Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

ERAMMP Report-133: ERAMMP2 Integrated Modelling Platform (IMP) Assumptions

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Abbreviations Used in this Report

DMU	Decision Making Unit – a managerially homogenous cluster of soil type, average rainfall and land cover.
FBI	Farm Business Income.
FBS	Farm Business Survey.
FTE	Full Time Equivalent (job).
IMP	Integrated Modelling Platform – a series of linked models developed to explore cross-sectoral interactions and potential unintended consequences of policy interventions within ERAMMP.
JAS	June Agricultural Survey.
LAM	Land Allocation Module – the central module within the IMP that simulates how landowners might respond to the scenarios and policy interventions through farm and land use transitions using a set of rules and thresholds.
LFA	Less Favoured Areas (the sum of DA + SDA).
N, P, Z	Nitrogen, Phosphorous, Sediment respectively (water quality indicators).
NPV	Net present value – comparable economic indicator used by both forest and farm models to allow on-farm profit decisions to be made.
PWF	Preferred Way Forward.
SDA	Severely Disadvantaged Area (UK basic payment scheme designation for poor quality, often upland farmland). Likewise, DA = Disadvantaged Area.
RFT	Robust Farm Type – broad farm categories developed by ADAS to be comparable across the UK.
EFT	ERAMMP Farm Type - In ERAMMP we combine the RFTs with categorisations of LFA for Wales: Cereals, General cropping, Dairy, Lowland cattle / sheep, Mixed, Specialist Sheep (SDA), Specialist Beef (SDA), SDA mixed grazing, DA various grazing.
WFD	Water Framework Directive (policy).

Contents

1 Overview

This report describes the assumptions underlying the Integrated Modelling Platform (IMP) version 2 and its constituent models/methods that have been agreed between the IMP team and a Welsh Government for the PWF scenario work. Additional IMP capability, unused in the PWF scenario work is detailed in the Appendix.

This version was signed-off to cover the PWF scenario work on 18/09/2025.

2 GENERAL

1. Farms under 1 FTE are excluded from the modelling and are not included in the IMP's underlying DMUs:
    a. The 1 FTE agreement is a legacy from ERAMMP Quick Start where it was agreed with WG.
    b. The logic was that below 1 FTE, farmers were either farming for lifestyle reasons ("micro farms") and/or made their wages elsewhere. Therefore, the prediction of behaviour based on purely farm economic drivers was not appropriate for this group of farms.
    c. We recognise that there are alternative cut-offs to 1 FTE (e.g., the €25,000 Standard Output) and that this would have the advantage of a direct link to the Farm Business Survey. Basing the decision on Standard Output, Standard Labour or Standard Margins is largely a matter of choice. They are all broad proxies based on weighted sums of livestock numbers and crop areas. They identify a broadly similar set of farms as "micro", although the Standard Labour has more "micro" farms than the others.
    d. IMP version 2 continues to use the 1 FTE threshold.

3 FARMLAND

2. The agricultural model, the Silsoe Whole Farm Model (SFARMOD), uses a combination of relationships driven by soil type, land cover and annual rainfall and farm category averages to simulate farm management choices and practices. This assumes that these values are representative of the range of farm practices, land types, finances, etc. for each farm category. A farm is modelled as a set of multiple relatively homogenous blocks called DMUs within enclosed and unenclosed areas. The IMP team recognise that this is a significant assumption and explicitly acknowledge the heterogeneity between and within farms that it is not possible to include with the available (particularly spatially explicit) data.

3. The on-farm modelling is based on constrained profit maximisation and applies a long-term (>5 year) perspective. We recognise that this is an imperfect approach, as not all (<25%) individual farms self-report[1] as being driven by profit maximisation/farm output. However, this is a pragmatic assumption and there are limited alternatives that can be justified in comparison. When aggregated, profit maximisation is one of the best predictors of the collective behaviour of the population of farmers.

4. The baseline scenario uses activity and economic data for the latest available harvest year of 2022-23. It is recognised that some actual costs and prices were above longer-term averages in this year, affecting the profitability of some farm types (particularly dairy farms) but it was agreed by the Expert Group that the most recent available data should be used to inform the modelling.

5. Typical input economic data to the models are those used by farmers for planning, hence, reducing the impact of short-term spikes in costs and revenues. Data from farm planning cost books, such as John Nix Pocketbook or The Agricultural Budgeting and Costing Book (ABC), are longer term averages used to derive expected values of economic inputs, including for example the price of milk, beef or lamb.

6. Basic Payment Scheme subsidy levels in the baseline and PWF scenario counterfactual runs are based on 2022-23.
    a. Direct payments to farmers: Basic Payment Scheme (BPS). The descriptions of the available payments were taken from the John Nix Pocketbook for Farm Management 54th Edition - 2024[2]. For the baseline modelling, the following were applied:
        (i) a flat rate BPS payment of £121/ha;
        (ii) a redistributive payment on the first 54 ha of £111/ha.
    b. Payments (i) are implemented in the SFARMOD optimization across all farmable land.

[1] Lee-Woolf, C., Hughes, O., King, G, & Fell, D. (2014). Development of a segmentation model for the Welsh agricultural industry. A report by Brook Lyndhurst for the Welsh Government.
[2] Redman G. (2024). John Nix Pocketbook for Farm Management for 2024. Agro Business Consultants Limited; 2023.

c. Payment (ii) is added during the post-processing of SFARMOD outputs up to 54 ha when we aggregate the DMUs to farms.

d. Rural Investment Schemes (RIS)[3]. The Land Allocation Module (LAM) brings together farming and non-farming costs and revenues to derive overall farm profits. We assume that these grants do not affect the baseline because (1) the grants relate to the wider rural economy, (2) in the baseline we assume farm woodland is revenue neutral and managed at cost, or (3) the grants are revenue neutral and cover costs plus revenue forgone.

