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Dynamic SlowDown: a flood mitigation strategy complying with the integrated management concept – implementation in a small mountainous catchment

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ABSTRACT

The "Dynamic SlowDown" concept (noted hereafter "DSD") promotes flood mitigation by slowing down, using transverse obstacles or temporary storage works distributed throughout the catchment. In accordance with Sustainable Development, it aims at reducing the use of the flood defence structures that damage riverine ecosystems. DSD hydraulic projects must be planned at catchment scale and must take all the problems into account, including ecological issues.

Cemagref and Cracow Institute of Water Engineering carried out a DSD feasibility study in a small mountainous catchment in Poland, the Isepnica catchment. To deal with flood and erosion problems, they proposed small storage works on hillslopes and a dry reservoir. To assess their impact on design floods, they developed two simple distributed hydrologic models, and linked them with a hydraulic model built for the main torrent. They concluded that the proposed strategy was efficient. In a further stage, it is envisaged to build and monitor pilot structures, in order to check their behaviour, better calibrate the models, and issue maintenance requirements.

RÉSUMÉ

Le concept de "Ralentissement Dynamique" (noté "RD") propose de lutter contre les crue par des ouvrages ralentissant les écoulements répartis sur tout le bassin, obstacles transverses ou petits ouvrages de stockage temporaire. Inscrit dans la lignée du Développement Durable, il a pour but de réduire le recours aux aménagements hydrauliques lourds qui perturbent le fonctionnement des hydrosystème. Les projets hydrauliques de RD se mènent à l'échelle du bassin versant, et doivent prendre en compte tous les enjeux –dont l'environnement.

Le Cemagref et l'Institut de Génie de l'Eau de Cracovie ont conduit une étude de faisabilité RD sur un petit bassin montagneux, celui de l'Isepnica en Pologne. Pour résoudre les problèmes de crue et d'érosion, ils ont proposé des petites structures de stockage dans les pentes, et une retenue sèche. Pour quantifier les effets de ces ouvrages, deux modèles hydrologiques distribués simplifiés ont été spécialement développés, et couplés avec un modèle hydraulique du torrent principal. Ils ont conclu à l'efficacité de la stratégie proposée. Dans une prochaine étape, il est envisagé de construire et de suivre des ouvrages pilote, pour vérifier leur fonctionnement, mieux calibrer les modèles, et de juger des mesures de maintenance à prévoir.

Keywords: Dynamic SlowDown; dry reservoir; rainfall-runoff models; small water storage structures; flood mitigation; erosion.

Introduction: Dynamic SlowDown: a golden rule for catchment management

"Dynamic SlowDown" is a flood management strategy complying with environmental issues and catchment-scale interests. This concept is also sometimes called "dynamic flood retention".

Throughout Europe, flood problems are too often addressed with mono-objective and local thinking: river training and levees do alleviate flooding locally, but they displace flood problems downstream and may disturb the river dynamics and ecosystems. Many river works, and dams in particular, modify river dynamics, sediment balance and ecosystems. Recent national and European legislations emphasize the need for protecting and improving water bodies (French "Water Act", 1992; EC Water Framework Directive, 2000). Practitioners need guidelines to achieve the flood protection required by the floodplain inhabitants without hampering river dynamics and habitat value.

The main cause of floods is heavy precipitation. But many human activities in the catchment's area and in the river bed may result in worsening the floods. Indeed, the increase of impervious surfaces means shortened water travel-time, and the reduction of flood-prone areas leads to runoff concentration, which shortens the duration of flood events but increases their peak values.

In reaction to the negative impacts of artificial acceleration arose the "Dynamic SlowDown" concept, noted hereafter "DSD" (*e.g.* [1]). DSD aims at solving flood and erosion issues by re-creating conditions close to the natural ones, by slowing the flows wherever possible and relevant in the catchment, and storing them temporarily. The adjective "Dynamic" stresses that the flows are slowed but that the continuity of flow is always maintained, in particular in river channels. Ensuring flow and corridor continuity are crucial points to alleviate the side-effects on the river-system.

The objective of the authors was to carry out a feasibility study for DSD works against both floods and slope erosion in a small

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mountainous catchment, complying with the Integrated Management concept. The advantages and difficulties are underlined, and the methodology is described.

The first part is devoted to the DSD concept and its main principles, on the floodplains and on the slopes. The second part describes the Isepnica catchment and the DSD strategy proposed for flood mitigation, using mainly hillslope DSD works. The third part presents the computations carried out to assess the effect of the proposed works, hillslope works and a dry reservoir, on the floods.

1 DSD for integrated and catchment-scale water management

This part presents the principle of a DSD strategy against flood and erosion in a catchment.

Like any hydraulic project, DSD projects must begin by the definition of the problems: which zones need protection, what are the protection objectives, and what are the other important issues.

Then, field surveys should be carried out. All the relevant existing natural and man-made features must be documented, in the network (hydraulic works) and the hillslopes (features that accelerate runoff, such as a road parallel to a slope). These surveys must also locate all the suitable sites for temporary storage.

A diagrammatic catchment is shown in Figure 1, with representative natural and artificial structures influencing water runoff.

Specific works can be designed both on the hillslopes, or on the floodplain to reduce flood damage. But adaptations of linear structures also can have a significant impact on runoff (paths, roads, hedges, ditches, grassed strips). An agricultural ditch, for instance, can be adapted for temporary water storage, by limiting the outflow. Of course, this will create temporary flooding, which must be tolerated by the landowner. Land-use on the hillslopes will also influence runoff, although their effect is less acute for rare events. Table 1 summarizes the main actions that can be undertaken to implement DSD for flood mitigation.

