Int. Agrophysics, 1998, 12, 259-269

RECONSTRUCTION OF RETENTION CAPACITY OF SMALL RIVER BASINS AS A PROTECTION MEASURE AGAINST FLOODS AND DROUGHTS

W. Mioduszewski

Institute of Land Reclamation and Grassland Farming, Falenty, 05-090 Raszyn, Poland

Accepted September 1, 1998

A b s t r a c t. Poland have poor water resources. What is more, they are unevenly distributed in space and time. Human activity has made water balance even worse in many cases and increase in the frequency of extreme phenomena such as floods and draughts.

One of the methods to improve water balance is development of the so called small retention consists mainly in the increase of the potential retention abilities of small basins. The studies and approximate calculations carried out show that treatment consisting in the increase of swampy areas, number of water pools and small water reservoirs, damming up of eroded rivers and canals, improvement of the soil structure, inhibition of outflows from melioration systems, etc. can significantly increase water supply both for the natural environment and for the economic and communal needs.

Increased ability to hold water in the river basin by the methods of small retention is considered to be one of the indispensable conditions to secure balanced development. It refers specifically to agriculture and water management especially in the melioration objects connected with it.

K e y w o r d s: small river basins, water retention, floods, draughts

INTRODUCTION

Water reserves are generated in the areas utilised agriculturally or forest areas as a result of precipitation that vary in time and space (rainfall, snowfall). Reserves of water from precipitation are partially stored and utilised. Ability to hold water (store it) is called retention. Every basin is characterised by a different degree of its ability to hold water. Water is retained by forest, soil, water bearing soil layers, terrain reclines, as well as natural and man-made water reservoirs. Retention allows for holding water that appears "in excess" (thawing, intensive rainfalls) and using it in the periods of "deficit" (without precipitation). Nevertheless, momentary high water levels in rivers, high moisture levels in soils, together with periods of water deficiency manifested by low flows in rivers, soil drying-out, low levels of ground water are all natural phenomena. The lower retention ability is, the higher flow variability in rivers, the higher the amplitude of variation in the levels of ground waters, and the bigger the hazard for the human economic activities.

Natural retention ability of water basins in many areas was significantly decreased as a result of deforestation, construction of drainage systems, covering earth surfaces with tight layers of asphalt and concrete, degradation of mineral and organic soils, getting rid of ponds and small lakes, etc. It is believed that human economic activity contributed significantly to enhancing irregularity of the water flow in rivers and an increase in the frequency of occurrence of extreme phenomena such as floods and draughts. The measures undertaken so far to protect against unfavourable influence of draughts and floods have been mainly technical in character and included, among others: construction of water reservoirs, dams, and melioration systems. In many cases the results achieved were not satisfactory. Taking the above into consideration and considering the requirements imposed by the natural environment, it is believed that water balance and ways to minimise losses due to water excess of deficiency must be sought by some other methods that would be closer to nature. One of the pro-ecological methods is increasing or reconstruction of retention abilities of water basins together with implementation of correct rules of water management in the agricultural areas. Formation and control of water circulation in small basins directly influence conditions of ground waters and flows also in the rivers of higher order that are located below the mouths of smaller water races.

WATER AS DANGER FACTOR IN THE AGRICULTURAL LANDSCAPE

Poland is one of the countries with low water resources. Renewable resources of surface water, i.e., mean annual outflow from the area of Poland is 1580 m^3 per capita (data according to IMiGW – the Institute of Meteorology and Water Management). Whereas in Europe this index is equal to 4560 m^3. The above places Poland in the group of countries with very low water resources (Fig. 1). This poor water resources are moreover very varied in time and space. In our climatic conditions the highest flows in the water races (the biggest resources of surface waters) take place in spring and the lowest in autumn and winter. The ratio between the maximum and minimum average monthly outflow from the area of Poland. The above ratio is considerably higher for some of the rivers and reaches a two-digit value for mountain streams and small lowland rivers [16]. Momentary flows vary even more. For example, in the case of the Wisłoka river the ratio between the minimum and maximum flow is already 1:1000. Extreme natural phenomena are natural. It is also true for atmospheric precipitation and flows in the water races. Hence, it is only natural that water races swell and periods of after-draught with low precipitation and small flows in the water races occur. A lot of ecologists are of the opinion that one cannot talk about water excess or deficiency in nature. According to this concept extreme phenomena including floods and draughts are natural phenomena that are indispensable for keeping the right natural balance. One can call them dangerous only when they influence human economic

