

# THE HEUREKA FORESTRY DECISION SUPPORT SYSTEM: AN OVERVIEW

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**ABSTRACT.** Mathematical programming and computers have been used for several decades to solve complex and long term forest management planning problems. The ever increasing demand on the forest ecosystem to produce wood and other goods and services poses a corresponding demand on a forest decision support system. As a response to meet new requirements the development of the Heureka system was initiated at SLU in 2002 and a first version of the system was released in 2009. Based on a common kernel, a number of applications of the system for different problem areas and users have been developed. The three main applications are made up by an interactive stand simulator, a tool for long term forest level planning containing an optimization module, and a simulator for regional analyses. The system contains models for growth projections, simulation of treatments, estimation of recreation values and carbon sequestration, and habitat suitability. It is also possible to make projections under different climate scenarios. In addition the system includes a number of supporting applications for importing data from different sources, for field inventory, and for comparing and ranking alternative management plans.

**Keywords:** forestry, planning, optimization, multi-criteria, spatial analysis

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## 1 INTRODUCTION

Long term forest management planning is an exceedingly complex task. A multitude of possible actions stretching over time and space will determine what ecosystem functions and services are delivered. Already in the 60's practitioners combined mathematical programming and computers to analyse and find solutions to large scale forest management problems (Martell et al. 1998). While decision support systems (DSS) initially were focused on timber management, there are now a great number of forest DSS that cover a wide range of aspects (Johnson et al., 2007).

Forest DSS can be classified along a large number of dimensions. One is to differentiate them on stand, forest or landscape level systems, and systems for regional or national assessment. Examples of stand level systems are Silva (Pretzsch et al., 2002), CAPSIS (Courbaud et al., 2001), and MOTTI (Hynynen et al., 2005). These systems allow the user to do detailed studies of the results of different stand management regimes. MELA

(Siitonen et al., 1999), Monsu (Pukkala, 2004), FMPP (Jonsson et al., 1993) and SGIS (Næsset, 1997) are examples from Scandinavia of forest DSS that are addressing long term planning problems. As is not uncommon among forest level systems they assist the user by optimizing a forest planning problem. Among systems aiming at regional and national assessment you tend to find systems that simulate the development of the forest system.

The first forest DSS tended to have a rather narrow problem domain, i.e. they were created for a specific and well-defined problem. Especially over the last 10 years there has been a tendency that systems are developed to cover a wider domain (Reynolds et al. 2008). The Heureka forest DSS (SLU, 2010) follows this trend. Built on the same platform, Heureka offers support for stand, forest and regional analysis and planning. From the same kernel different economic, ecosystem and social models can be reached, allowing for a problem to be approached from a number of different angles. Today, the system can handle economic values, silvicultural treat-

ments and harvesting, timber production, forest fuels, biodiversity, recreation, and carbon sequestration.

The Heureka research program spent eight years in developing the forest DSS before the first version was released in 2009. The Heureka program had from the outset the objective of developing software for users both within and outside the research community. The target group includes a wide range of different users and needs, starting from the small-scale forest owner to large companies and authorities, and the system is intended both for applied planning and research.

The system contains a suite of applications which are freely available for downloading (<http://heureka.slu.se/wiki>): StandWise (figure 1), an interactive simulator for stand-level analysis and includes visualisation in 2D and 3D; PlanWise (figure 3 and 4), intended for forest-level planning with a built-in optimization tool; RegWise for regional scenario analyses; PlanEval for multi-criteria decision making of plans generated in PlanWise; PlanStart, the entry point to the system in which the user imports data from different sources to a dedicated database; and Ivent, a new mobile application for carrying out field inventory.

The purpose of this paper is to give a description of the system as an example of the new generation of multi-purpose forest DSS that is emerging. It will show how a system built on modern systems architecture can enhance the ability to achieve the adaptability needed to meet the diverse challenges facing forestry today.

## 2 SYSTEM ARCHITECTURE

The purpose of the system architecture was to obtain a system that should be easy to modify. Especially, it should be easy to add new models. The system structure is multi-tier, with three main layers called Base layer, Domain layer, and Application Layer. Each layer may be divided into a number of subsystems, each with its own sub-layers (figure 2).

