

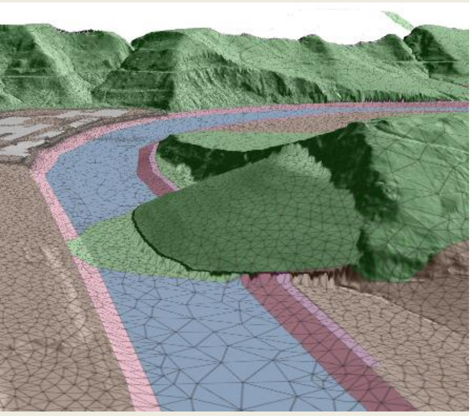

Extremhochwasser an der Aare

Detailbericht G Projekt EXAR

Ereignisbaumanalyse und Gefährdungskurven

Fotos Umschlag

1. Stauanlage Mühleberg, Mühleberg. Foto: IUB Engineering AG, Begehung vom 5. April 2017.
2. Mündungsbereich Hagneckkanal in Bielersee. Foto: IUB Engineering AG, Begehung vom 10. April 2017.
3. Höhenmodell der Rutschung Brättele, nahe des Beurteilungsperimeters Mühleberg. Quelle: GEOTEST AG, 2020.
4. Wasser- und Kernkraftwerk bei Beznau. Foto: Schweizer Luftwaffe 2005, © VBZ.
5. Verklausung der Mattenschwelle bei Bern während des Hochwassers im August 2005. Foto: Schweizer Luftwaffe 2005, © VBZ.

Impressum
Datum: 15.02.2021

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Zitiervorschlag
Dang, V.N., Whealton, C. 2021: Extremhochwasser an der Aare. Detailbericht G Projekt EXAR. Ereignisbaumanalyse und Gefährdungskurven. Paul Scherrer Institut PSI. 117 S.

Contents

1 Introduction

The overall goal of the project was to develop the methods, tools, and datasets to perform probabilistic flood hazard analysis at sites along the Aare River. With this basis, the analysis for several sites on the Aare River were performed.

The report *EXAR – Grundlagen Extremehochwasser Aare-Rhein: Hauptbericht Phase B,* referred to as *Hauptbericht* in this report, presents an overview of the whole project and its results. This report provides detailed information on the methodology, input data, and results related to the estimation of the probabilities of the scenarios, to the construction of the hazard curves, and to uncertainty propagation. Complete information on the distributions used in uncertainty propagation are also included.

Chapter 2 provides information on the methodology, general hazard curve development, and event tree modelling, and uncertainty propagation. The discussion is often general or parameters are derived for all sites. For each assessment site (German: *Beurteilungsperimeter*, BP) treated in this project, Chapter 3 provides detailed results including all hazard curves, the event tree models, the frequencies and probabilities specific to each assessment site used in the quantification of scenarios and in uncertainty propagation, and key assumptions made in the assignment of simulation outcomes to event tree scenarios. The appendices to this report provide definitions of distributions, the uncertainty distributions for hydraulic model and morphology uncertainty, a sensitivity analysis of the hazard curve with respect to the clogging probabilities. For ease of access, the scenario tables listing the results for every event tree scenario for all sites are provided in the last appendix.

The event tree analysis integrates the work of many other parts of the project in a probabilistic synthesis; other detailed reports and the main report are therefore heavily referenced. Among the other detailed reports, the following reports may be especially of interest:

Detailbericht A: Hydrometeorologische Grundlagen (Flood initiating event data)

Detailbericht C: Rutschungen und Schwemmholz (Landslide and driftwood probabilities)

Detailbericht D: Kollaps und Versagen wasserbaulicher Einrichtungen (Detailed structural information)

Detailbericht F: Morphologische Untersuchungen (Morphology modelling)

The hydraulic (and morphological) simulation results used in this work are provided in the *Resultatmappen* for the assessment sites. These results include the maps representing maximum WSPL and maximum flow velocities for all decisive (German: massgebend) scenarios and selected other scenarios and the time plots of WSPL, energy height, and flow velocity at selected reference and scenario points.

2 Methodology Overview

The hazard curves for the assessment sites, showing the frequency of exceedance for the water level elevation (German: *Wasserspiegellage*, WSPL) for the site, provide an overview of the hazard profile of the assessment site. On the other hand, multiple event trees are used to define and quantify the diverse scenarios whose frequencies and outcome (the hazard) enter into the hazard curve.

Following a big picture to details approach, the methodology in this chapter (as well as the results in Chapter 3) are presented in the following order:

- Hazard curve
- Event trees
- Frequency and probability inputs / initiating events and top events and their probabilities

The chapter concludes with information on uncertainty propagation in the event trees and hazard curves.

2.1 Hazard curves

Hazard curves are the main tool for understanding the risk at a site and the relative importance of scenarios. They aggregate all the scenarios, which are combinations of flood events with further events related to the state of structures and/or natural processes, to determine the frequency with which water levels will be exceeded (frequency of water level greater than or equal to elevation).

2.1.1 Interpretation

This section summarizes the concept of the hazard curve and how it can be interpreted. A simple, general hazard curve is used as an example, illustrated in Figure 1. In this figure, the hazard curve is the stair-step curve that shows the exceedance frequency of water levels. In addition, the figure includes the scenarios that yield this hazard curve as points, plotted at the frequency and water level for each scenario. To be precise then, the horizontal axis is both exceedance frequency (for the stair-step curve) and scenario frequencies (for the points).

The hazard is water level (German: *Wasserspiegellage*, WSPL), which is plotted on the vertical axis ($x > y > z$). The frequency or exceedance frequency is plotted on a reversed x-axis with higher frequencies to the left and lower frequencies to the right. The range of frequencies for the hazard curve depends on the frequencies of the scenarios considered; the curve cannot reach higher frequencies than the sum of all the scenario frequencies.

In discussing hazard curves and the contributing scenarios in the project results, the term 'decisive' (German: *massgebend*) is used. Decisive scenarios are those scenarios for which a change in frequency would tend to 'move' the hazard curve.

Scenarios *S1*, *S2, S3,* and *S4* are decisive scenarios for the hazard curve. At point *A*, the exceedance frequency of water level *x* is approximately 2E-5/a and only scenario *S1* is decisive. This is also the scenario with the highest water level and therefore it defines the upper limit of the hazard curve.

Scenarios *S2* and *S3* are decisive for the exceedance of water level *z*. The frequency at the corner point *C* is the sum of the frequencies of all scenarios with that water level or higher; however, scenarios *S2* and *S3* are the only decisive ones for understanding the hazard at point *C*.

The hazard curve does not pass through *S4* because the hazard curve was only computed at discrete points (the y-axis is discretized) to represent that there is some lack of precision in the results; however, the insights into the decisive scenarios are not affected by this discretization.

At point *B*, scenario *S1* is decisive. There is a slight increase jag in the exceedance curve shown by the small step, but the scenario that causes this is nearly an order of magnitude smaller in frequency than *S1*.

For the definitive curves for the assessment sites, the uncertainties of the scenario frequencies (and other uncertainties) are propagated, yielding an uncertainty envelope read as a frequency uncertainty. An example of this envelope can be seen in the hazard curve in Figure 11 (in Chapter 3 of this report) and in all the final results of hazard curves for reference points.

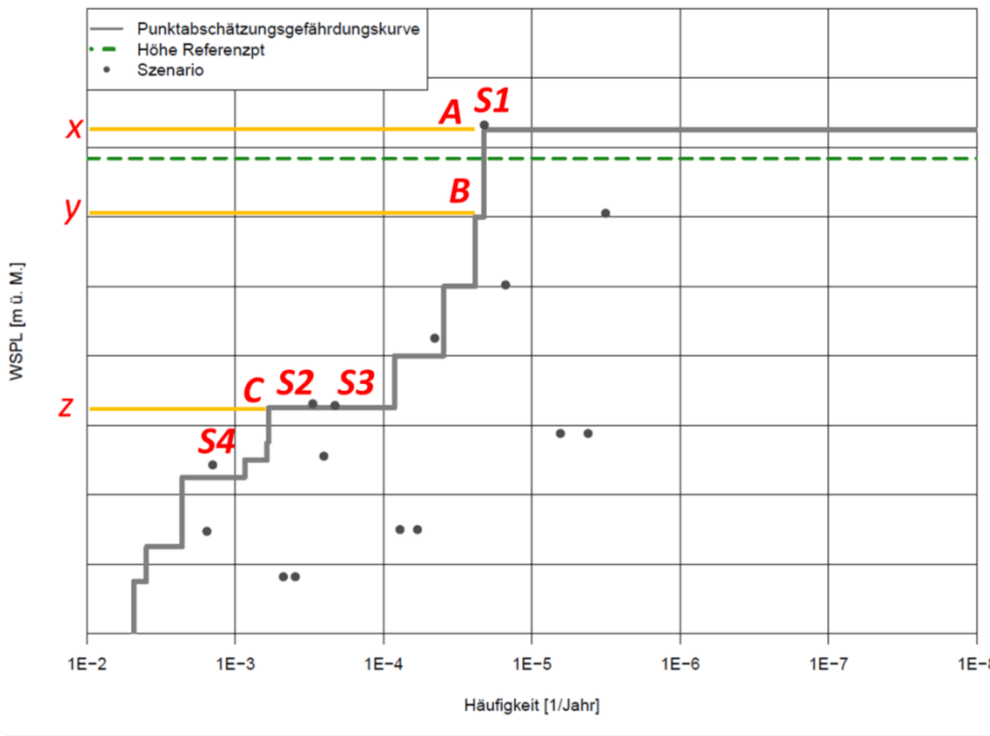


Figure 1: Example hazard curve with key locations marked for discussion in text. Water levels x, y, and z and corner points A, B, and C are discussed in the text. Marked scenarios are S1, S2, and S3.

2.1.2 Construction

At a given site, the hazard curve represents the estimated relationship between exceedance frequency and water level (WSPL) or other hazard measure. In this project, it is defined based on a discrete set of events that have been simulated and their estimated frequencies. If uncertainties are not considered, the frequency and water level from each scenario can be calculated, and from those values the hazard curve derived as the exceedance frequency curve. The scenario frequencies are quantified using the event trees, as discussed below in Section 2.2.

In Figure 1, the scenario frequencies and the water levels associated with the scenarios are point estimates. The hazard curve value is calculated as the sum of the frequencies of all scenarios (points in Figure 1) that yield a water level equal to or larger than the water level of interest.

More formally, the hazard curve $F_{ex}(.)$ can be computed as follows

$$F_{ex}(h^*) = \mathbf{1}_{[h]^t \geq h^*}\,[f]$$

Where, *[h]* is a column vector of hazard levels (water levels for this project),

h^* is the hazard threshold being computed,

[f] is a column vector of frequencies (paired values to [h]), and

1 is an indicator function that will return a vector of 1's and/or 0's (1 when subscript condition true, 0 when false) of the dimension of the vector subscript.

Figure 6, which is discussed in more detail in Section 2.3, illustrates the impact of the cumulative sum. The highest hazard level has the "corner" exactly at the scenario frequency. The other two scenarios have the hazard curve "corner" slightly to the left of the scenario, which is because the hazard curve corner accounts for the frequencies of higher events. Naturally, the hazard curve is monotonic.

The range of the hazard curve is limited by the range of scenarios considered. The highest frequency considered can only be as high as the sum of all the initiating event frequencies, which is approximately 6E-3/a in Figure 1. Studying the hazard at higher frequencies would require additional event trees with higher frequency initiating events. It is common for scenarios from multiple event trees to be spread over wide frequency ranges.

Throughout the analysis presented for the sites, the hazard curves are computed at 0.1 m intervals and the curve is plotted at that value. Although finer calculations are possible, the precision that would be implied by such calculations is likely not supported given the simulation and morphology uncertainties (e.g., *Detailbericht F, Tabelle* 3 uses 0.2 m ranges for the best estimate morphology outcomes). This is a visual representation that individual values cannot be taken to extreme levels of precision. There is often wide uncertainty on the water level from a given simulation due to either the hydraulic model parameter uncertainty, the morphology uncertainty, or both.

2.2 Scenarios and their quantification – event trees

Event trees are a tool used to define scenarios that are relevant to the outcomes at the site. The range of frequencies considered and the physical understanding of the system inform the structure of the tree. This section outlines the components of the event tree and how they are quantified.

Figure 2 is an example event tree that will be used in the following discussion. The initiating event is a flood event (FL). The remainder of the headings in the figure represent top events related to structures or processes on the reach of the river where the assessment site is located; top events represents those events that may or may not occur in the scenario.

Event trees are read left-to-right with the first event being the initiating event and all other top events conditional on those to the left of it. The convention adopted in this work is that the hazard is generally higher for scenarios that are farther down the branches (e.g. the branches for a bridge with driftwood clogging would be in order no clogging, 100-year clogging, 300-year clogging because the water level increases in this order). The first scenario is the “pure” flood event, referred to as the hydrologic scenario (German: *hydrologisches Szenario*), which represents the hydrologic event with no other processes or structural failures involved in the outcome.

2.2.1 Initiating events

Initiating events start an event tree, which is a sequence of processes at structures or locations on the reach that have an impact on the hazard. The initiating events considered in this project are focused on those that would cause high water levels at a site. For instance, characterization of the lowest water levels due to drought conditions is outside of the scope of the work.

Although the initiating event itself might be directly associated with high water levels, for instance with a flood, it can also include other events that would then trigger a failure or other process that can lead to high water levels. Any event that would lead to failure of a dam, for instance, could be considered an initiating event. Another case that is not a flood but could still lead to a high water level is a landslide that generates a wave in a lake.

Each initiating event must have a frequency. This frequency will then be partitioned among the scenarios in the event tree, but the sum of the scenario frequencies in the event tree is the initiating event frequency.

In this project, the following classes of initiating events were considered, although not all of them were used. The remainder of this report is focused on the flood events

- Flood events with exceedance frequencies ≤ 1E-3/a
- Landslides
- Earthquakes

2.2.2 Top events and conditional probabilities

After the initiating event, there are further top events. These top events relate to structures or processes that result in a change in the water level directly or influence the probability of an event later in the tree. Together with the initiating event, the sequence of branches in the tree constitutes a scenario. Because this is a river system, often the top events and scenarios move from upstream to downstream, but this is not always the case.

Probabilities must be estimated for each branch of a top event, which can lead to many probabilities that must be quantified. These probabilities are conditional on the initiating event as well as any branch that comes before it in the tree. The conditional probabilities on the branches from a single node are mutually exclusive and collectively exhaustive, in other words, they sum to 1.

Most of these conditional probabilities are derived from the work of other EXAR work groups and is summarized in *Detailberichte C* and *D*, for example. Some probabilities were directly computed by the other groups and could be incorporated into the event trees without further calculation. For instance, the probability of driftwood clogging initiating at a structure (p_H). In other cases, some work was required to convert the given input into the probabilities suitable to the event tree representation and delineation of the scenarios. Such transformations are described in Section 2.3 below while the data used in the event tree analyses for each of the assessment sites are presented in Chapter 3 of this report. An example of the transformation of input would be the failure model of the levee where best estimate, optimistic, and pessimistic models of the levee lead to different failure probabilities at the same level.

The top events considered in this project are generally in the following groups.

- Weirs (gate status leading to backwater, toppling of weir)
- Landslide (backwater to site, change in local flow paths)
- Levees (failure)
- Bridges (clogging with different driftwood levels)

The previous list is not exhaustive. Many of the structures might appear in event trees for multiple assessment sites, but their impacts are different at each one.

2.2.3 Event tree scenarios and their quantification

Each event tree scenario is a combination of the initiating event and further events. As mentioned, the scenario space is discretized. The frequency of each scenario is the product of the frequency of the initiating event and of the conditional probabilities of the further events. Figure 2 illustrates quantification of an event tree.

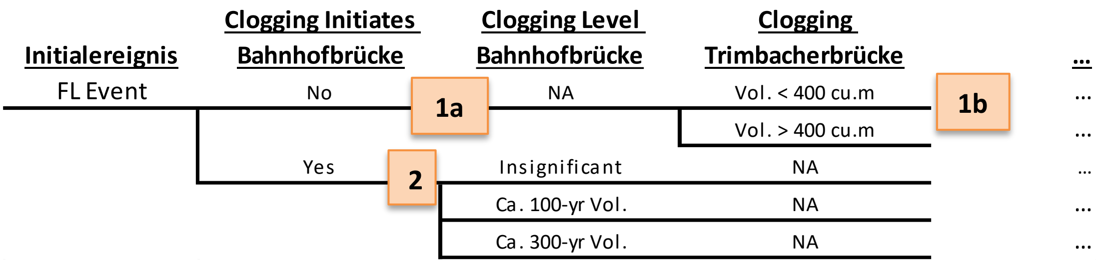


Figure 2: Example event tree for discussion of event tree quantification.

Point 1a illustrates a case where there is no branch. The top event for the clogging level resulting from the clogging of the bridge is not relevant if the bridge is not clogged. Similarly, toppling of a weir is not considered relevant when all the weir gates are open. A top event might also not be relevant when the impact in that scenario is minor or because its conditional probability is too small (e.g. a 1E-20 conditional probability can be neglected in this study). Often the structures or processes that cause about 0.02 m difference compared to the hydrologic scenario or another modelled scenario are not included as top events in the event tree.

In this case, the scenario that ends at 1b is the pure flood event (hydrologic scenario). In this case, the pure hydrologic event includes some minor clogging because there is a structure that is certain to collect some driftwood. Rare event approximations are not used and many of the branches, for instance at the Weir Gates top event, are highly probable. That implies the frequency at 1b might not be the highest of those from the event tree. The frequency of 1b is calculated as follows:

$$F(\text{Pt. 1b}) = F(\text{FL Event}) \times P(\text{No Clogging at Bahnhofbr} \mid \text{FL Event}) \times P(\text{Driftwood Volume} < 400\text{m}^3 \text{at Trimbacherbr} \mid \text{FL Event, No Clogging at Bahnhofbr.})$$

When there are only two outcomes at a branch, such as Bahnhofbrücke clogging initiating, the two probabilities are the complements of each other. Only one probability has to be estimated (the other will be 1-P). In many cases, such as the Weir Gate branches at Weirs Mühleberg or Beznau, there are different sources of estimates for each branch (example Pt. 2). The Gates Clogged branch is estimated based on the probability of clogging initiating under those hydraulic conditions. Scoping values are used for the "All Gates Closed" branch. Once all but one branch is estimated, the final branch is set to the complement of the sum of the estimated branches. The success branch at a node is by definition the complement of all the other branches at the node.

In these event trees, it is very common for for multiple branches of a top event to have relatively high probabilities, which means that rare event approximations cannot be used. This often leads to relatively unlikely pure hydrologic events (e.g. Pt. 1b). For instance, at Olten the pure hydrologic event (Pt. 1b) has a frequency of approximately 13% of the initiating event frequency. The pure hydrologic event requires that no clogging initiates at Bahnhofbrücke (~ 0.5) and driftwood volumes less than 400 m^3 (~0.25).

Although treated as point estimates in the above examples, the frequencies are technically distributions in most cases. The frequency of the final scenario is a distribution, which can be calculated from the convolution of the distributions of all the probabilities along the path that define the scenario or through the numerical Monte Carlo sampling method. The reported frequencies are always the mean frequencies; however, due to the convolution of the distributions the mean frequency of the scenario is not the product of the mean frequencies of the probabilities along the branches for the scenario.

2.3 Frequency and probability inputs to event trees (methodology)

The frequency and probability inputs to the event trees include the frequency of the initiating events and the probabilities for the branches under the top event that may be combined with the initiating event in a scenario.

This section discusses in more detail some of the initiating events and top events considered in the project. In particular, it describes the transformations of the frequency and probability estimates to the form needed for the inputs of the event tree. Two notable examples are the transformation of a) the discharge exceedance (frequency) curves produced by work package 2 into the frequency of a discharge range, as discussed in Section 2.3.1; and b) the discrete estimates for driftwood volumes (*Detailbericht C*) for different return periods into probabilities for ranges of driftwood volumes and the corresponding backwater level (German: Aufstau), as discussed in Section 2.3.5.

2.3.1 Initiating events (hydrological floods)

The derivation of the data used for this analysis is summarized in *Hauptbericht,* Chapter 5 (see also *Detailbericht A)* where the chain of weather, runoff, and routing models is discussed. The first step in computing the flood initiating event frequencies is defining a set of flows that are representative of the extreme, rare, and exceedingly rare floods that were analyzed in the project. For instance, the 1-yr or 10-yr floods alone are unlikely to pose meaningful risk to a location and they are outside the frequency range of interest defined for this project. Hence, the nominal exceedance frequencies of 1E-3, 1E-4, and 1E-5/a (1'000-, 10'000-, and 100'000-yr floods) were chosen as representative discharge values. The Aare at Stilli has peak flows corresponding to 1E-2 – 1E-5/a (HQ100—HQ100'000) as outlined in Table 1 for the median parameter set.

The frequencies associated with peak discharges used in the hazard analyses are based on the 289'000-yr series. *Hauptbericht*, Section 5.4 discusses this series in relation to the 300'000 years of simulation data.

Table 1: Aare at Stilli peak flows for median parameter set exceedance values. Peak flow values are taken from the annual maximum series of the 289'000-year simulation of the median parameter set.

Exceedance Frequency [1/a]	Peak Flow [m³/s]
1E-2	2956
1E-3	3760
1E-4	4402
1E-5	5226

Ranges of peak flows must be defined that sufficiently represent the behavior of the system for the peaks in that range. A single flood event will be used for this range, but the range determines the frequency. The smaller each range, the more simulations and event trees and finer representation of the hazard. We adopted a pragmatic rule that the lower edge of the class FLn is the average of 1E-(n-1) and 1E-n/a floods. For instance, the average of the 1E-2/a and 1E-3/a floods would be the lower edge of the FL3 class. The upper edge of the uppermost class, FL5, is somewhat ambiguous because the length of the series is 289,000 years and FL6 is not defined from the series. It was selected as a round number that is still within the simulated data for the median parameter set. FL6, which would be the 1,000,000-year flood, was not estimated or extrapolated from the data series. The class edges are summarized in Table 2 for Aare at Stilli. The ranges for other sites are reported in Tables 9, 12, and 16.

Table 2: Aare at Stilli FL range edges based on the flood values reported in Table 1. The upper edge of one range is the lower edge of the other. Peak flow values are reported for the annual maximum series of the 289'000-year simulation of the median parameter set.

Flood Level (FL) Event Class	Peak Flow [m³/s]	Class Lower Edge [m³/s]	Class Upper Edge [m³/s]
FL3	3760	(2956+3760)/2=3358	(3760+4402)/2 = 4081
FL4	4402	4081	(4402+5226)/2 = 4814
FL5	5226	4814	6000

Once the ranges are defined, the frequency must be calculated. Frequency from a given hydrologic parameter set is the number of floods that fall within the class divided by the total number of floods simulated with those parameters. For example, if 289 floods out of 289’000 years of simulated floods are within the class, the frequency is 1E-3/a.

This process of selecting the ranges can be represented visually using the exceedance frequency curve, as shown in Figure 3. The vertical black lines represent the nominal floods (e.g. 100-yr to 100’000-yr floods). The different color polygons represent the flow ranges for each resulting class. The mean frequency of the given class is the difference in exceedance frequency between the lower and upper edges of the class. For example, the frequency of $F(FL3) = F_{ex}(FL3\ Lower) – F_{ex}(FL3\ Upper)$. This can be repeated with the same flow ranges for the other parameter sets and the results are summarized in Table 3. These frequencies become the basis for the initiating event frequency.

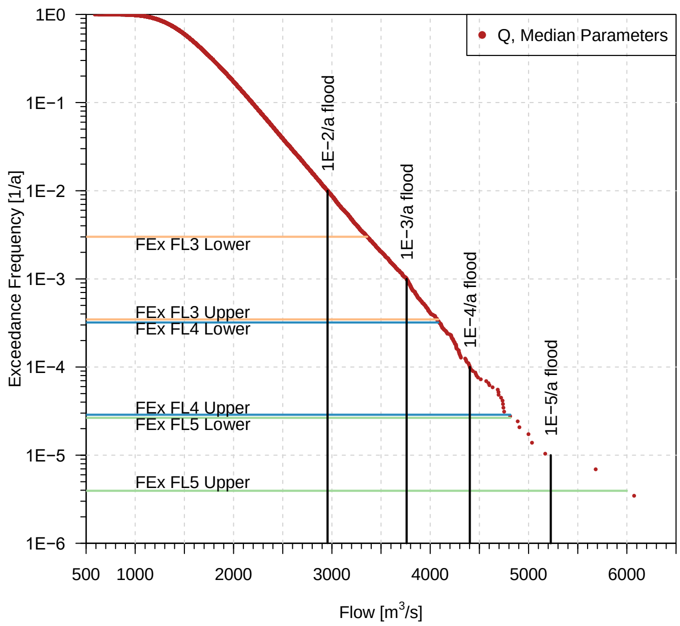


Figure 3: Example of frequencies of flow classes and relation to exceedance curves. This example is based on the annual maximum series at Stilli (median hydrologic parameter set, 300’000-yr series).

