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HYDROLOGICAL RESPONSES TO FOREST COVER CHANGE IN MOUNTAINS UNDER PROJECTED CLIMATE CONDITIONS

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1. ABSTRACT

This study quantified the hydrological responses to the forest cover change in the upper part of Soła 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 used to generate future possible climatic conditions. 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.

2. 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 a results of natural disaster or disease (Svoboda et al. 2010, Durło 2012, Croitoru and Minea 2014). 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.

The shape of the catchment (topographic parameters) and forest stability (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 (Wang et al. 2008, Deng et al. 2010).

A research has been carried in order to study the effect of forest degradation on selected elements of water balance (water retention and water runoff) of Soła River basin in the Silesian Beskid Mts., (Western Carpathians).

3. 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.

Fig. 1. The country map with research area

The highest peaks of the Silesian Beskid Mts. are Skrzyczne (1257 m a.s.l.) and Barania Góra (1220 m a.s.l.). The total surface of mesoregion is 690 km^2 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 km^2, average slope 19°, modal aspect 175°, length of stream 43.2 km, height difference 700 m) there were spruce stands, which by biotic and abiotic factors have collapsed.

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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).

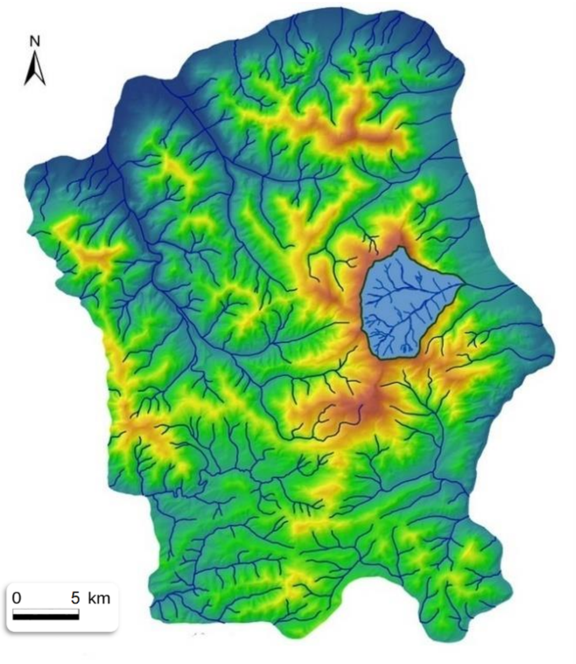

Fig. 2. Silesian Beskid Mts., with study area (blue polygon)

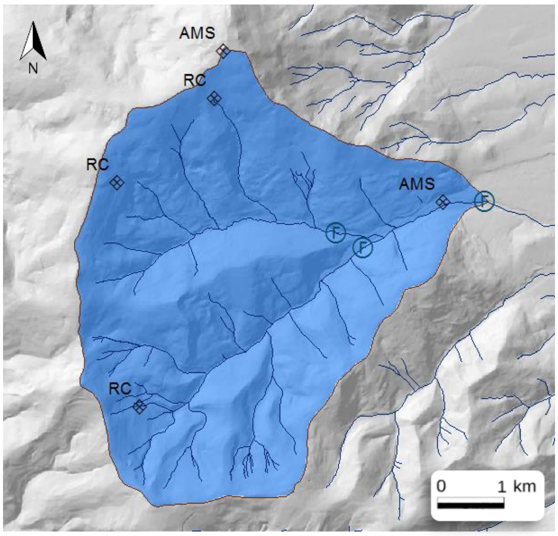

Fig. 3. Forest Creek catchment (Silesian Beskid Mts.)

The detailed information's of geographical and natural environmental features of research area are provided in Figures 4 and 5.

4. METHODOLOGY

The Soil and Water Assessment Tool (SWAT) is watershed model that can be applied to simple and complex watersheds. It is a continuous-time model that operates on a daily time step (Zhang et al. 2007). 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 and land use (Richardson and Wright 1984, Kuchar 2004, Rahman et al. 2014).