7. Baseline farm woodland is assumed to generate no net income, i.e., is managed at cost. It might be that it is unmanaged or managed for recreation. However, on this scale it is unlikely that timber is being harvested and, if it is, that any income covers not much more than the cost of harvest. Therefore, existing areas of farm woodland are inert in the baseline and do not form part of the optimisation or estimation of farm profitability.

8. In scenario runs, all improved grassland that can technically be cultivated is considered to be potentially able to convert to cropland. Areas above 400m are excluded to protect hills from being ploughed.

9. The acid grassland class on the Land Cover Map covers a continuum from low quality permanent grassland to rough grazing. To align the grassland type areas within the DMUs to the JAS, the acid grassland area was sub-divided. All enclosed acid grassland on non-peat soils that was below 375 mOD (Ordance Datum) was classed as low-quality permanent grass and given a modelled grass yield that was the average of the values for permanent grass and rough grazing for the given soil type and climate. The remaining acid grassland was defined as rough grazing.

10. Conversion of rough grazing and low-quality permanent grass to improved pasture is not considered. In this situation the soils are assumed to be not cultivatable / plough-able due to thin, steep or wet soils and may also be too steep to work safely and apply fertilisers and other inputs.

11. SFARMOD can only model one set of livestock on one DMU. A farm consists of one or more DMUs. To allow for farms whose baseline Robust Farm Type contains more than one stock option (e.g., mixed lowland cattle and sheep), the DMUs are assigned to a farming/stocking system based on the Farm Type, altitude, Land Cover Map (Arable, Improved Grass, Rough Grazing) and grassland system (ley/temporary grass, permanent grass, rough grazing) according to Appendix 1.1.

12. The Control of Agricultural Pollution Regulations (2021) are represented in the IMP:

a. Nutrients in excreta and manures, in particular nitrogen, have been set to match the planning assumptions in The Control of Agricultural Pollution Regulations (2021).

b. Manufactured nutrients to grassland and arable crops have been calibrated to match the British Survey of Fertiliser Practice.

[3] https://www.gov.wales/rural-schemes-application-dates and Multi-Annual Support Plan Agriculture (page 7)

c. To accommodate the restrictions on spreading manures and fertilisers we have introduced closed seasons and created more opportunities in more crops to apply manure in season to avoid creating logistical bottle necks. To avoid high-risk periods, we have reduced the number of soil-weather workdays for manure/ slurry spreading to 70% of the hours available for ploughing. To allow for high-risk areas, we have reduced the area of land available for manure by 5%.

d. If a farm exceeds the manurial N limit of 170 kg N / ha across the farmed area, excess manure/slurry is exported off-farm. It is assumed that there is sufficient available land within the farm's local catchment area to accept it. A penalty function is applied of £1.61/ kg N in excess. This is based on an additional 10km transport costs of £4.83 m^3 as slurry (Nix, 2024) with a typical N content of 3 kgN/m^3.

4 Forestry and Hedgerows

4.1 Forestry

13. Woodland maintenance is assumed to have no impact on carbon. Woodland maintenance may result in carbon loss or gain, depending on the baseline condition, type and age of the woodland. In the absence of this information, no change was assumed.

    a. There are conflicting views on woodland maintenance and implications for carbon and biodiversity.

    b. The IMP does not model displacement (i.e., carbon benefits of using woodland for energy or construction in place of other options).

    c. Modelling woodland maintenance without considering displacement may result in carbon loss if no maintenance is assumed at baseline.

14. Woodland creation does not form part of the PWF SFS Scenario so was not modelled. The IMP has the capacity to simulate woodland creation (see Appendix A1.2 Assumptions related to IMP Additional Capability).

4.2 Hedgerows

15. Hedgerow creation does not form part of the PWF SFS Scenario so was not modelled.

16. Hedgerow maintenance was modelled based on the following assumptions:

    a. Change in above-ground, below-ground and soil carbon are modelled.

    b. Carbon stocks in above-ground hedgerow biomass were calculated at 14.2 t C ha^{-1} per metre of height[4] applied to specified hedgerow sizes (width and height) for each year in t C km^{-1}. Rates of carbon stock change (t C km^{-1} yr^{-1}) were calculated from annual carbon stocks. Below-ground carbon stocks were calculated as one third of the above-ground carbon[5]. Carbon stocks in the existing biomass were excluded. Soil carbon stock change was calculated at 0.5 t C ha^{-1} yr^{-1} applied only to the area immediately under the hedgerow[6]. Rates of carbon stock change were averaged over the modelled time periods.

    c. To prevent overestimation of carbon stocks over the lifecycle of the hedgerow, coppicing or laying is assumed to be undertaken every 20-30 years as part of hedgerow maintenance. Carbon stocks in removed biomass are assumed to be zero and substitution effects are not represented. The long-term average annual

[4] Biffi, S. Chapman, PJ., Grayson, RP., Ziv, G. (2023). Planting hedgerows: Biomass carbon sequestration and contribution towards net-zero targets. *Science of the Total Environment*, 892: 164482, ScienceDirect.

[5] Crossland, M. (2015). The carbon sequestration potential of hedges managed for woodfuel. Organic Research Centre, TWECOM ORC Carbon report v1.0.pdf.

[6] Robertson, H., Marshall, D., Slingsby, E., and Newman, G. (2012). Economic, biodiversity, resource protection and social values of orchards: a study of six orchards by the Herefordshire Orchards Community Evaluation Project. *Natural England NECR090, NECR090_edition_1.pdf.*

carbon stock change accounts for the removal of biomass during coppicing or laying, followed by re-growth.