The possible actions in the "slow down" column of Table 1 mainly concern "passive" works, which will curb erosion for moderate rainfall events, but whose effect on more intense flood peaks is more doubtful. Generally, the main concern is flood mitigation and this mainly involves dealing with rare events. Temporary storage facilities are more adjustable: weir levels or outlet capacities can be adjusted to suit mitigation requirements for a

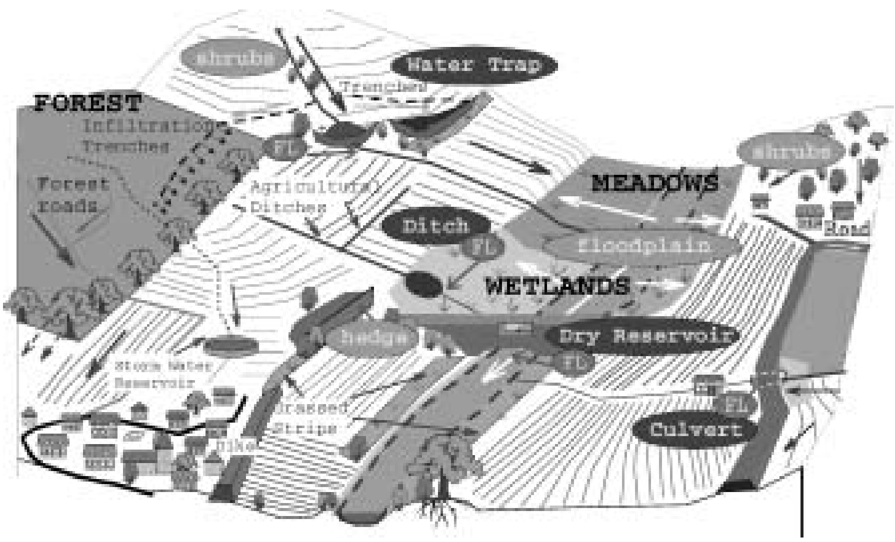

Figure 1 Opportunities for slowing down (light tags) or temporary storage (dark tags) using flow limitation ("FL" tags) in a catchment.

Table 1 DSD tools with respect to location in the catchment and process (SlowDown/storage).

	SlowDown	Store
Hillslopes	Increase water travel-time throughout the catchment, using transverse obstacles, and by regulating land-use (by laws)	Locate and use all storage opportunities by limiting outflow (behind a road, in an agricultural ditch…). If necessary, build specific structures ("water traps")
High runoff zones/temporary rivers	Slow the flow and protect from erosion, using shrubs or ripraps	Create temporary storage zones by limitation of outflow
River floodplains	Control of land-use (by local authorities) Protect and re-plant vegetation on the banks	Make the best use of the floodplain: make overflowing easier where relevant, increase roughness, and if necessary limit existing bridge outflows or build dry reservoirs

given set of project hydrographs. Works are not expected to interfere with small events, but will begin slowing or storing water only for heavy rains.

It is important to stress that DSD does not mean renouncing other hydraulic works. Simply, the project maker should take care to limit their side-effects. Dykes will sometimes be unavoidable to protect some important places; in order not to reduce the floodplain area too much, they should be placed close to the area to be protected, not directly close to the riverbank. In the river bed, dry reservoirs are preferable to small mitigation dams, because the former do not modify the flow in the riverbed except during flows.

The next paragraph describes how the Dynamic SlowDown concepts can be applied to the Isepnica catchment.

2 Case study of the Isepnica torrent

Previous DSD studies took place on plains, with wide floodplains and a very gentle longitudinal slope [1, 2]. Here, the objective of the authors was to carry out a feasibility study for DSD works in a mountainous catchment, where flash floods and landslides have occurred several times in the last few years. A particular site was chosen, the Isepnica, since it is as representative as possible of the regional situation for the purpose of extrapolation [3].

The Isepnica case-study is a very important stage in long-term research on DSD. The study was therefore carried out very thoroughly, and could lead to construction of pilot structures within a few years.

To make a realistic proposal, the authors kept in mind environmental, maintenance and cost issues.

2.1 Description of Isepnica catchment

The Isepnica Torrent is a right tributary of Soła River in the Beskid Mountains (Figure 2), the catchment area is 7.8 km^2, the length 4.7 km and width 1.7 km, the average catchment slope varies from 18° to 19° (up to 40° locally) on the left and 10° to 13° on the right side of the valley. 62% of the catchment area is covered by forest, which is partly used for timber exploitation and partly belongs to "Landscape park", i.e. an area where the landscapes are protected. In the land development plans, the development of tourism is considered to be the most important issue for the region. In the torrent there are many hydraulic control structures like sediment check dams and sills. Near its mouth, the river passes through a village, and has been transformed into a concrete canal. The torrent is very unstable, after every flood major erosion of the bed and banks is observed; the same process occurs in the tributaries. Gully erosion and landslides occur in the catchment. The situation is aggravated after every major flood. The existing hydraulic structures were supposed to limit the sediment discharge to the main recipient (Soła reservoir). In fact, they are now completely filled up with sediments and raise the water level by several meters, which increases the flood hazards upstream. The catchment is typical of the Beskid Mountains and was chosen because of the proximity of Cracow University of Technology experimental catchment at Wielka Puszcza.

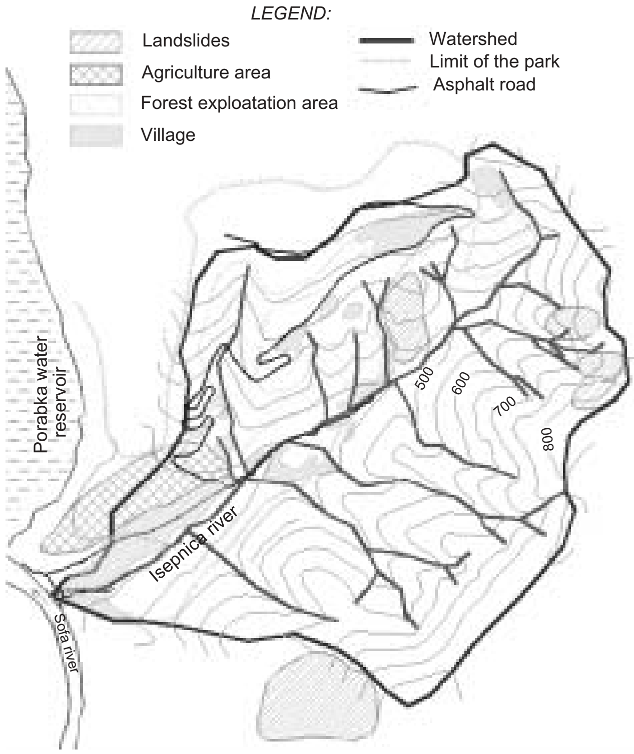

Figure 2 Isepnica catchment map – land-use and landslide-prone areas.

