The choice of an outlet for Ispenica Dry Reservoir

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English summary

Dry reservoirs are one of the Dynamic Slowing Down techniques applicable in mountainous areas. They can efficiently mitigate floods, with as little negative effects as possible on the hydrosystem.
This paper focuses on the design and dimensionning of a dry reservoir proposed for Isepnica. We show how the dimensions of the sluice can be adjusted to optimize its behaviour for a design hydrograph.
However, our work confirms the importance of the hydrological analysis. Indeed, we found a one-to-two factor between 100-year return period peak discharges estimated by two different methods. We also showed that two successive 50-year floods are equivalent to one 100-year flood downstream the dam.

Résumé français : *Dimensionnement du pertuis de la retenue sèche de l'Isepnica*

Les retenues sèches sont une technique de Ralentissement Dynamique applicable en milieu de relief. Elles sont efficaces pour laminer les crues, avec peu d'effets négatifs sur l'hydrosystème.
Cet article traite de la conception et du dimensionnement d'une retenue sèche proposée pour l'Isepnica. Nous montrons comment les dimensions du pertuis peuvent être ajustées pour optimiser son fonctionnement pour la crue de projet.
Cependant, l'étape déterminante est l'analyse hydrologique. En effet, deux méthodes différentes pour estimer l'hydrogramme centennal ont conduit à des débits de pointe allant du simple au double. De même, deux crues cinquantennales successives reviennent à une crue centennale à l'aval du barrage.

Polish summary : *Upust denny w suchym zbiorniku na zlewni potoku Isepnica.*

Suche zbiorniki są jedną z technicznych metod Opóźnienia Dynamicznego stosowaną w zlewniach górskich. Mogą one efektywnie zmniejszyć objętość fali powodziowej w niewielkim stopniu wpływając na hydrosystem.
Prezentowany artykuł skupia sie na projekcie i wymiarowaniu suchego zbiornika proponowanego w zlewni potoku Isepnica. Pokazujemy w nim jak wymiar upustu dennego może modyfikować odpływ dla przyjętego do projektu hydrogramu dopływu. Nasza praca potwierdza wagę analizy hydrologicznej. Stosując dwie różne metody obliczeń hydrogramu 1% otrzymaliśmy wyniki różniące się prawie dwukrotnie. Wykazaliśmy także, że dwie kolejne fale 2% dają w korycie poniżej zapory podobny efekt.

Introduction

Dry reservoirs are one of the possible Dynamic Slowing Down techniques applicable in mountainous areas. These techniques are not means a new idea : some are over one century old. Located in main river beds, they are efficient on flood mitigation, and were found to be a good complement to hillslope structures.
This paper will address the questions of their design for hydraulic efficiency, adjusted here by adapting the outlet dimensions, and of their stability. In addition to these criteria, their design must also respect some ecological requirements to become truly an effective DSD tool with little or no negative effect on the environment.

1. Existing dry reservoirs

The only objective of the dry reservoirs is flood wave mitigation. They are composed of a dam blocking the floodplain, but with an opening for the main channel (Fig. 1). During the low and average flows all the water flows through the sluice, no water is stored – hence the name "dry" reservoir. Thus, the bowl can be used for agriculture because it will be flooded only very occasionally – once every 10 or 100 years, depending on the project design.

In the beginning of the XXth century in today Poland (Sudety Mountains), 13 dry reservoirs were constructed, all in the Oder water basin – on Bober, Kaczawa rivers and their tributaries, and in watershed of Nysa Kłodzka. These dry reservoirs represent small storage reservoirs mostly built in mountainous areas in the upper course of mountain torrents. Their catchment is from few to few hundreds square km. As seen from the preserved design documentation, previously the dams were built with automatic outlets (spillways and orifices) – the maximal outflow was determined by the outlet devices dimensions. Later on, in the XXth century (1925-30) in order to control the outflow manually-controlled valves were installed. The two reservoirs Bukówka on Bober River and Słup on Nysa Szalona River were turned into storage reservoirs with constant head. The dams are mostly made of earth with concrete outlet structures. Only dams of Żarek and Międzygórze Reservoirs were constructed from stones with cement mortar. The heights of dams are from 4 to 20 meters, and the storage capacity varies from 0,74 to 6,0 millions cubic meters, the inundated area is from 7 to 214 hectares. Detailed information concerning the reservoirs and dams are presented in Table 1.

