# Direct structure tests

Dimensional consistency

The variables within the model maintain dimensional consistency, and the dimensions of the variables correspond to their real world representations:

Forest area	Hectares
Volume of wood	Cubic meters
Changes in forest area	Hectares/Year
Changes in volume of wood	Cubic meters/Year
Forest density	Cubic meters/Hectare
Forest growth	Cubic meters/Hectare/Year

The only 'fudge' variable used is 'Unit of measure of transit time' (1 Year), which was used for the 'leakage outflows' of conveyors that had to be expressed as a dimensionless fraction. This variable was also used to express the growth potential of the last stock in the aging chain of forests.

The software indicates unit warnings for each 'Growth within stock' variable. These warnings are a bug in the software, and it is demonstrated within the model supplied.
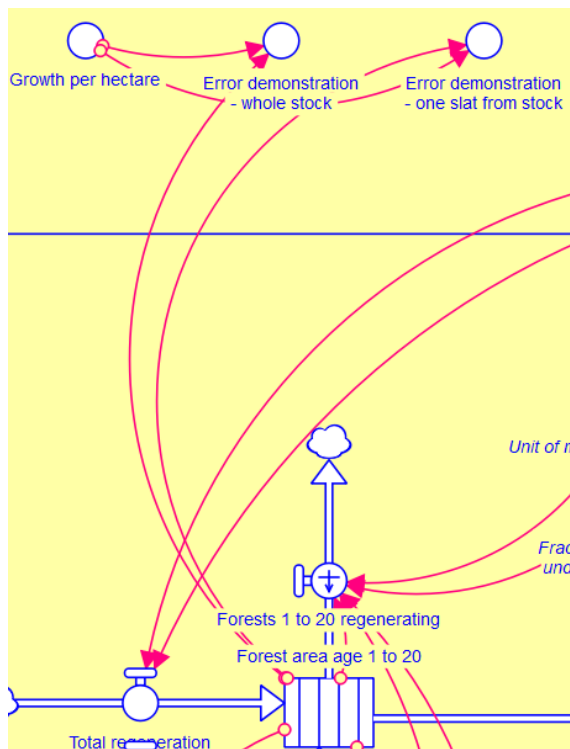
Each 'Growth within stock' variable expresses a non-linear function by directly referencing each separate slat from the conveyor. The unit warning bug is cause by referencing the slat instead of the entire stock. This is demonstrated through the two variables from the model shown in the image to the left.

'Error demonstration – whole stock' = 'Growth per hectare' * 'Forest area age 1 to 20'

'Error demonstration – one slat from stock' = 'Growth per hectare' * 'Forest area age 1 to 20'[160]

Where [160] indicates the number of the slat. Even though 'Forest area age 1 to 20' and 'Forest area age 1 to 20'[160] are both expressed in hectares, the software indicates that 'Error demonstration – whole stock' is has dimensional consistency', while signaling a unit warning for 'Error demonstration – one slat from stock'.

Extreme condition test

If the model fails under extreme conditions, it is an indication that the equations are not robust, meaning that they are not applicable under every condition. There are a limited number of variables that can be tested for extreme conditions. The extreme condition tests have been saved as separate runs.

1. 0 logging, 0 forest area growth

Under these conditions, the expected result is that over the course of 200 years, all forested areas will reach old age and will have a stable volume. As can be seen below, this is the result, so the model passes this extreme condition test.
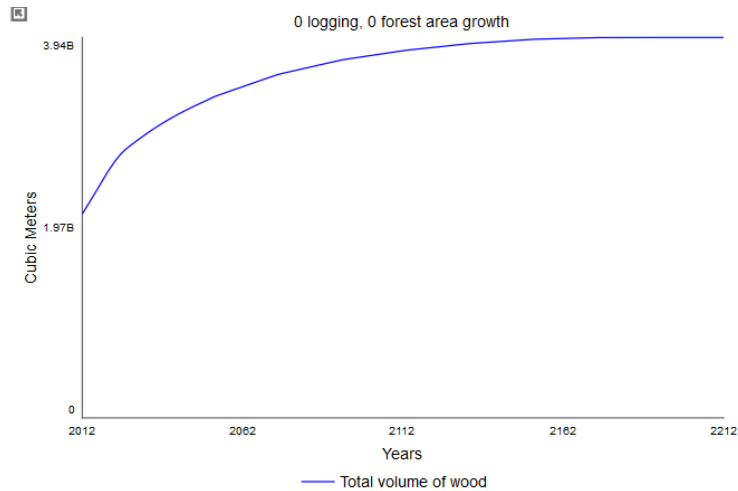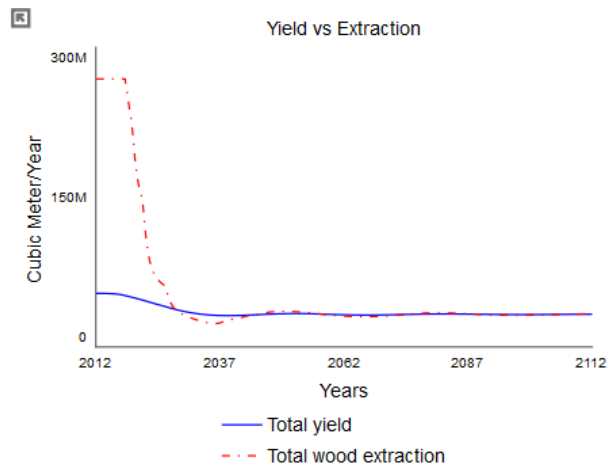

