JOURNAL OF WATER AND LAND DEVELOPMENT
ISSN 1429–7426, e-ISSN 2083-4535

Polish Academy of Sciences (PAN), Committee on Agronomic Sciences
Section of Land Reclamation and Environmental Engineering in Agriculture
Institute of Technology and Life Sciences (ITP)

JOURNAL OF WATER AND LAND DEVELOPMENT
2020, No. 44 (I–III): 126–135
https://DOI.org/10.24425/jwld.2019.127053

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://journals.pan.pl/jwld

Received 16.10.2019
Reviewed 18.11.2019
Accepted 29.11.2019

**A** – study design
**B** – data collection
**C** – statistical analysis
**D** – data interpretation
**E** – manuscript preparation
**F** – literature search

# Use of different forms of retention as the condition of sustainable management of water resources in rural environment

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**For citation:** Patro M., Zubala T. 2020. Use of different forms of retention as the condition of sustainable management of water resources in rural environment. Journal of Water and Land Development. No. 44 (I–III) p. 126–135. DOI: 10.24425/jwld.2019.127053.

**Abstract**

The paper presents the problem of the growing water deficit and the possibility of sustainable development of water resources in rural areas of Central and Eastern Europe (using the example of Poland). It is estimated that the amount of resources in this region is reduced by about 70% compared to the average for Europe. In drought periods it comes to limitation of economic activity, including agriculture. Particular attention was paid to the necessity to extend landscape, underground, and snow retention, as an alternative to dams, which are currently the most popular in lower-order catchments. It has been shown that the construction of small agricultural reservoirs is not always preceded by adequate consultations and pre-design studies, which may result in financial losses and legal problems. Simultaneous use of many alternative forms of retention should be more effective than the implementation of reservoirs. In addition, increasing the hydraulic roughness of the catchments slows down the outflow of products of erosion and contributes to the protection of surface retention structures (maintaining natural and economic usefulness of reservoirs).

**Key words:** *agricultural areas, catchment, water resources management, retention*

## INTRODUCTION

Water resources are among the most important factors enabling the existence and proper functioning of natural systems. They affect the diversity of biological elements, and they are the necessary condition of preserving natural values and the development of ecological balance. They are also vital for sustainable and balanced socio-economic development. In rural areas they determine the yield to a great extent [DAVIS 2007; TENDALL, GAILLARD 2015].

Many countries in the world have scarce water resources, and the possibility of their use is often limited due to poor quality. This problem also refers to the European continent – for example its central and eastern part [MIODUSZEWSKI 1996; 1999; ZUBALA, PATRO 2016]. In Poland, renewable resources of surface water per capita amount to about 1600 $m^3$, with a minimum in dry years of 1100 $m^3$ [Eurostat 2015]. According to the FAO report [FAO 2003], countries with less than 1000 $m^3$ of water per capita per year are considered to be affected by a deep deficit, which may contribute to the inhibition of economic development, particularly agriculture.

The observed deterioration in the structure of the water balance of some countries came about because of incorrect activities, resulting in acceleration of the land phase of the water cycle. The lack of an efficient system of management and exploitation of water resources within small agricultural catchments contributed to the drainage of entire regions and the occurrence of adverse changes in the natural environment. Among the causes of reducing the natural retention capacity, excessive deforestation, prevalence of drainage land reclamation, soil degradation, elimination of small water reservoirs, and an impervious surface are the most common [MIODUSZEWSKI 1999; VAN DER BRUGGE *et al.* 2005]. Climate changes also overlap limited water resources, causing extreme meteorological and hydrological phenomena [RUNHAAR *et al.* 2016].

The effects of water scarcity generally manifest themselves in the reduction of flows in streams, lowering of groundwater levels, loss of water in small water bodies and erosion intensity. Eliminating these risks is possible by collecting water in periods of its excess (e.g. winter melts) and using it in periods of deficiency (e.g. droughts in summer) [EEA 2012; MIODUSZEWSKI *et al.* 2014]. For this purpose, programmes for extending water retention were developed in some countries. Their assumptions are appropriate, but the implementation sometimes raises concerns.

The programme of small retention in Poland was launched in 1995 and consists of comprehensive activities in the field of water management of small agricultural catchments [Porozumienie… 1995]. Their basic aim is to improve, increase and use rationally water resources, taking into account both economic needs and environmental requirements. National programme assumed developing regional programmes of small retention, including the modernisation and construction of water storage facilities with a capacity of up to 5 mln $m^3$. It also included the need to limit implementation of the drainage of wetlands, peatlands and forest areas. The assumptions are compatible with the demands of the EU Water Framework Directive [Directive 2000/60/EC].

