Highlights

This interdisciplinary paper assesses the applicability of a soil-based national mapping approach, for identifying opportunities for woodland and run-off management measures to reduce flood risk within lowland catchments of southern England, with local farmers .

The farmers experiential knowledge supported the technical map in terms of targeting of deep clay and silt soils over mudstone as high priority for improved land and soil management to reduce rapid runoff.

While national incentives correctly target the problem areas, there was frustration about the lack of flexibility in choice of NFM measures on target soils. Our farmers favoured soil-based NFM measures, such as the use of cover crops, diverse crop rotations and minimal tillage, that would support continued agricultural use.

They were resistant to wider woodland creation and critical of a perceived mismatch between the availability of incentives for tree planting but lack of funding to encourage soil and land management practices to reduce rapid runoff.

Overall, our study highlights the need for a more integrated approach in which both technical and local soil knowledge is exchanged and combined in the development of local NFM schemes to aid delivery of national policy.

Incorporating technical and farmer knowledge to improve land use and management for natural flood management in lowland catchments

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Abstract

Natural flood management (NFM) involves measures to restore and protect natural hydrology and geomorphology to minimise flood risk. NFM is promoted as part of the nation's flood resilience response. Government agencies have created national maps of opportunities for specific NFM measure to target available grant aid and encourage landowners and managers to deliver effective NFM measures where most needed. Mapping opportunities within a regulatory framework ensures that measures are targeted towards areas with a presumption of suitability thus minimising the burden of the application process.

The viability of NFM depends on the responsible authority and community at risk accepting the proposed measures as both effective and appropriate. Top-down initiatives can fail to meet their targets when landowners and managers feel left out of the decision making and their experiential local knowledge is at odds with the spatial prioritisation derived from national datasets.

This interdisciplinary paper assesses the applicability of a technical-based national mapping approach with local stakeholders for identifying opportunities for woodland and runoff management measures to reduce flood risk within the lowland catchments of the West Thames River Basin, in southern England. Farmer surveys supported the technical map in terms of targeting areas of deep clay and silt soils over mudstone as high priority for improved land and soil management to reduce rapid runoff. However, while incentives correctly target the problem areas, farmers desired greater flexibility in choice of NFM measures to reflect local soil knowledge and the sustainability of management practices within farm systems. It is argued that a more integrated and co-designed mapping approach would enhance NFM uptake and thus achieve a greater reduction in downstream flood risk.

1. Introduction

Natural flood management (NFM) involves the creation and maintenance of environmentally sensitive measures to enhance natural hydrological and geomorphological processes to reduce flood risk within a catchment. NFM has been incorporated into UK flood management policy and increasingly used to supplement engineered solutions where dynamic natural processes can be restored and accommodated (Short et al., 2018). The Flood & Water Management Act (England & Wales) 2010 advocates NFM, and the Flood Risk Management Act (Scotland) 2009 requires that NFM approaches are considered when designing flood management schemes. In our case study area, the Thames Basin Flood Risk Management Plan (EA, 2016) adopts an integrated catchment-wide approach which aims to encourage measures to restore natural processes to reduce runoff at source, alongside engineered defences in the floodplain or river channel. Although NFM pilot projects are underway across the West Thames River Basin (WTRB) (CABA, 2020), evidence of the effectiveness of the NFM measures within lowland groundwater fed systems is limited, particularly at a catchment scale. In this paper we explore to what extent farmers recognise and are motivated to achieve the potential the NFM benefit of their own crop choice, land management and tree planting decisions.

Soil and land management is recognised as an effective NFM measure by the Environment Agency, the government agency for flooding, and included in the Working with Natural Processes (WWNP) framework (EA, 2014). Agricultural land management practices alter the structure of the soil, which can impede infiltration and reduce the soil water storage capacity, increasing rainfall runoff and subsequent flood risk (Palmer, 2015; Holman et al.,2003). Arable agricultural use can be particularly damaging, causing soil compaction, smearing and capping (Palmer and Smith 2013). Muddy floods occur when the degraded topsoil becomes saturated and rainwater flows laterally above the zone of compaction (Harris et al., 1993; Godwin and Dresser 2003), resulting in rapid surface runoff (Boardman and Vandaele, 2019). Land management-based NFM measures focus on improving water infiltration through the restoration of physical and chemical soil characteristics (Boardman and Vandaele, 2019; Hathaway-Jenkins et al., 2010); they include altering the timing and choice of equipment to reduce pressures on the soil, the use of cover crops and targeted tree planting.

Changing the soil's capacity to receive and store rainwater can be slow and incremental (Acin-Carrera et al., 2013). To be effective for reducing downstream flooding, NFM measures need to be implemented across a large portion of the catchment, requiring multiple landowners to co-ordinate efforts (Old, 2017). Initiatives based around collaboration, such as the Farmer Facilitation fund, Catchment Partnerships and Catchment Sensitive Farming encourage knowledge sharing and collective action to deliver benefits beyond the farm gate (Pragar 2022, Jones et al., 2020; Thomas et al., 2020). The initiatives fund farm and environmental advisors to facilitate collective modes of working and develop local catchment based NFM schemes with landowners, land managers and agricultural contractors. To provide direction, government agencies have created national maps to represent their strategic spatial prioritisation of land management and land use change incentives to deliver flood risk benefit (EA, 2014; FC, 2018). NFM opportunity maps use a variety of soil and/or geology data to help target measures to increase soil infiltration and reduce rapid runoff (EA, 2017). The Forestry Commission is the government department responsible for the regulation woodland in England, it offers additional payments in areas where woodland creation can deliver environmental, including flood, benefits (FC, 2018). However the utility of such mapping in the integration of local and scientific knowledge in the planning of environmental management lacks systematic evaluation (Raymond et al., 2010).

The scale of the national maps makes them best suited for strategic and regional use and they should be considered as indicative at a field scale. The incentives for which the maps were created are open to all but entirely voluntary. Despite improved sharing of agricultural knowledge and innovation through more collaborative processes (Ingram et al., 2018), the degree to which national mapping facilitates engagement with farmers and land managers remains unclear (EA, 2019; Rust et al., 2020). Farmers' soil knowledge is primarily gained from direct experience rather than technical maps and published soil survey memoirs (Roland et al., 2018; Yageta et al., 2019). Whereas environmental sciences can perceive personal experiences as 'anecdotal' and struggle to use such information, social sciences recognise this local, lay or tacit knowledge as 'data' (Raymond et al., 2010). The growing acceptance that farmers' knowledge should be recognised and used to deliver effective soil management rather than imposing top-down prescriptions has been a key focus of Countryside Stewardship (CS) (Thomas et al., 2020, Pragar 2022).

Effective deployment of NFM requires (i) accurate characterisation of the natural environment (soils, topography, hydrology and climate), (ii) local knowledge of flood risk in the landscape accumulated over decades and (iii) an understanding of landowner motivations, management systems and financial constraints. It is essential for all three factors to converge for NFM interventions to be realised at the scale necessary to be effective. There is increasing recognition of the value and role of farmer knowledge (Mills et al., 2017; Pragar 2022), this paper sets out to compare the national soil derived opportunity maps with the responses from land managers, to determine if there is sufficient affinity for a collaborative process to be developed. The issue of motivations and behavioural characteristics needs to be considered, represented by the ability, engagement and willingness by Mills et al., (2017). In this characterisation, the sweet spot is where land managers are using a farming system that offers an opportunity for NFM to be integrated (ability); have a clear understanding of what is expected (engaged) and a set of normative behaviours that recognises the underpinning environmental issues (willingness). National opportunity maps are intended to be used for strategic planning and as an initial scoping mechanism, meaning that at some point they become an underpinning narrative of projects and initiatives involving discussions with farmers and other local stakeholders. In this paper we assess the applicability of national opportunity maps for local targeting of NFM measures and evaluate the match with farmer knowledge and perceived benefits and barriers to adoption.

LANDWISE is one of three projects funded by the Natural Environment Research Council (NERC) to assess the effectiveness of NFM and explore the evidence required to support decision making and planning around NFM. The project focuses on lowland agricultural catchments and uses the case study of the WTRB catchment to evaluate farmer knowledge and uptake of woodland and runoff management based NFM measures. We adopt an interdisciplinary mixed-methods approach and compare farmer use of technical and scientific knowledge in the form of national soil derived opportunity maps with lay knowledge of local soils and land management collected through farmer surveys and interviews. Specific objectives are to (1) characterise the extent of NFM opportunities across the key soil types of the WTRB and (2) assess how mapped opportunities match farmer knowledge of soils' perceived limitations and the degree of fit with cropping and land management systems, and thereby if soil derived national mapping is an appropriate means to target land based NFM interventions.