Table 3: Frequencies of FL events from low, median, and high parameter sets at Stilli. Frequencies are calculated with the 289’000-yr series.

Flood Level, FL [range in m³/s]	Median [1/a]	Low [1/a]	High [1/a]
FL3 [3358,4081]	2.4E-3	1.8E-3	3.6E-3
FL4 [4081,4814]	2.1E-4	1.7E-4	4.0E-4
FL5 [4814,6000]	2.1E-5	1.4E-5	5.6E-5

Initiating event frequencies for each assessment site are summarized in the subsection “Initiating events and their frequencies” for that site in Chapter 3. The values reported there are based on bootstrap resampling of the values with replacement.

The frequencies reported in Table 3 are higher than the exceedance frequency of the simulated event. This is a result of several factors.

- First, the frequency of an FL event is not the exceedance frequency of the event. It is the difference in the exceedance frequency of the lower edge and the exceedance frequency of the upper edge of the flow range. If the data were distributed with an exponential tail, which is reasonable approximation for back of the envelope calculations with this data in most cases, the frequency of the FL event would be roughly 2.8 times the exceedance frequency of the event using the method outlined above using the FL interval definitions.
- Second, in some cases the high parameter set gives much higher exceedance frequencies at the same flow. This is most noticeable at Aarburg (*Hauptbericht*, *Abbildung* 17), and that will increase the mean frequency compared to the median parameter set. Generally, the low and median parameter sets have very similar frequencies.
- Third, there were some substantial changes to frequencies as a result of the adjustment to the peak flows (*Hauptbericht*, Section 5.4; *Detailbericht A*, Chapter 4). This had the most impact for assessment site (German: *Beurteilungsperimeter*, BP) Mühleberg, then BPs Olten and Gösgen. These generally increased the frequencies.

The frequencies are assigned based on the simulated annual maximum series. Partial-duration series analysis was not used.

2.3.2 Other initiating events

In addition to floods resulting directly from precipitation events, other events can be considered as candidate initiating events provided that they produce outcomes relevant to the water level at an assessment site, either independently or in conjunction with further events involving structures and natural processes. Both earthquakes and landslides have been considered.

The calculation of the frequencies of seismic scenarios is documented in Appendix G-5. For the consequences of these scenarios, see *Hauptbericht*, Section 12.3.3.

Candidate initiating events were eliminated if the associated scenario frequencies (initiating events combined with further events, if applicable) were below 1E-7/a.

Buttenried landslide is at Wohlensee and induces a wave in the lake that would flow over Weir Mühleberg and downstream towards BP Mühleberg. The frequency of the event is estimated at approximately 1E-5 to 2E-5/a (*Detailbericht C*, *Tabelle* 18); however, simulation showed that this landslide had no meaningful impact at the site. It did not wet the reference points on the bank (A and B) of the river and it did not induce failure of other structures. If it were added as an initiating event, it would be irrelevant.

2.3.3 Weirs

Weirs can enter an event three through two processes. The weir gates can be closed or clogged and the weir itself can fail.

2.3.3.1 Weir Gates

Weirs are present near all of the assessment sites considered in this project. In many cases, the flood hazard itself or the probability of other events depends on the status of these gates. For instance, the state of the gates at Weir Beznau impacts the probability of clogging on the Oberwasserkanal bridges. During extreme flood events, the normal state of the gates assumes that all the gates are open, in line with typical flood management strategies. Therefore, the corresponding failure is that gates are closed or left closed, which could be due to organizational, human, or technical reasons. The clogging of weir gates is a separate failure mode (see 2.3.5).

A realistic estimate of the probability that gates are left or put in their closed state is difficult. The contribution of technical failures is expected to be small relative to the contribution of potential organizational or human failures. The operating organizations point to the redundant mechanisms for opening the weir gates. On the other hand, the operating experience for the extreme floods of interest in this project is naturally limited. As a result, the probabilities for the closed weir gate cases used in scenario quantification were developed based on expert judgment. The values are intended to represent an inappropriate strategy or a decision-making failure rather than a manipulation error.

There is some literature on the failure of similar key components of infrastructure, and the values reported are summarized in the Table 4. The structures are generally critical parts of infrastructure and many of these, such as the Thames Flood Barrier or the Maeslant Barrier, protect large population areas. Therefore, one would expect that they are designed to high levels of reliability.

Table 4: Reported probabilities or frequencies of failures for flood control structures and dams. Values are rounded to one significant digit. This list is not comprehensive.

Structure	Probability or Frequency	Failure Description	Source
Thames Flood Barrier, United Kingdom	1E-3	Failure to close, common cause	Lewin 2003
	2E-4	Failure of 2 gates to close	Lewin 1998
	2E-4	Failure of 1 gate to close	Lewin 1998
Maeslant Barrier, The Netherlands	<1E-3	Failure to close	Lewin 2003
	<1E-4	Failure to open	Moovaart and Jonkman 2017
Katwijk System, The Netherlands	2E-4/a	Failure to close dominated by human error	Vrijling 2001
	5E-4/a	Failure to close without human error	Vrijling 2001
Huntington District Dams, United States	1E-1	Failure to close single gate	Lewin 1998
	1E-2	Failure to close single gate after quick repairs	Lewin 1998
	1E-4	Common cause failure to close	Lewin 1998
Seven Mile Dam, Canada	1E-5	Failure to open, environmental causes	Lewin 1998
	2E-7	Failure to open, electrical or mechanical causes	Lewin 1998

A wide range of probabilities can be seen in Table 4. Failure to close is generally the failure mode considered, whereas the scenarios of interest in this project are mostly failure to open or improper closing of the gate when it should remain open. Only one source explicitly mentions human error, and it is roughly three times more likely than the technical failure. Applying probabilities from other systems and structures is also inherently difficult. For instance, the way that gates operate at Mühleberg is different from at Winznau, so the probabilities would likely not be the same.

Consequently, we adopted scoping values for the cases "all gates in closed state" (also referred to as n-n) and "half of the gates closed" (also referred to as n-x, where x is approximately half the gates). These probabilities are intended to be plausible first estimates that provide insight into the role of those scenarios on the hazard curve.

Values of 1E-3 and 3E-3 for the cases "all gates closed" and "half of the gates closed", respectively, were adopted in this project. Given the information basis, these values should not be interpreted as either optimistic nor pessimistic. Although the probabilities for all gates closed might seem high, one elicitation method used in the water resources and dam safety community considers that "virtually impossible" events should be assigned a value of 1E-3 (USBR, 2011). While "all gates closed" would appear to reflect a deliberate strategy, the case "half of the gates closed" is assumed to be more likely because it could arise from a combination of decision failures and unforeseen technical failure mechanisms.

These probabilities would need to be refined if decisive scenarios are identified that include these events. Such refinement would require a more detailed analysis of the technical systems, procedures and strategies, as well as a more extensive expert elicitation based on this information. (In these analyses, other failure events had a more decisive impact on the scenarios.)

2.3.3.2 Weir Stability

Stability of weirs is discussed in *Detailbericht D*. Generally, the failure modes of the weir are considered (sliding, toppling, etc.) and a fragility curve is developed. The fragility represents the probability of failure given the water level in the lake above the dam, with higher water levels leading to higher probability of failure. The probabilities of failure are based on the stability of the weir through the balance of forces.

There is uncertainty about many of the parameters in the balance of forces. For instance, the density of concrete used in a dam. This leads to some uncertainty about the failure probability of a dam. Pessimistic (higher failure probability), best estimate, and optimistic (lower failure probability) estimates were provided for each water level. A log-triangular distribution was used to represent the uncertainty of these values. More discussion is in Section 3.1 regarding Weir Mühleberg. None of the weirs considered in the project had failures of this type with estimated scenario frequencies within the range of interest.

2.3.4 Levees (Seitendämme)

In a few assessment sites, there are levees to be considered in the hazard analysis. Failure of the levee is generally assumed to change the local flow path or activate retention, although the change in flow paths or activation of new ones are the critical ones that were modelled for the risk. The model for levee failure is discussed in *Detailbericht D*. The failure criteria are generally based on water level rising above a certain threshold of the levee and uncertainty in the failure comes from uncertainty on the dam height and physical properties of the dam (*Detailbericht D, Tabellen* 7-9). Best estimate, pessimistic, and optimistic probabilities of failure are provided for the levee at each water level.

As was the case with weirs, these three estimates were used to create a log-triangular distribution of the failure probability. This was sampled in the uncertainty propagation.

2.3.5 Driftwood and clogging (weirs and bridges)

Driftwood clogging can occur at weirs and bridges; however, most of the clogging cases of interest occur at bridges. The same principles can be applied to the clogging at weirs.

As discussed in the *Detailbericht C*, the probability of clogging at a structure (p_c) is the product of the probability that clogging initiates hydraulically (p_H) and the quantity of driftwood is delivered (p_w) as given in Equation 1. The probability of clogging initiating (p_H) is addressed in *Detailbericht C*, Section 2.5. This section will focus on how p_W is derived and these two components of the clogging probabilities are modelled.

$$p_c = p_H \times p_W \quad [1]$$

All driftwood volumes discussed in this section are m^3 solid.

2.3.5.1 Probability of Driftwood Delivered (p_w)

The probability of driftwood delivered is based on the Bruttoprinzip values for the 30-year and 300-year driftwood volumes described in *Detailbericht C*, Chapter 2. It was assumed that the 30-year (D_{30}) and 300-year (D_{300}) driftwood volumes represent a reasonable 90%-interval for the volume of driftwood that can be expected at the first structure in the event tree. Additionally, it was assumed that the volume of driftwood delivered is distributed lognormally. The log-space mean (μ) and standard deviation (σ) can be calculated as in Equations 2 and 3, where $\Phi^{-1}(.)$ is the standard normal distribution inverse CDF.

$$\mu = \frac{\ln(D_{30}) + \ln(D_{300})}{2} \quad [2]$$

$$\sigma = \frac{\ln(D_{300}) - \ln(D_{30})}{2\Phi^{-1}(0.95)} \quad [3]$$

The resulting median of the distribution is close to the estimated 100-year driftwood volume. Although a 3-parameter distribution could be fit to match the three driftwood values perfectly to some assumed quantiles or statistics, a lognormal distribution was deemed sufficient given the uncertainties on the estimates.

It was agreed upon in the project that the 30-year and 300-year driftwood volumes would be a reasonable representation of the range of driftwood volumes that could be experienced given the estimates available for the project. There are two components of the assumption: lack of dependency on the flood event and overall driftwood volume generated. The project, because of lack of data, deemed it not advisable to assign a dependency between the volume and the flood event.

The overall volume was estimated using standard methods, as outlined in *Detailbericht C*; however, estimation of driftwood volumes of a similar order of magnitude return period as the floods considered is beyond the current methods for this project. It has been identified as an area of further research. Appendix G-4 provides an example for BP Gösgen decisive scenarios where the driftwood distribution is scaled by a multiple ranging from double to twenty times the assumed distribution. The rough result is that when the driftwood distribution is doubled, the 100-year clogging scenarios have a minor change in frequency and the 300-year clogging scenarios have about a factor of three change in frequency.

In the limiting case, as driftwood tends towards infinity, the only two cases are that clogging does not initiate (with probability p_H) or that the 300-year clog appears (with probability 1-p_H); however, this ignores the dynamics of the formulation of the driftwood clog. Practically, five times the driftwood volume is close to the limiting case and the 300-year driftwood scenarios would be nearly an order of magnitude more likely.

The distribution for driftwood is assumed. Driftwood estimates are highly uncertain, especially for such extreme events. This has been identified as an area of further research based on the results of the project.

At most structures with clogging, there is a separate 100-year and 300-year clogging level that was simulated. These different clogging levels have different hazard levels. In Olten, the 100-year and 300-year driftwood volumes are 701 m^3 and 2613 m^3, respectively. The total probability distribution of delivered driftwood must be partitioned among the three simulations including the hydrologic scenario. The simulation must represent a range of clogging values. For instance, a clog with 600 m^3 would likely have an outcome more similar to the 100-year clogging simulation (701 m^3) than the no clogging scenario (hydrologic scenario) simulation.

As a first approximation, the backwater-volume (German: Aufstau-Volumen) relationship was taken to form the ranges of the driftwood for which each simulation would be used. This backwater relationship is for the theoretical case of a bridge or other structure in a rectangular channel. It was derived based on the lab experiments and does not reflect possible flow onto the banks and around the structure. Figure 4 shows the backwater-volume relationship at Bahnhofbrücke in Olten. The 300-year simulation is used for all backwater values that are above the mean of the 100-year and 300-year backwater values (1.76 m and 2.74 m, average 2.25 m). This value can be directly read as a volume through the linearized curve, and it is 1657 m^3. This process can be repeated to determine the lower edge of the 100-year clogging simulation backwater and volume.

For this example, there are only backwater values for 100-year and 300-year volumes. Therefore, this is equivalent to taking the average of the volumes used in each simulation (average of 701 and 2613 = 1657 m^3). However, the backwater is the basis for the probabilities and if there were more simulations or more intermediate points included the backwater relationship would be used.

Table 5 provides the driftwood ranges and probabilities of delivered wood for different structures. The p_w values for BPs Gösgen and Beznau cannot be provided because there is an additional step that involves splitting the driftwood between the Oberwasserkanal and the Aare. The fraction that goes to each part is itself modelled as uncertain and the distributions of the fractions vary with the initiating events.

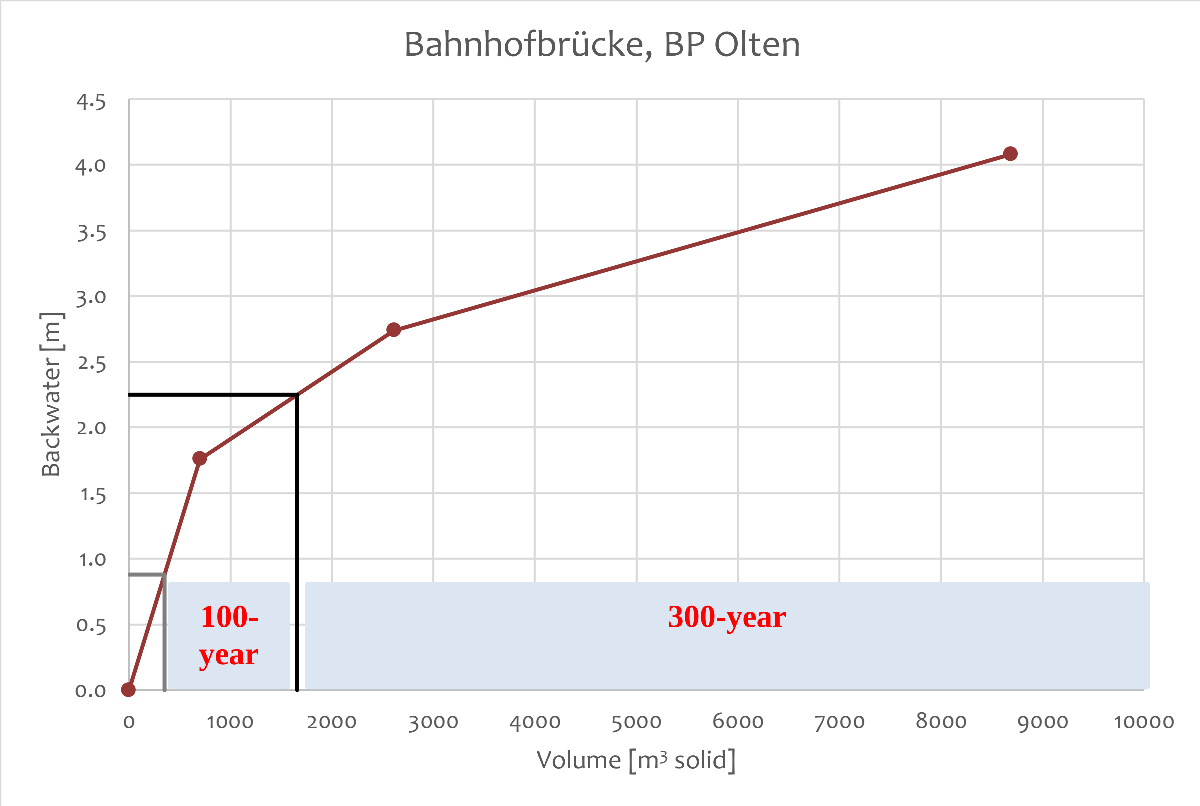


Figure 4: Example Backwater-Volume relationship for Bahnhofbrücke in BP Olten. The gray and black lines represent ranges for the driftwood volumes used in the 100-year and 300-year pw calculates based on the mean backwater between simulated scenarios. The values are based on the theoretical case of the bridge in a rectangular channel and do not reflect the flow around a structure.

Uncertainty on the p_W values can only arise from uncertainty about the distribution of the driftwood volume or the backwater-volume relationship, or both. Appendix G-4 provides an example of this uncertainty with propagation into the results. Throughout the analysis at the sites the uncertainty on these values was not propagated. The p_W values represent aleatoric uncertainty, but not epistemic in the event trees.

Table 5: Summary of driftwood intervals and Pw values for different structures analyzed in the event trees.

BP	Structure	Lognormal Parameters	100-year Lower (c_1)	300-year Lower (c_2)	Probability of Driftwood, p_w
Mühleberg	Weir Mühleberg	--	--	--	1[a]
Olten	Bahnhofbr.	μ=6.565 σ=0.792	350.5	1657	100yr: 0.671 300yr: 0.142
	Trimbacherbr.	μ=6.565 σ=0.792	400	--	0.766[b]
Gösgen	Fussgängersteg	μ=6.565 σ=0.792	350.5	1657	--[c]
	Sandackerstr.	μ=6.565 σ=0.792	350.5	1657	--[c]
	Giessenstr.	μ=6.565 σ=0.792	350.5	1657	--[c]
	Schachenstr.	μ=6.565 σ=0.792	350.5	1657	--[c]
PSI	Aare Brücke	μ=7.862 σ=0.800	1297	6141	--[c]
Beznau	REFUNA Brucke	μ=7.862 σ=0.800	1297	5812	--[c]
	Beznauerstr.	μ=7.862 σ=0.800	1101	6141	--[c]
	Beznau Weir	μ=7.862 σ=0.800	350	--	--[b,c]

[a] Sufficient driftwood volume is assumed such that insufficient driftwood is negligible probability.

[b] Only one clogging volume besides the hydrologic scenario is considered. No separation of 100-year and 300-year volumes.

[c] Driftwood volume also depends on a varying split between the Oberwasserkanal and the Aare main channel.

2.3.5.2 Event Tree Modeling (p_c from p_W and p_H)

Driftwood clogging is generally modelled in an event tree as shown in Figure 5. The basis for this structure is that driftwood must be conserved in the event tree. It is assumed that driftwood can only clog one structure at a time. Implicitly, this means that all the driftwood will be trapped at the structure where clogging begins and no driftwood will pass beforehand.

The probability that clogging initiates at the first structure ($p_{H,1}$) is first. If clogging initiates, then the driftwood will clog there and not move downstream; however, if clogging does not initiate at the first structure it can initiate at the second structure with probability $p_{H,2}$. This process continues until all the structures relevant for the assessment site and event tree are analyzed. The driftwood top events must be sequential to obtain the correct conditional probabilities.

The probability of clogging at a structure is reflected in the two separate top events: clogging initiates (p_H) and clogging level (p_W). This event tree structure explicitly accounts for cases when there is clogging but it is lower than the 100-year clogging range. In some cases, the clogging is considered certain and the only component of the probability is p_W. In other cases, the clogging initiating is uncertainty and only p_H is needed because there is sufficient volume. In either of these cases, the event tree structure can be simplified.

If there were only one structure involved, the probability of clogging initiating with approximately no volume (outcome 3) and the probability of no clogging (outcome 1) could be condensed into a single outcome. They are approximated as a single outcome; however, the interpretation of the event is different. The chosen method forces the evaluation of the assumption of minor clogging is equivalent to a hydrologic scenario ("pure" flood).

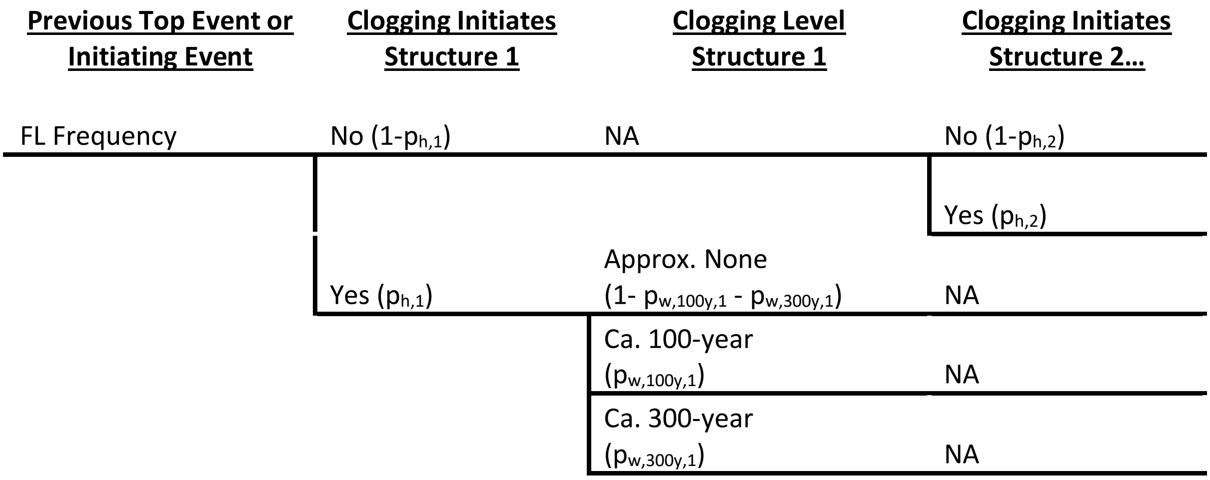


Figure 5: General structure of driftwood clogging cases for multiple structures. Nodes with no branches are indicated with NA. Probabilities are given in parentheses.

Only structures that are directly related to the assessment site are considered in the event tree modelling of the driftwood clogging probability. For instance, at Gösgen the clogging of the upstream bridge at Bahnhofbrücke is not considered because it does not have a direct impact on the site in terms of influencing the water level. If it were included, the probability of clogging cases at Gösgen would be roughly halved because in half the cases Bahnhofbrücke will clog and the driftwood will not continue downstream to Gösgen. Therefore, the method applied is conservative.

The clogging probabilities used have some limitations. In addition to the ones mentioned previously, there is the issue of when clogging initiates and the dynamics of the development of the clog. For instance, if some volume can pass before clogging is sufficient to trap all additional driftwood, then this would change the likelihood of probability of multiple clogging events. With the current analysis, multiple clogging events are not possible.

No uncertainty in the clogging probability is used in the uncertainty propagation. A sensitivity case for BP Gösgen Aare is provided in Appendix G-4. The main result is that the uncertainty of clogging probabilities do not have a major impact on the site, although the hazard for this site is dominated by clogging scenarios. Instead, the frequency and water level uncertainties dominate the uncertainty of the hazard curve.

2.3.6 Landslides

Landslides are discussed in *Detailbericht C,* Chapter 3 and the following is a very short summary. Two sources of information were combined to generate the landslide probability. First, a range of return periods (inverse of annual exceedance frequencies) was assigned to each landslide in a preliminary analysis of each landslide; these ranges do not refer to water tables. Second, there is a model of landslide failure with different water tables and volumes. These two sources were combined so that a typical water table condition resulted in the nominal frequency of the landslide. This leads to a conversion factor that makes landslides more likely when the water table is higher, and these higher water table landslide annual exceedance frequencies were used for the probabilities of landslides in the event trees. The conversion process is outlined in *Detailbericht C*, Section 3.6.

