

Modelling Forest Water Use: The Forest Hydrology Information System (FHIS).

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Introduction

A considerable body of information on the effects of afforestation with exotic tree species on catchment hydrology has been accumulated since 1936 when the first studies began in South Africa. Much of this information is summarised in numerous scientific papers and reports (Versfeld *et al.* 1994). There is nothing wrong in presenting the information in reports and publications, but it is generally not suitable for use by non-hydrologists such as policy makers, planners and managers. The chapter on hydrology in the Forestry Handbook (Versfeld 1993) gives a brief summary of the major findings and the key issues but, as the recent forest policy workshop showed, there is a need to make accurate and up-to-date information available to a broader audience.

The Division of Forest Science and Technology (Forestek) has also developed various models which can be used to provide, *inter alia*:

- information on the impacts of plantations on streamflow,
- information on tree water-use and soil moisture dynamics, and
- guidelines for determining the width of a riparian zone.

Forestek was commissioned by the Chief Directorate of Forestry, Department of Water Affairs and Forestry, to integrate the information and the models in a package that would enable them to find and use the information they needed to make decisions. This system needed to be accessible to managers and laymen alike, so it needed to be simple and convenient to use.

The FHIS package

The Forest Hydrology Information System (FHIS) was developed using hypertext software and the first version has now been completed. The FHIS has been developed to run within Microsoft Windows (version 3.1 or higher). The hypertext package used to develop the FHIS provides both text information and direct access to the models included in the FHIS. Hypertext is essentially an unstructured and very flexible information browsing system. The information on any topic that interests the user can be found using links between related information in different parts of the text. Structured shortcuts have been included to enable the user to move directly to certain topics and to the models provided with the system.

An overview of the system

The FHIS contains both text and models to answer questions and provide information on the following topics:

- **Evaporation:**
 - General information on evaporation from plantations and grassland
 - A model of daily evaporation from stands of pines and eucalypts
 - A model of mean annual evaporation from a stand of pines or eucalypts
- **Runoff:**
 - General information on the effects of plantations on runoff
 - A model of the percentage reduction in annual runoff after planting pines and eucalypts
 - A model of the percentage reduction in dry season (low) flows after planting pines and eucalypts
- **General information on**
 - Plantations and water resources
 - Answers to the most common questions about the impacts of plantations on water resources e.g.
 - * How much water do trees use?
 - * How can I plan and manage my plantation to minimise water-use?
 - * How can I choose the right land-use options for unplanted areas?
 - Regional scale land-use planning for optimising water resource usage, social and economic benefits and conservation
 - Large scale site-species matching using climatic data
- **Water quality:**
 - General information on the impacts of plantation management activities on water quality
 - How to monitor water quality in streams
 - Which water quality variables should be monitored
- **Best management practices for plantation areas:**
 - Guidelines for managing planted areas
 - Guidelines for managing riparian zones and unplanted areas
 - An expert system (Bosch model) for determining riparian zone widths for different streams
 - An expert system for selecting an appropriate land-use for a riparian zone

The first screen of the FHIS (Figure 1) shows the kinds of information provided and of some of the shortcuts. At the top is the Window title, underneath it there are standard Windows menu bar options (e.g. File) and below them there is text and a set of six labelled buttons: *About this package*, *C*ontents, *G*uide, *M*odels, *S*earch, *H*elp which can be selected.

About this package: this takes the user to an introduction to the FHIS, what is in it and some general notes on modelling.

Contents: takes the user to a set of contents pages which they can browse through to reach all the information and models in the FHIS.

Guide: this provides a structured route to the same information and models as the *Contents* button and has two keys designed to help the user find the topic or model that they want.

Models: this is a shortcut which will take the user directly to the section on the models included in the FHIS system and also provides a link to information on models not included in the FHIS. Each model also has some explanatory text which can be viewed using the *Text* button.

Search: this facility allows the user to locate information by searching for keywords that can be linked to particular topics in the FHIS. The keywords are alphabetically arranged and the *Search* function works just like the index of a text book.

Help: this takes the user to the information on how to use the *HyperReader!* software that was used to develop the FHIS.

The FHIS uses a standard layout for all its text screens (Figure 2). The scroll bar on the right of the text is used to scroll through the text. At the top there is a row of buttons which allow you to select various shortcut options:

Contents, *Guide*, *Models* and *Search* take the user directly to those facilities, while *Print* prints out the text on the topic displayed in the current window. *Help* gives the user instructions and advice on how use the hypertext software.

Go back: go back to the previous location. This can be used repeatedly to move back to where you started from.