Although there are many ways to increase the retention capacity of an agricultural basin, the managing authorities focus mostly on the construction of small dam reservoirs. Significant amounts of funding are allocated to activities in this field. In the framework of the Polish programme, storage of approximately 1 141 mln $m^3$ of water until 2015 was planned, mainly in reservoirs and dammed lakes. Results of the program of small retention in the middle of its duration (2007) amounted to 142 mln $m^3$ (12% of that planned) only [CSO 2008], while at the end of the period the retention increased by another 90 mln $m^3$ (8% of that planned) [CSO 2015]. This was due to insufficient financial expenditure and complicated formal procedures. The small increase of retained water at this time is also the result of poor utilisation of the possibility of retention drainage systems which are an important part of the infrastructure of agricultural land [KOWALEWSKI 2008; MIODUSZEWSKI 2004].

Unfortunately, the authors' findings indicate that the implementation of water bodies is not always preceded by professional pre-design studies (general recognition of the basin, water quality, geotechnical and hydrogeological conditions etc.). This may result in further financial losses, examples of which are shown later in this article. Far too little attention is paid to the protection and development of water resources using alternative forms of retention. This is probably due to the lack of knowledge and experience in this field and the attachment to traditional methods.

## MATERIAL AND METHODS

The aim of our article is to demonstrate the main problems and popularisation of the sustainable development of water conditions by using many forms of retention simultaneously. These issues are of particular importance in the context of the growing water deficit in some regions of the world. The analysis focuses on agricultural land, where water is a decisive factor in the size and quality of production. Considerable attention has been paid to the benefits of the development of less known types of water retention (including landscape, soil, and snow retention) – usually less expensive and easier to implement than the most popular retention tank. Examples of the effects of constructing dams on watercourses without carrying out appropriate pre-design studies were presented.

A significant part of the presented data comes from studies carried out in Poland as this part of Europe is characterised by extremely poor resources and growing water needs. In recent years an increase in interest in these phenomena has been observed, as a result of the need for making agriculture independent of weather conditions.

The article should also be a significant supplementation of knowledge of the problems of sustainable water management, an important source of information for agronomists, scientists in the field of water resources management and agricultural space planners.

## RESULTS AND DISCUSSION

Water retention is considered one of the most important conditions to increase the disposable resources of the agricultural basin. The size and character of retention depend on a number of natural and anthropogenic factors. Its expansion is based mainly on complex activities, causing rapid conversion of surface runoff on much slower ground outflow and water storage in reservoirs. The hydrological effect of increased retention is to reduce the variability of water resources in time. In Polish literature water retention is classified in different ways. It is divided into natural and artificial, or controllable and uncontrollable. According to another classification – surface, landscape, soil, underground and snow measures are also distinguished (characteristics in the following chapters) [KOWALEWSKI 2003; MIODUSZEWSKI 1999].

Natural retention is conditioned by natural factors occurring in the area. The possibility of creating this retention as a result of technical activities is small – only to take actions aimed at its correction. Artificial retention is created as a result of human activities, which may include constructing new water retention structures as well as increasing existing natural retention [ŁABĘDZKI 1997; MIODUSZEWSKI 1996].

A characteristic feature of controllable retention is the ability to dispose of water resources collected in different structures at any time. Reservoirs equipped with flow control devices are mentioned [DZIEWOŃSKI 1973; MIODUSZEWSKI 2012]. Most types of retention mentioned in the literature, including very small water bodies, represent uncontrollable retention. According to MIODUSZEWSKI [1999], it is automatically functioning retention with a capacity that is difficult to determine. Increasing landscape and ground retention influences the change of water circulation in the catchment, lowers states of flooding in streams and increases low flows; however, this process cannot be controlled.

## SURFACE MEASURES

Retention of surface water is related to the instantaneous volume of water which is in river courses, artificial ditches, canals and various reservoirs – dug ponds, damming structures, debris dams etc. (Fig. 1) [MIODUSZEWSKI 1999; MUSHTAQ *et al.* 2007].

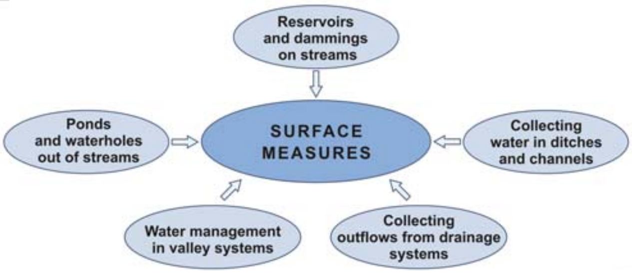


Fig. 1. Elements of surface water retention; source: own elaboration

Storing water in surface retention structures can significantly influence the improvement of the water balance of the agricultural basin. Many authors emphasize that the retention of water in reservoirs, canals and river backwaters increases the resources not only within them, but also in adjacent areas – including the increase of groundwater levels [WINTER 1999; ZUBALA 2005]. The use of small reservoirs to protect against erosion is increasingly common in agricultural areas. By slowing down the flow within the tank, the bed load and suspended material are stopped – including fertilizers. On the one hand, this phenomenon limits the storage space of the structure with time, on the other intensifies the processes of self-purification of water [FIENER *et al.* 2005; PATRO 2008].