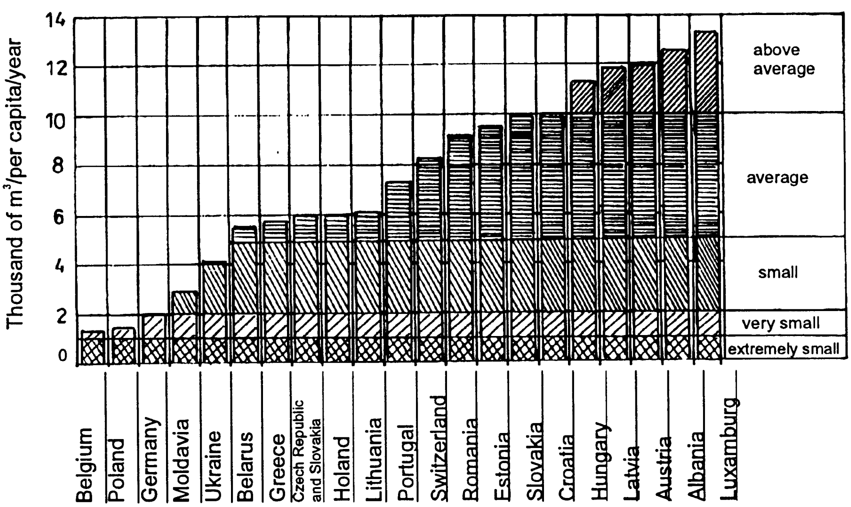

Fig. 1. Reserves of surface waters per capita in the European countries [m^3/year] according to IMiGW (the Institute of Meteorology and Water Economy).

activity in a negative way. Only on the background of human activities one can consider excess or deficit of water. In other words, "extreme natural phenomena" become "natural hazards" when they influence human activities in a negative way and result in countable losses (Fig. 2).

The most visible and perceptible hazards are floods. The first mention about floods in Poland dates back to the year 998. It is estimated that floods in the Wisła catchment-area occur every 5 years on the average, and in the Odra catchment - area every 7 to 10 years [10]. Excess of water in agriculture results not only from floods but also from long-lasting excess moisture levels in the soil. As late as in the 19th century there were starvation periods in Europe caused by wet years [11]. The last great flood took place in the Odra basin in July 1997 and caused uncountable economic and social losses.

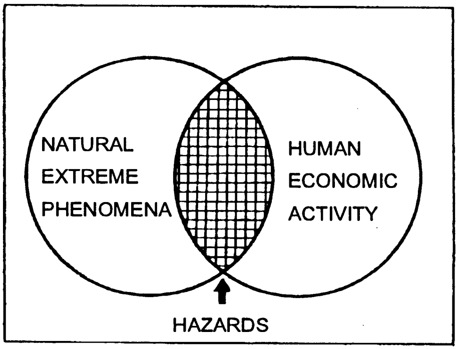

Fig. 2. Natural phenomena become dangerous when combined with human activities according to the Water Agency in New Zealand.

Chronicles did not give any mentions about starvation in Poland caused by water deficit, however such calamities happened in Ukraine and Russia [11]. Nevertheless, in a lot of regions severe atmospheric, hydrological or soil draughts occur and result in considerable losses for the national economy, and especially for agriculture. It has been estimated that the draught from 1992 that affected almost the whole territory of Poland resulted in the decrease of yields by at least 20%. The regions of central Poland are especially susceptible to draughts. It can be seen from, among others, the climatic water balance [6] presented in Fig. 3.