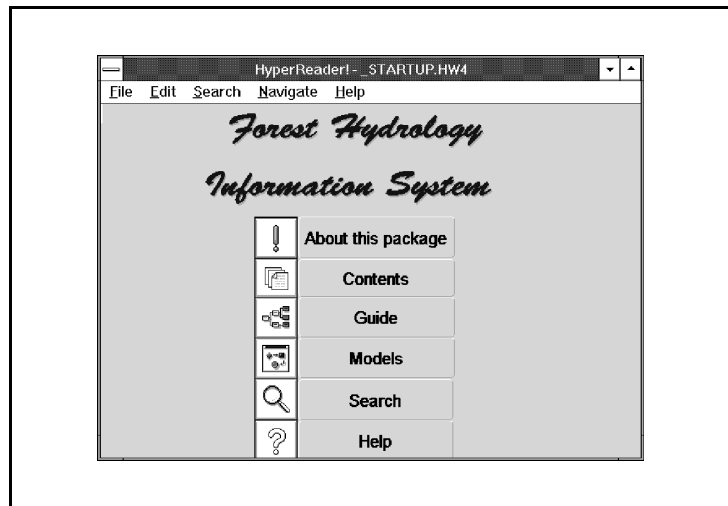


Figure 1 The first text screen of the FHIS showing the Windows menu bar, title and the options you can select. For more information see the text.

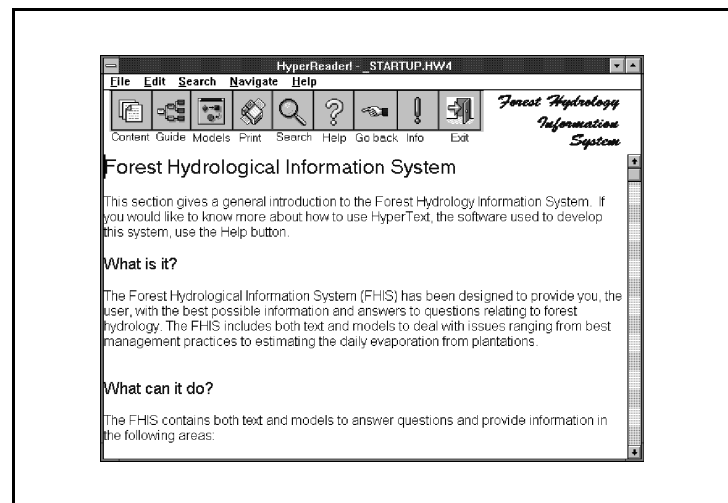


Figure 2 A typical text screen in the FHIS showing the header with a row of buttons and some text. For more information see the main text.

Info: move directly to the introductory text of the FHIS.

Exit: exit from the FHIS.

Hydrological models in the FHIS

Models of the hydrological impacts of plantations have been derived from two kinds of studies: (i) direct measurements of evaporation or water flow through trees and (ii) measurements of whole catchment rainfall and runoff. One approach makes use of studies of either the evaporation from plantations or of sap flow through individual trees. The other approach is based on studies of the whole catchment as a unit. The hydrological models in the FHIS can be divided into two groups based on the above distinction.

Models based on catchment studies

In catchment studies the typical procedure is to establish a streamflow gauging system and weather stations for a set of carefully selected, neighbouring catchments. The catchments are chosen to ensure that they are more or less the same size, have similar geology, topography, aspects and climates. After a calibration period to establish the relationship between rainfall and runoff in each catchment, and to compare the catchments, one or more of the catchments is afforested or is given some or other treatment and one is kept as a control. The changes in streamflow are then estimated by comparing the new flow patterns with those from the calibration period. This 'paired catchment' technique gives very reliable results and currently provides us with the best data to use in estimating the impacts of afforestation on rainfall water supply. The technique is also simple and useful because all the hydrological processes and the spatial heterogeneity within a catchment is integrated in the single measured output of streamflow.

Historically, catchment studies have examined the changes following different treatments and related them to the treatment or the species planted on the site. Changes in streamflow were simply related to the time after treatment without considering how fast the trees actually grew or attempting to determine the actual relationship between stand growth and water-use (Van Lill *et al.* 1980). The model used in the Afforestation Permit System (van der Zel 1995) did not distinguish between tree species or sites with differing potential growth rates (Bosch and Von Gadow 1990, Görgens and Lee 1992).

The *Flow Reduction Model* in the FHIS predicts the percentage reduction in the total runoff (or low flow) and does distinguish between pines and eucalypts and uses two classes of site quality (Smith and Scott 1992; Scott and Le Maitre 1994). The reduction is calculated as a percentage of the runoff before afforestation i.e. a 100% reduction in total runoff means that the streams will dry up completely. The model is designed to calculate the impacts of afforestation on the runoff at the scale of afforestation, and is useful for regional and broad scale studies.