Pic. 1. Silesian Beskid Mts., (Photo by Adrzym)

The SWAT model divides the water-shed 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, IPCC 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 and soil data also meteorological and hydrological variables. 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.

5. 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). At the same time, the parameters of water balance, primarily water retention changed. On average, on the site under research a change amounted to 7 mm per year. In the period from 2001 to 2012, a retention potential on the catchment decreased by 41% (Fig. 8). To stabilize the situation in the area under research an intensive reconstruction of the forest stand 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 (Małek et all. 2014), (Pic. 4). 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 (Tab. 1). 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, increased 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).

6. CONCLUSIONS

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. Furthermore, extreme weather may slow down reforestation process, in the case of unexpected disasters forest regeneration have 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.

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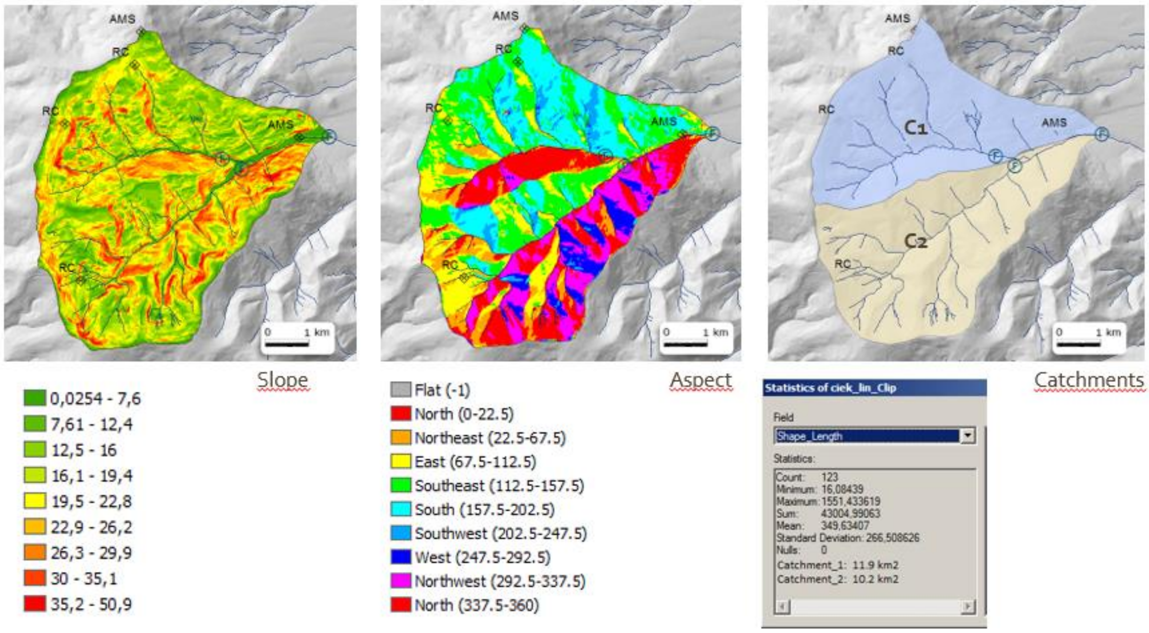

Fig. 4. The slope and aspect classifications of Forest Creek catchment with drainage pattern, Silesian Beskid Mts.

