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Simulating the Effects of Agricultural Adaptation Practices onto the Soil Water Content in Future Climate Using SWAT Model on Upland Bystra River Catchment

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Abstract: The article presents predicted changes in soil water content in the Bystra river catchment (eastern Poland) for various scenarios of climate change and adaptation practices obtained on the basis of a SWAT model simulation for three regional climate models driven by the global climate model EC-EARTH for the years 2041–2050 and the RCP 4.5 and 8.5 RCP scenarios. Climate scenarios were put against five adaptation scenarios presenting changes in land use and protective measures compared against a zero scenario of BaU (Business as Usual) kept in the future climate. Adaptation scenarios 1–5 are modifications of Scenario 0 (S-0). The 0–5 scenarios' analysis was based on comparing soil water content and total runoff, sediment yield, actual evapotranspiration. The first adaptation scenario (AS-1) assumes an increase in afforestation on soils from the agricultural suitability complex of soil 6–8 (semi-dry, permanent dry, semi-wet). The second adaptation scenario (AS-2) assumes the creation of a forested buffer for the Bystra River and its tributaries. The third adaptation scenario (AS-3) shows one of the erosion prevention practices, the so-called filter strips. The fourth adaptation scenario (AS-4) assumes the reduction in plowing on arable land. The fifth adaptation scenario (AS-5) involves increasing soil organic carbon to 2%. Simulations revealed that each of the adaptation scenarios 1, 2, 3, 5 does not generally contribute to increasing the water content in soil on BARL (spring crops), CANP (rape), WWHT (winter crops), CRDY (other crops) on arable lands (which together account for over 50% of the catchment area). However, they can contribute to the reduction in sediment yield, total runoff and changes in actual evapotranspiration. The adaptation scenario 4 (AS-4) shows a slight increase in the soil water content on Bystra catchment in the 2041–2050 perspective. Scenario 4 indicated a slight increase in total runoff and a decrease in sediment yield, which in combination with slightly higher water content reflects the protective role of plant residue mulch, lowering the evaporation from the bare soil surface during warm seasons. The no-till adaptation practice had the highest effect in positively affecting water balance at the catchment scale among the adaptation scenarios considered.

Keywords: SWAT; SWAT-CUP; climate change; adaptation scenarios; soil water content; afforestation; no plowing; filter strips

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1. Introduction

Soil water content is an important component of the hydrological cycle. The formation of water resources in the catchment area is greatly influenced by the amount of precipitation, evapotranspiration, temperature as well as soil properties (water storage capacity, texture, structure), management practices and the existing vegetation [1,2]. The main source of soil water content is precipitation through infiltration and surface runoff [3]. Temperature, on the other hand, influences the evapotranspiration process [4].

There are numerous studies focusing on the calculation of soil water content using the Soil and Water Assessment Tool (SWAT) model [5,6]. These authors used SWAT to simulate soil water content at levels of large catchments (Vistula, Odra). They demonstrated the ability to generate long-term series of soil water content even in the absence of comparative data. On the other hand, for a small catchment located in Poland, one of the few similar studies to the present one in terms of climatic scenarios as well as parameters studied (soil water content, actual evapotranspiration) is a publication concerning the Barycz and Upper Narwia catchments [7].

In the publication on soil water retention and drought risk assessment based on water balance for the area of the Lower Silesian province [1], soil retention parameters were determined: Available Water Capacity (AWC), Wilting Point (WP), Field Capacity (FC) for soil species found in Poland. The retention parameters were determined by expert methods [1].

The aim of the article is to analyze five adaptation scenarios (AS-1, AS-2, AS-3, AS-4, AS-5) in relation to the 2041–2050 climate projections GCMs/RCMs for the RCP 4.5 and RCP 8.5 climate change scenarios described as scenario 0 (S-0) [8], as well as their assessment against the current state of knowledge related to research involving similar adaptation studies. Adaptation scenarios 1–5 are modifications of Scenario 0.

The need for such studies of small catchments (up to a few hundred km^2) is due to the small number of studies that would be based on adequate preparation of soil parameters (e.g., retention). Moreover, for the Polish area, there are no studies on adaptation scenarios that would attempt to increase the water content of soil and minimize the adverse effects of climate change (RCP 4.5, RCP 8.5) in future decades.

Among the many hydrological models in use today, the SWAT model, widely used by scientists and developed by the USDA [9,10], was selected for this study because of its ability to predict the impact of practices of land management onto the hydrology and water quality in the catchment area.

Much research is currently being conducted on climate change and the associated unpredictability of extreme weather events. This raises legitimate concerns about the possible emergence of environmental, social and economic threats in the decades to come. These changes may also have an impact on agriculture in Poland [11]. The increase in air temperature, which was observed in recent decades, contributed to the increase in potential evapotranspiration, especially in the last decade 2011–2020. A large increase in potential evapotranspiration and an increase in the variability of this indicator were found [8,12,13]. Recent decades also brought observations of climate change in Poland resulting from the world global warming, changes in precipitation and a number of weather extremes [14–16].

These changes also concern the extension of the growing season in Poland. For the years 1971–2000, the length of the growing season was 218 days (from March 31 to November 4) [17]. According to studies on the change in the growing length in Poland [17], the length of the growing season will extend by 18–27 days in the perspective of 2050 compared to the years 1971–2000.

The increase in evapotranspiration, temperature and precipitation in the coming decades will, to a greater or lesser extent, also apply to all European countries [18,19].

According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [20], the average temperature of the Earth's surface will reach 1.5 degrees Celsius in the coming decades above pre-industrial levels. Moreover, in Poland, a projected 10-fold increase in the occurrence of droughts by 2020 [21] is observed in the data; hence, the predictions using climate change models seem to reflect changing climate quite well for Poland [22]. Until recently, climate change adaptation received less attention in Poland than climate change mitigation. The vast majority of national communications have been devoted to climate projections, vulnerability and impacts. However, recently there has been increasing attention to adaptation measures in agriculture, among others [16].

There is a need to look for solutions that will reduce the negative impact of climate change [23], inter alia, the occurrence of weather extremes, including drought [12,24,25] in the coming decades. Climate change adaptation in agriculture is associated with a number of preventive measures (adapting crops to changing thermal and water conditions). These include changes in adaptation practices and the introduction of new varieties. Protecting the soil and its water resources is also extremely important. Soil moisture can be maintained through mulching and water conservation through efficient irrigation and water storage (small retention, filter strips). Soil fertility and its potential for water storage can also be increased by increasing soil organic matter [16].

For the sake of this paper, we chose the Bystra river catchment (South-Eastern Poland) as the study area. In order to check the effectiveness of the designed adaptation solutions, it was necessary to develop boundary conditions that would indicate the reference level [8]. These conditions show the behavior of the hydrosystem of the Bystra catchment in the Business as Usual scenario. It takes into account changes in the hydrological cycle caused solely by climate change while maintaining unchanged conditions of human activity. The described boundary conditions for the 2050 horizon must be based on simulation modeling, which is calibrated on archival data. The appropriate tool for this is the SWAT model.

The article presents a comparison of the results of soil water content (profile 1.5 m) for five adaptation scenarios obtained via a simulation of a calibrated and validated SWAT model [8] for three regional climate models derived from the global EC-EARTH climate model for the years 2041–2050 (S-0). Then, the results of scenario 0 were compared with the results of adaptation scenarios 1–5, which included land use changes and protective measures.

The publication is presented as follows: Section 1 presents the Introduction; Section 2 introduces the methodology and describes the study area. Section 3 describes the results, and Section 4 presents the discussion in terms of results regarding soil water content, total runoff and sediment yield, followed by conclusions in Section 5.

2. Material and Methods

This section is divided in 5 sub-sections. The first one describes the study area; the second and the third describes the SWAT model and SUFI-2 model; the fourth presents climate change scenarios, and finally the fifth presents climate change adaptation scenarios 1–4.

2.1. Characterization of the Study Area

The Bystra catchment area is situated in the north-western part of the Lubelskie Province (Figure 1). The length of the Bystra River is 33 km, and it is the right tributary of the Vistula river. According to the generated SWAT model, the lowest point of the catchment area is 126 m above sea level, and the highest point is 246 m above sea level. The catchment area delineated from a 5 m resolution DEM is 296.6 km^2 [8].

The Bystra catchment area is part of the Lublin Upland [26–28]. The valley of the Bystra river and its tributaries are strongly carved in a thick loess layer overlaying calcareous bedrock. It consists of numerous valley forms with a constant or episodic tributary. The largest valley with a constant tributary, the Bystra valley, is 35 km long. In the part where the Bystra valley flows into the Vistula, it cuts up to 35 m in rocks and marls [29–31].

The upland nature of the Bystra catchment area, consisting mostly of loess soils, with a high slope of the slopes at the mouth of the Vistula, poses a high risk in terms of medium and very strong water and surface erosion [32].

Most of the Bystra catchment area is made of loess up to 20 m. In the deeper layers, there are Quaternary Pleistocene sediments: water-glacial sand and gravel and, at a little deeper level, tilts. On the other hand, there are geodes under the clays. Under the geysers, on the other hand, there are deposits of the Upper Cretaceous: rocks with lime inserts [33].

The study area consists mainly of podzolic and lessivage (49%) soils, which extend mainly in the south-eastern part of the catchment as well as cambisols (47%) in the north-western part. The predominant soil texture in the catchment area is loess (73%) [34–36] and silt (18%) [8].

In the Bystra catchment area, arable land (78%) and forests (16%) dominate [8]. The largest part of agricultural land is arable land beyond the reach of irrigation facilities (52%);

large areas are also orchards and plantations (11%), complex systems of arable plots (9%) and meadows and pastures (6%) [8].

Figure 1. Location of the study area, Bystra catchment, with marked main tributaries and their catchments (own study).

