DRIFTWOOD RETENTION TO MINIMIZE FLOOD RISK FOR THE CITY OF ZURICH – PHYSICAL EXPERIMENTS

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ABSTRACT

Laboratory experiments are conducted at the VAW to test and optimize the design of a planned driftwood retention site in the River Sihl. The concept of the construction is to separate and retain driftwood during floods >200 m^3/s in a bypass at a distinct right hand bend. The retention will minimize the risk of log jams and hence the inundation risk in the City of Zurich, which is located 15 km downstream. The retention of driftwood is part of an integral concept to save the riparian Zurich area from larger floods. First model tests show, that the pre-designed retention site is able to hold back 60-80% of the supplied driftwood. First improvements of the design lead to cost reduction by a multiple of the expenses of the physical model tests. Experiments are conducted since May 2011 up to summer 2012. The driftwood retention project is planned to be realized in 2015.

Keywords: driftwood retention, urban flood, flood protection, inundation maps, log jam, sediment transport, laboratory experiment

INTRODUCTION

The Sihl is a river in the foothills of the Alps. The flood events 2005 and 2007 in the River Sihl showed that especially driftwood can lead to a strongly increased inundation risk in Zurich. Log jams especially at the culverts where the Sihl flows underneath the central station would lead to large inundation areas in Zurich's city centre with a return period of 100 to 300 years (B&H AG, 2008). Up to V_{loose} = 6,000 m^3 of driftwood are expected to be transported in the river during a 100year flood with maximum discharges of Q = 360 m^3/s, and a doubled amount during a 300year flood with a maximum discharge of Q = 450 m^3/s (Flussbau AG, 2010). The estimated potential damage to Zurich's city centre is about 3 to 5 billion CHF (Denzler, 2011) – without consideration of follow up costs or damage to persons.

As part of an integral concept to save the city of Zurich from larger floods, a driftwood retention site is planned 15 km upstream of the central station in the river section Rütiboden where the Sihl follows a distinct right hand bend (B&H AG, 2010). Fig. 1 gives an overview of the River Sihl from the Rütiboden-area to the central station (km 16 to km 0).

Primary measures of the integral flood protection concept of Zurich's city are already realized: In 2007, combined with the building of a new underground railway station underneath the Sihl, the river was dredged in the area of the central station and the culverts were smoothed. This resulted in a slightly increased capacity of the Sihl. In 2008, a discharge forecast and flood warning system, called IFKIS-Sihl, was installed (e.g., Romang et al. 2011). This warning system was very helpful during the construction phase of the underground railway, where up to three of five culverts had to be closed temporarely.

However, the primary measures as well as the retention of driftwood will not give a sufficient protection against larger floods, if conditions of the freeboard safety are taken into consideration. Therefore, several feasibility studies are currently carried out which will lead to a definite flood protection concept for the Sihl. The regarded topics are: (1) improving the fortification of urban flood protection measures, (2) building a release tunnel to Lake Zurich (IUB, 2011), (3) increasing the upstream retention capacities – especially of the lake Sihl reservoir 50 km upstream from Zurich–, and

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combinations thereof. The studies will be finished in the end of 2011. Consequently, a decision towards the type of final solution will not be made earlier than mid-2012.

