soil cover, which prevents surface sealing caused by rain drop impact. Equally, practicing cropping system in combination with conservation tillage also reduces soil erosion (Al-Kaisi 2000).

2.6 Water quality

Water needs to be suitable for many uses such as drinking, crop irrigation and the support of aquatic life. To this end, water pollution studies to provide sustainable water quality approaches are essential. Pollution can be defined as the negative alteration of the physical, chemical or biological integrity of water as a consequence of natural or human-induced activities (Tollner 2002). The key water quality issues within the study area are nitrates and phosphates, pesticides and sediment. Furthermore, an Environment Agency (2007) report says that diffuse pollution is now a bigger threat to river water quality than point source pollution and is therefore the focus here. Point sources, including sewage treatment works and industrial factories are easily identified and within developed countries have been largely regulated and cleaned up during the past several decades. Diffuse (non-point) pollution sources, in contrast, are difficult to identify and control posing a continued threat to water body receptors including surface water bodies and groundwater (Brady and Weil 2008). Water quality within each of these receptors is monitored in the region by Anglian Water, Thames Water and the Environment Agency. Managing the quantity of pollutants entering surface and groundwater bodies from diffuse sources is integral to meeting the environmental objectives of the Water Framework Directive (EC 2000) and Groundwater Directive (EC 2006) (See Appendix A1). Tollner (2002) described four main characteristics of diffuse pollution (Table 2.2).

Table 2.2 Characteristics of diffuse pollution (Adapted from Tollner 2002)

Pollution transported from diffuse sources as a consequence of meteorological events.
Pollution reaches surface waters or shallow aquifers after being generated in extensive land areas.
Recognisable source is hard to determine.
Main constituents are usually nutrients, suspended soils and toxic compounds.
Monitoring is more land than water based.

2.6.1 Sources of pollution

In the East of England the main sources of pollution are diffuse water pollution from agriculture through the use of pesticides, fertilisers, slurries and manures. Pollution from unmonitored sewage discharges, including small sewage treatment works and septic tanks, pollutant runoff from roads, pavements and industrial areas also contribute to the reduced water quality (EA 2010). In the Upper and Bedford Ouse catchment and Upper Lee land use is predominantly agriculture and nutrient enrichment, from nitrates and phosphates, is the main pressure on surface and groundwater water quality (EA 2009). Within the Upper Lee catchment, urban runoff is an additional major pressure impacting the River Lee which flows through the large urban conurbation of Luton (EA 2009b). Table 2.3 shows the water quality parameters analysed in this study. This represents the major pressures on the water environment in the Anglian River Basin District and Thames River Basin District (EA 2009; EA 2009b).

Table 2.3 Major pressures on the Water Environment in Central Bedfordshire (EA 2009; EA 2009b)

Sediment	Un-dissolved particles floating on top of or suspended within water, for example those caused by increased rates of soil erosion from land based activities. Sedimentation can smother river life and spread pollutants from the land into the water environment.
Phosphate	Nutrient in sewage and fertiliser that can cause too much algae in rivers when in excess quantities.
Pesticides	Chemical and biological products used to kill or control pests include insecticides, fungicides and herbicides.
Nitrate	Nutrient found in fertilisers used in agriculture, and in sewage effluent.

Pollutant pathways are essentially linked to water movement processes and also to adsorption onto soil particles. The main pathways for strongly adsorbed particles are erosion and sedimentation. For weakly adsorbed particles and pollutants in solution, the main pathways to water bodies are runoff and leaching. In summary, erosion and sedimentation of soil particles, surface runoff, subsurface flow, infiltration, and percolation in the soil are the processes that essentially control the transfer of pollutants to water bodies (CIGR, 1999). These processes can be simplified schematically within the source-pathway-receptor framework (Figure 2.7 and Table 2.4).

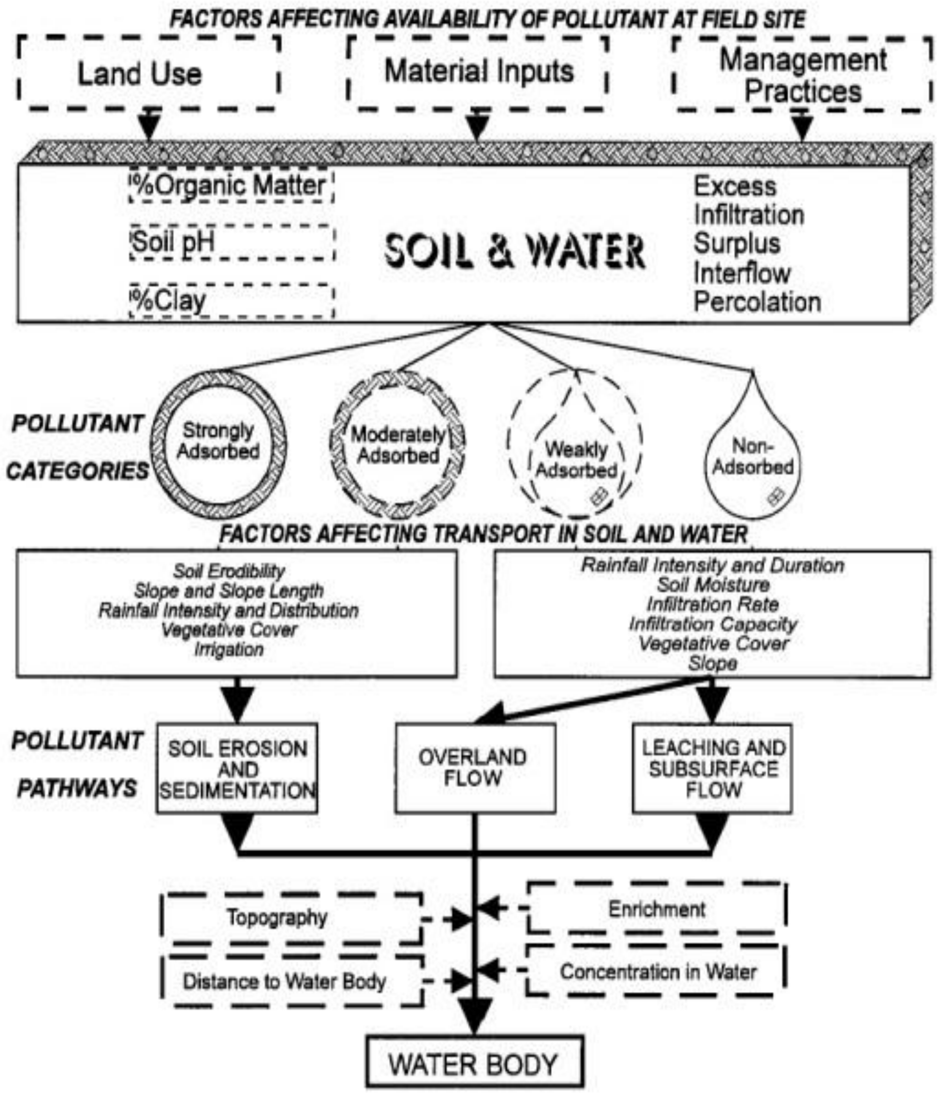

Figure 2.7 Elements and factors that intervene in the process of pollution transfer from nonpoint sources to receiving water bodies (CIGS 1999).

Table 2.4 Source-pathway-receptor framework for the main pollutants

Pollutant	Source	Pathway	Receptor
Sediment	Urban Arable Woodland Pasture (grassland)	Soil erosion Overland flow Subsurface flow	Water bodies (Surface water)
Phosphates	Urban Arable Pasture (grassland)	Adsorption → Soil erosion Overland flow	Water bodies (Surface water)
Pesticides	Urban Arable	Adsorption → Soil erosion Overland flow Subsurface Flow Leaching	Water bodies (Surface and groundwater)
Nitrates	Urban Arable Pasture (grassland)	Overland flow Subsurface Flow Leaching	Water bodies (Surface and groundwater)

2.6.2 Sediment

Soil is transformed into sediment by the process of erosion. The impacts of soil erosion are often divided into on- and off-site effects. The off-site impacts of soil erosion are closely related to the processes of transport and sedimentation of soil particles. This can occur naturally as wind and rain wears down the land and subsequently deposits the eroded sediment. The rate of this type of erosion may be accelerated up to 1,000 times where humans disturb this system through agriculture and construction (Brady et al. 2002). At locations where the eroded material is deposited the environmental and economic impact can be greater than that incurred on the sites where the material was removed.

Rising costs for dredging and sediment disposal, in addition to the range of legislation being implemented, has increased the need for controlling the sediment at source rather than to carry out reactive management (Sandberg 2008). However, if correctly managed, soils can buffer flooding and moderate pollution transmission.

Sediments are the most visible nonpoint pollution pollutant, and a priority problem (CIGR, 1999). Water with excessive sediment load can have effects as aesthetic value deterioration, loss of reservoir storage capacity, aquatic populations and their food supply changes (CIGR, 1999).

The two main pathways of sediment pollutant transport to surface waters can be broadly defined as surface and subsurface processes (Table 2.4). Subsurface flows can occur in areas of high water table conditions. Water may also infiltrate through cracks in the soil structure. This is particularly noticeable for clay soils, which can be prone to cracking under dry soil conditions. During a rainfall event following a dry period, water may infiltrate through these cracks generating subsurface flows. Water movement in artificial drainage systems is also an important subsurface process.

Surface runoff is initiated when rainfall intensity exceeds the infiltration capacity of the soil, or the soil becomes saturated due to high water table conditions.

2.6.3 Phosphates

According to EA (2011), the main sources of water bodies' phosphate (P) pollution are sewage treatment plant effluents and agriculture. Contributions from agricultural, household, industrial and background sources to the Anglian River Basin are 20.3%, 69.6%, 0.8% and 9.2% respectively out of a total of 3,391 t y^{-1}. An interesting proportion comes from household circa 70%. In agriculture P comes from manures and fertilisers. From urban areas, it mainly comes from laundry detergents. Despite the fact Anglian Water has installed P removal facilities at its larger sewage treatment plants, a small contribution to water bodies from some sources is still happening, (EA 2011).

A consequence of excess of P is that eutrophication could be accelerated. This process could be manifested in an exaggerated production of organic material by algae, macrophytes, and other organisms containing chlorophyll. According to the Organisation for Economic Co-operation and Development (OECD, 1982), the minimum concentration leading to eutrophication is 0.02 mg l^{-1}. Though some factors limit the amount of P in the soil solution, eutrophication often occurs because flow from arable fields usually contains larger concentrations (Fullen et al. 2004).

P is less mobile in soils than nitrate (N) because phosphate ion could be fixed to soil particles. The phosphorus fixation process is mainly controlled by the following factors:

- Aluminium and iron oxides, responsible for retention in acid soils
- Calcium compounds , controlling solubility in calcareous soils, and
- Clay and organic matter percentage, contributing to adsorption.

Due to P association with soil particles, loss and transport of P from arable fields to surface water bodies is mainly associated with soil particles transport processes as surface runoff and soil erosion. Pollutants can also reach groundwater bodies because of water infiltration and percolation into aquifers (Tollner 2002). Brady and Weil (2008) report that on cultivated agricultural land 10 kg ha/yr of P can be transported via erosion of P-carrying soil particles, 3 kg ha/yr of P can be transported dissolved in surface runoff, compared to 0.4 kg ha/yr of P transported via leaching to groundwater. It is assumed here that the major pathway for P is therefore via soil erosion and overland flow (Table 2.4) (Brady and Weil 2008).

Adsorption is not an instantaneous process: it starts with an initial rapid phase, followed by a slower one. Despite this, in some cases leaching losses of soluble P can occur immediately after P fertiliser applications. This can happen especially during heavy rain and in strongly fissured soils, in which rapid percolation do not allow enough time for plant uptake or sorption of P on soil particles (Catt et al. 1998). Losses can also remain quite large for several months due to the slower phase of the process.

2.6.4 Pesticides

Pesticides are hazardous due to their ability to kill organisms. Their deliberate introduction to the environment presents a risk not only to target organisms but also a lesser risk to non-target species. Pesticide risk assessment within the water environment is fundamental with regard to human health, non-target species and the environment (Carlile 2006). Levels in drinking water should not exceed the 0.1µg/l standard set by the Drinking Water Inspectorate, in line with the European Drinking Water Directive (EC, 1998).

Pesticides are applied to crops within agriculture, to provide protection from pests and competition and to ensure yields and quality are maximised (Hunter 2009). Within the Anglian region such pesticide use within agriculture provides a major source of diffuse pollution and is the focus here. Other sources include industrial discharges, sewage treatment works and urban runoff in combination which further contribute pesticides to the environment. (EA 2010) Urban pesticide sources in the Anglian region include gardening, parks, railways and sports grounds (Ward et al. 1993)

Agricultural pesticide use in the Anglian region is high compared to other regions in the UK due to large areas of arable and horticultural land, with the total area treated increasing between 1990 and 2006 (EA 2010). Two widely used pesticides as stated in EA (2010) are Metaldehyde and Clopyralid. In the Anglian region Metaldehyde slug pellets are mainly applied in the autumn to protect autumn-sown crops such as winter wheat and oilseed rape. It is also used on potato crops. Clopyralid is a herbicide which removes broad-leaved weeds in oilseed rape and sugar beet crops.

Herbicides are the type of pesticide most frequently found to contaminate water courses in England; Figure 2.8 shows that herbicide usage in terms of the application rate of active substance (AS) per hectare of crop grown dominates pesticide use on cereals on arable land in England (DEFRA 2010).

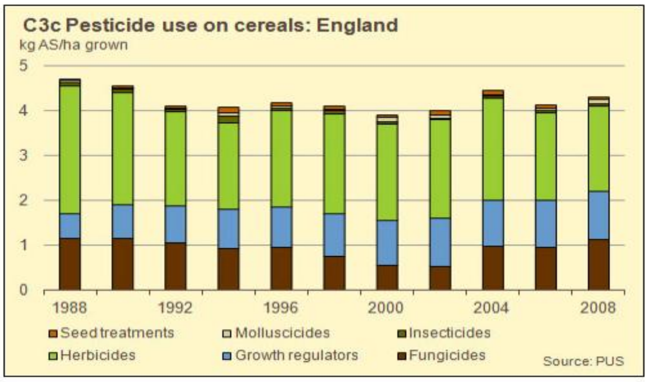

Figure 2.8 Pesticide use on cereals (application rate of active substance (AS) per hectare of crop grown) in England 1988-2008 (DEFRA 2010)

Pathways (Table 2.3) determine the extent to which pesticides degrade and move from the source to adjacent water bodies (Hunter 2009). The two main pathways are surface transport (overland flow or runoff), and subsurface transport (including the processes of infiltration, leaching, and through flow.

Pesticide activity can decline when adsorbed on soil colloids. However, this process can be prevented when pesticides are transported rapidly out of the soil, for example following a heavy rainfall event (Hunter 2009; Jarratt 2010).) Direct applications of pesticide to surface water bodies may also occur through spray drift (Jarratt 2010).

If the pesticides are subjected to prolonged storage in the soil, and if the chemical make-up of the pesticide variant allows, adsorption to soil particles will lead to the transport of pesticides to surface water bodies via soil erosion. Vertical pathways occur in the subsurface where pesticides bound to clay particles act as liquids which are transported via macropores, in well structured soils under minimum tillage, to groundwater; a process accelerated if field drains are in place (Jarratt 2010).

2.6.5 Nitrates

Water pollution due to nitrates has two different implications: public health problems and environmental risks. The main environmental issue is linked to eutrophication. To prevent and reduce nitrate pollution the European Commission adopted a Nitrate Directive. This Directive required the member states to identify the waters that are polluted or likely to be polluted as Nitrate Vulnerable Zones (NVZ). As it is shown Appendix A2, Central Bedfordshire falls within the NVZ area.

The major source of N is known to be agriculture and around 60% of nitrate present in English waters is originated in agricultural land (DEFRA 2008); the principal source of nitrate is fertiliser application which is typically equivalent to 159 kg N ha^{-1} on arable land and 57 kg N ha^{-1} on grassland in the Eastern region (DEFRA, 2010). In the Anglian catchment, it is considered that 20% of nitrate derives from sewage treatment works in urban areas (Hunt 2004). Nitrate is a very soluble anion, which means that it is readily carried by moving water, either vertically through leaching or overland flow across the surface (Table 2.3). The nitrate lost in drainage is affected by the volume of water leaching (which depends on precipitation, evapotranspiration and soil characteristics) and the nitrogen concentration of nitrogen (which is affected by the environmental conditions, rate of applied N and crop management) (Brady and Weil 2008).

2.7 Land use options

This final section focuses on some of the key agricultural land use options. The Common Agricultural Policy (CAP) enables the European Commission (EC) and UK Government to ensure that environmentally responsible agricultural land management is promoted through regulations and economic incentives. Farmers, who receive payment under the CAP, must as a minimum satisfy the conditions for cross-compliance to be eligible for the baseline Single Payment Scheme (Figure 2.9). The majority of cross-requirement standards relate to the Statutory Management Requirements (SMRs) and the need to maintain the land in good agricultural and environmental condition (GAEC) (Figure 2.9) (DEFRA 2011)

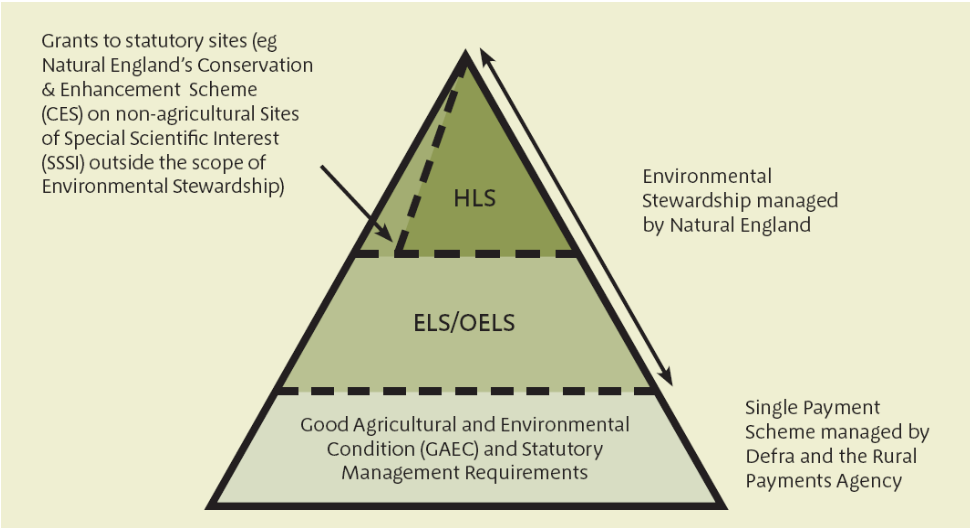

Figure 2.9 Common Agricultural Policy (CAP): Scheme Hierarchy (Natural England 2010

SMRs are requirements set under UK and EU law related to issues such as public, animal and plant health, animal welfare, the environment and landscape features. Conditions related to GAEC include soil, water and habitat protection, and are determined on a national or regional basis (DEFRA 2011).

The proposed reform of the CAP from 2014, as proposed in October 2011, is for a new Basic Payment Scheme to replace the existing Single Payment Scheme. There is also a proposal for a a new 'Greening' element which will incorporate 30% of the annual payments. The proposed practices include crop diversification, maintenance of permanent pasture, and maintaining 7% of eligible arable land or temporary grassland in ecological focus areas.

Within the Agri-environment scheme hierarchy (Figure 2.9), above GAEC, the next level is England is the Environmental Stewardship Scheme (Natural England 2010a). Environmental Stewardship involves actions taken to look maintain or improve wildlife habitats, landscape, historic features and natural resources (soil and water). Some of these actions will provide benefits for soil organic carbon, water quality and control of runoff and soil erosion.

The scheme is structured in three levels and farmers score "points" for implementing stipulated measures (Natural England 2010a); the three elements of ES are:

- **Entry Level Stewardship (ELS)**: This is the simplest level of ES. Farmers are required to meet basic cross compliance requirements and additional practices to enhance wildlife, landscape, historic features and natural resources (soil and water) across their farms; specific unique measures are stipulated for those managing upland farms. The scheme is non-competitive. (Natural England 2010a)

- **Organic Entry Level Stewardship (OELS)**: This is the organic version of the ELS. The scheme is non-competitive (Natural England 2010b).

- **Higher Level Stewardship (HLS):** In targeted priority areas (Figure 2.10) target areas within Eastern England are shown in light green however non target areas shown in darker green are also eligible to enter into HLS schemes if applications are multi-objective applications currently actively sought by Natural England (Natural England 2008). Significant and specific improvements to land use and management are critical and in these areas. The competitive HLS scheme build on the non-competitive ELS scheme and is more demanding, tasking the farmers to achieve more than in the ELS including: improving the management of larger areas and supporting more complex environmental management (Natural England 2010c).

Figure 2.10 East of England: Higher Level Stewardship Target areas (Natural England 2008).

3. Methodology

3.1 Overall project methodology

The requirement for spatially-explicit information means that the project methodology requires a spatially explicit land use model (Figure 3.1). Such models are useful for policy formulation with regards to changes in land use and cover (Lambin and Geist 2006). Suitability/risk maps were created for the three groups of ecosystem services: carbon storage, runoff and soil erosion control, and water quality regulation. These maps, combined with a map of current land use and algorithms were then used to predict changes in the ecosystem services resulting from quantified changes in land use. Rather than restrict land use changes to specific areas, for the purposes of demonstration we established scenarios which allowed us to describe the impact of a specified land use change across the whole Central Bedfordshire area. Obviously such scenarios are not realistic, but they provide a method for starting to identify areas particularly sensitive to change.

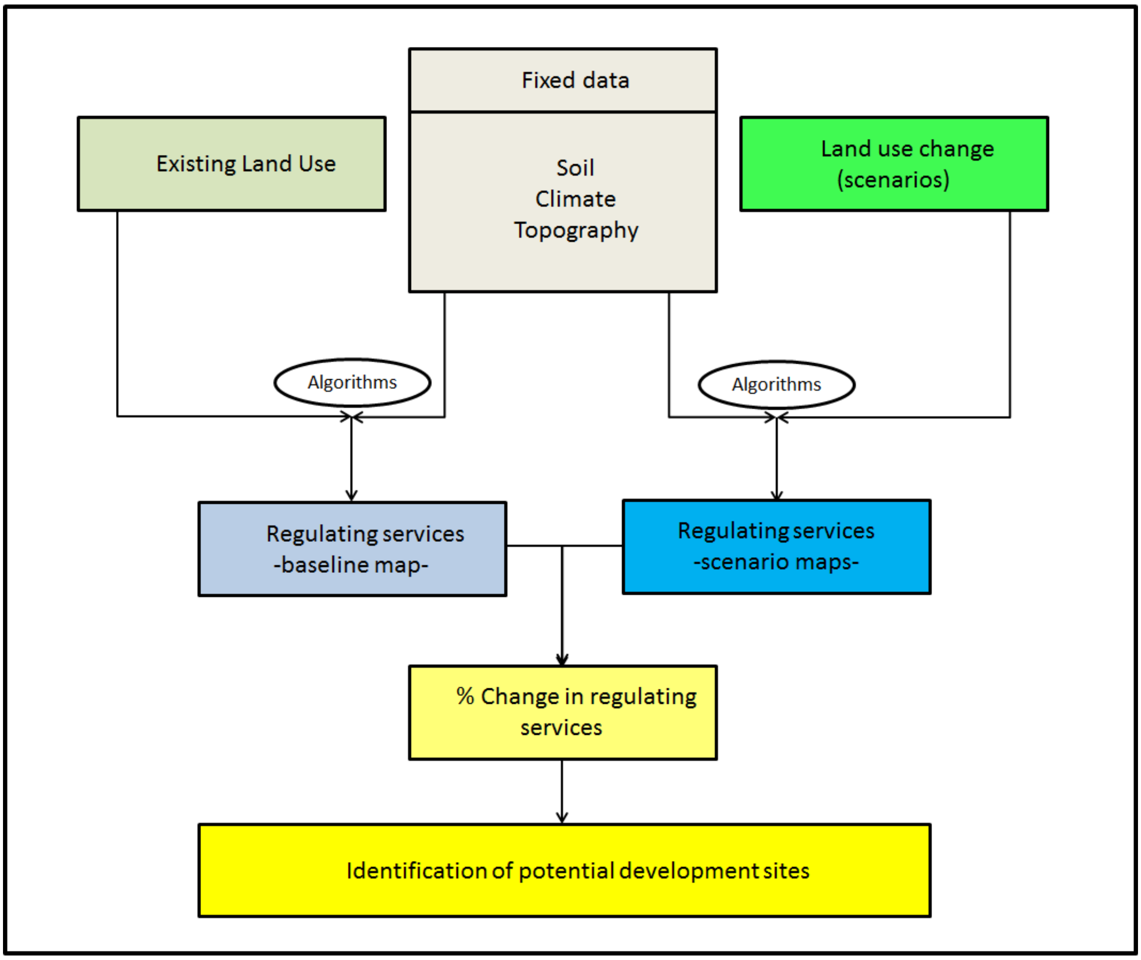

Figure 3.1 General structure of spatially explicit land use change model.

The scenarios investigated included:

1. Urban development: all non-urban land converted to urban land use
2. All pasture: all non-urban land converted to pasture
3. All woodland: all non-urban land converted to woodland vegetation
4. Biodiversity Action Plan (BAP) implementation: Implementation of all actions where there are opportunities for under the BAP (see appendix A5)
5. Changes in land management: e.g. implementation of good land management practices on arable land (only carried out for the runoff section).

In this way, the intention was to identify priority areas where changes in land use and management had the greatest beneficial effects or smallest detrimental effects, or vice versa.

Three site-level case studies were also carried out, using the same methodology as the scenarios, to illustrate the above scenarios on a smaller, more focussed scale. They are examples of how the method used can be applied to specific sites of land use change or changes in land management practices. The sites chosen for these case studies were: 1) an urban development just north of Luton, 2) a BAP implementation site: Biggleswade Jubilee Woodland, and 3) a possible change in land management at Church Farm in the Flit Valley between Flitwick and Shefford. The methodology, results and discussion for these case studies can be found in Appendix E.

3.2 Land cover

Data on land use can be found in maps like LCM2007 (Land cover map) created by the Centre for Ecology & Hydrology (2011), and Corine (EIONET 2006). Within the time constraints of this project, the CEH land cover map could not be secured. Therefore, the Corine 2006 land cover map developed by the European Environment Agency provided the most up to date land cover data at a resolution of 100 m x 100 m.

The Corine map is available in scale 1: 100 000 with a minimum mapping unit being 25 ha and minimum width of linear elements being 100 m. The standard CLC 2006 (Corine Land Cover) nomenclature includes 44 land cover classes grouped in a three level hierarchy. Its main categories are 1) artificial surfaces, 2) woodland areas, 3) agricultural areas, 4) wetlands, and 5) water bodies. Two satellites provided imagery for Corine: Spot-4 and IRS P6. The time consistency is 2006 +/- 1 year (EEA 2007).

To improve clarity for the purposes of this project, Corine land use classes were combined into five main classes (Table 3.1). It is possible that the arable land classification within Corine includes some areas of grassland, which are included within arable rotations. A pasture class was formed out of pasture and areas of heterogeneous agriculture (land predominately occupied by agriculture with significant areas of natural vegetation; a mix of cereals, grassland, and deciduous woodland). A woodland vegetation class was formed out of forest and transitional woodland shrub. The urban class can be sub-divided into four sub-groups. Each class had its own data layer.

Five land uses, and data on urban and woodland sub-groups present in Central Bedfordshire were derived on the data obtained from the Corine database (Table 3.2) (EIONET 2006). The data on pasture and arable land use subgroups included data on agri-environmental schemes downloaded from magic.defra.gov.uk.

Table 3.1 Reclassification of the Corine 2006 urban land cover into five groups (EIONET 2006)

<table>
<tr><th colspan="2">Land use</th><th>Corine classification included</th></tr>
<tr><td rowspan="4">Urban</td><td>Open spaces</td><td>Airports, green urban areas, sport and leisure facilities</td></tr>
<tr><td>Residential</td><td>Discontinuous urban fabric</td></tr>
<tr><td>Impervious</td><td>Mineral extraction, dump, and construction sites</td></tr>
<tr><td>Commercial and business</td><td>Industrial and commercial units</td></tr>
<tr><td colspan="2">Woodland</td><td>Broad-leaved forest, coniferous forest, mixed forest, transitional woodland-shrub</td></tr>
<tr><td colspan="2">Pasture</td><td>Pastures, Land principally occupied by agriculture with significant areas of natural vegetation</td></tr>
<tr><td colspan="2">Arable</td><td>Non-irrigated arable land</td></tr>
<tr><td colspan="2">Water</td><td>Water bodies</td></tr>
</table>

Table 3.2 Description of sub-categories of land use

<table>
<tr><th>Main class</th><th>Sub-categories</th></tr>
<tr><td rowspan="4">Urban: this was classified based on amount of “open/grassland area” within the land use.</td><td>a) Commercial</td></tr>
<tr><td>b) Residential</td></tr>
<tr><td>c) Impervious</td></tr>
<tr><td>d) Open spaces</td></tr>
<tr><td rowspan="6">Arable: this was classified basing on the Agri-Environment Scheme used to manage the land or lack of. The subgroups are:</td><td>a) None (No Agri-Environmental Scheme (AES))</td></tr>
<tr><td>b) Entry level</td></tr>
<tr><td>c) Entry level + higher</td></tr>
<tr><td>d) Higher level</td></tr>
<tr><td>e) Organic entry level</td></tr>
<tr><td>f) Organic entry level + higher</td></tr>
<tr><td rowspan="6">Pasture: used the same approach as the Arable land use.</td><td>a) None (No Agri-Environmental Scheme (AES))</td></tr>
<tr><td>b) Entry level</td></tr>
<tr><td>c) Entry level + higher</td></tr>
<tr><td>d) Higher level</td></tr>
<tr><td>e) Organic entry level</td></tr>
<tr><td>f) Organic entry level + higher</td></tr>
<tr><td rowspan="4">Woodland</td><td>a) Broad-leaved: woodlands with mainly broadleaved trees</td></tr>
<tr><td>b) Coniferous: woodland with mainly coniferous trees</td></tr>
<tr><td>c) Mixed forest: mix of broadleaved and coniferous trees</td></tr>
<tr><td>d) Transitional woodland-shrub: includes scrub and/or herbaceous vegetation associations</td></tr>
<tr><td>Water</td><td></td></tr>
</table>

3.3 Soil type

LandIS was developed by The National Soil Resources Institute (NSRI) at Cranfield University and contains soil maps and land information system for England and Wales. This data is available under license and is useful for a wide range of organisations managing conservation, water, waste, environment, construction, property, food and timber production, (NSRI 2012b). Data offered by LandIS was also the most up to date, complex, small scale source of information which was decided to be incorporated into the project. The available and used datasets are outlined below.

The National Soil Map package contains digital National Soil Maps available in different scales describing spatial soil distribution in England and Wales. In our study we used the NATMAP vector which is a map in 1:50 000 scale and NATMAP associations which provides associated proportions of soil series within each map unit (NSRI 2012a & b).

Soil Types Package represents values of horizon and soil series properties for each soil type available in NATMAP. The data describes the whole soil, top metre or individual layers that make up the soil profile. Soil maps can be converted into land suitability, risk ratings and vulnerability through a range of interpretation keys. The available datasets are: SOILSERIES Info, SOILSERIES Pesticides, SOILSERIES Hydrology, SOILSERIES Agronomy, SOILSERIES Leacs, HORIZON Fundamentals, HORIZON Hydraulics. The datasets used in our study were HORIZON Fundamentals and HORIZON Hydraulics. Both contain detail properties of each soil horizon (layer) from the topsoil to the parent material and information for the same soil series under different land use. HORIZON Fundamentals includes information on textural properties along with layer thickness while HORIZON Hydraulics holds information about hydraulic properties along with layer thickness (NSRI 2012b). SOILSERIES and HORIZON data are tabular datasets that can be combined with NATMAP. In Central Bedfordshire 13 soil types were specified with the use of LandIS data (Table 3.3).

Table 3.3 Description of 13 main soil types found in Central Bedfordshire

Soil type	Description of dominant soils
Deep clay	Slowly permeable calcareous clayey, and fine loamy over clayey soils.
Deep loam	Deep calcareous and non-calcareous fine loamy and clayey soils with slowly permeable subsoils and slight seasonal waterlogging.
Deep loam over gravel	Well drained fine and coarse loamy soils locally calcareous.
Deep loam to clay	Fine loamy over clayey soils with slowly permeable subsoils and slight seasonal waterlogging associated with similar but wetter soils.
Deep sandy	Deep well drained sandy and coarse loamy soils.
Deep silty to clay	Well drained flinty fine silty soils in valley bottoms.
Loam over chalk	Well drained calcareous coarse and fine loamy soils over chalk rubble.
Loam over red sandstone	Well drained coarse loamy and sandy soils over sand or sandstone, in places ferruginous.
Seasonally wet deep clay	Stoneless clayey soils, in places calcareous variably affected by groundwater.
Seasonally wet deep peat to loam	Deep permeable coarse loamy often stoneless soils affected by groundwater mainly with a peaty or humose surface horizon.
Seasonally wet loam over gravel	Calcareous fine loamy soils over gravel variably affected by groundwater,
Shallow silty over chalk	Shallow well drained calcareous silty soils over chalk. Mainly on moderately steep, sometimes very steep land.
Silty over chalk	Well drained calcareous fine silty soils deep in valley bottoms,

3.4 Carbon storage and sequestration

To create maps of soil carbon and land use in Central Bedfordshire, LandIS soils data (see appendix A3 for summary of LandIS datasets) and Corine land use data were used (EIONET 2006). Using ArcGIS v.10 software, a Corine land cover 2006 raster file with 100 m x 100 m resolution was converted into a vector polygon file using the raster to polygon (conversion) tool.

3.4.1 Data on soil organic carbon density

According to the Kyoto agreement, the international standard of measurement of soil carbon density is that within the top 30 cm of soil (Hazelton and Murphy 2007). In our project we decided to use the data available to show total carbon density in the soil profile down to 150 cm, which includes data for not only topsoil but also subsoil.

LandIS contains a dataset (HORIZONfundamentals.csv) of values for organic carbon present in each layer of soil (horizon) as a percentage of total soil weight (% C) under four land uses: AR (arable), PG (permanent grassland), LE (lay grassland) and OT (other). However to estimate soil carbon per unit volume requires an estimate of soil bulk density.

Caroline Keay from Cranfield University developed SQL codes (Appendix A4) for obtaining a table with data on mean, minimum and maximum soil organic carbon percentage at different depths (0-30, 30-100, and 100-150 cm). Using estimates of soil bulk density from a second file (HORIZONhydraulics.csv), the results were converted to carbon stocks (t SOC ha^{-1}) with average, minimum, maximum values for each depth interval (0-30, 30-100, and 100-150 cm). The resulting data was then linked to the attribute table of Central Bedfordshire soil map (NATMAPvector.shp).

3.4.2 Conversion factors

The original data extracted from LandIS by Keay was present in four land use categories: AR, PG, LE, and OT. For the use of this project five land use classes were created to be more representative for Central Bedfordshire: arable – AR, permanent grassland – PG, urban – UR, woodland vegetation – WL, and water – WA. There are differences in land use, vegetative and impermeable surface cover patterns that occur among urban areas (Pouyat 2006). Four land use sub-groups were created to obtain more precise data about carbon storage in urban soils: open spaces, residential, impervious, and commercial and business.

The soil carbon data was originally present in four separate Excel files, one for each land use, and organized by MUSID code. One Excel file was created which incorporated all four land uses, with their LU codes, and LUMUSID codes. It was assumed that soil carbon density associated with water bodies was zero (Xu 2011). LandIS datasets didn’t contain data on carbon density in urban and woodland vegetation areas. This data had to be calculated from other land uses which already had data from LandIS (see below) with the use of ratios derived from the literature. Values for soil carbon density under woodland vegetation and urban land cover were calculated by multiplying those for the same soil types (using MUSID) under grassland by a conversion factor. The term grassland is used with pasture.

Conversion factors for urban areas were derived from the literature. The National Engineering Handbook (USDA 2012) specifies the proportion of pervious land cover for different urban cover types. We assumed that the pervious areas were grassland to estimate soil carbon in urban areas from the grassland data (Table 3.4).

Table 3.4 Percentage of pervious surface in urban areas (USDA 2012).

Urban land use sub-group	Pervious surface (%)
Open spaces	90
Residential	35
Commercial and business	15
Impervious	0

The soil carbon for the woodland vegetation areas was based on grassland values, which showed less variability than arable soils. A conversion factor of 1.25 of the grassland value was derived from Bradley et al. (2005), which is similar to other estimates (Table 3.5). Jobbagy and Jackson (2000) studied the distribution of SOC content at different depths for dominant vegetation types and the trends appear relatively similar for our vegetation classes of grasslands and woodland vegetation for the top 200 cm, and significant differences only appearing in the 200-300cm horizon. Therefore, a constant figure of 1.25 was applied throughout the top 150 cm.

Table 3.5 Comparison of conversion factors for woodland and grassland areas

Soil depth (m)	Woodland soil carbon content (tC ha^{-1})	Grassland soil carbon content (tC ha^{-1})	Woodland : Grassland Ratio	Source
0 – 0.3	13.6 (deciduous) 12.9 (coniferous)	10.9	1.24 1.18	Jobbagy and Jackson (2000) (Global temperate figures)
0 – 1.0	10.4 (d) 8.4 (c)	6.6	1.63 1.27	
0 – 0.3	38	32	1.18	Xu et al. (2011) (Ireland)
0 - 0.3	10	8	1.25	Bradley et al. (2005) SOC t ha^{-1} England
0 – 1.0	17	13	1.31	

3.4.3 Maps of soil organic carbon

Maps were created for four soil depth intervals: 0-30, 30-100, 100-150, and 0-150 cm (Figures 4.1-4.4). In addition maps were produced describing soil carbon density in relation to land use (Figures 4.6-4.7).

3.4.4 Carbon storage in vegetation

Carbon storage in the vegetation was estimated using values provided for the Republic of Ireland by Cruickshank et al. (2000) (Table 3.6). It was assumed that the climate conditions and therefore the results would be similar to those in the UK.

Table 3.6 Carbon storage in vegetation according to Corine land use classification (Cruickshank et al. 2000).

Corine legend code (clc2000_le)	Above ground C (t ha^{-1})	Land Use
2	3.1	Discontinuous urban fabric
3	0.0	Industrial or commercial units
6	0.5	Airports
7	0.0	Mineral extraction sites
8	0.0	Dump sites
9	0.0	Construction sites
10	0.9	Green urban areas
11	6.8	Sports and leisure facilities
12	2.2	Non-irrigated arable land
18	0.9	Pastures
21	2.0	Land principally agriculture, significant natural veg
23	38.0	Broad-leaved forest
24	29.9	Coniferous forest
25	32.8	Mixed forest
29	14.5	Transitional woodland-shrub
41	0.0	Water bodies

3.4.5 Scenarios and case studies

In order to identify areas where land use change offers the greatest potential gains and losses in soil organic carbon, scenarios 1 to 4 (see page 26) were modelled.

After calculating and mapping the predicted current SOC density across Central Bedfordshire, mean values of SOC density for each soil type under each land use were calculated as weighted averages (by area). Using these values, the scenarios were carried out. For each scenario, areas covered by each soil type were assigned the mean value of SOC density for that soil type under the future land use, to give a predicted “scenario SOC density” under the future conditions. Therefore, from this calculated “scenario SOC density” and the “current SOC density”, a change in SOC density could be predicted for the proposed change in land use for each polygon on the map of Central Bedfordshire.

3.5 Runoff and soil erosion

3.5.1 Runoff methodology

The aim of the runoff study is to identify the areas which can contribute to high flooding risk within the Central Bedfordshire County. Therefore, the output of the study was a map showing the risk of runoff production over the Central Bedfordshire County and the drainage areas where flooding tends to accumulate. In order to produce such map, the runoff generated by a 1 in 10 years, and a 1 in 100 years rainfall event was estimated. The 1 in 10 years flooding event can, often, be ameliorated by mean of changing some land uses and improving the land management techniques, according to the Agri-Environment Schemes established by DEFRA. The risk of flooding within the area over the next 100 years probably should be solved by means of engineering techniques.

There are more than a hundred different models to estimate runoff generation at catchment scale as a consequence of rainfall events (O’Conell et al. 2007). The model used to estimate the runoff generation should be sensitive to the effect of the land use, land management, soil features, and climate. The SCS curve number (CN) method meets the features aforementioned (USDA 2012). The model was developed in the USA, therefore it might not be totally adequate for the UK (Hess et al. 2010). However, it was robust across a large range of land covers, climatic conditions and soil types within several modelling studies in the UK, Europe and other regions of the world. Indeed, the Environment Agency use this model in their Catchment Flood Management Plan (CFMP) tool to assess the impact of changes in rural land management and land use on flood generation (Environment Agency, undated). This model is designed for catchments smaller than 6500 ha (USDA 2012). Within this project the model was applied to individual pixels of 100 m^2. Finally, comparisons between the runoff depths calculated by the UK’s Flood Estimation Handbook (FEH) methodology and by the CN method showed that the CN method usually estimated lower floods than the FEH method. Nevertheless, estimations of both models converged with increasing rainfall events (Holman et al. 2003), which cause the most significant flood risk.

The SCS curve number method used some equations to estimate the direct runoff originating as consequence of a rainfall event. It takes into account the amount of rainfall, the previous soil moisture and the catchment features. Catchment characteristic are represented by the CN, which are land use, soil conservation practices, soil hydrologic group, and soil hydrologic condition. Detailed information about the CN method, including CN values used for calculations in Central Bedfordshire, can be found in Appendix A6.

Land use information was gathered from Corine Land Cover map 2006 (EIONET 2006). The Catchment Flood Management Plan (CFMP) tool of the Environment Agency reclassifies land uses in five categories in order to apply the CN model in UK catchments (Environment Agency, undated). Nevertheless, the CLC map (2006) does not distinguish between small grain crops and row crops. Therefore these two categories suggested by the Catchment Flood Management Plan (CFMP) tool were merged in one “arable land” (Table 3.7). The CN of the arable land class was weighted according to the abundance of small grain crops and row crops in the Luton & Bedfordshire (DEFRA 2009b).

The CFMP tool does not consider the effect of urban areas in the runoff production (Table 3.7). However, one of the aims of the project was to assess the effect of new urban developments. Therefore the different types of urban surfaces distinguished by the Corine Land Cover 2006 were classified according to the urban cover types described in the CN method handbook (Table 3.8). Finally, a CN was assigned to the urban areas in order to include their effect in the runoff production (USDA 2012).

Table 3.7 Reclassification of the Corine Land Cover (2006) map’s land uses into CN method’s land uses (Adapted from Environment Agency, undated).

Curve Number land cover type	Corine Land Cover Map 2006 classification
Arable land	Arable land (cereals, horticulture/non-cereals)
Managed grassland	Not annual crop, improved grassland, set-aside grass, calcareous grass, neutral grass
Unmanaged/semi-natural (others)	Dwarf shrub heath, acid grassland, bracken, montane.
Semi-natural woodland	Coniferous woodland, Broad-leaved /mixed woodland.
Not simulated	Sea/estuary, littoral rock, littoral sediment, saltmarsh, supralittoral rock, supralittoral sediment, inland bare ground, water, bog, fen, urban , marsh and swamp.

Table 3.8 Reclassification of the Corine Land Cover Map 2006’s urban land covers into CN method’s urban land uses.

Curve Number land cover type	Corine Land Cover Map 2006 classification
Residential district (65 % impervious)	Discontinuous urban fabric.
Commercial and business (85 % impervious)	Industrial and commercial units.
Open spaces	Airports, green urban areas, sport and leisure facilities.
Impervious area (Dirt)	Mineral extraction sites, dump sites, Construction sites .

Soil type information was provided by the Land Information System (LandIS), maintained by the National Soil Resources Institute (NSRI) at Cranfield University. Soil types were classified in one of the four Hydrologic Soil Groups (HSG’s) described in the CN method (see Appendix A6) according to the equivalent list between HOST class and HSG’s made by Cranfield University (J.

Hollis, unpublished data). A map displaying the distribution of the four HSG's in Central Bedfordshire can be found in Appendix A6. Moreover, a table showing the correspondence between the HSG's and the soil types used in the results tables of other ecosystem services apart of the runoff also can be found this appendix.

The hydrologic condition of the soil, influenced by the soil management, ranged from very poor to excellent in the runoff model (see Appendix A6). As there is no information about the amount and effectiveness of soil conservation practices in the area, a normal distribution of the hydrologic soil condition was assumed (Table 3.9).

Table 3.9 Assumed distribution of the soil hydrologic condition within the different land uses for a given soil hydrological condition.

Arable land, pasture, semi-natural		**Semi-natural woodland**	
Soil hydrologic condition	%	Soil hydrologic condition	%
Very poor	10	Very poor	15
Poor	20	Poor	35
Fair	40	Fair	35
Good	20	Good	15
Excellent	10	Excellent	Not applicable

The antecedent wetness is classified in three categories within the CN method (see Appendix A6). In order to simplify the calculations, an average condition of antecedent wetness was considered to carry out the runoff estimation. As a consequence, the flow rates estimated could be smaller than real worst flood events. However, that was not a great inconvenience for the main purpose of the hydrology study, which was to identify areas where the runoff is generated, and flood risk areas. Indeed, the maps generated are still useful for assessing how different land uses and land management techniques affect runoff generation and flooding risk areas.

Daily rainfall data were recorded at the Silsoe campus of Cranfield University from 1989 to 2006. It was assumed that equivalent rainfall records were applicable to all Central Bedfordshire County. The Generalised Extreme Value (GEV) distribution, which has been used widely for UK flood frequency analyses (Robson and Reed, 1999), was used to estimate the 1 in 10 years, and the 1 in 100 rainfall events.

The topography of the area was analyzed using a Digital Terrain Model (DTM) of 10 x 10 m resolution (Ordnance Survey 2012) in order to obtain a drainage network, showing the areas where the runoff water tends to flow. Microsoft Excel 2010 software was used to carry out the rainfall statistical analysis. ArcGIS 10 was used to run the CN method, to create the flood network, and to map the results.

3.5.2 Erosion methodology

Erosion can be modelled with three main approaches: empirical models, physics-based models, and conceptual models (Merritt et al. 2003). All three can require a varying amount and type of input data. Some of them are semi-quantitative, and involve making subjective assumptions whereas some others are purely quantitative models. Having precise soil data provided by LandIS, purely quantitative models were possible, and were preferentially chosen. Another reason for the use of purely quantitative models is they can be easily implemented with GIS.

Within the empirical class of models, the USLE model is suitable for the client's needs. The USLE model may not be the most precise model for this geographical location. However, it has the advantage of allowing decision makers to compare different scenarios under different land use and different management practices. In addition, the aim of the erosion study is to create a **relative** erosion risk map, rather than quantify exactly the amount of erosion of the area. Finally, it also takes into account local conditions (climate, soil and topography) that are often considered as constants.

The USLE model involves five factors in the model (Wischmeier and Smith, 1978):

$$A = R*K*LS*C*P$$

Where:

A is the mean annual soil loss (t ha^{-1} yr^{-1}).
R is the annual erosivity. This quantifies the ability of rain drops to cause erosion, and is function of the rain kinetic energy and the rainfall intensity.
K is the soil erodibility. It is the sensitivity of the soil to erosion. It is based on soil properties such as texture, structure, organic matter content and permeability.
LS is the slope factor, which depends on the slope length and slope steepness.
C is the cropping factor or 'c' factor (varying from 0 to 1). It can be defined as the capacity of the crop or soil cover to prevent soil erosion in comparison with bare soil.
P is the land management factor (varying from 0 to 1). It involves the effectiveness of different land management practices to avoid erosion.
Full details of the USLE implementation are provided in Appendix A7.

3.5.3 Scenarios

Scenario 1: Conversion to urban land use

The aim of this scenario was to assess the effect of new urban developments in Central Bedfordshire. Therefore, this scenario involved a land use change for each non-urban area within Central Bedfordshire. Urban areas have different cover types. Therefore, it was necessary to estimate representative CNs and C-factor value for the urban areas in the county. In order to achieve that, the CNs and the C-factor values corresponding to the different urban cover types were weighted according to the relative abundance of each urban cover type within the total urban area in Central Bedfordshire (Table 3.10 and 3.11). In addition of the land cover, CN also depends on soil types. These are designated by A, B, C, and D in Table 3.10 (see Appendix A6). The CN method was used to assess the runoff issues and the USLE method was used for the erosion estimation.

Table 3.10 Weighted curve numbers (CNs) according with the relative importance of each urban land cover in the total urban area in Central Bedfordshire (EIONET 2006, USDA 2012).

Soil	Weighted Residential CN (50.2 %)	Weighted Commercial CN (11.1 %)	Weighted impervious CN (27.4 %)	Weighted open spaces CN (11.3 %)	Weighted Urban CN
A	38.7	9.9	19.7	5.8	**74.1**
B	42.7	10.2	22.5	7.9	**83.2**
C	45.2	10.5	23.8	9.0	**88.4**
D	46.2	10.6	24.4	9.5	**90.6**

Table 3.11 Weighted C- factor values according with the relative importance of each urban land cover in the total urban area in Central Bedfordshire (EIONET 2006, USDA 2012).

Urban cover type	Relative importance (%)	Normal C-factor value	Weighted C-factor value
Residential	50.2	0.0094	0.0047
Commercial	11.1	0.0046	0.0005
Airport	2.8	0.0190	0.0005
Mineral extraction site	9.4	1.0000	0.0943
Dump site	1.4	0.6500	0.0092
Construction	0.4	0.6500	0.0028
Green areas	24.7	0.0226	0.0056
Weighted total urban C-factor value			**0.1176**

Scenario 2: Conversion to woodland land use

The purpose of this scenario was to illustrate the effect on erosion and runoff of woodland land use over the county. Therefore, this scenario involved the woodland land use in every non-urban areas within the county (EIONET 2006). CNs corresponding to woodlands (Appendix A6, Table A4) were used to assess runoff generation and flow accumulation using the CN method. The C-factor value of woodland (Appendix A7, table A10) was used as crop factor of all non-urban areas in the USLE equation in order to assess the erosion under woodland land use.

Scenario 3: Conversion to pasture

The purpose of this scenario was to assess the effect on erosion and runoff of the pasture land use in non-urban areas of county (EIONET 2006). CNs corresponding to pasture (Appendix A6, table A4) were used to assess runoff generation and flow accumulation using the CN method. The C-factor value of pasture (Appendix A7, Table A10) was used as crop factor of all non-urban areas in the USLE equation.

Scenario 4: Biodiversity Action Plan (BAP)

The purpose of this scenario was to assess the effect on erosion and runoff of the BAP over the county. Therefore, current land uses were substituted by the land cover proposed in the BAP in the areas where such plan will be developed (Central Bedfordshire Council, undated; EIONET 2006). Where no modification in land use was planned, the CLC map 2006 (EIONET 2006) was used. The BAP consists of woodland and a variety of grassland areas. CNs for these land uses (Appendix A6, table A4) were used to assess the runoff by mean of the CN method. C-factor values corresponding to woodland and grassland (Appendix A7, table A10) were used to evaluate the impact of the biodiversity action plan in erosion using the USLE model.

Scenario 5: Land management

The effect of some land management techniques to prevent erosion and runoff were implemented in the arable land of Central Bedfordshire (table 3.12). The majority of them are included in the Entry Level Agri-Environment Schemes (Natural England 2010a).

Table 3.12 Management practices implemented in scenario 5 in order to reduce erosion and runoff.

Management practice	Location	Agri-Environment scheme
Contouring	Within the field	No
Winter cover crop*	Within the field	Yes
12 m grass buffer strip close to permanent water courses	Close to water courses	Yes
6 m hedge buffer strip + hedgerow	Hedge of the field	Yes
In-field grass areas	Within the field	Yes
Field corners	Hedge of the field	Yes
Beetle banks**	Within the field	Yes

* Effect of cover crop only was quantified in erosion reduction.

** The effect of beetle banks on runoff reduction and erosion was not estimated.

Contouring reduces the erosion rate and the runoff generation. However, rills formation can reduce considerably their efficiency (Jasa and Dickey, 1991; McIsaac et al. 1991; Quinton and Catt 2004). Beetle banks placed across the slope could be useful to reduce surface water speed, favouring sedimentation and, consequently, reducing the erosion rate (Natural England

2010). Effects of contouring are quantified by the P factor of the USLE equation (Table 3.13). Although the effect of the beetle banks on erosion and runoff was not quantified in the scenario, their presence reduces the likelihood of a drainage network formation, which decreases the efficiency of the contouring.

Table 3.13 P- factor values for contouring (Morgan 2005).

Slope (°)	P-factor value
0 – 1.49	0.60
1.50 – 5.49	0.50
5.50 – 7.49	0.60
7.50 – 9.49	0.70
9.50 – 11.49	0.80
11.50 – 14.99	0.90
More than 15	1

Contouring improves the soil hydrologic condition. As consequence, a new frequency distribution of such soil feature was used in the scenario (table 3.14). In order to deduce this frequency distribution, the CN values of the NEH (USDA 2012) and the CN values used by Hess et al. (2010) were compared, since the CN table presented on Appendix A6 is based on the latter CN set. For a given type of crop and HSG in good (excellent in our project methodology) soil hydrologic condition, the CN in Hess et al. (2010) usually coincided with the CN of the NEH table corresponding to the same land use and HSG in a good soil hydrologic condition when contouring occurs. For a given type of crop and HSG in poor soil hydrologic condition, the CN in Hess et al. (2010) matches with the CN of the NEH table corresponding to the same land use and HSG in a poor soil hydrologic condition when straight rows occur. Moreover, the CNs in straight row conditions are greater than CNs in contouring conditions in the NEH. Therefore, it could be concluded that contouring improves the soil hydrologic condition on arable land in such way that the soil hydrologic condition vary from Fair to Excellent in the CN table described in the methodology. A normal distribution was assumed within the mentioned range.

Table 3.14 Soil hydrologic condition after contouring for a given HSG in arable land. Comparison with the assumed soil hydrologic condition for the current situation.

Assumed current situation		Scenario 5 (after contouring)	
Soil hydrologic condition	%	Soil hydrologic condition	%
Very poor	10	Very poor	0
Poor	20	Poor	0
Fair	40	Fair	25
Good	20	Good	50
Excellent	10	Excellent	25

Cover crops reduce between 40 and 90 % of the annual erosion rate (Kort et al. 1998; Laloy and Bielders 2010). In order to avoid overestimate the effect of the cover crops, a reduction of 50% in the crop factor (C) corresponding to arable land (Appendix A7, table A10) of the USLE equation was assumed. The CN method does not allow estimating the runoff reduction by cover crops. However, researchers showed that cover crops effectively reduce the runoff in areas prone to winter runoff generation, while their effect is rather smaller in areas of low winter runoff (Howarth et al. 2007). Therefore, the highest rates of runoff estimated in this scenario could probably be smaller in the reality.

Permanent in-field grass areas are especially recommended in areas with high rate of erosion. Therefore, it was implemented only in areas where the potential current erosion estimated previously had been greater than 100 t $ha^{-1}y^{-1}$. High runoff generation areas were not taken into account to choose the location of such in-field grass areas because the riskier runoff areas are located in urban zones or in arable land with erosion rate of at least 100 t $ha^{-1}y^{-1}$. It was assumed that arable fields with a high erosion rate have a 25% of permanent in-field grass areas, which is within the limit of the Entry Level Agri-Environment Schemes (Natural England 2010). Therefore, the C factor of the USLE model (Appendix A7, table A10) and the CN (Appendix A6, table A4) of the arable land were weighted with 25% of grass in the areas where this measure was applied.

Hedge buffer strips and field corners were implemented for all arable land. If the mean area of a English farm is 50 ha (Living Countryside 2012) and it is assumed that the shape of the farm is a square, a 6 m hedge buffer strip will take up around 3.4 % of the total surface. Moreover, it was assumed than the field corner take up 6.6 % of the farm area, which is within the Entry Level Stewardship limits (Natural England 2010a). The C factor (Appendix A7, table A10) and the CN (Appendix A6, table A4) corresponding to arable land were weighted with this amount of grass.

A 12 m grass buffer strip was assumed along both sides of the permanent water courses, i.e. rivers, using the C factor and the CN corresponding to grass. The river network was obtained from the Biodiversity Opportunity Map layers (Bedslife, undated).

The combination of minimal tillage and the use of crop residues as soil cover is an effective technique to prevent erosion and runoff (Jasa and Dickey, 1991; McIsaac et al. 1991; Quinton and Catt 2004). However, it was not considered in the scenario, because it is not specifically included within any current agri-environment scheme (Natural England 2010a). Subsoiling improves the soil structure and, consequently, their infiltration ability. As a result it could be considered as an efficient technique in runoff reduction (Jasa and Dickey, 1991). Nevertheless, it was not taken into account because of its expense and again it is not including in any current agri-environment scheme (Natural England 2010a, b, c).

3.6 Water quality

The aim of the water quality study is to identify areas predicted to have higher/lower water quality in the future as a result of changes in land use or management practices. Analysis of water quality has generally been based on the study of water pollution risk.