Table 6 summarizes the distributions used in for the landslides considered in this report, although not all of them were modelled or simulated. The range of uncertainty is a direct result of the uncertainty in the original return period of the landslide.

In sampling the uncertainty of the landslides, each landslide is taken as having epistemic uncertainty itself but the uncertainty of separate landslides are independent. The Brättele landslide will have a higher (or lower) probability in all event trees in one sample, but it is not related to the probability of the Runtigenflue landslide.

Table 6: Summary of distributions for landslide probabilities. The parameters are defined for a log-triangular distribution (see Appendix G-1 for definition)

Landslide Name	Return Period [a]	Best Estimate [-]	Lower Bound [-]	Upper Bound [-]
Buttenried	5E4-1E5	6.9E-5	4.9E-5	9.8E-5
Salvisberg	5E4-1E5	4.3E-5	3.0E-5	6.1E-5
Brättele	1E3-1E4	4.3E-4	1.4E-4	1.4E-3
Runtigenflue	1E4-5E4	2.0E-4	8.9E-5	4.5E-4
Schlosshubel	1E3-1E4	3.7E-4	1.2E-4	1.2E-3
Burgstelle	1E4-1E5	1.1E-4	3.5E-5	3.5E-4
Chaltebründli	1E3-1E4	1.4E-3	4.4E-4	4.4E-3

2.4 Uncertainty propagation

2.4.1 Uncertainty in event tree (results) and hazard curves

There is uncertainty in the frequencies, probabilities, and resulting water level for all the scenarios considered in this study. Table 7 summarizes a simple three-scenario set of events that will be used to illustrate hazard curve construction and uncertainty propagation. This section will focus on the point estimate values and uncertainty propagation will use the distributions.

According to these three scenarios, the frequency of exceeding 3.0 m of water level is 0 because no scenarios result in that high a water level. The frequency of exceeding 0.5 m is 2.2E-4, which is the sum of FL4 and FL5, both of which have a water level above 0.5. This process can be repeated for any elevation to generate a continuous hazard curve, although it will look like a step function, as shown in Figure 6. The drops in frequency are caused by the fact that once the hazard level is slightly above the scenario's water level, the cumulative frequency drops to those remaining scenarios.

Table 7: Example scenario information for examples with point estimate, frequency uncertainty, and water level uncertainty.

Scenario	Point Estimate		Distributions	
	Water Level [m]	Frequency [1/a]	Water Level	Frequency
1	0.0	2E-3	Normal(0.0,0.15)	lognormal(ln(2E-3),0.3)
2	1.0	2E-4	Normal(1.0,0.15)	lognormal(ln(2E-4),0.4)
3	2.5	2E-5	Normal(2.5,0.15)	lognormal(ln(2E-5),0.5)

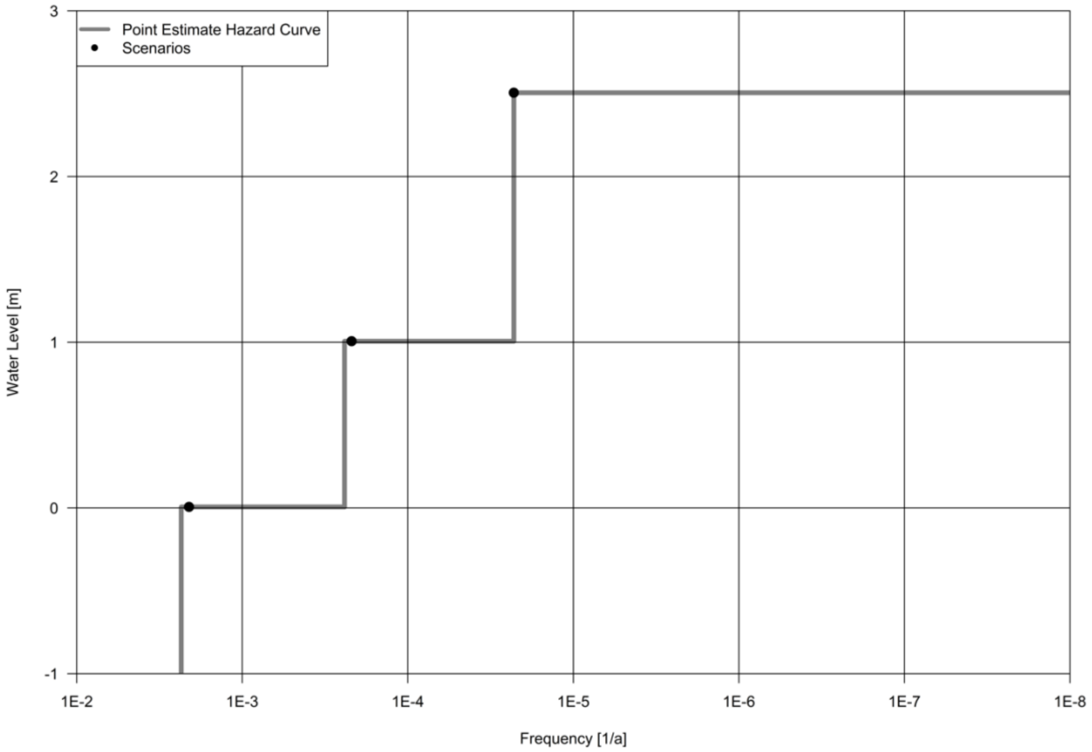


Figure 6: Example hazard curve with point estimates. Scenarios and frequencies are defined in Table 7.

2.4.2 Uncertainties in inputs to the probabilistic hazard analysis

Water level and frequency uncertainty are both propagated to the hazard curve.

Scenario frequency uncertainty comes from the uncertainty of initiating event and all conditional probabilities in the event tree. These uncertainties are taken as epistemic. Epistemic uncertainty also means that when a particular structure appears in multiple event trees, the conditional probabilities for that structure will be positively correlated.

Water level uncertainty comes from either the morphology at the site, or the hydraulic model uncertainty, or both. These are taken to be individually epistemic uncertainties, but the uncertainties are independent of each other (morphology is independent of hydraulic parameters). It is considered unlikely that the parameters that would impact the morphology uncertainty would also play a large role in the hydraulic parameter model uncertainty.

Table 8 provides a short summary of the uncertainties that can affect the hazard curve and some brief details on how the uncertainty is treated.

Table 8: Summary of treatment of uncertainties in frequency, probability, and water level.

Source of Uncertainty	Assumption
Initiating Event	Epistemic with Parameter Set Epistemic about model of frequencies within set
Structural Failure	Epistemic across all cases with failure
Landslide	Epistemic for given landslide Independent for different landslide locations
Hydraulic Parameters	Epistemic across and within cases (overland and channel)
Morphology	Epistemic within type of outcome Independent for different types of outcomes

2.4.3 Propagation methodology (implementation)

The uncertainty from the frequency and water level were propagated into the hazard curve using Monte Carlo sampling methods. The frequencies, probabilities, and water levels are sampled to generate many realizations of the hazard curve. Statistics can be computed based on those values. This section outlines some specific information on each type of uncertainty and then the combined sampling method.

2.4.3.1 Frequency uncertainty of initiating events

Frequency uncertainty is calculated by bootstrap resampling with replacement of the three annual maximum series from the low, median, and high parameter sets. Because the same flow range is used with each parameter set, the uncertainty represents the uncertainty of the range of peak flows. The general algorithm for sampling is:

1. Randomly select the parameter set for the simulated annual maximum series (low, median, or high)
2. Resample the peak annual flow from the selected series with replacement
3. Calculate frequency of events in each flow interval
4. Store the three initiating event frequencies for use as a set
5. Repeat steps 1-4 until there are 5,000 sets of initiating event frequencies.

Empirical results show that correlation of initiating event frequencies within a parameter set is relatively low, although it could be statistically significant in several cases. Therefore, the dominant source in correlation between the initiating events is because of the parameter sets. In some instances, such as at Aare by transfer point (TP) Aarburg, there are two sets that are close to each other (low and median) and one that is substantially separated (high) (*Hauptbericht*, *Abbildung* 17). This would induce correlation because one parameter set is always higher than the others are.

Resampling is taken as a representation of epistemic uncertainty in that we do not know the parameters of the distribution of the model although we are not fitting a parameter distribution to the data. There are three hydrologic parameter set worlds and each of them as an uncertain frequency distribution due to the limited time series.

The three parameter sets were selected with equal likelihood. This reflects a maximum uncertainty about the behavior of the system in the extremes. In some catchments, the exceedance curves of the parameter sets will cross each other. The gauged record generally consists of “smaller” floods that were used in the calibration, and whether these are as informative for the extreme events considered is uncertain. The relevant parameters for a 100-year flood might not be the same as for a 10,000-year flood. This is the most conservative assumption if one does not hypothesize other parameterizations outside of the parameter sets.

Sampling frequencies that are beyond the sampling uncertainty of these three parameter sets would require an additional assumption about the epistemic uncertainty of the parameter sets. Given that there are three parameter sets, a parametric assumption about the distribution of the frequencies and the correlation would be potentially difficult to estimate. There is no strong indication of symmetry, asymmetry, or other distributional properties. The only trend is that the median and low parameter sets tend to be similar in the extremes.

Using the example from Table 7, the propagation of frequency uncertainty alone would result in Figure 7. The frequency uncertainty results in a shift of the curve to the right or left. This pattern would continue if there were some top events.

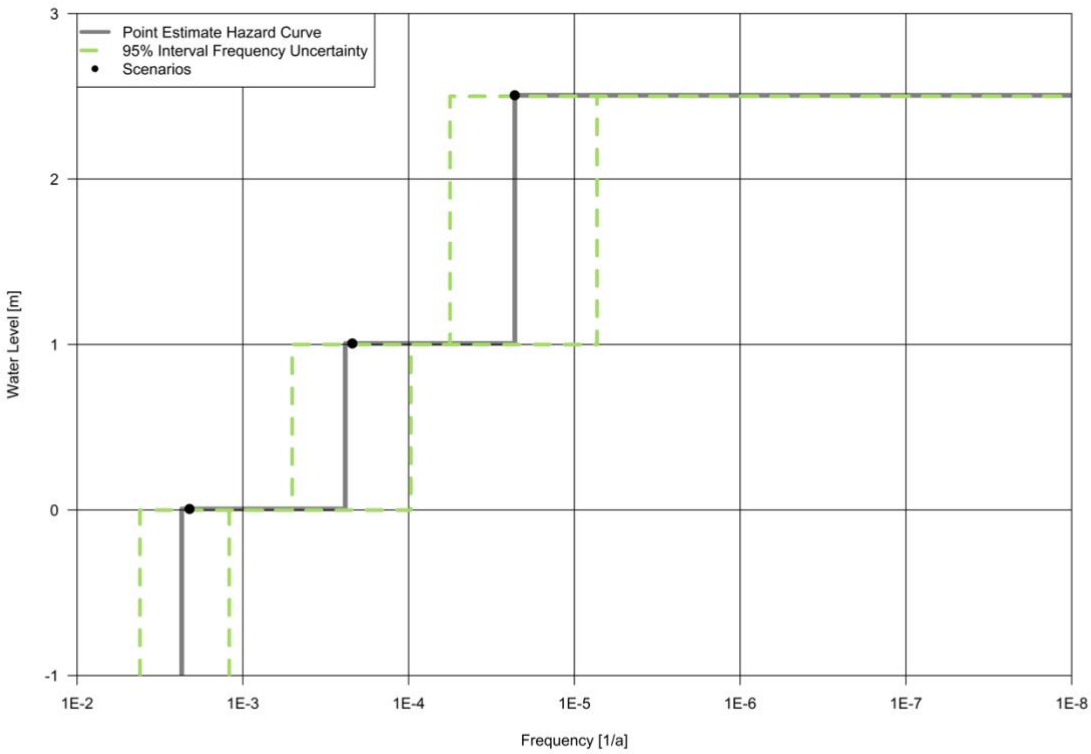


Figure 7: Example hazard curve with only initiating event frequency uncertainty propagated. Scenarios and frequencies are defined in Table 7.

2.4.3.2 Top event uncertainty

Top events are conditional on the initiating event and represent a subsequent process or behavior of a structure. Across the event trees for all the assessment sites, the top events with uncertainty in the probabilities are the toppling probabilities of a weir (Weir Mühleberg), the failure of a levee (Oberwasserkanal Gösgen), landslides (Brättele and Runtigenflue), and in some cases the driftwood volume.

For the two structures with failures considered, weir and levee, the uncertainty is taken as epistemic uncertainty. The uncertainty will represent lack of knowledge of the parameters that influence the failure. Hence, the same percentile of the distribution is used for all failure cases across all the event trees in a sample. This means the cases are positively correlated and would have perfect rank correlation with each other in the trees. This is a conservative assumption about uncertainty, although these failures are generally not decisive.

Landslides are considered independent of each other when their distributions are sampled. For instance, Brättele might be at the high end of its probability range and Runtigenflue is at the low end. This implies the models of failure at the sites are independent and there are no common events that would influence failure, such as erosion of the base (*Detailbericht C*). Therefore, the probability of two landslides occurring is highly unlikely. In sampling, the individual landslide has one frequency used throughout the event trees in the given sample.

Driftwood delivered volumes at Gösgen and Beznau are considered uncertain due to uncertainty in the split of driftwood between the Oberwasserkanal and the Aare. More details are provided in Sections 3.3.4 and 3.6.4. Although an analytical solution or numerical solution might be possible, this distribution is sampled.

The event trees provided in this document have point estimates for the different probabilities and frequencies. Scoping values have no uncertainty. For probabilities with uncertainties, it is the mean of the sampled distribution. In most circumstances, the product of these point estimates will not equal the mean frequency of the scenario; the product of the means of random variables is not the mean of the product of random variables generally speaking. One exception to this rule is if all the probabilities and frequencies were distributed lognormally; however, this is not the case.

2.4.3.3 Water level uncertainty

The two sources of water level uncertainty are the hydraulic model parameters and the morphology. These uncertainties are combined to give the final hazard value as described in Equation 4.

$$H_{j,i} = WSPL\ sim_j + \Delta_{morph,j,i} + \Delta_{hydraul,j,i} \quad [4]$$

Where $H_{j,i}$ is the sampled water level for scenario *j* in replicate *i*,
$WSPL\ sim_j$ is the simulated water level for scenario *j*,
$\Delta_{morph,j,i}$ is the morphology offset for replicate *i*, and
$\Delta_{hydraul,j,i}$ is the hydraulic model offset for replicate *i*.

These uncertainties are discussed more in the details for each site and their distributions are summarized in Appendices G-2 and G-3. The morphology offset is usually the same for all scenarios for a given sample *i* because only one assessment site had different cases. The hydraulic offset is composed to two values depending on whether the flow is channel or overland, but the two uncertainties are positively correlated. The uncertainty value of the reference point was used regardless of whether the elevation was translated from another point (pseudo elevation below point, elevation in river).

Figure 8 shows an example of propagating the water level uncertain only with values taken from Table 7. The water level uncertainty results in shifting the curve up or down. Note that the intervals can be interpreted as either frequency or water level, but it is constructed in the frequency domain. The curve shifts up or down.

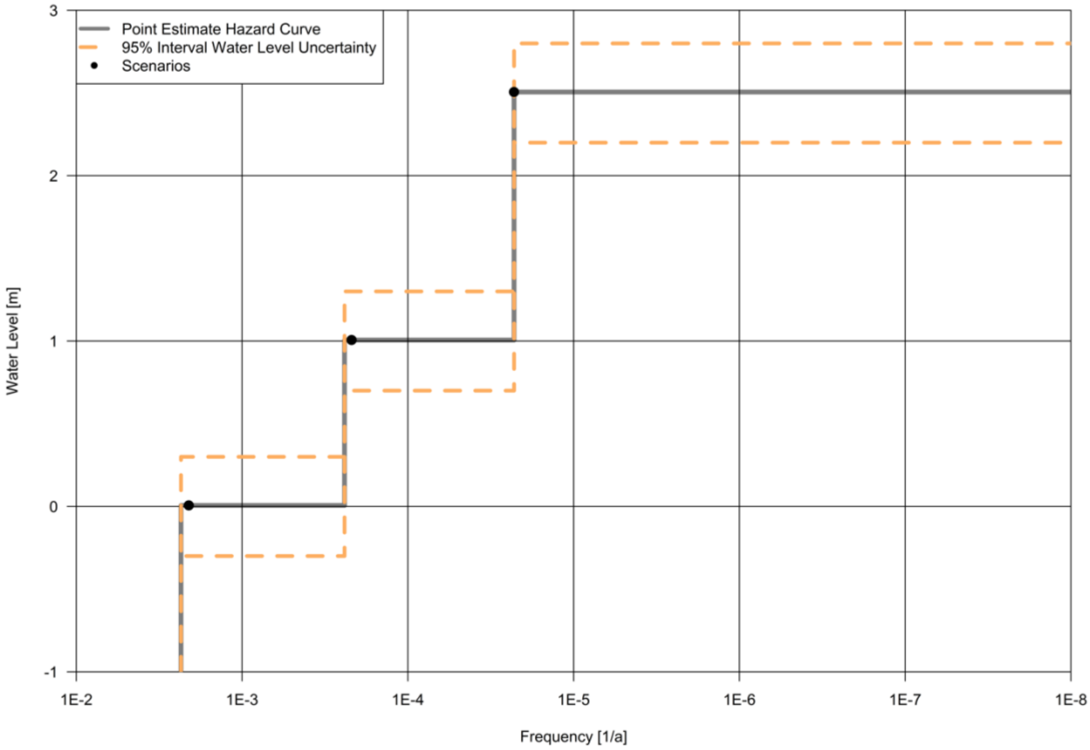


Figure 8: Example hazard curve with water level uncertainty only. Scenarios and frequencies are defined in Table 7.

The applicable uncertainty in hydraulic model parameters depends on whether overland flow or channel flow occurs for the scenario at the reference point. The hydraulic model uncertainty is taken as epistemic and the same percentile of the distribution is used regardless of whether the scenario has channel or overland flow. This is conservative for the propagation and will lead to higher uncertainty bands.

The distribution for this uncertainty is defined based on reported 5th and 95th percentiles, which are used to calculate a normal distribution. The mean of the distribution is typically less than 0.01 m from zero. In sampling, the distribution is not truncated, which can lead to very low probabilities of higher water levels than were simulated (e.g. Figure 27).

Overland and channel flow are sampled at the same percentile, representing epistemic uncertainty across those two flow conditions.

Morphology is also taken as an epistemic uncertainty within a given type of outcome, but independent across outcomes. This represents an assumption that the parameters of the model are uncertain. The only location where there are significant different morphology outcomes is Mühleberg (Brättele landslide is a different case than the other probabilistically relevant ones). Therefore, for practical purposes at most sites it is epistemic uncertainty and reflects uncertainty about the morphology model parameters. Again, this is a conservative assumption for the propagation.

The distribution for morphology is taken as a triangular distribution where the minimum and maximum values (parameters a and b) are solved for so that the 5th and 95th percentiles of the distribution match the range provided. The most likely value is the best estimate. Most of the morphology results are skewed, which leads to the mean morphology outcome not equalling the most likely. Because the assumed distribution is triangular, the uncertainty from morphology is bounded.

Morphology distributions for each site are summarized in Appendix G-3. Hydraulic model parameter uncertainty distributions are summarized in Appendix G-2.

2.4.3.4 Combined treatment

The Monte Carlo method samples from the distributions of each frequency, probability, or water level as specified. Frequency and probability distributions are discussed generally in Section 2.3 and more details are provided for each site in its respective section of Chapter 3. Water level uncertainty distributions are provided in Appendices G-2 and G-3.

The general algorithm for sampling is as follows:

1. Select a set of FL3-FL4-FL5 initiating event frequencies (Section 2.3.1)
2. Set *m* = 1, which is the top event (structure or process) in the event tree.
3. Sample percentile of failure for structure/landslide/process number *m* in the event tree (Sections 2.3.3-2.3.6). Use this percentile to generate correlated failure probabilities using the inverse CDF for each tree and branch location.
4. Increment *m* and repeat step 2 until all *m* structures/landslides have a sampled percentile.
5. Multiply the sampled frequencies and probabilities to generate a sampled set of scenario frequencies. Some probabilities are the complement of those sampled.
6. Sample a morphology offset for each morphology case. The same morphology offset is used for all scenarios with that case at the site (Appendix G-3).
7. Sample a percentile of hydraulic model uncertainty. Use the inverse CDF to generate correlated water level errors (Appendix G-2).
8. Add the morphology and water level errors to the simulated water level.
9. Store paired frequencies and water levels from steps 4 and 8.
10. Repeat steps 1-9 until 5,000 replicates are generated.
11. Compute statistics on the stored output from step 10.

Dependence and independence are included in the sampling algorithm. When a single percentile is used is sampled, it implies correlation among the failure probabilities in all cases in all event trees. If the probability of a failure is higher in one tree it will be higher in another. This represents epistemic uncertainty about our knowledge of the failure model. It means we are systematically over- or underestimating the failure probabilities.

The water level uncertainties from morphology and hydraulic parameters are treated as independent, which by definition means there is no correlation between these two uncertainties. It is possible to have a high value of the hydraulic model offset and a low value of the morphology offset. The hydraulic model uncertainty is correlated between the overland and channel flow cases.

Formally, the result of the algorithm are two *n*-by-*k* matrices of water level (*H*) and scenario frequency (*F*), where *n* is the number of Monte Carlo samples and *k* is the number of scenarios. These are defined in Equations 4 and 5.

$$H = \begin{bmatrix} h_{1,1} & \cdots & h_{k,1} \\ \vdots & \ddots & \vdots \\ h_{1,n} & \cdots & h_{k,n} \end{bmatrix} [4]$$

$$F = \begin{bmatrix} f_{1,1} & \cdots & f_{k,1} \\ \vdots & \ddots & \vdots \\ f_{1,n} & \cdots & f_{k,n} \end{bmatrix} [5]$$

The Monte Carlo approximation of the exceedance frequency $F_{ex}(.)$ of a given hazard level (h^*) can be calculated as follows (Equation 6).

$$F_{ex}(h^*) \sim Monte\ Carlo\left([\mathbf{1}_{H \geq h^*} \odot \mathrm{F}\,] \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \right) [6]$$

Where **1** is an indicator function matrix (1 when the condition in the subscript is satisfied, 0 otherwise),
$\odot$ is the Hadamard product (element-wise), and
the column vector of 1 serves to sum the values of a row to give the frequency for the replicate.

The result of the multiplication is a vector of frequencies, which represent the Monte Carlo sample of the frequency of exceeding the given water level. Any statistics that are desired can be calculated from this, provided that the statistics are defined for the data. For instance, calculation of the log-space moments might not be possible if any replicate had a zero exceedance frequency at the given hazard.

A comparison of the mean frequency hazard curve versus the point estimate hazard curve is provided in Figure 9 based on the example in Table 7. The mean frequency curve has more rounded corners than the step function behavior from the point estimate. A result of the uncertainty is that the scenario plotted at the mean frequency and mean water level is to the left of the curve. With a symmetric water level uncertainty will be less than the mean water level elevation with probability 0.5. This results in the frequency that the mean exceedance frequency of the water level for the given scenario is about half the value.

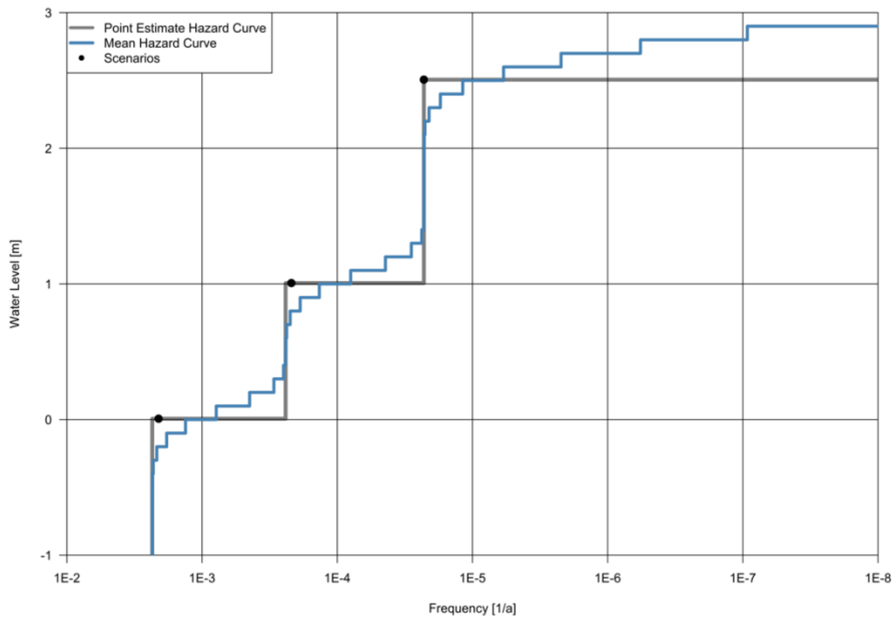


Figure 9: Example point estimate hazard curve versus frequency mean hazard curve for the example in Table 7.