Species	Catchment_1	Catchment_2
Spruce	**78.7**	**78.2**
Beech	14.6	14.1
Fir	5.1	5.3
Larch	1.3	2.1
Birch	0.2	0.23
Sycamore	0.1	0.1
Ash	0.01	0.01
Other	0.01	0.01

Decidous/Coniferous = 0.17

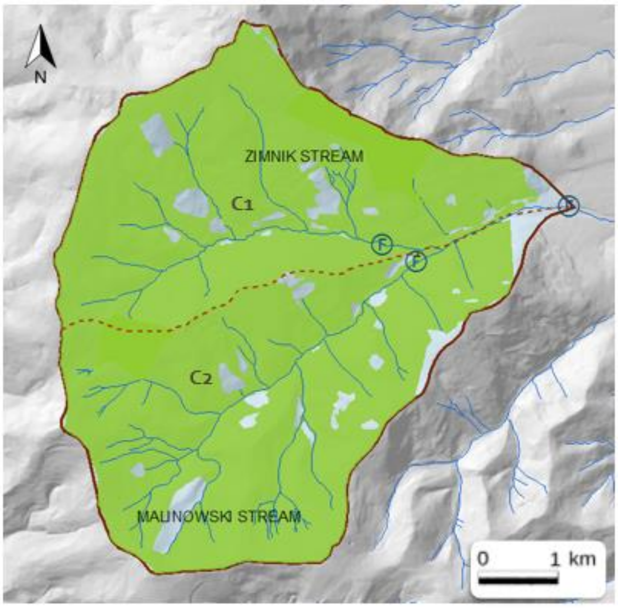

Fig. 5. The share of tree species in the area of research by sub-catchments

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)

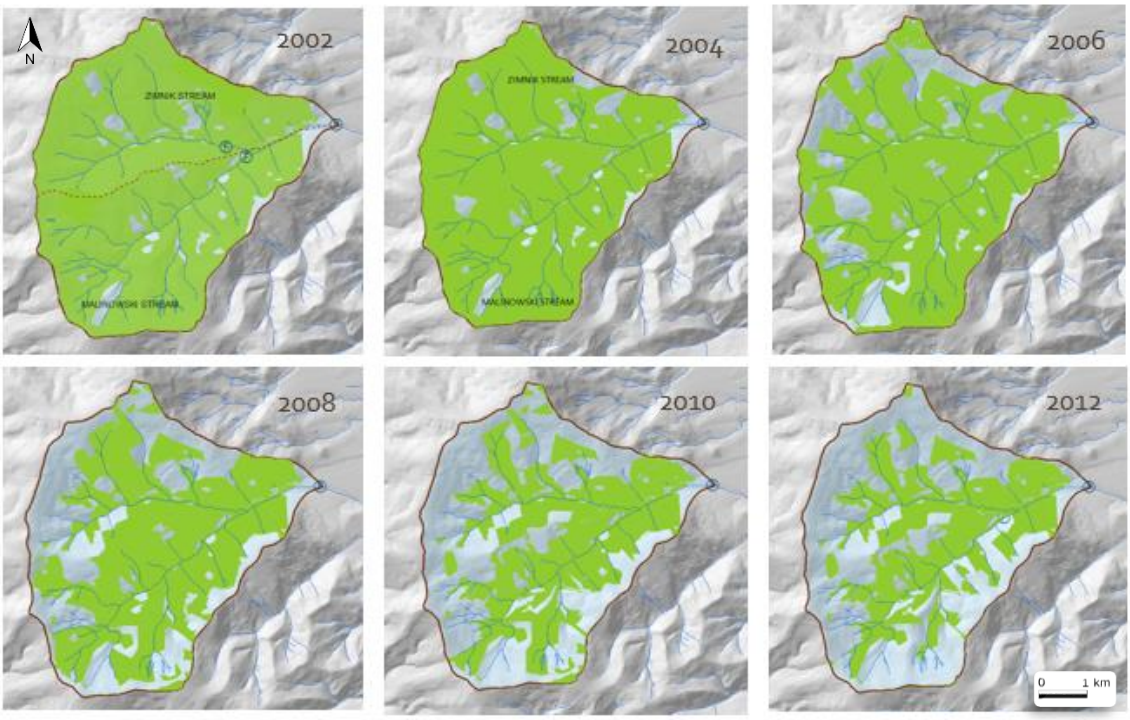

Fig. 6. The changes in forest area in a catchment of the Forest Creek, from 2002 to 2012

