Paper I-2

MODELLING MULTI LAND AND WATER USE SCENARIOS FOR THREE TYPICAL PILOT AREAS ON CRIMEA, UKRAINE

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ABSTRACT

The use of GIS models for water quantity and quality modelling is indispensable for the determination of impacts of land-use changes or climate changes that are expected to approach.

Southern Ukraine suffers from severe droughts, floods and soil salinisation already today. It is therefore of utmost importance to use the available water resources optimally to provide food security for the regions and to avoid loads of coastal waters.

The paper reports the results of studies that were carried out on three Crimean pilot areas. These pilots comprise the whole catchments of the rivers Salgir and Pobednaya because the quite various land-uses contribute to the river water discharge in different ways.

The main problems of the upper Salgir sub-basin are related to erosion and urbanisation impacts. The transfer zone and coastal areas are subject to intensive restructuring and agricultural developments, including the reconstruction and reorganisation of irrigation systems.

The river Pobednaya drains a coastal area in the North-East of Crimea. Here, irrigation and drainage and additionally waste water discharges have impacts on the Sivash wetlands that increasingly cover the coastal area of the Sea of Azov.

In order to solve all these problems, regional stakeholders have been invited to develop scenarios that are further evaluated by modelling exercises. Model results show the consequences of those scenarios and thus support finding the best solution.

INTRODUCTION

Land use and river basin management planning has a long tradition in many parts of the world. Many examples (like Oregon Department of Land Conservation and Development, 2010), can be viewed on the Internet. The quality of such planning in terms of potential scope, sustainability and convincing force has significantly increased since Geographical Information Systems (GIS) and GIS-based models are available. In former times, much of the planning work was based on expert opinion and thus dependent on subjective experiences; this included a lot of conflict potential and delays for the planning phase.

Mathematical models helped to overcome the restrictions only partly; models that could be used for a broad range of cases were often not exact enough, more detailed models could not easily be generalised.

GIS and GIS-based models enable including, amongst others, even small details of land use, gained with support of Remote Sensing imagery, vertical profiles of soil characteristics and future climate scenarios. They can be supplemented, adapted, calibrated, and validated and so offer the opportunity to control the output quality before decisions are made. GIS and GIS-based models are therefore nowadays indispensable.

As an example / proof for this statement the paper describes how GIS-based modelling was used to study the impacts of present land use and alternatives for land use planning in three pilot areas of the Autonomous Republic of Crimea (ARC), Ukraine. The goal was to optimise rural landscape development in the pilots according to political, social and ecological requirements. This is of utmost importance for Ukraine, especially the southern half of the country where water resources are not sufficient for a sustainable agricultural development. In this context, GIS-based modelling provides an instrument for spatial analyses of water availability and for sustainable planning of water resources use.

The paper describes how impacts on water availability have been quantified using GIS, which kind of planning scenarios have been foreseen to be modelled in the three pilots and how first results of these modelling exercises have been interpreted and used for policy recommendations. These should also respect the requirements of the Water Framework Directive (WFD, 2000) as for example to reach a good ecological state of the two rivers in the pilots with support of local stakeholders.

INVESTIGATION PROGRAM FOR THE PREPARATION OF SCENARIOS MODELLING

The first step consisted in selecting the three pilots and determining the main characteristics and needs for further planning efforts. The final choice is shown on the map (Figure 1).

