# Study of the effects of a distanced retention basin combined with open check dam

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# Study of the effects of a distanced retention basin combined with an open check dam on a physical model

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## INTRODUCTION

Sediment traps are thus classically used in flood hazard mitigation (Zollinger, 1983; Ghilardi et al., 2012). Typical sediment traps consist of an upstream basin combined with an open check dam at the outlet (Fig. 1 a). However, in some cases spatial or geotechnical constrictions do not allow for the construction of one of the two elements. It is possible to limit the structure to a simple basin without open check dam when the space is sufficient, as the longitudinal bed slope can be reduced by levelling the river, thus enhancing the process of sediment deposition (e.g. Kaitna et al., 2011).
In steep narrow valleys or due to anthropogenic infrastructures, there is sometimes not enough space available for a basin. An open check dam without widened basin has to be considered in this case. Sediments are then stored directly in the river bed upstream of the structure. In some particularly critical cases, i.e. when it is neither possible to implement a sufficiently large retention basin, nor a big enough open check dam, a combination of an open check dam with a retention basin built at a given distance is conceivable (Fig. 1 b). This kind of situation has been analyzed with the physical model of the Drance river, upstream of Martigny in the upper Rhone valley (Switzerland). The paper presents in which extend it had been possible to achieve the mitigation objective using this specific configuration.

## CONTEXT

The Drance river has several debris flow prone tributaries before it passes the town of Martigny. During severe floods, as occurred in 2000, the tributaries supply significant sediment amounts to the main-stem. The Drance then transports the sediments downstream which aggravate the flood hazard in the city of Martigny. The creation of a sediment trap downstream of the tributary confluences and upstream of the area to protect has been studied using small scale experiments.
As the tributaries are situated close to the city, few sites exist for the implementation of the sediment trap where not enough space is available to create a classical structure (Fig. 1 a). The installation of an open check dam, with an upstream distanced basin creates a storage volume by means of a trap basin and a 100 m long channel section between the check dam and the basin.

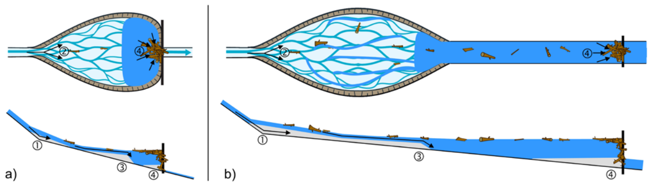


Figure 1. Concept of sediment traps: a) the classical scheme, i.e. the check dam is directly connected with the basin and b) the herein studied scheme, i.e. the retention basin is situated at some distance upstream of the open check dam. The different processes that control deposition are illustrated by ① ② ③ ④ and commented in the text.

## OBJECTIVES

Four different effects lead to sediment deposition in sediment trap basins (Zollinger, 1983; Piton and Recking, 2015). Two of them are related to the basin feature:

1. decrease in sediment transport capacity due to milder slopes in the basin;
2. decrease in sediment transport efficiency due to flow spreading in the basin which is wider than the upstream channel.

And the two other effects are induced by the open check dam:

3. open check dam backwater effect inducing a drop in shear stresses in the tranquil water area and;
4. mechanical blockage of coarse elements against the open check dam. In this case the distance of 100 m between the sediment trap outlet and the basin could disconnect the system. Therefore, a small scale model is used to analyze this system.

## METHODOLOGY

The physical model has already been tested for the hydraulic functioning of an open check dam only. The reproduced river section is about 800 m long, where the average bed slope is about 2.4 % and the width of the main channel varies between 10 m and 15 m in prototype dimensions. The height of the check dam is limited due to railway line on the right river bank. The expected amounts of sediments to be retained as well as the grain size distribution are subjected to some uncertainty. About 100 m upstream of the check dam, it is possible to implement a retention basin of the shape of a deposition area. The effects of this retention basin on sediment transport in the Drance were analyzed by experiments with discharges of the order of an annual flood, a 100 - years flood and the average river discharge. Sediments were added continuously at the model inlet and in shape of a debris flow deposition from another lateral torrent which is situated about 700 m upstream of the check dam.

