Ecosystem Services

The Windsor Estate Case Study

May 2019

Executive Summary

This case study has assessed & evaluated 6 Ecosystem Services delivered by the Windsor Estate

- **Flood Risk Mitigation**
  - The estate retains on average 49 % more floodwater than surrounding areas (sub-catchments)
    - Indicative annual economic value: £ 2.9 M / Year
- **Water Quality**
  - The estate retains 23 % and 22 % (for P and N, respectively) more nutrients than surrounding areas
    - Indicative annual economic value : £ 1.0 M / Year
- **Water Supply**
  - The estate yields an average 9 x 10^6 M3 of water annually
    - Indicative annual economic value : -
- **Recreation**
  - The estate hosts an estimated 5.5 M visitors per year
    - Indicative annual economic value: £ 14.1 M / Year
- **Agriculture**
  - The estate hosts arable, dairy and cattle farming activities across c.1000 Ha
    - Indicative annual economic value: £ 0.005 M / Year
- **Greenhouse Gases**
  - The estate net sequesters an estimated 52K Tonnes of greenhouse gases)
    - Indicative annual economic value: £ 2.8 M / Year

The combined annual economic value of these services is estimated to be c. £ 21 M / Year

Recreation, Flood Risk Attenuation & Carbon Sequestration are the key ecosystem services

Hydrologic Ecosystem Services

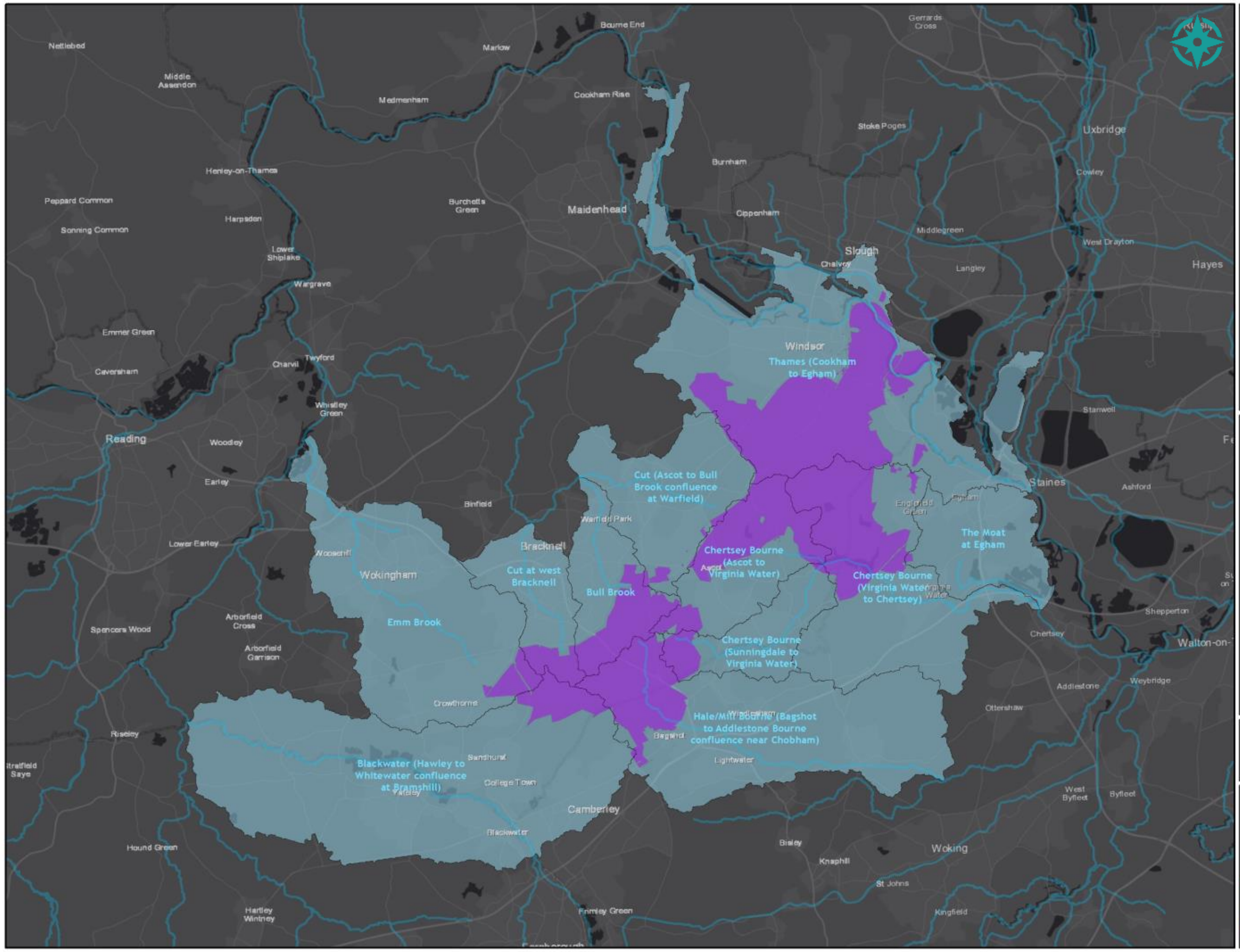
Overview

The Windsor Estate represents a 6,266 hectare area in the Thames basin and cuts across 11 sub-catchments

The main sub-catchments are Thames-Egham, Chertsey-Bourne & Hale-Mill

All sub-catchments are draining south-east

River Catchments Local to the Windsor Estate



Key

- Rivers
- TCE Ownership
- Catchments

Notes

The Windsor Estate covers an area of 6,300 hectares and overlaps a total of 11 sub-catchments within the Thames basin.