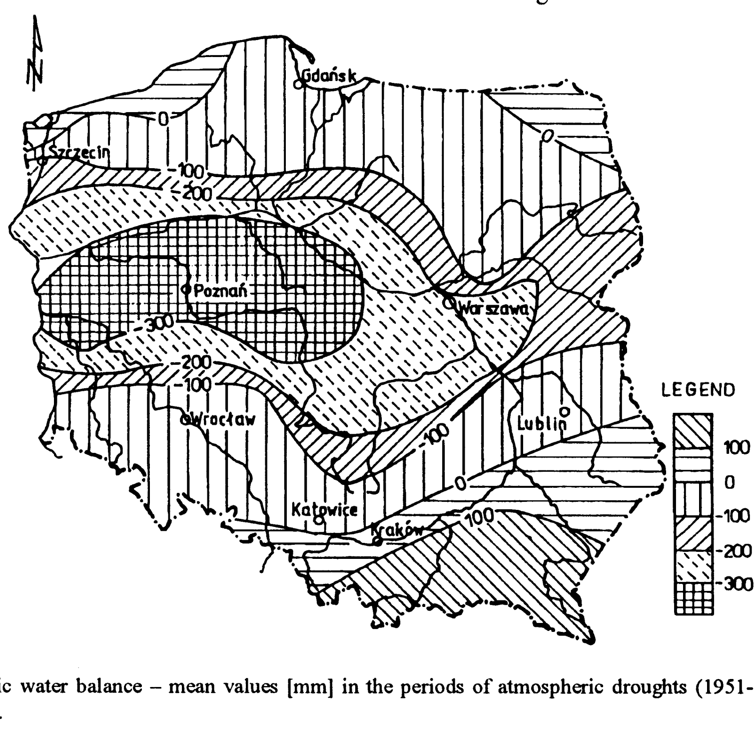

Fig. 3. Climatic water balance – mean values [mm] in the periods of atmospheric droughts (1951-1980) according to Kowalczak [6].

Danger of water deficit occur not only in the agriculture. In many regions of the country, especially in the mountains and in the piedmont regions where the resources of underground waters are small, severe water deficits for industry and human usage take place. Water deficit occurs also in the regions with disturbed water balance, i.e., in the region with intense water uptake (e.g., in part of the Kielce district, and in Śląsk) or in the regions that are strongly dewatered (e.g., close to the open pits).

In the recent years opinions on the strategy of preventive measures against natural calamities caused by water have changed. It results from the observations on the unreliable large technical infrastructures and dawning of the realisation that it is necessary to protect natural environment.

The methods of protecting and preventing water hazards can be divided into two groups:

- Adaptation of extreme natural phenomena to human needs, i.e., becoming independent from the changing environmental conditions. In this instance technical solutions such as dams, water reservoirs, and melioration systems are decisive.
- Adaptation of human activities to natural phenomena, i.e., management and exploitation of terrain in such a way that natural phenomena would exert the smallest possible negative influence on human life and human economic activity.

Fulfilling the conditions of balanced development means that more attention must be paid to the latter method of water hazard prevention, i.e., adaptation of human activity to the conditions of natural environment.

Wasteful exploitation of natural reserves, also water reserves, enabled development of human civilisation and economy but resulted in some unfavourable changes in the natural environment as well. Many researchers think [3] that worsening of the structure of water balance (more frequent appearance of extreme hydrological conditions) took place due to the decrease of natural retention capacity of river basins.

Reconstruction of retention capacities of basins seems to be the most environment friendly method to improve water balance and limit hazards caused by draughts and floods that fulfils the conditions of balanced development. It should be noted, however, that at the present state of land utilisation in the area of river basins and valleys and high population density complete reconstruction of the retention abilities of basins and full limitation of the negative effects of extreme phenomena by the adaptation of human activities to them (e.g., resettling inhabitants for the areas endangered by floods or increasing the retention in the inhabited regions, etc.) do not seem to be possible. On the other hand the regions utilised agriculturally can be substantially reorganised. Due to role they could play in the improvement of water balance, three types of regions that should be distinguished in the site planning and other plans for agricultural restructuring:

- Regions that are intensively exploited agriculturally with optimum water management from the agricultural point of view (drainage, irrigation) but where the conditions for the protection of water resources are followed.
- Regions that are extensively exploited agriculturally in which water management is adapted to agricultural needs, flora and fauna requirements, and protection of water resources.
- Regions that are not agriculturally utilised in which water management should be adapted to the requirements of natural environment, and any site planning for these regions should contribute to, among others, the improvement of the water balance of the basin.

No matter how and to what intensity the region is agriculturally exploited, attempt must be taken to limit quick outflow of thaw and rain waters which is identical with the renewal of the natural retention capacity of the river basin.

RECONSTRUCTION METHODS FOR THE RETENTION CAPACITY OF BASINS

Retention ability of the basin depends on many factors such as: geological structure, type of soil, topographic conditions, natural and hydrograpic net, water reservoirs. A typical, most often used method of increasing retention capacity is construction of water reservoirs. In the 60-ties a notion of small retention has been introduced. It denotes construction of small reservoirs (with capacity of below 5 mln m^3) that exert smaller influence on the environment [4]. In the 90-ties the notion of "small retention" has been extended to include the whole complex of activities aiming at an increase of the retention capacity of river basins [8].