## RESULTS

The retention reservoir enhanced the sediment deposition upstream of the open check dam and reduced the sediment transported towards the open check dam at the beginning of a flood event. Once the bed slope in the deposition area reached an equilibrium state, the natural bed load transport continuity reestablished and entered the channel between the open check dam and the basin. In this reach, closer to the open check dam, the backwater effects enhanced the deposition of sediments which were then trapped during the backfilling process in front of the check dam. This backfilling was suffcient enough to reach the retention basin, thus increasing the deposition in this area.

## CONCLUSIONS

A deposition area in some distance upstream, but still in the influence region, of an open check dam has been proven to increase the sediment storage capacity compared with the construction of an open check dam only. The combination of the two measures, i.e. a bed load trap in two separated structures therefore represents a remedy in case of spatial constrictions.

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KEYWORDS

Retention reservoir; Open check dam; Sediment deposition; Bed load

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# STUDY OF THE EFFECTS OF A DISTANCED RETENTION BASIN COMBINED WITH AN OPEN CHECK DAM

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Living with natural risks

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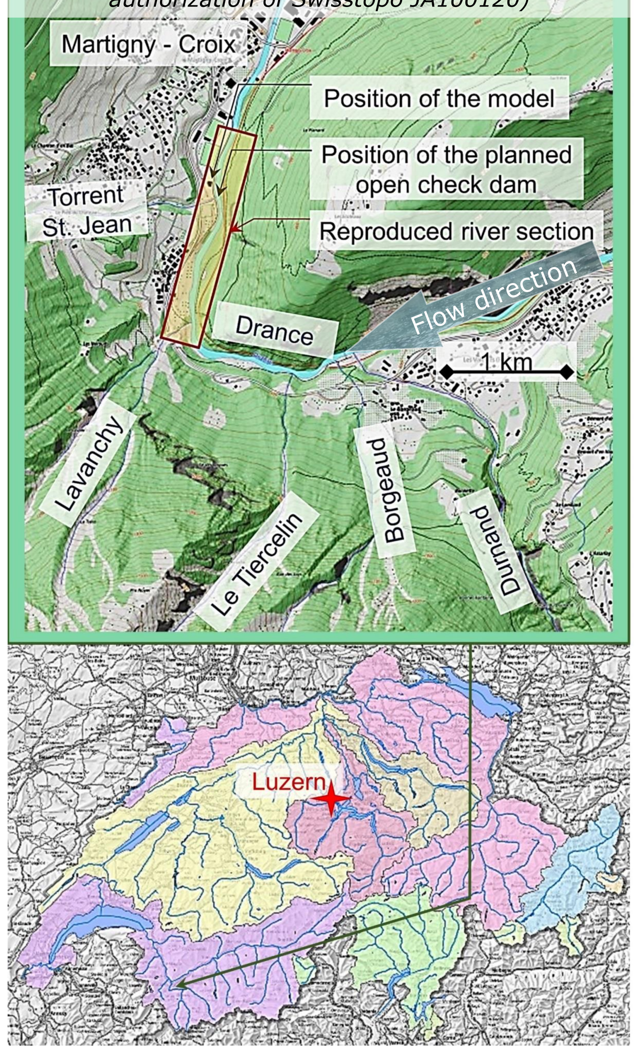
**In alpine environments, open check dams are constructed for retaining sediments which cannot be transported in critical downstream river sections in case of floods. Critical sections are settlement areas where the river has undergone torrential corrections works. For maximizing the sediment storage volume of open check dams, upstream retention basins are essential elements. Based on a case study on a physical model, it turns out the retention basins which are not directly connected with the check dam do not only still fulfil their basic purpose, but also optimize the clogging process of the open check dam.**

*Figure 2:* ***Project location*** *(with the authorization of Swisstopo JA100120)*

