

Integrating hydrology, land use and socio-economics in supporting spatial planning for the Tisza basin

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Abstract: In the Tisza basin anthropogenic interventions affect land use, water use, and ecosystems and may compromise the development potential of the whole catchment area. The area faces complex challenges of economic, social, and environmental character, which need transnational cooperation for sustainable solutions. Until present, various models could be applied to support the development of the different aspects of this plan, but no model has yet been developed that is able to simulate the interaction between the range of cross-sectoral processes under consideration.

This paper will present an integrated spatial decision support system that was developed to support strategic integrated planning in the Tisza basin. It includes two widely-applied models: the MIKE SHE model for simulating hydrological processes and the Metronamica model for simulating land use change processes. Main drivers incorporated are climate change and socio-economic developments. By integrating both models into a Spatial Decision Support System, decisions on water resource management and spatial planning can be made in an integrated fashion; facilitating analyses of trade-offs and uncovering win-win situations.

To be able to tailor the system to the specifics of the Tisza basin, the characteristics of the various countries included in the basin needed to be investigated and the underlying models needed to be tuned and in some cases enhanced to meet the specific requirements of its users. In the presentation we will focus on the integration between the models, the application of two generic models to meet the location-specific conditions and requirements, and the translation of scientific output from the models into information relevant for the socio-economic and political context of the decision makers.

Keywords: integrated modelling; hydrological modelling; land use modelling; decision support systems; regional development scenarios.

1 INTRODUCTION

1.1 Integrated planning in the Tisza Basin

The Tisza Catchment Area is located in the eastern part of Europe and has a territory of 157 thousand square kilometres that is rich in natural resources such as water, mineral deposits and fertile soils. It has a talented workforce with people

from various cultural and ethnical backgrounds. This same area, however, has suffered tremendous losses by wars and animosities and is tormented by natural and technological disasters. Large stretches of land have become unproductive because of subsequent draughts and floods, wastewater has contaminated the waters, and neglect and un-thoughtful developments have resulted in a decay of the traditional characteristics of the river basin (TICAD partnership).

In March 2001 the Ministerial Committee of the European Council asked the concerned states (Hungary, Romania, Serbia and Montenegro, Slovakia and Ukraine) to cooperate in order to prevent disasters and plan for a sustainable development within the river basin. This has resulted in the Tisa Catchment Area Development – TICAD – transnational project, which has the aim to harmonise the integrated territorial developments implemented in the river basin, to facilitate the creation of a sustainable economic structure, to optimise the use of natural and cultural resources, to develop areas of competitive growth and to promote the establishment of the internal and external functional interdependencies of the network of settlements.

As part of the TICAD project, a spatial decision support system (SDSS), the TICAD SDSS, was developed to support the development of a transnational strategy, in particular by improving the understanding of 1) the reciprocal relationship between the various processes at stake, in particular land use, hydrology and socio-economics and 2) the spatial implications of (a combination of) policy measures under different climate and socio-economic scenarios.

1.2 State of the art and current limitations

Modelling land systems has evolved from a disciplinary science with models such as CLUE (Verburg et al., 1999), Sleuth (Clarke et al., 1997) and Metronamica (White and Engelen, 1997; RIKS, 2011) to an interdisciplinary science in which the original land use models are coupled with other disciplinary models related to the land system, thus creating integrated models such as the Environment Explorer (Engelen et al., 2003), MedAction (Van Delden et al., 2007), LUMOCAP (Van Delden et al., 2010), and LandSHIFT (Rudiger, 2011). More and more these systems are aimed at providing support to policies as they have the ability to provide an integrated assessment of policies on a range of sectors.

However, in current SDSS applications we experience two main difficulties that limit their use: 1) generic integrated land use - hydrology models that can be widely applied to new regions based on region-specific data and calibration, without the need for additional software development are not yet available and 2) many SDSS fail to connect to the policy context well enough to actually support policy analysis.

The TICAD SDSS is developed with the aim to overcome the current limitations. This has resulted in the selection of generic models, (Metronamica and MIKE SHE) with a long track record and applications worldwide, for incorporation in the SDSS, and a development process with frequent user interaction (Van Delden et al, 2011) to ensure an application of the generic system that would meet the user requirements and could work with the data available in the Tisza basin.