The role of a single, small tank to increase water resources and protect against flooding, in contrast to a large water body, is relatively small. However, with a larger number of such tanks, located both along streams and watershed areas, their importance in improving the water conditions of the catchment is usually very high [KOWALEWSKI 2003; REINHARDT *et al.* 2011]. The presence of numerous micro-reservoirs determines an increase in the intensity of water exchange in the agricultural landscape. KĘDZIORA [2008] reports that at a wind speed of 1 $m \cdot s^{-1}$, evaporation from the surface unit of a small tank is 24% higher than of a large tank (compared reservoirs covering an area of 0.4 and 40.0 $km^2$). The intensification of the vertical exchange of water vapour eventually brings a benefit of increasing precipitation, especially in summer.

The correct water management within the drainage valley systems is of great importance to both agriculture and the protection of water resources. Such systems often include a large number of drainage or drainage-irrigation ditches and flow control structures. According to some authors, the basic premise of the operation of such systems should be the maximum possible utilisation of own waters. Adequately early closing of dams in spring (before ground water falls not more than a 12 centimetres below the ground surface) gives an opportunity to retain a large amount of water, supplying the needs of plants during their intensive growth [BRANDYK 1990]. MIODUSZEWSKI [2003] estimates that by controlling the outflow from the drainage network it is possible to store 50–70 mm of water including nutrients carried away from farmlands. Studies of NYC and POKŁADEK [2009] showed that the use of a regulated outflow in small valleys covered by permeable soils eliminates a shortage of water in excess of 150 mm. The authors point out that in conditions of limited water resources only a year-round control of damming can produce a beneficial effect of drainage.

Significant valley retention characterises flat and wide river valleys built from organic soils. Increasing retention is possible there by conducting activities delaying the flow of high waters. Among the most recommended solutions are: the creation of dry reservoirs in the river valley, allowing the flooding of poorly utilised agricultural polders (grasslands) by flood waters, making dikes and narrowings in the course of the river and its valley [MIODUSZEWSKI 2014; TRYBAŁA 1996]. These measures may be taken only if they do not cause any economic damage or have no negative effect on the environment as a result of prolonged flooding of the valley.

## SURFACE MEASURES – EXPANSION OF SMALL DAMMING STRUCTURES

For various reasons, surface retention is associated most often with the retention of water in reservoirs. More and more small structures of such type are built in the rural regions of Central and Eastern Europe. Their main task is to increase the available water resources. However, they can perform different specific functions, e.g. economic, recreational, and ecological. Small dams are sometimes built spontaneously without solid consultations and preliminary research. Underestimation of existing environmental and economic conditions results in economic losses and legal problems. Two reservoirs (Dys and Czajki) built in the Lublin Upland (southeastern Poland) in recent years are presented as an example (Fig. 2). They are located in loess agricultural catchments – strongly exposed to water erosion. These areas are characterised by a variety of landforms. Significant relative heights and slopes are conducive to rapid surface run-offs. Intensive processes of ero-


Fig. 2. Location of the Dys and Czajki reservoirs; source: own elaboration

sion are often intensified by improper layout of fields and ground roads. In many places, ploughing involves both steep slopes and valley bottoms in the vicinity of watercourses.

The first of the presented damming structures was built within the framework of the concept of the impoundment of the valley of the Ciemięga River. Initially a cascade of six structures was scheduled, but so far only one has been completed in the village of Dys. The area of the reservoir is 0.9 ha, the average depth – 1.8 m and the capacity – about 17 thous. $m^3$ (Schindler's ratio – surface catchment area/reservoir volume – 7235 $m^2 \cdot m^{-3}$). The tank is surrounded by dikes and there are no facilities to protect against silting (no settler and buffer zone) – Photo 1a. Observations were carried out in 2004–2007 [ZUBALA 2009]. River water supplying the reservoir was described as having unsatisfactory quality. Phosphates ($PO_4^{3-}$) constitute a particular risk; the maximum concentration reached 1.7 $mg \cdot dm^{-3}$. Also, relatively high values were recorded for nitrites ($NO_2^-$) and oxygen demand ($BOD_5$, $COD_{Cr}$). In a short time, agricultural pollutants accumulated in the water of the reservoir, which resulted in eutrophication and dieback (Photo 1b). The concentration of $PO_4^{3-}$ exceeded even 3 $mg \cdot dm^{-3}$. Intense rainfall and snowmelt runoffs carried large amounts of suspended solids into the reservoir (mainly the eroded soil material). The effectiveness of retaining the suspended solids sometimes reached 97%. Within a few years, the thickness of the sediment layer reached 0.5 m on average, which corresponds to nearly 30% of the initial depth of the reservoir (limitation of the usable capacity). Up to now, this small structure was reclaimed twice (including drying and removal of sediments).