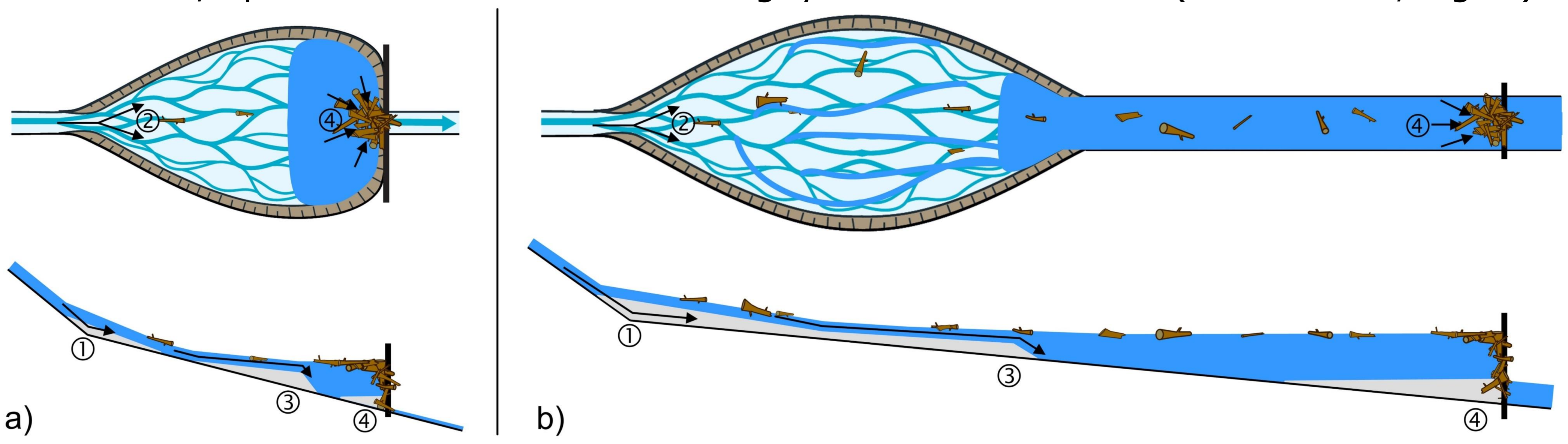



## INTRODUCTION

In mountain rivers and torrents, flood hazard is greatly influenced by **excessive sediment deposits**. Typical sediment traps consist of an upstream basin combined with an open check dam at the outlet (Fig. 1 a). In some cases spatial or geotechnical constrictions do not allow for the construction of one of the two elements. In some particularly **critical cases**, a **combination** of an open **check dam** with a **retention basin built at a given distance** is conceivable (Fig. 1 b). The retention basin is tested in terms of a river widening which is situated **still in the backwater of the open check dam**. This kind of situation has been analyzed with the physical model of the Drance river, upstream of the town of Martigny in the lower Valais (Switzerland, Fig. 2).

*Figure 1: Concept of sediment traps, a) the classical scheme, i.e. the check dam is directly connected to the basin and*

*b) the herein studied scheme, i.e. the retention basin is situated at some distance upstream of the open check dam. The processes that control sediment deposition are indicated by ① ② ③ ④ and commented below.*

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## I. SEDIMENT RETENTION MECHANISMS

**Four** different **effects lead to sediment deposition** in sediment traps. **Two** of them are **related** to the **basin**:

① decrease of the sediment transport capacity due to a **milder slope**
② decrease of the sediment transport efficiency due to **flow spreading** in the basin which is wider than the upstream channel.

While the **two** other **effects** are **induced by the open check dam:**

③ backwater effects of open check dam induce a drop in shear stresses in the tranquil water area (**typical delta formation**)
④ direct **mechanical blockage** of coarse elements against the open check dam.

