Hydrological responses to forest cover change in mountains under projected climate conditions
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Abstract—This study quantified the hydrological responses to the forest cover change in the upper part of Sola River basin, Forest Creek catchment, southern Poland, under projected climatic conditions. The Soil Water Assessment Tool (SWAT) will be applied to investigate the response of the hydrology regime to deforestation and reforestation processes. Under two emission scenarios (A1B and B1, IPCC) of the general circulation model GISS_E (NASA Goddard Institute) were employed to generate future possible climatic conditions. The detailed research was performed on a Forest Creek catchment during the 2002-2012. A key point is to assess both the rate of change in hydrological conditions after the collapse of the spruce stands and the time necessary to stabilize the water management after the afforestation. The results of elaborations show that deforestation process reduces the retention by 40% (10 years), in the same time water drainage from the catchment shortened by 47%.
Keywords—climate change, forest decomposition, water balance, SWAT.

I. INTRODUCTION
Understanding the effects of deforestation and afforestation on the hydrological process is crucial to protecting water resources. Unfortunately, in recent years, in many parts of Europe, there has been a breakdown of forest stands as results of natural disaster or disease (Bréda et. Al. 2006, Schütz et al. 2006, Svoboda et al. 2010, Durło 2012). The effect of mountain's forest on the hydrologic cycle is most clearly seen. Therefore, any disturbance in this zone determine the functioning of the hydrological system across the entire basin. The most dangerous situations arise when the forest ecosystem is rapidly falling, and the soil is denuded (Deng et al. 2010). The damage of forest and conversion to cultivation, glades and coppice land increases streamflow and reduce of water retention. These results indicate that the stream flow dynamics are closely associated with rate of change in the environment and land use types within a watershed. Thus, this study is intended to provide a deeper understanding of the streamflow processes and useful quantitative information on land use changes in mountain catchments, enabling more informed decision-making in forest silvi culture and management (Huang et al. 2016). The shape of the catchment i.e. topographic parameters and forest stability i.e. vegetation features have great influence on the water balance and runoff. The magnitude of reforestation on water yield varies as a function of vegetation type, climate, soil, also the rate of forest regeneration. Hydrological models, for example the Soil and Water Assessment Tool (SWAT), allow for simulating the hydrological effects of catchment features, which can help to understand the effects of land cover change on water yield in small mountain catchment (Srinivasan et al. 1998, Zhang et al. 2007, Wang et al. 2008, Rahman et al. 2013, Huang et al. 2016).

II. STUDY AREA
The investigations were carried out in the Silesian Beskid Mts. (Western Carpathians) on the border of Poland and Czech Republic (Fig. 1). This is the second highest mountain range in Poland, located in the main watershed of the drainage areas of the Baltic Sea and Black Sea. The highest peaks of the Silesian Beskid Mts. are Skrzyczne (1257 m) and Barania Góra (1220 m). The total surface of mesoregion is 690 km² of which 62% covered by forest stands (Pic. 1). Most of the forest area is occupied by spruce (78%). The remaining surfaces are covered by natural forests of mixed beech (14.8%), larch (1.4%), birch (0.2%), riparian ash (0.1%), mountain sycamore (0.3%), lower subalpine fir (5.1%) and at higher altitudes acidophilous beech (0.1%). The detailed research was performed on a Forest Creek catchment (22.0 km², average slope 19°, modal aspect 175°, length of stream 43.2 km, height difference 740 m) there were spruce stands, which by biotic and abiotic factors have collapsed. There are two automatic weather stations (AMS), three automatic rain gauges (RC) and three flowmeters (F) (Fig. 2, 3). The automatic system of weather monitoring in the Silesian Beskid Mts. works (www.lkpmeteo.pl). The detailed information’s of geographical and natural environmental features of research area are provided in Figures 4 and 5.
Today, deciduous forest occupy approximately 39% of the study area, evergreen forest 28%, mixed forest about 1%, and the remainder are cultivation, coppices, glades and forest nurseries. The share of residential (low density) and forest roads is below 1%. The main soil types are podzolic soils (69.5%) and brown soils (30.5%) (Polish Classification of Soils), which corresponds to Entic Podzols and Acid Brown Soils, respectively based on the WRB Soil Taxonomy (Charzyński et al. 2005, IUSS 2014). The study area is located in moderately warm (valleys) and moderately cold (ridges and summits) climatic belts, the mean annual temperature is ranged from 6.7°C in lower parts to 3.1°C in upper parts of massif. The mean annual sum of precipitation from the period 1981-2010 was 1198 mm. The biggest amount of rainfall was usually recorded in June or July (approx. 130-150 mm/per month), August and October was little rain (80-90 mm/per month).
Fig. 4. The slope and aspect classifications of Forest Creek catchment with drainage pattern, Silesian Beskid Mts.