The second reservoir was built on the Milutka stream in the village of Czajki in 2012. It is located within the Skierbieszowski Protected Landscape Area and was established in order to improve water management of the agricultural municipality of Kraśniczyn. The reservoir covers an area of 21.3 ha and its total capacity is approx. 342 thous. $m^3$; the average water depth is 2 m (Schindler's ratio – 85 $m^2 \cdot m^{-3}$). It is supplied mainly from the current flow of the stream. Surface feeding occurs during snowmelt and heavy rainfall. Research carried out before the construction of the reservoir in 2009–2011 showed that the water quality in the Milutka stream was relatively good [PATRO 2013]. Indicators lowering water quality in respective periods were phosphates ($PO_4^{3-}$) and iron ($Fe^+$) with the maximum concentrations of respectively 5.5 and 1.1 $mg \cdot dm^{-3}$. In contrast, research into the quality of groundwater on the border of arable land and meadows showed very high concentrations of nutrients (mineral forms of nitrogen and phosphates), which indicates a large load of nitrogen and phosphorus introduced into the environment. Good water quality in the stream resulted from the use of the bottom of the valley as a meadow (green biogeochemical barrier). Research conducted after the construction of the reservoir indicates that the main threat is the direct vicinity of arable fields and pastures. Unfortunately, no buffer zones to protect the water body against inflow of pollutants were planned. In some places fields were ploughed up to the shoreline (Photo 2a). Before the tank was built, a thick layer of peat being a source of nutrients had been left at the valley bottom. In addition, the functioning of the reservoir was interrupted by the renovation of the earth dam (including the drain and overflow structure) six months after its construction and its partial disassembly in 2014 due to problems with dam stability and its unstable operation (Photo 2b). Currently, legal measures are undertaken to determine the responsibility for defective project performance.

The continuation of the programme to increase water retention requires accurate exploration of natural and economic conditions of individual agricultural catchments and providing anti-erosion protection. The majority of Polish agro-ecosystems are characterised by substantial simplification, resulting in the opening of matter cycles. Shifting nutrients contribute to the deterioration of the quality of surface water resources and to concomitant limitation of their availability [POWERS *et al.* 2014]. It is not accidental that Poland is a major supplier of pollutants into the Baltic Sea. It creates a concern that under the current pressure this process can lead to degradation of this water body in

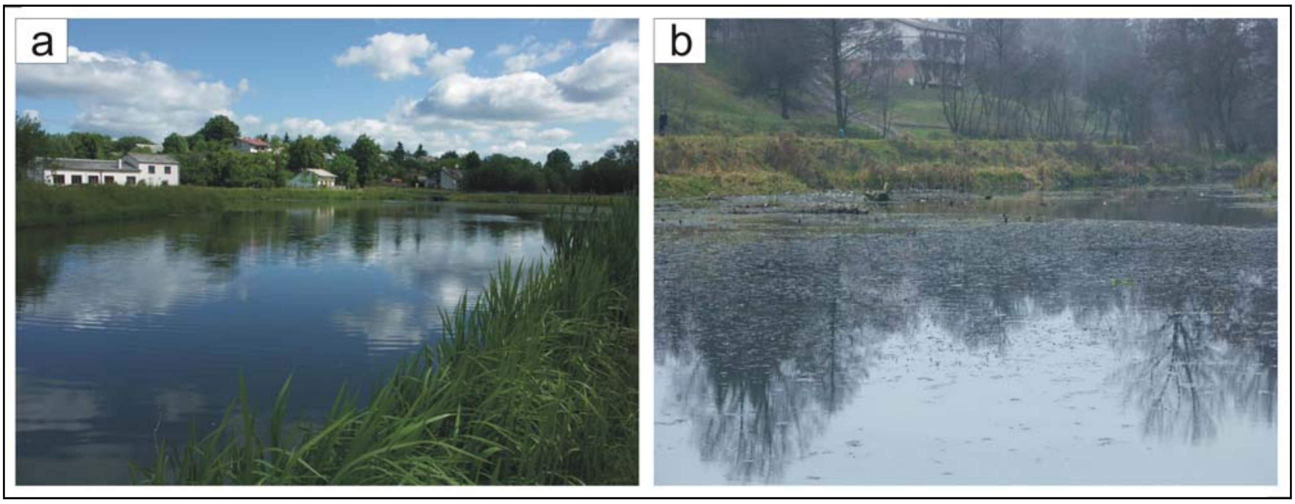


Photo 1. The processes of eutrophication and overgrow of the reservoir Dys: a) water surface free of vegetation – two years after the removal of sediment – June 2004, b) total infesting of the reservoir by vegetation – November 2006 (phot. *T. Zubala*)

