ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2001
Volume 4
Issue 2
Series
ENVIRONMENTAL DEVELOPMENT

PALUCH J., PARUCH A., PULIKOWSKI K., PALCZYŃSKI M., WOJTOWICZ J. 2001. PRELIMINARY ESTIMATION OF EFFECTIVE USE OF RETENTION OF SMALL CATCHMENT AREAS FOR FLOOD PROTECTION **Electronic Journal of Polish Agricultural Universities**, Environmental Development, Volume 4, Issue 2.
Available Online http://www.ejpau.media.pl

PRELIMINARY ESTIMATION OF EFFECTIVE USE OF RETENTION OF SMALL CATCHMENT AREAS FOR FLOOD PROTECTION

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ABSTRACT

The following study is under discussion.

Flood disasters of various intensity and random frequency occur all over the world. The losses resulting from floods are huge. Such disasters affect mostly people who live in river bed zones, whereas catchment area are left practically untouched. The authors suggest delaying the water run off from catchment area to river beds below, lengthening the run-off time and therefore decreasing the flood wave culmination. The principle of such an approach lies in taking an advantage of the bank storage, soil water retention and catchment area water retention.

Key words: run-off delayer, soil water retention, watershed zone, flood wave culmination

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INTRODUCTION

The environment has been changing under the influence of human activities. The phenomenon is not recent – for many hundreds, even thousands of years the mankind have been deliberately changing the surrounding environment to serve the needs of the human race [3]. In a Report of the World Commission on Dams we read: “By the year 2000, the world had built more than 45,000 large dams to irrigate crops, generate power, control floods in wet times and store water in dry times. Yet, in the last century, large dams also disrupted the ecology of half the world's rivers, displaced tens of millions of people from their homes and left nations burdened with debt. Their impacts have inevitably generated growing controversy and conflicts. Resolving their role in meeting water and energy needs is vital for the future and illustrates the complex development challenges that face our societies.” [2]. According to the Report, it is important to find a better and more effective way of using water resources located in catchment areas. The presented study aims to describe and explain the possibilities of more effective use of water resources.

In two Polish Public Forests Districts – Wołów and Milicz, in co-operation with the Regional Direction of Public Forests in Wrocław, the forest inspectors, and Kleszczów Pipe Plant (Poland), installations that delay the water run-off from the catchment area were built and tested. The installations were called “run-off delayer”. In October 2000 two run-off delayers in Milicz Forest Division were built and tested; in November and December 2000 further two run-off delayer were built and tested in Wołów Forest Division (Figure 1). The research was initiated in different environmental conditions in the middle of the catchment area of the rivers Barycz and Juszka Wołowska.

The experiment was based on the construction and technological solutions applied in the research project No 0952/5 P06H 04718/ 2000/18 [8].

Figure 1. Location of the research objects:
1 - Wołów Forest Division   2 - Milicz Forest Division

The focal point of the experiment was to estimate the possibility of building a flood control system based on run-off delayers. Theoretical considerations were to answer the question whether the flood control system based on run-off delayers can be put into practise. To obtain a positive answer we needed an empirical experiment that would prove or disprove the theoretical assumption. The current study presents:

1. The purpose of the project, its essence, reasons and prerequisites of building flood control system in Poland.
2. Current state of knowledge in the field of flood control systems.
3. Research methodology – a scientific base for solving flood control system problems.
4. The results of the experiment.
5. Practical effectiveness of the research.

The constructed run-off delayers (two devices in each river bed in the catchment areas of Barycz and Juszka Wołowska rivers – Figure 2 and 3) have been researched.

Figure 2. Measurement points in the catchment area of Barycz river - Milicz Forest Division.
1, 2 - position of run-off delayers
c - control ditch