Recent constructions can be now found in France, like in Roanne (Fig. 1b) or Ceyrac-Conqueyrac, and many more are under study (on the Huisne river upstream of Le Mans, in Millau...).

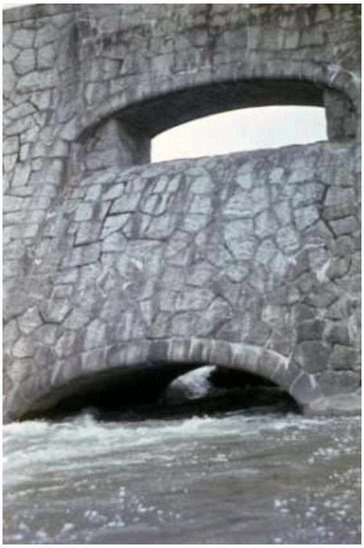
Reservoir	River (km)	Catchment area (km^2)	Type of Dam	Year of constru-ction	Height of Dam (m)	Permissible outflow (m^3/s)
Międzygórze	Wilczka (10+750)	25,0	Rip-rap	1905 1909	29,20	10,0
Stronie Śląskie	Morawka (2+400)	51,5	Earth dam+ embankment	1906 1908	16,58	37,1
Bolków	Rachowicka Woda (1+000)	19,0	Earth dam	1908 1912	13,6	4,0
Kaczorów	Kaczawa (85+500)	18,0	Earth dam	1929	15,1	6,0
Krzeszów I	Meta (0+300)	43,0	Earth dam	1905 1906	3,39	-
Krzeszów II	Zadrna (8+700)		Earth dam	1905 1906	4,8	20,0
Cieplice	Wrzosówka (1+600)	69,0	Earth dam	1906 1909	8,4	30,0
Sobieszów	Kamienna (9+500)	118,6	Earth dam	1906 1909	11,0	60,0
Mysłakowice	Łomnica (7+560)	49,6	Earth dam	1910 1913	9,8	50,0
Mirsk	Długi Potok (1+500)	62,6	Earth dam	1908 1910	12,3	32,0
Świerzawa	Kamiennik (0+400)	37,0	Earth dam	1907 1911	19,3	12,0
Jamołtówek	Złoty Potok		Earth dam	1907		9,5

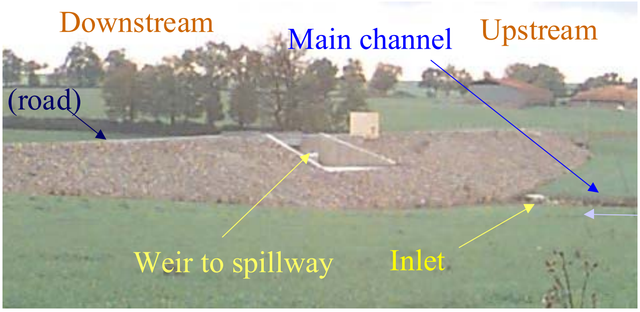
Table 1 : characteristics of 13 early- XXth century in Sudety mountains (Poland)

2. Proposition of technical solution

To make a realistic proposition for the Isepnica, the following requirements must be met :

- low cost, which can be achieved by locating the structure in a narrow section, and choosing local material to build the dam ;
- the upstream part, forming the bowl, must be large enough to let the structure store a sufficient volume, and its flooding must be accepted by the land owner ;
- reliability, and in particular non-controlled functioning: located in a small catchment, with no technical services dedicated to its maintenance, the structure must not use complex devices for fear they could be blocked during a flood ;
- not disturbing for low and medium flows ;
- no additional sedimentation behind the dam ;
- the outlet must withstand under-pressure flow;
- when the upstream bowl is full, the dam or a specifically designed weir and spillway must withstand overflow ,
- the outlet must allow invertebrates and fish movement from downstream to upstream and vice-versa, in particular, a long and dark outlet is an obstacle for most fish ;
- the dam must be well-accepted in the landscape.





a) – left : Sobieszów (Poland), built in 1906-1909 : sluice, weir and spillway
b) – above : Roanne (France), built in 2001 : general view (earthdam, concrete sluice and spillway, rip-rap covering)

Figure 1 : Examples of an old and a recent dry reservoir

Two possible locations were selected after field visits. The finally chosen one, at abscissa 1501m, is satisfactory for width, bowl capacity and land-use compatibility. Figure 2 displays the proposed solution : an earth dam, constructed mostly with local material, and a thin concrete wall anchored in the dam bearing sluice and overflow weir. The structure is bearing a road, to make the most use of it.