Water level uncertainty and its distribution can determine the behavior of extreme hazards. The mean curve is steadily rising for frequencies lower than 1E-5/a, but this is only a result of the water level uncertainty. Extremely high offsets become less likely leading to the lower frequency.

Sample percentiles can be calculated from the same vector used to define the mean frequency curve. Figure 10 provides an example of the result of accounting for both water level and frequency uncertainties and compares it to when the intervals are treated separately. It can be seen that the treatment of both uncertainties tends to round the corners of the interval. There are ranges in where the intervals match very well to either the frequency or the water level uncertainty, but this is a simple example with relatively highly differentiated scenarios in the frequency and water level. If the frequencies of scenarios were closer, it would be harder to isolate the impact of the frequencies and uncertainties separately.

Occasionally, the mean hazard curve can fall outside (above) the 95% frequency uncertainty envelope of the hazard curve; in Figure 10, this occurs at exceedance frequencies below 1E-7/a. Here, the mean value of the exceedance frequency is larger than the 97.5th percentile value of the uncertainty distribution. When the scenarios sampled during the uncertainty calculation include many scenarios with very low frequencies as well as scenarios with frequencies orders of magnitude higher. In such cases, the samples with high frequencies dominate the mean frequency value at that WSPL, leading to this behavior of the mean hazard curve.

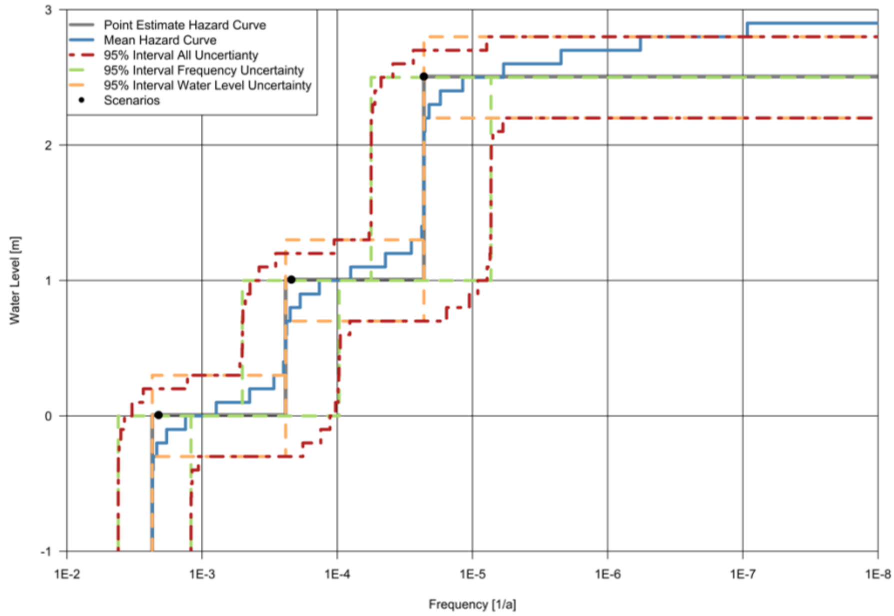


Figure 10: Example of uncertainty propagation in frequency, water level, and both frequency and water level.

3 Results, Models, and Inputs for Assessment Sites

This section gives detailed results and assumptions for each site.

3.1 Assessment site Mühleberg (BPM)

Assessment Site Mühleberg (BP Mühleberg, BPM) is located slightly upstream of the confluence of the Aare and Saane rivers. Upstream of the site is Weir Mühleberg, which controls the water level on Wohlensee. Brättele is a landslide very close to the site on the opposite bank and Runtigenflue is a landslide downstream of the confluence. More detail is provided in *Hauptbericht* Chapter 12.

3.1.1 Hazard curves for reference points A, B and E

Figure 11, Figure 12, and Figure 13 provide the hazard curves for these reference points with the propagated uncertainties. All three reference points show the same trends. More discussion of the decisive scenarios is in the *Hauptbericht* Chapter 12.

The core findings about hazard for these reference points are:

- The frequency of a water level exceeding the elevation of reference point A is approximately 3E-4/a. The water level does not reach Point A in the hydrological scenario FL3-H; it reaches an inundation depth of 4 cm in scenario FL4-H. Scenario FL5-H (1.5E-5/a) dominates the upper part of the hydrological curve, with an inundation of 85 cm at the same location. The mean water elevation accounts for morphological changes, which are estimated for a location in the Aare channel, therefore yielding fairly large uncertainties. The direct results of the hydraulic simulation for FL4-H, without morphology considered, would result in a water elevation 24 cm lower for Point A (approximately 20 cm below grade).

- The decisive scenarios for the mean hazard curve are the hydrological scenarios FL3-H, FL4-H and FL5-H, the combinations of these scenarios with clogging at the Mühleberg weir (scenarios 4, 7, 10), as well as the combination of FL5 with clogging at the Mühleberg weir and a landslide at Brättele (scenario 17).
- For the extreme discharges analyzed, the clogging of the Mühleberg weir is very probable. It should nevertheless be noted that the scenarios with such clogging have no influence on the water elevation at KKM (see *Hauptbericht*, Section 12.4), compared to a scenario with the same discharge but without clogging. The high probability estimated for clogging thus influences the hazard curve only in that the scenarios with clogging are more likely than the hydrological scenarios.
- Diverse landslides above and below the Mühleberg weir were analyzed; however, these have no decisive impact on the hazard curve (scenarios 13-21, *Hauptbericht*, Section 12.5). The exception is scenario 17, the combination of FL5 with clogging at the Mühleberg weir and a landslide at Brättele, although its frequency, 1E-8/a, is very small.
- The results of the 2-D morphological model show that vertical and side erosion tends to lower the WSPL whereas the deposition processes (aggradation on the order of 1-2 m) at the outlet of the Saane tend to increase the WSPL. Up to +0.2m water elevations at the assessment site can be expected as a result of the increased backwater due to this deposition. A landslide at Brättele also influences the water level at the assessment site (+0.4 m), because the erosion and downstream movement of the landslide mass hinders the return of the flow into the Aare. Vertical and side erosion (and channel formation) processes are not accounted for in the hazard curve, i.e. the Δh associated with morphology does not include these processes. See *Hauptbericht*, Section 12.6).
- For water surface elevations less than or equal to 466.00 m, the uncertainty in the frequency is of order 1.5. The frequency uncertainty is significantly larger in the region of scenarios 3 and 10, as a result of correlated water level uncertainties. These affect the shape hazard curve between scenarios 3 and 10 and the much lower frequency scenario 17.

Short descriptions of all scenarios shown in these hazard curves are available in Table G-6-1 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, and the mean WSPL at reference points A, B, and E. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the ‘source’ scenario will be higher than in the ‘target’ scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the ‘target’ scenario will be less than that of the ‘source’ scenario.

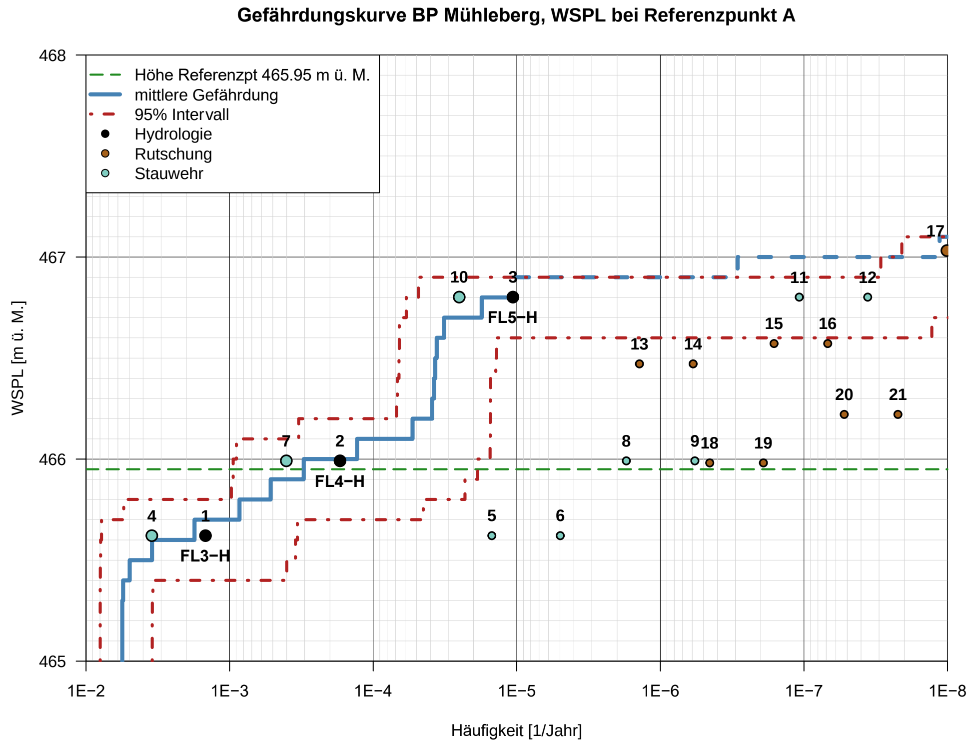


Figure 11: BP Mühleberg Reference Point A hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 466.95 m.a.s.l. (Duplicate of Hauptbericht Abbildung 44.)

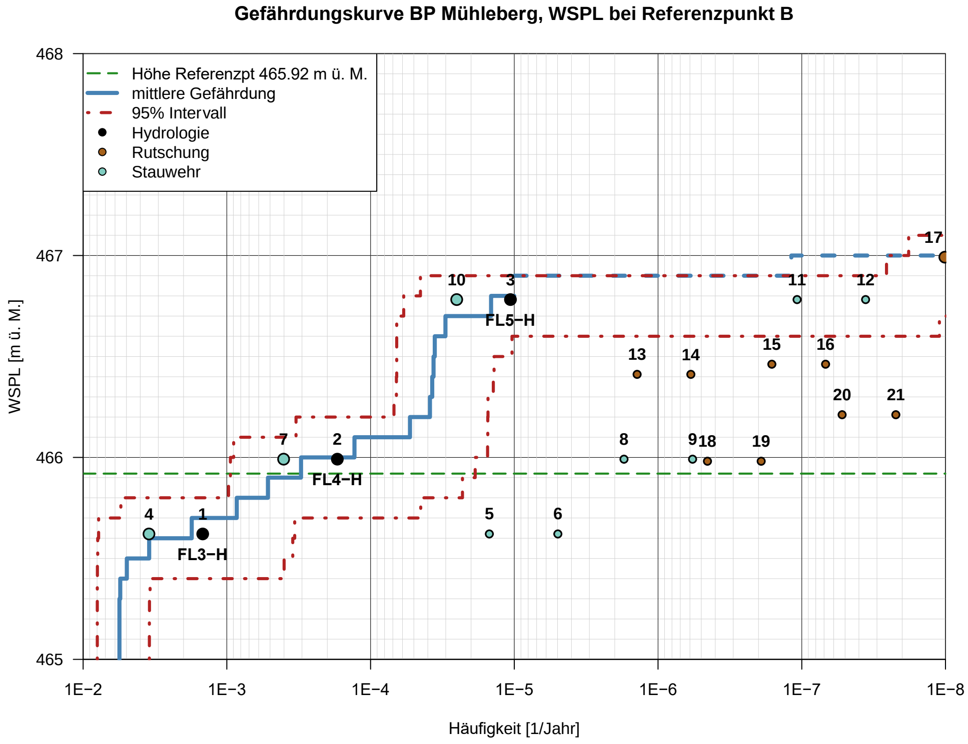


Figure 12: BP Mühleberg Reference Point B hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 466.92 m.a.s.l.

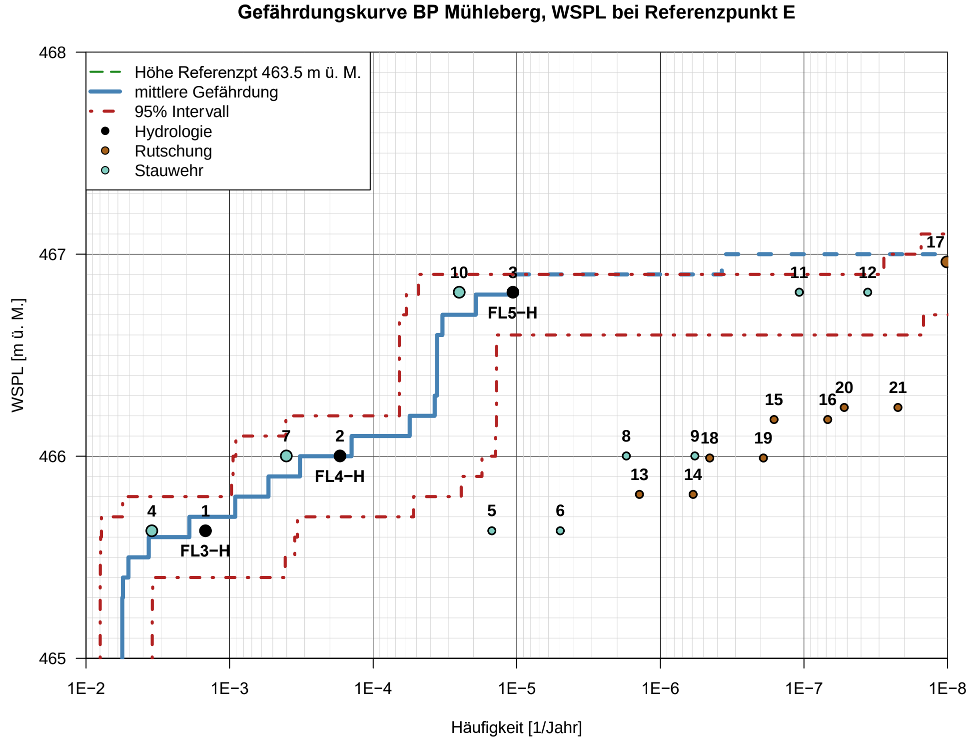


Figure 13: BP Mühleberg Reference Point E hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference point elevation is 463.50 m.a.s.l. and all scenarios considered wet the site.

In these BPM hazard curves, the mean hazard curve fall outside (above) the 95% frequency uncertainty envelope of the hazard curve, in these cases, near and below exceedance frequencies of 1E-7/a. In other words, the mean value of the exceedance frequency is larger than the 97.5th percentile value of the uncertainty distribution. This occurs because the scenarios sampled during the uncertainty calculation include many scenarios with very low frequencies as well as scenarios with frequencies orders of magnitude higher. The samples with high frequencies then dominate the mean frequency value at that WSPL, leading to this behavior of the mean hazard curve.

Table G-6-1 provides the water level from the simulation and the mean water level for all the reference points, along with some other information. There is information on the specific simulation and any justifications about the bounding behavior.

3.1.2 Site event trees

The general event tree for BP Mühleberg is shown in Figure 14. The only dependent events in the tree are the toppling probabilities, which depend on both the number of gates open and the flood initiating event. All the other probabilities are independent of the flood.

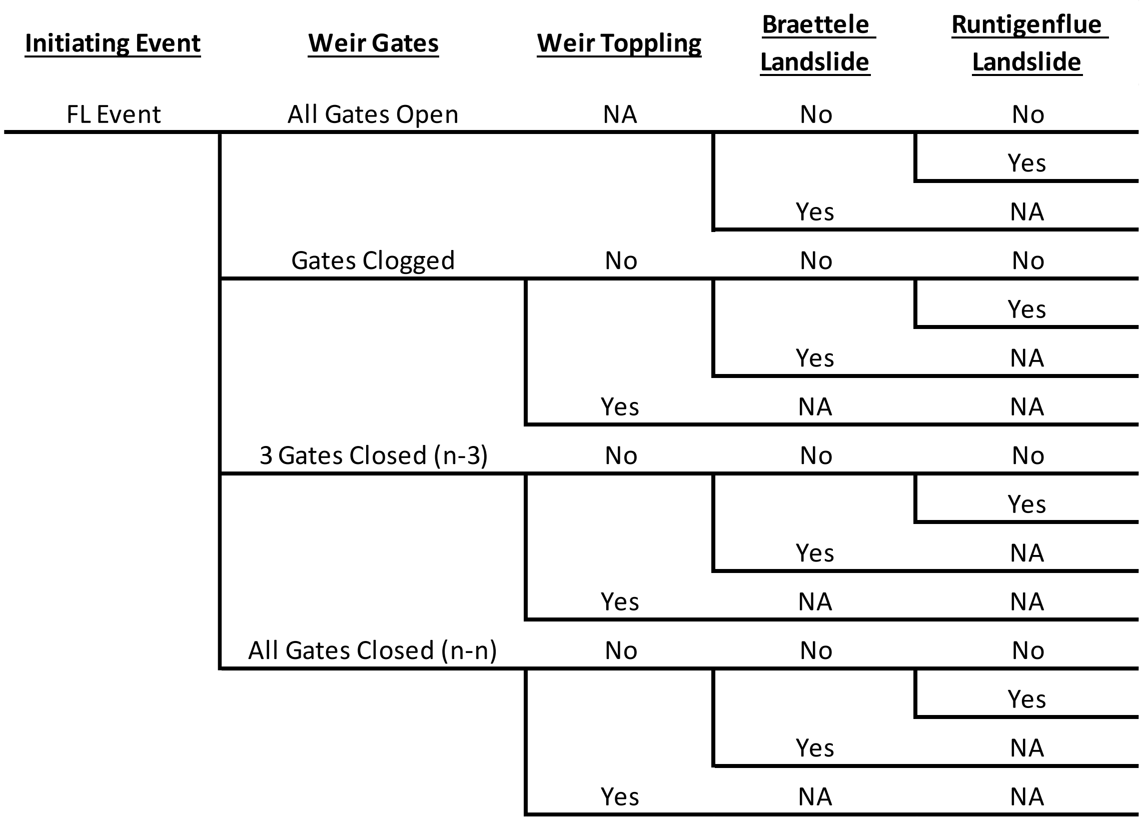


Figure 14: General event tree structure for BP Mühleberg. NA is used for nodes where there are no branches.

Some combinations of events have not been included. For instance, the probability of both Brättele and Runtigenflue landslides is not included. Because they are treated as independent and their combined probability is around 1E-7 without considering the flood initiating event, their combination is outside the frequency range of interest. Another case of combinations that are not considered are the landslides with toppling, but toppling is so unlikely that the frequency of the scenario will be very low.

The impact of the gates on hazards for non-toppling scenarios is not significant. Therefore, there are generally four scenarios at the same hazard with differing frequencies – one for each of the gate cases. Of these four scenarios, the two for all gates clogged and all gates open dominate.

The specific event trees with point estimates are provided in Figure 15Figure 17. The point estimate is taken as the mean initiating event frequency or the mean probability. Approximately half of the scenarios across the group of three event trees have mean frequencies below 1E-8/a. Toppling probabilities of less than 1E-10 were propagated with the estimate, but they should probably be viewed at <1E-10 and not relevant for the frequency range of interest.

IE FL3	Weir Gates	Weir Toppling	Braettele Landslide	Runtigenflue Landslide	Mean Scenario Frequency (/a)	Mean WSPL Ref. Pt. A	Mean WSPL Ref. Pt. B	Mean WSPL Ref. Pt. E	Sequence ID	Scenario ID
5.1E-3	3.0E-1 *[all gates open]*	1.0E+0 *[no toppling]*	1.0E+0 *[no landslide]*	1.0E+0	1.5E-3	465.62	465.62	465.63	FL3-1	1
				2.4E-4	2.0E-7	465.98	465.98	465.99	FL3-2	19
			6.5E-4	1.0E+0	5.8E-7	466.47	466.41	465.81	FL3-3	14
	7.0E-1 *[all gates clogged]*	1.0E+0 *[no toppling]*	1.0E+0 *[no landslide]*	1.0E+0	3.6E-3	465.62	465.62	465.63	FL3-4	4
				2.4E-4	4.7E-7	465.98	465.98	465.99	FL3-5	18
			6.5E-4	1.0E+0	1.4E-6	466.47	466.41	465.81	FL3-6	13
		1.8E-19	1.0E+0	1.0E+0	8.3E-22	467.24	466.94	467.10	FL3-7	--
	3.0E-3 *[3 gates closed]*	1.0E+0 *[no toppling]*	1.0E+0 *[no landslide]*	1.0E+0	1.5E-5	465.62	465.62	465.63	FL3-8	5
				2.4E-4	2.0E-9	465.98	465.98	465.99	FL3-9	--
			6.5E-4	1.0E+0	5.9E-9	466.47	466.41	465.81	FL3-10	--
		8.3E-22	1.0E+0	1.0E+0	1.6E-26	468.8	468.14	468.35	FL3-11	--
	1.0E-3 *[all gates closed]*	1.0E+0 *[no toppling]*	1.0E+0 *[no landslide]*	1.0E+0	5.1E-6	465.62	465.62	465.63	FL3-12	6
				2.4E-4	6.7E-10	465.98	465.98	465.99	FL3-13	--
			6.5E-4	1.0E+0	2.0E-9	466.47	466.41	465.81	FL3-14	--
		1.8E-13	1.0E+0	1.0E+0	1.1E-18	468.8	468.14	468.35	FL3-15	--

Figure 15: BP Mühleberg FL3 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL4	Weir Gates	Weir Toppling	Braettele Landslide	Runtigenflue Landslide	Mean Scenario Frequency (/a)	Mean WSPL Ref. Pt. A	Mean WSPL Ref. Pt. B	Mean WSPL Ref. Pt. E	Sequence ID	Scenario ID
5.9E-4	3.0E-1 [all gates open]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	1.8E-4	465.99	465.99	466.00	FL4-1	2
				2.4E-4	2.3E-8	466.22	466.21	466.24	FL4-2	21
			6.5E-4	1.0E+0	6.8E-8	466.57	466.46	466.18	FL4-3	16
	7.0E-1 [all gates clogged]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	4.1E-4	465.99	465.99	466.00	FL4-4	7
				2.4E-4	5.4E-8	466.22	466.21	466.24	FL4-5	20
			6.5E-4	1.0E+0	1.6E-7	466.57	466.46	466.18	FL4-6	15
		1.8E-19	1.0E+0	1.0E+0	9.7E-23	467.24	466.94	467.10	FL4-7	--
	3.0E-3 [3 gates closed]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	1.8E-6	465.99	465.99	466.00	FL4-8	8
				2.4E-4	2.3E-10	466.22	466.21	466.24	FL4-9	--
			6.5E-4	1.0E+0	6.8E-10	466.57	466.46	466.18	FL4-10	--
		6.0E-17	1.0E+0	1.0E+0	1.3E-22	469.40	468.66	468.87	FL4-11	--
	1.0E-3 [all gates closed]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	5.9E-7	465.99	465.99	466.00	FL4-12	9
				2.4E-4	7.7E-11	466.22	466.21	466.24	FL4-13	--
			6.5E-4	1.0E+0	2.3E-10	466.57	466.46	466.18	FL4-14	--
		1.2E-11	1.0E+0	1.0E+0	8.3E-18	469.40	468.66	468.87	FL4-15	--

Figure 16: BP Mühleberg FL4 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL5	Weir Gates	Weir Toppling	Braettele Landslide	Runtigenflue Landslide	Mean Scenario Frequency (/a)	Mean WSPL Ref. Pt. A	Mean WSPL Ref. Pt. B	Mean WSPL Ref. Pt. E	Sequence ID	Scenario ID
3.7E-5	3.0E-1 [all gates open]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	1.1E-5	466.80	466.78	466.81	FL5-1	3
				2.4E-4	1.4E-9	466.89	466.87	466.89	FL5-2	--
			6.5E-4	1.0E+0	4.2E-9	467.03	466.99	466.96	FL5-3	--
	7.0E-1 [all gates clogged]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	2.6E-5	466.80	466.78	466.81	FL5-4	10
				2.4E-4	3.4E-9	466.89	466.87	466.89	FL5-5	--
			6.5E-4	1.0E+0	1.0E-8	467.03	466.99	466.96	FL5-6	17
		1.8E-19	1.0E+0	1.0E+0	4.8E-24	467.24	466.94	467.10	FL5-7	--
	3.0E-3 [3 gates closed]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	1.1E-7	466.80	466.78	466.81	FL5-8	11
				2.4E-4	1.4E-11	466.89	466.87	466.89	FL5-9	--
			6.5E-4	1.0E+0	4.3E-11	467.03	466.99	466.96	FL5-10	--
		2.7E-15	1.0E+0	1.0E+0	3.1E-22	469.40	468.66	468.87	FL5-11	--
	1.0E-3 [all gates closed]	1.0E+0 [no toppling]	1.0E+0 [no landslide]	1.0E+0	3.7E-8	466.80	466.78	466.81	FL5-12	12
				2.4E-4	4.8E-12	466.89	466.87	466.89	FL5-13	--
			6.5E-4	1.0E+0	1.4E-11	467.03	466.99	466.96	FL5-14	--
		2.8E-10	1.0E+0	1.0E+0	1.1E-17	469.40	468.66	468.87	FL5-15	--

Figure 17: BP Mühleberg FL5 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency

3.1.3 Initiating events and their frequencies

In contrast to the other assessment sites analyzed in this study, the Mühleberg site is directly impacted not only by the Aare but also by the Saane. The confluence the two rivers is a short distance downstream of the assessment site. Consequently, the hydrological initiating events for BP Mühleberg need to combine an Aare discharge and a Saane discharge. The estimation of the hydrological initiating event frequencies for this site therefore required an extension of the method outlined in Section 2.3.