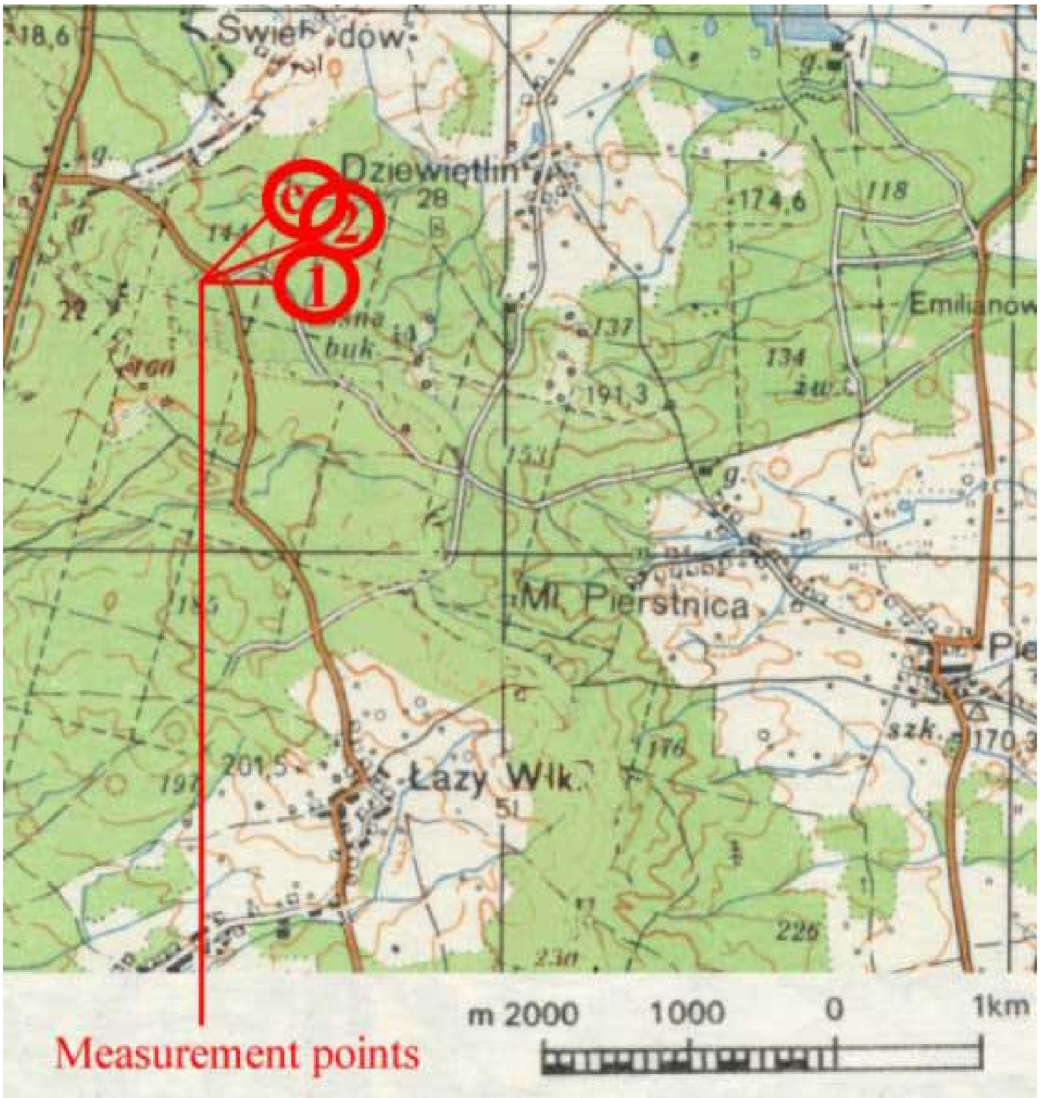
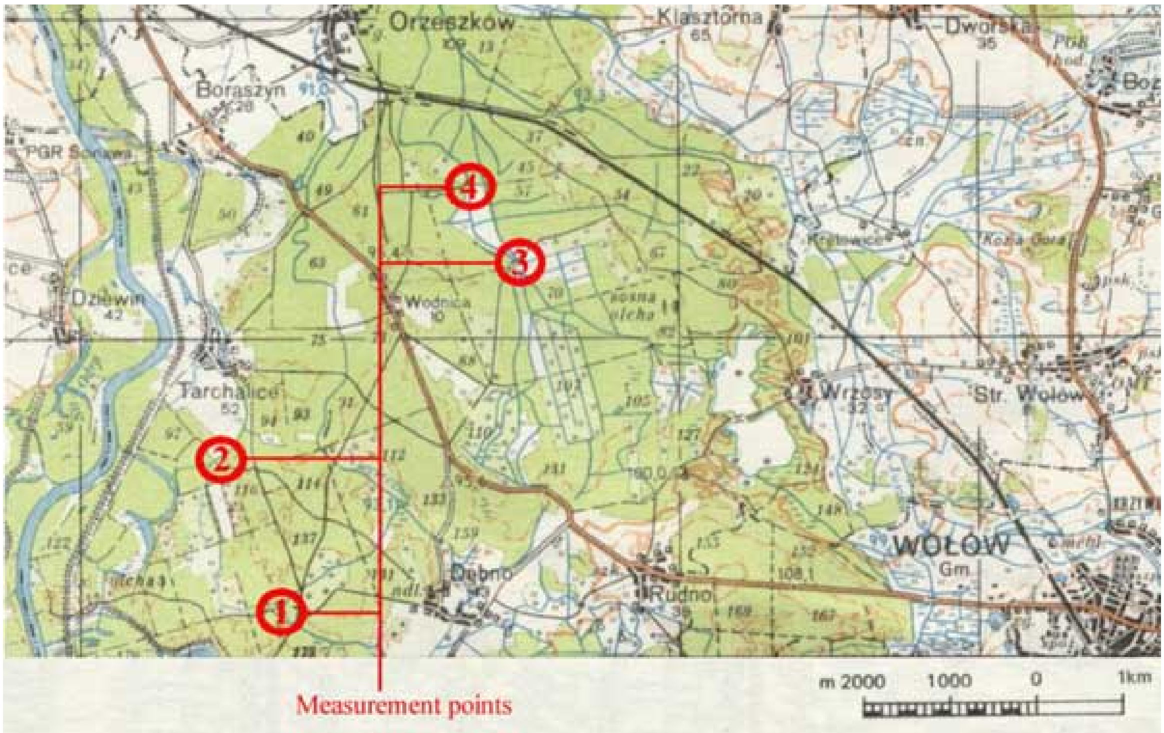