2. Methods

2.1 West Thames River Basin

The LANDWISE project used the WTRB to investigate the practicality and potential of soil and land management based NFM measures. The case study contains twelve tributary catchments of the River Thames and covers approximately 7,225 km^2 in southern England. The WTRB is predominantly rural in the west becoming increasingly urbanised downstream towards Maidenhead (Fig. 1). There has been repeated extensive river flooding affecting communities across the catchment. Thousands of properties were flooded in July 2007, through the winter of 2013-14 and again in December 2015. A total of 47,900 people are at high risk from regular flooding (more than a 1 in 30 chance of being flooded in any year), with an additional 164,050 at risk from more extreme events (EA 2016).

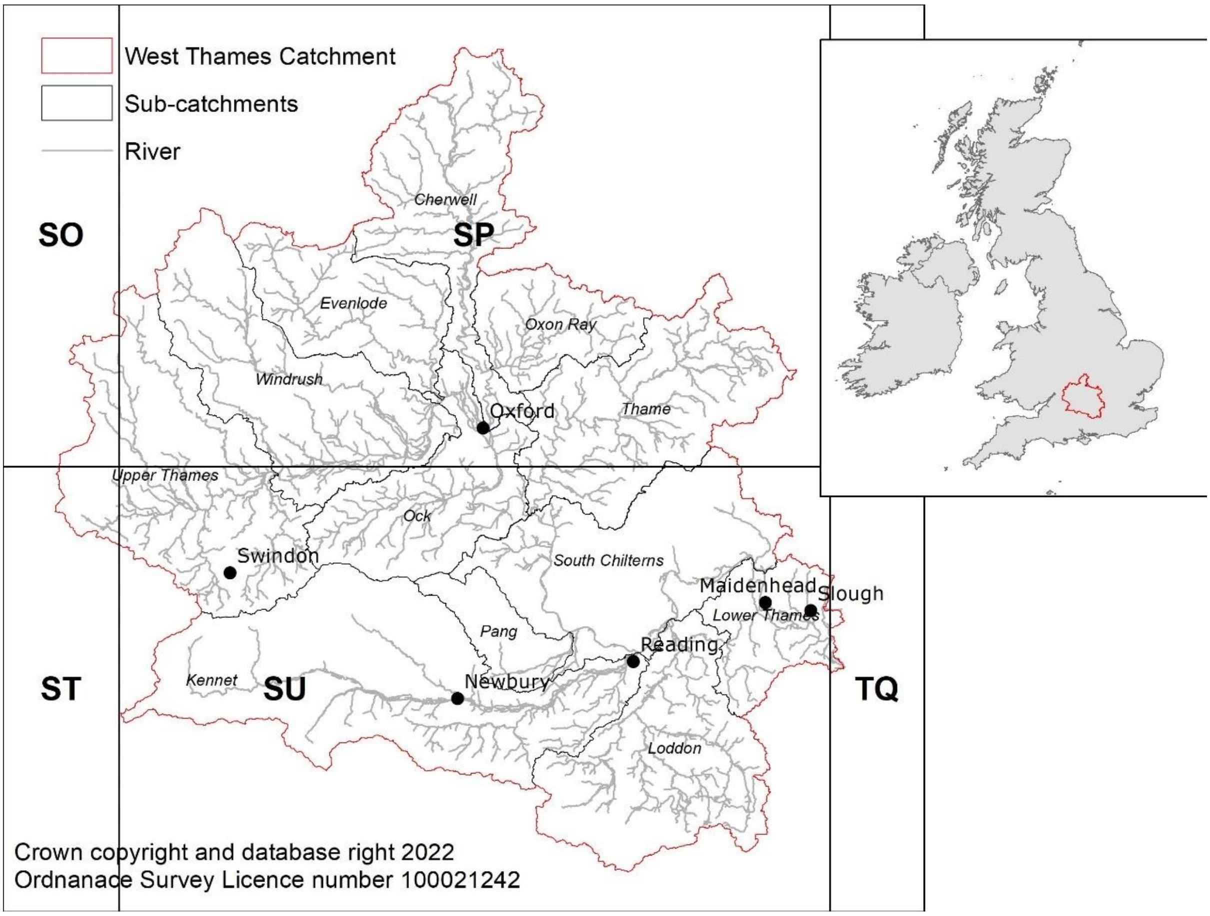

Figure 1 The six major towns and twelve sub-catchments of the WTRB, the LANDWISE project study area.

The River Thames drains the rolling chalk and limestone hills of the Chilterns, Berkshire Downs and Cotswolds, then flows through wide valleys with flat floodplains and variable geology. The main river responds slowly to rainfall but the flow regimes of tributaries vary depending on catchment size, geology, soils and landuse. Those dominated by clay soils, such as the Thame are characterized by high levels of surface runoff and a flashy response to storm events, whereas those draining chalk and limestone are more affected by groundwater than fluvial flooding (Bloomfield et al. 2009) (Fig 2).

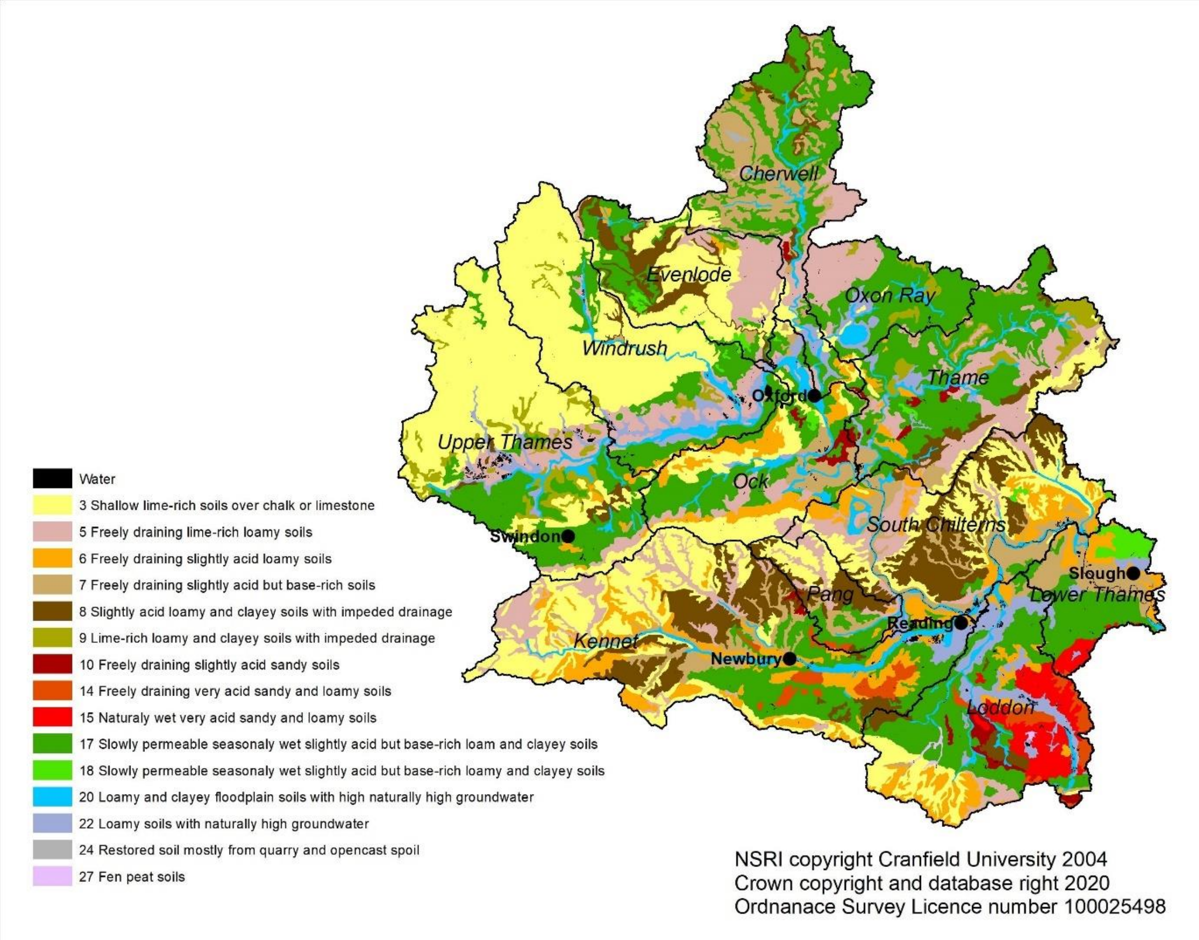

Figure 2 LandIS Soilscapes map of soil groups in the WTRB. Data supplied under licence by Cranfield University sponsored by DEFRA

Soil knowledge is fundamental when making responsible management decisions, whether preparing a strategic catchment flood management plan or planning annual cropping and farm nutrient regimes. Several soil classification schemes are routinely used by different stakeholders, adding to the complexity of decision making. Each classification scheme identifies groups of soils that reflect a range of relevant soil properties and function, e.g. in terms of texture, hydrology or nutrient retention and availability. Table 1 compares the different schemes, ranging from the national soil classification system based on soil associations (Cranfield, 2021) to a more practical-based soil classification used by farmers and their advisors in the UK (Defra, 2010).

