Use of Gis and Gis-based Models for River Basin Management Tasks and Water Management within Rural Areas

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Introduction

The implementation of GIS software, remote sensing and GIS based models provides new opportunities for solving present time and future problems. In Ukraine, GIS and remote sensing imagery is used since many years now but the use of GIS based models is less widespread and mainly restricted to water discharge simulation related to the flooding of landscapes in the Pre-Carpathian and Trans-Carpathian lowlands (rivers Siret, Prut, Dnjester, Tisza a.o.). Today, the Institute of Hydraulic Engineering and Land Reclamation (IHELR) of the Ukrainian Academy of Agrarian Science also profits from the new GIS software opportunities that can be applied now in various fields of activities having been performed without GIS software in the past. GIS and GIS-based models are crucial to cope with new challenges related to floods and droughts, management of irrigation and sustainable land use planning and global warming, especially the change of temperature and precipitation. Those influences are very complex and therefore models represent an efficient tool to overcome difficulties in understanding and assessment.

The IHELR faces additional new challenges with respect to the planned implementation of the Water Framework Directive (WFD, 2000). WFD related cartographical materials and RBM plans have to be prepared using GIS software as described in the GIS Guidance Document (2002) (s. tab.1) and other guidelines. For RBMP GIS based models represent an excellent tool to evaluate alternative plans with respect to water quantity and water quality before a final decision is made.

The main aspect is to find out how land use changes can influence water quantity and quality in a river and thus improve the "ecological status" of water bodies.

Tab.1: Shorted list of GIS layers (scale 1:500 000) required by the WFD (2000)

1. Assigning individual river basins, ground waters and coastal waters to individual river basin districts
2. List of the competent authorities for river basin districts
3. GIS layer containing names of the main rivers and boundaries of the river basin districts
4. Map of the geographical location of the surface water body types consistent with the degree of differentiation required under system
5. Summary report of the analyses required under art.5
6. Summary report of the analyses required under art.8
7. Publishing of river basin management plans:
    - Map of the location and boundaries of surface water bodies
    - Map of the eco-regions and surface water body types
    - Map of the location and boundaries of groundwater bodies
    - Summary of the register of protected areas (location and description of the legislation under which they have been designated)
    - Map of the surface water monitoring networks
    - Map of the groundwater monitoring network
    - Map of the results of the monitoring programs for protected areas
    - Map for each river basin district illustrating the classification of the ecological status for each body of surface water
    - Map for each river basin district illustrating the classification of the ecological potential for each body of surface water
    - Map for each river basin district illustrating chemical status for each body of surface water
    - Map of groundwater quantitative status
    - Map of groundwater chemical status
8. Review and updating of the analysis of the characteristics and of the review of the impact of human activity on the status of surface waters and on groundwater within a river basin district
9. Review and updating of the river basin management plans
10. Presentation in map form of monitoring results for the period of the previous river basin management plan

Investigation program

For the here described study the Salgir River basin has been selected; the catchment size is 3750 km^2 and is by far the biggest in Crimea. The main land uses are forest, agriculture and settlements. Point source pollutions as wastewater discharges from sewage treatment plants and industry exist in the lowland reaches of the river. The main study goal is to evaluate different types of land uses and land management practices including the impacts of irrigation and drainage on water quantity and quality and thus on the ecological status of related ecosystems like the Salgir River itself and the Sivash wetlands. For this purpose, three pilot areas have been selected, beginning with the mountainous area (A) till the drinking water reservoir upstream of Simferopol, the second area (B) is related to a river reach downstream of Simferopol, followed by the last reach (C) and neighboring study areas influencing the Sivash wetlands and the Azov Sea (s. table 2).

Tab. 2: Simulation of water quantity and quality in dependence of:

Pilot Area: A	B	C
Influence on drinking water reservoir	Influence on ground and surface waters	Influence on nature (Sivash wetlands)
==================	==================	==================
1. Different land uses (forest, agriculture, urban settlements) 2. Climatic influences (temperature and precipitation changes)	1. Different land uses (forest, agriculture, irrigated agriculture, urban settlements) 2. Climatic influences (temperature and precipitation changes) 3. Water abstraction for agriculture, industry, drinking water	1. Different land uses (forest, agriculture with irrigation and drainage, urban settlements) 2. Climatic influences (temperature and precipitation changes) 3. Crops, agriculture practices.

In this paper, only results gained in the first pilot area are described. The sources and headwaters are in the Crimea Mountains up to more than 1400 m above sea level. The river passes forests open landscapes (pastures, agriculture) and settlements until it reaches the drinking water reservoir. Simferopol also gets drinking water from two other reservoirs and discharges its sewage further downstream into the Salgir. The basin forms also a part of the pilot area of the SCENES project (Zhovtonog et al. 2009) that is presented in another conference paper.

Methods

Choice of software

The work with GIS was performed using the commercial program ArcView 3.2a (ESRI) and the “open source” program MapWindow. ArcView has been selected because many additional extensions can be linked for a broad spectrum of tasks. These modules are the hydrological simulation model SWAT (AVSWATx), also usable for statistics and graphics; L-THIA NPS GIS and ATtILA are additionally used to generate maps of hydrological parameters, water quality and related landscape assessments. They require similar input data and maps as AVSWATx and broaden the spectrum of attainable results.