The notion of "small retention" covers a vast range of technical and non-technical measures that result in quantitative and qualitative improvement of water resources due to the slowing down of the circulation of water and chemical compounds in the small water basins. It is assumed that the water retained in the period when there is an "excess" of it feeds water races during after-draught periods and can be utilised for industrial needs as it ensures proper levels of moisture in the natural ecosystem.

Small retention is treated as a complex, long term activity that covers vast areas of whole river basins. The methods of small retention do not introduce any significant changes into the natural water regime. They introduce indispensable adjustments that allow for the improvement of water balance without any disturbances in the biological balance of the ecosystem. Activities carried out in the framework of small retention can, to some degree, reconstruct (re-naturalise) some of the elements of the water system distorted by the so-far conducted human economic activity.

There are a lot of forms and types of natural and artificial retention that are interrelated and connected with one another. It is possible to divide retention into the following forms in a simplified way:

- related to landscape (biotopic),
- related to soil,
- related to ground and underground soils,
- related to surface waters,
- related to snow and glaciers.

Landscape retention results from the terrain relief and the way river basin is exploited and managed. An increase in the retention capacity consists in the limitation of the amount of surface outflow of thawing and precipitation waters. Forest retention is of utmost importance in this case [2]. Also preventive measures against erosion, planting trees and bushes, construction of grooves and dams along contour lines, relations between the patterns of arable- and grassland exert influence on slowing down quick surface outflow. Swamps (moors and peat-land) have enormous influence on the hydrological conditions and slow down the outflow of big waters.

Soil retention results from water storage in the sphere of unsaturated soil profile. Retention capacity depends on the type, mechanical composition and soil structure. Correct agrotechnical treatment, liming, agromelioration, etc.. are the treatments that improve soil structure increasing at the same time retention capacity. Additional water volume stored in the soil pores is utilised by plant during their vegetation.

Retention of underground waters results from water storage in the water-bearing layers. Any activities that limit surface outflow or speed up infiltration of precipitation water contribute to the increase of the underground water reserves. In most of the cases any activities aiming at the increase of landscape surface water retention increase water supply to the water-bearing layers at the same time.

Retention of surface waters is understood as water collection in the natural and artificial water races, ponds and other small reservoirs. Beside typical water reservoirs and ponds, any types of canals, ditches, water races and small water collection points on which there are constructions enabling adjustment of water levels and outflows can be treated as surface retention.

Retention of snow and glacial is a certain form of water storage. There are no practical methods to increase the resources of retained water in the form of snow or ice. However, it is well known that snow thawing in the forest is slower.

The review of methods of small retention (Table 1) presented here shows that there are potentially high possibilities for carrying out various types of activities aiming at an improvement in the structure of water balance. For example, approximate calculations show that it is possible to increase soil retention of arable land by about 2 billion m^3 and to collect above 0.5 billion m^3 of water in the melioration ditches. It constitutes about 4% of the average river outflow from the area of the country. These assessments are very approximate and are not confirmed by any in-depth studies. It should be noted that in many cases any activities to improve small retention result in the higher uptake of water by plants. An increase in the area of forest, swamps and moors, an improvement of the soil moisture conditions, etc., contribute to the increase of the evapotranspiration, and can, in some cases, cause a decrease of the absolute volume of surface and underground water resources. It is indispensable to carry out detailed studies on the quantitative evaluation of the influence of small retention on the dynamics of river flows and the level of ground waters.

Small retention, together with small reservoirs, is treated as the so-called uncontrollable retention as opposed to big reservoirs in which it is possible to control usable capacity in relation to the needs and climatic conditions (e.g., keeping up flood volume, conscious increase of the low flows). From the point of view of water management "small retention" is uncontrollable, automatic retention with the capacity that is difficult to assess [13]. An increase in the landscape, soil, or ground retention influences the changes in the water circulation in the basin, lowers flood levels in the river, and in many cases increases the states of low flows. However, this process cannot be freely controlled. An increase in the uncontrollable retention causes and increase in the potential abilities to collect water in the periods of its excess levels and longer periods of water retention in the soil, water-bearing layer or on the terrain surface in a way that is friendly for the natural environment.