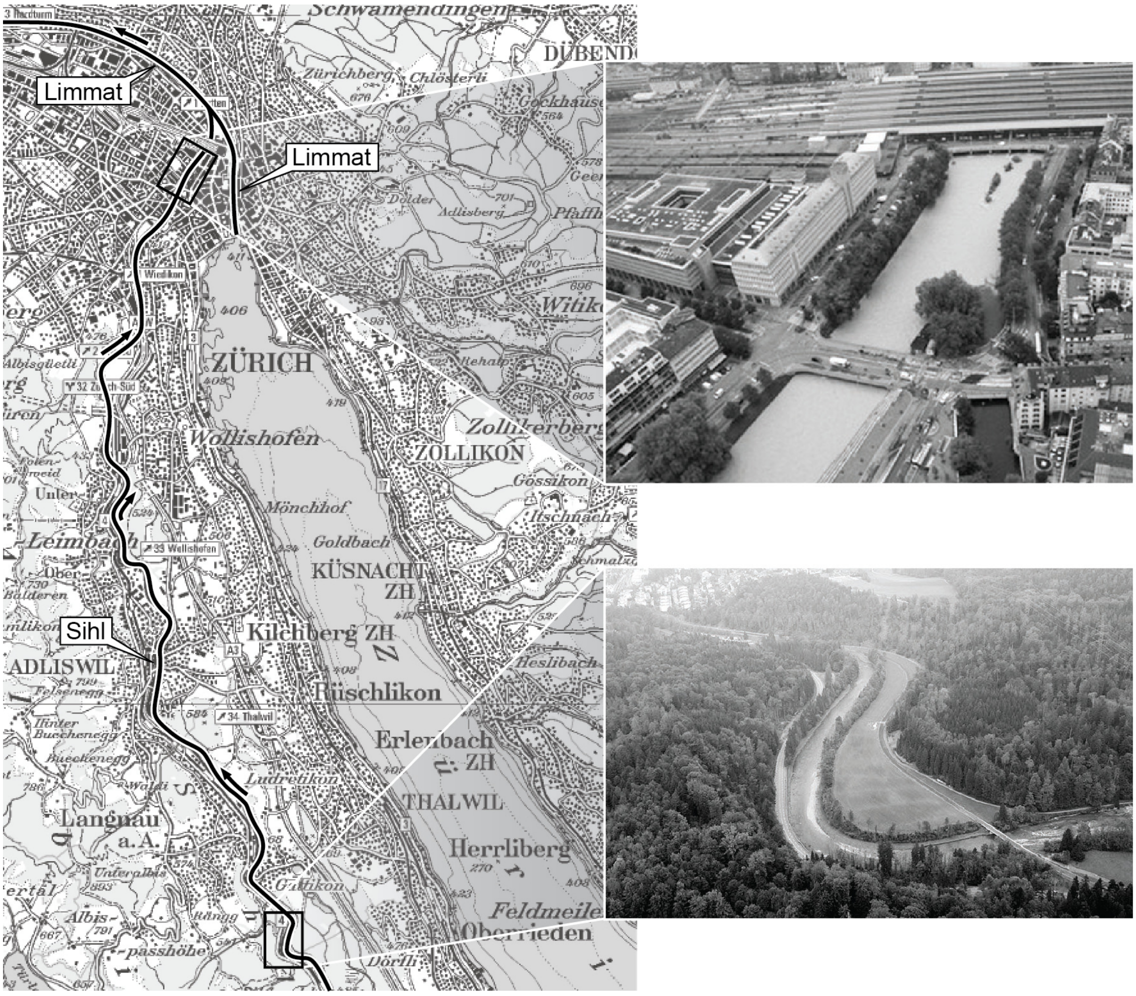

Fig. 1 Situation of River Sihl, Lake Zurich and River Limmat; photo at the top: Zurich, central station at the flood of 2005; photo below: river section Rütiboden (photos by courtesy of AWEL, Zurich)

THE DRIFTWOOD RETENTION CONCEPT

The driftwood retention construction is planned 15 km upstream of the central station in the river section Rütiboden where the River Sihl follows a distinct right hand bend. Fig. 2 gives a project overview. On a length of almost 400 m, the main channel is moved to a new position in the inner bend. Thus, the total river cross section is widened. In the old channel, the driftwood retention section is placed (see Fig. 2, photo below).

Among three possible sites, the location at Rütiboden was considered best, mainly due to two reasons: (1) The conflict of land use and consequently the delay in realization due to objections is expected to be less, allowing to compensate the flood protection deficiency as soon as possible. (2) Concerning geological and hydraulic conditions, the left hand bend downstream of the driftwood retention site is seen to be ideal for a release tunnel intake that is planned in a forthcoming project part; especially as this construction is best possible protected against driftwood as the retention construction is placed upstream.

The driftwood retention includes the following elements (AWEL, 2010; B&H AG, 2010): The driftwood bypass with a pylon rack construction is installed in the outer bend. The main channel of the River Sihl is moved to a new position in the inner bend. A key element is the weir between the new main channel and the driftwood bypass. The idea is that driftwood, which is expected to flow along the outer bend due to the centrifugal force, will be carried over the weir into the driftwood retention section during floods with $Q > 200$ m^3/s. Sediment transport will still take place through the main channel. The pylon rack construction is aligned with the main flow to minimize the risk of log jam and larger inundations. The construction is able to withstand overload floods.

