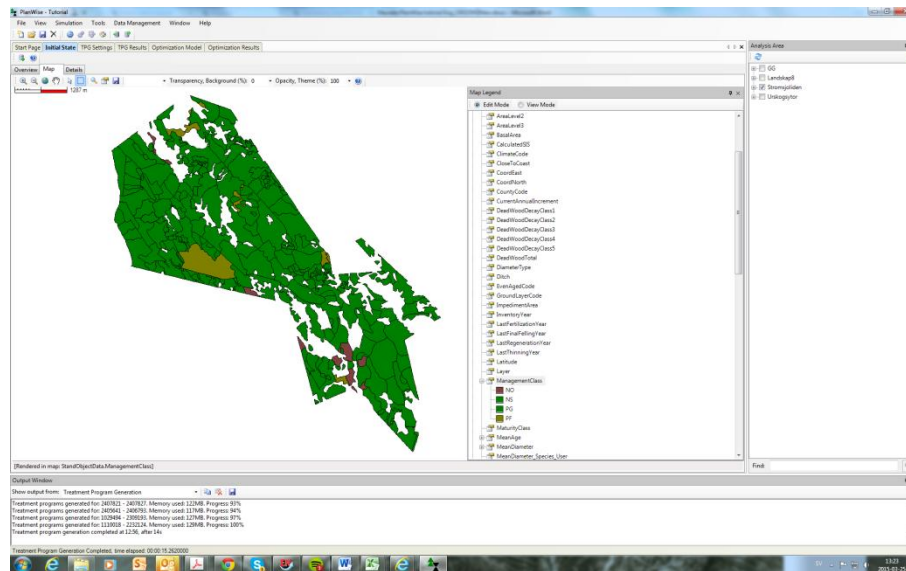


# Tutorial – Heureka PlanWise



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# Preface

The Heureka system is a set of software developed at SLU that allows the user to perform a large amount of different analysis and management plans for forestry. The system can perform short and long term projections of e.g. timber production, economy, environmental conservation, recreation and carbon sequestration. The software within the system can be applied to both individual stands and entire landscapes. The central softwares are: StandWise, RegWise, PlanWise and PlanEval (but also HabitatPrognosis). In this tutorial we will work with the PlanWise application.

Information on how to install the Heureka PlanWise application can be found on:

[http://heurekaslu.org/help/en/index.html?installera\\_heureka.htm](http://heurekaslu.org/help/en/index.html?installera_heureka.htm)

Input and output data are stored in two separate databases. The databases are created on a database server. Each of these can be placed either locally, on your PC, or on a server. Often it is best if the output (the result database) is stored on your PC. This requires a local installation of the database server program SQL Server (version 2005 or later). SQL Server is available as freeware, the latest is called SQL Server 2012 Express. If you also have the input data (the forest database) on your PC you do not have to be online when you run an analysis.

Information on how to install the SQL Server can be found on:

[http://heurekaslu.org/help/en/index.html?installera\\_sql\\_server.htm](http://heurekaslu.org/help/en/index.html?installera_sql_server.htm)

To be able to do the tutorial you also need to use the help web pages:

<http://heurekaslu.org/help/en/index.html?introduktion.htm>

Necessary data for the tutorial can be found on:

<ftp://salix.slu.se/download/Heureka/Data>

Tip: You can change the language setting via the menu Settings > Language, but you have to restart Heureka to make this change take place. A setting other than the default setting of a control parameter appears normally in bold style in the Properties window.

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## Creating a long-term plan with Heureka PlanWise

PlanWise is a powerful analysis and planning tool that has a wide range of applications both in terms of the size of the geographical area of analysis and the type of questions that can be addressed. It could be used for analyzing different forest management options in order to identify the best approach based upon different objectives. The foundation of PlanWise is projection of the tree cover development. Data on current forest conditions, management actions (regeneration, thinning etc) and ecosystem processes, e.g. growth and yield functions, and biomass production are used to project the future state of the forest. Projections can be made for a large number of stand variables not only variables connected to timber and forest fuel production but also to carbon storage, suitability for recreational use and environmental aspects. The system can perform short and long term projections and the results are presented in five-year periods. In PlanWise there is also a module for shorter-term, tactical planning which can be undertaken on an annual scale for periods of 10-15 years. Normally the effects of forest management operations are analyzed at the forest holdings scale. However, PlanWise can also be applied to, for example, forest landscapes, drainage basins or near-urban areas.

Once information about the initial forest condition has been provided, alternative development of the forest is in PlanWise simulated by first generating number of alternative management alternatives, i.e. treatment schedules (often >100 actions for each spatial unit. A treatment schedule is a sequence of treatments e.g. regeneration, thinning, clear cutting or doing nothing, for a planning unit from period 1 to the end of the planning horizon. Each schedule contains forest management operations and the resulting impacts on the stand's development over time including the income and cost connected to the management. Then, the most appropriate treatment schedule for each spatial unit, based on the overall objective function and specified constraints is selected using the system's built-in optimization tool.

In this tutorial we will use PlanWise for creating a long term plan for Strömsjöleden, a forest estate in northern Sweden, as analysis area. It is suitable in size for strategic planning but so small enough so that the time waiting for the simulations and optimizations will be limited. Strömsjöleden is owned by the state-owned company Sveaskog and has an area of about 2200 hectares and more than 200 stands which is perhaps a little larger than the average forest owner/manager is accustomed to. Strömsjöleden has a somewhat uneven age distribution, so that it is not easy but also not impossible to set up a plan with a relatively even harvesting profile.

The creation of a long term plan includes the following main steps:

- Import stand register and forest map
- Calculate and view the input data and initial state
- Create forest domains
- Specify the simulation of the forest management
- Generation and examination of treatment schedules
- Examination of the resulting landscape plan – the default landscape results
- Creating a realistic landscape plan – using optimization

# Import stand register and forest map

In this step we will import the stand register and forest map for Strömsjöleden. We will first create the necessary databases:

- Launch PlanWise
- Select "New Project..." (from the home page or via the File menu), and define your databases for input data and results. You create these databases in this step but you could also link to existing databases. If you are creating new databases select the browse button. After "Server:" the SQL Server name should be specified; LOCALHOST or LOCALHOST\SQLEXPRESS (if the free express version is used) if the software (the "server") has been installed locally on the computer, or the name of the instance ("remote server"), e.g., HEUREKA.SLU.SE. By entering Windows Authentication you will connect to the database with the same username and password as the Windows login. After "Database:" specify database name, either by typing or selecting from the dropdown menu. Then select the Ok button. You will be asked if you wish to include some demonstration data (including some plot inventory data from the National Forest Inventory and plots from Fertilization and Thinning trials) – accept this. Then you can enter the new databases for the new project.

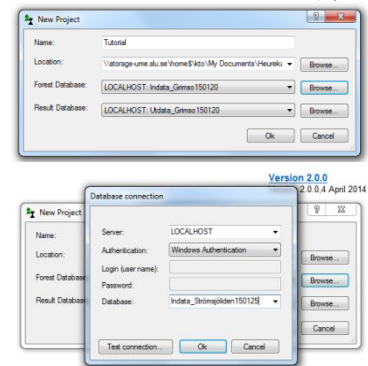


Figure 1

- Next we will import the stand register and the associated forest map:
- Select Data management> Import > Stand register > Import register...
- Browse for and select Stromsjoliden.csv as stand register (which, hopefully you have been provided with). Type "Strömsjöleden" as the name of the stand register you want to import.
- Click Import (and continue without linking to an existing directory - that functionality may be used to import additional data, such as results from a GIS analysis).
- Answer "Yes" to the question if you want tree lists to be simulated. You can leave the default settings to be applied (plot size: 100 m<sup>2</sup>, etc.). If you happened to answer "No", then you can do this also by Data management> Import> Stand register > Simulate tree list (Weibull)...
- In the tree list simulation, you may get alerts about values that deviate significantly from the expected values (regarding both site index and tree height data). Depending on how much you trust the stand register data, you can choose to ignore the warnings and continue or to let the system correct the divergent data. A third option would involve interrupting tree list simulation to fix the deviations in the stand register manually and then import the register again.

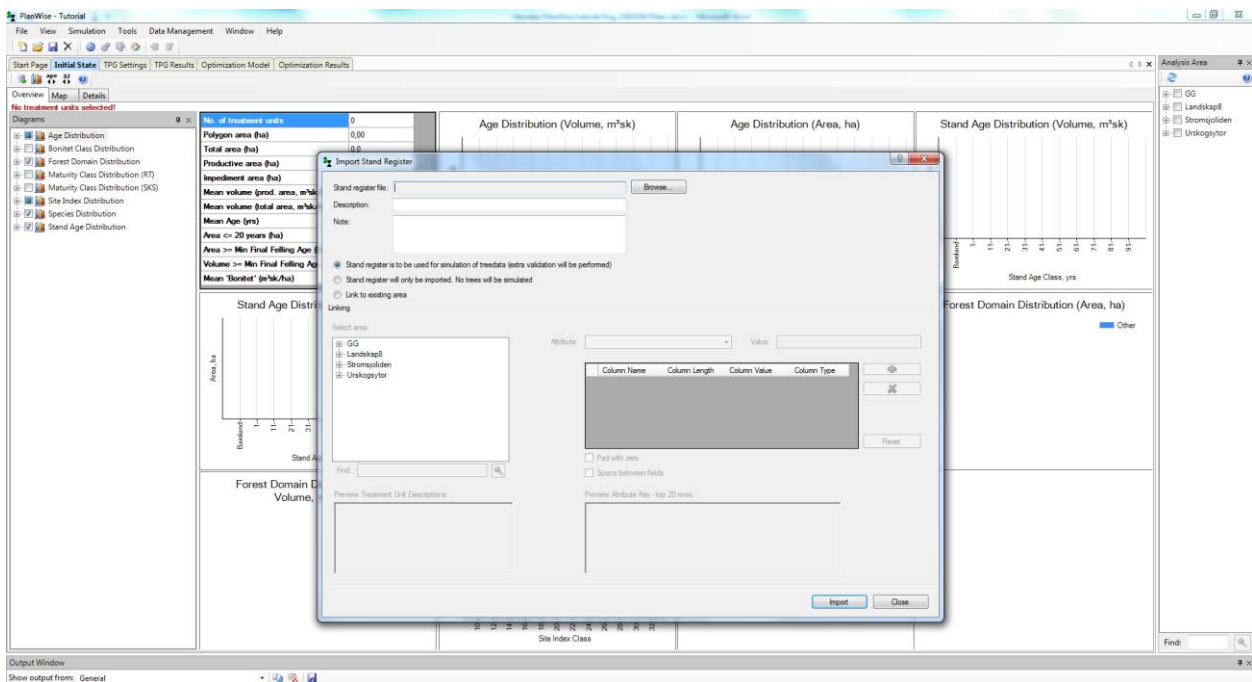


Figure 2 Import of stand register

Time to import the map:

- This is done via Data management>Import>Import forest map...
- First select "Strömsjöleden" among analysis areas to the left. Then browse for the file Strömsjöleden.shp (from the same place as the stand register file).