Dr. Ian Holman from Cranfield University (pers. comm.) suggested developing two different models, one for leaching risk and one for overland flow risk, following the source-pathway-receptor model.

3.6.1. Data layers

Existing data sets of physical features, land use and land management, and land classification in terms of risks to water quality (nitrate, phosphate, pesticides, sediment) and current water quality, within the boundary of Central Bedfordshire, were collated. Table 3.15 describes the initial data layers used, a description of the layer and each layer reference.

3.6.2. Reclassification and redefinition of data

The definition of each potential risk classification range is included in Appendix A8. Potential risks have been reclassified, following the same range and the key (see Table 3.16). The reclassification table for each layer can also be looked up in Appendix A8.

Risks have also been redefined based on the current land use due to the presence/absence of the studied pollutant (see Appendix A8, table A20).

A seven level range has been used and a numerical value and a colour key have been assigned to each level. The classification system used is shown in Table 3.16.

Table 3.15 Classification system used for water quality risk

Risk classification	Null	Very low	Low	Moderate	High	Very High	Excessively High	No Data
Numerical value	0	1	2	3	4	5	6	

Table 3.16 Initial layer description and source

Data Layer	Description	Source
PHYSICAL FEATURES		
NATMAPvector [Soil Type- Simple description]	Simple description of soil association	Soilscapes national soil data from land information system (LandIS), based at Cranfield University (NSRI 2008a-c; NSRI 2009)
Rivers	Named rivers and streams	OS Open Data: Meridian II (Ordnance Survey 2010)
Boundary Layer	Central Bedfordshire Council Boundary	OS Open Data (Ordnance Survey 2010)
LAND USE AND LAND MANAGEMENT		
BAP	Bedslife targets and opportunity for the BAP	Bedslife undated
Land use	Land use classified by different levels of specification	EIONET 2006
Agri-Environment schemes	Environmental Stewardship applied schemes within the Central Bedfordshire	Magic.gov.uk
MAIN WATER QUALITY POLLUTANTS AND PATHWAYS LAYERS		
Soil Erosion Risk	See runoff methodology (section 3.3)	
Pesticide Potential Leaching Risk	Vulnerability classes, defining the fate and behaviour of pesticides, derived from soil type (natural permeability and water regime), geology and groundwater depth. (Land cultivation which may have a significant impact on pesticide behaviour is not taken into account) (NSRI 2012).	Land information system (LandIS), based at Cranfield University (NSRI 2008a-c; NSRI 2009)
Pesticide Potential Runoff risk	Potential for pesticide runoff (speed and extent of lateral water movement over and through the soil at different depths (NSRI 2012)) and adsorption potential of different soil types; derived from the physical properties and natural water regime of soils.	Land information system (LandIS), based at Cranfield University (NSRI 2008a-c; NSRI 2009)
Nitrate Potential Leaching Risk	Nitrate Leaching Risk based on soil permeability and parent material.	Land information system (LandIS) based at Cranfield University (NSRI 2008a-c; NSRI 2009)
Potential Risk of soil leaching to groundwater	Leaching potential of pollutants through the soil and the likelihood of pollutants reaching groundwater (NSRI 2012). The ability of the soil to transmit adsorbed and non-adsorbed pollutants based on the depth, type and hydrologic properties of soil.	Land information system (LandIS), based at Cranfield University (NSRI 2008a, b, c & 2009)
River Quality (Nitrate and Phosphate)	Levels of nitrate and phosphate within surface water bodies	Interactive maps. River water quality. Chemical quality. Environment Agency Interactive Maps (Environment Agency 2012)
River Quality (Specific pollutant)	Ecological status based on water quality with respect to specific pollutants (synthetic and non synthetic)	River Basin Management Plan-Rivers. Specific pollutant quality status Environment Agency Interactive Maps (Environment Agency 2012)

3.6.3. Risk model

Leaching and overland flow risks have been mapped using ESRI ArcGIS v.10. The leaching risk of the current model could be defined as the risk of water pollution by particles within leaching flow. The overland flow risk could be defined as the risk of water pollution by particles within overland flow.

Leaching risk

To simplify the description of the data, pesticide and nitrate potential leaching risk were referred to as pesticide leaching and nitrate leaching respectively (Table 3.17)

Table 3.17 Old and renewed layers name for leaching model

Old name	New name
Pesticide potential leaching risk	Pesticide leaching
Nitrate potential leaching risk	Nitrate leaching
Potential risk of soil leaching to groundwater	Other pollutants leaching (e.g. phosphate)

To derive the final map 'Mean Leaching Risk', the three layers were combined using the tool "raster calculator" in ArcGIS, and weighting them equally:

$$Mean\ Leaching\ Risk = \left[\left(\frac{1}{3}\cdot pesticide\ leaching\right) + \left(\frac{1}{3}\cdot nitrate\ leaching\right) + \left(\frac{1}{3}\cdot other\ pollutants\ leaching\right)\right]$$

The final leaching risk layer was then overlaid with soil and land use data to create a results table that shows the relationship between them.

Overland flow pollution risk

As with the leaching risk model, after additional work (reclassification and redefinition), the layers were renamed (Table 3.18).

Table 3.18 Old and renewed layers name for overland flow pollution model

Old name	New name
Soil erosion risk	Sediments overland flow risk
Soil erosion risk	Phosphate overland flow risk (adsorbed to soil particles)
Pesticide potential runoff risk	Pesticide overland flow risk

To get the final map of 'Mean Overland Flow Risk', three layers were combined using the tool "raster calculator" in ArcGIS, and weighting them equally, following the formula shown below:

$$Overland\ flow\ risk = \left[\left(\frac{1}{3}\cdot sediments\ overland\ flow\right) + \left(\frac{1}{3}\cdot phosphate\ overland\ flow\right) + \left(\frac{1}{3}\cdot pesticide\ overland\ flow\right)\right]$$

The final overland flow risk layer has been overlaid with soil and landuse to create a results table that shows the relationship between them.

3.6.4. Scenarios

An analysis for different scenarios has been carried out using results tables to identify target areas where future changes in land use or management would have particularly beneficial or detrimental effects in terms of water quality. Risk data obtained has been assigned to the different soil types and land uses following the predicted change.

There is no analysis of the Land Management scenario (All Entry Level) for Water Quality, as the data showed no significant change occurred.

To analyse the change, new tables were created with the fields: current risk, scenario risk (future) and predicted risk variation. "Risk variation" was calculated as [Current Risk – Scenario Risk Value]. Table 3.19 shows the text and colour key established to facilitate map interpretation. Increase of risk also means loss of quality, therefore decrease means improvement.

Table 3.19 Classification system used for risk variation analysis

Risk Variation	2 levels increase	1 level increase	No change	1 level decrease	2 levels decrease	3 levels decrease	No Data
Numerical value	2	1	0	1	2	3	

4. Soil carbon storage and sequestration

4.1 Results and interpretation

4.1.1 Current levels of carbon storage

Spatial distribution (0-30 cm)

Soils with the greatest predicted soil organic carbon (SOC) density in the topsoil are located North of Biggleswade, and store 240 tonnes of carbon per ha to 30 cm depth. Areas with a high SOC density (over 100 t ha^{-1} to 30 cm depth) are also present close to the River Ivel, Flit, Ouzel, Ouzel Brook and Grand Union Canal. Other areas showing high levels can be found in central and eastern part of Central Bedfordshire near Barton-le-Clay, Shillington, Higham Gobian, and Church End (near Stotfold). Most of Central Bedfordshire has a topsoil SOC density (to 30 cm depth) of 51-100 tonnes per hectare. Areas with predicted low SOC density (less than 50 t ha^{-1}) are the urban areas surrounding Leighton Buzzard, Dunstable, Biggleswade, Flitwick, and Ampthill (see Figure 4.1)

Spatial distribution (30-100 cm)

The highest soil organic content between 30 and 100 cm depth generally follow those described for 0 to 30 cm. A peat area north of Biggleswade (340 t ha^{-1}), and the areas surrounding the River Ivel, Flit, Ouzel, Ouzel Brook and Grand Union Canal are again evident. Lower SOC concentrations are in the southern, north-western and north-eastern parts of the county (see Figure 4.2).

Spatial distribution (100-150 cm)

Smaller quantities of SOC can be found at this depth than in the shallower soil horizons. In Central Bedfordshire, most soil contains less than 50 tonnes of organic carbon per hectare between a depth of 100 and 150 cm. Only areas adjacent to Biggleswade Common, the River Ouzel, Ouzel Brook and the Grand Union Canal show higher SOC densities (see Figure 4.3).

Spatial distribution (0-150 cm)

Total SOC density takes into account the whole soil profile from the surface down to a depth of 150 cm. The area with the highest soil organic carbon content is located in between the towns of Biggleswade, Sandy and Potton, including and surrounding the Biggleswade Common Land and adjacent to the River Ivel and its tributaries (see Figure 4.4). The highest predicted content of 760 tonnes of carbon per hectare to 150 cm depth is predicted below a broadleaved forest at this location. The equivalent value for arable land in the area is 664 t ha^{-1}. Both these areas have soils of seasonally deep peat to loam, known as the Hanworth soil series, and have Aeolian drift and peat geology. The soil here is described within the LandIS dataset as “dominant deep soil with permeable coarse, loamy often stoneless soils affected by groundwater mainly with peaty or humus surface horizon”.

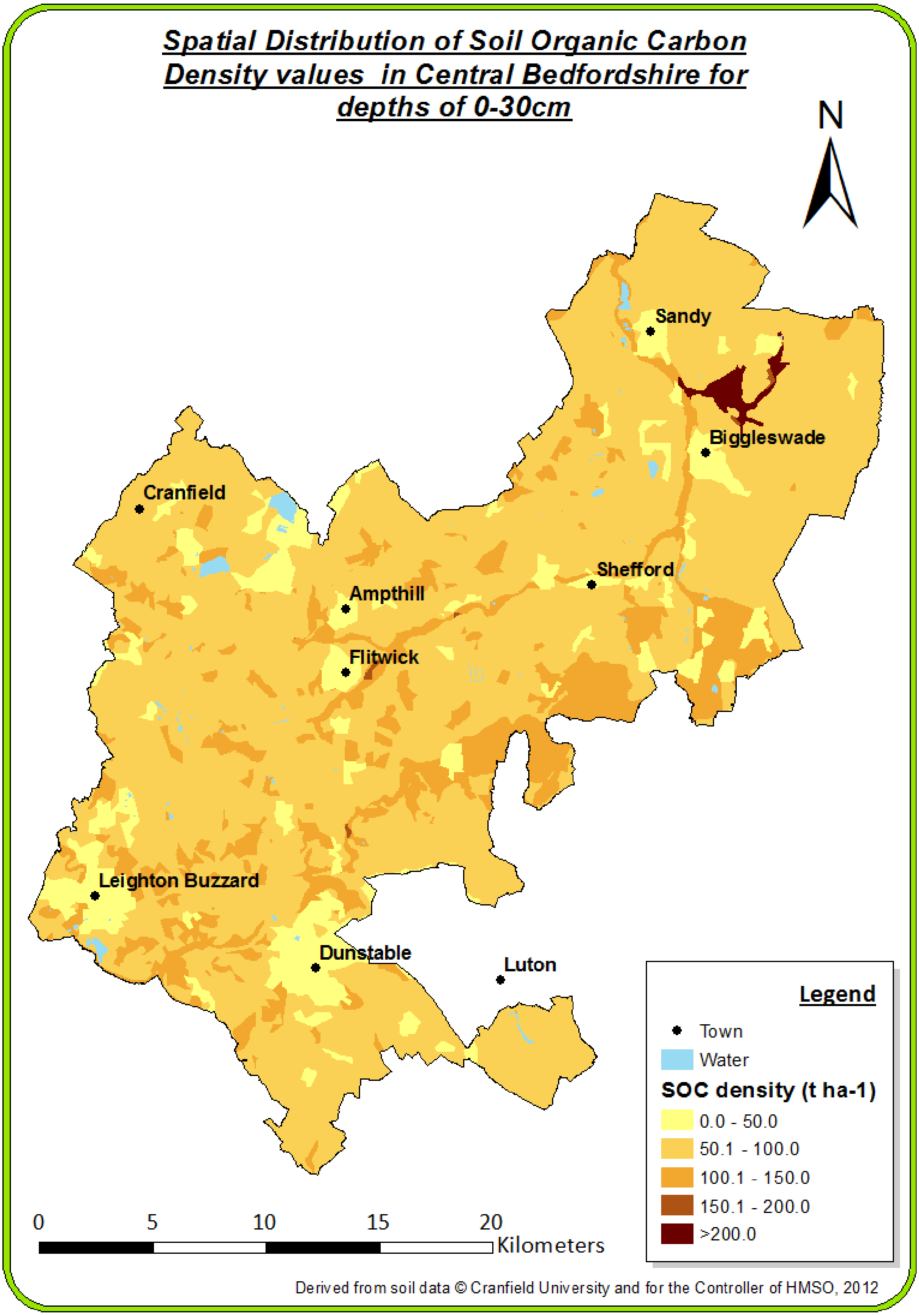

Figure 4.1 Predicted spatial distribution of soil organic content in Central Bedfordshire to a depth of 30 cm

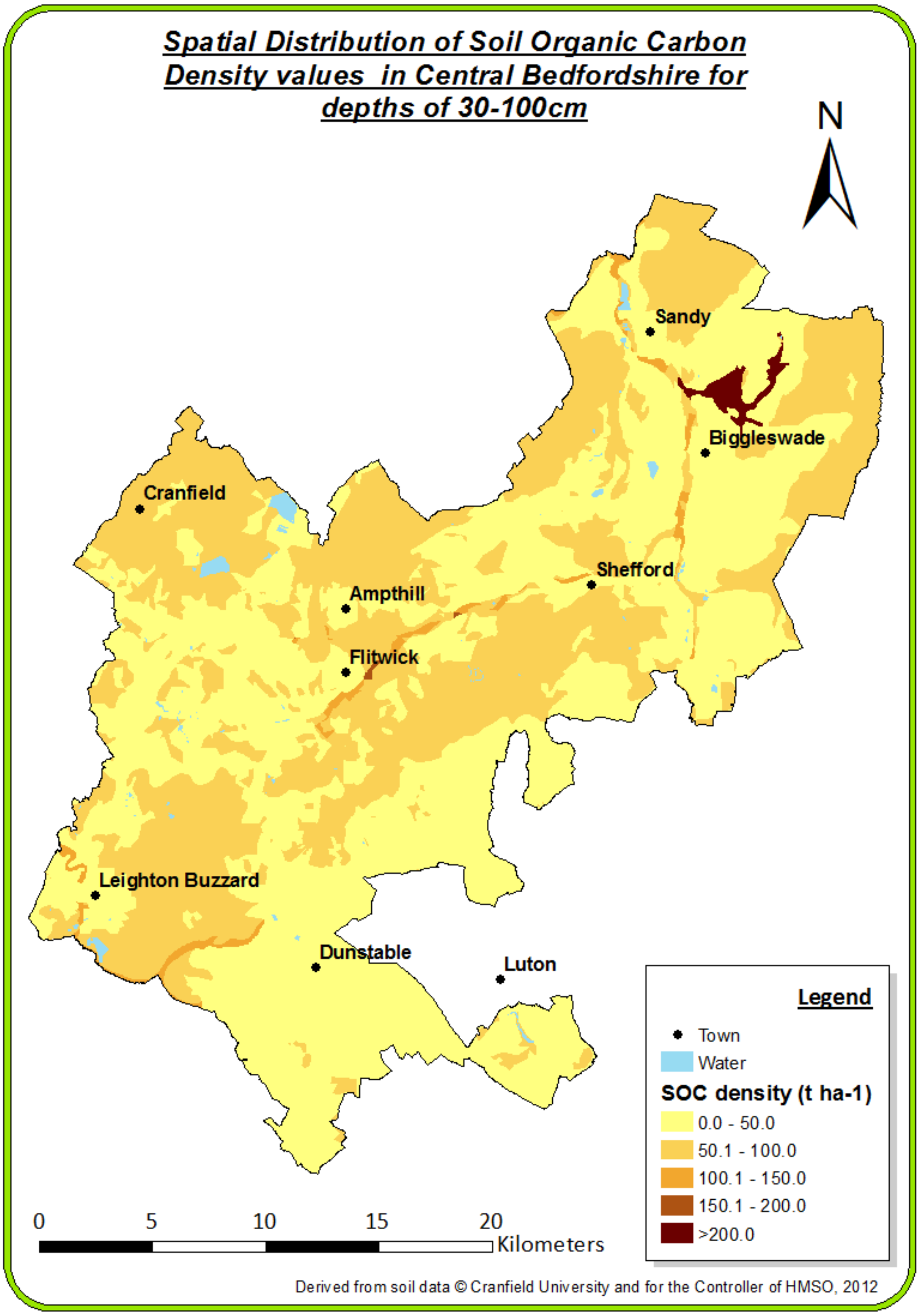

Figure 4.2 Predicted spatial distribution of soil organic content in Central Bedfordshire between a depth of 30 cm and 100 cm

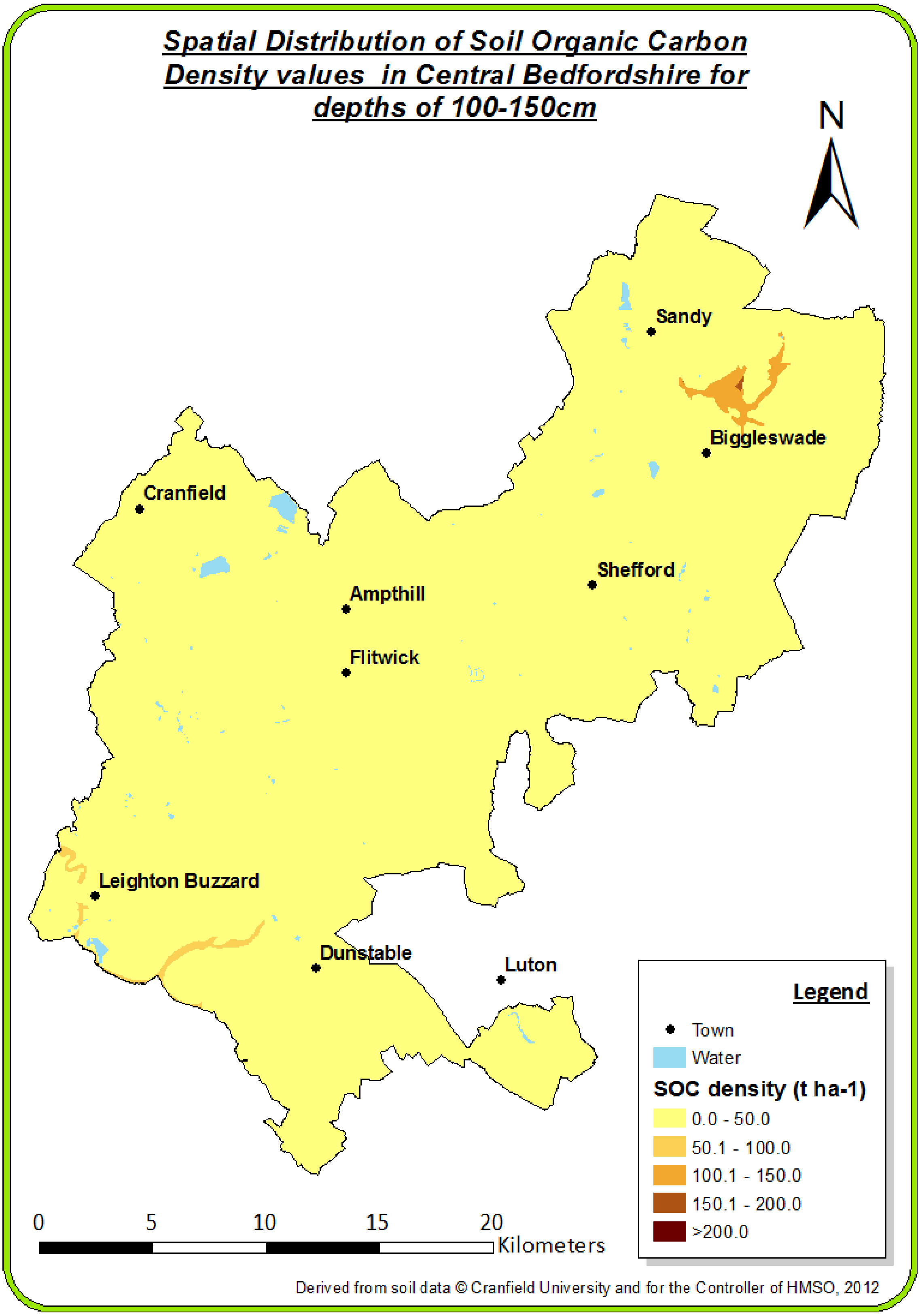

Figure 4.3 Predicted spatial distribution of soil organic content in Central Bedfordshire between a depth of 100 cm and 150 cm

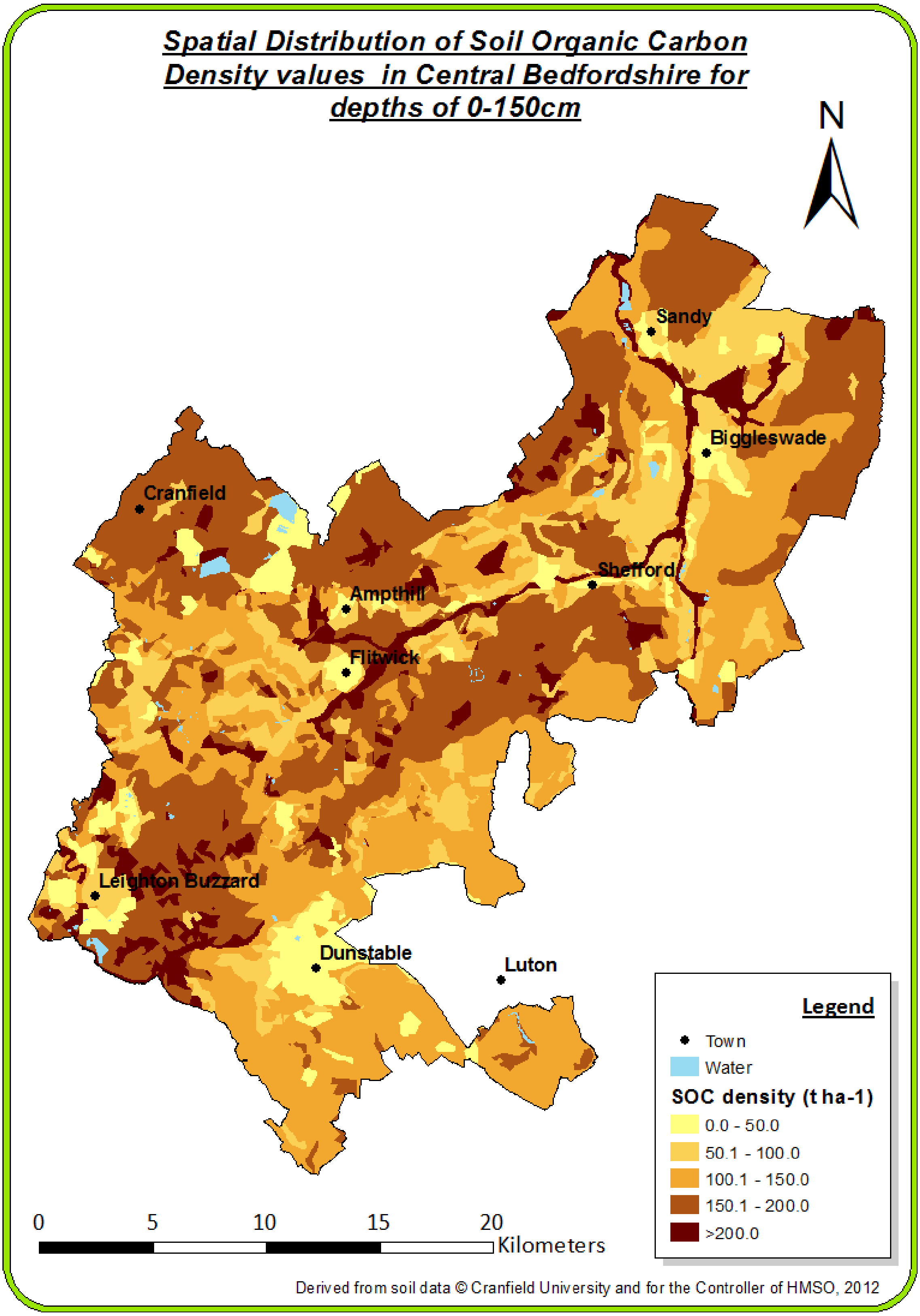

Figure 4.4 Predicted spatial distribution of soil organic content in Central Bedfordshire to a depth of 150 cm

Under current land use and management practices, in total there is estimated to be 9.52 million tonnes of SOC across the whole of Central Bedfordshire, down to a depth of 150 cm in the soil profile (see Table 4.1.). In total, 8% (5520 ha) of Central Bedfordshire was predicted to be composed of soils with a total soil organic carbon content (to 150 cm) of more than 200 t ha^{-1}. About 1% (1050 ha) and 19% of the soils (13290 ha) were predicted to have a content of less than 50 t ha^{-1} and 50-100 t ha^{-1} respectively. Lastly 37% (26090 ha) and 35% (25000 ha) had soils with contents of 100-150 and 150-200 t ha^{-1} respectively (Figure 4.5).

Table 4.1 Estimated total amount of soil organic carbon (SOC) in tonnes to a depth of 150 cm in the soil profile across Central Bedfordshire under current land use and management practices.

Land use	Total SOC (tonnes)
Arable	7,396,000
Pasture	1,547,000
Woodland	516,400
Urban	63,000
Total	9,523,000

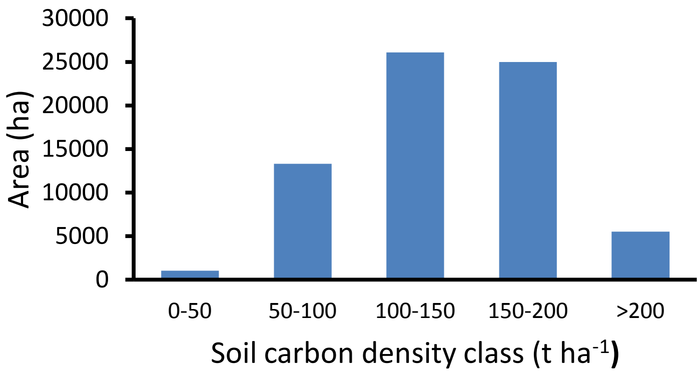

Figure 4.5 Area of Central Bedfordshire within each soil organic carbon content class (0-150 cm)

4.1.2 Effect of land use on current soil carbon

Maps of soil carbon in relation to the five land covers (arable, grassland, woodland, urban, and water) for 0-30 cm, 30-100 cm and 100-150 cm depth increments are included in Appendix B. The summary map to a depth of 150 cm is shown in Figure 4.6. A high variability in SOC density was predicted under arable land use. Low SOC values (0-50 t ha^{-1}) are predicted for the urban areas around Dunstable and Biggleswade, whereas the open space areas around Woburn and Cranfield were predicted to have a value of 100 -150 t ha^{-1}. Areas of woodland vegetation and pasture are mostly represented by darker shades (greater than 150 t ha^{-1}). Water is presented in a uniform blue colour as SOC density was estimated as zero according to the methodology. The urban land use can also be illustrated for the four sub-groups (impervious, industrial, residential and open space) (Figure 4.7).

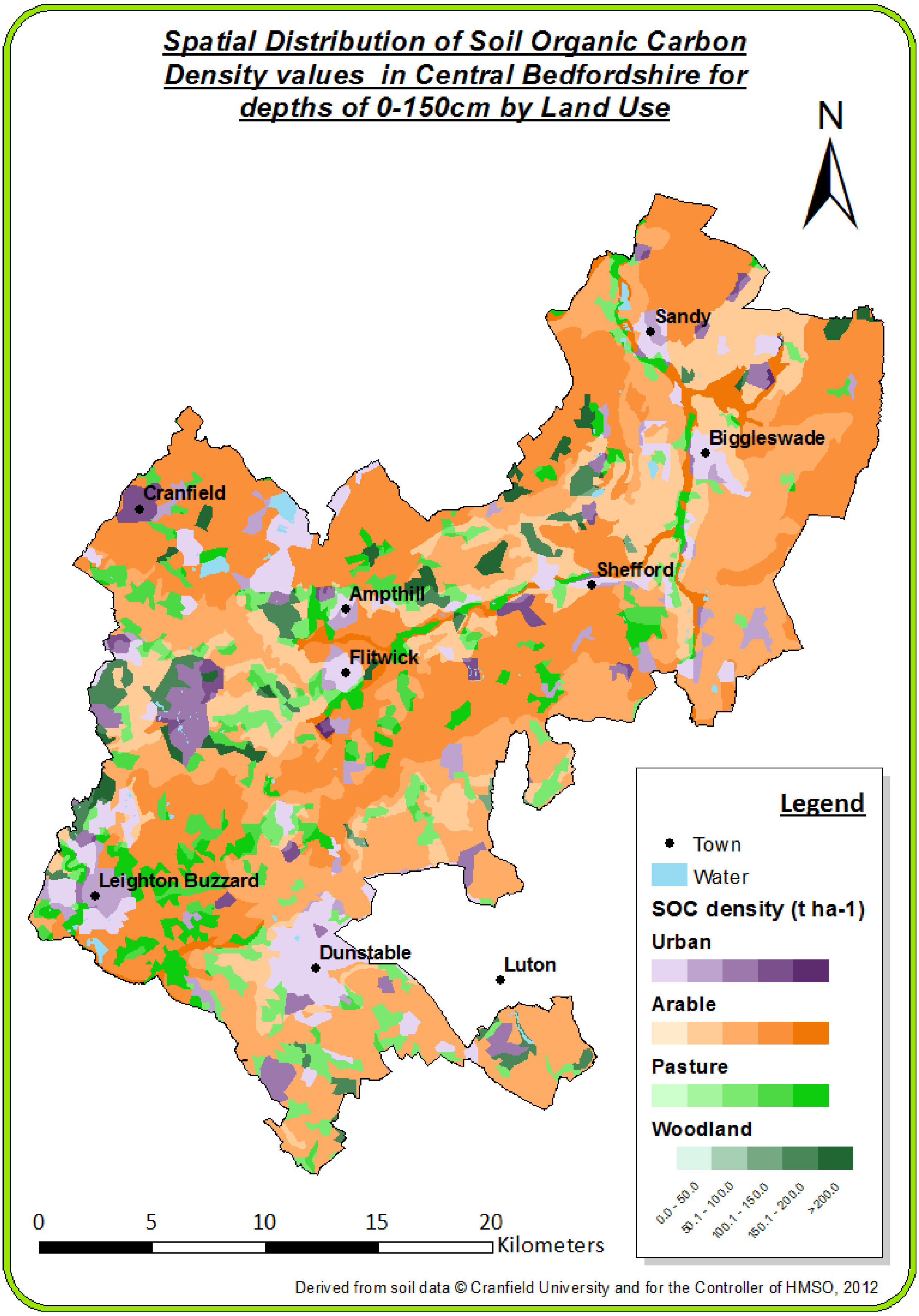

Figure 4.6 Interaction between land cover and spatial distribution of soil organic content in Central Bedfordshire to a depth of 150 cm

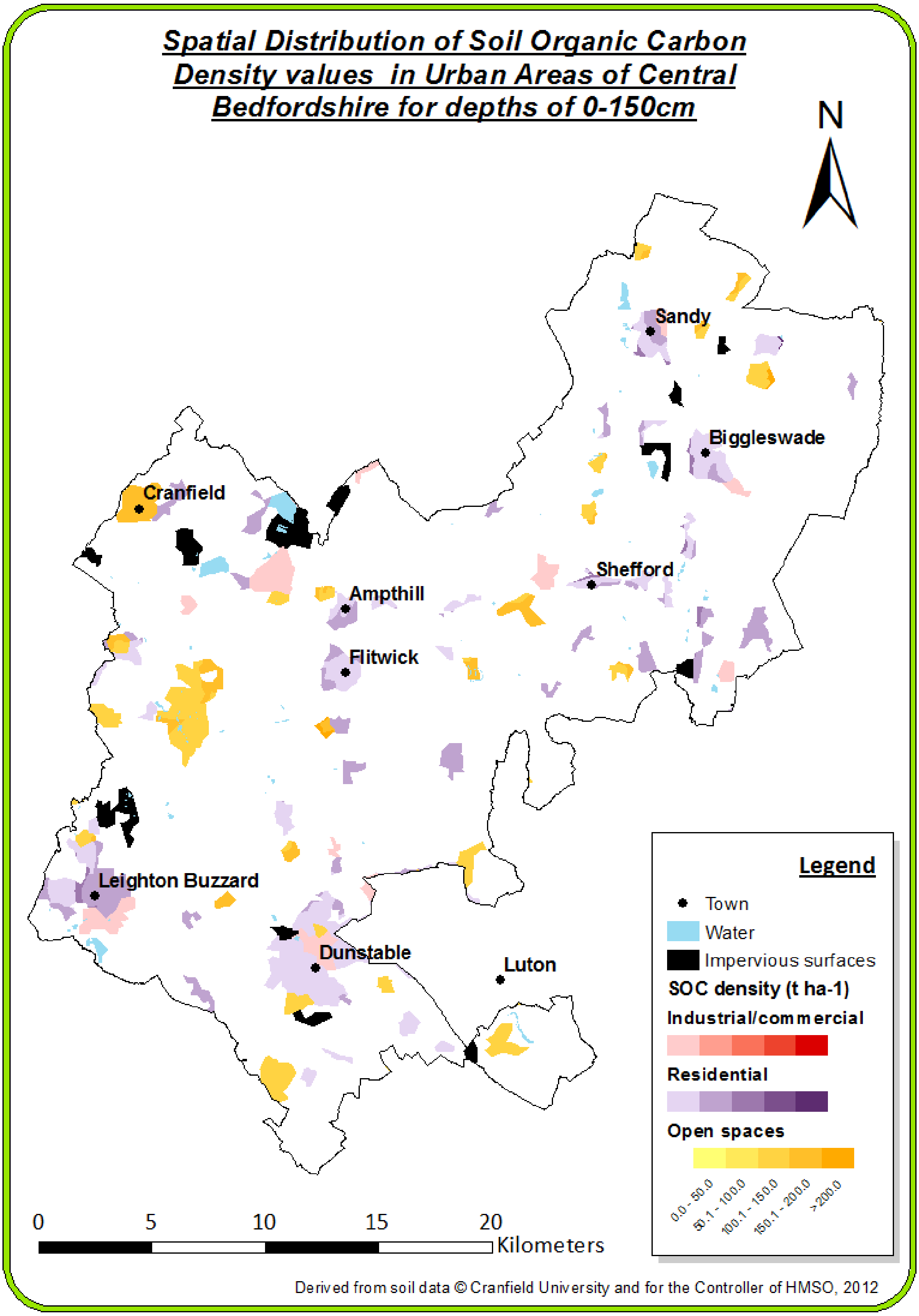

Figure 4.7 Interaction between urban land cover type and spatial distribution of soil organic content in Central Bedfordshire to a depth of 150 cm

4.1.3 Effect of land use on above ground carbon

Most of Central Bedfordshire is arable, and the vegetation present on this land use type stores approximately 2.2 tC ha^{-1}; this is located within the class of 0.01-10 t ha^{-1} in Figure 4.8. The model predicted that there was no significant vegetation present in impervious urban areas like mineral extraction sites, dumpsites and construction sites. Therefore, along with water bodies, these areas are represented by a null value on the map of 0 tC ha^{-1}. The darkest patches represent areas with the highest carbon densities, which are woodland vegetation. The total amount of above-ground carbon stored under different land uses can be seen in Table 4.2, with a total of 244,283 tonnes stored in total across the whole county.

The above-ground carbon provides a small contribution to the total of 9.7 million tonnes of carbon stored in the soils and vegetation of Central Bedfordshire (Table 4.3). This is equivalent to round 38.3 tonnes per person in the area (based on 2010 mid-year population estimate, Central Bedfordshire 2011).

Table 4.2 Estimated total above-ground carbon stocks in Central Bedfordshire under different land uses,

Land use	Above ground carbon stocks (tonnes C)
Arable	108,274
Pasture	8,259
Woodland	97,019
Urban*	30,731
Total	244,283

Note*: urban in this case is as defined by Cruickshank et al. 2000, and not based on percentage grassland area as used in deriving the SOC values.

Table 4.3 Estimated total above- and below-ground carbon stocks in Central Bedfordshire under different land uses, and the total combined stocks.

Land use	Above ground carbon stocks (tonnes C)	Soil organic carbon stocks (tonnes C)	Total (tonnes C)
Arable	108,300	7,396,000	7,504,300
Pasture	8,300	1,547,000	1,555,300
Woodland	97,000	516,400	613,400
Urban	30,700	63,000	93,700
Total	244,300	9,523,000	9,767,300

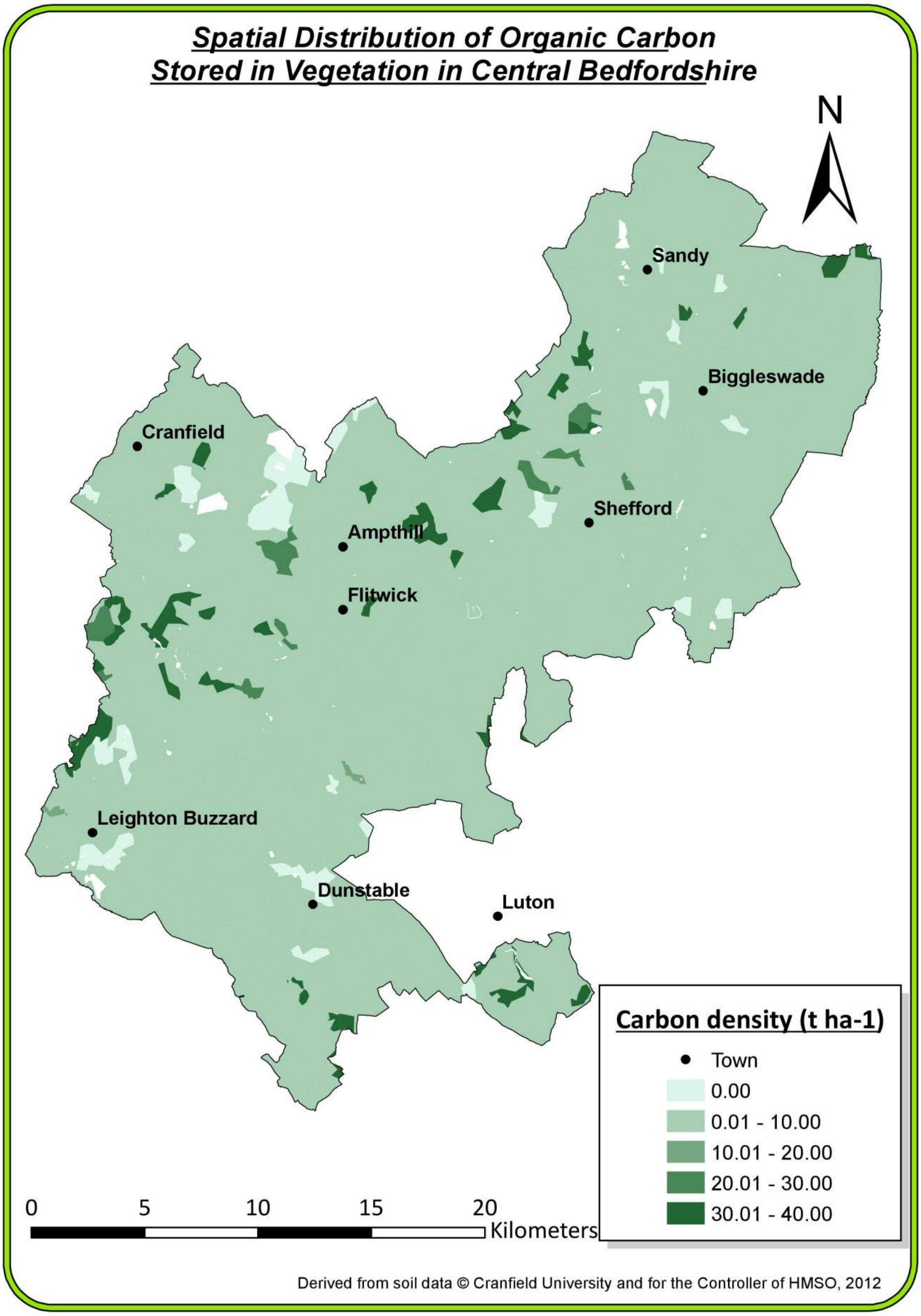

Figure 4.8 Predicted spatial distribution of above ground vegetation-based carbon in Central Bedfordshire.

4.1.4 Analysis

Soil carbon at different depths under different land uses

All land uses show the same tendency: soil carbon content decreases with depth. The greatest densities of SOC can be found in the topsoil. Among land uses woodland vegetation has the highest total mean carbon density (187 t ha^{-1}), followed by pasture (171 t ha^{-1}), arable land (149 t ha^{-1}) and finally the lowest amount of carbon is stored under urban areas (67 t ha^{-1}) (see Table 4.4). The lowest predicted value of SOC density, was for an urban soil (0 t ha^{-1}) and the highest for a woodland on a peat soil (760 t ha^{-1}).

Table 4.4 Mean, minimum and maximum soil carbon density (t ha^{-1}) at different depth under four land use classes

Depth (cm)	Woodland	Pasture	Arable	Urban
0-30	109 (9, 244)	98 (74, 195)	82 (57, 226)	40 (0,176)
30-100	63 (7, 343)	57 (6, 275)	49 (6, 301)	21 (0,247)
100-150	15 (1, 172)	17 (1, 138)	18 (1, 138)	5.3 (0,124)
0-150	187 (141, 760)	171 (104, 608)	149 (94, 664)	67 (0,547)

The greatest mean SOC density in urban areas was predicted for open space areas (137 t ha^{-1}), followed by residential (52 t ha^{-1}) and commercial and business areas (26 t ha^{-1}). Impervious areas were predicted to have a carbon density equal to zero (see Table 4.5).

Table 4.5 Mean, minimum and maximum soil carbon density at different depth under four subgroups of urban land use.

Urban land use	Depth (cm)			
	0-30	30-100	100-150	0-150
Commercial and business	15 (11,21)	8 (1,20)	3 (1,12)	26 (17,50)
Residential	33 (26,68)	16 (2, 96)	4 (1,48)	52 (36,213)
Impervious	0	0	0	0
Open spaces	80 (67,176)	45 (5, 247)	12 (1,124)	137 (102,547)

Above ground carbon storage

It was assumed that water, impervious areas, commercial and business areas did not contain significant stores of carbon due to the relatively low levels of vegetation. The highest amounts of carbon are predicted within woodlands (36 tC ha^{-1}). The second largest above-ground vegetation carbon store were open spaces (4 tC ha^{-1}), residential urban areas (3 t ha^{-1}) and then arable (2 t ha^{-1}) and pasture (1 t ha^{-1}**)** (see Table 4.6).

Table 4.6 Weighted average of above ground carbon storage under different land uses in Central Bedfordshire

Land use	Arable	Pasture	Woodland	Open spaces	Residential	Impervious	Commercial	Water
Carbon storage (t ha^{-1})	2.2	0.9	35.7	4.4	3.1	0.0	0.0	0.0

Soil carbon storage in different soil types under arable land use

Under arable land use, the methodology predicted the lowest levels of soil carbon (94 t ha^{-1}) with a deep loam over gravel soil type and the highest (664 t ha^{-1}) on seasonally wet deep peat to loam (Figure 4.9). There were variations in the values calculated for six soil types.

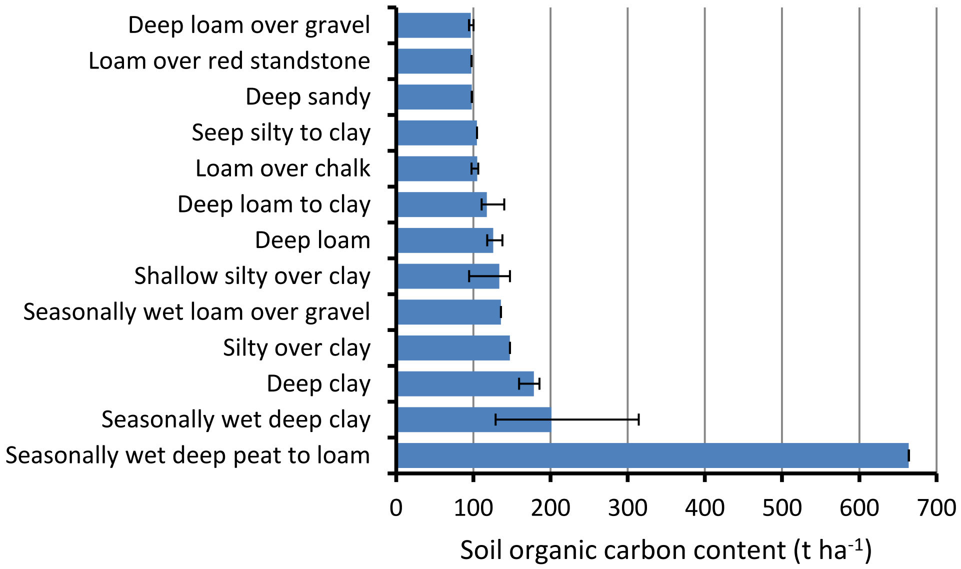

Figure 4.9 Predicted effect of soil type on soil carbon under arable systems (0-150 cm depth). Maximum and minimum values are shown

Soil carbon in different soil types under pasture

Under pasture, the lowest carbon values (0-150 c,) were found with deep loam over gravel (113 t ha^{-1}) and the highest level for seasonally wet deep peat to loam (608 t ha^{-1}) (Figure 4.10). It was not possible to establish a relationship between soil carbon and agri-environment schemes.

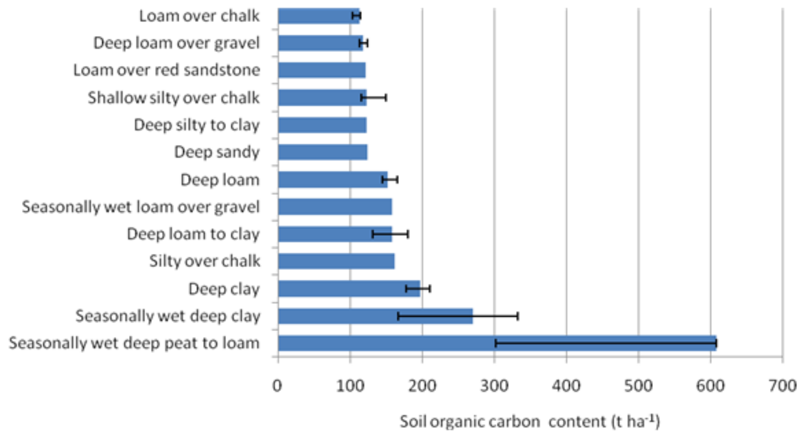

Figure 4.10 Predicted effect of soil type on soil carbon under pasture (0-150 cm depth. Maximum and minimum values are shown. The data shown relates to sites outside of an Agri-Environment Scheme.

Soil carbon in different soil types under woodland

No obvious difference was found between the soil carbon contents (0-30 cm) under the four woodland and semi-vegetation types: broadleaved woodland, coniferous woodland, mixed woodland, and transitional woodland-scrub. Under broadleaved woodland, the highest carbon density (244 t ha^{-1}) was found on seasonally wet deep peat to loam; the lowest (93 t ha^{-1}) occurred with a deep loam over gravel soil (see Figure 4.11).

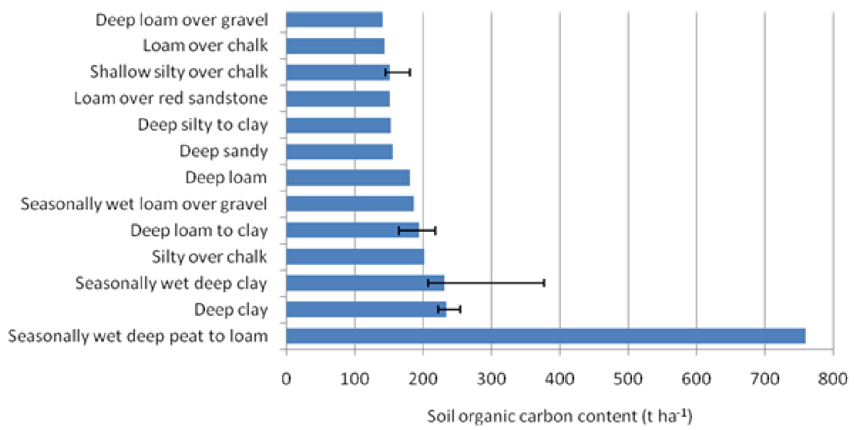

Figure 4.11 Predicted effect of soil type on soil carbon under woodland (0-150 cm depth). Maximum and minimum values are shown. The data shown relates to sites outside of an Agri-Environment Scheme.

Data on soil carbon in different soil types under urban land use

Impervious urban areas were predicted to have soil carbon density of zero for each soil type, as a result of the assumed conversion factor. The highest mean carbon values for different soil types can be found under open spaces, followed by residential areas, and then commercial areas. The highest value is found under urban open spaces on seasonally wet deep peat to loam (547 t ha^{-1}). One of the lowest values was for commercial grounds on deep sand (19 t ha^{-1}) (see Figure 4.12)

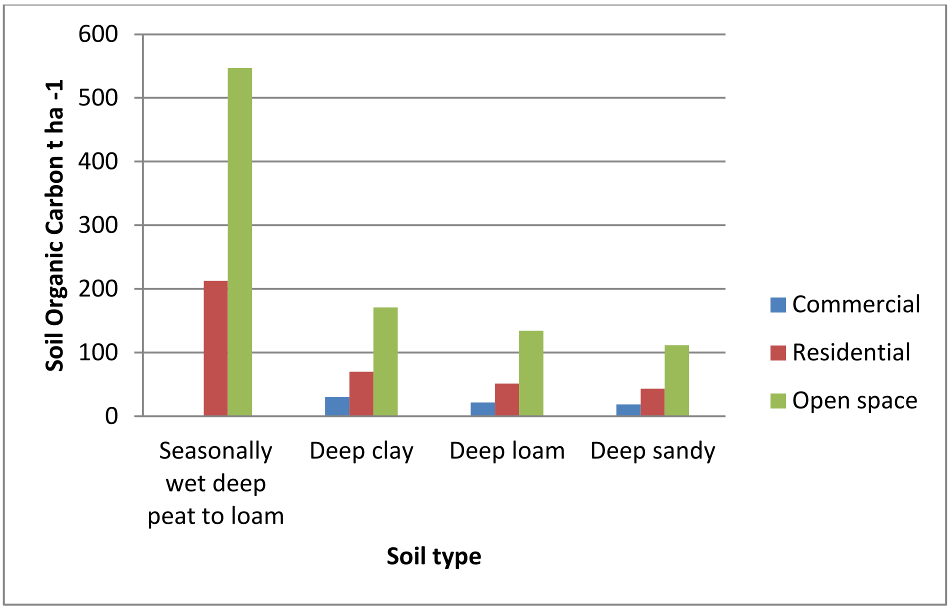

Figure 4.12 Predicted effect of urban type and soil type on soil carbon (0-150 cm depth). No data for commercial on seasonally wet deep peat to loam.

Soil carbon storage (0-150cm) and soil types and land use

Most soil types (deep clay, deep loam, deep loam over gravel, deep loam to clay, deep sandy, deep silty to clay, loam over chalk, loam over red sandstone, seasonally wet loam over gravel and silty over chalk) show the greatest carbon content where soil disturbance is minimised and vegetation is allowed to develop to its full potential. Hence carbon content increases from urban to arable, to pasture and woodland (see Table 4.7). However, three types of soil (seasonally wet deep clay, seasonally wet deep peat to loam, shallow silty over chalk) showed a different pattern of soil carbon content under different land uses.

For urban land, the lowest mean value can be found on deep loam (44 t ha^{-1}) and highest on seasonally wet deep peat to loam (498 t ha^{-1}). For arable areas, the lowest mean SOC density occurs on deep loam over gravel (97 t ha^{-1}) and the highest on seasonally wet deep peat to loam (664 t ha^{-1}). For pasture, the smallest value was discovered on loam over chalk (113 t ha^{-1}), and the highest density on seasonally wet deep peat to loam (608 t ha^{-1}). For woodland, the lowest mean density was found on deep loam over gravel (142 t ha^{-1}) and highest on seasonally wet deep peat to loam (760 t ha^{-1}). The most carbon-rich soil is seasonally wet deep peat to loam, and the least is deep loam over gravel.

Table 4.7 Average soil carbon density (t ha^{-1}) 0- 150 cm depth under different land use and soil types

Soil type	Mean urban	Mean arable	Mean pasture	Mean woodland
Deep clay	77	177	197	235
Deep loam	36	126	152	180
Deep loam over gravel	39	97	117	142
Deep loam to clay	90	118	158	195
Deep sandy	61	98	124	155
Deep silty to clay	51[c]	105	123	153
Loam over chalk	456	106	113	143
Loam over red sandstone	73	98	122	152
Seasonally wet deep clay	80	192	270	232
Seasonally wet deep peat to loam	462	664	608	760
Seasonally wet loam over gravel	54	136	158[d]	187[a]
Shallow silty over chalk	51	132	123	152
Silty over chalk	38	148	161	203[b]

a: No value was present for this space, as it was not present in the survey data. To calculate this value a mean conversion factor for mean arable into mean woodland woodland was found, by dividing each value for semi-nat. veg. by its respective value for arable for each soil type. Arable was chosen since it was represented by all soil types and had large sample sizes. The conversion factor used was 0.727.

b: Same method as above.

c: Same method as above. Conversion factor used was 0.4868.

d: Same method as above. Conversion factor used was 1.160.

4.1.5 Scenarios

Scenario 1 Urban development

In the scenario of converting present land use into urban areas, each area was predicted to show a loss in soil carbon.(Table 4.8). The greatest loss of SOC was predicted close to the River Ivel, Flit, Ouzel, Ouzel Brook and in the peat land North of Biggleswade. Current woodland areas were also predicted to lose large amounts of carbon. Current urban areas are represented by a zero value in the map (see figure 4.13)

Looking at the Central Bedfordshire proposed urban development sites areas (Figure 4.13) North and East of Sandy, south and east of Potton, North of Sheffield, around Leighton Buzzard, along the west boundary of Biggleswade and all sites falling within river valleys and the peat lands would result in predicted losses of SOC between 75 and 200 t ha $^{-1}$. Those sites where the predicted losses would less than 75 t ha^{-1} include sites around Lidlington, North East of Dunstable, North and East of Luton, North of Silsoe, East of Ampthill, East of Biggleswade, and North of Broom.

Table 4.8 Predicted change in soil carbon (0-150 cm) of land from current use to urban.