Fig. 5. The share (%) of tree species in the area of research by sub-catchments (12-31-2002)

III. Methods

The Soil and Water Assessment Tool (SWAT) is a watershed model that can be applied to simple and complex watersheds. It is a continuous-time model that operates on a daily time step (Wang et al. 2008, Arnold et al. 2012). The model is physically-based, uses readily available inputs, is computationally efficient, and is able to continuously simulate long-term impacts. Major model components include hydrology, weather, vegetation type, soils and land use. The SWAT model divides the watershed into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogenous land use, forest management and soil characteristics. Models calibrated using watershed and water quantity data have been used to forecast water retention in response to deforestation process (2002-2012) and climate change scenarios A1B and B1 (Smith and Pitts 1997, IPCC Rep. 2000). To construct the Forest Creek basin (Silesian Beskid Mts.) water balance model, a database was compiled using topographical data, forest inventory data, land use, land cover and soil data also meteorological and hydrological variables (air temperature and humidity, solar radiation, precipitation and wind speed). The original weather data came from two fully equipped stations: Skrzyczne (1255 m a.s.l) and Lipowa (560 m a.s.l). A IMGW (Polish Institute of Meteorology and Water Management) and RZGW (Regional Directorate of Water
Management) gauging station at Lipowa-Ostre has observed daily mean streamflow data for the study period 2002-2012. The details of all hydrological parameters are found in the ArcSWAT interface for SWAT user’s manual (Neitsch et al., 2004; Winchell et al., 2007). There are two sub watershed, first in northern part - Zimnik Stream (C1, 10.2 km²) and second in southern part - Leśnianka Stream (C2, 11.8 km²); common section of both streams has a length 2.5 km (Fig. 3, 4, 5). The Forest Creek catchments were discretized into 27 sub-basins and 288 HRUs units.

**PIC. 2. DEFORESTATION PROCESS OF SPRUCE FOREST STANDS IN RESEARCH AREA, CATCHMENT_1 (PHOTO BY MARCIN REJMENT)**

**PIC. 3. DEFORESTATION PROCESS OF SPRUCE FOREST STANDS IN RESEARCH AREA, CATCHMENT_2 (PHOTO BY MARCIN REJMENT)**

**FIG. 6. THE CHANGES IN FOREST AREA IN A CATCHMENT OF THE FOREST CREEK, FROM 2002 TO 2012**

During the simulation procedure the layers of soil and land slopes were unchanged, while the layer of land use changed eleven times, for each year between 2002 and 2012. Based on the above assumptions, we estimate changing the water retention and speed of water runoff (Huang et al. 2016, Wang et al. 2008). The manual method was implemented for minimizing the difference between measured and predicted flow at study area. To evaluate of model quality correlation...
techniques were used (Coffey et al. 2004, Grizzetti et al. 2005, Moriasi et al. 2007, Zhang et al. 2007). Based on monthly hydrographs the yearly average of water retention and speed of water runoff were presented as a summary plots.

IV. RESULTS

The spruce forests have been weakened as a result of adverse weather conditions, increased activity of insects and numerous cases of pathogenic fungi. Within two years (2000-2002) their process of partial and then complete decay began. From 2002 to 2012, nearly 56% of the total forest area decomposed. In average about 4.5% per year (Pic. 2, 3, Fig. 6). Following cleaning activities, a network of surface waters was disturbed, erosion processes occurred, while the rate of water drainage from the catchment increased in the first 6 years from 22 to 19 hours; by 2012 the time of water drainage from the catchment shortened by 47% in the northern part (C_1) and 48% in the subcatchment C_2 (Fig. 7).

**FIG. 7. THE CHANGES OF THE SPEED OF WATER RUNOFF TLAG(HOURS) IN THE FOREST CREEK BY SUB-WATERSHED**

At the same time, the parameters of water balance, primarily water retention changed. On average, on the site under research a change amounted to 7mm per year (averagely). In the period from 2001 to 2012, a retention potential on the catchment
decreased by 41% (Fig. 8). The statistical evaluation of the predicted hydrological parameters yielded an \( r = 0.900, R^2 = 0.811 \) (SE=1.11, MSRE 1.250, \( p \leq 0.001 \)) for the monthly predictions. Overall the model was able to predict the Forest Creek streamflow very well. To stabilize the situation in the area under research an intensive reconstruction of the forest stands began, while surfaces after forest decomposition were reconstructed using seedings produced in the container technology to ensure a rapid growth. For this purpose, seedings of beech, fir, sorbus as well as pine and mountain pine in the upper part of the catchment were used. In order to obtain information on the possible consequences of impaired water balance in the future and the probable time of return to balance on the basis of climate change scenarios a simulation of hydrological cycle parameters has been carried out (Table 1).