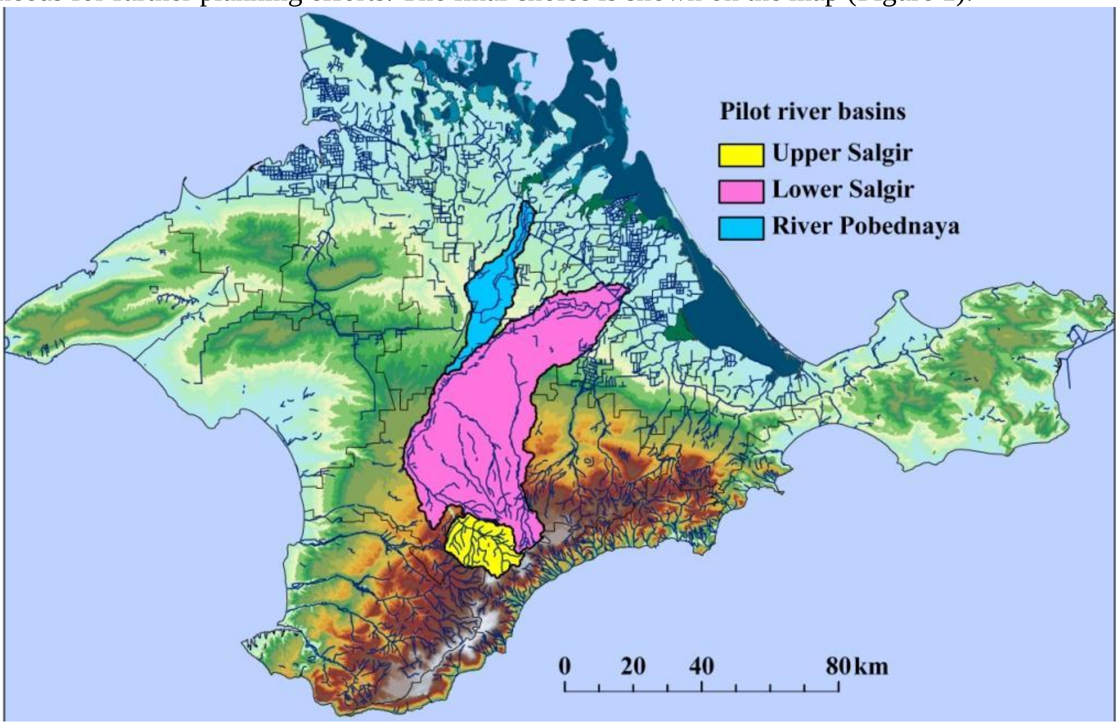


Figure 1. Topographical map of Crimea with the three selected pilot areas

The main problems of the three pilots can be summarised with the focus on 'water system services' (Kämäri et al. 2008) that have to be secured differently for each singular pilot:

1. *Water for People.* In the basin of the upper Salgir river (from the sources to the drinking water reservoir of the Crimean capital Simferopol) anthropogenic impacts of the past, present and the future have to be assessed, alternative measures to secure *water for people* have to be shown up and required measures for the future – with respect to further expected climate changes – have to be determined;
2. *Water for Food.* The transfer zone and the lower river reaches downstream to the Sea of Azov are mainly used for irrigated and rainfed agriculture. The local water resources for irrigation are however scarce and must be completed by water from the Dnieper delivered over a 400 km distance through the North Crimean Canal (NCC). This has relevant economic impacts and requires an economical and well balanced use of available *water*

for food;

3. *Water for Nature*. The basin of the Pobednaya River in the North-East of Crimea is subjected to on-going land use changes. The amount of irrigated agriculture could be increased using water from the NCC and thus ensure higher incomes for the rural population. But then the Sivash wetlands would receive more water (and nutrients) leading to a decrease in salinisation and stronger reed expansion and thus endanger the ecological value of the area. Therefore, the main aim in this study is to show up how agriculture can be supported while securing *water for nature*.

First of all, already existing information had to be collected from various sources, mainly state agencies for river basin management, hydro-meteorological services and local administrations. Geographical thematic maps are available from atlases (e.g. Bagrov et al., 2004) and the Internet, but most of them were not detailed enough and not sufficiently up-to-date. Therefore, the second step was to update and/or digitise maps to provide a basin-wide overview of relevant information. For this purpose, satellite imagery (Rapid Eye, 2009) and, where convenient, Google Earth maps have been used.

Last not least, field trips had to be undertaken in order to confirm some of the mapped details and to assess the hydromorphological status (according to WFD specifications) of the upper Salgir (not reported here) and Pobednaya River and their floodplains.

The following scheme below (Figure 2) summarises the whole procedure and shows how regional and local stakeholders have been involved in the whole process. The work was done in accordance with methods developed in the frame of the EC 6th Research Framework Programme *Water Scenarios for Europe and for Neighbouring States* (*SCENES*) (Contract number: 036822). The methodology is described more in detail on a webpage of the Finnish Environment Institute (SYKE, 2011) and by Zhovtonog et al. (2009).

