The effect of land use changes on runoff generation in the High Tatras region

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Abstract: The impact of land-use changes on the runoff regime in the High Tatras region was estimated with an emphasis on the parameterization of the land cover properties in a runoff simulation. A spatially distributed physically-based hydrological model FRIER was applied to simulate runoff generation under unchanged and changed land use conditions. The Poprad river basin was divided into a number of grid cells for which the water and energy balance were maintained and hydrological processes were simulated continuously both in time and space. Parameters of the hydrological model were calibrated on data from the period of 1981-2000. The land use changes connected to agricultural and forest management were expressed by several scenarios. The effect of the changes in surface runoff, interflow, base flow, and total runoff in the basin's outlets and changes in runoff distribution on the basin after the wind calamity in 2004 were compared and discussed.

Key words: Scenarios of land use changes, High Tatras region, hydrological rainfall-runoff model with distributed parameters, total runoff and its components

1. Introduction

Estimating the effects of land use changes on the hydrological responses of catchments is an actual topic in hydrologic research. Changes in runoff generation due to land use changes, particularly those connected to agricultural and forest management, have often been documented in the literature. The removal of forest cover is known to change the stream flow, the water quality and temperature as a result of reduced evapotranspiration, changes in interception, infiltration and soil properties, surface roughness and higher

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water tables. Consequently numerous studies attempted to assess and model such changes. For example *Zhang et al. (2001)* developed simple and easily parameterised models to predict changes in mean annual flows following afforestation. *Ranzi et al. (2002)* quantified the effects of urbanisation on the flood volumes and peaks in the 311 km^2 Mella river basin. Changes in land use in the past 50 years have been compared using two land use maps; the first was based on aerial photographs taken in 1954 and the second on photointerpretation and surveys in 1994. *Sikka et al. (2003)* showed that a change from grasslands to Eucalyptus globulus plantations in India decreased a low flow index by a factor of 2 during the first rotation (9 years), and by 3.75 during the second rotation, with a more subdued impact on peak flows. *Scott and Smith (1997)* reported proportionally greater reductions in low flows (75–100th percentiles) than annual flows from South African research catchments under conversions from grass to pine and eucalyptus plantations, while *Bosch (1979)* found the greatest reduction in seasonal flow from the summer wet season. *Fahey and Jackson (1997)* reported that the reduction in peak flows was twice that of the total flow and low flows for pine afforestation in New Zealand. Recently *Bronstert et al. (2007)* investigated land-use changes and their effects on floods by a multi-scale modelling study of the Rhine basin, where runoff generation in catchments of different sizes, different land uses and morphological characteristics was simulated in a nested manner. For more information on these topics see also *Bosch and Hewlett (1982); Harr (1986); Jones and Grant (1996); Stednick (1996); Mattheusen et al. (2000); Brown et al. (2005); Lane et al. (2005); Wang et al. (2006); Webb and Crisp (2006); McVicar (2007); Gökbulak et al. (2008); Juckem et al. (2008).* As for ecologic consequences stream flow changes coupled to changes of land use which, however, will not be treated in this paper, *Van Sickle and Johnson (2008)* present an extensive review.

Rainfall-runoff model simulations are often used to evaluate the impact of land use changes on runoff generation (e.g. *Bultot et al., 1990; Parkin et al., 1996*). In connection with this topic, the representation of runoff processes and land use changes in a hydrological model are frequently discussed (*Niehoff et al., 2002*). *Bronstert, Niehoff and Buerger (2002)* summarized the present knowledge and modeling capabilities on the effects of climate and land-use change on storm runoff generation in a review. A widespread tool for assessing how land use changes affect hydrologic processes in a catchment are distributed models, which rely on a physically-based description of the runoff generation and the effects of different land covers. Distributed hydrologic models have the advantage of reflecting the effects of spatially distributed model parameters on stream flows; moreover, the present-day availability of spatially distributed data such as digital elevation models, land use, and soil information makes the use of distributed models much easier. However, assessing the effect of land use on runoff generation is very complicated; since land use and soil cover have an effect on interception, surface retention, evapotranspiration, and resistance to overland flow. Due to the complexity of the processes involved, the magnitude of their impact on runoff generation and subsequent flood discharges into a river system is still highly uncertain (*Niehoff et al., 2002*).

The awareness that distributed hydrological models are different from models in other disciplines grows. This is due to the highly heterogeneous and poorly known media properties (soil and vegetation), their spatial variability within grid elements and poorly defined boundary conditions.