1.3 Research scope and structure of the paper

The aim of the research is to assess the use of a generic integrated spatial decision support system for supporting spatial planning in the Tisza basin. This has led to the following two research questions:

1. Can the generic integrated model incorporating Metronamica and MIKE SHE be applied to the Tisza basin with the available data?
2. Can the applied SDSS, the TICAD-SDSS, provide support in assessing the implications of various spatial planning scenarios on selected policy-relevant indicators?

In section two of this paper the TICAD-SDSS and the integrated model it comprises will be described together with the methods followed to answer the research questions. The third section will report on the results obtained, followed by some conclusions and recommendations in section four.

2 The TICAD Spatial Decision Support System

The TICAD SDSS is a forecasting tool for planners and policy analysts working in urban and regional development. It encompasses a spatially explicit integrated simulation model that allows exploring future developments of the Tisza basin. It encompasses a set of socio-economic and environmental indicators that allow policy analysts to assess and compare the impact of various policy alternatives on those aspects that are found important in the transnational strategy. The TICAD SDSS simulates the dynamics of changing land use patterns and hydrological conditions and is able to work for a time horizon of up to 30 years.

The system consists of a global model covering the whole Tisza basin and three local case studies. The global model incorporates two spatial levels: the regional level and the local level, the latter being a grid of cells of 500x500 m. The case studies all operate at local level and use the same grid as the global model. The difference between the case studies and the global model is that additional information is included in the case studies, either through additional data and plans or through additional modelling. In the following sections we will describe the global modelling and the additional modelling carried out in one of the case studies.

2.1 Integrated modelling

The TICAD SDSS includes the following three model components from two mature models, MIKE SHE 2011 WM (e.g. Graham and Butts, 2005) and Metronamica 4.2.2 (RIKS, 2011; www.metronamica.nl):

- A spatial interaction model component for calculating the regional population and jobs in main economic sectors. This component simulates the interaction between centres of gravity in the basin (the cities and regions) in their competition for people and jobs. The distribution of the national growth of these activities over the various regions as well as the migration between regions is based on the relative attractiveness of regions and their distance to each other. Main drivers are the total socio-economic developments of the basin, as well as the local and regional characteristics contributing to the attractiveness (Metronamica);
- A cellular automata model component for simulating land use developments at local level (land use maps and related indicators). This component simulates a competition between the various actors to occupy locations of interest. Main drivers are physical suitability, spatial planning, accessibility and human behaviour, the latter represented by the inertia of land use functions, the attraction or repulsion of neighbouring land uses and the power to actually occupy locations of interest. Based on the combination of drivers a transition potential is calculated at cellular level which forms the basis for land allocation (Metronamica);
- A process-based model component to calculate the water balance and groundwater levels. This integrated modelling framework simulates all components for the land-phase of the hydrological cycle and focuses on the most important processes: groundwater flow approximated by a 3D finite difference scheme, overland sheet flow (diffusive wave) and drainage flow routed to the river channel, 1D hydrodynamic approximation of flow in the Tisza and Sajó river channels, actual evapotranspiration computed based on a time series of potential rate and actual soil moisture and vegetation status in every grid cell of the model, 2-layer simplified accounting water balance model for soil column in every grid cell, degree-day-factor method used for snow melt. This component has climatic and bio-physical characteristics as main drivers (MIKE SHE).

The global model includes only the first two model components. In one of the pilot regions (the region covering parts of Borsod-Abaúj-Zemplén, Hajdú-Bihar and Szabolcs-Szatmár-Bereg) the full set of components is incorporated.

The TICAD SDSS uses Geonamica (Hurkens et al., 2008) as a software environment for model integration and includes both modelling tools as embedded components. This has resulted in a coupled system that enables dynamic feedback between Metronamica and MIKE SHE. Figure 1 gives a schematic representation of this interaction: the soil water content and the groundwater table are used as components in the calculation of the physical suitability, which is a main component in calculating the attractiveness and hence transition potential of locations. The integration of hydrological information in the suitability layers builds on the approach from the MedAction Policy Support System (Van Delden et al., 2007), which uses response curves for the different natural and agricultural land uses, describing the relation between plant growth and the physical variables, and applies those to transform the model output into suitability values ranging between 0 and 1 (1 being very suitable, resulting in a maximal possible growth). The suitability maps are recalculated on a five-yearly basis using up to date model output from the MIKE SHE model. The overall regional water balance impacts on the water available for the various agricultural land uses and assumes a decline in agricultural land uses with persisting drought. The simulated land use maps, in turn, impact on the vegetation parameters Leaf Area Index and root depth in MIKE SHE, which directly influence the soil moisture content at cellular level and, if the change is significant, also the total water balance and the ground water level.

