Dynamic Simulation based Evaluation Feedback over Possibility Space for Natural Resource Management

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ABSTRACT

The recently developed multidisciplinary methodology is based on our Direct Computer Mapping based simulator, combined with a Multi-objective Genetic Algorithm. This paper focuses on the conceptual framework of this dynamic simulation based tool, through the example of Lake Balaton and its Southern catchment basin. The objective is to manage sustainable and reasonable land use by the investigation of various scenarios, considering the preferences of various interest groups.

The coherence of the model is given by the dynamic network of water flows and reservoirs. The completeness is solved by the complete and disjoint covering of the whole area by modeled patches, corresponding to the typical parts of natural and human built environment, associated with typical partial interests. The complexity of the large scale and long term process is managed by evaluating detailed models only for one representative patch from each class, while the calculation and assessment of the similar patches is solved by simple multiplication rules. Automatic and impersonal development of scenarios is realized by a multi-objective evaluation feedback over the possibility space of the human controlled characteristics, supporting the computational analysis of the conflict between the interests. First experiences proved that the developed multiscale methodology is flexible enough for the continuous development of the multidisciplinary models, which can support the multicriteria decision making for the agricultural and natural resource management.

Keywords: Integrated natural and human-built processes, prototyped patch modeling, Direct Computer Mapping, dynamic simulation, evaluation feedback, Hungary

1. INTRODUCTION

Our recently started work focuses on the complex multidisciplinary investigation of a sensitive geographical area, near a shallow lake. Considering the highly multidisciplinary character of the work, it is based on the cooperation of four research groups, from natural to social sciences. The gross structure of investigated processes can be seen in Fig. 1. Main goal of our Research Group on Process Network Engineering is to link the results of the various research groups, and to develop a new methodology and tool for its utilization in management of sustainable and reasonable land use. The computational model based investigation of various scenarios is tested in the example of southern catchment basin of Lake Balaton. The paper focuses on the overview of the conceptual framework of the recently started work.

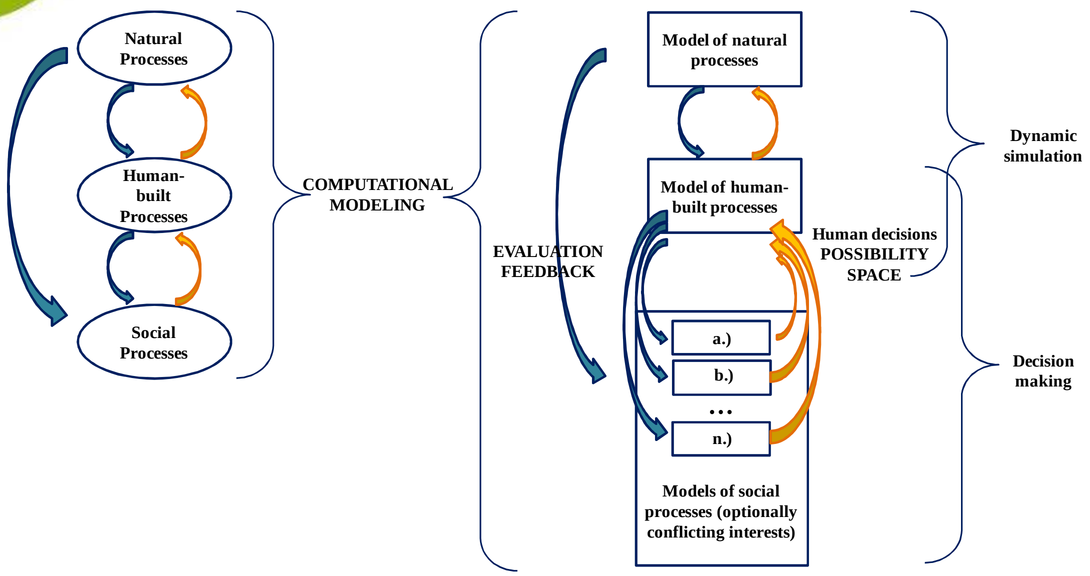

Figure 1. Gross structure of investigated processes and of their models.