		Arable		Woodland	
Data / Soil type	**Scenario SOC density (t ha^{-1})**	**Mean Current SOC density (t ha^{-1})**	**Mean Change in SOC density (t ha^{-1})**	**Mean current SOC density (t ha^{-1})**	**Mean Change in SOC density (t ha^{-1})**
Deep clay	77	177	-100	197	-120
Deep loam	36	126	-90	152	-116
Deep loam over gravel	39	97	-58	117	-78
Deep loam to clay	90	118	-28	158	-68
Deep Sandy	61	98	-37	124	-64
Loam over chalk	45	106	-61	113	-69
Deep silty to clay	51	105	-59	123	72
Loam over red sandstone	73	98	-24	122	-48
Seasonally wet deep clay	80	192	-112	270	-190
Seasonally wet deep peat to loam	462	664	-202	608	-145
Seasonally wet loam over gravel	54	136	-82	158	-104
Shallow silty over chalk	51	132	-81	123	-72
Silty over chalk	38	148	-110	161	-123

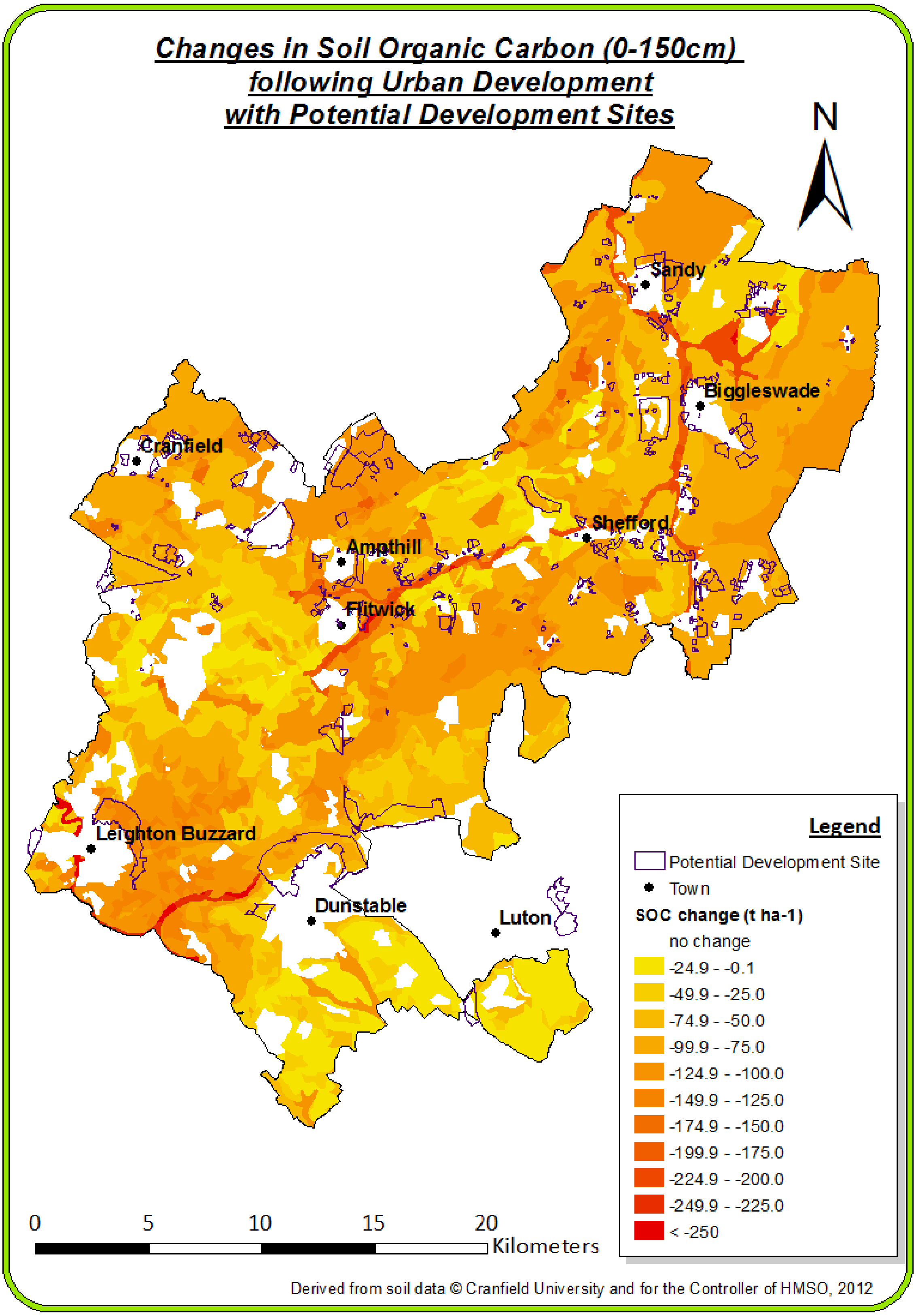

Figure 4.13 Predicted change in soil carbon (0-150 cm) of land from current use to urban.

Scenario 2 Woodland land use

Current urban and woodland areas weren't taken under consideration and are represented by a null value. For areas along the River Ivel, Flit, Ouzel, Ouzel Brook and Grand Union Canal located on seasonally wet deep clay there appear to be losses in SOC (see table 4.9 and Figure 4.14). Most of the area of Central Bedfordshire would benefit from an increase soil carbon storage when converted to woodland. The area of greatest improvement is a current arable area to the East and West of Milton Bryan.

Table 4.9 Predicted change in soil carbon (0-150 cm) of land from current use to woodland.

		Arable		Woodland	
Data Soil type	Scenario SOC density (t ha^{-1})	Mean Current SOC density (t ha^{-1})	Mean Change in SOC density (t ha^{-1})	Mean Current SOC density (t ha^{-1})	Mean Change in SOC density (t ha^{-1})
Deep clay	235	177	58	197	38
Deep loam	180	126	55	152	28
Deep loam over gravel	142	97	45	117	24
Deep loam to clay	195	118	77	158	37
Deep Sandy	155	98	57	124	31
Deep silty to clay	153	105	48	123	31
Loam over chalk	143	106	38	113	30
Loam over red sandstone	152	98	54	122	30
Seasonally wet deep clay	232	192	40	270	-38
Seasonally wet deep peat to loam	760	664	95	608	152
Seasonally wet loam over gravel	187	136	51	158	28
Shallow silty over chalk	152	132	20	123	29
Silty over chalk	203	148	55	161	42

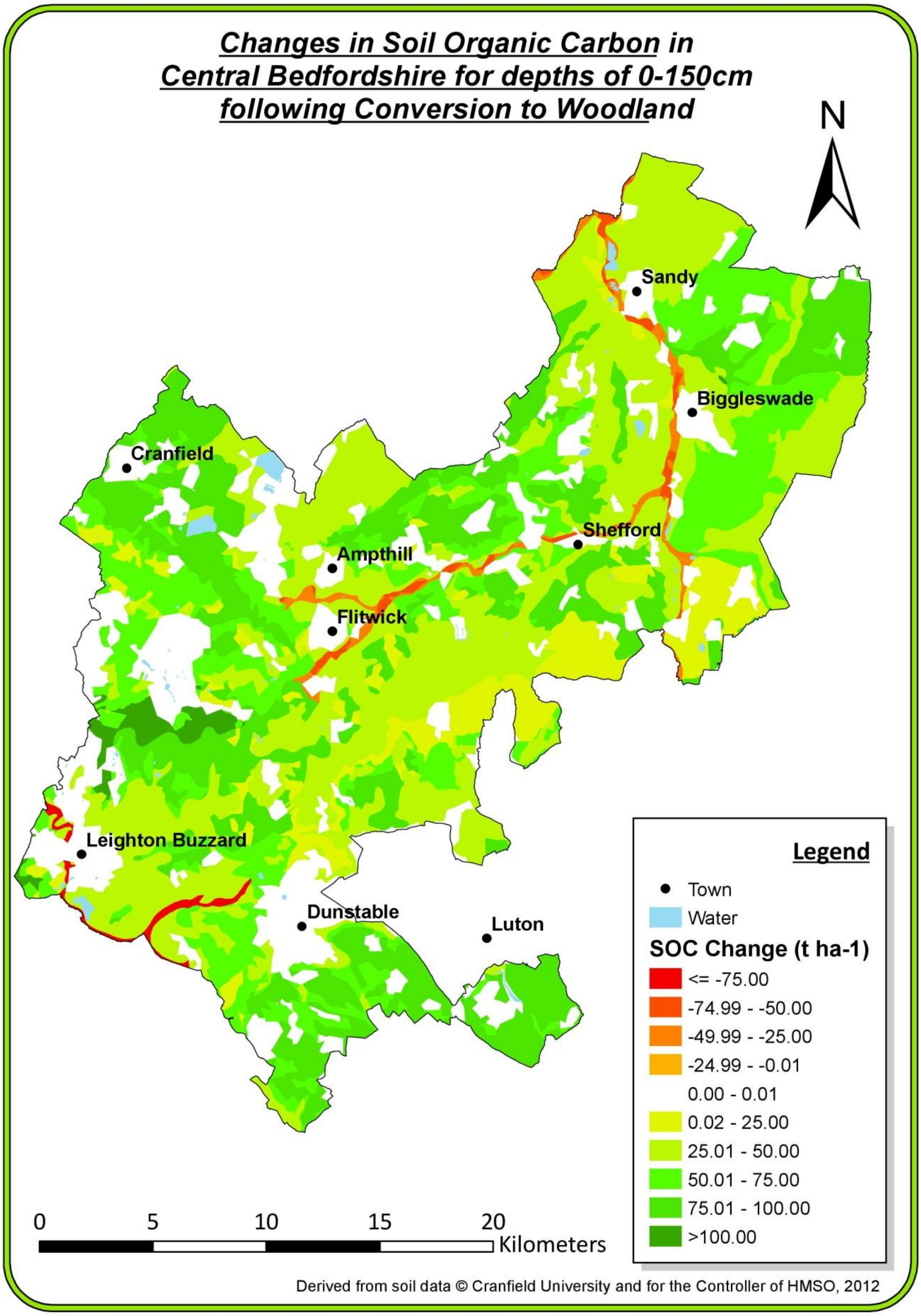

Figure 4.14 Predicted change in soil carbon (0-150 cm) of converting non-woodland and non-urban areas to woodland.

Scenario 3 Pasture landuse

Ignoring current urban and pasture areas, which were given a zero change value, the primary areas predicted to benefit in terms of SOC from conversion to grassland are arable areas. High responses were predicted for arable land close to Brogborough landfill and lake, east and west of Milton Bryan, west of Potton, and areas around Dunstable, Steppingley, Chicksands Wood, Barton-le-Clay, and East Hyde (see Figure 4.15). All other arable areas would also slightly benefit. The scattered woodland areas were predicted to lose carbon if converted to pasture. Peatland located in-between Sandy and Biggleswade, as well as arable areas surrounding Shillington, Higham Gobian, and Church End (near Stotfold) appear to lose soil carbon when converted from arable land to pasture, as they are located on seasonally wet deep peat to loam or shallow silty over chalk (see table 4.10).

Table 4.10 Predicted change in soil carbon (0-150 cm) of land from current use to pasture.

		Arable		**Woodland**	
Data **Soil type**	**Scenario SOC density ($t\ ha^{-1}$)**	**Mean Current SOC density ($t\ ha^{-1}$)**	**Mean Change in SOC density ($t\ ha^{-1}$)**	**Mean Current SOC density ($t\ ha^{-1}$)**	**Mean Change in SOC density ($t\ ha^{-1}$)**
Deep clay	197	177	20	235	-38
Deep loam	152	126	26	180	-28
Deep loam over gravel	117	97	21	142	-24
Deep loam to clay	158	118	41	195	-37
Deep Sandy	124	98	26	155	-31
Deep silty to clay	123	105	18	153	-31
Loam over chalk	113	106	7	143	-30
Loam over red sandstone	122	98	24	152	-30
Seasonally wet deep clay	270	192	79	232	-38
Seasonally wet deep peat to loam	608	664	-57	760	-152
Seasonally wet loam over gravel	158	136	22	187	-28
Shallow silty over chalk	123	132	-9	152	-29
Silty over chalk	161	148	14	203	-42

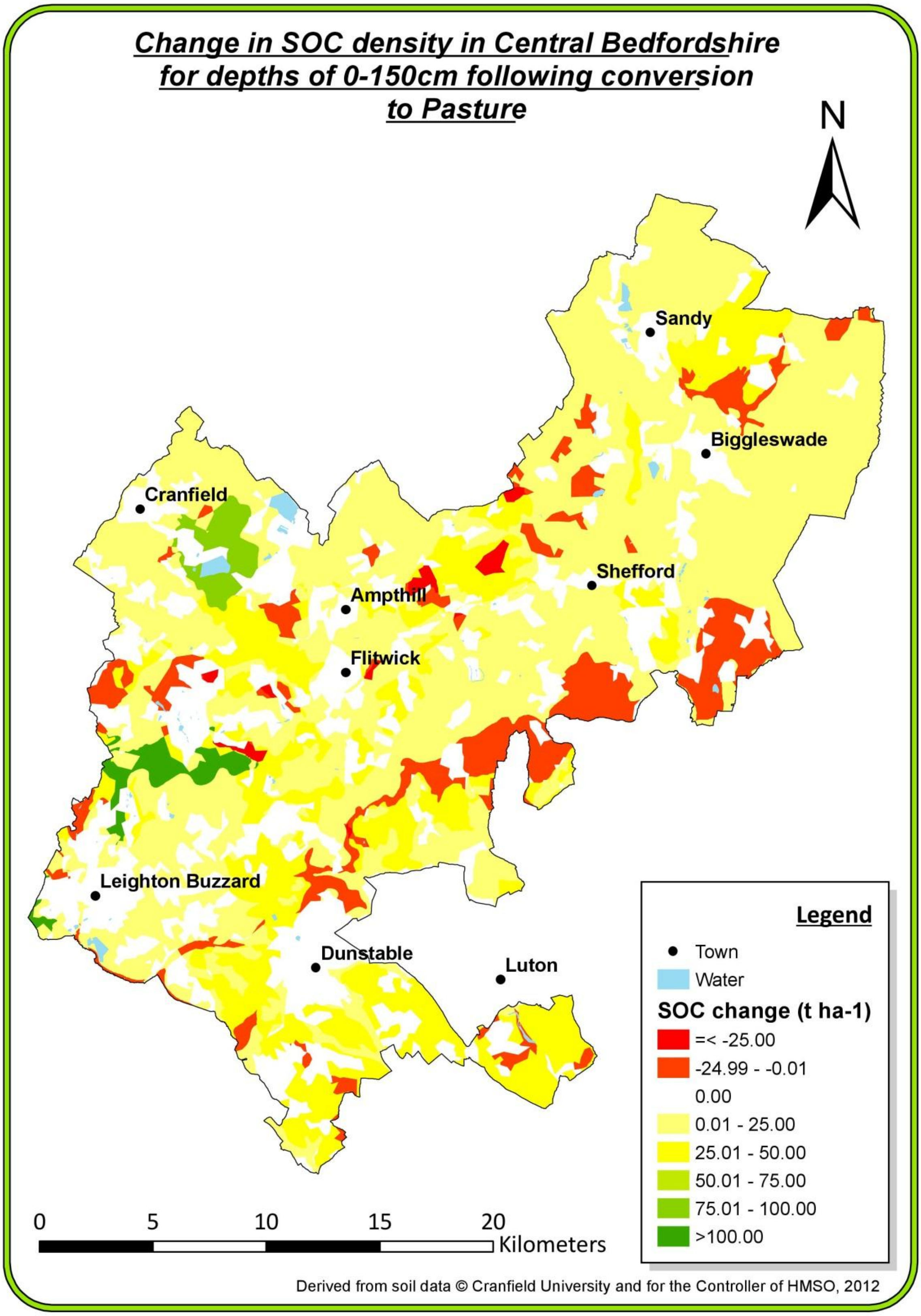

Figure 4.15 Predicted change in soil carbon (0-150 cm) of converting non-grassland and non-urban areas to grassland.

Scenario 4 Biodiversity Action Plan

Current urban, pasture and areas with woodland vegetation are not taken into account and represented with a null value. Figure 4.16 shows areas of possible improvement of SOC storage after extending woodland and grassland areas according to the BAP (see Appendix A5). The Biodiversity Action Plan covers only parts of Central Bedfordshire, areas with unavailable data are presented in white. The majority of Central Bedfordshire would experience gains in SOC following implementation of the BAP, with only small areas along the river valleys appearing to experience losses. See tables 4.9 and 4.10 for values of mean change in SOC density (t ha^{-1}) for each combination of land use and soil type converted to woodland or pasture.

Arable areas West of Potton, North-East of Clophill, surrounding Old Warden and Northill, South of Houghton Conquest, North and South of Brogborough lake, West of Woburn, North-East of Eversholt, East of Tottenhoe, North of Whipsnade, surrounding Studham and Holywell, East of Dunstable, East of New Mill End would benefit in terms of soil carbon storage from implementing the BAP. The greatest improvements would be observed on arable areas North-East of Milton Bryan and close to the A5 junction with Sheep Lane. A slight increase would occur East of Warden Hill Road, Luton. Soil carbon loss only appears to occur on a few small areas like Pennyfather's moor and Flitwick moor where the soil carbon density is higher than the average for that soil type. Losses were predicted on seasonally wet deep clay when converted from arable to pasture, pasture to woodland, arable to woodland. Seasonally wet deep peat to loam was also predicted to experience a decline of SOC when arable areas become pasture. Shallow silty over chalk soil converted from arable to pasture also loses SOC.

The BAP seems to capture most of the areas of Central Bedfordshire that would greatly benefit from conversion to pasture or woodland, but does omit some areas where large gains in SOC were observed in the woodland scenario. For example, the area East South of Potton, including Wrestingworth and Cockayne Hatley, the area South-East of Luton and Dunstable, as well as the area around Meppershall and Upper Stondon, and between Cranfield and Marston Moretaine, all of which show large increases in SOC following conversion to woodland, and have not been included in the proposed BAP.

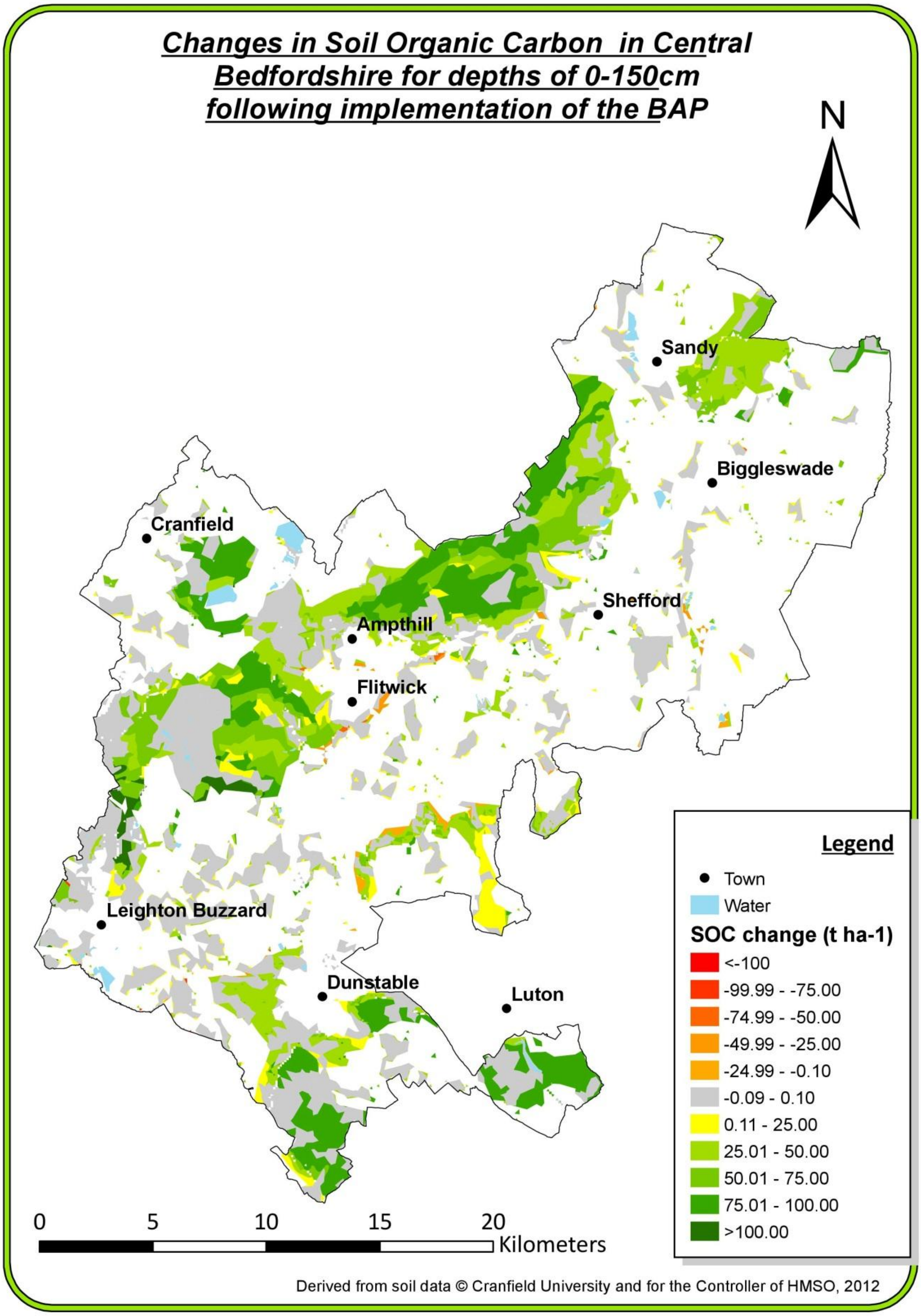

Figure 4.16 Predicted change in soil carbon (0-150 cm) of land from current use to that indicated in the Biodiversity Action plan, if appropriate.

4.2 Discussion

4.2.1 Study limitations

Corine land cover map inaccuracies

The land cover data used in this assessment was based on the Corine 2006 database. It is a pan-European database, which does contain significant errors when viewed at the resolution in this study. For example, according to the European land cover database, the area East of Marston Moretaine is a mineral extraction site and was reclassified in this project as an impermeable area. The site used to be a clay extraction pit for nearby brickworks, but was transformed into Forest Centre and Millennium Country Park in 1999, comprising woodland, wetland, grassland and open water (Charles 2012). Even though the Corine data was collected in 2006 $\pm$ 1 year (EEA 2007), approximately 7 years after the establishment of the Park this area was not classified correctly. Therefore, data on land use obtained from Corine may not always be up to date.

Soil carbon storage below the 150 cm horizon

Data obtained from LandIS allowed us to investigate soil carbon storage down to a depth of 150 cm in the soil profile. However, carbon is also stored in deeper soil horizons, so the obtained data is incomplete. According to Jobbagy & Jackson (2000), estimates for the vertical distribution of SOC are as follows: 64% of total SOC at 0-100 cm, 21% for 100-200 cm and 15% for 200-300 cm horizon. Studies also suggest that SOC decreases with depth in mineral soils, and increases with depth for organic soils (Hiederer 2009).

Creation of conversion factors

Original LandIS data contained four broad land use categories for soil organic carbon data: arable, ley grassland, permanent grassland, and other. In this project, five classes were created: arable, pasture (permanent grassland), woodland vegetation, urban and water. Within the urban class, four sub-classes were created. Conversion factors were needed to obtain data for woodland vegetation areas and all four sub-classes of urban land use. There is a lack of comprehensive studies on carbon storage in different types of urban land uses in England or UK. Soil carbon levels in urban soils were estimated from the equivalent value for permanent grassland areas using a conversion factor derived from literature. An assumption that the impervious areas have no soil carbon, and the pervious areas have an equal amount of carbon to grassland had been made to create ratios. All this creates a level of uncertainly about the accuracy of the conversion factors used. Matching classes of land use in Corine and LandIS would be an advantage.

Combining of soil series into soil types

Although maps of current SOC were mapped at the soil association level, mean values for each soil type were used to create the scenarios. This meant that some spurious results were generated. This is explained in more detail in section 4.2.3 and in figure 4.18.

Unmanageable data validation

Most of the NSI point data is for arable areas, and there are only a small number of samples for soil types under other land uses. Therefore, a validation and comparison of results could not be carried out.

Using literature from countries other than UK

For the estimation of carbon storage in vegetation, and the creation of conversion factors for areas of woodland vegetation, research from Ireland was used. A more accurate approach would have been to use a study carried out in the UK, but such was unavailable. It was assumed that conversion factors used in Ireland would be appropriate for England as the climate and broad soil categories are similar.

Trans-border character of issues under investigation

This research presents results for regulating ecosystem services in Central Bedfordshire, however, some of the processes involved have dependencies which go beyond the county borders. There are also outside factors affecting the ecosystems of Central Bedfordshire. This was unfortunately not possible to take into account in this study.

4.2.2 Current situation

Soil carbon

Total soil carbon stocks in Central Bedfordshire were estimated at 9.5 million tonnes of SOC. Soils under arable land contributed the largest share of this, storing 7.4 million tonnes; this was to be expected, as over 70% of the area of Central Bedfordshire is under arable land. Even though soils under pasture and woodland vegetation have higher densities of soil carbon, the total area under those land uses is smaller than that under arable land. Soils under pasture in Central Bedfordshire were estimated to store 1.5 million t of SOC and soils under woodland vegetation 0.5 million tonnes of SOC.

The largest terrestrial carbon sinks lie below the ground, in the soil. Vegetation type, climate, precipitation, topography, nutrient content, and hydrology influence the soil's capacity for carbon storage (Ostle et al. 2009). Soil texture is also an important factor; the higher the clay content, the lower the C outputs, as clay has a stabilizing effect on SOC (Jobbagy and Jackson 2000).

SOC storage in soil depends on the balance between losses and additions of C (Lorenz and Lal 2005), which can be affected by numerous factors, both natural and human-induced (Jones et al. 2004, FAO 2000). These factors include natural soil properties, climatic properties, vegetation, land cover and land management.

Carbon density also decreases with soil depth; on average 56% of carbon in the top 100 cm of soil is found in the 0 to 30 cm layer (Bradley 2005). This is because the vast majority of SOC is found within the SOM, which tends to accumulate in the upper horizon and diminish down the soil profile (Brady & Weil 2008). Our results show a similar trend.

Soil carbon and geology in Bedfordshire

The SOC density in Central Bedfordshire is affected by geology. There is a visible striped pattern of SOC density across the county, from South-West to North-East, following the geology (see Figure 4.17). The carbon rich soils are located on the Gault clay and Oxford clay while lower SOC densities can be found on chalk and the Woburn sands formation.

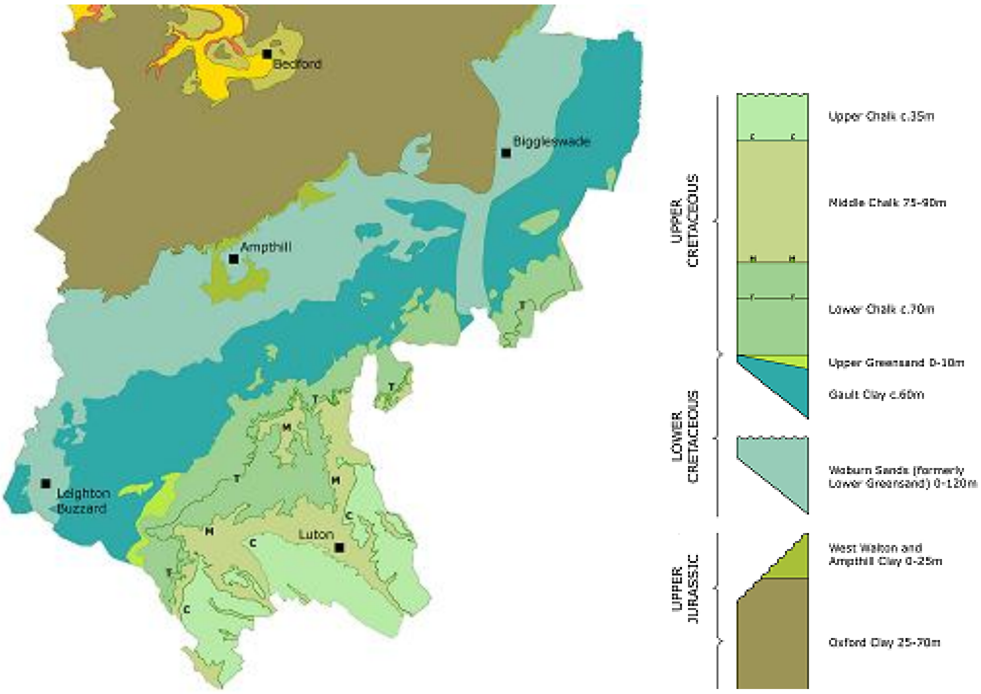

Figure 4.17 Geology across Bedfordshire (Bedfordshire Geology Group 2012)

Land use and soil depth

Soil carbon is related to land cover (Ostle et al. 2009). The carbon density results presented here (Table 4.11) are similar to research presented by Bradley 2005 (Table 4.12), using a similar or the same dataset.

Table 4.11 Density (t ha^{-1}) of soil carbon in soil of different land uses in Central Bedfordshire

Depth	Pasture	Arable	Woodland
0 – 30 cm	98	83	109
30 – 100 cm	57	49	63
0 – 100 cm	154	131	172

Table 4.12 Density (t ha^{-1}) of carbon in soil of different land uses in England (Bradley 2005)

Depth	Pasture	Arable	Woodland
0 – 30 cm	80	70	100
30 – 100 cm	50	50	70
0 – 100 cm	130	120	170

Soil carbon dynamics

Soil carbon sequestration is a dynamic process which needs to be taken into account when assessing carbon stocks in Central Bedfordshire. Chemical, physical, biological conditions in the soil affect SOC pool. Modifying the soil chemistry can influence the rate of accumulation of humic material and redistribution of carbon in deeper subsurface layers. Pedogenesis, mineralization, aggregation, microbial decomposition of soil organic matter, and pH change are processes that affect soil carbon stocks. Organic soil carbon can move from the upper soil layers into less oxidative deeper layers through sorption under suitable hydrological conditions. Fertilizers widely used in arable land also transport carbon to deeper soil layers, therefore increasing total carbon stocks (Rachley 2010).

Carbon stored in vegetation

Carbon stored in vegetation accounts for approximately 5% of UK terrestrial carbon stocks. Grasslands, arable and horticultural crops make up 6% of the total UK vegetation carbon stocks. Forest and woodland account for 80% (Ostle et al. 2009).

In Central Bedfordshire, vegetation has a small contribution to carbon storage in comparison to soils. Terrestrial ecosystems interact with the atmosphere creating the complex processes of carbon cycling. Carbon storage can be increased by manipulating the flux of CO_2 from the atmosphere into long-lived terrestrial carbon pools like above- and below-ground biomass, wood products, and soil (Rackley 2010).

Organic carbon vertical distribution in soil varies with vegetation type. The most noticeable decrease in soil carbon with depth is seen under shrubs, followed by grassland, and the least prominent is under forest. On arable land, a rapid change in SOC content can occur at ploughing depth. Interdependences between land use and soil type, and their combined effect have an influence on SOC content (Hiederer 2009). Above-ground vegetation provides inputs such as plant residues, root litter and rhizodeposition (organic C released by living roots) which contributes to SOM, and therefore SOC (Lorenz and Lal 2005). The presence and type of vegetation has a large influence on soil carbon storage, with the best being deep-rooting plants which store carbon deep in the soil profile, extending the capacity of soil to become a long-term C sink (Jobbagy and Jackson 2000).

Urban

Urban soils have modified physical, chemical and biological properties due to human activities including destruction of vegetation, covering with impervious surfaces, building foundations, compaction, changes in soil chemistry, addition of waste and water, reducing infiltration, removal of topsoil, cutting and filling, and changes to biodiversity (Hazelton and Murphy 2011). Among urban areas, soils under open spaces have the highest carbon densities as they support above-ground vegetation such as grassland and scattered trees which build up carbon stocks. Residential areas are mostly houses with gardens, so they were assumed to consist of approximately a third grassland, therefore they are second in terms of carbon storage. Industrial areas consist of mostly impervious surfaces, so according to our findings do not store soil carbon. The role of permeable surfaces is very important in building urban carbon stocks.

Arable

The large amount of variation in soil carbon densities under arable land is caused by the diversity of geology and soil types that those areas are located on. In arable land, the subsoil consists of 70% of the topsoil SOC (Hiederer 2009); a similar tendency is found in Central Bedfordshire. Topsoil is vulnerable to disturbance due to agricultural practices.

Pasture

The carbon content of soil under pasture is higher than that under crops. Pasture might have lower above-ground carbon stocks than woodland, but quite often the below-ground SOC can be higher in pasture. Overgrazing is one of the main causes of pasture degradation (FAO 2001). Over 12% of Central Bedfordshire is pasture and could become an important carbon stock if well managed.

Woodland

There is a tendency for rapid decrease in SOC with depth under woodland vegetation, which is mainly due to a carbon-rich organic upper layer. On average, subsoil SOC content amounts to 25-30% of SOC in topsoil content (Hiederer 2009) Just under 4% of Central Bedfordshire is covered by woodland vegetation; these small areas are high in SOC. However, woodland patches are fragmented, and poorly connected within the landscape.

4.2.3 Future Scenarios

Urban development scenario

Expanding urban development in Central Bedfordshire will tend to reduce the carbon stored in soil and vegetation, and areas close to rivers and peatlands are especially vulnerable. Planning decisions should be made with consideration of these points. A case study for urban development can be found in Appendix E1**.**

Urban Development Recommendations:
Urbanization often involves the conversion of fertile agricultural land. In turn this may mean that agriculture then moves to areas with less suitable soil conditions. Urban planning and decisions should aim to minimise the loss of good quality agricultural land, including appropriate consultations with scientists, stakeholders and policy makers (Hazelton and Murphy 2011).

Pasture and Woodland scenarios

According to Ostle et al. (2009) "land use and land use change are the most important short-term determinants of landscape carbon stocks and sequestration in the UK, and that careful management of existing natural and managed environments (particularly peatlands, forests, grasslands and arable lands) is crucial to the UK land carbon stock."

Changes in land use can affect the amount of carbon stored in soils. These changes in SOC can take place over many years or even decades, until eventually a new stable equilibrium is reached (Vesterdal et al. 2011). Table 4.13 below shows the main directions of change in SOC which occur with changes in land use, based on studies of temperate regions.

Table 4.13 Main directions of change in SOC stocks following land use change based on studies of temperate regions (Poeplau et al. 2011, Adopted from Jandl et al. 2011).

New Land Use / **Old Land Use**	**Cropland**	**Grassland**	**Forest**
Cropland		Gain in SOC	Gain in SOC
Grassland	Loss in SOC		No clear change
Forest	Loss in SOC	No clear change	

Our calculations show that converting from arable land use to pasture, in Central Bedfordshire could result in gains in SOC of up to 50 t ha^{-1}, although some areas currently under woodland showed declines, consistent with findings that soil under pasture has less SOC than that under woodland (Bradley 2005). Generally most areas were predicted to show an increase in soil carbon if the land use was changed to woodland.

However, using the described methodology, conversion of land use to pasture and woodland for some areas close to rivers were predicted to result in a decline in soil carbon. This appears to be a problem with method rather than a true representation of what we expect to happen.

The reason for this is explained below (Figure 4.18).

Explanation of why the methodology results in underestimates of SOC change when arable land is converted to woodland or pasture near a river

Arable land

The baseline SOC content is determined at a soil series data level. Hence a soil of Series Y within Soil type A, typically having a high moisture content because located near a river, will have a higher SOC than other series within the soil type

Soil type A	Series X	100 t SOC ha^{-1}
	Series Y	200 t SOC ha^{-1}
	Mean Soil type under arable	150 t SOC ha^{-1}

Conversion to pasture

By contrast the SOC after conversion, in this case to pasture, is based only on soil type rather than soil series data. Hence the effect is that soils with a high baseline SOC are predicted to show a decline.

Soil type A	Mean	180 t SOC ha^{-1} (All soil series with soil type A assigned mean value for soil type A under pasture)
	Series X	+80 t SOC ha^{-1}
	Series Y	-20 t SOC ha^{-1}

Figure 4.18 Explanation of methodology issue with multiple soil series within soil types

In summary, the baseline estimate for soil carbon was derived from the predicted soil carbon for a particular soil series. Hence within a given soil type, e.g. "seasonally wet deep clay" there could be a range of estimated soil carbon contents for the different soil series within that type. By contrast the estimate of soil carbon following land use change was only based on a mean value for a soil type. The effect of this is that if the initial baseline soil carbon content was particularly high for a specific soil series, then the change in land use may be predicted to result in calculated decline in soil carbon. This appears to be the reason why areas located around rivers or in poorly-drained areas were predicted to have losses in the pasture, woodland and BAP scenarios. Such soils have higher moisture contents than normal and hence higher SOC levels due to slower decomposition rates (Brady & Weil 1996). Hence by simply looking at the difference between that value and the mean SOC content for woodland on a "seasonally wet deep clay" soil will result in a lower predicted SOC content, whereas the high moisture conditions would mean that in practice the woodland would also have higher SOC than average.

It is therefore likely that these areas in reality would not experience a loss in SOC following conversion to pasture from arable land, or conversion to woodland, but a gain. It is also possible that since these soils have high current SOC densities, they will experience even greater gains in SOC following conversion to pasture than soils with lower current SOC densities. Further studies should be done into the effects of changes in land use or management on these specific soil types with high current SOC densities, possibly by sub-dividing soils located near rivers and examining them separately, as any future changes here could have great impacts.

To conclude, converting some of the arable land of Central Bedfordshire into pasture or woodland would generally increase carbon stocks, but further refinement of the method is still needed and hence the results need to be treated with caution.

Biodiversity Action Plan (BAP) scenario

Implementing the BAP in Central Bedfordshire would significantly improve carbon storage. The Biodiversity Action Plan scenario can help us identify and target areas of special interest that would be of highest interest in terms of increasing carbon storage. The best solution seems to be extending existing woodlands which would not only increase SOC density but provide more habitats and create higher biodiversity. Moors and peatlands need to be protected. Some soils rich in carbon (seasonally wet deep clay, seasonally wet deep peat to loam, and shallow silty over chalk) appear to experience losses in SOC following conversion to pasture or woodland. Again, this is due to the method used. It is likely that these areas would still experience gains in SOC, but further research is needed. A BAP Case study can be found in Appendix E3.

BAP recommendations:
Pasture: Soil carbon stocks in grassland can be increased by reducing grazing intensity and lime and N fertilizer additions, through species management, improving grassland productivity, and returning farm waste (i.e. slurry) to the soil (Ostle 2009). The intensity, frequency, and seasonality of grazing should be managed. Above-ground biomass protects and increases the amount of organic carbon in the soil. This is partly due to the root systems of vegetation, which bind the soil together, and the activity of microorganisms on the root surfaces (Robert 2001).

Woodland vegetation: Actions that can be undertaken to improve soil carbon content in woodland areas are: planting of native hardwood species, longer rotation periods, reduced liming and nitrogen fertilizer use, conscious site preparation and harvesting, protection against disturbance and reduced harvest residue (i.e. branches) removal (Ostle et al. 2009).

A potential solution and compromise between agricultural production and increasing carbon storage is agroforestry. Trees in combination with crops or pasture would be a sustainable alternative to intensive cultivation, deforestation and land use conversion commonly carried out today, and could drastically increase the potential for carbon sequestration in cropland (Robert 2001).

Land use management scenario

Our data suggested that increasing the level of Agri-Environment Scheme had no significant effect on carbon storage in soil under pasture and arable land, and so the results were not included in the report. Since there was no clear pattern in the results, AES do not seem to increase or protect soil carbon storage. The reason for this may be that Agri-Environment Schemes are focused on improving biodiversity and creating habitats, as opposed to increasing carbon storage (Natural England 2010a & b). However, there are other land management practices which can affect soil carbon significantly which are currently not included in, or are not the main focus of the Agri-Environment Schemes. A Land use management case study can be found in Appendix E2.

Land management recommendations:

Improving soil carbon stocks in cropland can be achieved by agronomic practices which increase the amount of plant biomass returned to the soil, such as the use of improved crop varieties, perennial crops, extension of crop rotations, and management of residues and tillage (Follett 2001, West and Post 2002, Lal 2003, Cerri et al. 2004, Freibauer et al. 2004). Good water management helps to maintain soil carbon stocks, and land use conversion from arable or urban land to forest or grassland is widely known to increase carbon sequestration (Follett 2001, Ogle et al. 2003, Lal 2004, Falloon et al. 2004).

The amount of carbon present in a soil depends on the long-term factors of soil formation such as parent material and texture, but can be strongly modified (degraded or improved) by land use changes and management (Ostle et al. 2009, FAO 2001). Studies have shown that different land management practices can lead to a decrease in carbon loss, an increase in carbon sequestration, or a combination of the two. Increasing SOM is beneficial not just for climate change mitigation, but increases the productive potential of soils and improves soil and water quality through fixation of pollutants like pesticides and heavy metals (FAO 2001).

Figure 4.19 below shows a summary of the different ways in which changes in soil carbon occurs. Carbon enters the soil through inputs of organic matter from plant litter and residues and losses are due to erosion, leaching and mineralisation. The balance between these two is the amount of carbon stored in the soil.

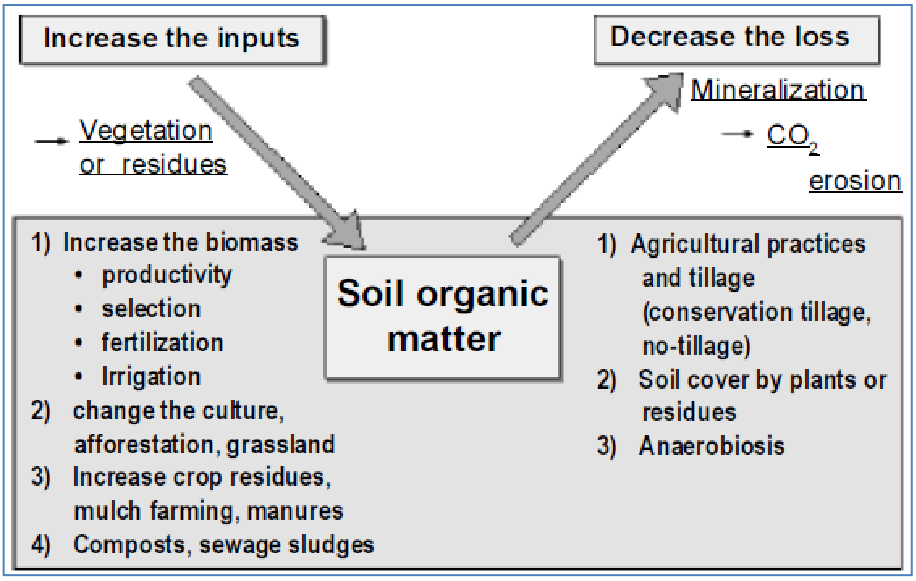

Figure 4.19 Summary of processes affecting amount of SOC (Adopted from FAO 2001)

Soil erosion: as the top soil layer is carried away by wind and/or water during erosion, a significant amount of organic matter is lost (Lal 1990, Quinton et al. 2006). Therefore, any land management technique that increases the risk of soil erosion, such as downslope cultivation, inherently increases the risk of SOC loss. Conversely, any measure taken to reduce the risk of soil erosion, like cover cropping or mulching, also reduces the risk of loss of SOC (Brady & Weil 1995).

Tillage: soil organic matter incorporated within large soil aggregates is physically protected from access by microbes which would otherwise break it down in a process called mineralisation. Breaking large soil clods into smaller aggregates reduces this protection and also results in increased soil aeration, increasing oxidation of organic matter (Balesdent et al. 2000). Therefore, reducing tillage can help protect soil carbon, with the best-case scenario being minimum or zero tillage.

Crop residue management: leaving straw and other plant residues in field at harvesting has been shown to improve SOM content in direct proportion to the amount of residue left (Lal 1997). The amount and rate of carbon sequestration depends on the crop type, for example lignin decomposes slower than cellulose. Residue incorporated into the soil also breaks down faster than that left on top due to greater contact with soil microbes (Hael et al. 1997). Residue burning has the reverse effect as carbon is lost to the atmosphere as carbon-dioxide.

Vegetation enhancement: any practice that increases the amount of plant biomass present. This can be through practices such as agroforestry, reduced clearing or stocking, improved pasture systems and range land management, or by increasing productivity through the addition of fertilisers, irrigation, or selection of faster growing plant varieties, potentially contributes to an increase in SOC as there is increased litter generation (Charman & Murphy

1007, Leu 2007). Using legume crops to increase soil nitrogen is preferred to the use of synthetic fertilisers, as these have negative effects on the soil microbes responsible for converting plant litter into more stable forms of SOM like humus and favour microbes that consume SOM for energy (Leu 2007).

Soil conservation: this may include all of the above, but also more specific practices which aim to control erosion or rehabilitate degraded land, including land affected by repeated wetting/drying cycles, salinization, or interactions between different types of organic matter (Charman & Murphy 2007).

Some of the current options within the Entry Level Stewardship scheme which may impact on soil carbon are described in Table 4.14.

4.2.4 Climate change

Effects of Climate Change on Carbon Sequestration

The UK Climate Projection (2009) predicts that from 2020 to 2050, the climate in the East Midlands region of the UK will experience between 1.3^{o}C to 2.8^{o}C rise in both winter and summer mean temperatures. There will be increases in mean winter precipitation by 6-16% and a corresponding decrease in mean summer precipitation. Overall there is a predicted increase in CO_2 concentration in the atmosphere.

With regards to Carbon sequestration, increased CO_2 in the atmosphere will result in increased plant productivity, particularly in C3 plants, leading to increased carbon sequestration by above ground biomass and a corresponding soil carbon input from plant residues and from growth and decay of plant roots (van Ginkel et al. 2000). However, this effect is expected to be short-lived as other factors affecting plant productivity, like nutrient supply, are likely to be limiting (Bargette et al. 2008).

An increase in temperature will also precipitate higher organic matter mineralisation rates by soil microbes and increased root respiration rates, resulting in an increase in CO_2 emissions (van Ginkel et al. 2000). An increase in temperatures and associated droughts may also cause drying-up of carbon-rich peatlands resulting in release of soil carbon (Bellamy et al. 2005).

Climate-change conclusion

Understanding the role of land use and land use change in carbon sequestration is essential for carrying out a sustainable management of UK land carbon reservoir. Soil management is an essential planning tool to protect and increase soil carbon stocks. By increasing carbon storage in Central Bedfordshire the Council will be able to respond to the demands of Kyoto Protocol and under the UNFCC for soil carbon inventories and the UK target (Bradley 2005). The UK government accepted a policy to implement a climate change mitigation policy which aims at accomplishing at least an 80 percent reduction in net greenhouse gas emissions in comparison to 1990 baseline for the year 2050 (UK Climate Change Act 2008).

Table 4.14 Impact of Entry Level and Organic Level stipulations on soil organic carbon (SOC).

ES Code	ELS/OES stipulation	Impact on SOC	Description
EB	Hedge row management: maintenance of one or both sides of the hedgerow, use of native species encouraged	+	Increases area under semi natural vegetation, which has high SOC levels (Falloon et al. 2004)
EC	options for woodland including: protection of infield trees on arable land, maintenance of woodland fences, hedge row buffer strips on cultivated land and grasslands	++	Increases area under semi natural vegetation and native species which supports high SOC levels (Falloon et al. 2004)
EE	Buffer strips on both cultivated land and intensive grassland	++	Increase grassland area in arable fields, reduces soil erosion hence reduces loss of SOC (Ogle et al. 2003)
EF	Options for arable land: management of field corners, unfertilised and unharvested cereal headlands, uncropped cultivated margins, reduced herbicide cereal crops followed by overwintered stubble, Bale or chop and spread straw after harvest	+/-	Leaving chopped crop harvest residue spread in field adds to SOC, baling and taking it off field leads to loss of SOC (Freibauer et al. 2004) Reduced herbicide used increases SOC (Rangel-Castro et al. 2004)
EG	Options to encourage a range of crop types: cereals for whole-crop silage followed by overwintered stubble, under-sown spring cereals	++	Extending crop rotations, use of perennial crops adds to SOC (West and Post 2002)
EJ	Options to protect soil and water: winter cover crops, management of maize crops to reduce soil erosion, buffer strips and infield grass areas to prevent erosion and run off, maintenance of water courses	++	Soil water management and reduced erosion risk helps maintain SOC stocks (Lal 2004)
EK	Options for grassland outside the severely disadvantaged areas (SDA): field corners out of management, permanent grassland with low/very low inputs(no fertilisers or manure), management of rush pastures, mixed stocking	+/-	Reduced lime and synthetic nitrogen fertiliser increase SOC, not returning farm waste to soil reduces SOC (Rangel-Castro et al. 2004)
EL	Options for grassland and moorland inside the SDA: Take field corners out of management, enclosed rough grazing, unenclosed moorland rough grazing	++	Managing grazing intensity and grassland productivity increases SOC stocks (Conant et al. 2001)

5. Runoff and Soil Erosion

5.1 Results and interpretation

5.1.1 Current predicted runoff

The first two maps of runoff demonstrate the predicted runoff for the maximum 1 in 10 year and 1 in 100 year storm event (Figure 5.1 and Figure 5.2). Light blue areas represent the smallest runoff (0-6 mm per 43 or 60 mm event); the dark blue represents the greatest runoff (28-47 mm per 43 or 60 mm event). For the 1 in 10 year event, the maximum runoff levels are associated with urban areas (e.g. Sandy, Ampthill, Dunstable, Leighton Buzzard) and are largely independent of soil permeability. For the 1 in 100 years precipitation event, runoff rates of some impermeable rural areas are predicted to be similar to the urban areas (Figure 5.2). In rural areas, lower soil permeability is associated with greater runoff. However, this is mediated by land use. Woodland areas were predicted to give the lowest runoff, followed by pasture, with arable land producing the greatest rural runoff rate (Tables 5.1 and 5.2).

Figures 5.1 and 5.2 also show the potential flow of runoff. The values represent the direct flow accumulation, and do not take into account the base flow of the rivers. The values also indicate the flow associated with a 24-hour rainfall event; in practice the timing of a discharge at a particular location may occur over a shorter or longer period depending on the detailed hydrology of the area. There are five categories for the stream showing different amount of water accumulation in each stream ranging from light green (5000 – 30000 m^3 d^{-1}), through yellow, orange, and red to brown (> 3,000,000 m^3 d^{-1}). As expected, the direct flow accumulation is much greater for the 1 in 100 years rainfall event than after the 1 in 10 years event.

5.1.2 Current predicted soil erosion

Data layers of soil type, slope, rainfall erosivity and land use were integrated to come up with polygons. The annual predicted rates of soil loss assuming no implementation of land management practices to prevent erosion are presented in colours ranging from green (0–80 t ha^{-1} $year^{-1}$), through yellow to deep red (80–1200 t ha^{-1} $year^{-1}$) (Figure 5.3).

The spatial analysis of predicted soil erosion is a result of various causal factors. Near Cranfield, predicted soil erosion is high due to the presence of steep slopes, erodible soils, and arable and land-fill land use. In areas where there is orange and red colour, erosion is highly related to the steep slope even though the soil is not very erodible. However, under the same soil type and slope conditions, erosion is greater on arable land than on pasture and forest areas. Finally, some urban land uses were associated with small erosion rates, such as residential areas, while others, such as mineral extraction sites and landfills, were associated with high soil loss rates (Table 5.3).

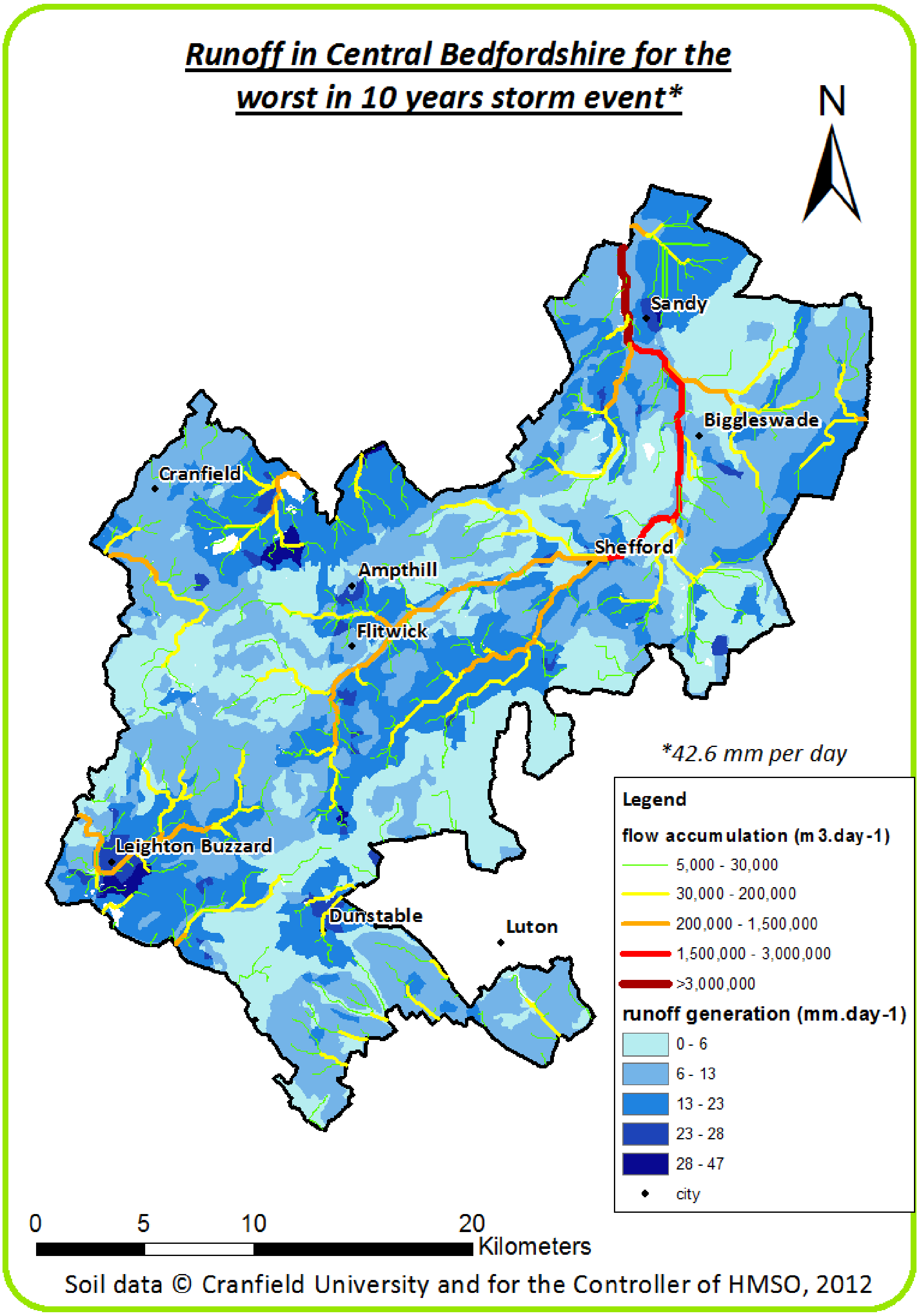

Figure 5.1 Runoff estimation in Central Bedfordshire for the 1 in 10 years storm event under current land use. It was assumed that no land management practices to prevent runoff were carried out in arable land because there is no detailed spatial information about it. Previous soil wetness was assumed to be intermediate.

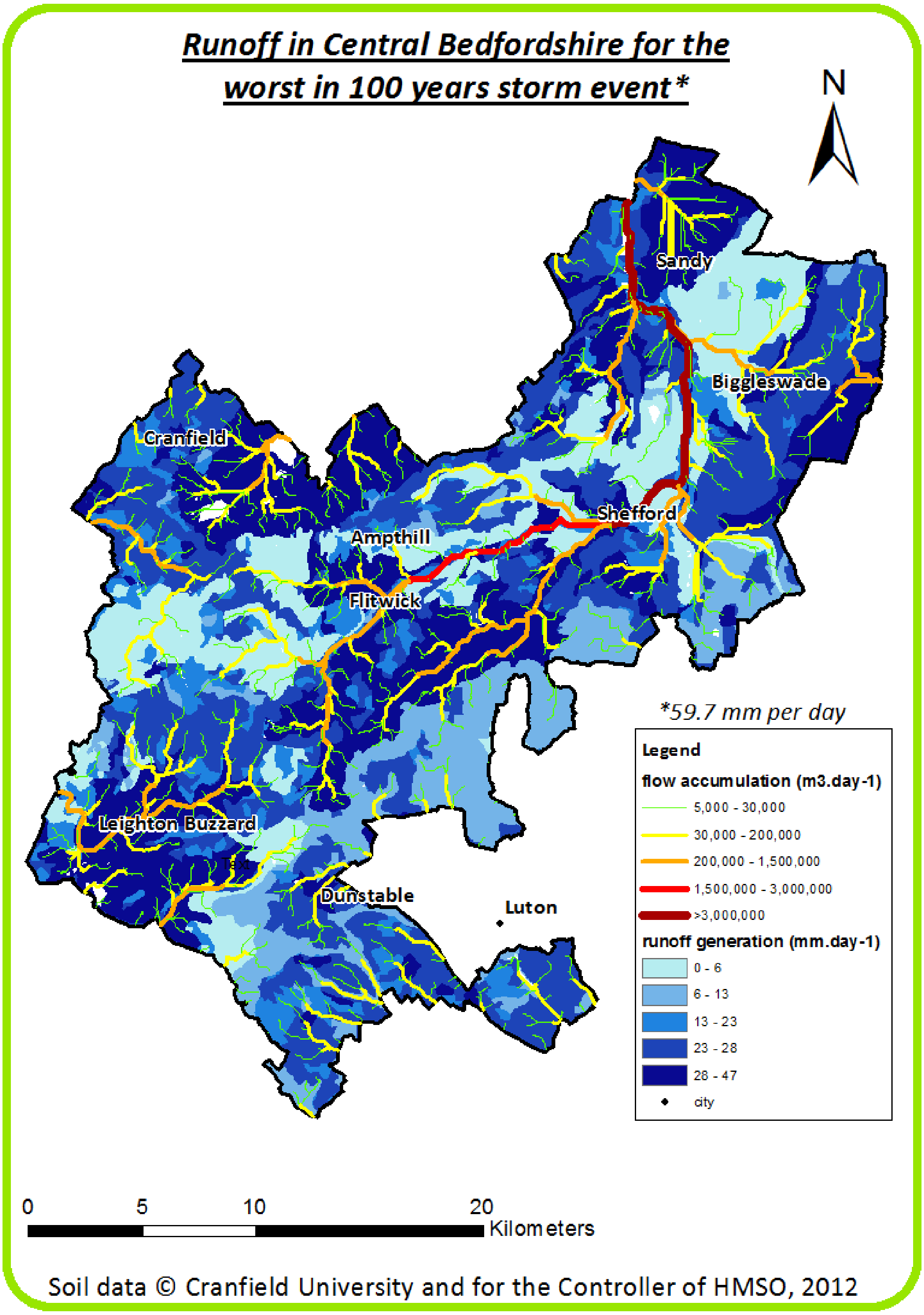

Figure 5.2 Runoff estimation in Central Bedfordshire for the 1 in 100 years storm event under current land use. It was assumed that no land management practices to prevent runoff were carried out in arable land because there is no detailed spatial information about it. Previous soil wetness was assumed to be intermediate.

