Forest Research

OpTS Model: Optimal Thickness of Soil Model Guidance

A decision support tool for woodland creation in sustainable brownfield regeneration

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Forestry Commission

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Table of Contents

1 General Information

Trees rely heavily on soil moisture during their growth period, and insufficient soil volume can lead to water stress. This may also be exacerbated under the warmer and drier summer conditions projected as a result of climate change. For sites that are undergoing reclamation and regeneration to woodland, such as brownfield sites, former mineral extraction sites, or any other site types requiring work prior to sustainable planting, ensuring sufficient soil thickness is crucial to successful tree establishment and long-term growth.

The OpTS Model takes into account current and projected future rainfall, woodland crop type, soil texture, stoniness, and site preparation methods to estimate the minimum thickness of soil required to provide sufficient water for mature trees. The OpTS Model is an updated version of the soil thickness model developed and published by Moffat (1995), and provides guidance on necessary soil thicknesses across the UK, offering recommendations tailored to local climate variations and soil properties to support optimal conditions for woodland development and long-term woodland health.

2 When to Use the OpTS Model

The OpTS Model is designed for two specific scenarios – firstly, if you have access to topsoil of a known quantity that will be laid on site post-reclamation and want to know how much soil-forming material (SFM) is needed below this topsoil layer to achieve water balance. Secondly, if you do not and will not have topsoil on site post-regeneration and want to know how much SFM is required for water balance. This tool is specifically designed for tree planting on regenerated land, and therefore assumes SFM as the main soil component. If you have subsoil on site instead of SFM, insert 'subsoil' in place of 'SFM' where it appears in this document and in the web-app.

See 'Model Variables and Contextualisation' below for definitions and further information.

3 Model Structure

3.1.1 Water balance equation:

The model structure for the updated soil thickness decision support tool was based on the water balance equation from the original Moffat (1995) model, with added variables introduced to account for more accurate soil characterisation as well as future climate projections. The conceptual equation for the OpTS Model is therefore:

Transpiration from stand = Topsoil available water + Soil-forming materials available water + Effective summer rainfall – Run-off

Where:

- *Transpiration from stand*: a set value dependent on the type of woodland selected for the site.
- *Topsoil available water*: this estimates available water in topsoil, if topsoil is present (details below). If topsoil isn't present on site, topsoil available water = 0.
- *Soil-forming materials available water*: this estimates available water in SFM (details below).

- *Effective summer rainfall*: a site dependent value cross-referenced with climate projection data, where growing period rainfall (Apr – Sept) is calculated for three time periods (2010-2029, 2030-2049, 2050-2069) and adjusted by a canopy interception value depending on woodland type.
- *Run-off*: this is assumed to be zero for this model.

Functionally, the model splits this equation into two separate calculation steps, calculating the water provided by rainfall and topsoil (if present) first, and secondly, if required, calculating the thickness of SFM required to make up any deficit between transpiration from stand and available water from rainfall and topsoil.

3.1.2 Calculation Step 1:

Water from rainfall and topsoil = Topsoil available water + Effective summer rainfall

Where:

- ***Topsoil available water = (Topsoil Available Water Capacity derived from soil texture) * (Percentage stoniness adjustment factor) * (Thickness of topsoil)***

- ***Effective summer rainfall = (Site-specific rainfall value for growing period) * (Interception adjustment factor)***

If *Effective summer rainfall* is equal to or greater than *transpiration from stand*, the model ends and returns an output to the user. Similarly, if *Effective summer rainfall* is less than *Transpiration from stand*, but *Water from rainfall and topsoil* is equal to or greater than *Transpiration from stand*, the model ends and returns an output to the user. However, if *Water from rainfall and topsoil* is insufficient to meet water balance, the model progresses to Step 2 to calculate the required SFM thickness to address the deficit between *Transpiration from stand* and *Water from rainfall and topsoil*.

3.1.3 Calculation Step 2:

Required SFM = (Water deficit) / (Potential SFM available water)

Where:

- ***Water deficit = (Transpiration from stand) – (Water from rainfall and topsoil)***

- ***Potential SFM available water = (SFM Available Water Capacity derived from soil texture AND site preparation) * (Percentage stoniness adjustment factor)***

The model will run Step 1 and Step 2 (if required) three times, using the *Effective summer rainfall* for the three different time periods included in the model, and will output a final required soil thickness value (Topsoil + SFM) to achieve water balance on site. Soil thickness results are rounded to the nearest 10 mm value.