2.2 Problems: floods and erosion

The problems identified were erosion on the slopes and in the bed, and flooding in the inhabited zone.

Hillslope erosion is a problem because sediments are carried away by the Isepnica down to a reservoir on the Soła river. Some areas are indeed identified as prone to landslides, which threaten human property and infrastructures.

Inhabitants have reported that floods occur in the downstream village, and have given information about their extent. With a regional method using the data of the nearby Wielka Puszcza experimental catchment [4], the flood hazard return period was estimated as 10 years.

In collaboration with the local authority, the protection objective was set at reducing the peak of the 100-year return flood down to the value of the present 10-year return flood. The additional constraints to be respected were landscape and habitat protection.

The 3-step work program was:

1. detailed field survey to find suitable places for slowing down and storing water;
2. design of structures adapted to these purposes;
3. assessment of the effect of the whole set of structures on the design hydrographs.

For the third stage, hydraulic tools had to be tested and adapted.

2.3 Available data

Data included: a 1:2000 torrent map, 1:5000 catchment map, geological map, average precipitation at the mouth of the Isepnica, and the data obtained during the field survey (existing structures measurements, measurements concerning the location of future structures, general catchment information etc.).

As with most small mountainous catchments (about 95%) the Isepnica catchment is ungauged. The only available hydrological data was the average annual precipitation, and was used for comparison with precipitation and runoff data from the adjacent experimental catchment.

We could not program a measurement campaign at this stage, and had to make the best use of these limited data. The scarcity of the data forced us to use the local empirical formulae for statistical precipitation distribution (*e.g.* [5]), the precipitation was assumed to be a function of altitude. The values were compared to those measured in Wielka Puszcza experimental catchment.

2.4 Diagnostic of opportunities and proposal

Field visits were organized in this mountainous catchment. A problem with forest roads was detected, because they often concentrate runoff and create local erosion. Suitable places which offered opportunities for building storage structures at a reasonable cost were looked for and found. On the base of field investigations and research (topographical, geological and environmental) we analyzed the possibilities for implementing different DSD techniques and proposed new types of SlowDown structures. From this starting point, a proposal was set up, using road remodelling, water traps and trenches distributing or diverting water.

Figure 3 shows the principles of the small structures in a schematic way. Small storage structures, called "water traps", were proposed (Figure 3, top). These facilities are built with small earth dikes up to 3 m high. Located in topographically convenient places to collect water from their own catchments and from transferring trenches, they are able to store from 2000 to 10 000 m^3 each. If all the suitable locations are used, the total storage volume reaches about 60 000 m^3. The problem of outflow needs specific solutions according to the local situation and type of construction. In order to avoid erosion and landslides, overflows must be re-directed to a thalweg through a delimitated path, protected from erosion.

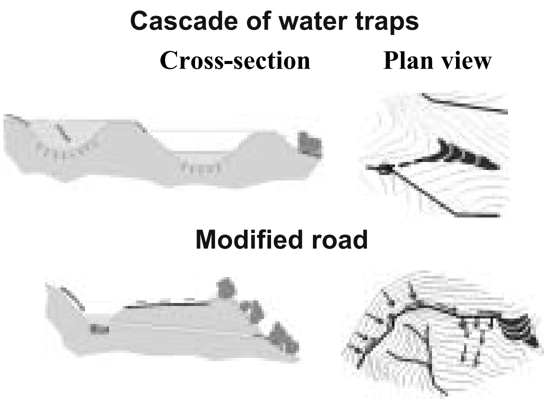

Figure 3 Diagrams of small hydraulic structures.

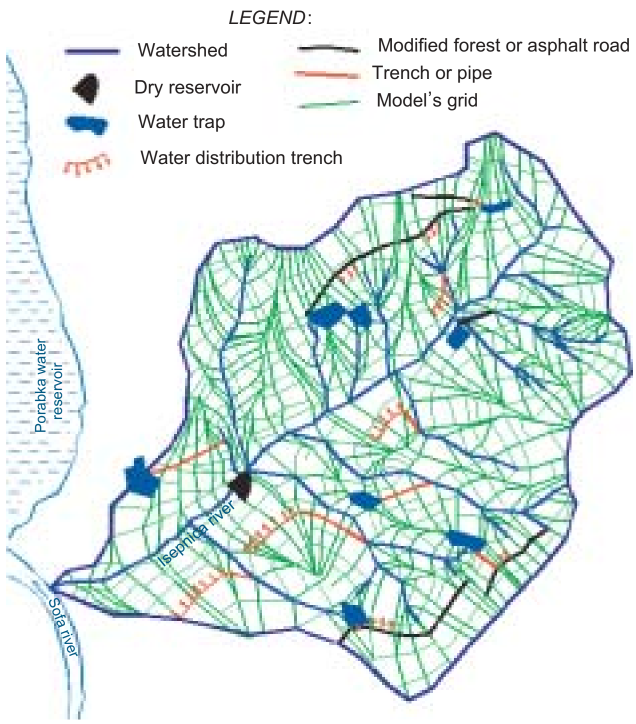

Figure 4 The Isepnica Torrent catchment with computation net and proposed SlowDown structures.

Along with derivation trenches towards these water traps, we propose water infiltration trenches where land use allows it and where there is no risk of landslide.

For future forest roads, it is advisable to build them with a transverse slope opposite to the hill slope, and to equip them with water trenches on the upstream side (Figure 3, down). This will permit to concentrate the outflow in the trenches, which could either distribute water into areas free of erosion risk, through culverts, or direct it to the water traps. Sediment collectors should be added to facilitate maintenance.

Figure 4 shows the distribution of the works throughout the catchment.

3 Computations for Hillslope works

After all the possible works were listed, the effect of the proposed ensemble must be assessed.