Figure 3. Measurement points in the catchment area of Juszka Wołowska river - Wołów Forest Division.
1, 2, 3, 4 - position of run-off delayers



PURPOSE OF THE RESEARCH

The main goal of the research is to find and elaborate solutions enabling more equal distribution of flood waters over the entire catchment area, not just in its lowest parts. Particular attention must be paid to realising both practical and cognitive solutions aimed at getting unambiguous answers concerning:

- determination of methods enabling more uniform use of both soil and area water retention located in the watershed of the catchment area in order to employ local ecosystems in more compete utilisation of the precipitation water,
- automatic, free of any human intervention time lag needed to discharge temporary excessive waters due to storms or thawing snow,
- possibility of protection from flood wave culmination on main rivers and the extent to which the culmination wave might be reduced,
- procedures for estimation of the magnitude of secure water-flows for random cross-section of rivers,
- determination of number of run-off delayers necessary to minimise the danger of flood,
- discharging the excessive waters in the catchment area,
- minimising consequence of temporary water shortage within watershed of catchment areas,
- defining the necessary environment conditions required to apply run-off delayers,
- indicate the necessity of formal and law regulations.

A catastrophic flood, which happened in Poland in summer ’97, gave way to publishing the study. Before 1997 a flood-wave culmination on one tributary of Odra river, namely Ślęza river, were analysed. The study showed that when in the lower part of Ślęza river the regions that were the closest to the riverbed were flooded, the waters in the watershed had already fallen. In the following years Poland was troubled with floods in many regions, even in regions where floods had never happened before.

The results of the completed at that time research on a small agricultural catchment area revealed that for the same precipitation, building and sealing facilities but different water tables, the magnitudes of flows measured at equal cross-section were significant different. The analysis of the infiltration of precipitation, surface water run-off and the changes observed in the water tables indicate that there is still room to take the full advantage of both soil and area retention. The field research that has been performed recently shall allow to determine effective ways of employing small catchment area retention to prevent floods in the lower parts of the concerned catchment area without any side-effects on both the natural environment and the inhabitants of such zones.

Valley water retention is significantly limited by local drainage systems that quickly and effectively pipe away temporary excessive waters to bigger watercourses. The process of building the storage reservoirs that could stop the excess of water takes years, is expensive and frequently raise objections and causes protest of green-peace movements. Moreover storage reservoirs are not always used efficiently enough for flood control in the event of disastrous flood. Therefore, it seems indisputable that the valley retention needs to be supplemented with other protective solutions.

THE CURRENT STATUS OF KNOWLEDGE

The knowledge gathered so far escapes an easy assessment. Operation principles for individual water structures of different construction but serving similar purposes have been known for years, whereas the presented solution remains an original conception and to the best of our knowledge such a reference has not been registered. At the heart of conception lies the idea of building a flood control system based on run-off delayers described in "Melioration and Meadow Cultivation News" ["Wiadomości Melioracyjne i Łąkarskie"] [4] – (Figure 4). Figures 5 a, b ,c present watercourse in three possible situations:

- Figure 5a presents water-course where no flood-control facilities were installed,
- Figure 5b presents the water-course with stages of fall,
- figure 5c presents the water-course with a run-off delayer.

Comparison between figures 5a and 5b reveals that for lower water head in the water-course in which the stages of fall were applied, the water speed decreased and the water surface gradient was lowered remarkably, whereas for the high water head the stages of fall decreased neither the water speed nor the water surface gradient. The speed of the river and its transportation force increased as the water bed was filled up. Run-off delayers decrease neither the water surface gradient nor the water flow conditions for the lower states but decreased the water speed before flood control facilities for high water head (Figure 5c).