The domain layer contains a number of subsystems. For example, one is called ProductionModel and contains growth models, volume functions, mortality models, and recruitment models. Another subsystem is called TreatmentModel and contains all models for simulating treatments (silviculture and harvest operations).

A similar structure is proposed by the IBM Rational Unified Process, and has been used in frameworks such as IBM's San Francisco (Evans, 2004, chapter 4). The advantage of defining the layers this way, rather than proposed by for example Microsoft, is that the number of dependencies between layers are few, while the pertinence between classes within the same layer, and especially within the same subsystem, is strong. A low degree of dependency and a high degree of pertinence are

two cornerstones to obtain a modifiable system (Yourdon, 1979).

A programming standard document was written for the software developers. Design patterns were adopted, for example "MVC", "Façade", "Dependency Inversion", "Strategy", "State", and "Reflection" (Gamma et al., 1995).

The system was developed in Visual Studio 2005, using C# as programming language. The database is Microsoft SQL Server 2005. All code will soon be migrated to Visual Studio 2010 and .NET 4.0, which supports easy implementation of parallel programming for multi-processed processors. This will speed up computation times, which are now a limiting factor for solving large problems. The field application for sample plot inventory (Ivent) is a Windows Mobile application.

## 3 HIERARCHICAL FOREST MODEL

In Heureka, a forest is represented as a hierarchy. At the top level, the *top area node* contains one or more *sub area nodes* in a recursive way, so there can be an arbitrary number of area levels. For example, the top level may be a region, which may be divided into districts, which in turn may be divided into municipalities. The area node at the bottom of the area node tree contains a number of *treatment units*. A treatment unit is the lowest level at which a treatment activity is defined, such as a thinning. The treatment unit is normally equivalent to a stand. The treatment unit is in turn divided into a number of *cells*. Each cell is linked to a *reference unit*, which is usually a sample plot, real or simulated. Each sample plot contains a number of *trees*. The separation of cells and sample plots allows for having a database of sample plots, with a many-to-one relation, so that different cells can share the same sample plot. This is useful when using imputation such as *k*NN for simulating or assigning data when actual measurements data are not available.

## 4 INPUT DATA

The system was designed to handle "next generation" data in terms of detailed, tree-level data retrieved partly from high-resolution laser scanning and other remote sensing imagery. But models and import functions are available so that stand-level data, such as mean age and tree species distribution, is used as input in models that generate tree lists from theoretical diameter distributions (adult trees) or height distributions (saplings in young stands). Data from a number of different sources can be imported.