17. Carbon stocks in the above-ground biomass, below-ground biomass, soil, litter and deadwood of hedgerow trees are modelled.

    a. Carbon stocks in the stem were calculated from the yield table[7] for Yield Class 4 poplar at 188 stems per hectare scaled to a single tree. An expansion factor of 0.2 was applied to calculate carbon stocks in the branches. Carbon stocks in below-ground biomass were calculated at 20% of above-ground biomass, which is the total carbon stocks in the stem and branches. Carbon stocks for soil, deadwood and litter were calculated using the CARBINE sycamore, ash birch model for yield class 4, managed with no thinning and no harvesting, with a previous land use of cropland and a site type of warm-moist-loam. CARBINE represents higher levels of soil disturbance due to ground preparation than would occur for hedgerow trees, therefore the same initial rates of soil carbon stock change as for hedgerows were applied (0.5 t C ha^{-1} yr^{-1}). Rates of carbon stock change for soil, deadwood and litter were scaled to 3.5 m x 3.5 m (1/800th hectare). Rates of carbon stock change were averaged over the modelled time periods.

[7] Matthews, R.W., Henshall, P.A., Jenkins, T.A.R., Mackie, E.D. & Dick, E.C. (2016). Forest Yield: a PC-based yield model for forest management in Britain. User Manual. Forestry Commission: Edinburgh. A PC based yield model.pdf

5 Land Allocation Module (LAM)

18. The LAM aims to assess the (uncertain) response of every ≥ 1 FTE farm across Wales to a scenario. We recognise that there are many factors that influence the decisions of an individual farm business and that there is limited understanding and data that can be applied to all ≥ 1FTE farms across Wales. The LAM modelling therefore necessitates significant assumptions. It was also a key area for sensitivity testing to explore the impacts of different parameter settings.

19. Given the sampling limitations of the Farm Business Survey (FBS), we link the RFT-specific average FBS data to the specified ERAMMP Farm Type (EFT) of each ≥ 1 FTE farm across Wales:

    a. EFTs are: Cereals, General cropping, Dairy, Lowland cattle / sheep, Mixed, Other[8], Specialist sheep (SDA), Specialist beef (SDA), SDA mixed grazing, DA various grazing.

    b. These are based on ADAS' RFTs with extra detail included between SDA and DA grazing to better reflect the Welsh agricultural landscape.

20. Farm business income (FBI) can be estimated from SFARMOD Farm Net Profit + Non-Agricultural Farm Income - Unaccounted costs + Unpaid labour:

    a. SFARMOD Farm Net Profit takes account of agricultural outputs, basic payments, variable costs and a subset of fixed costs. It assumes that all current agri-environment payments are cost-neutral and are thus not explicitly included.

    b. Non-agricultural income derived by the farm, expressed as £/ha, is estimated from average values for full-time farms based on weighted population estimates using the 2022-23 June Survey of "Miscellaneous income" (which considers contract work, farm cottage rents, benefit value of farmhouses, and profit on resale of purchased agricultural produce) and "Income from energy generation" (which includes income from farmer and non-farmer owned energy generating projects, including wind, solar, biomass, hydro etc.). No data were provided where the calculations would rely on less than 5 farms. The classes were Cereals & General Cropping (applied to the Cereal and General cropping EFTs), Cropping, cattle & sheep (applied to Other and Mixed EFTs), Dairy (LFA) and Dairy (lowland) (applied to the Dairy EFTs as appropriate), Various grazing livestock (lowland) (applied to Lowland cattle / sheep), Various grazing livestock (DA), Mixed grazing livestock (SDA), Specialist beef (SDA), Specialist sheep (SDA). It is assumed that all farms of the same farm type have the same unit area non-agricultural income and thus larger farms will have larger non-agricultural income.

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[8] Classification of farm businesses by type is done using the weighted contributions of each farm enterprise in terms of their associated outputs (Standard Outputs, or SOs). A farm is allocated to a type according to the source of the majority of its total SO. A farm is allocated to a particular type when the contribution of a crop of livestock type comprises more than two-thirds of its total SO. 'Other' EFTs are holdings that fit into no single category.

(i) If farm transitions are switched on in an IMP run and a farm is simulated by the LAM to change farm type (EFT), it is assumed that the level of non-agricultural income remains unchanged.

c. Unaccounted costs are estimated by scaling the SFARMOD costs (for labour, contracting, machinery hire, fuel and repairs, and machinery depreciation) according to the ratio of the weighted average FBS data for the above farm types of unaccounted costs (general farming costs, land expenses, buildings depreciation, rent and finance) to the accounted costs (for labour, contracting, machinery hire, fuel and repairs, and machinery depreciation).

21. SFARMOD costs all labour (whether paid or unpaid, including by farmer and spouse) used for farm activities, but does not include managerial labour.

    a. We account for the value of unpaid labour by scaling the simulated farm labour FTE from SFARMOD by the ratio of unpaid labour to total labour from FBS data using farm-type specific-values (subject to a maximum of 1.5 FTE of unpaid labour), assuming the SFARMOD labour rate of £29,470/FTE.
    b. We assume that all managerial labour is unpaid, is provided by the farmer and/or spouse, and does not significantly affect FBI, i.e., it can be ignored from the calculation of FBI.

22. Welsh Farm Business Survey data for April 2022/23 were selected for consistency with the year used in other datasets (e.g., Land Cover Map 2021) and farm activity data used in SFARMOD.

23. The following details the steps within the Land Allocation module (LAM). Assumptions related to each step are described below.

24. Step 0: Does the farm enter the SFS?

    a. To determine SFS uptake in its baseline EFT (prior to any farm transitions being considered if they are switched on), a threshold of > £1 more profitable is set; i.e., if an SFS scenario is being run, a farm would be considered to enter SFS if the FBI was £1 greater than outside of SFS (but not receiving any transitional BPS payments), otherwise the farm would be considered not to be in SFS in its baseline EFT.

25. Step 1: Does current farm type remain viable?

    a. Farm viability is based on FBI and we assume a threshold of £0/yr.
    b. In consultation with the WG Expert Group it was decided that historical FBS data shows that many farms have periods of loss and low profit but continue to operate. The WG Expert Group therefore agreed setting the viability threshold at £0/yr did not make any assertions as to the long-term viability of a farm and therefore was a sensible threshold to use.