## II. EXPERIMENTAL SETUP

- → 100-yrs return flood: peak discharge = 230 m³/s cumulated sediment supply = 64'000 m³ (prototype scale)
- → preliminary tests evaluating the sediment handling and the hydraulic behavior of the open check dam
- → the reproduced **river section** is about **800 m long**
- → the average **bed slope** is about **2.4 %**
- → main **channel width** varies between **10** and **15 m**, the check dam height is limited due to railway line on the right river bank
  - o increasing the volume is possible about 100 m upstream of the check dam by a river widening on the left bank
  - o study of the solution by simulating a 100-yrs flood with continuous sediment injection
- → model uncertainties due to the expected grain size distribution and sediment amounts

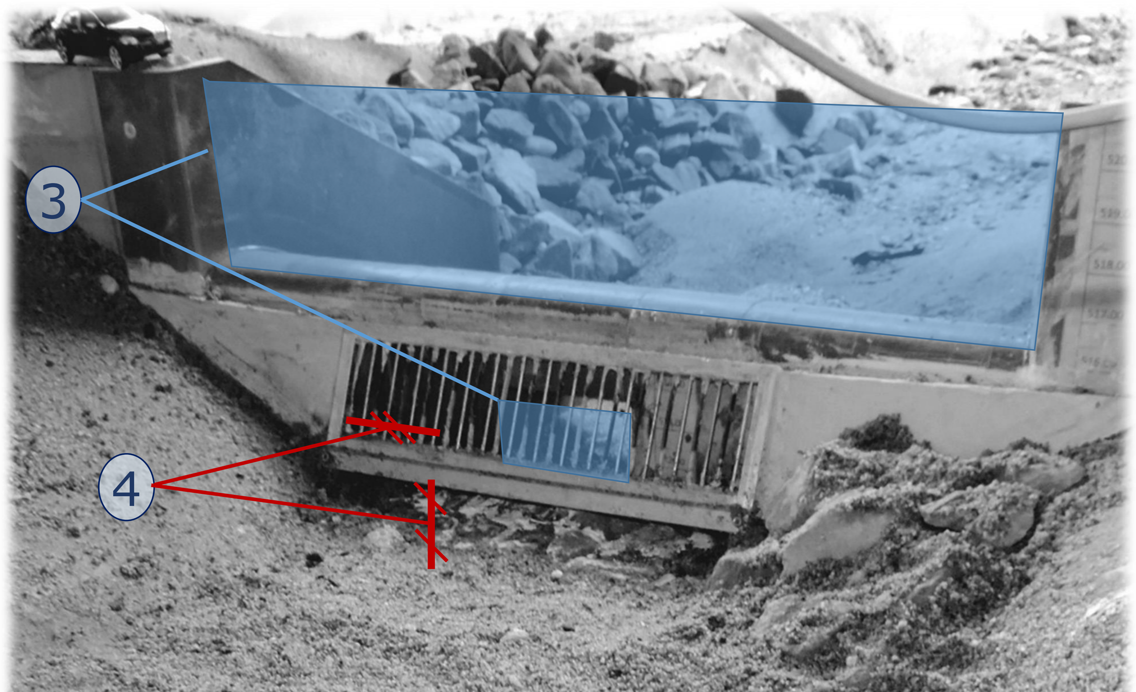


*Figure 3: Illustration of the studied check dam combining both hydraulic and mechanical controls: (i) hydraulic control ③ of the flow through a base orifice and a wide spillway controlling* ***water stage discharge of clear water*** *and; (ii) mechanical control ④ of sediment deposits reaching the structure with a wider base orifice and a superior orifice with inclined grill → weak impact on low flows &* ***strong influence on sediment and woody debris laden floods***

After optimization, the best adjusted configuration is a filter check dam equipped with a combination of three orifices (Fig. 3):

i. The **main dam culvert** imposes the development of backwater. The orifice is 4 m wide and 2.5 m high.
ii. An **inclined screen** (12 m wide, 2.6 m high) with vertical-oriented bars aiming at mechanical blockage of the deposition front (bar spacing of 0.3 m according to the $D_{84}$ of the transported grains) protect the culvert from woody debris clogging.
iii. The **base opening** (12 m wide, 0.9-1.2 m high) which is clogged by the coarsest grains transported during a 100-yrs flood event.