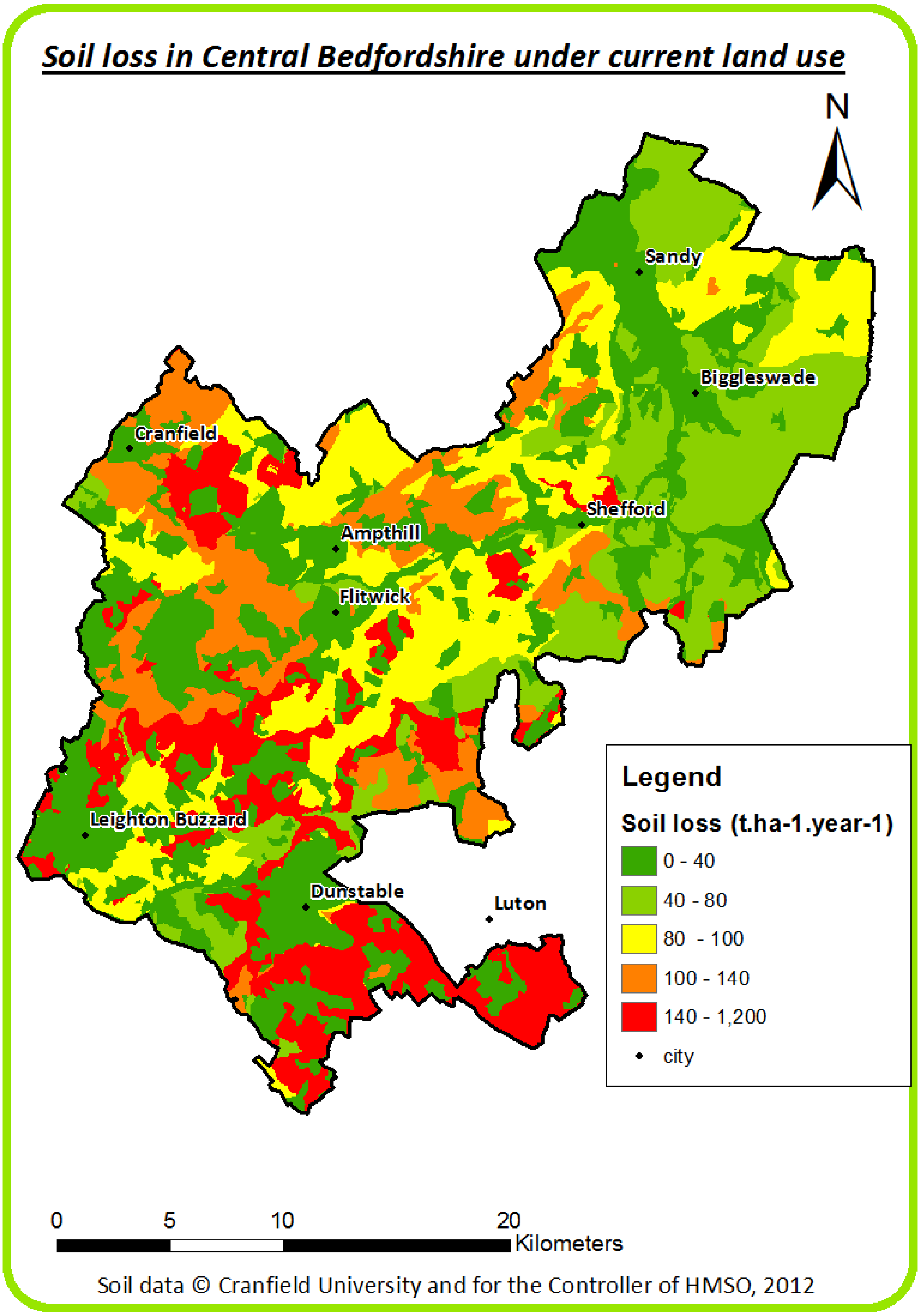

Figure 5.3 Predicted soil loss estimation in Central Bedfordshire under current land use. It was assumed that no land management practices to prevent erosion were carried out in arable land. Due to the coarse resolution of the land cover map, the effect of the crop cover was assumed to be similar over all arable land, but the proportion of each crop in the region was taken into account to estimate the crop effect.

5.1.3 Results table analysis

Average values of the predicted runoff for each combination of Hydrologic Soil Group (HSG) and land use for the 1 in 10 years and 1 in 100 years rainfall events in Central Bedfordshire are shown in Table 5.1 and 5.2, respectively. As observed, the greater the soil impermeability, the greater the runoff under every land use.

Excluding the open spaces, greater runoff was predicted in every urban land cover for a given HSG in comparison with non-urban land uses. Within the non-urban land covers, arable land usually presented the greater mean runoff values for a given HSG. Predicted runoff shows very similar values under pasture land use and open urban areas. Interestingly, urban green areas usually had mean runoff values slightly lower than pasture. Therefore, maximization of open spaces could be advisable in new urban development. Finally, woodland areas usually presented the lowest values.

Average values of the predicted erosion for each combination of soil type and land use in Central Bedfordshire are shown in Table 5.3. However, atypical values of soil erosion are sometimes found in the table because the effect of the slope was not taken into account to create such summary tables, while it was taken into account to estimate the erosion rates throughout the County. For example, the average value of predicted erosion in deep silty to clay soils is greater under woodland land cover than under pasture land cover. That is probably due to the tendency to locate woodlands in steeper areas.

The greatest erosion rate in urban areas and across the county was usually predicted for the impervious urban land cover, i.e. mine sites, landfills and construction sites, independently of the soil type. Green urban areas usually presented low erosion values while residential and industrial areas were normally associated with very low predicted erosion rates.

Within the non-urban land uses, arable land usually presented the greatest erosion rate. Nevertheless, this erosion rate was frequently smaller than for impervious urban land cover. The smallest predicted erosion rate often is associated with woodland areas. Pasture tended to show low predicted erosion rates, which often were similar to the values displayed by urban open spaces. However, depending of the soil type, predicted erosion values were greater in pasture or open spaces. Finally, erosion rates in woodland usually were smaller than in pasture areas.

Attending to the soil type, the greatest erosion rates usually were predicted in silty over chalk, deep loam to clay, and shallow silty over chalk. On the other hand seasonally wet deep loam over gravel and seasonally wet deep peat to loam shown the smallest predicted erosion rate.

Table 5.1: Mean runoff predicted (42.6 mm day^{-1}) after the 1 in 10 years rainfall event for the current land use in Central Bedfordshire. Values on the table are interpreted as follows: mean runoff estimated for each combination of land use and Hydrologic soil group (standard deviation – SD- for each combination of land use and soil type. (*See appendix A6*).

	URBAN AREAS				NON-URBAN AREAS		
Soil type	**Residential areas**	**Impervious**	**Industrial or commercial**	**Open spaces**	**Pasture**	**Arable land**	**Woodland**
A	7.3 (0.92)	4.3 (0.7)	19.4 (1.41)	0.2 (0.75)	0.3 (0.91)	1.4 (0.8)	4.6 (0.3)
B	14.4 (0.73)	11.3 (0.77)	24.1 (1.14)	3.2 (0.63)	1.6 (0.71)	4.1 (0.49)	0.6 (0.41)
C	20.9 (1.08)	16.7 (0.77)	27.8 (1.26)	9.2 (0.41)	11.3 (0.63)	12.7 (0.5)	5.1 (0.62)
D	24.1 (0.89)	19.5 (0.23)	29.8 (0.91)	13.5 (0.99)	15.2 (0.57)	17 (0.52)	9.6 (0.78)

Table 5.2: Mean runoff predicted (59.7 mm day^{-1}) after the 1 in 100 years rainfall event for the current land use in Central Bedfordshire. Values on the table are interpreted as follows: mean runoff estimated for each combination of land use and Hydrologic soil group (standard deviation – SD- for each combination of land use and soil type (*See appendix A6*).

	URBAN AREAS				NON-URBAN AREAS		
Soil type	**Residential areas**	**Impervious**	**Industrial or commercial**	**Open spaces**	**Pasture**	**Arable land**	**Woodland**
A	16.5 (1.41)	11.5 (1.1)	33.6 (2.19)	0.6 (1.41)	2.8 (1.62)	5.9 (1.3)	1.6 (0.56)
B	26.9 (1.11)	22.6 (1.14)	39.4 (1.57)	9.5 (0.96)	6.3 (1.18)	11.2 (0.76)	0.2 (1.21)
C	35.4 (1.48)	30.1 (1.11)	43.7 (1.6)	19.4 (0.71)	22.5 (1.05)	24.5 (0.79)	13.0 (1.02)
D	39.4 (1.17)	33.6 (0.29)	46.1 (1.11)	25.7 (1.76)	28.0 (0.87)	30.4 (0.77)	20.0 (1.22)

Table 5.3 Mean predicted soil erosion (t ha^{-1} year^{-1}) predicted for current land use and soil type combination in Central Bedfordshire. It was assumed that no measures to prevent erosion are implemented. Values on the table are interpreted as follow: mean erosion for each combination of land use and soil type (standard deviation – SD - for each combination of land use and soil type). NA means that a **certain combination of land use and soil type does not appear in the area.**

	URBAN AREAS				NON-URBAN AREAS		
Soil type	**Residential areas**	**Impervious**	**Industrial or commercial**	**Open spaces**	**Pasture**	**Arable land**	**Woodland**
deep clay	0.6 (3.7)	150.5 (32.39)	0.7 (2.73)	8.1 (12.62)	10.9 (8.05)	98.4 (29.07)	1.3 (4.24)
deep loam	0.3 (0.89)	45.9 (1.17)	0.7 (3.31)	2.0 (2.37)	3.6 (2.05)	56.6 (13.02)	2.0 (6.46)
deep loam over gravel	0.3 (2.92)	27.8 (12.25)	0.4 (1.57)	2.4 (4.55)	6.0 (5.05)	41.5 (29.38)	0.6 (1.92)
deep loam to clay	1.1 (5.5)	641.2 (205.21)	0.6 (0.1)	13.1 (6.61)	8.8 (13.23)	141.2 (47.68)	1.4 (5.82)
deep sandy	0.7 (4.55)	253.2 (160.28)	1.5 (0.23)	9.9 (3.72)	12.0 (6.9)	96.9 (23.67)	1.2 (5.14)
deep silty to clay	NA	79.0 (46.31)	6.0 (24.6)	7.4 (5.45)	6.4 (7.28)	52.6 (54.9)	0.7 (1.34)
loam over chalk	0.1 (3.2)	1.3 (8.68)	0.2 (2.71)	1.3 (2.49)	4.4 (6.68)	109.7 (32.44)	3.9 (7.64)
loam over red sandstone	0.5 (1.96)	NA	0.5 (1.97)	5.6 (2.98)	3.8 (5.15)	88.4 (23.46)	1.0 (2.78)
seasonally wet deep clay	0.7 (4.82)	231.9 (116.93)	0.5 (0.57)	9.4 (3.05)	4.1 (7.68)	98.2 (59.5)	1.5 (4.69)
seasonally wet deep peat to loam	0.3 (0.13)	1. 8 (0.23)	0.0 (0)	0.6 (0.35)	1.0 (0.26)	11.0 (2.52)	0.4 (0.88)
seasonally wet loam over gravel	NA	NA	NA	NA	NA	13.5 (2.86)	NA
shallow silty over chalk	1.0 (9.43)	329.7 (308.96)	0.5 (3.18)	17.7 (23.27)	26.4 (16.24)	151.8 (126.15)	7.0 (6.93)
silty over chalk	0.2 (0.32)	1122.2 (78.00)	NA	2.4 (0.1)	21.7 (11.72)	246.5 (59.94)	NA

5.1.4 Future Scenarios

Scenario 1: Urban development

The first scenario focused on the effects of widespread urban development. The predicted runoff generation across Central Bedfordshire is presented in Appendix C. Average values of predicted runoff for each combination of Hydrologic Soil Group (HSG) and land cover type in Central Bedfordshire in Scenario 1 are presented in Appendix C. Figures 5.4 and 5.5 illustrate the change in runoff rates between the predicted current and future rates assuming urban development for the 1 in 10 year and the 1 in 100 year events. Obviously, runoff rates for urban areas remained constant. For the rest of the area, runoff rates generally increase. The greatest increase occurs in current grassland and woodland areas. Such figures also show how the potential development sites proposed by the Central Bedfordshire Council could affect the runoff generation.

The greater runoff generation under urban land use is also noticed in the direct flow accumulation along the drainage network, which was considerably greater in this scenario than in the current situation (figures 5.4 and 5.5). As a result, the different flow risk categories usually occurred closer to the drainage network heads (Appendix C). The most important changes in direct flow accumulation as consequence of the 1 in 10 years precipitation event occurred after the junction of the River Flit with the rivers Ivel and Hiz. The greatest increases in direct flow accumulation after the 1 in 100 years rainfall event were located in the river Ouzel, and along the River Flit and its tributaries. Finally, a direct flow accumulation increase greater than 500,000 m^3/day occurred after the junction of the River Flit with the Rivers Ivel and Hiz as consequence of the 1 in 10 years rainfall event. However, that category of direct flow accumulation increase occurred a few kilometres down stream from Flitwick after the 1 in 100 years event.

The predicted soil erosion rates under widespread urban development are shown in the Appendix C. In areas where pasture and woodland currently occurs, erosion rates increased after changing to the urban land use. By contrast erosion rates decreased following a change from arable to urban in majority of the soil types. Figure 5.6 shows the changes in predicted soil erosion after widespread urban development. Interestingly, the erosion rate increase was high in areas of steep gradient. Therefore such areas could be considered as less appropriate for urban development, requiring erosion prevention measures. Haapala (2002) also reported that new urban development could lead to erosion problems as consequence of the indirect erosive effects of the greater runoff generated in the urban areas if such runoff is not properly managed.

Average values of predicted erosion for each combination of soil type and land use in Central Bedfordshire are displayed in Appendix C. Mean predicted erosion values under widespread urban land use ranged between 3.72 ton ha^{-1} $year^{-1}$ in seasonally wet loam deep peat to loam and 110.39 ton ha^{-1} $year^{-1}$ in silty over chalk.

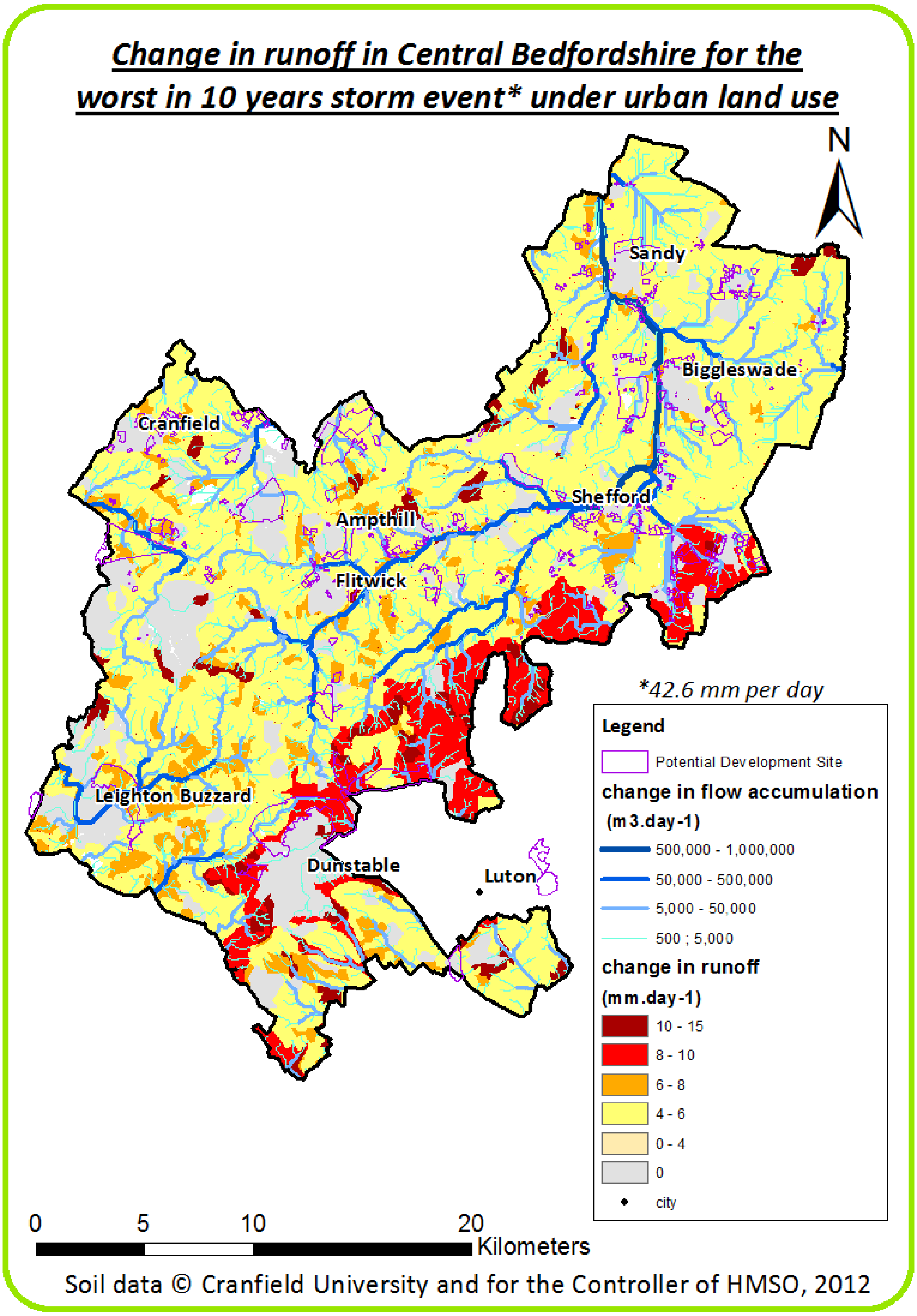

Figure 5.4 Runoff change in Central Bedfordshire County in comparison with the current situation when the urban land use is established throughout the entire county after the 1 in 10 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation. Potential development sites are shown in the map.

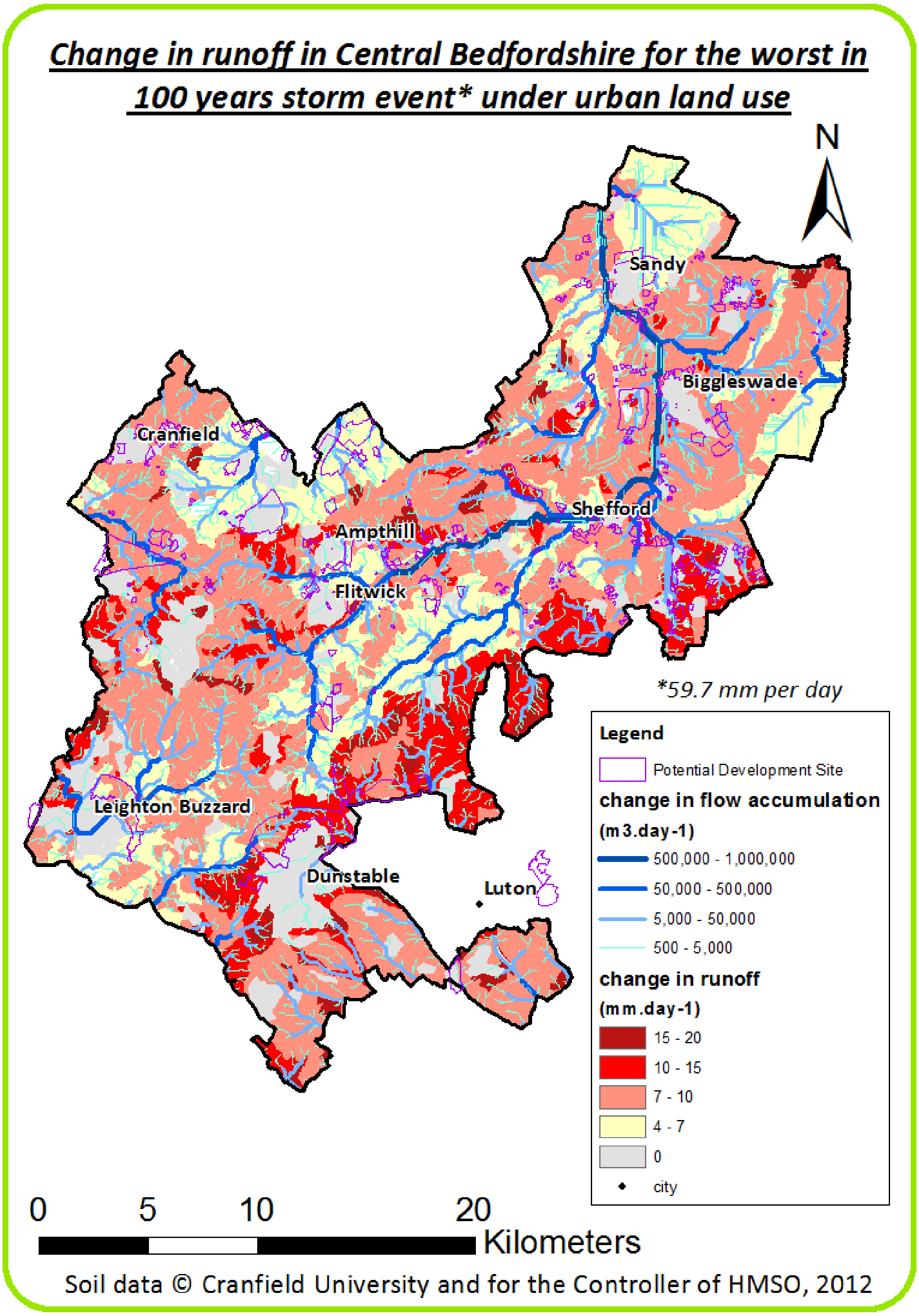

Figure 5.5 Runoff change in Central Bedfordshire County in comparison with the current situation when the urban land use is established throughout the entire county after the 1 in 100 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation. Potential development sites are shown in the map.

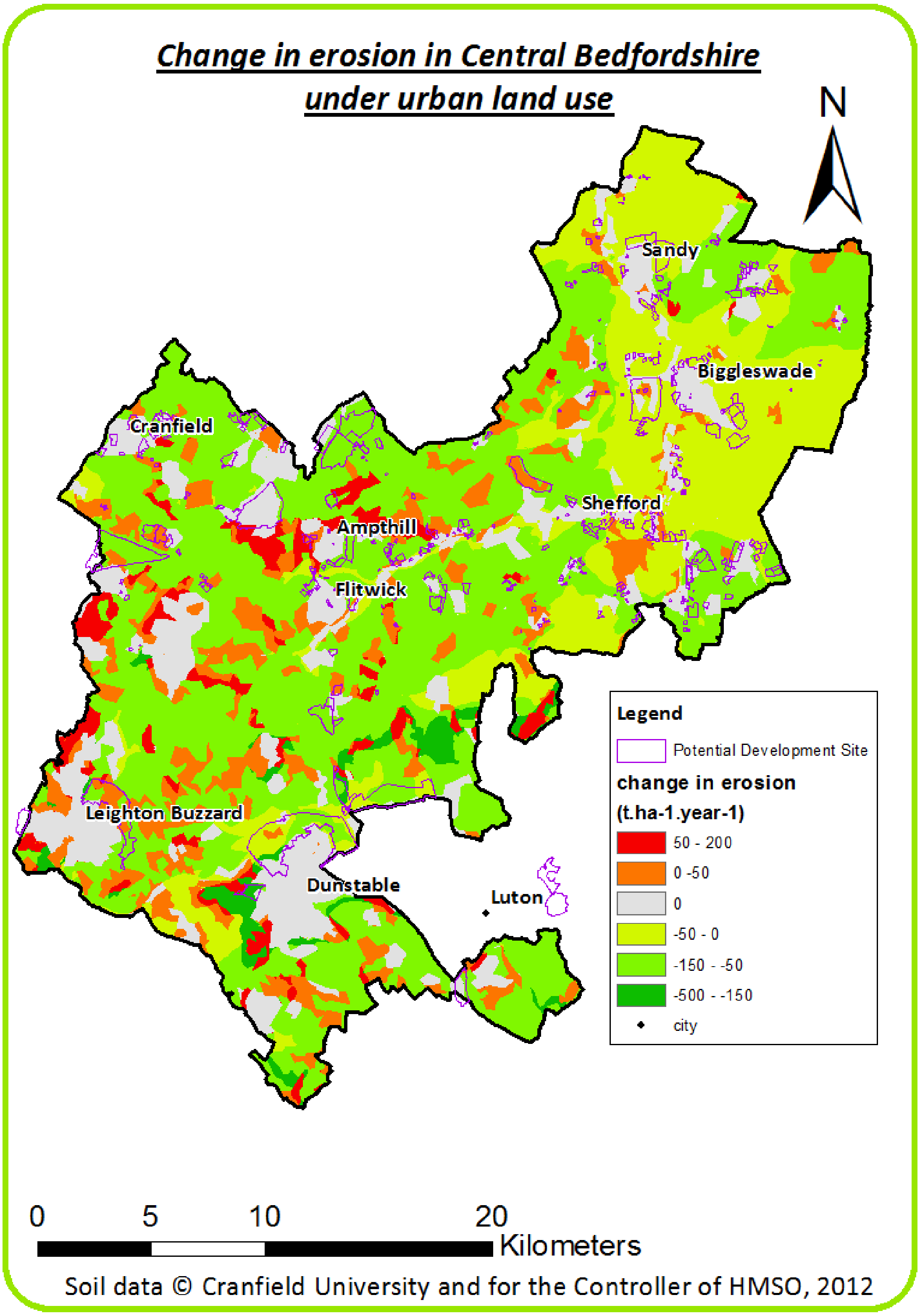

Figure 5.6: Predicted potential soil loss change in comparison with the current situation as consequence of the urban development throughout the entire county. Negative values (green) mean soil loss decrease. Positive values (orange-red) mean soil loss increase. Potential development sites are shown in the map.

Scenario 2: Woodland land use

The second scenario focused on the effects of widespread woodland land cover. The predicted runoff generation across Central Bedfordshire is presented in the Appendix C. Average values of predicted runoff for each combination of Hydrologic Soil Group (HSG) and land cover type in Central Bedfordshire in the Scenario 2 are presented in Appendix C. Figures 5.7 and 5.8. illustrate the change in runoff rates between the predicted current and future rates assuming forest land cover throughout the entire county, excepting in current urban areas, for the 1 in 10 year and the 1 in 100 year events. Obviously, runoff rates for woodland areas remain constant. For the rest of the areas where forest was assumed, runoff rates generally decrease. The greatest decrease occurs in current arable areas. The predicted runoff generation decrease was smaller in grassland. Finally, a remarkable reduction of runoff was predicted in the southern part of the county, which could prevent flood hazards in Luton.

The smaller runoff generation under forest land use is also noticed in the direct flow accumulation along the drainage network, which was considerably smaller in this scenario than in the current situation. This effect was especially significant in areas of low permeability soils (figures 5.7 and 5.8). As a result, the different flow risk categories usually occurred further away to the drainage network heads. In addition, the greatest direct flow accumulation category did not appear after the 1 in 10 years rainfall event (Appendix C). The most important effects on the flow accumulation were located in the River Flit, after junction of River Flit with Rivers Ivel and Hiz and in the western area of the county. It also was significant the direct flow reduction in the river Ouzel. Effects of forest cover on direct flow accumulation were slightly less noticeable in the western area due to the greater surface proportion of the catchments currently occupied by urban land cover.

The predicted soil erosion rates under widespread woodland land use are shown in the Appendix C. Erosion rates generally decreased throughout the entire area. However, they remain constant in current woodland areas and current urban areas (mine sites and landfill included) because no land use change occurred there. The greatest decrease in erosion rate was estimated following a change from arable to woodland. Soil loss reduction estimated was smaller in current pasture areas. Figure 5.9 shows the changes in predicted soil erosion following to widespread forest establishment. Interestingly, negative effects of the slope and the soil erodibility were compensated by the woodland land cover. Therefore, woodland could be suggested to reduce soil loss in areas with a high erosion risk.

Average values of predicted erosion for each combination of soil type and land use in Central Bedfordshire are shown in Appendix C. Mean predicted erosion values under woodland land use ranged between 0.51 ton ha^{-1} $year^{-1}$ in shallow silty over chalk and 0.03 ton ha^{-1} $year^{-1}$ in seasonally wet deep peat to loam.

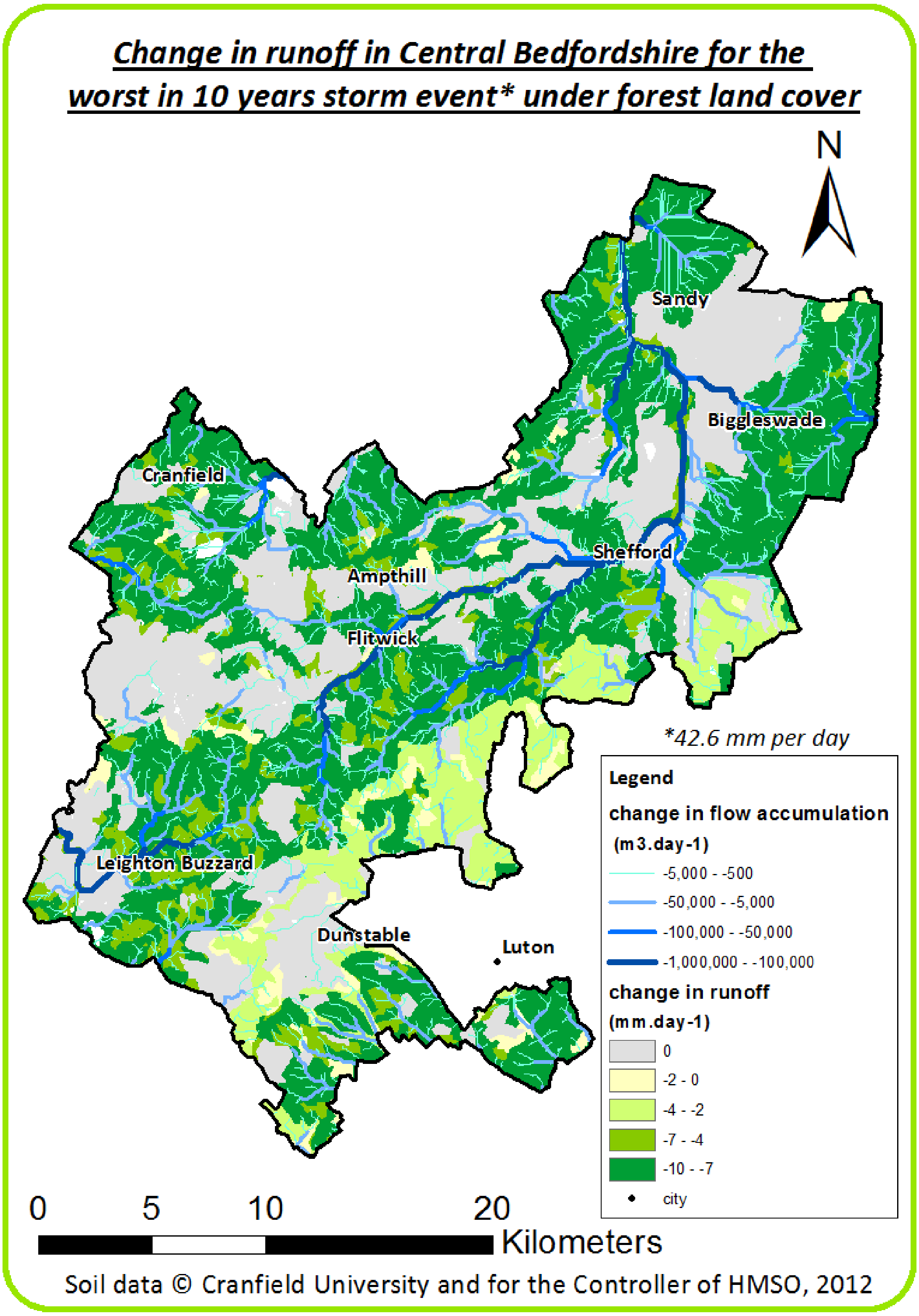

Figure 5.7 Runoff change in Central Bedfordshire County in comparison with the current situation when the forest land use is established throughout the entire county after the 1 in 10 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

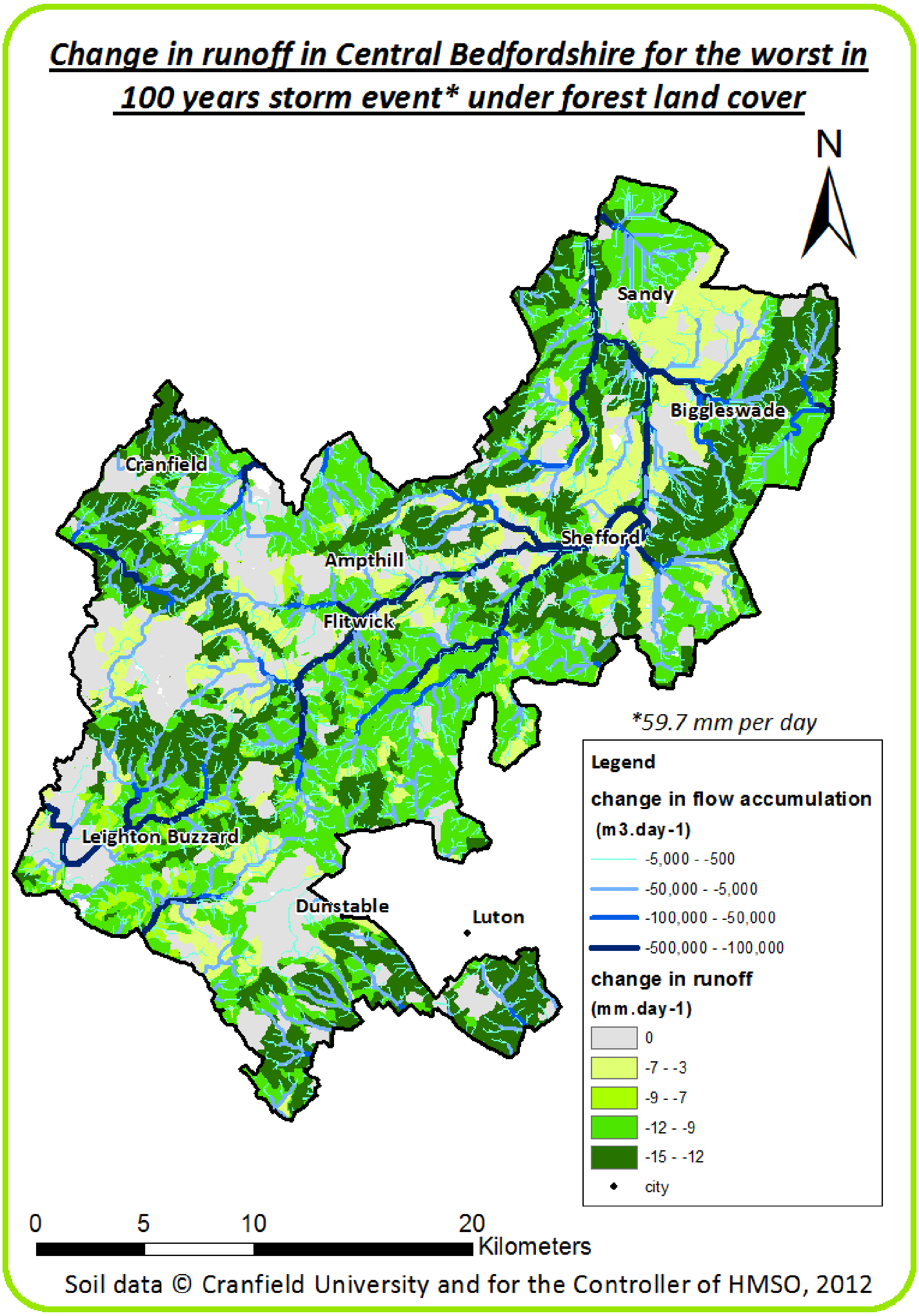

Figure 5.8 Runoff change in Central Bedfordshire County in comparison with the current situation when the forest land use is established throughout the entire county after the 1 in 100 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

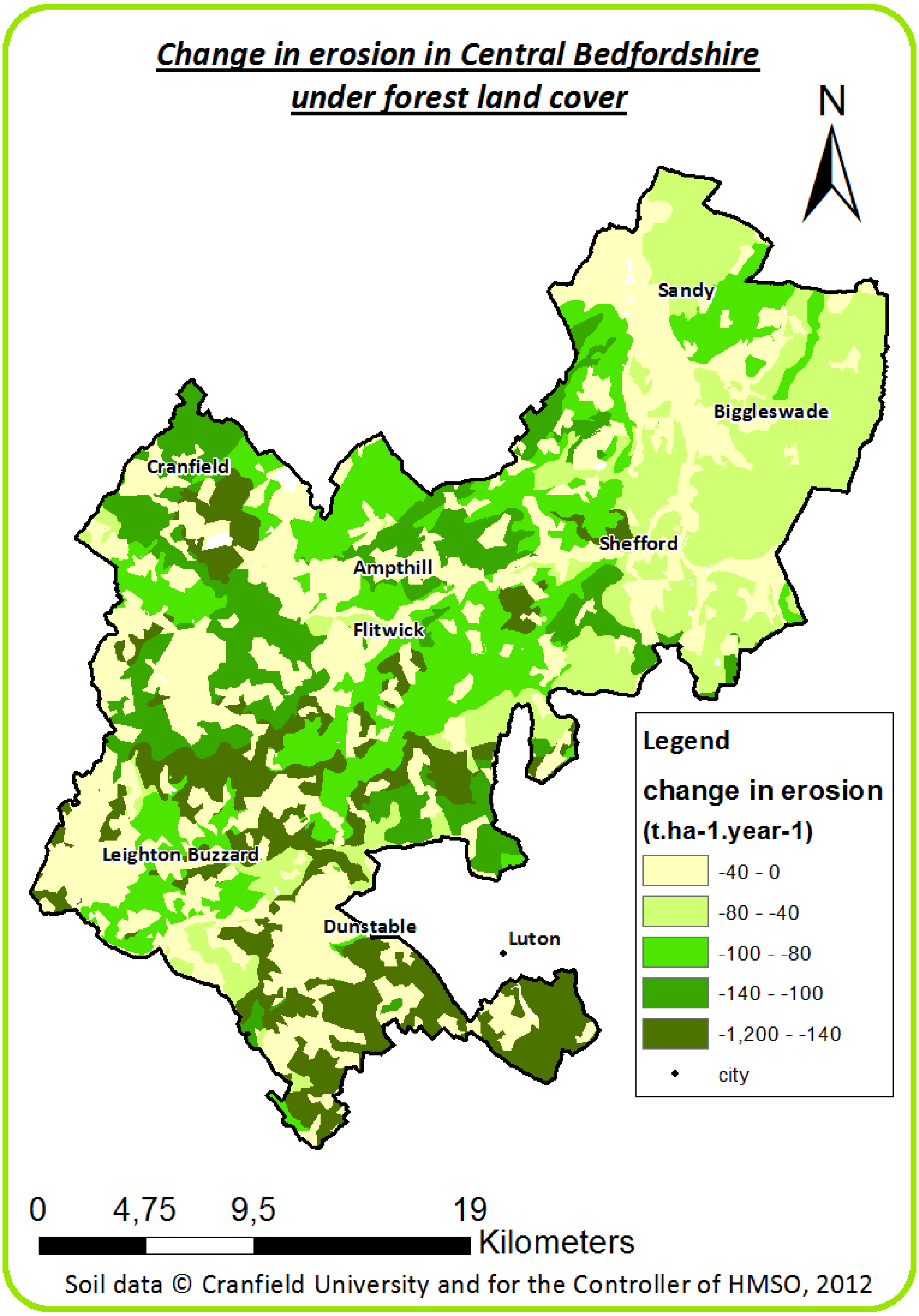

Figure 5.9 Soil loss change as consequence of the forest land use throughout the entire county in comparison with the current situation. Positive values mean soil loss increase. Negative values mean erosion rate decrease.

Scenario 3: Pasture land use

The third scenario focused on the effects of widespread pasture land cover. The predicted runoff generation across Central Bedfordshire is presented in the Appendix C. Average values of predicted runoff for each combination of Hydrologic Soil Group (HSG) and land cover type in Central Bedfordshire in the Scenario 3 are presented in Appendix C. Figures 5.10 and 5.11. illustrate the change in runoff rates between the predicted current and future rates assuming pasture land cover throughout the entire county, except in current urban areas, for the 1 in 10 year and the 1 in 100 year events. Obviously, runoff rates for current pasture areas remain constant. Predicted runoff generation increased when woodlands were substituted by grassland. Nevertheless, the predicted runoff was smaller after changing the arable land use. Such changes are greater in soils with high permeability, which are the less concerned in runoff risk.

The smaller runoff generation under pasture land use in comparison with the arable land, which occupies the 70% of the county area, is noticed in the direct flow accumulation along the drainage network, which was smaller in this scenario than in the current situation (Figures 5.10 and 5.11). As a result, the different flow risk categories usually occurred further away from the drainage network heads. In addition, the greatest direct flow accumulation category did not appear after the 1 in 10 years rainfall event (Appendix C). Nonetheless, direct flow reduction was smaller in this scenario than in the scenario 2. Some streams of the southern part of the county present a interesting direct flow reduction after the 1 in 100 years rainfall event. This fact can be very useful to prevent flood hazards on Luton. Finally, small direct flow increases were predicted in some stretch of the drainage network associated with current forest areas.

The predicted soil erosion rates under widespread pasture land cover are shown in the Appendix C. Erosion rates remain constant in areas where pasture and urban areas (mine sites and landfills included) currently occurs, because no land use change was implemented in this scenario there. Smaller soil loss rates were predicted in areas following a change from arable to pasture, while greater erosion rates were estimated in areas where forests currently occur Figure 5.12 shows the changes in predicted soil erosion after widespread pasture establishment. It is important to highlight that pasture land cover efficiently addresses the effect of the slope in arable land.

Average values of predicted erosion for each combination of soil type and land use in Central Bedfordshire are presented in Appendix C. Mean predicted soil loss values under pasture land use ranged between 18.0 t ha^{-1} $year^{-1}$ in silty over chalk and 0.8 t ha^{-1} $year^{-1}$ in seasonally wet deep peat to loam.

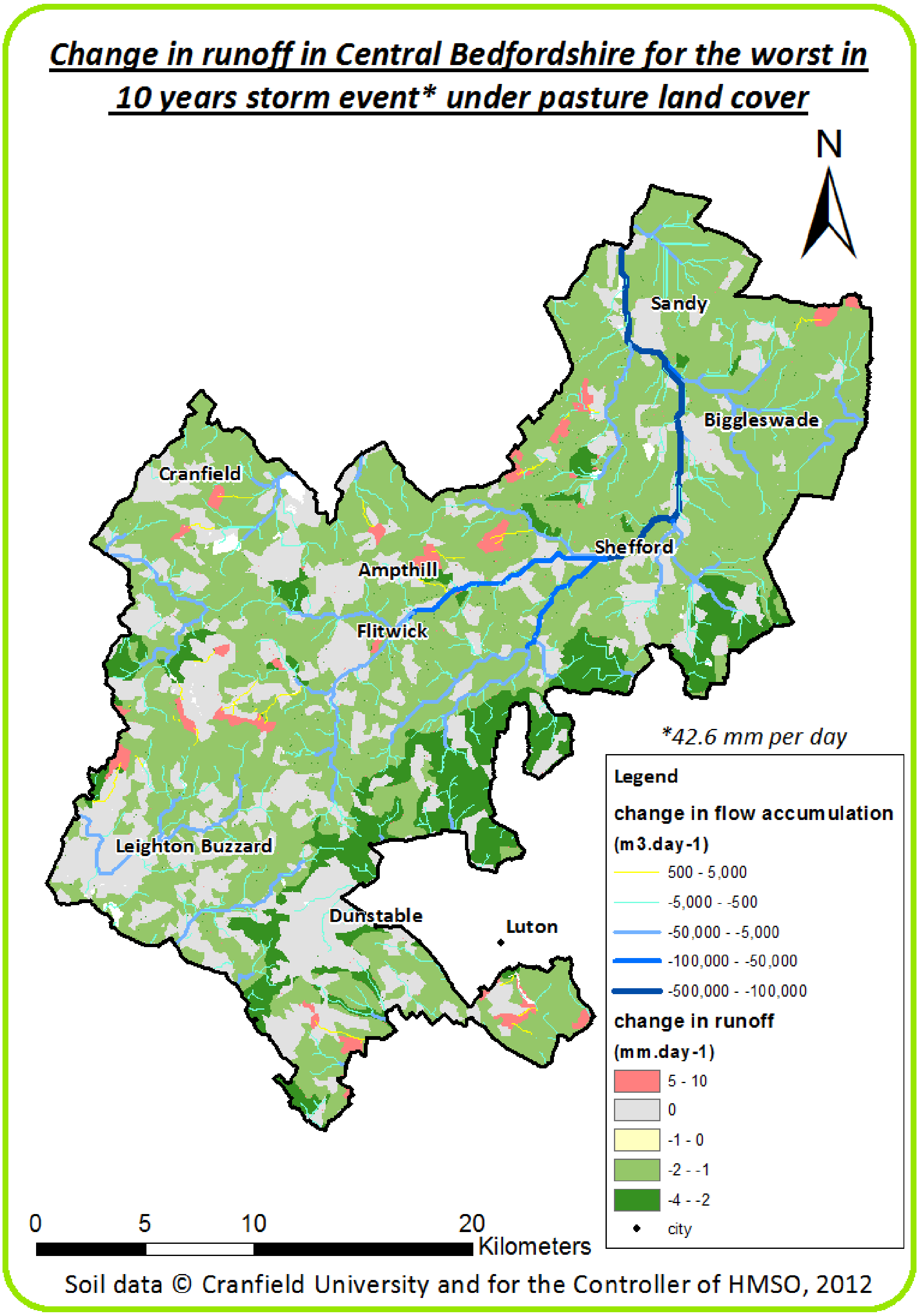

Figure 5.10 Runoff change in Central Bedfordshire County in comparison with the current situation when the pasture land use is established throughout the entire county after the 1 in 10 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

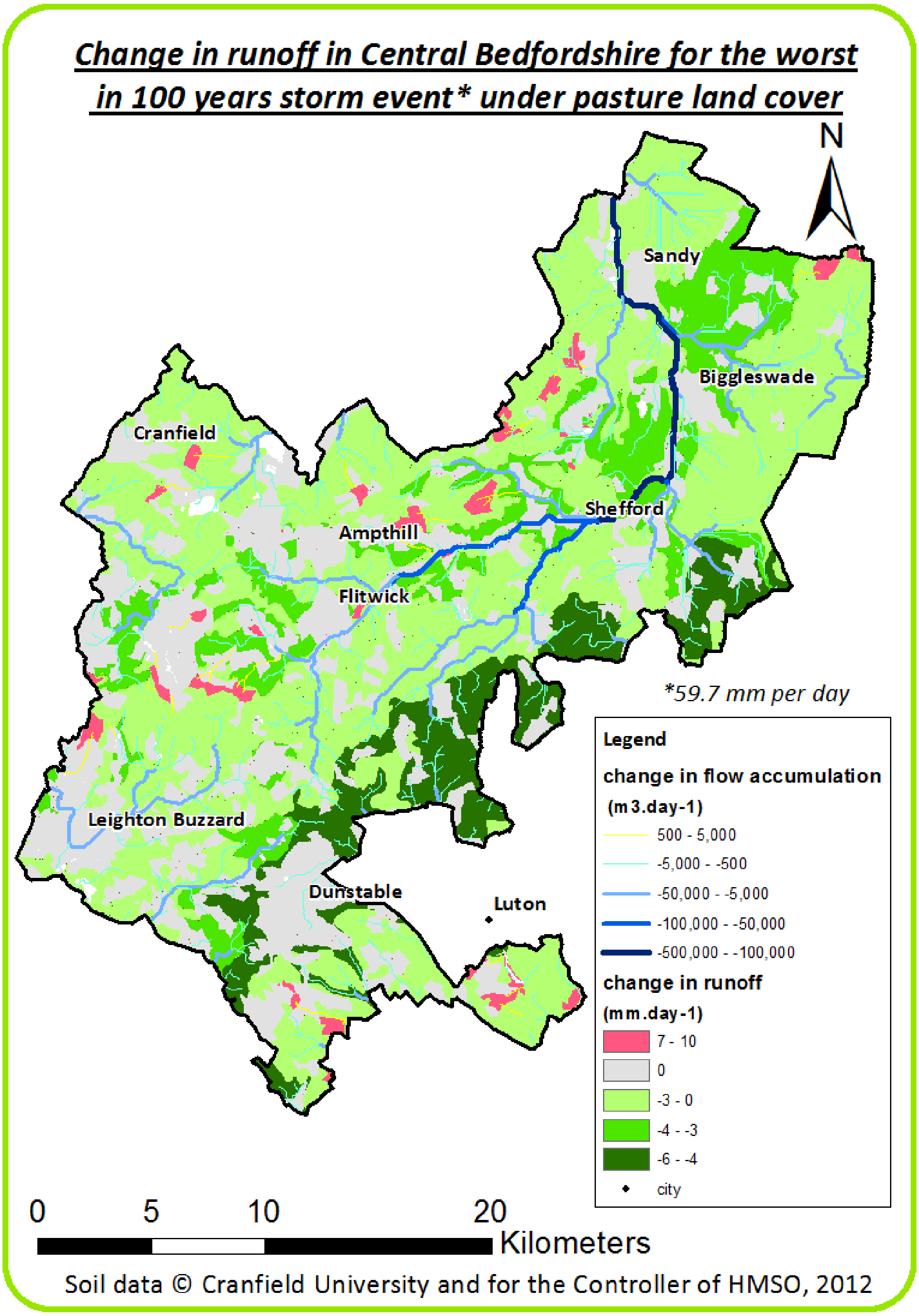

Figure 5.11 Runoff change in Central Bedfordshire County in comparison with the current situation when the pasture land use is established throughout the entire county after the 1 in 100 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

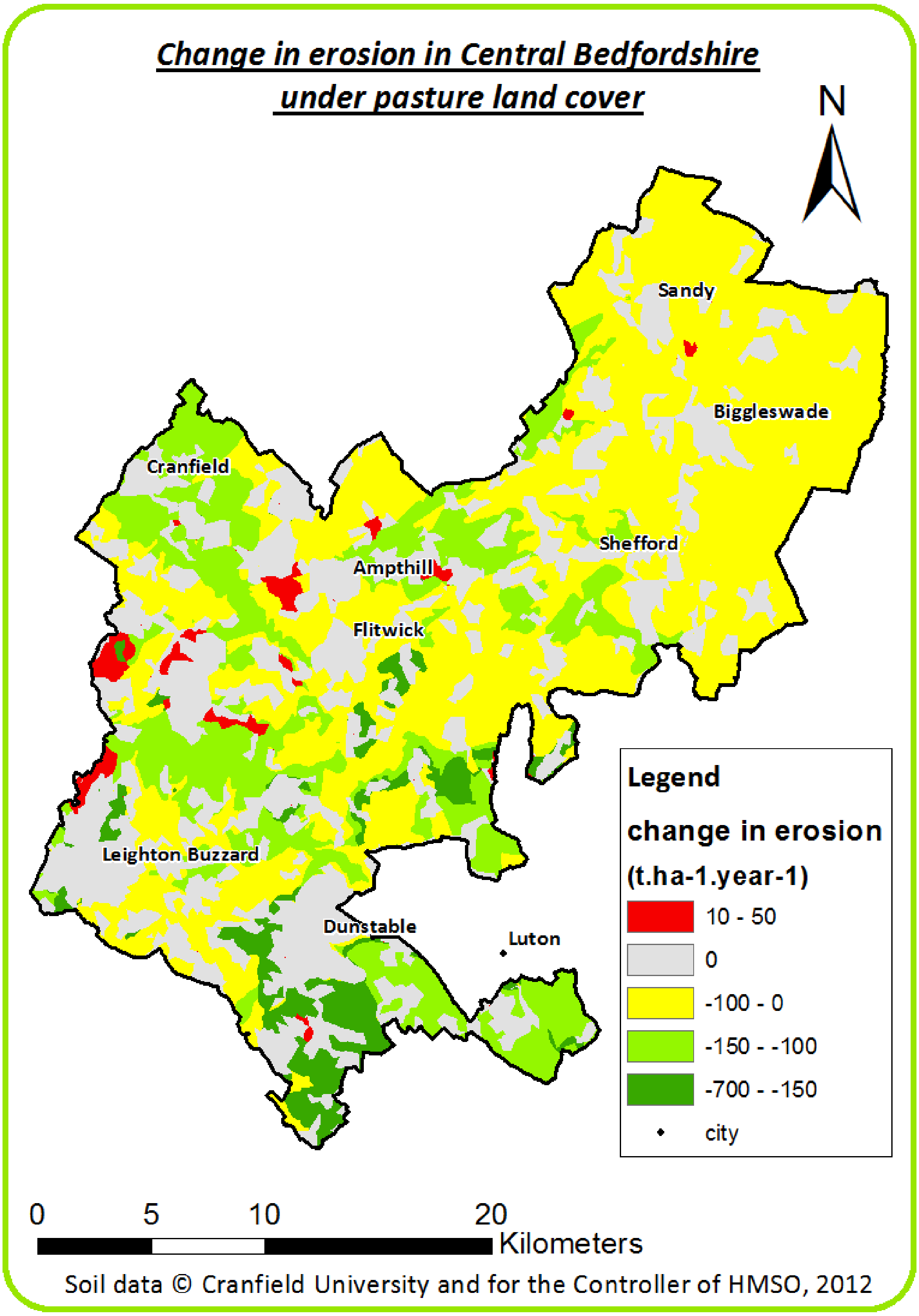

Figure 5.12 **Soil loss change as consequence of the pasture land use throughout the entire county in comparison with the current situation. Positive values mean soil loss increase. Negative values mean soil loss decrease.**

Scenario 4: Biodiversity Action Plan (BAP)

The fourth scenario focused on the effects of the Biodiversity Action Plan (BAP). Average values of predicted runoff for each combination of Hydrologic Soil Group (HSG) and land cover type in Central Bedfordshire are displayed in Appendix C. Figures 5.13 and 5.14 illustrate the change in runoff rates between the predicted current and future rates assuming the complete implementation of the BAP for the 1 in 10 year and the 1 in 100 year events. Obviously runoff rates in current pasture and forest areas remain constant. However where arable land is substituted by pasture and woodlands, a reduction in the runoff is estimated. As observed in scenarios 2 and 3, the runoff reduction is generally greater with woodland than pasture. The establishment of forest or pasture cover on mine sites and landfill areas to reduce runoff. Appears particularly advisable.

The smaller runoff generation in some areas as consequence of the BAP implementation was noticed in the direct flow accumulation along the drainage network, which was smaller in this scenario than in the current situation (Figures 5.13 and 5.14). As a result, the different flow risk categories usually occurred further away from the drainage network heads in streams associated to areas where the BAP is implemented (Appendix C). Direct flow reduction is especially noticeable with the 1 in 100 year rainfall event. Substantial direct flow reductions were estimated in some of the northern tributaries of the River Flit. Furthermore, the river Ouzel also reported great direct flow reduction. In addition, it also was estimated a direct flow reduction in some streams on the South-West area of the county. Finally, some streams of the southern part of the county presented a slight direct flow reduction, which can be very useful to prevent flood hazards on Luton.

The predicted soil erosion rates under the implementation of the BAP are shown in the Appendix C. Erosion rates remain constant in areas where no land use change took place. Smaller soil loss rates were predicted in areas following a change from arable to either pasture or forest. However, soil loss reduction under woodland land use was estimated greater than under pasture land use. Figure 5.15 shows the change in predicted soil erosion in Central Bedfordshire as consequence of the BAP implementation. Interestingly, significant erosion reduction was estimated in the South-West area of the region, where the current erosion rate is high as consequence of the steep slope and the soil erodibility. The erosion rate was also considerably reduced in some areas of the South of the county, i.e. northern Luton. A great erosion rate reduction was predicted in the North of the area as consequence of the BAP implementation. Finally, it is interesting to point out that the implementation of the BAP, i.e. either forest cover or pasture cover, efficiently reduced the erosion rate in some mine sites and landfill areas. Therefore, restoration of derelict mine sites is advisable to reduce soil loss.

Average values of predicted erosion for each combination of soil type and land use in Central Bedfordshire are shown in Appendix C. Interestingly, the land use change involved in the BAP implementation caused a great decrease in predicted soil loss for in majority of soil types under arable land. Indeed, the current situation showed the potential soil erosion rate for silty over chalk under arable land use of 246 t ha^{-1} $year^{-1}$ in arable land (Table 5.3), while in this scenario the potential erosion rate was reduced to 16 t ha^{-1} $year^{-1}$. That is caused by the substitution of arable land located in steep slopes with pasture and woodland.