26. Step 2: Does the farm consider going part-time?

    a. If the existing farm type does not meet the minimum FBI threshold, the farm is assumed to continue farming as a part-time enterprise in its current farm type.

b. When a farm transitions to part-time, there are many options available to the farmer, including reducing the herd size, changing its composition or renting out land. However, due to large and potentially complex range of options the LAM/IMP assumes no change to the current management of the farm as it goes part-time.

27. Steps 3, 4 and 5: Are there sufficiently profitable alternative farm types?

a. If the LAM is run with farm transitions on, alternative more profitable farm types will be considered to transition to. Transitions will be subject to the criteria laid out below. The LAM will be able to choose the most profitable SFS or non-SFS alternative for a given farm. If farm transitions are off these steps will not be considered. Note, transitions were turned off for the PWF scenarios.

(i) For a viable farm type to consider transitioning to an alternative more profitable farm type, its current FBI must be sufficient to give the business capacity to systematically adapt to change of enterprise/farming system. This FBI threshold is set at £13,000/yr.

(ii) For a viable farm type to convert to an alternative more profitable farm type a minimum farm profit increase threshold of the greater of £5,000/yr or 25% of the current farm FBI is required to even consider transition.

(iii) The simulated decision to convert is based on whether there is sufficient additional FBI beyond the minimum farm profit increase threshold to finance the change, with transitions requiring larger investments or being irreversible needing a larger increase in FBI.

- The additional FBI is set as 10% of the investment required, reflecting the risks associated with conversion.
- The additional investment required is based on the calculated difference in tenants' capital (machinery, livestock, crops and stores) between farm types using FBS data. Where a farm type has lower tenants capital than the existing farm, no additional investment is assumed. In addition, for a farm to consider transitioning to dairy, the farm (1) needs to be able to support a minimum of > 91 Grazing Livestock Units, equivalent to a minimum dairy herd of 70 milkers and (2) finance additional investment in non-tenants-type capital of sheds, parlours and slurry stores of around c.£2.5k per cow using second-hand equipment and repurposing existing facilities.

28. Step 6: Stays farming as current farm type

a. If a viable farm does not meet the minimum FBI threshold of £13,000/yr to consider alternative options or there are no more profitable options available (see criteria in step 3-5) then the farm will remain farming as its existing ERAMMP farm type.

29. Step 7: Land outside > 1 FTE holdings:

a. For woodland and forest outside of > 1 FTE farm holdings, we assume that woodland/ forest type and management is constant.

b. For land that is not within > 1 FTE farm holdings and is not currently woodland or forest, we assume that the land cover is insensitive to the scenario and remains constant (as per Land Cover Map 2021).

6 On-farm Agricultural Pollutants

30. The impacts of any changes in practice are expressed relative to current practice, excluding the impacts of the CoAP Regulations. These implementation rates are based upon data from national stratified surveys, primarily the Defra Farm Practice Surveys and the 1st and 2nd Welsh Farm Practice Surveys.

31. Emissions of climate change gases (nitrous oxide and methane) and ammonia in Farmscoper v5 are calculated using a methodology that mimics the UK agricultural ammonia and GHG inventory (AAGHGI; Brown et al., 2021[9]) from 2019 as close as possible, with the exception that indirect emissions of nitrous oxide are calculated from the modelled nitrate losses rather than using the inventory approach. The only modifications made to Farmscoper for use in the IMP were a reduction in the nitrous oxide emission factors for poultry manure to reflect changes in the AAGHGI since 2019, and modifications to the fertiliser calculations to reflect the specific environmental conditions in Wales (as Farmscoper uses the average values for England and Wales).

32. There are a number of fixed farm practice assumptions in the modelling work that are used to calculate the pollutant coefficient data in Farmscoper – these include fertiliser and manure application timing, soil P status and duration of livestock grazing. Assumptions are based on data from national stratified surveys, including the British Survey of Fertiliser Practice and the Defra Farm Practice Survey.

33. The full model of Farmscoper v5 (from which the IMP coefficients are extracted) was built using 1981-2010 climate data, and the results area weighted by rainfall category and the three soils represented by Farmscoper. This area weighting was undertaken for the whole of England and Wales. The data may thus not be as representative as possible of the current climate in Wales.

6.1 Aggregating farm pollutants to the landscape scale to estimate water quality

34. SFARMOD management data are linked to Farmscoper coefficients at a DMU scale to calculate baseline and change in ammonia, methane, nitrous oxide emissions, and nitrate, phosphorus and sediment loading to the watercourse.

35. For DMUs for farms < 1 FTE that are not modelled by SFARMOD, we instead apply small farm average data for nutrient inputs and livestock excreta. For commons DMUs, we assume all land is rough grazing and that nutrient inputs from grazing livestock are accounted for elsewhere (since livestock would be moved in/out of the commons DMUs). Pig and poultry nutrient loadings were calculated by spatial re-aggregation from small agricultural area totals - spreading excreta loadings evenly across all DMUs in that

[9] Brown P, Cardenas L, Choudrie S, Del Vento S, Karagianni E, MacCarthy J, Mullen P, Passant N, Richmond B, Smith H, Thistlethwaite G, Thomson A, Turtle L, Wakeling D, 2021. UK Greenhouse Gas Inventory, 1990 to 2019. Annual Report for Submission under the Framework Convention on Climate Change. 655pp. UK Greenhouse Gas Inventory 1990 to 2019

small agricultural area. These additional DMUs and pollutant loadings are linked to Farmscoper coefficients in the same way as those modelled by SFARMOD.

36. The water quality pollutants are added up at a WFD sub-catchment scale to calculate total loading for a sub-catchment for N, P and sediment. These are accumulated downstream, accounting for downstream links between the sub-catchments.

37. The SEPARATE spreadsheet (Zhang et al., 2014[10]) is used to account for non-agricultural loadings of N and P, and to convert these to measures of concentration to allow assessment of water quality.