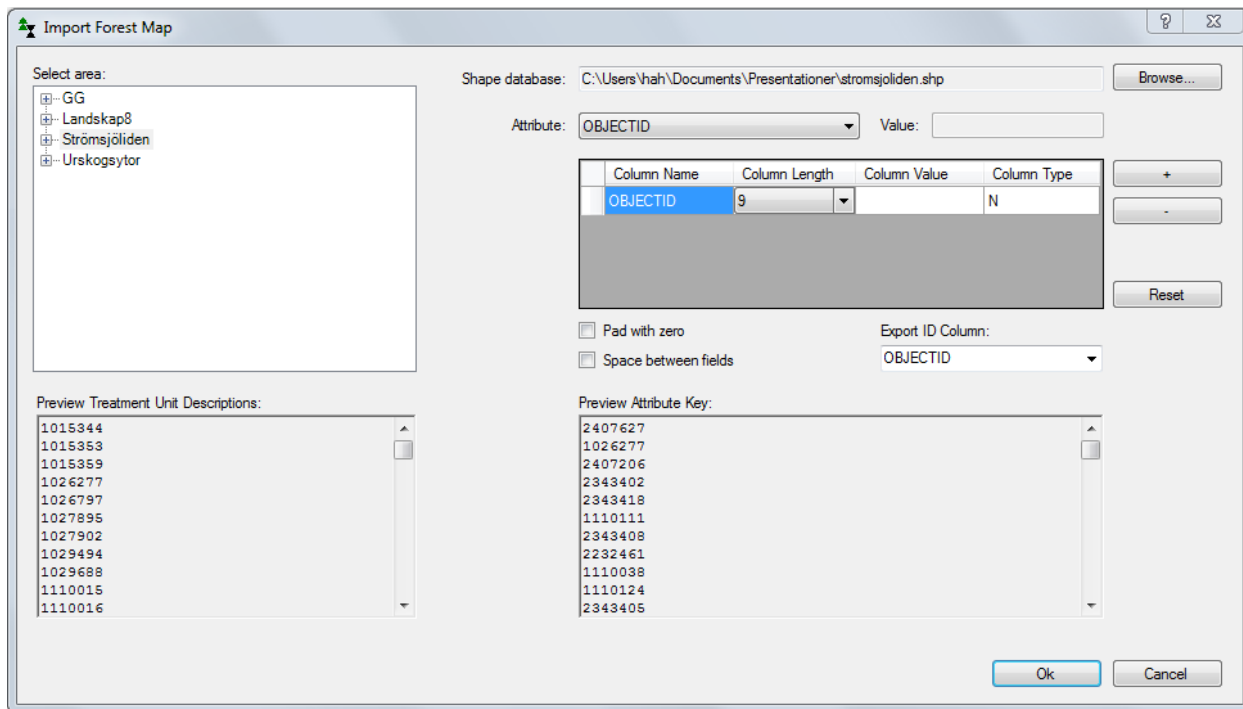


Figure 3 Import of forest map

- Now create a key to the stand register so that it can be linked to respective stand polygons in the forest map. Select the attribute "objectID" and click the button with a plus sign to the right of the table. Select the same attribute in export ID Column. Click Ok and the import of the map is complete. Linking stands and polygons may be more complicated – to get a unique key you may sometimes need to add more attributes, to adjust the column lengths, to fill with zeros and to use spaces between the attribute fields. When importing the map, you are often warned that there are more polygons than matching items in the stand register – this is usually ok because only forest stands are imported to Heureka in the stand register while a forest map may contain polygons with other types of land than forest.

## Calculate and view the input data and initial state

In this step, we will let the software calculate an initial state to be used in further analysis and simulate individual tree data based on the stand level average. We will compare the standing volumes that the simulation of treelists provides with the standing volumes in the stand register. Furthermore, we will also look at the distribution of stands into different classes based on the goal of forest management for the individual stands, both in terms of area of forest in the different management classes (percentages of the total forest area) and in terms of spatial location using a simple theme map.

- In the Analysis area section to the far right, select "Strömsjöleden".
- This will start the calculation of an initial state (under the Initial state tab).
- Study the results under the tabs (Overview, Map and Details) on the Initial state page. Create a theme map of Strömsjöleden based on the management classes:

- Under Map properties, expand the StandObjectData node, right-click Management Class and select Add Items Automatically. Select appropriate theme colors.
- Right-click Management Class again and select Show in map. Will this estate fulfill the certification requirements for 90% PG (production forest with general consideration to ecological values), 5% PF (production forest with extra consideration to ecological values) and 5% NO/NS (forest set aside or managed to promote ecological values)? With Select Treatment Units In Map (marked in the figure below), you can choose to study a stand in detail (this one consisting of three polygons) in terms of descriptive values in the table Treatment Unit Properties.

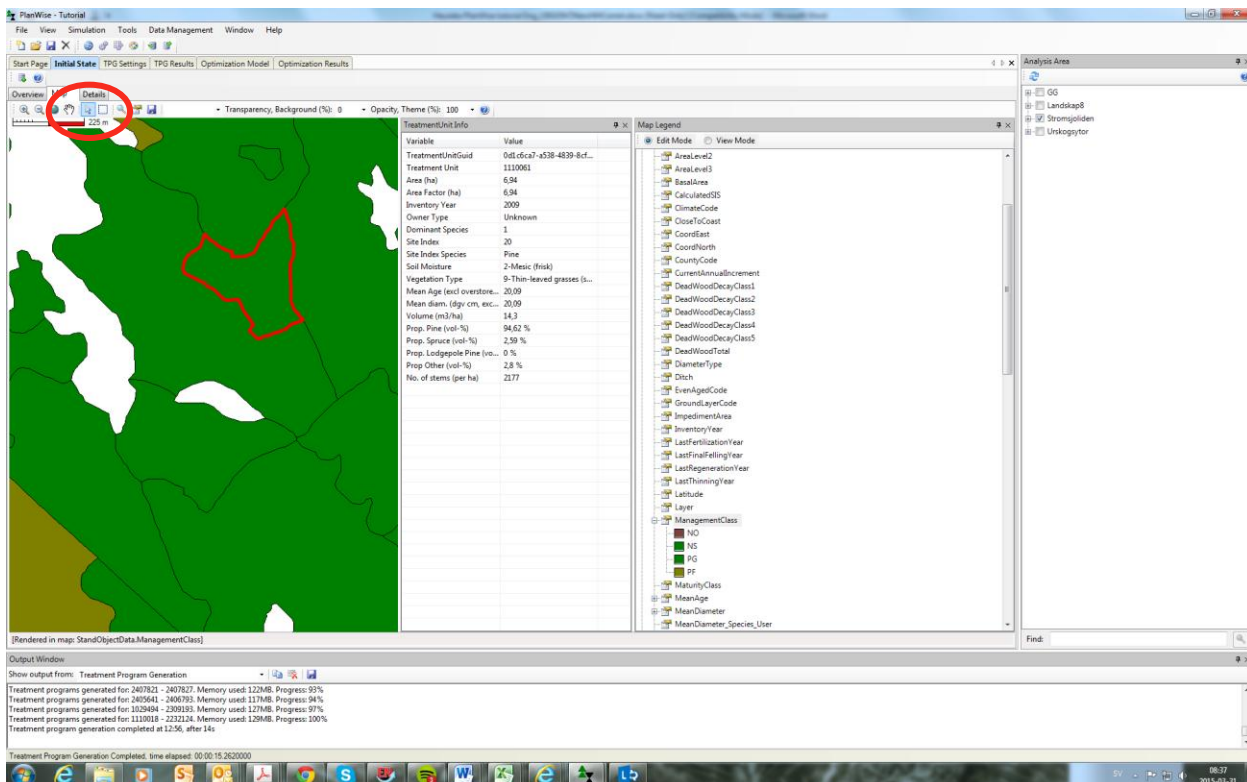


Figure 4 Viewing initial state

- Under Details, click on Select Columns For Detailed View (marked in the figure below) and select the outcome variables you want to have a closer look at, such as:
- Under Forest Data, select Basal Area, Mean Age, Dgv, Hgv and Volume (incl overstorey). By putting the pointer on the variable name, you will see the unit in which the variable is measured.
- Under StandObjectData, select Basal Area, MeanAge, Mean Diameter Total, MeanHeightTotal, Volume, Management Class and ProductiveArea.



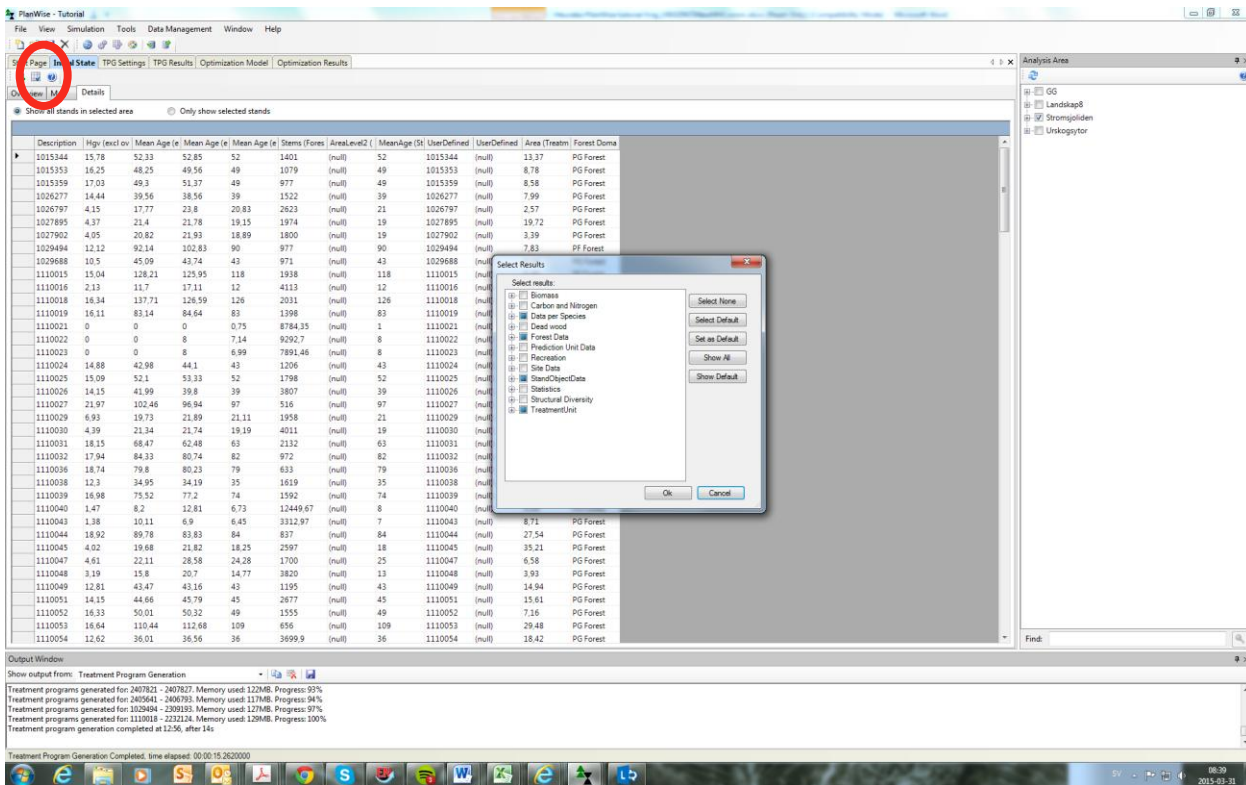


Figure 5 Viewing initial state (cont.)

Forest Data are variables calculated in Heureka while StandObjectData are variables that are imported directly from the stand register. As you will see, there are many more variables (by expanding the nodes under nodes...) describing the forest state. It's easy to get lost and you may not instantly find the variables you are looking for – but after using the software for some time, you will find what you look for quite easily.

- Copy the table with as many rows as there are stands in the current analysis area and as many columns as the result variables you have chosen to view, right-click and choose Copy All. Paste for example in an Excel sheet and continue there to review the detailed forest state. How consistent is the stand register data with the treelists simulated by Heureka? What is the area distribution of management classes (will the target of 90% PG, 5% PF and 5% NO/NS be achieved)?