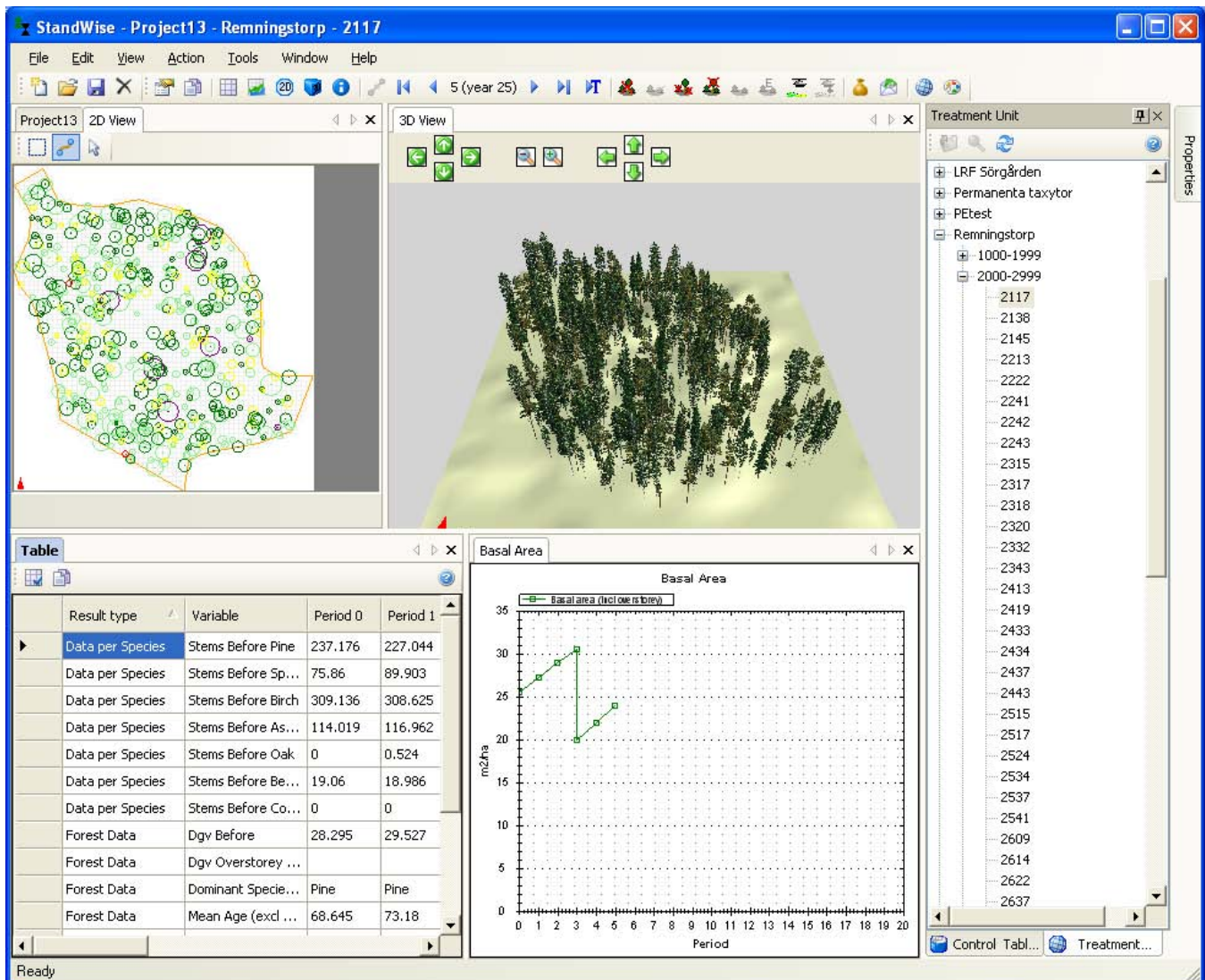


Figure 1: Heureka stand-level management simulator StandWise

## 5 HANDLING MODELS

The purpose of an analysis can be exploration (theoretical), decision-making (practical), or somewhere in between. An example of an exploratory question is if there were no tree mortality, how would that affect economic results or habitat suitability for a certain species? In that case, it is convenient for the user to be able to turn off the mortality model and run the scenario. On the other hand, if the purpose is planning and the results are intended for actual management decisions, the requirement on prediction accuracy and realism is more critical. In Heureka, The user must take notice of whether a certain model is more predicative, or more explorative.

The majority of models in the system are in one way

or another linked to the development of the trees and treatments applied. The development of the tree layer is based on single-tree models for growth, ingrowth, and mortality. Different models can be selected. For example, the user can select from three different growth models and three different height functions. New models can easily be added by a programmer, and a new model will “tell” the system itself that is available.

## 6 SIMULATION OF MANAGEMENT PROGRAM ALTERNATIVES

The treatment program generator is one of the main components of the system. It automates the computation of a large set of alternatives individually adapted to each treatment unit. There are three different manage-