These software components can be used to answer the following questions related to hydrophysical aspects, land management, and landscape ecology:

Hydrophysical aspects:

- How does the river network look like under different weather and hydrological conditions (dry reaches, length of streams)?
- From which areas does the river water mainly come from and what are the related shares?
- How big are the slopes, slope lengths and potential flow accumulation in the basin?
- How are the different soil types and land uses distributed in the subbasins?
- Which run-off potential (in terms of curve numbers, CN) can be attributed to the singular subbasins?

- Where are soil erosion risks and where do the suspended solids in the river come from?

Land managements aspects:

- From which subbasins do nutrients mainly come from and which concentration range can be expected?
- Where can be identified erosion risks that can be reduced by land use changes?
- How does land use influence the above mentioned hydrophysical parameters?
- How to optimise irrigated lands allocation and irrigation performance?

Ecological aspects:

- What will be the land use and landscape changes if climate (temperature, precipitation) continues changing?
- What will be the impact of land use changes as for example enlargement of riverbank buffer stripes?
- How can the existing landscapes be reshaped to reach better preconditions for endangered species, biodiversity increase?
- How can nature and agriculture landuse be balanced for ecosystem (wetland) protection?

Where are anthropogenic impacts or human stressors located? (density of roads and other impermeable surfaces, vicinity of roads close to streams or rivers)

Results of SWAT are further planned to be used for more sophisticated water quality modeling with the help of programs like Aquatox (not reported in this paper). The principles of the other GIS-based models are shortly described in the following chapters.

SWAT principle

SWAT is a simulation model (Arnold et al. 1998) that requires a big amount of input data related to more than 200 parameters including the optional inputs, various thematic maps and time series of weather data (for an overview s. fig. 1). If the input data are insufficient, the model will use default values, but if too many data is missing, delivered results might be inaccurate or the model will not work at all.

SWAT is a physically based, basin scale model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in

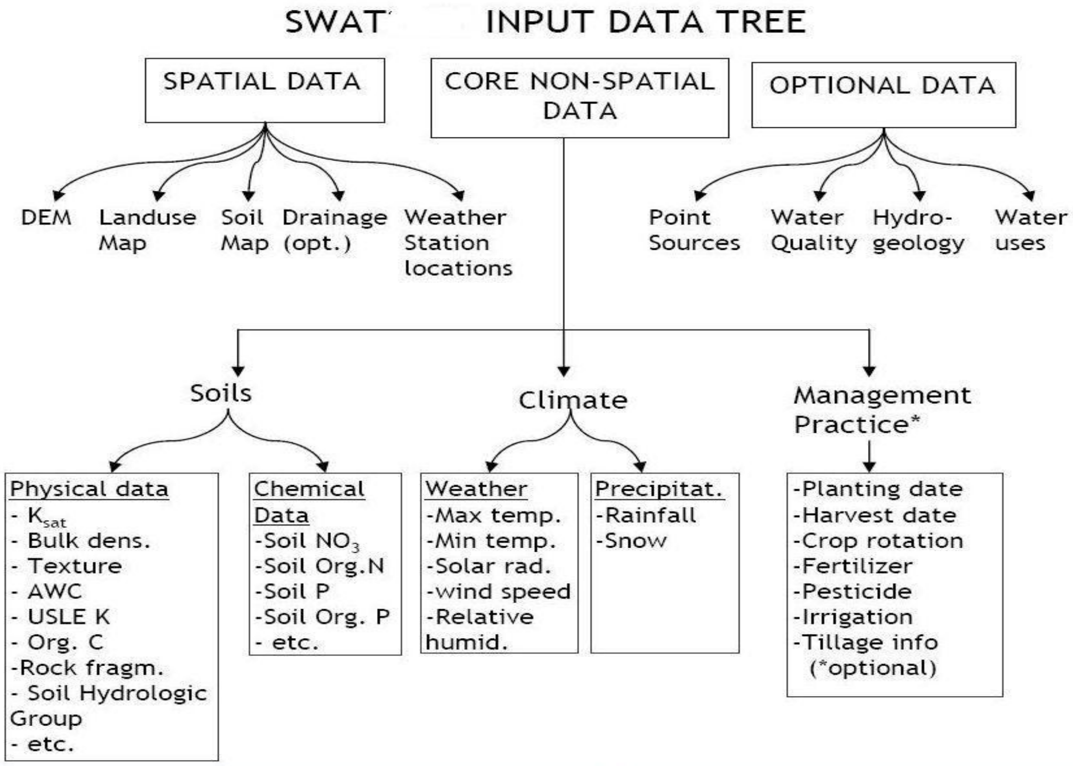


Fig. 1: Overview on required input information for SWAT (from [4])

watersheds. The model is capable of continuous simulation over long periods. Major model components include weather generator (to fill in missing data and for forecasting), hydrology, various physical soil properties, plant growth parameters, nutrients, pesticides and land management. In SWAT, a watershed is divided into multiple subbasins, which are then further subdivided into hydrologic response units (HRUs) that are homogeneous with respect to land use, soil type and elevation above sea level. The following list summarizes the main model characteristics:

- Daily time step long term simulations

- Basin subdivided into subbasins, HRUs or grid cells
- Basins subdivided to account for differences in soils, land use, crops, topography, weather, etc.
- Basins of several thousand square miles can be studied
- Soil profile can be divided into up to ten layers
- Reach routing command language to route and add flows
- Hundreds of cells/subbasins can be simulated in spatially displayed outputs
- Groundwater flow model
- SWAT accepts measured data and point sources
- Water can be transferred from (irrigation) channels and reservoirs
- Nutrients and pesticide input/output