The frequency used for the site was determined using a combination of the Aare and Saane frequencies. The original selection of the floods was based on the Aare peak flow and then a typical flow from the Saane. The timing of these two peaks was not considered, although the two peaks generally arrive close to each other. The Aare has a very flat peak compared to the Saane (*Hauptbericht*, *Abbildung* 37), so any backwater impact would likely be controlled more by the Saane flow than the Aare.

Figure 18 illustrates the method of defining the space used for each initiating event. The "bin" is in the shape of a rotated "L" to account for risk being associated with higher floods on the Saane and the associated backwater. There are multiple ways to select what events should be considered in the two-dimensional space, but this was chosen because it accounts for frequencies on both the Saane and Aare and it covers much of the exceedance space for floods of interest. Very high flows on the Aare (or Saane) and very low floods on the Saane (or Aare), which would be in the white space in the diagram, are not typical for risk, and are therefore not as frequent.

The uncertainty of the frequency was derived in the same way as for other sites, except the frequency is based on the number of events in this two-dimension bin. The Saane edges of the bins were derived in the same way as for the Aare.

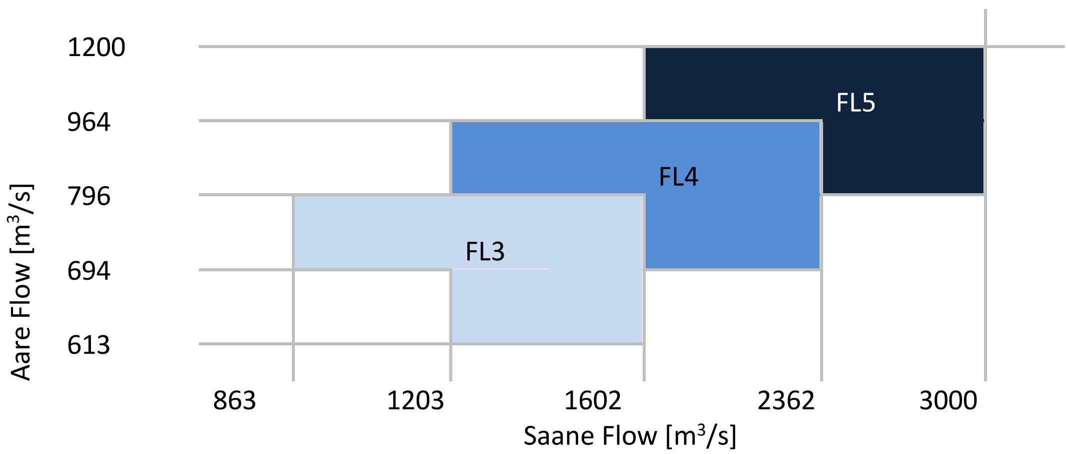


Figure 18: Example of two-dimensional space used to define the initiating events for BP Mühleberg. Drawing not to scale.

Table 9: Summary statistics of flood initiating events for BP Mühleberg. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is denoted cor(.,.). Figure 18 shows the real shape of the bins because they are not rectangular.

Initiating Event	Low Set	Median Set	High Set
FL3 Aare: (613-796) Saane: (863-1602)	cor(FL3, FL4)= -0.041 cor(FL3,FL5)= 0.053 mean = 3.29E-3 std. dev. = 1.05E-4	cor(FL3, FL4)= -0.020 cor(FL3,FL5)= 0.004 mean = 4.94E-3 std. dev. = 1.29E-4	cor(FL3, FL4)=-0.035 cor(FL3,FL5)= 0.033 mean = 7.07E-3 std. dev. = 1.56E-4
FL4 Aare: (694-964) Saane: (1203-2362)	cor(FL4, FL5)= -0.018 mean = 3.56E-4 std. dev. = 3.42E-5	cor(FL4, FL5) = -0.028 mean= 5.62E-4 std. dev.=4.30E-5	cor(FL4, FL5)= 0.008 mean = 8.54E-4 std. dev. = 5.48E-5
FL5 Aare: (796-1200) Saane: (1602-3000)	Mean = 2.77E-5 std. dev.= 9.85E-6	Mean = 3.83E-5 std. dev.=1.12E-5	Mean = 4.52E-5 std. dev.= 1.26E-5

3.1.4 Top events and their probabilities

The following structures or processes are included in the event trees. Details on structures or processes that are not included are available in *Hauptbericht*, Chapter 12. The distributions of the conditional probabilities are given in Table 11.

3.1.4.1 Weir Mühleberg (*GEWISSkm* 157.000)

There are two top events related to Mühleberg: weir gates and toppling. The number of gates open or clogging on Mühleberg has a direct impact on the probability of toppling because of the increased level in Wohlensee. The four gate status options considered in the event tree are as follows:

- All Gates Open (n-0, no clogging)
- Three Gates Closed (n-3, no clogging)
- All Gates Closed (n-6, no clogging)
- All Gates Clogged

The probability of Three Gates Closed and All Gates Closed are scoping values, which are discussed in more detail in Section 2.3.3.1. The clogging probability is discussed in *Detailbericht C*. There is no uncertainty considered for scoping values.

Water levels from the different gate cases are the same at the site. All Gates Clogged was only run for FL4 to confirm that there is no impact on the hazard. For FL3 and FL5 floods, the All Gates Open case was used as an approximation. The assumption that the number of gates does not significantly change water level is also used for landslide cases (e.g. FL3 with n-n gates and Runtigenflue is equal to FL3 with n-n gates and Runtigenflue).

Conditional toppling is not considered when all gates are open, but it is considered in all other cases. These other cases are probabilistically negligible as well. Table 10 summarizes the toppling values from the model developed in *Detailbericht D*. Most of the probabilities are very low. Toppling with all gates open is not considered credible because of the capacity of the gates compared to the flood initiating events. The probability distributions for the conditional toppling are given in Table 10. Where the log-triangular distribution is used to represent that most of the probabilities range order of magnitude and the parameters come from the toppling model of the weir.

Table 10: Toppling probabilities from structural model as outlined in* Detailbericht *D, Section 6.1. Values below 1E-10 were used in the analysis, but should be interpreted as < 1E-10. Pessimistic, Optimistic, and Best Guess values were taken as parameters a, b, and c of the log-triangular distribution defined in Appendix G-1.

Weir Gate Status	FL Initiating Event	Wohlensee Water Level [m.a.s.l]	Probability of Toppling		
			Optimistic Parameters	Best Guess Parameters	Pessimistic Parameters
All Gates Open (n-0)	FL3	480.95	3.0E-67	4.8E-41	1.3E-18
	FL4	480.95	3.0E-67	4.8E-41	1.3E-18
	FL5	481.91	8.9E-57	2.8E-35	2.3E-15
All Gates Clogged	FL3	481.65	2.3E-59	1.1E-36	3.6E-16
Three Gates Closed (n-3)	FL3	481.01	1.3E-66	1.1E-40	2.0E-18
	FL4	482.43	3.0E-51	2.7E-31	8.8E-14
	FL5	483.07	1.0E-45	4.4E-27	3.0E-12
All Gates Closed (n-n)	FL3	484.23	4.7E-36	3.8E-20	1.0E-9
	FL4	484.53	5.8E-34	1.1E-18	6.7E-9
	FL5	485.04	1.2E-30	1.7E-16	1.3E-7

Toppling occurs in four scenarios: FL4 and FL5 combined with n-n and n-3 gates (Three Gates Closed and All Gates Closed). Simulation results show that the water level was higher for FL4 with All Gates Closed than for FL5 with All Gates Closed; this difference is attributed to the timing of the Saane peak flow. The water level calculated for FL4 with All Gates CLOSED is then used for the other three scenarios (the bounding simulation is used for all four scenarios).

3.1.4.2 Brättele Landslide (*GEWISSkm* 155.285)

Brättele is very close to the assessment site and can affect the flow. Simulations indicate that there was an impact form the landslide with a volume of ca. 270’000 m^3 (*Resultatmappe 3, BPM, Section 1.4 IV*). Because it leads to a substantial increase in water level, a smaller volume with higher frequency was also simulated; however, it was found to have a negligible effect of 0.01 m increase in water level at most. Therefore, only the larger landslide volume was used as a branch in the event tree. The result is often a slight reduction in the water level at point AAR_155170, but it is sufficient to wet points A and B when with FL3 when they were about 0.55 m dry in the hydrologic scenario.

The probability of the landslide is taken as the annual exceedance probability. Discussion of this value and the uncertainty is in *Detailbericht C.*

3.1.4.3 Runtigenflue Landslide (*GEWISSkm* 153.300)

Runtigenflue is after the confluence of the Aare and the Saane. The main impact is anticipated to be backwater due to blockage of the channel. Only one landslide volume is considered because a much smaller landslide would still be expected to block around 90% of the channel, whereas the volume considered was sufficient to block 100%. This difference in blockage is not expected to have a large difference in the results. The increases compared to the hydrologic scenario simulation ranges from 0.09 to 0.36 m at point AAR_155170 (*Resultatmappe 3, BPM, Section 1.4 V*).

The probability of the landslide is taken as the annual exceedance probability. Discussion of this value and the uncertainty is in *Detailbericht C*.

Table 11: Summary of distributions for top events for BP Mühleberg. Toppling scenarios are dependent and the same percentile of the distribution is used in all cases, which reflects uncertainty of the toppling model. Distributions are defined with their parameterization in Appendix G-1.

Structure	Top Event	Conditions	Probability	Comment
Weir Mühleberg	Three Gates Closed (n-3)	Independent	3E-3	Scoping Value, Section 2.3.3
	All Gates Closed (n-n)	Independent	1E-3	Scoping Value, Section 2.3.3
	All Gates Clogged	Independent	7E-1	*Detailbericht C*, Section 6.; Table 8
	Toppling	Number of gates; FL Event	log-triangular	Table 10
Brättele Landslide	Landslide of ca. 270’000 m^3	Independent	Triangular a=1.4E-4 b=1.4E-3 c=4.3E-4	*Detailbericht C, Section 3.6; Section 2.3.6*
Runtigenflue Landslide	Landslide of ca. 890’000 m^3	Independent	Triangular a=8.9E-5 b=4.5E-4 c=2.0E-4	*Detailbericht C, Section 3.6; Section 2.3.6*

3.1.5 Notes on the use of reach simulation results for BPM scenario outcomes

Scenarios that did not wet the site were assigned the water elevation of AAR_155170, a point in the river upstream of the assessment site. Point E was always wetted, but points A and B were generally not wetted with FL3 and FL4 unless there was a landslide or toppling. FL5 scenarios wetted the site. Figure 19 compares the water elevations for the Aare point versus the reference points for scenarios in the range of interest. In most cases, the point elevations are within 0.1 of the Aare elevation. The two points that show significant divergence are for Brättele landslide, which could cause changes in the flow near the Aare point.

Several scenarios are approximated or bounded. The first approximation is that the water level at the site is not dependent on the clogging of the gates. Scenario 7, which is FL4 with clogging of the gates at Weir Mühleberg, showed the same hazard as the all gates open (Scenario 2), n-3, and n-n gates cases. Therefore, Verklausung was not simulated separately for FL3 and FL5. This approximation is used for Scenarios 4 and 10.

Based on the above information, the landslide top events were only simulated with all gates open and the results are assumed to apply to the other gate cases (n-3, n-n, clogged). This assumption applies to Scenarios 13, 15, 17, 18, and 20 and Sequences FL3-9, FL3-10, FL3-13, FL3-14, FL4-9, FL4-10, FL4-13, FL4-14, FL5-5, FL5-9, FL5-10, FL5-13, and FL5-14.Toppling water levels were approximated or bounded; however, all of these scenarios have frequencies less than 1E-8/a and are not visible in the plots. The water level with clogging seems to not vary too much, so the water level at the site would not change too much. Sequence FL3-7 was used to approximate the water levels for FL4-7 and FL5-7. Toppling with n-n gates FL3 (FL3-15) was used to bound toppling with n-3 gates FL3 (FL3-11), which is conservative because the Wohlensee levels are lower for FL3 n-3 than FL3 n-n. The final bounding value was that FL4 n-n toppling (FL4-15) was used for FL4 n-3 toppling (FL4-11) and FL4 n-n and n-3 toppling (FL5-15 and FL5-11). Simulation showed lower water levels for the FL5 toppling cases, which was attributed to the timing of the toppling with respect to the Saane peak.

The hydraulic parameter uncertainty is taken for the reference point and not AAR_155170 even when the site is dry, but the differences are small. Table 24 provides the parameters of the specific distributions.

The three cases of morphology uncertainty are outlined in Appendix G-3 and more details are in *Detailbericht F.* The only two morphology cases that are relevant for the hazard curve above 1E-8/a are Brättele landslide and general case (no breach or no toppling of Weir Mühleberg). These two cases are considered independent of each other. The morphology outcome is sampled epistemically within a given case.

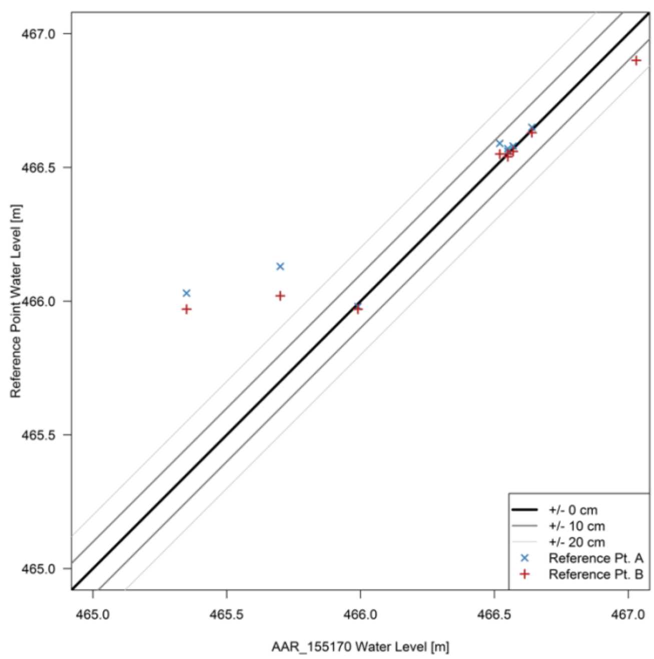


Figure 19: Comparison of AAR_155170 water elevations to reference point A and B water elevations for scenarios that wet A and B with elevations below 467 m.a.s.l.

3.2 Assessment site Olten (BPO)

Assessment site Olten (BP Olten, BPO) is location on a relatively straight section of the river with high banks on both the left and right sides. Two bridges, Bahnhofbrücke and Trimbacherbrücke, are able to clog and would induce a backwater effect. Point A is located upstream of both bridges and points B and C are located downstream of Bahnhofbrücke and upstream of Trimbacherbrücke. Trimbacherbrücke is highly likely to clog on the truss structure but not anticipated to clog on the central arch. More details are in *Hauptbericht* Chapter 13.

3.2.1 Hazard curves for reference points A, B and C

The hazard curves for these reference points, with the propagated uncertainties, are presented in Figure 20, Figure 21, and Figure 22. No morphology uncertainty was considered for this site (*Detailbericht F*). The important scenarios at the site are related to the driftwood clogging at the structures.

The core findings about hazard for these reference points, with an emphasis on point A, are:

- The frequency of a water level exceeding the elevation of reference point A is approximately 2E-5/a. Hydrological flood events without the failure of structures, namely FL3-H, FL4-H, and FL5-H, are not decisive for the hazard curve.
- Point A remains dry for the majority of the analyzed scenarios. The water elevation remains 6.02, 5.34, and 3.96 m below the elevation of Point A in the hydrological scenarios FL3-H, FL4-H, and FL5-H.
- The sole scenario in which Point A is inundated (to a depth of 0.48 m) is the clogging of the Trimbacherbrücke with a driftwood volume of 400 m^3.
- For Point A, the clogging of the Bahnhofbrücke (scenarios 5, 6, 8, 9) and the Trimbacherbrücke (scenario 15) with 100- and 300-y driftwood volumes are decisive. For other reference points, different scenarios are decisive (see Section 3.2.1, this report).
- For all reference points of the BP Olten, the backwater related to the Winznau weir and the landslide at Burgstelle are not significant relative to other processes. Closed weir gates at Winznau (n-n) lead to increases in the water level of 26-33 cm in combination with FL3 and of 17-22 cm in combination with FL4.
- Morphological dynamics have a weak impact on the Olten reach (see Detailbericht F, Chapter 6). The influence of morphological processes on the water level were estimated to be negligible. On the other hand, caulking at the pillars was examined in the frame of the analysis of structures.
- The uncertainty for the portion of the hazard curve with the largest frequencies is smaller than an order of magnitude. This uncertainty increases to 1.5 orders of magnitude in the middle of the hazard curve, around scenarios 6 and 8. The scenario with the largest WSPL (scenario 15) has a large uncertainty, where the lower bound of the interval is below 1E-8/a. The smoothness of the mean hazard curve is due to the effect of the large uncertainties due to the hydraulic parameters. On the other hand, the steps in the uncertainty bound curves reflect the uncertainties of the individual scenarios.

Short descriptions of all scenarios shown in these hazard curves are available in Table G-6-2 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, and the mean WSPL at reference point A and B. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the 'source' scenario will be higher than in the 'target' scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the 'target' scenario will be less than that of the 'source' scenario.

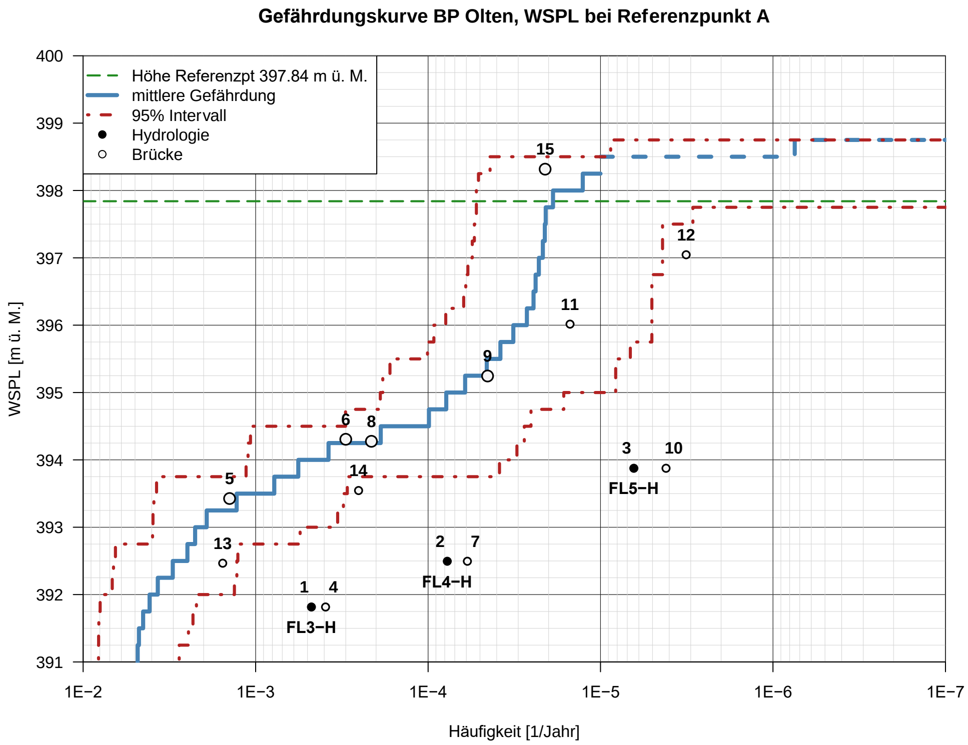


Figure 20: BP Olten Reference Point A hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 397.84 m.a.s.l. (Duplicate of Hauptbericht Abbildung 52.)

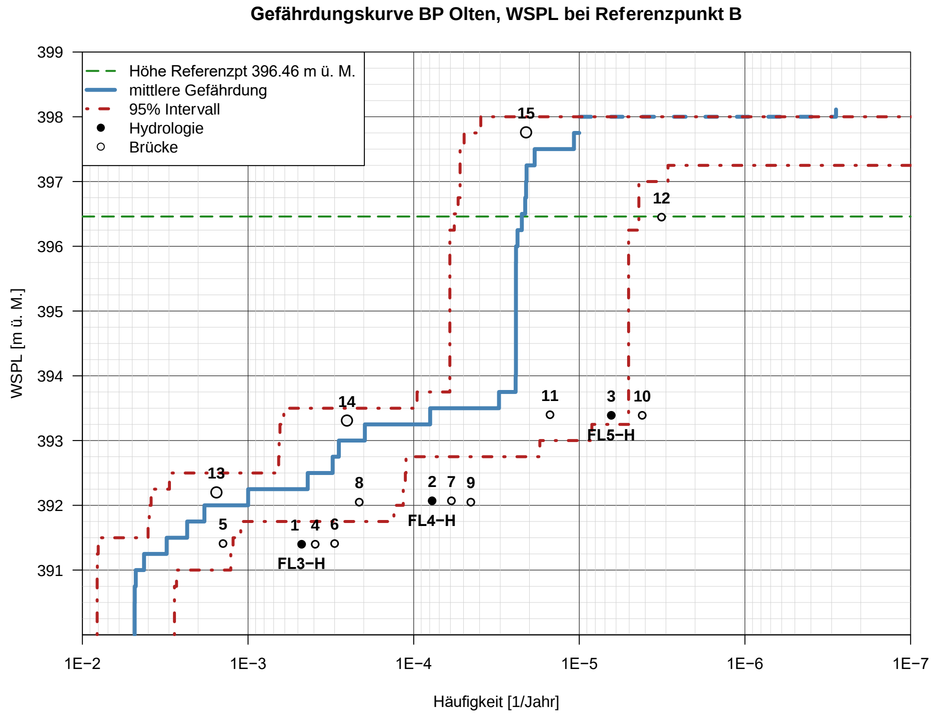


Figure 21: BP Olten Reference Point B hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 396.46 m.a.s.l.