The current generation of distributed models can often be considered as semi-distributed conceptual models because they use equations based on small-scale physics and apply them on a grid scale. In ideal cases (intensive data collection), land use parameters in a model are measured or estimated from catchment characteristics. More commonly, however, distributed models have their parameters determined from calibration, because of the unknown spatial heterogeneity of parameter values and the cost involved in their measurement. Therefore, there is always calibration needed for any model parameterization to accurately represent the hydrological processes in a particular case (*Bloeschl et al., 2008*).

Distributed hydrological models are usually parameterized by deriving estimates of parameters from measurements and look-up-tables or GIS based databases on the topography and physical properties of the soils and vegetation of the basin. The estimation of model parameters is uncertain due to the large degree of subjectivity involved in assigning parameter values to land use classes, which cannot be directly measured in the field.

In distributed models, land cover properties have to be characterized by plant-specific parameters (*Eckhardt et al., 2003*), but reliable results of modelling can only be obtained if the parameter values for the land covers involved are known with some degree of accuracy. A review of the literature (*Breuer et al., 2003*) shows a high degree of uncertainty in the parameterisation of land covers. This uncertainty is caused by problematic observations of some parameters, and difficulties with the regionalization of point measurements because of the natural variability of plant characteristics for reasons of climate, soil, stand age, etc. Against the background of these uncertainties, it is questionable whether different land covers can be significantly distinguished at all in their effect on the simulation results (*Eckhardt et al., 2003*).

In consequence model calibration is necessary (manual, automatic or the combination of both). Manual calibration is often used for distributed type. Despite being time consuming and subjective, it enables the modelers to use their experience and their knowledge of the studied watershed and can lead to a set of robust and realistic parameters. Automatic calibration which involves the use of a search algorithm to determine best-fit parameters (e.g. *Ajami et al., 2004*) is less subjective and makes an extensive search of the existing parameter spaces. However, it may not necessarily lead to realistic and valid parameter sets. As a solution, a modeling strategy that is based on multi-source model identification and verification is recommended, where the development, calibration and testing of a distributed model involves observed spatial patterns of catchment response and the assimilation of data from different sources (*Bloeschl et al., 2008*).

Ideally calibration should be accompanied by sensitivity analyses. This is a suitable instrument for the assessment of the influence of the model parameters on the model output. It can be used not only for model development, but also for model validation and reduction of uncertainty. It enables identifying important model parameters, testing the model conceptualization, and improving the model structure. It can also help to apply the model more efficiently in the given conditions, and on the long term, also the planning of data collection and assimilation (*Sieber and Uhlenbrook, 2005*).

In Slovakia, several physically based hydrological models with distributed parameters were recently used for assessing land use or climate change impact on runoff and snow melting processes and for simulating sediment transport, e.g. Wasim, Topmodel and UEB-EHZ (*Kostka and Holko, 2001, 2002*), WetSpa (*Papánková et al., 2005; Poórová et al., 2005; Hlavčová et al., 2005, 2006*), FRIER (*Horvát, 2006; Hlavčová et al., 2007*) and AGNPS

(*Miklánek et al., 2004; Pekárová et al., 2004a,b; Pekárová and Miklánek, 2007*).

In this paper, changes in the runoff regime in the High Tatras region due to land use changes were estimated using the FRIER model and GIS approach. Several scenarios of land use changes were created and an impact on runoff formation was expressed by changes in the long-term mean annual runoff and its components. Simulated runoff changes were confronted with expert judgments and estimates from literature. Limitations of the use of distributed models for land use change estimation were discussed.

2. Methodology

2.1. Model structure

The rainfall-runoff model FRIER (*Horvát, 2006*) used in this study is based on the structure of the physically-based WetSpa model, which was originally developed by *Wang et al. (1997)* and adapted for flood prediction by *De Smedt et al. (2000) and Liu et al. (2003).* The applicability of the conceptualization of runoff generation in this model has proved its applicability under various physiographic conditions in Slovakia, e.g. in the Hornad River, the Torysa River and in the Tisza River Project (*Bahremand et al., 2005, 2006*).