Graph 1

2. Ten times higher logging level

With extremely high logging levels, the expectation is that the forests will completely disappear. This test, however, reveals two interesting limitations in the model.
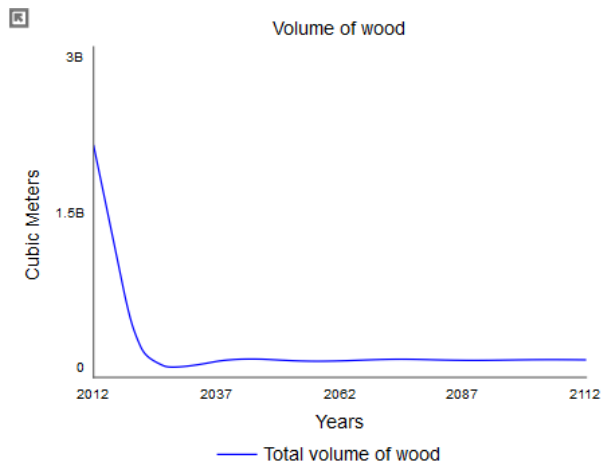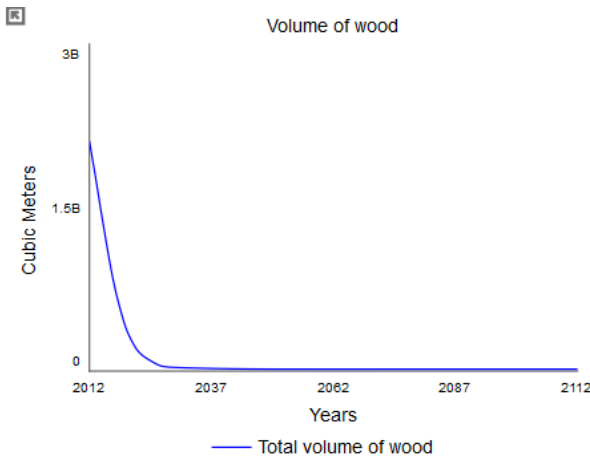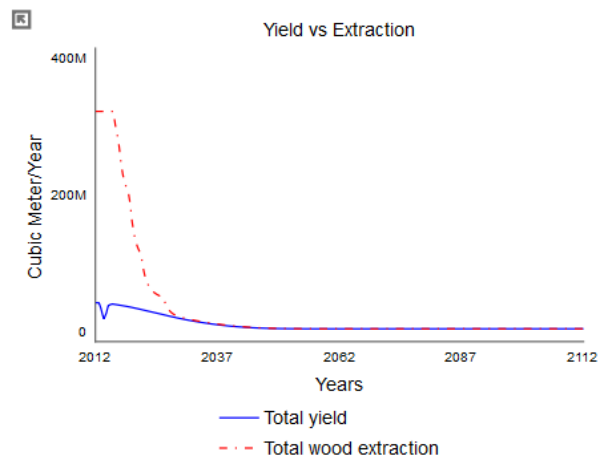

Graph 2

Graph 3

As it can be seen, the volume of wood does drop significantly, but not to 0, while yield and wood extraction converge at a fairly high level: almost 33 million cubic meters/year. This is due to two structural elements:

a. All wood extraction is assumed to either lead to forest regeneration, or not decrease the specific stock of forest area. There is no possibility of wood extraction leading to 'deforestation' or 'land use change'. This does, in some regards, reflect reality, since by law, any decrease in forested area through land use change must be compensated for by an increase in afforested area elsewhere (the compensation area is usually larger than the original area).