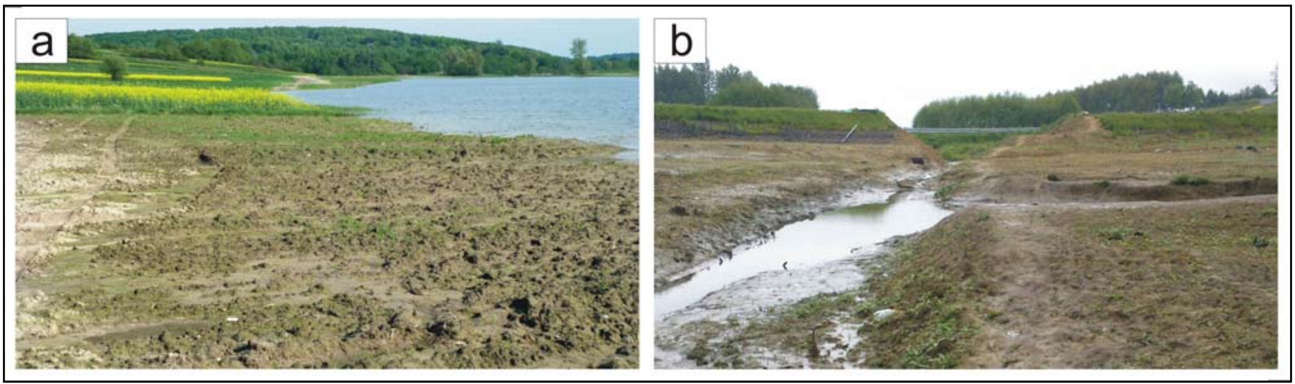


Photo 2. Operating and structural problems of the reservoir Czajki: a) crops coming to the shore – May 2013, b) oversized settling of the dam and disassembly of its central part (a thick layer of sediments on the bottom) – May 2015 (phot. *M. Patro*)

a short time [CONLEY 2012; HELCOM 2007]. In order to reduce the risk, it is necessary to introduce effective biogeochemical barriers against pollution – permanent grasslands or shelterbelts near watercourses and water reservoirs and grasslands in the line of periodic runoff [BORIN *et al.* 2010; ZUBALA, PATRO 2016]. PAVLIDIS and TSIHRINTZIS [2017] report that tree roots in agro-forestry systems are able to reduce nitrogen and phosphorus residues in soils from 20% up to 100%, have significant potential to reduce pesticides leaching and runoff, and simultaneously they provide additional benefits to the ecosystems, including erosion control, improvement of soil quality and enhancement of biodiversity.

In the slope valleys shallow reservoirs should be built as biofilters and storage facilities of soil material and water runoffs from the agricultural catchment area [PATRO 2008]. Protective measures that must be undertaken in order to protect the reservoirs should also result in developing landscape retention.

## LANDSCAPE MEASURES

Landscape retention is closely linked to shaping and developing the area. Its size depends on the hydraulic roughness of the surface of the agricultural basin. Increasing landscape retention is associated with reducing surface runoff, usually resulting in increasing the volume of water infiltrating into soil [CHEN *et al.* 2010; FU *et al.* 2005]. Special attention should be paid to developing an appropriate system of crop fields, grasslands, shelterbelts, etc. In many cases, this means the necessity of redistribution of agricultural land and changes in their usage (Fig. 3).

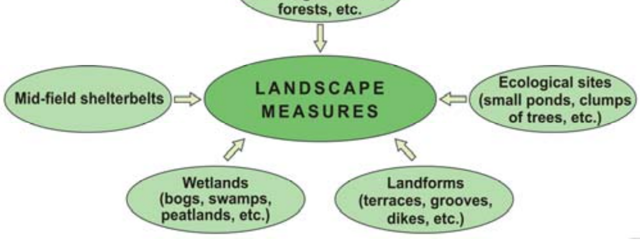


Fig. 3. Elements of landscape water retention; source: own elaboration

Forests are of great importance to controlling the outflow of water from the basin. It has been shown that in a partly afforested catchment snowmelt and rainfall floods are delayed in time. This is explained by significant interception, slower melting of snow, high litter retention capacity as well as increased porosity and permeability of soils in the forest [BIEGER *et al.* 2015; SUN *et al.* 2006]. According to MIODUSZEWSKI [1999, 2003], the larger the wooded area of the catchment and the more natural character of the forest, the stronger the impact of the forest on the water cycle. The author emphasises the major role of forest planting in reducing floods in areas with large declines and poorly permeable soils.