## Create forest domains

The forest can be divided into groups or zones called Forest Domains. The purpose of this division is to be able to make various settings (management simulations) for different types of forests (stands). The settings are made in something called Control Tables. A Control Category contains one or more Control Tables. Each Forest Domain is linked to one (or several) Control Categories. By default, all stands in the current analysis area belongs to the same Forest Domain (Other), that is linked to Control Categories (currently two, one for the specific purpose of simulating nature conservation – Default Domain Settings) with the default Control Tables. When you define a new Control Category, you only need to add the Control Table(s) containing the control

parameters you want to change from the default settings – for the other Control Tables the system falls back on the default settings in the default Control Categories.

Under the tab TPG settings (TPG = Treatment Program Generator) there are three windows, see figure 6.

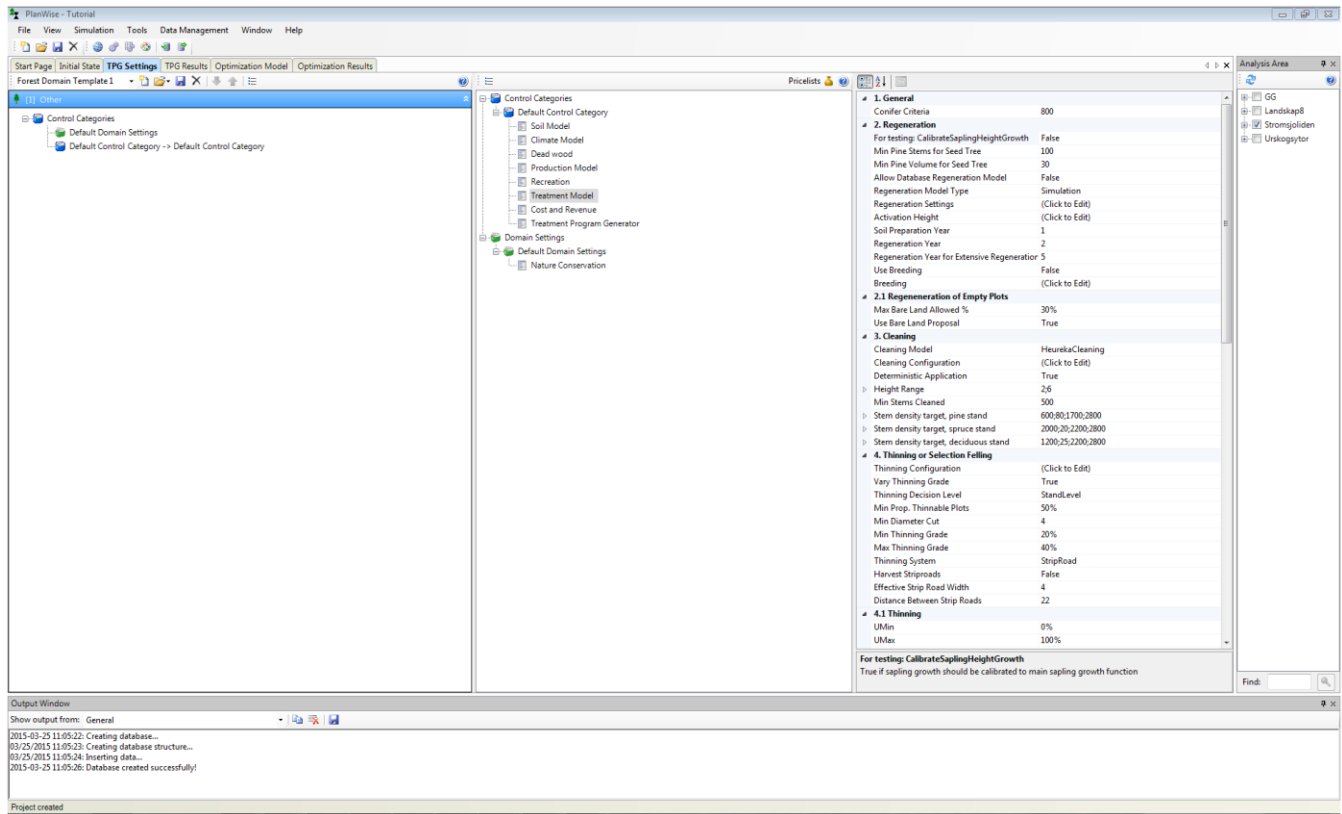
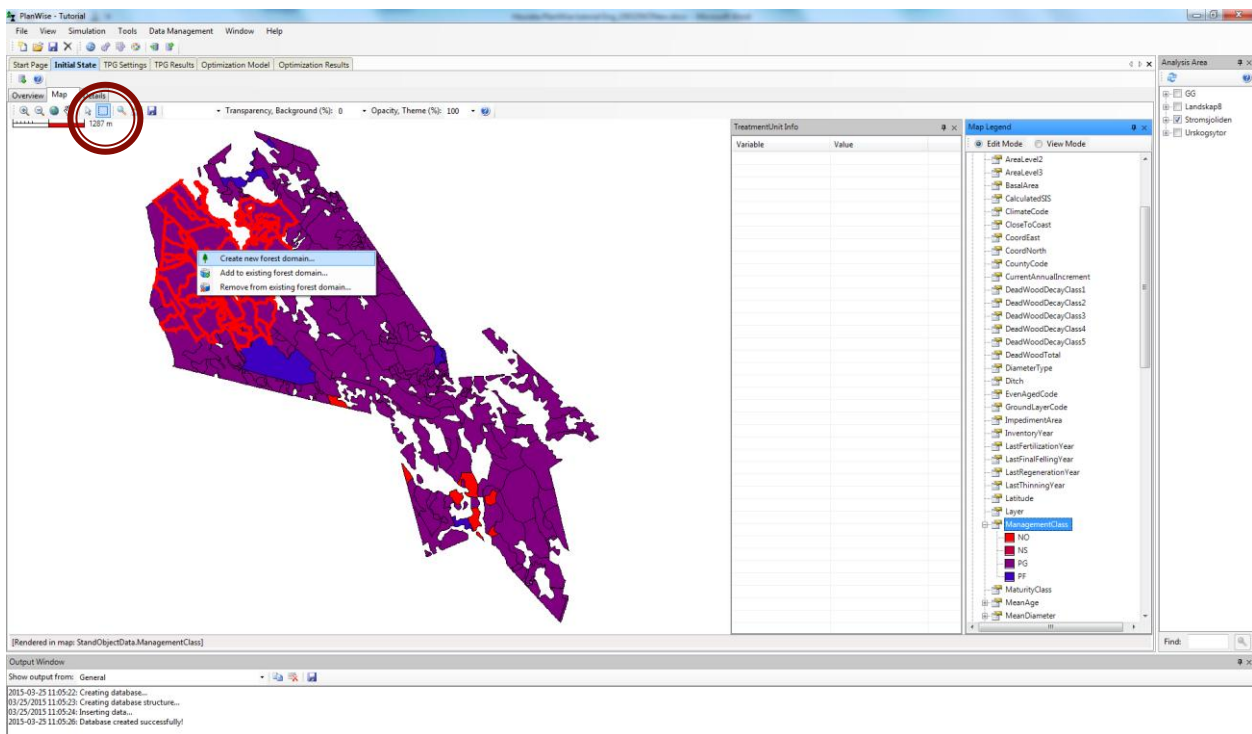


Figure 6 The treatment program generator

On the left is the Forest Domain Builder. In this, Forest Domains are defined using conditions upon the initial state of the stands. In the middle are the Control Categories with their Control Tables. To the right is the Properties window, which displays the properties of the selected Forest Domain/Control Category/Control Table. In this window the user makes the changes to the control parameters.

Forest domains could be created in two different ways. The first way is to use the Forest Domain builder in the TPG tab. The other way is to use the map in the initial tab, see figure 7.



**Figure 7** Create forest domains in the map

In this tutorial we will create Forest Domains based on the management classes in Strömsjölidens stand register.

- Right-click Other under Forest Domain Builder and select Add Forest Domain...
- In the dialog Edit Conditions, select the variable Management Class (available under StandObjectData) and define the condition that this variable should be equal (Equal under Operator) to "NO" (under Expression).
- You can then rename the Forest Domain you just created, from Forest Domain 1 to, e.g., "NO forests" (click once on the name to edit it).
- Repeat the three previous steps for the remaining management classes so that you also have the Forest Domains "NS forests" and "PF forests" (PG stands end up in the default domain Other, the evaluation is done from the top down, as an ever denser sieve, which does not matter in this example when we do not condition domains upon any outcome variables, but what if we also want to include "old-growth spruce" – such forests can probably be found in stands belonging to different management classes).
- To view the outcome of the division into Forest Domains, right-click any Forest Domain and select Evaluate Forest Domains (or View Treatment Unit Assignment...). Then the Properties window will show the number of stands in the chosen domain or a table of the domain affiliation for each stand.
- But what about the domain "NS forests"? Probably the count of stands resulted in zero. Your task now is to change the conditions for the domain so that you still get some stands that are suitable for nature conservation-oriented management. Perhaps some stands adjacent to NO stands may be suitable for this (though spatial conditions complicate the modelling) or some PG stands with a large percentage of broadleaves may be appropriate?

To sum up, here we adapt the forest management to be simulated with consideration to different management classes, i.e., forestry with consideration to ecological values. Of course you can adapt the management with regard to other values. For example, Lodgepole pine-forests, forests for hunting and recreational interests, or forests near lakes and rivers are probably best managed not with the default settings and conventional clear cutting system but with management adapted to the context and the goals of the forestry.

## Specify the simulation of the forest management

Through the control parameters in the Control Tables you can make settings for what models to use, what management and harvesting operations to be simulated, what price lists and cost functions to be used, etc. One or more Control Tables belong to one Control Category. There is always a Control Category called Default Control Category. When creating a new Control Category, select only those Control Tables which needs to be modified. We will now create a Control Category called Unmanaged which controls the management in NO stands by linking the Control Category to the "NO forests" domain. Then this procedure will be repeated for the NS and PF forests so that the treatment schedules for these stands are simulated according to the respective management class.

- Right-click in the middle window in the TPG tab, where the Default Control Category is listed, and select Add Control Category>New Control Category.
- Right-click the new Control Category (Control Category 3) and choose Add/Remove control tables>Add. Select and add the Control Table Treatment Program Generator. Note that you can select the Control Tables from other projects and other Control Categories by selecting Add Control Category From File... or Add Control Table From File...
- Select the new Control Table and, in the Properties window to the right, change the control parameter Management System to Unmanaged.
- Rename the new Control Category to, e.g., "Unmanaged" by clicking on the name Control category 3.
- Now connect the Control Category Unmanaged to the Forest Domain "NO forests" by right-clicking on the domain and select Edit Control Category Connections. Change from the Default Control Category to the "Unmanaged" control category, both for Generation 1 and Generation 2 and later.
- A little challenge: Do the same for the "NS forests", which may be linked to a new Control Category, e.g., "Uneven-aged/Continuous Cover Forestry", for which you change Management System to Uneven-aged (CCF) in the Control Table Treatment Program Generator. For "PF forests", you can try to postpone the time of final felling (to prolong the rotation time) to promote nature conservation – see the Control Table Treatment Program Generator and control parameter Rotation Age Adjustment Factor. Ecological values may also be promoted by simulating natural regeneration (rather than the default - planting). To do this, add the Control Table Treatment Model and modify the control parameters Regeneration Settings and Type of Final Felling.
- A bigger challenge: The Control Category Default Domain Settings has only one Control Table, Nature conservation. The default setting is that no nature conservation is simulated (but it must still be attached to all Forest Domains). For our PG stands in the Forest Domain "Other" we may like to simulate that general nature conservation measures are carried out when harvesting. This is done by right-clicking in the

center window, selecting Add New Domain Settings (change the name to, e.g., "General nature conservation") and adding the Control Table Nature Conservation. Change the control parameter Area Ratio to 5% (find out what it means) and RetainTrees to True. For the Forest Domain Other, change the existing connection to the Default Domain Settings to a connection to the new General nature conservation instead.