4 Model Variables and Contextualisation

4.1.1 Site location (Ordnance Survey six-figure grid reference)

An Ordnance Survey six-figure grid reference consists of two letters followed by six numbers (e.g. NT249639) which corresponds to a 100 m x 100 m square in the UK. The OpTS Model requires this information to identify the location of your land regeneration site, which is then cross-referenced with the climate projection data to calculate the projected growing period rainfall values.

For smaller sites, we recommend using the centre of the site as the focal point for the six-figure grid reference. However, due to the 100 m x 100 m resolution of the OS six-figure grid, larger sites may fall across multiple grid cells, in which case we recommend conducting multiple runs of the OpTS Model, using appropriate grid references to ensure the site is fully represented. Third-party tools, such as the British National Grid, can be used to find your grid reference.

There is more detailed information on OS grid references available on the Ordnance Survey website (Beginner's guide to using grid references | OS GetOutside).

4.1.2 Soil definitions: topsoil and soil-forming material

The OpTS Model refers to topsoil and soil-forming materials, either already present on site, or to be added to the site.

In this context, we define topsoil as per the Defra Construction Code of Practice for the Sustainable Use of Soils on Construction Sites (2009), as follows:

Topsoil (natural): *Upper layer of a soil profile, usually darker in colour and more fertile than the layer below (subsoil), and which is a product of natural biological and environmental processes. The thickness of natural topsoil will vary* *from only a few centimetres in some sites to more than 350 mm in deeply cultivated agricultural sites.*

We define soil-forming materials as per Soil-forming Materials: Their use in Land Reclamation, by Bending, McRae, and Moffat (1999), as follows:

Soil-forming materials: *Parent material for a new soil used as a substrate for, or as supplement to, natural soils in the course of land reclamation. The material should, with appropriate surface treatment and the use of amendments as necessary during the period of aftercare, be capable of sustaining the required vegetation beyond this term by the implementation of normal management practices.*

This tool is specifically designed for tree planting on regenerated land, and therefore assumes SFM as the main soil component. If you have subsoil on site instead of SFM, select "SFM" as your soil type.

4.1.3 Measuring soil thickness

If your site has variable topsoil thickness, we recommend selecting the shallowest thickness in the OpTS Model web-app. This is to account for worst-case scenarios on site (i.e. shallowest topsoil thickness) to avoid underestimating overall soil thickness requirements.

Thickness of soil (topsoil and/or soil-forming material) in situ can be measured by digging a soil profile pit, or by using an augur or probe. Further advice on soil pits can be found in The Identification of Soils for Forest Management Field Guide by Kennedy (2023).

For the calculations involved in this model, we require a single value to represent the soil thickness range categories, and therefore selected the midpoint value in the thickness range. Therefore, for the model calculations:

- No soil = 0 mm

- 0 – 100 mm soil = 50 mm
- 101 – 200 mm soil = 150 mm
- 201 – 300 mm soil = 250 mm
- 301 – 400 mm soil = 350 mm
- 401 – 500 mm soil = 450 mm

4.1.4 Identifying soil texture

Soil texture can be identified by hand or through laboratory analysis. For the purpose of the OpTS Model, we use 11 different soil texture classifications, namely: clay, silty clay, sandy clay, sandy clay loam, clay loam, silty clay loam, silt loam, sandy silt loam, sandy loam, loamy sand, and sand. These classifications do not include peaty soils or marine light silts, as they are not relevant in this context.

Information on soil texture classification can be found via a number of sources, including:

- Natural England Technical Information Note TIN037: Soil Texture (2008)
- The Identification of Soils for Forest Management Field Guide by Kennedy (2023) (see pages 53 and 54)
- Agricultural and Horticultural Development Board website: How to determine soil texture
- Hodgson, J. M. (Ed.). (1997) Soil Survey Field Handbook—Describing and Sampling Soil Profiles. Soil Survey and Land Research Centre.

4.1.5 Identifying soil stoniness

Soil stoniness in the OpTS Model uses the stoniness classifications from Hodgson's Soil Survey Field Handbook (1997), and the categories are as follows:

- Screened to < 6 mm (no stones)
- Very slightly stony (1 – 5%)
- Slightly stony (6 – 15%)
- Moderately stony (16 – 35%)
- Very stony (36 – 70%)
- Extremely stony (> 70%)

For the calculations involved in this model, we require a single value to represent the stoniness range categories, and therefore selected the maximum value in the stoniness range, to account for the worst-case scenario on site. Therefore, for the model calculations:

- Screened to < 6 mm = 0% stones
- Very slightly stony = 5% stones
- Slightly stony = 15% stones
- Moderately stony = 35% stones
- Very stony = 70% stones
- Extremely stony = 90% stones

Information on identifying soil stoniness can be found in the Soil Survey Field Handbook (1997).