2. STATE-OF-ART

2.1 IT Supported Sustainability

The first and mostly cited definition of sustainability is originated from Bruntland Report (1987). IT supported sustainability and management of natural resources started from computer assisted studies on particular (mainly ecological) problems in the last decades. Nowadays, it covers the computer assisted solution of large scale, long term problems of mankind. Considering the rapid development of IT tools and the increasing needs for solving multiscale problems, computational sustainability became a dynamically developing field. It can be seen from literature that besides the investigation of field specific problems (e.g. Halim et al., 2011), there are large efforts to develop effective computational tools (e.g. Azevedo et al., 2009). Increasing demand for new, sustainable solutions appeared also in systems biology, in material science, as well as in the energy and food sector (Kowalski et al., 2009).
Generally we can say that the biggest challenge for the engineers' community is to find IT solutions to support the needs of a sustainable future.

2.2 Computational Modeling of Shallow Lakes and Catchment Basins

Having analyzed the literature and the web sources, many tools for hydrological modeling of shallow lakes and their catchment basins are available. Website of the US Environmental Protection Agency contains a comprehensive list (http://www.epa.gov/ceampubl/swater/index.html), summarizing the software tools and databases, supporting the water and watershed modeling.
It is worth to highlight the widely used and freely available Soil and Water Assessment Tool (SWAT, http://swat.tamu.edu/education/), developed by Texas A&M University

as an extension of ArcGIS software. This continuously developing tool gives a GIS supported framework for investigation of various scenarios, with the consideration of soil types, meteorological datasets, land use and various contaminants in the waters. We found reference about former SWAT based investigations of Lake Balaton (Chatenoux et al., 2008). Accordingly, in the initial stage of our work we also tried to discover the applicability of this tool. In spite of the advantages, we concluded that because of the tremendous data need we would not involve it in the further work.

GISHydro (http://www.gishydro.umd.edu/) is another free tool for hydrological modeling, developed by University of Maryland. Unfortunately, its update is stopped at the ArcGIS9.x compatibility.

WateRisk software (http://www.vkkt.bme.hu/feltoltesek/2012/10/waterisk_2012.pdf) is a Hungarian development, resulted by an earlier R&D project. It supports the investigation of various climate and water governance scenarios on the basis of integrated hydrological models, but is not available for public use.

3. METHODOLOGICAL ELEMENTS OF THE ONGOING WORK

Having overviewed the available software tools and the particular needs of the problem to be solved, it became clear that we need a method and tool, which is able to search for sustainable solutions in the possibility space of natural processes, according to the different evaluations of various interest groups. Analyzed tools are not prepared fully for the process model based evaluation and development of the sustainable scenarios, considering the increasing importance of agriculture, the complex utilization of natural resources and the diverging social interests. Consequently, we try to implement our Direct Computer Mapping based methodology, combined with Multi-objective Genetic Algorithm. Basic methodological elements are summarized in the followings.

3.1 Direct Computer Mapping Based Process Model

Direct Computer Mapping (DCM) based modeling methodology (Csukás, 1998; Csukás et al., 2011.a.) has been applied successfully for various problems in the past years (e.g. pharmaceutical applications, multiscale biological processes, agrifood process networks). The basic idea behind the method (see Fig.2.) is "let the computer know about the very building elements and structures of the investigated processes, directly":

• by mapping the elementary model elements onto an executable (declarative) code,
• by restricting the model to stay in the feasibility domain, and
• to get a common representation for conservation law based and rule based informational processes.

Coherence of the model, is based on the compartmentized network of water flows and water bodies in the investigated area. The water network model contains the main water courses (cca. 200 watercourse compartment) and the connecting water bodies (lakes, fishponds and reservoirs) in the South catchment basin of Lake Balaton.

Water network (bottom left part of Fig.3.) was determined according to the related shapefiles from the National Watershed Management Plan, edited with ArcGIS software. The structure and the parameters (length and flow rate of river compartments, surface of fishponds, ad hoc investigated components, etc.) of the dynamic model are in line with the principles of DCM based modeling method, via ArcGIS. Accordingly, in expert side, GIS description is extended with the data, determining model structure and parameters. It is to be noted, that Google Earth can be used for a popular interface at user's side. The exported XML description is forwarded to the simulator to generate and execute the dynamic simulation by its kernel program. Meteorological and other databases are considered in the course of dynamic simulation, too.

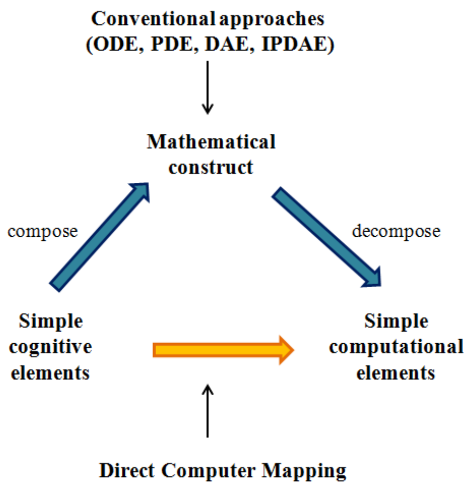

Figure 2. Idea of Direct Computer Mapping.