When this is done, it could look something like figure 8.

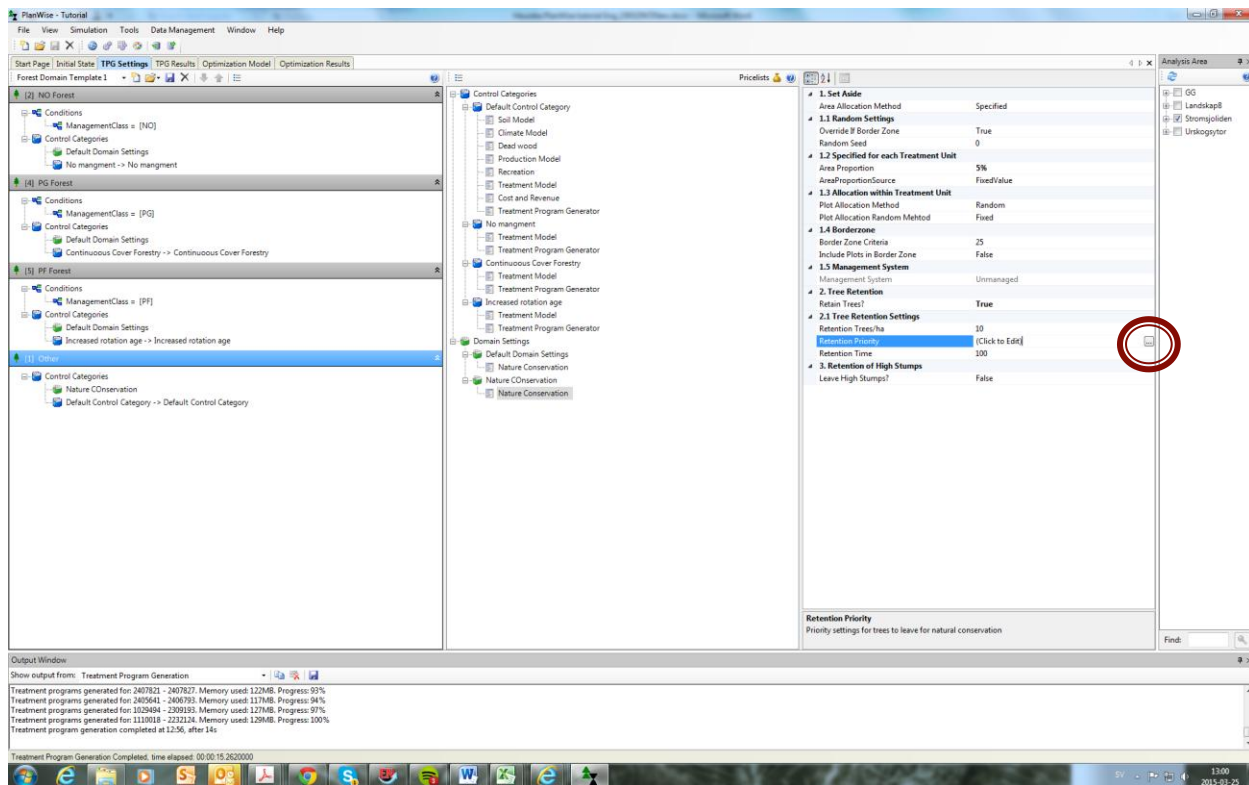


Figure 8

Note that for certain control parameters a button with three dots (marked in the figure above) will be shown. By clicking the button a dialog box will appear with additional control parameters and further opportunities for user-defined settings.

Note that for calculations of net present value you can click the Control Table Cost and Revenue so see what pricelists are used and possibly change them. The discount rate is set later when you run the simulation of treatment schedules.

## Generation and examination of treatment schedules

Before starting the TPG, you should consider the memory and performance of your computer. The simulation of treatment programs may lead to very long waiting times and very large data sets. For instance, the simulation of general nature conservation suggested above implies that stands are divided into two parts – the productive forest area and the nature conservation area. Thus, this procedure leads to a doubling of the number

of treatment units in the analyses. When the simulation of treatment program is initiated (Action>Generate Treatment Programs), the user defines the number of treatment programs to be generated for each stand (default is 20). By limiting the numbers of programs generated, the simulation can be quicker. However, the number should not be set too low since too few alternative treatment programs may make it hard to find feasible solutions in the optimization (and can lead to a "boring" plan which is a consequence analysis of sub-optimal forestry rather than a relevant plan). Instead, to save space and time, it may be better to choose not to include some result types in the simulations if they are not needed for the present analysis, e.g., carbon and nitrogen data is usually not necessary in calculations of harvest levels for sustainable yield. Finally, one can restrict the length of the planning horizon, though this should be done with caution – in a long-term plan the sustainability of the forest management is usually of interest and may be overseen if the horizon is too short. Although certain restrictions could be applied in the optimization model to ensure this, it is often better to include this aspect already in the simulation of treatment programs.

- Under the menu Action, select Generate Treatment Programs. Set the maximum number of (5-year) periods to 21 (which is default) for a 100-year planning horizon. In addition to the default Result Properties, select some other interesting results to be included, e.g., Data Per Species>Volume and Growth>CAI and MAI respectively, to be included for each treatment program for each stand. If you check Use period midpoint, the results will be presented for the middle of each period just before the system simulates potential management (which are usually but not always simulated to take place in the middle of the period). Set the interest rate (default 3%). Finally, name the simulation (the set of treatment programs) appropriately, e.g., "ManagementClassAdapted\_3%".
  - When the simulation of treatment programs is completed, inspect some of the alternative programs for some stands under the tab TPG Results.
  - Choose a simulation result and then select View Treatment Programs (marked in the figure below), view the different stands in the Treatment Unit window by clicking the arrows or selecting from the dropdown list.
  - Select the result variables you want to view by clicking Select Variables (marked in the figure a little further down). Now you see why there may be vast amounts of data to handle... You'll also see that the alternative treatment programs are sorted in descending order according to net present value (NPV), with Alt No = 1 for the standwise maximum NPV.
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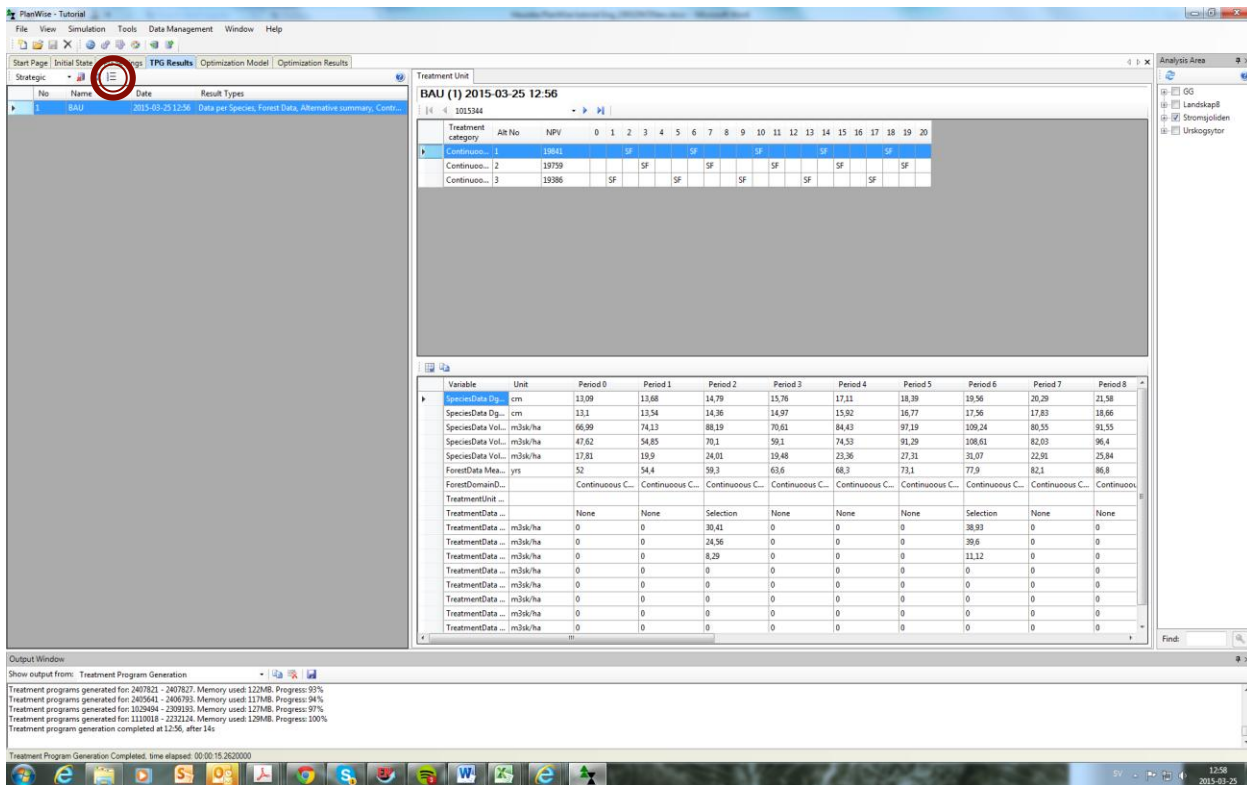


Figure 9

The treatment program overview contains management proposals for each period, coded in the upper window (where FF = final felling, Th = thinning, etc.). You also get the treatments proposals written out in full in the lower window for the result variable Treatment.

Consider again the top window, and the column Treatment Category. You'll see that for all stands, the management programs belong to the same Treatment Category. This is because of the TPG settings, where we for Forest Domains that were connected to new (user-defined) Control Categories removed the link to the Default Control Category. We could have kept the link to the Default Control Category, as well as made links to several new Control Categories for a single Forest Domain. Thus, for stands belonging to that Forest Domain several different types of treatment programs will be generated, and thus there may be several different "Treatment Categories". This enables us to, e.g., compare rotation (even-aged) forestry with continuous cover (uneven-aged) forestry and let Heureka assist us in determining for which stands (or forest types) continuous cover forestry could be appropriate (and under which conditions).