0 1 2 4
Miles

Hydrologic Ecosystem Services

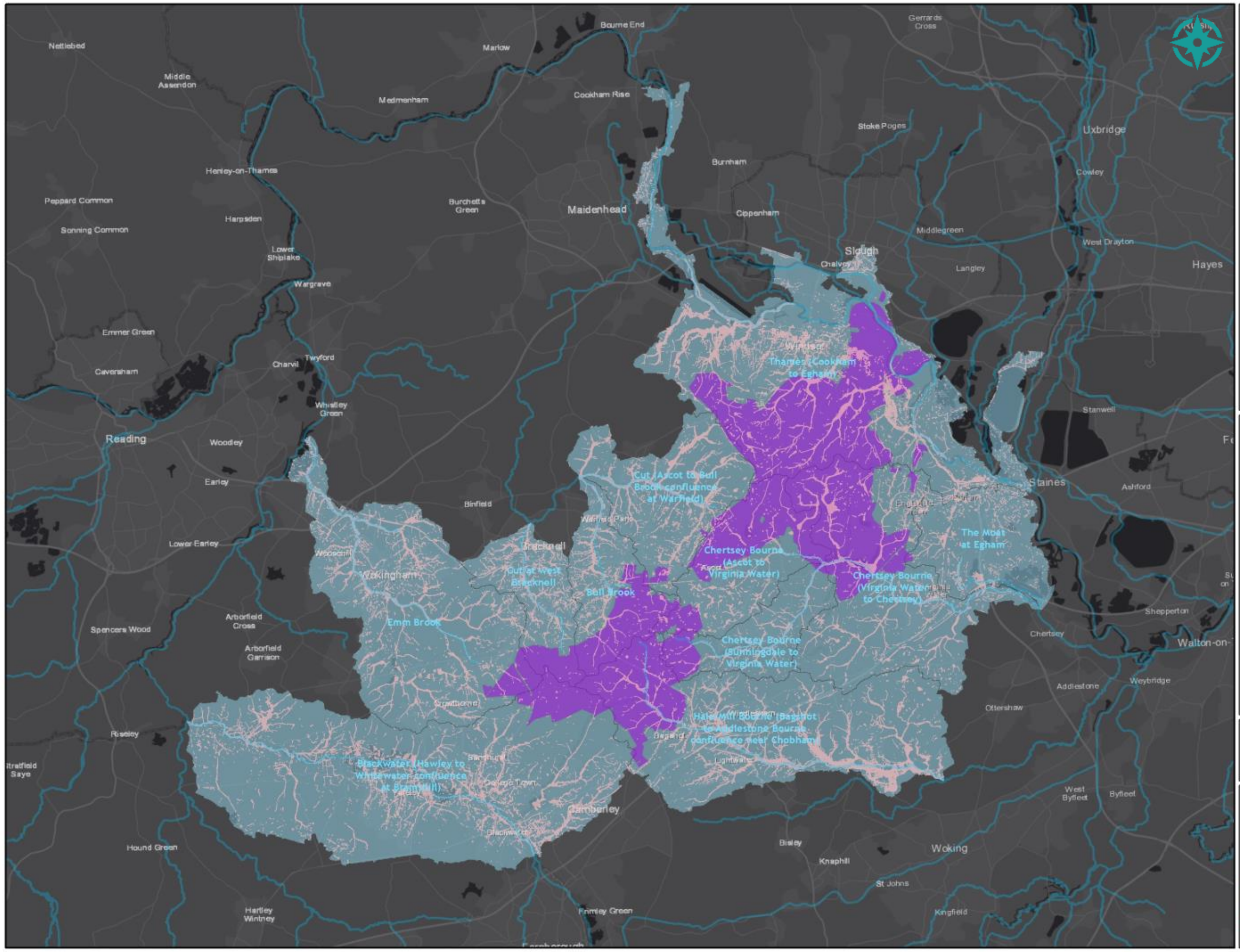
Attenuating Flood Risk

Surface water flood risk results from run-off flowing over the surface and accumulating in low-lying areas during high-intensity rainfall events.

Surface run-off also contributes to higher river flow and potentially exacerbates river flooding downstream (i.e. when the capacity of the river is exceeded).

This map represents the surface water risk for a 1 in 100-yr event. It shows that flood risk exists in many sub-catchments (esp. Hale-Mill Chertsey-Bourne and Thames-Egham) so run-off retention on the Windsor Estate is needed to mitigate this risk (see slide 8 for service value)

Risk of Flooding Local to the Windsor Estate



Key

- Rivers
- 1 in 100-yr Flood
- TCE Ownership
- Catchments

Notes

Surface water risk for a 1 in 100 year flood event. Water retention on the Windsor Estate helps mitigate this risk.

0 1 2 4
Miles

Route2
THE CROWN ESTATE

1 in 100-yr surface water flood risk (Source: DEFRA)

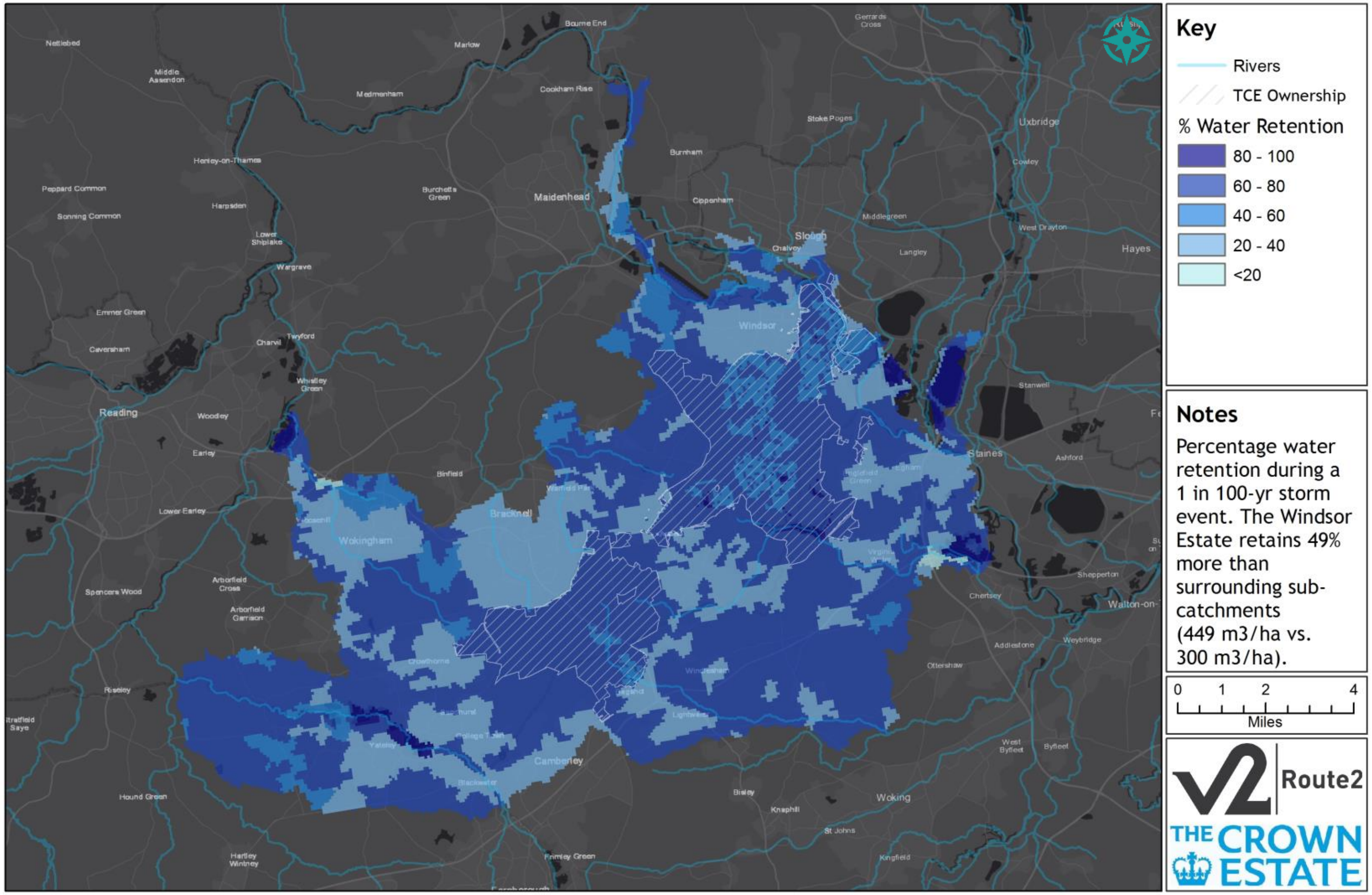
Hydrologic Ecosystem Services

Attenuating Flood Risk

This map represents flood water retention as a proportion of the 1 in 100-yr storm event (63 mm in 6 hr), for all the Windsor Estate sub-catchments.

It shows that the Windsor Estate generally retains more flood water than surrounding lands (due to the presence of forests and open parkland): on average, the Windsor Estate retains **49%** more than the rest of surrounding subcatchments (449 m^3/ha vs. 300 m^3/ha).