The model to be used must cover not only the river network, but all the catchment area, and take into account varied small-size features such as roads, water traps and trenches.

3.1 Development of models OneSecond and Roof&Pipe

The review of existing hydrological models [5, 6] for the surface runoff showed that it was difficult to find one that was entirely suitable for our assumptions and to the distribution of small structures in the morphologically diverse mountainous catchment. There are very complex hydrological models taking into account many important factors including evapotranspiration and infiltration, such as the WISTOO model [6], but they require numerous data and are too sophisticated for preliminary calculations. This is why new mathematical models, called OneSecond and Roof&Pipe, were developed [7, 8], which are a compromise between robustness and accuracy.

(a) Requirements and assumptions

This work is a preliminary study, to choose between possible scenarios and carry out a feasibility study before undertaking a detailed project. Therefore, the model must be able to take into account various works, but still it must be relatively robust and not too costly in computation time. For further stages, such as the actual design stage, measurement campaigns must be undertaken and more advanced models should be used.

For the dimensioning the worst-case scenarios were considered, in particular for the elements where hydraulic structures are located. So, an assumption of a completely saturated catchment and intensive storm type of precipitation was used for the computations.

The data required for the models were: detailed topography, hillslope and river roughness coefficients, infiltration coefficients and design hyetographs. It has to be mentioned that in most small mountainous catchments there are no measured data, not only for surface runoff, but even for local precipitation. Therefore in-depth analyses are necessary for existing empirical formulae, hydrological methods of rainfall data extension, catchment runoff coefficients and surface roughness.

(b) Computation procedures

Both OneSecond and Roof&Pipe models are distributed parameters models and their shared features are:

– the catchment is divided into small unit areas which well represent the varied topography and allow introduction of the small structures;
– they belong to the "grey box" type; the elementary units are described in a simplified way without mathematical description of the physical process.

In both models the first division of the catchment is based on its morphological characteristics (Figure 5); the catchment is divided into units which well represent the varied topography and allows the small structures to be introduced. The difference between models is in the second order division. In OneSecond the first order areas are divided into unit areas whose length corresponds to the distance covered by the flow during one second; therefore the second order division depends on the intensity of precipitation, and moreover the units are of irregular form depending on surface relief. The Roof&Pipe model is based on the first order division (there is the possibility of more dense grid). The Roof&Pipe model has an advantage of quick computations (10 minutes for one run) and very easy introduction of new management scenarios. OneSecond represents more exactly the physical nature of the runoff. Examples of the computational grid are presented in Figure 6.

These models need as input a rainfall event, and as parameters roughness coefficients.

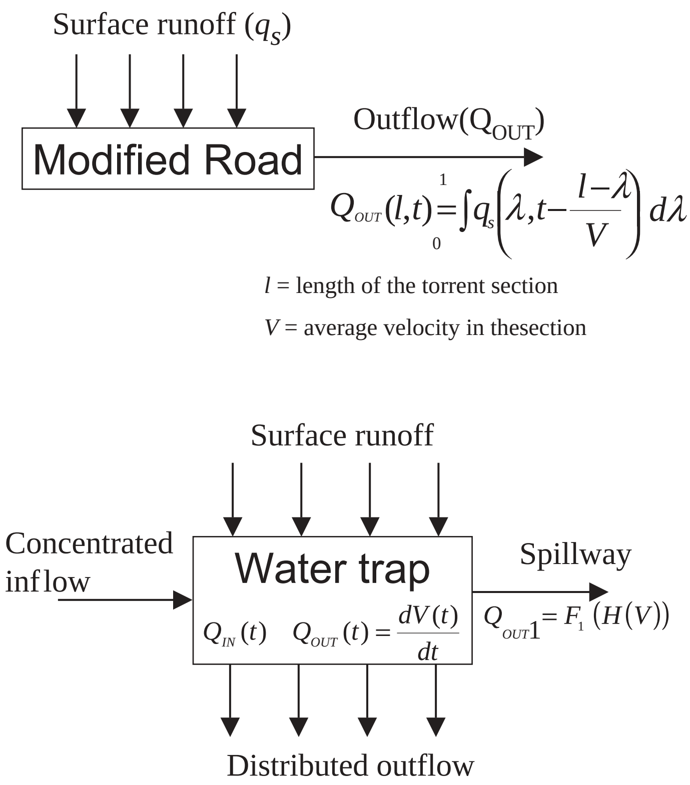

Figure 5 The schematic work of SlowDown structures (λ = length element).

(c) Rainfall duration

Since this catchment is ungauged, we chose to use a regional formula. It appeared that, among the available formulae used in Poland, the Blaszczyk one was the best related to Wielka Puszcza rainfall data [4].

It is a regional empirical formula estimating rainfall intensity for a given return period and duration:

$$q = 6.631^*(H^2 \bullet C)^{(1/3)}/d^{0.67}$$

where: q = rainfall intensity [L.s^{-1} ha$^{\cdot -1}$]
H = mean annual precipitation (for Isepnica H = 750 mm; it may be influenced by altitude) [mm]
C = (100/rainfall return period expressed in years) [ ]
d = rainfall duration [min]

For a given return period, a whole set of events can therefore be designed, with different durations. According to our approach, it was decided to choose the one which produced the most severe floodwave downstream.

The Blaszczyk method proposes setting the duration d equal to the concentration time. But the time of flow from the highest point of the catchment to the outlet, in particular if this point is located in a part of the catchment that contributes significantly to the total runoff volume, also appears as a possible optimal concentration time. So, several simulations were run to find the duration d provoking the maximum flood peak. For Roof&Pipe, this duration was 20 min. This figure fits with the observations in Wielka Puszcza.

