Determining the potential retention of a forest catchment based on the CN parameter

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Abstract

Forests play one of the most important roles in the hydrological cycle; as a result, knowledge about the water relations in forest areas should be of great importance in the context of global change. In Poland, the level of groundwater in forest areas has been decreasing for several decades, which negatively affects forest stands. To prevent this, activities have been carried out to increase water resources. Therefore, there is a need to develop a method for prioritizing the locations of retention investment projects. While searching for simple methods to achieve this goal, it was assumed that retention facilities should be located first in the partial catchments with the greatest possible retention capacities. This value, which is called the potential retention of the catchment, can be calculated using the CN parameter, which is used in the soil conservation service–curve number (SCS–CN) method. The CN parameter contains information on the type of land cover, the type of soil, and the moisture content. The source of the obtained land-use data was the Corine Land Cover (CLC) database, which was developed by the European Environment Agency for the area of the European Union. The analyses were carried out on the forest catchment of the Łutownia River, which is located in the Białowieża Primeval Forest.

Keywords Forest · Retention · CN parameter · Water management

Introduction

Given that climate change contributes to increased air temperatures and decreased rainfall, water scarcity may become one of the biggest social problems in the near future. Among all ecosystems, forests play one of the most important roles in the hydrological cycle; therefore, knowledge about the water relations in forest areas should be of great importance in the context of preventing global climate change. Forests play a particularly strong role in regulating runoff in small catchments where the forest covers over 50% of the total catchment area (Scholz et al. 2015). In addition, if all small catchments in a larger catchment area are managed to retain water, the effects of potential floods can also be reduced (Schüler 2005). Unfortunately, the groundwater levels in forest areas have been decreasing in Poland for several decades, which adversely affects forest stands (Mioduszewski 2008; Frydel and Miler 2014; Wróbel et al. 2016). For this reason,

at the end of the 1990s, programs began to be implemented to increase the surface and groundwater retention in forest (Matczak et al. 2019). As part of this effort, modernization is planned for small reservoirs and the structures damming drained wetlands; where possible, restoration of the natural river paths and the leveling and slowing of the flow of flood waters are planned. For this reason, there was a need to develop a method for prioritizing the locations of retention investment projects, e.g., in a group of partial catchments of a selected river catchment. In searching for relatively simple methods to achieve this goal, it was assumed that retention facilities should be located first in the partial catchments with the greatest possible retention. The retention capacity can be calculated using a relatively simple SCS–CN model. The Łutownia River catchment was chosen as a methodical example.

Methodology

The SCS–CN method was used to determine the potential capacities of the partial catchments. This method was created in USA in the 1950s and has since been one of the

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most common methods for determining effective precipitation. The method was originally developed mainly for agricultural areas, but has been modified and successfully used over the years in various regions and climatic conditions (Ara and Zakwan 2018; Kim et al. 2018; Lal et al. 2016; Mishra et al. 2003) including forest areas (Soulis 2018; Vojtek and Vojteková 2016). In this method, the effective rainfall depends on the type of soil, the soil use, the nature of the plant cover, and the moisture content. All these features are included in the CN parameter. To determine the CN parameter, among others, the land-use category should be specified. The Corine Land Cover method was chosen for this purpose (Büttner and Kosztra 2007). However, it contains fairly general information on forest areas. Forest areas were divided into broad-leaved forests, coniferous forests, and mixed forests. For more accurate calculations, specific data are required; hence, in Poland, a modification was used that was more detailed than in the original and used such terrain categories as managed forests, forest glades, windfall forests, forest roads, and young forests (Ciepielowski et al. 2002). A method was also developed for the commercial forests using a parameter applied in forest management, viz., the so-called tree cover (Miler 2012; Wróbel et al. 2020). The SCS–CN method is based on the water balance equation and the two following assumptions: the equality of total precipitation and the sum of the initial losses, current infiltration, and effective precipitation; and the equality of the quotient of the effective precipitation and the total precipitation reduced by the initial losses and the quotient of current infiltration and the maximum potential retention of the catchment (Rallison and Miller 1981; Mishra et al. 2003):