The **culvert maximizes the backwater effect**, increasing the sediment trapping during the **rising limb of the hydrograph**. The **screen and base opening** are obstructed with the arrival of the sediment front. Thus, **self cleaning** during the hydrograph recession is hindered.

## III. OBSERVATIONS & RESULTS

### *Rising limb of the hydrograph*

- → sediment trap basin volume is significantly lower than the bulk sediment supply for the 100-yrs flood scenario.
- → The **river widening increases** the **trapping capacity** and **slows down** the sediment deposit **front velocity** (the deposit must fill the whole section to evolve downstream).
- → The **sediment transfer downstream** of the dam (sediment transport re-connectivity) **occurs later** than without widening. Thus, the phase of clear-water flow downstream is increased and the remaining sediment stocks in the downstream bed are flushed with a risk of bed incision and armoring.

*Figure 4: Pro-gradation and spreading of the sediment front in the river widening up-stream of the filter check dam.*

### *Peak discharge*

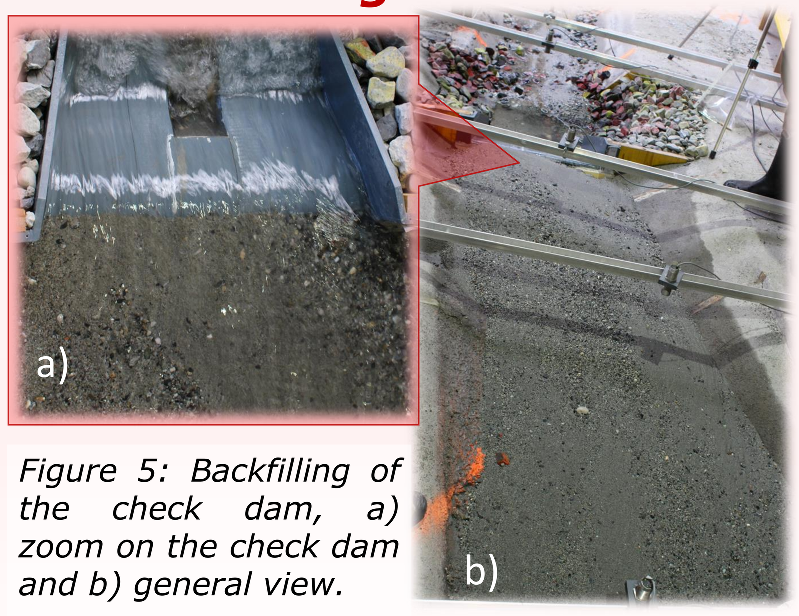


*Figure 5: Backfilling of the check dam, a) zoom on the check dam and b) general view.*

- → The dam culvert **never clogs** in the configuration **without** upstream **screen**.
- → The optimized configuration **with screen** (Fig. 3) to be clogs with the arrival of the sediment front. **Once clog-ged**, the dam is rapidly **back-filled** up to the spillway crest (with and without widening).

### *Controlled self cleaning*

- → The partial self cleaning has been studied to optimize the maintenance costs by limiting mechanical dredging operations.
- → **After the flood event**, the **base opening** is **activated** mechanically to initiate self cleaning. However, it may be necessary to re-activate the opening due to anew clogging.
- → First, the self cleaning is dominated by incision processes in the sediment deposition. A channel pointing at the base orifice develops and the **backward migration** of the **knickpoint** in the channel passes rapidly.
- → Once the channel has developed a stable armor, channel width increase begins. But, the sediment release is limited as the lateral erosion is weak.
- → **Terrace**–like patterns form in the deposits which are **progressively eroded** by the flow.

*Figure 6: Self cleaning channel development: a) backward propa-gation of the knickpoint and incision of the deposition b) stabilization of the longitudinal profile of the channel, beginning of the widening and c) bank erosion and channel widening.*