3.2 Prototyped Patch Model

Completeness of the model is solved by the complete and disjoint covering of the whole studied area with typical patches. The equivalency classification of patches is determined by human activities (e.g. various land use scenarios) or natural characteristics (e.g. natural land types). Typical patch classes are the protected marshes, forests, fields, as well as towns, resorts and agricultural areas. Each class of patches has represented by (at least) one prototype patch, and the detailed process models are prepared and calculated only for these prototypes. This helps to reduce the complexity of the large model, because all of the other patches can be calculated according to the result of prototype patches, using case-specific multipliers (e.g. population of towns, area of fields, etc.). It is to be noted, that every patch belongs to one and only one water flow or body compartment. An example covering of broad-leaved forest patches can be seen in the bottom right part of Fig.3.
In the patch covering of the studied area, helpful starting point was the Corine land cover database. However, because of the insufficient accuracy of dataset, it needs serious corrections sometimes.

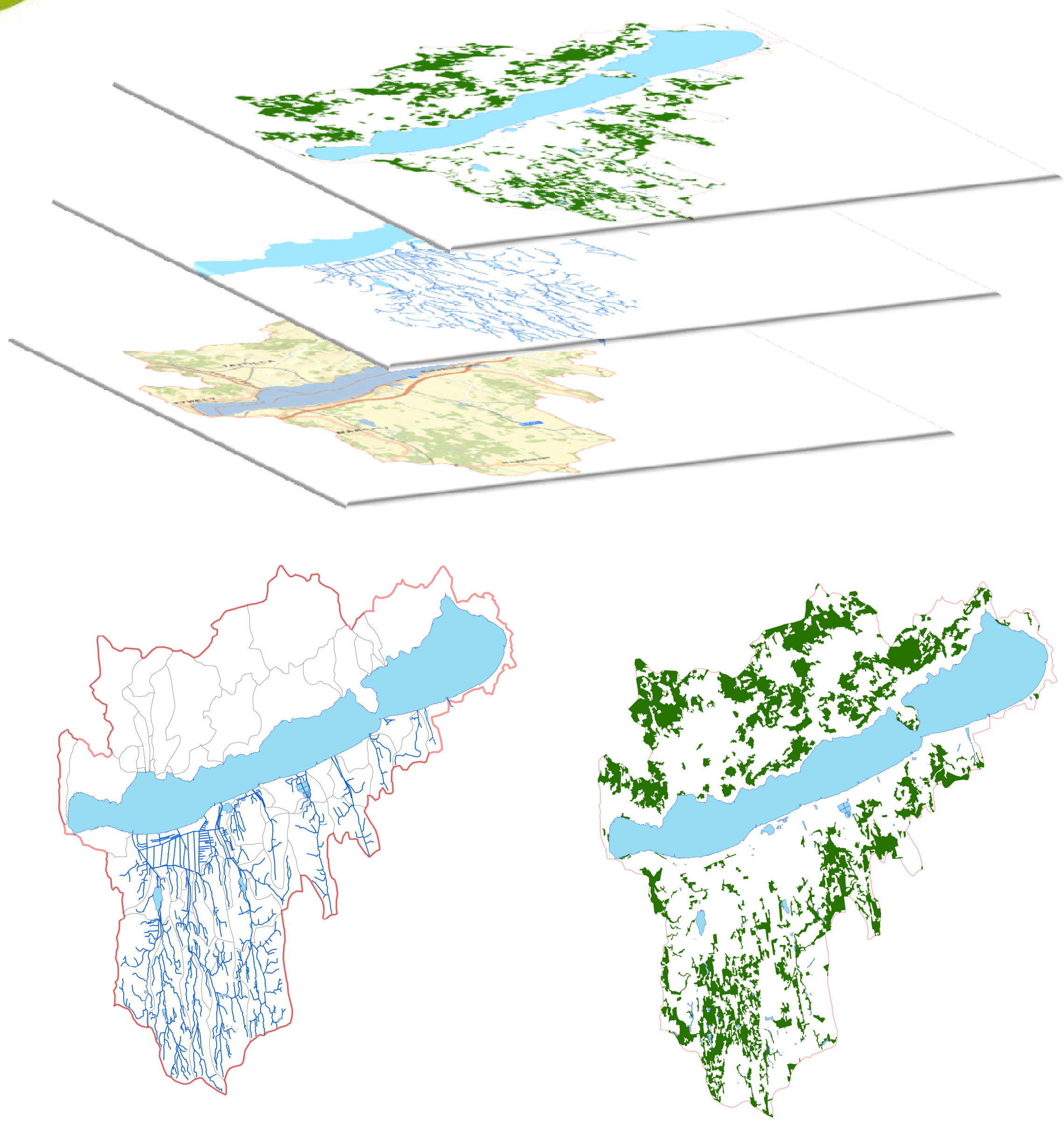

Figure 3. Map-based illustration of process model layers.