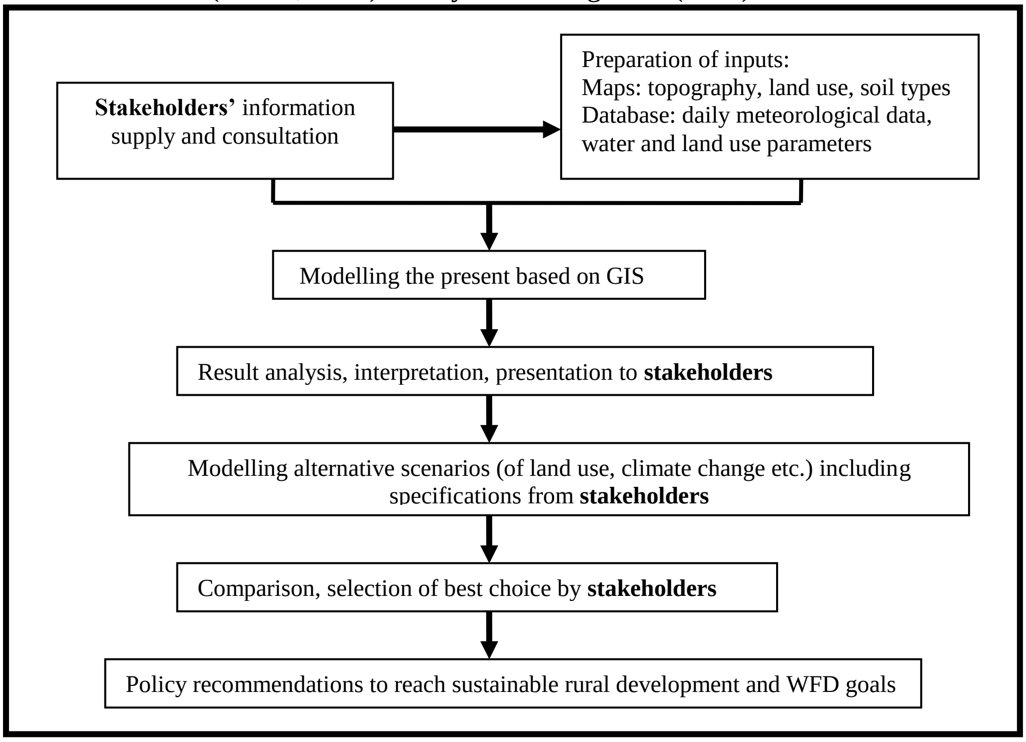


Figure 2. Involvement of stakeholders in the modelling process according to WFD requirements and SCENES project methodology

METHODS

The GIS was set up using the *ESRI* software ArcView3.2a, ArcGIS 9.3 and additional *open source* programmes like 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 (Arnold et al., 1998) and ATtILA (EPA, 2007) to generate maps of hydrological parameters, water quality and related landscape assessments. The two modules require similar input data and maps and provide a broad spectrum of attainable results (see also Hoffmann et al., 2009). The Microsoft Access program *GSK-Eingabe* described in Bayerisches Landesamt fuer Wasserwirtschaft (2002) has been used to calculate the hydromorphological state of the river and its floodplain.

RESULTS

Case study Upper Salgir River sub-basin

Present situation and problem setting

This part of the Salgir River basin comprises an area of 27,288 ha situated in the karst region of the northern slopes of the Crimean Mountains and their forelands (maximal elevation: 1447 m+MSL (Mean Sea Level), minimal elevation 294 m+MSL and mean elevation 628 m+MSL) down to the Simferopol drinking water reservoir (Figure 1).

The area is mainly covered by forests and vegetation comparable to steppes growing on red-brown mountain soils (partly former agricultural areas). Residential areas have been built in many places and are still developing in the rivers floodplain that is covered by alluvial soils.

The main driver of this basin part is the increase of the population density that is still on-going today. Resulting pressures are groundwater pollution by sewage (as a canalisation does not exist) and horticulture. Former anthropogenic landscape changes like deforestation, agricultural land use on steep areas and last not least the (partly) channelisation of the river bed have resulted in a severe increase of soil particles transport down to the drinking water reservoir. Grazing cattle causes additional impacts, such as erosion, on steppe and river habitats. Table 1 shows the overview on the main issues.

After crossing the sub-basin boundary, the Salgir flows into the reservoir that delivers drinking water for the southern part of the Crimean capital Simferopol. It is about 5 km long (depending on the actual water level) and nearly 1 km wide. Its total capacity is 36 billion m^3, out of which 32 billion is available. The depth of the reservoir near the dam is 35 m; raw water is abstracted in a depth of 32 m. In recent years, the reservoir showed indicators of eutrophication, as, for example, a bad smell of rotten eggs (H_2S) in the abstracted raw water.

Results and recommendations

Modelling was used to analyse the impact of the whole complex of those factors that influence water quantity and quality at the outlet of the last sub-basin just a few hundred meters upstream of the reservoir inlet. The next four maps (Figure 3) show examples of the differences between the sub-basins in the land use, surface run-off, sediment yield and organic phosphorous (orgP).

Erosion, sediment transport and suspended matter in the river and reservoir play a key role for the understanding of the nutrient loads of the reservoir. As can be viewed in the map sediments originate mainly from the North-East of the basin and are washed away during heavy rainfall events. Nitrogen, mainly ammonium, and phosphorous compounds are adsorbed at the surface of eroded particles. It is therefore important to reduce erosion. Additional loads from sewage play a minor role at present but could become an important pressure in the future. To determine the importance of this impact one has to set up a *scenario* that includes several assumptions because it is not yet clear how many inhabitants (mainly Tartars) will settle in the floodplain in the future and if any reasonable solution will be implemented to reduce the load of soil and groundwater. In a first approach, yearly average values of nutrients have been calculated for the present using the SWAT model. If the Salgir floodplain will be populated by e.g. additional 10,000 inhabitants in the future the phosphorous load, originating in the floodplain, will double. A rough calculation, for the (wet) year 2004, (based on the assumption: no canalisation, no soil adsorption) gives the figures as shown in Table 2.