ATtILA2004v.1.0 principle

The program is used to assess landscape diversity, the role of riparian zones, hydrophysical characteristics and human stressors. Correspondingly, the work with ATtILA is subdivided into four “metrics” (Environmental Protection Agency 2007):

1. landscape characteristics (main input is a land use grid, soil grid and precipitation grid),
2. riparian characteristics (focusing on the buffer stripes along the water courses),
3. human stresses (including anthropogenic impacts on rivers by agriculture, settlements and roads)
4. physical characteristics (slope, erosion risks)

L-THIA NPS GIS principle

This module also works based on a land use map, soil type map and precipitation time series (Purdue University 2004). It firstly calculates CN (curve numbers)

(United States Department of Agriculture 2009), average and peak flows under different weather conditions as well as a set of inorganic and organic water quality parameters, and then allows for presenting the results in the GIS project.

Preparation of Inputs

It is crucial to prepare the input information very carefully. In many western countries, suitable maps and data on land use, soil types and weather data are available on the Internet in digital form and retrieving them is a matter of a view minutes. In Ukraine, data are more difficult to find, expensive to get and usually they are on paper only. This is why the preparation phase can comprise many months or even years.

The main materials required to work with SWAT in the pilot area (Crimea) are (s. fig. 1):

- Topographical map available from SRTM (Jarvis et al. 2008)
- In special cases (flat landscape): a map of the river network (prepared as shapefile)
- Land use map (prepared as shapefile, updated or edited using Google Earth)
- Map of soil types (and related physical characteristics to be stored in a database); a soil map is available from the *European Commission and the European Soil Bureau Network (2004)*, for editing some details, Ukrainian maps were used (SL-studio 2005, Bagrov and Rudenk 2004. Some of the missing hydrological soil parameters have been estimated using the program *Soil Water Characteristics*, version 6.02.74 (Saxton 2007).
- Weather data time series for precipitation and minimum and maximum temperature; optional: time series of solar radiation, relative humidity and wind speed (CGMS data; European Commission 2009)

Statistics

The results of simulations (SWAT) were compared with observed data (using monitoring results as far as available) for model calibration and verification. The first step is to compare simulated and observed river water discharge. In order to compare water quality data, more monitoring results still have to be collected and will be reported later.

For comparison (preliminary verification), yearly and monthly data have been used to calculate the coefficient of correlation and the efficiency (Nash and Sutcliffe 1970).

First results

- The here presented maps are just examples. They are briefly described to give an overview on materials that can be obtained using the mentioned GIS software ArcView, AVSWATx (alternatively MapWindow plus MWSWAT), ATtILA, and L-THIA GIS.

Following, selected maps are described to give examples of the GIS and GIS models outputs.

The first map (**fig. 2**) shows the landscape topography in the form of a digital elevation model (DEM); 4 peaces had to be merged to obtain the map of Crimea. The pilot areas that are investigated in the frame of the SCENES project (Zhovtonog et al. 2009) are marked with circles.