Several of its components were changed for this study in order to make it more appropriate for modelling the runoff from rainfall and snowmelt in the pilot basins of the High Core Mountains of Slovakia (*Szolgay et al., 2004; Hlavčová et al., 2005, 2006, 2007; Horvát, 2006*). The rainfall-runoff model with distributed parameters divides the basin into uniform spatial units on a grid scale, in which the hydrological balance and the runoff simulation are calculated up to the basin's outlet. The individual components of the hydrological balance are liquid and solid precipitation, interception, soil moisture, infiltration, actual evapotranspiration, surface runoff, interflow in the root zone, percolation into the groundwater, groundwater runoff and production of a groundwater recharge in the saturated zone. Transformation of the surface runoff in the catchment is simulated by approximating a diffusive wave model using geometric and hydraulic characteristics of hillslopes and of the stream network. The interflow and percolation of each cell is calculated using Darcy's law and a method of approximating the kinematic wave model. The model is executed as an ArcView GIS extension, and the whole preparation of the spatial distributed data is linked to the GIS interface. Three spatial map layers of catchment physiographical characteristics are needed: a digital elevation model, a map of the land use types and a map of the soil types. From these maps other physiographical characteristics are derived in a digital form as maps: the map of flow accumulation, the map of flow direction, the map of the stream network, the slope map, the map of hydraulic radius and the map of subwatersheds.

The hydrological and climatic data are daily or hourly total precipitation values from the measurements from the rain gauge stations, the mean daily or hourly values of air temperature from the measurements of the climate stations and the mean daily or hourly measured discharges from the river gauging station at the basin outlet. Besides the large number of physically-based parameters derived from the physiographic properties of the catchment, the model requires 12 calibrated "global" parameters which are not spatially distributed, and which are constant for all cells of the basin.

2.1.1. Parameterization of the water balance processes

Soil moisture storage is the actual quantity of water held in the soil at any given instant, usually applied to a soil layer of the root depth. Based on the different soil water content, the moisture storage can be divided into saturation capacity, field capacity, plant wilting point, residual soil moisture, etc. The FREIR model calculates water balance in the root zone for each grid cell. Soil water is fed by infiltration and removed from the root zone by evapotranspiration, lateral interflow and percolation to the groundwater storage.

Interception is a portion of the precipitation, which is stored or collected by vegetal cover and subsequently evaporated. In studies of major storm events, the interception loss is generally neglected. However, it can be a considerable influencing factor for small or medium storms, and water balance computations would be significantly in error, if evaporative losses of intercepted precipitation were not included. In the FRIER model, two parameters characterizing the minimum and maximum interception capacity are assessed by land use categories and the rainfall rate is reduced until the maximum interception storage capacity is reached. If the total rainfall during the first time step is greater than the interception storage capacity, the rainfall rate is reduced by the capacity. Otherwise, all rainfall is intercepted in the canopy, and the remainder of interception is removed from the rainfall in the following time steps.

Precipitation that reaches the ground may infiltrate, or get trapped into several small depressions, which are retained in puddles, ditches, and on the ground surface. As soon as rainfall intensity exceeds the local infiltration capacity, the rainfall excess begins to fill depression. Water held in depression at the end of rain either evaporates or contributes to soil moisture and subsurface flow by the subsequent infiltration. Actual depression storage is calculated on the basis of the depression storage capacity. The depression storage capacity is a parameter, which depends on land use classes, soil type and slope.

The runoff coefficient of a grid or catchment is the ratio of runoff volume to rainfall volume. A simple and practical technique is developed to estimate the runoff coefficient under varying land use, soil type, slope, rainfall intensity and antecedent soil moisture condition. Undoubtedly, these variables act independently but also interact in their effect on the runoff coefficient. A table of potential runoff coefficient is built for different land use, slope and soil type combinations and under the condition of near saturated soil moisture. Water lost from the soil surface is considered to infiltrate into the soil used for further vertical percolation, evapotranspiration and lateral interflow. To simplify the table, the land use classes are generalized into 5 classes as forest, grass, crop, bare soil and impervious area. Values in the table attain reference values from literature.

Default parameters characterizing different land use classes in the FRIER model are listed in Table 1. Sources of these parameters have been taken from the literature: [1]*Dickinson et al. (1993)*, [2]*Lull (1964); Rowe (1983)*; [3]*Chow (1964); Haan (1982); Yen (1992) and Ferguson (1998).*

2.2. Data

For the High Tatras region the Poprad river basin up to the Chmeľnica gauging station, which has an area of 1264.21 km^2, was selected as the pilot

