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A MODEL FOR EVALUATION OF THE HYDROLOGICAL ROLE OF A FOREST

MODEL ZA VREDNOVANJE HIDROLOŠKIH ZNAČAJKI ŠUME

Špela PLANINŠEK, Andreja FERREIRA, Anže JAPELJ

ABSTRACT: The aim of this paper is to present a method for allocating and evaluating forest areas with hydrological roles and for determining the necessary forest management measures. The method was tested in the Draga watershed, which is characterised by a high proportion of forest cover (83 %). The development of a GIS-based decision support model first required determining the needs for the forest hydrological role as well as the capacity of forest sites for providing that role. The needs for the hydrological role of forest are expressed by external, ecological factors (terrain slope and forest soil types distinguished by their erodibility and ground porosity). A forest's capacity to assure the hydrological role is expressed by internal, forest stand factors (stand structure, stand density and the degree of stand naturalness). The merged variables describing the needs and capacity were further divided into three groups: low-medium-high needs and high-medium-low capacities for providing the hydrological role. Overlapping the needs and capacity revealed locations where the needs exceed the capacity, and where erosion problems may occur in the field. A side-result of the model is the list of necessary forest management measures for enhancing forest hydrological role that can be applied to every combination of external and internal factors.

Key words: forest, hydrological role, evaluation model, multiple-use forestry, suitability evaluation, alpine watershed

1 INTRODUCTION – Uvod

Forests are significant consumers of water, but they simultaneously function as natural water filters and reservoirs. In extreme weather and growth conditions, the forest canopy cover is a factor that can greatly affect water runoff. With its aboveground and underground parts, forests regulate (moderate) the runoff and infiltration of surface water, while simultaneously protecting the soil against water erosion (Chang, 2006).

Due to numerous influential factors and their correlation, the water cycle in forest ecosystems has been examined from various perspectives. The first experimental measurements of water runoffs from watersheds were carried out in Switzerland at the beginning of the 20th century (Von Casparius, 1959), when the positive effect of forest canopy cover on the water regime was confirmed. Research of forest hydrology was initially focused on the quantity of water, which was the most easily obtainable information (Black, 1996). This was followed by a period of research and monitoring of the quantities of elements, sediments and pollutants in the water (Binkley and MacDonald, 1994; Prybolotna, 2006; Oshurkevych, 2006), while research into the entire water cycle from both physical and chemical aspects is still uncommon. Forests undoubtedly have an impact on the water balance at the basin scale: forest water consumption is generally higher than that of other types. Deforestation, therefore, results in an increase of water yield and reforestation in a decrease. However, much remains unknown about the consequences of the aging of forest stands, and about the densification of forest cover at the watershed-scale (Andreassian, 2004). There is also very little research prepared in such a way that the obtained results would help forest managers to identify

Špela Planinšek, Andreja Ferreira, Anže Japelj, Address: Slovenian Forestry Institute, Večna pot 2, SI-1000 Ljubljana, Slovenia, Telephone: 00386 (0)1 2007828, Fax: 00386 (0)1 2573589, E-mail address: andreja.ferreira@gozdis.si

critical areas and measures for the maintenance or establishment of the optimal hydrological role of a forest.

Within the present research, two effects of the forest on soil – protection from water erosion and soil conservation – have been combined into one aspect called "hydrological role of a forest". This was possible due to the close relation of both issues in terms of forest management measures for their consolidation. The aim of this study is to transfer theoretical knowledge into practice, which is beneficial for the successful realisation of management objectives related to the hydrological role of forests. Using the results obtained in our research, we have attempted to show an example of the optimal spatial distribution of measures providing the existence and development of the hydrological role of a forest.

2 METHODS – Metode rada

2.1 Research area – *Područje istraživanja*

The model was tested in the Draga watershed in the Alpine region of Slovenia. The area covers 1,786 hectares at altitudes ranging from 600 to 2,060 meters. Soil types are highly heterogeneous, from rocky ground to fertile brown soils (IGLG, 1967). The predominant land use in the watershed is forest, covering 83 % of the area, while the remaining 17 % is covered by alpine grasslands and rocky terrain overgrown with mountain pine (MKGP, 2005). Regarding vegetation, the area belongs to the pre-Alpine phytoclimatic territory. Owing to certain historical conditions, the planted Norway spruce (*Picea abies* (L.) Karst.) and naturally occurring European beech (*Fagus sylvatica* L.) predominate in the valley. The stand mixture is further composed of European silver fir (*Abies alba* Mill.), sycamore maple (*Acer pseudoplatanus* L.), European ash (*Fraxinus excelsior* L.), wych elm (*Ulmus glabra* Huds.) and green alder (*Alnus viridis* (Chaix.) D.C.) (ZGS 1999). The various plant associations intertwine mosaically in relation to soil conditions and other site factors.

The annual precipitation ranges between 1,950 and 2,600 mm, with the minimum between December and March and the maximum in the autumn months (ZGS, 1999). High values of daily precipitation indicate a permanent danger of torrential waters and, therefore, the exceptionally significant hydrological role of the forests in the immediate vicinity of torrent beds as well as in the wider watershed. This highly diverse relief is greatly influenced by the porous limestone parent material.

2.2 Definition of the model's basic factors – *Definicija osnovnih čimbenika modela*

In addition to the hydrological role as defined in this research, the term "hydrological function" is also defined in Slovenian legislation; however, it does not include the characteristics of a forest stand as factors affecting forest hydrology, but is based primarily on the protection of sources and collectors of drinking water in forests (Official Gazette of the Republic of Slovenia, 1998). This research was aimed at investigating the importance of suitable stand structure, canopy cover and tree species composition for an optimal water cycle and the protection of soils in the forest ecosystem. On that note, this analysis represents an alternative insight into the relation between forest characteristics and the impact of precipitation on forest soils.

