# An information system of ecological models

R. Lenz, M. Knorrenschild, C. Herderich, O. Springstubbe, E. Forster* J. Benz†
M. Asshoff, W. Windhorst ‡

## Contents



## 1 Foreword

During the course of development of the concept of the information system many discussions with modelling experts throughout Germany took place. We are very much indebted to their critical remarks and valuable input, particularly to H. U. Bartsch, J. Bauhus, K. Budaeus, G. Dubsky, W. Gärtner, K. Grossmann, V. Hennings, J. Kaiser, M. Matthies, P. Schall, Ch. Scholz, J. O. Wagner, P. Wernecke.

*GSF – Forschungszentrum für Umwelt und Gesundheit / PUC, 85764 Oberschleißheim, Germany, e-mail: ufis@gsf.de
†University of Kassel, Faculty of Agriculture, International Rural Development and Environmental Protection (FB 11), Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany, e-mail: benz@wiz.uni-kassel.de
‡Ecosystem Research Centre, University of Kiel, Schauenburgerstr. 112, 24118 Kiel, Germany, e-mail: meinolf@pz-oekosys.uni-kiel.d400.de

# 2 Introduction

## 2.1 The Problem

Due to increasing activities in ecological modelling over the past decades it has become difficult for the individual ecologist to stay informed about the state of the art. Worldwide there is a huge number of models available designed for various purposes. Doubtless sharing one's expertise with others is the base of scientific progress, but in reality this is hard to come by. Publications in scientific journals serve more as brief summaries of a model's properties, but not as a source for details on approaches taken by the authors. They are also not meant to serve this purpose due to limited space available. At the end one has to approach the modeller, i. e. the author himself, in order to get the information one is looking for. Examples from electronic mailing lists give an idea what typical inquiries among ecologists are: "I wonder if anyone knows of any models (and input data needed) simulating the growth of winter and spring cereals, in particular, barley and wheat" or "I am looking for a good nitrate leaching model under corn. A model that tries to account for corn nitrogen use and soil microbial activity might be helpful instead." These were posted to agmodels-l[1] in April 1994. It is obvious that the present situation does not support a free flow of information on models. Therefore, occasionally double work is carried out, the wheel is being reinvented sometimes. Also, for example in ecosystem modelling expertise from different areas is needed, e. g. soil sciences, biology, physics, etc.. Modelling nowadays is an interdisciplinary task, modellers need to use knowledge outside their own specialty.
Furthermore modellers are not the only ones who would benefit greatly from a further distribution of modelling knowledge. Local authorities, legislative bodies, and funding agencies need to keep an overview on models in order to fulfil their tasks.
The kind of information on models that is being looked for varies greatly due to the different background of the inquirer. One of the most important items of information is the setting in which a particular model is valid. A lack of reliable information on validity significantly restricts the application of models. Modellers also want information on process formulations, possible applications, input data needed, output data yield. The generic ecologist who merely wants to apply the model may not care for process formulations but needs details on data requirements, and technical questions. On the other hand funding agencies e. g. would be happy with more general information only.

## 2.2 A possible Solution

As outlined above scientific journals cannot be a remedy in this situation. For the question of availability and access to ecological data there are widely used tools at hand: online-databases on various kinds of data like climate, weather, vegetation, and data of geographical nature. One premier example is the Australian ERIN – system that is readily available to scientists via a worldwide and unrestricted computer network. It is natural to consider a similar device that would distribute information on models. We are not aware of the availability of such an information system at the moment, and it is clear that the development of it is not an easy task. Due to the wide range of demands that are posed to an information system of models, it does not appear feasible to please all requests with a single information system. Currently there are two information systems under development, UFIS at the GSF research centre for environment and health near Munich and ECOBAS at the University of Kassel. Either one will provide general information on models, but the projects differ in their intended uses. Basically, UFIS is an information system on models as a whole (and in a later stage also on data) and ECOBAS is an information system on process descriptions within models. Details can be found in the later sections in this report. The basis for the information on models maintained in UFIS and ECOBAS is identical. Acquisition of model information is via a comprehensive questionnaire which is described in section 4. In the following we outline the ideas of each of the two projects.

[1] For information on this list send a one-word message "help" to listserv@unl.edu

# 3 Concepts

## 3.1 The UFIS Concept

Work on the UFIS[2] – project started in fall 1992 at the GSF Research Centre for Environment and Health and is being funded by the BMBF[3]. One part of UFIS is designed to offer information on ecological models as a whole. The goal of UFIS is to provide a tool that supports interdisciplinary work among modellers as well as to give administrative bodies an overview over national and international activities in ecological modelling. The availability of such an information system is believed to be crucial to international coordination of modelling activities. Due to increasing ecological problems on a global scale coordination has become a key issue to the scientific community and has led e. g. to the formation of the International Geosphere-Biosphere Program (IGBP). Model comparisons and questions of model coupling have been defined as key goals in many IGBP activities (see e. g. [igb94]). Consequently UFIS will pay particular attention to data requirements of models, areas of application, and scales of the model.

The second part of UFIS which is closely linked to the model documentation focuses on the description of data. The interface to be established follows the items "need of data" and "data yield" in the model documentation. Hence in a final stage of development UFIS will consist of two meta data bases, one on models and one on data.

The background of archiving, describing and the retrieval of such information can be elucidated by reflecting within UFIS the pathways and stages necessary in developing models, and thus boiling down and concentrating the knowledge gained by scientific work. This should make sure that the context of a model - from data requirements to the characterization of the ecological system considered - is documented within UFIS and therefore retrievable (see figure 1). The reason that models and their respective data descriptions were chosen for documentation is that they represent condensed knowledge of complex situations. This does not hold for data, keywords, etc. alone. Here we use the term "model" in the widest sense, basically any kind of combination of data, even simple ones.

The method of modelling can be characterized by five mutually related "sources of information" (see figure 1):

1. Conceptual models, i.e. verbal models, hypotheses and theories, strategies etc.. These are derived from observable reality as well as real data about reality (i.e. empirical and quantifying).

2. Mathematical simulation models: they represent the formal counterpart of conceptual models and allow similar as in an experiment to produce data that could be compared to reality. If successful, prognoses and transfer in areas not considered is possible.

3. Computed data, 4. measured data, and 5. observable reality (e. g. certain species and their overall behaviour) have been mentioned already as required input to and output yielded by models resp. (see 1. and 2.).

These five sources of information have their counterparts in the components of the information system UFIS: the retrieval system contains a user guidance by thesauri, systems ecological classifications and environmental media, thereby covering essential parts of the model concept. More detailed information reaching as far as the mathematical description of ecological processes is then accessible from the full model documentation which is available as a paper-based completed questionnaire as well as online from the database. This enables identification of data requirements of a model as well as data yield by the model. Note that UFIS contains only data- and model-descriptions (so called meta data), not data themselves. The data themselves usually relate to an ecological context, i. e. they permit conclusions only under certain ecological conditions. Basically UFIS contains five (or four, if one considers the retrieval system only as a means of access to ecological classification and model documentation) mutually related categories of information covered by the questionnaire. Therefore it is likely that ecological knowledge has been described in a transparent way and qualitatively verifiable.

The systems ecological classification has to cover all ecological systems from the cell (and its environment) up to the ecosphere. The general structure is based on a hierarchical concept of the organization of matter

[2]UFIS is the acronym for the German term for environmental research information system ("Umweltforschungsinformationssystem").

[3]Federal Ministry of Education, Science, Research and Technology

Figure 1: Concepts of modelling vs. concepts of information systems

[Mil75, Len94], on the one hand, and the environmental media (soil, water, air) on the other. Although "ecological" by definition counts for feedbacks of biotic and abiotic factors, a lot of so called ecological research is classical work in physics, chemistry or biology. Hence the keywording by disciplinary thesauri already in use might be sufficient. Therefore we decided to give further and more flexible orientation in UFIS also by just key-wording what is modelled while not disregarding the ecological classification above. Because of the novelty of the classification in UFIS it is reprinted in the appendix. Further descriptions of the context are budget modelled (if applicable; e. g. water), geographical location, and environmental setting (see also section 4).
Besides the focus on the context of ecological knowledge documented by models and data another feature of UFIS is the flexible degree of details of the information in order to meet the needs of a wider range of users. This is described in section 6 and is to some extent also true for the ECOBAS concept (see section 4).

### 3.2 The ECOBAS Concept

ECOBAS is a project run by J. Benz at the University of Kassel. Its focus is on mathematical descriptions of ecological processes. It is intended mainly as a source of information for development of models and for theoretical ecologists. The conceptual background of ECOBAS is as follows:
an ecosystem (or part of it) can abstractly be seen as a number of processes that interact with each other in various ways. Mathematical formulations provide a mean to quantify the relation between input and output variables and therefore the overall behaviour of the system. There are two kinds of input variables, the ones that enter the system from the outside ("explicit" input variables) and those that are included already in the mathematical formulation of a process ("implicit" input variables) (see figure 2). Therefore a complete documentation of a process needs to include

- the *type of process*, i. e. the equation (or system of equations) itself
- sets of parameters and limits of validity. For each type of process there are several choices of parameter values possible depending on the context. These are called *realizations* of a process.

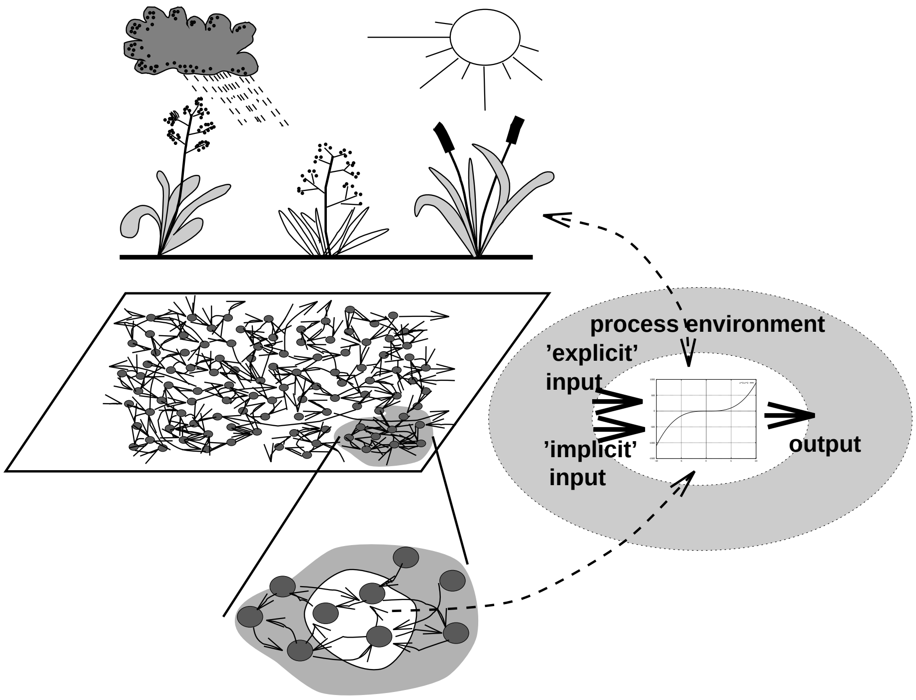



Figure 2: ecosystems and processes

- a description of the environmental setting corresponding to the specific realization.

Example: primary production can be described by

$$\frac{dB}{dt} = f(B, T, L, a, b)$$

with input variables temperature ($T$) and radiation ($L$) and parameters $a$ and $b$. With varying plant species and varying location $a$ and $b$ will have varying values. The equation itself is the type of process, the documentation of the parameter sets is the realization and the ecological environment of the object modelled is the environmental setting. See also figure 3. Another aspect to be considered is the network of processes within a complete model. Output produced by one process can be input

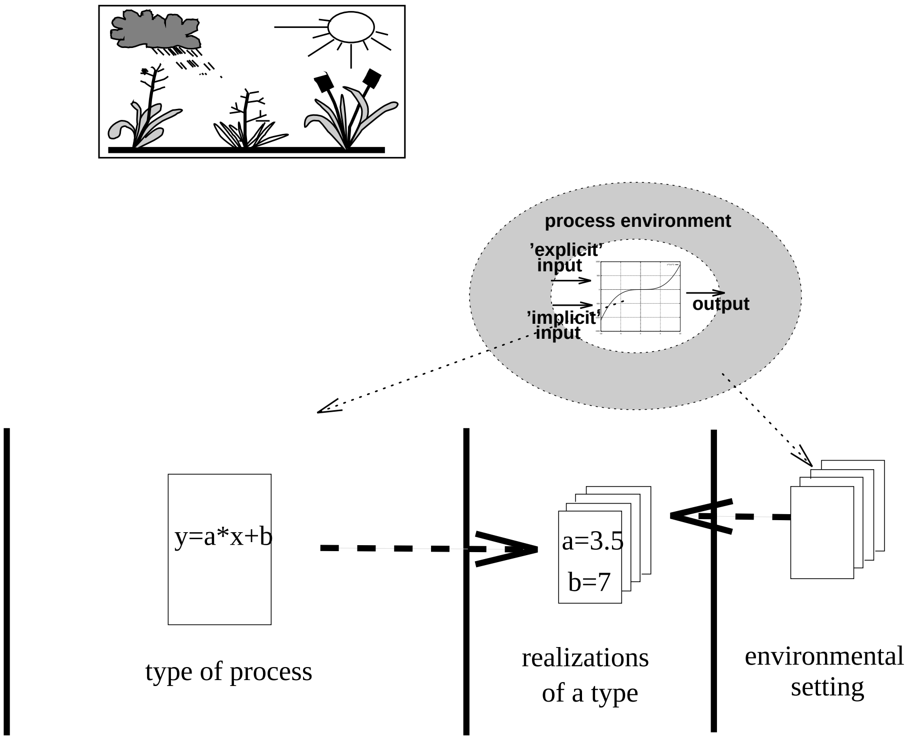



Figure 3: relation between type of process, realization, and environmental setting

to another one, reflecting the complex interaction of processes in nature. In order to document this aspect appropriately, one needs to include a full description of the quantities involved in the processes, classifying into input and output variables resp. and reflecting the network of processes within a model. The specific needs have been described in [BK93], [Ben94].

# 4 The Model Questionnaire

Model questionnaires have been developed already for specific purposes. There is e. g. one for forest models [TvGe93], and one for crop models [gct94]. These references contain completed questionnaires of 18 and 12 models resp.. A common feature is that these schemes are tailored for their specific area of application, and they cannot be applied to general ecological models. However, this does not apply to the "handbook of ecological models" ([JNHS95]) on which work is currently in progress. This handbook will contain information on several hundred models. All these references give a good sample on the contents of the models but do not provide details like process descriptions. Also the information on the models is not available in a computerized database, but only in printed form. Therefore searches are convenient if one knows the names of the models one is looking for. A severe drawback of all questionnaires that we are aware of, is the freedom that they grant for making entries on it. Most entries are in free text, so the amount of detail given is up to the person who completes it. Furthermore this freedom undermines convenient searches with prescribed keywords. As a consequence we were confronted with the task to design a new questionnaire that is applicable to a wide variety of models keeping the intended use in a computerized database in mind. The development of our model questionnaire started out from a first concept by Asshoff ([Ass91]). Its origin is the idea of the Ecosystem Research Centre of the University of Kiel to set up a database for the models developed there. The goal was a standardized model documentation scheme. The nature of a standard requires that there is only one of it (also unfortunately this does not necessarily hold in reality), so the requirements of the UFIS and ECOBAS information systems were merged with Asshoff's scheme and the result is the questionnaire that is included in this report (section 7.1). It comes with detailed instructions on how to complete it (section 7.2). Since it is designed to serve as a basis of two information systems with different goals, it is quite comprehensive.