The following aims should be fulfilled by the design of the drift wood retention site:

- retention of as much driftwood as possible, ideally more than 80%
- minimal influence of the driftwood construction on the bed level and the sediment transport in the River Sihl
- verification of flood protection in spite of occurring backwater effects at the rack
- good-natured, controlled behavior in case of extreme flood events, i.e. no sudden collapse of the construction's functionality

The functionality of driftwood retention concepts are hardly to prove solely by analytical, empirical or numerical approaches (e.g., Tamagni et al., 2010, Moeller et al., 2009). Therefore, the driftwood retention concept is tested currently in a physical scale model at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) at the ETH Zurich, commissioned by Amt für Abfall, Wasser, Energie und Luft (AWEL), Canton Zurich, Switzerland. The model perimeter is arranged to be able to examine the design of the spillway intake to the potential release tunnel in a later stage and to test possible interactions of both constructions. This paper focusses mainly on the physical experiments concerning the driftwood retention concept.

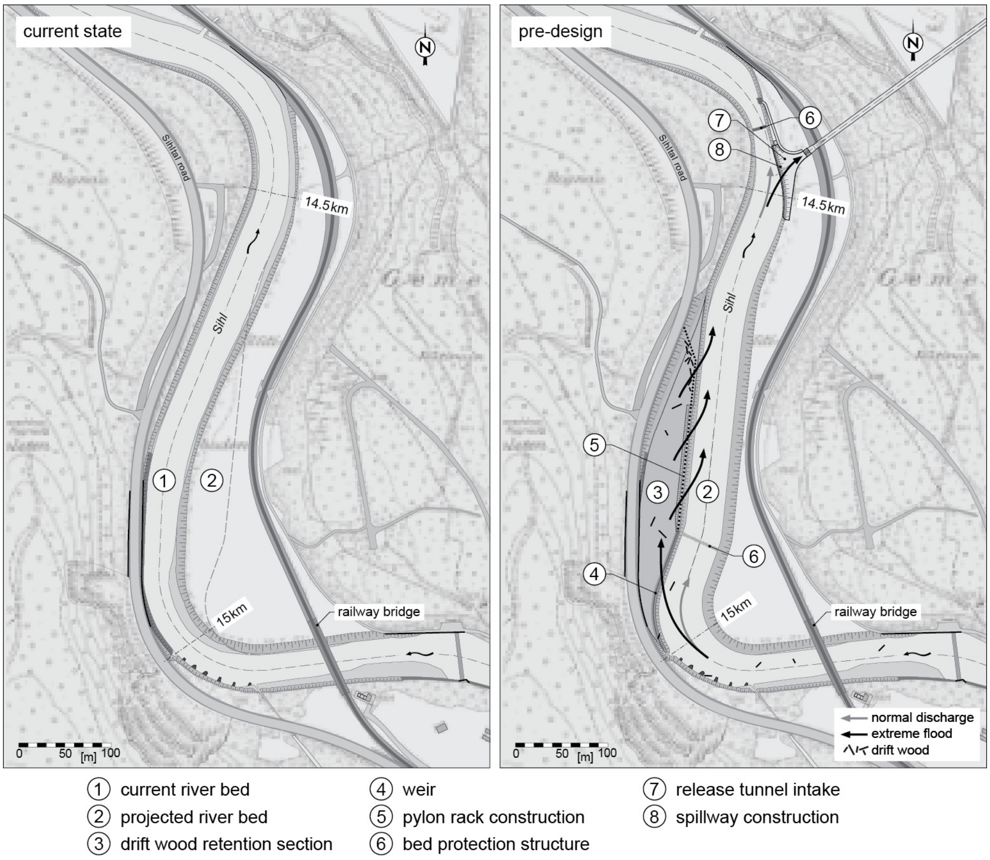

Fig. 2 Location of the planned driftwood retention construction; left: current state; right: pre-design by AWEL (2010) and B&H AG (2010), where also the intake of a possible release tunnel (IUB, 2011) can be seen. Note: The necessity of the tunnel is currently checked against several alternatives.

PHYSICAL MODEL OF THE DRIFTWOOD RETENTION CONSTRUCTION

Experimental Setup

The physical model is built at a 1:40 scale leading to maximum model dimensions of 21 m x 11 m. Tab. 1 gives information about further typical geometric model parameters. Fig. 3 shows a photograph of the ready-built and equipped model, here: with alignment of the new Sihl river bed.