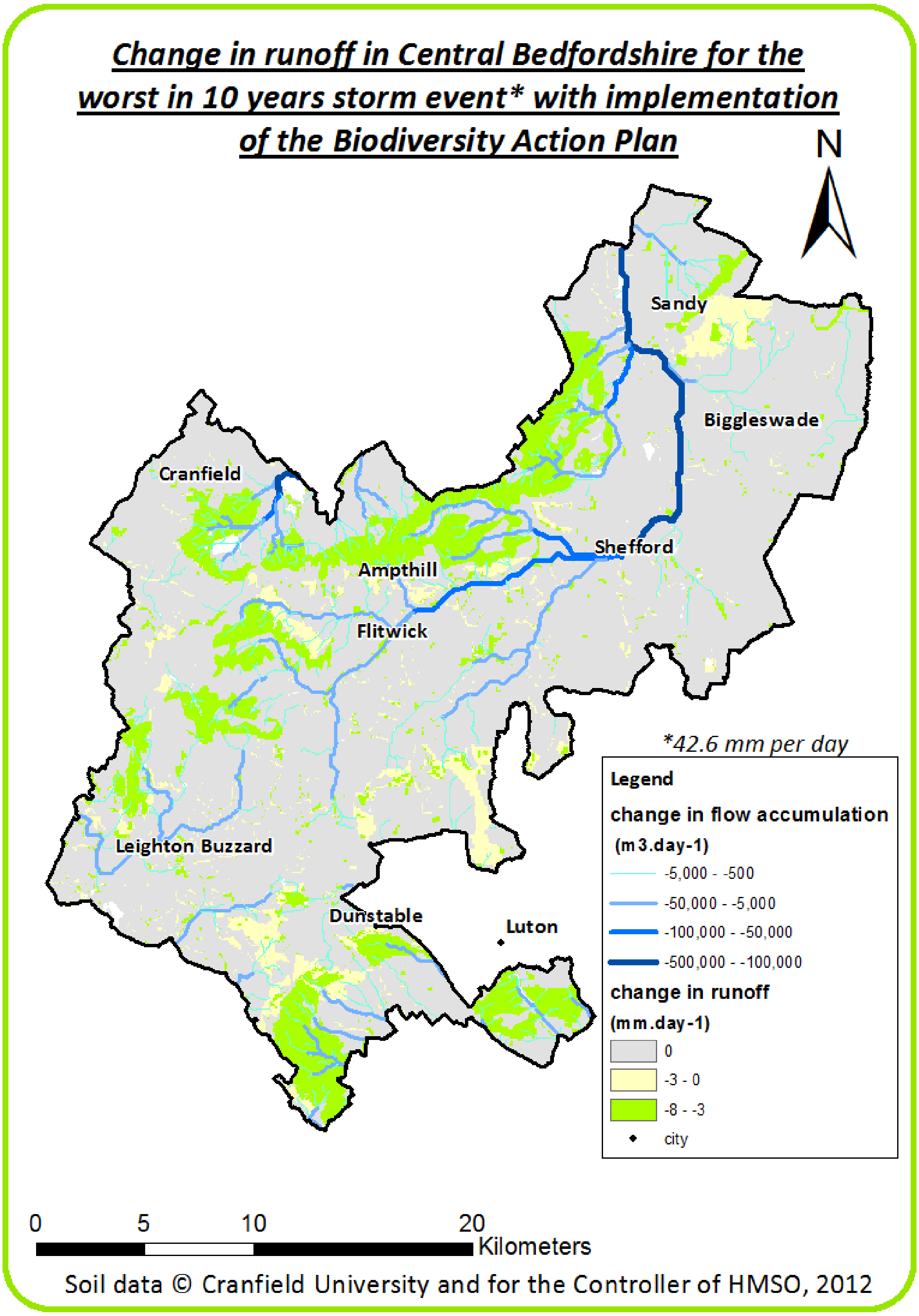

Figure 5.13 Runoff change in Central Bedfordshire County in comparison with the current situation when the BAP is implemented after the 1 in 10 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

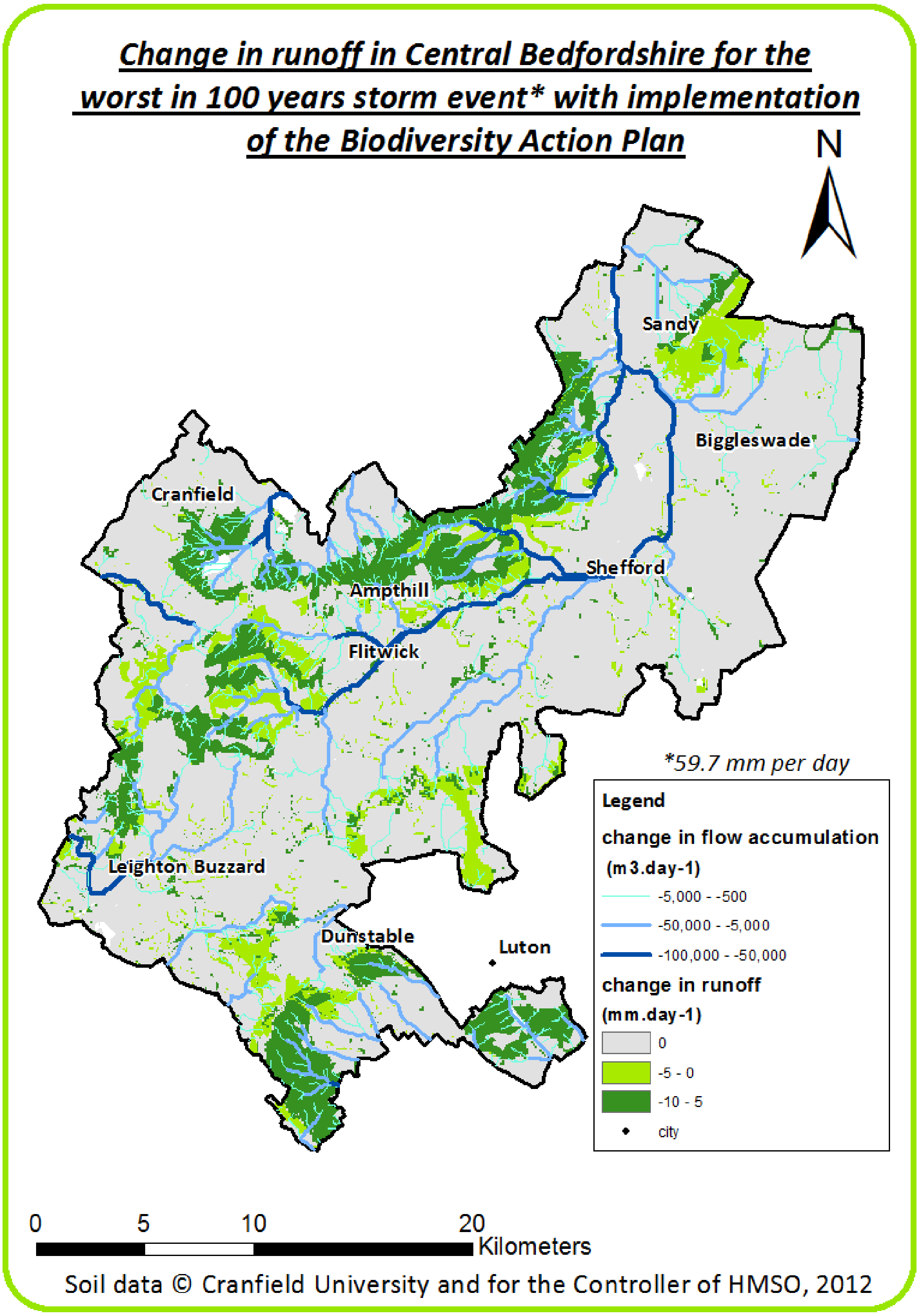

Figure 5.14 Runoff change in Central Bedfordshire County in comparison with the current situation when the BAP is implemented after the 1 in 100 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

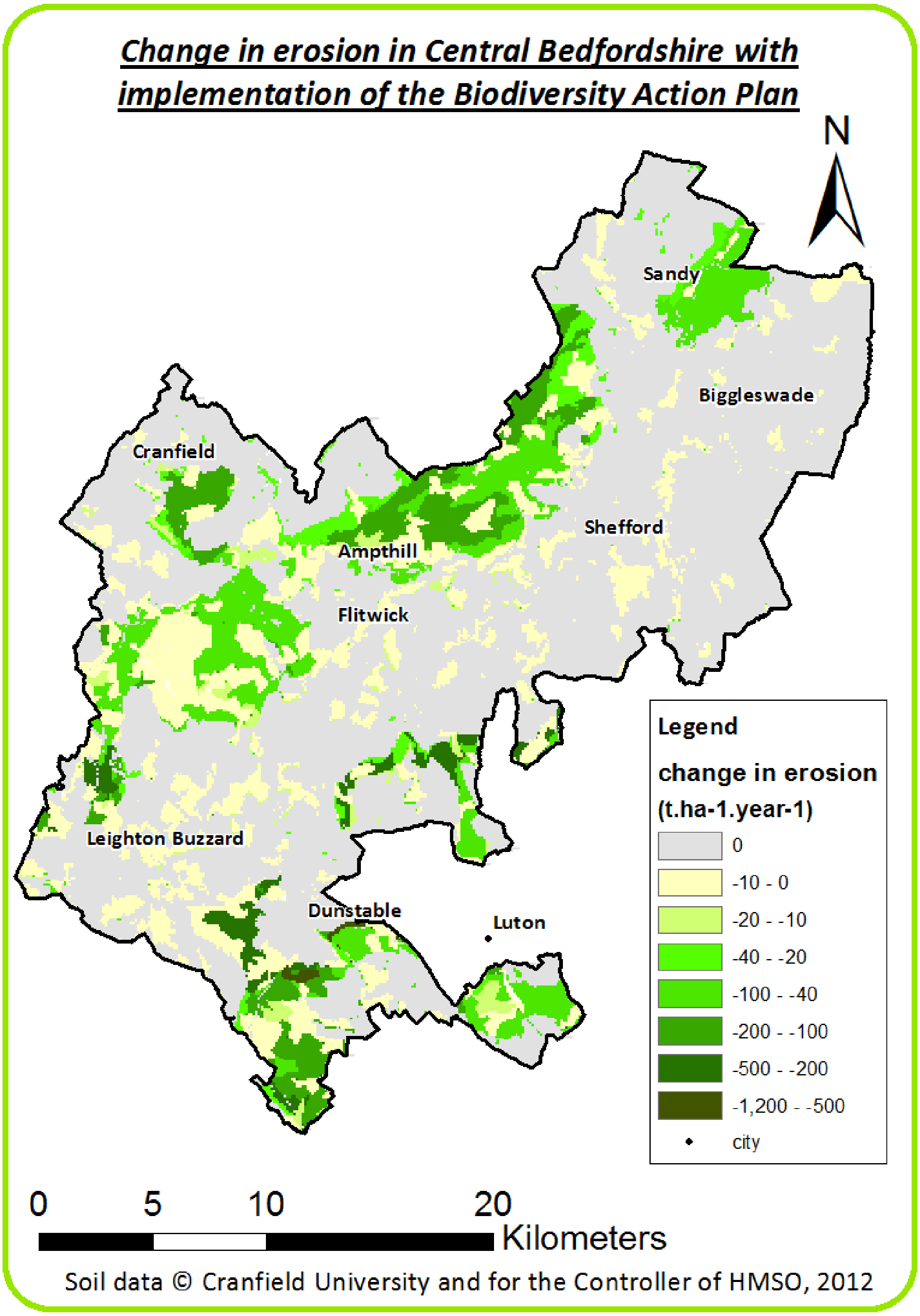

Figure 5.15 Soil loss change as consequence of the implementation of the BAP in comparison with the current situation. Positive values mean soil loss increase. Negative values mean soil loss decrease.

Scenario 5: Land management

The fifth scenario focused on the effects of different arable land use practices across Central Bedfordshire. The predicted runoff generation across Central Bedfordshire is presented in the Appendix C. Average values of predicted runoff for each combination of Hydrologic Soil Group (HSG) and land cover type in Central Bedfordshire in the Scenario 5 are shown in Appendix C. Figures 5.16 and 5.17 illustrate the change in runoff rates between the predicted current and future rates assuming the implementation of certain land management techniques in arable land for the 1 in 10 year and the 1 in 100 year events. Obviously, runoff rates for non-arable areas remained constant. Runoff reduction predicted was usually slightly greater in areas with high current erosion rate, especially in the South part of the county, because measures applied there implied a greater proportion of grass in arable fields. Finally, it is appropriate to remember that the effect of cover crops on runoff decrease was not quantified. Therefore, runoff reduction could be greater than estimated, especially in fields with a high tendency to produce runoff (Howarth et al. 2007).

The smaller runoff generation in arable areas as a consequence of the implementation of good land management techniques was noticed in the direct flow accumulation along the drainage network, which was smaller in this scenario than in the current situation (Figures 5.16 and 5.17). As a result, the different flow risk categories usually occurred further away from the drainage network heads. Indeed, the greatest direct flow category did not appear after the 1 in 10 years rainfall event (Appendix C). Greatest effects of the land management techniques applied in arable land were noticed in the River Flit and their tributaries. Direct runoff reduction was also important in the river Ouzel. Finally, smaller direct runoff was estimated in some streams of the southern part of the county, which can be very useful to prevent flood hazards on Luton.

The predicted soil erosion rates under the different arable land management practices are shown in the Appendix C. Erosion rates stay constant in areas where no-arable land is currently located. On the other hand, the effect of the management techniques implemented in this scenario was noticed over a large area, since arable land occurs over the majority of the county. Figure 5.15 shows the change in soil erosion as consequence of the implementation good land management techniques preventing erosion in arable land. Interestingly, predicted erosion rate is efficiently reduced by the land management techniques implemented in this scenario. The greatest reduction occurred in areas with the highest current erosion risk, because some extra measures, such as in field permanent grass areas, were implemented there. As described in the methodology many of the erosion reduction measures implemented in the scenario are within the ELS (Natural England 2010a). Therefore, this level of erosion reduction could be achieved without a large reduction in farm income.

Average values of predicted erosion for each combination of soil type and land use in Central Bedfordshire are presented in Appendix C. Interestingly, the majority of the soil types under arable land use show an important reduction of the predicted erosion rate after the implementation of the set of good arable management techniques studied in this scenario. Indeed, the greatest predicted mean erosion rate for arable land in the current scenario, i.e. 152 t ha^{-1} $year^{-1}$ (table 5.3.), was reduced to 75.2 t ha^{-1} $year^{-1}$.

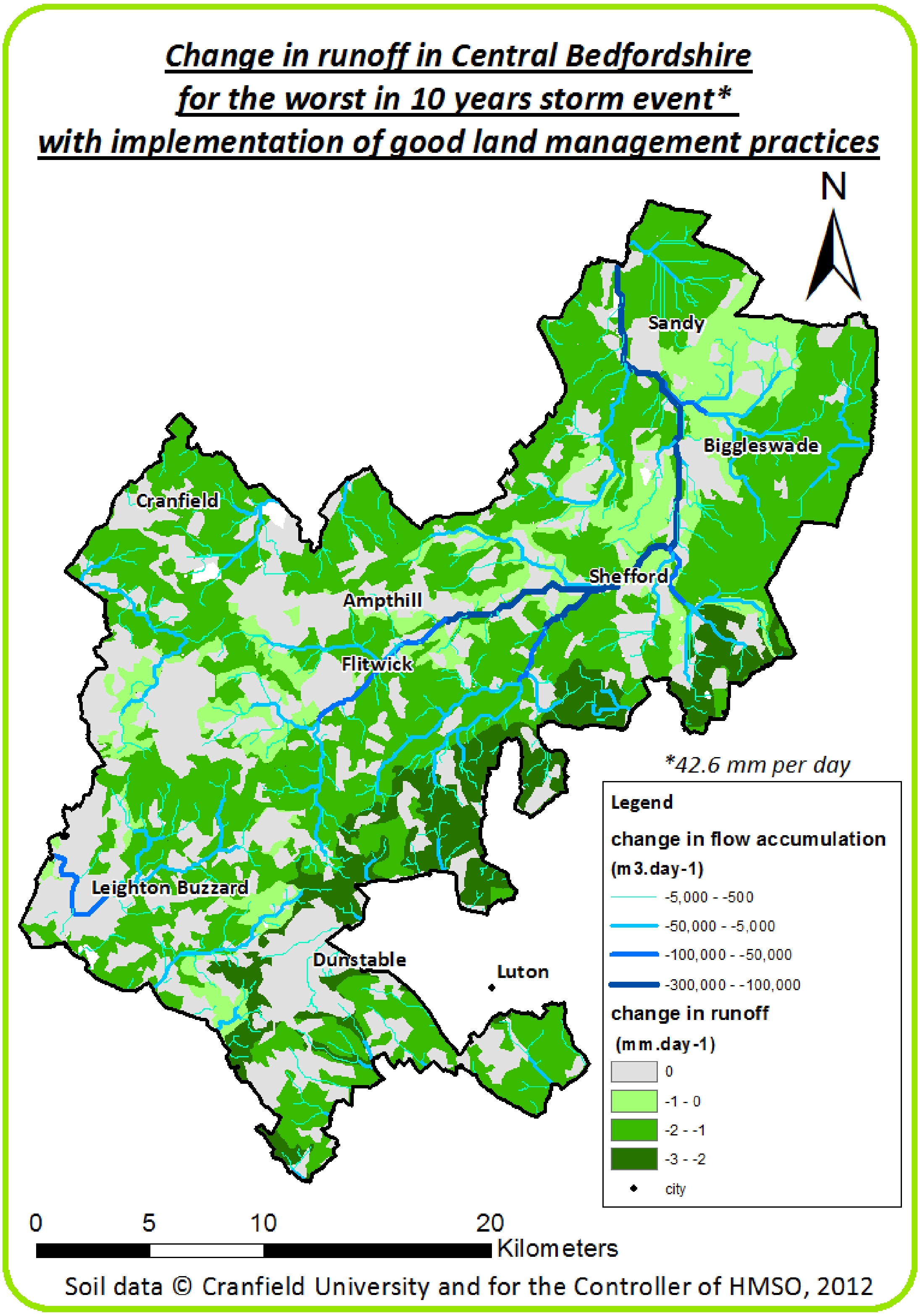

Figure 5.16 Runoff change in Central Bedfordshire County in comparison with the current situation when the good land management practices are implemented in arable land after the 1 in 10 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

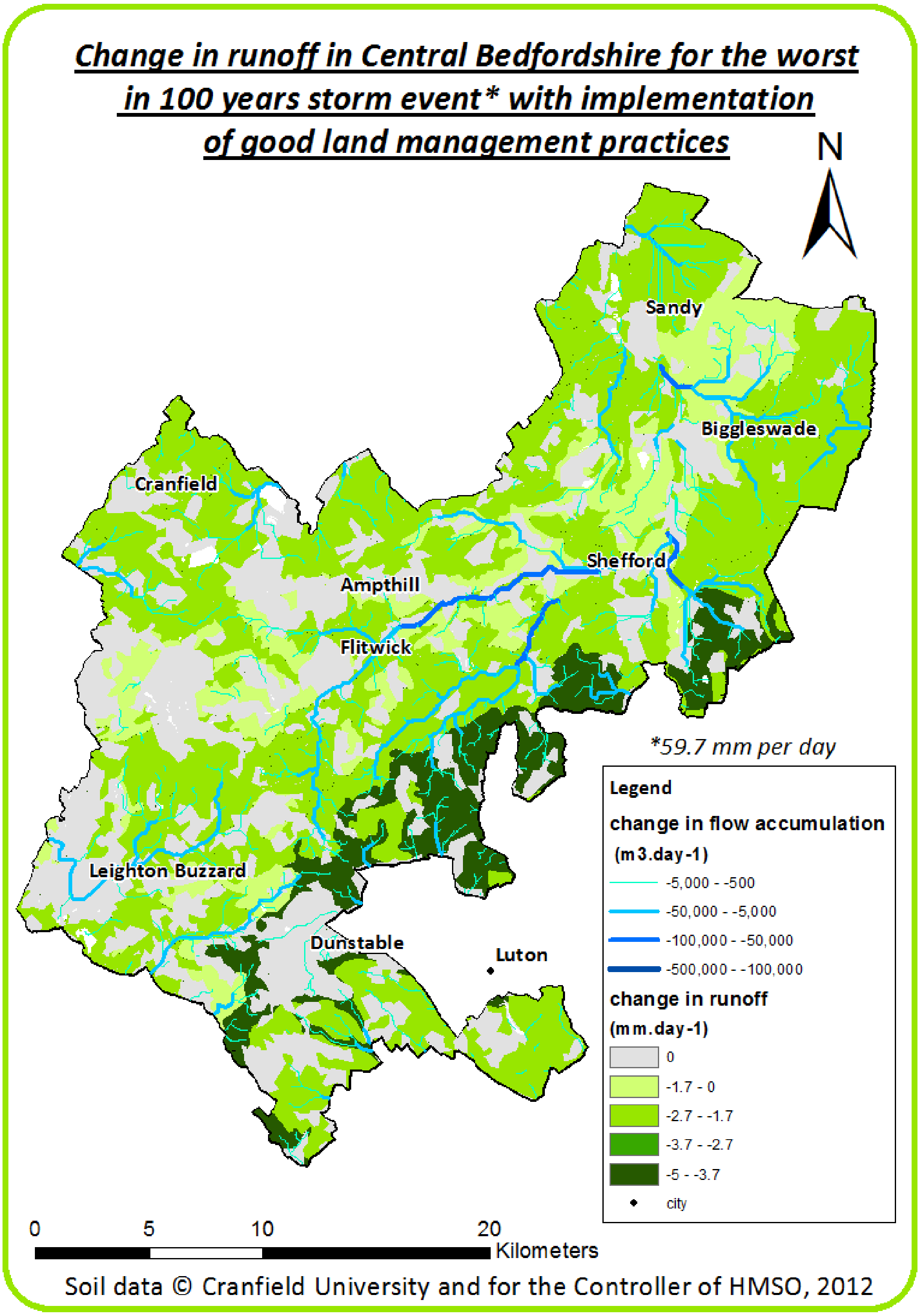

Figure 5.17 Runoff change in Central Bedfordshire County in comparison with the current situation when the good land management practices are implemented in arable land after the 1 in 100 years rainfall event. Negative values mean a decrease of the direct flow accumulation and/or the runoff generation. Positive values mean an increase of the direct flow accumulation and/or the runoff generation.

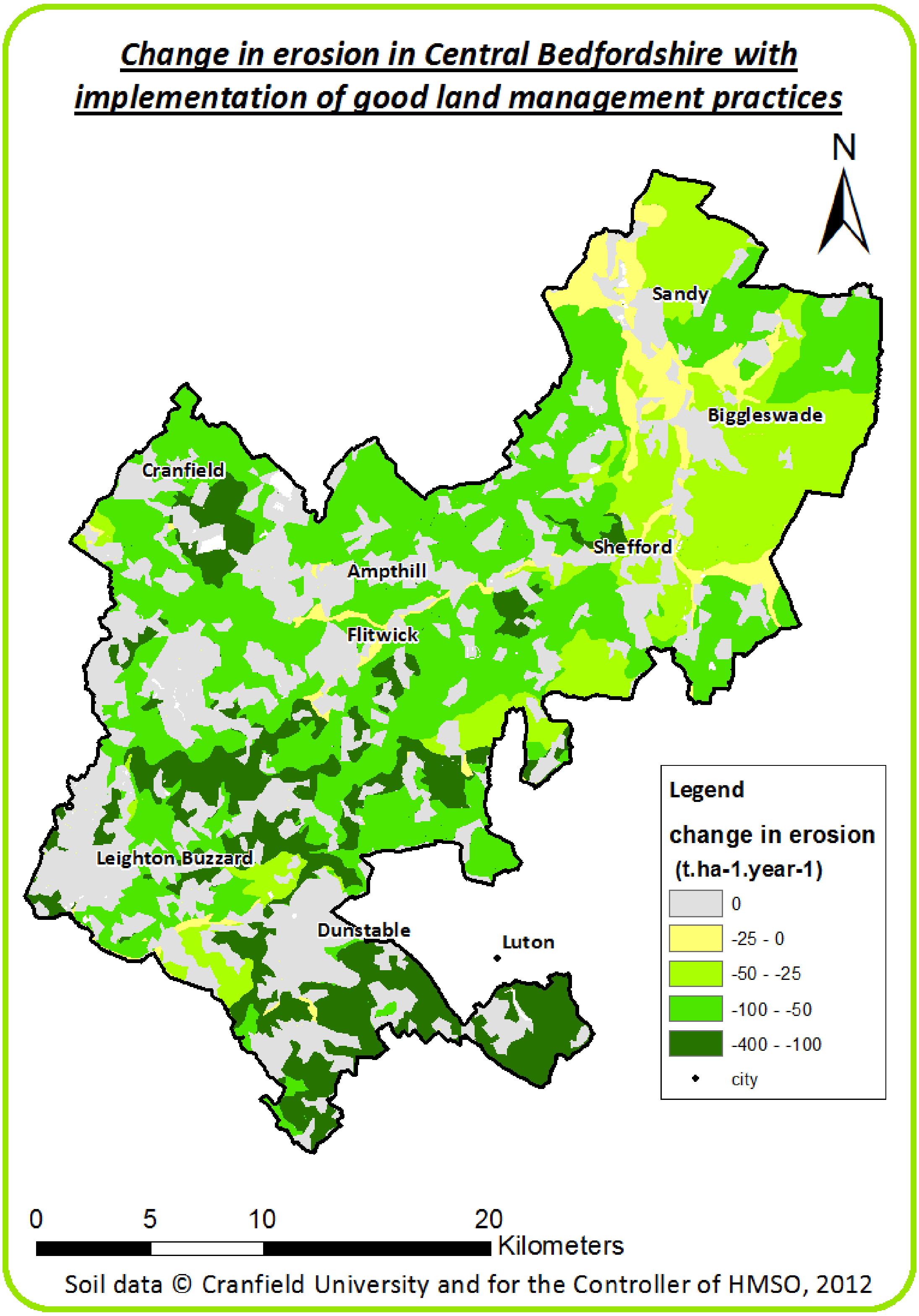

Figure 5.18 Soil loss change as consequence of the implementation of some good management practices in arable land throughout the entire county in comparison with the current situation. Positive values mean soil loss increase. Negative values mean soil loss decrease.

5.2 Discussion

5.2.1 Study limitations

Model inaccuracies

It is important to stress that the maps show modelled rather than measured values. The figures displayed should therefore be used to gauge relative rather than actual changes. In addition some of the models were developed for use in the USA, although they have been used both in the UK and the other parts of Europe (e.g. Environmental Agency, undated; Gallego-Alvarez et al. 2002; Hess et al. 2010).

Runoff values estimated in Central Bedfordshire were compared with the peak flows predicted at Shefford for the 1 in 10 years event and the 1 in 100 years event (Table 5.4). Annual maximum flows for the River Flit at Shefford, 1967 – 2003, (Environment Agency 2011) was used to make the estimation of peak flows. The calculations were made according to the Flood Estimation Handbook (FEH), supplementary report No. 1 (Kjeldsen, 2007). As expected, the estimation using the Curve Number method is considerably smaller than the estimation using FEH for the 1 in 10 years event. However, the estimation for the 1 in 100 years event is closer (Holman et al. 2003). One reason that could explain this tendency is that the Curve Number estimation made in this project only accounts for the direct flow, while the FEH estimation accounts for the total flow (direct flow as consequence of the rainfall event, and the river base flow). As the base flow has a greater relative importance in the 1 in 10 years peak flow estimation, differences between the methods are greater in the 10 years return period than in the 100 years return period.

In future studies, field samples would be beneficial in order to validate the accuracy of the erosion model in the area.

Table 5.4 Comparison between peak flow estimation at Shefford using the FEH method and the Curve Number method.

Return period (years)	Peak flow using FEH method (m^3/day)	Curve Number estimation (m^3/day)	Relative difference (%)
10	1,211,760	984,429	18.8
100	1,791,936	1,911,848	-6.7

In spite of the possible inaccuracies commented above, the models used to make the maps take into account the soil type, the climate, the topography, the land use, and the land management, thus they are useful to show runoff and erosion patterns. They are also helpful to assess potential risk and how land use changes and/or land management techniques affect runoff and erosion rates.

Corine Land Cover Map inaccuracies

The land use map used in the project (EIONET 2006) includes numerous different crops within the same category. Therefore, arable land was treated as a uniform cover type and, consequently, spatial variations due to the different types of crops found throughout Central Bedfordshire were not displayed in the results. Nevertheless, the proportion of each type of crop was taken into account to implement the erosion and runoff models (DEFRA 2009).

In addition, the land use categories on this land cover map showed some spatial inaccuracies, as was described in section 4.2.1.

Result tables making

The Curve Number method used to estimate the runoff classifies soil types according to their hydrologic behaviour. Such soil classification was adapted to the area using a conversion table made by Cranfield University, which shows the equivalences between the HOST system and the hydrologic soil groups (HSG) described in the CN method handbook. Therefore, runoff results table were made according to the four HSG instead of the other soil types used for the rest of the ecosystem services.

The USLE erosion model is based in five variables to predict erosion. However, the result tables were expressed using the land use and the soil type. Therefore the values in the tables for a given land use and soil type are averaged over other factors that affect erosion such as slope.

Trans-border character of issues under investigation

This research presents results for regulating ecosystem services in Central Bedfordshire, but some of the processes involved have dependencies which go beyond the county borders. There are also outside factors affecting the ecosystems of Central Bedfordshire. This was unfortunately not possible to take into account in this study. For example, water coming from outside the County could have different values to those estimated in the study for factors such as direct flow accumulation.

5.2.2 Current situation

The soil erosion map shows the potential erosion as determined from properties of soil, ground slope, vegetation, and rainfall amounts and intensity (DEFRA 2005; Montgomery 2007). In some areas, soils with a high infiltration rate have a high organic matter and good soil structure, and hence they show a high resistance to erosion. Soil textures such as sand, sandy loamy and loam can be less erodible than silty, very fine sand and certain clay textured soils. There is often high runoff and water erosion associated with sandy and light silty soils. Erosion rate can also be reduced by vegetation cover such as grassland or woodland (RPA and DEFRA 2010).

The erosion maps illustrate that slope and slope length play a very important role in water erosion. The highest erosion risk occurs in areas with steep slopes, and the associated increase in the energy and speed of water movement. In addition, steep slopes promote concentrated flows which can create rills and gullies (Staff et al. 1997; DEFRA 2005).

The soil erosion map also illustrates high runoff and soil erosion in areas where there is little or no vegetation, i.e. mine sites (RPA and DEFRA 2010). Vegetation which can provide soil protection for a greater part of the year will be more effective in minimizing erosion than vegetative which only occupies the ground for part of the year (Staff et al. 1997).

Arable land often has a low infiltration capacity, perhaps due to soil compaction. Although drainage systems were not taken into account in the model, it is important to state that a decline in their maintenance may lead to an increase in surface water runoff (O'Connell et al. 2007). Urban areas are another important factor in the runoff map. Urban development which replaces vegetative soils with impermeable surfaces can increase surface runoff, which is then collected in pipes and rapidly delivered to the streams. This rapid accumulation of water can lead to local flooding. The effect depends on the size of the urban development and the natural reaction of the catchment (Wheater and Evans 2009).

As commented in the Model Inaccuracies Section, the calculated values are only estimates. The predicted erosion values in some areas seem excessive. For example an erosion rate of 140 t ha^{-1} y^{-1} is equivalent to a soil loss of about 1 cm depth per year. Other erosion models such as the Morgan, Morgan and Finney (MMF) model, could have offered a greater accuracy. However the MMF model does not incorporate the effect of the land management practices on erosion, which was an objective of the project (Morgan 2005). Therefore, some precision was sacrificed in order to use a more versatile erosion model. In addition, the R factor was estimated using an alternative approach to that described in the USLE handbook due to the format of the rainfall data.

5.2.3 Future scenarios

Scenario 1: Urban development

As an immediate conclusion of the urban development scenario, small erosion rates on site were usually predicted in developed urban areas, i.e. residential areas, commercial areas, and open spaces, since concrete surfaces are difficult to erode. However, they often produced a greater runoff generation rate (Appendix C), because of the imperviousness of the concrete, many types of pavements, roofs, etc. (NIPC, 1997). The relative increase in runoff on a new urban development is greater in highly permeable soils, because there is a greater difference between the infiltration rate prior to the urbanization and after urbanization. The previous land use and soil management techniques also are very important in the runoff increase as consequence of a new urban area. For instance, the runoff increase would be greater if the land use before the urban development is forest rather than arable land (USDA 2012).

Urban areas have underground drains to collect runoff which feed into streams. These drains increase the speed of the water and, consequently, its ability to erode stream banks, to degrade streamside vegetation, and to make wider stream channels. A wider stream means smaller flow depth in normal flow conditions, which could have negative effects in water fauna (EPA 2012). Therefore, a good management of the urban runoff is needed to prevent collateral erosion hazards from urban areas.

Mine sites, construction sites, and landfills are classified as urban areas by the CLC map (EIONET 2006). Mine sites and landfills presented high erosion and runoff rates (figures 5.1, 5.2 & 5.3), which was an expected result due to the steep slope and great proportion of bare soil usually associated with them. Construction sites are a particular concern, especially with regard to the current plans to build new urban development within the region. Construction sites are usually associated with a high erosion rate, ranging from around 30 to more than 1000 t ha^{-1} $year^{-1}$ (Broz et al. 2003; Wisconsin Department of Natural Resources 2003). Nevertheless, low erosion was estimated in the project for such areas. This could be due to the the low slope and the low soil erodibility associated to the unique construction site of the county according to the CLC map (EIONET 2006). As consequence of the aforementioned, some management techniques should be implemented at mine sites, landfills and construction sites in order to reduce the erosion and runoff risk. An urban development case study can be found in the Appendix E1.

Urban development recommendations

Although more significant soil loss reductions were estimated in some areas of the county as consequence of concreting over soil, after widespread urban development relatively acceptable erosion rates on site are predicted throughout majority of the County. In fact, the potential development proposed by the CBC located in the South-West of Luton is the only one related with an area of high erosion risk in the widespread urban scenario (Appendix C, figure C3). Therefore, the runoff increase associated with new urban areas could be used as a criterion to select the best and the worst location for a new urban development. As a basic principle, a new urban development must maintain a similar runoff rate to that of the land use prior to the development. Thereby landscape changes will not disturb runoff patterns in the catchment (EPA 2012). Apart from an appropriate urban design, placing development areas on a soil where drainage is naturally already impeded could help to minimize the need for landscape changes in the catchment runoff pattern. Sealing a sand soil could, for instance, reduce the potential for water infiltration, but building in a clay area could increase the risk of soil subsidence. Furthermore, drier and hotter summers predicted by climate change models, might increase such problems in the UK (NERC 2012). Due to the smaller clay proportion in the group C Hydrologic Soil Group (HSG) in comparison with the D HSG, the likelihood of subsidence problems is smaller in C HSG (Appendix C, figure C1). Finally, the previous land use also plays an important role in the relative change in runoff after urbanization.

Figures 5.4 and 5.5 show the predicted changes in runoff generation after urban development taking into account soil permeability and previous land use. Areas with small runoff increase after urbanization may be preferable for urban development, but this needs to be balanced with possible hazards of soil subsidence, which are identified in maps from the British Geological Survey. In some cases subsidence resistant foundations are necessary (NERC 2012).

Figures 5.4 and 5.5 suggest that proposed urban developments close to Cranfield, west of Flitwick and Ampthill, to the north-East of Sandy; and the North-West of the area will result help minimise the baseline increase in run-off. By contrast sites north of Luton and in the South-West corner of Central Bedfordshire; some developments to the East of Ampthill; and the development North-East of Shefford will tend to result in increased run-off before the inclusion of additional measures.

Here urban recommendations to reduce runoff and soil erosion are outlined. As indicated in Table 2.4 (see Section 2.6), water quality can be described within a source-pathway-receptor framework. As soil erosion and runoff are *pathways* for the pollutants, reducing soil erosion and runoff will also reduce the connectivity between the pollutant source and the receptor.

As an immediate conclusion of the urban scenario, residential areas, commercial areas, and open spaces, usually do not cause a great soil loss on site (Appendix C, Figure C3). Nevertheless, residential and commercial areas produce a considerable amount of runoff which can cause indirect erosion problems in non-urban land. In addition, urban runoff is usually associated with water pollutants (Miller, 1997). Therefore, urban runoff should be managed properly to avoid major threat to non-urban land and water quality in the region.

Good structural design of controls for sustainable urban runoff within new urban developments is one of the aims of the Central Bedfordshire Council (Table 5.5) and a priority with regard to the Flood and Water Management Act 2010 and the commencement of the National Standards for Sustainable Drainage (2012). Such design could reduce the cost of urban runoff control, which is traditionally expensive especially if applied in developed urban areas, and make it more efficient.

Sustainable Urban Drainage Systems (SUDS) are surface water drainage methods integrated into urban areas which efficiently and sustainably manage water quantity (runoff) and water quality, as well as acting to improve urban biodiversity, amenity and aesthetic value. Furthermore, as Figure 5.19 shows conventional approaches to urban drainage focus on water quantity have negative effects on downstream watercourses (Table 5.5). Moreover traditional approaches are expensive and also unsustainable in the long term with future urban development and climate change (CIRIA 2012a).

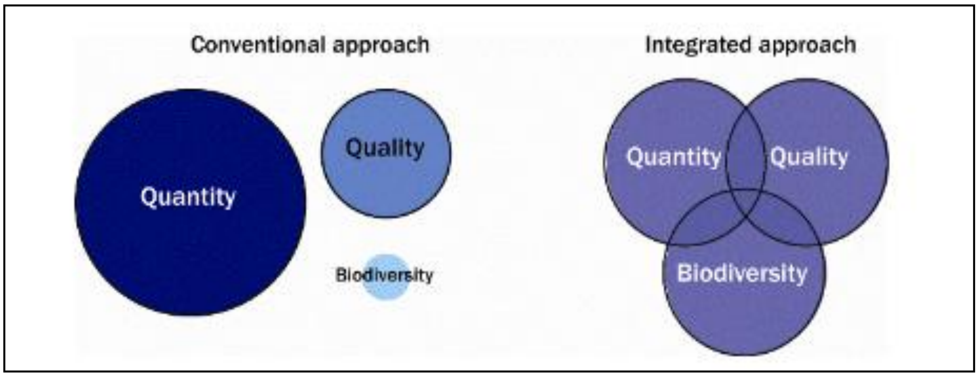

Figure 5.19 The change in effect in terms of regulating ecosystem services water quantity, water quality and biodiversity between conventional and integrated (SUDS) approaches to urban drainage (CIRIA 2012a)

Table 5.5 Urban drainage system recommendations to sustainably control runoff and water quality

Site of application	Management strategy	Effect on Ecosystem Services
Urban	**Traditional urban sewers**; conveying water as quickly as possible via underground pipes to the surrounding catchment (Not recommended) **Sustainable Urban Drainage System (SUDS)** (Recommended). SUDS require good site management and maintenance and include a variety of components to be incorporated into the design of new urban areas or retrofitted to existing urban areas including: • **Runoff Prevention**: Minimise paved areas, rainwater harvesting, minimise directly connected areas by draining hard area to unpaved areas (CIRIA 2012e) • **Filter strips (sloping areas) and swales (long shallow channels):** Vegetated surface features that drain water evenly off impermeable surface areas (CIRIA 2012f) • **Permeable surfaces and filter drains:** Runoff flows to permeable material below the ground which stores surface water via grass, gravel and permeable/ porous paving (CIRIA 2012g) • **Infiltration devices** including soakaways, infiltration trenches and infiltration basins as well as filter drains and ponds • **Basins** including flood plains and detention basins and **ponds** including balancing and attenuation ponds, flood storage reservoirs, lagoons, retention ponds and wetlands (CIRIA 2012h). • **Urban green areas** including lawn, trees and shrubs; proper design and management essential to ensure a good soil hydrologic condition that maximizes the infiltration ability of the soil. For example, addition of organic matter and soil cultivation prior to planting efficiently improve the infiltration rate of the soil (Bradley, 1995; Miller, 1997) • **Grass roofs** to increase permeable areas	Urban sewers increase the speed of water and consequently its ability to erode stream banks, to degrade streamside vegetation, and to make wider stream channels. A wider stream means smaller flow depth in normal flow conditions, which could have negative effects in water fauna (EPA 2012). In terms of water quality, there is a pollution risk when sewers are unable to cope with rainfall. Furthermore, there have been issues with pollutants from urban areas being washed into surface watercourses and groundwater and with urban diffuse pollution (including from sediments, fertilisers and pesticides) which are not managed by traditional drainage systems (CIRIA 2012b). More sustainable than traditional urban sewers, runoff volume and flow rates are managed minimising downstream flood risk posed by urbanisation and water quality enhanced; additional benefits include biodiversity and amenity enhancement and aesthetic value (CIRIA 2012a) Controlling the flow rate of runoff also prevents indirect downstream erosion hazards and minimises water pollution by sediment. SUDS behave as natural drainage systems (CIRIA 2012b): • Attenuate runoff: Store runoff and release it slowly • Enhance infiltration and reduce runoff: allow water to soak into the ground and reduce conveyance of pollutants (can cause pollution of groundwater through leaching unless pollutants filtered out first) • Slow conveyance of water on surface and reduce flow rate of runoff • Filter out urban pollutants either by settlement or biological breakdown • Controlling the flow of the water so sediments settle out preventing sediment pollution of water courses

However, SUDS are a more efficient integrated approach, which are less expensive, they creates a smaller disturbance to the natural environment and they tackles two regulating ecosystem services in equal proportion, water quantity (runoff) and quality, within one system (CIRIA 2012a). SUDS can also be sustainable in the long term. In terms of urban development they allow new development within existing developments where existing sewerage systems are close to full capacity. Furthermore climate change is accounted for as infiltration and water quality is enhanced and aquifers recharged with high quality water. Additionally, rainwater is harvested for uses such as flushing toilets and irrigation that do not require treated water from the mains (CIRIA 2012c). On the other hand, some disadvantages of SUDS should be considered. Many of these surface drainage methods need maintenance to ensure good results. In addition, the water table, the soil permeability, the slope and other factors should be taken into account to assess the suitability of the site for certain drainage methods (EPA 2000).

In the future Central Bedfordshire is expected to undergo a significant amount of urban development, and as previously stated, construction sites have high erosion and runoff risks. Therefore, management techniques should be implemented in future new construction sites to reduce erosion and runoff hazards, and thus protect water quality of surface water bodies (Table 5.6).

Cost, efficiency and technical features of the erosion prevention measures exposed in Table 5.6 vary from one technique to another in order to offer a set of possible solutions that meet the objectives and constraints of each particular construction site. Therefore, the greater or lesser suitability of every technique will vary according to several factors such as the development budget, erosion rates, topography, soil type, etc.

Some management techniques could be implemented at mine sites and landfills to reduce the high erosion rates predicted in the Scenario 1 (Tables 5.7 and 5.8). In addition, such management techniques should improve water quality in surface water bodies.

Vegetative covers efficiently reduces the erosion rate in derelict mine sites. Moreover, runoff channels and stabilizations ponds also can be useful to prevent erosion (Loch 2000; Wong 2003). However, vegetative cover establishment is difficult in mine sites because the soil is usually degraded, e.g. poor structure, compaction, lack of nutrients. Therefore, soil physical conditions and growing conditions should be improved before vegetation establishment (Table 5.8). A good physical structure allows root growth and improve hydrologic characteristics of the soil. Nevertheless, that is not enough to ensure plant growth. As consequence, different techniques are used to increase soil nutrients, and to regulate pH and temperature.

Table 5.6 Land management recommendations to prevent erosion at construction sites (Broz et al. 2003).

Site of application	Management strategy	Effect on Ecosystem Services
Construction site	Temporary/permanent vegetative cover	Stabilization of the soil, reducing raindrop detachment and the input of sediment to runoff; protects water quality of surface watercourses.
	Natural mulch	
	Geotextile	
	Soil amendments	
	Silt Barriers	Reduction of runoff speed, leading sedimentation and sheet flow, reduces sediment input to runoff. Interception of sediment-laden runoff further which protects water quality.
	Straw bale barriers	
	Temporary sediment traps	
	Diversions	Dike or channel (or group of them) to avoid sediment-laden water leaving the construction site as off-site runoff and therefore protecting water quality.
	Check dams	Reduce concentred flow and, consequently, erosion on channels; reduces sediment entering surface water bodies and improves water quality
	Rock dams sediment basin	
	Inlet protection	Prevent drainage block in construction sites where required.

Table 5.7 Land management recommendations to prevent erosion on landfill slopes (Grobe 2007).

Site of application	Management strategy	**Effect on Ecosystem Services**
Landfill slopes	Hydro-seedling	Stabilization of soil surface by mean of vegetation establishment, reducing raindrop detachment and preventing the rills and gully creation. Reduction of sediment input to runoff protects water quality of surface water courses.
	Compost + seedling	

Table 5.8 Management techniques to reduce erosion at mine sites (Loch 2000).

Site of application	Management strategy	Effect on Ecosystem Services
Mine sites	Crushing	Improving physical conditions of mine soils
	Ripping	
	Grading	
	Drainage	
	Topsoil addition in poor substrates	Improving growing conditions
	Inoculation with mycorhiza and N-fixing bacteria	
	Organic waste addition	
	Mulch	
	Inorganic Amendments	
	Fertilization	
	Vegetative cover (terracing if needed)	Erosion reduction. Reduction of sediment input to runoff protects water quality of surface water courses.
	Runoff channels	
	Stabilization ponds	

Land management scenario

According with the USLE and the Curve Number method, the land management techniques applied in the scenario 5 effectively reduce the erosion and the runoff in arable areas. Nevertheless, predicted reduction in erosion were more significant than in runoff (Figure 5.16, 5.17, 5,18). That is probably because the effect of the cover crops in runoff is not quantified by the Curve Number method. Therefore, it is important to highlight that the effect of the good land management techniques in arable land could be greater than predicted in this scenario.

Good land management techniques in arable land techniques are generally based on two principles: increasing the vegetation cover, and improving the soil structure. The objective of such techniques is to minimize the erosion and runoff generation, maximizing at the same time the sedimentation and infiltration rate within the field.

Techniques such as buffer strips, permanent in field areas, field corners, hedgerows and beetle banks aim to increase the vegetative cover within the field in order to protect the soil against raindrop detachment. Furthermore, such permanent grass covers slow down water, preventing concentrated flow which is more erosive than the sheet flow and increasing sedimentation and infiltration within the same field where runoff in originated. Finally, roots systems increase the cohesion of soil particles, increasing its resistance against erosion (DEFRA 2008; Morgan 2005). Cover crops have a similar effect. Nevertheless they are especially important during the crop cycle stages in which the main crop of the field is not able to provide enough protection to the soils. Although the effect of cover crops in runoff was not estimated, they effectively reduce the runoff in areas prone to winter runoff generation, while their effect is rather smaller in areas of low winter runoff (Howarth et al. 2007).

Land management practices such as contouring try to shape the terrain so as to maximize the infiltration rate of the soil and, consequently, the amount of water needed to start the runoff. Furthermore, runoff is kept on the site avoiding floods and water erosion. Therefore, greater rainfall events are needed to lead significant surface water movement in the field. However rills formation could considerably reduce the effect of these techniques, but beetle banks were proposed to reduce the likelihood of a runoff network formation in the field, preserving the contouring efficiency (Jasa and Dickey, 1991; Natural England 2010a; McIsaac et al. 1991; Quinton and Catt 2004).

Finally, the costs of runoff and erosion prevention were taken into account in order to choose the set of land management techniques implemented in Scenario 5. Therefore, majority of these land management practices are included in the ELS. In this way, the farmer income reduction as consequence of the crop surface decrease and other extra expenditures during the crop cycle, such as cover crop and grass areas maintenance, is compensated with a grant. Moreover, permanent in-field grass areas, which involve a great crop surface reduction, were implemented only in areas where the current erosion rate estimated was greater than 100 t ha^{-1} y^{-1} (Natural England 2010a, Silgram 2012).

The land management case study can be found in the Appendix E2.

Land management recommendations

The good land management practices for arable land implemented in this scenario reduced the predicted runoff and especially the predicted erosion rate in the majority of the County's arable land (Figures 5.16, 5.17 and 5.18). Erosion, which is a particular concern on arable land, should be controlled to improved water quality. Therefore, implementation of good land management techniques to prevent erosion and runoff is recommended in all the arable land in Central Bedfordshire. Farmers might not have serious problems to afford the extra costs involved in runoff and erosion prevention, since majority of the land practices assessed in the scenario are included in the Entry Level Stewardship (Natural England 2010a). As a bare minimum, land management practices mitigating erosion and runoff should be encouraged in the areas where the greatest soil loss rates were predicted (Figure 5.3).

The scenario considered ELS measures. However, in areas where predicted erosion rate after implementation of the management techniques was still quite high (See Appendix C), it could be recommended to undertake some extra erosion and runoff prevention measures such as minimum tillage and the use of crop residues as soil cover. Furthermore a land use change, turning the area into either pasture or woodland, could be also implemented in such areas. That measure is included within the High Level Stewardship (Natural England 2010c).

Here land management measures to reduce runoff and soil erosion are outlined. As mentioned in the literature review, the European Commission (EC) and the UK government work towards good agricultural and environmental conditions through the CAP, which includes the promotion of good management of water and soil (Natural England 2010a). At the most basic CAP level (Section 2.7, Figure2.9) farmers achieve Single Payment Schemes through satisfying cross-compliance requirements (DEFRA 2011; RPA 2012) (Section 2.7). In this scenario, some of the ELS schemes were implemented to assess their efficiency controlling soil erosion and runoff. However, there are other land management practices included within the ELS handbook that could be implemented to minimize soil loss and runoff (Table 5.9).

A Basic Payment Scheme is planned to replace the existing Single Payment Scheme in 2014 as part of a CAP reform by the EC. Importantly for the control of soil erosion, runoff and water quality, a new 'Greening' element will place 7% of eligible arable land or temporary grassland in ecological focus areas (e.g. Fallow or buffer strips); it is likely this will not include land receiving payments for Environmental Stewardship. (Bidwells 2012). This will be a step forward for improving soil erosion, runoff and water quality at the most basic CAP level.

Even though there is close relationship between water runoff and soil erosion, there is some variation in how effective the application of ELS package options are in changing either of them. The application of buffer strips within the field or edge of the field has significant reduction in water runoff as compared to soil erosion. Buffer strips retard water runoff by their surface roughness (DEFRA 2005; Findlay et al. 1991; Pan et al. 2010). . Verstraete et al. 2006 also said that grass buffer strips do not significantly bring down soil loss. They only reduce runoff erosion downstream. Similarly, Stevens et al. (2007) found out that application of beetle bank option brings in significant reductions in runoff variables when established on contours and contribute additional biodiversity benefit to the farmer. It has been shown by National Research Council (2003) that establishment of in-field grass areas has significant impact in preventing gully erosion formation by conveying water runoff downstream in a non-erosive manner.

DEFRA (2005) reported that management of arable land in the whole field with overwinter stubble display significant impact in effectively reducing the erosive power of rain. This also agrees with what Inman and DEFRA (2005) indicated about management of high erosion risk cultivated land. It was said that there is significant reduction for both runoff and erosion due to the stubble in the field, increased infiltration due to rough surface which retard runoff and erosion.

O'Connell et al (2007) indicated that runoff management on free draining loamy, silty and sandy soils can reduce the runoff from maize crops by 30-100%. Moreover there was up to a 80% reduction in surface runoff when using winter cover crops.

In targeted priority areas (Figure 2.10), specific significant improvements to land use and management is critical. In these areas it is recommended that land is entered into competitive Higher Level Stewardship Schemes.

Table 5.9 Predicted ELS management requirements that reduce runoff, soil erosion, and therefore pollutant pathways (Natural England 2010a). Note that ↓ means reduced impact in the relative regulating ecosystem service; ↓ is reduction in impact, ↓↓ is significant reduction in impact, ↓↓↓ is dramatically high reduction in impact.

ELS code	ELS stipulation	Location	Impact on surface runoff of water	Impact on soil erosion	Recommendation
SPECIFIC TO PROTECTING SOIL AND WATER (EJ)					
EE1/EE2/EE3 EE4/EE5/EE6	Buffer strips:2-6m buffer strips on cultivated land and intensive grassland.	Within field/edge of field	↓↓	↓	2-6m buffer strips on cultivated land and intensive grassland. Do not use buffer strips for regular vehicular access, turning or storage; there should be no tracks, compacted areas or poaching by animal stock. (Natural England 2009)
EF7	Beetle Banks	Within field	↓↓	↓	Establish an earth ridge at least 2 m during cultivation across the slope. Grow a mixture of perennial grass which has to be trimmed during summer to enhance its establishment. Make sure it does not divert water to worsen the problem (Natural England 2009).
EJ1	Management of high erosion risk cultivated land	Whole field	↓	↓↓	Pigs should be kept indoors. Crops such as potatoes, sugar beet, maize, brassica fodder should not be grown. (Natural England 2009)
EJ2/ EJ10	Management of maize crops	Whole field	↓	↓↓	Harvest by October 1st, plough or cultivate the field and leave a rough surface for 2 weeks of harvest, then establish an autumn-grown crop or under sow the crop with a grass or clover based mixture after harvest , within the 2 weeks, remove any areas of soil compaction (Natural England 2008 and 2009)
EM1	Soil management plan	Within field	↓↓	↓↓	Get and follow appropriate DEFRA publication on runoff and erosion control. Come up with risk assessment of runoff and erosion for the farm. Come up with measures to manage the soil good structure and maintain rainfall infiltration. This has to be repeated on yearly basis by incorporating the previous years' experience (Natural England 2009)

EJ5	*Infield* grass areas to prevent erosion and runoff	Within field	↓	↓↓	Careful location of permanent grass areas: 1) Grass areas vulnerable to erosion e.g. Light soils on steep slopes 2) Grass natural drainage path ways (e.g. Valley bottoms) Do not use buffer strips for regular vehicular access, turning or storage; there should be no tracks or compacted areas. Do not graze the grassed area to prevent poaching (Natural England 2010).
EJ9	12m buffer strips for watercourses on cultivated land.	Close to watercourses	↓↓	↓	Do not use buffer strips for regular vehicular access, turning or storage; there should be no tracks or compacted areas. Do not graze the grassed area to prevent poaching (Natural England 2009 and 2010).
EJ13	Winter cover crops	Whole field	↓↓	↓↓↓	Establish cover crops early with general benefits derived from dense sowing of crops (Natural England 2010).
MULTI-FUNCTIONAL: CONTRIBUTES TO PROTECTION OF SOIL AND WATER					
EB1/EB2/EB3	Field boundary feature: Hedgerow management.	Edge of field	↓↓	↓	Maintain hedgerows and minimise livestock poaching and channelling of water runoff (Natural England 2010)
EC24	Hedgerow tree buffer strips on cultivated land	Within field/edge of field	↓↓	↓	Do not use buffer strips for regular vehicular access, turning or storage; there should be no tracks, compacted areas or poaching by animal stock (Natural England 2010).
EF1/EL1	Management of arable land and grassland: Management of field corners		↓↓	↓	Management of field corners taking land out of production and leaving as areas of permanent grassland; grassy areas can also be strategically placed between fields and between fields and water courses. Do not use buffer strips for regular vehicular access, turning or storage; there should be no tracks, compacted areas or poaching by animal stock (Natural England 2010).
EF6	Management of arable land: Overwintered stubble	Whole Field	↓↓	↓↓	Leave crop stubble and no grazing. Not to be done in areas of high runoff risk or erosion, for example tramlines, headlands and other severe compaction in fields with high slope, as these areas must be sub-soiled to reduce the risk (except where there are archaeological features or where conditions are wet) (Natural England 2010).

Apart of the ELS and HLS schemes, farmers have other choices to prevent erosion and runoff, such as contouring (Silgram 2012). In addition minimal tillage and the use of crop residues as soil cover can reduce erosion and runoff. Finally, subsoiling can improve soil structure and infiltration rates and can be considered as an efficient technique in runoff reduction (Jasa and Dickey, 1991; McIsaac et al. 1991; Quinton and Catt 2004).

Biodiversity Action Plan scenario

The Biodiversity Action Plan (BAP) in Bedfordshire focuses on "maintaining the natural balance of variety of organisms on land, in water, in the air and the relationship that exist amongst them in the habitats they live. The BAP is a means of engaging everyone in taking care of the natural world" (Bedslife, undated).

It is against this background that there are deliberate creations of arable field margins between crops and the field edges. These strips are there to underpin endangered species for instance corn parsley, field cow-wheat and shepherd's-needle (Bedslife, undated). Maintenance of hedgerows and traditional orchards also contributes to conservation of nature as some organisms find their niche habitat there. The field hedge-rows assist in changing the catchment properties of land and tend to slow down the runoff which may erode the soil, and at the same time enhance infiltration, thereby reducing both runoff and soil erosion (DEFRA 2008).

Biodiversity Conservation interventions in Bedfordshire can also offer runoff reduction and erosion prevention benefits. For example, meadows in the North and East of Luton and in the Ouse valley west of Bedford can provide vegetative cover to reduce soil erosion and increase infiltration. Woodland can also assist in controlling water runoff and soil erosion. Tree roots can bind the soil and understorey vegetation can slow the movement of water. Likewise the maintenance of floodplain grazing marshes and ponds can absorb flood waters. Reed beds are mentioned in the Biodiversity Action Plan, and in addition to providing a diverse habitat for birds, they can regulate water flow (Douglas et al. 2005). Details of a Biodiversity Action Plan case study can be found in Appendix E3.