2.2. Description of SWAT Model and SUFI-2 Model

SWAT was used to model and examine the water balance of the Bystra river catchment area. SWAT is a model [9,10] developed by the USDA Agricultural Research Service [37]. The model operates on assigning one resource to another (physical, chemical, biological) using mathematical formulas that were developed to predict the impact of management practices on water efficiency and agricultural chemistry at the catchment scale [38,39]. We used the QSWAT3 v1.1 model with an interface in Quantum GIS 3.10.13 Coruna [40]. However, the calculations of the SWAT model were performed in the SWAT Editor on 10 December 2012 [41].

The water balance is the fundamental driving force behind all the processes that take place in the catchment area regardless of the choice of the SWAT model analysis. SWAT modeling for the catchment area is carried out in the land phase [42] and in the routing phase [43].

One of the formulas that is used in the SWAT model is the water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} (P_d - SURQ - E - w_{seep} - GWQ)$$

where: SW_t is the final water content of the soil (mm); SW_0 is the initial water content of the soil (mm); t is the time in days; P_d is precipitation (mm); $SURQ$ is surface runoff (mm); E is evapotranspiration (mm); w_{seep} is the amount of water entering the wad zone from the soil profile (mm); GWQ is the groundwater flow (mm) [10].

Calibration and validation in the SWAT-CUP program are used to adjust the SWAT model to real conditions in the catchment area. The commonly used example of calibration is stream flow, which includes water balance processes. The calibration process is used to adjust the relevant parameters so that the simulated results are consistent with the observational data. Validation involves running the model using the parameters that were used during the calibration process. The purpose is to compare simulated results with observed data that were not used in calibration [44–46]. The SWAT-CUP program is used to analyze the uncertainty and sensitivity of the model [44,45] using the SUFI-2 algorithm, also used in small catchments [44,47,48].

2.3. Application of SWAT and SUFI-2

To simulate the water balance in the SWAT model, data were obtained from many sources (Table 1), which were used to build the SWAT model.

Table 1. Input data used in SWAT model (own study).

Data Type	Description	Information	Source
Digital Elevation Model	Watershed delineation	Raster, 5 m-resolution	Central Geodetic and Cartographic Documentation Center [49]
Hydrographic	Site hydrographic data (e.g., rivers, lakes, partial catchments); (reference scale 1:50.000)	Shapefile	Computer Map of the Polish Hydrological Department with descriptions [50]
Land use	Land-use classification (r.s. 1:100.000)	Shapefile	Corine Land Cover [51]
Orthophotomap	High resolution orthophotomap	WMS	Geoportal [52]
Open Street Map	Open Street Map data	Shapefile	Open Street Map [53]
Soil type	Digital maps of soil and agriculture in digital form (scale 1: 25,000 and 1: 100,000)	Shapefile	Institute of Soil Science and Plant Cultivation in Pulawy [54,55]
Geological	Geological data describing lithology	Shapefile	Polish Geological Institute in the form of the Detailed Geological Map of Poland [33]
Weather	Precipitation (mm), temperature (°C), wind speed (m/s), humidity, solar total radiation (MJ/m^2)	Daily	Institute of Soil Science and Plant Cultivation in Pulawy and Institute of Meteorology and Water Management [56]
Streamflow	Calibration and validation	Monthly	Institute of Soil Science and Plant Cultivation in Pulawy
Sewage treatment plants	Average daily water loading (m^3/day)	Daily	National Program of Municipal Wastewater Treatment [57]

The SWAT model generated for this study consists of 31 generated partial catchments (Figure 1) [8]. The soil map was developed on the basis of digital soil and agricultural maps (scale 1:25,000 and 1:100,000) and geological data describing lithology. Descriptive soil data were collected within the statutory research projects of IUNG-PIB. Available water capacity and wilting point values were obtained from the study “Assessment of water retention in soil and the risk of drought based on the water balance for the Lower Silesian Voivodeship", which was developed in 2013 by the employees of the Department of Soil Science, Erosion and Land Protection of IUNG-PIB in Pulawy [1].

The land use map was developed on the basis of Corine Land Cover maps with additional vectorization of land cover and land use using an orthophoto-map and Open Street Map data.

Based on the generated maps of soils, lands and slopes, 484 HRU (Hydrological Response Units) areas were created. When creating HRU areas, the land cover class of agricultural areas beyond the reach of irrigation CRDY was additionally separated with WWHT winter crops (43%), BARL spring crops (31%), CANP rape (14%) and other CRDY (12%) [58]. APPL apple orchards were separated from the land use class of ORCD [58]. On the other hand, forests were divided into coniferous FRSE forests (49%), deciduous FRSD forests (13%) and mixed FRST forests (38%) [59].

After generating HRU areas, the following meteorological data were used in the SWAT model: daily precipitation totals (mm); daily minimum and maximum air temperature (°C); average daily wind speed (m/s); average daily relative humidity; daily sums of total solar radiation (MJ/m^2) (Table 2) [8].

Table 2. Meteorological data for the Bystra catchment [8].

Weather Station	Measurement Period				
	Precipitation (mm)	Temperature (°C)	Wind Speed (m/s)	Humidity	Solar Total Radiation (MJ/m^2)
Pulawy	2005–2017	2005–2017	2005–2017	2005–2017	2005–2017
Rogalow	2005–2017				
Lublin Radawiec	2005–2017	2005–2017	2005–2017	2005–2017	

In the SWAT model, the parameters related to the point discharge of sewage, as well as for water bodies located outside the river network, for water bodies, rivers, and parameters for planned non-irrigated arable land management operations (WWHT, BARL, CANP, CRDY) were supplemented and corrected. The current value of CO_2 concentration was also entered.

In the next stage, the SWAT model simulation was run for the period of 2010–2017 in a monthly step, with a five-year model start-up period.

Then, calibration and validation of the obtained SWAT model for the Bystra catchment area [8] was performed using the SWAT-CUP program. To obtain a more accurate coverage of the model with reality, the average monthly flow velocities (m^3/s) obtained under the statutory projects of IUNG-PIB, obtained near the mouth of the Bystra River to Vistula for 2010–2014 (calibration) and 2015–2017 (validation), were used. A five-year warm-up period was used. Calibration and validation were performed in a monthly increment. This resulted in parameter ranges that fell within the ranges of calibration and validation accuracy [44,60,61]. The NSE coefficients (calibration: 0.58; validation: 0.70) and R^2 (calibration: 0.60; validation: 0.71) for calibration and validation [8] were within the satisfactory ranges [60].

The results concerning the value of potential evapotranspiration were also analyzed with the results of the statutory service of IUNG-PIB implemented under the project Agricultural Drought Monitoring System [62]. It was found that the SWAT model for the Bystra catchment area accurately reflects the potential evapotranspiration in the study area.

Additionally, the results concerning the soil water content were compared with the available values of water capacity and the wilting point, which were obtained from the study prepared in 2013 by the employees of the Department of Soil Science, Erosion and Land Protection, IUNG-PIB in Pulawy [1].

2.4. Climate Change Scenarios

The daily grid climate data used in the SWAT model were prepared and tested in the recent paper on SWAT model calibration in the Bystra catchment [8]. Three RCM (Regional Climate Models)—RACMO22E, HIRHAM5 and RCA4—were selected for further study. They were selected to cover the range of the available two climate scenarios RCP (Representative Concentration Pathways) in terms of temperature increase and precipitation—RCP 4.5, RCP 8.5 (Table 3)—reflecting extreme and average variants of climate change, hence covering the widest range of uncertainty about possible scenarios (three RCM × two RCP). Most of the data were obtained at a spatial resolution of 0.11 degrees from the EURO-CORDEX database for the years 1951–2050 (widely available via the ESGF—Earth System Grid Federation, https://esgf-data.dkrz.de/search/cordex-dkrz for Europe) (accessed on 3 March 2021) [18,63].

Table 3. Description of GCM/RCM simulation with its division depending on radiative forcing. Comparison of temperature and precipitation changes in 2021–2050 in GCM/RCM simulation for RCP 4.5 and RCP 8.5 to the base period 1971–2000 (own study).

Models	**Scenario Assumptions**				**Radiative Forcing**	
GCM/RCM Simulation	**Change in Average Annual Air Temperature**		**Change in Average Annual Precipitation**		**+4.5 W m^{-2}**	**+8.5 W m^{-2}**
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
EC-EARTH/RACMO22E	+1.5 °C	+1.8 °C	+15%	+6%	RCP 4.5.1	RCP 8.5.1
EC-EARTH/HIRHAM5	+1.6 °C	+1.9 °C	+12%	+5%	RCP 4.5.2	RCP 8.5.2
EC-EARTH/RCA4	+1.6 °C	+2.2 °C	+15%	+11%	RCP 4.5.3	RCP 8.5.3

Climate scenario daily meteorological derivatives (minimum and maximum daily air temperature, daily precipitation, solar radiation, daily average wind speed, relative humidity) are based on the RCM for two RCPs (three RCM x two RCP). The RCMs are powered by one GCM (General Circulation Model): EC-EARTH. The RCP corresponds to the radiative forcing values in 2100 compared to pre-industrial values of +4.5 W m^{-2} (RCP4.5) while RCP8.5 to + 8.5 W m^{-2} (RCP8.5) [18,64,65] (Table 3). Table 3 also presents the boundary values of changes in the characteristics of selected models for the period 2021–2050 in relation to the period up to the base period 1971–2000.

Climate projections that were used in the SWAT model were extracted from grid cells that correspond to weather stations' location. Air temperature and precipitation data were additionally corrected by the SMHI (Swedish Meteorological and Hydrological Institute) using the DBS (Distribution-Based Scaling) method [48] and regional MESAN reanalysis (MESoscale Analysis) for the 1989–2010 dataset [66]. The data used were taken in a rotated polar grid. Therefore, we used bilinear interpolation to remap the dataset to a common latitude/longitude grid. CDO (Climate Data Operators) software [67] was used for this purpose.

For the analysis of the climate projections (RCP 4.5.1, RCP 8.5.1, RCP 4.5.2, RCP 8.5.2, RCP 4.5.3 and RCP 8.5.3), one iteration in SWAT-CUP was used for the set of the best calibration parameters for the years 2021–2050 in the prepared scenarios (Table 3) [8]. In the RCP 4.5 and RCP 8.5 scenarios, CO_2 concentrations were changed for the periods 2021–2030, 2031–2040 and 2041–2050, developed by the Potsdam Institute for Climate Impact Research [68,69].