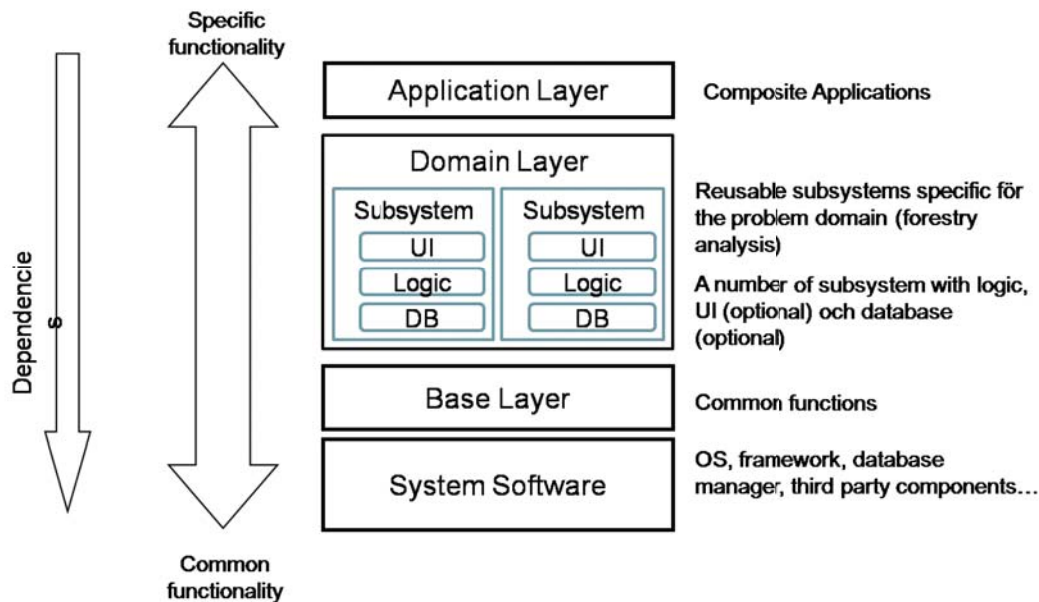


Figure 2: Overview of the Heureka system architecture.

ment system types on which treatment schedules can be based on: even-aged, uneven-aged, or unmanaged. The generation of a set of management schedules for a stand then consists of (i) selection of management system, (ii) determining what treatments that should be included and rules for how these should be applied. For example, the rules for the generation of management schedules may be that even-aged management and unmanaged management should be simulated. In even-aged management, a setting can be made on how thinning should be performed (thinning from below or above), how many times a stand can be thinned during a rotation, and within what limit the rotation length can be varied. Treatments that can be simulated today are planting, natural regeneration, sowing, cleaning, thinning, selection felling, final felling, removal of seed trees, tree retention, and fertilization. In addition, a stand can be wholly or partly set aside for nature conservation.

Of course, it is almost impossible to define a unique set of rules for each stand when the number of stands is large. Therefore, the user can classify the forest into groups, called *forest domains*. A forest domain is created by defining conditions. For example, a forest domain could be called “Old pine stands”, to which a stand is classified on the condition that pine volume should be at least 50 % of the total volume in the stand, and that the mean age should be at least 100 yrs. In the next step, settings for what treatments and rules for their application are associated with each forest domain. A

set of such instructions are stored in a box called *control category*. For example, a control category could be called “Pine management”, and have specific rules for how pine stands should be managed.

## 7 OPTIMIZATION

An optimization tool for formulating and solving linear and mixed-integer programming problems is built-in (figure 3). It uses the ZIMPL programming language (Koch 2004, Koch 2009) to which a graphical user interface with syntax checking and highlighting has been developed.

Opening size constraints can be automatically generated resulting in a so called EARM model developed by Goycoolea et al. (2005). There is a built-in function to compute adjacency pairs, and enumeration of harvest blocks (combinations of polygons) that meet a given maximum opening size tolerance.