Flood Water Retention Local to the Windsor Estate

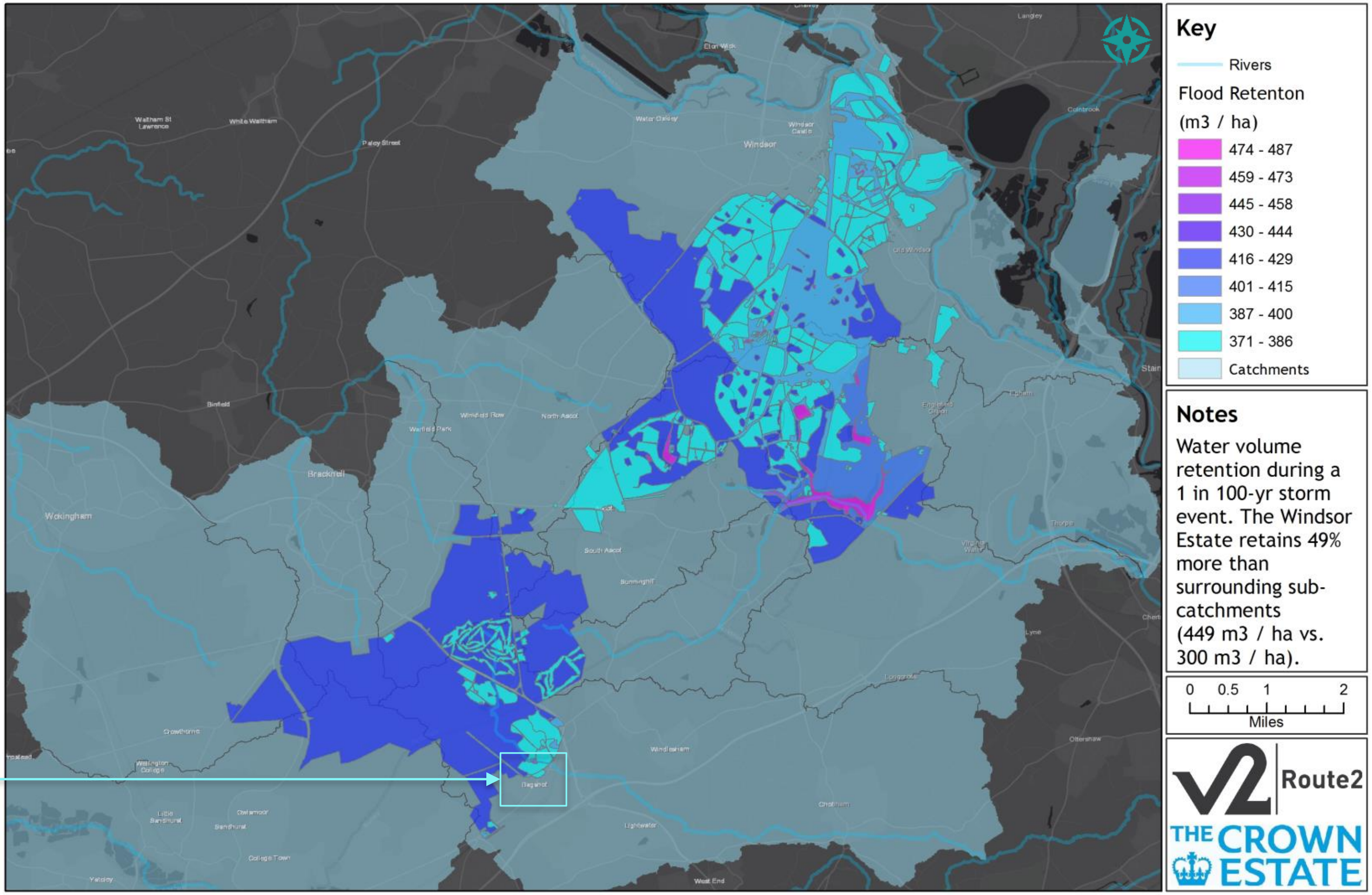


Hydrologic Ecosystem Services

Attenuating Flood Risk

This map represents flood water retention for all the Windsor Estate sub-catchments in intensity terms (M3 / Hectare). It shows the more vulnerable areas within the Windsor Estate, for example Bagshot in the southern part of the estate

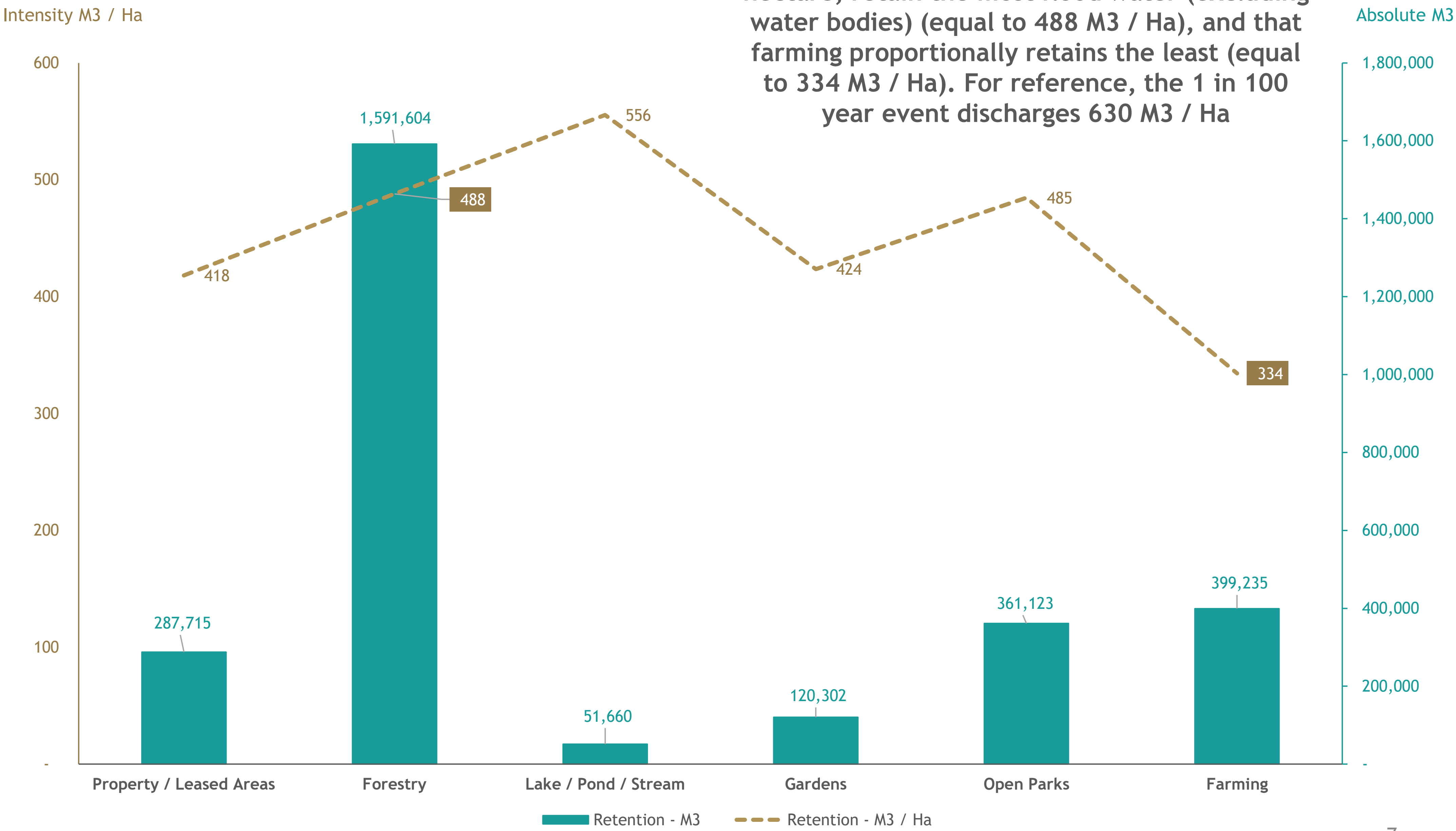
Flood Water Retention Volumes within the Windsor Estate