Figure 4. Operation principle of a run-off delayer.
D1 - diameter of vertical pipe of run-off delayer
D - diameter of road pipe culvert (horizontal pipe of run-off delayer)
d - diameter of inlet
H - height of run-off delayer
LF - limit of flood

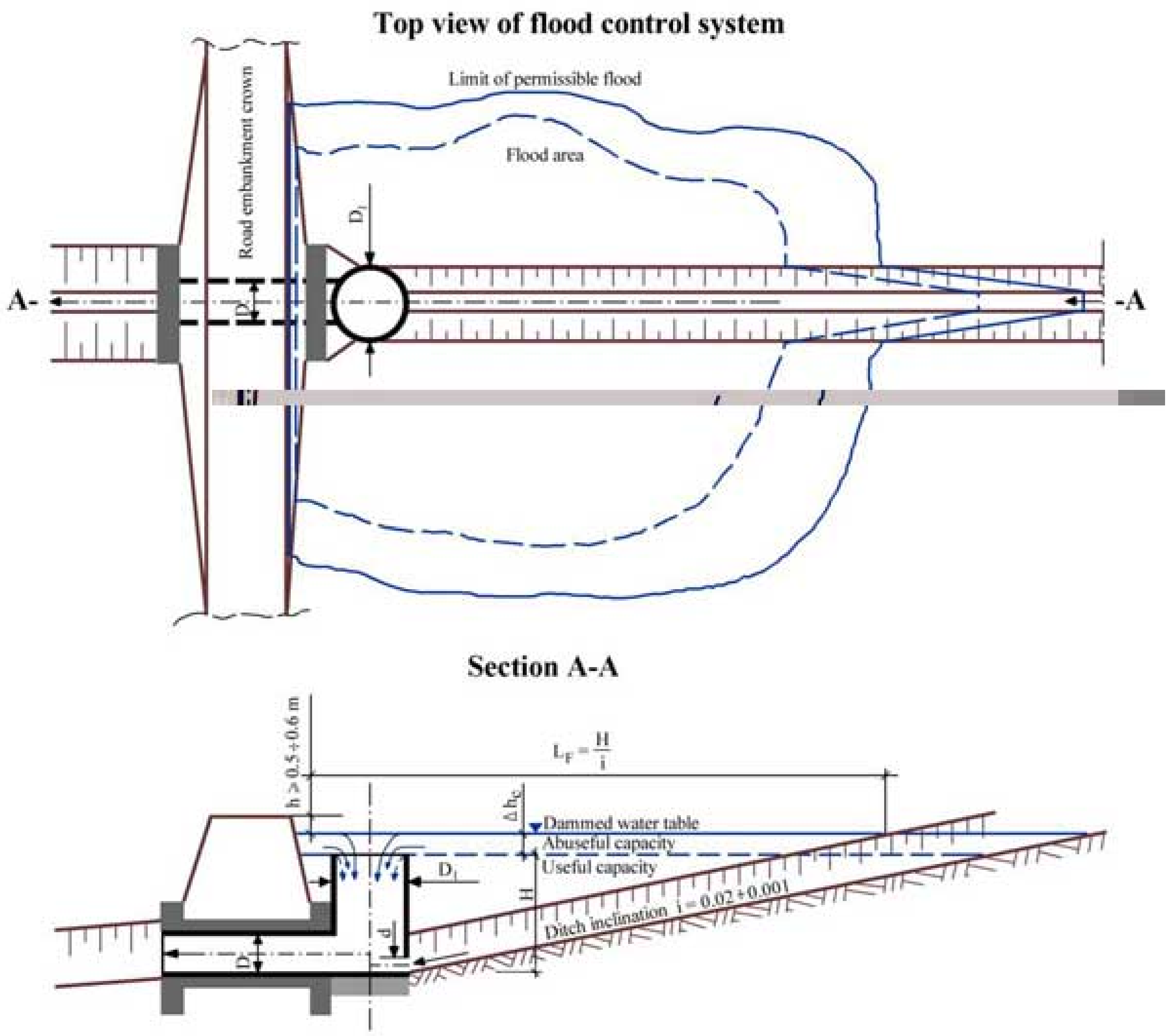
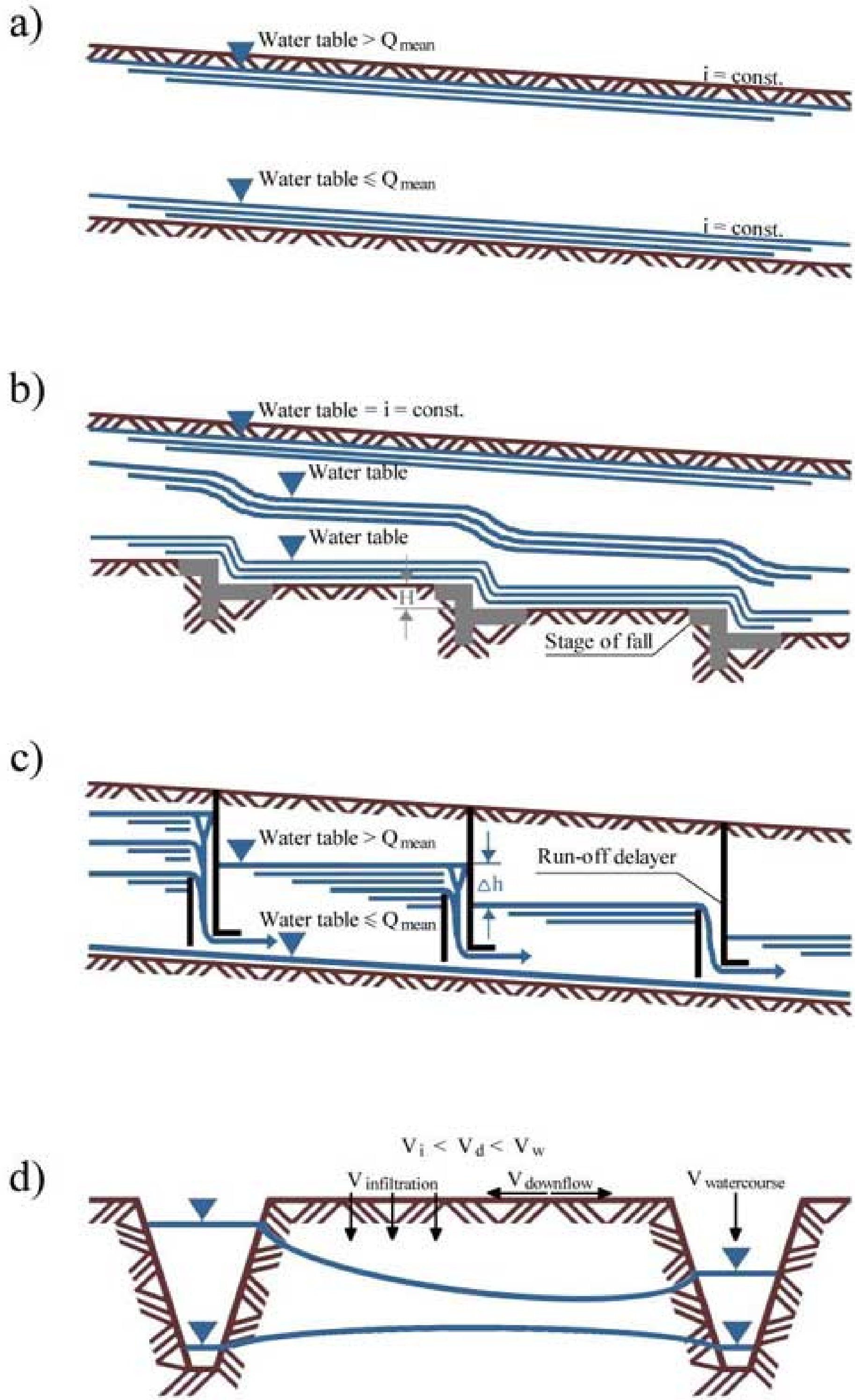