## 8 BIODIVERSITY

To compare different plans or scenarios with respect to biodiversity, a number of habitat suitability models have been developed, and are available as a stand-alone GIS program. The program contains six different habitat suitability models. Each model represents an indicator species. Together, these models are proposed to measure to what degree a certain forest landscape or plan can

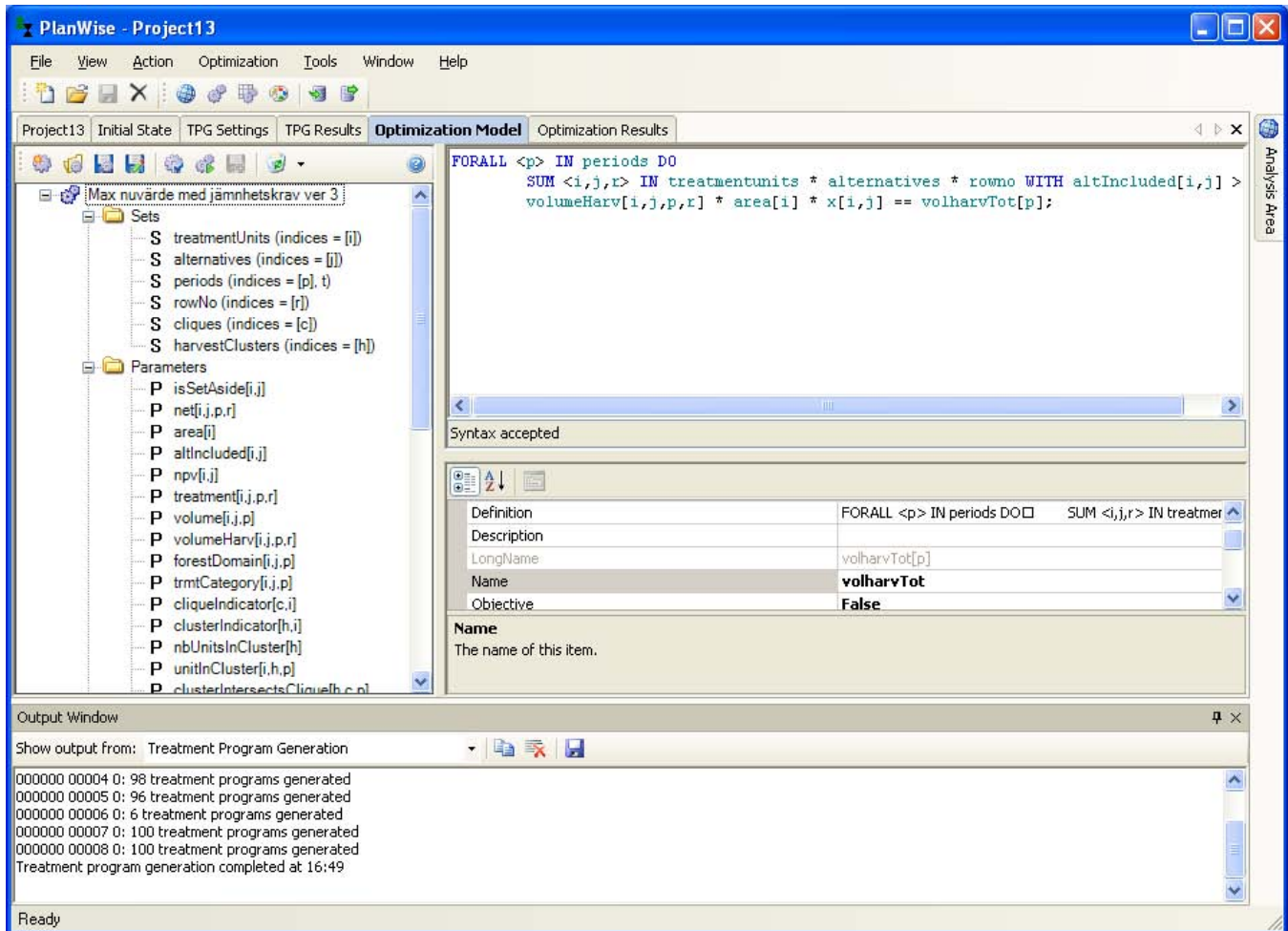


Figure 3: Interface to Heureka’s optimization model, which uses ZIMPL as optimization programming language.

host a variety of species with different ecological niches (Edenius and Mikusiński, 2006; Mikusiński and Edenius, 2006). The GIS program is based on ArcGIS Engine (ESRI) and requires an ArcGIS runtime license to run.

