Current development and application of the modular Java based model JAMS to meet the targets of the EU-WFD in Germany.

Ulrike Bende-Michl

Manfred Fink

Sven Kralisch

Wolfgang-Albert Flügel

Peter Krause

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U. Bende-Michl, P. Krause, S. Kralisch, M. Fink and W.-A. Flügel

FSU Jena, Department of Geoinformatics, Hydrology and Modelling, Germany

Abstract: The European Water Framework Directive (EU-WFD), implemented in the year of 2000, requires general ecological protection and a minimum chemical standard to be obtained in all European surface waters at different spatial and temporal scales. To meet these requirements the knowledge of spatially distributed sources and movements of contaminants, e.g. nutrients entries on stream systems is essential.

In Germany some major water quality problems are related to non-point sources of nitrogen export. For a collaborative pilot study the need was identified to integrate solute turnover and transport processes into the object-oriented Java based JAMS modeling framework (Jena Adaptable Modelling System). The innovative potential of JAMS was enhanced to consider, describe and model hydrologic and solute processes within the appropriate spatial and temporal context. Moreover JAMS provides the possibility of exchanging process modules according to individual needs and problems.

This paper will give a conceptual overview of the current developments on the implementation and integration of process modules for different nitrogen components and their turnover, and soil temperature and crop growth as well as options for land use management scenarios. The preliminary results of an application in a mesoscale catchment in Germany are also described.

Keywords: Modular model development, Integrated Water Resources Management, EU-WFD, nitrogen process modelling

1. INTRODUCTION

The European Water Framework Directive (EU-WFD) of the European Commission was entered into force in December 2000 to establish a framework for community action in the field of water policy (2000/60/EC).

The area covered by the EU-WFD extends to all aquatic systems, surface waters (rivers and lakes), groundwater and coastal waters within Europe. The main target of the EU-WFD is to provide a ’good ecological and chemical status’ of all waters in the Community by 2015. The basic thinking behind the term ‘good status’ is that water can be used by humans as long as the ecological and hydro chemical function of the water body is not significantly impaired. Therefore water resources should be managed across national boundaries, choosing a co-ordinated, integrated approach within river catchment areas. This will be attained by the development of river management action plans based on a holistic, ecologically oriented analysis and assessment of an appropriate river system. In Germany the implementation of basin specific management action plans are under the responsibility of federal state water agencies with respect to their ministries. For the state of Thuringia the 'Thuringian Environmental Agency' (Thüringer Landesanstalt für Umwelt-TLUG) is in charge of the planning processes and working tasks for implementing the EU-WFD. Since nutrients inputs in some of the tributaries of the Thuringian rivers are some of the major water quality problems in Thuringia there is a need to have adequate modelling tools for developing and assessing appropriate land management options to alleviate stream nutrient impacts. These options are assumed to be chosen with knowledge of the effects of land management on stream flow, stream water quality and land productivity. Therefore the model operates over different temporal and spatial scales and is designed to address nested approaches as well as different distribution concepts (lumped, semi or fully distributed approaches) and diverse process description ranging from physically-based to empirical and/or conceptually oriented.

2. DEMANDS FOR IMPLEMENTATION OF THE WFD IN THE STATE OF THURINGIA

For this particular issue a collaboration between the TLUG and the Department of Geoinformatics at the Friedrich-Schiller-University of Jena was established. The overall goal of this collaboration is the development and implementation of a comprehensive, hydrologic and solute modelling toolbox implemented in custom-tailored software. It is designed to assist in validation and to assess the measures and land use management actions that are proposed to meet the targets of the EU-WFD.

The first stages of this project included a) selection of a pilot basin for parameterisation and application of the object oriented hydrologic model J2000, respectively J2K (Krause 2001) to provide a base of hydrologic process knowledge for the pilot watershed (Krause & Flügel 2005, Krause et al. 2006) using a fully distributed hydrologic response unit (HRU) approach (Flügel 1995); b) parameterisation and application of the semi-distributed solute transport model Soil Water Assessment Tool 'SWAT' (Arnold et al. 1998; Arnold & Fohrer 2005) for the same pilot watershed to quantify its ability for modelling solute process dynamics (Bende-Michl et al. 2005).

On that base the current development involves coupling both the quantitative and qualitative process representation as a fully distributed concept. Solute transport modelling approaches mainly based on the SWAT model have been recently implemented into the JAMS model (Jena Adaptable Modelling System) by adapting advanced modelling techniques.