**Table 1**

<table>
<thead>
<tr>
<th>Climate indicators</th>
<th>Time period 1961-1990</th>
<th>Time period 1991-2010</th>
<th>GISS_E 2081-2100</th>
<th>GISS_E_WC 2081-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly average air temperature</td>
<td>5.6</td>
<td>6.3</td>
<td>8.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Average of vegetation season air temperature</td>
<td>10.5</td>
<td>11.2</td>
<td>13.9</td>
<td>12.2</td>
</tr>
<tr>
<td>Average of yearly maximum air temperature</td>
<td>8.9</td>
<td>9.3</td>
<td>12.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Average of yearly minimum air temperature</td>
<td>2.2</td>
<td>2.5</td>
<td>5.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Vegetation period duration (days)</td>
<td>185</td>
<td>192</td>
<td>222</td>
<td>202</td>
</tr>
</tbody>
</table>

**Picture 4. Reforestation process in research area, Forest Creek catchment (photo by Grzegorz Durło)**

Preliminary modelling results are presented in the table No. 2. Results confirm that in the optimistic scenario along with the ongoing process of the afforestation, the ability to achieve stabilization of the water regime is possible after 50-60 years (Fig. 9). Beneficial retention conditions can be expected already around 2030. A change of species composition, in-creased biodiversity and diverse age structure of target forest stand is of high importance in this respect. Unfortunately, critical periods appear in the simulations, which may contribute to the deterioration of trees growth conditions, which involves a risk of destabilization of the hydrological system. The likelihood of their occurrence is high and amounts to 7% (Fig. 10).
TABLE 2
PRELIMINARY RESULTS OF MODELLING OF WATER BALANCE COMPONENTS, FOREST CREEK CATCHMENT

<table>
<thead>
<tr>
<th>Catchment_1 (northern part)</th>
<th>Time period 1961-1990</th>
<th>Time period 1991-2010</th>
<th>GISS_E 2081-2100</th>
<th>GISS_E_WC 2081-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly average sum of precipitation (mm)</td>
<td>1268.6</td>
<td>1223.5</td>
<td>1289.2</td>
<td>1297.1</td>
</tr>
<tr>
<td>Yearly average sum of evapotranspiration (mm)</td>
<td>694.5</td>
<td>671.6</td>
<td>692.7</td>
<td>670.4</td>
</tr>
<tr>
<td>Yearly average streamflow (dm³ s⁻¹·km⁻²)</td>
<td>16.24</td>
<td>15.21</td>
<td>14.78</td>
<td>15.29</td>
</tr>
<tr>
<td>Yearly average retention change (mm)</td>
<td>+214.1</td>
<td>+195.0</td>
<td>+176.2</td>
<td>+188.7</td>
</tr>
</tbody>
</table>

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</thead>
<tbody>
<tr>
<td>Yearly average sum of precipitation (mm)</td>
<td>1214.0</td>
<td>1189.1</td>
<td>1265.3</td>
<td>1277.5</td>
</tr>
<tr>
<td>Yearly average sum of evapotranspiration (mm)</td>
<td>688.3</td>
<td>663.9</td>
<td>689.3</td>
<td>679.5</td>
</tr>
<tr>
<td>Yearly average streamflow (dm³ s⁻¹·km⁻²)</td>
<td>16.78</td>
<td>15.66</td>
<td>14.69</td>
<td>15.43</td>
</tr>
<tr>
<td>Yearly average retention change (mm)</td>
<td>+223.2</td>
<td>+199.0</td>
<td>+178.5</td>
<td>+195.8</td>
</tr>
</tbody>
</table>
V. CONCLUSION

The SWAT model was used to create a hydrological model of the Forest Creek (Silesian Beskid Mts.) catchment to investigate the effect of land use change and climate scenarios on its water regime. The analysis confirmed that the rate of changes of forest cover played a dominant role in catchment water balance. The effects of deforestation on the hydrological processes have been strengthened by changes in weather and climate change. Further–more, extreme weather may slow down reforestation process, in the case of unexpected disasters forest regeneration has to start from the beginning. It is possible to improve the water balance conditions after ca. 50-60 years, when young forest will reach density parameters to increasing retention. Based of pessimistic scenario (A1B, IPCC), restoration of water balance stability will be delayed. Based on the results the main following conclusions can be drawn:

- Rapid deforestation contribute to huge reduction of water retention in shallow skeleton podzolic soils, the change amounted to an average 47.5% during the decade 2010-2012
- Rapid denude of the forest soils impart to significant increase in the water runoff speed, the change amounted to about 41.0% from 2002 to 2012
- The simulated and observed water balance indexes compares closely, thus shows a strong applicability of the SWAT model in accounting for these processes in small mountain watersheds.
- The very high coefficient of determination and efficiency obtained for monthly streamflow and water retention confirm that the performance of the SWAT on a monthly time step is excellent.

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REFERENCES