2.5. Climate Change Adaptation Scenarios 1–5

For the main purpose of this article, 5 scenarios for the adaptation of agriculture to climate change were prepared, which assume changes in land use (adaptation scenario 1 and 2) and protective measures (adaptation scenario 3, 4, 5) in the area of the Bystra catchment. The first adaptation scenario (AS-1) assumes an increase in afforestation on soils from the agricultural usefulness complex of soils 6 (temporarily too dry), 7 (permanently too dry) and 8 (temporarily too wet). The second adaptation scenario (AS-2) assumes the creation of a forested buffer for the Bystra River and its tributaries. The third adaptation scenario (AS-3) shows one of the erosion prevention practices at the riverbed, the so-called filter strips. The fourth adaptation scenario (AS-4) assumes the reduction in plowing on agricultural land. The fifth adaptation scenario (AS-5) involves increasing soil organic carbon to 2%. Adaptation scenarios are aimed at checking the possibility of increasing the soil water content in the 2041–2050 perspective. In doing so, the effects of adaptation scenarios on total runoff, sediment yield and actual evapotranspiration were also checked.

In the zero scenario (S-0), the Bystra catchment area is dominated by agricultural land (78%) and forests (16%). The largest part of agricultural land is arable land beyond the range of irrigation facilities (52%); a large area is also orchards and plantations (11%), complex systems of cultivating plots (9%) and meadows and pastures (6%) (Table 4). For adaptation scenarios 1 (AS-1) and 2 (AS-2), there will be changes in land use compared to scenario 0 (S-0), which are described later. In contrast, adaptation scenarios 3 (AS-3), 4 (AS-4) and 5 (AS-5) remain unchanged in terms of changes in land use.

Table 4. Division of the land cover and land use as well as the percentage of land use in the Bystra catchment generated in the QSWAT interface. CLC code 112–142 means artificial surfaces; code 211–243 means agricultural areas; code 313–324 means forest and semi natural areas; code 411 means wetlands, and code 511 is water bodies (own study).

Corine Land Cover Legend	CLC Code	SWAT Code	S-0 Part (%)	AS-1 Part (%)	AS-2 Part (%)
Discontinuous urban fabric	112	URML	0.92	0.9	0.9
Industrial or commercial units	121	UCOM	1.55	1.49	1.49
Mineral extraction sites	131	UIDU	0.02	0.02	0.02
Sport and leisure facilities	142	FESC	0.02	0.02	0.02
		SUM=	2.51	2.43	2.43
Non-irrigated arable land	211	CRDY	52.35	50.57	52.23
Vineyards	221	GRAP	0.03	0.03	0.03
Fruit trees and berry plantations	222	ORCD	10.85	10.55	10.83
Pastures	231	PAST	5.89	5.35	5.55
Complex cultivation patterns	242	AGRL	9.04	8.68	8.86
Land principally occupied by agriculture with significant areas of natural vegetation	243	CRGR	0.05	0.05	0.05
		SUM=	78.21	75.23	77.55
Mixed forest	313	FRST	16.34	19.65	17.37
Transitional woodland-shrub	324	SHRB	2.43	2.18	2.23
Inland marshes	411	WEHB	0.26	0.25	0.21
Water courses	511	WATR	0.27	0.26	0.21

In the first adaptation scenario (AS-1), the land use on all soils of complexes (representing soil habitats in Polish soil-agricultural mapping)—6 (semi-dry), 7 (permanently dry) and 8 (semi-wet) (6Bw-pgl.ps, 7Bw-ps, 8A-l)—was changed to mixed forest. The soils where the land use was changed are described in more detail in Table 1 of the publication on the water balance of the Bystra catchment [8]. Replacement of the above-mentioned soils is made through delineating the ranges of these soils on the land use maps and changing the attributes to mixed forests. After this change, afforestation in the Bystra catchment area increased by 3.31% (Table 4).

In the second adaptation scenario (AS-2), a forested buffer strip 80 m wide along the bank of the Bystra River was created and a smaller buffer strip 50 m wide for its tributaries [70–72]. The creation of buffer zones by rivers consisted of deleting the ranges of buffer zones on the land use maps and changing the attributes to mixed forests. The afforestation area compared to the zero scenario increased by 1.03% (Table 4).

In the third adaptation scenario (AS-3), filter strips were used, which are one of the protective measures used to drain water slowly from the field, thanks to which larger particles, including soil and organic material, may be deposited [73].

Filter strips [9,74] are areas covered with vegetation that are located between surface water bodies (rivers, ponds, lakes) and arable land, pastures and forests. They are generally found in areas where runoff leaves the field to filter sediment, organic material, nutrients and chemicals from the runoff. Filter strips are also known as vegetative filters or buffer strips. Due to the retention of sediment and the establishment of vegetation, nutrients can be absorbed into the sediment that settles and remain in the field landscape, making it possible for plants to take it up [73].

A protective treatment is also tillage without plowing [73], which is the fourth adaptation scenario (AS-4).

Plowing is defined as the mechanical disturbance of soil for crop production that has a significant impact on soil properties such as soil water behavior, soil temperature, infiltration and evapotranspiration [75]. In the long term, tillage can lead to soil degradation [76]. An alternative to traditional plowing is protective treatments (tillage without plowing, minimal mechanical disturbance of the soil) which consist of maintaining the surface soil cover by retaining crop residues. Retention of harvest residues protects the soil from direct exposure to raindrops and sunlight, while minimal soil disturbance improves soil biological activity and air and water movement in the soil [75].

No plowing cultivation was implemented in WWHT, BARL, CANP and CRDY arable land and simulated in SWAT.

In the fifth adaptation scenario (AS-5), the soil organic carbon content was increased from 1% to 2%. The original soil organic carbon values were studied as part of IUNG-PIB statutory research [8]. Soils in Poland are characterized by low soil organic carbon content. According to the European Soil Bureau (ESB), an organic carbon content of about 1% (Bystra catchment area) is a very low or low value [77]. The decrease in organic matter in soils and the associated decrease in organic carbon content result in increased CO_2 emissions (exacerbating the greenhouse effect). The opposite situation, i.e., sequestration of CO_2 in the soil, causes carbon to bind to soil organic matter for a longer period of time. Particularly large amounts of carbon are stored in peats, organic soils and organic-mineral soils [77].

3. Results

Section 3.1 describes the analysis of soil water content in S-0 for the period 2041–2050.

For the 10-year period (2041–2050), Table 5 presents a comparison of the seasonal soil water content in the Bystra catchment for each climate projection GCMs/RCMs under the RCP 4.5 and RCP 8.5 climate scenarios.

For the 10-year period (2041–2050), Figure 2 shows the average soil water content (1.5 m) for each season of DJF, MAM, JJA, SON for the GCMs/RCMs climate projections under the RCP 4.5 and RCP 8.5 climate scenarios, while Figure 3 shows the spatial comparison of average soil water content in 31 sub-catchments for the SWAT simulation period 2010–2017 and 2041–2050 for the GCMs/RCMs climate projections under the RCP 4.5 and RCP 8.5 climate scenarios.

Section 3.2 describes the climate change AS-1, AS-2, AS-3, AS-4, AS-5 analysis for the period 2041–2050.

For the period 2041–2050, Table 6 presents a comparison of AS-1, AS-2, AS-3, AS-4, AS-5 with respect to S-0 for seasonal soil water content in the Bystra catchment for the RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, and RCP 8.5.3 projections.

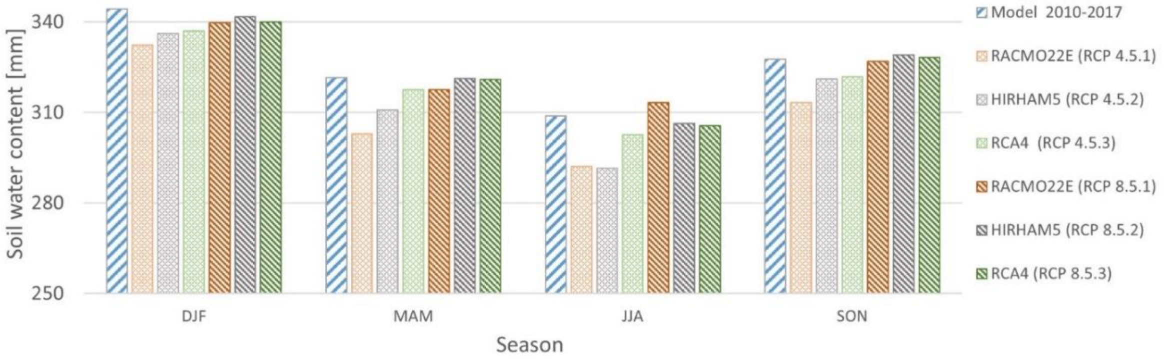

Figure 2. Seasonal average soil water content (1.5 m) for 2041–2050 and for the SWAT 2010–2017 model for individual climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3 (own study).