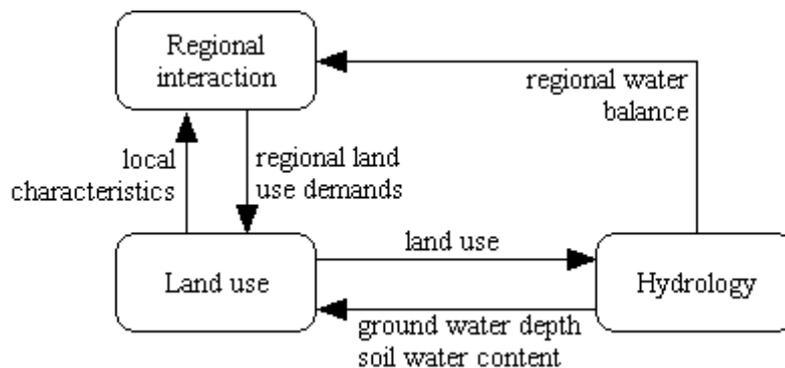


Figure 1 Schematic representation of the interaction between the three models incorporated in the TICAD SDSS.

In the current approach, the MIKE SHE model uses a monthly time step, while Metronamica runs at a yearly resolution. To overcome annual fluctuations a five year average of hydrological output is used for the integration with Metronamica.

2.3 Customisation to the Tisza basin

2.3.1 Application

The study area for this project is the Tisza basin, which runs through the Ukraine, Hungary, Romania, Slovakia and Serbia. However, only part of each of these countries is actually included in the Tisza basin. This had some implications for the setup of the application. Administrative boundaries do not necessarily coincide with catchment boundaries and hence socio-economic data is typically not available for catchments and sub-catchments. For this reason we decided to include all regions that are partly or completely covered by the Tisza basin. The small pilot area is defined as a 'strip along the river'. This area comprises parts of three administrative boundaries and besides the local impacts on the land use model, impacts from the hydrology component affect the regional model at the level of the entire administrative region. The resolution at local level was kept similar for both the hydrology and the land use component to facilitate the integration at this level.

2.3.2 Data and calibration

For the European countries we used Eurostat data to populate the regional interaction component, and Corine Land Cover maps and GISCO transport data together with base layers for suitability and spatial plans provided by the TICAD partnership, to set up the land use component. To ensure plausible model behaviour we have used expert judgement in setting the parameters and carried out a historic calibration to test and fine-tune these settings. Due to the changes that have taken place in the Tisza basin in the late nineties, and the understanding that these would not be representative for future developments, we have selected the period 2000-2006 for the historic calibration, comparing simulation results for 2006 with data for 2006. A neutral model, applied over the same simulation period, was used as a bench mark. Both model components were able to outperform the neutral model and hence we evaluate the historic calibration positively. We used expert evaluation to assess the plausibility of the long-term model behaviour. We had insufficient data to calibrate the regional interaction model for Serbia and the Ukraine and therefore initial conditions were included based on which the user can create scenarios for the growth of population and jobs per region. There was also insufficient data to calibrate the land use model for the Ukraine and therefore it was decided to map the land use classes of the initial map from the Ukraine to the (aggregation of) Corine Land Cover classes used for the other countries and apply the parameter settings for the remainder of the basin also to the Ukraine.

For the hydrology model (3062 km²) the same DEM, soil and land use map were used as in the land use model. The soil map was simplified to 6 main soil types, accompanied by generally available hydraulic parameters. The saturated zone was simplified to one layer with a thickness of 5 – 20 m. 5 sets of hydraulic parameters were subject of the calibration. Their distribution was compiled from maps available from different sources. 47 important pumping wells were included with measured time series of withdrawal. Three time series of observed discharge (input to modelled parts of rivers) were used: Tizsalök station (Tizsa), Gesztely station (Hernad) and Felsozsolca station (Sajó). As climate input, precipitation time series in 24 stations, temperature and potential evapotranspiration in 9 stations was interpolated between observation points in monthly time steps for the period 2000-2006. For future climate change use is made of the REMO 5.7 model results, using climate change scenario A1B (CLAVIER project results presented at <http://www.clavier-eu.org/clavier/>).