3. JAMS MODEL DEVELOPMENT

The development of the J2000 modelling system first started in 1997 as a process oriented hydrologic modelling framework for large catchments, and was implemented in C++. In that version it was successfully applied to three large tributaries of the Elbe River in Germany (Krause 2001). More recently however the system has been reviewed and evaluated for application at different scales, in different environments and for different purposes. In summary it was found that this system was not flexible enough to meet various kinds of application because of technical aspects. Limitations were mainly due to intrinsically tied process modules and the system core.

Therefore current efforts are directed to designing a hydrologic modelling system as a modular framework and toolbox that is able to assist in enhancing and adapting existing models for user specific requirements and demands by incorporating a high level of system flexibility. This challenge is met in the generalised JAMS architecture since a lot of work has been carried out to identify basic requirements for the system. As a result it involves a strict separation of a system core and its generic components from a knowledge part, called the J2K process components. Since JAMS was implemented in Java the system is fully platform independent. JAMS is partly inspired by the Modular Modelling System MMS (Leavesley et al. 1996) and the Object Modeling System OMS (Ahuja et al. 2005).

3.1 Model Description

From the technical point of view a detailed overview of the Java based model JAMS is given by Krause & Kralisch (2005, 2006). Thus only a brief overview of the systems capability is given here. In general the JAMS system consists of two major parts (fig.1): the JAMS core and the hydrologic knowledge part, J2K. The JAMS core basically comprises libraries of tools, methods and corresponding Java packages for regionalisation, data input and output of parameter files and their initialisation and results as well as for statistical analyses, physical calculations, and geographic transformation.

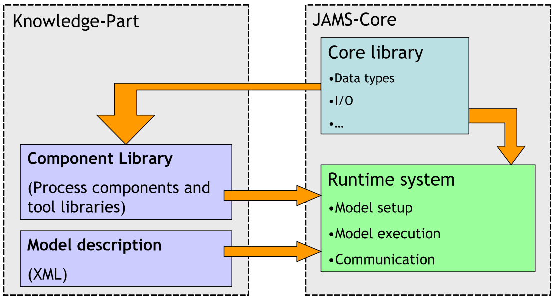

Figure 1: Common layout of JAMS (Kralisch & Krause 2006)

Tools for visualisation by specific GUI components are currently under development. In addition the knowledge part provides process components for modelling hydrologic processes like evapotranspiration, interception, snow, soil water and lateral reach routing as well as ground water dynamics, which are fully described by Krause (2001, 2002).

The knowledge part is completed by the control of component execution and data exchange which is basically parameterised by a XML-based user-defined configuration. The latter contains the specified model structure and corresponding metadata. Moreover it provides the communication between the JAMS components and the JAMS runtime environment.

New process components are required to have a standardized functionality which is provided by a few documented methods. These process components, called *JAMS objects*, are defined by having (i) a set of attributes capable of data exchange with other components, (ii) three runtime stages: *init(), run(), cleanup()*. The first stage is used once during the first time the model executes, e.g. for initial setting of parameters, opening files, etc., In contrast the cleanup procedure manages is responsible for closing files and therefore is also only performed once.

During the run stage all JAMS components are executed, e.g. to calculate the evapotranspiration rates, snow melt etc. In particular these procedures are accomplished in different spatial and temporal domains, defined as *Context Components*, reflecting process specific needs. Currently three *Context Components* are used: *Model Context (MC), Temporal Context (TC) and Spatial Context (ST).*

The *MC* manages an ordered list of components whose *run()*- procedure is sequentially performed only once. The *TC* guides the temporal aspects of the model in order to manage start and end times as well as the execution step size the model is iterating on (e.g. daily, weekly, and monthly). Similar to this, *ST* is in charge of managing so called spatial model entities (e.g. hydrologic response units (HRUs), nitrogen response units (NRUs) described by their geographic and spatial attributes (e.g. id, lat, long, height, soils characteristics, land use etc.). As shown in fig. 2 these *Context Components* can be arbitrarily configured and hierarchically structured by specific spatial and temporal methods.