Figure 5. Operation principle of run-off delayers on the background of a watercourse bed
5a - free from hydrotechnical objects
5b - built up by typical stage of fall, and
5c - by using of run-off delayers. Moreover,
5d -influence of the bed filling on nearby areas.
Vi - velocity of infiltration
Vd - velocity of downflow
Vw - velocity of watercourse



According to the standard after storm observations, storm waters carry not only eroded soil but also other objects such as wooden logs etc. Stages of fall do not work effectively enough if the carried objects are big. A cascade of run-off delayers assembled in the smallest watercourses might effectively reduce flood wave. The problem undergoes an extensive practical testing. Some issues might be even illustrated with purely theoretical consideration like analysing flow velocity in a watercourse with traditional stages of fall and with run-off delayers applied. It can be proved that for the stages of fall and cascade of run-off delayers of the same total height, the flow velocities differ significantly. Mathematical calculations for a watercourse with the stages of fall and run-off delayers cascade can serve as an example.

Further analysis and studies of environmental conditions were presented in "Water Management" ["Gospodarka Wodna"] [5, 6, 7].

At present neither the criteria nor system solutions enabling an automatic regulation or limiting the surface flow are available. Floods in Poland and all over Europe proved that such standard procedures even if they exist are not excised, which together with the updated knowledge, leads to the conclusion that floods will still remain a destructive element [3, 9].