An important activity to limit surface water runoff from agricultural lands with high relief is creating shelterbelts. Particularly important for the improvement of water resources in a basin is planting trees and shrubs in strips perpendicular to the direction of water flow. According to the literature, mid-field shelterbelts also favourably affect microclimate (increasing relative humidity, reducing potential evaporation) and increase the depth of snow and delay its melting in the spring [WĘGOREK 1985; WILUSZ, JAWORSKI 1960]. This all means that in an area of 1 ha covered with strips of trees up to 300 $m^3$ more water soaks into the soil than in an open area (equivalent to 30 mm precipitation) [RYSZKOWSKI *et al.* 2003]. It was also shown that fields protected by shelterbelts evaporated less water than open fields (wind protection), although the evapotranspiration of trees is greater than that of fields. It gives a positive effect of increasing the intensity of an exchange of water vapour between the surface and the atmosphere, protecting water resources of arable land lying between belts of trees at the same time. The results obtained by VIAUD *et al.* [2005] confirm the conservation and reclamation importance of hedges on slopes. The authors suggest that this type of solution can act as an element to control surface runoff, reduce the frequency of floods and be a barrier against water erosion. The level of water saturation of the soil is more important here than the amount of precipitation.

An important role in reducing surface runoff is attributed to grasslands. It was found that water flows much more slowly in meadows than in arable lands, which is particularly visible in spring and autumn when the fields are not covered with vegetation. FIENER and AUERSWALD

[2006] have shown a great potential of sodded areas to reduce the volume of runoff, sediment and pollution from agricultural catchments. In the observation period the reduction of runoff and sediment delivery was 87 and 93% respectively. Under study conditions 70% of the total outflow and 68% of deposits was established in the period of February to April (seasonal phenomena).

In some cases, the arrangement of the agricultural road network accelerating or delaying runoff of rainwater on the surface of the land can be important. Field roads with ruts are normally zones of concentrated water runoff, even as a result of low intensity of rainfall. A flood wave forms particularly quickly when roads run in the direction of slopes, which also implies a high risk of erosion [BOARDMAN, POESEN 2006; ORLIK, WĘGOREK 1995].

Peat bogs in river valleys and land depressions feature special retention capacity. According to MIODUSZEWSKI [1999, 2003], the presence of peatlands within the basin reduces the flow of high water as the result of slower outflow of floodplains. This is due to the high hydraulic roughness and surface retention of fluviogenic wetlands. It was established that when the proportion of the area of peat bogs in the whole catchment area is 10%, the flood wave is reduced by 30–40%.

Anti-erosion measures used on areas of high relief, in addition to their essential function of limiting soil washouts, also have a positive impact on water resources – reducing the flow of water on the surface of the land. Therefore, any measures to prevent erosion, e.g. terracing of slopes, ploughing along contour lines, using after-crops, introducing mid-field shelterbelts, and creating settling tanks are actions to improve water conditions in the area [BOARDMAN, POESEN 2006; ORLIK, WĘGOREK 1995].

DRUŻKOWSKI [2001] draws attention to the need to take comprehensive action to reduce the dynamics of water circulation in areas of high relief. Converting a part of existing agricultural lands into forests, increasing the area of pastures and meadows, restoring the natural character of valleys, and performing small land improvement facilities are mentioned.

## SOIL MEASURES

Soil retention is associated with the ability of soil to retain a part of rainwater in the soil pores in the unsaturated zone (above the groundwater level). The capacity of this form of retention depends on the type, particle size distribution, structure and actual moisture of the soil. These characteristics can be improved by appropriate measures (Fig. 4) [RONG *et al.* 2017; TRYBAŁA 1996].

It is the consensus that improvement in the structure of both heavy and light soils increases their capacity to retain water, at the same time causing improvement in moisture conditions for crops. Proper agrotechnical measures, the use of organic fertilizers, and other activities increasing the content of humus combine to create a crumb soil structure, and thus lead to an increase of potential water resources in the soil [KUDUK 1985; WANKE 1993]. Studies of some authors have shown that an increase of 1% in the content of