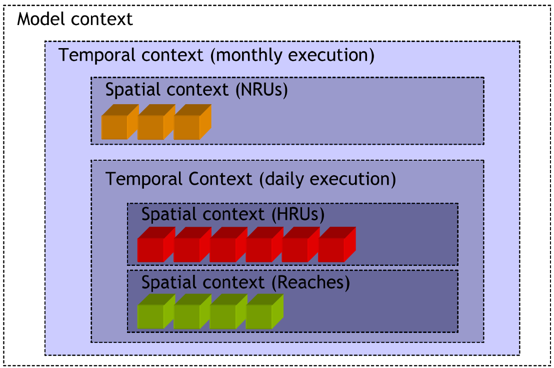

Figure 2: JAMS model example (Kralisch & Krause 2006)

3.2 Process Components for Nitrogen Dynamics

Since nitrogen has been determined to be one of the major nutrient inputs in Thuringia the need for integrating new modules has been identified to address the following issues:

- different nitrogen pools with their specific kinetic turnover rates,
- soil temperature,
- crop growth,
- land use management scenarios.

The successful application of the semi-distributed solute transport model Soil Water Assessment Tool 'SWAT' (Arnold et al. 1998) in one test catchment in Thuringia (Ac=543 km²) has led to some of its basic methods being implemented into the knowledge core of JAMS, called now *J2KSN*.

3.3 Land use Management

To simulate crop growth, data for (i) parameterization of crops and (ii) land use management are needed. Although parameters for crops as well as for fertilizers and tillage are adaptable from those provided by the SWAT model, the linkage and interaction of these parameters however has to be controlled in JAMS. The approach is to clearly structure this information according to its functionality and link them together in a generic land use Management *JAMS object.* The outcome of this is an object that references and manages the interactions of crops and management parameters that are needed for the simulation of nitrogen dynamics within each particular modelling entity.

As shown by fig. 3 the basic idea was to generate basic *JAMS objects* first for tillage and fertilizer parameters (J2KSNTillage, J2KSN Fertilizer) which is done by reading the SWAT databases and transforming these data into JAMS objects. Hence they contain parameters for: type of tillage (TID) and its description (desc), mixing efficiency (effmix) and depth of mixing (depttil). For fertilizers the type of fertilizer (FID), description (desc), the organic total and NH_4-N content (forgN, forgNH4N) as well as mineralised N contents (fminN) were identified. These are stored as Java HashMaps which, in general, contain a *key* and a *value.* For the J2KSNTillage and J2KSNFertilizer objects the id's (TID, FID) are referenced as *keys* and the describing parameters are defined as *values* and handled as a JAVA *<ArrayList>*.

Second in order to reflect the actual cropping system the sequence of management operations must be parameterised in a sequential manner to order by date tillage, fertilization, seeding,

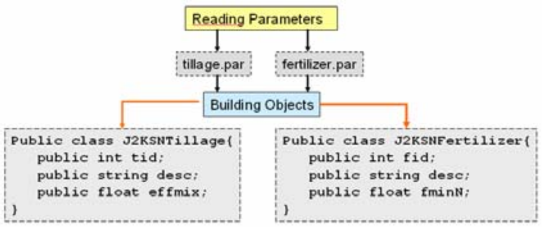

Figure 3: J2KSNTillage and J2KSNFertilizer objects in JAMS

harvesting etc. for each crop. Since this information is stored in the crop management file (J2KSNLMArable) these parameters are handled again as HashMaps in JAMS. As shown by fig. 4 the linking of the actual land use management operations to their related tillage and fertilizer objects is provided by assigning the J2KSNTillage and J2KSNFertilizer objects as *value* in the J2KSNLMArable HashMap.

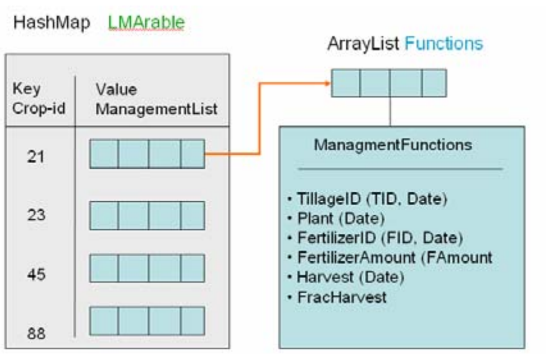

Figure 4: Representation of agriculture management operations in JAMS

Following this procedure crop parameters (J2KSNCrop) and crop-rotations (J2KSNRotation) were built to allow an arbitrary number of management scenarios wherein the crop-rotation-id (RID) triggers the chronological order of the crop-rotations elements represented by the crop-id (fig.5). Again the HashMap *values* are extended through the respective, previous <*ArrayList*>.