Table 1. Identification of drivers, pressures, state change, impacts and possible responses (according to WFD guidance document no.3, 2003)

Drivers	Pressures	State change	Impacts	Response
population growth	1. environmental pollution: • sewage discharge (un-flushed toilets, absence of canalisation) • storm water run-off in settlement areas and from roads • diffuse agriculture and horticulture pollution (nutrients, pesticides, cattle breeding) • landfills, wild deposits and cemeteries	• soil contaminated • permissible nitrate concentration in groundwater • exceeded	health risks (increase of cancer rates, blue-baby syndrome)	• sewage and waste water treatment • restrictions in horticulture • garbage management
use of landscapes	2. pressures on landscapes: • forestry activities (clear cuts, construction of forest roads, erosion) • alteration of hydrological regime (e.g. river straightening) • changes of landscapes (settlements, gardens, roads, grazing livestock)	erosion rate higher than for typical natural landscape	eutrophication of the reservoir	ecologically optimised landscape planning

The increase (12% for organic phosphorous compounds) could be even bigger depending on population density, climatic factors and other impacts; for sure, this will aggravate water quality problems. According to model calculations of Vollenweider (1980), Dillon & Rigler (1974) and Bendorf (1979) about a load of 2 kg/ha*year P in the catchment are tolerable for lakes and reservoirs

Additional pressures will come up related to the groundwater quality. One can expect that the nitrate concentration will soberly increase leading to health problems and enforcing investments for other drinking water sources.

Countermeasures that can be recommended facing the described pressures include measures to reduce erosion and soil transport across the concerned sub-basins and to develop an urbanisation plan that gives room for nature and people and that solves the sewage problem locally or on region level.

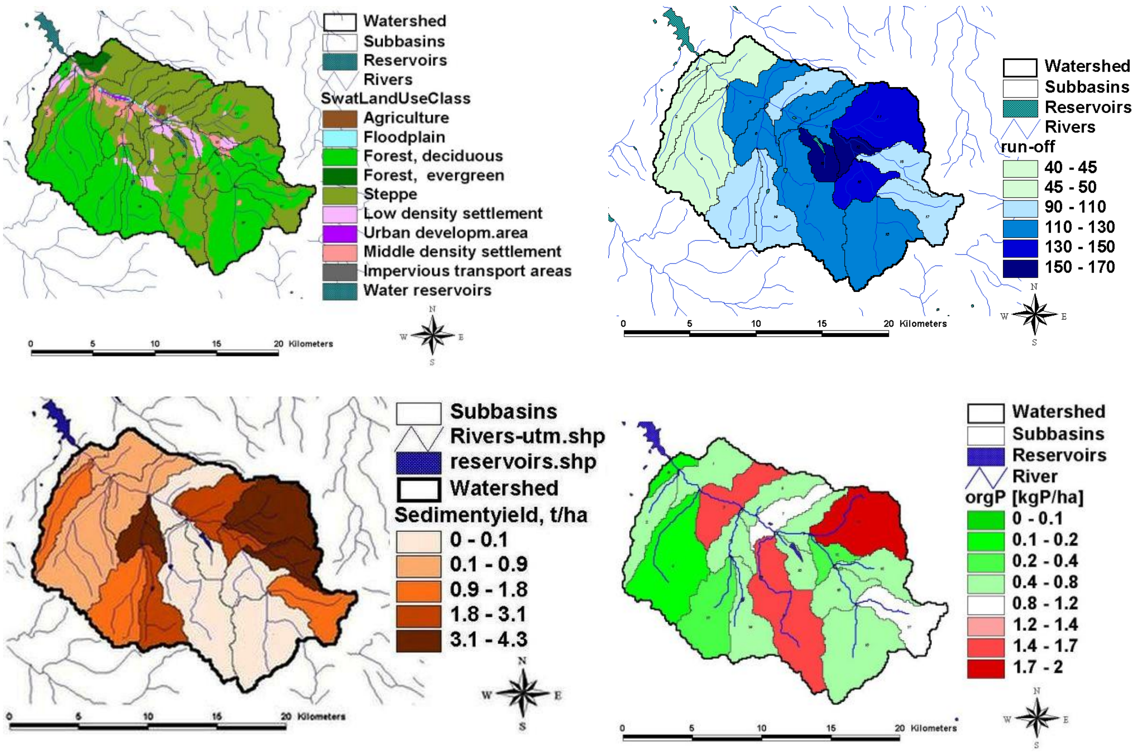


Figure 3. From left to right hand side: Land use map, surface run-off (mm/month), in the second row: sediment yield (tons/ha*year) and phosphorous load (kg/ha*year)