b. The base logging level for forests aged 1-20 is 0. Therefore all of the forests are perpetually cut at the ages 21-40 and 41-60 in this scenario, leading to a sustained yield and extraction level. Once logging is also introduced to forests aged 1-20, it leads to significantly lower volume of wood and lower yield and extraction levels.
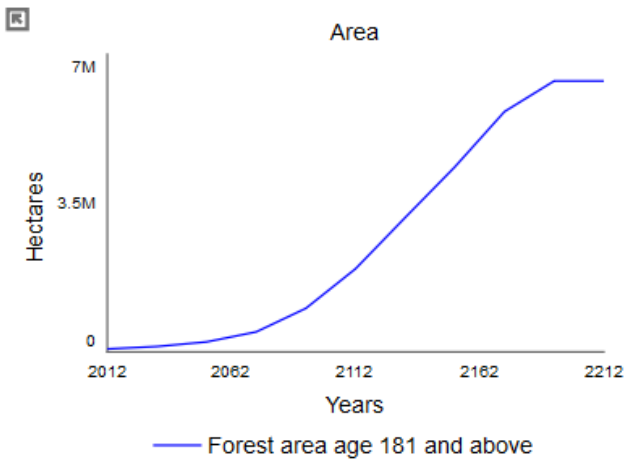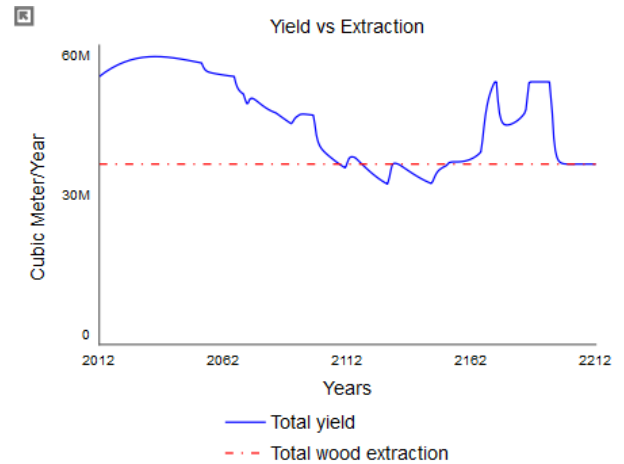

Graph 4

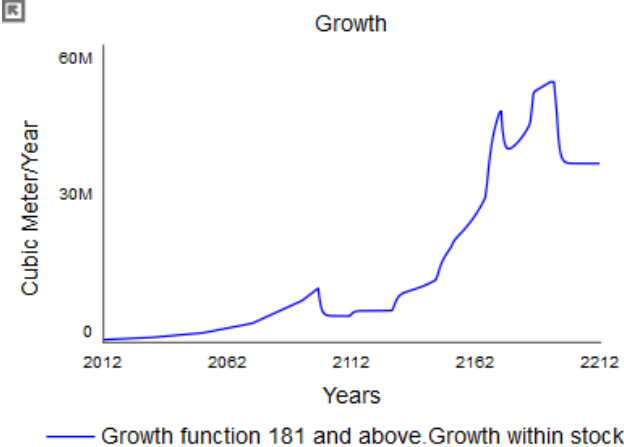*Graph 5*

3. Zero forest regeneration

If forest regeneration is set to 0, the expectation is that all forest areas will eventually grow to become over 180 years old, and all logging will take place at that level of the aging chain. This expectation is met by the model, as can be seen below in the graph showing the area of forests age 181 and above. The overall yield of the forests displays a peculiar pattern. This is due to the maximum density of the forests. Once this is reached, growth either halts completely, or decreases to the level of extraction. The abruptness of the shape is due to a limitation in the formulation of the growth function, as density only affects growth once maximum density is reached, and not before.
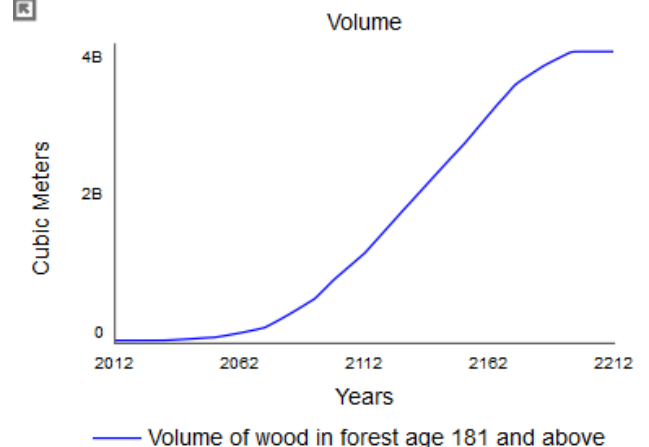