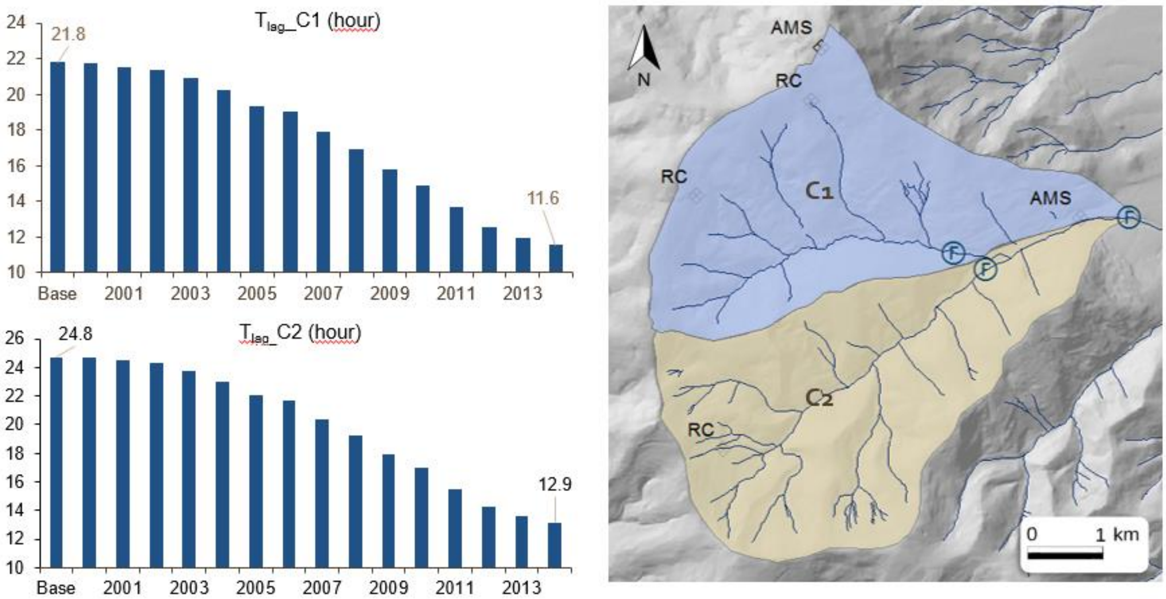

Fig. 7. The changes of the speed of water runoff in the Forest Creek by sub-catchments