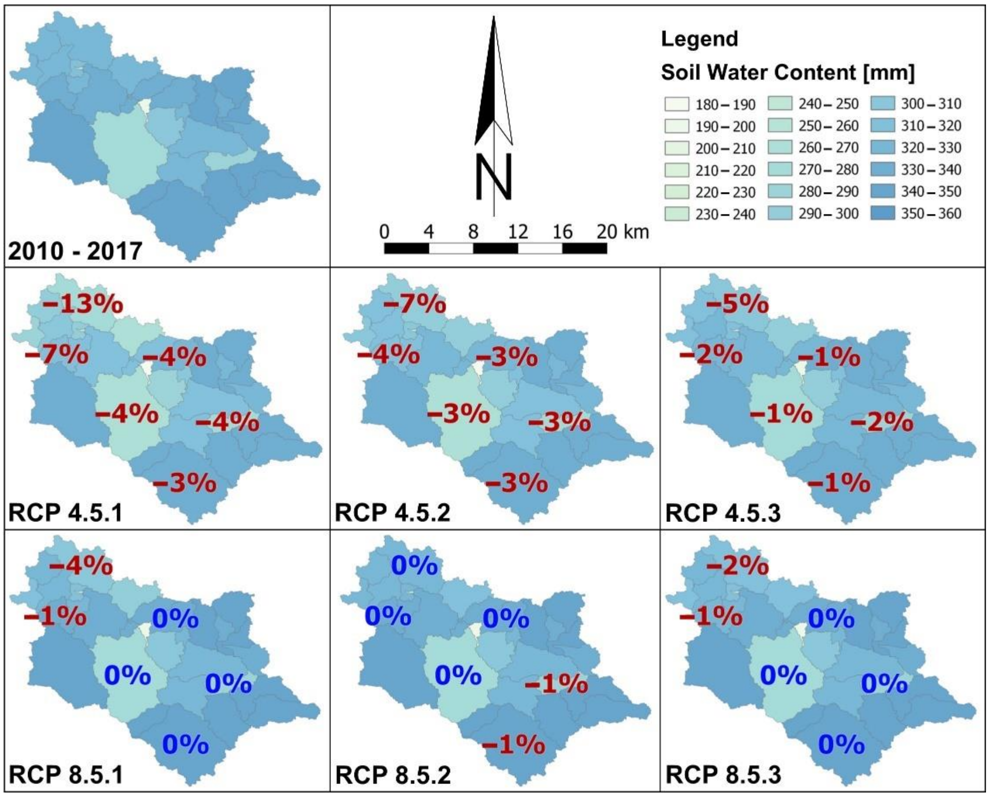

Figure 3. Comparison of average soil water content in 31 sub-catchments during the SWAT simulation period 2010–2017 and 2041–2050 for individual climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3 (own study).

Table 5. Comparison of average soil water content by season for the SWAT 2010–2017 simulation period with climate projections (RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3) for the years 2041–2050 in the Bystra catchment. Bold numbers indicate soil water content, while shaded numbers indicate percentage change (red is % decrease in content; blue is % increase in content). Dark red and dark blue shading means large changes, while light red and light blue shading means small changes (own study).

Climate Scenario		**RCP 4.5**			**RCP 8.5**		
Climate Projection	**Model 2010–2017**	**RACMO22E (RCP 4.5.1)**	**HIRHAM5 (RCP 4.5.2)**	**RCA4 (RCP 4.5.3)**	**RACMO22E (RCP 8.5.1)**	**HIRHAM5 (RCP 8.5.2)**	**RCA4 (RCP 8.5.3)**
Time interval		2041–2050					
Season		Seasonal average of soil water content (mm)					
DJF	**344**	**332** −3.5%	**336** −2.3%	**337** −2.1%	**340** −1.3%	**342** −0.7%	**340** −1.2%
MAM	**322**	**303** −5.8%	**311** −3.3%	**318** −1.3%	**318** −1.2%	**321** −0.1%	**321** −0.2%
JJA	**309**	**292** −5.4%	**291** −5.6%	**303** −2.0%	**313** +1.4%	**306** −0.8%	**306** −1.0%
SON	**328**	**313** −4.4%	**321** −2.0%	**322** −1.8%	**327** −0.2%	**329** +0.4%	**328** +0.2%
Average annual	**326**	**310** −4.7%	**315** −3.3%	**320** −1.8%	**324** −0.4%	**325** −0.3%	**324** −0.6%

Table 6. Comparison of average soil water content by season between scenario 0 (S-0) and adaptation scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) for 2041–2050 in the Bystra catchment for climate projection RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3. Bold numbers indicate soil water content, and shaded numbers indicate percentage change (red indicates % decrease in content and blue indicates % increase in content). Dark red and dark blue shading indicates large changes, while light red and light blue shading indicates small changes (own study).

Time Interval	**2041–2050**													
Type of Scenario	**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**		**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**	
Season	Seasonal average of soil water content (mm)													
DJF	**332**	**318** −4.2%	**332** −0.1%	**332** 0.0%	**333** +0.1%	**330** −0.6%	RACMO22E (RCP 4.5.1)	**340**	**326** −4.0%	**340** 0.0%	**340** 0.0%	**339** −0.1%	**339** −0.1%	RACMO22E (RCP 8.5.1)
MAM	**303**	**290** −4.1%	**303** 0.0%	**303** 0.0%	**303** +0.1%	**301** −0.7%		**318**	**305** −4.1%	**318** 0.0%	**318** 0.0%	**318** 0.0%	**317** −0.2%	
JJA	**292**	**278** −4.8%	**292** −0.1%	**292** 0.0%	**293** +0.3%	**288** −1.4%		**313**	**299** −4.6%	**313** −0.1%	**313** 0.0%	**314** +0.1%	**312** −0.4%	
SON	**313**	**299** −4.6%	**313** −0.1%	**313** 0.0%	**315** +0.4%	**310** −1.0%		**327**	**313** −4.4%	**327** −0.1%	**327** 0.0%	**328** +0.2%	**326** −0.3%	
Average annual	**310**	**296** −4.4%	**310** 0.0%	**310** 0.0%	**311** +0.2%	**307** −0.9%		**324**	**311** −4.3%	**324** 0.0%	**324** 0.0%	**325** +0.1%	**324** −0.2%	
DJF	**336**	**322** −4.1%	**336** 0.0%	**336** 0.0%	**337** +0.1%	**335** −0.2%	HIRHAM5 (RCP 4.5.2)	**342**	**328** −4.0%	**342** 0.0%	**342** 0.0%	**342** 0.0%	**342** 0.0%	HIRHAM5 (RCP 8.5.2)
MAM	**311**	**298** −4.1%	**311** 0.0%	**311** 0.0%	**311** 0.0%	**310** −0.2%		**321**	**308** −4.0%	**321** 0.0%	**321** 0.0%	**321** 0.0%	**321** −0.1%	
JJA	**291**	**277** −4.8%	**291** −0.1%	**291** 0.0%	**292** +0.2%	**288** −1.1%		**306**	**292** −4.6%	**306** −0.1%	**306** 0.0%	**307** +0.1%	**304** −0.6%	
SON	**321**	**307** −4.4%	**321** −0.1%	**321** 0.0%	**322** +0.3%	**319** −0.5%		**329**	**315** −4.3%	**329** −0.1%	**329** 0.0%	**330** +0.2%	**328** −0.2%	
Average annual	**315**	**301** −4.3%	**315** −0.1%	**315** 0.0%	**315** +0.2%	**313** −0.5%		**325**	**311** −4.2%	**324** 0.0%	**325** 0.0%	**325** +0.1%	**324** −0.3%	
DJF	**337**	**323** −4.1%	**337** 0.0%	**337** 0.0%	**337** 0.0%	**336** −0.2%	RCA4 (RCP 4.5.3)	**340**	**326** −4.0%	**340** 0.0%	**340** 0.0%	**340** 0.0%	**340** 0.0%	RCA4 (RCP 8.5.3)
MAM	**318**	**305** −4.1%	**317** 0.0%	**318** 0.0%	**318** 0.0%	**317** −0.2%		**321**	**308** −4.0%	**321** 0.0%	**321** 0.0%	**321** 0.0%	**321** −0.1%	
JJA	**303**	**289** −4.6%	**302** −0.1%	**303** 0.0%	**303** +0.2%	**300** −0.8%		**306**	**291** −4.7%	**305** −0.1%	**306** 0.0%	**306** +0.2%	**303** −0.7%	
SON	**322**	**307** −4.5%	**322** −0.1%	**322** 0.0%	**323** +0.2%	**320** −0.5%		**328**	**314** −4.3%	**328** −0.1%	**328** 0.0%	**329** +0.2%	**327** −0.4%	
Average annual	**320**	**306** −4.3%	**320** −0.1%	**320** 0.0%	**320** +0.1%	**318** −0.4%		**324**	**310** −4.3%	**324** −0.1%	**324** 0.0%	**324** +0.1%	**323** −0.3%	

Table 7 presents a comparison of total runoff by season for S-0 and AS-1, AS-2, AS-3, AS-4, AS-5 for the period 2041–2050 in the Bystra catchment. Next, Table 8 compares sediment yields by season for S-0 and AS-1, AS-2, AS-3, AS-4, AS-5 for 2041–2050 in the

Bystra catchment. In turn, Table 9 compares actual evapotranspiration by season for S-0 and AS-1, AS-2, AS-3, AS-4, AS-5 for the years 2041–2050 in the Bystra catchment.

Table 7. Comparison of seasonal total runoff between scenario 0 (S-0) and adaptation scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) for 2041–2050 in the Bystra catchment for climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3. Bold numbers indicate soil water content, and shaded numbers indicate percentage changes (red indicates % decrease in content, and blue indicates % increase in content). Dark red and dark blue shading indicates large changes, while light red and light blue shading indicates small changes (own study).