38. WFD P status is assigned based on P concentration thresholds which vary with elevation and alkalinity as well as being lower in areas designated SAC. We use the same thresholds as used by NRW, with some assumptions to reflect our approach. We assess P status based on the concentration at the outflow of each WFD sub-catchment, and therefore we use the most downstream threshold available. Note: NRW compare concentration to thresholds at monitoring points throughout the sub-catchment and then use these to assign an overall status for the WFD sub catchment.

[10] Zhang, Y.; Collins, A.L.; Murdoch, N.; Lee, D.; Naden, P.S. (2014). Cross sector contributions to river pollution in England and Wales: Updating waterbody scale information to support policy delivery for the Water Framework Directive. Environmental Science & Policy, 42: 16-32 https://www.sciencedirect.com/science/article/pii/S1462901114000823/pdfft?md5=052c61a6c0fc28a23fb3fd3647519ef9&pid=1-s2.0-S1462901114000823-main.pdf.

7 Biodiversity and Ecosystem Services

7.1 Birds

39. In the BIMLA model, bird data were used from multiple years (2013-2017) to reduce impact of between-year variability and to capture data for rarer species. Species were only selected if they occurred in at least 35 1km squares to ensure development of robust models:

    a. The bird abundance and diversity estimates in this study are derived from raw BBS/GMEP count data, which describe relative abundances within species and are not, strictly, comparable between species (due to variation in detectability), but are not biased for comparisons in space and time.

    b. This means that the data should not be used for comparison with data from elsewhere that were collected using different methods, but that they are robust in respect of variations due to environmental factors.

40. Changes within each scenario are only driven by land use transitions from the upstream Land Allocation Module (LAM). These land use transitions are either direct replacements of land cover or signals to indicate where interventions take place if simulating a given scenario. Interventions are applied via three routes:

    a. Direct Replacements: If a scenario introduces a land cover type already present in the baseline, it replaces that cover directly. The same method applies to changes in stocking levels or farming intensity, using livestock units and yield values calculated in SFARMOD.

    b. Agri-environment schemes: Where interventions align with previous agri-environment schemes and sufficient bird data are available, we model them as separate management variables in addition to land cover. Because the spatial data do not align at the parcel level, we cannot measure the true scheme area within each parcel. Instead, we label the entire parcel as being under the scheme and use this as a proxy for the actual managed area. As actual uptake (e.g., for field margins) is typically smaller, we assume that the proportion of managed area relative to parcel size is broadly consistent across parcels. Baseline scheme designations are taken from spatial uptake data, while scenario designations are derived from the LAM. If a scenario does not include a baseline agri-environment scheme, we set the value of that management to zero, under the assumption that funding has ceased. However, baseline management is retained if it is likely to have a longer-term ecological impact, such as woodland planting.

    c. Insufficient data: Where a land cover or management intervention has no direct match, or baseline data are insufficient, we use the variable with the most similar expected effect on birds as a proxy and apply the same replacement.

41. For each species, we compare the predicted national populations of the baseline and scenario over thousands of model runs. These runs capture a wide range of potential relationships species have to land cover based on the survey data, capturing uncertainty. We consider a population as being significantly likely to change if they are increasing or decreasing in > 95% of model runs.

42. We do not align scenarios to fixed years, but instead the estimated year it would take for the newly introduced land cover to reach maturity.

43. When summarising data for the 1km square, where 1km square boundaries intersect DMUs, it is assumed that attributes are evenly spread across the DMU.

44. Our modelling assumes that species are sensitive to differences in land cover and management, and their abundance in survey data reflects this. However, for hedgerows managed under the PWF SFS scenario, which promotes increased width and height, we find only a very limited effect even on typical hedgerow species. We believe our model underpredicts the impact of this management. This is likely to be because it relies on survey data at the 1km grid square level, which may not capture the fine-scale differences between managed and unmanaged hedgerows. Based on expert opinion, we would expect a small to moderate rise in common hedgerow-nesting species as a result of this intervention.

7.2 Plants

45. In the MultiMOVE plant species modelling, it is assumed that soil changes drive correlated changes in suitability of conditions for plant species. Therefore, MultiMOVE implicitly rather than explicitly models plant-soil feedbacks. This makes things simpler, but less able to generate novel dynamic outcomes.

46. MultiMOVE models 'habitat suitability' rather than actual presence or abundance of species. This involves fewer assumptions and usefully separates intervention or climate-driven change in conditions favouring each species from the processes of dispersal and establishment required for a species to realise changes in conditions by becoming established.

47. The pool of modelled species is drawn from those observed at modelled locations plus those recorded in the wider 10km square. This ensures that changes in habitat suitability are possible as species composition turns over. This assumption is considered to be realistic because such turnover draws on nearby species populations. Even if this might depend upon managed introduction, we assume this is more achievable from local sources than distant populations.

48. Changes in habitat suitability are driven by land use transitions from the upstream Land Allocation Module (LAM) and by uptake and assumed implementation of management actions if a given scenario is being run. These transitions and actions are converted into associated changes in soil conditions (i.e., MultiMOVE inputs) by reference to the literature and to observations from Countryside Survey. This is done by setting up non-linear models of the change in soil C, N, pH and soil moisture that predict the impact of an intervention or land use transition over time. The predicted changes in soil conditions are then translated into mean Ellenberg[11] scores that are the inputs into MultiMOVE.

49. MultiMOVE only models changes at ERAMMP survey point locations that coincide with the DMUs modelled by SFARMOD and the LAM. This covers approximately 50% of the

[11] https://www.brc.ac.uk/biblio/plantatt-attributes-british-and-irish-plants-spreadsheet

point locations in ERAMMP that have soil and vegetation data drawn from the field survey data.

50. Summary metrics are output that convey potential species richness of subsets of plant species that support specific ecosystem functions or services:

   a. Nectar supply;
   b. Forage grass richness;
   c. Richness of plants that provide food for lowland farmland birds;
   d. Injurious weed richness;
   e. Indicators of Ancient Woodland in Wales;
   f. CSM positive indicator richness.