The forests' hydrological role has been evaluated with the matrix model (Wullschleger, 1982) comprising external (ecological) and internal (stand) factors (Table 1). The ecological factors define the needs for the hydrological role, whereas the stand factors determine the capacity to provide for it.

Data processing was carried out with Idrisi software (Idrisi Andes, 2006). All data layers were created in a raster data model with a pixel size of 12.5 × 12.5 m, which provided valid site accuracy. The selection of the basic criteria and differences between the ranks was made on the basis of the studied national (Pogačnik, 1976; Anko, 1982; Fajon, 2007) and foreign literature (Binkley and MacDonald, 1994; Nisbet, 2001; Twery and Hornbeck, 2001; Chang, 2006; Prybolotna, 2006; Oshurkevych, 2006).

In relation to the external, ecological factors, we evaluated the terrain slope with the digital elevation model with a spatial resolution of 12.5 m (GURS, 2006) and soil types with regard to their erodibility and porosity (IGLG, 1967; Košir, 1976, FAO, 2006). Together with parent material, climate and topography, soils affect the forest's capacity to perform its hydrological role in a stimulating or restraining manner.

Ranking of the ecological factors into three separate groups originates from an extensive overview of foreign and national literature, forest soil types maps and expert knowledge by pedologists and phytosociologists from the Slovenian Forestry Institute. We have also been aided by the expert opinions and advices of forest management planners from the Slovenia Forest Service.

Evaluation of soil types with regard to soil-water relationships (erodibility and porosity) contributes to the identification of areas where the probability of slides is higher and is, in combination with greater terrain slopes, critical (Binkley and MacDonald, 1994).

Table 1 External – ecological and internal – stand factors
Tablica 1. Vanjski – ekološki i unutarnji – strukturni čimbenici

	EXTERNAL-ECOLOGICAL FACTORS *VANJSKI – EKOLOŠKI ČIMBENICI*		INTERNAL-STAND FACTORS *UNUTARNJI – STRUKTURNI ČIMBENICI*		
Rank *Rang*	terrain slope *nagib terena*	soil - erodibility and ground porosity *tla - erodibilnost i propusnost za vodu*	stand structure *sastojinska struktura*	stand density *sklop (gustoća sastojine)*	stand naturalness *prirodnost sastava drveća*
1	0.0°-24.9°	low erodibility, normal porosity	unevenly-aged forests, forest shrubs	high, normal	preserved (over 70 %)
2	25.0°-34.9°	medium erodibility, normal porosity	mature stands, pole stands	low	changed (31–70 %)
3	35.0° and more	high erodibility, low porosity	young stands, rejuvenated old stands	gaps, interrupted	highly changed (0–30 %)

The input data for the assessment of soil erodibility and ground porosity was a pedological map of the study site at a scale of 1:10 000 (IGLG, 1967). The basic unit that was subjected to pedological mapping was a pedosystematic soil unit, according to the Slovenian soil classification system (Urbančič et al., 2005). In addition to specific courses of soil development, soil depth, depth of soil horizons, permeability, content of rock fragments, texture, porosity, water capacity and content of nutrients were also taken into account during the mapping process. The risk of erosion due to the morphology of terrain and (in)stability of bedrock was also included as a factor. Stony and rocky areas were excluded. Pedo-systematic soil units were assessed by means of excavation and analysis of soil profiles and by utilisation of soil probes. Each unit was depicted with a characteristic soil profile and the results of laboratory analyses of the physical and chemical characteristics of soil samples. Units had a minimal area of 0.5 ha and were, due to their heterogeneity and the small area they occupied, later joined into so-called mapping soil units. Domestic and foreign experts from the fields of geology, pedology and vegetation ecology participated in pedological mapping (Pavšer, 1966, 1967).

When assessing the erodibility and ground porosity of soils in the study area, we were referring to Košir's (1976) methodology for assessment of sites and the characteristics of forest ecological communities according to their protection role. Košir (1976) categorised soils into five classes of erodibility. The set of classes spans from completely stable (e.g. developed soils on limestone and dolomite) to very unstable soils (e.g. silicate colluviums that are poor in bases, organogenic calcomelanosols). As an additional criterion, porosity was added to erodibility, as it significantly affects the water runoff and consequently the erosion. The final ranking of soils was carried out on the basis of expert knowledge.

If the slope is increased from 20° to 30°, the quantity of runoff is threefold, in spite of the unchanged vegetation cover, while the quantity of sediment increases by eight times, as ascertained by Prybolotna (2006). According to Frehner et al. (2005), the danger of avalanches being triggered in coniferous forests increases at about at 35° slope, while in the open land and in larch stands, they can be triggered at 30°.

The final thresholds for classes were defined upon the provisions of the Regulation on the Forest Management and Silviculture Plans (Official Gazette of the Republic of Slovenia, 1998) and the criteria for the assessment of forest sites and characteristics of forest ecological communities according to their protection role (Košir, 1976). The Regulation (Official Gazette of the Republic of Slovenia, 1998) states that the first level of importance of forest's protection role (in such cases this kind of designation determines the set of management measures) is assigned to forests growing on slopes characterised by solid bedrock and inclinations of more than 35°, and forests on slopes with bedrock that is susceptible to sliding and inclinations of more than 25°. Košir (1976) categorised inclination into five classes and set the thresholds for the upper two classes at 25° and 35°.

