

DEVELOPMENT OF A GIS BASED WIND RISK SYSTEM FOR BRITISH FORESTRY

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Abstract

In this paper we describe the development of a computer based risk analysis modelling system for British coniferous forests. The basic scientific principles behind the model are outlined and the use of the model as both a stand-alone and as an add-on to a GIS system is described. Finally, there is a brief discussion of the technology transfer process for implementing the system within the British forest industry.

Introduction

A large afforestation programme that was undertaken in Britain particularly during the latter part of the 20th century. As the forests reached maturity substantial damage occurred due to the effects of strong winds. A risk system, the Windthrow Hazard Classification (WHC) was developed to guide forest managers on thinning and the selection of appropriate rotation lengths (Miller, 1985). The system was a subjective ranking based on region of the country, elevation, topographic shelter and rooting depth that predicted a height at which the trees would begin to blow down. The system was formulated in such a way that it did not permit incorporation of new information or understanding, the testing of alternative silvicultural systems or species differences. Furthermore, validation of the WHC proved that predictions were overwhelmingly pessimistic.

ForestGALES

ForestGALES (Geographical Analysis of the Losses and Effects of Storms in Forestry) is a mechanistic model designed to replace the WHC (Gardiner and Quine, 2000; Dunham et al., 2000). The program calculates the critical wind speed to cause any damage and the return period for that damage to occur. The use of such a model creates more flexibility for testing different forest management scenarios such as choice of cultivation, thinning options, drainage improvements, the impact of clearfellings, or the creation of retentions.

The Stability Model Project Team (SMPT) in Forest Research has developed ForestGALES over an 8-year period. Program development has been envisaged as a PC application from the beginning instead of more traditional methods of technology transfer such as bulletins or papers. A clear separation between model kernel and interface ensures the operability of the program both as a standalone application and as part of a GIS. In addition, this separation makes it much easier to introduce future upgrades to the system as a result of new research

findings. The development of the kernel has been done following an Object-Oriented design methodology to increase the modularity, reusability, and easy of understanding of the code.

Model Description

ForestGALES calculates the wind forces on trees within forest stands as a function of the tree characteristics. Firstly the model calculates the threshold wind speeds required for overturning and breakage as a function of tree height, diameter, current spacing, soil type, cultivation, drainage and choice of species (Gardiner et al., 2000; Dunham et al., 2000). The average wind loading on each tree is calculated from the stress imposed on the canopy by the wind from a calculation of the aerodynamic roughness (z_0) and the zero plane displacement (d).

The resistance to breakage is based on the calculation of the bending moment required to cause the stress in the outer fibres of the stem to exceed the Modulus of Rupture (MOR) of the wood. It is possible to write an equation to give the critical wind speed at canopy top for breakage:

$$uh_{break} = \frac{1}{kD} \left[\frac{\pi MOR \times dbh^3}{32G(d-1.3)} \right]^{\frac{1}{2}} \left[\frac{f_{knot}}{f_{edge}f_{CW}} \right]^{\frac{1}{2}} \ln \left(\frac{h-d}{z_0} \right) \quad (1.1)$$

where $k = 0.4$ is Von Karman's constant, D is the average spacing between trees, G is an empirically derived gust factor, dbh is diameter at breast height and h is mean tree height. The factors f_{knot} , f_{edge} , and f_{CW} account for the reduction in wood strength due to knots, the position of the tree relative to the edge and the additional load due to the overhanging weight of the crown respectively. In the most recent versions of the model the need for f_{CW} has been removed by the calculation of the bending of the stem following the methodology outlined by Neald and Wood, 1999).

The resistance to overturning has been obtained from tree pulling experiments on almost 2000 trees (Nicoll and Gardiner, 2003) and is found to be strongly related to stem weight. A similar equation to Equation 1.1 can be derived for the critical wind speed at canopy top for overturning:

$$uh_{over} = \frac{1}{kD} \left[\frac{C_{reg} SW}{\rho G d} \right]^{\frac{1}{2}} \left[\frac{f_{knot}}{f_{edge}f_{CW}} \right]^{\frac{1}{2}} \ln \left(\frac{h-d}{z_0} \right) \quad (1.2)$$

where C_{reg} is a regression constant that is dependent on soil and rooting depth and SW is the stem weight of the tree. See Gardiner et al. (2000) for more complete details.