7.3 Air quality

51. The air quality outputs are based on a meta-model approach using relationships derived from the outputs of a detailed atmospheric chemistry transport model, EMEP4UK[12], and health data for 2015.

52. Removal rates of $PM_{2.5}$ vary with:

   a. Initial pollution concentrations;

   b. The spatial location of woodland in relation to pollution concentrations;

   c. Interactions among other pollutants;

   d. Meteorology in the original model runs which were run at approximately 4 x 6 km^2 resolution.

53. It is assumed that pollution removal due to the action of vegetation within a local authority is greater than the effects of vegetation outside of the local authority. Local authority level is used for aggregating calculations because:

   a. The health data underlying the calculations are provided at this scale;

   b. It is the most appropriate spatial scale to infer changes in pollution concentrations due to pollution removal by woodland. Benefits from a particular patch of woodland may be experienced some distance downwind (up to tens of kilometres).

54. Some spatial variation in pollution concentrations and benefitting population within a local authority is accounted for in this approach. This is achieved by calculating a population-weighted change in $PM_{2.5}$ concentration for each local authority (using population aggregated to EMEP4UK grid cells of approximately 4 x 6 km^2 resolution).

55. Proportion of woodland cover is aggregated to an approximate 40 x 40 km^2 grid cell resolution as input to the calculations.

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[12] Vieno, M. et al. (2009). Application of the EMEP Unified Model to the UK with a Horizontal Resolution of 5 × 5 km^2 . In: Sutton, M.A., Reis, S., Baker, S.M. (eds) Atmospheric Ammonia. Springer, Dordrecht. doi

56. The meta-modelling approach takes changes derived from the scenarios as inputs. Since the scenarios do not provide information on $PM_{2.5}$, the change in $PM_{2.5}$ concentrations are linked to changes in ammonia emissions (derived from SFARMOD outputs linked to Farmscoper coefficients), using statistical relationships derived from the original model runs of EMEP4UK.

57. Health impacts are derived from epidemiological studies:

    a. Dose response functions for the health impacts of each pollutant are derived from statistical studies, which extract a response relationship while controlling for variation in other socio-economic and environmental factors and other pollutants.

    b. The equations are calculated using existing morbidity and mortality data for each local authority.

7.4 Carbon storage

58. LULUCF calculate change in carbon storage at the devolved national level using a Monte Carlo approach based on: (a) estimated area of land use transitions (± 30% around mean); (b) equilibrium carbon database values for each transition (up to ± 11% of mean); and (c) rate of change (50-300 years; the maximum and minimum rate varies with type of transition). We have adapted the LULUCF method to map carbon storage spatially at the DMU level (see next assumption) for categories 4A,B,C,G. However, it is not possible to calculate exact transitions between land use types at the DMU level. This is because the DMUs contain rotational land use (e.g., 80% arable, 20% grassland), which may transition to multiple land uses or to a new rotation. We assume that our rotation proportions apply spatially. Land which is assigned to rotational grassland by SFARMOD is modelled using soil carbon coefficients for arable, because equilibrium values for grassland would not be expected, due to the rotation with arable and associated soil disturbance.

59. Our adapted LULUCF carbon stock method is applied as follows:

    a. Calculate change as: (((total baseline C - total scenario C)/rate of gain or loss) * proportion not woodland) + change in carbon under new woodland and/or hedges.

    b. For rate of gain or loss, we use the mean rate for the dominant direction of transition (gain or loss), accounting for the non-linear rate of change, but do not apply Monte Carlo for each DMU, since this would be too computationally expensive.

    c. To enable accurate economic valuation, the calculations are repeated for each year and multiplied by the carbon value for that year. The outputs are averages (or totals) of these data for the relevant time period (8, 28 and 101 years).

60. A separate approach is applied for peat DMUs in line with the LULUCF wetland carbon approach for category 4D:

    a. DMUs are assigned as peat/not peat based on dominant coverage.

    b. We calculate emissions for the baseline using LULUCF coefficients assigned based on land cover. This process is repeated for the scenario, and the difference between these values represents change in annual emissions.

Cumulative change for a given output year is the change in annual emissions multiplied by the number of years.

c. We assume that changes occur immediately in response to changes in land use and agricultural management, although in reality changes which reflect ecological recovery may be delayed.

8 VALUATION

61. There are multiple ways to value changes in ecosystem services, including:
    a. Use data that matches current economic data but does not capture the full value of the environment.
    b. Use data that captures full environmental value but is not strictly comparable to GDP. This is akin to the social welfare approach set out in HMT Green Book[14].
    c. IMP version 2 uses option (b) as this underpins the appraisal of policy options.
    d. A "valuation methodologies paper" (ERAMMP report 27) has been published to provide further details underlying this assumption[13].

62. Water quality valuation:
    a. Welfare values for achieving WFD status are used. ONS use a replacement cost approach (i.e., the costs of achieving the same water quality improvement through end of pipe treatment kit), which is theoretically closer to an exchange value, but methodologically problematic.
    b. Change in load of N, P and sediment is calculated from Farmscoper outputs aggregated to WFD catchments on an area basis. These are then accumulated to downstream waterbodies.
    c. The use of values for changes in WFD status means that following aspects are valued:
        (i) Change in P status modelled as in point 38 (above).
        (ii) Change in N drinking water status relative to UKTAG 2008[14] drinking water thresholds (95th percentile of 11.3mg/NO3-N). N concentration calculated as in points 34-36 above.
        (iii) Changes in sediment were not valued.

63. Carbon valuation: we use UK non-traded cost of carbon (similar to ONS):
    a. We follow HMT Green Book guidance on non-traded cost of carbon values (see DESNEZ supplementary guidance)[15].