The flow discharge is automatically added via a PC-controlled gate valve. The model is equipped with a movable bed. Flow and sediment hydrographs as well as the driftwood supply of different flood scenarios can be represented. Sediment is added upstream automatically by a sediment dispenser (K-Tron Soder, 0.25-1.200 kg/s) and retained and weighted during the experiments at the downstream end. After each experimental run, the resulting bed levels are measured with a laser distance meter mounted on a 3D traversing system. Measuring bed levels during the experimental runs through the water surface is not possible. Driftwood is added by hand during the experiments. After each experiment, driftwood balances are determined. Water levels are measured continuously via ultrasonic sensors to evaluate e.g. the backwater effects emerging from the retention construction. Two digital cameras (AXIS 211M, 1.3 MPix) are mounted above the physical model recording the processes during each experimental run.

Tab. 1 Characteristic parameter of the modelled perimeter

	Natural scale	Model scale
dimensions [m]	840 x 440	21 x 11
Reach length [m]	1,120	28
Mean bed slope [-]	0.006	0.006
Mean river width [m]	40	1

Fig. 3 Physical scale model of Sihl/ Rütiboden with the driftwood retention Sihl/ Rütiboden (here: alignment as pre-designed), equipped with fixed ultrasonic probes and the traverse system for point level gauging on additional points.

Driftwood

The driftwood is downscaled geometrically and prepared from smaller wood branches. The geometric characteristics of the driftwood are simplified by five classes as given in Tab. 2 and shown in Fig. 4. The classification and the quota in [Vol.%] are based on a reanalysis of the data from Flussbau AG (2010, here: quota by number) and a projection of the data of Waldner et al. (2007) concerning the drift wood mixture of comparable rivers during the 2005-flood. The relation between the solid package volume to loose package volume is estimated by the factor 1:4.

Tab. 2 Characteristic driftwood parameters, in natural scale

	twigs	branches		trunk wood		
class	neglected	A	B	C	D	E
colour		orange/brown	yellow	brown	blue	red
length [m]		1.0 – 2.5	2.5 – 5.0	5.0 – 6.0	6.0 – 7.5	7.5 – 10.0
diameter[m]		0.1 – 0.3	0.1 – 0.3	0.3 – 0.4	0.3 – 0.4	0.3 – 0.4
quota [Vol.%]		16	24	24	24	12

Fig. 4 Photograph of the driftwood classes, in model scale 1:40, measuring tape in (cm)

Sediment

The river bed in the section Rütiboden is considered to consist of two main sediment classes: the coarse-grained in-situ material *SM* and the fine-grained bed load *Ge* that is transported at medium floods. Flussbau AG (2010) gives an estimation to the grain sizes in the section Rütiboden as [d_m, d_{90}](*SM*) = [90-150; 210-430] mm and [d_m, d_{90}](*Ge*) = [40-50; 100-130] mm. Large erosions can be excluded in cases of discharges $Q < 200$ m^3/s, while sediment transport of the moving material *Ge* is initiated at $Q > 20$ m^3/s (Flussbau AG, 2010). As the experimental runs are conducted mainly with $Q > 200$ m^3/s, the model sediment should reflect the characteristics of both main classes, i.e. the in-situ material as well as the fine-grained moving material.

To approach an appropriate grain size distribution for modelling the sediment, several samples have been taken from different locations within and upstream the project perimeter. A mean grain size distribution was determined that is characterized by [d_m, d_{90}](*SM*,*Ge*)= [74; 190] mm. The natural grain size distribution was downscaled geometrically and was coarsened with regard to the dip in the Shields-curve (VAW, 1997). Grain sizes smaller than 0.25 mm are removed to avoid misleading scale effects, e.g. due to cohesion or the generation of ripples. Finally, the grain size distribution for modelling sediment transport is characterized by [d_m, d_{90}](*SM*,*Ge*) = [2.6; 4.9] mm (in model scale).

Scenarios

The design of the driftwood retention will be tested and optimized for four flood scenarios, namely for HQ30, HQ100 and HQ300 with return periods of 30 a, 100 a and 300 a and for the extreme flood event EHQ (here: 1.5 x HQ100). Tab. 2 gives an overview to the four scenarios and their characteristic maximal flow discharge, transported sediment volume and transported driftwood. The quantity is based on Flussbau AG (2009, 2010).

Simulations are conducted via flow hydrographs and, for simplification, via steady state flows. The hydrographs are adopted from the shape of the 2005-flood that was slightly less intense than a HQ30. Fig. 5 gives an example of a hydrograph, here according to a HQ300 event.