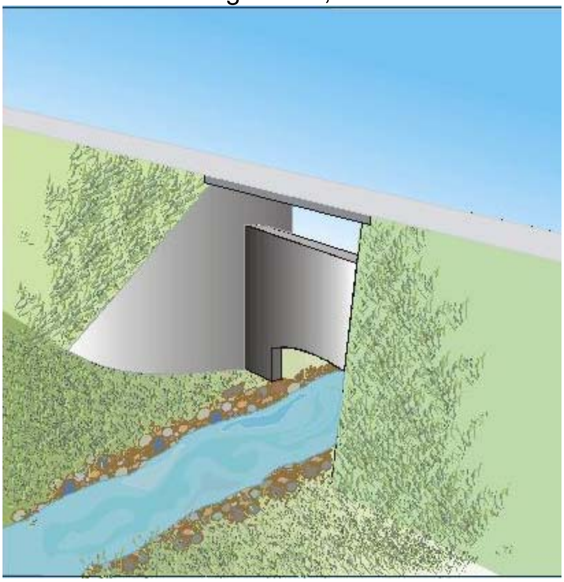


Figure 2 : Sketch of proposition for dry reservoir in Isepnica

3. Computations

Once the principles are set, the dam must be designed to meet both hydraulic and ecologic requirements. This paper will mainly address hydraulic issues.
The first step consists in fixing the requirements. Here, the reservoir is expected to mitigate the one-hundred return period flood. More frequent floods are expected to be mitigated well-enough by hillslope strucutres, and pose no threat to the village.
To optimise flood mitigation, computations must be carried out to check that the sluice is :

- large enough to let medium floods pass ; the reservoir must be empty while there is no need for outflow reduction
- small enough to limit the design hydrograph(s) as wished.

Here, we made our computations with only one dry reservoirs, no hillslope works are taken into account.

3.1. Required data

To calculate the transformation of the flood wave by dry reservoir the following data are necessary :

- Inflow hydrograph ;
- Reservoir capacity curve ;
- Characteristics of outflow devices: orifice and spillway.

Hydraulic tools

The calculations can be carried out either by mathematical model of Saint-Venant equations or by simple hydraulic computations.
These latter consist in successive computations for fine time-steps, for each step the volume and depth of corresponding layer is determined, the outflow from outlets is calculated.
The following stages of the outflow can be determined (Figure 3) :

- the first when the orifice is not filled by water-the outflow is then calculated as open channel flow when there is no contraction, or in the case of contraction as broad crested weir ;
- the second when the water head is slightly higher than orifice edge – then cavitation appears, perturbing the outflow (Figure 3 : the curve seems to go backwards) ;
- the third when the water head is important and the outflow could be calculated as underpressure outflow, using formulae depending on the outlet shape and length ;
- the fourth when the emergency spillway starts to work.

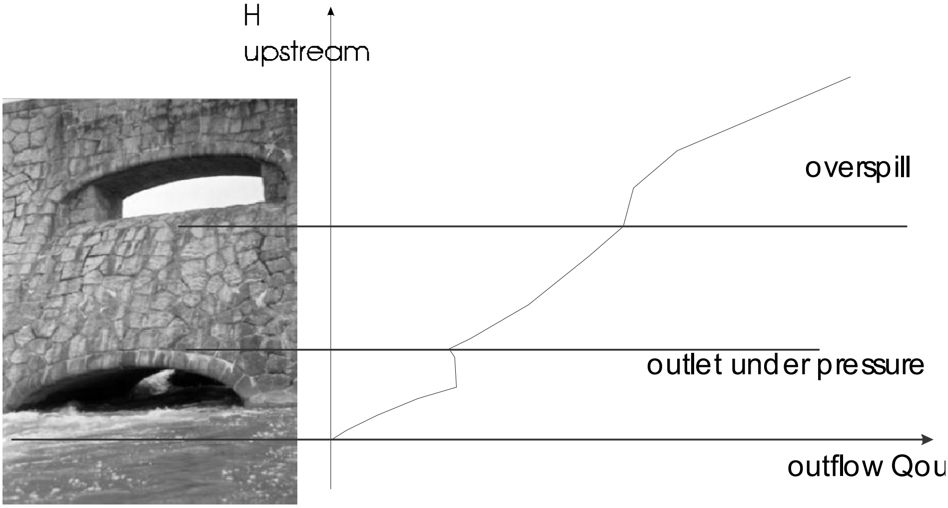


Figure 3 : Example of rating curves water height/outflow used for simple hydraulic computations with regard to the different stages

Comparing 1% flood waves obtained through 2 approaches

In small mountainous catchments, as studied here, the maximal flood waves are caused by storm rains or long duration rains. The storm waves give maximal outflows but not maximal flood wave volume, which occurs during the rains of long duration. Therefore the capacity of the dry reservoir should be calculated for the most unfavourable conditions, that is for high and long-lasting flow.