## Examination of the resulting landscape plan - the default landscape results

The TPG simulation generates a number of management alternatives for each stand. As a result, after running the simulation, alternatives must be selected for each stand in order to create a landscape plan. Thus, we have to solve an optimization problem. The choice of treatment programs should be made in the "optimal" way

according to the objectives of the forest owner given certain restrictions. This is usually done on analysis area level, e.g., on the estate or landscape level, so that all forest stands are considered simultaneously. The optimization tool is used for this step. However, as "default result" for each individual stand the treatment program with the highest net present value is chosen. This default solution is thus obtained without using the optimization tool and the results for this solution are given names that start with "Max NPV". Let us begin by considering this default outcome (and examine whether the results are relevant – as you may guess, this kind of solution is often suboptimal...). We start by inspecting, e.g., the harvested volumes over time:

- Select the tab Optimization Results.
  - This tab has two sub-tabs: Details and Maps and Tables and Graphs, respectively. Click the Tables and Graphs-tab.
  - To the right there is a list of the optimization results. When you have not used the optimization tool yet, only the Max NPV results are available. There is one solution for one for each treatment program simulation. Select Max NPV - Strategic (1 - 0).
  - Below the Results window is the Report Templates window, with an overview of available reports for presenting the results. Reports that you create will be automatically saved under User Defined. There are also a number of "system defined" report templates that you can use (though these are named in Swedish). First time used these templates must be downloaded using the download tab to the right in the Report Templates window. For creating a new report, do as follows to create, e.g., a report on the proposed harvest volumes over time for each period (i.e., a harvesting profile):
    - Select Create New... > Period Graph...
    - Select Add... and then after Variable: choose Select variable... in the drop-down list and choose Treatments > Volume Harvested Total.
    - Add conditions by clicking the button Add Conditions and choosing Select variable... and then Treatments > Treatment. To define the expression, choose "In" and "Select multiple values..." and Final felling, Final felling with seed trees/shelterwood, and Removal of seed trees/shelterwood. Enter an Alias, e.g., "VolumeFF". This will then sum the total volumes harvested in final fellings (in m<sup>3</sup>sk) in each period.
    - Repeat the last two steps but now add conditions that the harvested volumes will come from thinnings and from selection felling, respectively. Finally, enter a report name, such as "Harvesting Profile":
-



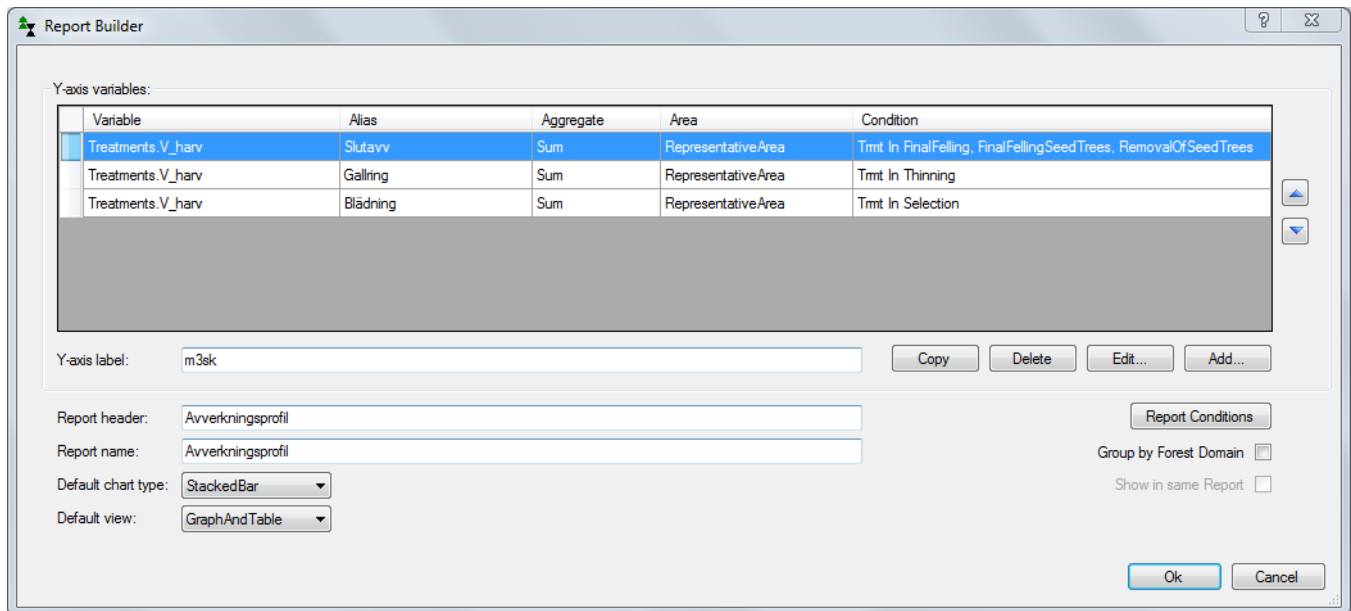


Figure 10

- Select the new report, right click and select the View checked graphs/reports and you will see something like in figure 11.

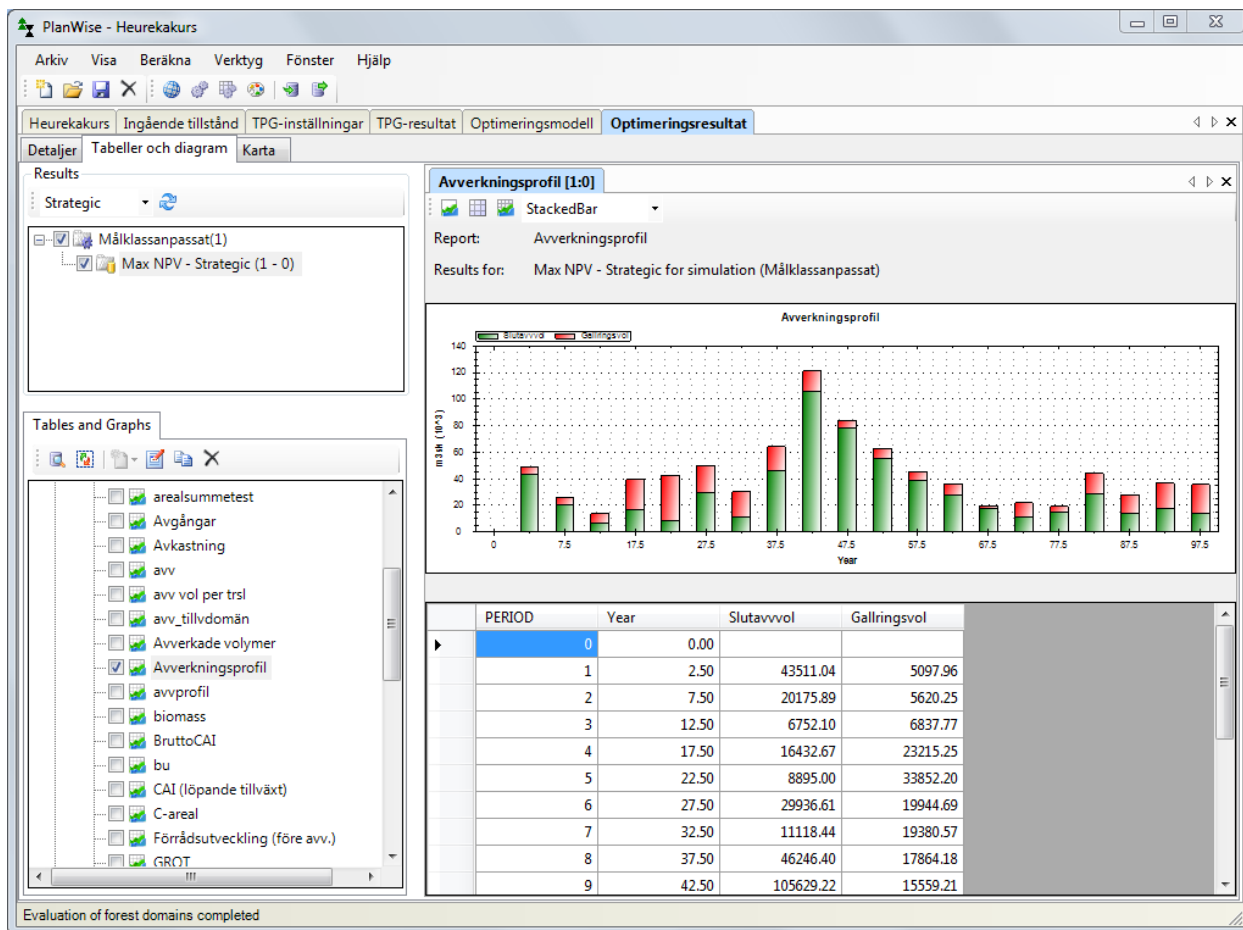


Figure 11

Thus you see the volumes harvested in the different treatments in stacked bars and also a table with the corresponding values (if you selected this option for the current report).

- By right-clicking the table and selecting Copy All you can copy and paste the values into another software, such as Excel, and continue the analysis there. For instance, consider the harvesting proposed in  $\text{m}^3\text{sk}/\text{ha}$  and year (to be compared with the growth) and the share of thinning (in %). Here we chose to define the harvesting profile in  $\text{m}^3\text{sk}$  to be able to compare with the growth which is measured with the same unit. Harvested volumes may of course also be measured in  $\text{m}^3\text{fub}$  ("solid under bark", divided into saw timber and pulpwood) if you like.

It is both instructive (learning to find the way among all the results) and good (so you know you consider the correct data) to create your own report templates. But you can also download ready-made report templates from the Heureka ftp-server.

- Make a graph (a user-defined or with a ready-made report template) showing the development and the standing volume. The standing stock depends largely on the proposed harvesting. The same holds true for the growth, the current annual increment "CAI" (not to be confused with average growth, the mean annual increment "MAI"), for which you can create a (line) chart.

And now a different type of graph, a report for the proposed area of final felling. From the area of final felling we can then calculate the mean area of final felling per year and the average rotation time for the forest in the current area of analysis (in doing this we have to consider how areas dedicated to nature conservation and areas treated with selection fellings are to be handled). Areas for any other proposed treatments may be presented in the same way. Do like this:

- Select Create New... > Period Graph...
- Select Add... and after Aggregate Type: select Sum of area.
- The click Add conditions, choose Select variable... and then Treatments > Treatment, use the expression "In Final felling" and "In Final felling with seed trees/shelterwood" (but not "In Removal of seed trees/shelterwood" because then there would be double counting of the area with seed trees/shelterwood). Enter an Alias, e.g., "AreaFF". This report sums the area of final felling (in hectares) in each period and may look like figure 12.

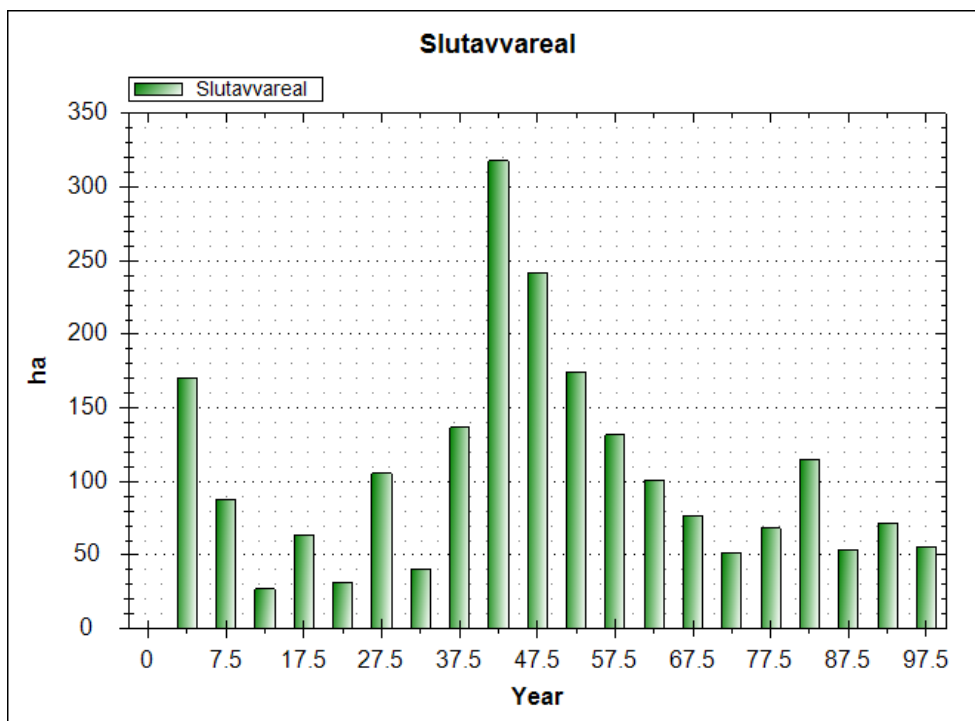


Figure 12

If we add the area of thinning (by an additional condition), it may look like figure 13:

