Paper

Ricerca

Modelling the impact of rural land use scenarios on water management: a FREEWAT approach to the Bakumivka catchment case study, Ukraine

Modelling the impact of rural land use scenarios on water management: a FREEWAT approach to the Bakumivka catchment case study, Ukraine

Mykhailo Grodzynskyi, Daria Svidzinska

Riassunto: Il bacino del fiume Bakumivka, in Ucraina, è uno dei casi di studio per l'applicazione di FREEWAT per la gestione delle risorse idriche superficiali e sotterranee. L'obiettivo principale di questo studio è comprendere la distribuzione spaziale ottimale delle risorse idriche per soddisfare la domanda delle aziende agricole, modificando la configurazione legata all'uso del suolo nel bacino. E' stato implementato un modello numerico integrato per fornire delle stime quantitative delle componenti del bilancio idrico. Il modello si basa sull'implementazione di quattro strati, che rappresentano le principali unità idrostratigrafiche, e diverse tipologie di condizioni al contorno lungo i bordi dell'area di studio, a rappresentare le principali componenti del bilancio idrico mediante termini di ricarica ed estrazione. Il modello è stato implementato utilizzando la piattaforma FREEWAT.

Sono stati implementati tre scenari di gestione della risorsa idrica, al fine di confrontare diverse configurazioni legate all'uso del suolo nel bacino del fiume Bakumivka. Tali scenari rappresentano un compromesso tra l'adozione di strategie orientate al mercato e la scelta di soluzioni sostenibili da un punto di vista ambientale. L'obiettivo delle attività modellistiche è ottenere bilanci di massa e mappe per la rappresentazione di tre scenari di gestione della risorsa idrica. Ognuna di queste mappe mostra la distribuzione delle aree in cui il bilancio idrico risulta ottimale, oppure si verifica un deficit della risorsa idrica (zone aride) o un eccesso di acqua (zone umide) per determinate colture (uso del suolo). Le simulazioni dimostrano che modificare la configurazione spaziale della copertura del suolo rappresenta una misura efficace per ridurre la fornitura di acqua alle aziende agricole, tuttavia questo non previene allagamenti nelle aree adiacenti alle piane alluvionali e situazioni di deficit idrico durante la stagione estiva nelle aree interessate dalla presenza di suoli sabbiosi e sabbioso-argillosi, dove l'irrigazione dovrebbe essere vietata. Nonostante vengano registrati elevati livelli di falda, la piana alluvionale interessata dalla presenza di torbiere dovrebbe essere irrigata per prevenire incendi in primavera e in estate. L'introduzione di eco-corridoi nella configurazione della copertura del suolo nel bacino è positiva da una prospettiva ecologica, ma potrebbe impedire il drenaggio delle acque causando allagamenti nelle aree agricole.

Abstract: *The Bakumivka River's catchment, Ukraine serves as a case study to the application of FREEWAT to the ground and surface water management. The main objective of the study is to find out the optimal spatial distribution of the water supplied to the farms by modifying the land cover pattern of the catchment. An integrated numerical model was developed to provide quantitative estimates of the water budget components. The model includes four model layers, representing the main hydrostratigraphic units, different types of boundary conditions assigned along the area's boundaries, major components of the water balance introduced through source and sink layers. It was implemented through the FREEWAT software.*

Three water management scenarios were developed in order to compare different spatial patterns of land cover and distribution of water within the Bakumivka River's basin. The scenarios represent continuum from market oriented pattern to environmentally sounding pattern of land cover. The objective of the modeling exercise is to obtain mass balances and maps representing three scenarios of water management. Each map shows distribution of the areas where the water balance is optimal, insufficient (dry) or excessive (wet) for vegetation (land cover) of particular type. The simulation shows that changing spatial land cover pattern is an effective measure to reduce water supply to the farms, however it does not prevent water logging in the areas adjacent to the flood plains and drying on summer stress periods in lands of sandyloam soils. Irrigation should be excluded in the areas with sandy and sandyloam soils. The flood plain with peat bogs despite the high water head in spring and late summer stress periods should be irrigated to prevent peat fires. The intrusion of eco-corridors to the land cover pattern in the catchment is positive from ecological perspective, but could prevent drainage causing water logging in the arable lands

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Introduction

The drainage-irrigative systems constructed in the northern part of Ukraine during 1960-80s have changed dramatically the water regime of catchments, not only in turning wetlands into arable lands but also into peatlands. Commercialization of agriculture in Ukraine since the beginning of the 2000s has changed the crop composition and land cover pattern. Transformations of water regime and of land cover were simultaneous causing synergetic effects in landscape changes, such as peat fires, dehumification, wind erosion, and loss of biodiversity. Strategy and practices in water management should react on this synergism by integrating water management with land management. Particularly the water regime could be regulated not directly through the limitation of the water user's demands in water but through the planned changes of land cover and spatial distribution of water within the catchment.

Such an approach is in compliance with the basin and integrated principles of water management stated in the Water Framework Directive of the EU (Water Framework Directive 2000) and the National water regulations, specifically with the Water Code of Ukraine (Law of Ukraine 1995), the Law of Ukraine On implementation of integrated approaches to water resources management on the basin principle (Law of Ukraine 2016) and other.

The study area

The catchment of Bakumivka River is located at the North of Ukraine. Its total area is about 64 km². It encompasses one main channel (18 km long) and thirty secondary channels (34 km of total length). The area lies within the Baryshevskyi administrative district of Kyiv oblast (region), Ukraine (Figure 1).