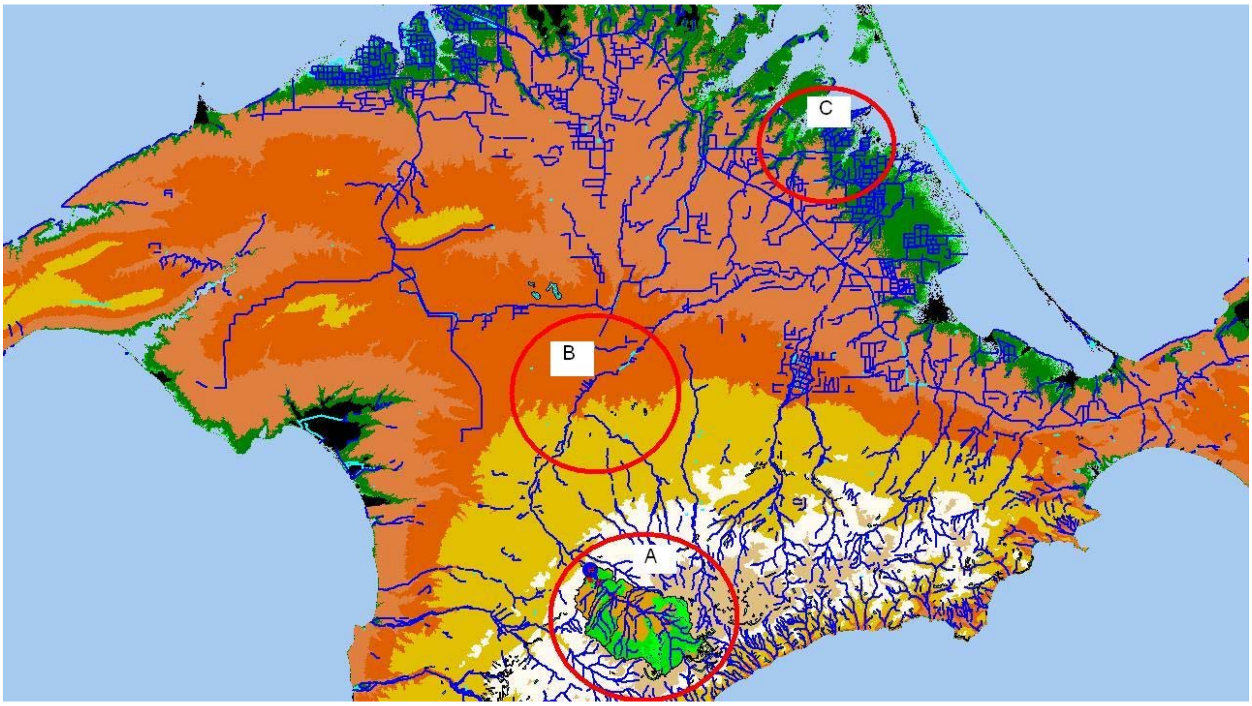


Fig. 2: Digital Elevation Model (DEM) of Crimea. Three pilot areas marked with circles.

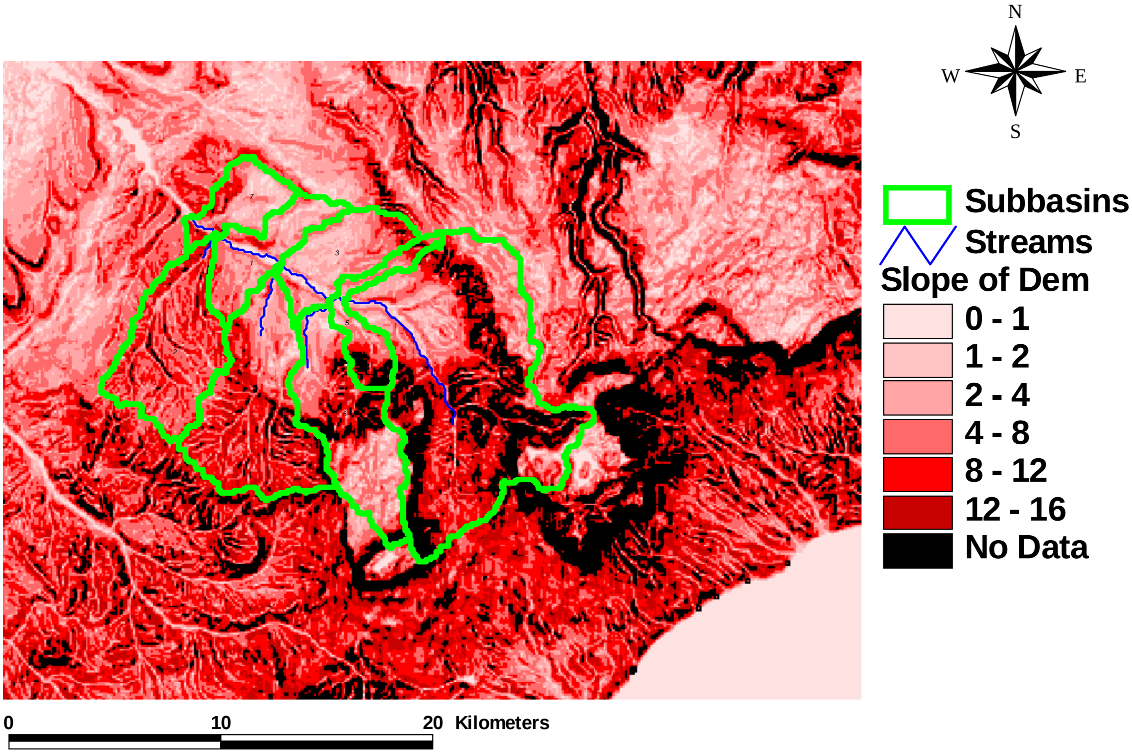


Fig. 3: Slopes of landscapes in South Crimea. The subbasins of the Salgir headwaters are marked green

The map of **figure 3** shows the slope of the landscape, which, together with other inputs, is further used to calculate erosion risks.

The basin and subbasins of the upper part of the Salgir River (pilot area A in fig. 2) are shown by green lines; they have been delineated using AVSAWTx. Number, size and location of subbasins can be freely selected by the user.

Figure 4 shows the river basin (upper part, pilot area 1) in 3 D view for better imagination