The water movement model focusing on the subsurface part and the water balance was calibrated against monthly average observed ground water levels in 24 wells for the period 2000-2003 and validated for the period 2003-2006. For most wells, a satisfactory fit of observed data was reached. Simulated monthly average discharge values in Tizsapalkonya station were compared to observed time series. The correlation coefficient is above 0.9 for the whole period. Finally, water balance trends were checked for a simulation over the whole period (2000-2006). Main components of the water balance are the precipitation input and the evapotranspiration loss (reaching about 93% of precipitation input). The remaining 7% (i.e. 297 mm / 7 years) represents the flow through the boundaries of the modelled area. The total outflow from the modelled area to the Tisza river is about 298 mm. The overall subsurface water storage reaches just a very small value at the end of simulation period (decrease of about 14 mm), which corresponds to the total of amount of water pumped out (4 mm), outflow from the model area through the model boundaries (6 mm) and a computation error (3 mm). A seasonal variation of total subsurface storage up to +/- 100 mm (annually) was found. Based on the above, we may conclude that the model very well keeps the overall water balance for the period 2000-2006, without any significant trends to drying or accumulation of water.

2.3.3 Planning support

Policy-relevant drivers and indicators provide an important link between the integrated model and the policy context in which the TICAD SDSS operates. As part of the development of the TICAD SDSS main issues, external factors, policy options and indicators relevant for simulation have therefore been discussed and agreed upon between the TICAD consortium and the SDSS developers. Next, an

assessment was made to what extent the current selection of models would be able to provide information on the relevant drivers and indicators and based on this a final selection of drivers and indicators for incorporation in the TICAD SDSS was made. Main drivers include climate change, socio-economic development, spatial planning, and infrastructure development. Indicators include population, jobs, urban clusters, distance from residential to work, value at stake in flood prone areas, built-up in ecologically sensitive areas, land use, soil sealing, expansion of urban areas, forested areas, land abandonment and habitat fragmentation.

To assess the ability of the TICAD-SDSS to provide planning support, we have analysed the questions raised during the development of the transnational strategy and selected a sub-set of them as test cases to be incorporated in the TICAD SDSS. To meet the expectations of a support tool, the system should provide support in answering policy-relevant questions. We therefore set up and ran several scenarios to test if the system is able to incorporate relevant drivers and provide information on changes to these drivers on relevant indicators.

3 RESULTS

3.1 Findings on the application of the TICAD SDSS

The models comprising the TICAD SDSS have been successfully applied to the Tisza basin. They proved to be sufficiently flexible to adapt them to the characteristics of the river basin using the data and knowledge available for the basin. The TICAD SDSS was also able to deal with differences in data availability in the different regions and thus making use of better quality and richer databases where available. Dealing with a mix of catchment and administrative boundaries, however, led to complications in the integration of the hydrological information in Metronamica as the output from MIKE SHE caused changes to the suitability in parts of three administrative regions, while this impacted on the relative attractiveness and transition potential of locations in the entire regions and hence caused undesired artefacts in the land use allocation.

The plant response curves linking the hydrological information to the suitability layers have been set based on a more detailed plant growth model and expert judgement. Final curves have been verified by external regional experts. Furthermore we have assessed the impact of changing hydrological conditions on the land suitability by comparing a simulation with the integrated model with a simulation with only the land use and regional interaction components. We found that including the hydrological model resulted in the average decline of the attractiveness of most agricultural and natural land uses, which are strongest for permanent crops and heterogeneous agricultural areas, showing a decrease in average suitability of 0,11 and 0,10 respectively and land use of 3650 ha and 1350 ha respectively. According to expert evaluation this can be seen as plausible behaviour under the given climate scenario, which causes the region to become slightly dryer over time.

3.2 Findings on the ability of the TICAD SDSS to provide policy support

In order to investigate if the TICAD SDSS would be able to support the transnational strategy, main elements proposed in the strategy were linked to relevant drivers of the TICAD SDSS and a set of socio-economic and environmental indicators was selected in collaboration with the users of the system (DHI-RIKS consortium, 2012). Subsequently, values were set for the main drivers for a business as usual scenario based on ongoing trends and a scenario that assumes an implementation of the transnational strategy, which has a focus on reforestation and enhancing socio-economic developments, while dealing with ongoing trends of population decline and climate change. Main policy instruments in the system are spatial planning and infrastructure development. An overview of all drivers settings for both scenarios is provided by DHI-RIKS consortium (2012).