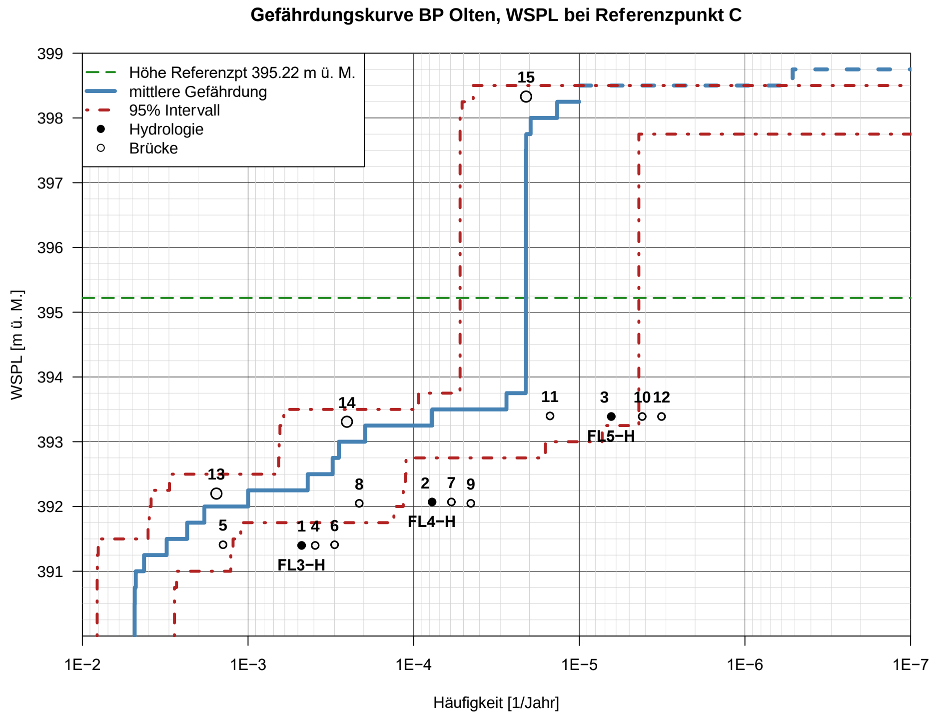


Figure 22: BP Olten Reference Point C hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 395.22 m.a.s.l.

In the hazard curve for BP Olten Reference Point C (Figure 22), the mean hazard curve below 1E-5/a fall near and then outside (above) the 95% frequency uncertainty envelope of the hazard curve. This occurs because the scenarios sampled during the uncertainty calculation include many scenarios with very low frequencies as well as scenarios with frequencies orders of magnitude higher. The samples with high frequencies then dominate the mean frequency value at that WSPL, leading to this behavior of the mean hazard curve.

3.2.2 Site event trees

Figure 23 is the general event tree structure for BP Olten. As can be seen, the top events identified in Section 3.2.2.2 are included. The structure is simple because there are few structures and relatively few processes. The result is that it comes down to if the bridges clog and how much driftwood comes down the river.

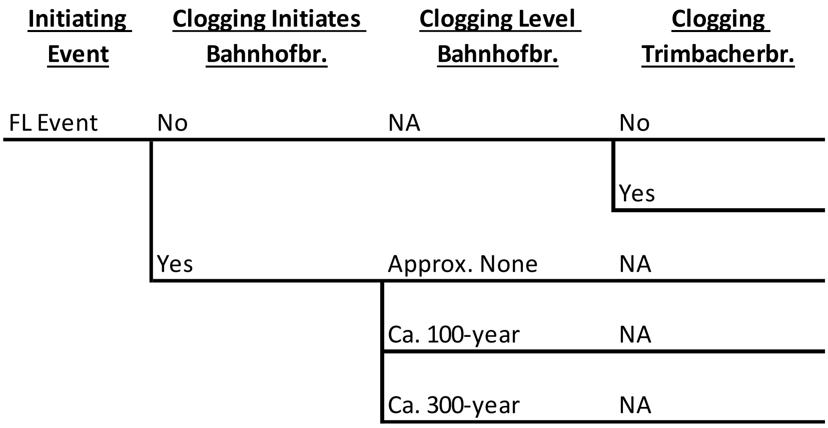


Figure 23: General event tree structure for BP Olten. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

The event trees with point estimates are given in Figure 24, Figure 25, and Figure 26. Only the initiating event frequency and the probability of clogging initiating at Bahnhofbrücke change across the event trees, so the relative likelihood of the different scenarios remains nearly constant. The most frequent scenarios are the clogging of Trimbacherbrücke and the 100-year clogging of Bahnhofbrücke. The spread in the frequency of the different scenarios in a given event tree is relatively small because the probabilities are on the same order of magnitude at each branch.

IE FL3	Clogging Initiates Bahnhofbr.	Clogging Level Bahnhofbr.	Clogging Trimbacherbr.	Mean Scenario Frequency (/a)	Mean WSPL Ref. Pt. A	Mean WSPL Ref. Pt. B	Sequence ID	Scenario ID
4.1E-3	4.9E-1	1.0E+0	2.3E-1	4.7E-4	391.82	391.40	FL3-1	1
		[>400m3]	7.7E-1	1.6E-3	392.47	392.20	FL3-2	13
	5.1E-1	1.9E-1	1.0E+0	3.9E-4	391.82	391.40	FL3-3	4
	[Ca. 100-yr]	6.7E-1	1.0E+0	1.4E-3	393.43	391.41	FL3-4	5
	[Ca. 300-yr]	1.4E-1	1.0E+0	3.0E-4	394.31	391.41	FL3-5	6

Figure 24: BP Olten FL3 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

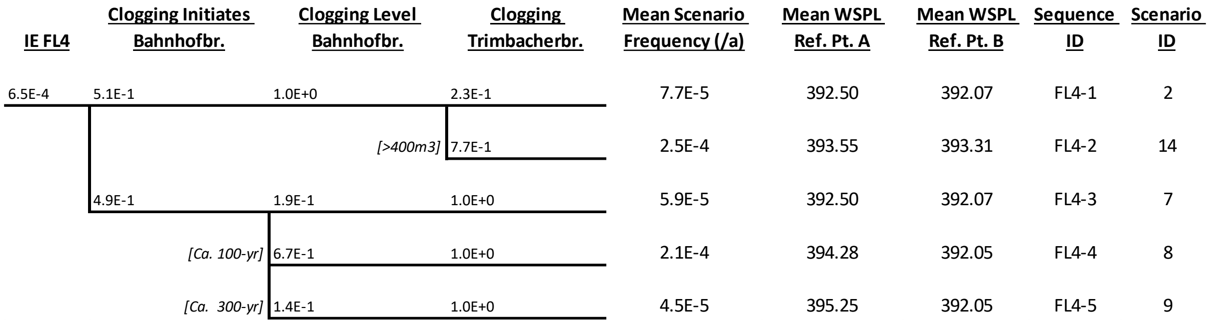


Figure 25: BP Olten FL4 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

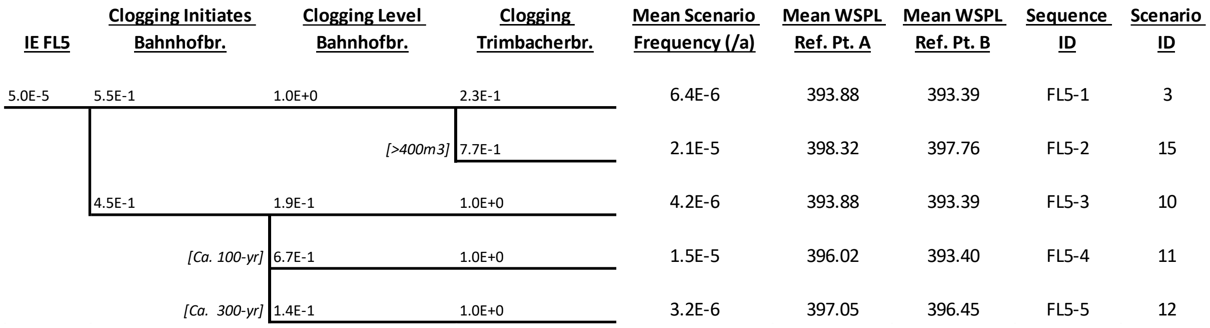


Figure 26: BP Olten FL5 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

3.2.3 Initiating events and their frequencies

Only floods are considered initiating events for BP Olten. Some summary statistics of these events are provided in Table 12. The statistics and frequencies are derived through resampling the three hydrologic parameter set annual maximum series, as outlined in Section 2.4.

Table 12: Summary statistics of flood initiating events for BP Olten and BP Gösgen. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is cor(.,.).

Initiating Event (Flow Range)	Low Set	Median Set	High Set
FL3 (1451-1794)	cor(FL3, FL4)= 0.015 cor(FL3,FL5)= 0.014 mean = 2.62E-3 std. dev. = 9.60E-5	cor(FL3, FL4)= -0.023 cor(FL3,FL5)= 0.007 mean = 3.29E-3 std. dev. = 1.04E-4	cor(FL3, FL4)= -0.035 cor(FL3,FL5)= -0.034 mean = 6.51E-3 std. dev. = 1.50E-4
FL4 (1794-2289)	cor(FL4, FL5)= 0.042 mean = 2.85E-4 std. dev. = 3.10E-5	cor(FL4, FL5) = 0.000 mean = 3.67E-4 std. dev.=3.48E-5	cor(FL4, FL5)= -0.056 mean = 1.30E-3 std. dev. = 6.79E-5
FL5 (2289-3000)	Mean = 2.09E-5 std. dev.= 8.42E-6	Mean = 3.12E-5 std. dev.=1.04E-5	mean=9.75E-5 std. dev.= 1.87E-5

3.2.4 Top events and their probabilities

Table 13 presents a brief summary of all the distributions used for the conditional probabilities.

3.2.4.1 Bahnhofbrücke (*GEWISSkm* 55.294)

Bahnhofbrücke is upstream of reference point B and downstream of reference point A. Clogging at the structure is the main processes considered. The probability that clogging initiates is about 5E-1, but it depends on the flood initiating event. Therefore, there is a branch for clogging initiating and a second one for the level of clogging. The volume of driftwood is divided into three ranges:

- Approximately None [<350.5 m^3 solid]
- Ca. 100-year volume [350.5 – 1657 m^3 solid]
- Ca. 300-year volume [>1657 m^3 solid]

The probabilities for each of these cases is calculated from the hypothesized distribution of driftwood arriving to Olten. The ranges of are defined based on the backwater-driftwood volume relationship.

Point B has less impact from Bahnhofbrücke clogging. When combined with FL5, it appears that it might activate another flow path to reference point B.

3.2.4.2 Trimbacherbrücke (*GEWISSkm* 54.602)

Trimbacherbrücke is downstream of all the reference points in BP Olten. Again, the main influence is because of backwater in the river. It is generally less substantial than Bahnhofbrücke clogging for point A and more substantial than Bahnhofbrücke clogging for point B. The driftwood analysis shows that clogging initiating is virtually certain, so then the only uncertainty is whether enough driftwood will be delivered. The probability is taken as the probability that 405 m^3 solid (*Resultatmappe 3, BPO, Section 2.4 III*) is delivered to the site. Because the site is downstream of Bahnhofbrücke, clogging here can only occur when it does not occur at Bahnhofbrücke.

Table 13: Summary of distributions for top events for BP Olten.

Structure	Top Event	Conditions	Probability Model	Comment
Bahnhofbrücke	Clogging Initiates	FL3	p_H = 5.1E-1	Resultatmappe 3, BPO, Section 2.4 II
		FL4	p_H = 4.9E-1	
		FL5	p_H = 4.5E-1	
	Ca. 100-year Clogging	Independent	p_W = 6.71E-1	*Detailbericht C* for general discussion. For driftwood volumes, Table 5
	Ca. 300-year Clogging	Independent	p_W = 1.42E-1	
Trimbacherbrücke	Clogging (>400 m^3 solid)	Clogging does not initiate at Bahnhofbrücke	p_W = 7.66E-1	*Detailbericht C* for general discussion; Table 5

3.2.5 Notes on the use of reach simulation results for BPO scenario outcomes

Most scenarios did not wet points A, B or C. When point A was not wetted, the water level was taken from point AAR_055379 in the river and when points B or C were not wetted the water level was taken from point AAR_054858 in the river.

Three types of clogging scenarios are modelled: “small volume with minor impact on hazard”, 100-yr, and 300-yr volumes. The case “small volume with minor impact” is defined on the basis of the clogging backwater relationship and approximated by the simulation run without clogging. For instance, Scenario 4 is approximated with Scenario 1, which is the pure hydrological scenario. The rationale for treating Scenario 4 and analogous scenarios as separate scenarios is related to probabilistic scenario delineation. See Section 2.3.5 for a general discussion on the probabilistic modelling of clogging. This approximation is used in Scenarios 4, 7, and 10. These are the only approximations and all other scenarios are simulated.

Hydraulic parameter uncertainty is defined in Appendix G-2 and morphology uncertainty was not considered at the site.

3.3 Assessment site Gösgen (BPG) – Gösgen Aare

The assessment site Gösgen (BP Gösgen, BPG) has reference points on both the Aare and the Oberwasserkanal. The processes or events that might influence one set of reference points will not necessarily influence the other reference points in the same way. As a result, the scenarios for the two sets of points are analyzed with two sets of event trees, which contain different top events (since the structures and processes relevant to the two sets differ, yielding separate hazard curves that are applicable to their respective reference points.

The structures and terrain around BP Gösgen are described in *Hauptbericht* Chapter 14.

The two reference points referred to as “Gösgen Aare” consists of ‘A’, in the Aare channel, and ‘C’, close to the Aare. The reference point on the Oberwasserkanal, labelled ‘B’, is referred to as “Gösgen Oberwasserkanal” (OWK). The results, models, and input data for the first are documented here in Section 3.3 while those for the Gösgen OWK are documented in the next section, Section 3.4. Each section contains hazard curves, the documentation of the input data, and a summary of results.

In brief (see *Hauptbericht* Chapter 14 for details), the Gösgen Aare points are along a stretch of the Aare river below the weir at Winznau. Two bridges, Fussgängersteg and Sandackerstrasse are located adjacent to and downstream of the plant, respectively. The Oberwasserkanal is north of the Aare section of the river.

3.3.1 Hazard curves for reference points A, C

The hazard curves for reference points A and C at BP Gösgen are presented in Figure 27 and Figure 28. For each of the analyzed scenarios, the absolute water level will be approximately 0.5 m higher at point A than at point C. However, point A has an elevation of 375.11 m while point B has an elevation of 382.15. The reference point is inundated for all scenarios at point A (with the lowest water elevations at approximately 380.8 m). For instance, scenario 9 with a mean frequency of 2.5E-4/a produces a water elevation of 382.63 m at point C and 383.10 m at point A, corresponding to 0.48 m inundation at point C and 8 m at point A.

Because of the similarities in the decisive scenarios and dominant contributors, the discussion of the hazard for the BP Gösgen Aare reference points will focus on reference point C.

The core findings about hazard for these reference points are:

- The hazard for Reference Point C arises from scenarios on the Aare as well as scenarios on the Oberwasserkanal, whereby the Aare scenarios constitute the main hazard.
- The hydrological events without additional failures (FL3-H, FL4-H, and FL5-H) are not decisive for the hazard curve.
- Clogging of the Fussgängersteg KKG (scenarios 8, 9, 11, 12, 14, 15) due to 100- or 300-y driftwood volumes, combined with FL3-FL5 are decisive for Point C. All of these scenarios, except scenario 8, inundate Point C. The consequence is that Point C is inundated starting at 1E-3/a. At 1E-4/a, the inundation at Point C is 65 cm.
- The largest inundation depth occurs due to the clogging of the Fussgängersteg KKG due to a 300-y driftwood volume in combination with FL5 (scenario 15, inundation of 1.3 m).

- Clogging at the Sandackerstrasse bridge also leads to increased inundation (scenarios 16-24); however, these scenarios are not decisive for the hazard curve.
- A breach of the Oberwasserkanal near Brücke 4 (Schachenstrasse) (e.g. scenario 6) increases the discharge at Point C; however, these scenarios are not decisive for the hazard curve.
- Uncertainties on the hazard curve generally fall between 1.5 and 2 orders of magnitude for scenarios, with the larger uncertainties occurring at the higher water levels. The main contributors to these uncertainties are the uncertainties of the hydraulic parameters and morphology.

Short descriptions of all scenarios shown in these hazard curves are available in Table G-6-3 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, the mean WSPL at both reference points A and C. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the 'source' scenario will be higher than in the 'target' scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the 'target' scenario will be less than that of the 'source' scenario.

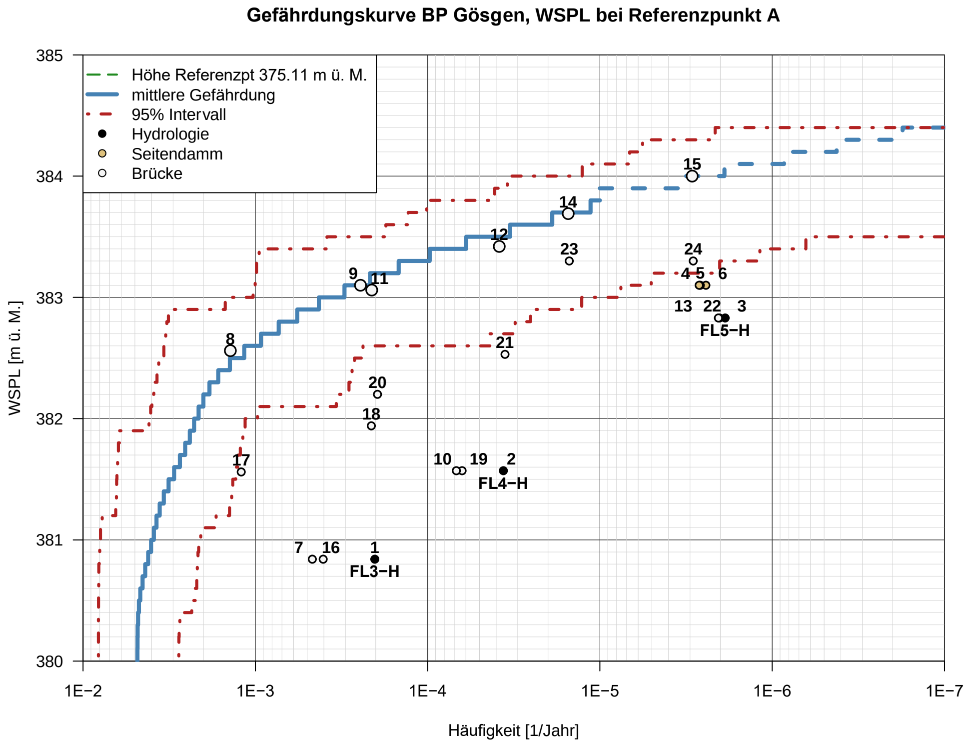


Figure 27: BP Gösgen Reference Point A hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The elevation of the point is 375.11 m.a.s.l. and all scenarios considered lead to inundation at reference point A.

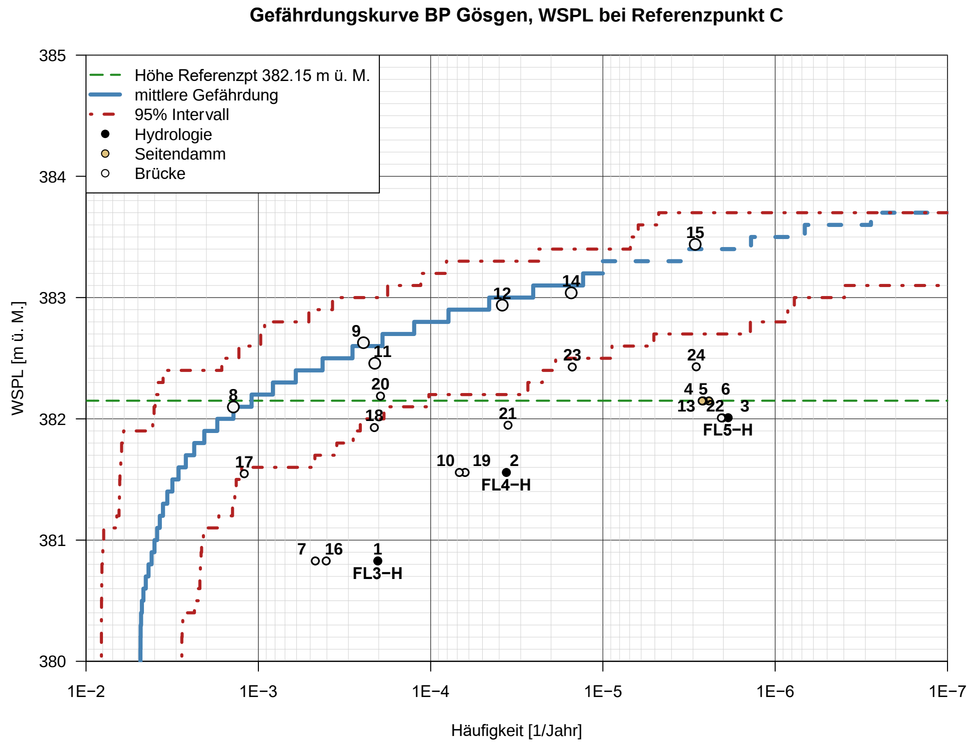


Figure 28: BP Gösgen Reference Point C hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 382.15 m.a.s.l. (Duplicate of Hauptbericht Abbildung 61.)

3.3.2 Site event trees

For the scenarios initiated by the FL3, FL4, and FL5 floods, the event trees for BP Gösgen Aare are based on a common structure, shown in Figure 29. The main events are related to clogging at the bridge Fussgängersteg and clogging at the bridge Sandackerstrasse. As is usual with driftwood clogging, the downstream bridge can only clog when clogging does not initiate at the upstream bridge. No other structures and processes considered for candidate top events were found to be relevant.

The BP Gösgen Aare event trees are shown in Figure 30, Figure 31, and Figure 32. The values of the initiating event frequencies, branch probabilities, scenarios frequencies, and the scenario outcome (WSPL, the water level at the reference point) shown in these figures are mean values of their respective uncertainty distributions. The mean scenario frequency is the mean value of the frequency distribution obtained from propagating the uncertainties in the initiating event frequencies and branch probabilities. The WSPL mean value is the result of propagating the uncertainties in the hydraulic simulations.

The first trend in the BP Gösgen Aare event trees is the increase in the probability of driftwood volume delivered to the Aare as the flood discharge increases. This is a direct result of the assumption that the driftwood split between the Aare and Oberwasserkanal is proportional to the flows in the two combined with the relatively constant flow in the OWK; higher floods increase the driftwood on the Aare section.

A second major feature is that the FL5 event trees have an additional top event modelling the failure of levees on the OWK levee. These failures have a high probability but are only relevant in the absence of clogging. This leads to three additional branches and scenarios in this tree relative to the trees for FL3 and FL4.

Initiating Event	Clogging Initiates Fussganger	Clogging Level Fussganger	Clogging Initaites Sandacker	Clogging Level Sandacker
FL Event	No	NA	No	NA
			Yes	Approx. None
				ca. 100-year
				ca. 300-year
	Yes	Approx. None	NA	NA
		ca. 100-year	NA	NA
		ca. 300-year	NA	NA

Figure 29: General event tree structure for BP Gösgen Aare.