The surface of Bakumivka catchment is a flat occasionally low-angle wavy plain, with numerous hillocks up to 2 m height. Elevations vary from 100 m to 125 m above the mean sea level. The top of the hillocks, especially those covered with sandy podzolic soils, are the main arenas of wind erosion.
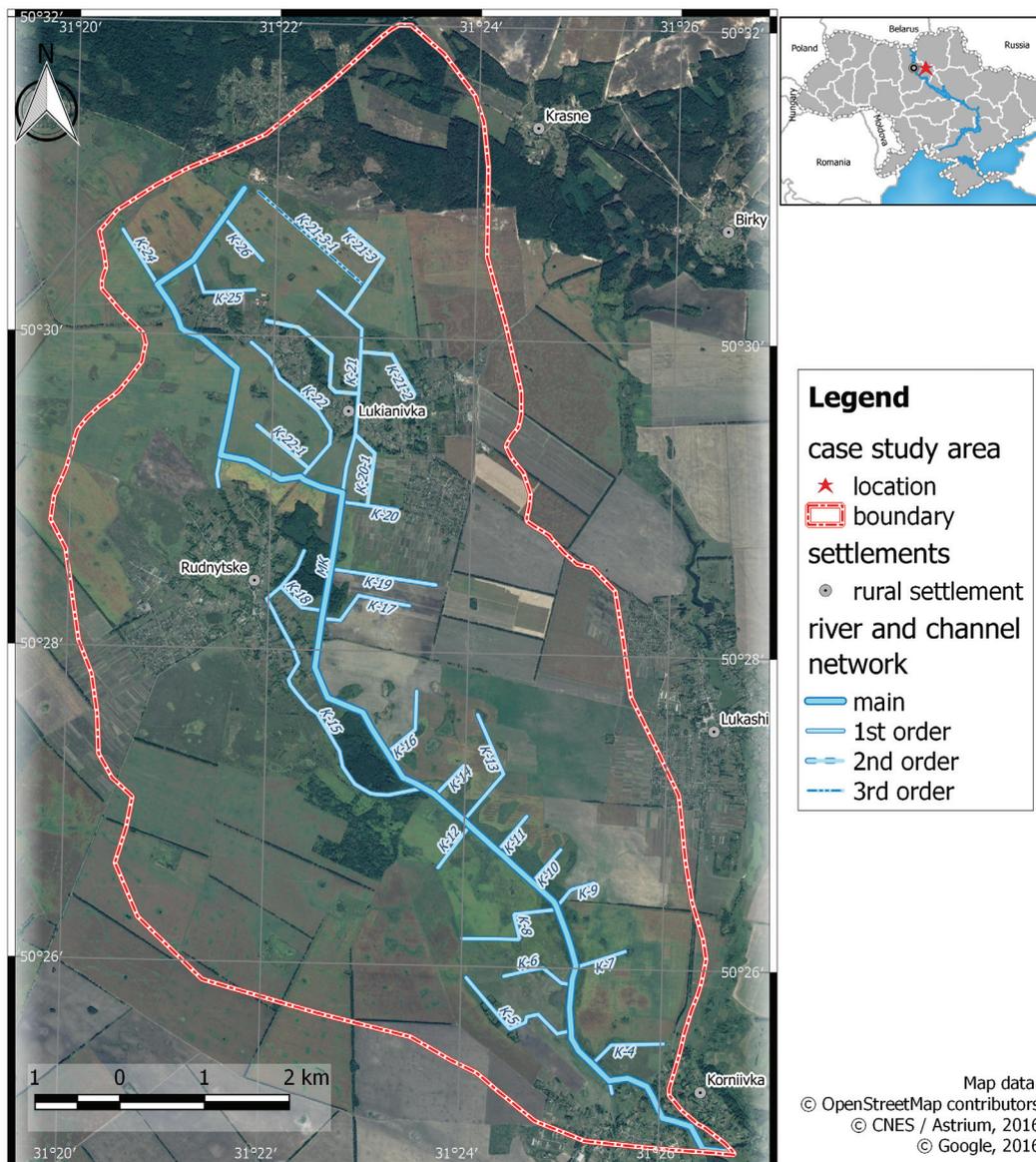
Fig. 1 - Location and general view of the study area.

Fig. 1 - Inquadramento geografico e configurazione dell'area di studio.

Sheet water erosion is a new process for the study area and was caused mainly by deforestation, overwatering, and cultivation of row crops.

Bakumivka River's catchment nearly lies within the 2nd-5th alluvial terrace of the Dnieper River. The major part of it corresponds to the periglacial area of the Pleistocene Dnieper glacier. Tectonically it corresponds to the southern part of the ancient East European platform. It has two clearly separate structural stages. The lower stage is a crystalline foundation composed of intricately dislocated and metamorphically altered rocks of Archean–Proterozoic age. The upper stage is composed by Paleozoic, Mesozoic (Triassic, Jurassic, Cretaceous), Cenozoic and Pleistocene clay and by sandy deposits (State Geological Survey of Ukraine 2009).

Soil cover of the Bakumivka rivers catchment is diverse due to its "transitional" position (from mixed forest to forest-steppe natural zones), and due to the spatial variations of forming rocks and landforms at the local scale. Chernozems and dark-grey subpodzolic soils are dominant soils in the study area. They occupy several parts of plain and its hillocks on loess-like deposits. Both these soils are very fertile when sufficient water is available. However, their intensive cultivation, especially on slopes of hillocks has led to soil erosion. Soddy-podzolic soils occupy a narrow strip along the northern border of the study area. They have low humus content, light texture, and high acidity. Turf-pinery soils appear in areas with a high moisture content, as well as on sandy terraces of creeks (Ukrzemproject, 1975).

Land cover of the study area is mainly represented by agricultural lands. Usually tenants of land do not respect crop rotation schemes and use extensive soil resources, posing a threat to soil depletion and the loss of their fertility. Other land cover types include pine forest fragments (in the northern part of the area), built-up settlement areas, grasslands and wetlands related to the river floodplain

The climate in the study area is temperate continental with warm summers and temperate cool winters. Average temperature is 8.7 °C, mean annual precipitation over 660 mm, mean annual evapotranspiration is 610 mm, and wind velocity is normally 2–3 m/s (State Geophysical Observatory, 2016). The available air temperature data indicate a tendency to rise in recent decades. According to the data for all meteorological stations of Ukraine, the average air temperature has increased by at least 1.5 oC compared to the 1880s (Lipinskyi et al. 2003). The study area lies within the belt of moderatly humid climate, where precipitation-evaporation ratio slightly exceeds 1. However, along with humid years, dry years also occur. The uneven distribution of precipitation by month determines alteration of dry and wet seasons. That is the reason why the ameliorative system here is of combined "irrigation-drainage" type, allowing both irrigation and drainage while needed.

The Middle Eocene marls of Kiev are the oldest deposits predetermining hydrogeological conditions of the study area. Their thickness vary from 8 m to 12 m; the deposits are dense with the hydraulic conductivity (saturated) ranging between 0,001 m/day and 0,005 m/day. The aquifer is composed with the Pleisticene alluvial sandy deposits and fluvio-glacial sands.

Above the aquifer, the late Pleistocene clays and loams are laying. The depth of the aquifer varies from 2 m to 14 m. The schematic cross-section of the case study area is shown in Figure 2.

Hydrodynamic characteristics of the four model layers are summarized in the Table 1. The values of hydraulic conductivity based on the data from (UkrGiproVodhoz 1986, 1978), the other parameters were set according to the reference information (Klementov, Bohdanov 1977; Maksimov 1979; Walton 2007; Kruseman, Ridder 1994)
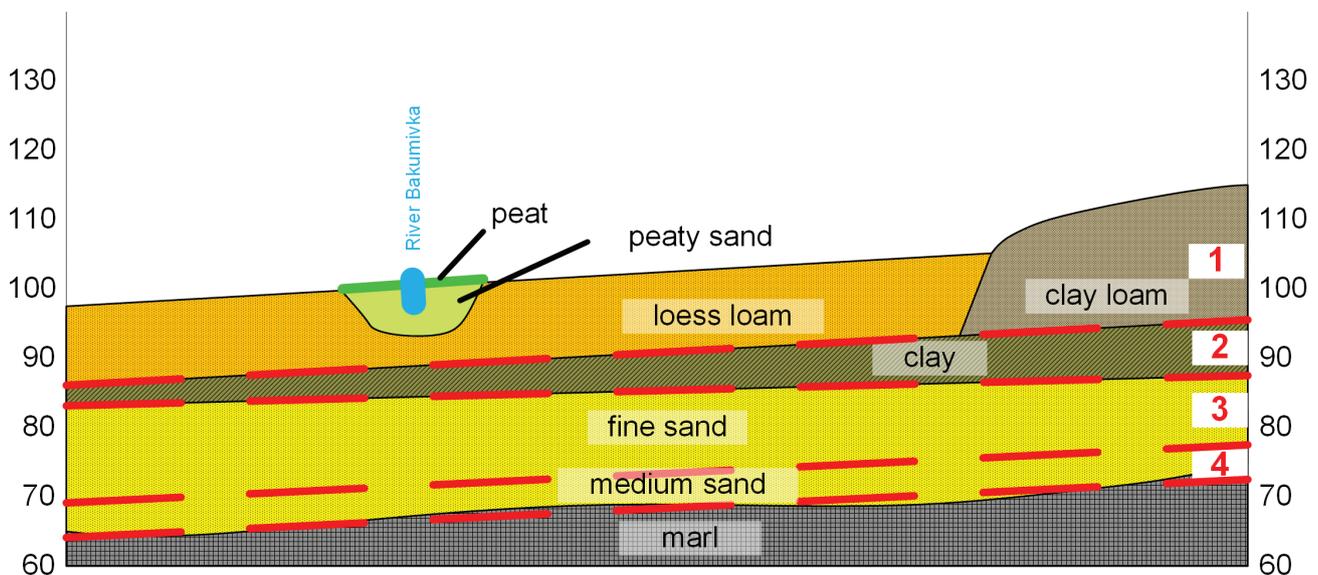
Fig. 2 - Schematic Cross-section of the study area (UkrGiproVodhoz 1968, 1976; State Geological Survey of Ukraine, 2009); the red numbers and lines refer to the model layers.