The information contained in this scheme on a particular model is threefold: general information, description of processes within the model, and technical information. The first section provides general information on the model. Besides the obvious items like name and address of the modeller, a brief summary of the aim of the model and its basic ideas, valuable information regarding the range of applications is given. This includes references to other models that could possibly be coupled with the one under consideration. The suitability of the model for purposes other than the original one can to a certain extent be judged from reports on calibrations and validations performed (and the data been used) as well as spatial and temporal scales. References to user manuals and to a detailed model documentation are available as well. A flow diagram of the model structure will provide the UFIS user with an idea of the organization of the model and its submodels.
The second part of the scheme is influenced by the ideas of ECOBAS as outlined above. As the hierarchy among the processes within the model is given by the coupling between these equations via variables information is stored for each process separately, refering to underlying subprocesses via pointers. This information includes for each process: brief description, mathematical formulation, possible constraints, initial/boundary conditions, spatial and temporal resolution, references to the literature and embedded subprocesses. A set of keywords regarding the type of process, type of equation, type of balance/flow enables an efficient retrieval. Quantities used in the mathematical formulation will be classified as *input* and *output* for each process, indicating also which quantities are input and output resp. to the full model. For each of the quantities a brief description, values used, range of ecologically relevant values is given and also the source of the data (where applicable). It is also reported on sensitivity analyses performed by the modeller. In case the mathematical description of a model cannot be split into different processes there is the option to describe the model verbally. However, we designed the structure of the scheme in a very general way, such that this case is considered the exception rather than the rule. For each single process a table of environmental conditions contains a description of its environment. Entries in this table describe the physical environment in which the underlying process formulation is valid. One of the items asked is the "level of organization" (see [Mil75], [Len93]) on which the process takes place and a more specific characterization within the chosen level (which type of ecosystem, which species etc.). Checking lists for these specifics are supplied; in particular a comprehensive thesaurus for types of ecosystems has been developed. Further items sought are geographic location, type of climate, and type of soil. The particulars are to be given as general as possible without violating the validity of the process formulation. Where meaningful and available, information will be given by means of commonly used classification schemes (e. g. the FAO – scheme for soil types). The classification schemes intended to be used can be found in sections 7.4, 7.5, 7.6.
The third section of the questionnaire deals with the computer implementation of the model. It is divided in software and hardware related information. Software questions covered are the possible requirement of certain libraries in order to run the model, programming language used and where to get complete program documentation. For the goal of UFIS as outlined above the data question is of particular importance. The UFIS user will find here detailed description of the input files needed and also where to obtain them from. Of course sources of the program code itself, demo input, and sample output files are also given. Hardware requirements are also covered, i. e. for which operating systems model code versions are available, as well as disk space required.
In this report we also include a completed questionnaire as example in section 7.3. For this purpose we have used a winter wheat ontogenesis model from Agroökosystemforschung Quedlinburg. It is a medium sized model and its documentation illustrates the ideas of many of the items on the questionnaire.

# 5 Technical Realization

In view of the amount of paperwork required by the modeller who wants to (or is urged to) provide the full documentation of his/her model work on a computerized version of the questionnaire is in progress. This program will be PC – based and will guide the modeller through all the questions being asked, and will accept answers on screen. In particular it will provide access to thesauri. It will also run a few simple consistency checks on the input it is fed, such that obviously erroneous input will be rejected right away. It is intended that a modeller is rewarded for completing the scheme by returning him a full documentation of his model, along with a structural diagram (since the structural information on the network of processes within the models is required on the questionnaire, it can be used by the program to produce this diagram). Model information accepted by the program will be saved to a file and sent to the managers of the information systems. There it will be postprocessed by filter programs according to the needs of the two databases. Both databases will be implemented using the $INGRES^{TM}$ relational database management system in order to enable technical coordination between UFIS and ECOBAS.

## 5.1 Technical Realization of UFIS

The goal of the UFIS database development is the coverage of all items from the model questionnaire and their storage in a relational database management system. Therefore the questionnaire represents the foundation of the database. The database is currently being implemented with the database management system Ingres (version 6.3) on a Convex super minicomputer. Usage of the database is possible with very modest hardware requirements via worldwide networks.

**Database design:**
An analysis of the model questionnaire reveals that it is a strongly structured text document. The items inside the boxes on the questionnaire can each be viewed as a separate page on its own. Within the boxes further subdivisions are possible. These pages together with their mutual relations represent the complete model documentation. Therefore it is natural to view the model documentation as a hypertext document; this is the underlying idea in the design of the database. In order to realize this idea there was in general one table created for each box on the questionnaire. Due to technical limitations some boxes required two tables. Additional tables were also required for the list of keywords and the system ecological classification as well as for the purpose of database administration.
**User interface:**
There are two user interfaces available for retrieval in the database. The first one is alphanumerically orientated and can be used with any ascii-terminal. It offers two kind of screens, one for searching and one for browsing. The search screen allows the selection of a set of model documentations by prescribed conditions. The browsing screen provides views on the hypertext pages of the model documentation. Access is via X.25 or internet[4].
The second user interface is integrated in the world wide web (WWW), a world wide distributed hypertext system. The UFIS database is integrated into the WWW by allowing output of model information in HTML format (hypertext markup language) which is the standard format within the WWW. Access is via URL: http://www.gsf.de/UFIS/ufis.
In addition to the two interfaces for UFIS users, there is another interface for the UFIS managers for administration and input of data. For an illustration of the various interfaces see figure 4.

[4]For details on access contact the UFIS group at ufis@gsf.de

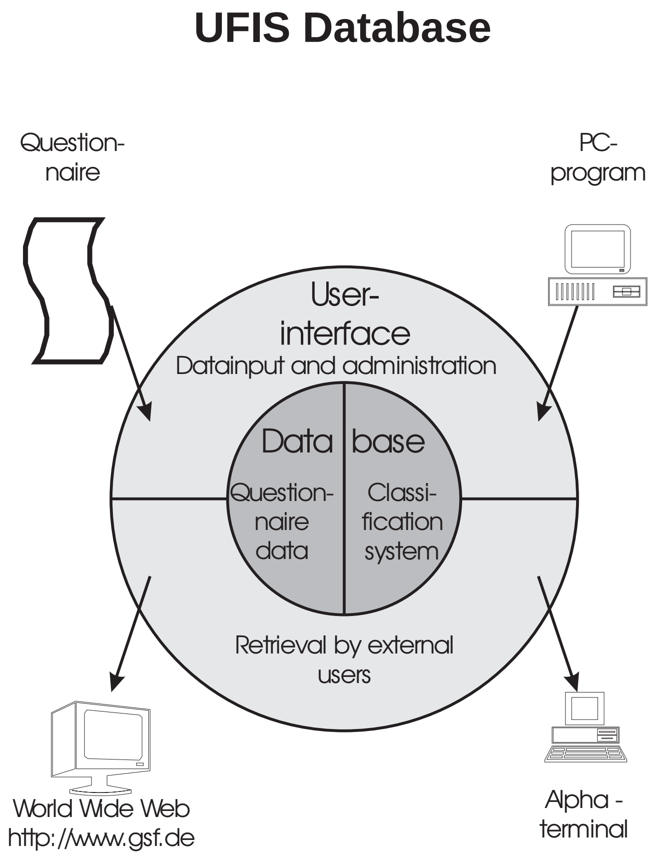



Figure 4: access to UFIS

### 5.2 Technical Realization of ECOBAS

The ECOBAS database design is governed by the relations between the processes and its related quantities as described above. The database is implemented like that of UFIS with the relational database management system Ingres.

**Database design:**

ECOBAS focuses on ecological processes rather than on models, so in order to make full use of the relational database for the goals of ECOBAS the structure of the database should reflect the mutual relations of processes and input/output quantities. Therefore the table of processes is at the centre of the layout of the database. From this table there are links to the tables of input-, output quantities, realizations and references.

**User interface:**

A user interface for the ECOBAS database is under development. Retrievals within ECOBAS will be possible via an online search form that can be filled out via one of the hypertext documents provided by the ECOBAS – ecological modelling WWW – server[5]. This WWW server will also maintain links with other WWW servers worldwide providing information on ecological models.

In the first stage of the implementation of ECOBAS, three basic retrieval functions are available:

- retrieval of types of processes (given: certain inputs, certain outputs)

- retrieval of realizations of certain types of processes (given: certain environment, certain model(s), certain ranges of validity)

- retrieval of variables or parameters

The combination of these basic retrieval functions allows a wide range of complex searches in ECOBAS. It also allows to recover possible coupling and therefore also possible networks of processes. In general there

[5]URL: http://dino.wiz.uni-kassel.de/ecobas.html

will exist a high number of alternative networks, most of them are not meaningful or justified in a certain context. Therefore it is necessary to give the user the possibility to check the consistency of such networks. At present, ECOBAS offers the following possibilities for checking the consistency by

- the description of models,
- the relation between the documentation of realisation and the description of the environment and
- the documentation of the ranges of validity

This will significantly cut down the number of possible networks. Further research in this direction is necessary.

### 5.3 The UFIS/ECOBAS File Server

This ftp-file server is a common project of UFIS and ECOBAS and will complement the efforts of UFIS and ECOBAS in improving access to modelling know-how. It has been established in October 1994 at the university of Kassel and contains codes of ecological simulation models. The idea is to provide ecological modellers and other people interested in models with an easy access to software. It is also thought for modellers who want to distribute their models easily without having to bother about file-servers themselves. Ideally, the server could become a central source for obtaining ecological model software; it is searchable by archie and is provided as a service to modellers throughout the world. It is also accessible from the ECOBAS ecological modelling WWW server.
Modellers are invited to contribute their codes to the server. Naturally, only software in the public domain can be accepted, since it will be accessible free of charge and without any registration procedures. Also, it is not intended to provide user assistance for the software; UFIS/ECOBAS will merely administer the server. The server is directly accessible in the following way:

- Name of ftp-server: ftp.hrz.uni-kassel.de
- login: anonymous (or simply: ftp)
- directory: /pub/ecosys/models

This directory contains

- a file named Contents containing a list of models currently available on this server together with a brief description of the models,
- one subdirectory per model.

Anyone who wishes to contribute models to the file server is welcome to do so. This can be done in the following ways: either it can be put directly on the ftp-server in /pub/ecosys/incoming or it can be sent on a disc to the UFIS or ECOBAS group.

## 6 Perspectives

In this section we want to deal with the questions (i) how to choose models for documentation, (ii) what kind of further interfaces to other information systems should be developed, (iii) how to convince the modelers to document in UFIS/ECOBAS, and (iv) how the availability of models and data itself could be improved.
The best way to start with the model documentation is not to do this randomly but systematically. Due to their respective duties and goals UFIS and ECOBAS are going somewhat different ways. UFIS started out with BMBF projects and models, selected about 30 from the BMBF-managed database DAVOR, and about 120 by an inquiry at ecosystem research centres throughout Germany.
In its early stages ECOBAS is focused on agricultural models, especially more complex ones, in order to facilitate the comparison of processes (see section 3.2). In general future selections will follow the principles

of representativeness which means a choice of a wide range of ecological models, both from different levels of organization as well as more aggregated and more process-orientated ones. UFIS and ECOBAS will continue in being complementary also from this point of view.
At present various information systems are under development, and in the near future a careful check of possible cooperations and interfaces has to be done. An intensive review of information systems in ecological research has been carried out[6]. Also the meetings of UFIS/ECOBAS and others supported further links of information systems for adapting the contents or technical features or both. Up to now it is planned to collaborate and possibly interface with the ecosystem research centres, the PIK[7], DKRZ[8], NLB[9], BGR[10], DLR[11], UNEP-HEM[12], GKSS[13], ZADI[14], KfK[15], UFZ[16]. The world wide web (WWW) will be the tool for most of these links, but hopefully the documentation scheme will be adopted by the institutions themselves, and many modellers will feed the UFIS/ECOBAS database with only little external support.
In order to convince others of UFIS/ECOBAS and ensure broad support a number of meetings and presentations has been scheduled. Also strong support from the sponsoring agencies is necessary. As can be seen from many other examples scientists and modellers themselves should adopt the concepts and carry out input work with the support by two measures:
– the documentation is part of the project itself ("forcing" the modeler)
– the documentation is widely accepted by the scientific community and leads to closer contacts with other scientists and ecological planners in these fields.
While the first kind of measure is a task of the sponsoring agencies, the second one is ours. Hence there is a need for permanent staff to support the modellers, update and represent the projects.
To improve the availability of models and data themselves is one of the major tasks for the future. We have to come to active libraries of models and data. Starting with the meta-level has the advantage to allow to specify the actual needs and gives a comprehensive overview on models and data that would otherwise possibly remain widely unknown. We should use this advantage for the selection and structuring of true model- and data-bases.

[6] available from the UFIS group upon request (in German)
[7] Potsdam Institute for Climate Impact Research
[8] German Climate Computing Centre, Hamburg
[9] Geological Survey of Lower Saxony
[10] Federal Institute for Geosciences and Natural Resources
[11] German Aerospace Research Establishment
[12] UN Environmental Programme - Office for Harmonization of Environmental Measurement
[13] Research Centre Geesthacht
[14] Centre for Agricultural Documentation and Information
[15] Nuclear Research Centre Karlsruhe
[16] Environmental Research Institute Leipzig – Halle

# References


[Ass91] M. Asshoff. Konzept einer Modelldokumentation. Interne Mitteilungen 5, Projektzentrum Ökosystemforschung, Univ. Kiel, 1991.

[Ben94] J. Benz. Ecobas – Dokumentation mathematischer Beschreibungen ökologischer Prozesse. In J. Benz H. B. Keller, R. Grützner, editor, *Bericht vom 3. Treffen des AK "Werkzeuge für Simulation und Modellbildung in Umweltanwendungen"*, pages 55–63. KfK Bericht 5310, 1994.

[BK93] J. Benz and M. Knorrenschild. Anforderungen an die Dokumentation mathematischer Beschreibungen ökologischer Prozesse. In H. B. Keller and R. Grützner, editors, *Bericht vom 2. Treffen des AK "Werkzeuge für Simulation und Modellbildung in Umweltanwendungen"*, pages 9–16. KfK Bericht 5159, 1993.

[Ell73] H. Ellenberg. Versuch einer Klassifikation der Ökosysteme nach funktionalen Gesichtspunkten. In H. Ellenberg, editor, *Ökosystemforschung*, pages 235–266. Springer Verlag, 1973.

[EMD74] H. Ellenberg and D. Müller-Dombois. *Aims and methods of vegetation ecology.* John Wiley, 1974.

[FU87] FAO and UNESCO. *Soils of the world.* Elsevier Science Publ., 1987.

[gct94] GCTE Focus 3 Wheat Network: 1993 model and experimental meta data. GCTE Report No. 2, Canberra, 1994.

[igb94] IGBP Global Modelling and Data Activities 1994-1998. IGBP Report 30, Stockholm, 1994.

[JNHS95] S. E. Jørgensen, S. Nors Nielsen, and B. Halling-Sørensen. *Handbook of Environmental and Ecological Models.* CRC Press, to appear, 1995.

[Len93] R. Lenz. Systemökologische Anforderungen an ein Umweltforschungsinformationssystem (UFIS) als operationale Basis für Scaling – Konzepte in der Umweltplanung. In A. Jaeschke, T. Kämpke, B. Page, and F. J. Radermacher, editors, *Informatik für den Umweltschutz, 7. Symposium Ulm*, pages 427–440. Springer Verlag, 1993.

[Len94] R. Lenz. Ecosystem classification by budget of material; the example of forest ecosystems classified as proton budget types. In F. Klijn, editor, *Ecosystem classification for environmental management*, pages 117–137. Kluwer, 1994.

[Mil75] G. T. Miller. *Living in the Environment – Concepts, Problems, and Alternatives.* Wadsworth Publ., 1975.