Hydrologic Ecosystem Services

Attenuating Flood Risk

The line demonstrates that forests, per hectare, retain the most flood water (excluding water bodies) (equal to 488 M3 / Ha), and that farming proportionally retains the least (equal to 334 M3 / Ha). For reference, the 1 in 100 year event discharges 630 M3 / Ha



Hydrologic Ecosystem Services

Attenuating Flood Risk

- The flood water retention service of the Windsor Estate has great value for the community …

- It is estimated that 277 residential buildings and 455 non-residential are at risk from the 1 in 100-year flood event in the Royal Borough of Windsor and Maidenhead (according to Royal Borough of Windsor & Maidenhead, Local Flood Risk Management Strategy)

Flood Depths	Residential	Non Residential
uFMfSW 1 in 100 < 0.3 M Deep	137	211
uFMfSW 1 in 100 > 0.3 M and < 0.6 M Deep	63	152
uFMfSW 1 in 100 > 0.6 M Deep	77	92
Total	**277**	**455**

- A loss of flood water retention would increase these numbers (but precise modeling of the impact of land use change on flood extent was outside the scope of this study)

- The average residential property price in Windsor & Maidenhead is £ 522K. Somewhat arbitrarily assuming the number of residential properties at risk would quadruple in the absence of the Windsor Estate's flood attenuation services, and further assuming 50 per cent damage to the properties, the value of the ecosystem service is equal to **£ 2.9 M / Year**

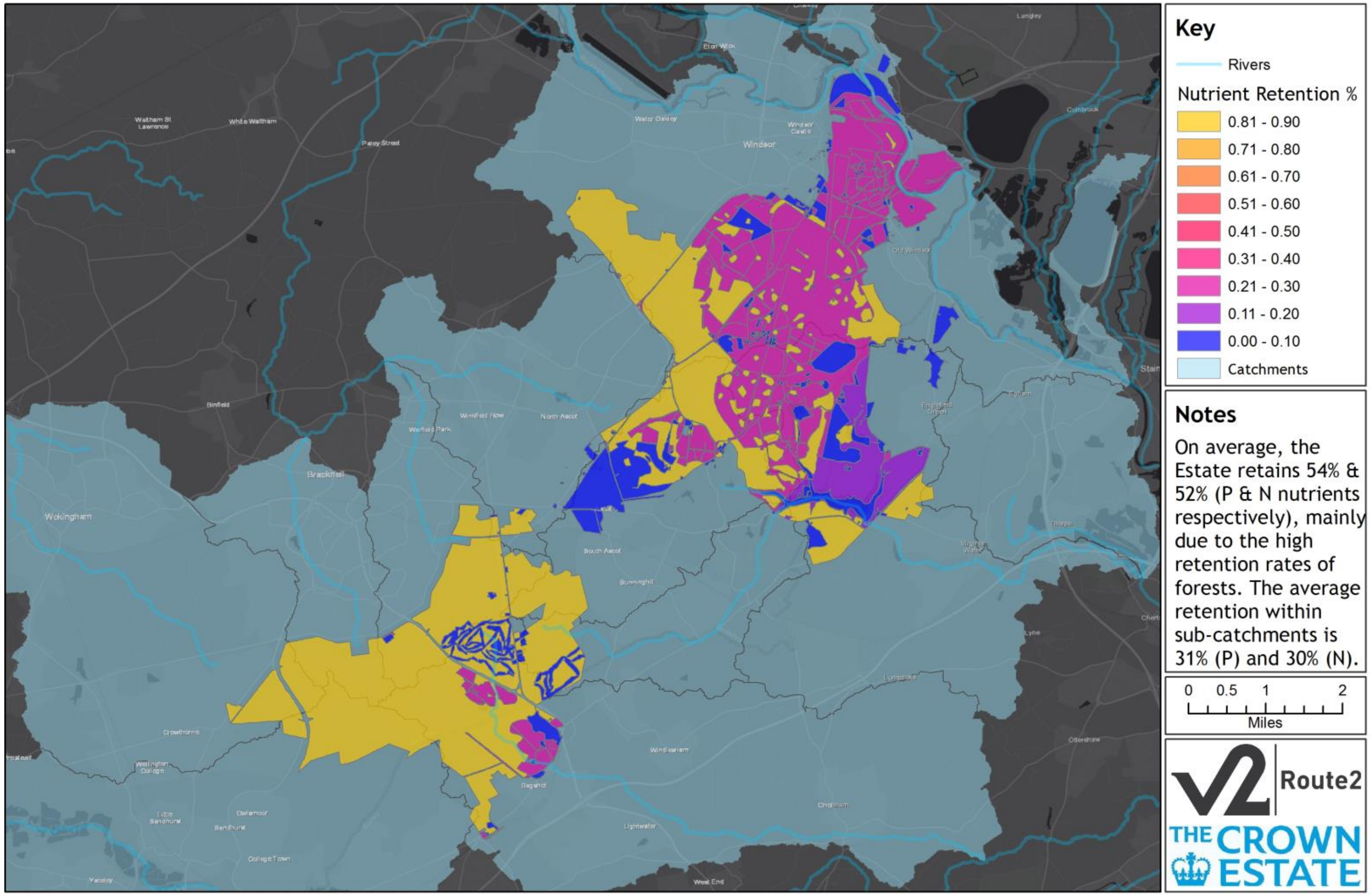
2.9 M = £522,000 Property Value * (277 * 4) Properties * 50% Damage * 1/100 Flood

Hydrologic Ecosystem Services
Water Quality

Ecosystems in the Windsor Estate contribute to higher water quality by retaining pollutants, including nutrients. High nutrient loads lead to algal bloom that have recently become an issue in the Estate (e.g. for recreational fishing in lakes).

The map and following graphs show nutrient retention rates for land use types on the Estate. On average, the Estate retains 54 % and 52 % (for P and N, respectively) of nutrients, mainly due to the high retention rates of forests. For reference, the rest of the sub catchments retain an average of 31 % (P) and 30 % (N) of nutrients.