Fig. 2 - Sezione schematica dell'area di studio (UkrGiproVodhoz 1968, 1976; State Geological Survey of Ukraine, 2009); i numeri e le linee in rosso si riferiscono agli strati del modello.

Tab. 1 - *Main characteristcs of the model layers implemented.*
Tab. 1 - Principali caratteristiche degli strati implementati.

Model layer	Hydro-tratigraphic unit	Specific storage SS [1/m]	Specific yield SY [1/m]	Horizontal hydraulic conductivity KX [m/day]	Horizontal hydraulic conductivity KY [m/day]	Vertical hydraulic conductivity KZ [m/day]	Total porosity [%]
1	Sandy loam	0.0001	0.05	0.5	0.5	0.05	30
2	Clay	0.001	–	0.1	0.1	0.01	20
3	Fine sand	0.001	–	10	10	1.0	30
4	Gravelly medium sand	0.0001	–	19	19	1.9	35

Water budget in the area is mainly positive throughout a year, with the following major incoming and outcoming components (Lipinskyi, Dyachuk, Babychenko, 2003; State Geological Survey of Ukraine, 2009; UkrGiproVodhoz 1968, 1976): incomes: precipitation is 600 mm/year; groundwater inflow for main aquifers is 5m/day at the north-eastern boundary of the area; river leakage - is estimated during the modelling; outcomes: evapotranspiration is 550 mm/year; river leakage and lower aquifer outflow towards the Dnieper river: to be estimated during the modelling.

The Bakumivka river catchment is a part of Trubizh drainage-irrigation system where for the irrigation shallow (river) water is used. The system was constructed in 1968-69, followed by its reconstruction in 1970s. Currently, the main function of water regime regulation is provided by extensive network of channels, as well as by numerous gates on the distributive main channel. Their principal function is to detain or drain water into the Bakumivka river, serving as a long-distance channel.

Data and Methods

The main objective of the case study as the search for optimal spatial distribution of the water supplied to the farms by modifying the land cover pattern of the Bakumivka River's catchment. For data aggregation, analysis and model implementation the FREEWAT software was used It is a free and open source platform, QGIS-integrated, for planning and management of ground- and surface-water resources (De Filippis et al. 2017). The FREEWAT platform, a large QGIS plugin, allows simulating the hydrologic cycle, coupling the power of GIS geo-processing and post-processing tools in spatial data analysis with that of process-based simulation models. This results in a modeling environment where large spatial datasets can be stored, managed and visualized and where several simulation codes (mainly belonging to the USGS MODFLOW family) are integrated to simulate multiple hydrological, hydrochemical or economic-social processes (Harbaugh 2005).

The developed model includes: four model layers representing main hydrostratigraphic units (see Tab 1); different types of boundary conditions assigned along the area's boundary; major components of the water balance introduced through the source and sink layers.

For the aims of the analysis the study area was discretized using model grid with square cells of 30 m×30 m that consists of 453 rows and 275 columns which produce 124 575 cells in total. Active modelling domain is defined by the area of Bakumivka River's catchment and includes 71 498 cells and is about 64.35 km^2 wide.

The time unit of the model is day. The first stress period lasts 1 day and aims to simulate steady state conditions, while the following two-week stress periods 2-14 were introduced to simulate different scenarios representing different land usages. The stress periods of the growing season only were considered and run at transitory state. For each stress period, variation of recharge and evapotranspiration rates is taken into account. The winter stress periods with snow cover were not considered.

In order to represent the interactions of the modelling domain with the external area in the terms of the groundwater inflows and outflows, the specific hydraulic conditions were assigned along the boundaries of the active domain. As the impervious marl layer underlying the sandy aquifer was not represented in the model, a no-flow boundary condition was assigned at the bottom of the deepest model layer. This means that no vertical exchanges are assumed to occur between the sandy aquifer and the underlying marl formation. The case study area is a closed watershed within which main groundwater flow directed from the north-east to the south-west towards the Dnieper river. Thus, along its eastern and western boundaries, which are not affected by the main groundwater flow, no-flow boundary conditions were assigned.

Inflow at the north-eastern boundary is simulated through recharge wells, applying the MODFLOW WEL package with positive flow rates to the model layers 3 and 4. Overall inflow rate was calculated using the Darcy's Law. Hydarulic gradient of 0.0004 m/day at the boundary was derived from the piezometric contours of the State geological map of Ukraine 1:200 000 (State Geological Survey of Ukraine, 2009), and was multiplied by the cross-section area (derived from width and thickness of the corresponding cells). The resulting values made up 5 m^3/day for each cell. Outflow at the south-western boundary is simulated through the MODFLOW Time-Variant Specified-Head Package (CHD). Its values were set to 100 m to represent the lowest absolute value of the water level in the Bakumivka river.

Distributed evapotranspiration was estimated separately for the three modelling scenarios. The MODFLOW EVAPOTRANSPIRATION (EVT) Package was applied and, within each layer, the required EVT parameters (elevation of the evapotranspiration surface, maximum evapotranspiration flux, and evapotranspiration extinction depth) were spatially and temporally determined according to the ten classes of land cover in the area.

Maximum evapotranspiration flux values are based on the reference evapotranspiration scaled by the crop coefficients. Daily reference evapotranspiration was calculated for each stress period, based on the times-series of meteorological observations (State Geophysical Observatory 2016) using the Penman-Monteith equation (Monteith 1965). The crop coefficients for different land cover classes were set based on the empirical data, taken mainly from the Ukrainian literature sources (Agroclimatic reference book 1958; Aidarov 1986; Kalinin 1989; Kolesnikov 1962; Markov 2011; Tsupenko 1990). Extinction (or root) depth values for different land cover classes were set based on the empirical data, taken mainly from the Ukrainian literature sources (Agroclimatic reference book 1958; Aidarov 1986; Kalinin 1989; Kolesnikov 1962; Markov 2011; Tsupenko 1990). Resulting evapotranspiration values were scaled by the relevant crop coefficients in order to obtain spatially and temporally distributed values. For the first stress period extinction depth and evapotranspiration of 0.5 m and 0.0014 m/day were set as the constant values. As the stress period represents steady state conditions these tentative values were calculated as averages.