Table 2. Results of a rough calculation for the (wet) year 2004.

	org P	inorg. P	org N	NO_3-N
average loads in kg/ha*year at present	2.5	0.13	19	5
% increase (calculated for 10000 additional inhabitants in the floodplain *)	12		8	

Transfer zone and lower Salgir case study

Present situation and problem setting

The transfer zone and the lower Salgir and its delta are located downstream of the Simferopol reservoir up to the Sivash wetlands and Sea of Azov in the eastern part of Crimea. The flow path is about 137 km, the height difference 255 m. Precipitation in the lowland area are rather small and reach an average of 466 mm yearly only. During drought periods the river can dry out in several reaches. More precipitation (snow and rain) is regularly detected during winter with sometimes heavy rainfall events in summer.

The river flow firstly depends on the amount of water released from the reservoir. This amount is rather constant over longer periods but is increased in times of bigger discharges, like usually in April. Further downstream, the river flow is influenced by a rather small water yield, that is however quite different in the various sub-basins, and by water abstractions along the river. To satisfy the needs of irrigated agriculture irrigation water is mainly withdrawn from the NCC, but its costs are high in this region because of charges for pumping and high energy tariffs. Therefore, there is a strong economic interest (mainly of small farmers) to use the cheaper water supply from local resources, e.g. for vegetables.

As shown in Figure 4, reservoir water is supplied for different sectors leading to temporal shortfalls and more reliance on the NCC water supply. That is another reason why local water resources should be used as efficiently as possible including the use of storage basins and drip irrigation. Further downstream sewage and industrial waste water is discharged into the river.

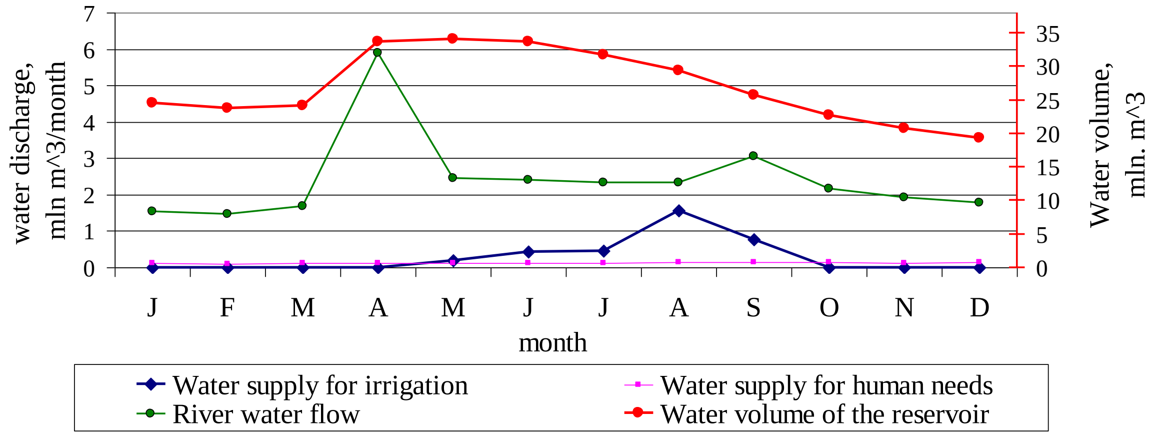


Figure 4. Water volume and discharges from the Simferopol reservoir in 2008

Results and recommendations

Using the SWAT model it is possible to calculate the water yield and the resulting outflow of each sub-basin (Figure 5). Besides the irrigated area, the figure also shows the irrigation project area that used to be operational in Soviet times and could be used in the coming years after some reconstruction. It is however obvious that additional water can not be abstracted from the river itself except during the time of snow melt, e.g. in April. This surplus could be stored in some selected places and used for irrigation in May or June. At present, the actual irrigation area is about 2264 ha, a similar sized area could be additionally irrigated if the spring surplus would still be available during the summer.