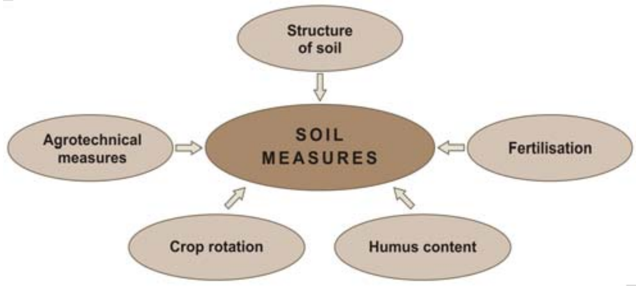


Fig. 4. Elements of soil water retention; source: own elaboration

humus in 1 m of soil layer corresponds to the increment of water retention of about 35 mm [RYSZKOWSKI *et al.* 2003]. If this increase is related only to the arable layer (30 cm) the increase in the retention capacity will amount to 10 mm – on one hectare of arable lands a one-time increase of retained water of 100 $m^3$ could be obtained. According to TRYBAŁA [1996], loosening of the arable layer causes a significant increase in total porosity and water capacity of the soil, which speeds up the absorption of water. As a result of conducted experiments an increase in total porosity from 36 to 48% was obtained, bumping the capillary capacity of the soil by 4%. MIODUSZEWSKI [1999] estimates that under favourable conditions appropriate measures could increase the retention capacity of the soil by about 20–50 mm. Assuming that in half of Polish agricultural areas (approximately 10 mln ha) the retention would be increased only by 20 mm; additional storage in the soil of about 2 $km^3$ of water would be possible. It is the size that counts in the water balance of the country in relation to existing possibilities of storing water in artificial reservoirs, as well as in relation to the volume of water flowing out to the sea during the year. BYCZKOWSKI [1999] emphasizes, however, that an increase in the retention capacity of sandy soil (groundwater recharge areas) connected to the conduct of crops with larger evapotranspiration (including afforestation) can cause a reduction in groundwater recharge, and thus the depletion of its resources. This is due to the fact that most of the precipitation is retained in the aeration zone, and then absorbed by plants. On the other hand, SHE *et al.* [2014] point out that the introduction of vegetation can be helpful in preventing soil erosion. However, the wrong choice of species and their inappropriate density can sometimes lead to deepening water shortages and ground overdrying (evapotranspiration). In experiments it was determined that the total loss of water from semi-natural grasslands of loess catchments was close to the amount of rainfall, which significantly reduced the outflow from the catchment [SHE *et al.* 2014].

On heavy soils, poorly permeable and compacted, it is recommended to conduct agro-melioration involving deep loosening. Research by BAUMHARDT *et al.* [2008] showed that appropriately carried out agro-melioration works can improve soil structure, increase the water conductivity and eliminate poorly permeable interbeddings inhibiting the vertical flow of water. The role of agro-melioration in this case is dual: to increase retention of the soil and facilitate the flow of water to aquifers.

**UNDERGROUND MEASURES**

Retention of groundwater arises from the ability of aquifers to store water in the saturated zone. The resources of these waters depend on the geological structure and the volume of infiltration (Fig. 5). Underground tanks are considered as the least unreliable and the most effective protection of agricultural water resources, because with increasing depth of the water table evaporation losses decrease [CHEŁMICKI 2002; YANG *et al.* 2015].

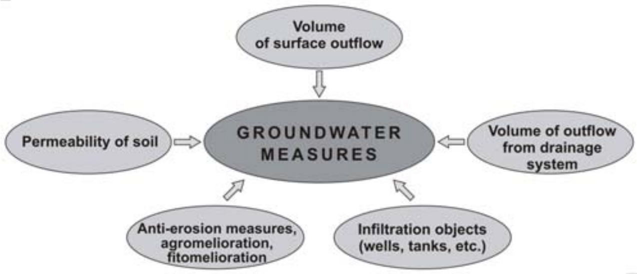


Fig. 5. Elements of underground water retention; source: own elaboration

The increase in supplying aquifers, thereby increasing resources of groundwater can be observed when actions are taken to reduce runoff and accelerate infiltration (e.g. increasing the permeability of soil, destroying poorly permeable layers). According to MIODUSZEWSKI [2003], implementing low dikes or grooves along contours can be a simple and effective measure, e.g. on the line of balks – also used as protection against erosion.

The presence of a drainage system has a high impact on the water conditions of the area. Agricultural drainage accelerates the outflow of excess water in a spring and after the precipitation, thereby allowing starting agrotechnical operations earlier and extending the growing season. In many cases, drains shed not only a harmful excess of water, but needlessly reduce water resources which could be used by the plants at a later date. Therefore, using devices to control the outflow of a drainage network is considered advisable [MUMA *et al.* 2016; TRYBAŁA 1996]. Research of KOSTRZEWA *et al.* [1998] showed that damming of water in drainage wells may even cause a threefold increase in the supply of water in sandy soils (raising ground water level by 20–30 cm compared with drainage watersheds without damming structures).

When there is a need for a rapid renewal of groundwater resources, artificial feeding is sometimes used. CHEŁMICKI [2002] gives two examples of such enrichment: injection using infiltration wells and infiltration using infiltration pools. In the process of artificial feeding, flood water can be used in areas where thick ground occurs, characterised by good permeability. Infiltration devices, due to high investment and operating costs, are used rarely and mainly in order to supply drinking water. However, in favourable geological conditions they can also be applied to increase groundwater resources in small agricultural catchments [MIODUSZEWSKI 1999].