Time Interval	**2041–2050**													
Type of Scenario	**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**		**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**	
Season	Seasonal sum of total runoff (mm)													
DJF	**35**	**35** −1.0%	**35** −0.1%	**35** 0.0%	**36** +3.7%	**34** −3.1%		**55**	**54** −0.8%	**55** −0.1%	**55** 0.0%	**56** +2.4%	**54** −1.3%	
MAM	**31**	**31** −0.5%	**31** −0.2%	**31** 0.0%	**32** +3.6%	**30** −3.3%	RACMO22E (RCP 4.5.1)	**47**	**47** 0.1%	**47** −0.1%	**47** 0.0%	**48** +2.4%	**46** −1.1%	RACMO22E (RCP 8.5.1)
JJA	**30**	**30** −0.2%	**30** −0.2%	**30** 0.0%	**31** +3.2%	**29** −3.9%		**49**	**49** 0.0%	**49** −0.1%	**49** 0.0%	**50** +2.1%	**48** −1.8%	
SON	**32**	**32** −0.4%	**32** −0.1%	**32** 0.0%	**34** +4.7%	**31** −3.5%		**49**	**48** −0.3%	**49** −0.1%	**49** 0.0%	**50** +3.2%	**48** −1.6%	
Annual sum	**128**	**127** −0.5%	**128** −0.2%	**128** 0.0%	**133** +3.8%	**123** −3.4%		**199**	**199** −0.3%	**199** −0.1%	**199** 0.0%	**204** +2.5%	**196** −1.5%	
DJF	**39**	**39** −0.4%	**39** −0.2%	**39** 0.0%	**40** +2.8%	**38** −2.7%		**52**	**52** −0.3%	**52** −0.1%	**52** 0.0%	**53** +2.0%	**51** −1.6%	
MAM	**43**	**43** −0.2%	**43** −0.2%	**43** 0.0%	**44** +2.4%	**42** −2.1%	HIRHAM5 (RCP 4.5.2)	**61**	**61** −0.2%	**61** −0.1%	**61** 0.0%	**61** +1.3%	**60** −1.2%	HIRHAM5 (RCP 8.5.2)
JJA	**36**	**36** +0.3%	**36** 0.0%	**36** 0.0%	**37** +2.3%	**35** −3.1%		**53**	**53** +0.2%	**53** 0.0%	**53** 0.0%	**54** +1.4%	**52** −1.6%	
SON	**36**	**36** −0.4%	**36** −0.1%	**36** 0.0%	**37** +3.5%	**35** −3.3%		**51**	**51** −0.2%	**51** −0.1%	**51** 0.0%	**52** +2.3%	**50** −1.7%	
Annual sum	**154**	**154** −0.2%	**154** −0.1%	**154** 0.0%	**159** +2.7%	**150** −2.8%		**217**	**216** −0.1%	**216** −0.1%	**217** 0.0%	**220** +1.7%	**213** −1.5%	
DJF	**50**	**50** −0.4%	**50** −0.1%	**50** 0.0%	**52** +2.5%	**50** −1.7%		**71**	**71** −0.2%	**71** −0.1%	**71** 0.0%	**72** +2.1%	**70** −1.3%	
MAM	**51**	**50** −0.2%	**51** −0.1%	**51** 0.0%	**52** +2.2%	**50** −1.3%	RCA4 (RCP 4.5.3)	**68**	**68** −0.2%	**68** −0.1%	**68** 0.0%	**69** +1.8%	**67** −1.0%	RCA4 (RCP 8.5.3)
JJA	**39**	**39** +0.2%	**39** 0.0%	**39** 0.0%	**40** +2.4%	**39** −2.0%		**60**	**60** 0.0%	**60** 0.0%	**60** 0.0%	**61** +1.6%	**59** −1.3%	
SON	**44**	**44** −0.3%	**44** −0.2%	**44** 0.0%	**46** +3.4%	**44** −1.9%		**70**	**69** −0.5%	**70** −0.1%	**70** 0.0%	**72** +2.5%	**69** −1.1%	
Annual sum	**185**	**184** −0.2%	**185** −0.1%	**185** 0.0%	**190** +2.6%	**182** −1.7%		**268**	**268** −0.2%	**268** −0.1%	**268** 0.0%	**274** +2.0%	**265** −1.2%	

Table 8. Comparison of seasonal sediment yield between scenario 0 (S-0) and adaptation scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) for 2041–2050 in the Bystra catchment for climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3. Bold numbers indicate soil water content, and shaded numbers indicate percentage changes (red indicates % decrease in content, and blue indicates % increase in content). Dark red and dark blue shading indicates large changes, while light red and light blue shading indicates small changes (own study).

Time Interval	**2041–2050**													
Type of Scenario	**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**		**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**	
Season	Seasonal sum of sediment yield (t/ha)													
DJF	**0.17**	**0.16** −9%	**0.17** −1%	**0.05** −72%	**0.12** −28%	**0.16** −5%		**0.25**	**0.23** −9%	**0.25** 0%	**0.07** −71%	**0.18** −30%	**0.24** −5%	
MAM	**0.08**	**0.07** −9%	**0.08** 0%	**0.02** −71%	**0.07** −14%	**0.07** −8%	RACMO22E (RCP 4.5.1)	**0.07**	**0.06** −7%	**0.07** 0%	**0.02** −71%	**0.06** −7%	**0.06** −7%	RACMO22E (RCP 8.5.1)
JJA	**0.15**	**0.14** −9%	**0.15** −1%	**0.05** −70%	**0.13** −13%	**0.12** −21%		**0.22**	**0.20** −9%	**0.22** 0%	**0.06** −72%	**0.16** −28%	**0.18** −17%	
SON	**0.15**	**0.14** −7%	**0.15** −1%	**0.04** −72%	**0.08** −48%	**0.13** −14%		**0.18**	**0.16** −11%	**0.18** −1%	**0.05** −72%	**0.11** −41%	**0.17** −5%	
Annual sum	**0.55**	**0.51** −9%	**0.55** −1%	**0.16** −71%	**0.40** −27%	**0.49** −12%		**0.72**	**0.65** −9%	**0.71** 0%	**0.20** −72%	**0.50** −30%	**0.65** −9%	

Table 8. *Cont.*

Time Interval														
							2041–2050							
Type of Scenario	**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**		**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**	
DJF	**0.11**	**0.10** −10%	**0.10** −1%	**0.03** −72%	**0.08** −23%	**0.10** −4%	HIRHAM5 (RCP 4.5.2)	**0.12**	**0.11** −9%	**0.12** 0%	**0.04** −71%	**0.09** −22%	**0.12** −4%	HIRHAM5 (RCP 8.5.2)
MAM	**0.13**	**0.12** −6%	**0.13** 0%	**0.04** −71%	**0.12** −7%	**0.12** −8%		**0.24**	**0.22** −8%	**0.24** −1%	**0.07** −71%	**0.21** −13%	**0.22** −8%	
JJA	**0.12**	**0.11** −11%	**0.12** −2%	**0.03** −72%	**0.09** −25%	**0.10** −16%		**0.21**	**0.20** −8%	**0.21** −1%	**0.06** −71%	**0.16** −23%	**0.17** −18%	
SON	**0.19**	**0.17** −9%	**0.19** −1%	**0.05** −73%	**0.10** −49%	**0.16** −13%		**0.22**	**0.20** −10%	**0.22** −1%	**0.06** −72%	**0.12** −44%	**0.20** −10%	
Annual sum	**0.54**	**0.50** −9%	**0.54** −1%	**0.15** −72%	**0.39** −29%	**0.48** −11%		**0.79**	**0.72** −9%	**0.79** −1%	**0.23** −71%	**0.59** −25%	**0.71** −11%	
DJF	**0.11**	**0.10** −9%	**0.11** −1%	**0.03** −73%	**0.09** −23%	**0.11** 0%	RCA4 (RCP 4.5.3)	**0.14**	**0.12** −9%	**0.14** −1%	**0.04** −72%	**0.10** −24%	**0.13** −7%	RCA4 (RCP 8.5.3)
MAM	**0.15**	**0.14** −11%	**0.15** 0%	**0.05** −70%	**0.14** −7%	**0.13** −12%		**0.16**	**0.15** −9%	**0.16** −1%	**0.05** −72%	**0.15** −6%	**0.14** −14%	
JJA	**0.11**	**0.10** −12%	**0.11** −1%	**0.03** −73%	**0.08** −25%	**0.09** −21%		**0.14**	**0.12** −11%	**0.14** −1%	**0.04** −71%	**0.13** −7%	**0.11** −23%	
SON	**0.20**	**0.18** −9%	**0.20** 0%	**0.06** −72%	**0.12** −42%	**0.18** −10%		**0.57**	**0.51** −10%	**0.56** −1%	**0.16** −72%	**0.32** −43%	**0.50** −12%	
Annual sum	**0.57**	**0.52** −10%	**0.57** −1%	**0.16** −72%	**0.43** −26%	**0.51** −11%		**1.00**	**0.90** −10%	**0.99** −1%	**0.28** −72%	**0.71** −29%	**0.87** −13%	

Table 9. Comparison of seasonal actual evapotranspiration between scenario 0 (S-0) and adaptation scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) for 2041–2050 in the Bystra catchment for climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3. Bold numbers indicate soil water content and shaded numbers indicate percentage changes (red indicates % decrease in content, and blue indicates % increase in content). Dark red and dark blue shading indicates large changes, while light red and light blue shading indicates small changes (own study).