Tab. 3 Characteristic parameters of flow scenarios, in natural scale

scenario	return period [1/a]	max. discharge [m^3/s]	sediment volume [m^3]	driftwood, loose [m^3]
HQ30	1/30	290	8,000	4,000
HQ100	1/100	360	17,000	6,000
HQ300	1/300	450	22,000	12,000
EHQ	~ 1/1'000	550	30,000	12,000

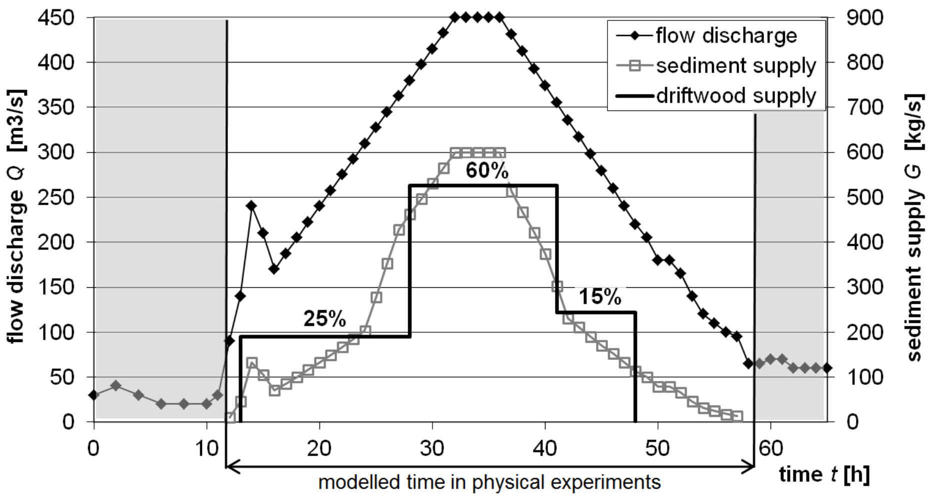

Fig. 5 Typical flow, sediment and driftwood hydrographs, in natural scale, here: HQ300 event, with a total amount of 22,000 m^3 sediment and 12,000 m^3 driftwood (loose package)

Molasse

In a depth of 0.5-1.5 m underneath the river bed in the Rütiboden section a genuine horizon of molasse, a weak sandstone from the Tertiary, is present. Its topography was surveyed and implemented in the physical model. In case of large floods, erosion processes that expose the molasse horizon are expected in the new alignment of the Sihl, e.g. in the outer bend where the driftwood is separated from the flow. Here, the molasse could scour out after decades by the transported sediment (millstone-effect) resulting in a consequently reducing water level.

2D hydro-numeric model

Another challenge to the physical model setup is to model adequately the left hand bend at the upstream boundary of the model Sihl. Here, only the downstream end of this bend could be modeled due to spatial restrictions in the laboratory. However, the distribution of the flow is of decisive importance to the transport behavior of both sediment and driftwood. To depict the flow distribution in the model as natural as possible, a 2D hydro-numeric model (BASEMENT, 2011) was additionally established for this section. The numerical results were used to adjust and verify the flow distribution at the location of the sediment and driftwood supply in the hydraulic model.

PRELIMINARY RESULTS

First model tests show, that the pre-designed retention site is able to hold back 60-80% of the supplied driftwood. Tab. 4 gives a detailed list. Fig. 6 gives two exemplary photographs.

Tab. 4 Preliminary results

retention during…	driftwood retention basin	banks, bridge pier, riverside	not retained
HQ30, steady flow	60%	15%	25%
HQ300, steady flow	80%	5%	15%
HQ300, hydrograph	70%	5%	25%

Fig. 6 Typical results during a HQ300, hydrograph; left: some driftwood jams at the riverside; right: most of the driftwood is trapped in the retention basin

The preliminary tests reveal two main points: (1) Strong sedimentation takes place at the inner curve of the right hand bend, indicating that the course of the River Sihl is not optimally designed for leaving the sediment regime almost unattended. (2) The drift wood retention section is overdesigned. The driftwood accumulation in the basin is very compact. The accumulation height consists of about four to five tree trunks lying above each other. The compact accumulation leads to a smaller volume needed than it was designed. The area of the retention basin can be reduced by at least 15% of its original size. Therefore, the pre-design was optimized. Fig. 7 shows the newly chosen course of the right hand bend and the size reduced retention site. With the new course of the right hand bend, the construction costs are lower as less material has to be excavated, especially as the Rütiboden soil is assumed to be slightly contaminated. A first cost estimation leads to a reduction of the total cost for the realization by 1 to 2.5 Million CHF – while the cost for all model tests will range only in a small fractional amount of this sum.