64. Health impacts of air quality valuation: we use the avoided health costs approach, which is consistent with, but more disaggregated (and therefore more accurate) than, the modelling used by the ONS for their air pollutant removal national account:
    a. We are aware of, and consistent with, guidance on methods and valuation provided in the HMT Green Book (Annex 2) and Defra supplementary

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[13] ERAMMP report 27 / Adroddiad ERAMMP 27 | ERAMMP
[14] TAG, UK. "UK environmental standards and conditions (phase 1): Final report." UK Technical Advisory Group (2008). https://www.daera-ni.gov.uk/sites/default/files/publications/doe/UKTAG-environmental-standards-and-conditions-phase-1.PDF
[15] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

guidance[16]. Damage costs estimates are relevant under the referenced conditionshttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf.

b. Note there are different sets of damage costs. The UKCEH + eftec work for ONS followed COMEAP guidance[17], which Defra damage costs are based on. However, the method used for the IMP differs in that we calculate change in morbidity and mortality directly from change in pollution concentration, and use existing health data, which varies by local authority.

c. The Defra damage costs are only provided per tonne of emissions, not per unit of change in exposure (i.e., concentration). The Defra costs apply a simplified correction for urban to rural setting, and intermediate and low population density, whereas we apply a population-weighted change in concentration to calculate impacts/benefits.

d. Note that this valuation is dependent on outputs from the air pollution and health modelling, i.e., follows on from assumptions 51-57.

[16] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf

[17] Committee on the Medical Effects of Air Pollutants - GOV.UK

9 Appendix 1.1: Aggregation of SFARMOD DMU outputs to the farm

This section describes how SFARMOD outputs per DMU are aggregated to the farm level.

Reflecting the complexity of Welsh agricultural farming enterprises, SFARMOD simulates a broad range of farming systems across the agricultural DMUs, that range from livestock-free arable and general cropping systems to mixed forage systems (ley arable, maize and ley forage crops) supporting beef and dairy cattle to permanent grassland systems for beef, dairy or sheep to rough grazing with beef or sheep.

To aggregate appropriate DMU-level farming system solutions to each modelled full-time farm, a series of heuristics were developed that take account of a farm's EFT and the land cover, slope and altitude of its DMUs (Table A1.1). These heuristics reflect the changing shift in the balance between arable–forage grass–rough grazing systems and between dairy–beef–sheep livestock types across the lowland–upland–hill gradient and between EFTs. They were developed based on a combination of expert judgement and calibration against JAS data in order to get appropriate crop and grassland areas and stock numbers/type.

When simulating the effects of a scenario, SFARMOD uses these heuristics to provide the LAM with alternative EFT solutions for each farm, subject to some conditions:

- No baseline SDA-type EFTs occur where the majority of a farm's area is in a Disadvantaged Area or lowland area. Consequently, EFTs of "Specialist Sheep (SDA)", "Specialist Beef (SDA)" and "SDA Mixed grazing" are not provided as alternatives for farms within the currently designed Disadvantaged Area and lowland areas.

- Most EFTs occurred in baseline farms in which the majority of the farm area was in a Severely Disadvantaged Area. However, based on analysis of the average area-weighted altitude and slope index of baseline EFTs:
    - Arable and General cropping EFTs as alternative options were constrained to farms with an average area-weighted altitude <=300m and slope index of <=1.
    - Dairy, Lowland cattle and sheep, and Mixed EFTs were constrained as alternative options to farms with average area-weighted altitude <=400m and slope index of <=1.5.
    - The "Other" EFT was constrained as alternative options to farms with average area-weighted altitude <=400m and slope index of <=2.
    - The remaining EFTs were unconstrained.

In addition, some DMU alternatives are infeasible:

- The general cropping (i.e., with potatoes in rotation) and cereal cropping systems are not allowed in DMUs with a slope index above 0 and 1, respectively. In these cases, they default to a sheep forage ley system.

- If an expected livestock type is infeasible on rough grazing, rough grazing is not allowed to change but its stocking can change to an alternative (i.e., beef or sheep).

In this way, all agricultural DMUs have a solution for a given EFT when aggregated to the farm.

Table 9-1 Aggregation of SFARMOD DMU outputs to the farm

EFT	LCM2021 Land Type	Over 400m altitude?[1]	SFARMOD DMU Cropping										
					SFARMOD DMU Stocking								
			Cereals	General Cropping	Grazing Livestock Ley Arable + Maize if suitable	Grazing Livestock Ley Arable + Maize if suitable	Grazing Livestock Ley Forage Crops + Maize if suitable	Grazing Livestock Ley Forage Crops +Maize if suitable	Grazing Livestock Permanent Grass	Grazing Livestock Permanent Grass	Grazing Livestock Permanent Grass	Grazing Livestock Rough Grass	Grazing Livestock Rough Grass
			None	None	Beef	Dairy	Beef	Dairy	Beef	Dairy	Sheep	Beef	Sheep
Cereals	A	No	X										
Cereals	IG	Yes									X		
Cereals	IG	No							X				
Cereals	RG	Yes									X (PG)[18]		X
Cereals	RG	No							X (PG)				X
General cropping	A	No		X									
General cropping	IG	Yes									X		
General cropping	IG	No							X				
General cropping	RG	Yes									X (PG)		X
General cropping	RG	No							X (PG)				X
Dairy	A	No				X							
Dairy	IG	Yes								X			

[18] The Land Cover Map rough grass area has been further subdivided into low yielding permanent grass and 'truer' rough grass. The permanent grass is shown in the table as X (PG) to differentiate it from the remaining rough grass shown as X.