IE FL3	Clogging Initiates Fussganger	Clogging Level Fussganger	Clogging Initaites Sandacker	Clogging Level Sandacker	Mean Frequency [1/a]	Mean WSPL Ref. Pt. C	Mean WSPL Ref. Pt. A	Sequence ID	Scenario ID
4.1E-3	4.9E-1	1.0E+0	1.0E-1	1.0E+0	2.0E-04	380.83	380.84	FL3-1	1
			9.0E-1	2.2E-1	4.0E-04	380.83	380.84	FL3-2	16
			[Ca. 100-yr]	6.6E-1	1.2E-03	381.55	381.56	FL3-3	17
			[Ca. 300-yr]	1.2E-1	2.1E-04	381.93	381.94	FL3-4	18
	5.1E-1	2.2E-1	1.0E+0	1.0E+0	4.7E-04	380.83	380.84	FL3-5	7
	[Ca. 100-yr]	6.6E-1	1.0E+0	1.0E+0	1.4E-03	382.10	382.56	FL3-6	8
	[Ca. 300-yr]	1.2E-1	1.0E+0	1.0E+0	2.5E-04	382.63	383.10	FL3-7	9

Figure 30: BP Gösgen Aare FL3 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL4	Clogging Initiates Fussganger	Clogging Level Fussganger	Clogging Initaites Sandacker	Clogging Level Sandacker	Mean Frequency [1/a]	Mean WSPL Ref. Pt. C	Mean WSPL Ref. Pt. A	Sequence ID	Scenario ID
6.5E-04	5.1E-01	1.0E+00	1.1E-01	1.0E+00	3.6E-05	381.56	381.57	FL4-1	2
			8.9E-01	2.1E-01	6.3E-05	381.56	381.57	FL4-2	19
			[Ca. 100-yr]	6.6E-01	2.0E-04	382.19	382.20	FL4-3	20
			[Ca. 300-yr]	1.2E-01	3.6E-05	381.95	382.53	FL4-4	21
	4.9E-01	2.1E-01	1.0E+00	1.0E+00	6.8E-05	381.56	381.57	FL4-5	10
	[Ca. 100-yr]	6.6E-01	1.0E+00	1.0E+00	2.1E-04	382.46	383.06	FL4-6	11
	[Ca. 300-yr]	1.2E-01	1.0E+00	1.0E+00	3.8E-05	382.94	383.42	FL4-7	12

Figure 31: BP Gösgen Aare FL4 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL5	Clogging Initiates Fussganger	Clogging Level Fussganger	Clogging Initaites Sandacker	Clogging Level Sandacker	OWK Failure	Mean Frequency [1/a]	Mean WSPL Ref. Pt. C	Mean WSPL Ref. Pt. A	Sequence ID	Scenario ID
5.0E-5	5.4E-1	1.0E+0	1.6E-1	1.0E+0	4.4E-1	1.9E-06	382.01	382.83	FL5-1	3
					5.6E-1	2.4E-06	382.15	383.10	FL5-2	6
			8.4E-1	2.1E-1	4.4E-1	2.0E-06	382.01	382.83	FL5-3	22
					5.6E-1	2.6E-06	382.15	383.10	FL5-4	5
			[Ca. 100-yr]	6.7E-1	1.0E+0	1.5E-05	382.43	383.30	FL5-5	23
			[Ca. 300-yr]	1.3E-1	1.0E+0	2.9E-06	382.43	383.30	FL5-6	24
	4.6E-1	2.1E-1	1.0E+0	1.0E+0	4.4E-1	2.1E-06	382.01	382.83	FL5-7	13
					5.6E-1	2.7E-06	382.15	383.10	FL5-8	4
	[Ca. 100-yr]	6.7E-1	1.0E+0	1.0E+0	1.0E+0	1.5E-05	383.04	383.69	FL5-9	14
	[Ca. 300-yr]	1.3E-1	1.0E+0	1.0E+0	1.0E+0	2.9E-06	383.44	384.00	FL5-10	15

Figure 32: BP Gösgen Aare FL5 event tree with point estimates for frequencies and probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

3.3.3 Initiating events and their frequencies

The same initiating events are used as for BP Olten. Table 14 summarizes the initiating event distribution. It is repeated in Table 14 for the convenience of the reader.

Table 14: Summary statistics of flood initiating events for BP Olten and BP Gösgen. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is cor(.,.). (Duplicate of Table 12.)

Initiating Event (Flow Range)	Low Set	Median Set	High Set
FL3 (1452-1794)	cor(FL3, FL4)= 0.015 cor(FL3,FL5)= 0.014 mean = 2.62E-3 std. dev. = 9.60E-5	cor(FL3, FL4)= -0.023 cor(FL3,FL5)= 0.007 mean = 3.29E-3 std. dev. = 1.04E-4	cor(FL3, FL4)= -0.035 cor(FL3,FL5)= -0.034 mean = 6.51E-3 std. dev. = 1.50E-4
FL4 (1794-2289)	cor(FL4, FL5)= 0.042 mean = 2.85E-4 std. dev. = 3.10E-5	cor(FL4, FL5) = 0.000 mean= 3.67E-4 std. dev.= 3.48E-5	cor(FL4, FL5)= -0.056 mean = 1.30E-3 std. dev. = 6.79E-5
FL5 (2289-3000)	Mean = 2.09E-5 std. dev.= 8.42E-6	Mean = 3.12E-5 std. dev.= 1.04E-5	Mean = 9.75E-5 std. dev.= 1.87E-5

3.3.4 Top events and their probabilities

3.3.4.1 Fussgängersteg (GEWISSkm 46.965)

The bridge Fussgängersteg is close to the assessment site BP Gösgen Aare. The increase in water level ranges from about 1.2 to 2.2 m, depending on the clogging level and the flood event (Resultatmappe 3, BPG, Section 3.4 IX). The probability that clogging initiates is about 5E-1, depending on the flood event. With regard to the probability of driftwood quantities, no retention is accounted for upstream in Olten (Bahnhofbrücke or Trimbacherbrücke) or at other structures (e.g. Weir Winznau); consequently, the probability of the clogging scenarios is to some degree conservative. The driftwood volume distribution from Table 5 results in the three cases of clogging:

- Approximately None [<350.5 m^3 solid]
- Ca. 100-year volume [350.5 – 1657 m^3 solid]
- Ca. 300-year volume [>1657 m^3 solid]

The probabilities of the different volumes of driftwood are uncertain because there is an assumption about the split of the driftwood between the Oberwasserkanal and the Aare. It was assumed that the typical value of the driftwood split is the fraction of the Aare flow divided by the peak flow at TP Aarburg. The Oberwasserkanal has a flow of approximately 150 m^3/s. Because of this constant OWK flow, the fraction of driftwood on the Aare ranges from about 91% to 95% for the FL3 and FL5 events, respectively. The uncertainty of this fraction is assigned as 50% of the OWK fraction (e.g. typical value of 8% on OWK would have an uncertainty of 4%-12%, implying the Aare driftwood fraction has range 88%-96%).

3.3.4.2 Sandackerstrasse (*GEWISSkm* 46.058)

Sandackerstrasse clogging is also associated with water level increases at the assessment site. It is not as substantial as Fussgängersteg, but the impact of clogging ranges from about 0.7 to 0.5 m depending on the flood initiating event.

- Approximately None [<350.5 m^3 solid]
- Ca. 100-year volume [350.5 – 1657 m^3 solid]
- Ca. 300-year volume [>1657 m^3 solid]

Clogging can initiate at this structure when it does not initiate at Fussgängersteg. In these cases, clogging is highly likely with a probability of initiating about 9E-1. The same driftwood outcomes are used as for Fussgängersteg.

3.3.4.3 OWK Levee (*GEWISSkm* 49.852)

The failure of the OWK can lead to higher water levels at the site, although the impact depends on the specific location of the failure. Only the levee by bridge 4 (Schachenstrasse) is considered in this analysis. The one farther downstream is at a location with higher banks, suggesting that the levee will not be overtopped there first (overtopping will initiate elsewhere), and levee failures further upstream are not anticipated to have a major difference in impact.

A failure probability of approximately 7E-1 is used; however, this is only used for the FL5 event tree. Failure leads to an increase of about 0.3 m at the site. Because the increases in water level are much higher with clogging at Fussgängersteg and Sandackerstrasse, this failure is only relevant when there is no clogging of the either of these two structures.

Table 15: Summary of distributions for top events for BP Gösgen Aare. Distributions are defined with their parameterization in Appendix G-1.

Structure	Top Event	Conditions	Probability Model	Comment
Fussgangersteg	Clogging Initiates	FL3	p_H = 5.1E-1	*Resultatmappe 3, BPG, Section 3.4 IX*
		FL4	p_H = 4.9E-1	
		FL5	p_H = 4.6E-1	
	Ca. 100-year Clogging	FL3	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for general driftwood information.
	Ca. 300-year Clogging	FL3	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_2 = 100y upper value	
	Ca. 100-year Clogging	FL4	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0768 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL4	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0768 σ = 0.792 c_2 = 100y upper value	
	Ca. 100-year Clogging	FL5	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL5	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ r ~ 1-beta(2,2,0.5R,1.5R) R = 0.0538 σ = 0.792 c_2 = 100y upper value	

Structure	Top Event	Conditions	Probability Model	Comment
Sandackerstrasse	Clogging Initiates	FL3	p_H = 9.0E-1	*Resultatmappe 3, BPG, Section 3.4 XI*
		FL4	p_H = 8.9E-1	
		FL5	p_H = 8.4E-1	
	Ca. 100-year Clogging	FL3	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for general driftwood information.
	Ca. 300-year Clogging	FL3	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_2 = 100y upper value	
	Ca. 100-year Clogging	FL4	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0768 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL4	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0768 σ = 0.792 c_2 = 100y upper value	
	Ca. 100-year Clogging	FL5	$p_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0925 σ = 0.792 c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL5	$p_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim$ 1-beta(2,2,0.5R,1.5R) R = 0.0538 σ = 0.792 c_2 = 100y upper value	
Seitendamm	Breach OWK near Schachenstr.	FL5	log-triangular a = 0.21 b=1.0 c=0.72	*Resultatmappe 3, BPG, Section 3.4 VI*

3.3.5 Notes on the use of reach simulation results for BP Gösgen Aare scenario outcomes

Scenarios that did not wet point C had the water elevation taken from reference point A. Figure 33 plots the water level comparison for cases when both locations are wetted. It shows that the water level at point A is regularly 0.5 to 1.0 m higher than at point C. This suggests that the assumption is conservative.

Three types of clogging scenarios are modelled: "small volume with minor impact on hazard", 100-yr, and 300-yr volumes. The case "small volume with minor impact" is defined on the basis of the clogging backwater relationship and approximated by the simulation run without clogging. For instance, scenario 7 is approximated with scenario 1, which is the pure hydrological scenario. The rationale for treating scenario 7 and analogous scenarios as separate scenarios is related to probabilistic scenario delineation. See Section 2.3.5 for a general discussion on the probabilistic modelling of clogging. This approximation is used in Scenarios 7, 10, 13, 16, 19, and 22.

One bounding value is used. Sandackerstrasse bridge clogging with 100-year volume and FL5 (Scenario 23) is approximated with Sandackerstrasse bridge clogging with 300-year volume and FL5 (Scenario 24). This is a conservative assumption.

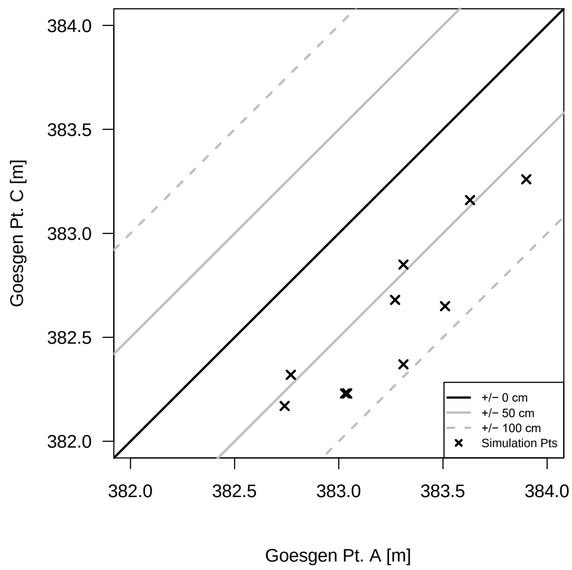


Figure 33: Water levels at Gösgen Reference Point A and Reference Point C. Reference point A elevation was used when Reference Point C was not wetted by the scenario.

3.4 Assessment site Gösgen (BPG) - Gösgen Oberwasserkanal

As noted in the introduction to Section 3.3, assessment site Gösgen (BP Gösgen, BPG) has reference points on both the Aare and the Oberwasserkanal. The processes or events that might influence one set of reference points will not necessarily influence the other reference points in the same way. As a result, the scenarios for the two sets of points are analyzed with two sets of event trees, which contain different top events (since the structures and processes relevant to the two sets differ, yielding separate hazard curves that are applicable to their respective reference points.

The structures and terrain around BP Gösgen are described in *Hauptbericht* Chapter 14.

The set of reference points close to the Aare, labelled 'A' and 'C', are referred to as "Gösgen Aare". The reference point on the Oberwasserkanal, labelled 'B', are referred to as "Gösgen Oberwasserkanal". This section documents the results, models, and input data for the reference point 'B', while those for "Gösgen Aare" are described above in Section 3.3.

In brief (see *Hauptbericht* Chapter 14 for details), at the upstream end of the island is Weir Winznau on the Aare branch, and the status of the gates at the weir can impact the water level at the site. Gates that are closed would raise the upstream water level, and this would impact the water level in the OWK. The flow through the canal is presumed to remain the same. There are many bridges along the OWK, of which Giessenstrasse (first bridge) and Schachenstrasse (fourth bridge) are relevant for clogging scenarios. There are several possible places where a breach could develop in the levee on the right-hand-side, which would then cause flow from the OWK into the Aare, and the breach near Schachenstrasse is considered in the analysis.

The flow through the OWK is assumed to be relatively constant at about 150 m^3/s regardless of initiating event. The Aare/OWK flowrate spilt is used to apportion the driftwood in the Aare and OWK.

3.4.1 Hazard curves for BP Gösgen OWK reference point B

The core findings about hazard for this reference point are:

- The highest hazard, is dominated by the status of the gates at the Winznau weir (scenarios 7, 8, and 9). These hazard levels are typically about 0.5 to 1.2 m of water level above the reference elevation.
- Clogging cases with small driftwood volumes (much less than 100-year) are decisive (scenarios 10, 13 and 16). These should be interpreted as some driftwood volume enters the OWK and clogs a structure, but the impact is minor and approximated with the unclogged case.
- The reference point is farther downstream than most of the bridges considered. This means that backwater from clogging scenarios is not relevant to reference point B. The failure of the OWK levee typically results in a level at point B that is not much different than the Hydrologisches Szenario. The minimum water level in the two scenarios presumably would be different, but because the tree is developed for the maximum water level the failure itself does not impact the maximum water level at point B.

Short descriptions of all scenarios shown in this hazard curve are available in Table G-6-4 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, and the mean WSPL at reference point B. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the 'source' scenario will be higher than in the 'target' scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the 'target' scenario will be less than that of the 'source' scenario.

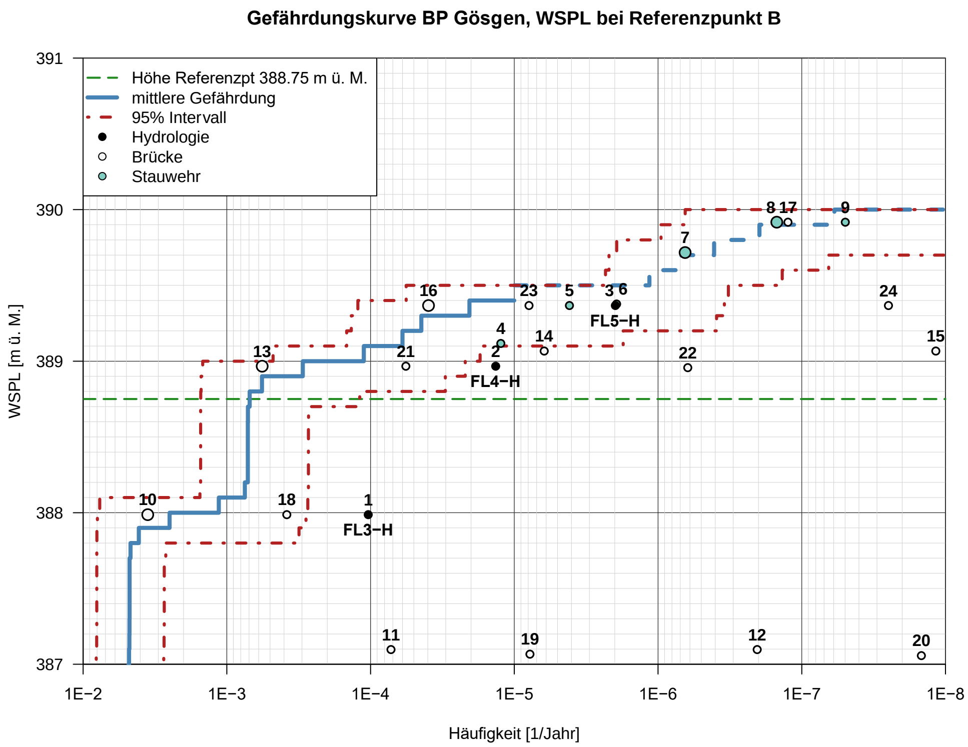


Figure 34: BP Gösgen Reference Point B hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The "Höhe Referenzpt" is only for reference and does not reflect an elevation related to the risk of the structure.

3.4.2 Site event trees

The general structure of the event tree is given in Figure 35. The main influence on the water level is based on the gates at Winznau. The remainder of events are associated with clogging of some bridges along the canal. There is a high likelihood of clogging, but the probability of either the ca. 100-year or ca. 300-year clogging levels is very low. This is a result of the split of driftwood between the Aare and the Oberwasserkanal.

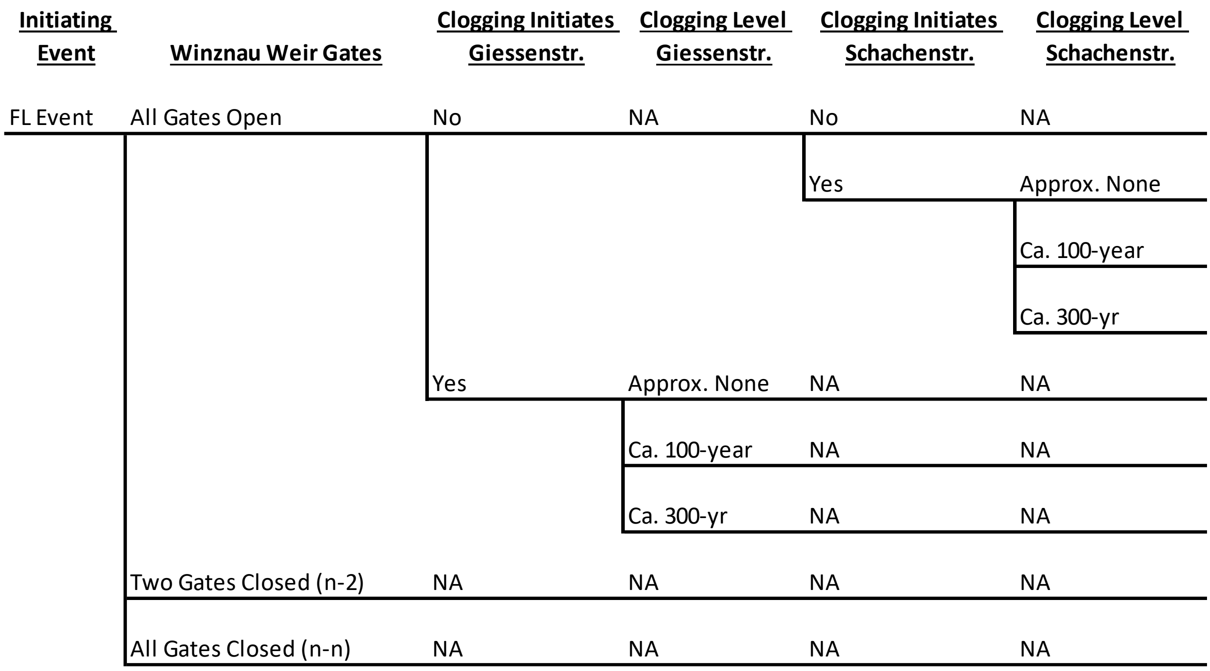


Figure 35: General event tree structure for BP Gösgen on the Oberwasserkanal.

As can be seen in Figure 36, Figure 37, and Figure 38, the general structure is unchanged. The highest frequency events are the hydrologic scenarios or approximate hydrologic scenarios events with little driftwood delivered to the OWK. Driftwood that affects the site have extremely low probabilities because the probability of delivered driftwood volume is very low, especially compared to other sites. Typically, the ca. 100-year volume would have a probability of around 0.6-0.7, but it is 0.02 in this case. The OWK has around 9-5% of the total flow, and this fraction of flow decreases with higher events, which leads to the decreasing values for 100-year and 300-year clogging when examining the FL3, FL4, and FL5 trees.

Bridge 4 has much lower clogging probabilities, about an order of magnitude less, than Bridge 1 because it can only clog when Bridge 1 does not clog, and this only occurs in about 10% of the cases. The clogging probabilities are themselves associated with unquantifiable uncertainty, much of which could depend on how much driftwood is caught on the other two bridges.

Failure of the OWK levee is not relevant for the OWK maximum hazard and it is discussed BP Gösgen Aare section. If failure of the levee were critical, a separate event tree with possibly different assumptions and approximations would be required.

IE FL3	Winznau Weir Gates	Clogging Initiates Giessenstr.	Clogging Level Giessenstr.	Clogging Initiates Schachenstr.	Clogging Level Schachenstr.	Mean Frequency [1/a]	Mean WSPL Ref. Pt. B	Sequence ID	Scenario ID
4.1E-3	1.0E+0	1.2E-1	1.0E+0	2.1E-1	1.0E+0	1.0E-4	387.99	FL3-1	1
				7.9E-1	9.8E-1	3.8E-4	387.99	FL3-2	18
				[Ca. 100-yr]	2.0E-2	7.8E-6	387.07	FL3-3	19
				[Ca. 300-yr]	3.7E-5	1.5E-8	387.06	FL3-4	20
		8.8E-1	9.8E-1	1.0E+0	1.0E+0	3.6E-3	387.99	FL3-5	10
		[Ca. 100-yr]	2.0E-2	1.0E+0	1.0E+0	7.2E-5	387.10	FL3-6	11
		[Ca. 300-yr]	5.6E-5	1.0E+0	1.0E+0	2.0E-7	387.10	FL3-7	12
[n-2]	3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.2E-5	389.12	FL3-8	4
[n-n]	1.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	4.1E-6	389.37	FL3-9	5

Figure 36: BP Gösgen Oberwasserkanal FL3 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL4	Winznau Weir Gates	Clogging Initiates Giessenstr.	Clogging Level Giessenstr.	Clogging Initiates Schachenstr.	Clogging Level Schachenstr.	Mean Frequency [1/a]	Mean WSPL Ref. Pt. B	Sequence ID	Scenario ID
6.5E-4	1.0E+0	1.1E-1	1.0E+0	1.9E-1	1.0E+0	1.3E-5	388.97	FL4-1	2
				8.1E-1	9.9E-1	5.7E-5	388.97	FL4-2	21
				[Ca. 100-yr]	1.1E-2	6.2E-7	388.96	FL4-3	22
				[Ca. 300-yr]	1.3E-5	7.6E-10	388.96	FL4-4	--
		8.9E-1	9.9E-1	1.0E+0	1.0E+0	5.7E-4	388.97	FL4-5	13
		[Ca. 100-yr]	1.1E-2	1.0E+0	1.0E+0	6.2E-6	389.07	FL4-6	14
		[Ca. 300-yr]	2.1E-5	1.0E+0	1.0E+0	1.2E-8	389.07	FL4-7	15
[n-2]	3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.9E-6	389.38	FL4-8	6
[n-n]	1.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	6.5E-7	389.72	FL4-9	7

Figure 37: BP Gösgen Oberwasserkanal FL4 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL5	Winznau Weir Gates	Clogging Initiates Giessenstr.	Clogging Level Giessenstr.	Clogging Initiates Schachenstr.	Clogging Level Schachenstr.	Mean Frequency [1/a]	Mean WSPL Ref. Pt. B	Sequence ID	Scenario ID
5.0E-5	1.0E+0	2.0E-1	1.0E+0	2.0E-1	1.0E+0	2.0E-6	389.37	FL5-1	3
				8.0E-1	1.0E+0	7.9E-6	389.37	FL5-2	23
				[Ca. 100-yr]	3.2E-3	2.5E-8	389.37	FL5-3	24
				[Ca. 300-yr]	1.8E-6	1.4E-11	389.37	FL5-4	--
		8.0E-1	1.0E+0	1.0E+0	1.0E+0	4.0E-5	389.37	FL5-5	16
		[Ca. 100-yr]	3.2E-3	1.0E+0	1.0E+0	1.2E-7	389.92	FL5-6	17
		[Ca. 300-yr]	2.8E-6	1.0E+0	1.0E+0	1.1E-10	389.92	FL5-7	--
[n-2]	3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.5E-7	389.92	FL5-8	8
[n-n]	1.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	5.0E-8	389.92	FL5-9	9

Figure 38: BP Gösgen Oberwasserkanal FL5 event tree with point estimates. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

3.4.3 Initiating events and their frequencies

The same initiating events are used as for BP Olten. Table 16 summarizes the initiating event distribution. Table 16 is the same as Table 12 and only repeated for the convenience of the reader.