Average flow out, m^3/s		
sub-basin	July	August
1	1.91	7.98
2	2.16	8.50
3	1.81	6.32
4	1.72	5.54
5	1.62	3.65
6	1.59	2.95
7	1.25	1.42

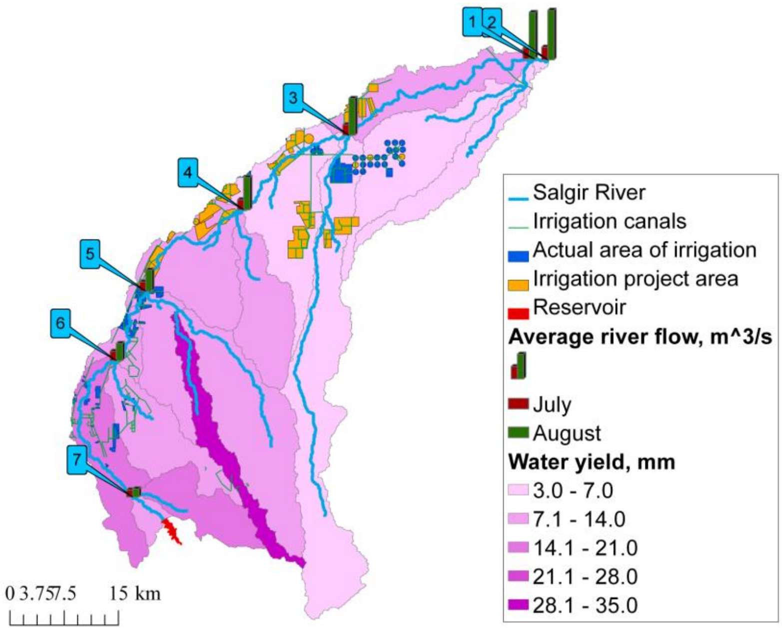


Figure 5. Average water yield of the seven sub-basins in August between 1998 and 2008 and resulting river flow (columns 1-7 and table to the left) at the sub-basin outlets of the main river channel

But even this amount of water would not be sufficient to cover the growing needs of irrigated lands in future. A possible scenario for a desirable future would be a tenfold increase of irrigated lands but this could not be realised without water from the NCC.

Pobednaya River case study

Present situation and problem setting

The Pobednaya River drains a rather flat landscape with slopes mostly less than 2%. It flows into the Sea of Azov in the North-East of Crimea.

The river has been heavily modified in the past. Originally a small water course (natural gulch) with a watershed area of app. 40,000 ha has been straightened and its bed deepened to serve as a collector for water drained from adjacent irrigated fields. This was necessary to increase the discharge and to avoid stronger salinisation of soils that were to be used for irrigated agriculture in Soviet times. At present, 75% of the watershed area is occupied by agriculture (around 30,000 ha), 35% of which (11,000 ha) can be irrigated (this area is equipped with irrigation and drainage infrastructure and used to be fully irrigated in Soviet times). Unfortunately, former landscape changes did not aim at creating ecologically useful structures; instead the river bed and banks are rather uniform and more similar to a channel than to a river. The river bed and banks are mostly covered with reed that builds up unwanted organic sediments that is dredged out in several places from time to time. Due to slight slopes and vegetation the current velocity in the river is not sufficient for a natural translocation of accumulated mud. Correspondingly, the hydromorphological assessments of the river itself and its floodplain delivered mostly unfavourable results as shown in Figure 6.

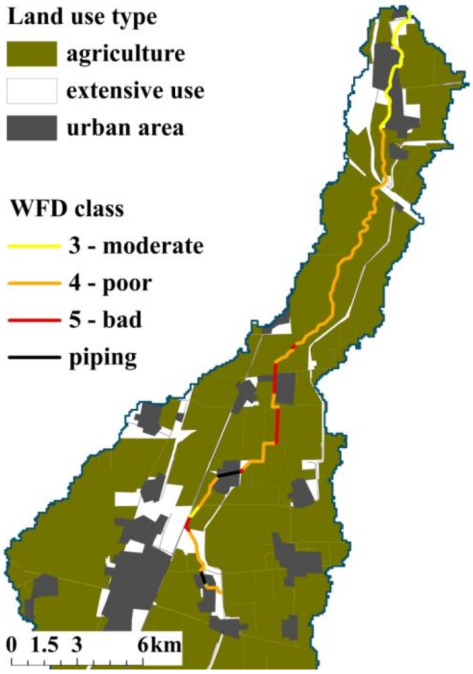


Figure 6. Results of hydromorphological assessments of the River Pobednaya including the nearby floodplain

Additionally, two major discharges of untreated waste water load the river's water body. One from the city Krasnogvardeiskoe and the other from a poultry farm nearby (Roerink et al., 2009). This results in heavy river pollution, an increase of nutrients and spread of reeds in the Sivash hindering several rare species of birds to find nesting places. Water quality is monitored by the regional ecological inspection, which takes samples for analysis at several locations each year and Figure 7 shows the location of sampling points and some analyses results (concentration of ammonium and BOD_5).

Further downstream, water from the NCC is directly added to the water body (Figure 7) to improve water quality and increase the water level in Sivash to keep the coastal areas from drying in summer time (Photo 1).

By this way, the freight of nutrients is of course not reduced and causes eutrophication, unchecked spread of reed and other problems in the Sivash wetlands.