Results for the entire Tisza basin (global model) show that despite an increase in infrastructure and socio-economic development, planning measures can avoid an expansion of built-up areas in ecologically sensitive and flood prone areas; built-up area in both these areas is 2984 km² in 2006, 3014 km² in 2031 in the baseline scenario and 2980 km² in the transnational strategy scenario. The increasing land uptake by forest and urban land is expected to come at the cost of the non-irrigated arable areas, especially on the less suitable locations, as these are expected to be less economically viable than other uses and not protected to the extent that some of the natural land uses are protected. Figure 2 shows a cut-out of the pilot area where similar developments take place as in the entire basin. The figure shows that with the implementation of the transnational strategy, the forested area is not only larger, but also more clustered and new forest locations are likely planned as an extension of existing forests.

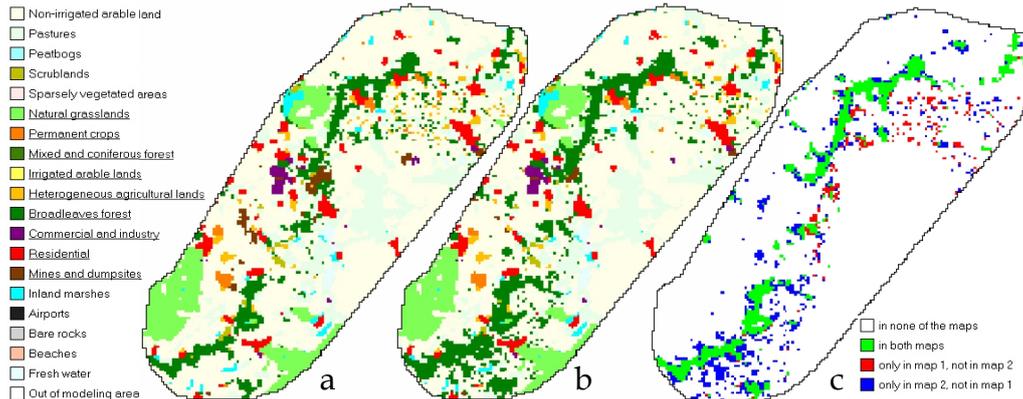


Figure 2 Land use results for 2031 for the baseline (a) and the transnational strategy scenario (b) and a comparison of the forested areas in both maps (c).

Although climate change is a rather slow driver for change, its long-term effects cannot be neglected and hence should be included in developing a long-term strategy. Furthermore, when aiming to gear development to locations found suitable for the particular use, the local hydrological conditions play a crucial role.

Discussions with users on the usefulness of the system have brought forward that the main added value of using the TICAD SDSS in policy analysis is that the system helps to assess the spatial consequences of policy measures (e.g. what is the impact on the landscape if 35% of the area will be forested?) and to see the integrated assessment of various policy measures from different sectors (e.g. what if the area for certain land uses is expected to increase, how does this affect the other land uses, i.e. what are the trade-offs?).

3 DISCUSSION AND CONCLUSIONS

The integration of the MIKE SHE hydrological model with the Metronamica land use model allows simulation of the impacts of climate change on land use developments and environmental processes, as well as the impact of socio-economic growth, infrastructure development and spatial planning on the hydrological conditions. Model results show that these feedback loops indeed have an impact on the main variables, indicating that the assumed reciprocal relationship can be simulated and in this way better understood.

Using widely applied models for the integration in the TICAD SDSS has resulted in a system flexible enough to be applied to the Tisza river basin. The study has shown that it was possible to include additional information for data richer areas and hence improve model results for these areas. For future applications it would be recommended to select the same regional boundaries for all model components to avoid model artefacts. We believe that applying one of the individual components to a regional configuration less than optimal, would result in fewer problems than trying to solve the boundary problem as part of the integration.

The scenario exercise shows that the TICAD SDSS is able to provide support to the development of the transnational strategy by showing the implications of various policy alternatives (reforestation, spatial planning, infrastructure development) on the future development of the region. As the system provides an integrated assessment, it emphasizes both the socio-economic and environmental impacts, as well as the side-effects on alternative policies. The MIKE SHE application in the current TICAD SDSS only covers a pilot region, due to its high data requirements. For future work it needs to be discussed if a detailed approach for selected areas of interest has more advantages than a less detailed approach that would be able to cover the whole area. This of course very much depends on the scope of the research and the questions that need answering.

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