Biodiversity Action Plan recommendations

The BAP recommendations to reduce runoff and soil erosion suggested here are:

1. Soils can be protected from rain impact by permanent vegetation cover (DEFRA 2005) therefore denuded calcareous grasslands should be replanted with natural species to control runoff and soil erosion.
2. Water attenuation ponds help in detaining runoff water (Environment Agency 2010). Therefore construction of additional ponds to replace lost ponds will help control runoff.
3. Reed beds assist in regulating runoff and have an advantage in underpinning wildlife habitats (Douglas et al. 2005), therefore additional reed beds should be established along the lakes and rivers.
4. High livestock numbers, and the associated poaching and compaction of the ground, can increase runoff and thereby flooding. It is recommended that stocking densities should be monitored in areas of high and runoff erosion risk (Holman et al. 2009; Meyles et al. 2006).

5.2.4 Climate Change

Key changes in Eastern England

The UK climate projections report (Murphy et al. 2009, EA 2009c) indicates future predictions in temperatures and precipitations under different emission scenarios and chances to occur. In Eastern England the identified changes, under medium emission scenario, would be:

- The annual mean precipitation is very unlikely to decrease more than 4% and increase more than 5%. The central estimate is that it will have a 0% of variation.
- The winter mean precipitation is very unlikely to increase less than 2% and more than 29%. The central estimate is that it will increase by 14%
- The summer mean precipitation is very unlikely to decrease more than 35% and increase more than 6%. The central estimate is that it will decrease by 15%.
- The mean temperature during winter is very unlikely to be less than 1.1°C and more than 3.4°C. The central estimate is that it will increase 2.2°C.
- The mean temperature during summer is very unlikely to increase less than 1.2°C and more than 4.3°C. The central estimate is that it will increase 2.5°C.

Nationally, it is predicted there will be an increase in the mean temperatures and changes in precipitation patterns; longer periods of drought during summer and punctual events of heavy precipitation during winter season.

Runoff, erosion and climate change

It has been reported that there could be an increase in winter rainfall in some areas by 30% by 2080s due to climate change while there could also be an increase in rainfall intensity both in winter and summer. More intense rainfall events would result in rising flood risks from drainage systems which are not well maintained (DEFRA 2008). Smaller base flows are also predicted in rivers in summer (EA 2009; Arnell, 2011). In the Anglian River Basin District, the Environmental Agency (River Management Plan 2009) has identified the potential impacts of climate change for the main pressures in the area (Table 5.10):

Table 5.10 Severity of climate change impacts on pressures in the Anglian River Basis District. Source : EA 2009c.

Pressure	Impact
Abstraction and other artificial flow pressures	Very High
Biological pressures	Low/Medium
Microbiological pressures	Medium
Organic pollution (sanitary determine and) pressure	Medium
Nutrients pressure (nitrogen and phosphate)	High
Priority hazardous substances, priority substances and specific pollutant pressure	Low
Acidification pressure	Medium
Salinity pressure	Medium
Temperature pressure	Low
Physical modification pressure	Medium
Sediment pressure	High

Flow pressure, nutrient pressure and sediment pressure will suffer the greatest effects. Flow pressure is meant to have a very high impact mainly due to demand for development growth. Development plans in the areas should contemplate sustainable ways of construction to minimize the negative effect that could have, both on increase the amount of sediment and increase the demanding population. Other possible cause for the increase in water abstraction identified in the River Basin Management Plan (EA 2009c) is related to the increase in temperatures. Higher temperatures will increase the water demand for domestic, leisure industries, agricultural and industrial uses.

The impact of climate change which has a direct effect on loss of base flow in rivers during summer could cause reduced flow velocities which result in long resident time for water in rivers hence creating an environment for algal growth (EA 2009).

More intense rainfall events involve greater erosion rates (Morgan 2005). In addition, alteration in crop types and seasonal patterns of forestry and agriculture may alter sediment runoff. Localized high erosion events, as a consequence of high rainfall events, are of particular concern in areas of bare soil, such as construction sites and derelict mine sites. The river capacity will be affected by sediments loads from channel erosion. There is also a possibility that climate change will increase the change of flow rate conditions. The river capacity will go down having high deposition of sediments upstream (EA 2009).

6. Water Quality

6.1 Results and interpretation

Water pollution sources, pathways and receptors

As described in the methodology, water pollution risk requires a source and a pathway, and the impact of that risk on the receptor (watercourse) will be dependent on the sensitivity of the receptor. For Central Bedfordshire area, four potential pollutants were considered (Table 6.1). The two main pathways for pollution to watercourses (receptors) are the more rapid pathways of soil erosion and overland flow (the main pathway for sediments, phosphates and some pesticides), and the slower pathways of leaching (the main pathway for other pesticides and nitrates) (Table 6.1). In the analysis it is useful to distinguish between these two pathways.

Table 6.1 Source-pathway-receptor framework for the main pollutants

Pollutant	Source	Pathway
Sediments	Urban, arable, woodland, and grassland	Soil erosion, overland flow and sub-surface flow
Phosphates	Urban, arable and grassland	Adsorption and soil erosion Overland and subsurface flow Leaching (secondary)
Pesticides	Urban and arable	Adsorption and soil erosion Overland and subsurface flow Leaching
Nitrates	Urban, arable and grassland	Overland and subsurface flow Leaching

6.1.1 Current Situation: Water pollution within surface watercourses (Receptors)

This section describes results showing the water quality of surface water bodies, receptors for pollutants transported via soil erosion, overland flow, subsurface flow and leaching; pollutants transported via these pathways include nitrate, phosphate, pesticides and sediments (Table 2.4).

Nitrate

Generally, the nitrate levels are graded as 6 (very high) with the exception of the River Great Ouse graded as 5 (high) and Henlow Brook graded as 4 (moderate); grades are taken from the Environment Agency's old system of the 'General Quality Assessment' since superseded by the WFD classification system (EA 2012e). Absolute values range from 24.9 to 75.2 mg NO_3 l^{-1} (Figure 6.1) (See Appendix D, table D1).

Phosphate

Generally, the phosphate levels are graded between 6 (very high) and 2 (low); the most frequent grade is 5 (high); grades are taken from the Environment Agency's old system of the 'General Quality Assessment' since superseded by the WFD classification system (EA 2012e). The absolute values range from 0.1 to 1.7 mg/l. (Figure 6.2) (See Appendix D, table D2).

Pesticides and sediments

Note that we could not access any information regarding the current levels of pesticides or sediments within the water courses of Central Bedfordshire.

Water Framework Directive (WFD 2000/60/EC) River status

Note that WFD status incorporates classifications for nitrates, phosphates and pesticides but not sediments.

Chemical Status (Pesticides)

The WFD ‘chemical status’ (WFD 2000/60/EC) of surface watercourses, includes certain pesticides as drivers (See Appendix A1). ‘Chemical status’ within Central Bedfordshire (Figure 6.3) shows classifications of either ‘good chemical status’ which means there are no discharges of priority substances including certain pesticides (EC 2012), into the surface watercourses, or as ‘does not require assessment’ which means that monitoring is not required as there are no known discharges of the priority substances including certain pesticides (EC 2012) into the surface watercourses (EA 2011a). Therefore no improvement to ‘chemical status’ within the rivers of Central Bedfordshire is required to achieve the WFD target of ‘good chemical status’ required by 2015 (WFD 2000/60/EC).

Ecological status

The WFD ‘ecological status’ (WFD 2000/60/EC) incorporates physico-chemical quality elements including phosphate status and specific pollutant status as drivers (See Appendix A1). Surface watercourses within Central Bedfordshire (EA 2012c) are classified as having an ‘ecological status’ ranging from ‘bad’ to ‘good’ (Figure 6.4). Watercourses showing ‘ecological status’ lower than ‘good’ require improvements in water quality to achieve the WFD target of ‘good ecological status’ by 2015 (WFD 2000/60/EC).

<u>Phosphate status</u>

Phosphates are a driver of ‘physico-chemical status’ and subsequently ‘ecological status’ of surface watercourses (WFD 2000/60/EC) (See Appendix A1). ‘Phosphate status’ is generally ‘poor’ within the major central rivers of Central Bedfordshire running across the central northeast to southwest strip of Central Bedfordshire (Figure 6.5) (See Appendix D, table D3); surface watercourses of Central Bedfordshire are yet to achieve the WFD target of ‘good phosphate status’ required by 2015 (WFD 2000/60/EC); smaller tributaries closer to the boundaries of Central Bedfordshire show generally ‘good status’ achieving the WFD target of ‘good phosphate status’ required by 2015 (WFD 2000/60/EC). Soil type to the northwest and southeast of this central ‘poor phosphate’ strip is mixed (Figure 2.6) however land use is predominantly arable (Figure 2.4) as is the case for the whole of Central Bedfordshire.

<u>Specific pollutant status</u>

Nitrates and phosphates (as substances which contribute to eutrophication) and pesticides (biocides and plant protection products) are included within ‘specific pollutant status’ (Figure 6.6), one of the drivers of the ‘physico-chemical status’ and subsequently ‘ecological status’ of surface watercourses (WFD 2000/60/EC) (See Appendix A1).

In terms of ‘specific pollutant status’ the majority of watercourses in Central Bedfordshire show a status of ‘good’ or ‘high’ (Figure 6.3) (Appendix D, table D3); these watercourses of Central Bedfordshire are achieving the WFD target of 'good chemical status' required by 2015 (WFD 2000/60/EC). The exceptions, classed as 'moderate' (Appendix D, table D4), are shown in Table 6.2 along with associated land use and soil type found within close proximity to the watercourse. These watercourses and surrounding areas are priority areas within which measures should be taken to improve the status of watercourses to ensure the WFD target of 'good specific pollutant status' is achieved by 2015 (WFD 2000/60/EC) as discussed in Section 6.7.2.

Table 6.2 Water courses showing moderate specific pollutant status within Central Bedfordshire and associated land use and soil type

River	Location	Soil Type (Figure 2.6)	Land Use (Figure 2.4)
Millbridge-Common Brooks	Between Sandy and Biggleswade	Deep loam over gravel Seasonally wet deep peat to loam Deep sandy	Predominantly arable; small discrete patches of urban and woodland
Running Waters-Steppingly	Between Ampthill and Flitwick	Deep clay	Urban (Ampthill and Flitwick) and arable in equal proportion
River Lee	Southwest of Dunstable	Deep loam to clay	Predominantly arable; small discrete patches of pasture, urban and woodland.

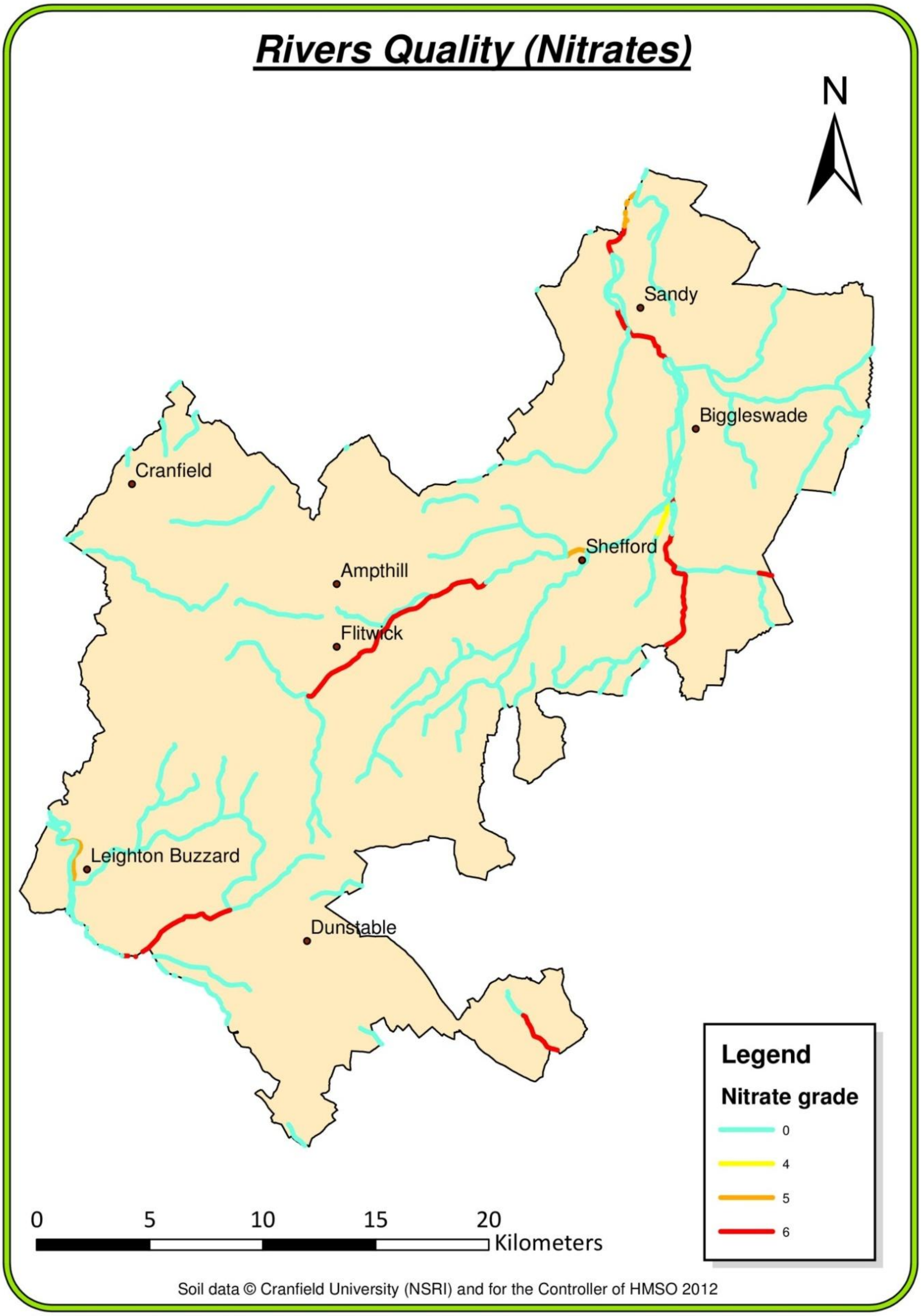

Figure 6.1 Nitrate content of watercourses. A higher number indicates a higher nitrate content ranging from 6 very high to 1 very low (Source: EA 2012c)

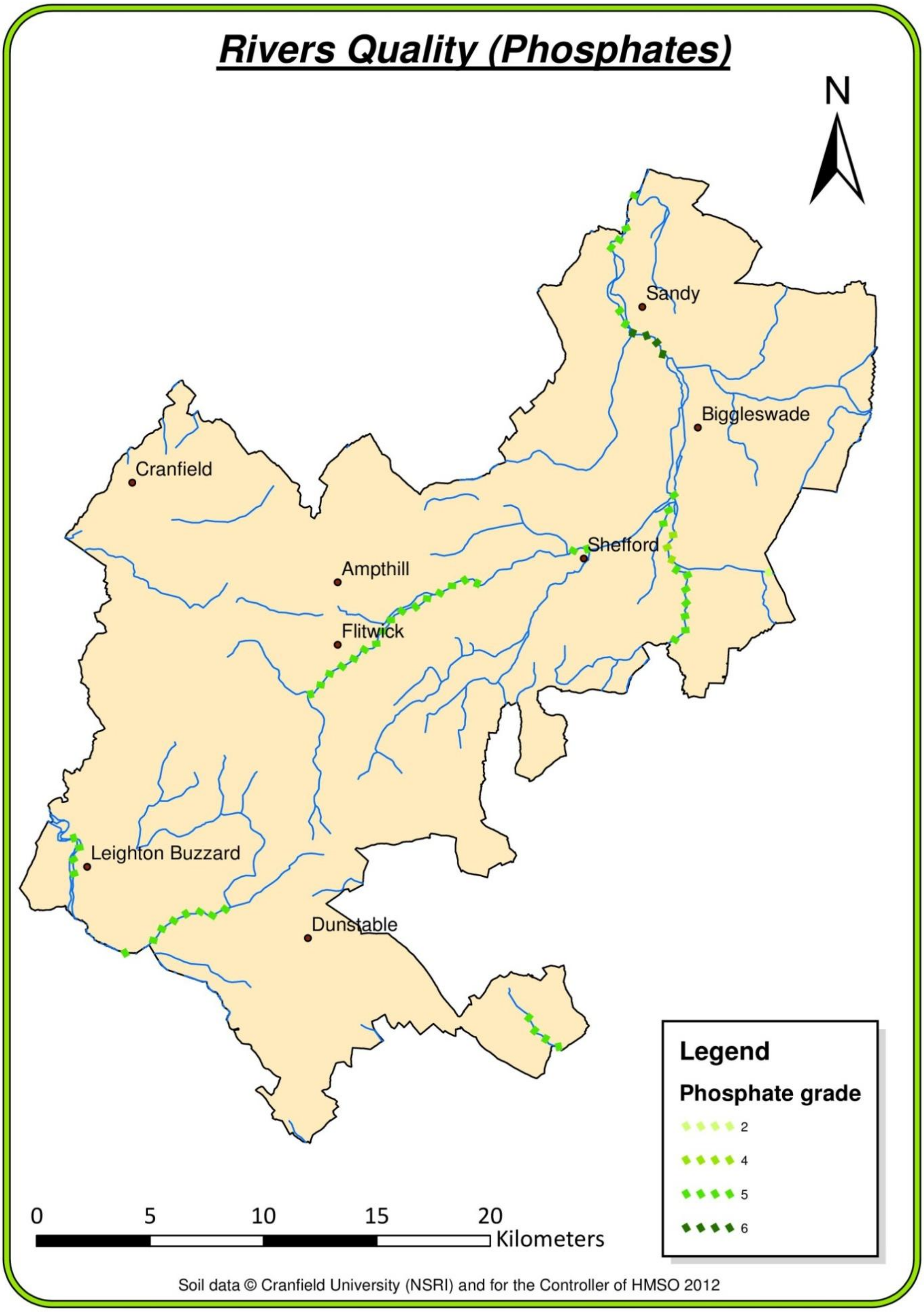

Figure 6.2 Phosphate content of watercourses. A higher number indicates a higher phosphate content ranging from 6 very high to 1 very low (Source: EA 2012c)

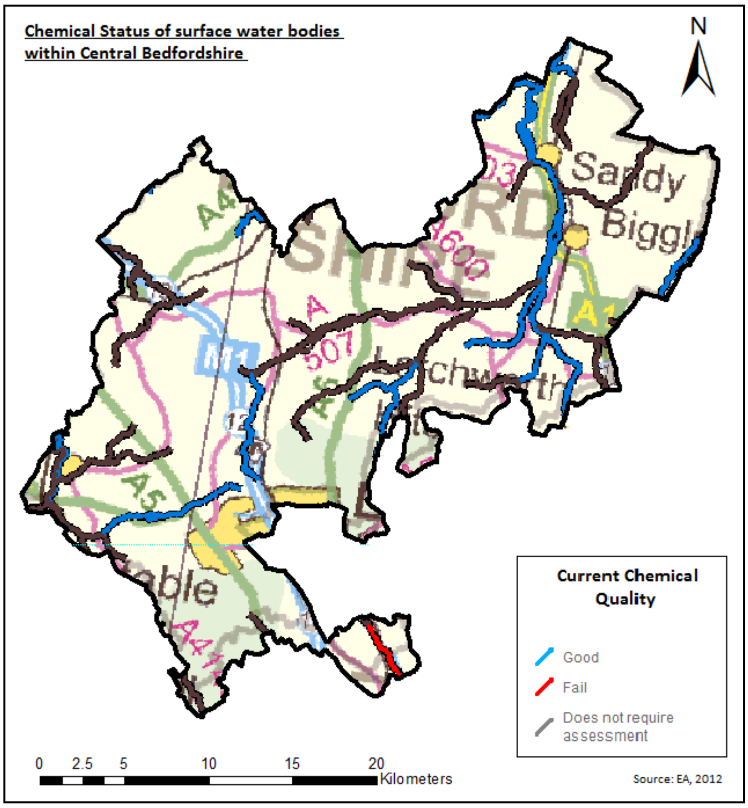

Figure 6.3 Chemical status of surface watercourses within Central Bedfordshire (EA 2012c).

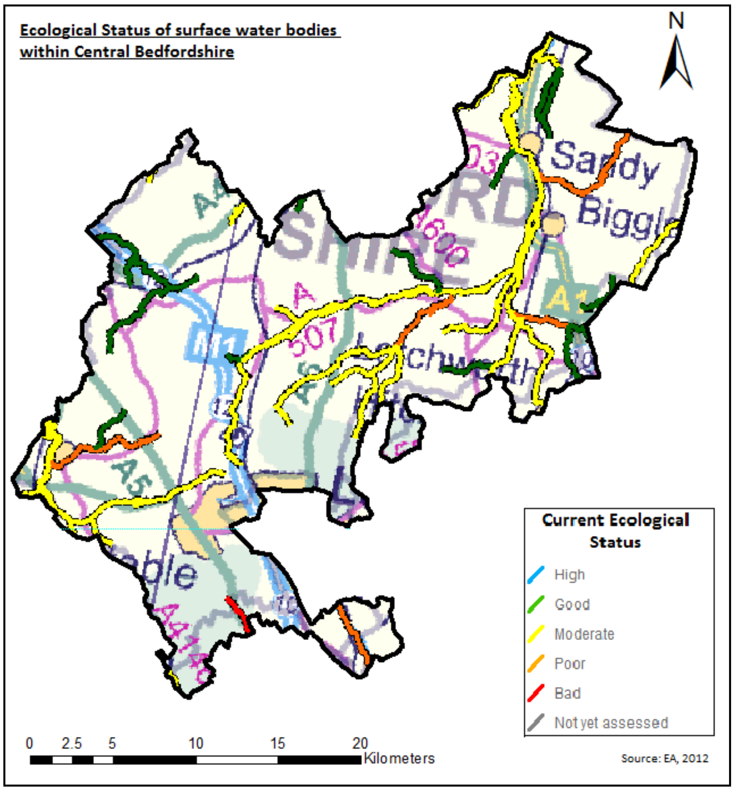

Figure 6.4 Ecological status of surface watercourses within Central Bedfordshire (EA 2012c)

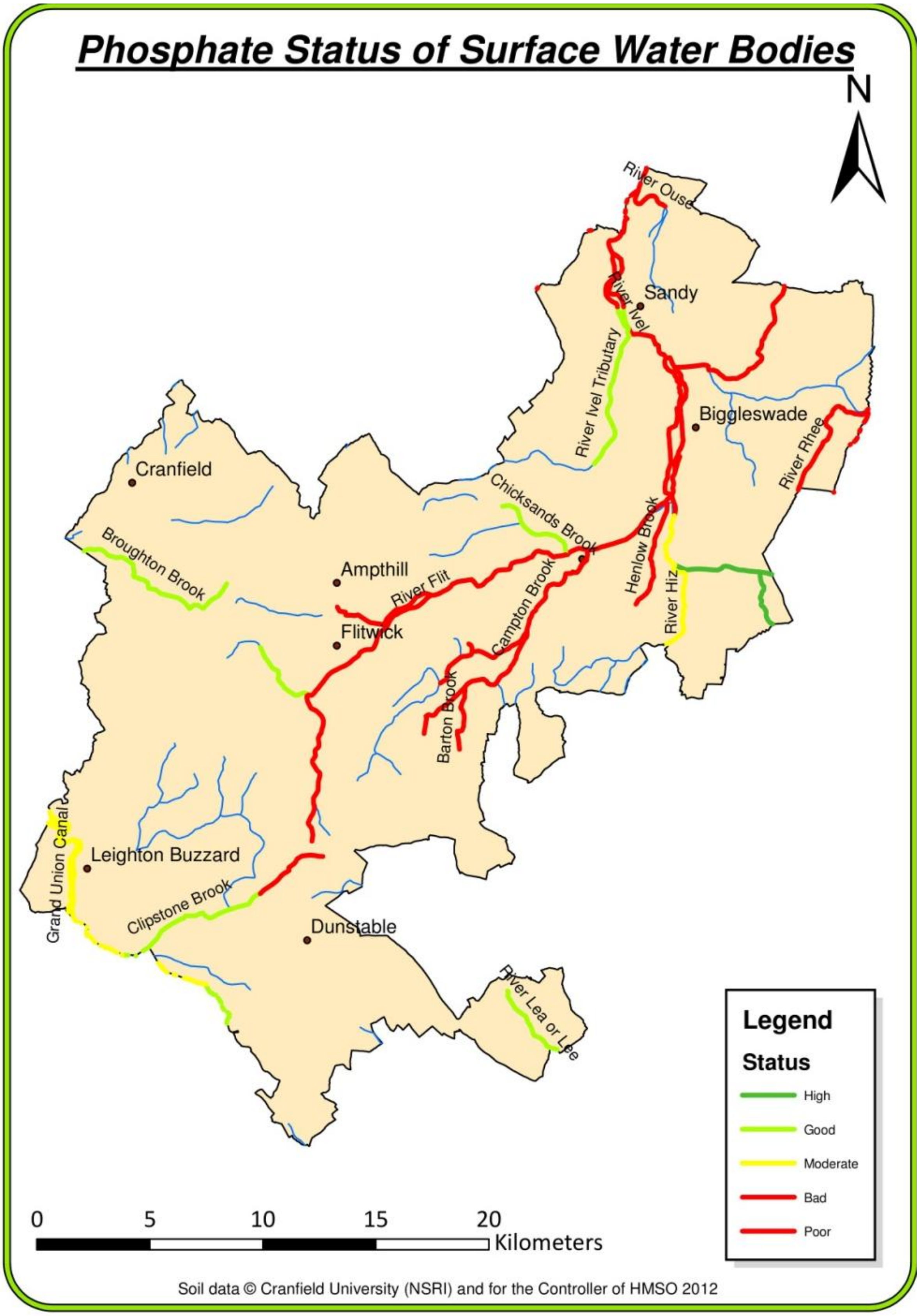

Figure 6.5 Phosphate status (WFD 2000/60/EC) of surface watercourses within Central Bedfordshire. (Source: EA 2012c).

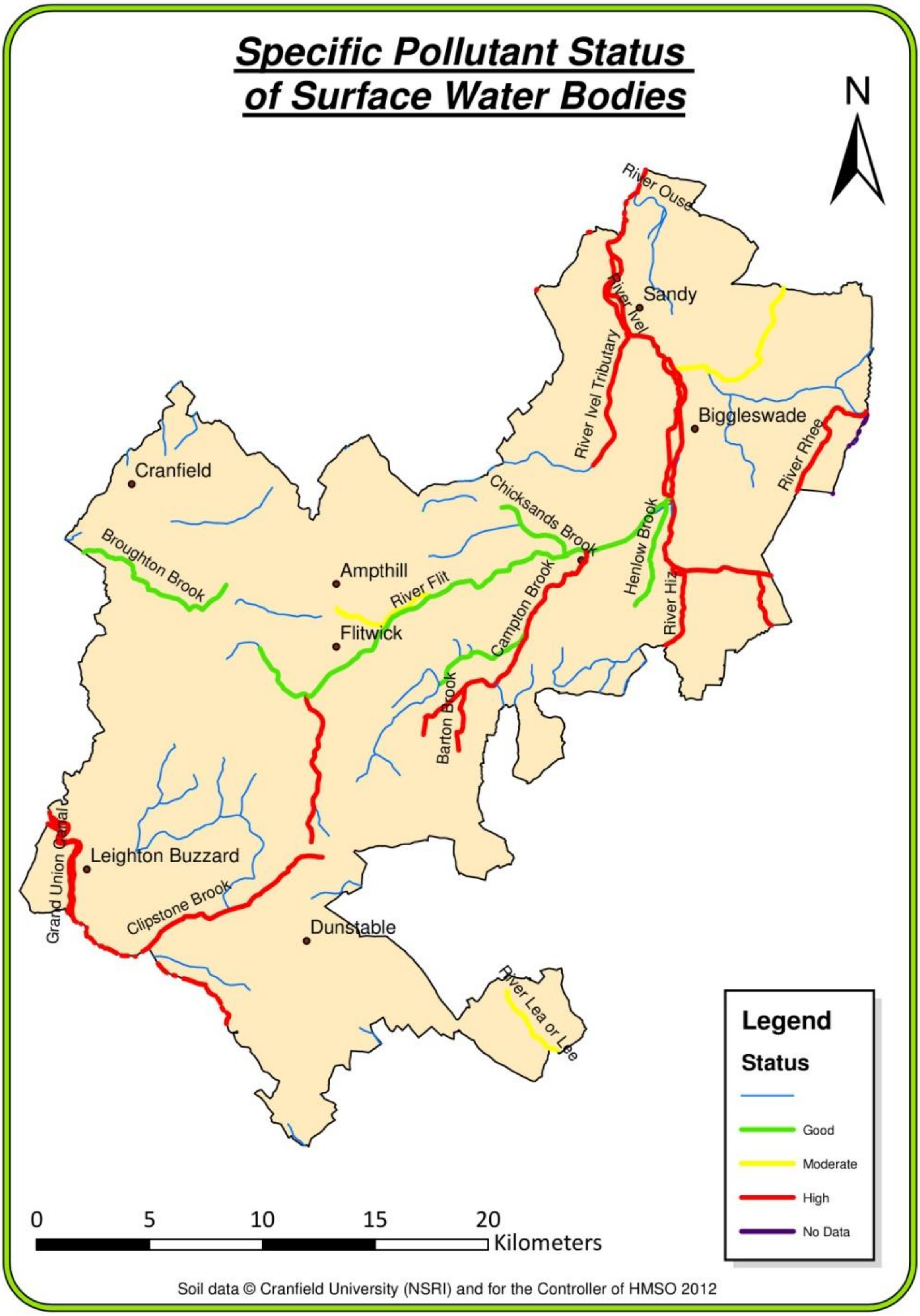

Figure 6.6 Specific pollutant Status (WFD 2000/60/EC) of surface watercourses within Central Bedfordshire

6.1.2 Current Situation: Water pollution within groundwater (Receptors)

This section describes the results showing the water quality of groundwater bodies, receptors for pollutants transported via leaching to groundwater; pollutants transported via these pathways include nitrates and pesticides (Table 2.4).

The Water Framework Directive (WFD 2000/60/EC) and Groundwater (Daughter) Directive (2006/118/EC) requires 'good status' in groundwater bodies by 2015. This status classification incorporates both the 'chemical' and 'quantitative status' of groundwater; the 'chemical status' classification includes nitrates and pesticides as drivers and the focus here (See Appendix A1). 'Chemical status' of groundwater within Central Bedfordshire (EA 2012f) (Figure 6.7) shows classifications of:

- 'poor' in a central strip trending southwest to north east across Central Bedfordshire
- 'good (deteriorating)' in a southern strip trending southwest to north east across Central Bedfordshire
- 'poor (deteriorating)' between Luton and Dunstable

These groundwater bodies of Central Bedfordshire therefore require improvements in water quality to achieve the WFD target of 'good chemical status' for groundwater required by 2015 (WFD 2000/60/EC and 2006/118/EC).

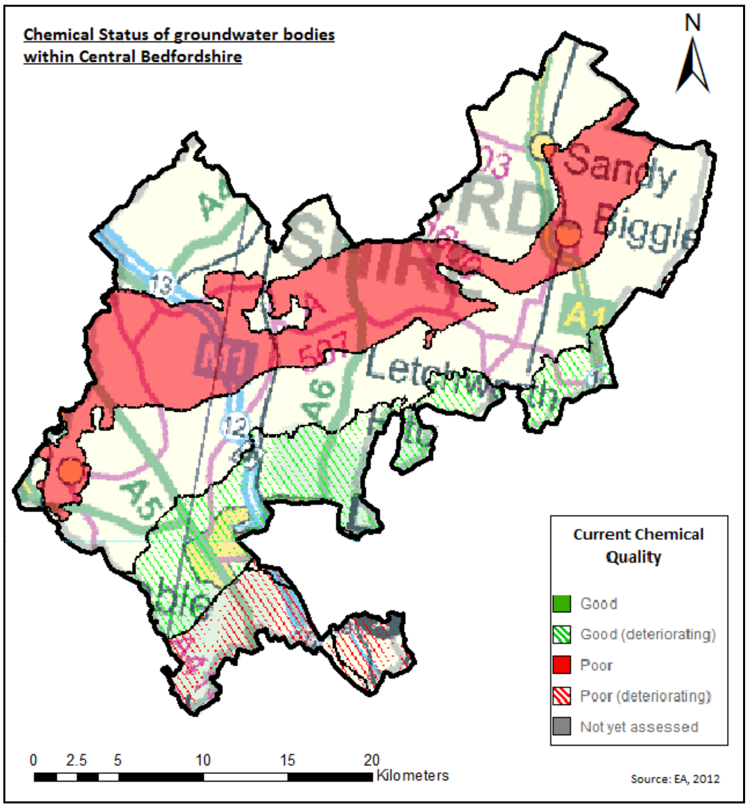

Figure 6.7 Chemical status of groundwater within Central Bedfordshire (EA 2012f)

The spatial pattern of groundwater status shown in Figure 6.7 is influenced by two major factors:

- **Geology:** 'Poor' status is seen across the central Woburn sands aquifer with the lower and middle chalk aquifers in the southern section having 'good (deteriorating)' and 'poor (deteriorating)' status (Figure 4.17).
- **Soil:** Deep clay areas are not classified in Figure 6.7 as there is minimal leaching soil to groundwater**;** the 'poor' status area in Figure 6.7 includes some clay soils, the 'good (deteriorating)' area includes shallow silty soil over chalk and loam over chalk. The 'poor (deteriorating)' status areas includes deep loam to clay soils.

6.1.3 Current Situation: Water pollution risk (Source and pathway)

Current water pollution risk (source and pathway) are linked to both soil type (Figure 2.6) and land use (Figure 2.4).

Overland flow risk

Sediment pollution risk through overland flow.

The sediment pollution risk map (Figure 6.8) bears similarity with the maps created in the runoff section (Figure 5.1). See the interpretation of it in section 5. Although different ranges of classification has been used to estimate the water pollution related issues (see Appendix A8, table A11), that will explain the different risk distribution.

Phosphate pollution risk through overland flow (adsorbed into soil particles).

Figure 6.9 of phosphate pollution risk shows that there is a concentration of the highest risk values in the area running from the middle part to the south of Central Bedfordshire. In this area soil type is heterogeneous and the predominant land use is agricultural, although other land uses are also present (Figure 2.4). The lower risk zone is mainly located as a continuous patch covering the north part. Most of this area presents a dominance of loamy and clayish soil types and again mainly under agricultural uses.

Pesticide pollution risk through overland flow**.**

Pesticide runoff risk was estimated to be greatest in a northern strip trending southwest to northeast centred on Cranfield, and a central strip trending southwest to northeast running from Leighton Buzzard to the north of Biggleswade (Figure 6.10). Deep clay is dominant in these areas (Figure 2.6), and the land use is predominantly arable with small discrete patches of pasture and urban (Figure 2.4).

Areas of very low and low risk of pesticide pollution of water through runoff similarly follow two strips extending from the southwest to northeast alternating with high risk areas (Figure 6.10). This pattern is mainly in line with the soil distribution map, low and very low risk areas are located where there is a fine or moderate fine textured soil such as deep sandy, shallow silty over chalk and loam over chalk (Figure 2.6). The majority of land use is again arable with small discrete patches of pasture and urban (Figure 2.4).

Areas assumed to contribute no source of pesticide and therefore no risk of pesticide pollution of water through runoff (null areas) include woodlands, water bodies, and some urban land uses (airports, mineral extraction sites and dump sites).

Overall risk of pollution through overland flow

The map of the overall risk of pollution through overland flow (Figure 6.11) is the combination of the different overland flow risk maps described before. Each layer has been weighted equally (33%). Most of the area is under moderate and high risk values (Figure 6.11). The highest values appear in two bands, the high risk value trends southwest to northeast in a northern, central and southern strip with a very high strip found in the south east part. Soil type is varied within these high risk areas including clay soil associated with higher values and sandy and loam soils associated with lower values (Figure 2.6). The land use under the higher risks is mainly agricultural (Figure 2.4). Areas of lower risk (Figure 6.11) include non arable land uses such as woodland and grassland (Figure 2.4)

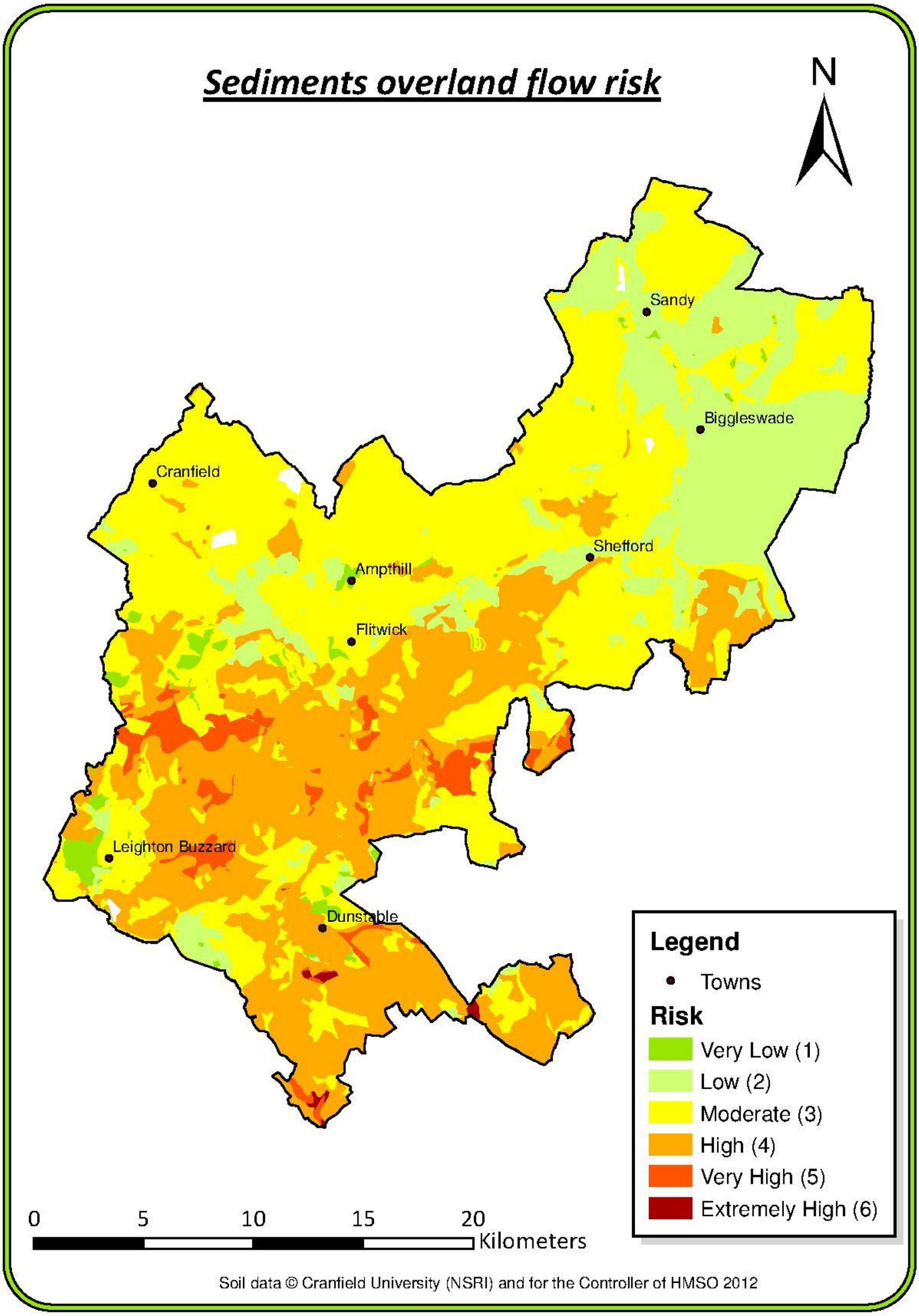

Figure 6.8 Spatial distribution of predicted sediment water pollution risk through overland flow in Central Bedfordshire

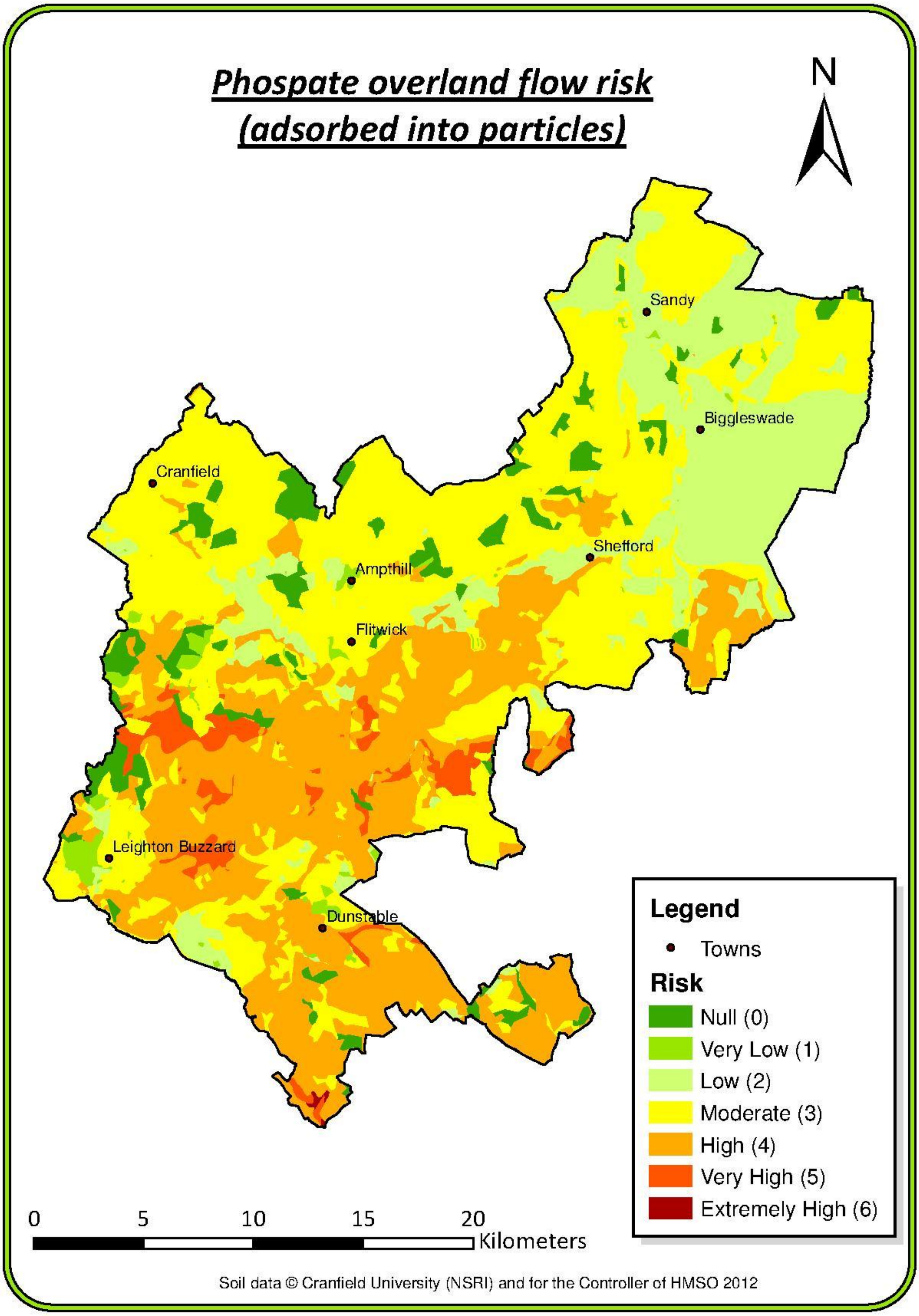

Figure 6.9 Spatial distribution of predicted phosphate water pollution risk through overland flow (adsorbed into soil particles) in Central Bedfordshire

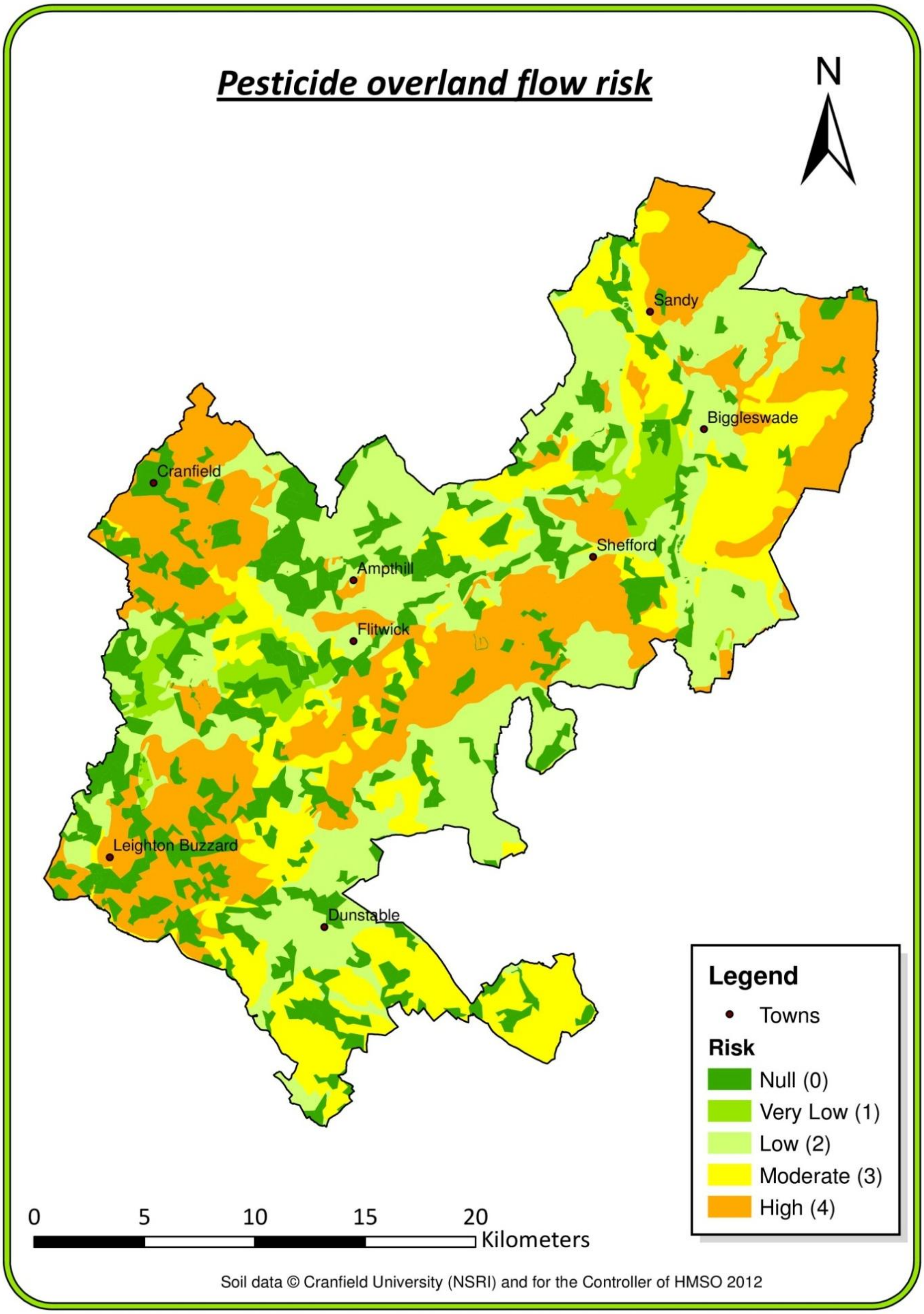

Figure 6.10 Spatial distribution of predicted pesticide water pollution risk through overland flow in Central Bedfordshire

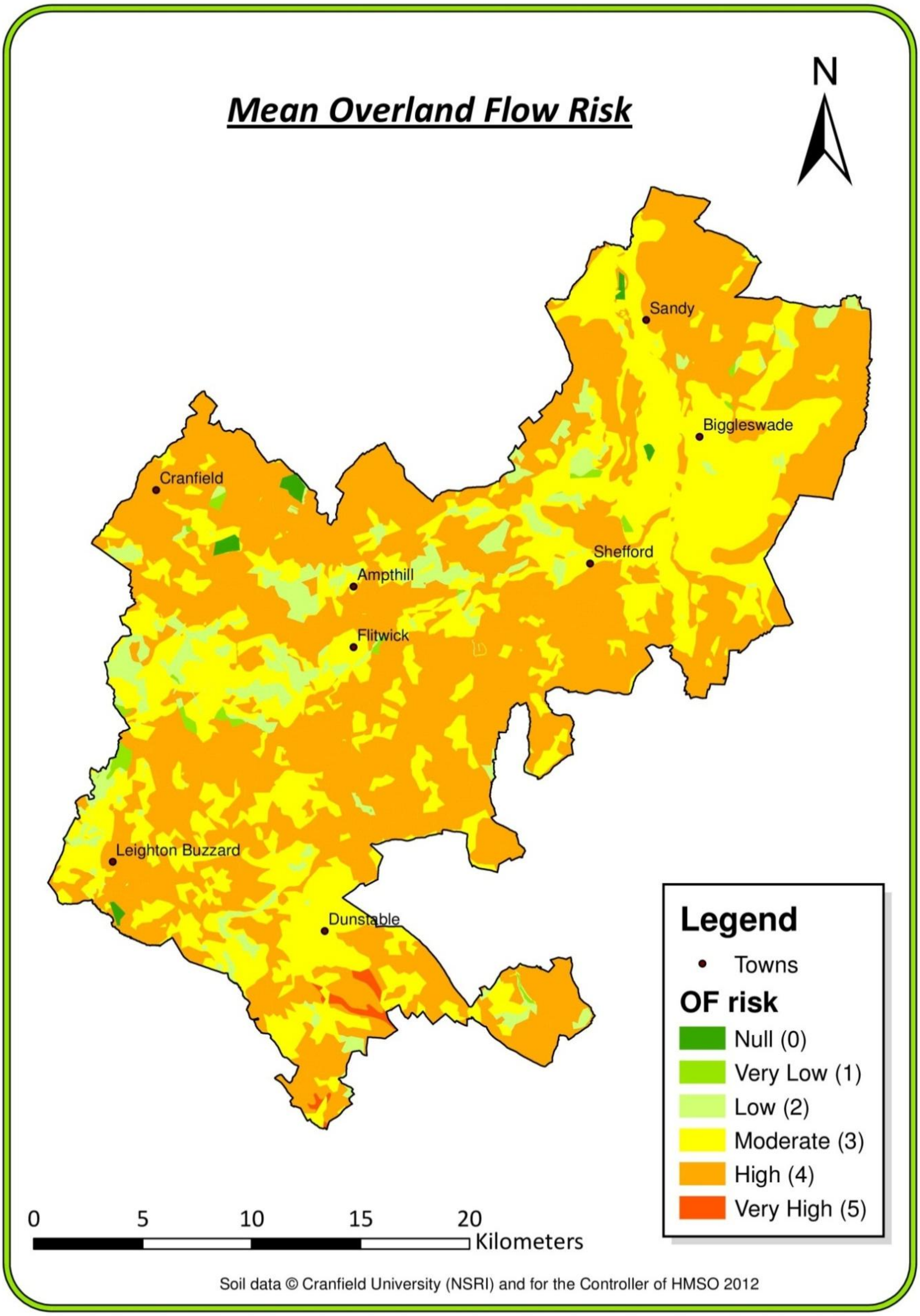

Figure 6.11 Spatial distribution of predicted overall water pollution risk through overland flow in Central Bedfordshire. Mean overland flow risk derived as the mean of pesticide, sediment and phosphate overland flow risk.

Leaching risk

Pesticide pollution risk through leaching

Areas of high risk include a broad area from Leighton Buzzard to Shefford (Figure 6.12) comprising deep sand and loam over red sandstone, and a southern west-east strip dominated by shallow silty soils over chalk and loam soils over chalk with a patch of seasonally wet loam over gravel in the east (Figure 2.6). Land use is a mix of arable, pasture and discontinuous urban fabric (Figure 2.4). Two discrete patches of low risk are observed in northwest of Central Bedfordshire (Figure 6.12). These patches present only one type of soil: deep wet clay (Figure 2.6). Land use is mixed in these areas (Figure 2.4)

Areas assumed to contribute no source of pesticide and therefore no risk of pesticide pollution of water through leaching (null areas on Figure 6.12) include woodlands, pasture, water bodies, and some urban land uses (airports, industrial/commercial, mineral extraction sites and dump sites).

Nitrate pollution risk through leaching

A strip of extreme risk of nitrate pollution through leaching risk crosses the east part of Central Bedfordshire (Figure 6.13), where two soil types can be found; loam over chalk and shallow silty over chalk (Figure 2.6). There is a mixture of land uses in this area (Figure 2.4).

There is a major high risk strip crossing Central Bedfordshire north to west (Figure 6.13) mainly over loamy and sandy soils (Figure 2.6) and a predominance of arable and grassland land uses (Figure 2.4). Lower risk areas (Figure 6.13) follow the pattern of deep clay soils (Figure 2.6).

Areas assumed to contribute no source of nitrates and therefore no risk of nitrate pollution of water through leaching (null areas on Figure 6.13) include woodland, water bodies, mines and construction sites.

Other pollutants risk of groundwater pollution through leaching

Areas of high risk of soil leaching to groundwater form two central strips, running west to east across Central Bedfordshire (Figure 6.14). The northern area is the greensand ridge running from north of Leighton Buzzard to Shefford, comprising deep sandy and loam soils over red sandstone (Figure 2.6). The southern area, including Dunstable, is predominantly shallow silty and loam soils over chalk (Figure 2.6). In this example, the land use is less important, as leaching risk to groundwater is primarily a function of underlying geology (see figure 4.17).

Areas assumed to contribute no source of nitrates or pesticides and therefore no risk of nitrate or pesticide pollution of groundwater through leaching (null areas on Figure 6.14) include woodland and water bodies.

Overall risk of pollution through leaching

Overall risk map is the combination of the different risk maps described above. Each layer has been weighted equally with a 33% of importance. Most of the area is under moderate and high risk values (Figure 6.15). Small patches of null and lower risk values are scattered throughout the territory (Figure 6.15), but always under land uses where the source of pollution is null or minimum (Woodland, grassland, water bodies, mines and some urban areas) (Figure 2.4). Higher risk values are mainly under shallow silty over chalk soils; and lowest under more clay rich soils including deep clay, deep loam to clay and seasonally wet clay (Figure 2.6). In these areas the predominant land use is agricultural (Figure 2.4).