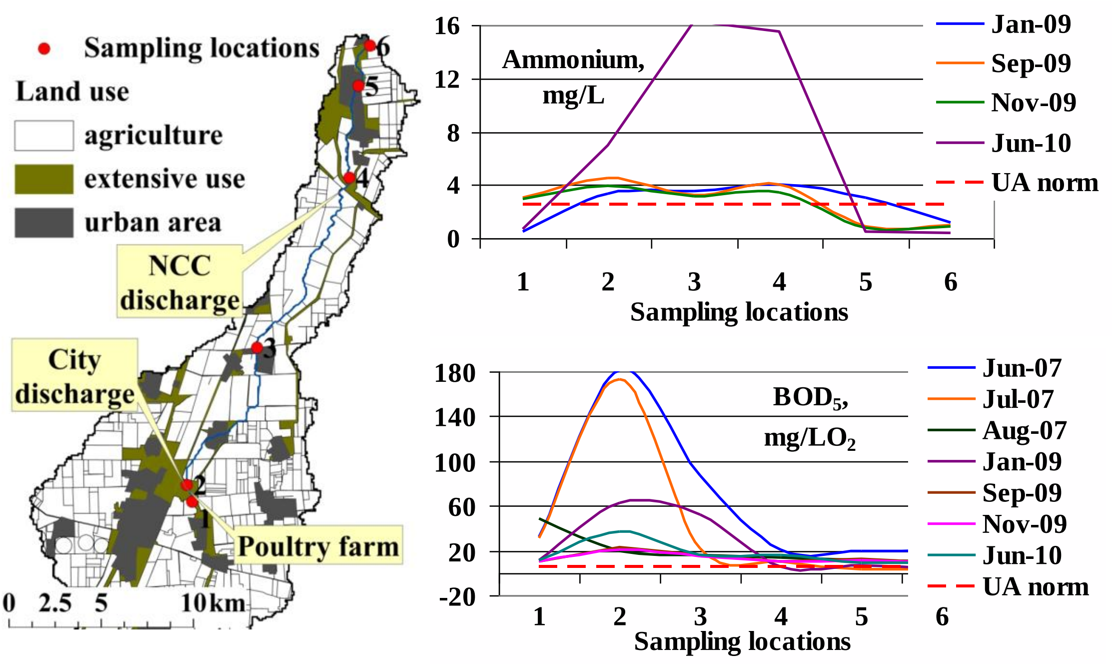


Figure 7. Location of the sampling points and results of water quality analyses (NH_4^+ and BOD_5) compared with Ukrainian (UA) ecological norms

Photo 1. Dried out wetlands in the Pobednaya River's estuary

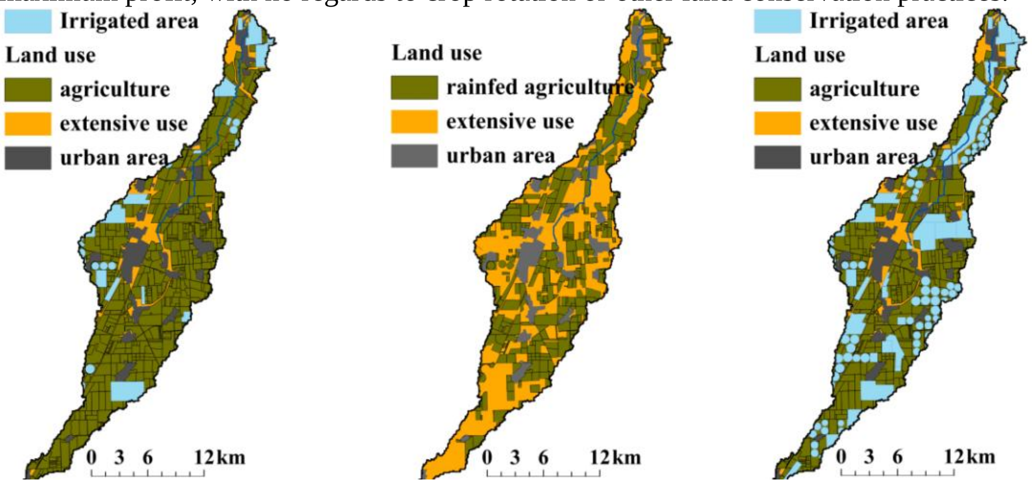
Scenarios

There are unique steppe landscapes and wetlands in the near-Sivash part of Crimea, which can be a source of business development for local economy (e.g. green tourism, birds watching). And though local stakeholders appreciate their value in the studied river basin, they see this area as a mainly agricultural region. For that reason, in scenarios developed for this case study, the main emphasis is on the area of cultivated land together with the area and location of irrigated farm fields.