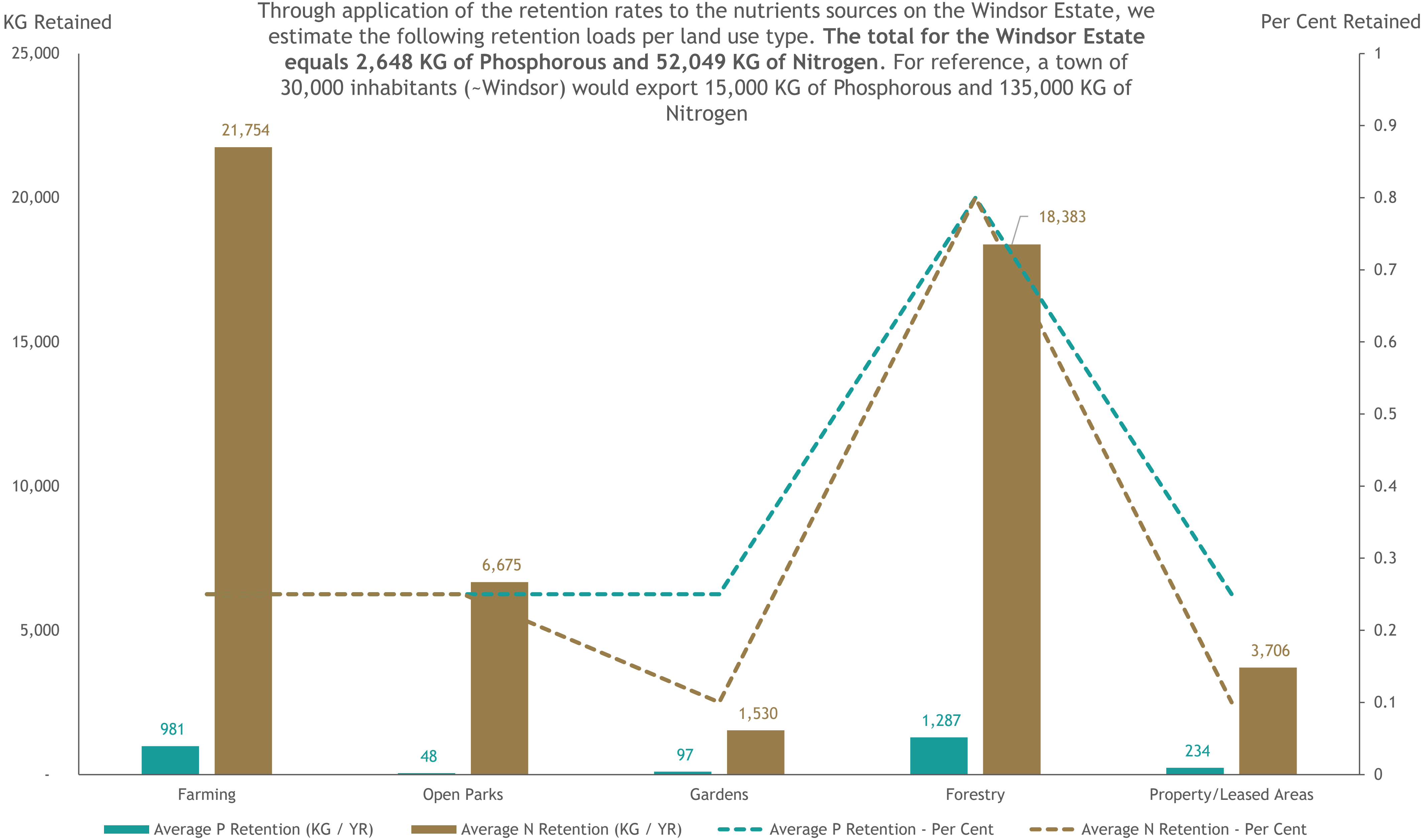
Nutrient Retention within the Windsor Estate



Hydrologic Ecosystem Services

Water Quality

Through application of the retention rates to the nutrients sources on the Windsor Estate, we estimate the following retention loads per land use type. **The total for the Windsor Estate equals 2,648 KG of Phosphorous and 52,049 KG of Nitrogen**. For reference, a town of 30,000 inhabitants (~Windsor) would export 15,000 KG of Phosphorous and 135,000 KG of Nitrogen



Hydrologic Ecosystem Services

Water Quality

	Shadow Price For Undesirable Outputs € / KG (2010)	
	Nitrogen [N]	Phosphorous [P]
River	16.4	30.4
Sea	4.6	7.5
Wetlands	65.2	103.4

Source: F. Hernańdez-Sancho et al. / Science of the Total Environment 408 (2010) 953-957

- **Currency Exchange Rate:** In 2010 0.863 GBP was equal to 1 Euro
- **Inflation:** 1 GBP in 2010 is worth 1.27 GBP In 2019

- Based on Nitrogen Treatment Cost equal to **£ 18 / KG** (16.4 * 0.87 * 1.27) and Phosphorous Treatment Cost equal to £ 34 / KG (30.9 * 0.87 * 1.27) the economic value of the Windsor Estate's water quality services (in terms of avoided treatment costs) is equal to **£ 1.03 M / Year.**

- Again this is an indicative value. Further research is required on the 'appropriate' avoided treatment unit costs and the percentage of the nutrients retained that would require treatment in the event of release to the hydrological network.

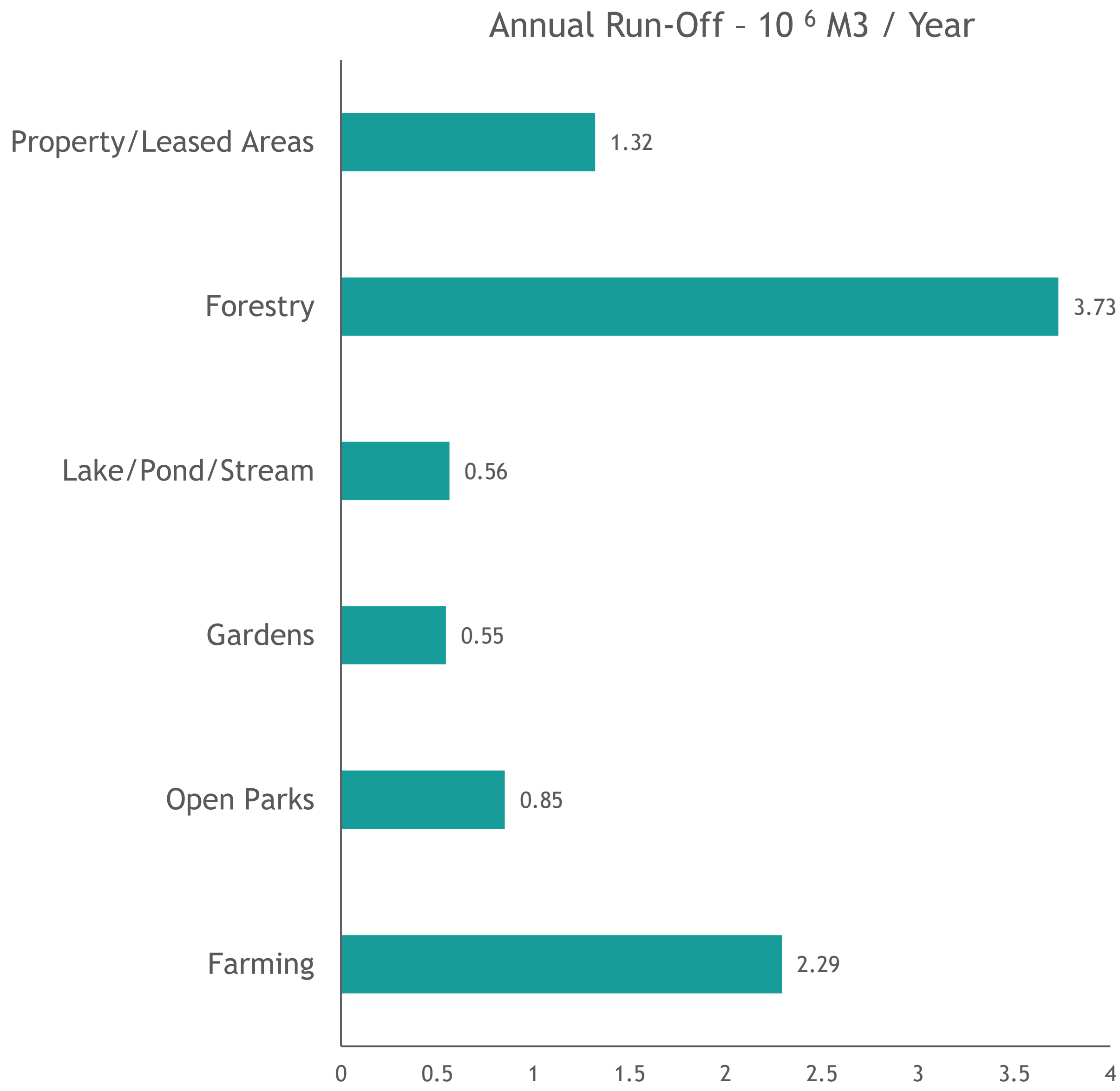
Hydrologic Ecosystem Services

Water Supply

Utilizing the InVEST Annual Water Yield Model the average long-term annual precipitation on the Windsor Estate is estimated to be 800mm.