With regard to the internal, stand factors, we evaluated the stand structure, density and stand naturalness of forests using a stand database containing field surveys, which are periodically performed by the Slovenia Forest Service (ZGS, 1999). Frehner et al. (2005) ascertained that the most suitable for providing the hydrological role of a forest is a small scaled unevenly-aged forest with a high degree of crown cover and proportionate distribution of developmental phases. In order to reduce high water discharges, Twery and Hornbeck (2001) recommend a share of non-forest land, gaps and up to 10-year-old stands to be below 25 % of the watershed area, by which a rapid runoff of precipitation that would freely flow down the agricultural and bare surfaces inside the forest would be prevented. With regard to erosion prevention, sustaining a constant shrub or tree cover in the entire watershed is recommended. Both in the watershed as well as in riparian zones, the density of the upper canopy layer should exceed 70 %, distinguishing high or normal density (Twery and Hornbeck, 2001). Research by Tikvić and Seletković (2003) revealed that degradation of vegetation cover in karst regions leads to soil erosion, which is a consequence of disturbed hydrological conditions. Gapped or interrupted stands are not suitable, due to the hastened water runoff.

The naturalness of forests is an indicator of the preservation of natural (potential) tree species mixture. It is a numerical indicator, calculated as a quadratic mean of deviations ($\hat{y}$) of actual portions (portions of all tree species sum to 1) of individual tree species (x_a) in the overall growing stock from its potential portions (x_p) (Bončina and Robič, 1998). This kind of measure (i.e. Euclidean distance) is commonly used in community-ecological analysis as a dissimilarity measure in comparison of pairs of samples (Eq. 1) (Gauch 1982). Potential state is defined as a situation in which no human interventions would occur and tree species mixture would be a product of only biotic and abiotic ecological factors (Bončina and Robič, 1998).

$$\hat{y} = \left[\sum_{i=1}^{n} \left(x_a - x_p \right)^2 \right]^{\frac{1}{2}} \quad \text{Eq. 1}$$

x – portion of tree species in overall growing stock

a – actual state of tree species' portion

p – potential state of tree species' portion according to phytosociological assessment (Braun-Blanquet method)

n – number of tree species in the area of interest (e.g. forest stand)

An indicator of tree naturalness is being used in Slovenian forest management planning (Official Gazette of the Republic of Slovenia, 1998) on the level of forest management units and forest management classes. Management measures are adapted to the status of naturalness of forest stands and are generally oriented towards the maintenance or establishment of close-to-nature tree mixtures. Forests that are closer to their natural state, hinder erosion better than changed forests, with their roots, ground vegetation, shrubs, trunks, canopies and dead organic matter performing soil protection. The forests' natural structure should not be altered through forest management measures, because it is adapted to the local ecological factors.

2.3 Database creation – *Stvaranje baze podataka*

The process of creating maps of conformity between the needs for the hydrological role of forest and its capacity to provide the same role is presented below:

1. determination of the main ecological factors that define the needs for the hydrological role of a forest, their classification and evaluation in relation to the intensity of these needs;
2. determination of the main stand factors that define the capacity of the forest to perform its hydrological role, their classification and evaluation in relation to the intensity of this capacity;
3. preparation of a needs layer for the hydrological role of a forest;
4. preparation of a capacities' layer of a forest to perform its hydrological role;
5. overlapping both layers as well as specification of the critical areas where the capacity of a forest does not meet the actual needs.

The needs layer was made on the basis of external, ecological factors, i.e. of the terrain slope and soil type. The values of both factors were ranked (Table 1). As both data layers were overlapped in the GIS environment, synthesis polygons were obtained, determined by the terrain slope rank and soil type rank as well as by a combination of both (Table 2). These combinations have been classified into three groups according to the intensity of needs for the hydrological role, expressed with a certain combination of both external factors.

Table 2 Combination of ranks matrix of the external factors and their groups.
Tablica 2. Rang matrica kombinacija vanjskih čimbenika i njihovih skupina

Group – the intensity of needs for the hydrological role *Skupina – intenzitet potrebe za hidrološkom funkcijom*	Group 1 – lowest intensity of need *Skupina 1 – male potrebe*	Group 2 – medium intensity of need *Skupina 2 – umjerene potrebe*	Group 3 – highest intensity of need *Skupina 3 – velike potrebe*
Combination of ranks for the factors terrain slope and soil type *Kombinacija rangova za znakove nagiba terena i tipove tla*	1.1	1.3	2.3
	1.2	3.1	3.2
	2.1	2.2	3.3

Note: e.g. case 1.2 indicates that the terrain slope is up to 24.9° and that erodibility of soil is medium and its porosity normal.

In the preparation of the layer of forest's capacity, three internal (stand) factors were used: the stand structure, stand density and stand naturalness. Only one source of data was used: the stand map of Slovenia Forest Service (ZGS, 1999). Each stand was defined with a certain rank (Table 1) for all three factors. With regards to the level of the forest's capacity to perform the hydrological role, the defined combinations of ranks were classified into three groups (Table 3).

Table 3 Combination of ranks matrix of the internal factors and their groups.
Tablica 3. Rang matrica kombinacija unutarnjih čimbenika i njihovih skupina

Group – forest's capacity for the hydrological role *Skupina – prikladnost šume za obavljanje hidrološke uloge*	Group 1 – highest capacity level *Skupina 1 – mala prikladnost*	Group 2 – medium capacity level *Skupina 2 – umjerena prikladnost*	Group 3 – lowest capacity level *Skupina 3 – mala prikladnost*
Combination of ranks for the factors stand structure, stand density and stand naturalness *nagiba terena i tipove tla Kombinacija rangova za znakove sastojinske strukture, sastojinski zaključak i prirodnost sastava drveća*	1.1.1	1.2.3	2.2.3
	1.1.2	1.3.2	2.3.2
	1.2.1	1.3.3	2.3.3
	1.1.3	3.1.1	3.1.3
	1.3.1	3.1.2	3.3.1
	1.2.2	3.2.1	3.2.2
	2.1.1	2.1.3	3.2.3
	2.1.2	2.3.1	3.3.2
	2.2.1	2.2.2	3.3.3

The capacity level is composed of polygons or surface areas, which are defined by one combination of ranks (group) each; accordingly, each polygon belongs to one group of the capacity level of a forest for carrying out its hydrological role.