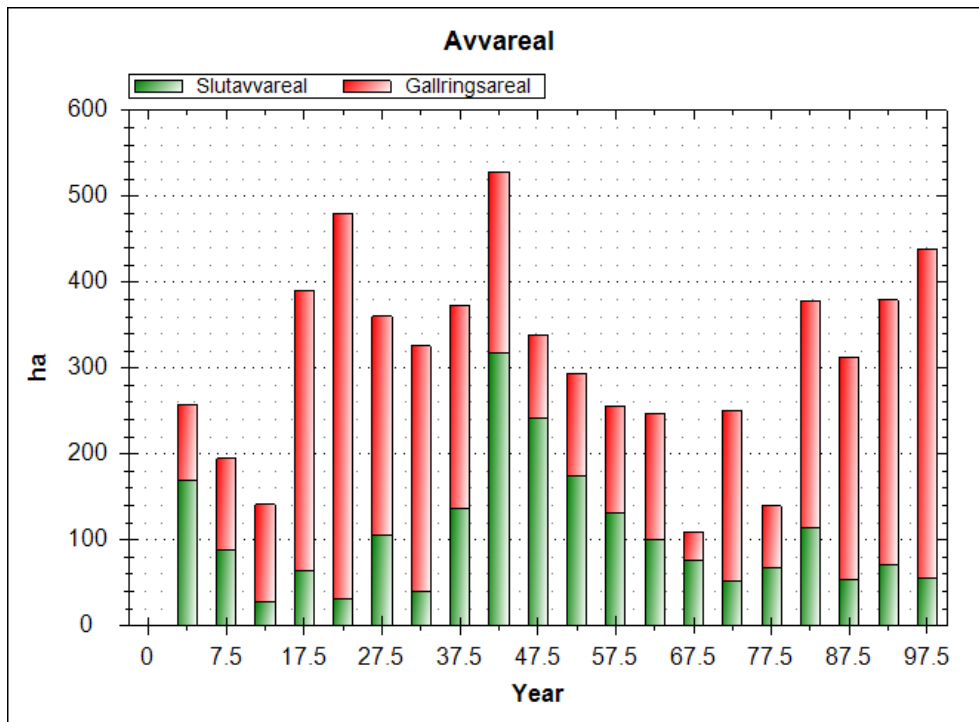


Figure 13

Thus, when we look at harvested areas rather than harvested volumes, we get a quite different share of thinning. The results can also be inspected using the map. Do like this:

- Select the Map-tab and select Result: Max NPV - Strategic (1 - 0).
- In the Map Legend, expand Treatments, right-click Treatment and select Add Items Automatically.
- Remove the treatments that we are currently not interested in; keep Final Felling, Final Felling With Seed Trees/Shelterwood, Thinning and Selection Felling. Display the first two treatments with a single color, and the other two with a different color.
- Right-click Treatment and select Show In Map. For period 0 (zero) no logging operations should appear in the map since this is the initial state. Treatments simulated generally occur only in year 2.5, 7.5 etc. – in mid-point of following periods. However, if we initially had stands consisting of seed trees/shelterwood, the treatment RemovalOfSeedTrees/Shelterwood could have taken place in period 0. Move to period 1 (marked in the figure below), and the proposed treatments show up like in figure 14.

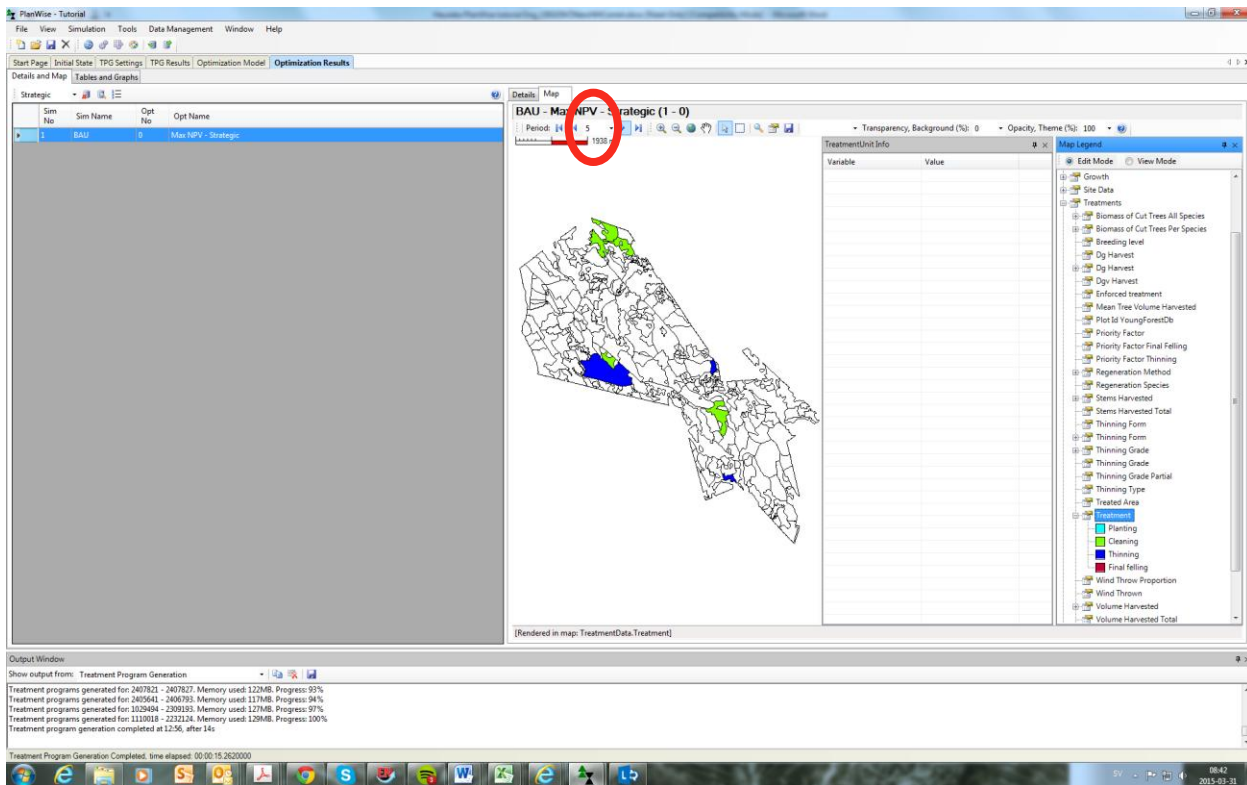


Figure 14

- Click to move forward and see proposed harvest treatments in following periods. If you are not satisfied with the spatial aggregation of harvesting activities (if they are too clustered or too scattered), remember that these are results for a five-year period. Normally, the spatial aggregation problem is dealt with in the tactical planning, by looking at annual results or as a restriction in the optimization model.

The standwise results may also be inspected under the Details-tab. To set up a management plan with proposed harvesting volumes in period 1 and 2, do the following:

- Select the optimization results Max NPV... and select View Treatment Programs.
- Under Select Variables, choose Treatments > Treatment, Treatments > Volume Harvested Total and Treatment Unit > Area.
- Choose to view the results for the first three periods by column.

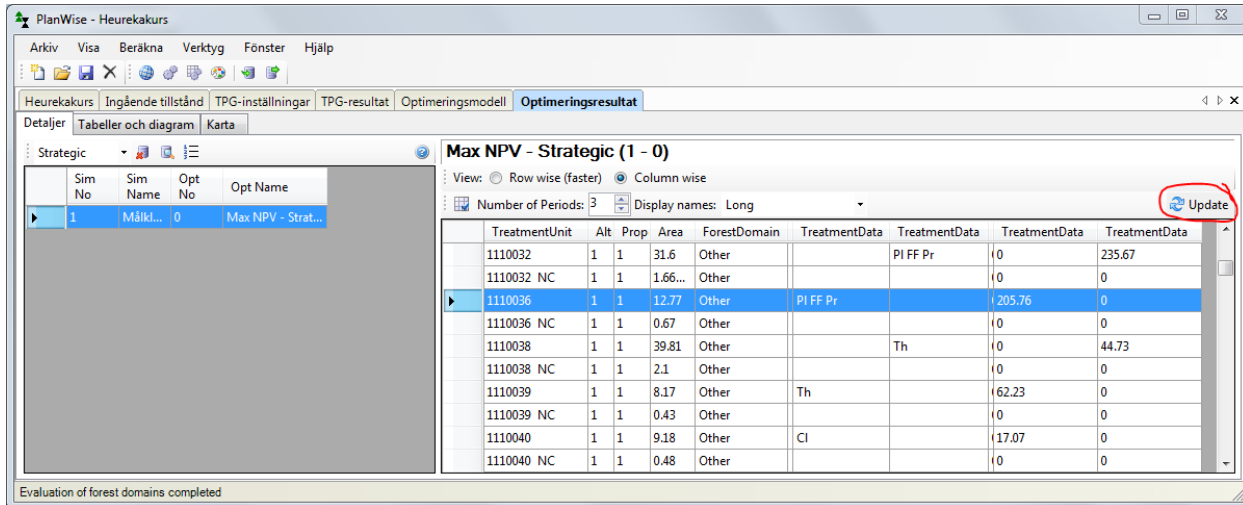


Figure 15 (The Update-button is no longer available)

- Right-click and select Copy all and paste into, e.g., Excel since this table needs to be processed a bit further. The data pasted into Excel includes things that may be deleted, for instance columns for period 0 with (when no treatments are simulated), rows for "NC" – the nature conservation part that has been simulated for all stands (where no treatment takes place) and the columns AlternativeNo and Proportion (these are both always 1 for the Max NPV solution). Also, the harvested volumes for cleaning (Treatment = Cl) is probably uninteresting since this volume is usually not commercial. The cleanings could have been disregarded by instead choosing to look at Financial Value > Pulpwood Volume Total and Timber Volume Total, respectively (measured in m<sup>3</sup>fub/ha). Now our edited table in Excel may look like this:

	A	B	C	D	E	F
1	<b>Bestånd Nr</b>	<b>Areal (ha)</b>	<b>Åtgärd Period 1</b>	<b>Åtgärd Period 2</b>	<b>Avverkning Period 1 (m<sup>3</sup>sk)</b>	<b>Avverkning Period 2 (m<sup>3</sup>sk)</b>
2	1110027	25.96	Slutavverkning		5839	
27	2407206	1.3	Slutavverkning		293	
28			<b>summa, slutavverkning period 1:</b>		43507	
29	1110031	2.18	Gallring		142	
45	2343444	3.44	Gallring		301	
46			<b>summa, gallringsavverkning period 1:</b>		5098	
47			<b>totalsumma, avverkning period 1:</b>		48605	
48	1110032	31.6		Slutavverkning		7447
54	2343423	2.79		Slutavverkning		729
55				<b>summa, slutavverkning period 2:</b>		20175
56	1110038	39.81		Gallring		1781
65	2406795	4.25		Gallring		419
66				<b>summa, gallringsavverkning period 2:</b>		5620
67				<b>totalsumma, avverkning period 2:</b>		25794

Unfortunately in Swedish, note that some lines (stands) are hidden in the spreadsheet in the table above.

Not satisfied with the results? It's time to move on to the optimization tool and find some better solutions!