The majority of this precipitation is evapo-transpired by vegetation. Farmland typically uses less water than forest, although forest areas yield more water due to the large area they cover.

In total, the estate yields an average of **9.3 x 10^6 M3 / Year** (less than the surrounding area, therefore retaining more water which again assists flood mitigation)



Recreational Ecosystem Services

Overview

- The Outdoor Recreation Value [ORVal] Tool is web application developed by the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter with support from DEFRA. It can be accessed at: http://leep.exeter.ac.uk/orval

- ORVal's primary purpose is to provide information that might be useful to government, businesses and communities in understanding the benefits that are derived from accessible greenspace in England and Wales

- It allows users to explore the visitation and welfare values that are generated by currently accessible greenspaces. Welfare values can be viewed at individual site level or aggregated by regions

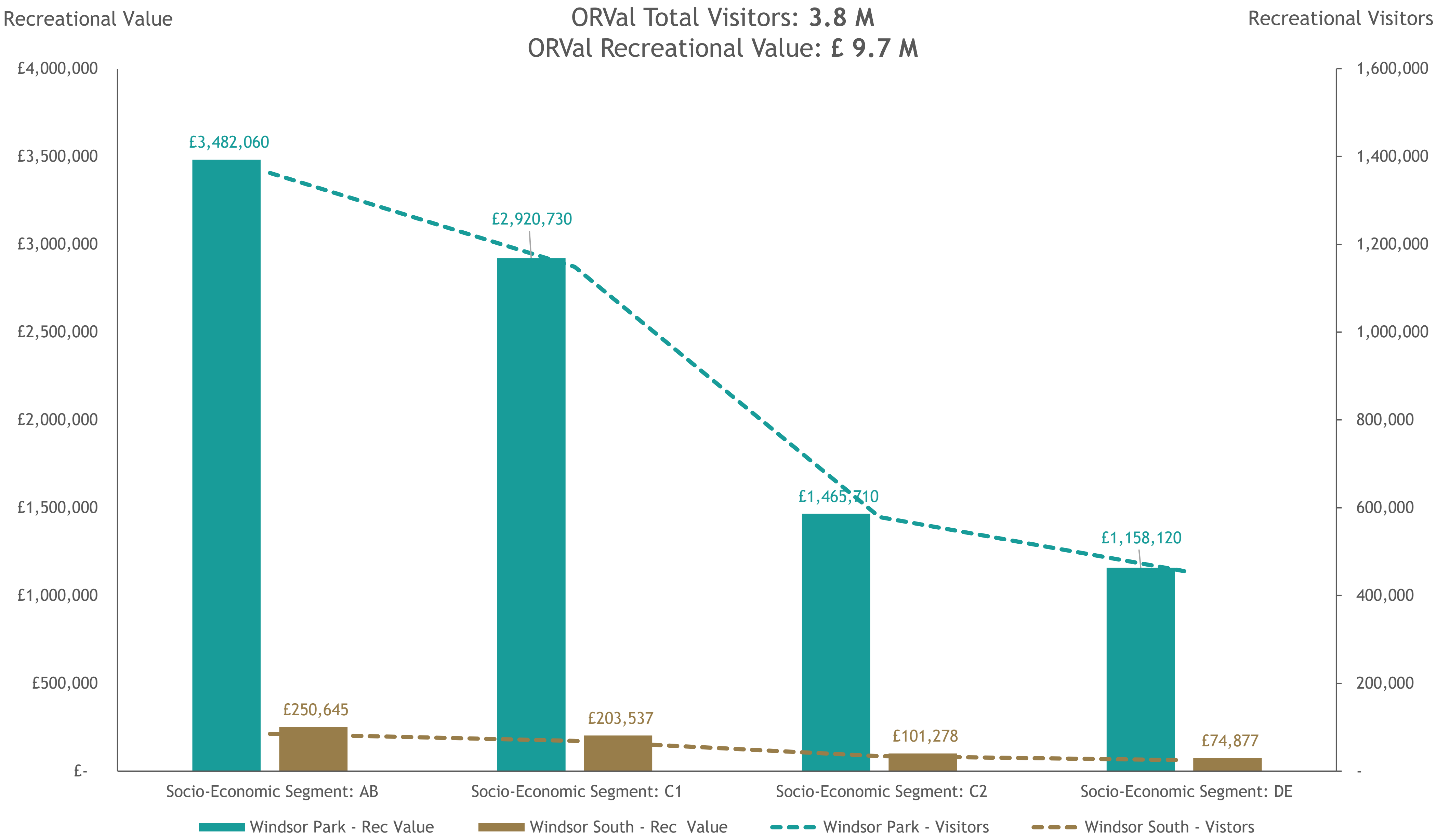
- It allows users to estimate how visitation and welfare values might change if the characteristics of a recreational greenspace were changed

- The model estimates the Windsor Estate receives **3.8 M** visitors per year equal to **£9.7 M** in recreational value. However the The Crown Estate believes the Windsor Estate actually receives closer to **5.5 M** visitors per year. Inflating from then model calculation yields a recreational value equal to **£14.1 M**