Distributed recharge was simulated through the MODFLOW Recharge (RCH) Package. Meteorological time-series data for the period 2004-2014 (State Geophysical Observatory 2016) were used to estimate recharge values. In order to obtain effective infiltration from precipitation, we subtracted the reference evapotranspiration values from the precipitation values (Miegel et al. 2013). In case of the negatives, the values were converted to zero. These values were applied as constant values all over the active domain.

Water exchange between river/cannel network and the aquifer was simulated with the MODFLOW River (RIV) Package. .A multi-segment river network shapefile was used to create the geometry. The package requires information on the elevation of the river bottom, width of the riverbed, hydraulic conductivity and thickness of the riverbed material. The elevation of river bottom was calculated as the difference between top elevation of the model and the depth of the channel. The values of the depth and width of the riverbed are taken from UkrGiproVodhoz (1968, 1976) and are equal for main channel 2.5 and 10 m respectively, while for secondary channels 2.0 and 1.0 m. River stage for all the channels throughout all stress periods was set to the constant value of 0.5 m above the river bottom (UkrGiproVodhoz 1968, 1976). The thickness of the riverbed was set to the tentative value of 0.5 m and the hydraulic conductivity value of 0.1 m/day was applied (UkrGiproVodhoz 1968, 1976). The conductance of the river bed material (m^2/day) is then automatically calculated according to the MODFLOW RIV standard parameters. As the first stress period was run under steady-state condition, no real initial conditions were assigned. The starting head was set to 100 m for each layer. This value was set according to the mean groundwater level in the modelling domain (UkrGiproVodhoz 1968, 1976). The MODFLOW PCG2 (Preconditioned Conjugate Gradient) Package was used as a numerical solver. The maximum number of outer and inner iterations was defined (100 and 10, respectively). The other parameters were set to the default values.

The irrigation term and pumping from the aquifer were not considered becuase of inacuracy of data available In order to judge on the model performance, we compared simulated head with the actual relief in the area to understand how groundwater table correlates to the absolute height values. The results of such comparison for the model layer 1 during the stress period 1 are presented in Figure 3.

Results

The current situation in Bakumivka River's catchment was analyzed by the experts enrolled in the Focus Groups. They helped to define the main objective of FREEWAT application in this case study as the comparison between different water management scenarios. The "key variable" of water management scenarios for Bakumivka river catchment is the spatial pattern of land cover classes within the basin. By the land cover class we mean areas (zones) covered with particular type of vegetation with characteristic root depth (extinction depth), evapotranspiration and productivity.

In total, ten land cover classes were used in simulation, namely: 1- "pinewood" (the forested area with Pinus sylvestris L. as dominant tree species), 2- "shrubs" (areas covered with perennial brush species or short tree species forming shrub layer), 3 – "grassland" (seminatural communities of grass species and other herbs; many of these areas are used as pastures, but the plant cover is not degraded), 4 – "peat bogs", 5 – "riparian vegetation" (areas along the riverbanks and of some suffosian depressions covered with hygrophilous vegetation; willow tree, scane (Phragmites communis), edge grass (Carex) prevails, fennel-leaved pondweed (Potamogeton pectinatus) and other), 6 – "private farming" (the areas owned by local peasants, normally located near their houses; vegetables and berries are mostly cultivated there), 7 – perennial herbs (fields with clover (Trifolium), alfalfa (Medicago), espacet (Onobrychis) and other species); 8 – "corn"; 9 – "sunflower"; 10 – "rapeseed" (the areas where in crop rotation schemes particular species predominates).

Combining these ten classes of land cover, we have obtained three scenarios representing the following assumptions: traditional for central Ukraine land cover, market oriented land cover, environmentally sounding land cover. The maps representing these scenarios of water/land management within the Bakumivka River's catchment are shown in Figure 4.

Traditional scenario (Fig. 4a) is the generalized ("averaged") pattern of crops and other classes of land cover used in the recent five years in forest-steppe environmental zone of Central
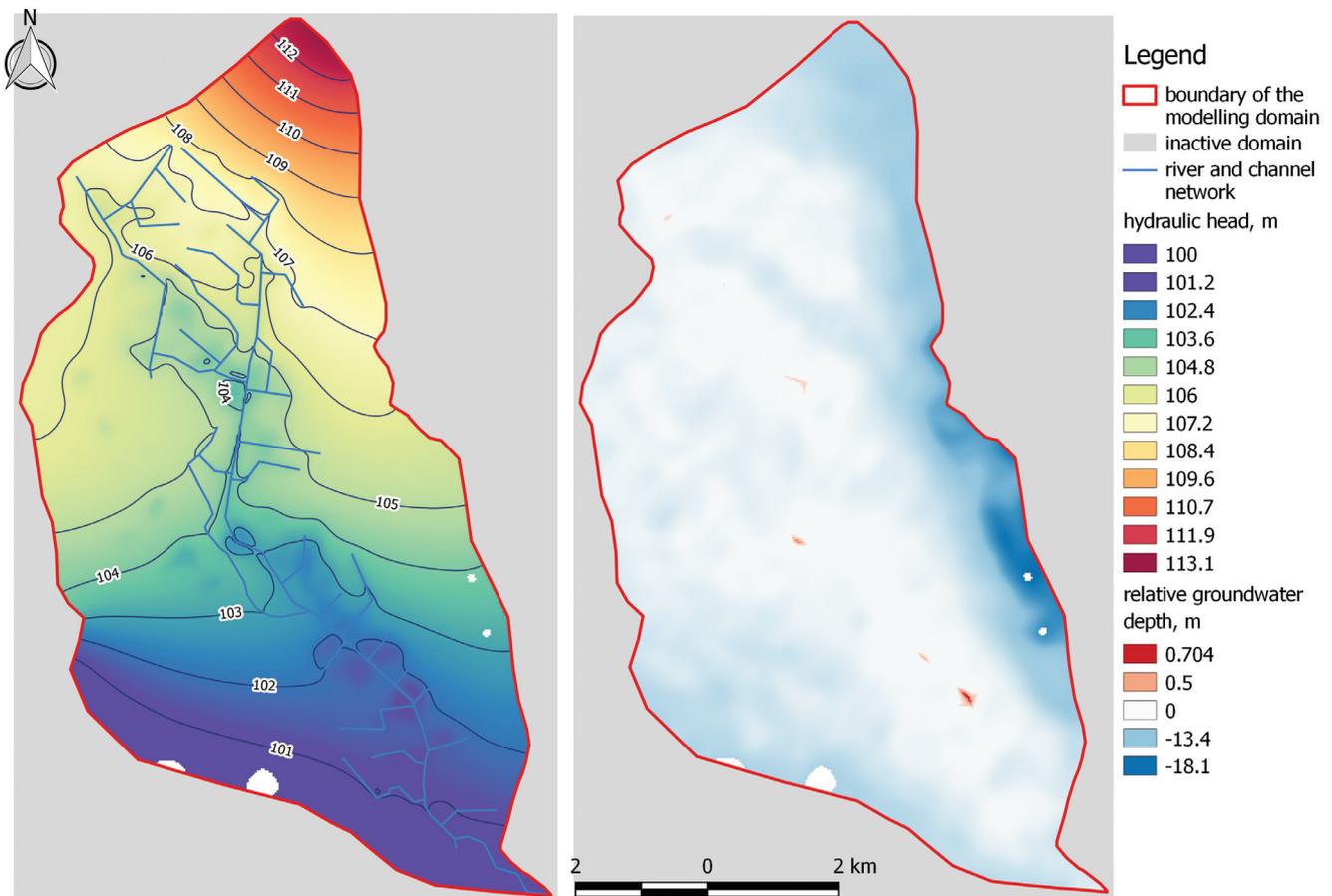
Fig. 3 - Simulated head of the model layer 1 and its comparison to the actual relief of the area.