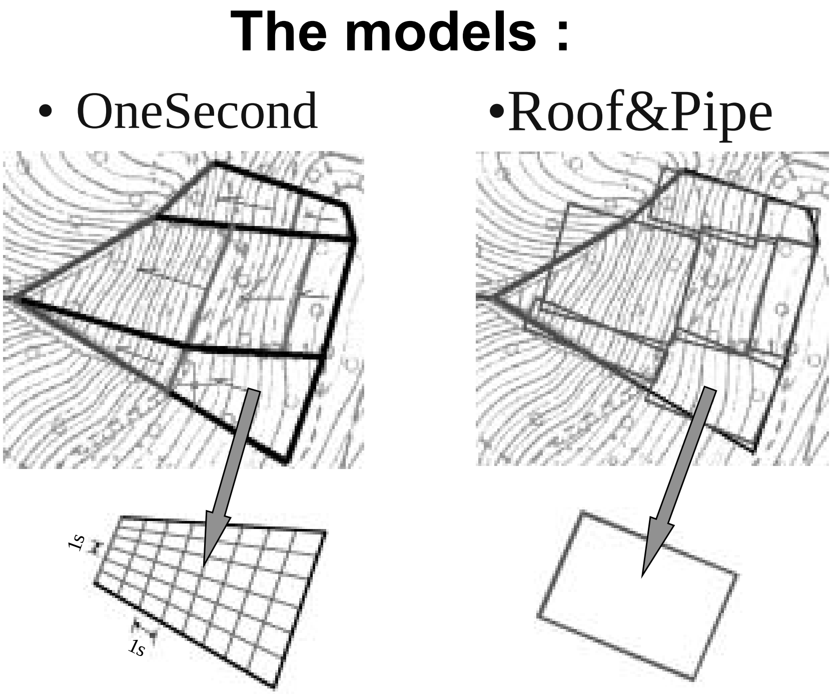

Figure 6 Grid for models OneSecond and Roof&Pipe.

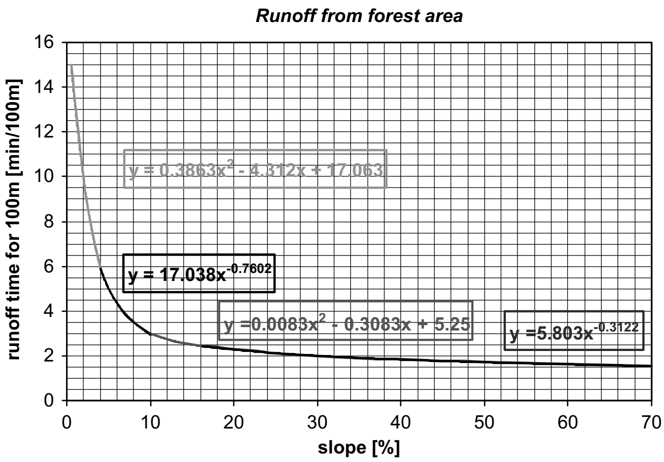

Figure 7 Runoff coefficients, example for forested areas.

(d) Roughness

Runoff coefficients were taken from graphs used in engineering practice according to the vegetation cover [9] (Figure 7).

3.2 *Models comparison on a sub-catchment*

The comparison was done for the small sub-catchments upstream. Figure 8 shows that there is little difference for the average discharge from one element, however only OneSecond can give the inlet and outlet values. For bigger catchments the difference in flood volume is insignificant. There is a small difference in discharge, but not exceeding a few percent (Figure 9). Concentration time may differ by a few minutes, which is not negligible in view of the total event duration for the small catchment.

The comparison of models allows us to conclude that:

– runoff from unit areas is more exactly represented by Onesecond – this model is convenient for the dimensioning of small structures ;
– for larger areas the differences are not too big – and thus Roof&Pipe is recommended because of significantly shorter computation time.

3.3 *Results for a sub-catchment with a water trap*

To show the local effects, the results obtained at the mouth of the tributary corresponding to one water trap (computed by OneSecond) are presented in Figures 10 and 11. The decrease of the peak discharge obtained is about 39% and delay for the peak about 6.5 min, which proves the effectiveness of the structures used.

The case of one water tap was presented to show its efficiency. Its capacity was such that there was no overflow. In the general case, emptying processes, overflow and sedimentation problems must be addressed. Here, it is assumed that seepage will empty the water traps after the floods.

For the final studies of the location and dimensioning of the SlowDown structures for the whole catchment, the Roof&Pipe model was used because of shorter computation time.

3.4 *Results for the study area*

The hydrographs simulated at the dry reservoir section (Figures 4 and 12) were compared to peak discharges estimated by regional formulae (Table 2). Our rainfall-runoff models yielded the second highest peak-flow values. This is not surprising, because the rainfall duration was calculated so as to maximize the outflow.

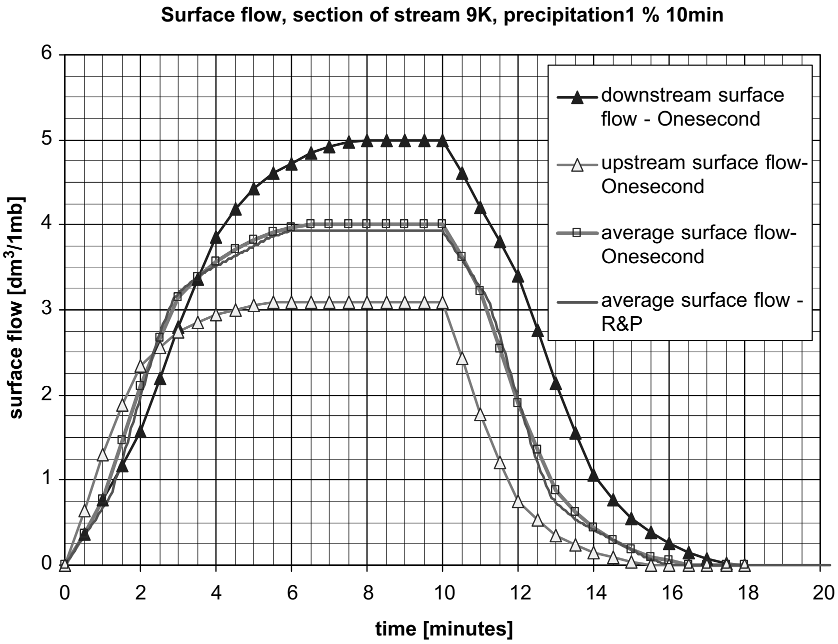

Figure 8 Comparison of surface flow computed by both models in a given segment.