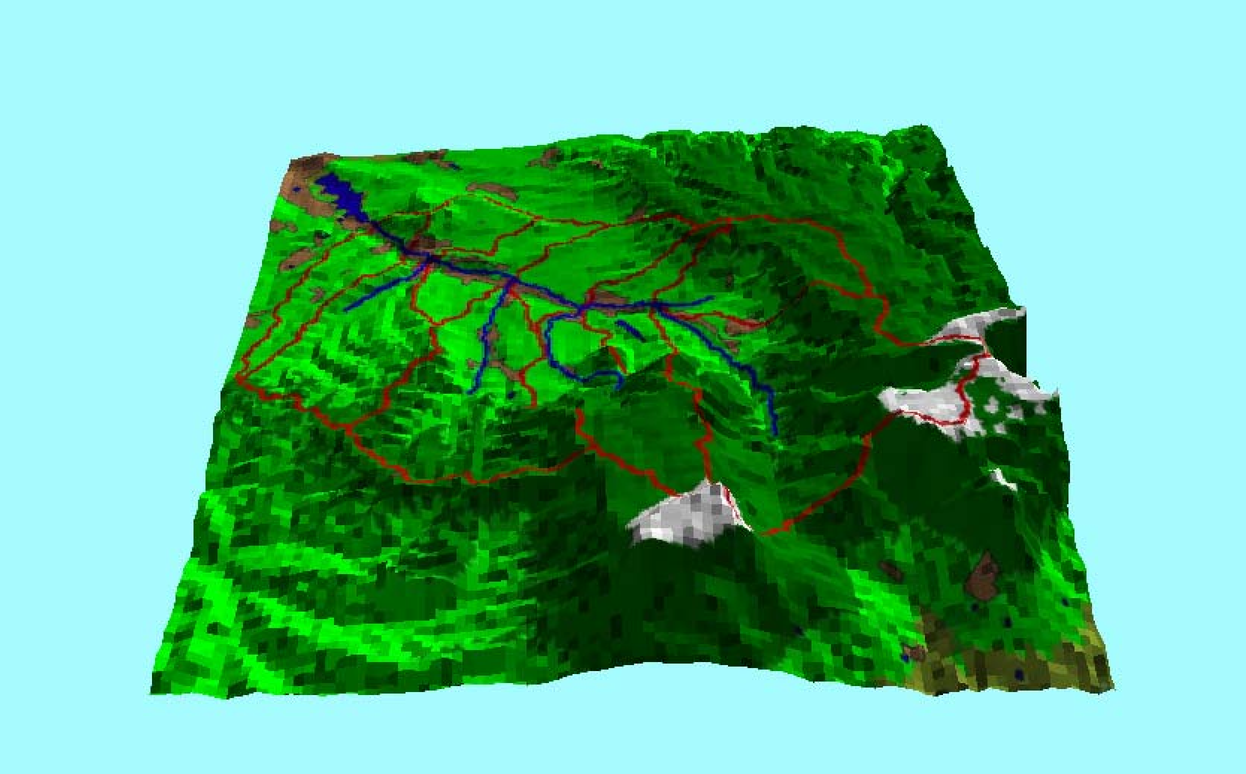


Fig. 4: 3-D view of the Salgir River subbasin till Simferopol

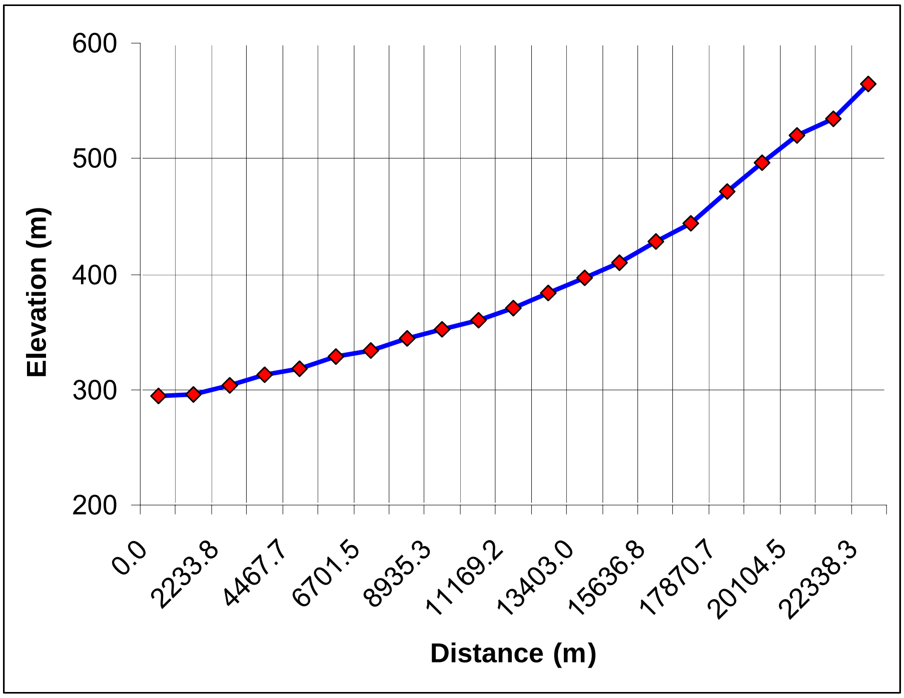


Fig. 5: Slope of the Salgir River headwaters till the Simferopol reservoir (calculated with the ATtILA program module)

The slope of the river itself (headwaters profile) is calculated with the program ATtILA (s. **fig. 5**). It is an important input variable for the calculation of current velocity, erosion/sedimentation assessment and has a strong influence on the composition of the river biocoenosis.

The main land uses within the catchments are shown in **figure 6.** The land use categories are named and defined according to model needs. Each land use type is connected to a set of parameters stored in a related dBase databank that can be edited or supplemented by the user.

The map of **figure 7** shows the CN (curve number) values in the delineated Salgir basin. The program ATtILA uses a land use and a soil grid for CN calculations.