Time Interval														
							2041–2050							
Type of Scenario	**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**		**S-0**	**AS-1**	**AS-2**	**AS-3**	**AS-4**	**AS-5**	
Season							Seasonal sum of actual evapotranspiration (mm)							
DJF	**27**	**27** −0.9%	**27** −0.1%	**27** 0.0%	**27** −0.2%	**27** −0.4%	RACMO22E (RCP 4.5.1)	**29**	**29** −0.7%	**29** 0.0%	**29** 0.0%	**29** −0.4%	**29** −0.5%	RACMO22E (RCP 8.5.1)
MAM	**154**	**151** −1.9%	**154** −0.1%	**154** 0.0%	**154** 0.0%	**156** +1.4%		**156**	**154** −1.7%	**156** −0.1%	**156** 0.0%	**156** −0.3%	**157** +0.7%	
JJA	**166**	**169** +2.0%	**166** +0.2%	**166** 0.0%	**163** −1.5%	**168** +1.4%		**165**	**168** +1.8%	**165** +0.2%	**165** 0.0%	**162** −1.5%	**166** +1.0%	
SON	**70**	**70** +0.4%	**70** 0.0%	**70** 0.0%	**67** −4.0%	**70** +0.1%		**70**	**70** +0.3%	**70** 0.0%	**70** 0.0%	**68** −3.2%	**70** +0.1%	
Annual sum	**416**	**417** +0.1%	**416** 0.0%	**416** 0.0%	**411** −1.3%	**421** +1.1%		**420**	**420** +0.1%	**420** 0.0%	**420** 0.0%	**415** −1.3%	**423** +0.7%	
DJF	**24**	**24** −0.7%	**24** 0.0%	**24** 0.0%	**24** −0.2%	**24** −0.4%	HIRHAM5 (RCP 4.5.2)	**23**	**23** −0.7%	**23** 0.0%	**23** 0.0%	**23** −0.3%	**23** −0.4%	HIRHAM5 (RCP 8.5.2)
MAM	**149**	**146** −1.9%	**148** −0.1%	**149** 0.0%	**148** −0.1%	**150** +1.2%		**135**	**133** −1.7%	**135** −0.1%	**135** 0.0%	**136** +0.1%	**137** +1.0%	
JJA	**152**	**155** +2.0%	**152** +0.2%	**152** 0.0%	**150** −1.2%	**154** +1.7%		**152**	**155** +1.7%	**153** +0.2%	**152** 0.0%	**150** −1.3%	**154** +1.3%	
SON	**61**	**61** +0.3%	**61** 0.0%	**61** 0.0%	**59** −3.6%	**61** 0.0%		**65**	**66** +0.1%	**65** 0.0%	**65** 0.0%	**63** −3.3%	**65** 0.0%	
Annual sum	**386**	**386** +0.1%	**386** 0.0%	**386** 0.0%	**382** −1.1%	**390** +1.1%		**377**	**377** 0.0%	**377** 0.0%	**377** 0.0%	**372** −1.1%	**380** +0.9%	
DJF	**31**	**31** −0.7%	**31** 0.0%	**31** 0.0%	**31** −0.2%	**31** −0.6%	RCA4 (RCP 4.5.3)	**34**	**34** −0.8%	**34** 0.0%	**34** 0.0%	**34** −0.2%	**34** −0.5%	RCA4 (RCP 8.5.3)
MAM	**136**	**134** −1.7%	**136** −0.1%	**136** 0.0%	**136** −0.2%	**137** +0.8%		**141**	**138** −1.6%	**141** −0.1%	**141** 0.0%	**141** −0.1%	**142** +0.8%	
JJA	**168**	**170** +1.5%	**168** +0.2%	**168** 0.0%	**165** −1.4%	**170** +1.3%		**158**	**161** +1.7%	**158** +0.2%	**158** 0.0%	**156** −1.5%	**160** +1.3%	
SON	**69**	**70** +0.4%	**69** 0.0%	**69** 0.0%	**67** −3.5%	**69** 0.0%		**72**	**73** +0.2%	**73** 0.0%	**72** 0.0%	**69** −4.2%	**72** 0.0%	
Annual sum	**404**	**405** +0.1%	**405** 0.0%	**404** 0.0%	**399** −1.3%	**408** +0.8%		**406**	**406** +0.1%	**406** 0.0%	**406** 0.0%	**400** −1.4%	**409** +0.7%	

3.1. Analysis of Soil Water Content in Zero Scenario for 2021–2050

This section compares the obtained seasonal average soil water content results for 2010–2017 (SWAT model) with the results for 2041–2050 for individual climate change projections (RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, RCP 8.5.1, RCP 8.5.2, RCP 8.5.3).

Regardless of the individual climate change projections evaluated, the seasonal average soil water content for the Bystra catchment is projected to decrease between 2041 and 2050 for most seasons compared to 2010–2017 (Table 5).

Lower soil water content will be especially evident for RCP 4.5.1 (MAM, JJA, SON) and RCP 4.5.2 (JJA) where the value of average soil water content may be lower by up to 5.8% compared to the 2010–2017 simulation period. Lower values in the MAM and JJA seasons, especially for the RCP 4.5.1, RCP 4.5.2, RCP 4.5.3 projections, may affect plant growth during the growing season. However, higher soil water content (1.4% higher) was found for the RCP 8.5.1 (JJA), RCP 8.5.2 and RCP 8.5.3 (SON) projections.

Regardless of the regional climate model, the seasonal average soil water content will be lower for climate projections RCP 4.5.1, RCP 4.5.2, RCP 4.5.3 compared to climate projections RCP 8.5.1, RCP 8.5.2, RCP 8.5.3. This is particularly evident when comparing the average annual soil water content results, where, for RCP 4.5.1, RCP 4.5.2, RCP 4.5.3, the average annual soil water content results (2041–2050) are lower between 1.8% and 4.7%, while, for RCP 8.5.1, RCP 8.5.2, RCP 8.5.3, these average annual results are lower between 0.3% and 0.6% compared to the SWAT 2010–2017 model.

The average soil water content by season for 2041–2050 and the SWAT model 2010–2017 is shown in Figure 2 (Figure 2). It shows that the average soil water content decreases throughout the year. The highest soil water values are reached during the winter season of DJF. On the other hand, in spring (MAM), during the growing season period, the average soil water content decreases, maintaining the lowest values in summer (JJA). In autumn (SON), the soil water content increases.

Analyzing the spatial distribution of changes in the average water content in soil in 31 sub-catchments for the simulation period in 2010–2017 in relation to the period 2041–2050 (Figure 3) in the climate forecasts RCP 4.5.1 and RCP 4.5.3, the average water content in the soil will decrease by a few percent points in the Northwest region for most of the projections. In the projections RCP 4.5.1, RCP 4.5.2 and RCP 4.53, a reduced water content in the soil will occur throughout the catchment area, while in the projections RCP 8.5.1, RCP 8.5.2 and RCP 8.5.3, the changes will be small.

3.2. Climate Change Adaptation Scenarios Analysis 1–5 for 2041–2050

The results presented in Section 3.1 indicate a decrease in soil water content in most seasons during the period 2041–2050 (Table 5, Figure 2). To counteract the negative effects of changes in soil water content, five adaptation scenarios (AS-1, AS-2, AS-3, AS-4, AS-5) were prepared and tested. They were designed to maintain or increase soil water content. The analysis covers the period 2041–2050. Additionally, the impact of adaptation scenarios on total runoff, sediment yield and actual evapotranspiration was compared.

AS-1 of increasing forested areas on soils of complex 6, 7, 8 compared to S-0 for all projections shows a decrease in soil water content for all seasons in the Bystra catchment (Table 6). The soil water content decreases from 4.0% to 4.8% for all seasons.

AS-2, which assumes a forested buffer zone near the Bystra River, shows a slight decrease in soil water content between 2041 and 2050 (Table 6).

AS-3, establishing filter strips, shows no change in soil water content (Table 6).

In AS-4, the application of plowing on arable land—BARL, CANP, CRDY, WWHT—was eliminated. This treatment showed a slight increase in soil water content. The increase ranged from 0% to 0.4%. The largest increases occurred in the JJA and SON seasons (Table 6).

AS-5 increased soil organic carbon to 2%. This treatment showed a slight decrease in soil water content. The decrease in soil water content ranged from 0% to 1.4% (Table 6).

Regardless of the GCMs/RMCs and the RCPs evaluated, the results are the same. This means that AS-1 is associated with a greater decrease in soil water content compared to S-0. AS-2 and AS-5 are associated with a decrease of a smaller magnitude compared to AS-1. AS-3 does not predict any significant change in soil water content. In contrast, AS-4 is associated with a small increase in soil water content.

Regardless of the regional climate model, the seasonal average soil water content will be lower under the RCP 4.5 climate change scenario compared to the RCP 8.5 climate change scenario. This is described in more detail in Section 3.1.

Differences in annual average soil water content between AS-2, AS-3, AS-4, AS-5 and S-0 are small. However, for AS-1, the annual average soil water content varies between 296 and 311 mm. In contrast, for S-0, the average annual soil water content is 310–325 mm (Table 6).

AS-1 and AS-2 show a slight decrease for most seasons of total runoff for 2041–2050 compared to S-0 in all climate projections. Changes in total runoff range from 1% (decrease) to 0.3% (increase) (Table 7).

Total runoff in AS-3 did not change (Table 7).

AS-4 shows an increase in total runoff for all seasons in all projections. The increase ranges from 1.3% to 4.7% (Table 7). For climate projection RCP 4.5.1, the increase in total runoff stands out from the other projections in all seasons (above 3%).

In contrast, AS-5 shows a decrease in total runoff for all seasons across all projections. The decrease ranges from 1.0% to 3.9% (Table 7). For climate projections RCP 4.5.1 and RCP 4.5.2, the decrease in total runoff stands out from the other projections in all seasons (above 2%) (Table 7).

Moreover, for total runoff regardless of the GCMs/RMCs and RCPs evaluated, the results are the same. AS-1 and AS-2 have smaller total runoff compared to adaptation S-0. AS-5 has an even smaller total runoff compared to AS-1 and AS-2.

In AS-3, the total runoff does not change. In contrast, AS-4 shows an increase in total runoff compared to all adaptation scenarios.

Regardless of the regional climate model, the average seasonal total runoff will be lower for the RCP 4.5 climate change scenario compared to the RCP 8.5 scenario [8].

Table 8 presents the seasonal sediment yield data (Table 8). AS-1, AS-2, AS-3, AS-4, AS-5 were compared to S-0 for the climate projections. For most adaptation scenarios, there is a reduction in sediment yield from 0% to as much as 73%. The smallest, slight decreases in sediment yield occur in AS-2 compared to S-0. Slightly larger decreases compared to S-0 and AS- 2 occur in AS-1 and AS-5. Large decreases in sediment yield occur in AS-4 (ranging from 6% to 49%). However, the largest occur for AS-3 (over 70%).

For sediment yield, regardless of the GCMs/RMCs and RCPs evaluated, the results are also the same (Table 8).

Regardless of the regional climate model, the seasonal sediment yield will be lower under the RCP 4.5 climate change scenario compared to the RCP 8.5 scenario. Differences in annual sum sediment yields range from 0.54–0.57 t/ha for RCP 4.5 to 0.72–1.00 t/ha for RCP 8.5 in S-0 (Table 8). For AS-4, the annual sum ranges from 0.39–0.40 t/ha for RCP 4.5 to 0.50–0.71 t/ha for RCP 8.5, while for AS-3, the annual sum ranges from 0.15–016 t/ha for RCP 4.5 to 0.20–0.28 t/ha for RCP 8.5.

Table 9 presents data on seasonal actual evapotranspiration (Table 9). The highest evapotranspiration values occur during the MAM and JJA seasons.