In the last step, the layers of needs and capacities were overlapped, so we were able to define the surface areas where needs and capacities were:

- adjusted: the surface areas from the first or second group (the intensity of needs and capacity level) overlap in combinations[1] 1.1, 1.2, 2.1;
- partially adjusted: the surface areas in the combination of groups 1.3, 3.1, 2.2 overlap;
- unadjusted: surface areas in the combination of groups 2.3, 3.2, 3.3 overlap.

Such an overview enables a prompt identification of the areas where the conditions are favourable (e.g. a low need for the hydrological role and a high capacity of the forest to perform this ecosystem function), acceptable or even unfavourable (high needs and low capacity).

3 RESULTS – Rezultati

The model's applicability is presented in the case of study area of the Alpine Draga valley. In this study, the measures refer to the forestry spatial unit of the stand, which is the smallest spatial unit that is used by the forestry practice for forest management planning and is larger than 0.5 ha (Official Gazette of the Republic of Slovenia, 1998).

The layer of needs for the hydrological role of a forest (Fig. 1) is the result of the integration of ecological factors. Rank 1 indicates a low need, rank 2 a moderate need, and rank 3 a high need for the hydrological role of a forest. Most of the surfaces in a managed forest show low (40 %) or moderate (41 %) needs, while on 19 % of the managed forest's surfaces high needs for its hydrological role are expressed. The situation is by far less favourable in the protection forests, where the expressed needs for the hydrological role are low on 9 %, moderate on 21 %, and high on 70 % of its surface.

Protection forests (see hatched areas in Figure 1) represent an independent category of forests, which are excluded from the usual/intensive forest management regime. They occur at sites with predominant extreme ecological conditions (also, soils subjected to erosion and great slope gradients) and, as such, protect the land on which they occur as well as the land below them.

By merging the layers of stand factors (stand structure, stand density and stand naturalness), the layer of the forests' capacity to provide for their hydrological role has been obtained (Fig. 2). Rank 1 indicates a high capacity, Rank 2 a moderate one, and Rank 3 a low capacity to provide for this role. In both categories, more than a half of the forests are suitably structured (55 % in managed forests, 56 % in protection forests) and indicate a high capacity to provide for the hydrological role. A total of 28 % of the surface areas in managed forests and 43 % in protection forests have a moderate capacity, while a minor part demonstrates a low capacity to provide for the forests' hydrological role. The capacity is low in younger stand developmental stages and low density. A high capacity to provide for the hydrolo-

[1] A combination is always represented by two surface areas or overlapping polygons, where one is from the layer of needs and the other from the capacity layer. The adjustment between needs and capacities is expressed with a combination of both groups.