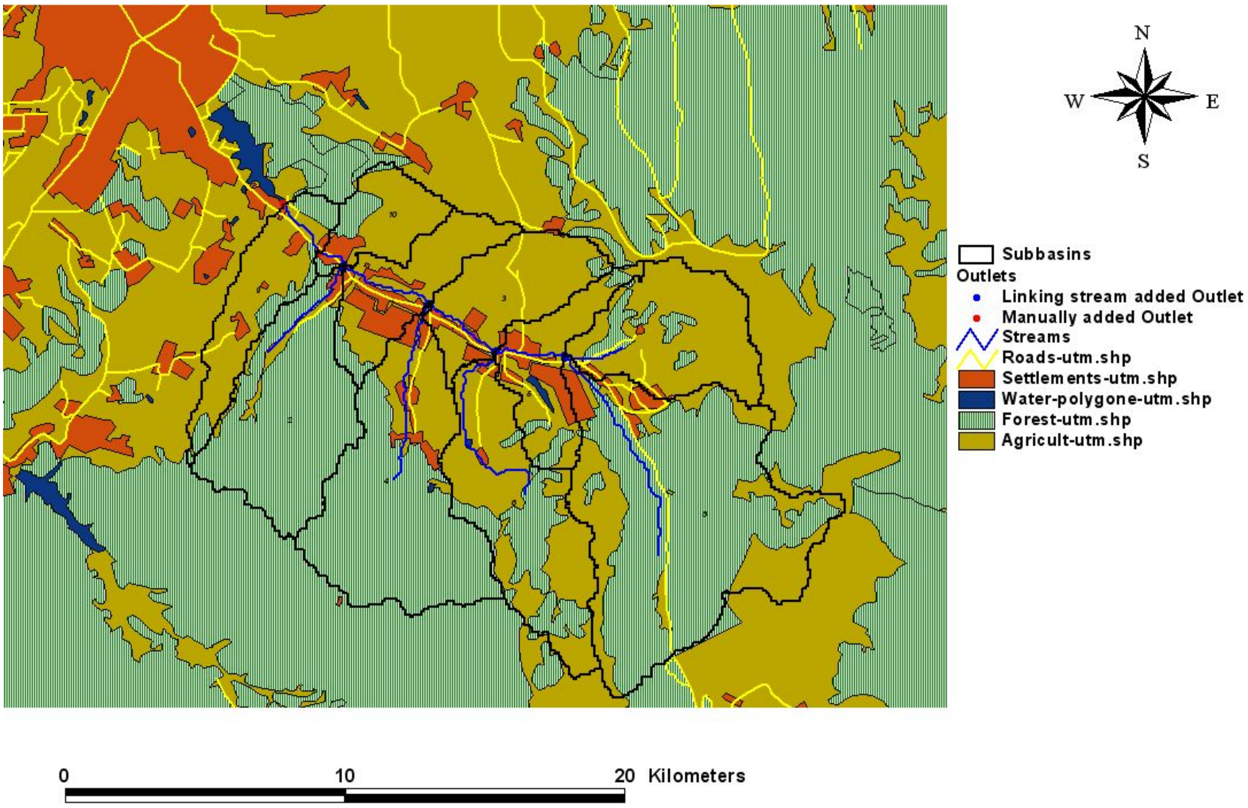


Fig. 6: Land use map using SWAT categories forest-evergreen, generic agriculture, low residential settlements and water polygons

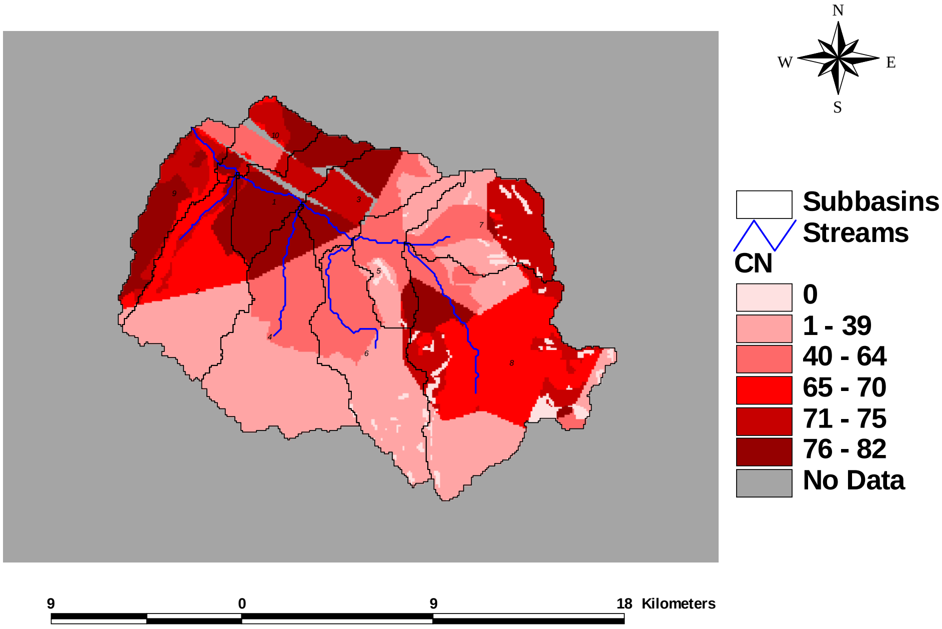


Fig. 7: Distribution of curve numbers (CN) [7] over the whole pilot area A

The map in **figure 8** combines information from the slope map and the land use map and calculates places of increased erosion risks; in this case slope > 9% and land use type is agriculture.