Table 1. Some chosen formation methods for water resources

Water resources	Methods
Landscape retention (biotopic)	- pattern of arable lands, grasslands, forests, ecological cropland, small ponds; - forestation, creation of protective belts, planting trees, bushes, construction of grooves and terraces; increase of the area of swamps, moor and peat-land;
Soil retention	- improvement of the soil structure, agromelioration treatment, liming, correct agrotechnical treatment, crop rotation, increase in the soil humus content;
Ground and underground waters	- limitation of the surface outflow; - increase in the soil permeability; - preventive measures against soil erosion, phytomelioration and agromelioration; - adjustment of outflow from the draining net; - ponds and infiltration wells; surface waters-small water reservoirs;
Surface waters	- small water reservoirs; - adjustment of outflows from the ponds, and small lakes; - water collection in the melioration ditches, canals, etc.; - retention of outflowing water in the drainage systems; - increase of the valley retention;
Snow retention	- delayed and slow snow thawing

INFLUENCE OF SMALL RETENTION ON THE RIVER FLOW

Positive influence of activities causing an increase of retention capacity of small basins on the water balance does not rise any doubts and is widely accepted. Whereas any numerical evaluation of these activities is very difficult. In many cases it results from the insufficient recognition of this phenomenon and very complicated and complex relations between physical and biological parameters of the basin and flow processes of surface and underground waters. Table 2 presents an estimation of an increase in the retention capacity of the Narew Górna basin [7].

Data presented in Table 2 point to a high potential abilities to retain water by the methods of small retention. Big differences in the calculations between the minimum and maximum retention capacity confirm very approximate character of these calculations. However, it is very clear how important melioration systems. With proper exploitation they do not have to play the role of drainage only.

Table 2. Estimation of an increase in the retention capacity of the Narew Górna basin

Specification	Retention level in mln m^3	
	Min.	Max.
Damming up water in rivers	1.9	3.1
Damming up water in canals	0.2	0.3
Adjustment of outflow from the valley melioration systems	21.5	43.4
Adjustment of water from the drainage systems	21.0	41.8
Small water reservoirs -capacity of less than 1 mln m^3	15.8	31.7
Soil retention	12.8	51.4
Total	73.2	171.2

Figure 4 presents results of numerical calculations of the influence exerted by the exploitation of a valley melioration system on the size of outflow from the basin. The calculations have been carried out for the basin of 15 km^2 in which river valley that covers about 40% of the basin surface has been drained by a dense net of ditches. The assumption taken for the calculations was that the ditches had been equipped with damming-up devices, and water was hold there during vegetation period (from the 8th of April) at the depth of - variant I: 0.2 m, variant II: 0.8 m, and variant III: 1.4 m below the terrain surface. The calculations were carried out for a specific basin and in real atmospheric and climatic conditions. The effect of damming up water in the ditches on the decrease of the amount of outflowing water can be seen very clearly. The level of ground water has also been raised, which meant better supply of water for plants (bigger evapotranspiration). Construction of small water reservoirs, damming up water in canals and natural water races, renewal of small ponds and lakes, etc., influence the regime of water outflow from the basin in a similar way.

Hydrogenic habitats especially swampy areas play a special role in the water balance of the basin. They influence the size and dynamic of the water flow in the race, location of underground waters, and the size of water resources. Disturbance of the natural water relations of hydrogenic habitats causes significant changes in the hydrological regime of the basin. Influence of swampy areas on the river flows is manifested by:

- Decreasing of the flows in big waters (flattening of the flood wave) as a result of slow water outflow from the flooded areas. It is caused by high surface retention of fluviogenic swamps. Figure 5 presents the influence on the reduction of the flood wave in relation to the size of swamp surface.

- Inhibition of underground water outflow from the highlands close to the valley as a result of closing the outlets of water-bearing layers by the increasing organic mass of soligenic swamps. It causes an increase of the underground water level in the areas adjacent to the valley. Figure 6 shows flow changes in the water race depending on the presence of soligenic swamps or their absence.