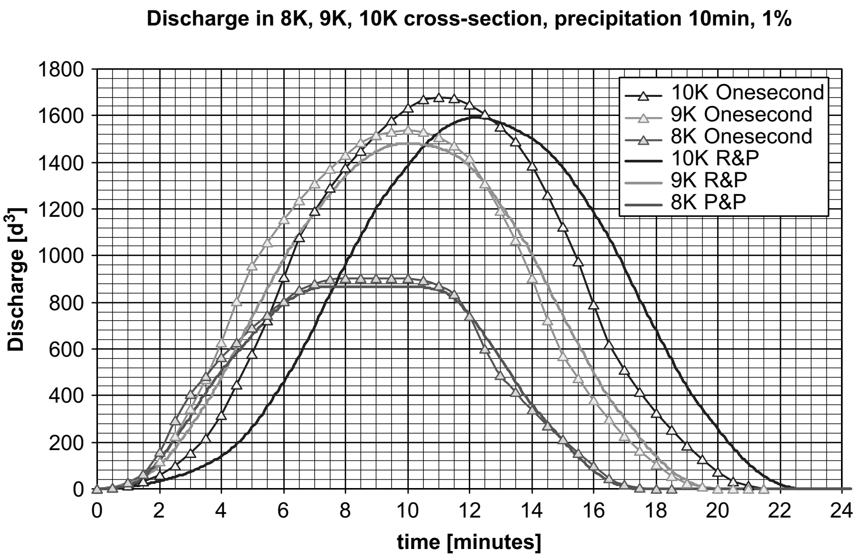

Figure 9 Comparison of discharges computed by both models in three cross-sections.

This represents the practical engineers' approach – the search for the worst conditions for the structure. The uncertainties on the statistical values and the consequence on the results will be discussed afterwards.

3.5 Results for the whole Isepnica catchment and linkage with RubarBE

The Roof&Pipe hydrological model was then linked to a 1D St-Venant model, RubarBe (e.g. [10]). This procedure was undertaken to introduce the hydraulic control structures existing in the main torrent, which Roof&Pipe cannot handle.

(a) linkage modalities

RubarBe, an explicit model, is well suited to the Isepnica flow conditions, where both highly supercritical flow and subcritical flow exist. It was used to model a 1.5 km long reach of the Isepnica river, in order to provide an accurate water level profile and the location of hydraulic jumps which could threaten bed stability.

The input to this reach was obtained from Roof&Pipe computations, *i.e.* outflow for reach tributary subcatchments and hillslope subcatchments bringing runoff into the main reach (Figure 12). Their output hydrograph is be computed by Roof&Pipe. In Figure 12, the computation grid is visible for one of the left bank tributary subcatchment, the one that was displayed in Figure 10. A hillslope subcatchment computation grid is shown on the other bank. In short, Roof&Pipe will provide two kinds of inputs for RubarBe (Figure 12, Figure 13):

– the inflow from tributaries: node input;
– the inflow from the hillslopes: distributed lateral inflow.

Figure 10 Plan view of a subcatchment with a water trap.

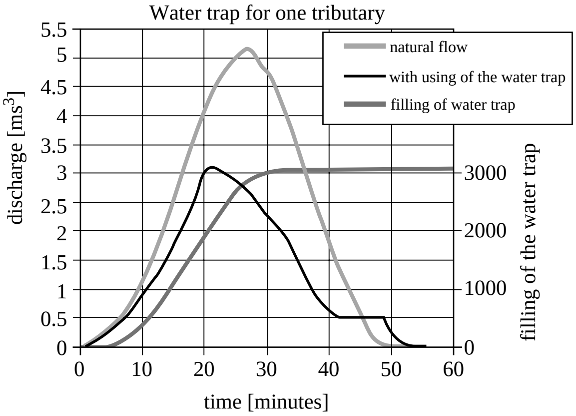

Figure 11 Results for one water trap (100 years return period rainfall).

Table 2 Estimated outflows from different regional formulae (m^3/s).

Return period in years (and probability %)	100	50	20	10
Formula	(1%)	(2%)	(5%)	(10%)
Rozwoda – Raczynski	49.69	40.63	30.07	23.04
Punzet	21.03	17.56	12.94	9.46
Stonawski	28.48	24.18	18.50	14.30
Stachy	22.41	18.39	13.75	10.03
Transformed outflows from Wielka Puszcza (*)	15.44	12.75	9.49	7.15
Simulated output from Roof&Pipe (d = 20 min)	37	32		

(*) with $\left(\frac{A_I}{A_{WP}}\right)^{\frac{2}{3}} = \left(\frac{6.57}{19.5}\right)^{\frac{2}{3}} = 0.479$ transformation coefficient, where A_I, and A_{WP} are the respective catchment areas of Isepnica and Wielka Puszcza.

Except for very local subcritical regimes in the main channel of Isepnica, all of the flow is supercritical. There is therefore no influence from the water levels in the Isepnica on the flow in the tributaries, and therefore there is no need for a feed-back up to the hydrological model. This would indeed involve much more work, because the result of RubarBe in the main channel should be re-injected into the hydrological model at each time-step.

Linkage was proposed to check the accuracy in the main reach, but also for modularity purposes.

In this way, simulations can be run separately for each subcatchment – provided that there is no inflow from a nearby catchment. This division makes it possible to use the time-consuming OneSecond if more accuracy is needed on some subcatchments. To test a new scenario with another distribution of structures, the existing files for each of the sub-catchment already computed are used as they are, and the hydrological model will be run only for a limited area, on the subcatchments where a new hypothesis is tested. Linkage also makes it easier to simulate scenarios with heterogeneously distributed rainfall, since the hydrological model only works with a homogeneous rainfall so far.