Fig. 3 - Carico idraulico simulato per lo strato 1 e confronto con la topografia dell'area.

Ukraine. It also considers that the technology of agriculture currently used in Bakumivka River's catchment will remain without serious transformation. The following features are typical for traditional scenario: 1 - the best soils are occupied by rapeseed and corn; 2 - areas along the Bakumivka river flood plain are used mostly for perennial herbs; 3 – forests and shrubs occupy small patches which are disconnected from each other; 4 – peat bogs are spread across the floodplain of Bakumivka river and its alluvial terrace.

Market-oriented scenario (Fig. 4b) is based on the assumption that the crops that are most profitable now will occupy about 70% of the arable lands within the river basin. Corn, sunflower and rapeseed are the most profitable crops in Ukraine's market and for many regions, including Bakumivka's catchment, there is a tendency of replacing other crops with these three plants. The characteristic features of market-oriented scenario are: 1- the sunflower is a "newcomer" to the Bakumivka catchment and replaces corn in some crop rotation schemes; 2- perennial herbs occupy less area and are found mostly within the floodplain and less productive soils (soddy-podzols); 3- grasslands and shrubs mostly disappear and are converted into perennial herbs or rapeseed fields; 4- most of small wooded patches are converted into arable lands; 5 – the same applies to the shrubs along the forest edges; 6- the spatial pattern becomes more homogenous.

"Environmentally sounding" scenario (Fig. 4c) is based on the assumption that the landscape will be spatially organized in compliance with the principles of landscape-ecological planning (Forman 1995). The main features of environmentally sounding pattern of the Bakumivka river catchment are: 1- rapeseed and suflower are removed from the landscape; 2 – the area of corn field is reduced; 3 – the area of perennial herbs is enlangered considerably and it becomes a relevant crop type in the catchment; 4 – the water protected belt along the Bakumivka riverbed becomes wider and is composed with riparian vegetation, grasslands, shrubs and woodlots; 5 – patches of forest, grasslands and shruds are connected with the eco-corridors creating local econet; 6 – along big forest and peatbogs with natural vegetation, ecotones are created.

For the assessment of how the land cover type affects water budget during the growing season three separate evapotranspiration grids with the MODFLOW EVT (Harbaugh 2005) boundary conditions were created. Each grid was assigned spatially distributed evapotranspiration parameters according to the spatial distribution of 10 land cover classes. The example of maps showing the spatial distribution of values applied in the model is shown in Figure 5.

The model was run three times with the different EVT layers in order to simulate three land/water management
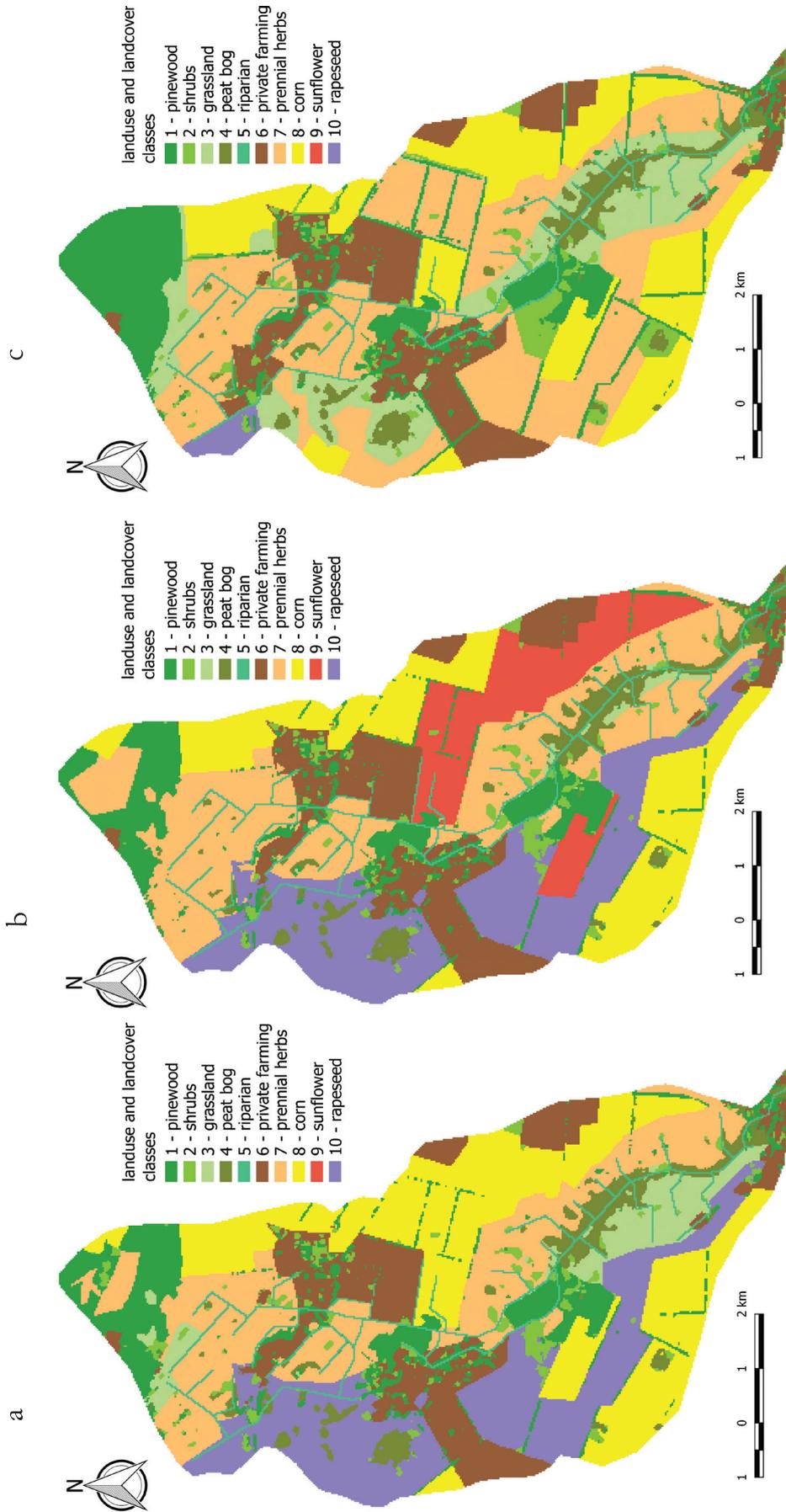
Fig. 4 – Water/land management scenarios of land cover taken into account within the Bakumivka River's catchment (from left to right): traditional, market-oriented, environmentally sounding.