According to some authors, techniques of artificial feeding combined with the collecting of water are the key to the sustainable management of groundwater. These methods are considered to be particularly cost-effective and easy to implement in alluvial aquifers. The increase of groundwater resources takes place using the existing surface water resources – including increasing the flow of a river, feeding by irrigation and drainage [JHA *et al.* 2009].

KEILHOLZ *et al.* [2015] carried out a hydrological study to evaluate the total water cycle in agricultural area, with particular reference to groundwater replenishment and the impact of agricultural irrigation on the riparian natural vegetation. The results show that natural flooding is the major contributor to groundwater recharge. There is also a close interaction between irrigated agricultural lands and adjacent natural vegetation for groundwater levels and salinity up to 300 m away from the fields.

**SNOW MEASURES**

Issues related to water retention in snow have been studied by few scientists. Some of them show a great similarity between the retention curve of snow and sand so standard models of soil physics are used in studies [YAMAGUCHI *et al.* 2010]. A strong relationship between the size of retention and size of snow particles was identified. Another parameter which influences the hydraulic permeability of snow is its density [JORDAN *et al.* 1999].

Snow retention in rural areas stems from the accumulation of snow in winter and the use of water contained in it during periods of expected drought (melting control). Favourable conditions for local snow accumulation occur near rows of trees and shrubs, and fences. It is also recommended to heap snow using snow ploughs (creating piles) in shady places. Melting can be delayed by firming and covering snow with insulating materials (straw, reed, and sawdust). On the other hand, acceleration of melting is possible by covering snow with dark materials (ash, crumbled peat, organic fertilizer) which absorb solar radiation (Fig. 6). According to some authors, the use of snow retention is particularly appropriate during winters with poor snowfall [CHEŁMICKI 2002; MIODUSZEWSKI 2003].


Fig. 6. Elements of snow retention; source: own elaboration

## CONCLUSIONS

Poor water resources in some agricultural regions of Europe and the growing demand for water indicate the necessity for its economical use and fulfilment of protection tasks – both in terms of quantity and quality. An important element of sustainable water management includes activities in the field of retention. Their role is to protect against extreme hydrological events with simultaneous improvement of natural values. Controlling retention should take place in areas used in various ways, but it is the most urgent task in rural areas where the biggest water deficit in drought periods is noticeable. Therefore, rural areas should not be considered solely as a place where economic processes are implemented (plant and animal production) – all measures regulating the local water cycle should also be undertaken (increasing disposable water resources).

Many types of water retention can be differentiated, but it is an accepted classification and often the impact on one form causes changes to another one. For example, changes in landscape retention (hydraulic roughness of catchment area) may change soil retention. The introduction of mid-field shelterbelts or the afforestation of arable lands affects the size of interception, evapotranspiration and the characteristics of the soil profile, and thus retention properties of the soil. On the other hand, increasing the retention of surface water by building reservoirs or damming water in ditches, automatically increases the groundwater resources of the adjacent areas, changes the hydrological regime of the watercourse and alters local aquatic and terrestrial ecosystems.

Selection of measures of water retention in the catchment should result from the potential ability of the area to store water and the real possibility of supplying it with water, so the accurate recognition of natural and economic conditions (relationships between elements of the environment, land use planning, natural and man-made hazards) is necessary before undertaking projects to improve the structure of the water balance. All activities should also take into account the need to preserve the biological diversity and balance of agroecosystems in the basin and the protection and improvement of natural values of the agricultural landscape.

Although, water retention can be increased in many different ways, in countries such as Poland, the construction of dams on watercourses is still a preferred solution. Unfortunately, sometimes the implementation of such structures is not preceded by adequate consultations and pre-design studies (this concerns mainly micro-catchments), which results in financial losses and legal problems. Far too little attention is paid to the protection and development of water resources with the use of alternative forms of retention. This is probably due to the lack of knowledge and experience in this field and the attachment to traditional methods. The big problem is the underestimation of solutions reducing the outflow of agricultural pollutants and erosion products from the catchment. In many places the improper layout of fields and dirt roads is visible, and ploughing reaches directly the shorelines. Consequently, in the newly constructed reservoirs the rapid accumulation of nutrients and sediments can occur, which significantly limits their economic usefulness and deteriorates operating conditions.

Further implementation of programmes for improving retention requires more detailed recognition of natural and economic conditions in specific agricultural catchments and the introduction of biogeochemical barriers. The introduction of permanent turf grass cover or shelterbelts near watercourses and water reservoirs, and grasslands in the line of periodical runoff will increase the roughness of the hydraulic basin and improve landscape retention. Such solutions should provide a good alternative to the reservoirs.

**ACKNOWLEDGMENTS**

This article is also an expression of the authors' deep appreciation for the recently deceased Professor Waldemar Mioduszewski – an indisputable scientific authority and specialist in the field of water management. Many solutions were proposed, which are consistent with the concepts presented in the works of this outstanding scientist.

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