4.1.6 Soil-forming material preparation and soil packing density

The OpTS Model has two options for the preparation of soil-forming materials – deep ripping or loose tipping. These preparation methods influence the soil packing density values used in model calculations. Soil packing density values used in the OpTS Model are derived from Hodgson’s Soil Survey Field Handbook (1997).

Deep ripping is a process of intensive soil tillage that involves mechanically breaking up compacted soil layers to improve soil structure and aeration.

Loose tipping is a technique where soils are deposited on site without the use of heavy machinery driving over them, which helps to minimise soil compaction during placement.

Loose tipping should be treated as standard practice for soil preparation, as deep ripping is severely limited by tine depth, often to depths of less than 1m. We have included it as an option in this tool as it is a technique still used in soil preparation, but would strongly advise practitioners to phase out deep ripping as a soil preparation technique for tree planting.

Further information on methods to address soil compaction can be found here: [Soil compaction - practical considerations - Forest Research]

4.1.7 Tree (crop) type: transpiration rate and canopy interception factor

The OpTS Model uses different transpiration values depending on crop type. For conifer crops, we use a transpiration value of 340 mm per year, for broadleaved crops we use 375 mm per year, and for mixed crops we use 360 mm per year.

The OpTS Model also uses a canopy interception value for different crop types, which estimates the percentage of rainfall which is intercepted by the canopy, branches and leaves, and then evaporates without reaching the soil. For conifer crops, we estimate that 35% of rainfall is lost to interception, for broadleaved crops we estimate 17.5% is lost, and for mixed crops we estimate that 25% of rainfall is lost.

These values have been derived from Nisbet's Information Note on Water Use by Trees (2005).

4.1.8 Growing period rainfall data

The OpTS Model uses rainfall projection data across the growing period, which here means April to September inclusive. For present and future rainfall values, projected climate data were obtained from the Met Office Hadley Centre, with UKCP18 local projections for 1980 – 2080, over a 5 km grid, selected for this project. An RCP (Representative Concentration Pathway) of 8.5 (Ensemble member 01, v20230125) was selected to incorporate projections under high-emissions scenarios.

As with the 1995 Moffat model, summer rainfall covered the growing period of April to September. The 20-year monthly average daily precipitation rate was used, averaged over April to September inclusive, and then multiplied by 182 to estimate the annual growing period rainfall. This was calculated for three different 20-year time periods: 2010–2029, to represent current rainfall conditions, and two future projection periods of 2030–2049 and 2050–2069. This allowed the model to estimate growing period rainfall, and therefore required soil thickness, across a range of time periods, allowing users to identify the minimum soil thickness required for sufficient available water for the lowest projected rainfall values in the future.

5 Model Limitations and Assumptions

The OpTS Model structure is simple, and relies on a number of assumptions about the site, soil conditions, and rainfall, as follows.

- Run-off and drainage are assumed to be zero for this model, this is not wholly realistic in real environments. Modelling run-off and drainage was determined to require substantial additional data and was not included here.

- The model also assumes that rainfall interception by the canopy is constant, regardless of rainfall intensity. This may be a consideration that is needed in future iterations of this model, as extreme rainfall events increase under climate change. Further, the model also assumes that water requirements and rainfall interception is constant regardless of tree age or size. This was selected to maintain model simplicity.

- The model assumes that soils under mature tree canopies return to field capacity during winter. This may not be accurate for all scenarios across all years, but is generalised here for simplicity and no safety or contingency values are built in to the model to address this.

- The model does not differentiate between different tree species within the two categories: conifer and broadleaf. There will be measurable differences in transpiration rate and rainfall interception between different species, but here we have used average values. Future iterations of the model may be able to offer a more species-specific option.

- If the total soil thickness recommended by the model output exceeds 3 m, the output text highlights that the site is unlikely to be suitable for tree planting. This 3m depth is at the extreme of realistic tree planting, given that loose tipping will not be realistic at this depth, and deep ripping to 3 m is not possible.

We acknowledge that the model is simple in its structure and inputs, and contains numerous assumptions. However, given the aim of providing a tool that is accessible and useful across the UK, without being overly complex or data-hungry, we feel these assumptions are acceptable, especially given the inherent uncertainty in the projected climate data necessary for this model to run.

If you have further questions, please contact Kieron Doick (kieron.doick@forestresearch.gov.uk) or Anthony Schultz (anthony.schultz@forestresearch.gov.uk).

6 References

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