Dairy	IG	No						X					
Dairy	RG	Yes								X (PG)			X
Dairy	RG	No						X (PG)					X
Lowland cattle / sheep	A	No			X								
Lowland cattle / sheep	IG	Yes									X		
Lowland cattle / sheep	IG	No									X		
Lowland cattle / sheep	RG	Yes									X (PG)		X
Lowland cattle / sheep	RG	No									X (PG)		X
Mixed	A	No		X									
Mixed	IG	Yes									X		
Mixed	IG	No							X				
Mixed	RG	Yes									X (PG)		X
Mixed	RG	No							X (PG)				X
Other	A	No		X									
Other	IG	Yes									X		
Other	IG	No							X				
Other	RG	Yes							X (PG)				X

Other	RG	No							X (PG)				X
DA various grazing	A	No		X									
DA various grazing	IG	Yes							X				
DA various grazing	IG	No							X				
DA various grazing	RG	Yes							X (PG)				X
DA various grazing	RG	No							X (PG)				X
SDA mixed grazing	A	No	X										
SDA mixed grazing	IG	Yes									X		
SDA mixed grazing	IG	No							X				
SDA mixed grazing	RG	Yes									X (PG)		X
SDA mixed grazing	RG	No							X (PG)				X
Specialist Beef (SDA)	A	No					X						
Specialist Beef (SDA)	IG	Yes							X				
Specialist Beef (SDA)	IG	No							X				
Specialist Beef (SDA)	RG	Yes							X (PG)			X	
Specialist Beef (SDA)	RG	No							X (PG)			X	

Specialist Sheep (SDA)	A	No	X										
Specialist Sheep (SDA)	IG	Yes									X		
Specialist Sheep (SDA)	IG	No									X		
Specialist Sheep (SDA)	RG	Yes									X (PG)		X
Specialist Sheep (SDA)	RG	No									X (PG)		X

[1] 400m was used an altitude demarcation of moorland and to prevent simulated conversion of high-altitude improved grassland to arable.

10 Appendix 1.2: Assumptions related to IMP Additional Capability

This section lists IMP assumptions for parts of the model that were not used when modelling the PWF scenario.

10.1 Forestry

1. Five UKFS compliant forestry scenarios were co-developed by the IMP team and the Welsh Government. Species were selected for each forest scenario:
    a. Enhanced mixed woodland: Sitka spruce (*Picea sitchensis*), Douglas fir (*Pseudotsuga menziesii*), Scots pine (*Pinus sylvestris*), Corsican pine (*Pinus nigra*), Western hemlock (*Tsuga heterophylla*), Western red cedar (*Thuja plicata*), European silver fir (*Abies alba*), Grand fir (*Abies grandis*), Noble fir (*Abies procera*).
    b. Near-native broadleaves: Silver birch (*Betula pendula*), Downy birch (*Betula pubescens*), Common oak (*Quercus robur*), Sessile oak (*Quercus petraea*), Small leaved lime (*Tilia cordata*), Rowan (*Sorbus aucuparia*), Aspen (*Populus tremula*), Common alder (*Alnus glutinosa*), Wild cherry (*Prunus avium*), White willow (*Salix alba*), Beech (*Fagus sylvatica*), Hornbeam (*Carpinus betulus*), Sycamore (*Acer pseudoplatanus*).
    c. Mixed food forest: Wild cherry (*Prunus avium*), Common walnut (*Juglans regia*), Black walnut (*Juglans nigra*), Silver birch (*Betula pendula*).
    d. Lowland agroforestry: Selected from near-native broadleaf category.
    e. Upland agroforestry: Selected from near-native broadleaf category.
2. Planting year: the models assume all new forest would be planted in year 1 (2023). This could be reviewed for later versions if needed.
3. An estimated net present value (NPV) for an area of new woodland is calculated, using the ESC-CARBINE outputs:
    a. The use of NPV allows the time-dependent costs and revenues associated with woodland creation, expressed in units of £/year, to be compared with the annual revenues from agricultural land use options.
    b. The NPV calculations first involve calculating the annual net sum of all costs and revenues incurred for each year of one rotation of the new woodland, from the time it is created. Hence, if the rotation applied to the new woodland is 75 years, all costs and revenues are calculated over this period. For stands managed without harvesting, NPV is calculated over 100 years. The annual values are multiplied by a discount factor (see below), before being summed over the rotation to give NPV. The NPV value is then divided by the sum of the annual discount factors to derive annualised NPV.
4. Discounting: Before the costs and revenues are added together, they are multiplied by a discount factor that applies for the year in which the cost or revenue occurs. The discount factor is calculated by assuming a discount rate:

a. CARBINE results are calculated for six possible discount rates of 0%, 3%, 3.5%, 5%, 6% and 10%.

b. An additional seventh result is calculated based on the HMT Green Book methodology, in which a discount rate of 3.5% is assumed for the first 29 years, then a discount rate of 3% is assumed from 30 to 74 years, with a discount rate of 2.5% applying thereafter.

c. The discount rate from the Treasury Green Book is used in the IMP modelling.

d. The results obtained for a specific discount factor, for use in the IMP, are selected for compatibility with IMP calculations for other land uses.

e. A discounting period equal to one rotation of the woodland type, or 100 years for non-rotational woodland systems, is assumed. The rotation period (where relevant) depends on woodland type and varies from 50 to 100 years.

5. Costs and revenues included in the forestry NPV calculations are: (a) initial woodland establishment costs; (b) net costs or revenues from thinnings; (c) net revenues from harvesting at the end of the rotation. Further information on each of these is given below:

   a. Establishment costs consider full costs of materials, planting, site preparation and post-planting maintenance based on costings in the Nix Pocket Book[19]

   b. The annual volume of timber removed during thinning and harvesting is calculated using the CARBINE model. Prices for standing sales were applied, for softwoods[20] at £30.33/m^3 and for hardwoods[21] £17/m^3 (firewood value, less harvesting costs).

   c. Incentive grant payments are discounted and combined with the forestry NPV to derive in-year net profits or losses.

[19] Redman, G. (2024). The John Nix Pocketbook for Farm Management 54th Edition. The Andersons Centre.
[20] Forest Research (2025). Timber Price Indices, Timber Price Indices - Forest Research.
[21] Forest Research and Grown in Britain (2023). Hardwood Price-size Curves for 2022 Calendar Year, Hardwood Price-size Curves.

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