[Spr93] O. Springstubbe. Grundzüge der Klassifikation und systematischen Beschreibung ökologischer Systeme als Gliederungsprinzip für ein Informationssystem ökologisch relevanter Daten und Modelle. diploma thesis, Techn. Univ. Munich, 1993.

[Tob92] Tobias. Die hierarchische Systemmethode. Erich Schmidt Verlag, 1992.

[TvGe93] A. Tiktak and J. M. van Grinsven (eds.). Model questionnaires. Handout at the workshop on comparison of forest-soil-atmosphere models, Leusden, 1993.

[Wal90] H. Walter. *Vegetation und Klimazonen.* Ulmer Verlag, 1990.

# 7 Appendix

## 7.1 The Documentation Scheme

**name and address:**
of person who supplied the information on this questionnaire

**date:**

### I. General Model Information

**I.1a name of the model:** name, unique abbreviation, version number

**I.1b author(s):** name, institution

**I.2 contact**
**contact person for the model**
**last name:**
**first name:**
**institution:**
**department:**
**address:**
**phone:**
**FAX:**
**e-mail:**

**supporting institution**
**name:**
**department:**
**address:**
**phone:**
**FAX:**
**e-mail:**

**administrative number:** ...........

**period of development:**

**I.3 aim of the model (compare I.7 recommended applications)**
Which kind of applications is the model designed for? (Check one or more from below.)
**parameter derivation** ○ **prognosis** ○ **research** ○
**education** ○
**other:** ..........................................

**I.4 type of model (technically)**
(Check one or more from below.)
**compartment model** ○ **individual orientated** ○
**expert system** ○ **cellular automat** ○ **fuzzy model** ○
**other:** ..........................................

**I.5 brief description of the model**

**contents of the model** (free text)

**list of keywords regarding contents of model:**

**model principles**

theoretical background of the model (free text)

**object modelled** **no.:** 0

information concerning the object modelled

**level of organization and type:** (Check one or more from below.) (See instructions for definitions and more information.)

| | | | |
|---|---|---|---|
| ◯ | **ecosphere** | | |
| ◯ | **society–environment–system** | **type:** | ................. |
| ◯ | **landscape** | **type:** | ................. |
| ◯ | **ecosystem** | **type:** | ................. |
| ◯ | **biocoenosis** | **type:** | ................. |
| ◯ | **population** | **type:** | ................. |
| ◯ | **individual** | **type:** | ................. |
| ◯ | **organ** | **type:** | ................. |
| ◯ | **cell** | **type:** | ................. |

in case of a purely medial model check one or more from below

**soil** ◯ **water** ◯ **air** ◯

↪ continued on next page ⟶

**type of model:** (Check one or more from below.)

**material (incl. water) balance** ○ **energy balance** ○

**flow of information** ○

**geographical location**

**name of area :** .............................................

**elevation above sealevel in meter :** ...........

in the following give coordinates in decimal degrees, and either point- or rectangular coordinates

| | **longitude** | **latitude** |
|---|---|---|
| **point** | ........... | ........... |
| **rectangle:** | | |
| **upper left corner** | ........... | ........... |
| **lower right corner** | ........... | ........... |
| **polygon (optional) :** | | |
| **1. point** | ........... | ........... |
| **2. point** | ........... | ........... |
| **etc.** | ........... | ........... |

**Please consider the following items only if they are meaningful.**

**type of climate :** according to Walter/Lieth, see appendix. .................

**type of soil :** according to FAO-classification, see appendix. .................

**type of soil :** use local classification of your choice

**type:** ........... **source:** give number from IV. .....

**further information on the object modelled:**

e. g. temperature, pH. .............................

**scales**

**spatial scales:** (free text)

**temporal scale**

**time frame from:** ........... **to:** ........... **unit:** .....

**verbal description** e. g. a vegetation period .............................

**stepsize: min.:** ..... **max.:** ..... **unit:** .....

**complete model documentation:** .....

give reference number (see IV.). Note it is not asked for a user manual.

**conceptual diagram of the model structure:**
attach flow chart here, if available. Flow chart may show relations between model components, data flow, or other aspects.

**I.6 state of development**
**status of model:** (free text)

**calibration**
parameter adjustment using data; to name parameter use abbreviation in list of quantities (II.2)

| parameter | data used | result |
|---|---|---|
| | | |

**validation**
verification of model output using independent data; to name output variable use abbreviation in list of quantities (II.2)

| output variable | data used | result |
|---|---|---|
| | | |

**further remarks concerning the state of development**

**I.7 recommended applications**
**limitations of use:**

**current users**

**number of users worldwide:** .....

**number of users nationwide:** .....

**uses aimed at:** (Check one or more from below.)

**model development** ◯ **education** ◯ **research** ◯
**engineering** ◯ **administration** ◯
**planning** ◯ **politics** ◯
**other:** .................

**use of the model**
**manual available:** if yes, give ref. no. (see V).
**to what extent is user support by the model's author(s) required?**

**to what extent is user support by the model's author(s) available?**

**interactive use possible?**

**suggested measures for transfer in areas of application other than the original one:**

**I.8 coupling with other models**
**which input-data could be taken from the output of other models?**
give name of input and model; leave void if unknown

| input variable (abb.) | name of model that supplies it |
|---|---|
| | |

**which output-data could be used as input to other models?**
give name of output variable and model; leave void if unknown

| output variable (abb.) | name of model that uses it as input |
|---|---|
| | |

# II. Mathematics of the Model

## II.1 equation chart

See instructions for definitions and use of this chart before proceeding. See also II.4

**name of the process:** **no.:** .....

**brief description** (free text)

**list of keywords:**

**mathematical classification** (Check one or more from below.)

- **table** ◯ **algebraic equation** ◯
- **dynamic equation (incl. ordinary differential equation)** ◯
- **partial differential equation** ◯
- **time discrete** ◯ **time continuous** ◯
- **other:** .................

**equation:** use TEX-notation, see instructions

**initial/boundary conditions:**

**constraints:**

**list of quantities involved in this process, their origin and further usage:**

Notation: name of quantity, followed by process numbers or "e" (origin resp. further use of quantity, e = external). Example: input variable: $C_{soil}(7)$: variable $C_{soil}$ (carbon content in soil) is computed in process no. 7; $C_{root}$ (i. e. no number given): variable $C_{root}$ is external input. Output variable: $C_{plant}(5, 8, e)$: variable $C_{plant}$ is computed in this process and again used in process no. 5 and no. 8, and as external output too.

| | |
|---|---|
| **input variables/parameters** | |
| **output variables** | |

↪ continued on next page ⟶

II.1 equation chart (cont.)

numerical implementation (Check one or more from below.)
finite elements ◯ finite differences ◯ exact implementation ◯
other: ............................
resolution in time range permitted: ................ unit: ....
if time discrete, stepsize: min.:.... max.:.... unit: ....
verbal description: ............................

spatial resolution
verbal description: ............................

| variable | meaning | range permitted | unit: | stepsize (if appl.) min.: | max.: | unit: |
|---|---|---|---|---|---|---|
| x–coord. | | | | | | |
| y–coord. | | | | | | |
| z–coord. | | | | | | |

literature refer to numbers in IV.
regarding the equation itself: .................
regarding this specific application of the equation: ...........

number of chart of environmental setting (of type II.3): .....

## II.2 list of quantities

fill out one of the following sections for each quantity in your model

name of quantity: abbreviation: ...........
brief description: (free text)

list of keywords:

type: (Check one from below.)
scalar ◯ vector ◯ matrix ◯ random variable ◯
dimension: ........... unit: ...........
type of values: (Check one from below.)
alphanumerical ◯ numerical ◯
metric ◯ ordinal ◯ nominal ◯
if numerical: discrete ◯ continuous ◯
range of values (ecologically relevant):
lower limit: ........... upper limit: ...........
if necessary, remarks: (free text)
range of values used:
lower limit: ........... upper limit: ...........
if necessary, remarks: (free text)
source of value used: give ref. nr. from IV. .....
aggregation in time:
keyword: ........... over period: ..... unit: ..
aggregration in space:
keyword: ........... over domain: ..... unit: ..

**II.3 environmental setting** **no.:** .....

Give conditions under which a process description II.1 is valid. The information is to be given as general as the validity permits. Entries here will be quite similar to the ones under "object modelled" (I.5) which is considered environmental setting chart no. 0. Therefore it is sufficient here to denote only the items different from chart no. 0.

**restrictions of validity on level of organisation and type:** (Check one or more from below.) (See instructions for definitions and more information.)

- ◯ **ecosphere**
- ◯ **society–environment–system** **type:** .................
- ◯ **landscape** **type:** .................
- ◯ **ecosystem** **type:** .................
- ◯ **biocoenosis** **type:** .................
- ◯ **population** **type:** .................
- ◯ **individual** **type:** .................
- ◯ **organ** **type:** .................
- ◯ **cell** **type:** .................

in case of a purely medial process check one or more from below

**soil** ◯ **water** ◯ **air** ◯

**geographical location**

**name of area :** .............................................

**elevation above sealevel in meter :** ...........

in the following give coordinates in decimal degrees, and either point- or rectangular coordinates

| | longitude | latitude |
|---|---|---|
| point | ........... | ........... |
| rectangle: | | |
| upper left corner | ........... | ........... |
| lower right corner | ........... | ........... |
| polygon (optional) : | | |
| 1. point | ........... | ........... |
| 2. point | ........... | ........... |
| etc. | ........... | ........... |

**Please consider the following items only if they are meaningful.**

**type of climate :** according to Walter/Lieth, see appendix. .................

**type of soil :** according to FAO-classification, see appendix. .................

**type of soil :** use local classification of your choice

**type:** ........... **source:** give number from IV. .....

**further restrictions of validity:**

e. g. temperature, pH.

**II.4 different formalism**
attach description of model formalism in free text here only in case charts II.1, II.2 are inappropriate. This could be the case e. g. for an expert system. If in doubt contact UFIS managers.

**II.5 analysis of model behaviour**
give details on sensitivity analysis performed: give range of output variables resulting from change in input variables and parameters. Format: (free text) .

## III. Technical Information

**III.1 Software**
**programming language:**
give programming language(s) your model is available in; give also simulation language packages as well as libraries etc. used.

**peripheral software required:**
denote graphic-packages, data base management system, etc.

**list of files:**
list all files required: program code, input files, demo files, sample output files.

| name of file | contents | source | access |
|---|---|---|---|
| | | | |

**reference to detailed program documentation (not manual):**
give ref. no. from IV. .....

**III.2 hardware requirements**
**type of computer(s):**

**operating system(s):**

**RAM:**

**disc space:**

**list of other computers, operating systems which the model is portable onto:**

## IV. References

fill out one of the following sections for each reference to literature regarding your model.

**author(s):** **no.:** .....
**title:**
**source (journal):**
**publisher:**
**year:**
**pages:**

## V. Remarks

space for further information, remarks and comments that you would like to add.

### 7.2 Instructions

## Instructions for the Completion of the Model Questionnaire

Inquiries and Comments to: Michael Knorrenschild, ufis@gsf.de

Note: in order to take advantage of these instructions we recommend to answer the questions in the order of appearance on the questionnaire. There do not exist comment to each of the items on the questionnaire; we assume that many items are clear from the formulation on the questionnaire itself. We have tried to take many different situations into concern. However, due to the variety of models the expected answers to questions on the form may appear unclear. In these cases it is recommended you contact one of the authors.

### I. General Model Information:

**I.1a name of the model:** specific name of model (abbreviation) including version number as well as the full (long) name of the model (that gives rise to the abbreviation)
**I.1b author(s):** give name and institution only. In case the author(s) serves also as a contact person for the model the full address is required in the next section.

**I.2 contact:**
**contact person for the model:** It is asked for the address of a person(s) dealing with the model *now*. "Dealing" means: answering inquiries, mailing program code, etc.. This person can be the author, but does not have to be.
**supporting institution:** the institution, e. g. governmental agency, or other funding body, that funded or is funding the development of the model.
**administrative number:** used by the funding body (if available).
**period of development:** Format: month/year until month/year. If the model is still under development please give expected end (end of funding).

**I.3 aim of the model:** A few keywords are sufficient. Specifics are asked later (I.7). This is only for a first orientation.

**I.5 brief description of the model:**
**contents of model:** give a brief summary formulated for non specialists.
**model principles:** Describe the theoretical background of the model, e. g. use of Darcy's equation. Only key processes should be mentioned at his point.
**object modelled:** The entries here serve as an chart of environmental setting no. 0 at the same time (see II.3).
The following classifications refer to the object modelled. In the first stage a **level of organization** is to be chosen, und the specific type of this level, e. g. the type of ecosystem. For the "type" field you will find a hierarchical organized terminology in the appendix. In particular this means:
ecosystem: choose the type from the appendix
biocoenosis: give all species involved
population: give the species involved
individual: give species; if relevant, also subspecies, gender, form of generation, state of development
organ: give type of organ, corresponding individual
cell: give type of organ, corresponding individual
If you use classifications for which there is not list in the appendix provided give a source for the systematics used (e. g. plant species according to Ehrendorfer).
**other environmental conditions:** Give special conditions here that are not covered above but nevertheless essential for the model, e. g. temperature, pH.
**scales:** Spatial and temporal scales in which the model is valid. Spatial scale could be a geographical term, or an area ("up to 10acres") or a combination of either. Temporal scale should indicate the period in which the model yields valid results. E. g. 3 days up to 3 months would be noted as "3-90", unit: "days". Within the time frame it is also asked for the stepsize (in time). Please note that information on scales is of extreme

importance for other users of the model. The limits given here should be reliable and applicable to the full model. Limits of validity for parts of the model are asked for later in II.3, separately for each process.
**detailed model documentation:** Literature is listed in IV. Therefore it is sufficient to give only the reference numbers from IV.
**conceptual diagram of the model's structure:** A flow chart that shows the relations between parts of the model and flow of information between them provides an easy access to an understanding of the model. If such a diagram exists (e. g. a Forrester diagram) please include it here. Any other type of diagram that illustrates the structure of the model and is readily available should be included as well.

**I.6 state of development:**
All information given here should reflect the state at the time of the completion of this questionnaire.
**status of model:** Use keywords to answer. E. g. fully calibrated, partially calibrated, fully validated etc.. Note that the answer refers to the full model, not only to certain moduls and processes within the model.
**calibration:** Note here which parameters in the model have been adapted (calibrated) with use of which data with what result. Parameters should be named in the same way as they occur on the list of quantities II.2 (abbreviation). Information on the data used for calibration includes origin of data (refer to literature or data supplier).
**validation:** Note here which output variable has been validated with independent data. Take name from II.2, do not forget source of data used.
**further remarks concerning the state of development:** Mention here e. g. ongoing work on extension of the model in question.

**I.7 recommended applications:**
**limitation of use:** comments on validity of model in particular regarding the application under different conditions than the ones used for validation, e. g. different geography, different soils.
The following questions are only applicable if a computer program for the model has been developed. In this case questions refer to the program.
**current users:** give only numbers asked for on the questionnaire.
**uses aimed at:** check the area(s) of application.
**use of model:**
**manual available?** If yes, give a full reference in IV.. Note it is asked for a manual that enables a user not familiar with the model to handle it. It is not asked for a model documentation (this is dealt with under III.1 (software). If no, void.
**to what extent is user support by someone who is familiar with the model already ...**
**... required?** To what extent can someone not familiar with the model handle it?
**... available?** To what extent is the contact person or the model's developer able and willing, to assist the users by phone, e-mail, or mail?
**interactive use possible?** Can input be entered into the program in a dialog?
**suggested measures for transfer in areas of application other than the original one:** Note possible areas of application other than mentioned above after and the required changes in the program, e. g. change in parameter values for different locations.

**I.8 coupling with other models:**
**which input-data could be taken from the output of other models? Which output-data could be used as input to other models?** Reference to other models that can be coupled with the model in question are asked for. Mention only couplings that have been proven to work. Specifics about the model required to be given are name of the model, version number, year, author(s). For this purpose two table are supplied, for coupling via input and output variable resp..