Generalised geology of soil parent material	RB209 - The Nutrient Management Guide	Soilscapes map	NSRI 1:250,000 soil map of England and Wales		World Reference Base
			Soil Association:	Hydrology	

			map unit and soil group		
Carbonate - Chalk	Shallow soil. [Chalk, limestone or other rock excluding sandstone within 40 cm of soil surface]	3. Shallow lime-rich soils over chalk or limestone	Rendzinas - 341*; 342a*; 343g; 343h*; 343i	Shallow, well drained; *steep slopes	Leptosol
			342b; 342c; 343a; 343b; 343c; 343d;	Shallow over slowly permeable calcareous clays	
	Medium soils [moist soil feels silty to depth of ≤100 cm]	9. Lime-rich loamy and clayey soils with impeded drainage	Calcareous pelosols - 411a; 411b; 411d	Slowly permeable clayey soils	Cambisol
		5. Freely draining lime-rich loamy soils	Brown calcareous earths - 511a; 511b; 511d; 511f; 511g; 511h; 511i; 512d; 512e; Brown earths - 541B	Well drained; locally affected by groundwater and prone to seasonal waterlogging; locally perennially wet in valley bottom	
		6. Freely draining slightly acid loamy soils	Brown earths - 541r; Argillic brown earths - 571e; 571g; 571h; 571i; 571s; 571w; 571z; 573a; Paleo-argillic brown earths - 581b; 581c; 581d; 581e		Luvisol
		7. Freely draining slightly acid but base-rich soils	Brown earths - 544; Argillic brown earths - 571j; 571m; 571u; 571v		
		8. Slightly acid loamy and clayey soils with impeded drainage	Argillic brown earths - 572h; 572k; 572q; Paleo-argillic brown earths - 582a	Locally affected by groundwater, seasonal waterlogging associated with slowly permeable subsoils	
	Deep soils [moist soil feels silty to depth of ≥100 cm or subsoil		Argillic brown earths - 572j; 572t; Paleo-argillic brown		

	>40 cm depth is clay based]		earths - 582b; 582c		
Sandstone	Light sand soil [moist soil is rough and gritty and subsoil >40 cm depth is sand or sandstone]	10.Freely draining slightly acid sandy soils	Brown sands - 554a	Well drained, locally affected by groundwater leads to seasonal waterlogging	
		15. Naturally wet very acid sandy and loamy soils	Gley podzols - 643a		Podzol
		14. Freely draining very acid sandy and loamy soils	Podzols - 631d; 634	Slowly permeable subsoil leads to seasonal waterlogging	
Mudstone	Deep silty soil [moist soil feels silty to depth of ≥100 cm] or Deep clayey soil [moist soil can be rolled into a ball or moulded like plasticine to depth of ≥100 cm]	17. Slowly permeable seasonally wet acid loamy and clayey soils	Stagnogley soils - 714d	Slowly permeable seasonal waterlogged, locally better drained and seasonally wet	Planosol / **Stagnosol
		18. Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	Stagnogley soils - 711f; 711g; 711h; 711j; 711m; 711t; **712b; **712c; 712g **714c;		
		20. Loamy and clayey floodplain soils with naturally high groundwater	Alluvial gley soils - 812a; 813b; 813d; 814a	Flat floodplain affected by groundwater, risk of flooding	Gleysol
		22. Loamy soils with naturally high groundwater	Cambic gley soils - 832; Argillic gley soils - 841b; 841c; 841d; 841e		
Man-made soil	Not included in classification	24. Restored soils mostly from quarry and opencast spoil	Man-made soils - 952	Variable	Regosols
Peat	Peaty soil	27. Fen peat soils	Peats soils - 1024b; 1024c	Flat ground affected by groundwater	Histosol

Table 1 Comparison of soil classification schemes in the West Thames River Basin. Generalised geology, after Bloomfield et al., (2011); The Nutrient Management Guide (RB209) classification (DEFRA, 2010); Soilscapes (Farewell et al., 2011); NSRI Soil Associations and hydrological characteristics (Cranfield, 2021); World Reference Base (IUSS, 2007)

The Nutrient Management Guide soil classification is based on a practical field assessment of topsoil texture and organic matter content. The approach, often referred to as the RB209 classification, is the standard method used by agronomists and farmers to assess a soil's ability to supply and retain mineral nitrogen in arable cropping (DEFRA, 2010). This contrasts with the taxonomy-based national soil map created by the Soil Survey of England and Wales, in which Soil Associations represent units of the landscape in which groups of Soil Series occur together in a predictable pattern. The national soil map legend includes a description of the hydrology and site characteristics of each Soil Association (Mackney et al., 1983). There are 730 defined, sampled and described Soils Series for which empirical data on many physical properties are available (Clayden and Hollis, 1984). In the WTRB the seventy-three mapped Soil Associations comprise 152 different Soil Series. Soilscapes is a simplified reclassification of the national soil map to define twenty-seven soil map units based on depth, texture, chemistry and hydrology (Cranfield University, 2022). Finally the World Reference Base (WRB) is an international soil classification system, based on morphology and pedogenesis, created by the International Union of Soil Sciences for systematic naming of soils and creating legends for international soil maps (IUSS, 2007). The WRB classification is widely used by academics to integrate diverse national soil classification systems.

2.2 The application of technical knowledge to create land drainage typology derived from national soil and geology mapping

The technical knowledge captured in national soil and geology mapping is used by regulators to help target woodland and runoff management based NFM measures to reduce flood risk.

2.2.1 Countryside Stewardship opportunity mapping for woodland creation grant for flood risk reduction

CS provides financial incentives for land managers to look after and improve the environment. In the higher tier, woodland creation attracts additional payments if the scheme location and design deliver public benefits such as reduced flood risk. The eligible area (Figure 3a) was identified through a reclassification of the national soil map (Broadmeadow et al., 2014) to identify soils vulnerable to structural degradation from agricultural use, where woodland creation is predicted to improve soil structure and thus reduce rainfall runoff.

2.2.2 Working with Natural Processes – Natural Flood Management opportunity mapping

Due to data licencing issues, the EA commissioned the creation of a set of national NFM opportunity maps that could be shared with catchment partners under an Open Government Licence (OGL). These draw on British Geological Survey superficial geology mapping to target clay deposits that are more likely to generate rapid runoff (Figure 3b). The maps identify potential opportunities for different NFM measures, including reconnecting floodplains, creating runoff attenuation features in areas of high flow accumulation, blocking gullies on steep ground, and woodland creation on slowly permeable soils.

2.3 Using local knowledge to derive a soil permeability classification from the farmer questionnaire

A mixed method approach was adopted to collect broad quantitative and in-depth qualitative data, including an online survey (n=56) and telephone interviews (n=20) of farmers. We aimed to assess how their experiential knowledge influences management practices and understanding of soil and land management as a NFM measure. The survey was designed by a collaborative working group of the LANDWISE research team and project partners with knowledge of agriculture, including farmers, farm advisers and staff from the statutory agencies. The initial online survey questions were revised following feedback from farmers. The final version of the questionnaire was developed using the

JISC online survey platform (JISC, 2022), which performed well on a range of mobile devices and computers. The survey was promoted to farmers and land managers at appropriate events during 2018-19 and through social media (Twitter and the LANDWISE project blog), contact with farm advisers and via the local catchment partnerships of the WTRB.