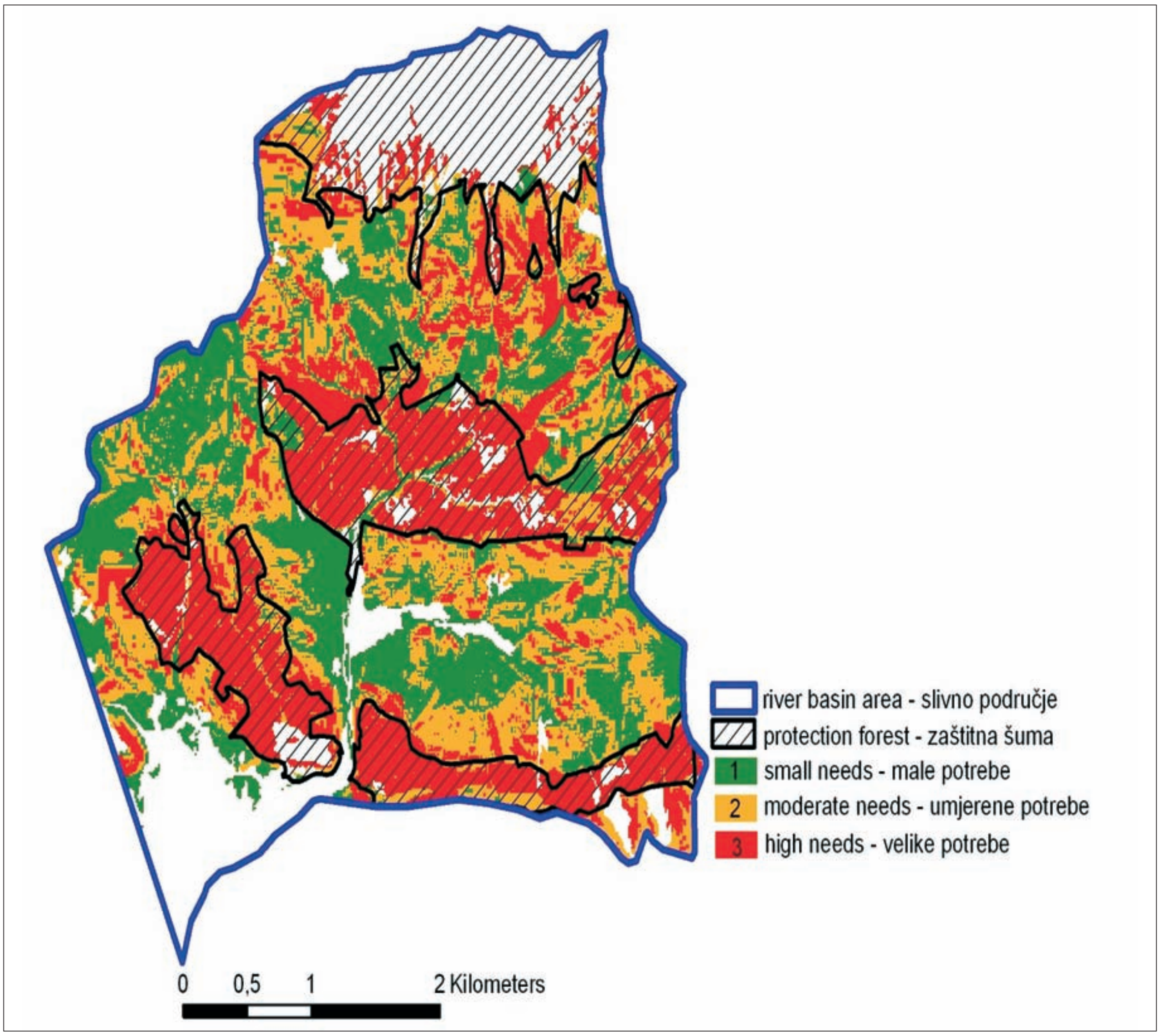

Figure 1 Needs for the hydrological role of a forest on the basis of various ecological factors.
Slika 1. Potrebe za hidrološkom ulogom šuma na osnovi različitih ekoloških čimbenika

gical role is exhibited in the areas where different stand structures with normal crown density and preserved tree structure are mosaically intertwined. Stand density is favourable on 79 % of the areas. Young and rejuvenated stands (3 % of the surface) are of low density, which is less favourable.

In the last step, we overlapped the layer of needs for the hydrological role of a forest and the layer of capacity to provide its hydrological role, and thus obtained the final, synthesis map (Fig. 3). Rank 1 exhibits a small need for the hydrological role and a high capacity of the forest to perform its hydrological role, which means a favourable condition (green areas). Rank 2 is a combination of moderate needs and moderate capacity, which means acceptable condition (orange areas), while Rank 3 is a combination of high needs and small capacity, which means unfavourable condition of a forest (red areas). Rank 3 delineates critical surfaces where, owing to the unfavourable tree composition, density or a poorly preserved tree mixture, the forest stands do not meet the high needs for their hydrological role. The results have shown that the conditions are favourable on 55 % of managed forests surfaces, acceptable on 29 %, and unfavourable on 16 % of them. The conditions are worse in protection forests, as they are favourable only on one fifth of the surfaces; 46 % of the surfaces indicate acceptable conditions, while almost a third of the surfaces demonstrate unfavourable conditions, which means that the forest capacity is not proportional to the needs for the hydrological role of a forest. The reasons for this should be sought in the absence of management actions.

In order to direct the development of forests towards the optimal realisation of their hydrological role, an array of forest management measures has been prepared (Fajon, 2007). Among them, we can select the measures that can contribute to the consolidation of the forests' hydrological role in a given stand (Köchli and Brang, 2005; Store, 2009).

If a constant cover with forest vegetation is provided for, the stand density will also be favourable. Measures should be taken gradually and collectively.