## II. Mathematics of the Model

The formalism of documentation of the mathematics of a model is based on the idea that a model is composed of mutually connected processes. The connection between these processes is the exchange of computed quantities. Quantities are feed into the model from the outside ("external input"), the mathematics behind

the processes yields a number of other computed quantities ("process output") which are being fed into other processes again ("process input" for these). Finally the model comes up with an output of computed variables that the modeller is interested in ("external output"). A process can consist of a single equation, or of a system of equations, even coupled with constraint equations. A process is considered to be composed of subprocesses only in case the subprocesses permit an ecological interpretation on their own.
This idea naturally creates a hierarchy on the set of processes involved in the model. The approach used for documentation is based upon this hierarchy.
Choose a process from your model that is as high as possible in the hierarchy of processes within your model; complete an equation chart II.1 for this equation and give it the number 1. The general process for the documentation of the equations in the model is best done using the following algorithm:

```
                              START
                                |
---->------> choose a process P that is as high as possible
|            within the hierarchy of processes (and which has
|            not been documented by an equation chart before).
|            If there is no such P, you are done ---> EXIT
|                               |
|   |--->----complete an equation chart II.1 for P, identify
|   |        process-input and process-output resp. as required
|   |        and write down these quantities in list II.2
|   |        (if they are not there already).
|   |                           |
|   |        Is there an suitable environmental setting chart
|   |        (II.3) already completed for P? If no, complete
|   |        one for P (it is sufficient to denote only the
|   |        deviations from chart no. 0 (see I.5)), and note
|   |        the number of this chart on P's equation chart. If
|   |        yes, continue.
|   |                           |
|   |        Are all processes that use output from P as input
|   |        documented already?
|   |                     |                          |
|   |                    YES                         NO
|   |                     |                          |
|--------<--------------|                            |
    |                                                |
    |        choose one of these processes that has not been
    |            documented as a new P
    |                            |
    ----<--------------<------|
```

The entries on the equation chart and the list of quantities will be explained in the following.

**II.1 equation chart**

**number:** Each equation in the model gets a number. These numbers permit an easy access to the hierarchy of processes, they will be referred to by other equation charts.
**name of process:** give a clear, widely used term
**brief description:** Explain the equation: which events are reflected in it, which are the essential variables.
**list of keywords:** give at most 10 keywords that summarize the brief description above.
**type of equation:**
table function: describes a relation between variables of discrete values; particularly alphanumeric variables in fuzzy models (e. g. "if temp=cold and hum=dry then evaporation=low"
algebraic equation: any other kind of equation in the classical sense, i. e. relations between variables.
dynamic equation: a time dependent equation that does not contain derivatives with respect to space. E. g. an ordinary differential equation, or a process that proceeds discrete in time. Also: an equation that contains derivatives only with respect to one space dimension.
partial differential equation: contains derivatives with respect to at least two different variables ($x, y, z$ or $t$)
deterministic: each variable and parameter in the equation has a unique value
stochastic: probabilities are involved in some terms in the equation
time discrete: the equation is only defined for certain time levels
time continuous: the equation is formally defined for all time points (within a certain interval)
state variable discrete:
state variable continuous:
other:
**equation:** Here you are asked to supply the complete equation in mathematical notation. If the equation involves terms that have been introduced only for notational convenience, but do not allow an ecological interpretation, note these here too, jointly with the equation. Those terms could be switching functions, interpolating functions, etc.. The notation to be employed is TEX or LATEX (see Donald E. Knuth: The TEX book, Addison-Wesley 1984). Some of the features of interest here are:

| TEX-notation | yields: |
|---|---|
| `\delta` | $\delta$ |
| `\Delta` | $\Delta$ |
| `\nabla` | $\nabla$ |
| `\vec a` | $\vec a$ |
| `\bar a` | $\bar a$ |
| `{ a \over b }` | ${a \over b}$ |
| `{ du \over dx }` | ${du \over dx}$ |
| `\dot u(t)` | $\dot u(t)$ |
| `a \cdot b` | $a \cdot b$ |
| `a^2, a^{b+2}=a^b \cdot a^2` | $a^2, a^{b+2}=a^b \cdot a^2$ |
| `x_1, x_2, etc.` | $x_1, x_2, etc.$ |
| `x_1^2 or x^2_1` | $x_1^2 or x^2_1$ |
| `\sqrt{2+3}` | $\sqrt{2+3}$ |
| `\int\limits_a^b f(x) dx` | $\int\limits_a^b f(x) dx$ |
| `\sum\limits_{i=1}^n a_n` | $\sum\limits_{i=1}^n a_n$ |

Example: (Navier – Stokes equations)
`\rho\cdot{dv\over dt}=\rho\cdot f-grad p +\mu\cdot\nabla^2v`
yields: $\rho \cdot \frac{dv}{dt} = \rho \cdot f - grad p + \mu \cdot \nabla^2 v$
A few more remarks:
Brace enable the TEX-compiler to recognize grouped expressions. They do not appear on the output. E. g. `e^{x_1}` yields $e^{x_1}$; compare: `e^x_1` yields $e^x_1$. If you want braces to appear on the output you have to type

\{ or \} resp..
If you have to enter table heres do not bother with TEX and write them as a scheme of numbers (ascii).
**initial/boundary conditions:** To be used in connection with ordinary and partial differential equations. In case of ordinary differential equations an initial value is required, general form: $x(0) = x_0$. In case of a partial differential equation on the boundary of the spatial domain (or parts of it) are required sometimes initial values in time as well, e. g. $x(0,t) = 0, x(1,t) = 1$ for all $t > 0, x(u,0) = u$. Use TEX-notation again! It happens frequently that the prescribed function values on the boundary are computed in some other parts of the model. In this case note e. g. $x(0,t) = f(t)$ and $f(t)$ (the function) is taken as an input to the process under consideration.
**constraints:** Space to note contraints of any kind, e. g. equations applies only if $r > 0$ (where $r$ some variable occurring in the equation. Also it is possible that a constraint equation is needed to be coupled with a system of equation in order to make it solvable.
**numerical implementation:** In case of a continuous equation the numerical method employed for its solution is to be mentioned, e. g. classical Runge-Kutta method with stepsize control. Equations whose solution do not require numerical methods (e. g. scalar linear equations) get the entry "exact implementation".
**resolution in time:** only to be completed for time dependent equations. The temporal range in which the equation holds is asked for. E. g. permitted range: "1-24", unit: "hours". The column for stepsize applies only in case of a time discrete equation. A different unit than for the range can be used.
**spatial resolution:** the spatial domain in which the equation holds is asked for (in case the equation involves spaces coordinates). "Spatial" includes 1-, 2-, or 3-dimensional (leave entries for coordinates not used void). Example: z-coordinate: variable: x; meaning: elevation above groundwaterlevel; permitted range: 1-10, unit: meter; stepsize: min., max.: 20 unit: cm. The stepsize column (incl. corresponding unit) applies only in case of space discrete equations of course (gridsize).
**list of references:** numbers to be noted here refer to the references IV., separately for the background or derivation of the equation in question and the application it is being used for here. Note that reference are definitly required to allow a deeper understanding of the equations (this information system can only give a limited amount of explanation).
**number of chart of environmental setting (of type II.3):** For each equation chart there is a chart of type II.3 (see below); it is possible (and not uncommon) that different equation charts refer to the same chart of environmental setting. The corresponding number is noted here.

**II.2: list of quantities:**
For each quantity a number of items are sought:
**abbreviation:** the abbreviation used in the model, e. g. $e_{max}$, use TEX-notation (see above).
**name of quantity:** full name of quantity.
**brief description:** describe meaning of the quantity; also specific characteristics in this application. In case of an alphanumeric quantity give range of values here explicitly.
**list of keywords:** should summarize the brief description above
**unit:** the physical unit in which the quantity is used within the model, e. g. meter.
**dimension:** in addition to the above: if type is "scalar", dimension is 1. If "vector" give dimension of vector, similar for "matrix" (e. g. 2x2).
**range of values (ecologically relevant):** Interpretation: in case the quantity is outside this range validity of the model is unknown. In case of multidimensional type (vector, matrix) an intervall is needed for each component. In case that this would yield one common interval giving this interval is sufficient (but only in this case). Input- and state variables are frequently time/space dependent; give an interval for them that applies independently of time and space. There is space for remarks that may cover special cases.
**range of values used:** Only for external input and parameters: give the subset of the range given above that was actually used in simulations.
**source of value:** Give a reference number (see IV.) from which the value used is taken (parameters only).
**aggregation in time:** Input-data could be required in the form of daily means. This can be noted here: a keyword is sufficient, e. g. "mean value" (also possible is "maximum" etc.). "Domain" would be in case of daily means "24", unit "hours". Of course "1" and "day", or "1440" and "minutes" is permitted as well.
**aggregation in space:** analog to the above.

**II.3 environmental setting** Analogous to I.5 (object modelled), but this time it applies to the validity of a single process description only. As a consequence the frame covered here will generally be wider than the data given in I.5 for the complete model. It is sufficient to denote the deviations from the entries on I.5 only.
**further restrictions of validity** note data that are not covered by the above but nevertheless are essential for the validity of the process description, e. g. temperature, pH.

**II.5 analysis of model behaviour:** see questionnaire. Remarks on aspects of model behaviour other than sensitivity can be given here as well.

## III. Technical Information:

**III.1 software:**
**programming language:** Give information on software environment in which the simulation program can be compiled (note: operating system is dealt with under "hardware"). E. g.: "C with curses libraries".
**peripheral software required:** Give information on software environment in which the simulation program can be executed. E. g.: "SQL data base".
**list of files:** This question deals with the underlying file structure of the full program. E. g.: "main.c: main program; create.c: preparation of data; client.c: SQL-interface; error.c: error treatment; sample.dat: real world sample input-data; sample.out: output file corresponding to sample.dat".
Source (example): "all files are available from lukas.oeko.inst.de (internet 146.108.0.2) in pub/models/grasshoppers via anonymous ftp." Or: "all files available from author upon request."
**reference to detailed program documentation (not manual):** Note it is not asked for a user manual but for a description of the source code.

**III.2 hardware-requirements:**
**type of computer(s), operating system(s), RAM, disc space"** This questions aims at the hardware environment and operating system in which the simulation program can be executed. E. g.: type of computer(s): "386 - PC with co-processor"; operating system(s): "DOS 5.0", RAM: "min. 4 MB", disc space: "3 MB for program code, min. 10 MB for sample data".
**list of other computers, operating systems which the model is portable onto:** Comment on the model's portability on different computers and operating systems: is it possible and how much work is required? E. g.: "thanks to use of ANSI-C and curses library for output it can easily by ported on unix workstations."

## IV. References

List all references here that are referred to from the remainder of this questionnaire(e. g. the equation charts). Referral was done by numbers, use corresponding numbers here. It is possible to mention unpublished literature here as well (in this case items not applying can be left empty).

## V. Further Information

Please add any comments here that are relevant to modellers and model users but are not covered in this questionnaire yet.

Please direct any inquiries, comments, and suggestions to:

Dr. Michael Knorrenschild
GSF – Forschungszentrum für Umwelt und Gesundheit / PUC
Neuherberg, Postfach 1129 Tel.: +49 89 3187-2953
85758 Oberschleissheim FAX: +49 89 3187-3369
Germany Internet: knorren@gsf.de

## 7.3 Example of a completed Questionnaire

The authors are indebted to G. Dubsky and P. Wernecke of Agro-Ökosystemforschung Quedlinburg (Germany) for providing the information on the Ontogenesis model by Wernecke and Claus given below and for many valuable discussions. The reader will notice that there are still many open spaces in this questionnaire. This is due to a variety of reasons. One major reason is that the questions do not apply to this particular model. Also, though questions apply to this model the answer is not known to the modellers (or at least not with a reasonable amount of certainty). And finally information may not have been released yet by the authors.

**name and address:**
**of person who supplied the information on this questionnaire**
G. Dubsky, P. Wernecke (Agro-Ökosystemforschung Quedlinburg), Chr. Scholz (GHK Kassel), M. Knorrenschild (GSF München)
**date:** July 29, 1994

### I. General Model Information

**I.1a name of the model:** **name, unique abbreviation, version number**
ontogenesis of winter wheat, ONTO-WW V1 (April 15, 1993)
**I.1b author(s):** **name, institution**
Peter Wernecke, Stephan Claus, Agro-Ökosystemforschung Quedlinburg

**I.2 contact**
**contact person for the model**
**last name:** Wernecke
**first name:** Peter
**institution:** Agro-Ökosystemforschung Quedlinburg
**department:**
**address:** Neuer Weg 22, D - 06484 Quedlinburg, Germany
**phone:** +49-3946-965616
**FAX:** +49-3946-965632
**e-mail:** aoeqlb@wiz.uni-kassel.de

**supporting institution**
**name:** Federal Ministry of Education, Science, Research and Technology (BMBF)
**department:** Referat 522
**address:** P. O. Box 200240, 53132 Bonn, Germany
**phone:** +49-228-59-0 (switchboard)
**FAX:**
**e-mail:** bmft@dfn.d400.de

**administrative number:** 0339431A

**period of development:** 1991–

**I.3 aim of the model (compare I.7 recommended applications)**
**Which kind of applications is the model designed for? (Check one or more from below.)**
**parameter derivation** ○ **prognosis** ⊗ **research** ⊗
**education** ○
**other:** control unit for switching and synchronization of submodels (e. g. growth models for wheat plants)

**I.4 type of model (technically)**
**(Check one or more from below.)**
**compartment model** ⊗ **individual orientated** ○
**expert system** ○ **cellular automat** ○ **fuzzy model** ○
**other:** ..........................................

**I.5 brief description of the model**
**contents of the model** **(free text)**
ONTO-WW is a dynamic model describing ontogenesis (development) and vernalization of winter wheat plants. The plant development is characterized by codes with respect to scales of development stages like germination, emergence, shooting, flowering and maturity of grain. The rates of the state variables of the model depend essentially on the air temperature, but also on soil temperature, relative air humidity, soil moisture, photoperiod (day length). The computed variables allow to predict phenological events and their durations.
**list of keywords regarding contents of model:**
development, ontogenesis, winter wheat plant, vernalization
**model principles**
**theoretical background of the model (free text)**
State variables of the model are development, vernalization, and water content of the kernel. The ordinary differential equation for the development variable represents a generalization of the heat or temperature sum concept. The development variable is independent of the used scale of codes for the development stages of the plants, and is converted into a scale of codes by means of a table function.
↪ **continued on next page** ⟶

**I.5 object modelled (cont.)**

**object modelled** **no.:** 0

information concerning the object modelled

**level of organization and type:** (Check one or more from below.) (See instructions for definitions and more information.)

| | | |
|---|---|---|
| ◯ | **ecosphere** | |
| ◯ | **society–environment–system** | **type:** ................. |
| ◯ | **landscape** | **type:** ................. |
| ◯ | **ecosystem** | **type:** ................. |
| ◯ | **biocoenosis** | **type:** ................. |
| ⊗ | **population** | **type:** TRITICUM AESTIVUM |
| ◯ | **individual** | **type:** ................. |
| ◯ | **organ** | **type:** ................. |
| ◯ | **cell** | **type:** ................. |

in case of a purely medial model check one or more from below

**soil** ◯ **water** ◯ **air** ◯

**type of model:** (Check one or more from below.)

**material (incl. water) balance** ⊗ **energy balance** ◯

**flow of information** ◯

**geographical location**

**name of area** : Quedlinburg (Germany)

**elevation above sealevel in meter** : 124

in the following give coordinates in decimal degrees, and either point- or rectangular coordinates

| | **longitude** | **latitude** |
|---|---|---|
| **point** | 51.78 N | 11.17 E |
| **rectangle:** | | |
| **upper left corner** | ........... | ........... |
| **lower right corner** | ........... | ........... |
| **polygon (optional)** : | | |
| 1. **point** | ........... | ........... |
| 2. **point** | ........... | ........... |
| **etc.** | ........... | ........... |

**further information on the object modelled:**

e. g. temperature, pH. .............................