## 9 REPORTS AND VISUALIZATION

A report builder enables creating tables and graphs, for a single treatment unit or for a whole forest area. A map viewer (figure 4) is included with which the user can create thematic maps for those variables and utilities that the system can make projections for. To be able to display maps, the user must supply a forest polygon map in shape file format. The user can make a report or map for almost any variable that is handled by the system.

In StandWise, a 2D- and 3D-viewer enables the user to interact with the map (figure 1). Strip roads can be drawn and trees can be selected for harvesting, or the user can let the program select trees automatically. A unique feature of the stand-level visualization is that

the actual stand boundaries are displayed, and there is also support for visualizing a digital terrain model. The same data is used in PlanWise, so the user can switch between the applications, with the same forest area or stand opened simultaneously.

## 10 RANKING OF PLANS

PlanWise allows the user to develop and inspect different solutions. Due to the ease by which treatments can be defined, stands redistributed on forest domains, and new solutions created with the built-in optimizer, the user can easily create a large number of alternative plans. Although plans can be presented in various ways PlanWise is not ideal for comparing and choosing among plans. For this purpose PlanEval was developed.

PlanEval is a multi-criteria decision making tool integrated with PlanWise (Korosuo et al. 2011). It shares the same tools for presentation as PlanWise, meaning that graphs and maps as well as scalar values can be