The suggested new flood control system might be a subject to discussions and doubts. The discussion, however, is the best way of perfecting ideas. It is excepted that run-off delayers will increase the effectiveness of flood control facilities and systems use.

Assumptions of flood control systems and water management at areas of small water reserves are being verified by field experiments and research. Both huge storage reservoirs with permanent water damming serving a variety of purposes which quite often happen to be conflicting, and embankments need expensive investments and last long. On the contrary to them, the suggested solution, based on run-off delayers might be implemented systematically and does not require large or spectacular investments since run-off delayers could be assembled during routine maintenance works. Hence, it was important to answer following basic questions:

1. Where, when, and under what conditions run-off delayers could be installed?
2. What are the advantages of such a solution?

To answer the questions reliably it was necessary to perform a field research. The results of the field research that has been in progress, will be extremely important to create the basic rules and procedures for flood control systems.

METHODOLOGY OF THE RESEARCH

A comparative method was applied in the research. Hydrographs from two adjacent catchment areas were compared, namely from:

- the catchment area where two measuring stations and two run-off delayers in each water-course were located,
- the control catchment area without run-off delay facilities,

Details of the applied methodology depended on the owners of the area (Milicz Forest Division and Wołów Forest Division) as well as other natural conditions.

The following parameters were monitored:

- the quantity of water registered with a hydrometric current meter in the watercourse below the run-off delayers. The measurement includes water levels registered by limnographs and staff gauge below and above run-off delayers,

- quantity, intensity and precipitation duration significantly speeding up the water velocity,
- bank storage time registered by limnographs together with water head changes; time of inflow-outflow balance for water at the run-off delayer, water run-off time from after the flood wave culmination,
- water levels remaining under the direct influence of water level changes on the tested watercourse,
- silting-up area within the range influenced by the tested run-off delayer,
- water percolation trough road embankment,
- run-off delayer costs, dependent on catchment area and flood control facilities in use,
- studies aimed to limit the negative effects of agricultural engineering that might affect the run-off into rivers.

It should be noted that not all the results from the list above could be presented in the current study. They will be presented successively upon their availability. Preliminary results seem to confirm the earlier assessments and opinions of Provincial Department of Environment and Regional Water Management, according to which neither agreements nor permissions for research facilities are necessary as long as they are built in compliance with the guidelines for special building in the field of transportation, with special regard of bridges and culvert clearance WP-12D [1]. At present, run-off delayers are tested in forest areas on different forests roads, usually excluded from public transport (Picture 1). The performed tests will yield the results for various arrangement applied for low water flows and will hopefully provide strong arguments for further negotiations with land and road owners, as well as river users in water deficient watershed zones having seasonal watercourses. Negative effects of the installed facilities at local land depressions in rainy years cannot be excluded. The presented solution can and should be applied in river watershed zones, on light soil and in dry coniferous forests, in regions of similar characteristics, or in the areas used for other purposes like grasslands or arable lands.

Picture 1. View of a road pipe culvert with the delaying elements

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RESULTS OBTAINED SO FAR

Due to a rather limited period of the research it was not possible to collect the results for each environmental conditions. Nevertheless, the results obtained so far confirmed the earlier assumptions. The most important results can be summarised as follows:

- the distance between a vertical pipe and an overflow crown over the top of a road pipe culvert cannot be bigger than 0.2 m and should protrude over terrain level (at the point where water flows into the culvert) above a road culvert,
- water should overflow run-off delayers along the length of the overflow crown,
- an average diameter of culvert with a run-off delayer should be 60 cm, the diameter of inlets in vertical pipes of delayers should be large enough to ensure free flow of water after standard precipitation and it should not be bigger than 20 cm. The diameter depends on local environmental conditions; diameters of horizontal pipes should be of 100 cm; the length of overflow crown should be 314 cm,
- the diameter of road pipe culverts should not be bigger than Φ=100 cm, the diameter of vertical pipes cannot be bigger than Φ+40 cm,
- run-off delayers should be plastic, assembly of the construction easy and light. Plastic components can be assembled on the spot by four people team without sophisticated equipment,
- diameter in the flood spillways of delayers that stop water after precipitation should be chosen carefully. Previous observations show that in standard delayers they should not be bigger than 20 cm but adjustable for further widening or closing. A 20 cm diameter of openings in vertical pipes is big enough to avoid clogging with leaves, sprigs etc. which usually float near the top edge of the opening. Even large object cannot be flushed over the overflow crown of run-off delayers into the road pipe culvert,
- ground water levels registered with piezometers and staff gauge in river beds with and without run-off delayers shown that after precipitation drainage watercourses turned into infiltration watercourses i.e. the level of water in the forest away from the river bed was lower than in the drainage ditch (see Figure 5d). Delayers work occasionally as weirs with bottom outlet until the bottom outlet fails to let water through even under the over pressure of water that overflowed the crown and increased water pouring level,
- velocity of the flow in watercourse is different from the surface run-off and infiltration to ground water. Retaining waters within the catchment area increases the efficiency of soil retention and lowers flood wave culmination, both in the watercourse and in the river,
- during the tests, because of large inclination of the catchment area in Milicz Forest Division as well as its small size, it was necessary to mount limiting rings round the bottom inlets of run-off delayers (Picture 2 – a view from the vertical pipe of a delayer, Picture 3 – a view from a road pipe culvert). The rings were to cause the water to outflow mainly via the overflow crown (Picture 4) over a prolonged period of time. Such an experiment was to answer the following questions:
    - might the dammed water damage the road embankment?,
    - how would the ground waters respond?,
    - might the capillary rise weaken the road crown?,
    - will the flow water below run-off delayers cause erosion of the river bed?
    - so far the run-off delayers have not affected negatively the durability of water facilities. It is however, necessary to prolong the experiment to test the