3.3 Multi-objective Evaluation Feedback over the Possibility Space

With the knowledge of the water network structure and of the patch model over it (upper part of Fig.3.), the biggest challenge is to combine them with the social processes and to support the decision-making that serves sustainable, but good enough (compromise) solution for all the interest groups. In computer implementation we use the combined tool of DCM and and MGA (Csukás and Balogh, 1998; Csukás et al., 2011.b.). In the conventional optimization approaches (e.g. MINLP), exact optimization is based on simplified models. In contrary, genetic algorithm searches for (sub)optimal solutions on the basis of the most detailed models. In practice, genetic algorithm compiles parameter combinations from the pre-defined possibility space, and gives them to the simulator for calculation. Simulation results are evaluated according to the objectives of the various interest groups. Considering these evaluations, genetic algorithm tends to find tendentiously better compromise solutions.

Actually, possibility space of natural and human built processes (e.g. control level of dams, various human activities in the catchment, etc.) makes possible to find a compromise in the conflicting situations. Involved interest groups (signed with a.), b.),...n.) in bottom left part of Fig.1.) evaluate the scenarios, simulated with various parameters, and feedback their evaluations to MGA.

4. RESULTS AND CONCLUSIONS

A new methodology has been developed for natural resource management of catchment basins.

The first experiences proved that the developed multiscale, hybrid methodology is flexible enough for the continuous development of the multidisciplinary models, supporting the multicriteria decision making for agricultural and natural resource management. The methodology has been tested on an example for the process model based analysis and development of South catchment basin at Lake Balaton.

As an illustrative example, spreading of an investigated component, starts from the 2nd compartment of an example creek can be seen in Fig.4.

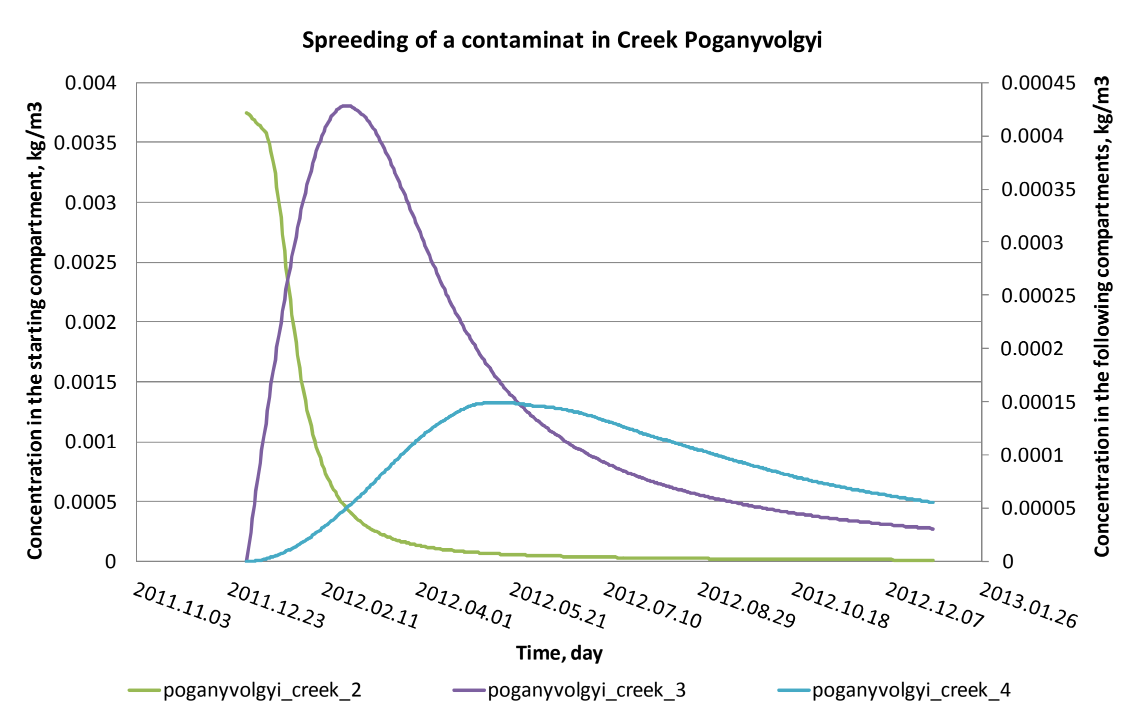

Figure 4. Spreading of a component in Creek Poganyvolgyi.