Retention abilities of the basin are greatly influenced by the way the basin area is managed and cultivated, e.g., the pattern of arable areas, grasslands and forests, anti-erosion and aglomeration treatments that improve soil

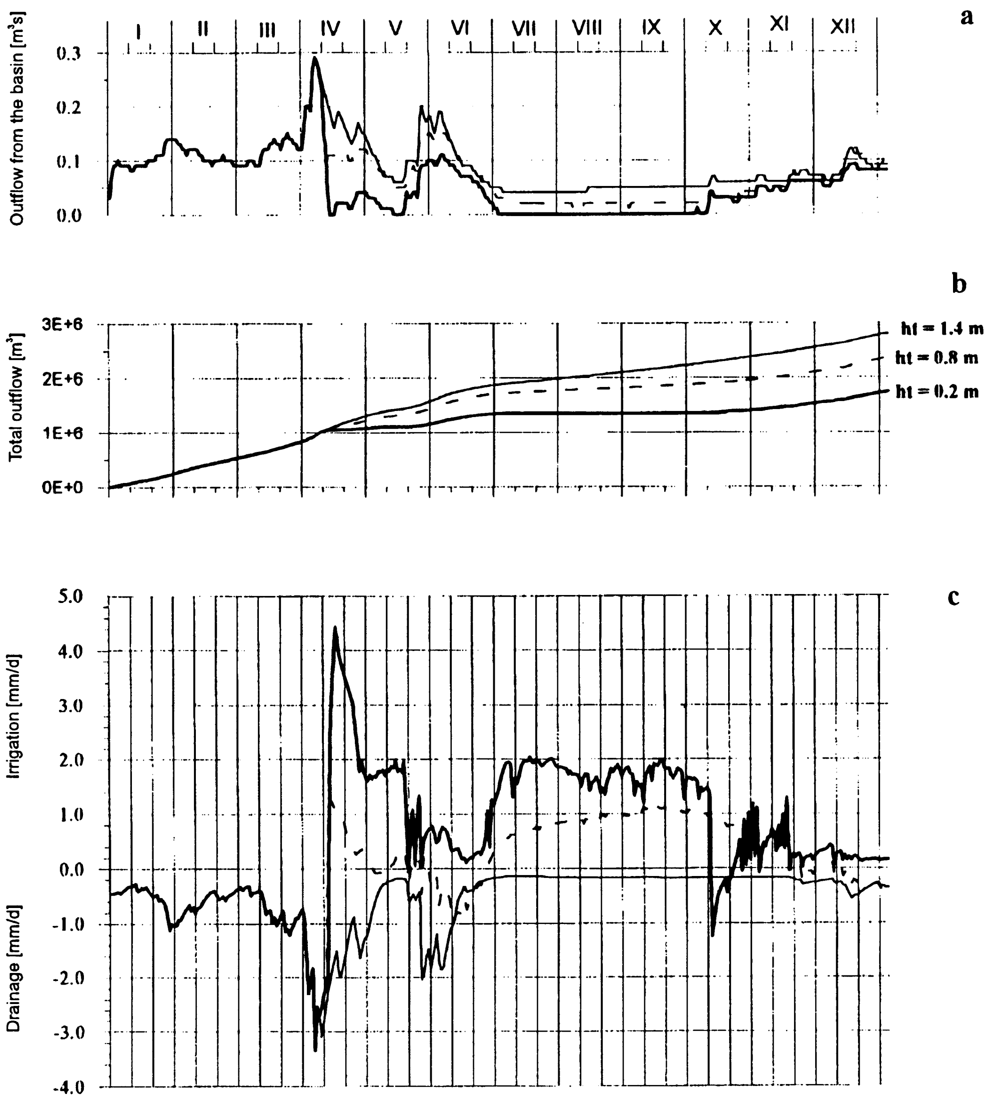

Fig. 4. Influence of water damming up in the valley melioration system (Rów Tartaczny) on water resources: a) mean outflow from the basin within 24 h, b) total outflow, c) mean inflow from the ditches (de-watering) or outflow from the ditches (irrigation). ht - depth of water in the ditch below terrain surface.

structure, plant protective belts, and bushes. The most important is forest retention. The bigger the forest area in the basin, the more natural the forest is (mixed forest with multi-level structure), the bigger its influence on the water balance. The effect of forest on the decrease of the flood wave in the mountain areas with the soil of low permeability is most visible. Figure 7 presents the results of flow measurements in the two adjacent basins (the Pieniny Małe) from the period of high atmospheric precipitation in July 1997. A markedly smaller unit outflows were observed in the Czarna Woda stream, which basin is covered with forest in 70% when compared to the outflows from the Biała Woda stream, where the forests cover only 20% of the basin area.