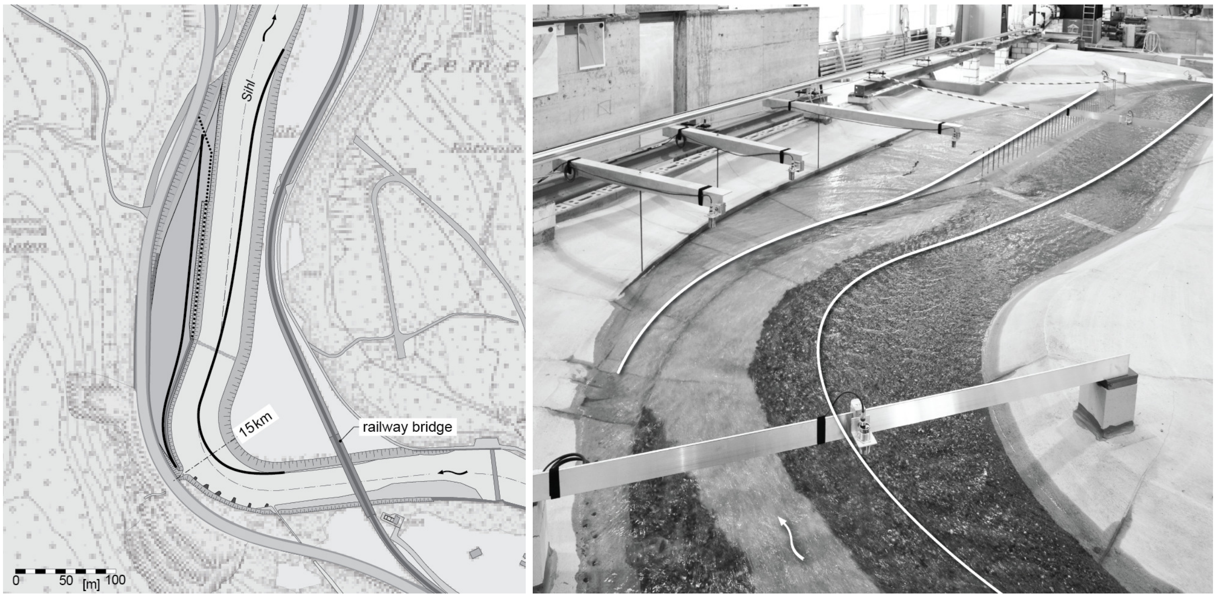

Fig. 7 First approach to optimize the driftwood retention basin and the course of the river Sihl by adapting its riverside to the river banks; left: top view, new course in black; right: photograph, new course in white

SUMMARY

Laboratory experiments are conducted at the VAW to test and optimize the design of a planned drift wood retention basin in the Sihl, a river in the foothills of the Alps. The physical model tests are commissioned by Amt für Abfall, Wasser, Energie und Luft (AWEL), Canton Zurich, Switzerland. The concept of the construction is based on the idea of separating and retaining driftwood during floods above 200 m^3/s in a bypass at a distinct right hand bend. The retention will minimize the risk of log jams and hence the inundation risk in the City of Zurich, which is located 15 km downstream. The

retention of driftwood is part of an integral concept to save Zurich from larger floods, where in addition the possibilities of a release tunnel to Lake Zurich, the fortification of urban flood protection measures, the build-up and extension of diverse retention capacities, and a combination thereof are currently taken into consideration.

The physical model represents accurately the flow and sediment transport regime in the River Sihl. First results show that the pre-designed retention site is able hold back 60-80% of the supplied driftwood. To meet the demand of more than 80%, adaptations of the project will be necessary, e.g. by reducing the weir height to increase the water and driftwood outflow into the retention section. By means of already conducted optimizations, namely the layout of the inner curve of the right hand bend and the retention basin, a reduction of the construction costs by 1 to 2.5 Million CHF is possible. In comparison to this, the cost for all experimental tests range only in a fractional amount of this sum. Thus, the expenses for the physical experiments are already amortized at the beginning of the laboratory tests, while the efficiency is expected to increase by forthcoming improvements to the current design.

The physical experiments are conducted since May 2011 up to summer 2012, where from 2012 on also a possible release tunnel intake located 500 m downstream of the driftwood retention will be tested. The driftwood retention site is planned to be built up in 2015.

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