The survey was completed thirty-six times when advertised online, farmers who had their soil tested as part of the LANDWISE project were also asked to complete the online survey, if they had not done so already, resulting in a total of 56 responses in the WTRB. The questions were not mandatory resulting in varying numbers of responses. Land holding and tenure varied amongst the survey participants, with an average farm size of 406 ha and range of 6 - 1,619 ha. Most participants owned at least some of their agricultural land.

The survey focused on farmer's attitudes to soil health and the relevance of soil hydrology to land management. The key topics were crop rotation; crops grown; soil cultivation; management of soil organic matter; experience of flooding and change in productivity in the last 20 years. Initially, the survey referred to the Soilscapes soil types, however the terms used were unfamiliar to the farmers and in subsequent interviews the RB209 classification system was adopted (DEFRA, 2010). Shallow soils were the most common (52%), with deep clay soils frequent (29%), medium soils present (15%) and light sandy soils rare (4%). Many farmers reported more than one soil type on their farm; the most common combination was shallow soil with deep clay (22%). It was presumed that areas reported as requiring specific measures to manage drainage and seasonal waterlogging, presented opportunities to adopt woodland creation and runoff management NFM measures for downstream flood alleviation, even if the farmer did not report flood risk management as a priority on their land holding.

3. Results

3.1 Technical knowledge of NFM opportunity from 'top down' mapping

3.1.1 Distribution of soil types between catchments:

The variety of soil in the WTRB is illustrated using the Soilscapes classification (Cranfield University, 2022) in Figure 2. Two Soilscapes soil types cover half the river basin: 'shallow lime-rich soils over chalk and limestone' (25.8%) and 'slowly permeable seasonally wet slightly acid but base rich loamy and clayey soils' (24.5%). The other half of the river basin is covered by a variety of loamy soils.

The Fertiliser Manual RB209 soil categories		Shallow Soil	Medium Soils	Deep Silty/ Clayey Soils	Light Sand Soil
Count (% of count) of survey participants reporting soil type as dominant on their land. [no data: n = 5 (8.5%)]		28 (47.5%)	8 (13.6%)	16 (27.1%)	2 (3.4%)
Average size (ha) of holding on which soil type is reported as dominant. [no data: 230 ha]		463	550	331	90
Total extent (ha) of the agricultural land on each soil type managed/owned by survey participants.		12,956	4,399	5,292	180
The proportion agricultural land of each soil type in the WTRB represented by the land holdings of the survey participants.		9.1%	2.4%	2.7%	2.4%
Division (%) of mapped soil types between land holdings of the survey participants. [no data: 4.8%]		54.0%	18.4%	22.1%	0.8%
NSRI soil mapping of the WTRB	Extent (ha)	185,220	235,094	266,757	25,966
	% WTRB	25.8%	32.8%	37.2%	3.6%
% of soil type in WTRB[1] mapped in UKCEH LC2015 as Arable or Improved Grassland[2]		76.6%	76.8%	73.2%	29.3%

[1]WTRB: West Thames River Basin; [2]UKCEH LC2015 Arable and Improved Grassland assumed to represent agricultural land

Table 2 The extent of mapped and reported dominant soil types in each sub-catchment as represented in the farm survey responses.

Table 2 presents the split of RB209 soil categories reported by the participants of the farmer survey in contrast to the extent of RB209 soil categories in the WRTB derived from the harmonisation of RB209 and NSRI soil mapping shown in Table 1. Soilscapes assigns only a single soil type to each postcode however, many survey respondents (n = 26) reported more than one soil type on their property. Most of the farmers with variable soils on their holding were managing combinations of Shallow soils with Deep clayey soils (n=13) or Shallow soils with Medium soils (n=7). Considering the difference in size of farm holding between the different soil types, there is broad alignment between the dominant soil type reported by the survey participants and the soil mapping of the WTRB (Figure 2). Typically, the farms on chalk (with shallow and medium soils) were larger than the mudstone farms (with deep silt and deep clay soil) and substantially bigger than the two farms with light sandy soil. The responses in the farmer survey best represent the management of the shallow soils in the WTRB; with survey participants responsible for 12, 956 ha or 8.5% of the agricultural land on shallow soils, whereas the responses only cover between 2.2 – 3.0% of the other soil types in the project area.

3.1.2 Extent and distribution of NFM opportunity mapping priority areas

Figure 3 illustrates the technical top-down mapping of spatial prioritisation of NFM opportunities in the WTRB; (3a) the soil-derived CS woodland creation grant priority areas for flood risk management (Broadmeadow et al., 2014) and (3b) the geology-derived WWNP opportunities for woodland creation to reduce flood risk in the wider catchment (EA, 2017). The maps reveal the extent of soils considered to be vulnerable to structural degradation where a change in land use may deliver increased infiltration and reduced surface runoff.

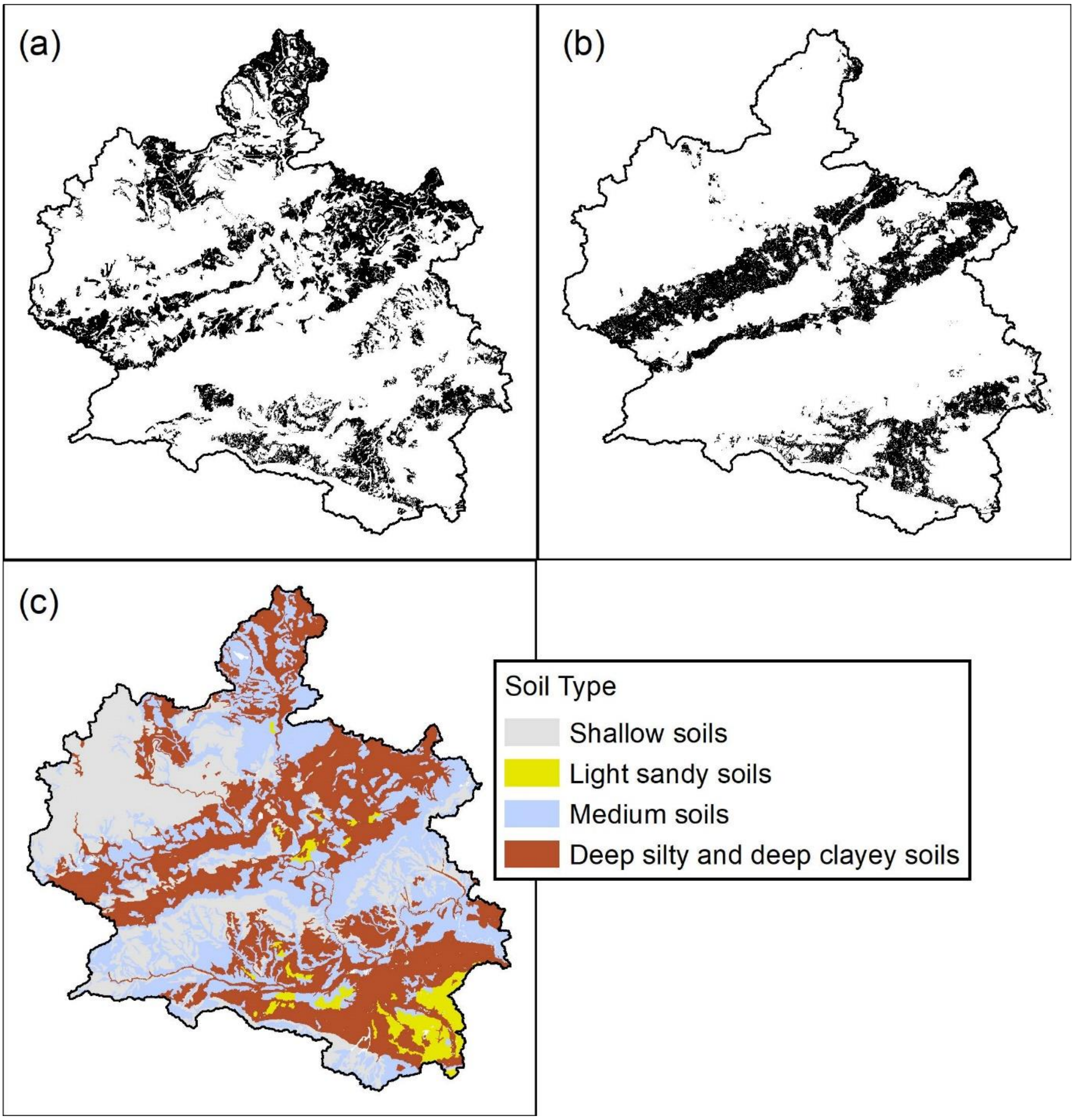

Figure 3 Comparison of the priority area for land use change in the WTRB defined by two national NFM opportunity mapping projects (a) the area in black represents the CS woodland creation grant priority areas for flood risk management, (b) the area in black represents the WWNP opportunities for wider catchment woodland planting and (c) the dominant RB209 soil categories of the WTRB.