Fig. 4 – Scenari di gestione della risorsa idrica e dell'uso del suolo nel bacino del fiume Bakumivka.
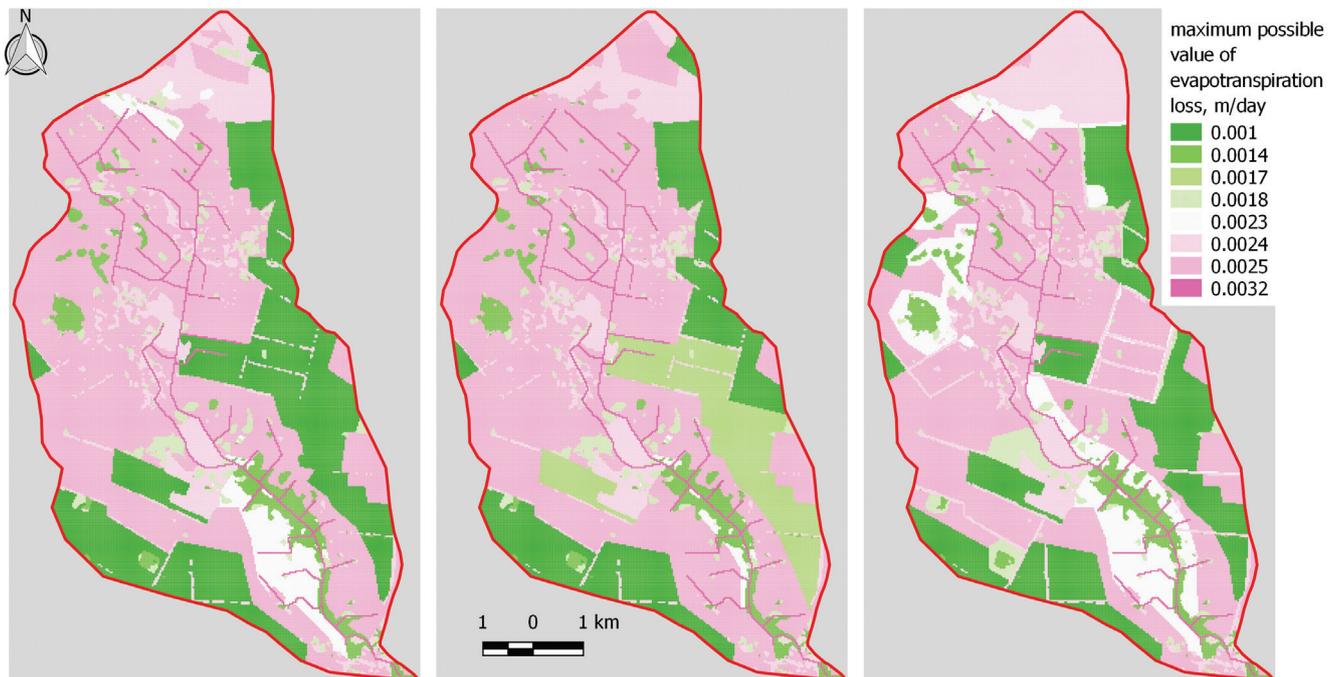
Fig. 5 - The example of spatial distribution of evapotranspiration parameters for different scenarios during the stress period 5 from left to right: traditional, market-oriented, and environmentally sounding respectively.

Fig. 5 - Esempio di distribuzione spaziale dei parametri di evapotraspirazione implementati per i diversi scenari durante lo stress period 5; da sinistra a destra: scenario tradizionale, scenario orientato al mercato, scenario sostenibile da un punto di vista ambientale.

scenarios. The criteria of evaluation, and simultaneously, of optimization of these scenarios, is represented by the difference (in meters) between the actual water head and the optimal water head for particular land cover class. The water level was considered as optimal if it falls within the range of minimal and maximum permissible levels. The maximum permissible level was defined as the extinction depth plus the capillary fringe, while the minimal permissible level is the extinction depth plus 0,5 of the capillary fringe. The capillary fringe for sandy loam soils is assumed equal to 0,8 m and for silt soils 1,8 m (Mironenko, 2001). The range of optimal water head were defined for each particular land cover class for each stress period. Using these data, two surfaces of minimal and of maximum optimal water head were created for all scenarios. Examples of these surfaces for the traditional scenario are shown in Figure 6 (see next page).

Subtraction of surfaces of water head and of optimal water head produces the map which shows the optimal areas (water head falls within the limits of optimal range), permissible areas (the difference between the head and its optimal limits does not exceed 3 meters, whihc corresponds to the multi-year variation of the water head in the area), and critical areas (the water head is above or below its optimal range for more than 3 meters). The examples of such maps as a result of simulations are shown in Figures 7-10.

Discussion

According to the traditional scenario, the average for vegetative period water head falls into its optimal ranges in few very small areas only (see Figure 7). However, permissible
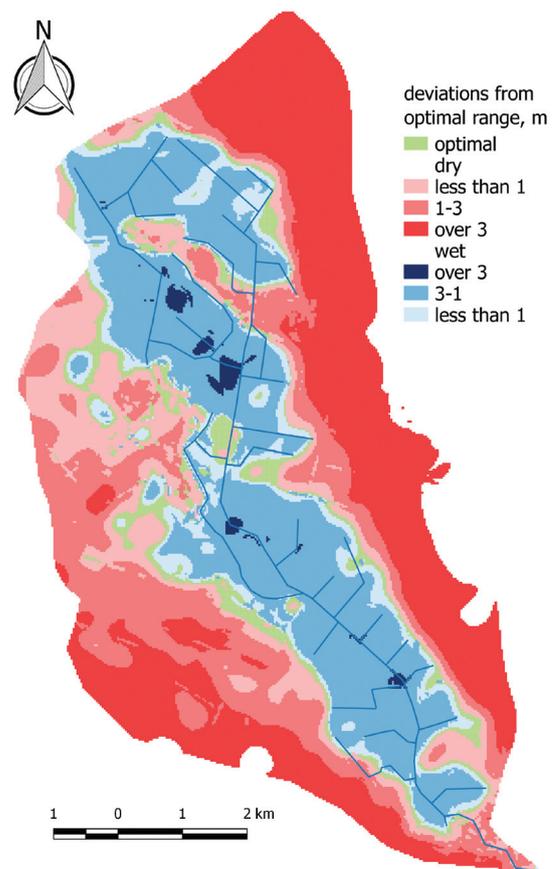
Fig. 7 - Deviations of water head from its optimal ranges for traditional scenario.