Table 1. Default parameters characterizing land use classes

Land use classes	Vegetated fraction[1] [%]	Leaf area index[1] [-]	Root depth[1] [m]	Manning's coefficient[2] [$m^{-1/3}s$]	Interception capacity[3] [mm]
Crop or mixed farming	85	0.5 – 6.0	1.0	0.15	0.05 – 1.00
Short grass	80	0.5 – 2.0	1.0	0.20	0.05 – 1.00
Evergreen needle leaf tree	80	5.0 – 6.0	1.5	0.40	0.10 – 0.80
Deciduous needle leaf tree	80	1.0 – 6.0	1.5	0.40	0.05 – 0.80
Deciduous broad leaf tree	80	1.0 – 6.0	2.0	0.80	0.05 – 2.00
Evergreen broad leaf tree	90	5.0 – 6.0	1.5	0.60	0.15 – 2.00
Tall grass	80	0.5 – 6.0	1.0	0.40	0.10 – 1.50
Irrigated crop	80	0.5 – 6.0	1.0	0.20	0.05 – 1.00
Bog or marsh	80	0.5 – 6.0	1.0	0.20	0.05 – 1.00
Evergreen shrub	80	0.5 – 6.0	1.0	0.40	0.10 – 1.50
Deciduous shrub	80	1.0 – 6.0	1.0	0.40	0.05 – 1.50
Bare soil	5	0.5 – 2.0	1.0	0.10	0.05 – 1.00
Impervious area	0	0.0 – 0.0	0.0	0.02	0.00 – 0.00
Open water	0	0.0 – 0.0	0.0	0.02-0.05	0.00 – 0.00

basin. The basin lies on the southern slopes of the Ľubovnianska Vrchovina and on the northern slopes of Levočské Vrchy. The minimum elevation of the basin is 509 m a.s.l.; the maximum elevation is 2628 m a.s.l.; and the mean elevation is 878 m a.s.l. The location of the basin on the territory of Slovakia is shown in Fig. 1; the digital elevation model with the locations of the rain gauge and climatic stations and the Chmeľnica gauging station is shown in Fig. 2. The land use map of the basin and percentages of areas covered by different land use categories for the present stage are illustrated in Figs. 3 and 4.

A digital elevation model (DEM) with a resolution of 100 × 100 m was interpolated from the digitalized contour lines of the Basic Map Work of the Slovak Republic (1:10 000). The land use map originated from the thematic

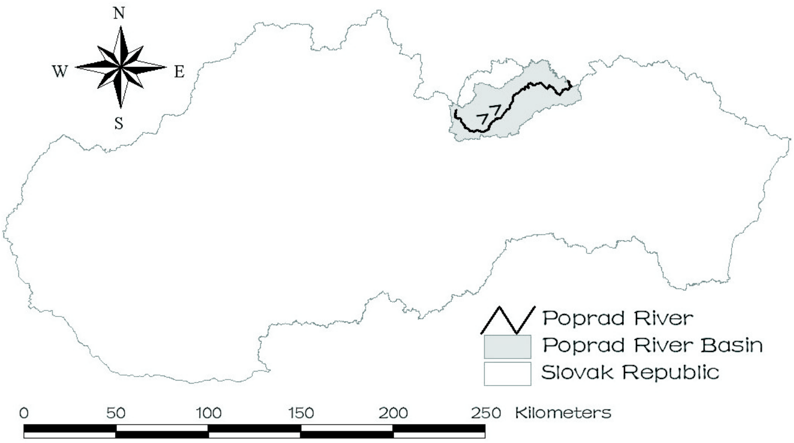

Fig. 1. Location of the Poprad river basin in Slovakia.

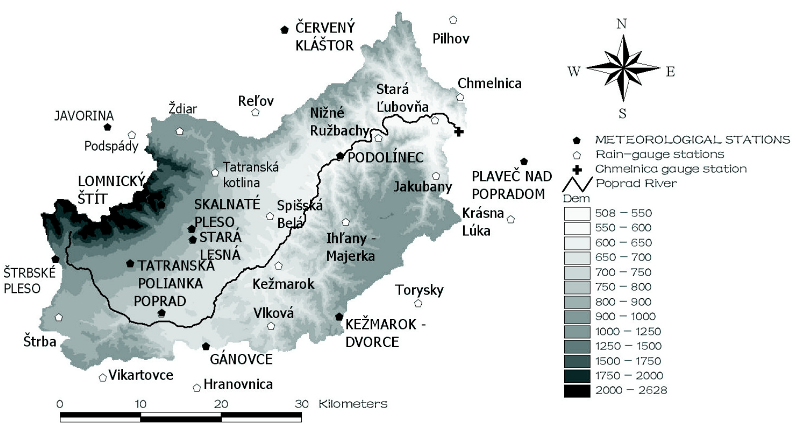

Fig. 2. Digital elevation model and location of climatic and rain gauge stations.

mapping of Slovakia by the Landsat satellite. Daily total precipitation was measured at 17 rain gauge stations and 12 climatic stations, and the mean daily temperature was measured at 12 climatic stations.