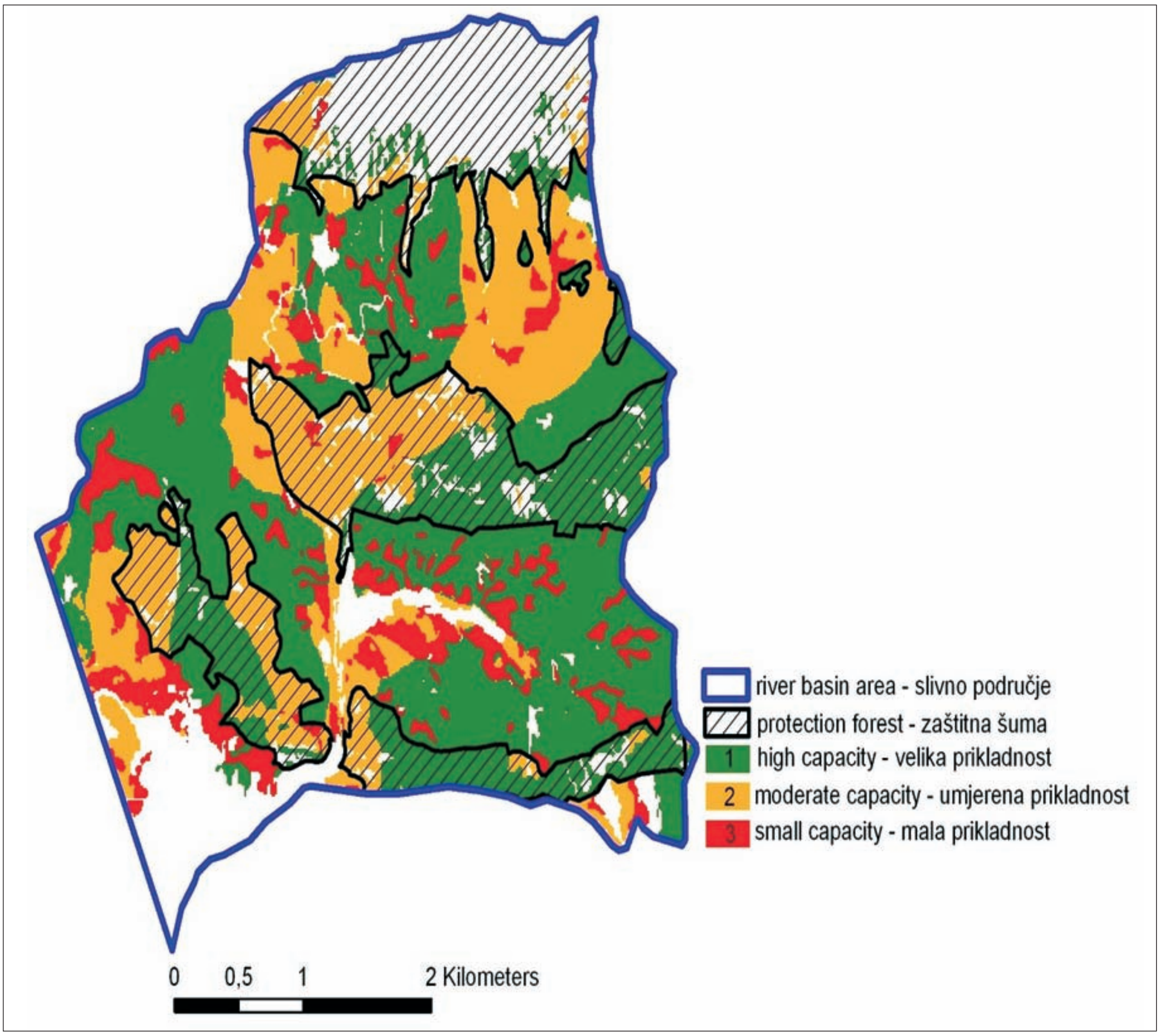

Figure 2 The forests' capacity to provide for their hydrological role.
Slika 2. Prikladnost šuma za osiguravanje njihove hidrološke uloge

Owing to the hasty planting of spruce, which was carried out at a large scale in the previous century, forestry is now facing a reduced ecological stability of the stands (monocultures) (Cimperšek, 1996) and greater biotic constraints (Spiecker, 2003). These problems, however, can be solved by providing a higher share of beech in the natural composition of young stands. In pure spruce stands, primarily in those of lower quality and stability, preliminary regeneration should be carried out. The first regeneration cuttings in the stands with prevailing shares of spruce should be of low intensity. The gaps in the stands, where regeneration is implicit, should be as small as possible; however, the efficiency of the regeneration should be considered. Where no natural regeneration is present, locally-grown seedlings should be planted. The rejuvenating periods should be longer and without multiple interventions in the forest, considering that forest management measures can cause erosion processes. Natural regeneration taking place under the shelter of an old stand is one of the foundations for the restoration of a natural tree structure.

On extreme sites in protection stands (great terrain slopes, higher altitude, certain plant associations), naturally present species with strong root systems (Mugo pine (*Pinus mugo* (Turra)), Scotch pine (*Pinus sylvestris* L.), European larch (*Larix deciduas* Mill.), sycamore maple (*Acer pseudoplatanus* L.), European silver fir (*Abies alba* Mill.)) should be preferred. In flatter areas, where reducing the surface water runoff is desirable, rejuvenation of noble deciduous trees as significant water consumers should be promoted.

4 DISCUSSION – Rasprava

In the past, the water cycle in the forest ecosystem was dealt with from different viewpoints, due to numerous influential factors and their mutual correlation. Through forest management measures, the runoff quantity has been altered in various ways (Von Casparius, 1959; Black, 1996; Robinson et al.,