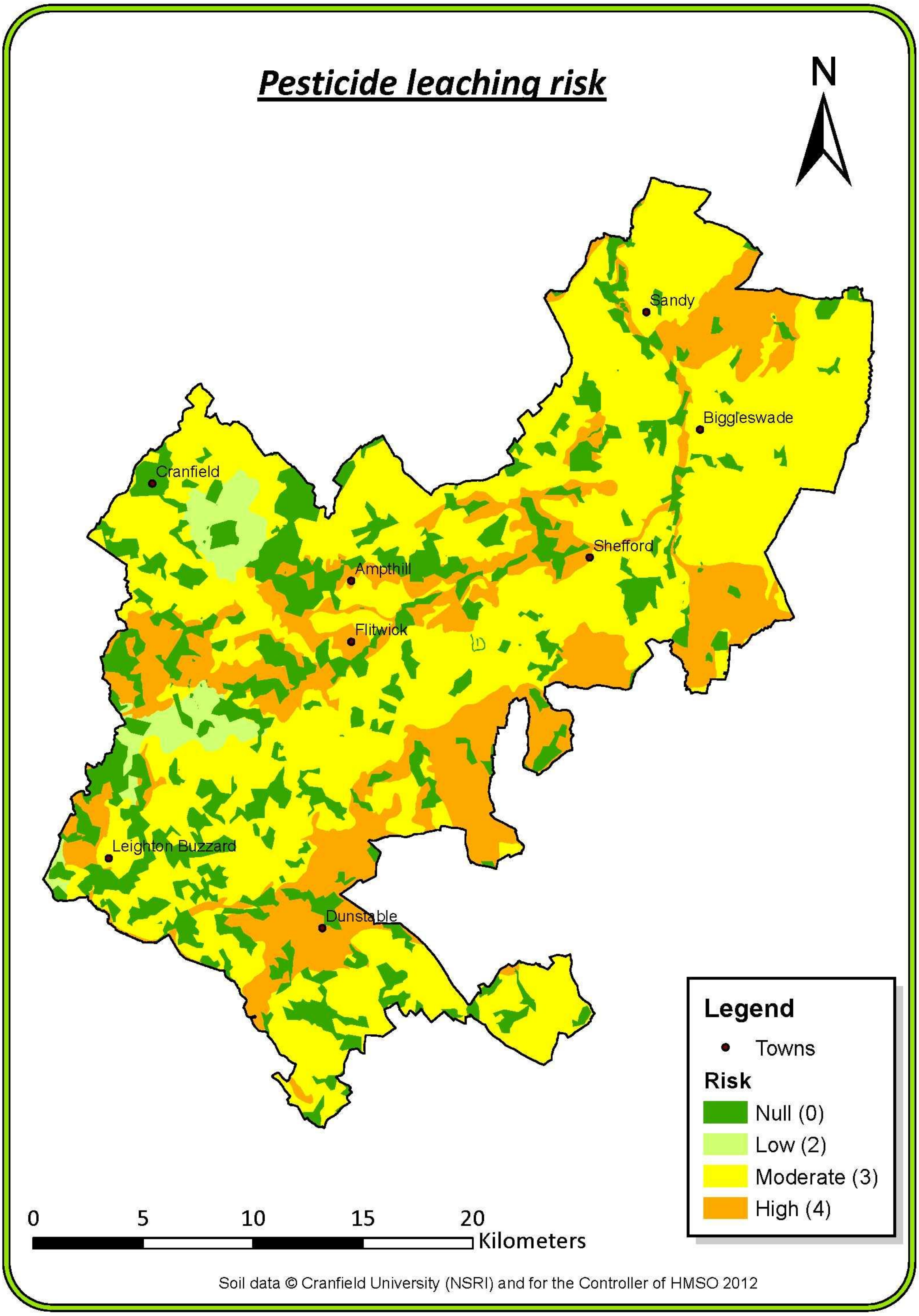

Figure 6.12 Spatial distribution of predicted pesticide water pollution risk through leaching in Central Bedfordshire

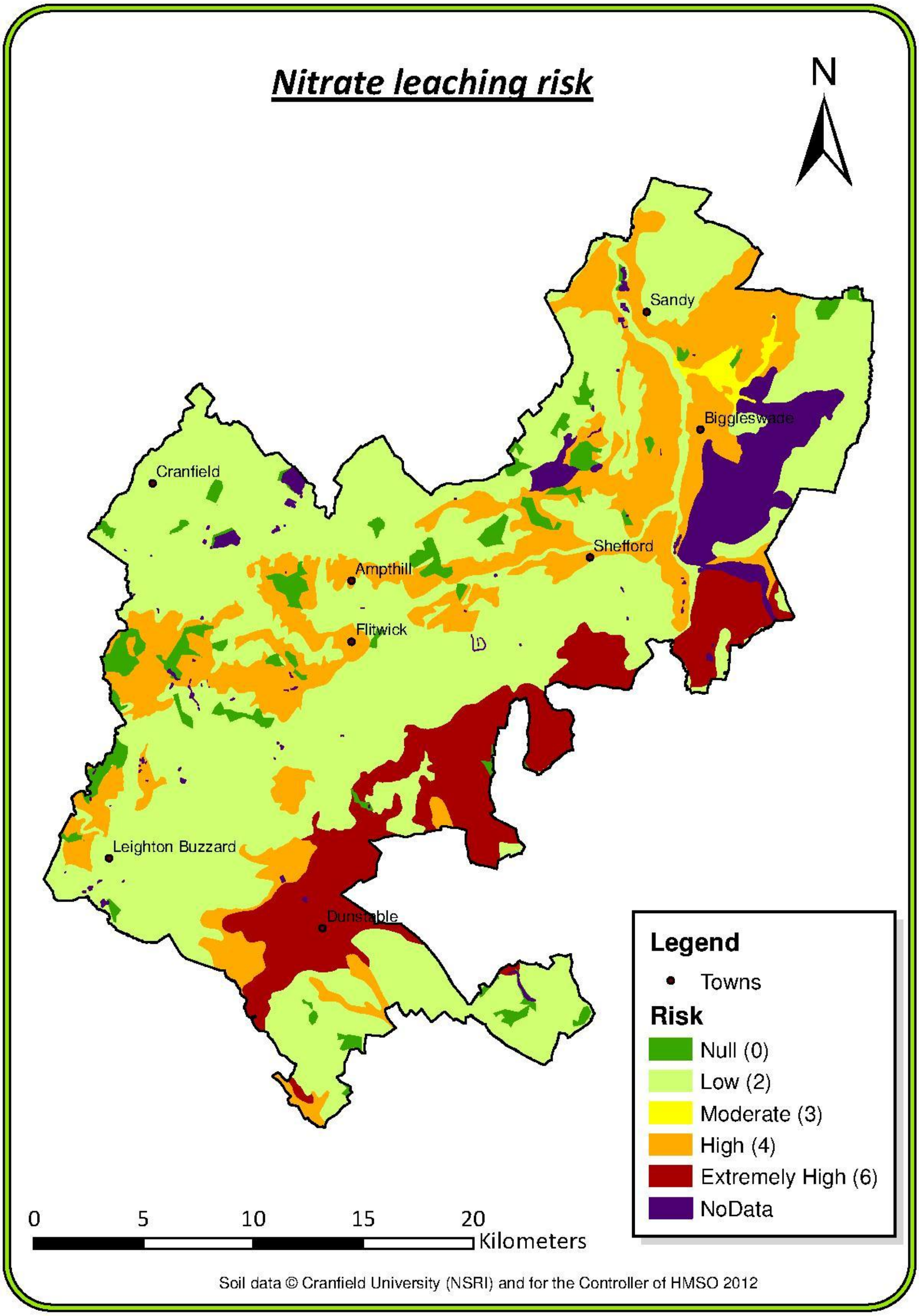

Figure 6.13 Spatial distribution of predicted nitrate water pollution risk through leaching in Central Bedfordshire

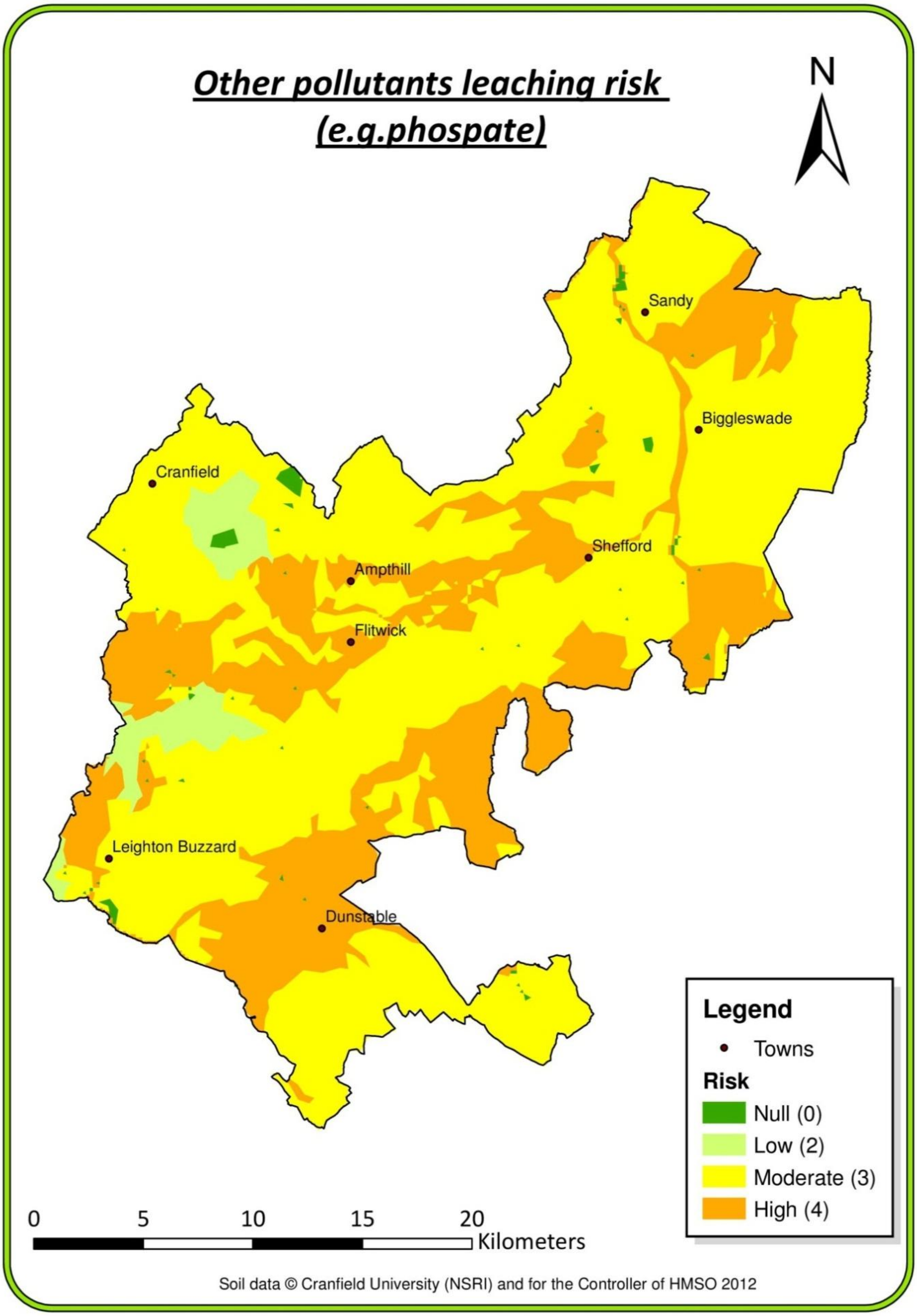

Figure 6.14 Spatial distribution of predicted risk of other pollutants leaching from soil to groundwater in Central Bedfordshire

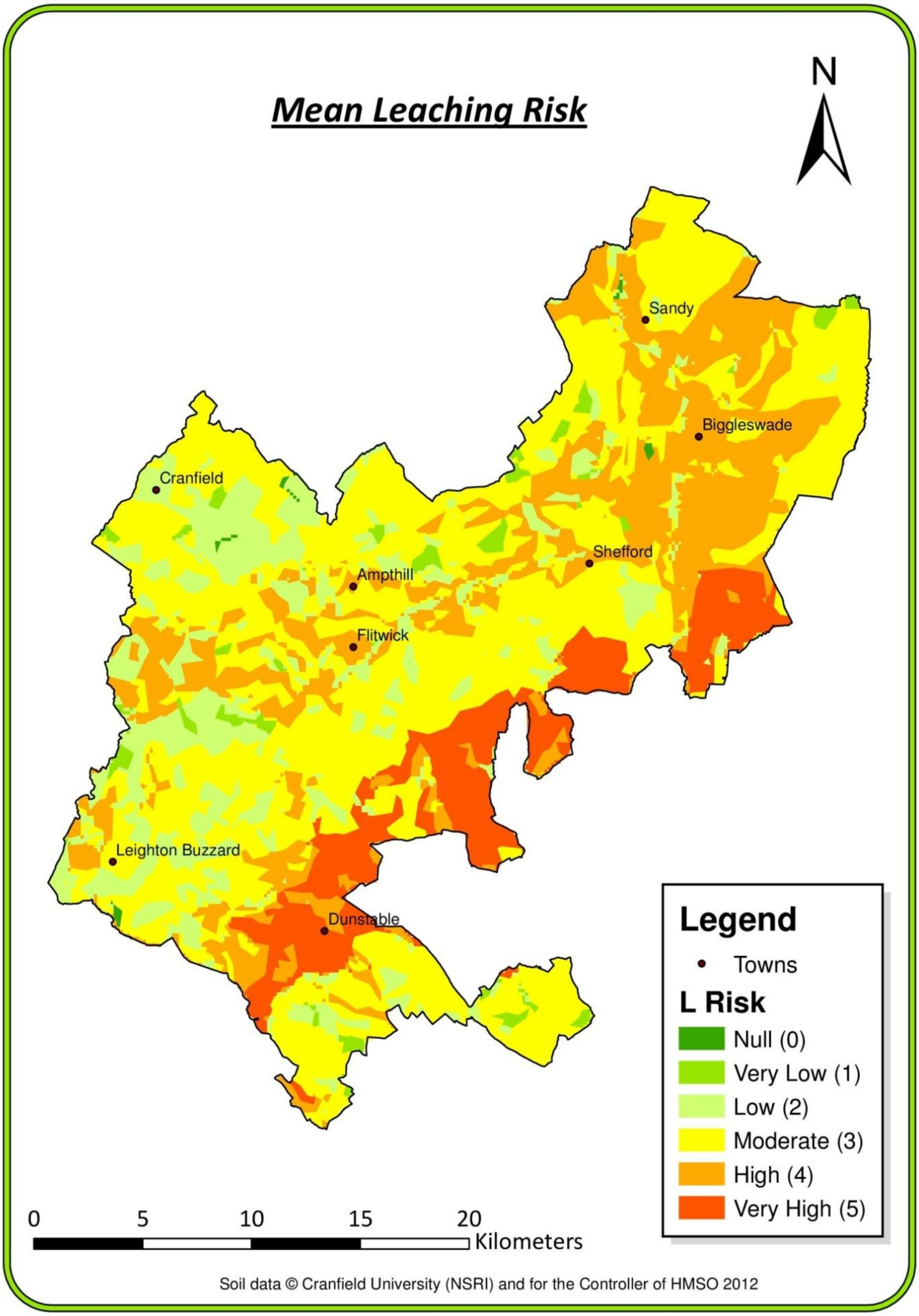

Figure 6.15 Spatial distribution of overall risk of water pollution through leaching in Central Bedfordshire. Mean leaching flow risk derived as the mean of pesticide, nitrate and other pollutant leaching.

6.1.4 Current results: Effect of land use and soil type on water quality

The lowest risk for both overland flow and leaching as associated with woodland land use, and the highest risk was associated with arable land (Tables 6.3 and 6.4). For three soil types, urban land was associated with a very high risk of pollution risk from leaching, and a very high risk of pollution risk from overland flow was associated with silty soils over chalk. A colour key is presented in Table 6.5.

Table 6.3 Categorisation of soil type according to water pollution risk through overland flow on arable, pasture, woodland and semi-natural vegetation, and urban land. See Table 6.5 for the colour key for the results.

Soil type \ Land use	Arable land use	Pasture land use	Urban	Woodland
Deep clay	4	3	4	2
Deep loam	3	2	3	1
Deep loam over gravel	3	3	3	1
Deep loam to clay	4	3	3	2
Deep sandy	4	2	3	2
Deep silty to clay	4	3	-	1
Lake or water body	3	2	2	1
Loam over chalk	4	3	3	2
Loam over red sandstone	3	2	3	2
Seasonally wet deep clay	4	3	3	1
Seasonally wet deep peat to loam	4	1	2	1
Seasonally wet loam over gravel	3	-	2	-
Shallow silty over chalk	4	3	3	2
Silty over chalk	5	3	3	-

Table 6.4 Categorisation of soil type according to water pollution risk through leaching on arable, pasture, woodland and semi-natural vegetation, and urban land. See Table 6.5 for the colour key for the results.

Soil type \ Land use	Arable land use	Pasture land use	Urban	Woodland
Deep clay	3	3	3	2
Deep loam	3	3	4	3
Deep loam over gravel	3	3	3	2
Deep loam to clay	3	3	3	2
Deep sandy	3	3	3	3
Deep silty to clay	4	3	-	3
Lake or water body	3	3	3	2
Loam over chalk	4	4	5	3
Loam over red sandstone	3	3	3	3
Seasonally wet deep clay	3	3	3	2
Seasonally wet deep peat to loam	3	3	4	3
Seasonally wet loam over gravel	4	-	5	-
Shallow silty over chalk	4	4	5	3
Silty over chalk	3	3	3	-

Table 6.5 Colour key for results interpretation

Value	1	2	3	4	5	6
Risk	Very low	Low	Moderate	High	Very high	Extremely high

6.1.5 Scenarios

Scenario 1: Urban development

Effects on overland flow risk: The most significant negative effect is on woodland shown in red, especially on deep clay, deep loam and seasonally wet deep clay (Table 6.6 and Figure 6.16). The most important positive result is on arable land with shallow silty and silty over chalk soil.

Table 6.6 Effect on overland flow risk from a change in land use to all urban.

Soil type	Land Use Change		
	Arable to Urban	Pasture to Urban	Woodland to Urban
Deep clay	0	1	2
Deep loam	0	1	2
Deep loam over gravel	0	0	2
Deep loam to clay	-1	0	1
Deep sandy	-1	1	1
Deep silty to clay	No Data	No Data	No Data
Lake or water body	-1	0	1
Loam over chalk	-1	0	1
Loam over red sandstone	0	1	1
Seasonally wet deep clay	-1	0	2
Seasonally wet deep peat to loam	-2	1	1
Seasonally wet loam over gravel	-1	No Data	No Data
Shallow silty over chalk	-2	0	1
Silty over chalk	-2	0	No Data

Effects on leaching risk: Changing land use from arable, pasture and woodland to urban generally increases the risk of water pollution leaching for most soil types (Table 6.7 and Figure 6.17). The most significant effect of modifying land use to urban is on loam over chalk and shallow silty over chalk on land currently utilised as woodland.

Table 6.7 The effect of land use change to urban on the level of risk from leaching.

Soil type	Land Use Change		
	Arable to Urban	Pasture to Urban	Woodland to Urban
Deep clay	0	0	1
Deep loam	1	1	1
Deep loam over gravel	0	0	1
Deep loam to clay	0	0	1
Deep sandy	0	0	0
Deep silty to clay	No Data	No Data	No Data
Lake or water body	0	0	1
Loam over chalk	1	1	2
Loam over red sandstone	0	0	0
Seasonally wet deep clay	1	0	1
Seasonally wet deep peat to loam	1	1	1
Seasonally wet loam over gravel	1		No Data
Shallow silty over chalk	0	1	2
Silty over chalk	0	0	No Data

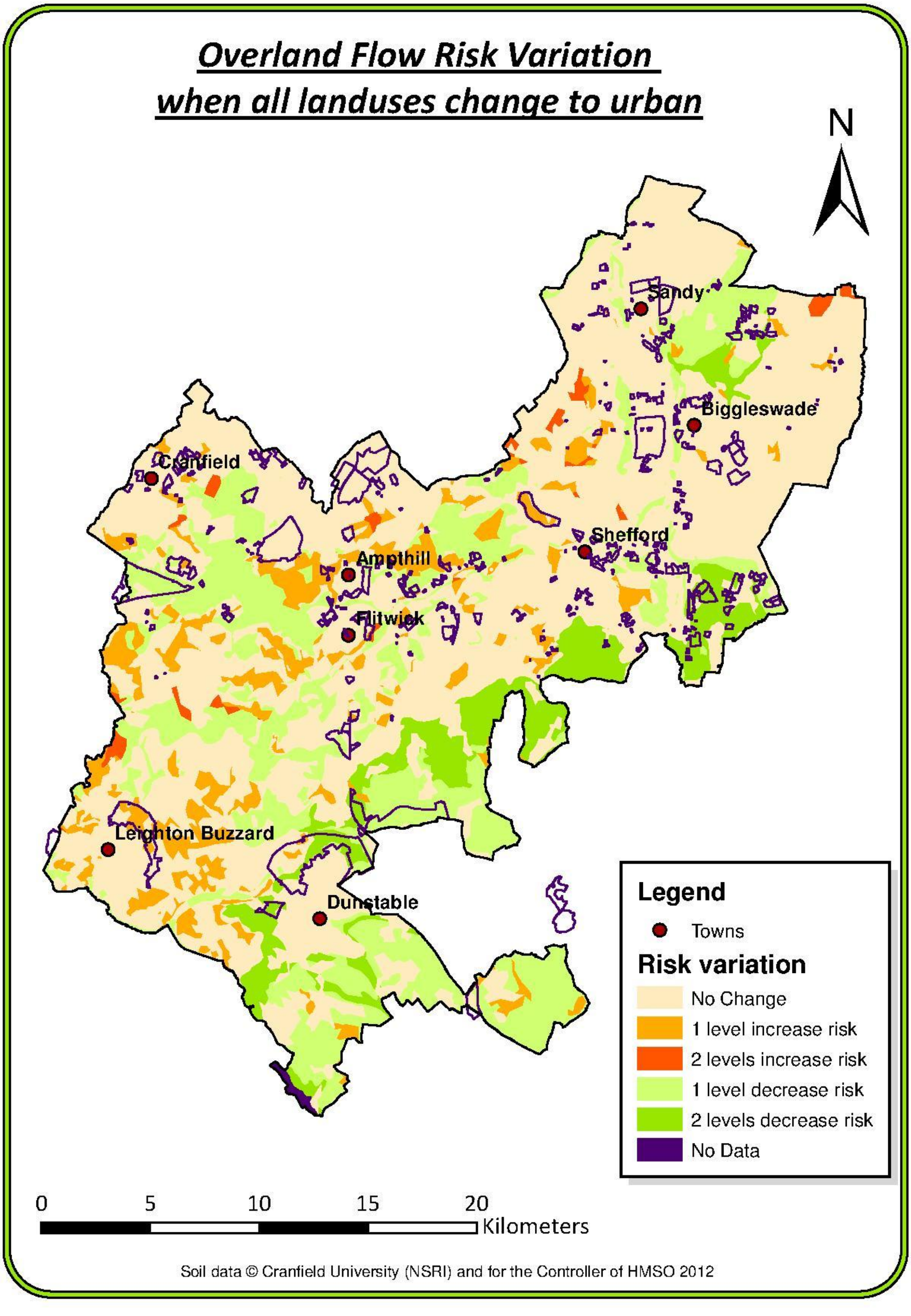

Figure 6.16 Predicted change in the risk of overland flow from a change in land use to all urban.

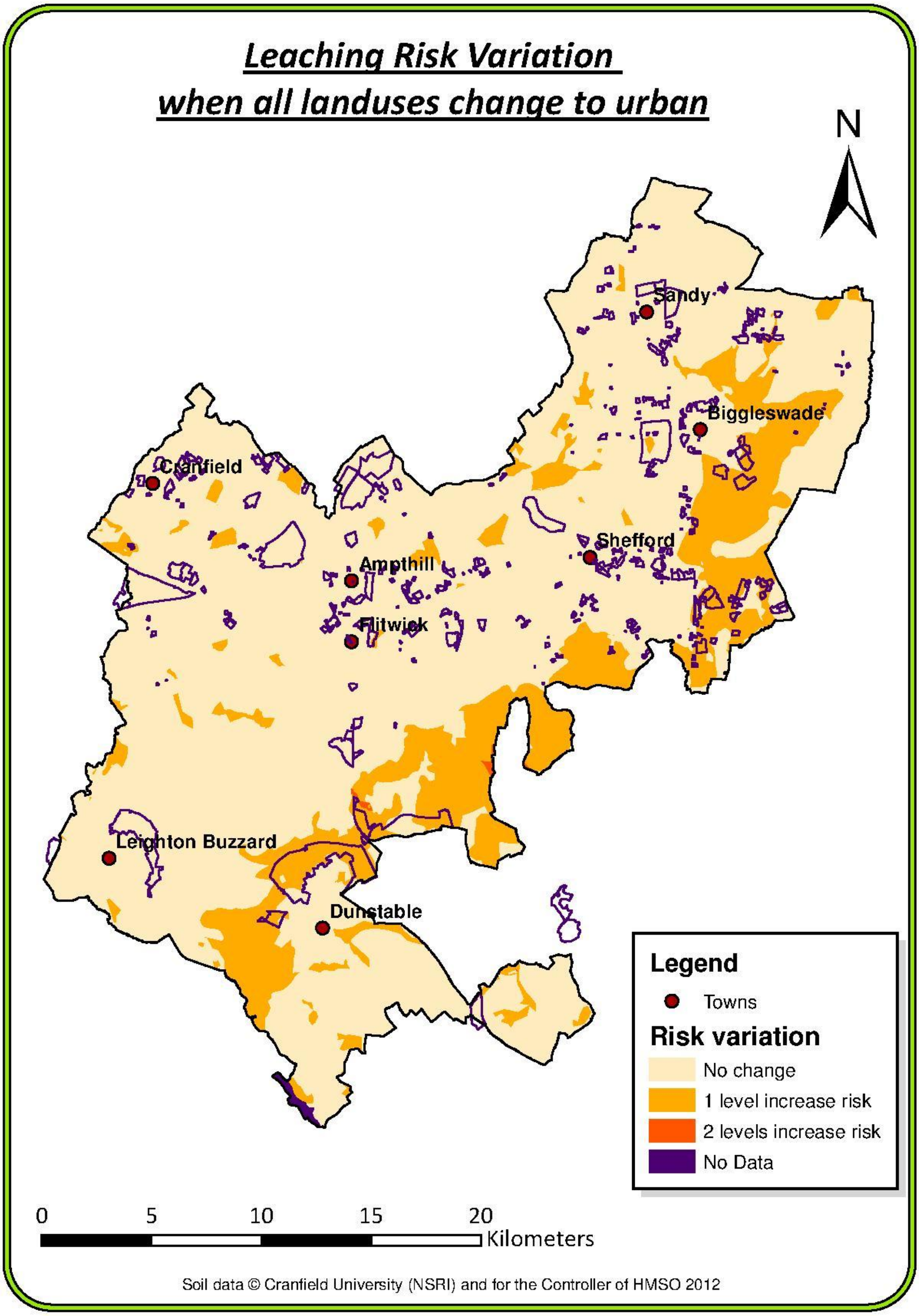

Figure 6.17 Predicted change in the risk of leaching from a change in land use to urban.

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Scenario 2: Woodland land use

Woodland

Effects on overland flow risk: all land uses and soil types show signs of improvement in pollution risk from overland flow by modifying land use to woodland (Table 6.8 and Figure 6.18) . The highest positive impact are found on arable land with seasonally wet deep clay, seasonally wet deep peat to loam and deep silty to clay highlighted below in dark green. More modest improvement was found on all other soil types under arable conditions where data was available. Pasture land presented a positive change in the level of overland flow risk but to a lesser extent than arable land.

Table 6.8 The effect on soil type on a change from arable or pasture land use to woodland on the overland flow risk

	Land Use Change	
Soil type	Arable to Woodland	Pasture to Woodland
Deep clay	-2	-1
Deep loam	-2	-1
Deep loam over gravel	-2	-2
Deep loam to clay	-2	-1
Deep sandy	-2	0
Deep silty to clay	-3	-2
Lake or water body	-2	-1
Loam over chalk	-2	-1
Loam over red sandstone	-1	0
Seasonally wet deep clay	-3	-2
Seasonally wet deep peat to loam	-3	0
Seasonally wet loam over gravel	No Data	No Data
Shallow silty over chalk	-2	-1
Silty over chalk	No Data	NoData

Effects on leaching risk: Modifying land use from arable and pasture to woodland reduces the risk of water pollution for most soil types as indicated by the green cells highlighted below (Table 6.9 and Figure 6.19).

Table 6.9 The effect of land use change to woodland on the level of risk from leaching

	Land Use Change	
Soil type	Arable to Woodland	Pasture to Woodland
Deep clay	-1	-1
Deep loam	0	0
Deep loam over gravel	-1	-1
Deep loam to clay	-1	-1
Deep sandy	0	0
Deep silty to clay	-1	0
Lake or water body	-1	-1
Loam over chalk	-1	-1
Loam over red sandstone	0	0
Seasonally wet deep clay	-1	-1
Seasonally wet deep peat to loam	0	0
Seasonally wet loam over gravel	No Data	No Data
Shallow silty over chalk	-1	-1
Silty over chalk	No Data	

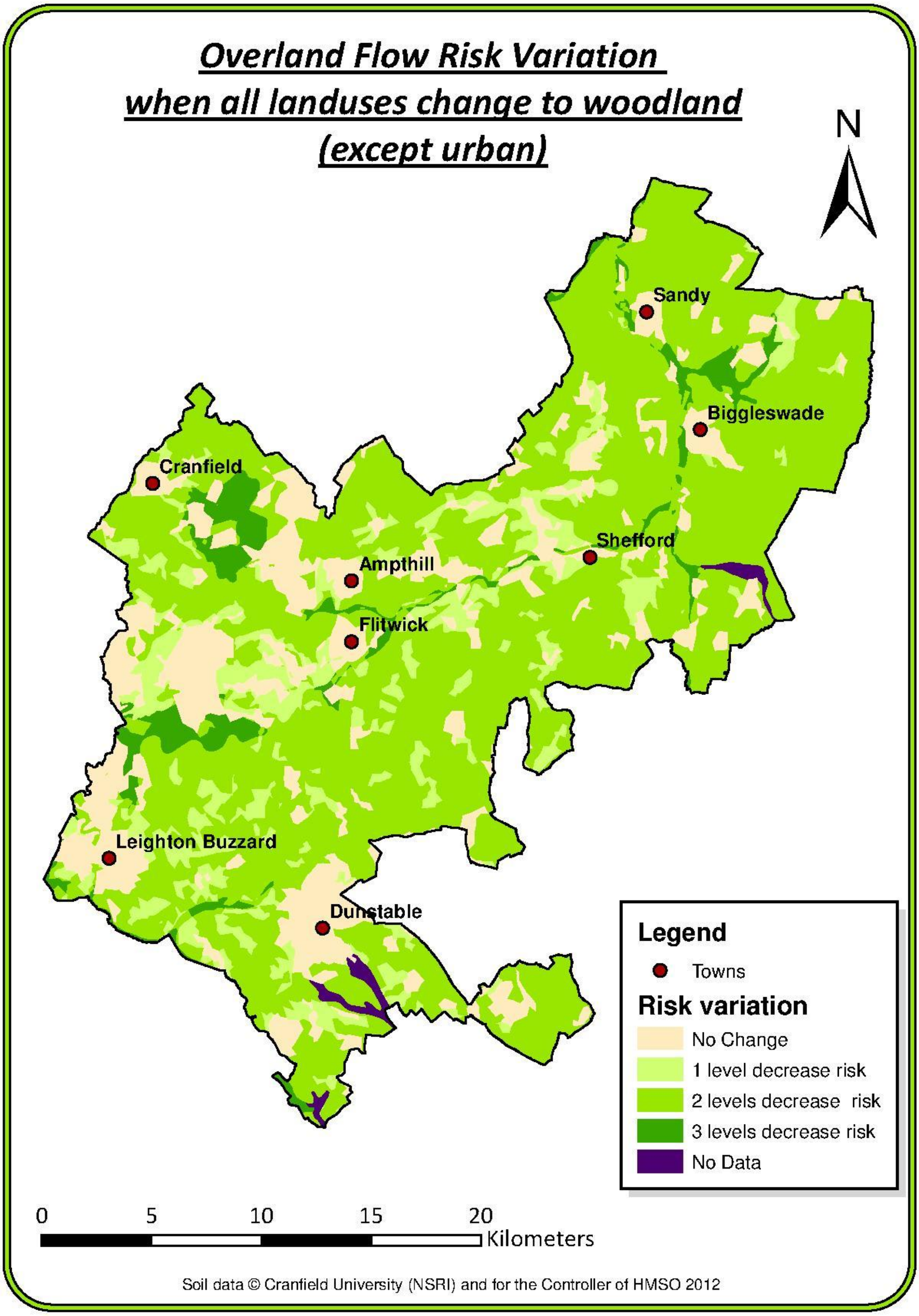

Figure 6.18 Predicted effect on the risk of overland flow from a change in land use to all woodland.

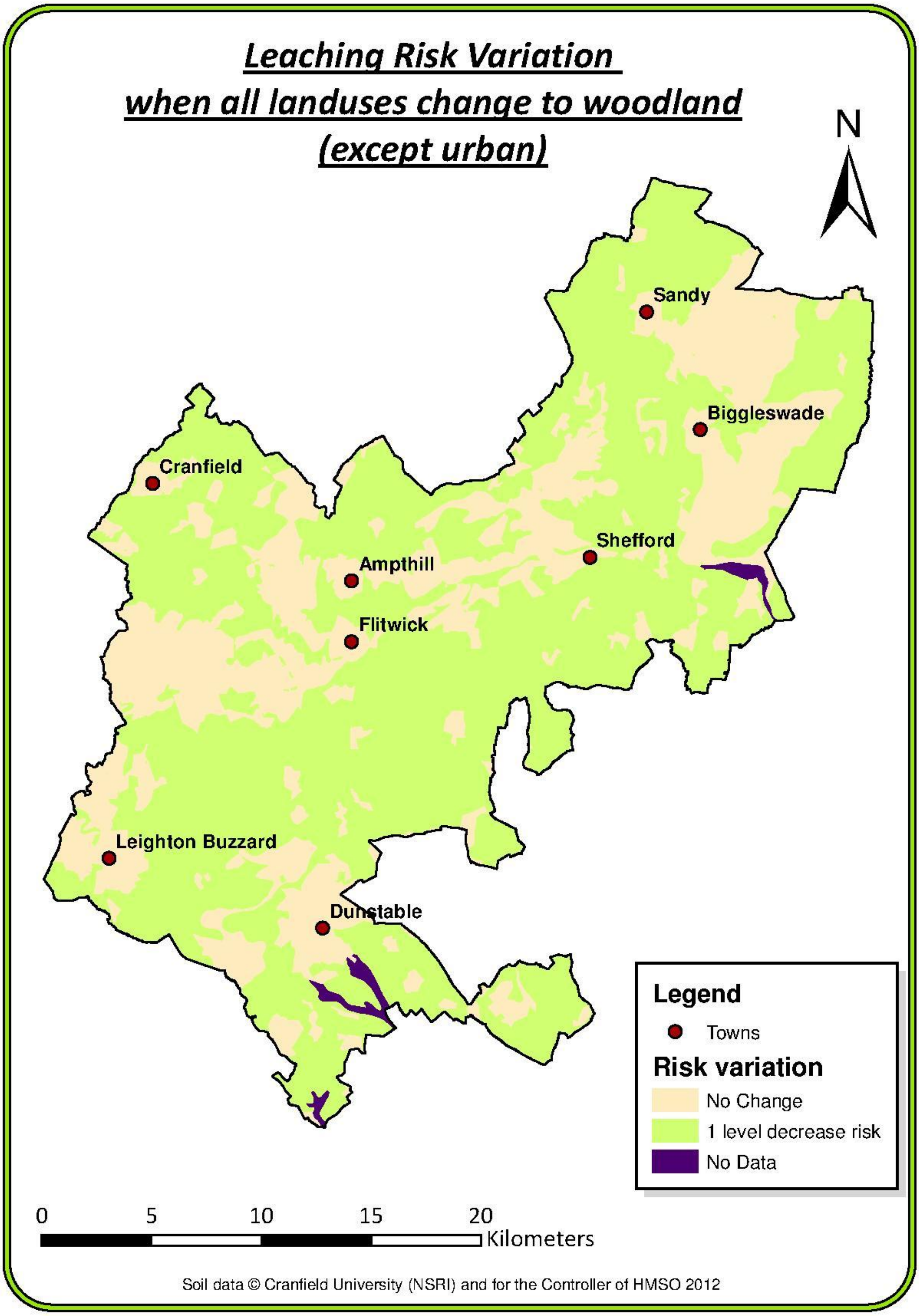

Figure 6.19 Predicted effect on the risk of leaching from a change in land use to woodland.

Scenario 3: Pasture land use

Effects on overland flow risk: the most significant negative effect on pollution risk due to overland flow is from converting woodland to pasture (red), especially on deep loam over gravel, deep silty to clay and seasonally wet deep clay (Table 6.10 and Figure 6.20). The largest positive impact is on arable land with seasonally wet deep clay shown in dark green. Considerable improvement is also found on deep sandy and silty over chalk soil on arable land.

Table 6.10 The effect of soil type on a change from arable or woodland land use to pasture on overland flow risk

	Land Use Change	
Soil type	Arable to Pasture	Woodland to Pasture
Deep clay	-1	1
Deep loam	-1	1
Deep loam over gravel	0	2
Deep loam to clay	-1	1
Deep sandy	-2	0
Deep silty to clay	-1	2
Lake or water body	-1	1
Loam over chalk	-1	1
Loam over red sandstone	-1	0
Seasonally wet deep clay	-1	2
Seasonally wet deep peat to loam	-3	0
Seasonally wet loam over gravel	No Data	No Data
Shallow silty over chalk	-2	1
Silty over chalk	-1	No Data

Effects on leaching risk: converting the land use of all of Central Bedfordshire (excluding urban areas) to pasture increases the risk of leaching pollutants for woodland on most soil types (Table 6.11 and Figure 6.20).

Table 6.11 The effect of soil type on a change from arable or woodland land use to pasture on leaching risk.

	Land Use Change	
Soil type	Arable to Pasture	Woodland to Pasture
Deep clay	0	1
Deep loam	0	0
Deep loam over gravel	0	1
Deep loam to clay	0	1
Deep sandy	0	0
Deep silty to clay	-1	0
Lake or water body	0	1
Loam over chalk	0	1
Loam over red sandstone	0	0
Seasonally wet deep clay	0	1
Seasonally wet deep peat to loam	0	0
Seasonally wet loam over gravel	No Data	No Data
Shallow silty over chalk	0	1
Silty over chalk	0	No Data

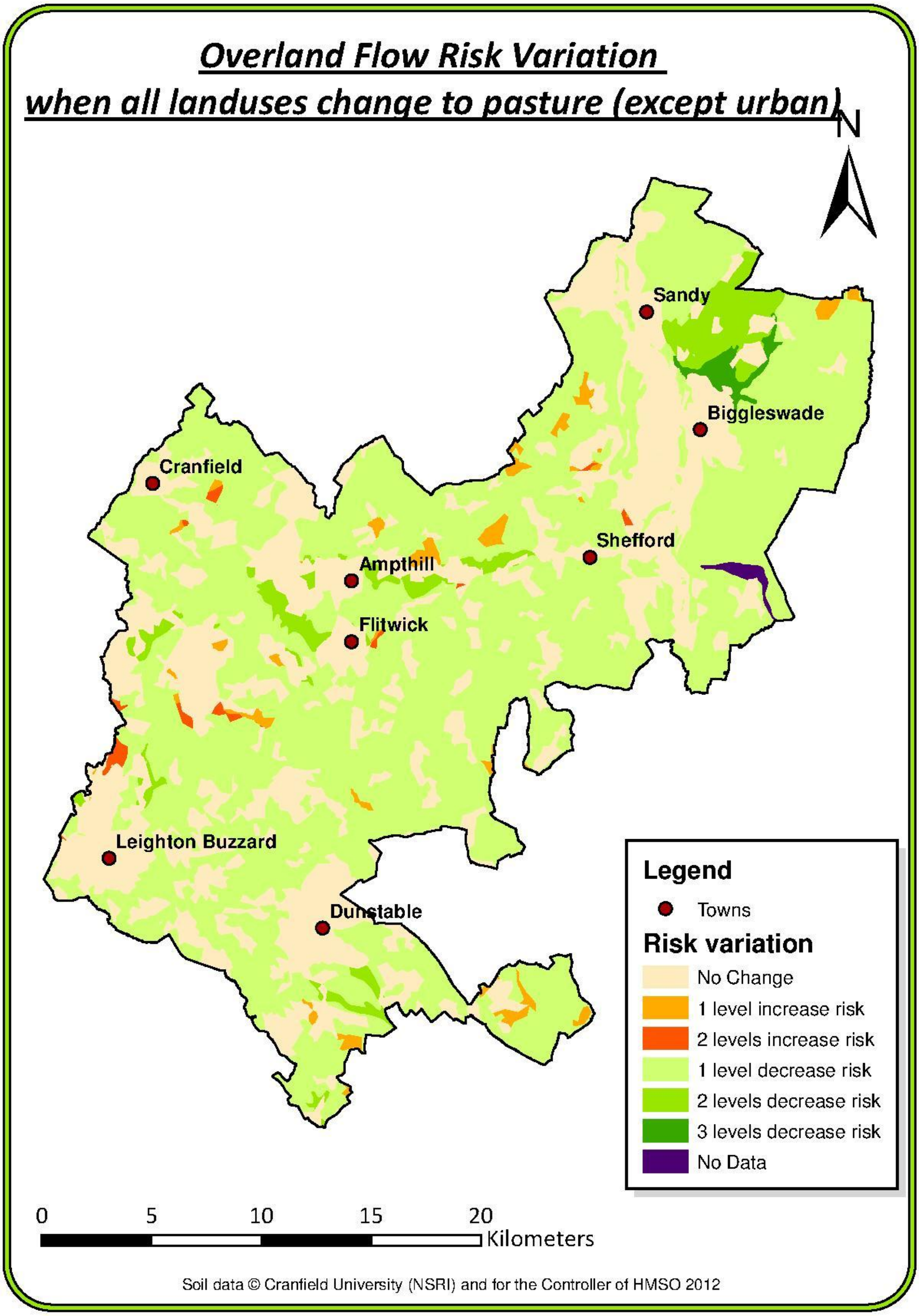

Figure 6.20 Predicted effect on the risk of overland flow from a change in land use to all pasture (except urban).

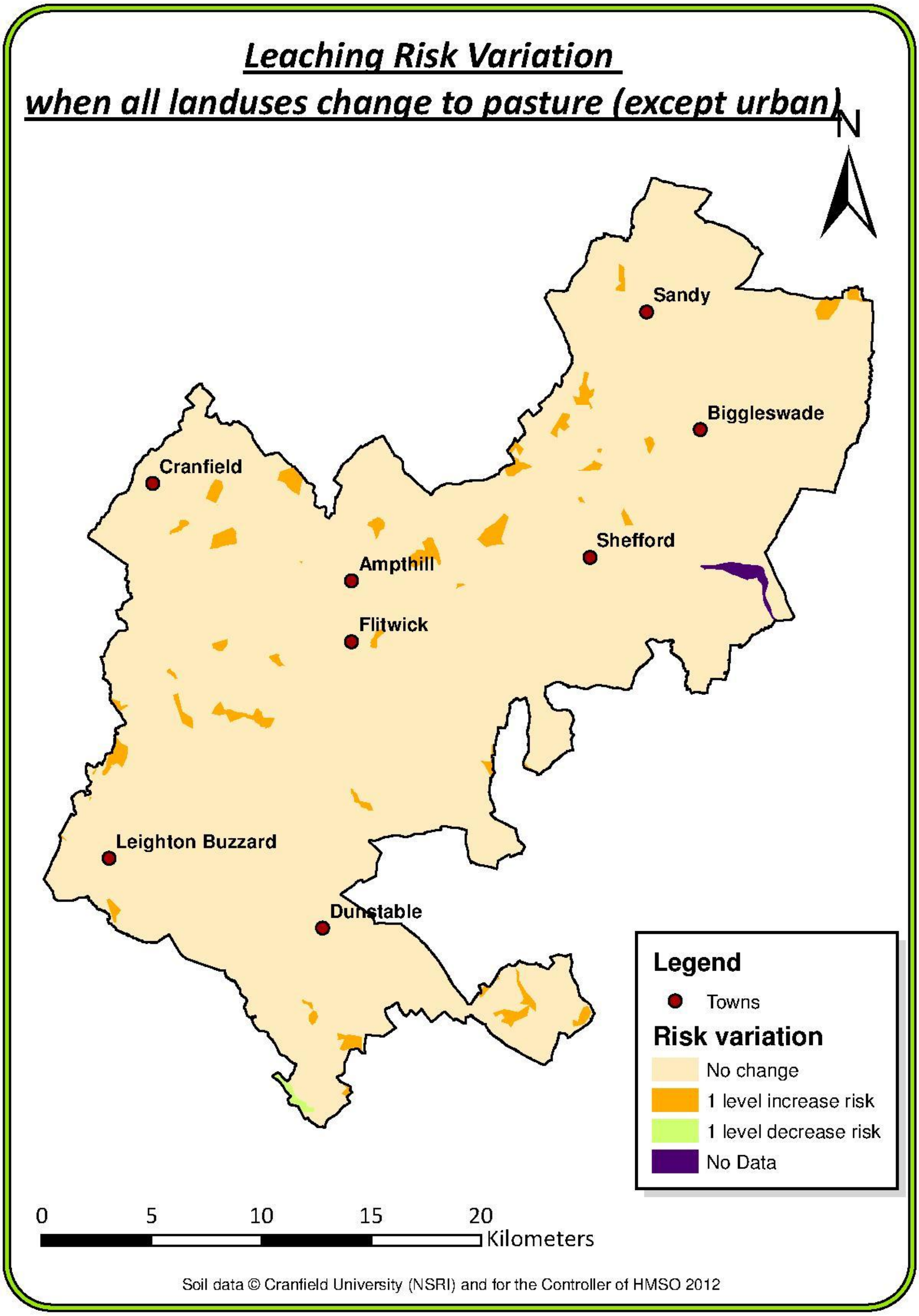

Figure 6.21 Predicted effect on the risk of leaching from a change in land use to pasture.

Scenario 4: Biodiversity Action Plan

Effects on overland flow risk

The result of the BAP scenario on overland flow risk is shown in Figure 6.22. The outcome is a modest improvement in overland flow risk, but the impact is not significant enough to change the level of runoff risk identified by the legend increments used in the map.

Effects on leaching risk

For the BAP scenario, all areas where there was an opportunity for conversion to grassland and woodland habitat have been converted to woodland or grassland (see Appendix A5). The results for this scenario predict that there will be a generally positive effect on reducing the level of leaching risk from CBC adapting land use to incorporate the BAP as shown in Figure 6.23.

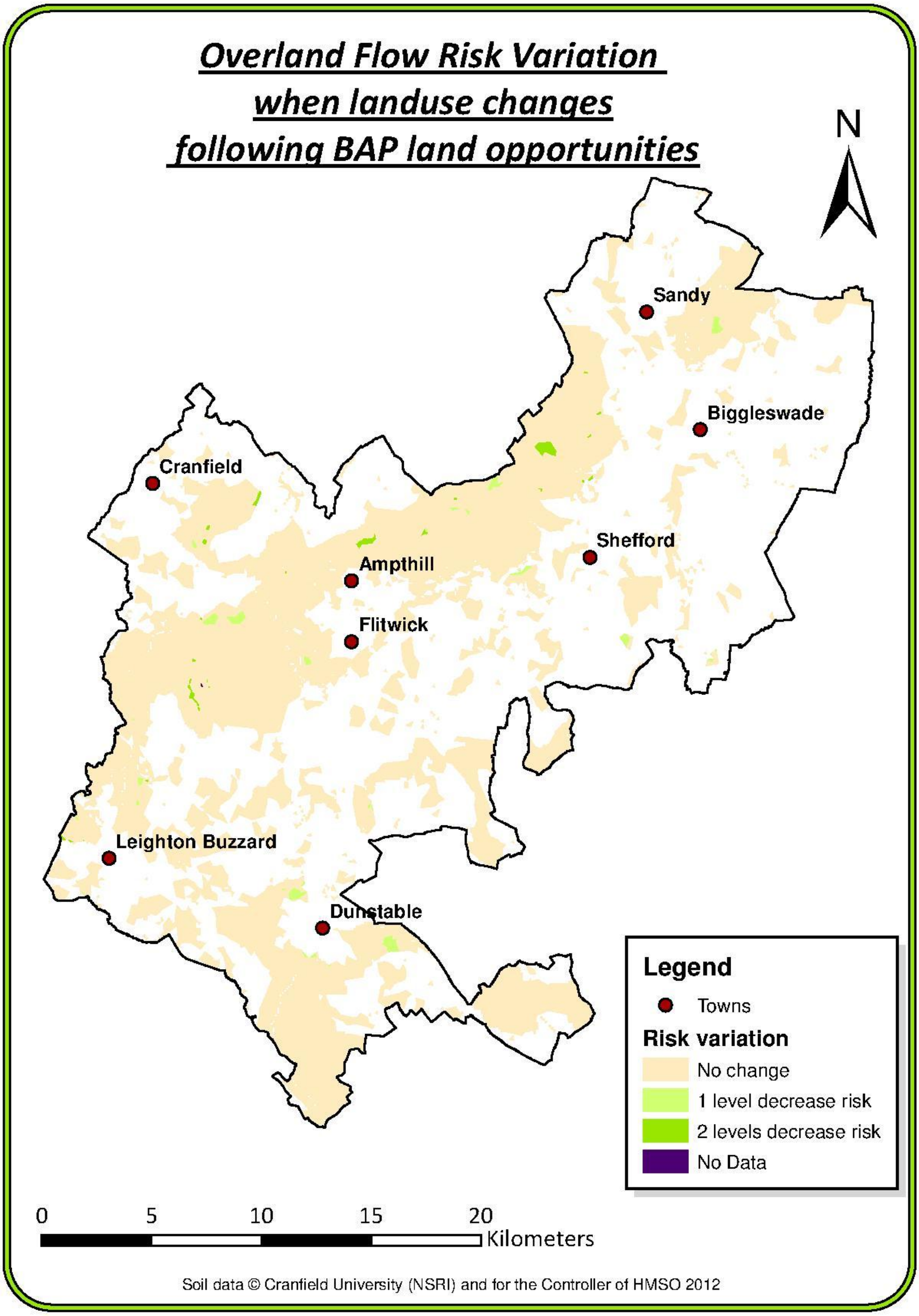

Figure 6.22 Predicted change in the risk of overland flow from a change in land use to implement BAP.

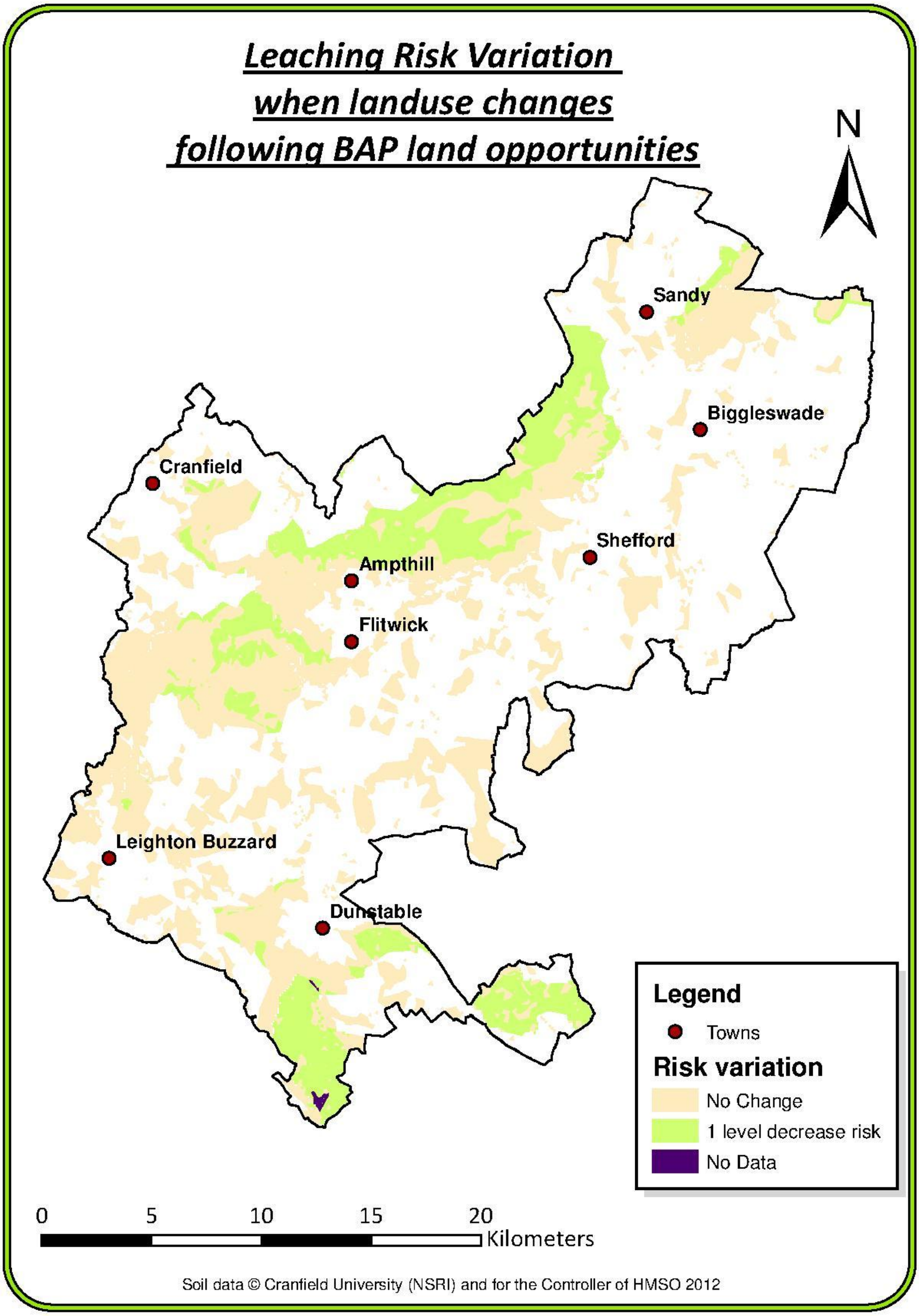

Figure 6.23 Predicted change in the risk of leaching from a change in land use to implement BAP

6.2 Discussion

6.2.1 Study limitations

No specific mapped data for phosphates

In the literature, phosphates are considered one of the main water quality pollutants; however, there is no specific mapped data for this pollutant within the Cranfield soil database (LandIS). Erosion of soil particles with adsorbed phosphate and their movement within overland flow is the main pathway which transports phosphates to surface water bodies. Assuming this, sediment overland flow risk has been used twice within our ‘overall pollution risk through overland flow model’ (Figure 6.10): It has been used once as sediments in general (Figure 6.8) and a second time as an edited version to consider sediment with adsorbed phosphates (Figure 6.9) but only for the land uses classified as a source of phosphate (See Appendix A8). This method could result in unrealistically high values of overland flow risk. However, at the same time, the output clearly highlights areas where pollutants exist within Central Bedfordshire and allows for identification of target areas which is advantageous.

Erosion risk layer limitations

The potential erosion layer, created within the runoff/erosion section (Section 5), and utilised here within our ‘overall pollution risk through overland flow’ model (Figure 6.10) is also subject to limitations; these are outlined within the limitation section of the runoff/erosion section (Section 5).

Problems due to “other pollutant risks”

The ‘other pollutant risk of groundwater pollution through leaching’ (Figure 6.15) layer may not just incorporate nitrates and pesticides as assumed here, the layer may have been generated to consider the risk of groundwater pollution by *other* pollutants, for example despite soil erosion and overland flow providing the main pathway for phosphates, leaching also provides a pathway for the transport of phosphates to water bodies. These other pollutants may therefore ‘contaminate’ our interpretations and conclusions which are based purely on nitrates and pesticides. As a consequence of these facts the generated model is less accurate than it was expected at the beginning of the work; recommendations for further research in Section 6.11 (Section on recommendations for further work) could work towards improving the accuracy and reliability of the results generated in this study for example acquiring more up to date and more spatially reliable datasets which could not be obtained as a result of the short duration of this project and which as a result limit the model precision.

Problems due to intersection of Corine and NATMAPvector data

Finally, to be consistent with the results and future scenarios analysis with the rest of the working sections (Sections 4 and 5), it has been assumed that working polygons in GIS should be the ones acquired from the intersection of Corine and NATMAPvector. This assumption has generated, in some cases, data with values which are too high as a result of the way in which the ‘Intersection’ and ‘Dissolve’ GIS tools generate statistical data and overall data for the polygons.

6.2.2 Current Situation: Water pollution within surface watercourses (Receptors)

Nitrates

The water courses in Central Bedfordshire are shown to be sensitive to nitrate pollution with the whole region is classed as a Nitrate Vulnerable Zone (See Appendix A2); Section 6.2.3 shows that in terms of overall pollution risk through leaching nitrate is the pollutant which poses the greatest risk.

Absolute values of nitrate within water courses of Central Bedfordshire are classed generally as ‘high’ under the ‘General Quality Assessment’ (EA 2012e) (Figure 6.1) which reinforces this sensitivity to nitrate pollution. However, in terms of WFD status the ‘specific pollutant status’ (Figure 6.6), which incorporates nitrate as a substance which contributes to eutrophication (WFD 2000/60/EC) (See Appendix A, figure A2), is shown to range from generally ‘good’ to ‘high status’ and therefore generally achieving the WFD target of ‘good specific pollutant status’ required by 2015 (WFD 2000/60/EC) and not a cause of eutrophication in these surface water bodies (Figure 6.24).

There are however some surface watercourses which are exceptions showing ‘moderate specific pollutant status’ (Figure 6.6) and yet to achieve the WFD target of ‘good specific pollutant status’ required by 2015 (WFD 2000/60/EC) and it is possible that nitrate is a substance contributing to eutrophication within these watercourses. Furthermore, some groundwater bodies have been identified as below ‘good chemical status’ for groundwater required by 2015 (WFD 2000/60/EC) and (2006/118/EC) for which nitrate is one of the drivers. Here these areas are identified as priority areas where action can be taken to reduce nitrate entering surface water courses (Figure 6.24) and groundwater (Figure 6.25) respectively.

<u>Recommendations:</u>

1) *Change land use to woodland*: priority areas to be targeted to improve nitrates in surface water courses and therefore specific pollutant status (Figure 6.24) are predominantly arable land (table 6.2). One method to reduce the risk of nitrate pollution via leaching and runoff is to convert current arable land to woodland or pasture (See section 6.1.5).

2) *Improve current land management practices*: it is recommended to reduce nitrate at source on current land use (predominantly arable). Recommendations to improve land management practices within arable areas can be found in section 6.1.5.

3) *Improve land management practices on non-clay soil to protect groundwater*: this recommendation is for priority areas which need to be targeted to improve groundwater status (Figure 6.25). Note that changing the land use in this area will not have an influence as land use is not shown to be driving groundwater status.