AS-1, AS-2, AS-3, AS-4, AS-5 were compared to S-0 for all climate projections. AS-1 shows a decrease in actual evapotranspiration from 1.7% to 1.9% for the MAM season. In contrast, there is an increase between 1.5% and 2.0% for the JJA season.

AS-2 shows little change in actual evapotranspiration (Table 9).

The actual evapotranspiration in AS-3 remains unchanged compared to S-0 (Table 9).

In AS-4, for the MAM and JJA seasons, actual evapotranspiration varies from 1.5% (decrease) to 0.1% (increase) (Table 9) compared to S-0. However, large decreases occur for the SON season (from 3.2% to 4.2%).

In contrast, AS-5 has increases in actual evapotranspiration of 0.7% to 1.7% for the MAM and JJA seasons compared to S-0.

For actual evapotranspiration, regardless of the GCMs/RMCs and RCPs evaluated, the results are the same (Table 9).

Regardless of the regional climate model, seasonal actual evapotranspiration will be similar under the RCP 4.5 climate change scenario compared to the RCP 8.5 scenario [8].

For AS-1, AS-2, AS-3, the annual sum of actual evapotranspiration changes little. However, for AS-4, the annual sum of actual evapotranspiration increases from 1.7% to 3.8% compared to S-0. In contrast, for AS-5, the annual sum decreases from 1.2% to 3.4% (Table 9).

Table 10 shows the percentage sets of changes in soil water content, sediment productivity, total runoff, and actual evapotranspiration under AS-1, AS-2, AS-3, AS-4, AS-5 with respect to S-0 (Table 10). The table was created based on supplementary Material: Figures S1 and S2, for averages of three GCMs/RCMs combinations under two RCP climate change scenarios (RCP 4.5, RCP 8.5).

Table 10. Percent summary of changes in soil water content, sediment yield, total runoff and actual evapotranspiration under adaptation scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) compared to scenario 0 (S-0) (created from Supplementary Material: Figures S1 and S2), for averages of three GCMs/RCMs combinations under two RCP climate change scenarios (RCP 4.5, RCP 8.5). The summary is for four seasons (DJF, MAM, JJA, SON) in the Bystra catchment. Shaded numbers indicate percentage changes (red indicates % decrease in content, and blue indicates % increase in content). Dark red and dark blue shading indicates large changes, while light red and light blue shading indicates small changes (own study).

	RCP 4.5				RCP 8.5				
Season	**Soil water Content (mm)**	**Total Runoff (mm)**	**Sediment Yield (t/ha)**	**Actual Evapo-transpiration (mm)**	**Soil Water Content (mm)**	**Total Runoff (mm)**	**Sediment Yield (t/ha)**	**Actual Evapo-transpiration (mm)**	
DJF	−4.1%	−0.6%	−9.3%	−0.7%	−4.0%	−0.4%	−9.1%	−0.7%	AS-1
MAM	−4.1%	−0.2%	−8.7%	−1.9%	−4.0%	−0.1%	−8.5%	−1.7%	
JJA	−4.7%	+0.1%	−10.4%	+1.9%	−4.6%	+0.1%	−9.1%	+1.7%	
SON	−4.5%	−0.4%	−8.5%	+0.4%	−4.3%	−0.4%	−10.5%	+0.2%	
Average	−4.4%	−0.3%	−9.2%	+0.1%	−4.2%	−0.2%	−9.5%	+0.1%	
DJF	0.0%	−0.1%	−1.0%	0.0%	0.0%	−0.1%	−0.4%	0.0%	AS-2
MAM	0.0%	−0.1%	0.0%	−0.1%	0.0%	−0.1%	−0.8%	−0.1%	
JJA	−0.1%	−0.1%	−1.3%	+0.2%	−0.1%	0.0%	−0.7%	+0.2%	
SON	−0.1%	−0.1%	−0.6%	0.0%	−0.1%	−0.1%	−0.9%	0.0%	
Average	−0.1%	−0.1%	−0.7%	0.0%	0.0%	−0.1%	−0.8%	0.0%	
DJF	0.0%	0.0%	−72.4%	0.0%	0.0%	0.0%	−71.5%	0.0%	AS-3
MAM	0.0%	0.0%	−70.4%	0.0%	0.0%	0.0%	−71.3%	0.0%	
JJA	0.0%	0.0%	−71.6%	0.0%	0.0%	0.0%	−71.4%	0.0%	
SON	0.0%	0.0%	−72.5%	0.0%	0.0%	0.0%	−72.2%	0.0%	
Average	0.0%	0.0%	−71.8%	0.0%	0.0%	0.0%	−71.7%	0.0%	
DJF	+0.1%	+2.9%	−25.3%	−0.2%	0.0%	+2.2%	−26.2%	−0.3%	AS-4
MAM	0.0%	+2.6%	−8.5%	−0.1%	0.0%	+1.8%	−9.8%	−0.1%	
JJA	+0.2%	+2.6%	−20.3%	−1.4%	+0.2%	+1.7%	−20.9%	−1.4%	
SON	+0.3%	+3.8%	−46.2%	−3.7%	+0.2%	+2.6%	−42.7%	−3.6%	
Average	+0.2%	+3.0%	−27.3%	−1.2%	+0.1%	+2.1%	−28.2%	−1.2%	
DJF	−0.3%	−2.4%	−3.1%	−0.5%	−0.1%	−1.4%	−5.1%	−0.5%	AS-5
MAM	−0.4%	−2.1%	−9.6%	+1.1%	−0.1%	−1.1%	−9.8%	+0.9%	
JJA	−1.1%	−2.9%	−19.5%	+1.5%	−0.6%	−1.6%	−18.8%	+1.2%	
SON	−0.7%	−2.8%	−12.2%	0.0%	−0.3%	−1.4%	−10.5%	0.0%	
Average	−0.6%	−2.5%	−11.2%	+1.0%	−0.3%	−1.4%	−11.2%	+0.8%	

4. Discussion

The results concerning the water content in the soil were compared with the available values of water capacity and the wilting point obtained from the study "Assessment of water retention in soil and the risk of drought based on the water balance of the Lower Silesia Voivodshi", developed in 2013 by the employees of the Department of Soil Science, Erosion and Land Protection, IUNG-PIB in Pulawy [1]. Based on the above-mentioned study, we prepared data on soils in the catchment area of the Bystra River. For a 1.5 m soil profile, the results of the above-mentioned studies are consistent with this publication.

The lowest water content in soil occurs in the summer (JJA), while the highest occurs in the winter (DJF) (Figure 2). For 2041–2050, the largest decreases in soil water content are associated with GCMs/RCMs for RCP 4.5, while small changes occur for RCP 8.5.

The analyzed adaptation scenarios present different results of the influence on the water content in the soil. AS-1 for an increase in forest area on soils of the complex 6, 7, 8 compared to S-0 for all projections shows a reduction in soil water content for all seasons across the entire Bystra catchment (Tables 6 and 10, Figures S1 and S2 in Supplementary Material). The same is true for total runoff. Again, for most seasons, there is a reduction in total runoff (all projections) compared to S-0 (Tables 7 and 10, Figures S1 and S2 in Supplementary Material). Sediment yields for all seasons also decrease (Tables 8 and 10, Figures S1 and S2 in Supplementary Material). In contrast, actual evapotranspiration shows a decrease in the MAM season and an increase in the JJA season (Tables 9 and 10, Figures S1 and S2 in Supplementary Material).

Forests play an important role in absorbing CO_2, which is an important factor in reducing the adverse effects of climate change [78]. In addition to absorbing CO2, forest ecosystems can counteract soil erosion and drainage. Within forests, there may be small retention reservoirs, increasing the areas' abundance of water. Forest ecosystems play very important natural, social and productive functions [79]. The results indicate that increasing afforested area in the Bystra catchment has to go beyond the scheme of using soil complexes less favorable for agricultural production, and the areas should be picked with care, focusing on locating forested areas close to catchment borders, so they can slow runoff and help accumulate water at its highest point from the river bed [80].

The large-scale research aimed at estimating the amount of tree stand in the world shows that there are currently 46% fewer trees than before the advent of human civilization [81]. Climate change may affect the condition of forest areas [19] manifested in extreme weather phenomena that begin to lose their anomaly status (hurricanes, droughts). Moreover, the species status of plants and trees may not be flexible enough to adapt to changing climate components (temperature, precipitation, etc.) [82]. Forests therefore should be probably re-designed to cope with changing biotopes. For many years, many concepts regarding forest formation in relation to a changing climate have been considered. These plans are based on the development of actions to reduce the effects of unfavorable phenomena which are occurring now and which may intensify in the future. Another concept will be activities aimed at adapting forest ecosystems to all current and future threats [82].

A program of increasing forest cover is implemented in Poland [83]. According to the report on the condition of forests in Poland in 2020 [84], the level of forest cover in 2020 amounted to 29.6% of the total area of the country. After 2050, the forest cover in Poland is expected to be 33%. The program assumes afforestation of land of low agricultural suitability [85], reflected in AS-1 of this study.

Research using afforestation scenarios was carried out on four sites in Bolivia and Ecuador [86]. They show that the water content in the soil and the total runoff decreased to a varying degree after the application of the forest ecosystem. AS-1 and AS-2 also show a reduction in soil water content (Tables 6 and 10, Figures S1 and S2 in Supplementary Material) and a slight reduction in total runoff (Tables 7 and 10, Figures S1 and S2 in Supplementary Material). Sediment yield also decreased (Tables 8 and 10, Figures S1 and S2 in Supplementary Material). The decrease in soil water content for AS-1 and AS-2 in the Bystra catchment may be caused by increased water uptake by the root system of forest vegetation species.

The afforestation scenario has the potential for further research, in which it is possible to design an appropriate location of forest ecosystems in the Bystra river catchment area, relying not only on the afforestation of soils of complex 6, 7 and 8, but also good tree planting practices in rural areas [87], the use of forested embankment fortifications (also preventing erosion) [72], which would counteract the unfavorable agro-forest checkerboard [88]. The unfavorable location of forest ecosystems near cultivated fields may result in a reduction in the yield of agricultural plants [89,90]. When designing afforestation, one should also take into account the adaptation possibilities of stands to new climatic conditions [82].