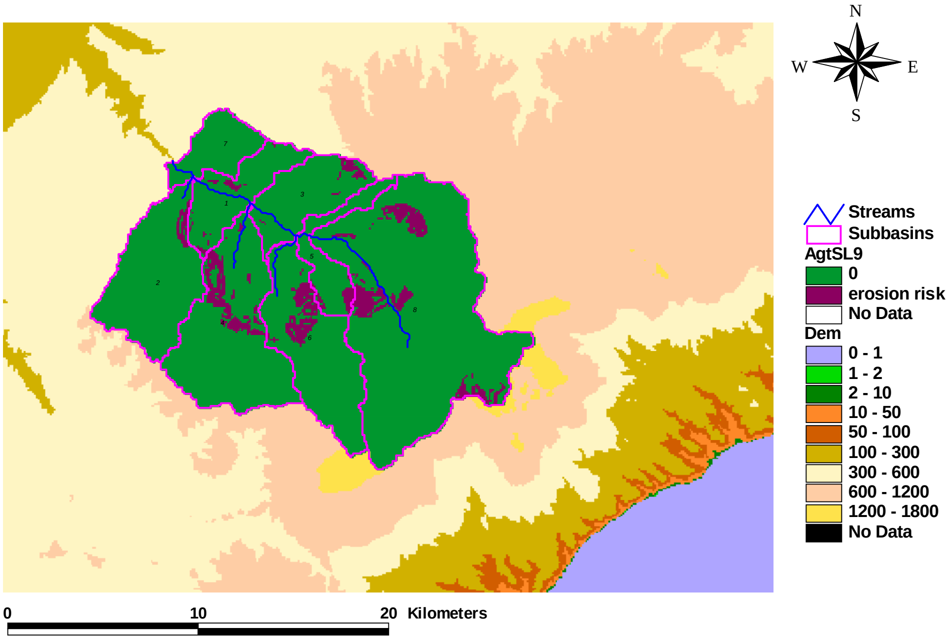
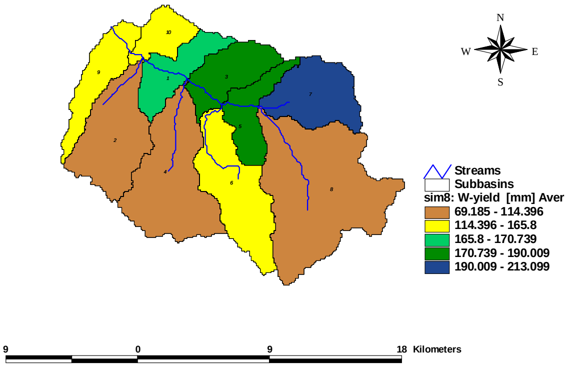


Fig. 8: Erosion risk within the pilot area A; the risk areas are in violet

The maps of **figure 9 and 10** are calculated with the AVSWATx model. They indicate the role of the different subbasins for the water (a) and sediment (b) yield in the river. This information is very important with respect to the limnology of the Simferopol reservoir. The sediments play an important role for the inflow of phosphorous and phytoplankton growth.



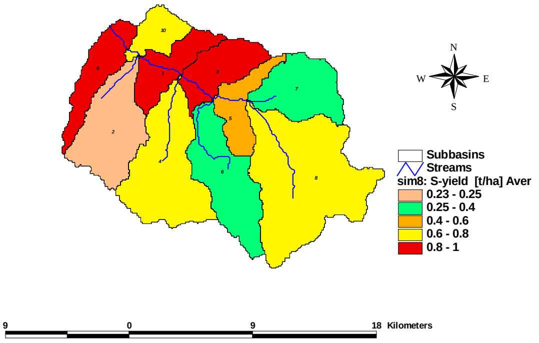


Fig. 9: “Water yield” of subbasins in mm/ha (t/ha (brown – low, blue – high water yield)

Fig. 10: Sediment yield of subbasins (beige – lowest, red – highest yield)

In **figure 11** is presented, the contribution of the singular subbasins to the nitrate load of the surface runoff and thus the Salgir (and the reservoir) given as NO_3-N in kg/ha.

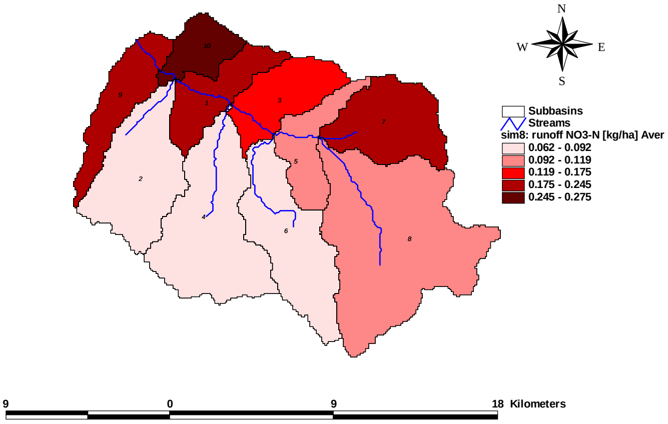


Fig. 11: Run-off nitrate freight of the subbasins in kg per ha (uncalibrated; intensity of red color increases with increasing nitrate level)

To evaluate the quality of simulated model results they have to be compared with observed data. Observed data can also be inexact and should be verified if possible. As an example, two sources of observed data have been compared as shown in figure 12. They have been received from the Global Runoff Datacenter at the German Bundesanstalt fuer Gewaesserkunde (BfG) and from the Ukrainian Hydromet Service; smaller differences exist and therefore both time series will be compared with SWAT data after calibration.