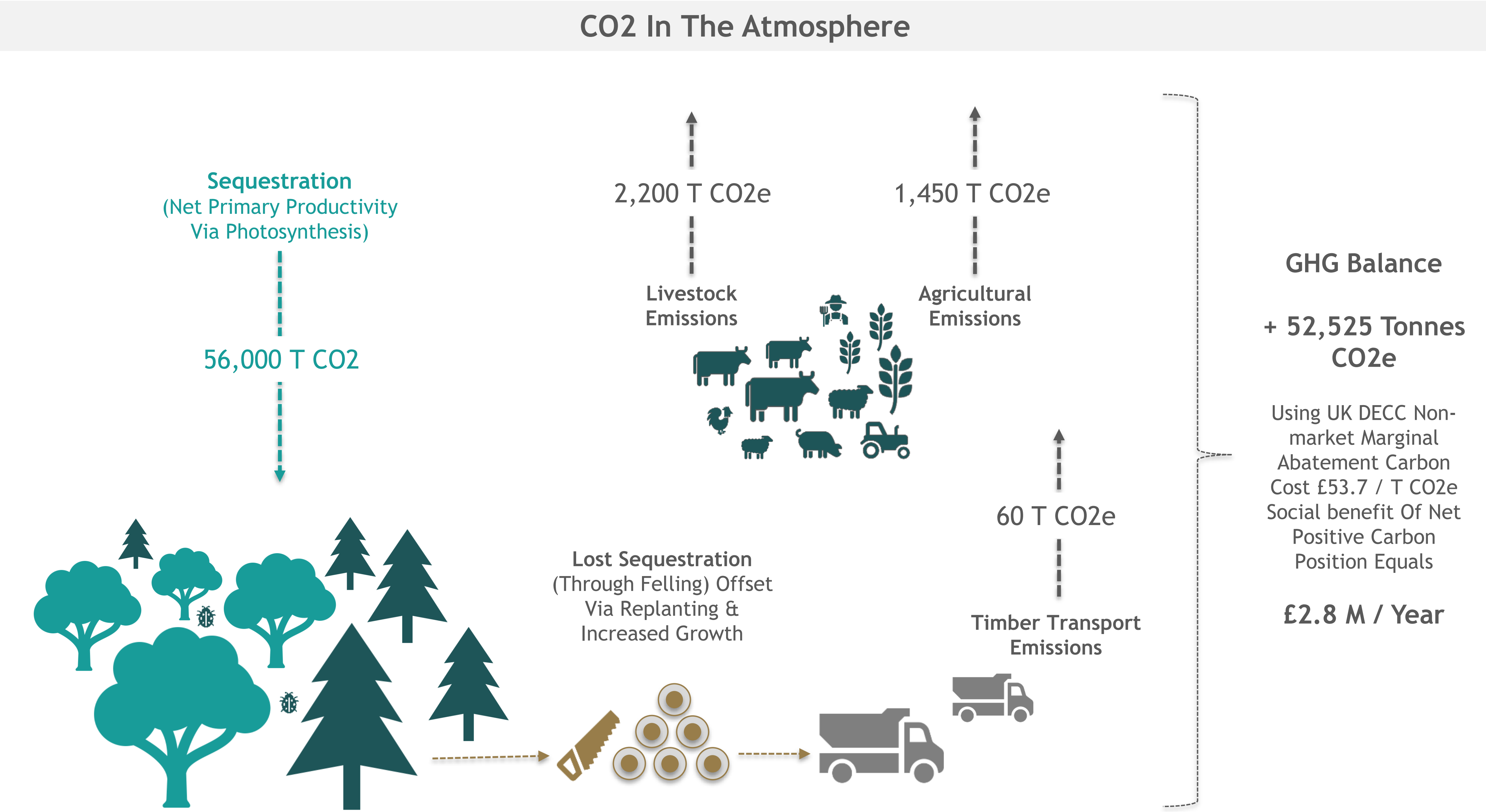
- Recreational visitors & values are provided by socioeconomic segment where: (i) **'AB'** denotes higher & intermediate managerial, administrative, professional occupations; (ii) **'C1'** denotes supervisory, clerical & junior managerial, administrative, professional occupations; (iii) **'C2'** denotes skilled manual occupations; and (iv) **'DE'** denotes semi-skilled & unskilled manual occupations, unemployed and lowest grade occupations

- According to ORVal the greatest proportion of visitors and values are within the **AB** grouping with **1.5 M** visitors deriving **£ 3.7 M** of recreational value. Full results, by socio-economic grouping are graphed on the following slide

Recreational Ecosystem Services
Results



Carbon Cycle
Overview



Agriculture
Overview

- *Based On The Work:*
  Bateman et al., 2013, ***Science****. Bringing Ecosystem Services Into Economic Decision Making: Land Use In The UK*

- *In Summary:*

In order to estimate ecosystem service values for the Crown Estate's rural portfolio we utilized the state of the art approach used by the UK's National Ecosystem Assessment [NEA]. The NEA used a mix of econometric, regression and biophysical process models to arrive at spatially-explicit monetary values for green-house gas emissions/sequestration, recreation, urban green space, and agricultural production (Bateman et al. 2013). Annual ecosystem service values were imputed by annualizing the difference in ecosystem service values between the years 2010-2060. The 2060 values were derived from future land cover distributions under a variety of scenarios representing a range of possible futures (see next slide).

Ecosystem Service-Related Good	Metrics	Main Data & Sources	Model	Valuation
`Agricultural Production	Proportion and output of land use in each 2 km grid square	Land use, soils, physical environment, climate and digital mapping	Environmental-econometric regression analysis of land use decisions as a function of the local physical environment, prices, costs and policies	Market values

Methods

Hydrologic Ecosystem Services

Attenuating Flood Risk: Method

- **InVEST Floodwater Retention Model**

  - https://naturalcapitalproject.stanford.edu/invest/
  - Rainfall-runoff model based on the Soil Conservation Service [SCS] Curve Number approach

Name	Source
Rainfall Depth	- Value: 63 mm (100 ARI 6-hr design storm) - DEFRA (2013). Rainfall runoff management for Developments. Report – SC030219. ISBN: 978-1-84911-309-0
LULC	- CORINE Land cover map (2018)
Soil Hydrologic Group	- Future Water's Hydro soil layer. - https://www.futurewater.nl/wp-content/uploads/2015/05/HiHydroSoil-A-high-resolution-soil-map-of-hydraulic-properties.pdf
Biophysical Table	- NRCS-USDA. (2004). Chapter 9. Hydrologic Soil-Cover Complexes. In Part 630 Hydrology. National Engineering Handbook
Sub-Catchments	- DEFRA (2019) WFD River Waterbody Catchments Cycle 2. - https://data.gov.uk/dataset/298258ee-c4a0-4505-a3b5-0e6585ecfdb2/wfd-river-waterbody-catchments-cycle-2

- **Flooded Properties**

Flood Depths	Residential	Non Residential
uFMfSW 1 in 100 < 0.3 M Deep	137	211
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uFMfSW 1 in 100 > 0.6 M Deep	77	92
Total	277	455

  - Flooded properties: Royal Borough of Windsor & Maidenhead, Local flood risk management strategy
  - Flood data: https://data.gov.uk/dataset/d5ca01ec-e535-4d3f-adc0-089b4f03687d/risk-of-flooding-from-surface-water-suitability

Hydrologic Ecosystem Services

Water Quality: Method

- **Nutrient Retention Rates & Loads Derived From Redhead et al (2018)**

  - Redhead et al. (2018). National scale evaluation of the InVEST nutrient retention model in the United Kingdom. *Science of the Total Environment*, *610-611*, 666-677. https://doi.org/10.1016/j.scitotenv.2017.08.092

  - **See values in table below**

Land use	Load P (kg/ha/yr)	P Retention	Load N (kg/ha/yr)	N Retention
Farming	1.52	25%	35.24	25%
Open Parks	0.12	25%	17.33	25%
Gardens	0.63	25%	10.42	10%
Forestry	0.73	80%	10.9	80%
Property/Leased Areas	0.63	25%	10.42	10%

  - The approach has averaged (area-weighted) these values to estimate the Windsor Estate retention rates

  - To obtain the absolute values of retention, we multiplied the nutrient loads by the average (area-weighted), maximum, and minimum retention rates (maximum and minimum values of land use types found in the previous table)

  - The estimated exports for the town of Windsor are calculated based on the per capita value cited in Redhead et al. (2018)

Land use	Total P loads (kg/yr)	Average P retention (kg/yr)	High estimate P retention (kg/yr)	Low estimate P retention (kg/yr)	Total N loads (kg/yr)	Average N retention (kg/yr)	High estimate N retention (kg/yr)	Low estimate N retention (kg/yr)
Farming	1,815	981	1,452	181	42,077	2,1754	33,661	4,208
Open Parks	89	48	72	9	12,911	6,675	10,329	1,291
Gardens	179	97	143	18	2,959	1,530	2,367	296
Forestry	2,381	1,287	1,905	238	35,556	18,383	28,445	3,556
Property/Leased Areas	433	234	347	43	7,169	3,706	5,735	717
TOTAL	**4,898**	**2,648**	**3,918**	**490**	**100,671**	**52,049**	**80,537**	**10,067**

Hydrologic Ecosystem Services

Water Supply: Method

- **InVEST Annual Water Yield Model**
  - https://naturalcapitalproject.stanford.edu/invest/
  - Annual precipitation was obtained from Redhead et al. (2016) (Catchment Surrey Wey)
    - *Redhead et al. (2016). Empirical validation of the InVEST water yield ecosystem service model at a national scale. Science of The Total Environment, 569, 1418–1426. https://doi.org/10.1016/j.scitotenv.2016.06.227*
  - Annual reference evapotranspiration was obtained from CGIAR-WLE (see reference in Redhead et al.'s paper).
    - Both represent the 2000-2010 period

Land use	Crop Coefficient: Kc	Plant Available Water Content	Annual runoff (mm)	Annual runoff (Mm3)
Farming	0.9	200	196	2.3
Open Parks	1	400	118	0.9
Gardens	0.9	200	196	0.6
Lake/Pond/Stream	1	1	610	0.6
Forestry	1	400	118	3.9
Property/Leased Areas	0.9	200	196	1.3
Total				**9.5**

Recreation
Method

- **Outdoor Recreation Valuation Tool**

    - https://www.leep.exeter.ac.uk/orval/

    - Focuses on an individual's choice of which of the array of different greenspaces to visit rather than how many trips to take to a particular greenspace. This 'discrete choice' approach is a form of 'travel cost modelling'.