The rainfall-runoff model with distributed parameters was calibrated on the Poprad River basin up to the outlet gauging station at Chmeľnica for the period of 1981-2000 with daily time steps. The model's efficiency was

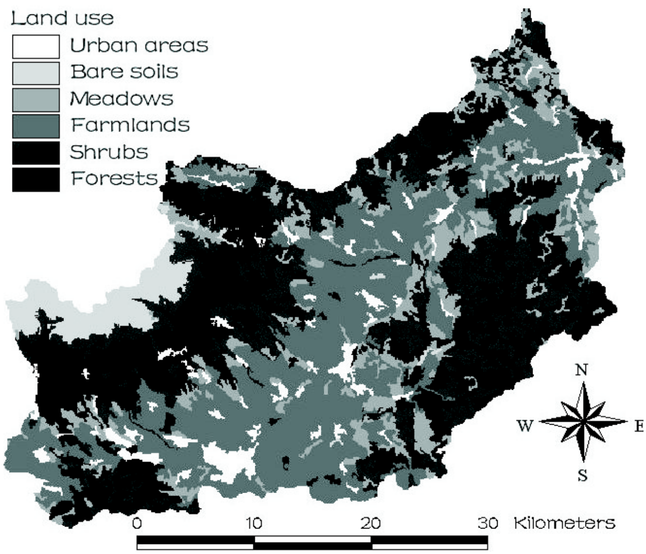

Fig. 3. Land use map of the Poprad river basin.

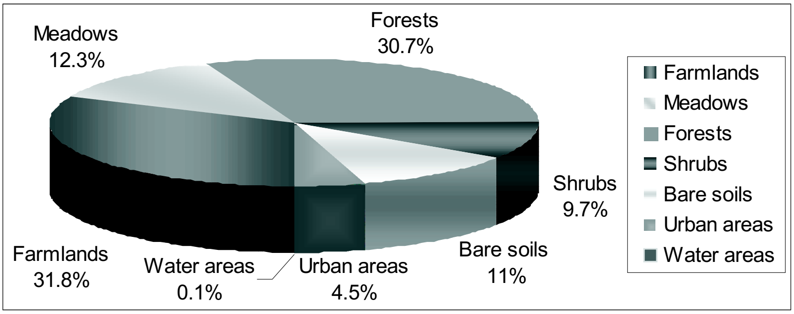

Fig. 4. Percentages of areas covered by different land use categories for the present stage.

tested by comparing the measured and simulated mean daily discharges using the Nash-Sutcliffe coefficient; the best value achieved for the calibrated period was 0.65. A comparison of the measured and simulated mean daily discharges [$m^3\,s^{-1}$] for a selected part of the calibration period is shown in Fig. 5.

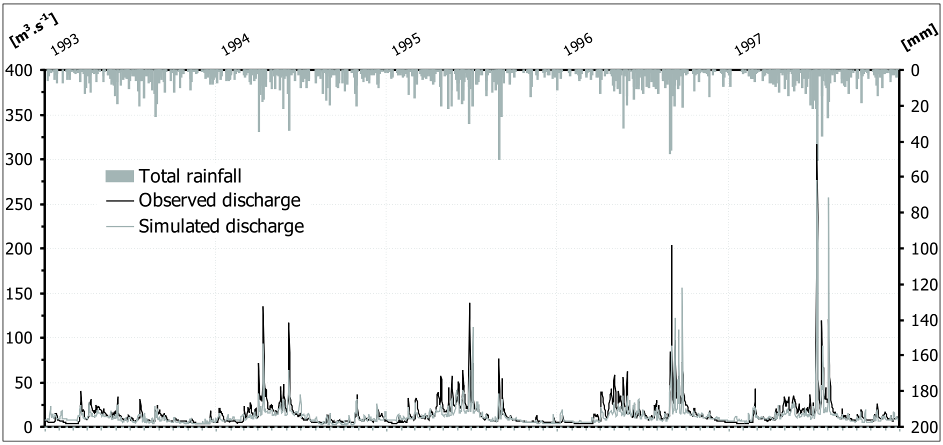

Fig. 5. Comparison of the measured and simulated mean daily discharges [$m^3\,s^{-1}$] for the period 1993-1998.

2.3. Land use change scenarios

Different land use scenarios, which mainly represent changes in the forest, farmland and urban area land use types were created to express the changes in land use in the Poprad River basin. The grass over forest (scenario 1) suggests the replacement of forest by grass lands. Grass over farmland (scenario 2) suggests the replacement of arable land by grass. Farmland over grass (scenario 3) suggests the replacement of grass by arable land. No initial water storage (scenario 4) represents changes in initial condition of the soil moisture distribution in the basin. The changes in the forest composition (scenario 5) represent changes in land use towards a natural land use, which would be possible with respect to the existing land use, i.e., urban land, farm land, etc. Natural land use (scenario 6) represents the land use closest to that of a potential natural, pristine landscape, with almost the whole basin area covered by forest. Wind calamity (scenario 7) expresses changes in land use after an extreme wind storm in the region in November 2004, when almost 14 000 ha of forests were destroyed.