RB209 soil categories	Relative rank[*1] and extent (% of WTRB) captured in the mapped priority area		Farmer survey
	Countryside Stewardship – woodland creation	Working with Natural Processes	
Shallow soils	Low (0.2%)	Low (0.1%)	-
Light sand soils	Low (0%)	Low (0.1%)	-
Medium soils	Medium (6.6%)	Medium (4.3%)	Low (n=1)
Deep clayey/silty soils - carbonate	Low (0.1%)	Low (0.1%)	High (n=8)

Deep clayey/silty soils - mudstone	High (23.2%)	High (12.8%)	

*1 relative rank assigned using natural breaks

Table 3 Ranking/relative prioritisation of the RB209 soil categories in the WTRB for land use change interventions for NFM objectives, comparison between the different opportunity mapping projects and farmer survey

Table 3 presents the ranking of the RB209 soil types in terms of the relative extent of NFM opportunities as captured in the target areas of national opportunity maps and a ranking of soil types derived from the responses in the farmer survey, based on the free text responses to three questions which refer to waterlogging, flooding or taking action to avoid wet conditions. In the WWNP map (EA, 2017) the opportunity area for land use NFM measures is defined by areas of Diamicton geology, which is clay rich sediment. The WWNP opportunity area covers 17.5% of the WTRB, predominantly comprised of deep clay soils over mudstone however the distribution within individual sub-catchments varies from just 4% in the Evenlode catchment to >41% in tributaries of the Thame (Table 4). In contrast, the CS woodland creation map for NFM (CS_WC) aims to identify soil associations that are vulnerable to structural degradation by agricultural use leading to reduced soil water storage and increased rapid rainfall runoff.

In the CS_WC map the target areas are defined using a revision of the Hydrology of Soil Types (HOST) classification (Boorman al., 1995). In the DEFRA Making Space for Water project (Packman et al., 2004), each HOST class was assigned an analogue class which best represents the hydrological response taking account of the impacts of agricultural use on soil structure. The increase in surface runoff parameters between the original and amended HOST classes indicates the impact of structural degradation on the proportion of rain draining via surface flow (Packman et al., 2004). The soils with amended Standard Percentage Runoff values of >50% defined the opportunities for woodland creation for NFM. As shown in Table 4, the CS_WC target area includes a wider range of soil types than targeted in the WWNP opportunity map. In the WTRB they consist principally the deep clay-loam soils over mudstone but also include some deep, medium and shallow soils over carbonate geology with impeded drainage. The maps target areas across the WTRB but opportunities are most extensive in the Oxon Ray sub-catchment and the tributaries of the Cherwell and Thame (Table 4).

Catchment	Extent of mapped priority area (% sub-catchment)		Relative ranking of sub-catchment in terms of NFM opportunities	
	WWNP	CS_WC NFM	WWNP	CS_WC NFM
Upper Thames	21.5	30.6	Medium	Medium
Windrush	25.3	26.6	Medium	Medium
Evenlode	4.4	34.2	Low	Medium
Oxon Ray	30.6	58.6	High	High
Cherwell	5.7	46.2	Low	High
Ock	20.8	31.3	Medium	Medium
Thame	41.1	50.8	High	High
Pang	-	17.3	-	Low
Kennet	9.6	23.9	Low	Medium
Loddon	21.6	11.8	Medium	Low
South Chilterns	3.2	15.9	Low	Low

Table 4 The extent and distribution of the priority areas for land use change interventions for NFM objectives within the WTRB. Comparison of the relative ranking of the sub-catchments between the two national opportunity mapping projects

3.2 Farmer knowledge of soil and land management constraints

The combined farmer survey responses provide details on the arable and livestock management systems employed and the farmers' rationale and objectives for selecting their farming system. Such temporal information is not available from the UKCEH land cover or crop maps. The responses provide some insight into the farm systems employed on broad soil types in the WTRB and the degree to which current soil management practices may be co-delivering NFM benefits or dis-benefits in the catchment. The summarized farmer survey responses are presented in Tables 5, 6 and 7; note the response numbers are small in some categories.

	Shallow soils (n=28)	Light sand soils (n=2)	Medium soils (n=8)	Deep clayey/silty soils (n=16)
Arable	3.6%			
Mostly arable	64.3%	100%	87.5%	43.8%
Dairy/livestock	7.1%			31.2%
Mixed	25%		12.5%	25%

Table 5 Question: Which best describes your farm type? response by dominant RB209 soil type

Both farmers on light sandy soils used the same three year rotation of winter sown arable crops (wheat, barley and oilseed rape), whereas, on the other soils farm types were variable and most (70%) included livestock in the farming system.

	Shallow soils (n=28)	Light sand soils (n=2)	Medium soils (n=8)	Deep clayey/silty soils (n=16)
Winter sown cereals, oil seed rape & beans	38.5%	100%	50.6%	23.5%
Spring sown cereals & beans	22.8%	-	13.0%	12.3%
No season cereals, beans & oil seed rape	6.2%	-	16.4%	8.2%
Grass ley	25.4%	-	-	39.7%
Maize	0.8%	-	13.2%	10.1%
Other (game cover, break & forage crops, peas, linseed, poppies, sugar beet)	6.5%	-	6.9%	6.2%

Table 6 Crop use within a standardized 6 year rotation by dominant RB209 soil type

The dominant crop was winter sown cereals although on deep soils they are grown less frequently than a grass ley. A wide range of spring sown cereals were grown on the shallow soils whereas spring barley was the only spring sown cereal on the deep soils. The farmers of shallow soils rarely grew maize. Grass leys were grown by farmers on both the shallow and deep soil types, specifically where there was livestock; but most participants (n=42, 86%) used at least one non-cereal break crop in their rotation.

	Shallow soils (n=28)	Light sand soils (n=2)	Medium soils (n=8)	Deep clayey/silty soils (n=16)
Mean (max) length crop rotation length (years)	5.4 (6)	3 (3)	4.4 (5)	5.7 (no rotation)
Cover crops are a valuable element in my crop rotation (%)	39.3	0	62.5	43.75
Livestock present	66.7	50	37.5	80
Proportion of livestock housed	50	0	40	66
Mean typical planned duration of livestock housing (days)	64	0	44	119
Agree that it is worth investing in good soil structure	100	100	100	93.75
Taking action to increase SOM	100	100	100	93.75
Taking action to reduce traffic on the arable fields	71.4	100	87.5	68.75
Conventional	21.4			18.75
Mixed	21.4			12.5

Tillage system undertaken on arable land	Reduced	32.1	100	62.5	31.25
	Zero	7.1		25	12.5
	other	7.1		12.5	25
Area of the farm have become unproductive/unusable in last 10 years		14.3	0	37.5	37.5
Restrict operations to dry conditions		7.1			18.75
SOM improves access to fields more quickly after wet weather		67.9	100	75	50
Flooding/Waterlogging reported as a cause of reduced yield		0	0	12.5	37.5
Considered significant change to farming methods		64.3	100	75	56.25

Table 7 Farmer survey responses to questions on cultivation practice and management problems by dominant RB209 soil type.

Good soil structure associated with the development of soil aggregates and network of soil pore spaces is beneficial for increasing infiltration, soil water storage and reducing surface runoff. Most farmers (95%) agreed it is worth investing in good soil structure; indicating they are aware of the importance of soil structure in maintaining healthy soils. Soil organic matter (SOM) is widely promoted to increase yields and make soil more resilient to machinery traffic (AHDB, 2020b), with the survey responses indicating that SOM is a key indicator of good soil health. Almost, every farmer agreed that SOM was extremely important for producing crops on their farm, however the response to whether SOM helped with accessing fields quickly after wet weather was variable between soil types. Although 5% disagreed with the statement, only half the farmers with deep soils believe strongly that SOM helped improve access after rainfall. Two questions were used to explore how farmers are attempting to increase SOM on their farms. Nearly all farmers (97%) state that they were proactively trying to increase or manage their SOM levels, with 93% adopting annual measures.