**scales**

**spatial scales:** (free text) WHEAT FIELD

**temporal scale**

**time frame from:** ........... **to:** ........... **unit:** .....

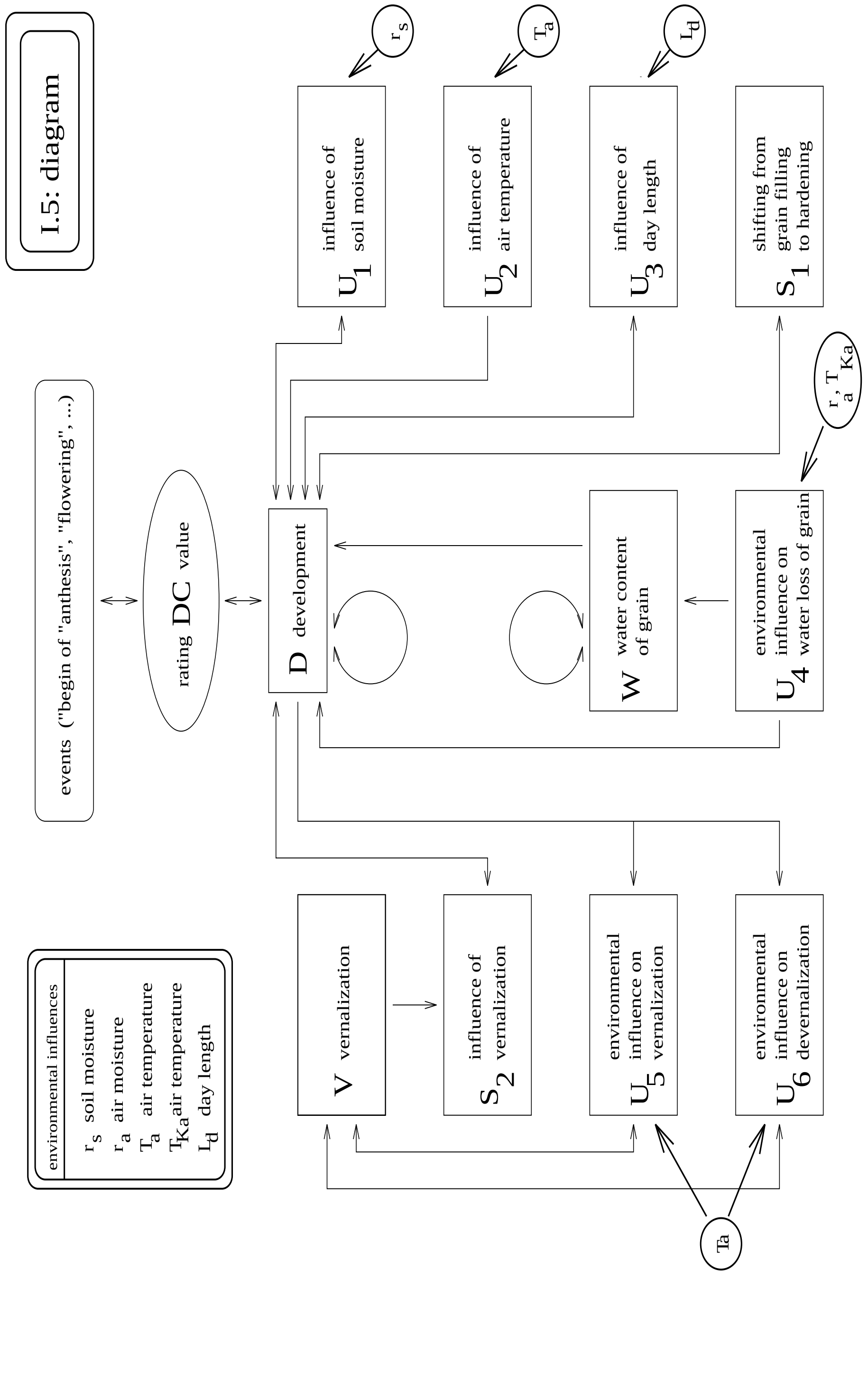
**verbal description** e. g. a vegetation period VEGETATION PERIOD

**stepsize: min.:** 1 **max.:** 1 **unit:** DAY

**complete model documentation:** .....

give reference number (see IV.). Note it is not asked for a user manual.

**conceptual diagram of the model structure:**
**attach flow chart here, if available. Flow chart may show relations between model components, data flow, or other aspects.**



**I.6 state of development**

**status of model:** (free text) VALIDATED, CALIBRATED

**calibration**

**parameter adjustment using data; to name parameter use abbreviation in list of quantities (II.2)**

| parameter | data used | result |
|---|---|---|
| ALL | QUEDL1 | MEAN DEV.: $DC$: 1.4<br>MEAN DEV.: $t_{<event>}$: 1.7 DAYS |

**validation**

**verification of model output using independent data; to name output variable use abbreviation in list of quantities (II.2)**

| output variable | data used | result |
|---|---|---|
| $DC$ | QUEDL2 | MEAN DEV.: 2.0 |
| $DC$ | KIEL | MEAN DEV.: 2.9 |
| $t_{<event>}$ | QUEDL2 | MEAN DEV.: 2.3 DAYS |
| $t_{<event>}$ | KIEL | MEAN DEV.: 3.5 DAYS |

**further remarks concerning the state of development**

NOTATION:

QUEDL1: DATA FROM EXPERIMENTAL FIELD "STUMPFSBURGER GARTEN", (INCL. SOME FROM CLIMATE CHAMBERS), TRITICUM AESTIVUM, VARIETY "REGINA", 1990/91, 1991/1992

QUEDL2: DATA FROM EXPERIMENTAL FIELD "STUMPFSBURGER GARTEN", TRITICUM AESTIVUM, VARIETY "REGINA", 1988/89, 1989/90.

KIEL: DATA FROM EXPERIMENTAL FIELD "HOHENSCHULEN" (UNIV. OF KIEL), TRITICUM AESTIVUM, VARIETY "ORESTES", 1990/91, 1991/1992

**I.7 recommended applications**

**limitations of use:**

USEABLE ONLY FOR THE QUEDLINBURG LOCATION

**current users**

**number of users worldwide:** ???

**number of users nationwide:** ???

**uses aimed at:** (Check one or more from below.)

model development ⊗ education ◯ research ⊗

engineering ◯ administration ◯

planning ⊗ politics ◯

other: .................

**use of the model**

**manual available:** if yes, give ref. no. (see V). NO

**to what extent is user support by the model's author(s) required?** ???

**to what extent is user support by the model's author(s) available?** ???

**interactive use possible?** ???

**suggested measures for transfer in areas of application other than the original one:**

TRANSFER OF ONTO-WW TO DIFFERENT SPECIES OF WHEAT PLANT REQUIRES CALIBRATION OF VARIOUS PARAMETERS (CHARACTERISTIC VALUES OF DEVELOPMENT) AS WELL AS MODIFICATION OF THE CONTROL FUNCTIONS FOR VERNALIZATION. WORK ON THE TRANSFER OF THE MODEL TO OTHER LOCATIONS IS IN PROGRESS.

**I.8 coupling with other models**

**which input-data could be taken from the output of other models?**

give name of input and model; leave void if unknown

| input variable (abb.) | name of model that supplies it |
|---|---|
| | |

**which output-data could be used as input to other models?**

give name of output variable and model; leave void if unknown

| output variable (abb.) | name of model that uses it as input |
|---|---|
| $DC(t)$ | GROWTH MODELS FROM QUEDLINBURG |
| $t_{<event>}$ | GROWTH MODELS FROM QUEDLINBURG |

## II. Mathematics of the Model

### II.1 equation chart

**See instructions for definitions and use of this chart before proceeding. See also II.4.**

**name of the process:** **no.:** 1

DEVELOPMENT OF WHEAT PLANT

**brief description** (free text)

THIS EQUATION DESCRIBES THE DYNAMIC DEVELOPMENT OF WHEAT PLANTS DUE TO VERNALIZATION, WATER CONTENT OF KERNEL, AIR TEMPERATURE, AIR HUMIDITY, SOIL MOISTURE AND PHOTOPERIOD (DAY LENGTH). THE DEVELOPMENT RESULTS FROM TWO "OVERLAPPING" EFFECTS, NAMELY THE "HEAT-SUM EFFECT" FOR THE FIRST PHASE ("GERMINATION TO ANTHESIS") AND THE "DRYING EFFECT" FOR THE LAST PHASE OF PLANT DEVELOPMENT. PRIOR TO ANTHESIS THERE ARE NO KERNELS, THUS THE WATER LOSS IN THAT PHASE IS SET TO ZERO. BOTH EFFECTS ARE LINKED WITH THE MONOTONICALLY INCREASING CONTROL CHARACTERISTIC $S_1$ WHICH CHARACTERIZES THE TRANSITION FROM THE FIRST TO THE THIRD PERIOD OF DEVELOPMENT. THE SWITCH FUNCTION $S2$ DESCRIBES THE FEEDBACK OF VERNALIZATION ON PLANT DEVELOPMENT. INSUFFICIENT VERNALIZATION IN WHEAT LEADS TO RETARDATION OR IN EXTREME CASES EVEN TO STAGNATION OF DEVELOPMENT. $U_1$ DESCRIBES THE INFLUENCE OF SOIL MOISTURE IN THE BEGINNING OF THE DEVELOPMENT, $U_2$ THE INFLUENCE OF AIR HUMIDITY, AND $U_3$ THE INFLUENCE OF DAY LENGTH BETWEEN EMERGENCE AND ANTHESIS.

**list of keywords:** RATING, DEVELOPMENT, WHEAT PLANT, CEREALS, SOIL MOISTURE, AIR HUMIDITY, DAY LENGTH

**mathematical classification** (Check one or more from below.)

- **table** ○ **algebraic equation** ○
- **dynamic equation (incl. ordinary differential equation)** ⊗
- **partial differential equation** ○
- **time discrete** ○ **time continuous** ⊗
- **other:** .................

**equation:** use TEX-notation, see instructions

$$\frac{dD}{dt} = \begin{cases} R1_D \cdot Q_a & \text{IF } D \leq D_{an} \\ R1_D \cdot (1 - S_1) \cdot Q_a + R2_D \cdot S_1 \cdot U_4 \cdot W & \text{IF } D > D_{an} \end{cases}$$

WHERE

$$Q_a = S_2 \cdot U_1 \cdot U_2 \cdot U_3,$$

$$S1 = \begin{cases} 0 & \text{IF } D < D_{meg} \\ (D - D_{meg})/(D_{mil} - D_{meg}) & \text{IF } D_{meg} < D < D_{mil} \\ 1 & \text{IF } D \geq D_{mil}, \end{cases}$$

$$S2 = \begin{cases} 1 & \text{IF } D \leq D_{v1} \text{ OR } D \geq D_{v2} \text{ OR } V \geq V_{sat} \\ 0 & \text{IF } V < V_{base} \\ (V - V_{base})/(V_{sat} - V_{base}) & \text{ELSE} \end{cases}$$

$$U_1 = \begin{cases} 1 - \exp(-r_s/r_0) & \text{IF } D \leq D_{em} \\ 1 & \text{IF } D > D_{em} \end{cases}$$

$$U_2 = \begin{cases} \frac{T_a - T_0}{T_{opt} - T_0} \cdot \exp(-\frac{T_a - T_{opt}}{T_{opt} - T_0}) & \text{IF } T_a \geq T_0 \\ 0 & \text{IF } T_a < T_0 \end{cases}$$

↪ continued on next page ⟶

II.1 equation chart no. 1 (cont.)

$$U_3 = \begin{cases} 0 & \text{IF } L_d < L_{d0} \\ (L_d - L_{d0})/(L_{d2} - L_{d0}) & \text{IF } L_{d0} < L_d < L_{d2} \\ 1 & \text{IF } L_d > L_{d2} \text{ OR } D \leq D_{em} \text{ OR } D \geq D_{an} \end{cases}$$
$$(\text{HERE } L_{d0} = L_{d1} + L_{d2} \cdot D/D_{an})$$

**initial/boundary conditions:** $D(t_0) = D_0$
**constraints:** –
**list of quantities involved in this process, their origin and further usage:**
Notation: name of quantity, followed by process numbers or "e" (origin resp. further use of quantity, e = external). Example: input variable: $C_{soil}(7)$: variable $C_{soil}$ (carbon content in soil) is computed in process no. 7; $C_{root}$ (i. e. no number given): variable $C_{root}$ is external input. Output variable: $C_{plant}(5, 8, e)$: variable $C_{plant}$ is computed in this process and again used in process no. 5 and no. 8, and as external output too.

| | |
|---|---|
| **input variables/parameters** | $R1_D, R2_D, r_s, r_0, T_a, T_0, T_{opt}, L_{d1}, L_{d2}, V_{base}, V_{sat}, V(2), W(3), U_4(4), D_{<event>}, D_0$ |
| **output variables** | $D(3, 5, 6)$ |

**numerical implementation** (Check one or more from below.)
**finite elements** ◯ **finite differences** ◯
**exact implementation** ◯ **other:** ???
**resolution in time** **range permitted:** ................ **unit:** ....
**if time discrete, stepsize: min.:**.... **max.:**.... **unit:** ....
**verbal description:** ...........................

**spatial resolution**
**verbal description:** NOT APPLICABLE

| variable | meaning | range permitted | unit: | stepsize (if applicable) min.: | max.: | unit: |
|---|---|---|---|---|---|---|
| x–coord. | | | | | | |
| y–coord. | | | | | | |
| z–coord. | | | | | | |

**literature** refer to numbers in IV.
**regarding the equation itself:** 1
**regarding this specific application of the equation:**

**number of chart of environmental setting (of type II.3):** 0

Note: from here on we report only entries that are available, skipping void entries.

**name of the process:** **no.:** 2

VERNALIZATION OF WHEAT PLANT

**brief description** (free text)

VERNALIZATION IS CALCULATED FROM THE STATE OF DEVELOPMENT AND AIR TEMPERATURE. $U_5$ AND $U_6$ DESCRIBE THE INFLUENCE OF AIR TEMPERATURE ON VERNALIZATION AND DEVERNALIZATION, RESPECTIVELY, DURING THE EARLY STAGE OF DEVELOPMENT; $U_5$ RUNS A TRAPEZOIDAL COURSE BETWEEN FOUR CHARACTERISTIC TEMPERATURE VALUES.