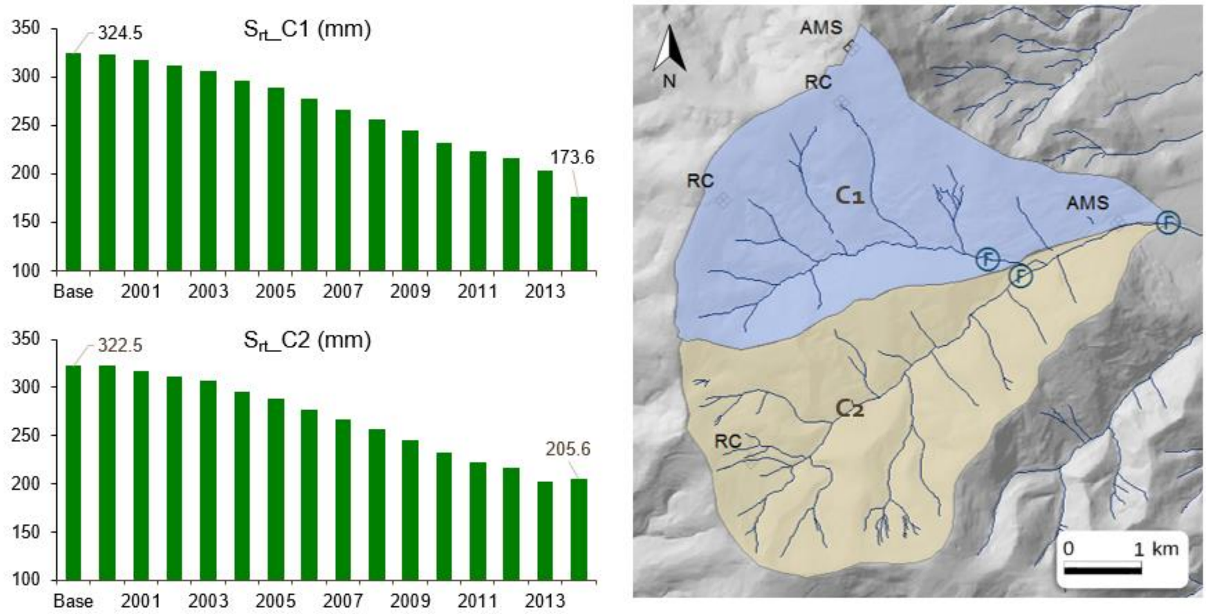

Fig. 8. The changes of the water retention in the Forest Creek by sub-catchments

Tab. 1. Climate change based on two circulation models for Silesian Beskid Mts.

Climate indicators	Time period 1961-1990	Time period 1991-2010	**GISS_E 2081-2100**	**GISS_E_WC 2081-2100**
Yearly average **air temperature**	5.6	6.3	8.8	6.8
Average of vegetation season **air temperature**	10.5	11.2	13.9	12.2
Average of yearly maximum **air temperature**	8.9	9,3	12.2	10.3
Average of yearly minimum **air temperature**	2.2	2,5	5.0	3.4
Vegetation period duration (days)	185	192	222	202

Climate indicators	Time period 1961-1990	Time period 1991-2010	**GISS_E 2081-2100**	**GISS_E_WC 2081-2100**
Yearly **sum of rainfall** (mm)	1270.5	1223.5	1299.2	1302.4
Sum of rainfall in vegetation season	825.4	746.7	771.5	783.4
Number of **days with rainfall** (year)	196	189	195	199
Number of **days with rainfall** (IV-X)	113	109	108	109
Winter to Summer **rainfall ratio** (%)	59.9	62.5	76.5	70.7

Pic. 4. Reforestation process in research area, Forest Creek catchment (Photo by Grzegorz Durło)

Tab. 2. Preliminary results of modelling of water balance components, Forest Creek catchment

Catchment_1 (northern part)	Time period 1961-1990	Time period 1991-2010	**GISS_E 2081-2100**	**GISS_E_WC 2081-2100**
Yearly average sum of **precipitation** (mm)	1268.6	1223.5	1289.2	1297.1
Yearly average sum of **evapotranspiration** (mm)	694.5	671.6	692.7	670.4
Yearly average **streamflow** ($dm^3 \cdot s^{-1} \cdot km^{-2}$)	16.24	15.21	14.78	15.29
Yearly average **retention change** (mm)	+214.1	+195.0	+176.2	+188.7

Catchment_2 (southern part)	Time period 1961-1990	Time period 1991-2010	**GISS_E 2081-2100**	**GISS_E_WC 2081-2100**
Yearly average sum of **precipitation** (mm)	1214.0	1189.1	1265.3	1277.5
Yearly average sum of **evapotranspiration** (mm)	688.3	663.9	689.3	679.5
Yearly average **streamflow** ($dm^3 \cdot s^{-1} \cdot km^{-2}$)	16.78	15.66	14.69	15.43
Yearly average **retention change** (mm)	+223.2	+199.0	+178.5	+195.8