delayers in more severe weather conditions such as ice floating, heavy downpours, thaws, etc.,

- at Wołów Forest Division in Juszka Wołoska catchment area below Wrzosy ponds (Figure 3), during summer precipitation, delayers raised the ground water table near the arboriculture. It was necessary to lower the overflow crown of the run-off delayers. In the area where run-off delayers were applied, water table was higher, whereas in sandy soil areas the water table did not change.

Picture 2. View from the vertical pipe of run-off delayer with a limiting ring inside

Picture 3. View of a limiting ring from a road pipe culvert

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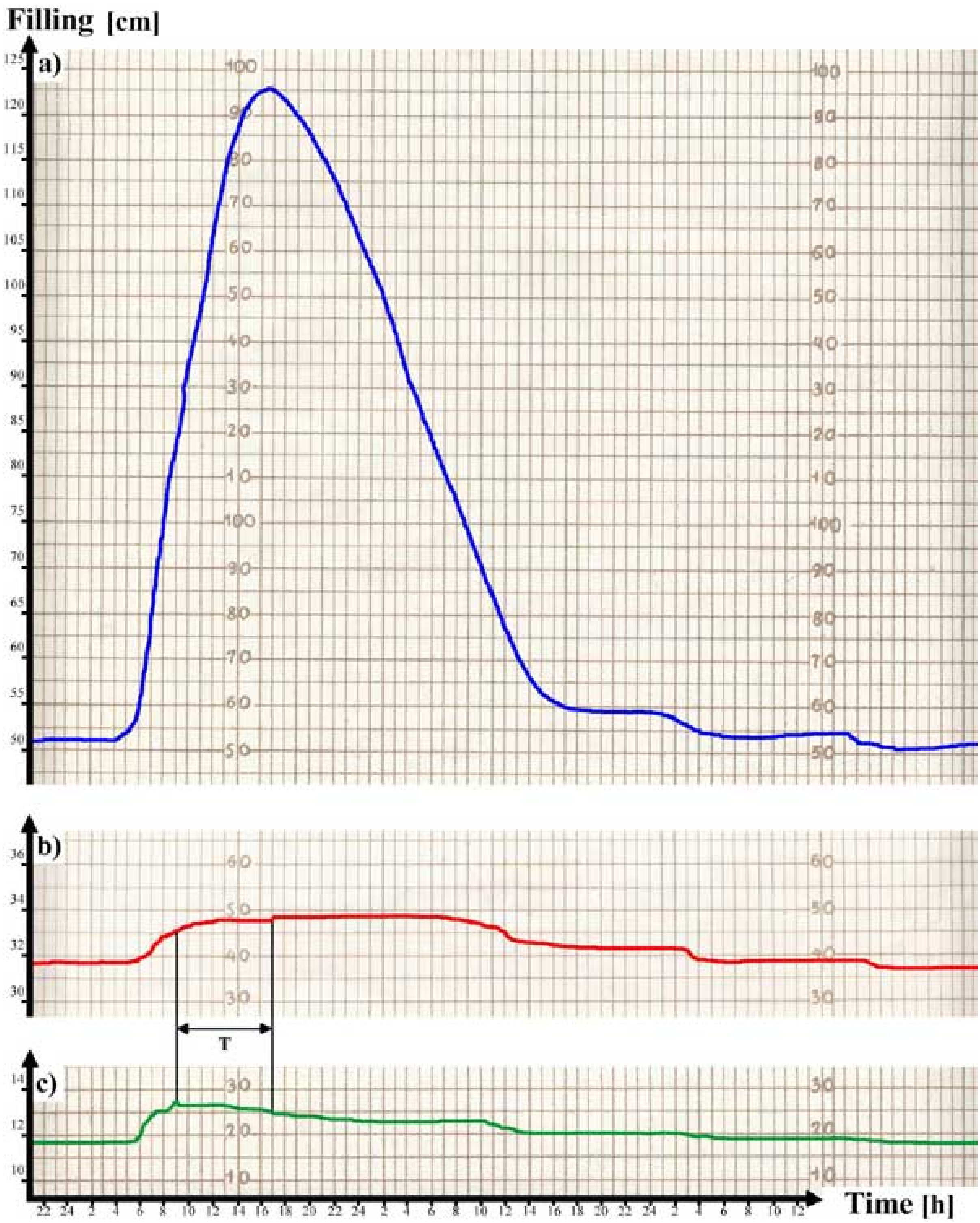
Picture 4. The outflow via the overflow crown of run-off delayer