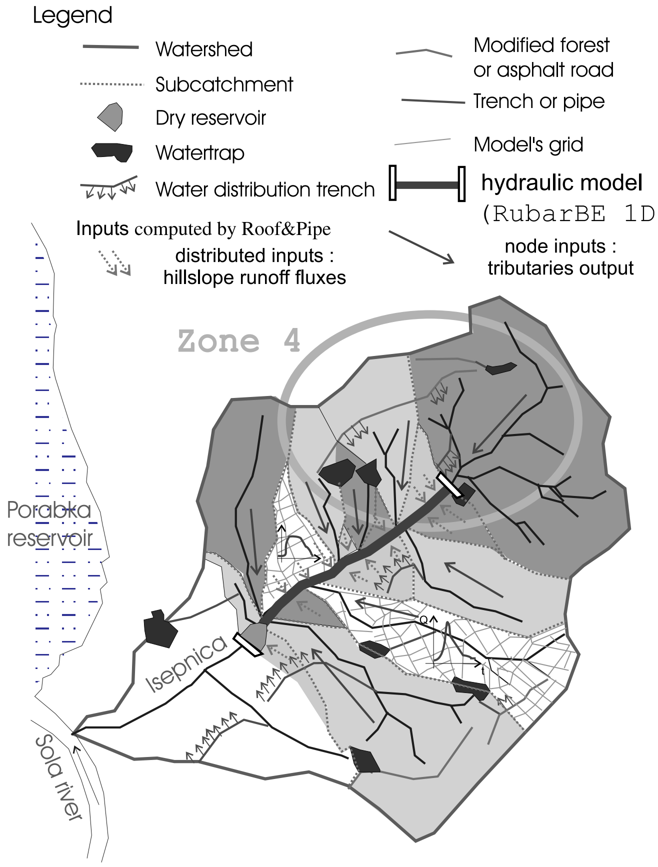

Figure 12 Input from Roof and Pipe into the hydraulic model.

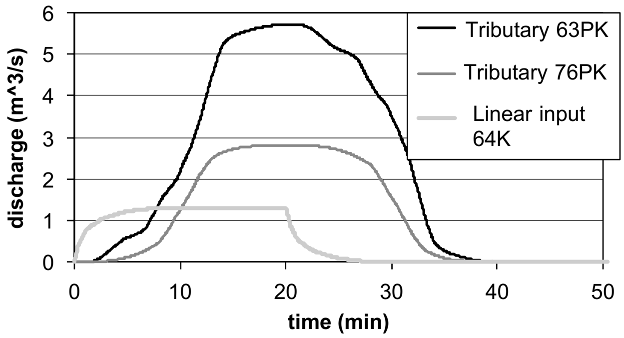

Figure 13 Example of hydrographs computed by R&P and used as input in RubarBe.

(b) Results

The first three curves on Figure 14 display the hydrographs simulated by the hydraulic model, respectively in the natural state, with hillslope works in Zone 4 – covering approximately 25% of the catchment area (Figure 12), and with all structures. The hillslope structures do mitigate floods, up to 30% if works are installed throughout the catchment. Moreover, erosive phenomena also decrease thereby. Nevertheless, they are not sufficient to protect

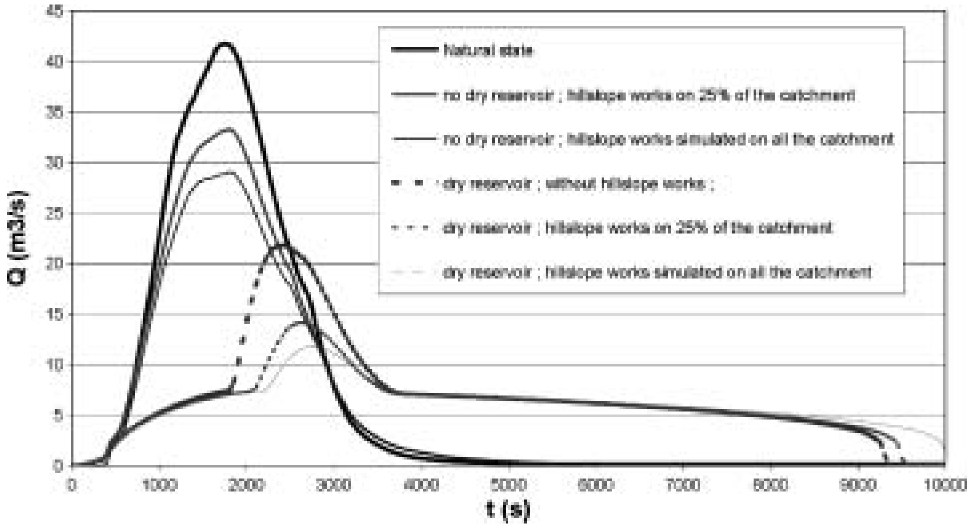

Figure 14 hydrographs at the dry reservoir abscissa for the 100-year return period rainfall (duration 20 minutes); results for several scenarios.

the village according to the set objective: the 100-year return period flood must be reduced to the 10-year level, which is 15 m^3/s. We therefore proposed a complementary structure, a dry reservoir in the main reach.

4 Dry reservoir design and assessment

A dry reservoir is constituted by a dam built on the floodplain, with an opening to let the main channel get through. For medium and low flows, this structure does not modify the flow in the river, and should not represent an obstacle to sediment or animal circulation.

4.1 Location and requirements

Two possible locations were selected after field visits. The finally chosen site, at abscissa 1501 m, is satisfactory for width, bowl capacity and land-use compatibility. Figure 15 displays the proposed solution: an earth dam, constructed with local material, and a thin concrete wall anchored in the dam bearing the sluice and overflow weir. The structure carries a road, to make the most use of it.

The danger of bed erosion was checked, but at the proposed location the rocky bed can withstand the estimated velocities during the floods, and there is no hydraulic jump after the structure because the flow remains supercritical, thus no stilling basin is necessary.

Efforts should be made to integrate the structure into the landscape. For example, we propose not to leave rough concrete surfaces on the dam sides, but to have them covered with local stones.

4.2 Effect of a dry reservoir alone

We designed a dry reservoir, with an overflow weir at the height of 8 m, and a 1×1 m outlet. We tested its effect on the 100-years return period rainfall as determined previously to maximize the flood.