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Fig.5. shows the spreading of the contaminant in the compartments of Lake Balaton.

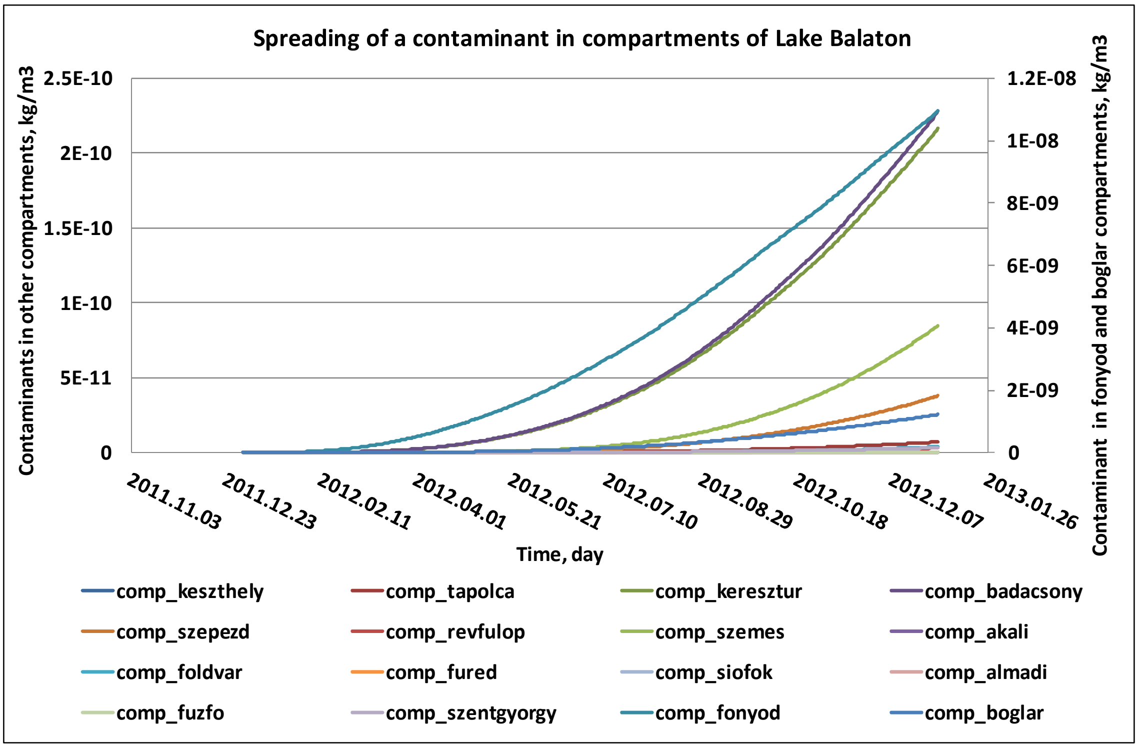

Figure 5. Spreading of a component in Lake Balaton compartments.

On the basis of the water- and patch network model, our ongoing task is to combine it with the proposed multi-objective social evaluation.

The principles of the proposed methodology can be summarized as follows:

• The coherence of the model is determined by the discretized dynamic network of water flows and bodies;

• The completeness is solved by the complete and disjoint covering of the whole area by classified patch types, responsible for the typical parts of natural and human built environment, and associated with typical partial interests. The natural and human-built patches over the network of creeks and lakes were the protected marshes, forests, fields, as well as towns, resorts, agricultural areas, respectively;

• The complexity of the large scale and long term process is managed by generating and evaluating detailed models only for one representative prototype patch form each class, while the calculation and assessment of the similar patches is solved by simple multiplication rules;

• The moderation of the conflicting interests can be based on the systematic overview of the possible elements and properties (the maximal possibility space) of the alternative solutions;

• Automatic and impersonal development of scenarios is realized by a multi-objective evaluation feedback over the possibility space of human controlled characteristics,

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supporting the computational analysis of the consensus and conflict between the interests.

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