The *Growth-Evaporation Model* is used to estimate the likely mean annual evaporation from a homogenous stand over the period of one rotation. Separate models are available for *Pinus radiata* (winter rainfall region), *P. patula* (summer rainfall) and *Eucalyptus grandis*. Stand growth is projected using a site growth index (SI₂₀) and a schedule of thinnings using stand

growth models. The annual evaporation is predicted from the stand growth, based on an empirical relationship between annual evaporation and the projected stand basal area. The model output should be interpreted in the same way as stand growth projection models i.e. to determine possible mean evaporation for a stand using the stand basal area. It is intended for use by planners and other people wishing to estimate the evaporation from a compartment.

Models of evaporation

The South African Patch-scale Hydrology Model (SAPHYR) integrates the results of a considerable body of research on forestry hydrology. The main aim and benefit of the model is to permit comparisons of the water use patterns of plantation forests and alternative vegetation types such as natural montane grassland and indigenous forests, and to predict the effect of changes in water use on streamflow. It must be emphasized that our understanding of forest hydrology in South Africa is very far from complete, and that the model will continue to be refined in future as more research results become available.

Currently only the models of daily evaporation from stands of pines and eucalypts have been completed. The strength of the SAPHYR model is its ability to estimate the daily evaporation, (interception and transpiration), soil wetness and streamflow for plantations of pines and eucalyptus trees. At present, the soil wetness and streamflow are simply modelled based on the difference between rainfall and predicted evaporation. Much more information on the background and development of the model is given in the FHIS hypertext system. Technical information on the model structure, some of the constraints on the model and the assumptions that had to be made in developing the model also are described in this text.

The SAPHYR model has been designed to allow the user to use it repeatedly with different sets of options, creating and saving the different outputs as scenarios. An example of a scenario would be a comparison of the impacts of planting pines or eucalypts on the same site. The model is run once with eucalypts and once with pines. The output graphs can then be compared to see if there are differences and how important they could be. The philosophy is that the user should be able to try different options and to learn how different options affect the outputs.

Expert system models

The FHIS also includes two expert systems, one for determining the riparian zone width (the *Bosch* model) and one for selecting an appropriate land-use for a riparian zone.

Riparian zone widths

The aim of the model described in this section is to provide a formal basis for consistent decisions on the width of the unplanted riparian zone to be reserved when afforesting natural areas (Bosch *et al.* 1993). The reasons driving the decision vary from location to location. For example, in one area it may be highly desirable to secure the flow of a small stream for which a relatively wide unafforested riparian zone would be needed. A different small stream may be regarded as unimportant with a consequent recommendation of a narrow open zone. In other cases it may be desirable to minimize evapotranspiration from a catchment by recommending wide zones along a strong flowing stream. In such a case the influence on the stream itself may not be that apparent.

The model asks a series of questions about the features of the stream (reach) under consideration. Three different aspects of the stream are evaluated:

- *water yield*: the expected change in evapotranspiration, and thus water yield, when natural riparian vegetation is replaced by exotic trees;
- *nature conservation*: the conservation merit of the natural stream environment; and
- *water quality*: the effectiveness of the remaining natural vegetation as a buffer strip in reducing sedimentation and pollution of the stream.

At the end the model expert system provides a summary screen which gives the recommended minimum width of the riparian zone for each one of these factors.

Riparian zone land-use options

Riparian zone management is an important part of commercial forestry practice and unsuitable riparian zone management can lead to degradation of riparian ecosystems, declines in water yield and quality, weed infestation and reductions in conservation status. The primary aims of this model are to ensure that low flows are protected, and that the riparian environment is not degraded. The riparian land-use selection model is a prototype rule model for selecting appropriate land-uses, or management options, based on features of the riparian zone such as its width, soil erosion potential and conservation merit (Bosch 1992). The model has been formulated so that you select a land-use, answer the questions, and it then accepts or rejects that land-use option based on certain criteria.

Concluding remarks

The FHIS is a structured way of organising and presenting a large body of hydrological information and a set of models. It provides a handy and easily accessed source of information on the impacts of both planted and unplanted areas of plantations on water resources. The development of the system and the process of organising the data and the models has identified gaps in our current knowledge and should lead to the identification of further gaps.

The FHIS has been developed at the request of the Chief Directorate of Forestry, Department of Water Affairs and Forestry, but we believe that it should be made available to anyone who wishes to use it. Some of the models, notable SAPHYR, are probably too highly detailed for everyday use by the general user but they are available should the need exist. We would like users to give us feedback so that we can incorporate the suggestions and improvements into future versions.

The FHIS is not perfect, but we believe that it can provide the material needed to get informed and constructive debate going on the issues relating to plantations and water, to replace the current conflict between forestry and conservation. This, of itself, will be a significant contribution to the sustainable development and effective use of South Africa's most important natural resources: water and productive land.

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