The percentages of areas covered by different land use categories for the individual scenarios are listed in Table 2.

Table 2. Percentages of areas covered by different land use categories for individual land use scenarios

Land use	Percentage of area [%]							
	Scenario							
		1	2	3	4	5	6	7
	Actual land use	Grass over forest	Grass over farmland	Farmland over grass	No initial water storage	Changes in forest composition	Natural land use	Wind calamity
Arable land	31.8	31.8	-	44.2	31.8	31.8	-	31.8
Grass	12.4	48.4	44.2	-	12.4	12.4	12.4	12.4
Coniferous forest	32.4	-	32.4	32.4	32.4	9.8	68.9	27.3
Deciduous forest	0.3	-	0.3	0.3	0.3	0.3	0.3	0.3
Mixed forest	3.3	-	3.3	3.3	3.3	25.9	3.3	3.1
Bush	10.8	10.8	10.8	10.8	10.8	10.8	10.8	9.8
Bare soil	4.2	4.2	4.2	4.2	4.2	4.2	4.2	10.9
Impervious area	4.7	4.7	4.7	4.7	4.7	4.7	-	4.7
Open water	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

3. Results of changes in runoff and its components

Using these scenarios, runoff from rainfall and snowmelt was simulated in daily steps for the 1981-2000 period. The resulting changes in runoff were evaluated by comparing the simulated mean daily discharges and their statistical characteristics for the existing land use and land use scenarios, as well as plotting the runoff changes spatially on a map. The changes in runoff were also evaluated for the runoff's partial components - overland flow, interflow and base-flow.

The comparison between the mean daily discharges for the actual land use and each land use scenario was expressed by the values of the mean annual runoff depth and its components (Table 3). The changes in the mean annual runoff for each scenario, as opposed to the actual land use are expressed in Table 4-5 and in Fig. 6.

In Fig. 7 the effect of wind calamity in 2004 on spatial distribution of

Table 3. Mean annual runoff [mm year^{-1}] and its components for the actual land use and the different land use scenarios

	Surface Runoff	Inter-flow	Base-flow	Total runoff	Actual evapo-transpiration	Infiltra-tion
Actual land use	22	62	183	267	543	701
Grass over forest	24	67	201	292	518	737
Grass over farmland	21	62	192	275	534	701
Farmland over grass	22	61	182	265	544	703
No initial water storage	21	60	177	258	533	694
Changes in forest composition	22	60	177	260	549	711
Natural landuse	18	60	168	246	563	663
Wind calamity	23	63	190	276	534	708

mean annual runoff is illustrated. In Figs. 7 a and b a comparison of actual land use and land use after the wind calamity can be seen. In Figs. 7c and d spatial distribution of mean annual runoff before and after the wind calamity is illustrated. Fig. 7e illustrates changes in spatial distribution of the mean annual runoff after the wind calamity as compared to the actual stage.

The comparison between the mean annual runoff for the land use scenarios and the actual land use showed the compatibility with the results obtained for different pilot basins in previous studies.

A comparison of the mean daily discharges for the "grass over forest" scenario with the actual state suggests an increase in runoff. The expected increase in the depth of the total runoff is about 25 mm year^{-1}, i.e., +9% in comparison with the actual state. The increase in total runoff is mainly caused by a substantial increase in the baseflow: up to 18 mm (+10%). The surface runoff increased by 2 mm year^{-1} (+10%), and the interflow increased

Table 4. The changes in mean annual runoff [mm year^{-1}] for the land use scenarios as opposed to the actual land use

	Surface Runoff	Interflow	Baseflow	Total runoff	Actual evapo-transpiration	Infiltra-tion
Grass over forest	2	5	18	25	-25	36
Grass over farmland	-1	0	9	9	-9	0
Farmland over grass	0	0	-2	-1	1	2
No initial water storage	-1	-1	-6	-9	-10	-7
Changes in forest composition	0	-2	-6	-7	7	11
Natural landuse	-4	-1	-15	-21	20	-37
Wind calamity	1	1	7	9	-9	7

Table 5. The changes in mean annual runoff [%] for the land use scenarios as opposed to the actual land use

	Surface Runoff	Interflow	Baseflow	Total runoff	Actual evapo-transpiration	Infiltra-tion
Grass over forest	10	9	10	9	-5	5
Grass over farmland	-4	1	5	3	-2	0
Farmland over grass	2	0	-1	-1	0	0
No initial water storage	-6	-2	-3	-3	-2	-1
Changes in forest composition	1	-3	-3	-3	1	1
Natural landuse	-17	-2	-8	-8	4	-5
Wind calamity	4	2	4	3	-2	1

by 5 mm year^{-1} (+9%). These consequences were due to the fact that 36% of the forested areas were replaced by grass with lower evapotranspiration, roughness and shallow root depth.