Fig. 7 - Deviazione del carico idraulico dall'intervallo ottimale per lo scenario tradizionale.
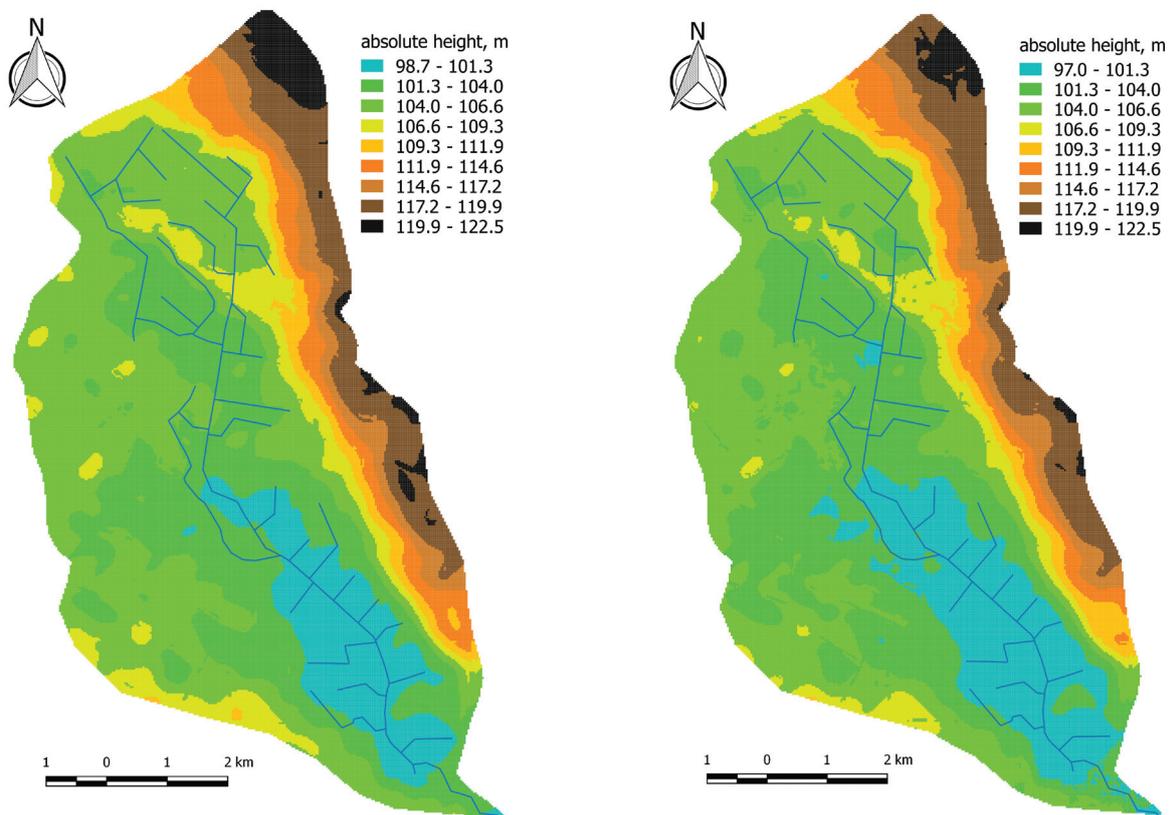
Fig. 6 - Surfaces of optimal range of the water head for the traditional scenario of land/water management: maximum (left) and minimum (right) limits of optimal water head.

Fig. 6 - Intervallo ottimale di carico idraulico per lo scenario tradizionale di gestione della risorsa idrica e dell'uso del suolo: limite massimo (a sinistra) e minimo (a destra) del carico idraulico ottimale.

conditions are typical for larger areas. Critical water regime (too wet or too dry) is typical for floodplain of Bakumivka River and the belts along the watersheds of its basin. Generally, the Bakumivka River's catchment is divided into two sections where different water management strategies and practices are needed. The central section requires drainage and crops of high water demand (rapeseed, perennial herbs). Irrigation here is needed mostly for prevention of peat fires in dry periods. The peripheral section of the catchment requires irrigation because water demanding crops are traditionally cultivated here. The drainage in this section could be limited. This is especially true because the soils here have light (sandyloam) structure. This fact is not taken into consideration in current water managemt of the Bakumivka River's catchment.

According to the marked-oriented scenario 2 (Fig. 8), more land should be irrigated, especially in the southern part of the Bakymivka River's catchment. Also more water should be supplied to the farms, especially planed with the rapeseed. Rapeseed is a water demanding plant. Its transpiration coefficient is 750 which is 1.5 – 2.0 more that for cereal crops (Agrocompany RAIZ, 2007). This will increase the irrigation rate, especially during stress periods from flowering to ripening of the rapessed and other commercial crops.

Comparison of figures 7 and 8 shows that the market-oriented scenario does not change considerably the relations between optimal and predicted water heads. On the one hand, this means that the commercialization of the agriculture in
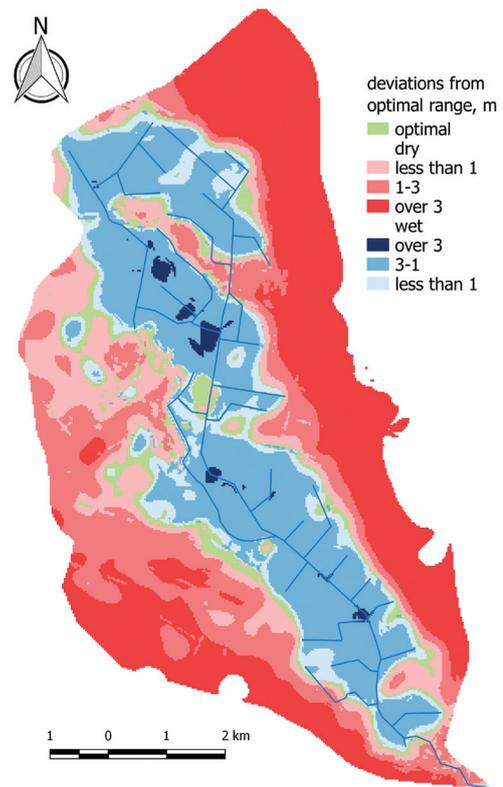
Fig. 8 - Deviations of water head from its optimal ranges for market-oriented scenario.

Fig. 8 - Deviazione del carico idraulico dall'intervallo ottimale per lo scenario orientato al mercato.

the catchment, particularly introduction of sunflower and rapeseed, with parallel increase of irrigation rates, would not affect the water regime of the catchment. On the other hand, these two crops require much fertilizers and water and cause dehumification (rapeseed) and soil erosion (sunflower). It is worth mentioning that the deviations of water head from its optimal ranges shown in Figure 6 are for the the end of the steady-state stress period. These deviations dynamically vary for different stress periods, due to the changes in the recharge, evapotranspiration and storage (Fig. 9).

The Environmentally sounding land cover pattern produces slightly better spatial relation between predicted and optimal water heads. It also needs less water supply to the farms because most water demanding crops (rapeseed and sunflower) are replaced with less vegetation consuming 1.5-2 time less water (with the transpiration coefficients 300 − 500 instead of 7500 for rapeseed). It should decrease the irrigation rates between 20-30%. The irrigated areas will also be reduced due to restoration of water protective belts along the channels (up to 50-70 m wide) and introducing ecocorridors into the land cover pattern. The deviations of the predicted water head from the optimal limits of the optimal range of water heads for the Scenario 3 is shown in Figure 10.