Scenario 1. Area under agricultural practice stays at the level of 2009 (29,500 ha) due to stabilisation of rural economy, but the costs of irrigation are so high that only big private farms can afford it (3,600 ha of irrigated lands).

Scenario 2. Various economic or socio-political reasons complicate the possibility for local farmers to irrigate from NCC. This leads to collapse of irrigated agriculture and switch to rainfed agriculture where possible (ca. 16,000 ha). The rest of the area stays abandon, which causes gradual restoration of natural steppe landscapes.

Scenario 3. Favourable economic situation in Ukraine and private investments facilitate restoration of the irrigation infrastructure and stimulate agricultural development in the region. It leads to maximisation of irrigated areas (up to 10950 ha) and focus on commercial crops for maximum profit, with no regards to crop rotation or other land conservation practices.



Scenario 1. Present rate of irrigation and area under agriculture (rate of 2009).

Scenario 2. No irrigation, only rainfed agriculture and non-agricultural land use.

Scenario 3. Maximisation of irrigated area (rate of 1990).

Figure 8. Maps of the Pobednaya river basin showing land use lay-outs for each of three scenarios

Results and recommendations

In this study we modelled the change of natural water flow in the river and amount of water discharge to Sivash in three scenarios described above and for years with different natural water deficits. Figure 9 shows the modelling results for each scenario in comparison with average actual values of yearly river discharge (red line shows natural discharge volume; blue – overall discharge, including water directly added from the NCC).

Today water from the NCC is added to the river for ecological purposes, but as we can see from Figure 9 the same result can be reached by increasing the area of irrigation. On one hand, this will give an economic effect (the profitability of irrigation in Crimea has been proved by previous studies (Zhovtonog et al., 2002)) and, on the other, will provide sufficient water flow in the Pobednaya River, better distributed along the river course than in case of one point-source discharge from the NCC.

Further investigation and analysis must be conducted for evaluation of the area and location of irrigated fields in the watershed, in order to find the balance between economic gain and positive ecological effect. To mitigate impacts from increase of irrigated areas and to improve the ecological situation in the river basin a set of environmental measures must be implemented.

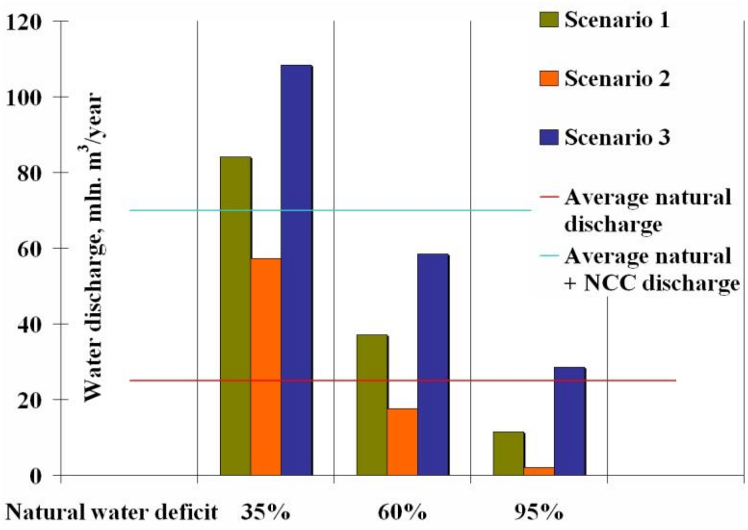


Figure 9. Water discharge at the outlet of Pobednaya river basin simulated under three scenarios for years with different water deficit values

The investigations carried out so far lead to the following recommendations:

1. Setting-up of buffer zones along the river: first zone – unused and planted with trees and bushes, second zone – with not fertilised pastures; and only behind these zones – development of drip-irrigation and rainfed agriculture. This will improve the hydromorphological state of the river and its floodplain.
2. Pre-treatment of waste water using already existing technical structures (concrete basins located nearby the waste water discharge points) and its use for irrigation as much as possible.
3. Use of special boats for mowing of Phragmites reeds and its use for different purposes.

CONCLUSION

The here presented three pilot areas are part of Crimean landscapes that have been formed by humans since longer time until the present respecting human needs in the first place. Upcoming problems are related to drivers as population growth, lack of finances and restricted respecting of ecological and social sustainability.

Today available modelling techniques based on RS and GIS help to reduce the problems created in the past and to find better solutions for the future. Various scenarios, including those recommended by stakeholders, can be simulated and discussed with them as in accordance with the WFD, article 14.

Modelling helps to understand the multitude of impacts that exert pressures on a good ecological state. First recommendations are given based on modelling results. They can, of course, be improved in close cooperation with regional stakeholders, thus reducing future conflict potential and improve social sustainability as well.

ACKNOWLEDGEMENT

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