The differences in the mean daily discharges for the "grass over farmland" scenario compared to the actual state mean that for this scenario, an insignificant increase in runoff can be expected. The increase represents

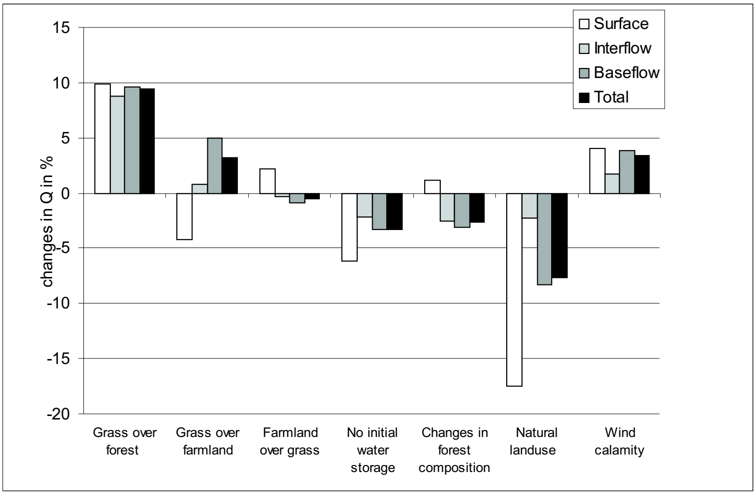

Fig. 6. The changes in mean annual runoff [%] for the land use scenarios as opposed to the actual land use.

9 mm year^{-1}, i.e, +3% in comparison with the present state. Similar results were obtained for the "farmland over grass" scenario where almost no change in runoff was indicated. Both these results were caused by the very

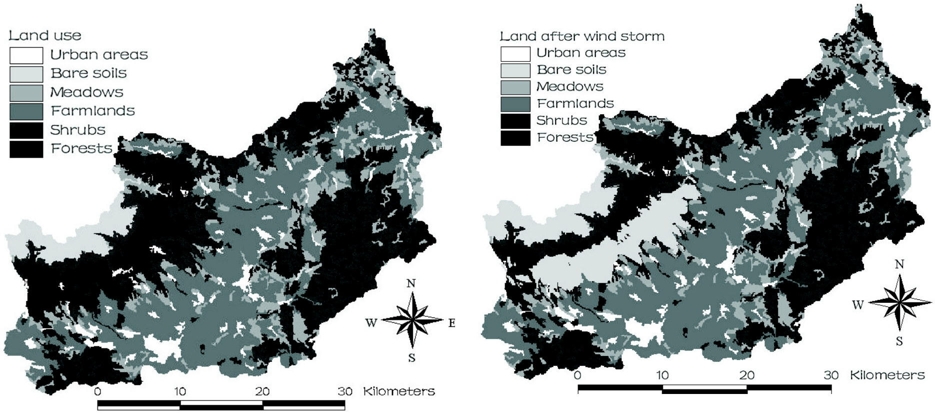

Fig. 7a. Land use of the Poprad river before the wind calamity (left).
Fig. 7b. Land use of the Poprad river after the wind calamity (right).

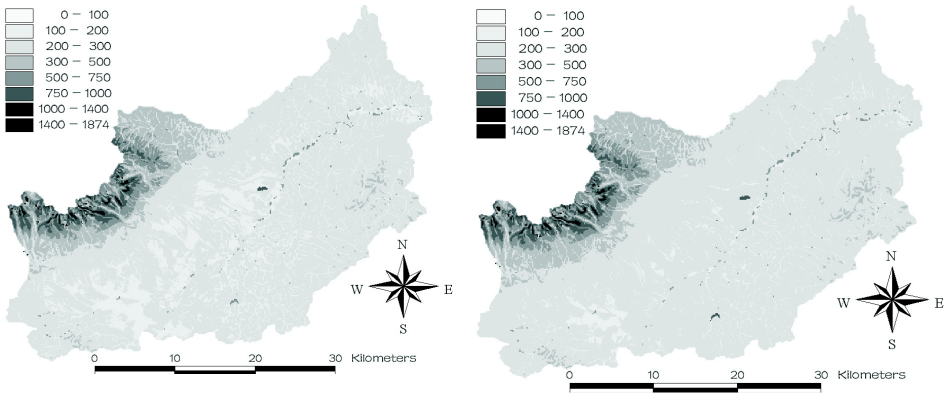

Fig. 7c. Long-term mean annual runoff [mm year^{-1}] before the wind calamity (left).
Fig. 7d. Long-term mean annual runoff [mm year^{-1}] after the wind calamity (right).