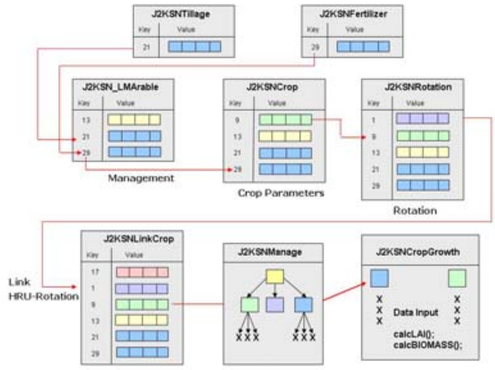

Figure 5: Procedure for implementing complex management operations in JAMS

The linkage of this land use management information to the spatial modelling entities is done by assigning an actual list of HRU-IDs and their corresponding rotation-ids (RID) (J2KSNLinkCrop). The final management object (J2KSNManage) enables the determination of the actual operations (e.g. actual position for the date of seeding, fertilization etc.). This information is directly accessible to the JAMS process components like the crop growth module.

3.4 Nitrogen turnover, Soil Temperature and Crop Growth

Since land use management is important in determining the amount of nitrogen inputs within temporal context it therefore also determines the beginning of crop growing and therefore the ability to reduce nitrogen. To model the nitrogen turnover within the soil-plant system in general six nitrogen pools have been included in the *J2KSN Knowledge part*: nitrate, ammonia, stable organic biomass, and active organic biomass, stable and fresh residues. These are initialised separately in order to provide stable pools when starting the model. To model the nitrogen turnover dynamics correctly in the vertical soil structure there was a need to adapt the current vertical representation of the soil layer compartment from a one layered profile to a multilayered description according to soil type classification. Since nitrogen turnover rates are highly dependent on abiotic factors, e.g. the soil temperature, procedures for calculation of these variables have been added additionally. So soil temperature is modelled as a function of the previous day's soil temperature, the average annual year temperature, the current day's soil surface temperature and the depth in the profile.

As shown by fig. 6 the J2KSNCropGrowth process component allows modelling of potential and actual crop growth in several steps. First the potential crop growth is simulated by describing the daily leaf area development curve, light interception, and the conversion of intercepted light into biomass given the plant species-specific radiation use efficiency. Moreover calculated total biomass is differentiated into the root development (below) and above ground biomass, each simulating the N-uptake, both residues and yield.

The potential crop growth is reduced by modelling water, temperature and soil nitrogen stress factors to determine the actual crop growth and to reduce the actual soil NO_3 pool by the amount of the plant's N uptake.

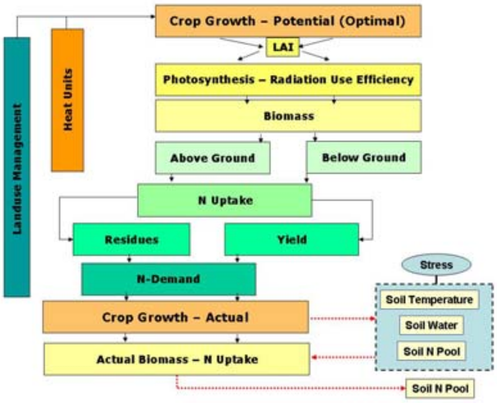

Figure 6. Conceptual stages for the J2KSNCropGrowth process component

As a consequence a constant matching of the actual and the required conditions is needed. To determine the temperature stress the actual daily air temperature and the species specific plant's base temperature are compared. Moreover it is determined if the actual plant's water and nitrogen demand can be met by the actual soil water storage and soil nitrate pool. Therefore stress factors are expressed by empirical functions.

4. Catchment Context

For a pilot study in Thuringia the 843 km² catchment of the upper Gera River was selected (fig. 7). It is a tributary of the Unstrut, which flows into the Saale River, which drains into the Elbe. Criteria for the selection procedure can be outlined as follows:

1. The study area should be representative of the central part of Germany. Therefore it should cover different topographical conditions like mountains and lowlands as well as mixed types. Land uses should cover urban areas, forests and mixtures of pastures and farm land including intense agriculture, and should be underlain by typical soil types and hydro-geologic formations. The climatic and hydrologic conditions should vary from cold and wet conditions with high precipitation rates and low evapotranspiration in the midmountain part up to dry and warm regions in the lowlands.
2. Investigation of scaling problems should be possible by covering meso and lower macro scales as well as small scale headwater catchments (< 20 km²) .
3. Water and land use management should represent regional problems related to the WFD.