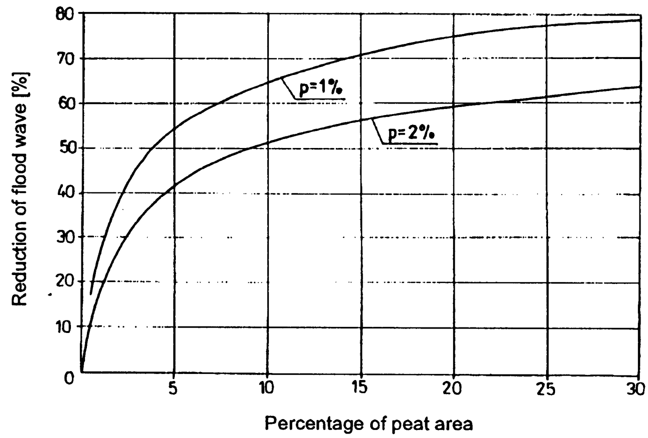

Fig. 5. Influence of the reduction of flood wave in relation to the basin area covered with peat, p - probability of occurrence of big water.

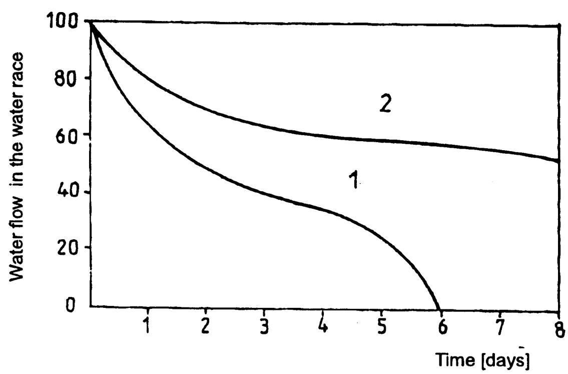

Fig. 6. Changes in water flow as a function of time: 1 - basin formed of minerals with poor permeability, 2 - basin formed of permeable materials, in more than 50% of the total area there are soligenic peats.

In the lowland areas, and especially in the basins built mainly from the permeable sandy grounds, the influence of forest on the reduction of flood wave will be considerably smaller.

Forests can also significantly influence the size of low flows in rivers. Table 3 presents the results of numerical simulations [12] carried out for the evaluation of the influence of forest cover on the frequency of occurrence of flows that are lower than the ones treated as reliable. In the basin that is totally covered by forest, average flow is smaller, and the frequency of occurrence of low flows is higher than in the basin without forest. It results from the higher interception and increase in the transpiration of trees in relation to the present field cultures. It also follows from the calculations that the bigger influence of forest on the low flows is observed in the basin built from the permeable grounds.

It should be stressed that the results of measurements and calculations presented above refer to specific basins. With different geological structure, changed atmospheric conditions, the influence of forest on the water balance can be of entirely different character. For example, it is believed that in some conditions an increase in the interception and evapotranspiration is compensated for by the lowered evaporation from the surface which in turn leads to an increase of the mean flow through the basins with forest cover and shortened periods after-draught.