Traffic by heavy machinery is a well-known cause of soil compaction, reducing infiltration and soil water storage, and increasing surface runoff (AHDB, 2020b). There were a wide variety of responses when asked what practices they adopted to reduce compaction. Most farmers (71.2%) report that they reduce trafficking through the adoption of reduced or zero tillage practices. The most common approach, across all soil types, was to restrict traffic in arable fields to fixed tramlines. Many farmers avoid trafficking the cropped land by using the headlands for trailers and large machinery. Six farmers, reported being responsive to the weather and soil conditions, avoiding trafficking when the soil was wet; selecting to use their small lighter tractors, floatation tyres or adjust tyre pressure to reduce soil damage. Some farmers on the shallow soils had invested in GPS controlled traffic systems and two drilled across the slope in an endeavour to protect their soil.

In the survey we asked what additional significant changes to their farming system were being considered. Many farmers, particularly on the shallow soils reported they intended to reduce soil cultivation by adopting a reduced or zero till practice or direct drilling in the future. Several farmers on heavy soil stated that they were considering changes in their crop rotation to increase the use of cover crops. The choice of crops and how they are integrated within a farming system through timing of use, fallow periods or bare soil, affects soil properties and surface runoff. For example bare soils are more likely to undergo structural degradation and generate surface runoff than soils covered by vegetation. Participants were also asked about their sources of advice and information. As most were arable farmers, predictably their agronomists were identified as a key source of trusted information on managing soil condition. Many participants were also members of local farmer groups and seek information and advice from a range of sources, including neighbours, advisory groups, and the internet, when considering a different farming system. Several farmers in the upper WTRB stated that their location on the margin of the NFU geographical regions, had been a key barrier to engagement, as participation in meetings and workshops had required significant travel time. Access to expert advice had been improved by the adoption of virtual meetings during Covid lockdown.

3.3 Comparison of targeting of NFM measures derived from technical mapping with local farmer knowledge

The effectiveness of top-down mapping to target interventions depends on how well the national scale soil maps accurately reflect soils on farms. The survey respondents were not obliged to provide their full address. However, twenty-three farmers provided a post code which enabled a comparison of the accord between the mapped NSRI soil association and the self-reported soil type on the farm. It was then possible to determine if the farm included any of the mapped priority areas shown in Figure 3. Fourteen of the twenty-three postcodes fell within a single mapped soil association, and in each case the mapped NSRI soil association matched exactly with the general soil type reported by the farmer. The postcode of nine farms fell over the boundary of two mapped soil associations but in each case the general soil type reported by the farmer was located within the postcode area. These results suggest that technical soil mapping data provide a good indication of the general soil types on farms. Furthermore, there was good concurrence between the farmers who reported water management as a problem and areas of mapped NSRI soil associations of deep heavy soils and the mapped priority areas for catchment land use NFM actions (Figure 3). Amongst the farmers that provided their full post code were seven farms located on deep clay soils all of which were located within the WWNP and CS_WC NFM priority area.

4 Discussion

The opportunity mapping was developed using empirical data and modelling at a landscape scale to identify areas where NFM measures could be effective at reducing flood risk. They are commonly used as a strategic tool to aid debate amongst policy makers and regulators when designing environmental land management schemes, setting budgets, and defining priority areas for incentivising land use change and management.

The availability of land for NFM measures is constrained by a range of factors including landowners' uncertainty around agricultural support post-Brexit. The opportunity maps are an instance of a top-down application of technical knowledge to 'target' resources to areas with the greatest potential to deliver the most benefit. The maps do not oblige landowners and managers to engage in NFM schemes as it is recognised that there are limitations to the accuracy of national mapping when applied to field scale assessments and there may be practical or farm business reasons which prevent NFM implementation. To be an effective, the mapping must represent conditions and risks that are familiar to the landowner and present opportunities to engage in NFM measures that can be integrated within local farming systems.

In this study, we found a reasonable agreement between the local farmers' knowledge and technical maps. The experiences of the farmers who reported problems with waterlogging, flooding, and restricted access to their land during wet conditions could be predicted using the national soil map and aligned with the presence of deep heavy clay soils. The farmer survey confirmed that the national soil mapping and associated technical information is appropriate to address issues at the local farm scale. However, it is recognised that opportunity mapping soil boundaries defined to aid policy implementation, may not concur with farmer knowledge and rarely align with land ownership they should therefore be considered as indicative. The approach works best as a multistep process in which the maps are used to shape incentives and focus initial engagement with landowners and farm advisors, but in a subsequent planning phase requires flexibility to incorporate local knowledge into the precise design of NFM schemes at the field scale.

Soil hydraulic properties are determined by soil structure and bulk density which are both affected by land use and management. The priority area in the national maps identify soils predicted to have a high propensity for surface runoff, where NFM measures present the greatest potential to reduce flood generation. However, strategic environmental management decisions should reflect the relative risk posed at the scale of application and the national maps require careful interpretation to prevent mixed messages and confusion. The EA WWNP mapping identified inherently wet ground defined by soils derived from Diamicton drift deposits (typically Soilscapes types 5, 18, 20 and 22), which are characterised by slow subsoil permeability. In contrast, the CS_WC NFM mapping prioritises soils based on their vulnerability to structural degradation by agricultural practices causing rapid surface runoff. These maps illustrate how technical soil knowledge can be utilised in policy delivery even though the terms and classification systems were unfamiliar to the farmers

A range of cropping and stock management systems in the UK have the potential to significantly modify soil hydrology; the trends for larger machinery and out-wintering of livestock can seriously degrade soil structure and condition (Boardman 2019, EA 2008). In particular, the cultivation, trafficking, and use of land in wet conditions can cause topsoil compaction changing the way water moves through the soil profile (EA 2005). Palmer and Smith (2013) observed that severe flooding in Somerset was exacerbated by overland flow from fields of maize and winter cereals. Palmer (2015) reported that a small percentage reduction in air space of the topsoil was sufficient to produce Hortonian over land flow resulting in muddy floods. Winter-sown cereals, oil seed rape and field beans were the most used crops within farm rotation on all expect deep soil types; cultivation of the later is known to compact the plough layer and tramlines, while the presence of young cereal crops during winter leaves fields prone to capping and erosion (Holman et al., 2003). The late harvested crops such as maize is particularly problematic, causing compaction and rutting (Holman et al., 2003). In the south-west, Palmer (2013) observed that over half of soils in arable cultivation were degraded such that rainfall resulted in rapid surface runoff.

While the priority area identified in the CS_WC maps target woodland creation it is also relevant to other NFM measures such as runoff management. This is important since although 67% of the deep soils (30% of the WTRB) were identified as a priority for additional grant support for woodland planting to reduce flood risk, all the participants in the farmer survey favoured agriculture as the preferred land use option for their land. Rates of woodland creation in the WTRB remain small and were similar to the national average of 1.7 ha of new woodland per 100 km^2 per year (FC, 2020).

Most participants in the farmer survey have livestock and three farms used animals from other farms to graze on stubble turnips and post-harvest vegetation. Livestock was kept on at least half the farms on every soil type. It is widely recognised that winter grazing, when soils are wet and vulnerable to poaching, may lead to topsoil compaction (Holman et al., 2003). The survey responses suggest farmers are mindful of the risk and planned the housing their livestock accordingly; a greater proportion of the livestock kept on deep clayey/silty soil is housed and the mean housing duration twice as long as on the other soil types.

Only two farms were dominated by sandy soil types, for which both farmers reported using reduced tillage methods probably to help retain water in the soil as reduced mechanical soil disturbance minimises losses of soil organic matter (SOM) (FAO 2017). In fact most farmers reported the use of zero or reduced tillage soil management which is also known to enhance earthworm populations (Holland, 2004). Earthworm burrows loosen and aerate the soil, creating preferential flow channels to improve soil drainage. Zero till water infiltration can be up to six times greater than in cultivated soils, while the soils with earthworms can drain up to ten times faster than those without (Line-Kelly, 1993). The SOM rich earthworm casts help cement soil particles together in water-stable aggregates, reducing the risk of slaking and soil loss via erosion (Line-Kelly, 1993).

Almost all the farmer survey participants take action to increase SOM which can be expected to enhance soil hydraulic properties, including maintaining infiltration capacity post cultivation and soil water retention (EA 2008; Murphy, 2014). Rawls et al., (2003) demonstrated that SOM has the greatest effect on the soil water holding capacity of light sandy soils; as in soils with low sand content, the hydraulic properties are dominated by the clay content. It is not possible to use our data set to determine the perceived value of SOM in light soils, although it would be straightforward to map the distribution of sandy soil types within the WTRB using the texture information in the NSRI database. This map could be used to identify additional opportunity areas for soil and land management NFM measures, specifically to encourage the farmers on sensitive soil types to adopt measures that enhance SOM and therefore help store more water for plant growth while minimising runoff following high rainfall.