The first computations were carried out using as input a hydrograph obtained through discharge regionalization, using Punzet formula (Q is calculated as function of catchment surface, torrent length, difference of altitudes, slope, mean annual precipitation, and land cover indexes). The simplified approach and the St-Venant model for the Isepnica river, using RubarBe[1] gave similar results. Figure 4 displays RubarBe results, which show a satisfactory mitigation, under 8 m3/s.
But an other approach was also used to estimate the 1% probability flood on the Isepnica. As presented in the previous paper, a rainfall-runoff model was designed for the Isepnica catchment, Roof&Pipe Using as input a 1% probability rainfall, also estimated by a regional formula (Błaszczyk's formula), the model estimates at the dry reservoir abscissa a much higher hydrograph (Fig 5).

- Błaszczyk formula (it was creaeted only for area of Poland):

$$J = \frac{6{,}631 \cdot \left(H^2 \cdot C\right)^{1/3}}{t^{0{,}67}}$$

J [l/s·ha] – intensity of rain
H [mm] – annual precitipation for Isepnica H = 750 mm it is for altitude of crossection of dam,
C – 100/probability of rain for example 100/10%
t[minutes] – time of pracitipation

[1] RubarBe is presented in previous paper

The dry reservoir sluice as previously dimensionned is no more adequate to mitigate the 1% flood probability as estimated by Roof&Pipe.

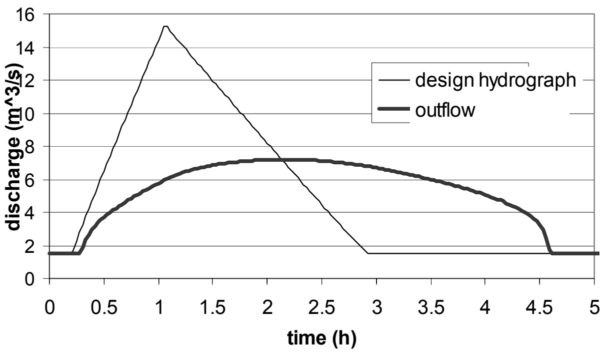


Figure 4 : mitigation of flood through the proposed dry reservoir, 1% probability hydrograph, 1m x 1m sluice (RubarBe computations)

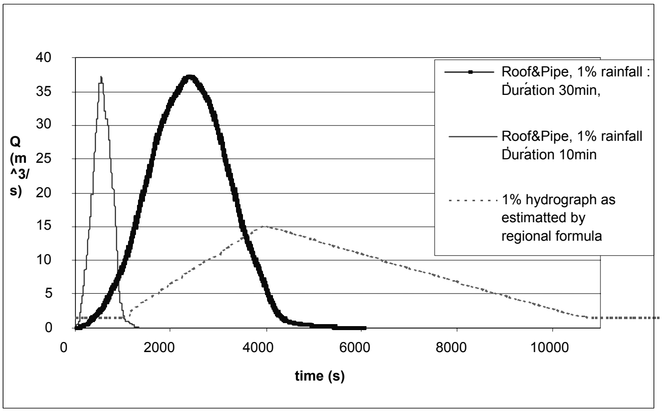
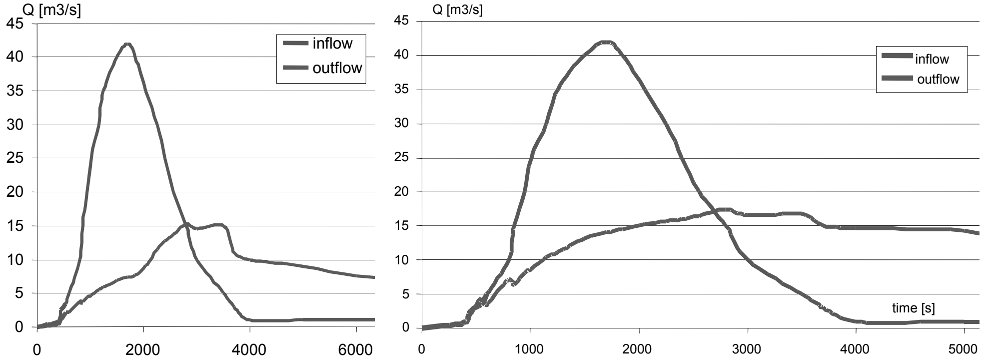