Potential adaptation of the culverts in use to controlling the runoff constitutes a separate issue. Assembling the delaying elements into already existing culverts is easy and does not require extra investments. Kleszczów Pipe Factory (Poland) – the producer of the components responsible for delaying the run-off – can deliver all the necessary components and incorporate them into the objects that were already built. According to our solutions mounting run-off delayers in watershed zones, i.e. in the catchment areas which are often water deficient, might delay the surface flow and could prevent lower parts of watercourses from flood wave culmination. It would also reduce flood damage and losses in the areas that frequently suffer severely from heavy floods.

The biggest advantage of run-off delayers was demonstrated by the comparison of limnograph readings from measurement points located in a watercourse with two run-off delayers and in a watercourse parallel to it with an unrestricted flow, both located near the village Wodnica in Orzeszków Forest Division, to the readings in a watercourse free from any facilities in the vicinity of the village Dębno in Wołów Forest Division. In Orzeszków Forest Division water level increased 6 hours earlier than in the watercourse with run-off delayers. The time lag resulted from rainwater retention of the soil and bank storage. The phenomenon was recorded on the 1st of September 2001 in local run-off delayers. The water levels in ditches located above the delayers decreased much faster than in the watercourse free from water facilities. A liminograph reading registering different water levels in the research objects in Milicz Forest Division on 22nd of June 2001 (Figure 6) is enclosed to illustrate the beneficial work of run-off delayers there.

Figure 6. Liminograph reading from measurement points situated in the same ditch
6a - above run-off delayer,
6b - below run-off delayer, and
6c - on a bordered (control) ditch without any water objects.
T - time of run-off delay



PRACTICAL EFFECTS OF THE PROJECT

The effects of the research can be visualised only after assembling the run-off delayers as a flood control system for an entire model catchment area. Reliable results can be obtained when the flood wave culmination is registered while progressing over the catchment area. It is expected that the project will help to achieve goals listed below:

1. Establish the rules and technical solutions that will reduce the negative effects of floods and overdeveloped drainage systems alike; the latter often lead to bankfull stage which in turn might be dangerous for lower parts of catchment areas.
2. Re-direct the funds from after flood compensations and infrastructure reconstruction to building effective flood control systems based on run-off delayers in watershed zones before the flood occurs.
3. Improve the efficiency of flood control protection in all catchment areas and optimal use of temporary water excess in water deficient regions of Poland.
4. Advantageous use of local conditions and infrastructure to improve water management.
5. Inclusion of the entire catchment area, i.e. together with watershed zones, into flood protected areas.
6. Elaboration of laws and regulations for flood control systems based on run-off delayers.

Apart from the practical aspects of the suggested solution, scientific research into the problem is planned. It seems difficult to precise the scale of economic effects, or to predict which of the suggested purposes will be accomplished or to which negative answers will be found. Nevertheless, each answer is undoubtedly important, no matter a negative or a positive one. We hope that the results will lay the basis for creating effective global flood control system of the future. Moreover, we hope that the subject will be worth for further scientific research. We are aware that collecting new results and performing more field experiments is needed to complete the knowledge. The results collected so far managed to prove the early assumptions. Run-off delayers systems engage citizens of catchment area, not just those who live in the lowlands. It is apparent that preventing the floods is beneficial over reducing flood damages. The simplest and the cheapest way to prevent floods is building flood control systems based on our solution.

Just recently the results for a hilly and lowland catchment areas, located in Milicz Forest Division and Wołów Forest Division, respectively, have been compared. The preliminary results show that during prolonged precipitation, when the soil profile becomes saturated, the negative results might occur, especially in young arboriculture where limiting the quantity of water in fresh and humid coniferous forests is of major importance. In dry coniferous forests with light soils water can be retained to much higher extent and the openings in vertical pipes shall be adjusted to allow aquatic organisms to pass through.

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