Technical knowledge is gained from scientific studies that tend to be reductionist in approach, which assumes the whole can be best understood through the systematic study of the parts. By contrast, the local or lay knowledge held by farmers, comes from a holistic view of their land shaped by experience and nature-society relations over time (Short, 2015). Farm advisors use scientific knowledge that has a deep ‘know why’ of soil system, whereas farmers have practical ‘know how’ and gain new knowledge through interactions with their community (Ingram et al., 2010). It is recognised that integrating the different types of knowledge is complex (Barrios et al., 2006); although increasingly a ‘hybrid’ of knowledge is sought in problem-focussed environmental management to build on the common core concepts and in-fill the gaps in existing technical and local knowledge (Raymond et al., 2010). In the LANDWISE project we adopted an integrated approach to developing a ‘hybrid’ knowledge of NFM opportunities in the WTRB to better reflect the knowledge of different stakeholders about the system and improve knowledge exchange.

For soil and land management measures that deliver NFM, soil type and associated properties are key factors underpinning maps targeting interventions. In this work, we adopted the RB209 soil classification used by the farmers to discuss soil, as other (more comprehensive) classifications developed by soil scientists were unfamiliar to some farmers and became a barrier to engagement. This may in part explain the low number of responses from the initial online engagement (just 36 responses from 1, 400 viewings). Establishing a common language linking technical and lay knowledge, about how water moves through different types of soils, remains a significant issue requiring ongoing commitment from both sides. The technical soil maps are insufficient on their own and investment in stakeholder engagement such as catchment workshops and farm walks are required to provide chances for discussion and interpretation of the science illustrated and opportunities they present. Establishing a common language around soil, particularly one that is accessible to everyone, is crucial to successful and widespread NFM delivery requiring co-ordinated effort from the national policy maker to the local landowner.

To secure land use or management changes requires landowners and managers to decide to do something different. A landowner may consider changing their farming practice when persuaded by the scientific evidence or the shared lived experience of people they trust such as their neighbours, peers or farm advisors if there is a commercial benefit to their business. Financial incentives are often necessary to stimulate or secure change. It is important to note, that farmers may have already made their own interventions prior to and/or independent of the targeted maps. Recently there have been changes in soil and land management within the farming community, driven by bottom up interest in managing soil health and minimising erosion (e.g. www.innovativefarmers.org). However, top-down initiatives like Catchment Sensitive Farming and development of the new Environmental Land Management Scheme enable wider delivery of NFM measures, alongside a range of other public goods from agricultural land (DEFRA, 2020; EA, 2019).

5. Conclusions

We assessed the applicability of a national mapping approach to identify NFM within the lowland catchments of the West Thames River Basin in southern England. The usability of different soil classification systems were also considered. Farmer surveys demonstrated reasonable agreement between farmers' soil knowledge and technical soil maps, both of which identified deep clay and silty soils as the target for attention. However, while national soil-based maps were appropriate for field-scale decision making, mapped boundaries often did not concur with farmer knowledge and rarely aligned with land ownership. Decision-making on siting and design of NFM measures works best as a multistep process in which the maps were treated as indicative and allowed flexibility to incorporate local knowledge and understanding. This concurs with the process outlined by Raymond et al., (2010) that there is 'no single optimum approach' for integration of different types of knowledge, more the need to accept a collaborative process for knowledge integration.

Some farmers expressed doubt and frustration about the lack of target NFM measures on their land. Farmers favoured soil based NFM measures that would support continued agricultural use, such as the use of cover crops, diverse crop rotations and minimal tillage. They were resistant to woodland creation and critical of a perceived mismatch between the availability of finance for tree planting but lack of capital funding to encourage soil and land management practices to reduce rapid runoff. Such frustrations can be linked to the incentives and processes associated with environmental management (Mills et al., 2017) involving a combination of ability, engagement and willingness, whereby some interventions fall within what is currently acceptable but others do not.

Overall, our study highlights the need for a more integrated approach in which both technical and local soil knowledge is exchanged and combined in the development of local schemes to aid delivery of national policy. Providing a forum for such a co-designed approach would enhance NFM uptake and achieve a greater reduction in flood risk to benefit downstream communities. Such a finding has implications for current policy decisions around land management and the priority given the catchment partnerships. Consideration within catchment governance systems should also be given to co-benefits and the use of local knowledge to help prioritise between objectives and deliver integrated outcomes. As a result, national opportunity maps should be considered as the start of the conversation rather than the answer.

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Competing interests/Disclaimer

The authors declare that they have no competing financial interests or personal relationships that have influenced the work reported in this paper.