Therefore water quality conditions should range from surface water bodies with good ecological and hydrochemical status to areas having major impacts from diffuse sources in addition to local inflows from sewage plants.

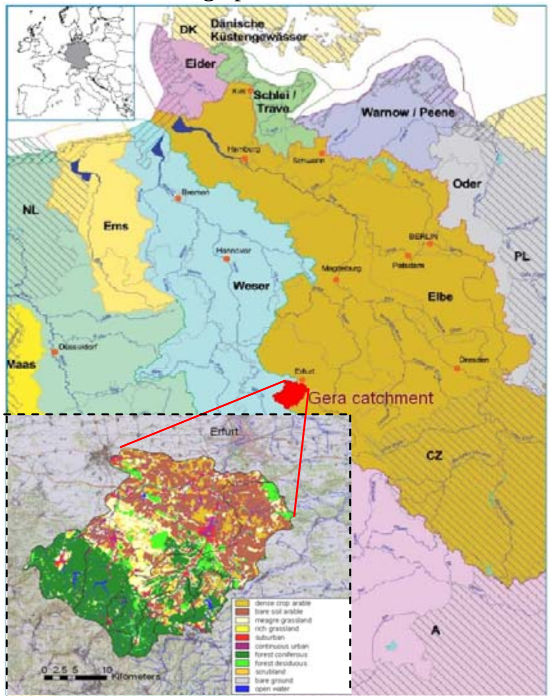

Figure 7. Geographic position of the upper Gera river system and its land use (September 1999)

Water management actions should be mostly concentrated in water reservoir storage facilities for flood prevention, power generation and drinking water supply. For investigation purposes the overall catchment of the upper Gera River can be divided into the three main regions of the (i) Thuringian forest, (ii) Ilm-Saale limestone plateau, (iii) central Thuringian farmland. Major water quality problems from nitrogen inputs are found in the intensely used regions II and III where water quality recommendations for surface waters in Germany are exceeded (Bende-Michl et al. 2005).

4.2 Model Application and primarily Simulation Results

After all necessary nitrogen pools, their turnover and transport process dynamics as well as the crop growth and the landuse management options were implemented and coupled with the hydrologic parts in the JAMS knowledge core, the enhanced model was tested. The model was applied within the Arnstadt subcatchment using 3864 spatial modelling entities comprising the modelling time period of 1996-2000 in which there were nitrogen validation data. Preliminary results for nitrogen exports separated by the flow components of surface runoff and baseflow, as well as by slow and fast interflow is shown in fig. 9 for the simulation period.

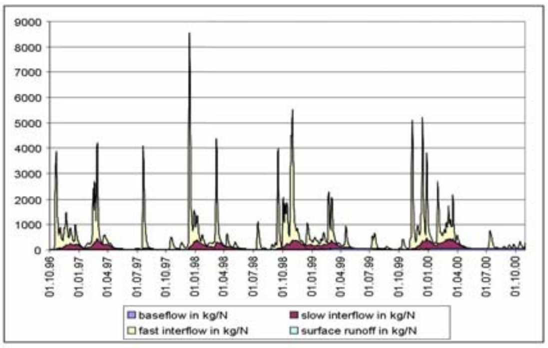

Figure 9. N loads by separated flow components at the Arnstadt outlet

Since the catchment's nitrogen response is remarkably driven by the combined outflow of the slow and fast interflow components, the surface runoff can be neglected. In contrast, baseflow shows only little influence at this time due to an insufficient storage setup. Therefore a longer simulation period is needed.

5. CONCLUSIONS

To attain the targets of the EU-WFD the need of enhancing the modular system JAMS framework was postulated to identify and assess landscape response functions for water and nitrogen. The overall goal of this study was to test the implementation of solute and turnover process and transport components. Moreover the enhanced JAMS should have flexible options for designing user-defined, arbitrary land use management scenarios for agricultural applications. Though programming knowledge of JAVA was a major advantage the implementation of the new J2K process components was successfully performed in a manageable effort by the component developers. Preliminary modelling results for one of the subcatchments of upper Gera shows promising results. Future work includes intensive testing and application of the model to the whole upper Gera catchment area.

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