Figure 5 : comparison of 3 possible 1% probability hydrographs at abscissa 1501 : with Roof&Pipe for durations 30 and 10 min, with regional formula

3.2 Results

Here, we modified sluice dimensions to better adjust the functionning to the mitigation requirements.

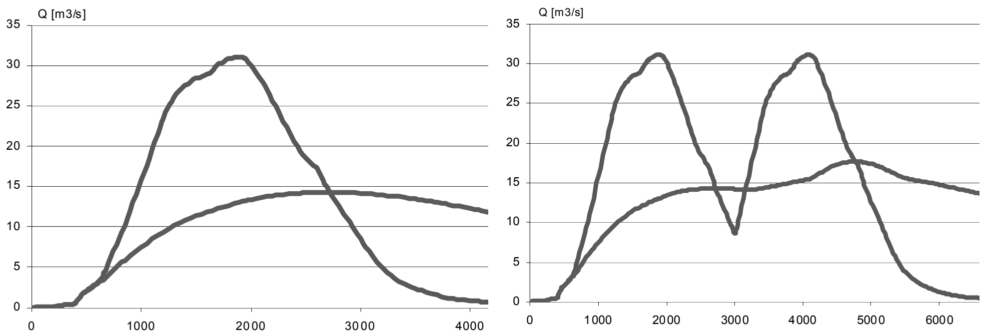
Figure 6 displays the results obtained for the 1% probability flood as calculated with Roof&Pipe, for two sluice dimensions. Figure 6b uses a wider opening ; the peak flow is about the same, but the spillway functions for half the time, which is better for structure stability.



(a) 1m x 1m sluice (b) 3m x 0,65m sluice

Figure 6 : mitigation of flood through the proposed dry reservoir, 1% probability hydrograph computed with Roof&Pipe, (simplified computations through dry reservoir, 6000 seconds simulation)

As we already stressed, designing the input hydrograph is a very crucial step, on which the all the following results depend. Though, it is a most delicate stage, especially when so little data are available. But even if we had a good knowledge of the flood regime, a single hydrograph is not always sufficient. Indeed, with one single hydrograph it is assumed that the reservoir is empty at the beginning of the flood, which is the most favourable case. Figure 7 shows that two successive 2% probability floods are of course more dangerous than one, and they are almost as dangerous as one 1% probability flood (Figure 6b).



(a) one 2% probability hydrograph *(b) two successive 2% probability hydrographs*

Figure 7 : mitigation of flood through the proposed dry reservoir, 3m x 0,65m sluice, 2% probability hydrograph computed with Roof&Pipe, (simplified computations through dry reservoir)

Michel (1987,1989) advises not to run one isolated design hydrograph, but if possible a whole discharge time series, to take successive floods into account when estimating a mitigated regime.

4. Conclusions

Our work emphasises the importance of the protection objectives definition and design hydrographs estimation. If the hydrological analysis is not made thoroughly, all subsequent results are questionable. A set of possible hydrographs, from optimistic to pessimistic options and with different durations, should be tested to take uncertainty into account. This is even more important when little data is available, and thus uncertainty on the design hydrograph is huge, like in the Isepnica case.

Besides, the assessment is often carried out on one design hydrograph; but it is interesting to check effect with a set of successive hydrographs, or -even better- with a whole time-series.

The dry reservoir designed by us takes into account fish needs, and in particular the choice of a thin wall was made in order not to create a dark passage. The risk of floating material clogging the sluice is also to be addressed during following stages.

On the whole the dry reservoir was proved here to be efficient for 100-year return period floods. Moreover, as shown in the previous papers, it is proposed to build it altogether with hillslope works, which will enhance flood mitigation. Both types of structures are complementary : hillslope works are very efficient on moderate and medium floods and reduce erosion, whereas the dry reservoir only interferes with rare floods.

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