Imagine, an individual has a choice between just two greenspaces. Both greenspaces provide visitors with 2ha of open grassland but the more distant greenspace also possesses 2ha of woodland. If we observe the individual choosing to visit the more distant greenspace we can conclude that the extra welfare derived from being able to visit a greenspace with woodland must be worth at least as much as the extra costs in travelling to that more distant location rather than the closer greenspace. Given sufficient observations on individuals choosing between quality-differentiated greenspaces at different distances from their homes, the discrete choice approach can inform on the economic value that individuals realise from greenspaces with different qualities. Moreover it can be used to predict how likely it is that an individual will choose to visit a particular greenspace from the set of greenspaces available to them"

    - The econometric method used to estimate discrete choice models are known as Random Utility Models (RUMs)

    - In particular, need to know:

        - *whether an individual took a trip to greenspace or not*
        - *what mode of transport they decided to use in getting to that location*
        - *what the qualities of that site were and the time and travel costs incurred in getting there.*
        - *qualities associated with each other recreational greenspace that individual might have visited instead*
            - *and the travel costs of different modes of transport associated with reaching each of those alternative locations*

    - The primary data set supporting estimation of the ORVal model is provided by the Monitor of Engagement with the Natural Environment (MENE) survey

Carbon Cycle
Methods

- *Based On*
  *Bateman et al., 2013, **Science**. Bringing Ecosystem Services Into Economic Decision Making: Land Use In The UK*

- *Utilising*
  Forestry Commissions: Understanding the carbon and greenhouse gas balance of forests in Britain

- *The method is based on the annual changes in potential equilibrium carbon stocks in above- and below-ground biomass due to changes in land use and the changes in annual emissions of GHGs associated with farm management for each agricultural land use.*

- *The carbon stocks included in this analysis refer to that stored as soil organic carbon (SOC; these being the largest terrestrial carbon stocks in the Great Britain) and in the above- and below-ground biomass (BIOC; the vegetative stock).*

- *Soil types were defined as either organic (peat) or non-organic (non-peat) based on the European Soil Database, as peat soils have the potential to store considerably greater amounts of carbon than non-organic soils and can release large quantities of carbon if change in land use occurs.*

- *National level estimates of average SOC for non-organic soils were used to allow for variation in climatic, hydrological and other characteristics. Specifically these were: 132.6 tC/ha for England, 212.2 tC/ha for Northern Ireland, 187.4 tC/ha for Scotland and 142.3 tC/ha for Wales*

- *It was assumed that UK organic soils under rough grazing had an average SOC density of 1200 tC/ha*

- *For each soil type, SOC levels are influenced by land use through its impact on processes such as soil disturbance and nutrient cycling.*

- *Non-organic soils under arable land uses (oilseed rape, cereals, roots crops and other agriculture land uses) were assumed to have 84% of the SOC they would attain under improved grassland (temporary and permanent grassland) while soils under rough grazing (semi natural grassland) were defined as having 33% more SOC than improved grasslands.*

- *In comparison, organic (peat) soils under temporary grass, permanent grass and woodland were assumed to have an average SOC of 580tC, while organic soils under arable land uses were assumed to have long term equilibrium SOC equal to the average non-organic soil SOC of the region within which the soils are located . All SOC estimates were based on soil depth of 1m.*

- *Average per hectare biomass carbon (BIOC) stocks for baseline woodland extents were taken as 36.84 tC/ha*

Carbon Cycle

Methods

Converting from carbon stocks to the annual flow of GHG emissions.

- *The annual net flow of emissions of GHG from land use change is defined as comprising two components: (i) Annual SOC fluxes due to land use change; for example, the conversion of arable land to permanent pasture will result in the accumulation of SOC, while a switch from rough grazing to permanent grassland is likely to reduce SOC; and (ii) Annual GHG fluxes from the changes in vegetative biomass associated with land use changes*

- *Given there was no land use change across the estate, flux in SOC (both leakage and sequestration) has been assumed to be negligible / nil*

- *Estimated accumulation of BIOC in woodland planted were taken as 4.61 tC/ha/yr for broadleaf woodland (based on the average of four UK estimates and 5.32 tC/ha/yr for coniferous woodland (based on three UK based estimates).*

- *GHG emissions from agricultural activities: Three major agricultural sources of annual, per hectare GHG emissions were considered: (i) energy use for typical farming practices such as tillage, sowing, spraying, harvesting as well as the production, storage and transportation of fertilizers and pesticides; (ii) emissions of N2O and methane from livestock, i.e., beef cattle, dairy cows and sheep, through the production of manure and enteric fermentation, and (iii) direct emissions of N2O emissions from the application of artificial fertilizers.*

- *The UK Department of Energy and Climate Change (DECC) non-traded carbon price of £53.70 /tCO2e was used in all analyses*

- *1 Tonnes of C equals 3.67 Tonnes Of CO2*

Land Use	Emissions From Ag Activities	N2O Emissions From Inorganic Fertilizer
	tCO2e/Ha/Yr	tCO2e/Ha/Yr
Cereals	O,55	0.95
Oilseed Rape	0.48	1.06
Rooty Crops	0.46	1.01
Temporary Grass	0.48	1.27
Permanent Grass	0.35	0.89
Rough Grazing	0.00	0.00
Other	0.40	1.03

Livestock	Enteric	Manure Deposits	Manure Fertilizer
	tCO2e/Head/Yr	tCO2e/Head/Yr	tCO2e/Head/Yr
Dairy	2.381	0.145	0.016
Beef	1.104	0.086	0.006
Sheep	0.184	0.054	0.001

Limitations

Limitations

- Attenuating Flood Risk
    - The model is based on the SCS Curve Number method, yielding uncertainty in the runoff estimates. More sophisticated models could be run (e.g. CADDIES, HEC-RAS).
    - The valuation approach could be improved by re-calculating the number of properties at risk in all the Estate's sub-catchments (currently these numbers are obtained from the Windsor and Maidenhead flood assessment study).
- Water Quality
    - UK-wide analyses have been conducted by Redhead et al. (2016, 2018).
    - The present water quality analyses use the model parameters (retention rates), without applying the InVEST nutrient retention model (since GIS input data are not freely available).
- Water Supply
    - UK-wide analyses have been conducted by Redhead et al. (2016, 2018).
    - The present water yield analyses use the global soil and climate (ET) data. Using the original study (input data can be obtained for a fee from the Centre for Ecology and Hydrology: https://eip.ceh.ac.uk/)

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