## Creating a realistic landscape plan - using optimization

Usually there are problems connected to a plan obtained from maximization of the net present value on stand level that makes the plan unrealistic and thus not a good solution for the decision maker (the forest owner or manager). The sum of many local optima is not equal to a global optimum. One of the main problems has to do with to the harvesting levels over time:

- The forest owner usually can't or won't harvest as much as suggested in the first period. A high level of harvest in the first period is a common consequence when strict maximization of the net present value is applied since there is usually quite a lot of old forest (often with high volumes and ready for harvest) where the "value growth" no longer corresponds to the interest rate expected by the forest owner.
- Large fluctuations in the harvesting profile between periods after the first period are often undesirable for several reasons. For instance, a forest owner may want an even flow of income from and expenses for the forest management, but also an even level of employment ("degree of activity") and diversification considering risks. What if a harvesting peak would coincide with low prices for saw timber and pulpwood or large areas have just been planted when there is an outbreak of insects that damage seedlings?

Do consider the volumes to be included in the harvesting profile that you want to make even. Should harvested volumes from both final felling and thinning be included? Perhaps volumes harvested in thinning's should not be included if thinning is regarded as a necessary forest management operation and not only as a source of income?

Other potential problems connected to the Max NPV solution are:

- The plan may violate forestry legislation, e.g., the Swedish Forestry Act stipulates that no more than half of the forest area on an estate should be young forest, 20 years or younger (so called rationing or greening-up rule). The rationing rule is complicated for larger forest holdings (like the estate of Strömsjöleden with an area of 2200 ha). But for the sake of practice, however, we will take the basic rationing rule into account.
- The plan may violate certification principles (e.g., FSC), for that there should be a certain share of broadleaved trees in the forest. The issue of broadleaved trees may require special attention; in reality, "failure" in forest management may produce a larger share of broadleaved trees since the conventional (Swedish) clear felling system mainly favor coniferous trees when net present value is to be maximized. (Thus, perhaps we should take failures into account somehow?)

The task here is to use the optimization tool to address the problems described above and develop a plan that is realistic with optimal forest management; i.e., optimal based on the forest owners objectives and the circumstances. We will do this stepwise, where each step implies that we run at least one but often several optimizations. We begin with the even-flow constraint to create a smooth harvesting profile.

- Under the tab Optimization Model, select Open Model... (marked in figure 16). Select the model Max nuvärde med jämnhetskrav ver X.Hops (Max NPV with even-flow constraint). A good habit is to save your own version of the model so that you can modify it but will still be able to go back to the original version if needed.

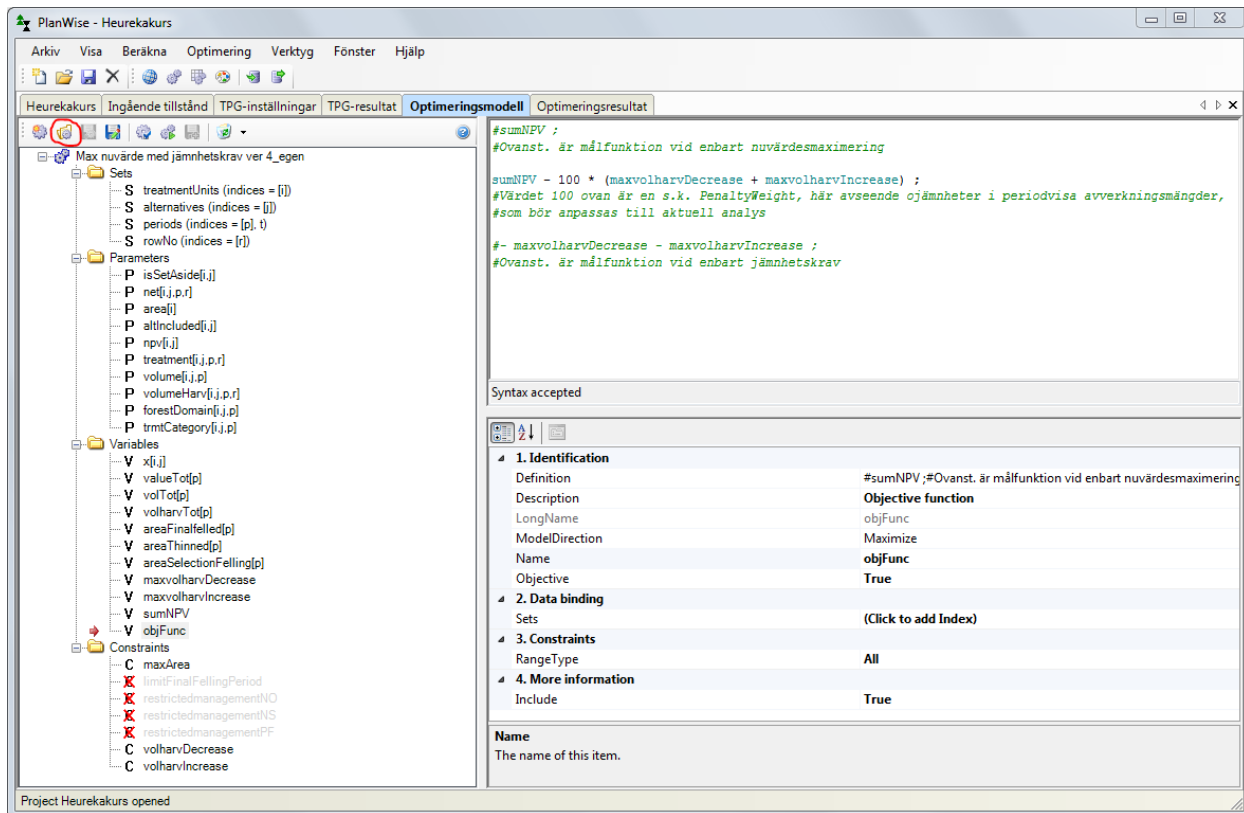


Figure 16

You can read more about optimization on the Heureka Wiki: <http://heureka.lu.org/wiki/Optimization>.

A brief introduction to get us started:

a) An optimization model is built from a number of defined Sets, Parameters, Variables and Constraints, as you see in the window to the left in the figure above. Right-click in the window or on any item, and you get access to various menus and functionalities.

b) Variables and constraints normally have a syntax (Heureka uses the programming language ZIMPL) as seen in the window on the top right. The hash tag symbol, #, at the start of a line means that the line is only a comment that explains the syntax meaning and not active code.

c) On the lower right is a property window. Not only variables and constraints, but also sets and parameters have properties. Here we see that the selected variable, "objFunc" is truly the objective function (because of Description: Objective Function and Objective: True, but the red arrow in the left-hand window also indicates this) and that the direction of the optimization is to maximize the value of the objective function (Model Direction: Maximize). But what kind of objective function do we have here?

d) The sumNPV part means that we maximize the sum of the net present value for a given treatment program for all stands in the analysis area, which may not be so difficult to understand but what does maxvolharvDecrease and maxvolharvIncrease mean? Tip: The constraints "volharvDecrease" and "volharvIncrease" can be seen as algorithms that sort out the largest increase and decrease, respectively, of



something – but concerning what? Is it really an even-flow constraint or rather an aspiration for increased evenness? (Hint: the latter.)

- Change the default penalty weight in the objective function from 100 to 1. Select Compile and Solve Model, choose your (probably only) current simulation (TPG results) for the optimization and when the optimization is finished, select Save Optimization Results with an appropriate name, such as "PW = 1". Go to Optimization Results to check if the harvesting profile became smoother.

Stop! We went way too fast forward. Some important things to keep in mind:

- Check the status window that is activated when the optimization is started – here you can see how the model building proceeds and if the model could be solved. You also see a list of the resulting values of all variables (even for all values of the decision variable  $x$ , which mostly takes the value 0 (zero) for all treatment programs that are not selected and therefore makes the list very long) and the restrictions. The value of the key variable sumNPV, the total net present value (for the plan for analysis area), you can also see here. You can also create a report (or use a pre-defined template) under Optimization Results > Tables and Graphs that report the net present value (preferably per hectare to make it comparable with other analysis areas).
- Under Optimization Model > Optimization > Settings... you may choose that the results should be rounded off to integer solutions. This is usually preferable if we have wall-to-wall input data and want a stand to be a treatment unit that is treated as a whole when a certain treatment is applied in a certain period. In contrast, with a sample-based approach (as in, e.g., the Forest Management Planning Package, FMPP) one should not round off to integer solutions.
- To complicate things further, period 0 represents year 0 (zero), i.e., the initial state of the forest. Period 1 represents the first 5-year period with the midpoint in year 2.5. This is important to know if you use optimization models with constraints regarding periodwise harvest levels. Consequently and without much more explanation, we change the two constraints volharvDecrease and volharvIncrease, respectively, to read as follows:

```
FORALL <p> IN periods WITH p >= 2 :...
```

- Now we are better prepared for running further optimizations. Test various penalty weights (PW) in the objective function, e.g., 10, 100 and 1000. Note the extent to which a higher aspiration for an even harvest flow affects the net present value. The rounding off to integers (for this relatively small analysis area, with only 209 stands) and an aspiration for even harvest flow from all kinds of treatments (even from cleaning) will force us to satisfy with only a half decent evenness; in the current example and for PW = 250 the net present value will decrease with approx. 1.3%:

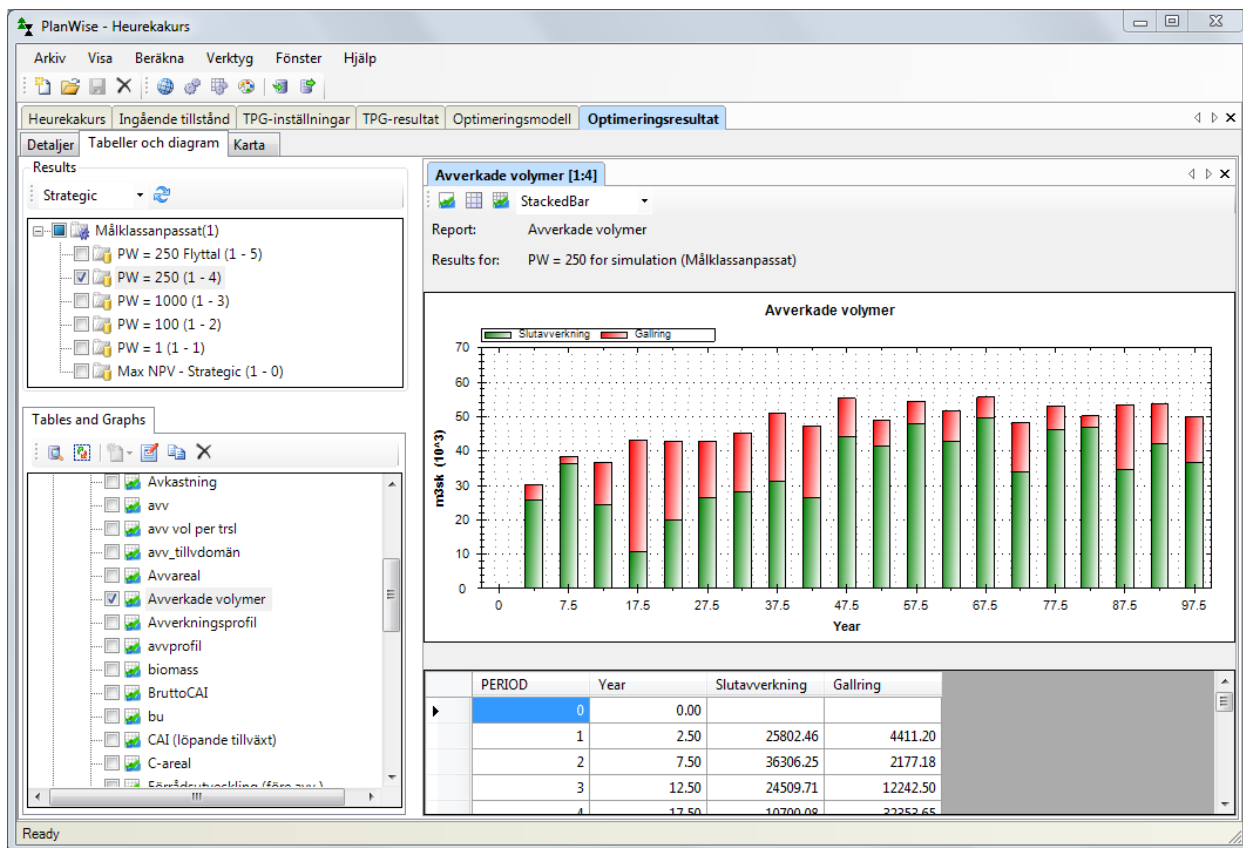


Figure 17

Let's change the optimization model so that the even-flow aspiration only applies to final felling harvesting. We start by adding a new variable:

- Right-click Variables and select Add New Variable and name it "volharvFinalfelled" (to harmonize with existing variable names).
- Assign an index (period) to the new variable: In the properties window, select Click to Add Index, mark Periods and select Add... Then new variable will be named volharvFinalfelled[p]. Move it upwards so that it is placed directly under volharvTot[p] in the list.
- Copy the code from volharvTot[p] to volharvFinalfelled[p], then change the code so that it ends with:

```
... == volharvFinalfelled[p] ;
```

Now the old value from volharvTot[p] will be assigned to the new variable which means that the variable still includes the harvested volumes from all kind of treatments, not only final fellings.