Graph 6

Graph 7

Graph 8

Graph 9

Parameter confirmation

The values for the initial age distribution, as well as the initial densities of the different forest stocks has been extensively documented as part of the research. All wood extraction values have been determined so as to reproduce the respective forest densities of each stock. The parameter for 'Fraction of forest area undergoing complete regeneration' is based on silvicultural system implementation data from government reports, and is documented as part of the research. The only parameter that is not confirmed is the 'Maximum forest density control', which determines the maximum density of the forest along each stock in the aging chain.

Structure confirmation

Interview for the confirmation of the structure is pending.
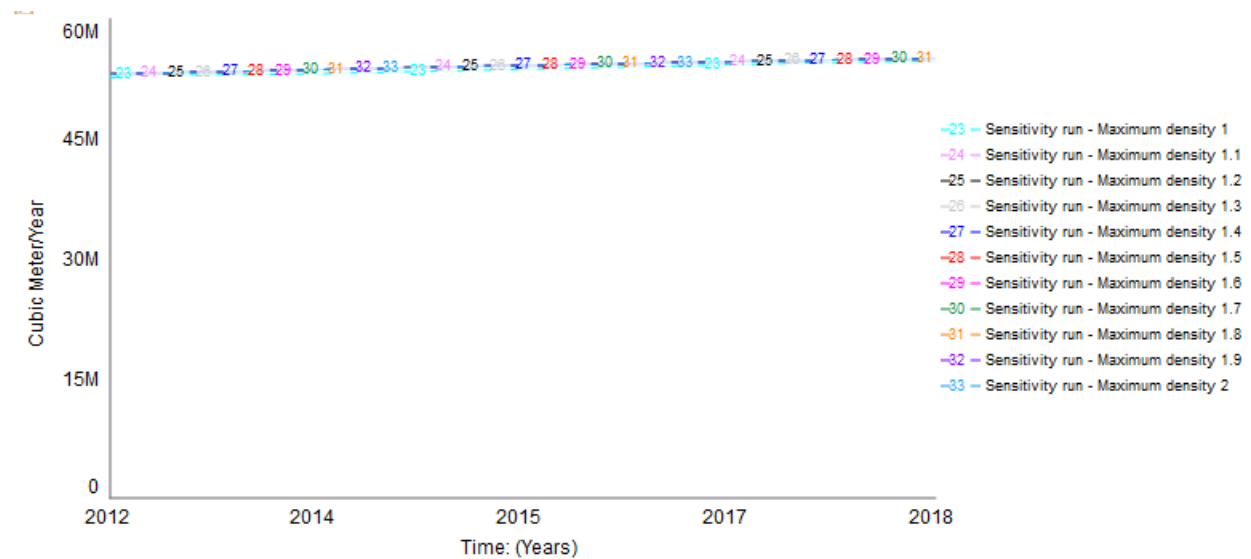
Behaviour tests

Timestep adequacy

If the timestep is too small, it can lead to numerical instability: oscillations in the model that are an artifact of the timestep, and not representative of the actual system behaviour. Furthermore, even if numerical instability does not occur, the model results may be skewed due to compounding inaccuracies in the calculations. I have chosen a base timestep of 1/8, and have tested the adequacy of this timestep by running the model with a timestep of 1/16 as well. A separate model has been supplied: 'Romanian forestry sustainability DT 0.0626.stmx' contains the model run with the timestep of 1/16[1]. Appendix C, sheet 'DT comparison' contains a comparison of the two base runs. The average difference between the two simulation runs over a period of 100 years is 0.02396%. This difference is negligible, and so a timestep of 1/8 is used for all simulation runs. There are some instances of numerical instability, but these last for only 1 DT, and do not lead to oscillations, or affect the shape of the behaviour.

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[1] A separate model had to be created due to technical issue of having to adjust the nonlinear growth function of forests. The slats of the conveyors serve as separate inputs for these functions. When the timestep is changed, the number of slats contained by the conveyors is also changed. The equations for the growth functions therefore had to be updated to match the change in the number of slats.