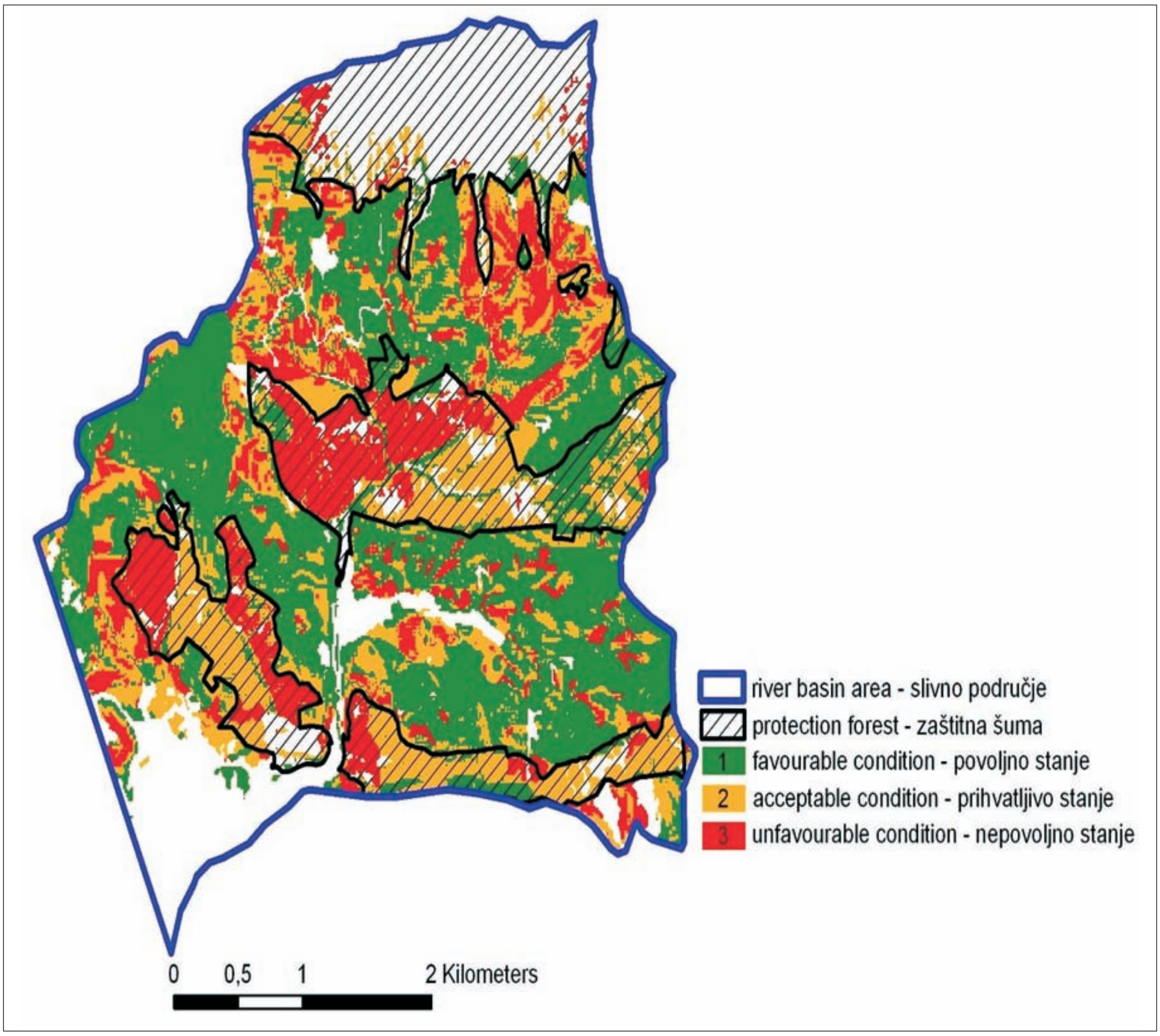

Figure 3 Synthesis map – needs for the hydrological role and the capacity of a forest to provide for it.
Slika 3. Sintezna karta - Potrebe za hidrološkom ulogom šume i njezina prikladnost da je ostvaruje.

2003), also owing to existing erosion processes. In scientific papers, the impact of forest canopy cover on water circulation and erosion processes associated with it has rarely been studied comprehensively (Neary at al., 2009). The significance of forest cover and the suitability of measures designed to consolidate the hydrological role of the forest have often been included in the studies by Nisbet (2001).

In spite of the numerous available models, we decided to construct a simple model that provided some very useful results. We wanted to expose the areas where a single factor could have had a negative impact on a forest's hydrological role. This kind of study is needed for guiding the land-use and forest management in alpine and mountain areas and where the soil erosion causes damage.

Every modelling of the processes in natural environments carries with it a certain share of criteria selection flexibility (Schwärzel et al., 2009). What if the basic criteria like slope or soil were classified using other thresholds? What if stand naturalness is not a variable that can explain the erosion control capacity? What if the different classes are not commensurable? The basic criteria selection was adapted to the actual research area. The Alpine regions climatic and site conditions were taken into account, while the principles of close-to-nature and sustainable forest management were considered in the selection of measures. Considering that no influence can be exerted upon the external-ecological factors, we have to focus all the more on providing for a favourable status of the internal-stand factors, which depends on foresters' work and a share of the implemented forest management measures. The forestry profession is liable to consider and accept, on the basis of the assessed facts, the appropriate forest management and site specific silvicultural measures (Lee et al., 2004; de Groot, 2006, Planinšek, 2010), with which it can substantially contribute to the suitable hydrological role of the forest.

5 CONCLUSIONS – Zaključci

The idea of multifunctionality in Slovenia's forestry practice lacks guided measures for the preservation and promotion of certain roles of the forests. This can provide an equivalent management in the entire region, in spite of the different local needs for the functions.

Forests have a significant and responsible mission in providing the hydrological role, which should be understood and implemented in two different manners. The first comprises protection of the existing ground and surface waters and waterbeds, as well as the prevention of erosion processes that can, together with high waters, pose a direct threat to the surroundings. The second manner involves maintenance and improvement of forest structures that indirectly increase the water capacity of soil.

The model for the evaluation of forest hydrological role presents a solid basis for planning forest management measures. We can maintain, in compliance with needs, existing conditions or enhance the capacity of a forest to perform its hydrological role. An advantage of the model approach is that it takes account of the natural conditions and assists in shaping as well as directing management actions to those areas where they are most needed. With verified and effective measures, forestry should provide for a forest structure that will optimally comply with the hydrological role where required by the forest or people themselves.

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SAŽETAK: Svojim nadzemnim i podzemnim dijelom šume reguliraju otjecanje i prodiranje površinske vode te ujedno štite tlo od vodene erozije (Chang, 2006). Oba su utjecaja šume u okviru tog istraživanja zbog tijesne veze između njih i usporedivih šumsko-privrednih mjera za njihovo jačanje združena pod pojmom hidrološka uloga šume. U članku je predstavljen model za procjenu hidrološke uloge šume. Međutim, rezultati predstavljaju osnovu za izbor odgovarajućih šumsko-uzgojnih mjera za jačanje spomenute uloge.

Model je ispitan na primjeru slivnog područja Draga, koje se nalazi na SZ alpskom djelu Slovenije. Područje obuhvaća 1.786 hektara na nadmorskim visinama između 600 i 2060 m. Tipovi tla vrlo su heterogeni, od kamenjaka do plodnih smeđih tala (IGLG, 1967). Šuma pokriva 83 % površine, ostatak su

*planinski travnjaci i kamenita zemljišta obrasla vrijeskom (MKGP, 2005). Vrlo je dinamičan reljef, nagibi na polovini obrađivanog područja premašuju 30°. Visoke količine oborina (1950–2600 mm godišnje) pokazuju stalnu opasnost od bujica, a time na iznimnu važnost hidrološke uloge šuma. Veći je dio područja isprepleten klancima planinskih potoka, grebenima, stijenama, ulegnućima zemlje i plazovima. U dolini zbog povijesnih razmjera prevladava posađena smreka (*Picea abies*) (L.) Karst.) i prirodno prisutna bukva (*Fagus sylvatica*) (L.). Smjesu sastojine čine jele, gorski javor, veliki jasen, gorski brijest i zelena joha (ZGS, 1999).*