The key points highlighted after the discussions of the results by the Focus Group include:

- changing spatial land cover pattern could be effective measure to reduce water supply to the farms, however it does not solve the problem of water logging in the areas adjacent to the flood-plains as well as the problem of drying in summer stress periods of lands on sandyloam soils;
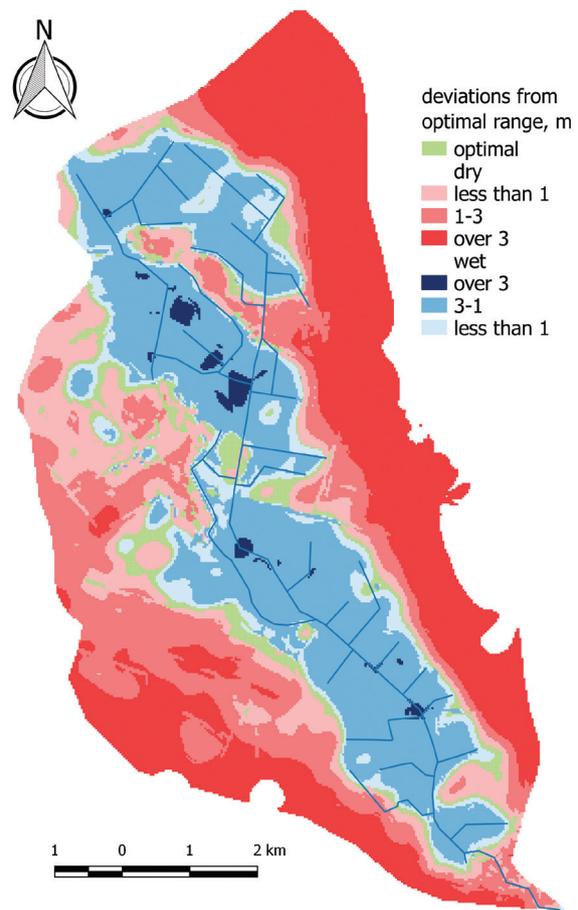
Fig. 10 - Deviations of water head from its optimal ranges for environmentally sounding scenario.

Fig. 10 - Deviazione del carico idraulico dall'intervallo ottimale per lo scenario sostenibile da un punto di vista ambientale.
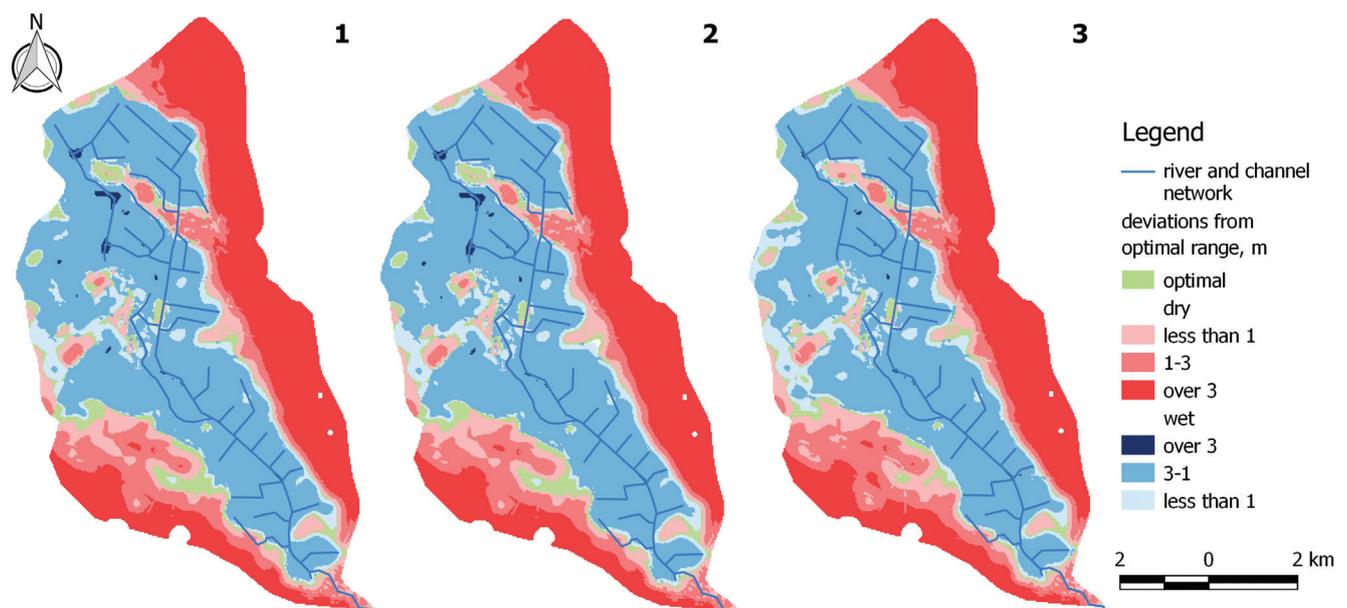
Fig. 9 - Deviations of water head from its optimal ranges during the stress period 5 for different scenarios from left to right: traditional, market-oriented, and environmentally sounding respective.

Fig. 9 - Deviazione del carico idraulico dall'intervallo ottimale durante lo stress period 5 per i diversi scenari; da sinistra a destra: scenario tradizionale, scenario orientato al mercato, scenario sostenibile da un punto di vista ambientale.

- the elevated lands with sandy and sandyloam soils characterized by the risk of soil drought during the summer and late spring stress periods should not be used for crops with high transpiration coefficients (above 250-300); they have to be replaced with the perennial herbs or pine woods;
- irrigation which currently covers almost all the Bakumivka River's catchment should be excluded in the areas with sandy and sandyloam soils; it also is needed in flat areas within the first alluvial terrace and floodplain used for perennial herbs where peat bogs are absent;
- the flood plain with peat bogs despite the high water head in spring and late summer stress periods should be irrigated to protect the peat bogs and prevent peat fires;
- introducing the elements of the econet to the land cover pattern (environmentally sound scenarios) is perhaps profitable from ecological point of view enhancing species migration but has little influence on the ground water of the watershed 0 it remains the same here. Moreover, the eco-corridors could prevent drainage causing water logging in arable lands.

Conclusions

The main objective of this case study was the search of the optimal spatial distribution of the water within the Bakumivka River's catchment modifying its land cover pattern. The FREEWAT approach has played an integrative role in the development and implementation of the modeled case study. The FREEWAT Platform has shown its strongest capabilities in this process, because of its ability to support the whole modelling cycle from the data input to the representation of the analysis results (Rossetto et al. 2015).

Three water management scenarios developed by the Focus Groups have helped to compare different spatial patterns of land cover and their distribution of water within the Bakumivka River's catchment. The most important findings of the simulation include measures concerning the spatial redistribution of lands with different evapotranspiration including defining the areas where irrigation and/or drainage are not actually needed. The measures propopsed could rise crop productivity, and to protect the environment of the Bakumivka River's catchment from water logging, peat fires, soil degradation and other undesirable processes. An important outcome of the realization of the set of scenarios is that no single one but few types of hypothetic land cover patterns with few schemes of spatial distribution of water attached to each of them could be regarded as optimal. The variety of optimal decisions is the ground for adaptive water/land(scape) management and planning.

Current modeling approach and obtained results can be improved in several ways. First, there is a need for more adequate representation of the layers with complex geometry that contain lenses and inclusions. For this purpose, model layers' depth and quantity can be reduced (for example, 2-3 aquifers of total thickness of about 15 m), and more detailed data from boreholes should be available in order to represent layers geometry with more details.

River stage parameters are constant in the model, however to simulate storage and discharge of water from the river network they could be varied in time and space (on the segments between slices). It will help to understand the role of the channel network in the maintenance of the optimum groundwater table level.

Further developments could include simulation of the groundwater pumping in the area.

The other important applications are mostly related to the development of the more advanced modelling scenarios that help to understand better the relations between the water storage in the river and channel network and groundwater heads and flows.

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