Sensitivity analysis

Ample sensitivity analysis has been conducted as part of the research, and is therefore not documented separately. The only exception is the unconfirmed 'Maximum forest density control', for which the base value is 1.1. A sensitivity analysis has been saved separately in the model file, testing for values between 1 and 2. While the result of the simulation run is unaffected over the reference mode reproduction time (Graph 10), it is greatly affected over a longer time horizon (Graphs 11 and 12). Though this parameter does require a more serious research effort, the situation is not as dire as it would first appear. The overall behaviour remains the same up to value of 1.5 – decrease of yield. Furthermore, the silvicultural systems in place are meant to increase the density of the forests as much as possible. It is therefore reasonable to assume that the maximum density to which forests can grow along the aging chain is not significantly higher than the actual density, meaning that it would be closer to the base value of 1.1 than to 2.
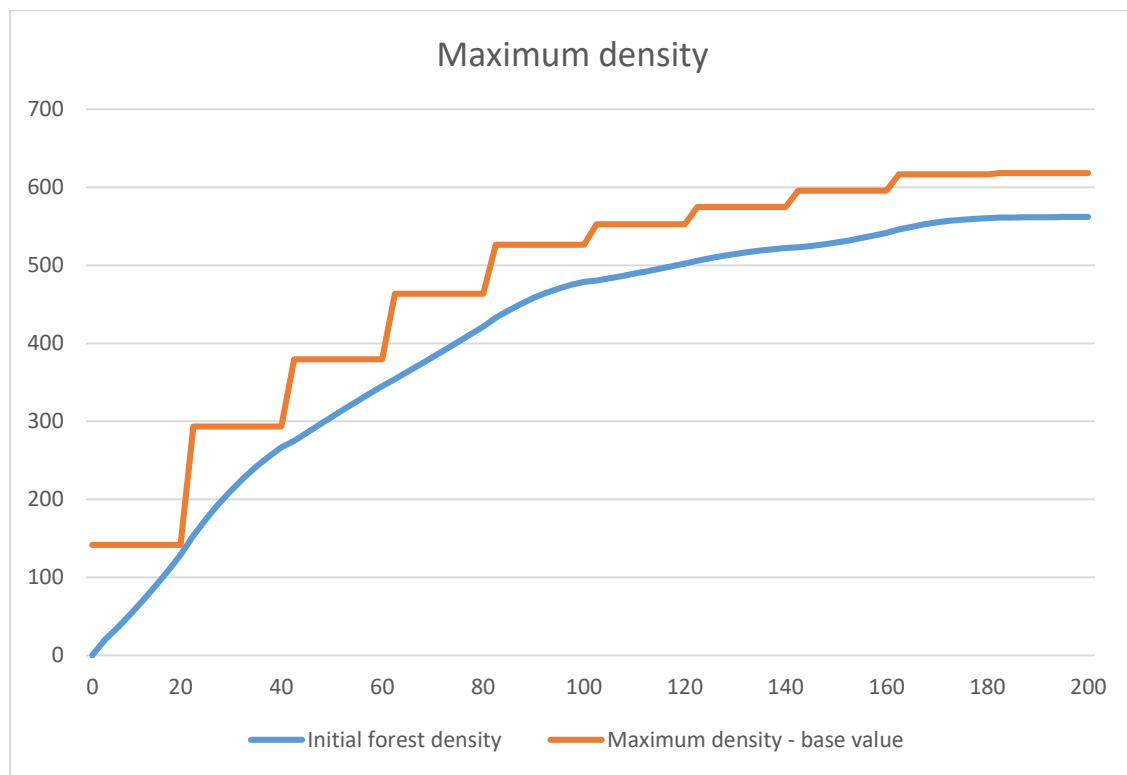