**list of keywords:** VERNALIZATION, WHEAT PLANT, DEVERNALIZATION, AIR TEMPERATURE, DEVELOPMENT

**mathematical classification** (Check one or more from below.)

**dynamic equation (incl. ordinary differential equation)** ⊗

**time discrete** ○ **time continuous** ⊗

**equation:** use TEX-notation, see instructions

$$\frac{dV}{dt} = R1_V \cdot U_5 - R2_V \cdot U_6, \qquad \text{WHERE}$$

$$U_5 = \begin{cases} 0 & \text{IF } D \geq D_{dr} \text{ OR } V \geq V_{sat} \\ & \quad \text{OR } T_a < T_{v1} \text{ OR } T_a > T_{v4} \\ (T_a - T_{v1})/(T_{v2} - T_{v1}) & \text{IF } T_{v1} < T_a < T_{v2} \\ 1 & \text{IF } T_{v2} < T_a < T_{v3} \\ (T_{v4} - T_a)/(T_{v4} - T_{v3}) & \text{IF } T_{v3} < T_a < T_{v4} \end{cases}$$

$$U_6 = \begin{cases} V \cdot (1 - T_{a.dv}/T_a) & \text{IF } D < D_{dr} \text{ AND } T_a > T_{a.dv} \\ 0 & \text{ELSE} \end{cases}$$

**initial/boundary conditions:** $V(t_0) = V_0$

**list of quantities involved in this process, their origin and further usage:**

| | |
|---|---|
| **input variables/parameters** | $R1_V, R2_V, T_a, T_{a.dv}, T_{v1}, T_{v2}, T_{v3}, T_{v4}, D(1), D_{dr}, V_{sat}$ |
| **output variables** | $V(1)$ |

**numerical implementation** (Check one or more from below.)

**finite elements** ○ **finite differences** ○

**exact implementation** ○ **other:** ???

**resolution in time** **range permitted:** ................ **unit:** ..........

**if time discrete, stepsize: min.:.... max.:.... unit:** ....

**verbal description:** ...........................

**literature** refer to numbers in IV.

**regarding the equation itself:** 1

**regarding the application of the equation in this context:**

**number of chart of environmental setting (of type II.3):** 0

**name of the process:** **no.:** 3

CHANGE OF WATER CONTENT OF RIPENING KERNEL

**brief description** (free text)

WATER CONTENT OF RIPENING KERNEL IS CALCULATED FROM AIR HUMIDITY AND AIR TEMPERATURE.

**list of keywords:** WATER CONTENT, WATER LOSS, GRAIN

**mathematical classification** (Check one or more from below.)

**dynamic equation (incl. ordinary differential equation)** ⊗

**time discrete** ○ **time continuous** ⊗

**equation:** use TEX-notation, see instructions

$$\frac{dW}{dt} = -R_W \cdot U_4 \cdot W$$

**initial/boundary conditions:** $W(t_{an}) = W_{an}$ $(0 < W_{an} < 1)$

**constraints:** $D > D_{an}$

**list of quantities involved in this process, their origin and further usage:**

| input variables/parameters | $R_W, U_4(4), D(1), D_{an}$ |
|---|---|
| output variables | $W(1)$ |

**numerical implementation** (Check one or more from below.)

**finite elements** ○ **finite differences** ○

**exact implementation** ○ **other:** ???

**resolution in time** **range permitted:** ................ **unit:** ..........

**if time discrete, stepsize: min.:.... max.:.... unit: ....**

**verbal description:** ...........................

**literature** refer to numbers in IV.

**regarding the equation itself:** 1

**regarding the application of the equation in this context:**

**number of chart of environmental setting (of type II.3):** 1

**name of the process:** **no.:** 4

INFLUENCE OF AIR TEMPERATURE AND AIR HUMIDITY ON THE WATER LOSS OF KERNELS

**brief description** (free text)

THIS EQUATION DESCRIBES THE INFLUENCE OF AIR TEMPERATURE AND AIR HUMIDITY ON THE WATER LOSS OF THE KERNELS IN THE PHASE OF MATURITY.

**list of keywords:** WATER LOSS, GRAIN, MATURITY

**mathematical classification** (Check one or more from below.)

**algebraic equation** ⊗

**equation:** use TEX-notation, see instructions

$$U_4 = (1 - R_a) \cdot \exp(-\frac{E_A}{R_G} \cdot (1/(T_a + 273.15) - 1/(T_{a0} + 273.15)))$$

**list of quantities involved in this process, their origin and further usage:**

| input variables/parameters | $r_a, E_A, R_G, T_a, T_{a0}$ |
|---|---|
| output variables | $U_4(1,3)$ |

**numerical implementation** (Check one or more from below.)

**exact implementation** ⊗

**literature** refer to numbers in IV.

**regarding the equation itself:** 1

**regarding the application of the equation in this context:**

**number of chart of environmental setting (of type II.3):** 1

**name of the process:** **no.:** 5

CONVERSION OF DEVELOPMENT VALUE INTO RATING VALUE

**brief description** **(free text)**

THE VARIABLE $D$ THAT DENOTES THE DEVELOPMENT STAGE OF THE PLANT IS CONVERTED VIA THE TABLE FUNCTION $f_{DC}$ INTO A RATING VALUE ON THE $DC$-SCALE. THESE RATING VALUES CAN BE USED IN OTHER MODELS TO DETERMINE THE TIME OF PHENOLOGICAL EVENTS LIKE EMERGENCE, FLOWERING, MATURITY OF WHEAT, ETC. OR ALSO TO SWITCH CERTAIN SUBMODELS ON AND OFF DURING A SIMULATION RUN. FOR EACH PHENOLOGICAL EVENT THERE IS A RATING VALUE $DC_{event}$ AND A CORRESPONDING VALUE $D_{event}$. THIS CORRESPONDENCE IS ONE-TO-ONE (SINCE $f_{DC}$ IS STRONGLY MONOTONE). FIXED VALUES FOR IMPORTANT RATING EVENTS (LIKE "BEGIN OF ANTHESIS", "BEGIN OF MILK DEVELOPMENT",...) ARE REQUIRED BEFOREHAND.

**list of keywords:** DEVELOPMENT, RATING

**mathematical classification** **(Check one or more from below.)**

**table** $\otimes$

**equation:** **use TEX-notation, see instructions**

$$
\begin{aligned}
f_{DC}(D_{<event>}) &= DC_{<event>} \qquad \text{FOR THE 8 EVENTS} \\
&\phantom{=}\ \text{LINEARLY INTERPOLATED ON } [D_{an}, D_{ma}] \\
f_{DC}(D) &= \begin{cases} DC_{em} & \text{IF } D < D_{an} \\ DC_{ma} & \text{IF } D > D_{ma} \end{cases}
\end{aligned}
$$

**list of quantities involved in this process, their origin and further usage:**

| input variables/parameters | $D(1), D_{<event>}, DC_{<event>}$ |
|---|---|
| output variables | $f_{DC}(e)$ |

**numerical implementation** **(Check one or more from below.)**

**exact implementation** $\otimes$

**literature** **refer to numbers in IV.**

**regarding the equation itself:** 1

**regarding the application of the equation in this context:**

**number of chart of environmental setting (of type II.3):** 0

**name of the process:** **no.:** 6

CALCULATION OF MOMENT OF PHENOLOGICAL EVENTS

**brief description** **(free text)**

DETERMINES THE MOMENT OF PHENOLOGICAL EVENT DIRECTLY FROM THE DEVELOPMENT VALUE $D(t)$ IN A STRAIGHTFORWARD FASHION.

**list of keywords:** DEVELOPMENT, RATING, PHENOLOGICAL EVENT

**mathematical classification** **(Check one or more from below.)**

**algebraic equation** ⊗

**equation:** **use TEX-notation, see instructions**

$$t_{<event>} = min\{\, t \mid D(t) \geq D_{event} \}$$

**list of quantities involved in this process, their origin and further usage:**

| | |
|---|---|
| **input variables/parameters** | $D(1)$ |
| **output variables** | $t_{<event>}(e)$ |

**numerical implementation** **(Check one or more from below.)**

**exact implementation** ⊗

**literature** **refer to numbers in IV.**

**regarding the equation itself:**

**regarding the application of the equation in this context:**

**number of chart of environmental setting (of type II.3):** 0

## II.2 list of quantities

fill out one of the following sections for each quantity in your model

**name of quantity:** **abbreviation:** $D_{<event>}$

RATING VALUES

**brief description:** (free text) THE VECTOR $D_{event}$ HAS 8 COMPONENTS, ONE FOR EACH PHENOLOGICAL EVENT. THE EVENTS ARE "EMERGENCE (EM)" (1), "DOUBLE RIDGE (DR)" (2), "BEGIN OF OBSTRUCTION OF DEVELOPMENT BY VERNALIZATION (V1)" (3), "END OF OBSTRUCTION OF DEVELOPMENT BY VERNALIZATION (V2)" (4), "BEGIN OF ANTHESIS (AN)" (5), "MIDDLE AIR GRAIN HALF FILLED (MEG)" (6), "BEGIN OF MILK DEVELOPMENT (MIL)" (7), "MATURITY, END OF DEVELOPMENT (MA)" (8). THE 8 PRESCRIBED VALUES ARE MONOTONELY INCREASING AND BY COMPARISON WITH VARIABLE $D$ DETERMINE THE PHENOLOGICAL STATE OF THE PLANT. VIA THE TABLE FUNCTION $f_{DC}$ THE 8 VALUES CORRESPOND TO RATING VALUES.

**list of keywords:** RATING, DEVELOPMENT, WHEAT PLANT

**type:** (Check one from below.)

**scalar** ○ **vector** ⊗ **matrix** ○ **random variable** ○

**dimension:** 8 **unit:** –

**type of values:** (Check one from below.)

**alphanumerical** ○ **numerical** ⊗

**metric** ⊗ **ordinal** ○ **nominal** ○

**if numerical:** **discrete** ○ **continuous** ○

**range of values (ecologically relevant):**

**lower limit:** ??? **upper limit:** ???

**if necessary, remarks:** (free text)

**range of values used:**

**lower limit:** $D_{em} = 0.0568$, $D_{dr} = 0.078$, $D_{v1} =?$, $D_{v2} =?$,

$D_{an} = 0.5109$, $D_{meg} = 0.5349$. $D_{mil} = 0.6097$, $D_{ma} = 0.7039$

**upper limit:** EQUAL TO LOWER LIMIT

**if necessary, remarks:** (free text)

**source of value used:** give ref. nr. from IV. 6

**aggregation in time:**

**keyword:** NONE **over period:** ........... **unit:** .....

**aggregration in space:**

**keyword:** NONE **over domain:** ........... **unit:** .....

Note: from here on we report only entries that are available, skipping void entries.

**name of quantity:** **abbreviation:** $DC_{<event>}$
TRANSFORMED RATING SCALE
**brief description:** (free text) $DC_{event}$ HAS 8 COMPONENTS, ONE FOR EACH PHENOLOGICAL EVENT. THE EVENTS ARE "EMERGENCE (EM)" (1), "DOUBLE RIDGE (DR)" (2), "BEGIN OF OBSTRUCTION OF DEVELOPMENT BY VERNALIZATION (V1)" (3), "END OF OBSTRUCTION OF DEVELOPMENT BY VERNALIZATION (V2)" (4), "BEGIN OF ANTHESIS (AN)" (5), "MIDDLE AIR GRAIN HALF FILLED (MEG)" (6), "BEGIN OF MILK DEVELOPMENT (MIL)" (7), "MATURITY, END OF DEVELOPMENT (MA)" (8). THE 8 PRESCRIBED VALUES ARE MONOTONELY INCREASING AND TAKE THE CORRESPONDING VALUES ON THE DC – SCALE (DECIMAL CODE).
**list of keywords:** RATING, DEVELOPMENT, WHEAT PLANT
**type: vector** ⊗ **dimension:** 8 **unit:** –
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** 0 **upper limit:** 100
**range of values used:**
**lower limit:** $DC_{em} = 11$, $DC_{dr} = 25$, $DC_{v1} =?$, $DC_{v2} =?$, $DC_{an} = 61$, $DC_{meg} = 65$, $DC_{mil} = 71$, $DC_{ma} = 92$
**upper limit:** EQUAL TO LOWER LIMIT
**source of value used:** give ref. nr. from **IV.** 6

**name of quantity:** **abbreviation:** $R1_D$
DEVELOPMENT CONSTANT 1
**brief description:** FITTING PARAMETER IN DEVELOPMENT EQUATION (NO. 1)
**list of keywords:** DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** 1/DAY
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 0.015 **upper limit:** 0.015
**source of value used:** give ref. nr. from **IV.** 6

**name of quantity:** **abbreviation:** $R2_D$
DEVELOPMENT CONSTANT 2
**brief description:** FITTING PARAMETER IN DEVELOPMENT EQUATION (NO. 1)
**list of keywords:** DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** 1/DAY
**type of values:** **numerical** ⊗ **metric** ⊗

**name of quantity:** **abbreviation:** $R1_V$
VERNALIZATION CONSTANT 1
**brief description:** FITTING PARAMETER IN VERNALIZATION EQUATION (NO. 2)
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** 1/DAY
**type of values:** **numerical** ⊗ **metric** ⊗

**name of quantity:** **abbreviation:** $R2_V$
VERNALIZATION CONSTANT 2
**brief description:** FITTING PARAMETER IN VERNALIZATION EQUATION (NO. 2)
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** 1/DAY
**type of values:** **numerical** ⊗ **metric** ⊗

**name of quantity:** **abbreviation:** $R_W$
WATER LOSS CONSTANT
**brief description:** FITTING PARAMETER IN WATER LOSS EQUATION (NO. 3)
**list of keywords:** WATER LOSS, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** 1/DAY
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 0.0584 **upper limit:** 0.0584
**source of value used:** give ref. nr. from IV. 6

**name of quantity:** **abbreviation:** $r_0$
REFERENCE VALUE OF RELATIVE SOIL MOISTURE
**brief description:** –
**list of keywords:** SOIL, MOISTURE, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** –
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 0.079 **upper limit:** 0.079
**source of value used:** give ref. nr. from IV. 2

**name of quantity:** **abbreviation:** $T_0$
REFERENCE AIR TEMPERATURE
**brief description:** –
**list of keywords:** AIR, TEMPERATURE, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** $^\circ$C
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 1.04 **upper limit:** 1.04
**source of value used:** give ref. nr. from IV. 2

**name of quantity:** **abbreviation:** $T_{opt}$
OPTIMAL AIR TEMPERATURE
**brief description:** –
**list of keywords:** AIR, TEMPERATURE, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** $^\circ$C
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 27 **upper limit:** 27
**source of value used:** give ref. nr. from IV. 2

**name of quantity:** **abbreviation:** $L_{d1}$
DAY LENGTH PARAMETER 1
**brief description:** –
**list of keywords:** DAY LENGTH, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** HOUR
**type of values:** **numerical** ⊗ **metric** ⊗

**name of quantity:** **abbreviation:** $L_{d2}$
DAY LENGTH PARAMETER 2
**brief description:** –
**list of keywords:** DAY LENGTH, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** HOUR
**type of values:** **numerical** ⊗ **metric** ⊗

---

**name of quantity:** **abbreviation:** $T_{a0}$
REFERENCE AIR TEMPERATURE 2
**brief description:** –
**list of keywords:** AIR, TEMPERATURE, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** °C
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 15.1 **upper limit:** 15.1
**source of value used:** give ref. nr. from **IV.** 2

---

**name of quantity:** **abbreviation:** $E_A$
ACTIVATION ENERGY REQUIRED FOR KERNEL TO EMIT WATER
**brief description:** ACTIVATION ENERGY FOR THE WATER TRANSPORT FROM THE RIPENING WHEAT KERNEL INTO SURROUNDING AIR (GRAIN HARDENING)
**list of keywords:** ENERGY, GRAIN, WATER, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** KJ / MOL
**type of values:** **numerical** ⊗ **metric** ⊗
**range of values (ecologically relevant):**
**lower limit:** ??? **upper limit:** ???
**range of values used:** **lower limit:** 80.7 **upper limit:** 80.7
**source of value used:** give ref. nr. from **IV.** 2

---

**name of quantity:** **abbreviation:** $V_{sat}$
VERNALIZATION: SATURATION VALUE
**brief description:** –
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** DAYS
**type of values:** **numerical** ⊗ **metric** ⊗

---

**name of quantity:** **abbreviation:** $V_{base}$
VERNALIZATION: BASE VALUE
**brief description:** –
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** DAYS
**type of values:** **numerical** ⊗ **metric** ⊗

---

**name of quantity:** **abbreviation:** $T_{v1}$
AIR TEMPERATURE FOR BEGIN OF VERNALIZATION
**brief description:** CHARACTERISTIC VALUE OF AIR TEMPERATURE FOR WHICH VERNALIZATION STARTS
**list of keywords:** AIR, TEMPERATURE, VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type: scalar** ⊗ **dimension:** 1 **unit:** °C
**type of values:** **numerical** ⊗ **metric** ⊗