The next step was to compare simulated results with observed data beginning with the river flow (discharge volume) by calculation of the correlation and the Nash-Sutcliff coefficient. As an example, river discharge and uncalibrated SWAT simulation data have been compared in figure 13 for the year 1998. Before continuing with final calibration and verification of model results, land use and soil maps have to be improved or updated and monitoring data for water quality parameters as nitrate and phosphate have to be collected and included.

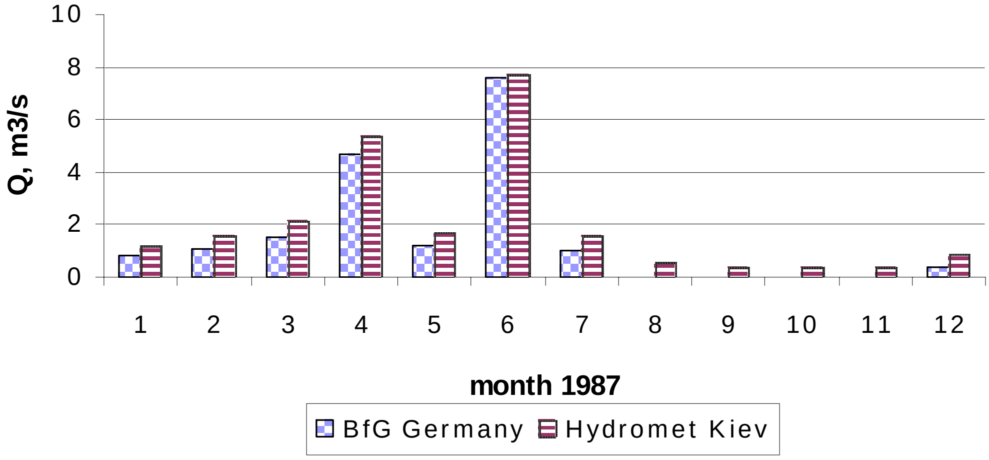


Fig. 12: Comparison river water discharges from different data sources

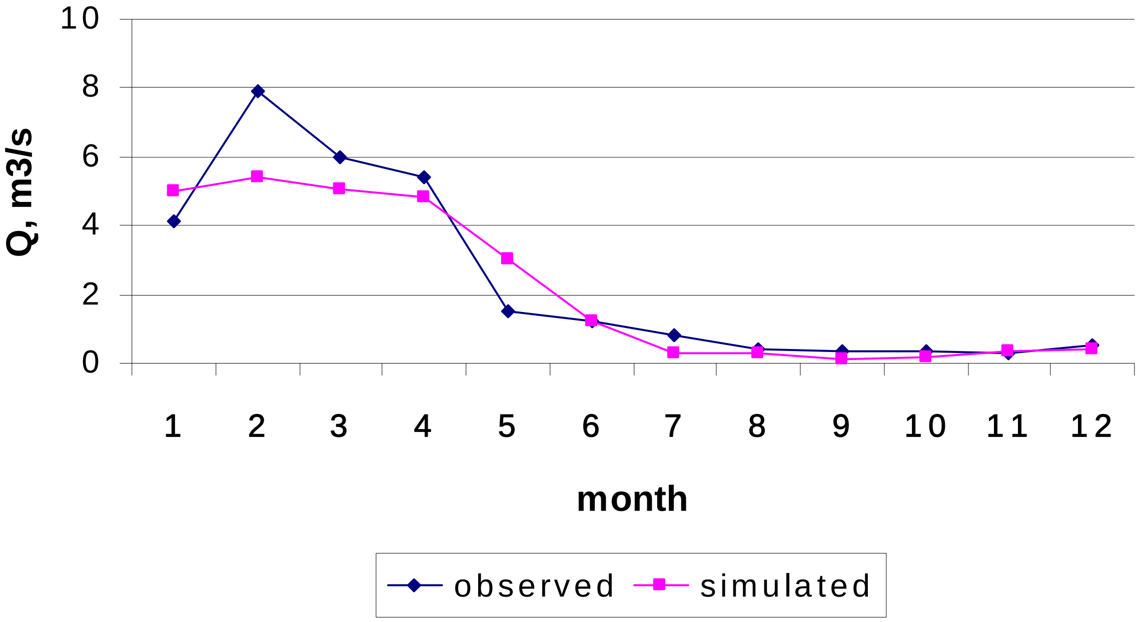


Fig. 13: First results of SWAT simulation before calibration (discharge data Jan. – Dec. 1998, observed/simulated)

Conclusion

The introduction of the model SWAT has led to a big amount of preparation work that is still on-going and that must be continued in the future for optimisation and deepening of the knowledge base for this application. First test runs have shown that satisfying results can be expected in spite of the limited data availability in Ukraine. Efforts to fill the gaps are on-going thanks to the support of the Institute of Hydraulic Engineering and Land Reclamation of the Ukrainian Academy of Agrarian Sciences, financing of the SCENES project and the help of local stakeholders. The quality and also the quantity of outputs is permanently increasing during the project phase. It can be expected that political decision makers will increasingly appreciate the availability of modeling results.

Among the preconditions for the work with GIS-based models are trained personal with skills to work with GIS, motivation to work with GIS based models and knowledge to work with English software and related documentations and literature. Of course, the preparation of model inputs is very time consuming but it can be expected that further planning and model works will profit from this time investment.

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