Once the critical wind speeds have been calculated it is necessary to predict the likelihood of such a wind speed occurring at that location. The wind climate model used in the program is obtained from the DAMS scoring system, which is a function of elevation, topographic exposure, aspect, funnelling effects and wind zoning of the country (Quine and White, 1993, Bell et al., 1995). The DAMS score is found to be well correlated to the Weibull a parameter (Quine, 2000) and the Weibull k parameter is assumed constant. The Weibull distribution is used to derive the extreme wind speed probability distribution (ESDU, 1987) and hence the probability of occurrence of any wind speed. These probabilities are transformed into return periods for both overturning and breakage expressed in the average number of years likely to occur before damage.

Future probabilities of damage are calculated using the Forestry Commission Yield Class Models (Edwards and Christie, 1971). This method allows the stands to grow in time so the program can estimate the annual probabilities for damage at different time steps. The temporal dimension of the model is very important for the estimation of risk during the life of the crop and for testing the best silviculture practices that may improve the retention of the crops.

Development environment

ForestGALES is a Windows-based program written in Delphi™ version 5 (Borland, 1995-2000), using an Object-Oriented design methodology. The system has been designed to operate as an independent module under the different Windows operating systems on standalone computers or in a networked environment using Windows emulators under UNIX or VMS.

The first commercial release of the program was in February 2000 and it was a purely non-spatial version. The beta version of the second release, which incorporates a new wind climatology and better batch processing, was in the January 2003 with an expected release date of August 2003. A spatial version of the model that is integrated with GIS is now under development and it is planned to be released to the British forest industry in December 2003. Before that time the spatial version is being thoroughly tested in two forest districts between June and September 2003.

Figure 1: Example input screen for ForestGALES 2.0 with the calculated return period displayed at the bottom left.

Data requirements for running the model are keyboard input through forms (Figure 1), data stored in text files or remote access from centrally held spatial datasets, such as the Forestry Commission Sub Compartment Database (SCDB) and the Forest Research Environmental Database (FRED). The program also interfaces easily with any spreadsheet and word processing application providing they support the ASCII format. These capabilities allow operations like reporting, input/output facilities and the storing of queries. All these operations are fully described in the User's Guide (Dunham et al., 2000).

Integration of ForestGALES with GIS

The ForestGALES link to GIS is achieved via Avenue scripting for ArcView (ESRI). This adds basic functionality to the system such as displaying of maps, zooming, panning, selection of layers and basic mouse queries.