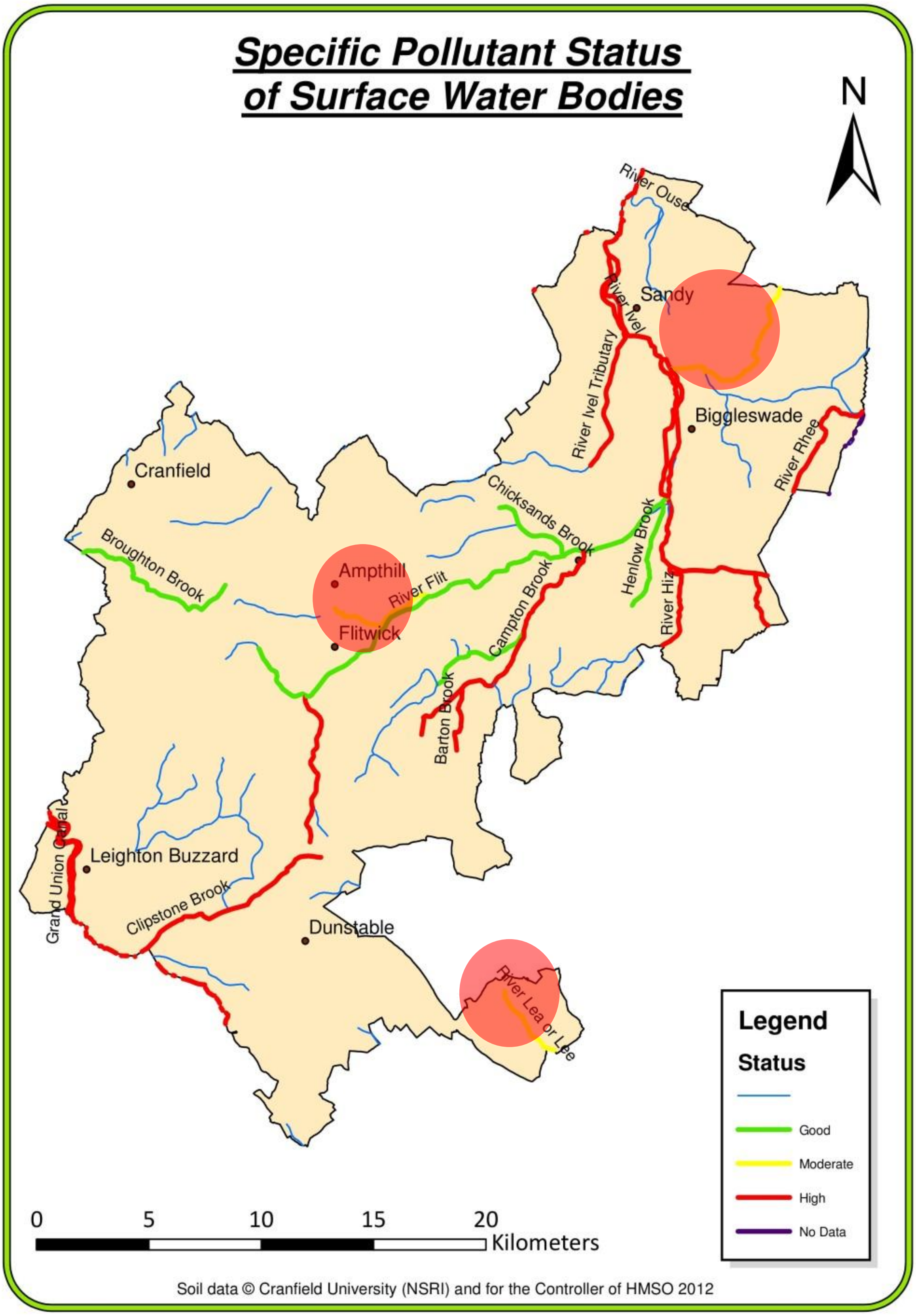

Figure 6.24 Identification of three priority areas (red circles) which are currently classified as having below 'good specific pollutants status 'to *change* land use or to take on recommendations for *current* land use, in order to reduce risk of pollution of nitrate, phosphate and pesticide pollution within surface water bodies through runoff and leaching.

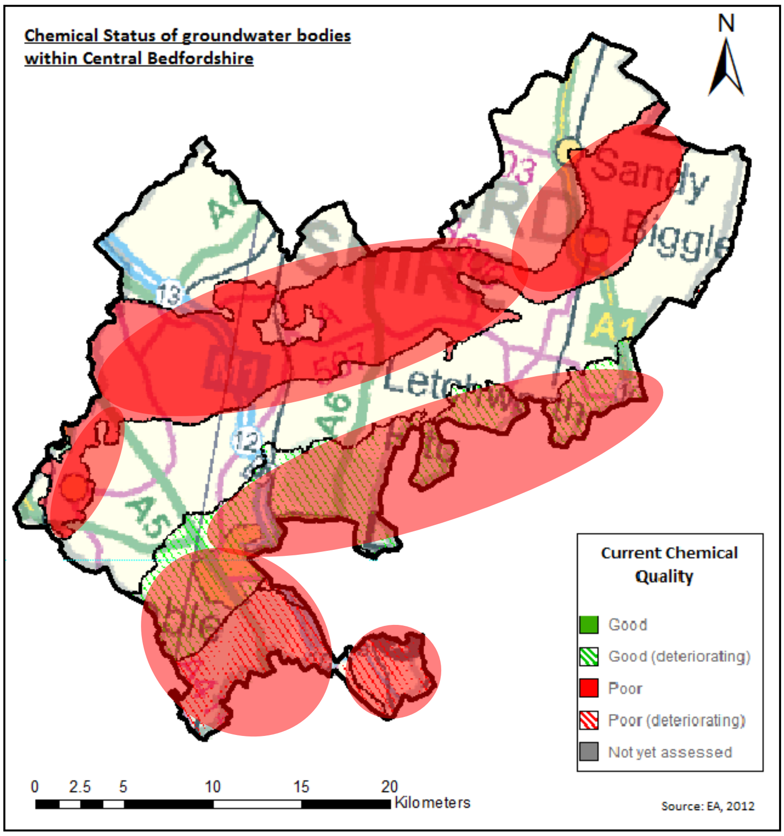

Figure 6.25 Priority areas (shown in red ovals), currently classified as below 'good chemical status ' for groundwater, to *change* land use or to take on recommendations for *current* land use, in order to reduce risk of nitrate and pesticide pollution of groundwater bodies through leaching (EA 2012f).

Phosphate

Phosphates are a driver of 'physico-chemical status' and subsequently 'ecological status' of surface watercourses (WFD 2000/60/EC) (See Appendix A1). Phosphate, as a substance which contributes to eutrophication, and a driver of 'specific pollutant status' (see Figure 6.6 and Appendix A1, figure A2) is shown to range from generally 'good' to 'high status' across the watercourses of Central Bedfordshire and therefore generally achieving the WFD target of 'good status' required by 2015 (WFD 2000/60/EC)

There are however some watercourses which are exceptions showing 'moderate specific pollutant status' (Figure 6.6) and yet to achieve the WFD target of 'good specific pollutant' status required by 2015 (WFD 2000/60/EC) and it is possible that phosphate is a substance contributing to eutrophication within these watercourses. Furthermore, phosphate as a driver of 'physico-chemical status' in its own right however are generally 'poor' within the major central rivers of Central Bedfordshire running across the central northeast to southwest strip of Central Bedfordshire (Figure 6.6). These areas are here further identified as priority areas where action can be taken to reduce phosphate entering surface water courses (Figure 6.26).Absolute phosphate values are also generally seen to be 'high; under the' General Quality Assessment' (EA 2012g) (Figure 6.2).

It can therefore be stated that phosphate is a pollutant within Central Bedfordshire currently contributing to certain watercourses falling below the WFD target of good ecological status required by 2015 (WFD 2000/60/EC) . Priority areas shown in Figure 6.24 and Figure 6.26 are areas of Central Bedfordshire where action can be taken to reduce phosphate entering surface water courses.

Recommendations

1) *Change land use to woodland*: Priority areas to be targeted to improve phosphates in surface water courses and therefore 'specific pollutant status' (Table 6.2) and 'phosphate' status shown in Figure 6.24 and Figure 6.26 is predominantly arable land. It is recommended to convert the current arable land use to woodland and/or pasture where possible to reduce the risk of phosphate pollution via runoff (Section 5.2.3).

Runoff section recommendations (Section 5.2.3) to reduce soil erosion are applicable here as transport of phosphates adsorbed to sediment via soil erosion is the major overland flow pathway of phosphate.

2) *Improve current land management practices:* It is recommended to reduce phosphate at source on current land use (predominantly arable). Recommendations to improve land management practices within arable areas can be found in Section 6.2.4 under land use management. The land use management recommendations for soil erosion (Section 5.2.3) are applicable here as transport of pesticides adsorbed to sediment via soil erosion is the major overland flow pathway of phosphates.

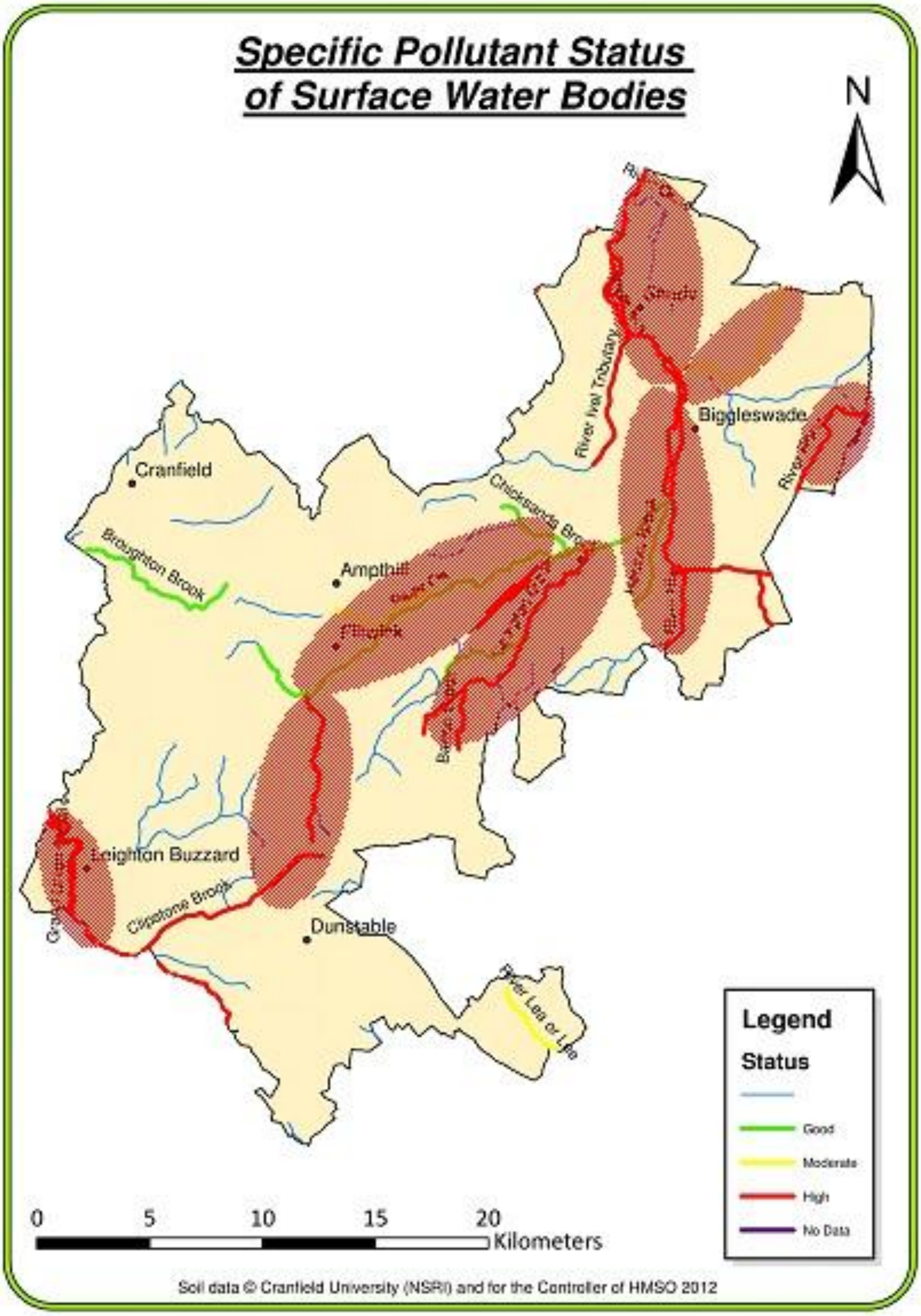

Figure 6.26 Priority areas to be targeted to improve ‘phosphate status’ (WFD 2000/60/EC) (shown in red ovals) currently classified as below ‘good phosphate’ status. (Source: EA 2012g) driven by the fact that they are in close proximity to both arable areas a major source of phosphate via overland flow (Source: EA 2012g)

Pesticides

As noted previously, absolute pesticide values in watercourses of Central Bedfordshire are not included here due to a lack of information.

The WFD 'chemical status' however, which includes pesticides (biocides and plant protection products) as a driver, is shown to be at 'good status' or 'does not require assessment' (see Appendix A1) achieving the WFD target of 'good chemical status' required by 2015 (WFD 2000/60/EC).

Pesticides (biocides and plant protection products), however, further contribute to 'specific pollutant status' (WFD 2000/60/EC) (Figure 6.6) (see Appendix A1, figure A2) which although generally is shown to range from generally 'good' to 'high status', and therefore generally achieving the WFD target of 'good status' required by 2015, there are some watercourses which are exceptions showing moderate 'specific pollutant status' (Figure 6.6) and yet to achieve 'good specific pollutant status' (EA 2012a).

It is therefore possible that pesticides are a pollutant within Central Bedfordshire currently contributing to certain watercourses falling below the WFD target of 'good ecological status' required by 2015 (WFD 2000/60/EC). Priority areas (Figure 6.26) surrounding these watercourses are areas of Central Bedfordshire where action can be taken to reduce pesticide entering surface water courses.

Recommendations

1) *Change land use to woodland:* Priority areas to be targeted to improve pesticides in surface water courses and therefore specific pollutant status (Figure 6.24) are predominantly arable land (Table 6.2.) It is recommended to convert the current arable land use to woodland and/or pasture where possible to reduce the risk of pesticide pollution via leaching and the risk of pesticide pollution via runoff. Runoff section recommendations (Section 5.2.3) to reduce soil erosion are applicable here as transport of pesticides adsorbed to sediment via soil erosion is the major overland flow pathway of certain pesticides.

2) *Improve current land management practices*: It is recommended to reduce pesticides at source on current land use (predominantly arable). Recommendations to improve land management practices within arable areas can be found in section (see land use management recommendations for leaching and runoff section 6.2.4). Runoff section land use management recommendations for soil erosion (Section 5.2.3) are applicable here as transport of pesticides adsorbed to sediment via soil erosion is the major overland flow pathway of certain pesticides.

Sediment

As noted previously, absolute sediment values in watercourses of Central Bedfordshire are not included here due to a lack of information. Furthermore sediment is not included within WFD watercourse classifications (WFD 2000/60/EC). For recommendations see section 6.2.4.

6.2.3. Current Situation: Water pollution risk (Source and pathway)

Overall risk of pollution through overland flow

Overall risk of pollution through overland flow (Figure 6.10) could be defined as the risk of water pollution by substances within the overland flow. This phenomenon is highly linked to erosion processes, which in turn is influenced by hydrology, slope, vegetation cover, land use (Figure 2.4) and soil type (Figure 2.6).

The overall risk map (Figure 6.11) has been created through the combination of three layers: sediment overland flow risk (Figure 6.8), phosphate overland flow risk (adsorbed to soil particles) (Figure 6.9) and pesticide overland flow (Figure 6.10). The factors influencing sediment and phosphate maps have been already described in Section 5, because they are driven by erosion components. Brady and Weil (2010) indicate that erosion occurs in surface and more fertile horizons, where organic matters, fine mineral particles and other organic particles are located. Phosphates are mainly adsorbed by clay and organic matter, or by soil with Al and Fe oxides (CIGR, 1999). Therefore, areas with higher loss of this type of soil will consequently be areas with high soil erosion risk for phosphate and the same for pesticides.

Silt and clay soils (if not aggregated) are the most susceptible to water erosion (Brady and Weil 2010) due to its soil textural characteristics and soil particles size.

As a consequence of that, and of the previous explanations, can be observed in the map that clay, loam and silt areas (Figure 2.6) are the ones with high erosion risk, varying it from 4 to 6, and consequently high sediments with/without aggregates generation risk.

However, in our model we have paid special attention to the source, in terms of pollutant presence within Central Bedfordshire. The land use source for sediment, phosphate and pesticide are shown in Appendix A8. Sediment is the only pollutant from woodland transported via the overland flow pathway however arable land provides a source of all pollutants transported by this pathway (see Appendix A8).

Overall land use is shown to be driving the overall risk of pollution through overland flow risk. In terms of land use, the results table for overall risk (Table 6.4) shows that the risk of pollution through overland flow is greatest in arable land compared to woodland; this is due to the fact that although there is a source of sediment within woodland there is no source of nitrate, pesticide or phosphate.

Overall risk of pollution through leaching

Considering uniform rainfall across Central Bedfordshire, the main driver for differences in overall risk of pollution of surface water through leaching (Figure 6.15) would be the soil type. Soil that efficiently holds water decreases the risk of leaching. Usually leaching losses are less in fine soil textures, such as clay, than in coarse textured soils, such as sand. This means that low permeability soils, clay soils, have less risk than high permeability sandy or loamy soils (Figure 2.6). The results table for overall risk of pollution through leaching (Figure 6.2) shows that high permeability soils generally drives the highest risk across the land uses, especially loam over chalk, shallow silty over chalk and seasonally wet loam over gravel (Figure 6.8)

As leaching risk also incorporates the risk of soil leaching to groundwater, the underlying geology (Figure 4.17) is an additional driver.

Soil type (Figure 2.6) is not the only factor that has an influence on the leaching process despite being the main factor when considering this pollutant pathway in high risk areas (Figure 6.15). Within lower risk areas (Figure 6.15) land use (Figure 2.4) also has a major influence. Woodland is the land use dominating very low risk in the overall leaching risk map due to the fact that there are minimal pollutants (nitrates and pesticides) being applied at the source (Figure 6.1) so the risk of pollution by leaching is very low or even null. Woodland as a land use therefore reduces water pollution risk through leaching and subsequently changing land use to woodland can be used as a measure to help control pollutants (nitrates and pesticides) at the source. This measure is of particular importance in areas where diffuse pollution is problematic, such as Central Bedfordshire, where, it is difficult to identify and control the source of pollutants (Brady and Weil 2008)

The overall leaching risk map (Figure 6.15) shows the trends described above, areas of very high and high risk (Figure 6.15) are located where sandy and loamy soils appear (Figure 2.6). Land use in these areas is mainly agriculture but other uses as pasture and urban areas are present as well (Figure 2.4).

The very high patch in the east part (Figure 6.15) has its origin in the nitrate leaching risk (Figure 6.13). As Central Bedfordshire belongs to the Nitrate Vulnerable Zones (see Appendix A2) and nitrate is the most mobile of the studied pollutants in water, the levels of risk from nitrate pollution through leaching are higher than in pesticide and other pollutants.

6.2.4 Future Scenarios

Urban development

An Urban development case study can be found in Appendix E1.

<u>Effects on overland flow risk</u>

Increasing urban development within Central Bedfordshire is predicted to increase the risk of overland flow. In this context, planning decisions need to take account of the impact of providing urban development. Particular consideration needs to be paid to transforming woodland as the results from the model suggest that the urban development would have the biggest detrimental effect on overland flow if woodland is used for development. Hazelton et al. (2011) highlight the issue with the urban development of woodland is that it will replace the vegetated surfaces – which provide shade, evaporative cooling and rainwater interception, storage and infiltration functions with impervious built surfaces. Conversely converting arable land to urban areas, especially on seasonally wet deep peat soils to loam, shallow silty soils over chalk and silty soils over chalk soil were predicted to have the most positive impact on reducing overland flow.

Recommendation:

1. Minimise pollution pathways in urban areas to reduce connectivity between the source and the receptor (Table 2.4) Section 5.2.3 outlined recommendations to reduce connectivity between source and receptor and therefore reduce overland flow, soil erosion and transport of associated pollutants

Effects on leaching risk

Further urban development within Central Bedfordshire would increase the risk of leaching. The negative impact would be observed across all soil types and under every land use. The greatest potential risk would be experienced on loam over chalk and shallow silty soils over chalk which are currently utilised as woodland. If the woodland is removed to develop urban areas on these soils the chalk, which is highly porous could experience increased leaching. This could be further exacerbated if urbanisation leads to an increase in the speed of sediment load or other pollutants being transported through drains. In the context of leaching the most favourable areas for development are arable and pasture land. The cost of draining the latter would suggest that arable and pasture areas with the lowest risk of leaching would make most sense for development. There are a number of soil types to choose from with a similar risk level such as deep clay, deep loam over gravel, deep loam to clay. The ultimate choice would be influenced by the suitability for arable farming of a particular soil type looking at fertility, soil characteristics etc.

Recommendations:

1. Building on arable land is predicted to have the least detrimental effects on leaching and overland flow risks; building on woodland is the least favourable. Developing upon impermeable soil reduces overland flow risk and on permeable soil reduces leaching risk.

2. Improving management of current urban land use is predicted to reduce the *source* of the pollutant. If SUDS are incorporated into all new developments and retrofitted to existing developments, together with good management, they will act to improve water quality at the source (CIRIA 2012e) (See Table 5.5). Additional measures to further manage pollutants at the source in urban areas are outlined in Table 6.12.

Table 6.12 Urban management recommendations to reduce the source of pollutants in urban areas

Management Strategy	Pollutant affected	Effect on Ecosystem Services
Urban site maintenance: Sweep hard surfaces regularly and keep paved areas around industrial and commercial areas clean to prevent accumulation of contaminants; place canopies over areas of potentially high contamination (CIRIA 2012e)	Sediment Nitrates Phosphates Pesticides	Minimise concentrated pollution in water courses following the first flush of a storm (CIRIA 2012e)
Education: Inform residents to use contaminants, including detergents from car washing, household chemicals and garden chemicals, carefully and to dispose of such contaminants properly and not by pouring them down surface drains. This will help prevent contaminants entering drainage system and subsequently watercourses. (CIRIA 2012e)	Nitrates Phosphates Pesticides	Help prevent contaminants entering drainage system and subsequently watercourses. (CIRIA 2012e)
Fertilisers. herbicides and pesticide use: Use sparingly and in accordance with manufacturer's instructions. Application should not take place where contaminants can be washed directly into a watercourse. (CIRIA 2012e)	Nitrates Phosphates Pesticides	Reduce fertiliser, herbicide and pesticide levels in watercourses
Avoid wrong connections: Avoid connecting foul water sewers to the surface water system (CIRIA 2012e) or incorrect plumping which connects untreated domestic wastewater to rivers (EA 2012b)	Nitrates Phosphates Pesticides	Prevent untreated water containing pollutants entering watercourses
Phosphate education: Use less detergent (minimal amount stated on pack); chose environmentally friendly brands with 5% phosphate/no phosphate at all; buy liquids or powders which contain less phosphate than tablets; only do a wash when you have a full load and ensure private sewage treatment works are well maintained and working effectively (EA 2012a)	Phosphates	Reduce phosphate inputs to surface water bodies

Potential urban development

Figure 6.27 shows the predicted combined risk of pollution from leaching (Figure 6.15) and overland flow (Figure 6.11) from current land use for potential urban development sites. Light green areas are areas where the current pollution risk from leaching and overland flow is low; red areas are where pollution risk is relatively high. Five areas with currently low risk levels are highlighted with green circles (Figure 6.27).

Site number 1 is located west of Biggleswade. The soil is predominantly deep loam over gravel (Figure 6.28) and is currently a combination of low, moderate and high risk. Conversion to urban areas is generally predicted to not have a major effect on changing the risk from overland flow (Figure 6.16) or leaching (Figure 6.17). However further consideration is needed of the effect of the inland water area (Figure 6.29) as a receptor of pollution.

Site number 2 (Rowney Warren Wood) is currently designated by CORINE as a woodland area, based on a loam soil over sandstone and thus currently an area of low pollution risk. Conversion to an urban area is predicted to result in an increased risk of pollution from overland flow (Figure 6.16).

Site 3 is classified by CORINE as an industrial site 5 km to the north west of Ampthill. It is based on a mostly deep clay and seasonally wet deep clay soil. Site 4 is about 5 km south of Cranfield is deep clay and deep loam to clay and appears to be a mixture of agricultural, forest and industrial land (Figure 6.29). Urban development at site 3 is predicted to have minimal effect on the pollution risk from overland flow (Figure 6.16) or leaching (Figure 6.17). The forested area at Site 4, if converted to an urban area is predicted to result in increased pollution risk from overland flow (Figure 6.16).

Site 5 is a forested and agricultural area predominantly on deep clay to the east and north east of Leighton Buzzard (Figure 6.28). Conversion of the forested areas to urban development is predicted to result in increased risk of pollution from overland flow (Figure 6.16).

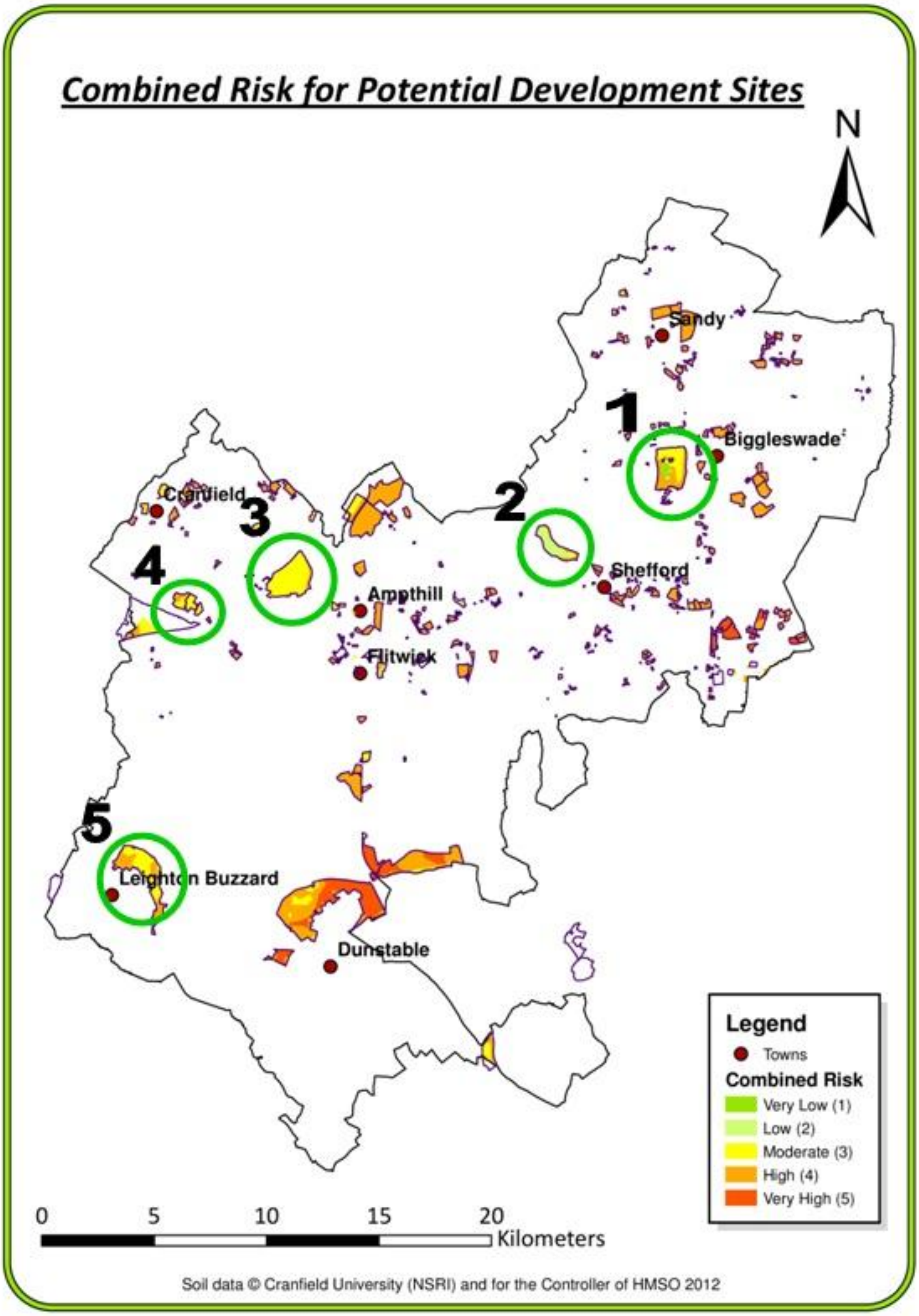

Figure 6.27 Predicted risk of current land use on potential urban development sites in Central Bedfordshire for leaching and overland flow.

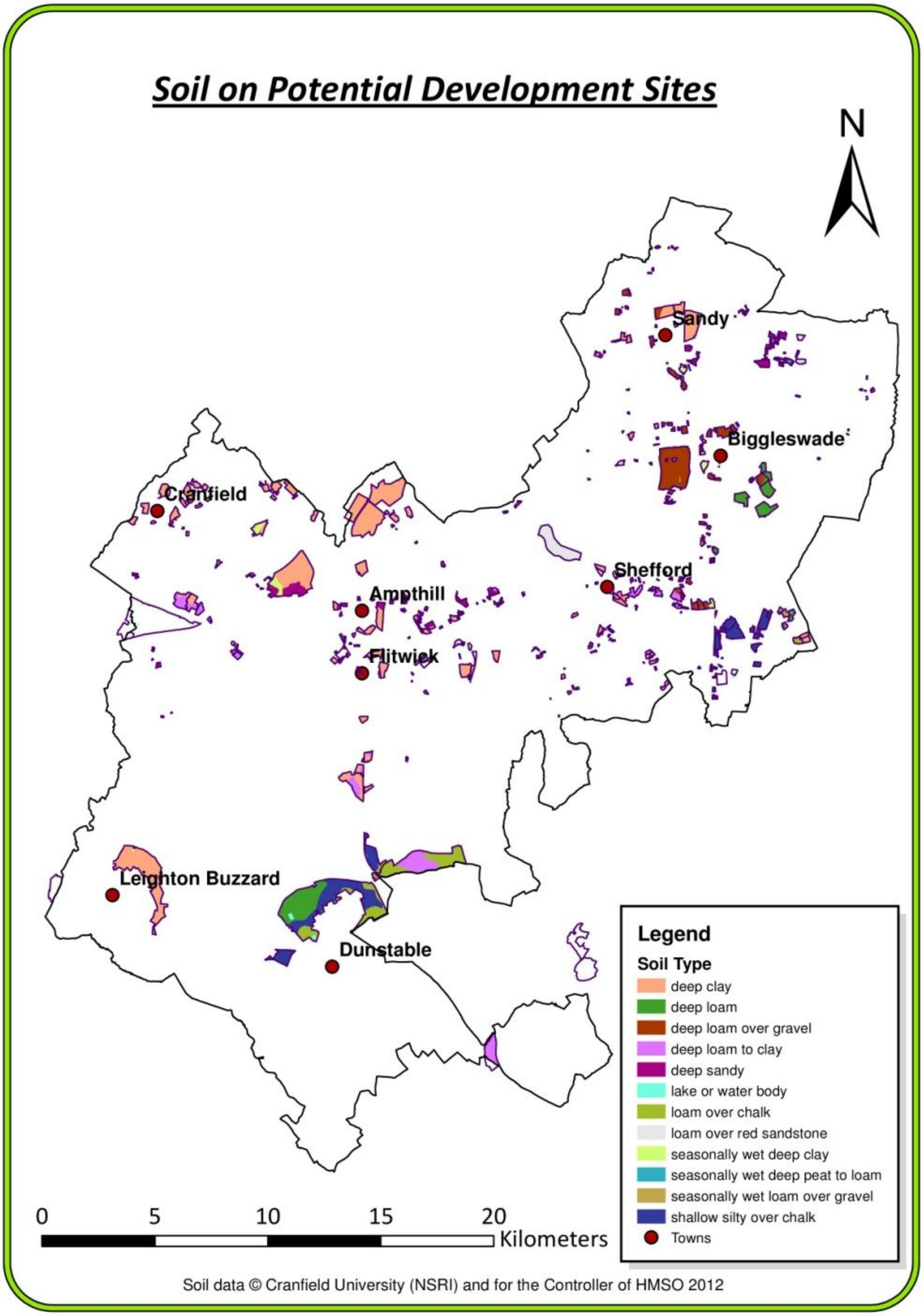

Figure 6.28 Soil types of potential urban development sites for Central Bedfordshire.

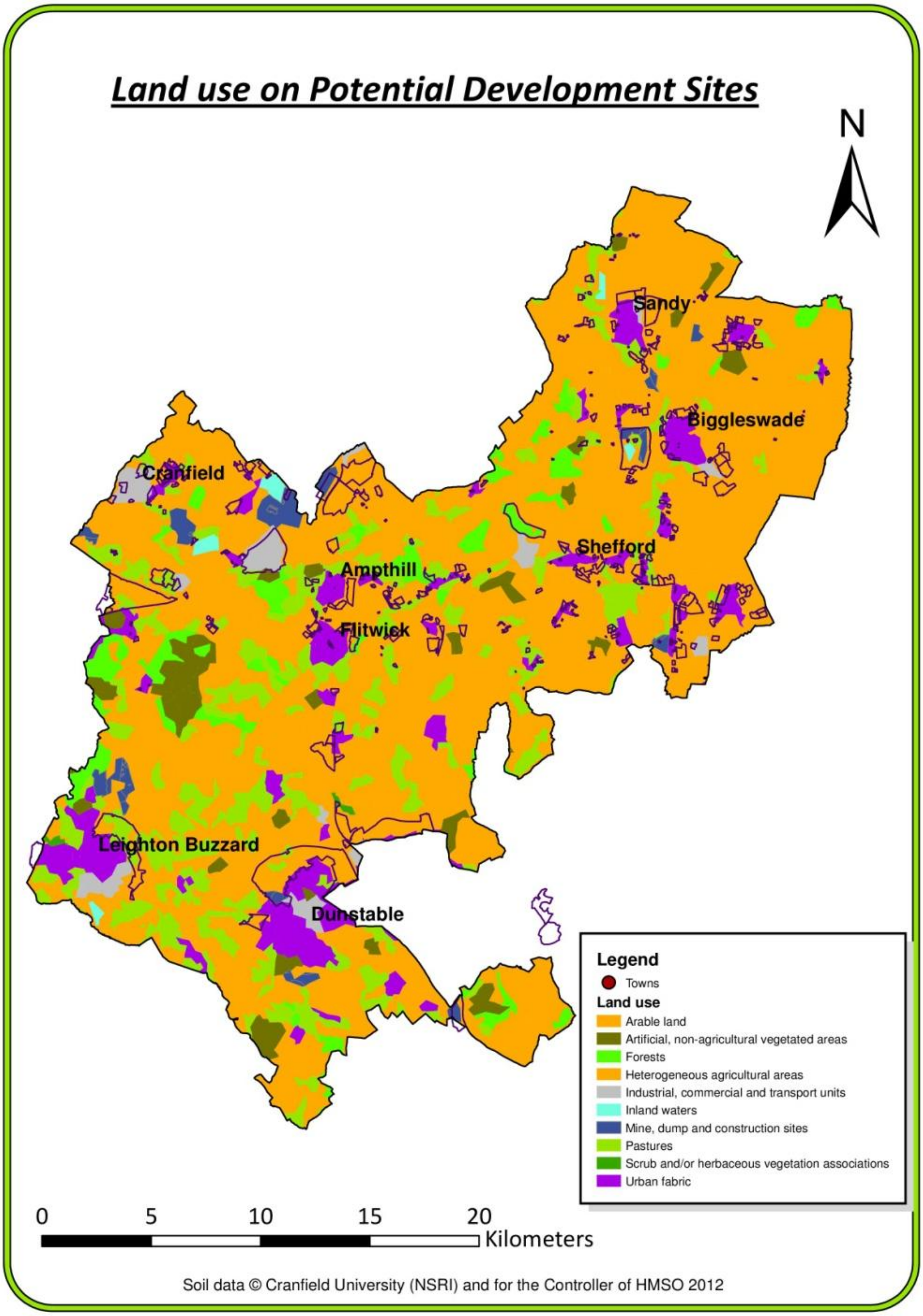

Figure 6.29 Current land use of potential urban development sites for Central Bedfordshire.

Land use management

The Land use management scenario has not been developed as data showed no significant difference in water quality when all arable land was given the values obtained for Entry-Level Schemes with the method employed. However, here land management practices are recommended to improve water pollution risk from arable land. Recommendations in this section focus on reducing water pollution risk at the *source*. Hunter (2009) states, low precipitation in the region reduces the capacity of runoff to dilute water pollution from agriculture and it is therefore important on arable land in Central Bedfordshire to control pollutants at the source.

Recommendations to minimise overland flow risk

1. Minimise pollution pathways on arable land to reduce connectivity between the source and the receptor. Section 5.2.3 gives recommendations to minimise pollutant *pathways* and reduce connectivity between source and receptor and therefore reduce runoff, soil erosion and transport of associated pollutants.

Recommendations to minimise leaching risk:

1. *Satisfy conditions for cross compliance*: An integrated approach to managing water quality and minimising pollutant sources and pathways across entire catchments, an approach required by the WFD to achieve ‘good status’ in watercourses (receptors) by 2015, is encouraged through cross-compliance; cross-compliance results in eligibility for the Single Payments Scheme) (DEFRA 2009; DEFRA 2010) within the Common Agricultural Policy (CAP) (See section 2.7). Conditions to satisfy cross-compliance for the pollutants nitrates, phosphate, pesticides and sediments can be achieved if farmers follow guidance outlined in the DEFRA document ‘Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers’(DEFRA 2009). This document includes management strategies to reduce these pollutants at source including for: nitrates (manure and nutrient management plans), phosphates (manure and nutrient management plans and soil management plans), pesticides (Crop protection management plans) and sediments (soil management plans)

Within ‘Nitrate Vulnerable Zones’, which covers the entire Central Bedfordshire region (see Appendix A2), ‘Nitrate Regulations’ (SI 2008/2349), which implement the European Commission’s Nitrate Directive, must be conformed with as a cross-compliance requirement; guidance to help farmers comply with the ‘Nitrate Regulations’ can be found at in the document ‘Guidance for Farmers in Nitrate Vulnerable Zones, PB 12736’ DEFRA and EA (2008).

Furthermore, farmers should follow DEFRA’s supporting documentation in the form of Fertiliser Manual RB209 (DEFRA 2010) which focuses on ensuring good agricultural practice with regard to supplying nitrates and phosphates to support economically viable yet environmentally friendly crop production (DEFRA 2010)

The recommendation to achieve cross-compliance will become increasingly valuable into the future with the EC reform of the CAP whereby a new Basic Payments Scheme will replace the current Single Payments scheme by 2014. This reform will ensure a new ‘Greening’ element is incorporated into even the lowest level of the CAP hierarchy (see section 2.9) whereby 30% of annual payments will be used to pay farmers to carry out environmental practices and including 7% of eligible arable land or temporary grassland placed in ecological focus areas, including making land fallow and introducing buffer strips; these measures are shown in Table 6.13, and in the pasture scenario in section 6.1.5 are shown to reduce water pollution on arable land.

2. *Satisfy conditions for Entry Level Stewardship (ELS) schemes*: Entry Level Stewardship (ELS) schemes (Natural England 2010a) within the Common Agricultural Policy (CAP) (see section 2.9). The measures within the ELS scheme which should be prioritised by farmers in order to reduce water pollution risk from nitrates *at source* can be found in Table 6.13.

3. *Satisfy conditions for Higher Level Stewardship (ELS) schemes*: Where possible and for enhanced reductions in water pollution risk, farmers should work to progress further up the CAP hierarchy to achieve land management practices which fulfil the conditions for the Higher Level Stewardship (HLS) schemes (Natural England 2010c) (See Literature Review section 2.6 and Figure 2.5).

4. Adopt principles from catchment management schemes: Catchment sensitive farming is a voluntary initiative run by DEFRA, Natural England and the Environment Agency which works towards reducing diffuse water pollution from agriculture and therefore protecting the water quality of watercourses and groundwater (Natural England, undated). Although Central Bedfordshire is not within a Catchment Sensitive Priority catchment (Natural England, undated) it is recommended here that measures form the initiative are adopted (Figure 6.30) particularly as the initiative aims to improve the WFD status (WFD 2000/60/EC) of surface and groundwater bodies through catchment wide land management advice (Hunter 2009).

Catchment Sensitive Farming Information
Aim: To reduce diffuse emissions of pollutants to ensure ecology, rivers and groundwater are protected
Location: Within the immediate catchment and further downstream
Pollutants:

- *Nitrates and phosphates:* Promotes appropriate management of fertilisers, manures and pesticides
- *Sediments:* Promotes good soil structure and rain infiltration (by reducing stock density and appropriate management of stock) to prevent runoff and erosion; Protects watercourses from sedimentation
- *Pesticides:* Introduces measures to protects watercourses from pesticides

Figure 6.30 Catchment sensitive farming information

4. *Organic Entry Level Scheme*: The Church Farm case study for water quality (Appendix E2) shows entering arable land into the Organic Entry Level Stewardship (OELS) Scheme (Natural England 2010b) is extremely beneficial in terms of water quality, particularly with regard to pollutant prevention in terms of reducing pollutants at the source.

Table 6.13 ELS management recommendations to prevent pollution at *source* and therefore improve water quality (Natural England 2010a). Note that ↓ means reduced impact in the relative regulating ecosystem service; ↓ is reduction in impact, ↓↓ is significant reduction in impact, ↓↓↓ is dramatically high reduction in impact.

ELS MANAGEMENT RECOMMENDATIONS					
ELS code	**ELS stipulation**	**Location**	**Impact on runoff (NO_3, P, pesticide and sediment pathway)**	**Impact on soil erosion (NO_3, P & pesticide paths)**	**Recommendation**
SPECIFIC TO PROTECTING SOIL AND WATER (EJ)					
EJ2/ EJ10	Management of maize crops	Whole field	↓	↓	Do not apply more than recommended amount of slurry or manure for maize or the following crop and apply at appropriate times to reduce risk of runoff.
EJ5	*Infield* grass areas to prevent erosion and runoff	Within field	↓ Nitrate [1] ↓ Phosphate[1]	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EJ5	*Field margin* grass areas (buffer strips)	Edge of field	↓	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EJ9	12m buffer strips for watercourses on cultivated land.	Close to watercourses	↓	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EJ11	Maintenance of watercourse fencing	Edge of field/close to watercourses	↓	↓	Where field are grazed to ensure exclusion of stock from ditch, river or stream bank; can be used alongside buffers or margins next to a watercourse.
EJ13	Winter cover crops	Whole field	↓	↓	Establish cover crops early to ensure that sufficient soil nitrate is taken up before winter drainage leaches it below roots of the developing plants; destroy cover crops by January/February to ensure nitrate leaching does not increase the following winter. General benefits derived from dense sowing of crops and not applying fertilisers or manures.
MULTI-FUNCTIONAL: CONTRIBUTES TO PROTECTION OF SOIL AND WATER					
EB1/EB2/ EB3	Field boundary feature: Hedgerow management	Edge of field	↓	↓	Maintain hedgerows. Establish 'protection zones' by not cultivating or applying fertilisers, manures or pesticides within 2m of the centre of a hedgerow or a watercourse.
EB6	Field boundary feature: Ditch management	Edge of field	↓	n/a	Management of ditches forming field boundaries which regularly contain standing or flowing water; must not apply fertiliser or pesticides to land within 2m of the centre of the ditch, or within 1m of the top of the ditch bank.

EC4	Trees and Woodland: Management of woodland edges	Edge of woodland at edge or within field	↓	n/a	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EC24	Tree and woodland: Hedgerow tree buffer strips on cultivated and grassland	Within field/edge of field	↓	↓	No cultivation within 2m of centre of hedgerow and only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EE1/EE2/E E3 EE4/EE5/E E6	Buffer strips (managed as low intensity grassland):2-6m buffer strips on cultivated land and intensive grassland.	Within field/edge of field	↓	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EE9/EE10	6m buffering on cultivated land and grassland next to a watercourse	Close to watercourse	↓	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EF1/EL1	Management of arable land and grassland: Management of field corners	Edge of field	↓	↓	Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EF6	Management of arable land: Overwintered stubble	Whole of field	↓	↓	No pesticide, fertiliser, manure, lime or post-harvest herbicide application to the stubble allowed
EL2	Grassland: Permanent grassland with low inputs of fertilisers and sprays	Whole field	↓	↓	Do not apply over 50 kg/ha N per year as inorganic fertiliser, or 100 kg/ha total N from all source per year. Apply during growing season and only when field dry enough to prevent soil compaction. If current manure and fertiliser use is less than this, do not increase applications. Only apply herbicides to spot treat or weed-wipe for the control of injurious weeds or invasive non-native species and do not apply fertilisers or manures.
EL3	Grassland: Permanent grassland with very low inputs of fertilisers and sprays	Whole field	↓↓	↓↓	Apply up to 12.5tonnes/ha per year of farm yard manure, but only where grassland is regularly cut. Apply during growing season and only when field dry enough to prevent soil compaction. No other type of fertiliser or manures to be applied. If current manure and fertiliser use is less than this, do not increase applications.

Biodiversity Action Plan, change to woodland land use and pasture land use

Implementing the BAP would generally have a positive effect on reducing the risk of pollution from overland flow and leaching within Central Bedfordshire.

<u>Effects on overland flow risk</u>

Recommendations:

1. The conversion of arable and pasture land cover to woodland is predicted to have water quality benefits in terms of overland flow risk. The impact of this land use change is greatest in arable land with seasonally wet deep clay, seasonally wet deep peat to loam and deep silty to clay and to a lesser extent for pasture.
2. Conversion to pasture was predicted to be most beneficial in terms of improvements in overland flow risk on arable land.

<u>Effects on leaching risk</u>

Recommendations:

1. The conversion of arable and pasture land cover to woodland is predicted to have water quality benefits in terms of leaching risk. The impact of this land use change is greatest in arable land with seasonally wet deep clay, seasonally wet deep peat to loam and deep silty to clay (Table 6.8 and 6.9) and to a lesser extent for pasture.
2. Conversion to pasture was predicted to be beneficial in terms of improvements in leaching risk on arable land.

Climate change

The Intergovernmental Panel on Climate Change's (IPCC) technical report (Bates et al. 2008) highlights the vulnerability of the freshwater resources to climate change. Therefore, management plans for water resources need to take into account the changing scenario. The Environmental Agency (River Management Plan 2009) in the Anglian Region has identified the potential impacts of climate change for the main pressures in the area (see Figure 5.10). Climate change scenarios predicted by UK Climate Projections indicate a decrease in the summer flows of rivers, implying less dilution of pollutants (Whitehead et al. 2009). Although soil mineralization increases with temperature, the implications of climate change for nitrate leaching are not well understood and site data is required to make any further assumptions (Stuart et al. 2010).

7. Conclusions and Recommendations

7.1 Soil organic carbon storage and sequestration

7.1.1 Conclusions

SOC storage and sequestration is vital not only in efforts to mitigate climate change, but it also influences other regulating ecosystem services such as water quality, soil erosion and flood control (Kimble et al. 2007).

The results from this study show that the “carbon calculator” method (Baloch et al., 2008) provides a method of estimating changes in SOC in the top 150 cm for different land uses and soil types. Forty nine out of fifty three(94%) of the results obtained were in agreement with trends observed in literature, with just three exceptions found involving the soil types shallow silty over chalk, seasonally wet deep clay and seasonally wet deep peat to loam soils. However, the methodology used in this study does require some refinement, as the combination of multiple soil series into soil types has generated averaging errors in some areas.

The overall trend found is that SOC is highest in the top soil (<30 cm), decreasing with increasing soil depth. SOC is also highest under soils with high clay contents, and lowest in soils with high sand contents. Regarding land use, SOC is generally highest under woodland, followed by pasture, arable land and finally, is lowest under urban areas. Hotspots of high SOC are located along rivers and in the peat land between Sandy and Biggleswade.

Above-ground organic carbon figures made very little difference to the area’s total carbon content, reiterating the fact that the soil is a much greater reservoir of SOC than vegetation.

Total soil carbon stocks in Central Bedfordshire were estimated at 9,523,000 tonnes of SOC. Most of the carbon is stored in arable areas as they comprise 70% of Central Bedfordshire. By increasing carbon storage in Central Bedfordshire the Council will be in a better position to meet the targets of Kyoto Protocol and UK targets.

Urban developments in any part of the county were predicted to result in losses of SOC. Proposed development areas which showed relatively low SOC losses (less than 75 t ha^{-1}) include Lidlington, North and West of Dunstable, North and East of Luton, North of Silsoe, and North of Broom. Proposed developments that are predicted to result in heavy losses (greater than 75t ha^{-1}) include: North and East of Sandy, South and East of Potton, North of Shefford, around Leighton Buzzard, West and South East of Biggleswade and all sites falling within river valleys and the peat lands.

Current values of SOC under arable land use appear not to be greatly affected by the presence or lack of agri-environment schemes. This is because, at present, such schemes do not particularly target soil carbon content. However, studies have shown that there are many land management practices that can be adopted to improve carbon sequestration. These include:

- Conservation agriculture with minimum/no tillage.
- Continuous protective cover over soils using live or dead vegetation.
- Organic farming and use of green manure.

- Increased crop productivity through species selection, fertilizer application (P, not N).
- Crop rotation including legumes.

Implementation of the proposed Biodiversity Action Plan (including woodland, neutral grassland and hedgerows) is predicted to result in a net gain in SOC, with the majority of sites gaining 50-100 t ha^{-1}. The greatest gains (over 100 t ha^{-1}) are predicted on arable areas North-East of Milton Bryan and close to the A5 junction with Sheep Lane. Other areas outside the BAP which could potentially give high SOC gains when forested include areas between Cranfield and Marston Vale, at Cockayne Hatley and South of Linslade.

7.1.2 Recommendations

Based on the findings of this study, the following are recommended to preserve SOC stocks and increase carbon sequestration:

- Focusing SOC conservation efforts on the peat lands, along river valleys, in woodlands and pastures would give the greatest benefit in preserving carbon stores in the soil. This includes measures such as water-table control in peat lands.
- Incorporation of recommended SOC enhancement measures within future agri-environment schemes would support soil carbon storage on arable soils.
- Implementation of the BAP as proposed, giving priority to afforestation, planting of neutral grasslands, and hedgerows is beneficial in terms of SOC. It would be worthwhile to explore the extension of the BAP to identified areas of high potential carbon gain in the woodland scenario that are currently outside the BAP.
- Urban developments on peat lands and along river valleys are predicted to be highly detrimental to soil carbon storage and sequestration.
- Proposed developments that are predicted to result in significant losses of SOC include: North and East of Sandy, South and East of Potton, West of Biggleswade, and around Leighton Buzzard. Proposed sites where urban development will result in the smallest SOC losses include those at Lidlington, North and West of Dunstable, North and East of Luton, North of Silsoe, West of Potton and North of Broom.
- Whereas population and development pressure demand an increase in urban development, incorporation of SOC conservation measures such as the inclusion of urban green space in the development design can minimize SOC losses.

With regards to further research, the following are recommended:

- Standardisation of land use classifications for LandIS data to overcome the need to derive figures for some land uses like woodland and urban using conversion factors.
- Ensure representative data sampling for all land uses and soil types to enable data validation, and therefore the ability to detect erroneous results.
- Where possible, obtain finer resolution and up-to-date land use maps for the study area.
- Repeating the analysis using other soil carbon models that incorporate the intermediate processes in land use changes in their calculations, e.g. Roth-C and Struc-C model, for comparison purposes (Stockman 2011).

7.2 Runoff and erosion

7.2.1. Conclusions

Runoff and erosion influence numerous other ecosystem services, such as water quality and SOC. Indeed, runoff causes soil particle detachment, including organic matter and pollutants, allowing such particles to enter water bodies, which can have various detrimental effects. It is therefore crucial to preserve these two regulating services.

The results from this study show that the Curve Number method gives reasonable results, and is especially useful for tracking the causes and visualizing the consequences of runoff, whereas the USLE model gives only relative rates of erosion to target priority areas. In a general way, the results obtained by both these models display trends similar to those observed in the literature. However, as both models have been developed in the USA some inaccuracies are expected, though they look greater in the erosion model. Therefore, erosion rates should not be interpreted quantitatively.

For a given Hydrologic Soil Group, the greatest runoff rates were associated with urban areas, followed by arable land, whilst woodland registered the smallest runoff predictions. For a given land use, different Hydrological Soil Groups drive runoff generation: whilst the Greensand Ridge has a high potential for infiltration, a significant area of Central Bedfordshire (North-West and South-East on either side of the Greensand Ridge) lies on soils of impeded drainage, where sealing will have the most moderate impact. The hydrological model also showed that development areas should be carefully chosen according to potential upstream land use change, that could provoke flooding downstream.

Erosion depends on several factors; some of these are inherent to the location (slope, rainfall erosivity, soil texture), other factors can be controlled by proper management (soil structure and organic matter, vegetation, and land management practices). It is especially important to control erosion with these leverages where local slope and soil types would be likely to trigger significant soil loss.

7.2.2. Recommendations

Based on the findings of this study, the following are recommended to tackle runoff issues:

- Urban development should aim to maintain runoff patterns prior to development, causing as little change as possible. In this context, runoff increases are minimised by focusing urban development on low permeability soil areas.
- The potential urban development sites which appear to offer the least negative impacts on runoff (as determined by our methodology) include those close to Cranfield, and those in the Western area of Flitwick and Ampthill, in the North-East of Sandy, and in the North-West area of the county. Conversely the sites that appear to create the largest negative impact on runoff include those north of Luton and in the south-west corner of Central Bedfordshire, that in the East of Ampthill, and the large development located North-East of Shefford.
- Undesirable effects of urban land use can be reduced with good structural design of the controls for sustainable urban runoff.

- Sealing in a catchment can be mitigated by forest establishment. Grassland establishment seems to be less effective.

Some key solutions to minimise soil erosion are:

- Areas with steep slopes should be covered with forest or permanent grassland.
- Implementation of realistically implementable good land management practices, some of which are proposed in the ELS (e.g. buffer strips, green corners, cover crops), whereas some other are not (e.g. contouring).
- Temporary measures (e.g. geotextiles, sediment traps) should be implemented on construction sites, as they are particularly sensitive to erosion.
- Permanent bare land areas (landfills and mines) should prioritised for covering with vegetation.

7.3 Water quality

7.3.1 Conclusions

Water status is below the WFD target of 'good' for nitrates, phosphate and pesticides within certain surface and groundwater bodies; changing land use and improving land management practices can resolve this to achieve good status by 2015 the WFD (EC/60/22) target. Diffuse water pollution from arable land is the main cause of pollution of water bodies:

- The overall risk of pollution through overland flow driven by land use, with arable areas showing the highest risk and woodland the lowest risk. Arable land can be a source of the overland flow of sediments, pesticide and nitrate, so it generally carries a high risk. However the only major overland flow pollutant derived from woodland is sediment, and hence it is generally associated with low risk. In terms of overland flow: clay, loam and silt soils create a higher risk than sand soils.

- The high overall risk of pollution through leaching is generally associated with highly permeability soils such as loam and shallow silty soils over chalk, and seasonally wet loam over gravel. Woodland does not generally provide a source of nitrates or phosphates (the main pollutants transported through leaching) so its presence can be important.

7.3.2 Recommendations

The report presents the proposal that river status can be improved by**:**

- Changing arable and pasture land cover to woodland where possible as this reduces the risk of pollution through overland flow. The impact of this change is greatest with arable land on seasonally wet deep clay, seasonally wet deep peat to loam, and deep silty soil above clay (Table 6.8).
- A decreased risk of pollution through leaching is seen when pasture is changed to semi-natural vegetation and woodland; there is only a limited effect when pasture is changed to arable.
- In the context of water quality the most appropriate land use for urban development is arable land; on permeable soil to reduce runoff risk and on impermeable soil to reduce leaching risk; woodland is the least suitable place for development with increased leaching and runoff risk.

7.4 Overall recommendations

- This project represents one of the first attempts to bring together soil and land use information for a unitary authority area, with the aim of describing the effects of land use and management options on soil carbon, runoff, soil erosion, and water quality. As such it serves as a useful framework to identify the effect of proposed land use and land management changes on some key regulating ecosystem services.
- Bringing the sections of soil carbon, soil erosion, runoff and water quality together the least suitable area for urban development would be woodland as it provides mitigation measures for soil erosion, stores large amounts of carbon, and helps to reduce runoff and leaching.
- The applicability of the maps is limited in part by the accuracy and resolution of the Corine land cover map. More detailed and recent data may be available from the maps associated with the Countryside Survey, but this could be not be accessed within the constraints of this project.
- Some of the water quality and erosion issues in Central Bedfordshire are related to land management practices outside of the area, and this requires a wider catchment based approach..

8. References

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