The maximum potential retention S is calculated in mm depending on the CN parameter and is expressed by the following formula:

$$S = 25.4 \times \left(\frac{1000}{\text{CN}} - 10 \right) [\text{mm}]$$

The determination of the CN parameter in the area of the forest river catchment was carried out on the example of the Łutownia River in the Białowieża Primeval Forest in north-eastern Poland. Due to the limitations of the SCS method (Ponce and Hawkins 1996), a lowland catchment area of 121 km² was selected for the analysis. The river catchment was divided into nine sub-catchments according to the hydrographic map of Poland (Fig. 1), which is a database on the hydrography of Poland. The Corine Land Cover was chosen as the basis for determining a land-use category in the partial catchment areas of the Łutownia River. The land-cover classes in the CLC database were divided into three levels. The first level included five main types of terrestrial land cover: agricultural areas,

Fig. 1 Division of the Łutownia catchment area into partial catchments along with a river network

anthropogenic areas, forests and semi-arid areas, wetlands, and water bodies. Within the second level, 15 forms of land cover were classified, which can be represented on the maps at scales from 1:500,000 to 1:1,000,000. Finally, 44 classes were distinguished on the third level. This level of detail was based on the land-cover databases in all European countries. The land-cover parameters for the discussed studies were estimated according to Corine Land Cover, which was modified to consider the degree of tree cover (Miler 2012). Soil is another factor affecting the CN parameter. Four soil groups were distinguished according to the permeability criterion. Group A includes the most permeable soils, and group D includes the soils with high clay contents. The average humidity conditions were calculated for the Łutownia River catchment. The soil group was determined for each of the 4944 designated areas according to the data from the State Forests IT System. Each area was also sorted by the degree of tree cover.

Results

Based on the weighted average, the share of precipitation in each soil group was determined, and the share of precipitation was determined depending on the tree cover in that area. Finally, based on the weighted average, the CN parameters were determined depending on the soil type, land-cover, and moisture conditions. The calculated values of the CN parameter for the individual partial catchments ranged from

Table 1 The CN parameters and potential retention for the Łutownia river catchment

Catchment	CN parameter	Catchment potential retention
1	43	337
2	46	298
3	38	414
4	40	381
5	41	366
6	45	310
7	47	286
8	44	323
9	54	216

38 to 54. The lowest values were recorded in the northern part of the catchment (Table 1). Based on the CN values, the potential retention capacities of the partial catchments were calculated. The calculated values were between 216 and 414 mm. According to the obtained values, the retention facilities should be arranged first in the partial catchments numbered 3–5, which are located in the central part of the catchment (Table 1).

The final stage of the procedure for prioritizing the locations of retention facilities was to develop a map that illustrated the grouping of the partial catchments depending on the calculated potential retention capacities. Five potential retention classes were adopted (Fig. 2). Low priorities for

retention investment projects were assigned to areas with values below 250 mm and high priorities were assigned for those above 400 mm, accordingly.

Discussion

The basic principle of retention should be to retain and properly allocate as much water in the landscape as possible and for the longest period of time, especially in the spring. Measures to retain water in forests must take into account different terrain conditions, meteorological conditions, and the state of the soil water balance. The effectiveness of retention measures varies depending on the precipitation and site characteristics. For this reason, it is important to properly arrange retention devices in the catchment areas. The analysis for the planning of retention facilities indicated that the lack of simple methods for arranging the layout of retention facilities in forest habitats on the catchment scale. This value can be calculated using the relatively simple SCS–CN method. The potential retention values obtained depend on the area in which we perform the analysis. The Corine Land-Cover method used to calculate the CN parameter is considered the most effective (Borowicz et al. 2011; Banach 2012). The analyses performed allowed us to state that the SCS–CN method can be used to determine the potential retention in partial catchments when deciding the locations of retention facilities.

Fig. 2 Division of the partial catchments according to the calculated potential retention capacities

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