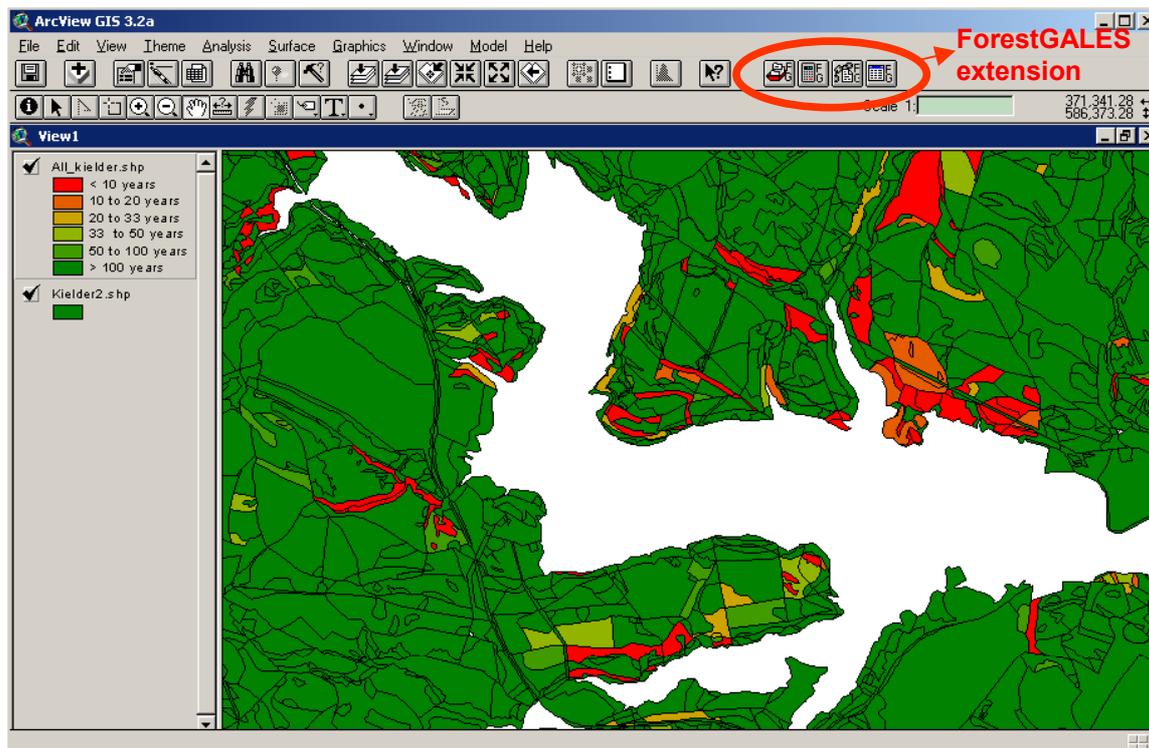


Figure 2: The ForestGALES extension to ArcView showing different levels of risk for part of Kielder forest in Northern England

The GIS functionality provides forest managers with an excellent tool for decision making (Figure 2). It allows a visual analysis of the implications of certain silviculture strategies in terms of wind risk such as thinning, retentions, design of felling coupes, new forest roads or the effect of clearfelling over neighbouring stands (edge effect).

5. Users and user groups - decisions on design, features, integration

ForestGALES was developed as part of the Stability programme within Forest Research. During the development stages a steering group that met on a 6-month basis supervised the work. The composition of the group contained members of the Forestry Commission and the private forest industry. The group made recommendations about the Graphical User Interface (GUI) of the program, the integration of growth models for the temporal mode,

reporting facilities and help system. In particular, it helped ensure that the model operated in a way that would be understandable by the target users.

ForestGALES was advertised widely through all the different development stages and approximately 30 people were invited to comment on a Beta version of the model prior to release. Articles were published every year in trade journals and 15 seminars were given around the country targeting forest managers to inform them about the product. Presentations were made to the Forest Enterprise Management Board (the forest management part of the Forestry Commission), Forestry Commission IT liaison group and Tilhill Economic Forestry (Britain's largest forestry consultant group). There were meetings with the forest district managers in different regions of the country (2 in Scotland, 1 in England and 1 in Wales) and seminars were organised at Universities and Colleges (Bangor, Aberdeen, Buckinghamshire College, Newton Rigg) and to the annual Timber Growers Association /Institute of Chartered Foresters research updates.

This ensured that potential users were familiar with the concepts and philosophy behind ForestGALES before it became available. ForestGALES was released in February 2000 and to date approximately 200 users have purchased the model. Most of these users have been on a one-day training course organised at different locations throughout Britain with the assistance of the Forestry Commission Training Branch. A user group was formed consisting of 9 people from both private forestry and the Forestry Commission who actively use ForestGALES and they provide us with feedback about the product. A similar process will be used for ForestGALES2 and the spatial/GIS version of the model.

The model is now part of the decision making process for many of Britain's forests. However, it will only become completely integral to the management process when finally made readily available through GIS, which has become the standard management tool for much of British forestry.

Acknowledgements

This work was funded by the Policy and Practice Division of the Forestry Commission and the European Commission (STORMS programme, EU contract AIR3-CT94-2392). We would like to thank the other members of the Stability team; Bruce Nicoll, Roger Dunham, Duncan Ray and Elspeth Macdonald, the foresters and technicians who spent so many hours pulling over trees and numerous students without which this work could not have been completed.

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