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $T_{v2}$ |
| CHARACTERISTIC VALUE OF AIR TEMPERATURE WITH RESPECT TO VERNALIZATION 2 | |
| **brief description:** – | |
| **list of keywords:** AIR, TEMPERATURE, VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** $^\circ$C | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $T_{v3}$ |
| CHARACTERISTIC VALUE OF AIR TEMPERATURE WITH RESPECT TO VERNALIZATION 3 | |
| **brief description:** – | |
| **list of keywords:** AIR, TEMPERATURE, VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** $^\circ$C | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $T_{v4}$ |
| AIR TEMPERATURE FOR END OF VERNALIZATION | |
| **brief description:** CHARACTERISTIC VALUE OF AIR TEMPERATURE FOR WHICH VERNALIZATION ENDS | |
| **list of keywords:** AIR, TEMPERATURE, VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** $^\circ$C | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $T_{a.dv}$ |
| AIR TEMPERATURE FOR BEGIN OF DEVERNALIZATION | |
| **brief description:** CHARACTERISTIC VALUE OF AIR TEMPERATURE FOR WHICH DEVERNALIZATION STARTS IF THE “DOUBLE RIDGE” STATE IS NOT REACHED | |
| **list of keywords:** AIR, TEMPERATURE, DEVERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** $^\circ$C | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $R_G$ |
| UNIVERSAL GAS CONSTANT | |
| **brief description:** – | |
| **list of keywords:** GAS, CONSTANT | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** J/(MOL*K) | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |

| | |
|---|---|
| **name of quantity:** | **abbreviation:** $T_a$ |
| AIR TEMPERATURE | |
| **brief description:** – | |
| **list of keywords:** AIR, TEMPERATURE | |
| **type: scalar** $\otimes$ **dimension:** 1 **unit:** $^\circ$C | |
| **type of values: numerical** $\otimes$ **metric** $\otimes$ | |
| **range of values (ecologically relevant):** | |
| **lower limit:** ??? **upper limit:** ??? | |
| **range of values used: lower limit:** −8 **upper limit:** 22 | |
| **source of value used:** give ref. nr. from IV. 2 | |

**name of quantity:** **abbreviation:** $r_a$
RELATIVE AIR HUMIDITY
**brief description:** –
**list of keywords:** AIR, HUMIDITY
**type:** **scalar** $\otimes$ **dimension:** 1 **unit:** –
**type of values:** **numerical** $\otimes$ **metric** $\otimes$
**range of values (ecologically relevant):**
**lower limit:** 0 **upper limit:** 1
**range of values used:** **lower limit:** 0.6 **upper limit:** 0.92
**source of value used:** **give ref. nr. from IV.** 2

**name of quantity:** **abbreviation:** $r_s$
RELATIVE SOIL MOISTURE
**brief description:** ORIGIN: FIELD VALUES FOR RELATIVE SOIL MOISTURE WERE CONVERTED INTO THIS QUANTITY RELATIVE TO PERMANENT WILTING POINT AND SATURATION VALUE
**list of keywords:** SOIL, MOISTURE, DEVELOPMENT, WHEAT PLANT
**type:** **scalar** $\otimes$ **dimension:** 1 **unit:** –
**type of values:** **numerical** $\otimes$ **metric** $\otimes$
**range of values (ecologically relevant):**
**lower limit:** 0 **upper limit:** 1
**range of values used:** **lower limit:** 0.3 **upper limit:** 0.68
**source of value used:** **give ref. nr. from IV.** 2

**name of quantity:** **abbreviation:** $L_d$
PHOTOPERIODICALLY EFFECTIVE DAY LENGTH
**brief description:** TIME DEPENDENT
**list of keywords:** PHOTOPERIOD, DAY
**type:** **scalar** $\otimes$ **dimension:** 1 **unit:** HOUR
**type of values:** **numerical** $\otimes$ **metric** $\otimes$

**name of quantity:** **abbreviation:** $D_0$
INITIAL VALUE OF DEVELOPMENT
**brief description:** AT TIME $t_0$
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type:** **scalar** $\otimes$ **dimension:** 1 **unit:** –
**type of values:** **numerical** $\otimes$ **metric** $\otimes$
**range of values (ecologically relevant):**
**lower limit:** 0 **upper limit:** ???
**range of values used:** **lower limit:** ??? **upper limit:** ???
**source of value used:** **give ref. nr. from IV.** ???

**name of quantity:** **abbreviation:** $V_0$
INITIAL VALUE OF VERNALIZATION
**brief description:** AT TIME $t_0$
**list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT
**type:** **scalar** $\otimes$ **dimension:** 1 **unit:** DAYS
**type of values:** **numerical** $\otimes$ **metric** $\otimes$
**range of values (ecologically relevant):**
**lower limit:** 0 **upper limit:** ???
**range of values used:** **lower limit:** ??? **upper limit:** ???
**source of value used:** **give ref. nr. from IV.** ???

| **name of quantity:** | **abbreviation:** $W_{an}$ |
|---|---|
| INITIAL VALUE OF WATER CONTENT OF KERNEL | |
| **brief description:** AT TIME $t_{an}$ | |
| **list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** ⊗ **dimension:** 1 **unit:** – | |
| **type of values: numerical** ⊗ **metric** ⊗ | |
| **range of values (ecologically relevant):** | |
| **lower limit:** 0 **upper limit:** 1 | |
| **range of values used: lower limit:** ??? **upper limit:** ??? | |
| **source of value used:** give ref. nr. from IV. ??? | |

| **name of quantity:** | **abbreviation:** $D$ |
|---|---|
| VALUE OF DEVELOPMENT | |
| **brief description:** TIME DEPENDENT, COMPUTED DEVELOPMENT VALUE | |
| **list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** ⊗ **dimension:** 1 **unit:** – | |
| **type of values: numerical** ⊗ **metric** ⊗ | |

| **name of quantity:** | **abbreviation:** $V$ |
|---|---|
| VALUE OF VERNALIZATION | |
| **brief description:** TIME DEPENDENT, COMPUTED VERNALIZATION VALUE | |
| **list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** ⊗ **dimension:** 1 **unit:** DAYS | |
| **type of values: numerical** ⊗ **metric** ⊗ | |

| **name of quantity:** | **abbreviation:** $W$ |
|---|---|
| WATER CONTENT OF KERNEL | |
| **brief description:** TIME DEPENDENT, IN PARTS OF MASS | |
| **list of keywords:** VERNALIZATION, DEVELOPMENT, WHEAT PLANT | |
| **type: scalar** ⊗ **dimension:** 1 **unit:** – | |
| **type of values: numerical** ⊗ **metric** ⊗ | |

| **name of quantity:** | **abbreviation:** $U_4$ |
|---|---|
| INFLUENCE OF AIR TEMPERATURE AND AIR HUMIDITY ON THE WATER LOSS OF THE KERNEL | |
| **brief description:** THIS QUANTITY REPRESENTS A QUANTITATIVE DESCRIPTION OF THE INFLUENCE OF AIR TEMPERATURE AND AIR HUMIDITY ON THE WATER LOSS OF KERNELS IN THE PHASE OF MATURITY. | |
| **list of keywords:** AIR, TEMPERATURE, HUMIDITY, WATER LOSS, GRAIN, MATURITY | |
| **type: scalar** ⊗ **dimension:** 1 **unit:** – | |
| **type of values: numerical** ⊗ **metric** ⊗ | |

| **name of quantity:** | **abbreviation:** $t_{<event>}$ |
|---|---|
| MOMENT OF PHENOLOGICAL EVENTS | |
| **brief description:** (free text) THE MOMENTS OF PHENOLOGICAL EVENTS OF WHEAT, WHERE "EVENT" IS ONE OF THE EIGHT DEVELOPMENTAL STAGES LIKE EMERGENCE, DOUBLE RIDGE, BEGIN OF VERNALIZATION RETARDATION, END OF VERNALIZATION RETARDATION, BEGIN ANTHESIS, MIDDLE AIR GRAIN HALF FILLED, BEGIN OF MILK DEVELOPMENT, MATURITY (END OF DEVELOPMENT). | |
| **list of keywords:** DEVELOPMENT STAGE, TIME | |
| **type: vector** ⊗ **dimension:** 8 **unit:** DAYS | |
| **type of values: numerical** ⊗ **metric** ⊗ | |

**II.3 environmental setting** **no.:** 1

Give conditions under which a process description II.1 is valid. The information is to be given as general as the validity permits. Entries here will be quite similar to the ones under "object modelled" which is considered environmental setting chart no. 0. Therefore it is sufficient here to denote only the items different from chart no. 0.

**restrictions of validity on level of organisation and type:** (Check one or more from below.) (See instructions for definitions and more information.)

| | | |
|---|---|---|
| ◯ | ecosphere | |
| ◯ | society–environment–system | type: ................ |
| ◯ | landscape | type: ................ |
| ◯ | ecosystem | type: ................ |
| ◯ | biocoenosis | type: ................ |
| ◯ | population | type: ................ |
| ◯ | individual | type: ................ |
| ⊗ | organ | type: KERNEL OF TRITICUM AESTIVUM |
| ◯ | cell | type: ................ |

**II.4 different formalism**

attach description of model formalism in free text here only in case charts II.1, II.2 are inappropriate. This could be the case e. g. for an expert system. If in doubt contact UFIS managers.

NOT APPLICABLE

**II.5 analysis of model behaviour**

give details on sensitivity analysis performed: give range of output variables resulting from change in input variables and parameters. Format: (free text) . NOT AVAILABLE

## III. Technical Information

**III.1 Software**

**programming language:**

give programming language(s) your model is available in; give also simulation language packages as well as libraries etc. used. TURBO PASCAL 7.0

**peripheral software required:**

denote graphic-packages, data base management system, etc. –

**list of files:**

list all files required: program code, input files, demo files, sample output files.

| name of file | contents | source | access |
|---|---|---|---|
| | | | |

**reference to detailed program documentation (not manual):**

give ref. no. from IV. .....

**III.2 hardware requirements**
**type of computer(s):** PC, at least 80286, coprocessor recommended
**operating system(s):** MS-DOS
**RAM:**
**disc space:**
**list of other computers, operating systems which the model is portable onto:**

## IV. References

**fill out one of the following sections for each reference to literature regarding your model.**


**author(s):** Claus, S.; Wernecke, P.; Mühle, H. **no.:** 1
**title:** Ontogenese und Vernalization von Winterweizen (Experimente und dynamisches Modell)
**source (journal):** Fortschritte der Simulation in Medizin, Biologie und Ökologie, 5. Ebernburger Gespräch, Informatik-Bericht 92/6
**publisher:** TU Clausthal
**year:** 1992
**pages:** 153-161

**author(s):** **no.:** 2
Claus, S.; Wernecke, P.; Mühle, H.; Schoop, P.
**title:** Ein dynamisches Modell für die Ontogenese von Winterweizen als Voraussetzung für die Prozesssteuerung in Wachstumsmodellen
**source (journal):** Agrarinformatik 24
**publisher:** Ulmer Verlag
**year:** 1993
**pages:** 109-121

**author(s):** Feekes, W. **no.:** 3
**title:** de tarwe en haar milieu
**source (journal):** Verl. techn. tarwe commiss. 17
**publisher:** ???
**year:** 1941
**pages:** ???

**author(s):** Kirby, E. J. M.; Appleyard, M. **no.:** 4
**title:** cereal development guide: cereal unit (1981), arable unit (1984, 1986)
**source (journal):** ???
**publisher:** ???
**year:** 1981-1986
**pages:** ???

**author(s):** Tottmann, D. R. **no.:** 5
**title:** the decimal code for the growth stages of cerals, with illustrations
**source (journal):** Ann. Appl. Biol. 110
**year:** 1987
**pages:** 441-454

| | |
|---|---|
| **author(s):** Wernecke, P.; Claus, S. | **no.:** 6 |
| **title:** extension and improvement of descriptive models for the ontogenesis of wheat plants | |
| **source (journal):** Modelling Geo-Biosphere Processes 1 | |
| **year:** 1992 | |
| **pages:** 131-144 | |

| | |
|---|---|
| **author(s):** | **no.:** 7 |
| Zadoks, J. C.; Chang, T. T.; Konzak, C. F. | |
| **title:** a decimal code for the growth stages of cerals | |
| **source (journal):** Weed Research 14 | |
| **year:** 1974 | |
| **pages:** 415-421 | |

## V. Remarks

**space for further information, remarks and comments that you would like to add.**

### 7.4 System Ecological Classification

The following classification is due to Springstubbe [Spr93]. It is based upon Ellenberg [Ell73], see also [EMD74].

```
z         levels of organisation

za        cells
  zaa       prokaryotic cells
  zab       eukaryotic cells
  zaa       prokaryotic cells
  zab       eukaryotic cells
     zaba      cells of unicellular organisms
     zabb      cells of multicellular organisms
         zabba     cells of multicellular plants
         zabbb     cells of multicellular animals
zb        organs
zc        organisms
  zca       archaebacteria
  zcb       eubacteria
  zcc       eukaryota
     zcca      plantae
     zccb      animalia
zd        populations
ze        biocoenoses
zf        ecosystems
  zfa       saltwater-ecosystems
     zfaa      oceanic ecosystems
         zfaaa     oligotrophic oceans
         zfaab     moderate oligotrophic oceans
         zfaac     moderate eutrophic oceans
         zfaad     eutrophic oceans
     zfab      neritic ecosystems
     zfac      marine-littoral ecosystems
         zfaca     coral reefs
         zfacb     rocky shores
         zfacc     gravel shores
         zfacd     sandy shores
         zface     sandy mud flats
     zfad      inland salt lakes
         zfada     moderate saline
         zfadb     sea-like inland salt lakes
         zfadc     intense saline
         zfadd     extremely saline inland salt lakes
         zfade     desiccative inland salt lakes
     zfae      estuaries
     zfaf      saline ground water-ecosystems
         zfafa     saline groundwater
         zfafb     saline subterranean rivers
         zfafc     saline underground lakes
  zfb       freshwater-ecosystems
     zfba      lakes
         zfbaa     oligotrophic lakes
         zfbab     mesotrophic lakes
         zfbac     eutrophic lakes
         zfbad     polytrophic lakes
     zfbb      ponds
         zfbba     oligotrophic ponds
         zfbbb     mesotrophic ponds
         zfbbc     eutrophic ponds
```

```
      zfbbd     polytrophic ponds
   zfbc      desiccative ponds
      zfbca     pools and puddles
      zfbcb     desiccative karsts lakes/waterfilled doline
   zfbd      perennial running waters
      zfbd      perennial running waters
         zfbda     eucrenal
             zfbdaa    helocrenes
             zfbdab    limnocrenes
             zfbdac    rheocrenes
         zfbdb     hypocrenal
         zfbdc     epirithral
         zfbdd     metarhitral
         zfbde     hyporhitral
         zfbdf     epipotamal
         zfbdg     metapotamal
         zfbdh     hypopotamal
   zfbe      desiccative running waters
   zfbf      subterranean freshwater-ecosystems
      zfbf      subterranean freshwater-ecosystems
         zfbfa     ground-water (freshwater)
         zfbfb     subterranean freshwater-brooks
         zfbfc     underground lakes (freshwater)
   zfbg      thermal springs
   zfbh      exploited freshwater-ecosystems
      zfbha     exploited lentic freshwater-ecosystems
      zfbhb     exploited running freshwater-ecosystems
zfc       semiterrestrial ecosystems
   zfca      sphagnum-peat bogs
      zfcaa     extremely oligotrophic sphagnum-peat bogs
                         (ombrogenuous sphagnum-peat bogs)
      zfcab     oligotrophic sphagnum-peat bogs
      zfcac     moderate oligotrophic sphagnum-peat bogs
      zfcad     semi-natural oligotrophic sphagnum-peat bogs
   zfcb      leaf mosses-peat bogs
      zfcba     oligotrophic leaf mosses-peat bogs
      zfcbb     moderate oligotrophic leaf mosses-peat bogs
      zfcbc     moderate eutrophic leaf mosses-peat bogs
   zfcc      sedge-peat bogs
      zfcca     tall-sedge-peat bogs
      zfccb     low-sedge-peat bogs
      zfccc     hartpolster-peat bogs
      zfccd     semi-natural tall-sedge-peat bogs
      zfcce     semi-natural low-sedge-peat bogs
   zfcd      dwarf-shrub- and shrub-peat bogs
      zfcda     oligotrophic dwarf-shrub-peat bogs
      zfcdb     mesotrophic shrub-peat bogs
      zfcdc     eutrophic shrub-peat bogs
      zfcdd     semi-natural oligotrophic dwarf-shrub-peat bogs
      zfcde     semi-natural mesotrophic shrub-peat bogs
      zfcdf     semi-natural eutrophic shrub-peat bogs
   zfce      forest-peat bogs
      zfcea     warm forest-peat-bogs
      zfceb     periodically warm forest-peat-bogs
      zfcec     cool forest-peat-bogs
zfd       terrestrial ecosystems
   zfda      closed forests
      zfdaa     warm-humid mainly evergreen broad-leaved closed
                  forests
```