- To change this we can copy from the variable areaFinalfelled[p]. Just like volharvTot[p], it is a so-called accounting variable that sums certain values. This variable sums up areas while the previous one sums up volumes. However, the variable areaFinalfelled[p] sums up only the areas of final felling, not all harvested areas. We can copy the code for this condition :

```
... AND (treatment[i,j,p,r] == 8 OR treatment[i,j,p,r] == 16384)
```

- ... and paste it at the corresponding location in volharvFinalfelled[p]. Check to make sure you get the parentheses right – to check the numerical codes of different treatments you right-click the parameter treatment[i,j,p,r] and select View Definition.
- In the constraints volharvDecrease and volharvIncrease you now replace volharvTot[p] with volharvFinalfelled[p].
- Solve this new optimization problem. Note that changing the even-flow constraints to include only volumes harvested in final fellings both magnifies and complicates the problem. The previously selected penalty weight for evening out the harvesting profile may have to be adapted to the new conditions. This is what it may look like (PW = 250):

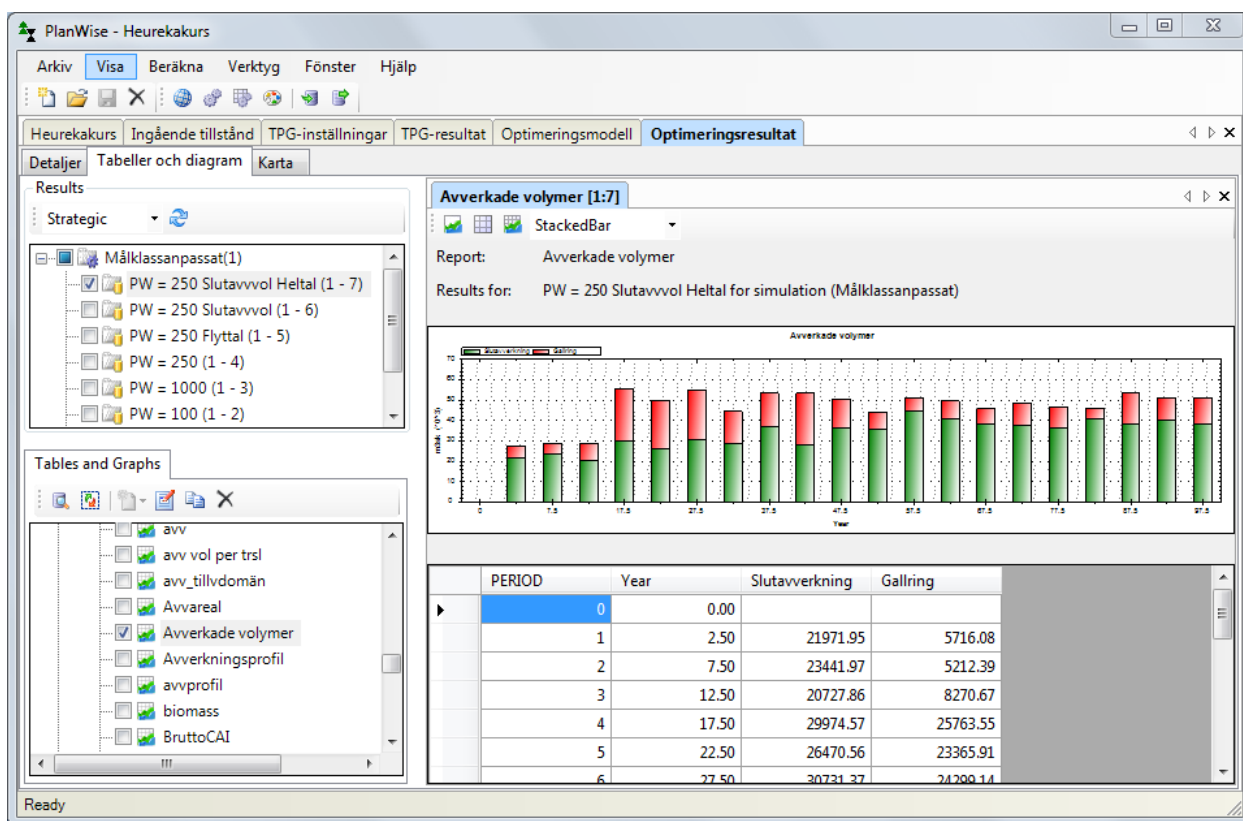


Figure 18

- The next task is to add the rationing rule (from the Forestry Act) and thus restrict the area of young forest in each period. Right-click Parameters and select Add New Parameter..., enter the name areaTot and select Formula. Select Next and in the window type:

```
sum <i> in treatmentUnits : area[i] ;
```

... and then select Finish.

- Again, right-click Parameters and select Add New Parameter..., enter the name meanAge but now select Heureka Result Variable. Select Next and then select Forest Data > Before > Mean Age (excl overstorey), finally select Finish.
- We can now create an accounting variable that sums the area of clear cuts and forest younger than 20 years. Right-click Variables and select Add New Variable, enter the name arealUngskog (areaYoungForest in English). Select the new variable and in its properties window, select Click to Add Index, add periods (the index p). In the variable syntax window, type:

```
FORALL <p> IN periods WITH p >= 1 DO
SUM <i,j> IN treatmentUnits * alternatives WITH (altIncluded[i,j] >= 1 AND meanAge[i,j,p]
<= 20) :
area[i] * x[i,j] == arealUngskog[p] ;
```

- Now add the actual constraint. Right-click Constraints and select Add New Constraint, name it "maxarealUngskog" (maxareaYoungForest in English). Select the new constraint and in its syntax window, type:

```
FORALL <p> IN periods WITH p >= 1 :
arealUngskog[p] <= 0.5 * areaTot ;
```

Test the new constraint by compiling and solving the optimization problem when this constraint is included. Did it affect the results? Probably not – in our test area Strömsjöleden there has been some final fellings but not that much in the last 20 years and hence the age class distribution is not that skewed. If our objective function is to maximize net present value and we use a "normal" interest rate (2-3%), there is not much pressure for final felling of relatively young forest, which could lead to conflicts with the rationing rule in future periods. Check the results for the accounting variable arealUngskog[p] in the status window, and you will probably see that in all periods we are relatively far from the restriction of the rationing rule to maximum "half of the total forest area" which in this case is approx. 1100 hectares. Try to make this constraint more difficult to overcome. Can the optimization problem be solved if we require, e.g., that a maximum of 20% of the total area can be younger than 20 years (in each 5-year period)? How can you deal with optimization problems that have no feasible solution?

The last task, to ensure that in each 5-year period there is at least 5% of broadleaved trees, you can now probably manage all by yourself. Learn from and use what we have already done. If you look at the parameters, variables and constraints, there is a lot of material that you can copy and that may help you to formulate new parameters, variables and constraints to solve the new problem. Tip: A new parameter volumeBroadleaves[i,j,p], a new variable volBroadleaves[p] and a new constraint minVolumeBroadleaves (minvolymLovskog in Swedish) may be appropriate. Maybe your model looks like this:

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PlanWise - Heurekakurs

Arkiv Visa Beräkna Optimering Verktyg Fönster Hjälp

Heurekakurs Ingående tillstånd TPG-inställningar TPG-resultat **Optimeringsmodell** Optimeringsresultat

max npv med jämna skrivet för Heurekakurs

Sets

- S treatmentUnits (indices = [i])
- S alternatives (indices = [j])
- S periods (indices = [p, t])
- S rowNo (indices = [r])

Parameters

- P isSetAside[i,j]
- P net[i,j,p,r]
- P area[i]
- P altIncluded[i,j]
- P npv[i,j]
- P treatment[i,j,p,r]
- P volume[i,j,p]
- P volumeBroadleaves[i,j,p]
- P volumeHarv[i,j,p,r]
- P forestDomain[i,j,p]
- P trmtCategory[i,j,p]
- P areaTot
- P meanAge[i,j,p]

Variables

- V x[i,j]
- V valueTot[p]
- V volTot[p]
- V volBroadleaves[p]
- V volharvTot[p]
- V volharvFinalfelled[p]
- V areaFinalfelled[p]
- V areaThinned[p]
- V areaSelectionFelling[p]
- V areaUngskog[p]
- V maxvolharvDecrease
- V maxvolharvIncrease
- V sumNPV
- V objFunc

Constraints

- C maxArea
- ~~C restrictedmanagementNO~~
- ~~C restrictedmanagementNS~~
- ~~C restrictedmanagementPF~~
- C volharvDecrease
- C volharvIncrease
- C maxarealUngskog
- C minvolymLovskog

```
FORALL <p> IN periods WITH p >= 1 :
volBroadleaves[p] >= 0.05 * volTot[p] ;
```

Syntax accepted

1. Identification	
Definition	FORALL <p> IN periods WITH p >= 1 :volBroadleaves[p] >= 0.05 * volTot[p] ;
Description	
LongName	minvolymLovskog
Name	<b>minvolymLovskog</b>
4. More information	
Include	<b>True</b>

**Name**  
The name of this item.

Ready

Figure 19

## Some final remarks

In this tutorial we have tested some of the possibilities in Heureka PlanWise. To fully learn the system you have to use it and probably make a number of analyses. One way to learn more is to read the help documentation. Another way to get some insights in the capacity of the system is to read some of the published articles that have used the system in different types of analyses. See for example: <http://www.slu.se/sv/centrumbildningar-och-projekt/sha/publikationer/>. Further in real-world planning for sustainable forest management, we often face complex problems where different values (or eco system services) have to be taken into account. One way to do this is to use the PlanWise application to create a long term plan based on high quality forest inventory data and reliable models. However, in many situations this is not enough since part of the problem is that objective information is not sufficient to solve the problem. The subjective preferences of the decision maker(s) are at least as important and need to be identified and included in the planning process. If you are interested in using a software that include consideration to the subjective preferences of e.g. the decision maker you should test PlanEval which also is a Heureka application: <http://www.slu.se/en/collaborative-centres-and-projects/forest-sustainability-analysis/en-heureka/planeval/>. PlanEval stands for Plan Evaluation and is intended to provide a systematical way to rank and evaluate plans and scenarios generated with PlanWise. PlanEval is based on methods for Multi-criteria decision analysis (MCDA).

Finally, we need to remember that Heureka PlanWise is a decision support method that does not produce an absolute truth, but can give information to a decision maker to understand the problem better and make better decisions.

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