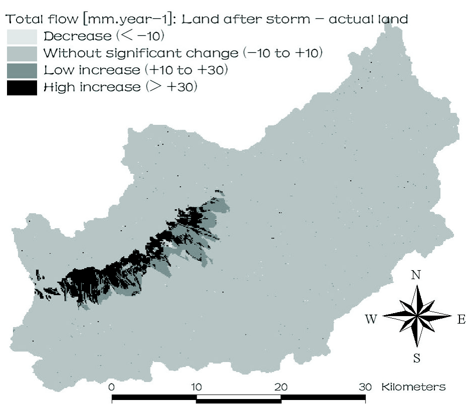

Fig 7e. Changes in the long-term mean annual runoff after the wind calamity [mm year^{-1}] as compared to the original land use stage.

similar parameters of grass and arable land in the model.

From the results of comparing the mean daily discharges simulated for the "change in forest composition" scenario to the actual state, it can be seen that the change in forest composition in the Poprad basin can cause a slight decrease in runoff. The decrease in the total runoff was –7 mm year^{-1}, i.e., –3% in comparison with the actual land use. Of the runoff components, surface runoff reflected very little of the change; the decrease in interflow and baseflow was around –3% in comparison with the actual state. These changes were caused by the fact that around 20% of the coniferous forests were replaced by mixed forest (with a deeper root zone and evapotranspiration).

The results for the "natural land use" scenario suggest that the almost complete afforestation of the basin can lead to a considerable decrease in the mean daily discharges and mean annual runoff. The depth of the mean annual runoff has decreased by 21 mm year^{-1}, which represents a difference of –8% from the existing state. Of the runoff components, the decrease was largest for the surface runoff, i.e., –4 mm year^{-1} and –17%, and for the baseflow, i.e., –15 mm year^{-1} and –8%. The changes in the interflow were insignificant. These consequences can be attributed to the parameterization of the forest and arable land (root depth, interception capacity, and roughness) and the fact that 32% of the arable land and 4% of the impervious areas have been afforested by coniferous forests.

From the comparison between the mean daily discharges for the "wind calamity" scenario and the actual state, an increase in runoff can be observed. The depth of the total mean annual runoff has increased by 9 mm year^{-1}, i.e., +3% in comparison with the present state. This increase was mostly caused by an increase in the baseflow of about 7 mm year^{-1}, i.e., +4%, as opposed to the present state. In spite of the fact that the wind calamity has caused only a slight increase in the mean annual runoff in the basin's outlet, in Fig. 7 it can be seen that the mean annual runoff on the area deforested by the wind storm increased by 30 mm/year and more.

4. Conclusions

The methodology based on distributed hydrological modeling presented in this paper can be used in integrated water resources management, especially for organizing land use and assessing the impact of land use changes on the runoff in a catchment. Apart from the evaluation of the total runoff, the changes in the partial runoff components (surface runoff, interflow and baseflow) and in the water balance components of evapotranspiration and infiltration can be evaluated separately.

On the other hand, when using the results of a distributed rainfall-runoff model, one has to consider the uncertainties of the approach used. The reliability of the results depends largely upon the availability and quality of the input data, the extent of the schematization of the processes represented by the model, the parametrization of the environmental characteristics for the simulated physical processes and the global parameters of the model calibrated. In distributed models, land cover properties have to be characterized by plant-specific parameters, but reliable results from the modelling can only be obtained if the parameter values for the land covers involved are known with some degree of accuracy *(Eckhardt et al., 2003)*. A review of the literature *(Breuer et al., 2003)* shows a high degree of uncertainty in the parameterisation of land covers. This uncertainty is caused by the problematic observation of some parameters, and difficulties with the regionalization of point measurements because of the natural variability of plant characteristics for reasons of climate, soil, stand age, etc. Against the background of these uncertainties, it is questionable whether different land covers can be significantly distinguished at all in their effect on the simulation results *(Eckhardt et al., 2003)*.

Generally, it can be stated that physically based, spatially distributed modeling systems provide a potentially powerful means for predicting the impacts of possible future changes in land use on river basin response. But, when interpreting results of this study and also results of similar studies, one has to keep in mind that the uncertainties of the methodology used must also be considered.

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