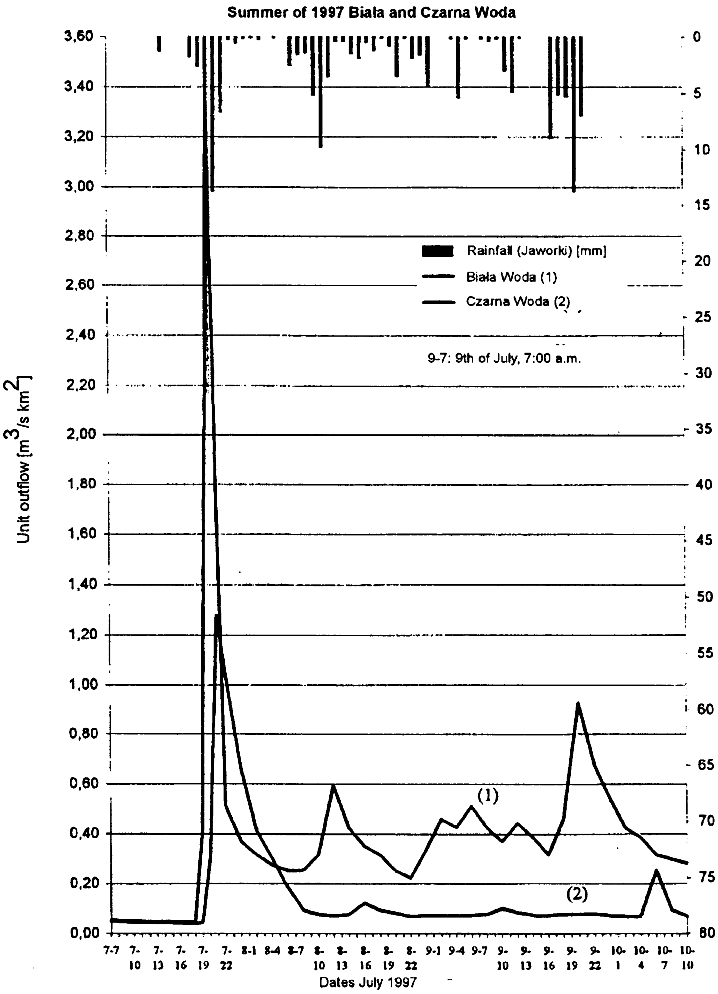

Fig. 7. Outflows from Białej Wody and Czarnej Wody - July 1997.

T a b l e 3. Influence of forest cover in the basin area on the low flows

Basin (MODEL)	Type of flow	Flow (mm. 24 h)		Occurrence of low flows in days in the 23-year period	
		without forest	with forest	without forest	with forest
Hupsel (MOGROW)	mean	0.66	0.43	2628	2835
	low	0.21	0.18		
Hupsel (HBUMOR)	mean	1.04	0.73	393	514
	low	0.14	0.07		
Monadyle (HBUMOR)	mean	6.01	5.79	133	147
	low	1.06	1.03		

CONCLUSIONS

One of the methods to improve water balance and to decrease extreme phenomena such as floods and draughts, is the potential ability of small basins. This ability is called a small retention. It refers specifically to agriculture and water management mainly in the melioration objects connected with it.

REFERENCES

1. **Ciepielewski A.**: Methods of water resources management in small river basins (in Polish). SGGW, Warszawa, 1995.
2. **Ciepielewski A., Dąbkowski L.**: Problems of small retention in forests (in Polish). Sylwan Rok CXXXIX, 11, 1995.
3. **Dynowska I.**: Changes of water conditions in Poland as a result of natural and antropogenic processes (in Polish). UJ, Kraków, 1993.
4. **Dziewoński Z.**: Agricultural retention reservoirs (in Polish). PWN, Warszawa, 1993.
5. **Graham W., Lest L.**: Non-structural aspects of flood management in India. ICID Journal, 44, 1, 1995.
6. **Kowalczak P., Farat R., Kępińska-Kasprzak M., Kuźnicka M., Mager P.**: Hierarchy of areal needs of small retention (in Polish). Materiały Badawcze. IMiGW, Warszawa, 1997.
7. **Kowalewski Z.**: Possibilities of water resources increase in Łomża voievodship (in Polish). Conf. „Natural and Technical Problems of Water Resources Management". SGGW, Warszawa, 1998.
8. **Mioduszewski W.**: Protection and formation of water resources in small agricultural river basins (in Polish). Materiały Informacyjne IMUZ, Falenty, 25, 1994.
9. **Mioduszewski W.**: Basic problems of water management in upper Narew basin (in Polish). Informacje Naukowe i Techniczne, 2, 1997.
10. **Mosiej K., Ciepielewski A.**: Protection against flood (in Polish). IMUZ, Falenty, 1992.
11. **Okruszko H.**: And water flows to the sea (in Polish). Nauka i Przyszłość, 9, 1981.
12. **Querner E., Tallaksen L.M., Kašpárek L., van Lanen H.A.J.**: Impact of land - use, climate change and ground-water abstraction on stream flow droughts, using physically based-models. Friend'97 - Regional Hydrology. IAHS Publ. No. 246, 1997.
13. **Radczuk L., Szczygielniak C., Olearczyk D.**: Proposal for the uniform scheme of the taking stock of small retention (in Polish). Gospodarka Wodna, 3, 1997.
14. **Twardy S., Kopacz M., Kostuch M.**: Influence of the spatial management of small mountain basins on the run of July 1997 flood (in Polish). Scientific conference "Flood in the upper Vistula basin". Kraków, 1998.
15. **Verry E.S.**: Water table and stream flow changes after striping and clearcutting an undrained sprace bog. Proc. Sixth International Peat Conference. Duluth, 1981.
16. **Zieliński J., Słota H.**: State and use of surface waters in Poland (in Polish). IMiGW Warszawa, 1996.