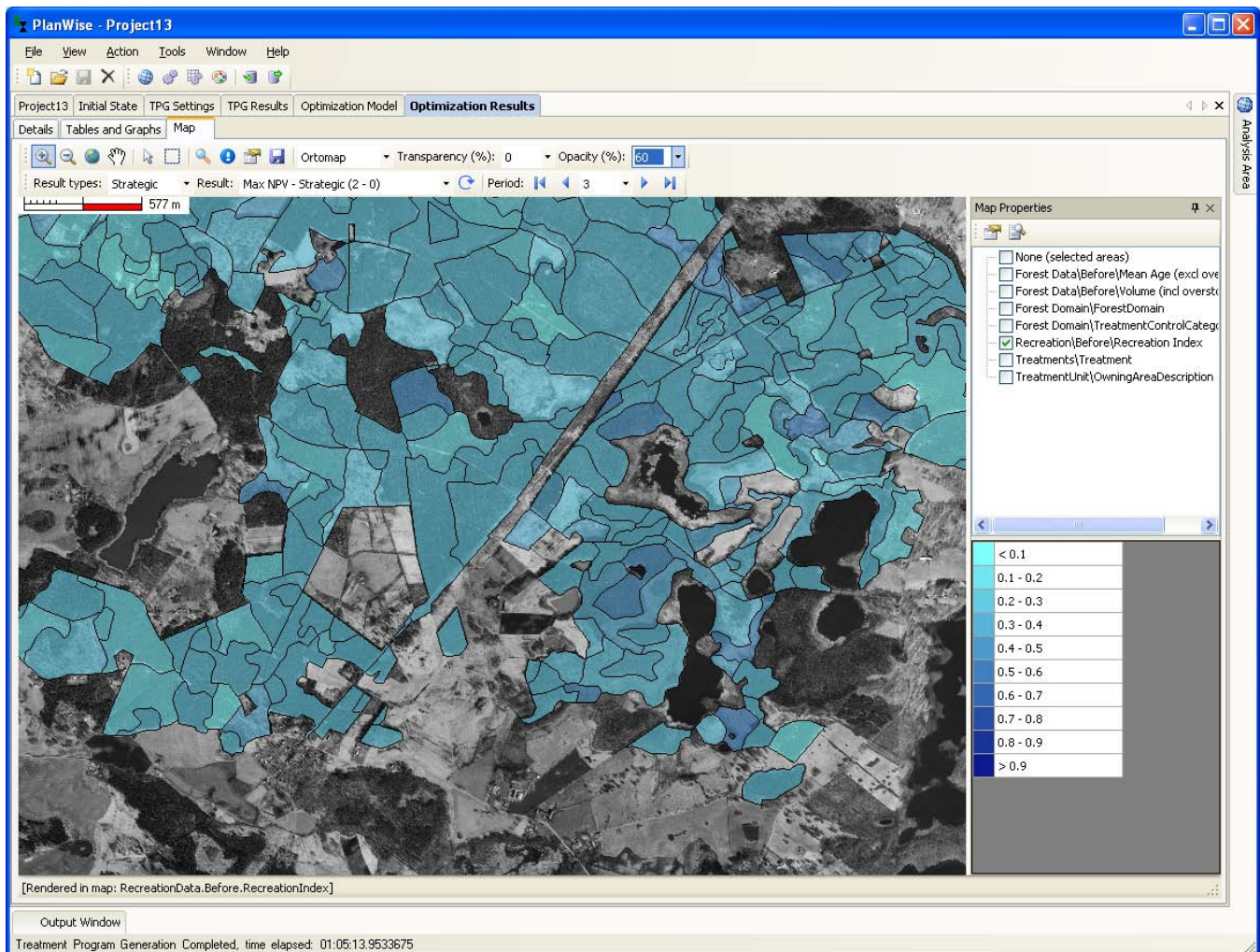


Figure 4: Screenshot from PlanWise showing a map over projected recreation index in a future period.

presented for the user. The integration also means that all data of the plans created in PlanWise are accessible in PlanEval.

The decision maker (DM) works through the choice process through five steps. (1) Once the DM is connected to the database all plans appear on a list. The DM marks the plans that should be subject to analyses. (2) The DM defines the hierarchy of objectives and criteria by creating an analog to a catalog structure. The structure can be of arbitrary width and depth. (3) The DM defines for each criterion, i.e. for each end node of the structure, what aspect of the plan is of interest and how it should be presented. The DM has at the disposal the entire PlanWise database with hundreds of items that can be presented as scalars, graphs or maps. (4) The DM evaluates (i) the relative importance of objectives and criteria in the hierarchy of objectives and (ii) evaluates the relative value of the plans for each cri-

terion. The DM can choose between the multi-criteria methods Analytical Hierarchical Process, AHP (Saaty 1994), and direct point allocation. When evaluating the plans, data is presented as defined in step (3). (5) When all the evaluations have been performed the summary result is presented in a table. It is then possible to analyze why – what criteria and which evaluation – has rendered a plan a specific value.

The tool is designed for a dynamic process. The DM can anytime go back and make changes, whether it be the plans, the hierarchy, the multi-criteria method or the item and mode of presentation of a criterion. In a test of PlanEval by Korosuo et al. (2011) the DM made use of this capability by redefining the objective hierarchy. What appeared to be a valuable feature of the integration with PlanWise was the ease by which data could be accessed from the database. The test also indicated that the methodology for how the tool should

be used to be truly appreciated by a DM needs to be developed.

## 11 CONCLUDING REMARKS

The Heureka system offers opportunities to enter new research areas or to attack old problems with renewed confidence. What are the challenges? The list presented by Martell et al. (1998) could still inspire to give a few examples. Massive spatial and temporal hierarchies make it necessary to work through a sequence of stages with different degree of detail at each stage. Heureka makes it easy to make plans. Combine this with more precise and detailed data sources and there are options for other ways to structure the planning process of larger forest owners. Heureka makes it possible to simultaneously analyze a range of different ecosystem functions and services, which enables new kinds of regional analyses. For instance, biofuel occurrence and carbon sequestration can be projected which makes it possible to couple an analysis to energy models at a national scale.

The forest is surrounded by many stakeholders with competing objectives. The multi-resource nature of Heureka makes it an ideal platform for studying how multi-criteria decision making should be implemented, also when there are several stakeholders.

Forests are complex biological systems that interact with complex social systems. This requires that different specialists, such as computer scientists, operations researchers and specialists in natural and social sciences, work together. The Heureka project proved that focusing on a well-defined and dedicated task, such as providing a multi-resource forest DSS, promoted cooperation over scientific boundaries. We are confident that Heureka will continue to foster that spirit.

All software can be downloaded free of charge, see <http://heureka.slu.se/wiki> for instructions.

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