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Figure

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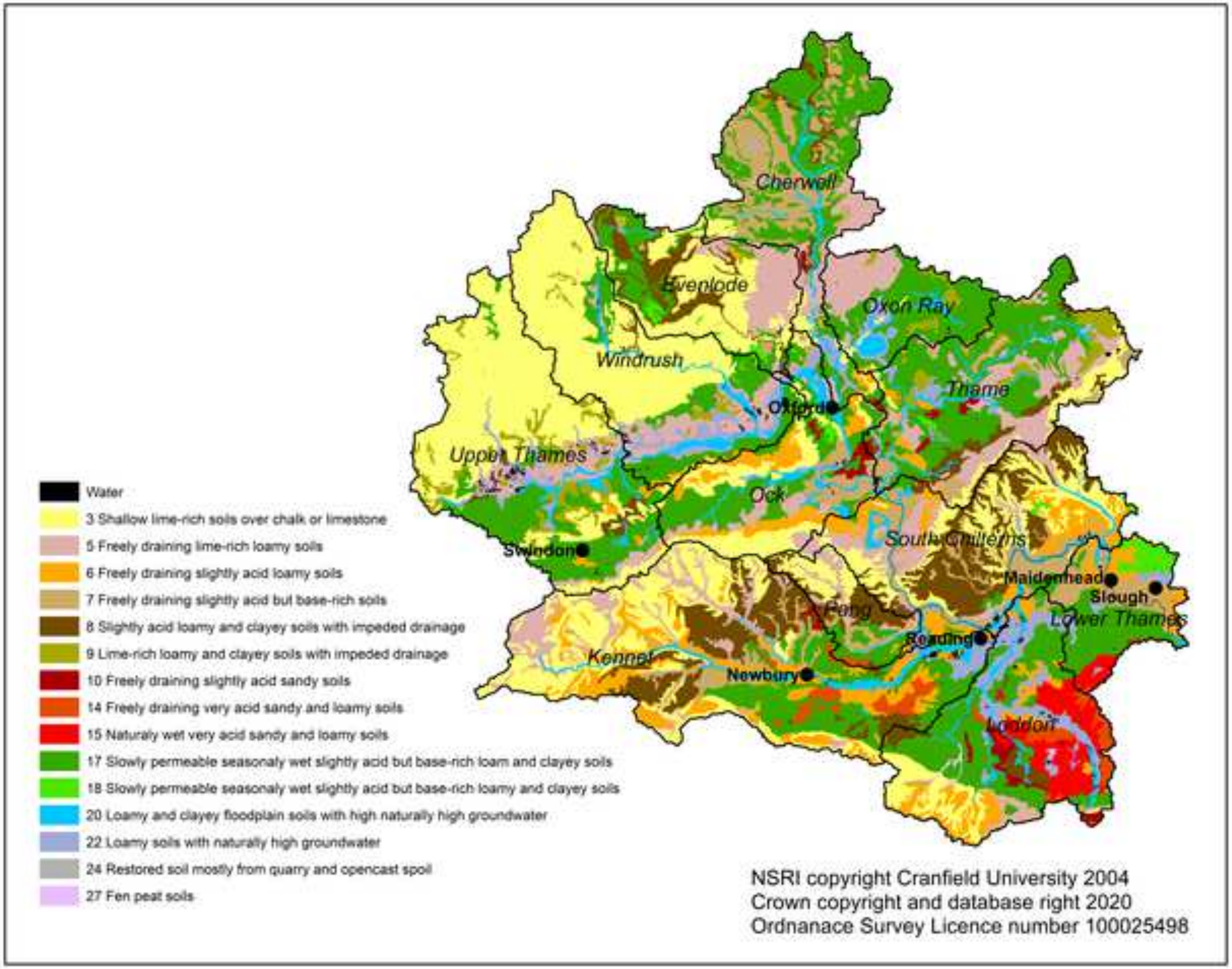
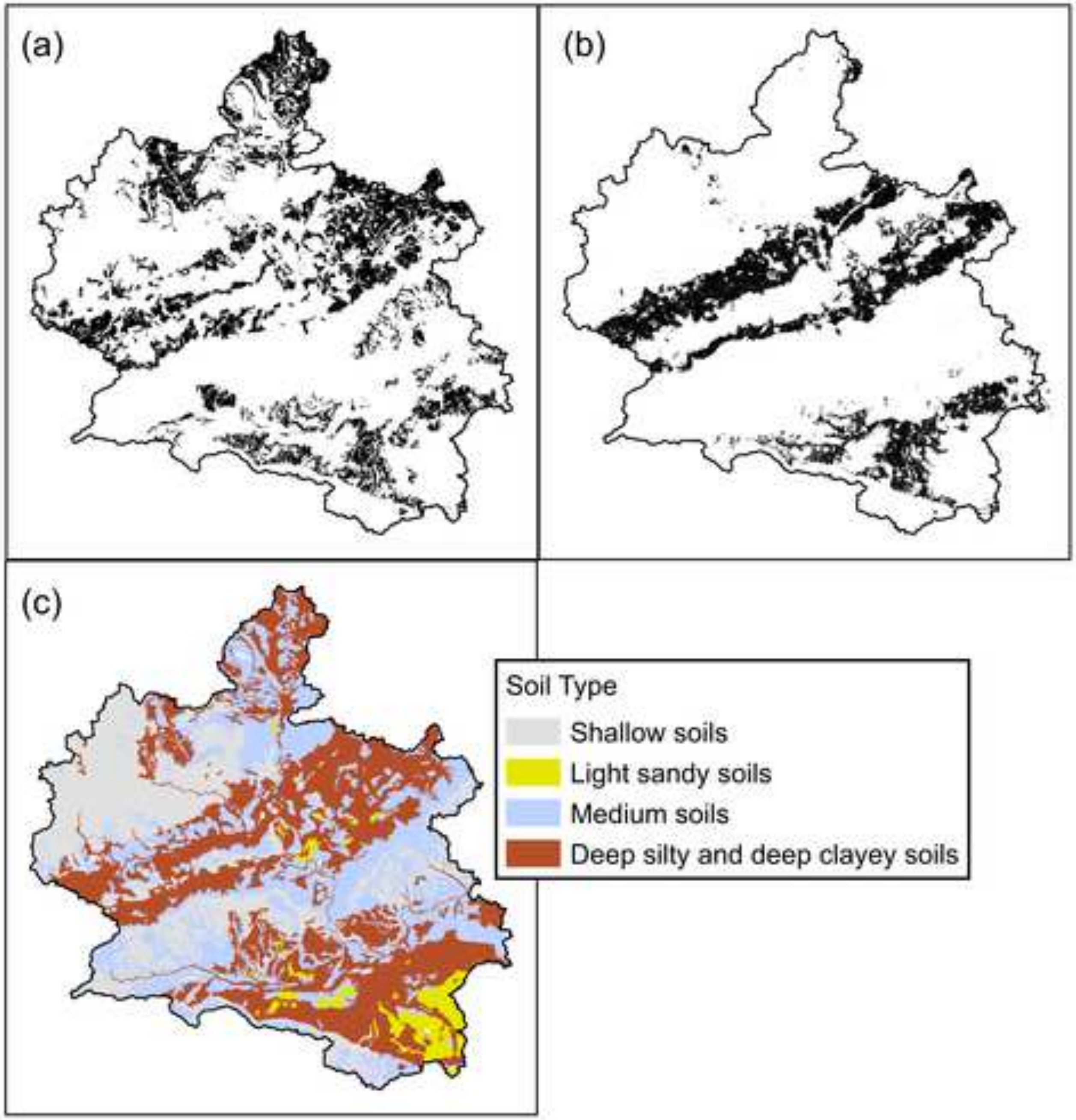


Figure


(a)
(b)
(c)
Soil Type
Shallow soils
Light sandy soils
Medium soils
Deep silty and deep clayey soils

Figure

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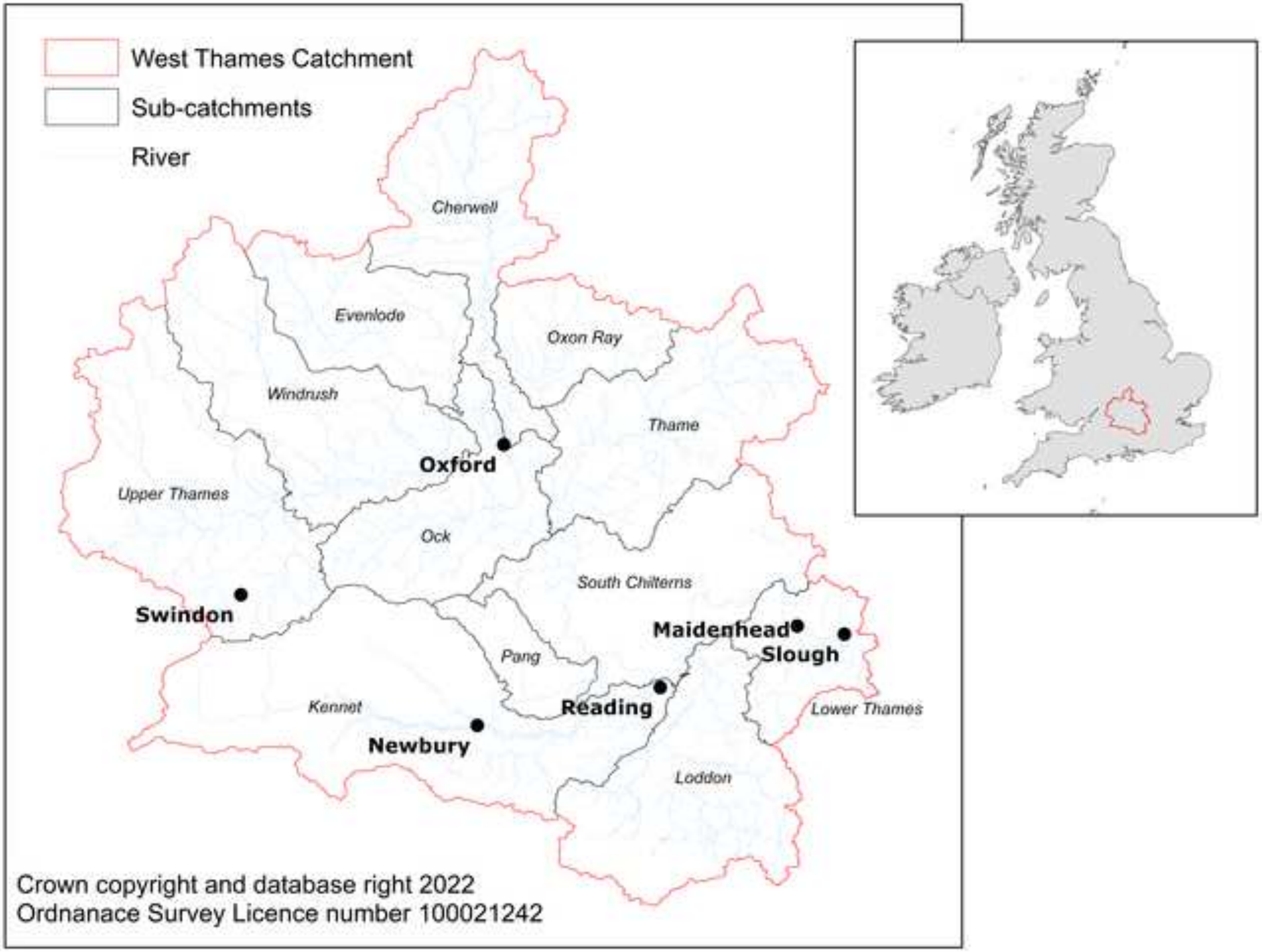

CRredit author statement

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Robert Palmer, Chris Short and Charlotte-Anne Chivers: Investigation, Data curation, Writing - review and revision

Joanna Clark: Conceptualization, Funding acquisition, Project leader, Writing – reviewing and editing;

John Hammond, Martin Lukac, Anne Miller, Richard Gantlett, Tom Nisbet and Louise Webb: Writing – review and editing