Hidrološku ulogu šume ocijenili smo matričnim modelom koji se zasniva na metodologiji Wullschlegerja (1982). Model uključuje vanjske , ekološke, i unutarnje sastojinske čimbenike (tablica 1). Ekološki čimbenici određuju potrebe za hidrološkom ulogom, a sastojinski adekvatnost šume da je osigurava. Podaci su obrađeni u programu Idrisi (Idrisi, 2006). Podatkovni slojevi bili su rasterski, veličinom ćelije od 12,5 x 12,5 metra. Kod ekoloških čimbenika ocjenjivali smo nagib i tipove tla s obzirom na njihovu erodibilnost i propusnost za vodu. Naklon ima velik utjecaj na otjecanje površinske, a posredno i podzemne vode. U kombinaciji s nagibima tipovi tala s obzirom na njihovu erodibilnost i propusnost vode omogućuju procjenu vjerojatnosti pojave klizanja. Među unutarnje, sastojinske čimbenike svrstali smo sastojinsku strukturu, sklop (gustoću sastojine) i prirodnost sastava drveća u šumama. Frehner et al. (2005) utvrđuju kako je za obavljanje hidrološke uloge šume najpogodnija raznodobna struktura drveća na maloj površini s visokim stupnjem zastiranja i ravnomjernom razdiobom razvojnih faza. Twery in Hornbeck (2001), dakle, preporučuju da u slivnom području i u obalnom pojasu gustoća gornjeg sloja krošanja bude iznad 70 %, predstavljajući tako tijesan, ali normalan zaključak. Poželjan je što viši stupanj prirodnosti šuma, jer prirodna je struktura šuma prilagođena lokalnim ekološkim čimbenicima, što je itekako bitno pri osiguravanju ekološke uloge šume.

Vanjski, ekološki, i unutarnji, sastojinski, čimbenici rangirani na osnovi temeljitog pregleda domaće i strane literature te stručnih mišljenja pedologa i fitocenologa Šumarskog instituta Slovenije (Gozdarskega inštituta Slovenije) i šumsko-privrednih planera Zavoda za šume Slovenije (Zavoda za gozdove Slovenije) u 3 razreda (tablica 1).

U sredini GIS najprije smo prekrili vanjske – ekološke čimbenike (nagib, tip tla) i dobili poligone s kombinacijom obaju rangova (tablica 2). Kod unutarnjih – sastojinskih čimbenika (sastojinska struktura, sastojinski zaključak i prirodnost) izvor podataka bio je samo jedan, naime sastojinska karta Zavoda za šume Slovenije, zbog toga nije bilo potrebno prethodno prekrivanje podatkovnih slojeva. U skladu s tablicom 1, svakom smo poligonu odnosno sastojini pripisali rangove za sva tri znaka koje smo dalje spojili u tri skupine (tablica 3).

Karta potreba za hidrološkom ulogom šume (slika1) rezultat je spoja vanjskih – ekoloških čimbenika. U privrednoj šumi većina površina pokazuje male ili umjerene potrebe za hidrološkom ulogom šume. Stanje je znatno nepovoljnije u zaštitnoj šumi, gdje su čak na 70 % površina izražene velike potrebe za hidrološkom ulogom šume. Udruženjem unutarnjih – sastojinskih čimbenika (sastojinske strukture, zaključka i prirodnost šuma) dobili smo kartu prikladnosti šume za osiguravanje hidrološke uloge (slika 2). Više od polovine šuma u objema je kategorijama odgovarajuće strukturirano i pokazuju veliku prikladnost za osiguravanje hidrološke uloge, 28 % površina u privrednoj i 43 % u zaštitnoj šumi ima umjerene prikladnosti, međutim, manji dio ima male prikladnosti za osiguravanje hidrološke uloge šume. U zadnjem smo koraku spojili kartu potreba za hidrološkom ulogom šume i kartu prikladnosti šume za osiguravanje hidrološke uloge šume i dobili konačnu – sinteznu kartu (slika

3). Rezultati su pokazali problematično stanje u zaštitnim šumama, budući da je samo na punoj petini površina stanje pogodno, 46 % površina pokazuje prihvatljivo, a gotovo trećina površina nepovoljno stanje, što znači da prikladnost šume nije proporcionalna potrebama za hidrološkom ulogom šume.

Budući da ne možemo utjecati na vanjske – ekološke čimbenike, moramo se što više koncentrirati na osiguravanje povoljnog stanja unutarnjih – sastojinskih čimbenika. Za tu je svrhu izrađen plan provedbe šumsko-privrednih i šumsko-uzgojnih mjera (Fajon, 2007). Model za ocjenjivanje hidrološke uloge šume predstavlja kvalitetnu osnovu za planiranje šumsko-uzgojnih mjera, s kojima možemo u skladu s potrebama održavati ili poboljšati prikladnost šume za osiguravanje hidrološke njezine uloge. Kritične površine moraju kod planiranja mjera imati prednost. Svaka je prostorna jedinica opremljena s pet vrsta podataka, koji omogućuju potpunu analizu čimbenika koji utiču na potrebe i prikladnost šume za ostvarivanje hidrološke uloge te opredjeljenje potrebnih mjera za poboljšanje stanja.

Ključne riječi: šuma, hidrološka uloga, model vrednovanja, višekorisničko šumarstvo, ocjenjivanje prikladnosti, alpski sliv