Graph 10
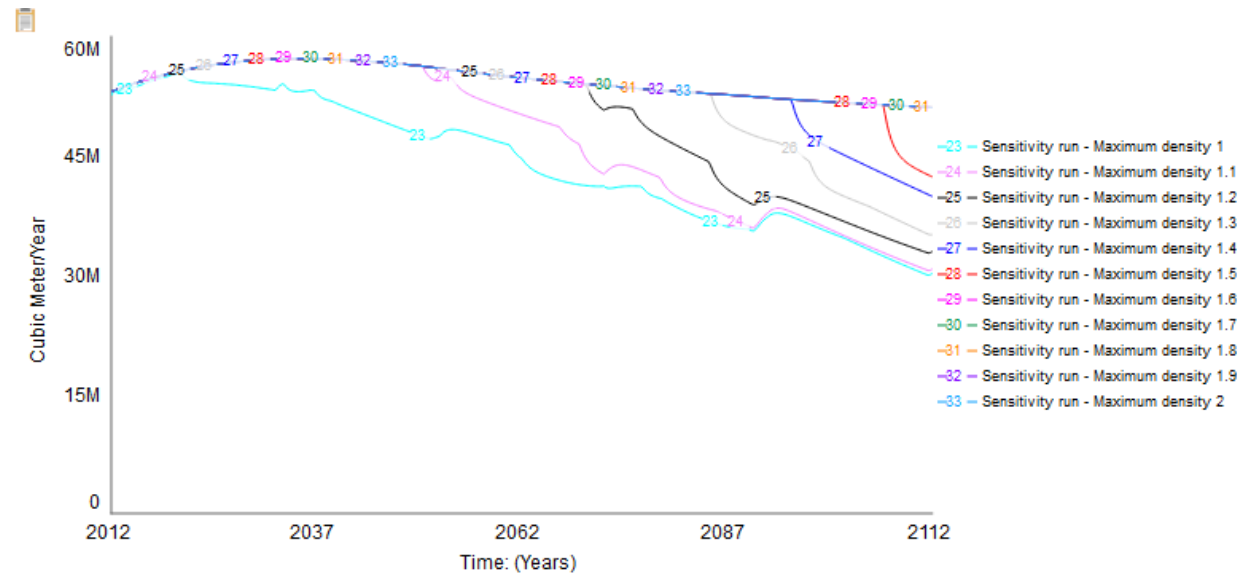
Graph 11
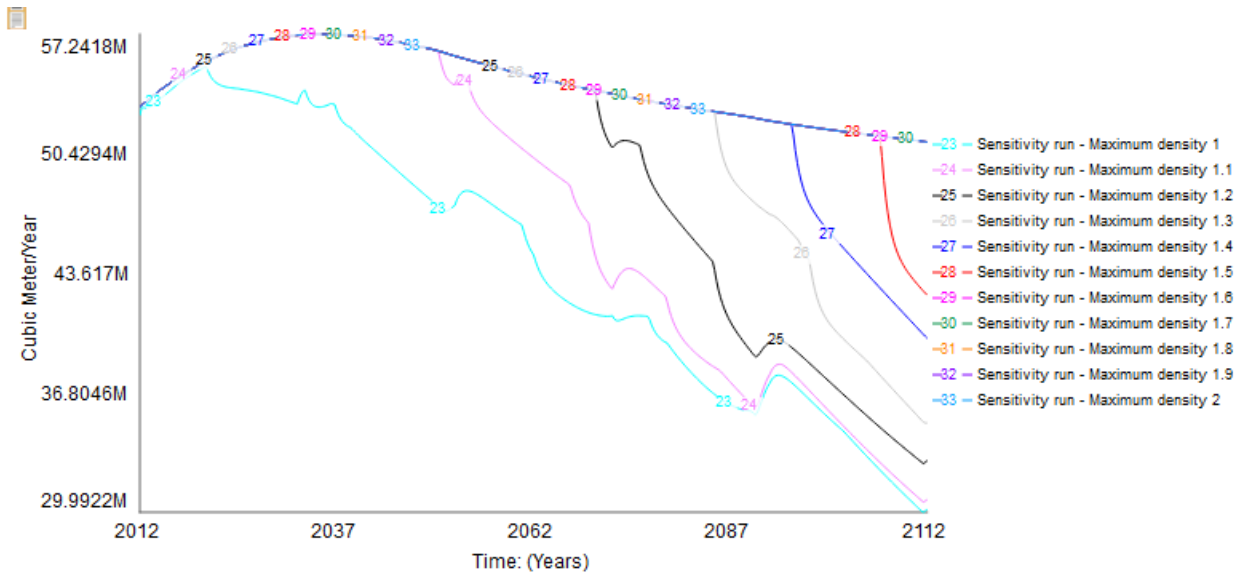
Graph 12

Graph 13

Reproduction of the reference mode of behaviour

There is not one single reference mode of behaviour, but 20. Furthermore, there are only 2 points in time when there is data for all of the reference modes: 2012 and 2018. The reproduction of the reference mode across two different datasets is documented as part of the research and not illustrated here separately. The reproduction of the reference mode is also indicative of the boundary adequacy of the model.