zfdab cool-humid frost-free evergreen broad-leaved closed forests
zfdac winter-rain evergreen broad-leaved sclerophyllous closed forests
zfdad temperate and subpolar evergreen coniferous forest
zfdae drought-deciduous closed forests
zfdaf cold-deciduous broad-leaved closed forest
zfdag extremely xeromorphic closed forests
zfdb woodlands
zfdba evergreen broad-leaved woodlands
zfdbb evergreen needle-leafed woodlands
zfdbc drought-deciduous woodlands
zfdbd cold-deciduous broad-leaved woodlands
zfdbe extremely xeromorphic woodlands
zfdc scrub
zfdca evergreen broad-leafed shrublands or thickets
zfdcb evergreen needle-leafed and microphyllous shrublands or thickest
zfdcc drought-deciduous shrublands or thickets
zfdcd cold-deciduous shrublands or thickets
zfdce extremely xeromorphic open (subdesert) shrublands
zfdcf evergreen broad-leafed semi-natural shrublands or thickets
zfdcg evergreen needle-leafed and microphyllous semi-natural shrublands or thickest
zfdch drought-decidous shrublands or thickets
zfdci cold-decidous semi-natural shrublands or thickets
zfdcj extremely xeromorphic open (subdesert) semi-natural shrublands
zfdd dwarf-scrub and related ecosystems
zfdda evergreen dwarf-shrub thickets
zfddb evergreen dwarf-shrublands
zfddc mixed evergreen dwarf-scrub and herbaceous formations
zfddd drought-deciduous dwarf-thickets or dwarf-shrublands
zfdde mixed cold-deciduous and evergreen dwarf-thickets or dwarf-shrublands
zfddf cold-deciduous dwarf thickets or dwarf-shrublands
zfddg extremely xeromorphic dwarf-shrublands
zfddh evergreen semi-natural dwarf-shrub thickets
zfddi evergreen semi-natural dwarf-shrublands
zfddj mixed evergreen semi-natural dwarf-scrub and herbaceous formations
zfddk drought-deciduous semi-natural dwarf-thickets or dwarf-shrublands
zfddl mixed cold-deciduous and evergreen semi-natural dwarf-thickets or dwarf-shrublands
zfddm cold-deciduous semi-natural dwarf-thickets or dwarf-shrublands
zfddn extremely xeromorphic semi-natural dwarf-shrublands
zfde terrestrial herbaceous ecosystems
zfdea steppes in winter-cold lowlands
zfdeb mountain-steppes in semiarid tropics and subtropics
zfdec paramos and similar ecosystems in permanent humid tropical mountains
zfded closed alpine mats
zfdee tundras
zfdef nivean herbaceuos ecosystems
zfdeg savannahs (semi-natural)

```
        zfdeh     grass-heaths (semi-natural)
        zfdei     poor grasslands (semi-natural)
        zfdek     semi-natural closed alpine mats
    zfdf      drought-deserts and -subdeserts
        zfdfa     drought-subdeserts
        zfdfb     drought-deserts
    zfdg      desert-like scarcely vegetated ecosystems
        zfdga     open dunes
        zfdgb     erosion-caused deserts
        zfdgc     scarcely vegetated screes
    zfdh      exploited terrestrial ecosystems
        zfdha     exploited forests
        zfdhb     plantations of fruit bearing trees
        zfdhc     plantations of fruit bearing shrubs
        zfdhd     tall-herbs and tall-grass plantations
        zfdhe     plantations of herbaceous perennials
        zfdhf     fertilised grasslands
        zfdhg     fodder fields
        zfdhh     grain fields
        zfdhi     root-crop fields
        zfdhj     gardens
  zfe       urban-industrial ecosystems
    zfea      built-up urban-industrial ecosystems
        zfeaa     detached houses and duplex buildings
        zfeab     town houses
        zfeac     low-story buildings
        zfead     high-story buildings
        zfeae     mixed-story development
        zfeaf     block development
        zfeag     low story/shed development
        zfeah     mixed development: sheds/high story
        zfeai     historic village centres
        zfeaj     mixed development
        zfeal     special buildings
    zfeb      vacant urban-industrial ecosystems
        zfeba     gravelled lots
        zfebb     parking lots
        zfebc     road
        zfebd     railroad tracks
        zfebe     sports fields
        zfebf     lawn and tennis courts
zg        ecosystem-complexes
  zga       chorical ecosystem-complexes
    zgaa      chorical land-use ecosystem-complexes
 zgaaa     near-nature chorical ecosystem-complexes
 zgaab     cultivated chorical ecosystem-complexes
 zgaac     urban-industrial chorical ecosystem-complexes
      zgaaca    metropolises
      zgaacb    big cities
      zgaacc    small and medium-sized towns
      zgaacd    villages
      zgaace    isolated industrial complexes
 zgaad     town/environs chorical ecosystem-complexes
      zgaada    metropolis/environs chorical ecosystem-complexes
      zgaadb    big city/environs chorical ecosystem-complexes
      zgaadc    small and medium-sized city/environs
                  chorical ecosystem-complexes
      zgaadd    village/environs chorical ecosystem-complexes
    zgab      chorical factor ecosystem-complexes
```

```
    zgac     chorical gradient ecosystem-complexes
    zgad     chorical catchment ecosystem-complexes
  zgb      regionical ecosystem-complexes
  zgc      geospherical ecosystem-complexes
    zgca     polar/subpolar ecozone
    zgcb     boreal ecozone
    zgcc     humid central latitudes
    zgcd     arid central latitudes
    zgce     arid tropical/subtropical ecozone
    zgcf     winterrain subtropical ecozone
    zgcg     summerrain subtropical ecozone
    zgch     wet subtropical ecozone
    zgci     wet tropical ecozone
zh       socio-environmental systems
  zha      chorical socio-environmental systems
    zhaa     chorical political-administrative systems
    zhab     chorical planning areas
    zhac     other chorical socio-environmental systems
  zhb      regionical socio-environmental systems
    zhba     regionical economic areas
    zhbb     regionical political-administrative systems
    zhbc     regionical planning areas
    zhbd     other regionical socio-environmental systems
  zhc      geospherical socio-environmental systems
    zhca     geospherical economic areas
    zhcb     geospherical political-administrative systems
    zhcc     other geospherical socio-environmental systems
zi       ecosphere
```

## 7.5 Climate Classification according to Walter/ Lieth

Classification is done by classes I-X and subclasses, denoted by small letters ([Wal90]).

- I equatorial humid zone or two periods of rain, frost-free, temperatures mostly above 20° C, low seasonal temperature course
- II tropical and subtropical area of summer rain, cooler dry period
- III arid subtropical desert zone, occasional radiation frosts
- IV area of winter rain, not completely frostfree, but no distinct cold season
- V warm temperate humid zone, with significant seasonal temperature course, but only occasional frosts
- VI temperate humid zone, with distinct, but not very long cold season
- VII temperare arid zone, with hot summers and cold winters
- VIII boreal zone with very long cold season, mean monthly temperature of the warmest months above 10° C
- IX arctic area, at most with brief frost-free season, warmest month below 10° C
- X mountain climate amidst the above mentioned climatic zone, individually very different
  denote: X(...) mountain climate of climatic zone ...

Subclasses:

- a relatively dry for this climatic zone
- h relatively humid for this climatic zone (hh extremely humid)
- oc oceanic variant (in non-tropical climate)
- co continental variant
- fr regular frosts in tropical regions

wr dominant winter rain, where not typical for the type of zone (e. g. V wr, III wr, I wr)

sr dominant summer rain, where not typical for the type of zone

swr summer- and winter rain, where not typical for the type of zone (e. g. III swr)

ep episodical precipitation in extreme deserts

nm not measurable precipitation in form of dew and fog in deserts

(r III) precipitation as low as in zone III (e. g. I(r III) = equatorial desert)

(t I) temperature course as in type I (e. g. II (t I): climate in which yearly changes in temperature are larger than yearly ones)

### 7.6 FAO – Soil Unit Classification Scheme

The following list gives the 28 classes and 153 subclasses of the updated FAO – soil unit classification scheme ([FU87]).

```
FL   FLUVISOLS               AR   ARENOSOLS

FLe  Eutric Fluvisols        ARh  Haplic Arenosols
FLc  Calcaric Fluvisols      ARb  Cambic Arenosols
FLd  Dystric Fluvisols       ARl  Luvic Arenosols
FLm  Mollic Fluvisols        ARo  Ferralic Arenosols
FLu  Umbric Fluvisols        ARa  Albic Arenosols
FLt  Thionic Fluvisols       ARc  Calcaric Arenosols
FLs  Salic Fluvisols         ARg  Gleyic Arenosols


GL   GLEYSOLS                AN   ANDOSOLS

GLe  Eutric Gleysols         ANh  Haplic Andosols
GLk  Calcic Gleysols         ANm  Mollic Andosols
GLd  Dystric Gleysols        ANu  Umbric Andosols
GLa  Andic Gleysols          ANz  Vitric Andosols
GLm  Mollic Gleysols         ANg  Gleyic Andosols
GLu  Umbric Gleysols         ANi  Gelic Andosols
GLt  Thionic Gleysols
GLi  Gelic Gleysols


VR   VERTISOLS               RG   REGOSOLS

VRe  Eutric Vertisols        RGe  Eutric Regosols
VRd  Dystric Vertisols       RGc  Calcaric Regosols
VRk  Calcic Vertisols        RGy  Gypsic Regosols
VRy  Gypsic Vertisols        RGd  Dystric Regosols
                             RGu  Umbric Regosols
                             RGi  Gelic Regosols


LP   LEPTOSOLS               CM   CAMBISOLS

LPe  Eutric Leptosols        CMe  Eutric Cambisols
LPd  Dystric Leptosols       CMd  Dystric Cambisols
LPk  Rendzic Leptosols       CMu  Humic Cambisols
LPm  Mollic Leptosols        CMc  Calcaric Cambisols
LPu  Umbric Leptosols        CMx  Chromic Cambisols
LPq  Lithic Leptosols        CMv  Vertic Cambisols
```

| | | | |
|---|---|---|---|
| LPi | Gelic Leptosols | CMo | Ferralic Cambisols |
| | | CMg | Gleyic Cambisols |
| | | CMi | Gelic Cambisols |
| | | | |
| CL | CALCISOLS | GY | GYPSISOLS |
| CLh | Haplic Calcisols | GYh | Haplic Gypsisols |
| CLl | Luvic Calcisols | GYk | Calcic Gypsisols |
| CLp | Petric Calcisols | GYl | Luvic Gypsisols |
| | | GYp | Petric Gypsisols |
| | | | |
| SN | SOLONETZ | SC | SOLONCHAKS |
| SNh | Haplic Solonetz | SCh | Haplic Solonchaks |
| SNm | Mollic Solonetz | SCm | Mollic Solonchaks |
| SNk | Calcic Solonetz | SCk | Calcic Solonchaks |
| SNy | Gypsic Solonetz | SCy | Gypsic Solonchaks |
| SNj | Stagnic Solonetz | SCn | Sodic Solonchaks |
| SNg | Gleyic Solonetz | SCg | Gleyic Solonchaks |
| | | SCi | Gelic Solonchaks |
| | | | |
| KS | KASTANOZEMS | LV | LUVISOLS |
| KSh | Haplic Kastanozems | LVh | Haplic Luvisols |
| KSl | Luvic Kastanozems | LVf | Ferric Luvisols |
| KSk | Calcic Kastanozems | LVx | Chromic Luvisols |
| KSy | Gypsic Kastanozems | LVk | Calcic Luvisols |
| | | LVv | Vertic Luvisols |
| | | LVa | Albic Luvisols |
| | | LVj | Stagnic Luvisols |
| | | LVg | Gleyic Luvisols |
| | | | |
| CH | CHERNOZEMS | PL | PLANOSOLS |
| CHh | Haplic Chernozems | PLe | Eutric Planosolss |
| CHk | Calcic Chernozems | PLd | Dystric Planosols |
| CHl | Luvic Chernozems | PLm | Mollic Planosols |
| CHw | Glossic Chernozems | PLu | Umbric Planosols |
| CHg | Gleyic Chernozems | PLi | Gelic Planosols |
| | | | |
| PH | PHAEOZEMS | PD | PODZOLUVISOLS |
| PHh | Haplic Phaeozems | PDe | Eutric Podzoluvisols |
| PHc | Calcaric Phaeozems | PDd | Dystric Podzoluvisols |
| PHl | Luvic Phaeozems | PDj | Stagnic Podzoluvisols |
| PHj | Stagnic Phaeozems | PDg | Gleyic Podzoluvisols |
| PHg | Gleyic Phaeozems | PDi | Gelic Podzoluvisols |
| | | | |
| GR | GREYZEMS | PZ | PODZOLS |
| GRh | Haplic Greyzems | PZh | Haplic Podzols |
| GRg | Gleyic Greyzems | PZb | Cambic Podzols |
| | | PZf | Ferric Podzols |

PZc Carbic Podzols
PZg Gleyic Podzols
PZi Gelic Podzols

LX LIXISOLS

LXh Haplic Lixisols
LXf Ferric Lixisols
LXp Plinthic Lixisols
LXa Albic Lixisols
LXj Stagnic Lixisols
LXg Gleyic Lixisols

HS HISTOSOLS

HSl Folic Histosols
HSs Terric Histosols
HSf Fibric Histosols
HSt Thionic Histosols
HSi Gelic Histosols

AT ANTHROSOLS

ATa Aric Anthrosols
ATc Cumulic Anthrosols
ATf Fimic Anthrosols
ATu Urbic Anthrosol

AC ACRISOLS

ACh Haplic Acrisols
ACf Ferric Acrisols
ACu Humic Acrisols
ACp Plinthic Acrisols
ACg Gleyic Acrisols

AL ALISOLS

ALh Haplic Alisols
ALf Ferric Alisols
ALu Humic Alisols
ALp Plinthic Alisols
ALj Stagnic Alisols
ALg Gleyic Alisols

NT NITISOLS

NTh Haplic Nitisols
NTr Rhodic Nitisols
NTu Humic Nitisols

FR FERRALSOLS

FRh Haplic Ferralsols
FRx Xanthic Ferralsols
FRr Rhodic Ferralsols
FRu Humic Ferralsols
FRg Geric Ferralsols
FRp Plinthic Ferralsols

PT PLINTHOSOLS

PTe Eutric Plinthosols
PTd Dystric Plinthosols
PTu Humic Plinthosols
PTa Albic Plinthosols