Increasing forest cover from 16.34% (S-0) to 19.65% (AS-1) or to 17.37% (AS-2) (Table 4) according to Lambo's forest cover index [91] allows for increased forest retention capacity that, among other things, counteracts the effects of flooding [92]. In addition to increasing forest cover, equally important is the location of forested areas within the catchment area which has a significant impact on runoff [93].

A buffer zone with a well-developed tree stand, located directly next to watercourses, can prevent the runoff of nutrients and suspensions from agricultural land, contribute to the strengthening of banks and prevent lateral erosion [72,87,94]. A marsh zone forming a belt of wetland and rush vegetation, flooded or boggy for most of the year or all the time, can also be a buffer. Such a zone with well-developed vegetation contributes to the retention of a significant amount of nitrogen and phosphorus from the catchment area, preventing eutrophication of waters [72,95].

AS-3, for the creation of filter strips in a planned management operation on BARL, CANP, CRDY, WWHT arable land, shows no changes in soil water content, total runoff or actual evapotranspiration (Tables 6, 7, 9 and 10, Figures S1 and S2 in Supplementary Material). On the other hand, the filter strips effectively reduce the sediment yield (t/ha) (Tables 8 and 10, Figures S1 and S2 in Supplementary Material). Similar results were obtained in the article describing the use of the filter strips in various scenarios on the example of the catchment area in Thailand [96], where, as a result of their use, the sediment yield was significantly reduced.

Adaptation scenarios involving increasing forest cover, creating buffers next to rivers and creating filter strips can help reduce erosion risk in the 2050 climate horizon in the Bystra catchment by reducing total runoff and decreasing sediment yield.

AS-4, for the cessation of plowing on BARL, CANP, CRDY, WWHT arable land, shows a slight increase (especially in the JJA and SON season) in soil water content (Tables 6 and 10, Figures S1 and S2 in Supplementary Material). The elimination of plowing also shows a significant reduction in sediment yield (t/ha) (Tables 8 and 10, Figures S1 and S2 in Supplementary Material). This may have the effect of reducing soil erosion. However, the total runoff increased, which is induced mainly by the reduction in actual evapotranspiration, especially limited evaporation form the soil surface covered by plant residue mulch (Tables 7, 9 and 10, Figures S1 and S2 in Supplementary Material). Observations by Wawer and Kozyra [97] confirm the prominent role of mulching in preserving soil water by covering the surface of the soil in warm periods.

The discontinuation of plowing is the subject of many articles as well as studies that mention as benefits the reduction in soil erosion, the reduction in surface and subsurface runoff, the reduction in sediment yield, nitrogen yield and phosphorus yield, the increase in soil water content, etc. [76,98–101], which are supported by numerous studies. The abandonment of plowing in the catchment areas in the climate of 2050 also shows a reduction in the sediment yield. On the other hand, the water content in the soil increases. This provides the grounds that new agricultural practices in the coming decades may prevent the negative impact of watershed water deficits from occurring.

Agriculture is closely related to the prevailing climatic conditions, but it also has a large impact on them. The risk of an increase in the frequency of unfavorable climatic conditions in agriculture may result in yield variability from year to year. The reduced amount of water in the soil during plant growth, illustrated in the climate change scenarios (Table 5, Figure 2), will become more frequent and more severe. Other threats will also include droughts, heavy precipitation, erosion [80], floods, landslides and strong winds [102].

AS-5, increasing soil organic carbon to 2%, shows reductions in soil water content, total runoff and sediment yield (Tables 6–8, Figures S1 and S2 in Supplementary Materials). However, actual evapotranspiration increases (Tables 9 and 10, Figures S1 and S2 in Supplementary Materials). In a paper on soil organic carbon changes and their response to climate warming and soil water content changes, a study of the Jinghe catchment in China was described [103]. The study showed that temperature and precipitation will increase by the end of the 21st century under three scenarios—RCP 2.6, RCP 4.5, RCP 8.5—and consequently soil water content will also increase, while organic carbon content will decrease, depending on the climate change scenario. The study also showed that there is a threshold in soil water content that can mediate the loss of soil organic carbon (when the change in soil water content was lower than the threshold, higher content accelerated the loss of organic carbon, while when the change in soil water content was higher than the threshold, higher content reduced the loss of soil organic carbon) [103]. The mechanism for the decrease in soil organic carbon (despite increased soil water content) due to a warming climate in the future is not fully known [103]. Global studies have found a link between faster CO_2 increases in warmer years with less water availability. This demonstrates the importance of warming on the decomposition of soil organic carbon [104]. There are studies in pols on the effect of soil organic matter on soil water management [105]. According to some estimates in the article, increasing soil organic matter by 0.01% increases the amount of organic matter by 480 kg (from 1 hectare of arable soil layer). This corresponds to 278 kg of organic carbon. On the scale of the national area (Poland), this means the sequestration of 11 million tons of CO_2 from the entire arable land area of Poland. This represents more than 3% of the total greenhouse gas emissions from the Polish area [77].

A convenient tool for carrying out beneficial changes (afforestation, retention reservoirs, irrigation) in terms of water retention in the landscape is land consolidation on an extended scope [80,106,107]. Several agricultural research centers in Poland deal with the issues of recomposing the rural landscape, including IUNG-PIB in Pulawy. At IUNG-PIB, a broader consolidation formula, called the Composite Development of Rural Areas CDRA [106], was developed, covering extended land consolidation, rural area management and rural development, which are included in addition to classic land consolidation works meant as the transformation of land, water drainage, water supply to farms aimed at improving the conditions for agricultural production on farms [106]. The comprehensive, holistic land consolidation approach remains the most effective way of introducing a wide range of changes in the agricultural landscape, also focusing on water management [106]. Based upon the outcomes of this study, the team plans to simulate a scenario of a fully designed land consolidation with the CDRA scheme as one of the options towards a better holistic water management in rural landscapes.

One of the more recent publications describing the methods of managing water resources and thus counteracting climate change in agriculture for the Polish area is the Code of Good Water Practices in Agriculture, which was commissioned by the Ministry of Agriculture and Rural Development [22]. The Code describes various sustainable and solidarity-based water management practices that can be successfully applied to agriculture in the coming decades in response to an increasing scarcity of water resources. We plan to model the effects of introducing the practices covered by the Code in future studies.

5. Conclusions

AS-1, AS-2 and AS-5 did not increase the water content of the soil. However, they can help to reduce sediment yield and total runoff. AS-1 and AS-2 have potential for further research using the SWAT model. The research would be aimed at adopting an appropriate strategy for spreading the location of afforestation in the catchment to reduce the adverse effects of climate change. Soil organic carbon sequestration (AS-5) also has potential for further research due to the reduction in negative effects of climate change.

The filter strips in AS-3 contributed to a reduction in sediment yield. Soil water content, total runoff and actual evapotranspiration remained unchanged. The lack of change may be due to suboptimal discretization of the filter strips in the SWAT input files. Further research on this issue will be conducted.

Practices for reducing or eliminating water shortages in soil can be those presented in AS-4 for no-tillage cultivation. Removal of plowing may also contribute to the reduction in sediment yield (t/ha). This may have the effect of reducing soil erosion. However, the positive influence on soil moisture contents throughout the season using the no-till simulation indicated an increase in runoff, which is mainly caused by limiting evaporation from bare soil covered by the mulch of crop residues.

The obtained results cover 150 cm of the soil layer as described by the Polish soil-agricultural map, which does fully reflect the conditions for plants, especially during sawing and in early stages of growth. Further research has to be conducted on discretizing soil hydrology dynamics in the SWAT input configuration to take into consideration the plough horizon as a separate hydrological entity to be modeled.

Higher soil water content, higher total runoff and higher sediment yield for the RCP 8.5 climate change scenario compared to the RCP 4.5 climate change scenario may be related to higher precipitation in 2041–2050 (Badora et al., 2022).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14152288/s1, Figure S1: Summary of changes in soil water content, sediment yield, total runoff and actual evapotranspiration in adaptive scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) compared to scenario 0 (S-0), for averages of three GCM/RCM combinations in the RCP 4.5 climate change scenario. The list covers four seasons (DJF, MAM, JJA, SON) in the Bystra catchment area. The first adaptation scenario assumes the growth of afforestation on soils from the agricultural usefulness complex of soil 6–8 (semi-dry, permanent dry, semi-moist, permanently wet). The second adaptation scenario assumes the creation of a forested buffer for the Bystra River and its tributaries. The third adaptation scenario shows one the erosion prevention practices in the river bed, the so-called filter strips. The fourth adaptation scenario assumes the reduction of plowing on agricultural land. The fifth adaptation scenario assumes an increase in soil organic carbon content to 2%. Adaptation scenarios 1–5 are modifications of scenario 0. Scenario 0 only covers climate change in 2041–2050 (own study); Figure S2: Summary of changes in soil water content, sediment yield, total runoff and actual evapotranspiration in adaptive scenarios 1–5 (AS-1, AS-2, AS-3, AS-4, AS-5) compared to scenario 0 (S-0), for averages of three GCM/RCM combinations in the RCP 8.5 climate change scenario. The list covers four seasons (DJF, MAM, JJA, SON) in the Bystra catchment area. The first adaptation scenario assumes the growth of afforestation on soils from the agricultural usefulness complex of soil 6–8 (semi-dry, permanent dry, semi-moist, permanently wet). The second adaptation scenario assumes the creation of a forested buffer for the Bystra River and its tributaries. The third adaptation scenario shows one the erosion prevention practices in the river bed, the so-called filter strips. The fourth adaptation scenario assumes the reduction of plowing on agricultural land. The fifth adaptation scenario assumes an increase in soil organic carbon content to 2%. Adaptation scenarios 1–5 are modifications of scenario 0. Scenario 0 only covers climate change in 2041–2050 (own study).

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