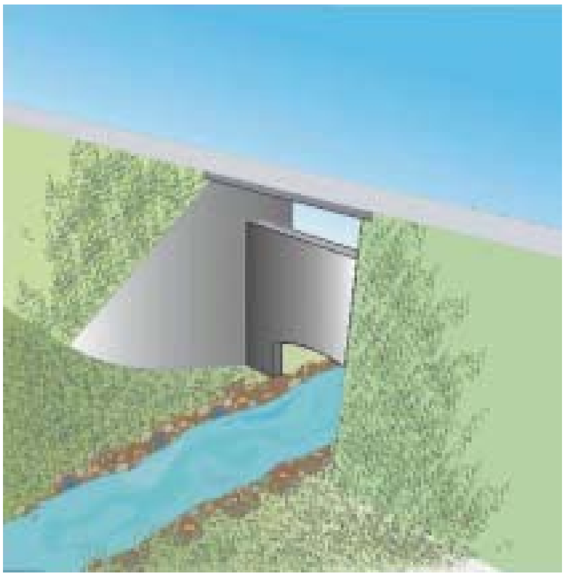

Figure 15 Proposed design for the dry reservoir.

Figure 14 displays the simulated hydrograph (fourth line). With this first draft of the outlet dimensions, 1m $\times$ 1m, outlet capacity is about 7 m^3/s. The simulations show that the peak discharge is reduced by half. The reservoir is filled after less than one hour, and the overflow begins spilling water, as shown by the brutal change in discharge slope.

With the dry reservoir alone, the mitigation of the 100-year return period flood is not satisfactory. We then re-introduced storage works in the hillslope.

4.3 Effects of the dry reservoir combined with hillslope structures

Figure 14 also displays the computed discharge for two scenarios involving the hillslope works, one with works only in a single zone, Zone 4, and another with hillslope works all over the catchment. The combination of both types makes it possible to reduce the peak down to 12 m^3/s, which is below the set reduction objective. This proposal is therefore satisfactory, but can still be improved in further stages.

The action of hillslope works diminishes the time of overflow, but does not suppress it. In further stages, it will be possible to adjust the reservoir behaviour by adapting the outlet dimensions. The effect on intense floods can be further enhanced by designing a wider outlet, so as to limit storage at the beginning of the flood and keep thereby storage volume available throughout the flood until the peak to ensure an optimal mitigation.

5 Discussion

The hillslope works and dry reservoir are complementary: the dry reservoir is necessary and very efficient for the 100-year return period flood, but it has an effect only on the downstream part of the catchment. In its proposed form, the dry reservoir has a very limited impact on the landscape and river system. Hillslope works reduce medium floods and also erosion throughout the catchment, and contribute to the mitigation of the 100-year return period flood.

The results of this feasibility study encourage us to carry on this promising project. In further stages, discharge and rainfall measurement campaigns should be carried out to validate the models and adjust the input parameters, such as roughness and rainfall. In particular, discrepancies appeared between the 100-year hydrographs estimated by different methods. As shown by Table 2, discrepancies appear between the 100-years peak discharge estimated by the most widely used regional methods. However, these formulae only give peak values, and only in the main torrents. For our purposes, we chose to develop a rainfall/runoff model. The rainfall used as input was calibrated to maximize the output. Logically, this approach gives a peak discharge close to the highest value obtained by regional methods. Since this catchment is ungauged, uncertainty on the project hydrograph is unavoidable, but nevertheless the simulations yield valuable information. Their efficiency is proved, and the order of magnitude of the percentage of mitigation is reliable.

Discharge and rainfall monitoring campaigns would help to calibrate the model and improve the estimation of event probabilities. If this can be obtained, the better knowledge of the flood discharge and duration probabilities, as well as time-to peak, will allow the works' design to be better adjusted and enhance their efficiency for the project hydrograph.

In parallel, the construction of some of the proposed hillslope works is envisaged to monitor them, in order to improve their design and to validate the way the hydrologic distributed model *Roof&Pipe* takes them into account. For the choice of the final proposal, the cost of the constructions must also be taken into account, as well as maintenance costs.

Conclusion

The first approach in Poland to the SlowDown methods with numerical results of their effects has shown that:

- There are major storage possibilities in the mountainous catchment, provided they are located with careful field visits.
- The local effects of the concentrated surface runoff decrease is significant and can result in a reduction of landslides and erosion hazards.
- The impact of SlowDown structures located in a catchment on flood wave in the main channel is significant, the decrease and flattening of the wave peaks could reduce the use of heavy hydraulic structures in the mountain torrents.
- The land development policy should include catchment management, taking into account the environmental and landscape protection.
- The numerical results show a very good mitigation. The peak reduction percentage estimated is reliable, however the exact value of 100-year return period flood remains uncertain because of the lack of field data. Field measurement campaigns are necessary to fine-tune calibration (rainfall distribution, runoff velocities, stream discharges and discharge-level rating curves…).
- The construction and monitoring of "pilot structures" would yield valuable information about their actual behaviour during floods (seepage, sedimentation, erosion due to overflows).

This project was carried out to help project-makers implement DSD for their own purposes. The Isepnica case proved that DSD works can be effective in small mountain catchments, provided that topography and particular features are thoroughly studied to make the best use of the opportunities. The works must be suited to the catchment, and the simulation tools must be adapted to the works and the topographical specificities.

DSD is a promising concept for flood mitigation meeting sustainable development standards, and the French Ministry of Ecology granted in 2003 130M€ to local authorities putting DSD into practice. A technical guide was written to help the project-managers; Cemagref researchers participated in that work, based on feedback analyses and research results, including the Isepnica project [11].

New feedback from the on-going projects should help to understand the actual behaviour of the works during the flood events, and also to design better suited modelling tools and methodologies for the specific needs of DSD.

To comply with "Integrated Management" principles, flood mitigation studies should be combined with assessment of their effects on water resources, erosion, habitat quality and diversity. . . . This is difficult to obtain in practice, because of the cost of these additional studies and the difficulties of quantifying the value of features such as landscape. Nevertheless, to protect environment and landscapes, these issues will have to be increasingly integrated into project requirements and assessment.

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