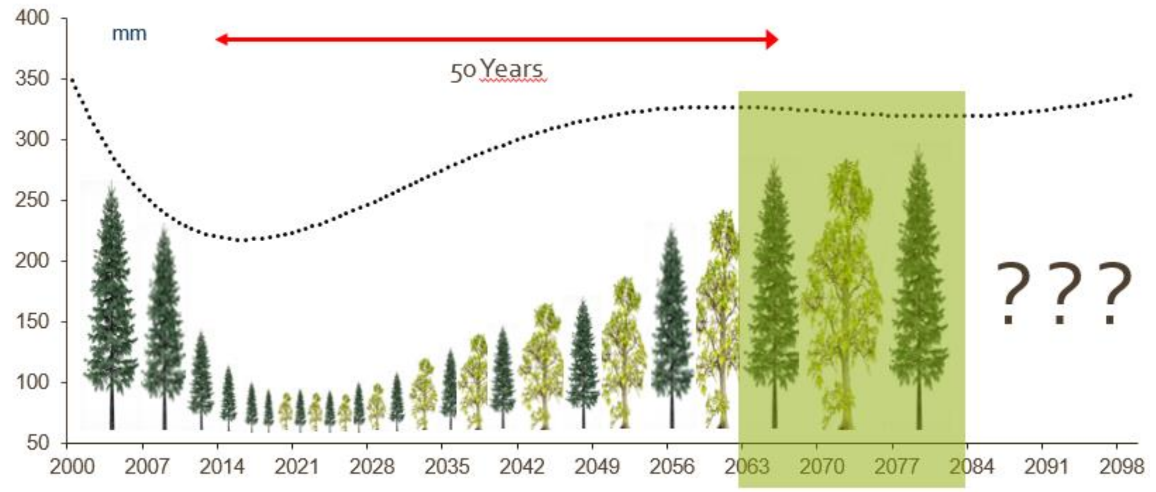

Fig. 9. Water retention change during the reforestation process on the surface of Forest Creek catchment

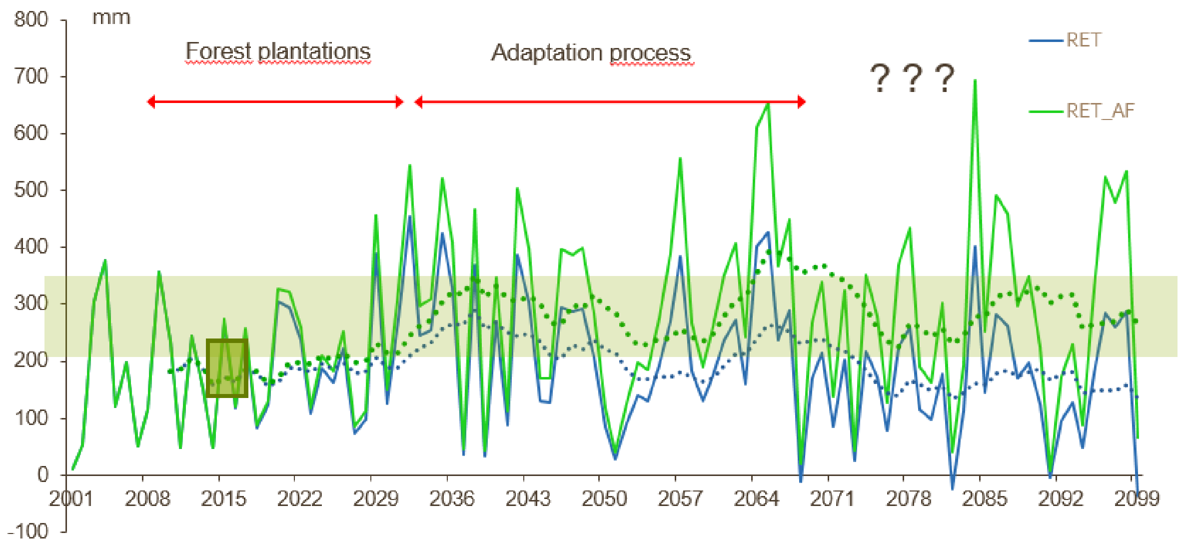

Fig. 10. The water retention in the future taking into account changes in land cover by forest under climate change simulated in the two climate scenarios