Table 16: Summary statistics of flood initiating events for BP Olten and BP Gösgen. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is cor(.,.). (Duplicate of Table 12.)

Initiating Event (Flow Range, m3)	Low Set	Median Set	High Set
FL3 (1451-1793)	cor(FL3, FL4)= 0.015 cor(FL3,FL5)= 0.014 mean = 2.62E-3 std. dev. = 9.60E-5	cor(FL3, FL4)= -0.023 cor(FL3,FL5)= 0.007 mean = 3.29E-3 std. dev. = 1.04E-4	cor(FL3, FL4)= -0.035 cor(FL3,FL5)= -0.034 mean = 6.51E-3 std. dev. = 1.50E-4
FL4 (1794-2289)	cor(FL4, FL5)= 0.042 mean = 2.85E-4 std. dev. = 3.10E-5	cor(FL4, FL5) = 0.000 mean = 3.67E-4 std. dev.= 3.48E-5	cor(FL4, FL5)= -0.056 mean = 1.30E-3 std. dev. = 6.79E-5
FL5 (2289-3000)	Mean = 2.09E-5 std. dev.= 8.42E-6	Mean = 3.12E-5 std. dev.= 1.04E-5	Mean = 9.75E-5 std. dev.= 1.87E-5

3.4.4 Top events and their probabilities

3.4.4.1 Winznau Weir Gates (*GEWISSkm* 52.537, on OWK)

The gate status at Winznau has significant impact on the water level in the Oberwasserkanal (*Resultatmappe 3*, *BPG, Section 3.4. III*), and hence the water level at reference point B. The cases considered are:

- All Gates Open
- Two Gates Closed (n-2)
- All Gates Closed (n-n)

3.4.4.2 Giessenstrasse Bridge (*GEWISSkm* 52.491, on OWK)

Bridge 1 is close to the beginning of the OWK. It leads to increased water levels of about 0.1 m at point B (*Resultatmappe 3, BPG, Section 3.4. IV*). There is a high likelihood of clogging at this bridge of about 9E-1, which means that in most cases the driftwood does not go down the OWK to Bridge 4.

The driftwood volumes are shown in Table 5 of this report.

The fraction of driftwood on the OWK is assumed to be proportional to the flow, which was taken as a constant 150 m3/s. This value is uncertain due to the geometry and flow paths in such extreme events. A factor of 0.5 was used to define the uncertainty on this fraction (e.g. if 10% on average goes on the OWK the range is 5% - 15%). Depending on the FL event, the typical fraction of driftwood on the OWK ranges from about 9% to 5%.

3.4.4.3 Schachenstrasse Bridge (*GEWISSkm* 49.852, on OWK)

The largest differences for point B are about 0.08 m for FL3 and 0.01 m for FL4 (*Resultatmappe 3*, *BPG, Section 3.4 V*). Point B is downstream of the site, so the backwater impact is not relevant. This would be potentially relevant for failure of the levee, but levee failure cases do not affect the maximum water level at point B.

Table 17: Summary of distributions for BP Gösgen OWK. Distributions are defined with their parameterization in Appendix G-1.

Structure	Top Event	Conditions	Probability Model	Comment
Weir Winznau	Two Gates Closed	Independent	3E-3	Scoping value
	All Gates Closed	Independent	1E-3	
	All Gates Open	Independent	9.96E-1	Complement of other cases
Giessenstrasse Bridge (Bridge 1)	Clogging Initiates	FL3	p_H= 8.8E-1	*Resultatmappe 3, BPG, Section 3.4. IV*
		FL4	p_H= 8.9E-1	
		FL5	p_H= 8.0E-1	
	Ca. 100-year Clogging	FL3	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for general driftwood information
	Ca. 300-year Clogging	FL3	$p_w \sim 1 - \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_2 = 100y upper value	
	Ca. 100-year Clogging	FL4	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0768$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL4	$p_w \sim 1 - \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0768$ $\sigma = 0.792$ c_2 = 100y upper value	

Structure	Top Event	Conditions	Probability Model	Comment
	Ca. 100-year Clogging	FL5	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL5	$p_w \sim 1- \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0538$ $\sigma = 0.792$ c_2 = 100y upper value	
Schachenstrasse Bridge (Bridge 4)	Clogging Initiates	FL3; No Clog Bridge 1	p_H= 8.8E-1	*Resultatmappe 3,BPG, Section 3.4 V*
		FL4; No Clog Bridge 1	p_H= 8.9E-1	
		FL5; No Clog Bridge 1	p_H= 8.0E-1	
	Ca. 100-year Clogging	FL3	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for general driftwood information.
	Ca. 300-year Clogging	FL3	$p_w \sim 1- \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_2 = 100y upper value	
	Ca. 100-year Clogging	FL4	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0768$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 300-year Clogging	FL4	$p_w \sim 1- \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim beta(2,2,0.5R,1.5R)$ $R = 0.0768$ $\sigma = 0.792$ c_2 = 100y upper value	

Structure	Top Event	Conditions	Probability Model	Comment
	Ca. 100-year Clogging	FL5	$p_w \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim \text{beta}(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_1 = 100y lower value c_2 = 100y upper value	
	Ca. 100-year Clogging	FL5	$p_w \sim 1 - \Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 6.565 + \ln(r)$ $r \sim \text{beta}(2,2,0.5R,1.5R)$ $R = 0.0925$ $\sigma = 0.792$ c_2 = 100y upper value	

3.4.5 Notes on the use of reach simulation results for BPG scenario outcomes

The point is wet in all scenarios, therefore no approximations for dry scenarios are need. The hydraulic parameter uncertainty is very asymmetric and attributed to uncertainty of the vegetation. The morphology has relatively low uncertainty at this location. The distributions for morphology and hydraulic model uncertainty are summarized in Appendices G-2 and G-3.

Three types of clogging scenarios are modelled: “small volume with minor impact on hazard”, 100-yr, and 300-yr volumes. The case “small volume with minor impact” is defined on the basis of the clogging backwater relationship and approximated by the simulation run without clogging. For instance, Scenario 10 is approximated with Scenario 1, which is the pure hydrological scenario. The rationale for treating scenario 10 and analogous scenarios as separate scenarios is related to probabilistic scenario delineation. See Section 2.3.5 for a general discussion on the probabilistic modelling of clogging. This approximation is used for Scenarios 10, 13, 16, 18, 21, and 23.

Another approximation is used for Schachenstrasse bridge clogging with FL5. The 100-year clogging was simulated (Scenario 24), but not the 300-year clogging (Sequence FL5-4). FL4 showed only 0.00 m difference between the 100-year and 300-year clogging cases (Scenario 22 and Sequence FL4-4), so this approximation seems reasonable.

The FL5 n-n gates case (Scenario 9) was used as a bounding value for FL5 n-3 gates (Scenario 8) and FL5 Giessenstrasse clogging with 100-year and 300-year volumes (Scenario 17 and Sequence FL5-7). This is a conservative assumption. Giessentrasse 100-year and 300-year clogging are associated with approximately 0.1 m increase in the water level at point B based on FL3 and FL4 results whereas n-n gates cause substantially higher water levels.

3.5 Assessment site PSI (BPP)

Assessment site PSI (BP PSI, BPP) is located after the confluence of the Aare, Limmat, and Reuss rivers. The banks of the Aare are lower on the right, where reference point A is located, and higher on the left, where scenario point B is located. Scenario point B is located on the left side upstream of the Aare Bridge, and reference point A is located on the right side downstream. Weir Beznau is downstream of the assessment site and can cause a backwater effect. More details are in *Hauptbericht* Chapter 15 including a map of the site (*Abbildung* 55).

3.5.1 Hazard curves for reference point A

The hazard curve for reference point A is shown in Figure 39. The clogging of the PSI bridge has a minor impact at point A, due only to some flow paths being activated on the bank leading to minor wetting of the site.

The core findings about the hazard for this reference point are:

- The frequency of a water level exceeding the elevation of reference point A is approximately 1E-5/a. Point A is not inundated in the hydrological flood events without the failure of structures, namely FL3-H, FL4-H, and FL5-H.
- The decisive scenarios for the mean hazard curve are the hydrological scenarios FL3-H, FL4-H and FL5-H (scenarios 1-3) and the combinations of the discharge events FL3, FL4, and FL5 with clogging at the PSI bridge (due to 100-y driftwood volumes, scenarios 5, 8, 11). Scenarios 5 and 8 with clogging yield water elevations that are similarly high as the corresponding hydrological scenarios because the bridge is located upstream of the assessment site.
- Point A is inundated only in scenarios 11 and 12, in which the PSI bridge is clogged during an FL5 discharge event.
- Scenarios with closed weir gates at Beznau cause a backwater effect, raising the water level at point A, but do not lead to site wetting. The largest water level in such scenarios occurs in scenario 15, where the closed weir gates are combined with FL5. The resulting mean water level remains 1.8 m below the elevation of Point A.
- Uncertainties on the hazard curve generally fall between 1 and 1.5 orders of magnitude for scenarios in which the reference points remain dry. The uncertainties due to the hydraulic parameters and morphology can be seen. The only uncertainties directly related to the frequency are those associated with the frequency of the initiating event. Other probabilities used in these scenarios were treated as fixed values without uncertainties (and addressed with sensitivity analysis).

Short descriptions of all scenarios shown in these hazard curves are available in Table G-6-5 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, and the mean WSPL at reference point A. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the 'source' scenario will be higher than in the 'target' scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the 'target' scenario will be less than that of the 'source' scenario.

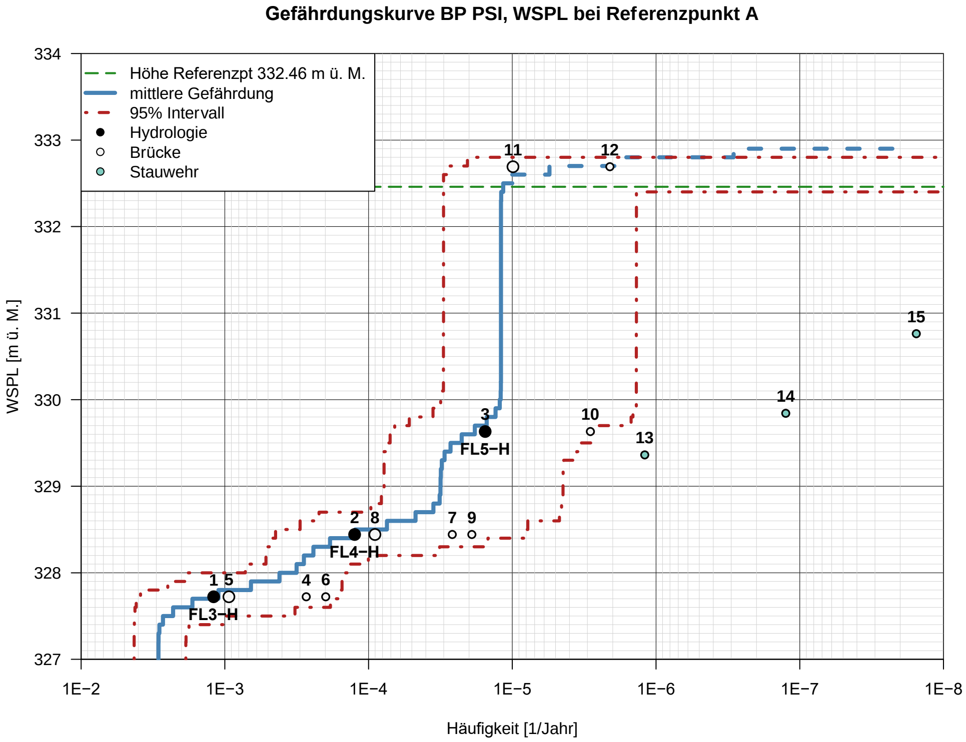


Figure 39: BP PSI Reference Point A hazard curve and scenarios. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is shown in red. The reference elevation for the site is 332.46 m.a.s.l. (Duplicate of Abbildung 72 in Hauptbericht.)

In this hazard, curve, the mean hazard curve below 1E-6/a falls near and then outside (above) the 95% frequency uncertainty envelope of the hazard curve. This occurs because the scenarios sampled during the uncertainty calculation include many scenarios with very low frequencies as well as scenarios with frequencies orders of magnitude higher. The samples with high frequencies then dominate the mean frequency value at that WSPL, leading to this behavior of the mean hazard curve.

3.5.2 Site event trees

The general event tree structure for the site is given in Figure 40. The relevant top events are the clogging of the PSI bridge and the status of gates at Weir Beznau.

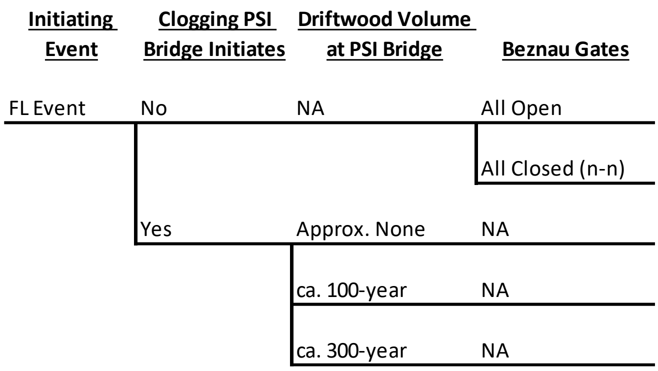


Figure 40: General event tree structure for BP PSI.

The detailed event trees for FL3-FL5 at BP PSI are presented in Figure 41, Figure 42, and Figure 43, respectively. The trees have the same structure and many of the conditional probabilities are the same. There is only a slight change in the probability of clogging initiating in the different trees. The main difference is the initiating event frequency.

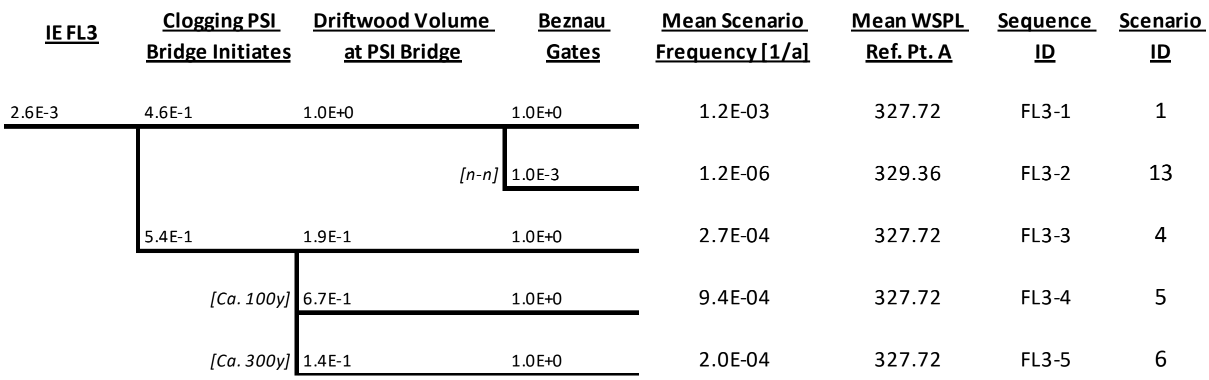


Figure 41: BP PSI FL3 event tree with point estimates and mean frequency of scenarios. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL4	Clogging PSI Bridge Initiates	Driftwood Volume at PSI Bridge	Beznau Gates	Mean Scenario Frequency [1/a]	Mean WSPL Ref. Pt. A	Sequence ID	Scenario ID
2.6E-4	4.8E-1	1.0E+0	1.0E+0	1.3E-04	328.44	FL4-1	2
			[n-n] 1.0E-3	1.3E-07	329.84	FL4-2	14
	5.2E-1	1.9E-1	1.0E+0	2.6E-05	328.44	FL4-3	7
		[Ca. 100y] 6.7E-1	1.0E+0	9.0E-05	328.44	FL4-4	8
		[Ca. 300y] 1.4E-1	1.0E+0	1.9E-05	328.44	FL4-5	9

Figure 42: BP PSI FL4 event tree with point estimates and mean frequency of scenarios. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL5	Clogging PSI Bridge Initiates	Driftwood Volume at PSI Bridge	Beznau Gates	Mean Scenario Frequency [1/a]	Mean WSPL Ref. Pt. A	Sequence ID	Scenario ID
3.0E-5	5.1E-1	1.0E+0	1.0E+0	1.5E-05	329.63	FL5-1	3
			[n-n] 1.0E-3	1.5E-08	330.76	FL5-2	15
	4.9E-1	1.9E-1	1.0E+0	2.9E-06	329.63	FL5-3	10
		[Ca. 100y] 6.7E-1	1.0E+0	9.9E-06	323.69	FL5-4	11
		[Ca. 300y] 1.4E-1	1.0E+0	2.1E-06	323.69	FL5-5	12

Figure 43: BP PSI FL5 event tree with point estimates and mean frequency of scenarios. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

3.5.3 Initiating events and their frequencies

The following were considered as initiating events.

- Flood events FL3, FL4, and FL5

These flood events were selected so that they would have approximate exceedance frequencies of 1E-3, 1E-4, and 1E-5/a in the median parameter set. The distribution of the initiating event frequencies is derived through bootstrap resampling with replacement of the three hydrological parameter sets; however, some summary statistics are provided. The exact distribution is not reported. The flows represented by each initiating event are summarized in Table 18.

The following was not considered as an initiating event.

- Earthquake failure of Weir Wettingen

Simulation showed that the peak flow from this event at the site is substantially below the hydrologic frequency of the same peak flow.

Table 18: Summary statistics of flood initiating events for BP PSI and BP Beznau. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is cor(.,.).

Initiating Event (flow range)	Low Set	Median Set	High Set
FL3 (3358-4081)	cor(FL3, FL4) = 0.011 cor(FL3,FL5)= -0.006 mean = 1.80E-3 std. dev. = 7.77E-5	cor(FL3, FL4) = -0.002 cor(FL3,FL5) = 0.007 mean = 2.35E-3 std. dev. = 9.02E-5	cor(FL3, FL4)= -0.020 cor(FL3,FL5)= -0.022 mean = 3.65E-3 std. dev. = 1.09E-4
FL4 (4081-4814)	cor(FL4, FL5)= 0.034 mean = 1.66E-4 std. dev. = 2.44E-5	cor(FL4, FL5) = -0.058 mean= 2.14E-4 std. dev.=2.71E-5	cor(FL4, FL5)= -0.019 mean = 4.02E-4 std. dev. = 3.79E-5
FL5 (4814-6000)	Mean= 1.42E-5 std. dev.= 6.99E-6	Mean=2.11E-5 std. dev.=8.42E-6	Mean=5.58E-5 std. dev.= 1.40E-5

3.5.4 Top events and their probabilities

3.5.4.1 PSI Bridge Clogging (*GEWISSkm* 10.341)

Clogging of the PSI bridge leads to substantial water level increases upstream of the bridge, which is mainly relevant for reference point B. Point B remains dry regardless of clogging. For the extreme events, the clogging seems to result in a new flow path towards point A, therefore it is relevant and must be included in the tree.

In addition to the parameters listed in Table 19, the driftwood volumes are listed above in Table 5.

3.5.4.2 Weir Beznau Gates (*GEWISSkm* 8.737)

Closed gates leads to a backwater towards the sites. For simplicity and because it is the dominant effect, only the all gates closed (n-n) case is considered. These scenarios are not decisive, and therefore elaboration with an n-3 gates case was not pursued.

Table 19: Summary of distributions of top events for BP PSI.

Structure	Top Event	Conditions	Probability Model	Comment
PSI Bridge	Clogging Initiates	FL3	p_H = 5.4E-1	*Resultatmappe 3, BPP, Chapter 4.4. II*
		FL4	p_H = 5.2E-1	
		FL5	p_H = 4.9E-1	
	No Significant Volume	Independent	p_W = 1.93E-1	*Detailbericht C* for background of driftwood.
	ca. 100y Driftwood	Independent	p_W = 6.66E-1	
	ca. 300y Driftwood	Independent	p_W = 1.41E-1	
Weir Beznau	All Gates Closed (n-n)	Independent	1E-3	Scoping value

3.5.5 Notes on the use of reach simulation results for BPP scenario outcomes

Reference point PSI B is not wetted by any of the scenarios considered and the water level was taken as the point AAR_010470 in the river. In scenarios when Reference point A is not wetted the water elevation is taken from point AAR_009830 in the river. Reference point PSI A is wetted by Scenarios 11 and 12. Scenario 11, which is 100-year clogging of PSI bridge with FL5, was not simulated. Scenario 11 was bounded using the conservative the more conservative Scenario 12, the 300-year clogging of PSI bridge with FL5.

Three types of clogging scenarios are modelled: “small volume with minor impact on hazard”, 100-yr, and 300-yr volumes. The case “small volume with minor impact” is defined on the basis of the clogging backwater relationship and approximated by the simulation run without clogging. For instance, Scenario 4 is approximated with Scenario 1, which is the pure hydrological scenario. The rationale for treating scenario 4 and analogous scenarios as separate scenarios is related to probabilistic scenario delineation. See Section 2.3.5 for a general discussion on the probabilistic modelling of clogging. This approximation is used for Scenarios 4, 7, and 10.

3.6 Assessment site Beznau (BPB)

Assessment site Beznau (BP Beznau, BPB) is the farthest downstream of the assessment sites considered in this project. It is located on an island in the river, with the main portion of the Aare flowing to the left over Weir Beznau and a small Oberwasserkanal (OWK) to the right. The REFUNA and Beznauerstrasse bridges are over the OWK. On the left side of the river after the weir is the location of the Chaltebründli landslide. Farther downstream is Weir Klingnau. One of the main sources of hazard at the site is anticipated to be elevated water levels upstream of Weir Beznau and in the OWK, which would flood the site from upstream or the right. No backwater effects to the site are anticipated to the large separation between the site and Klingnau. More details in *Hauptbericht,* Chapter 16.

3.6.1 Hazard curves for reference points D, E, and G

The hazard curves for the reference points at BP Beznau are presented in Figure 44, Figure 45, and Figure 46. The general trends are very similar in all three hazard curves.

The core findings about hazard for these reference points, with an emphasis on point D, are:

- The frequency of a water level exceeding the elevation of reference point D is approximately 5E-4/a. Point D is wetted in nearly all of the examined scenarios.
- None of the hydrological scenarios (FL3-H, FL4-H, and FL5-H) are decisive for the hazard curve. The hydrological scenario FL3-H, i.e. FL3 without additional events, has a negligible probability because the combination of FL3 with clogging at the Beznauerstrasse bridge is certain.
- Scenarios with the Beznau Weir (scenarios 4-12) dominate the hazard above 328.0 m.a.s.l., with scenarios 4-6, 9, and 12 being decisive for the curve. In the scenarios with closed weir gates (n-n or n-3) and in case of clogging, a backwater arises and a large proportion of the water will bypass the weir on the right and flow into the KKB perimeter.
- Scenarios with the clogging of the Beznauerstrasse bridge (scenarios 13-18) dominate the hazard below 328.00 m.a.s.l., of which 13, 16 and 18 are decisive. A complete clogging of this bridge does not occur because only a small fraction of the estimated driftwood volume enters the Oberwasserkanal.
- Scenarios with a combination of clogging of the REFUNA bridge and closed gates at the Beznau weir lead to high water levels at point D but are very unlikely. These scenarios are not decisive for the hazard curve.
- The uncertainties on the exceedance frequencies of the hazard curve generally fall between 1 and 1.5 orders of magnitude. The uncertainty intervals are larger at the higher water levels and are due to the uncertainties in the initiating event frequency, the hydraulic parameters, and morphology. The conditional probabilities for clogging and for failed weir gates were modelled as scoping values without uncertainties (and addressed with sensitivity analysis).

Short descriptions of all scenarios shown in these hazard curves are available in Table G-6-6 in Appendix G-6. The table provides the event tree sequence ID, the mean frequency of the scenario after the propagation of uncertainties, and the mean WSPL at reference points D and E. The event tree sequence ID and short descriptions both identify the flood initiating event FLn. Finally, the table indicates whether a specific 2D simulation was performed for the scenario or whether an approximation (evidence that two scenarios will yield the same level) or bounding value (the elevation of the ‘source’ scenario will be higher than in the ‘target’ scenario) was used to assign an elevation to the scenario. In the case of approximation, there is evidence that two scenarios will yield the same level. In the case of bounding, it can be deduced that the elevation of the 'target' scenario will be less than that of the 'source' scenario.

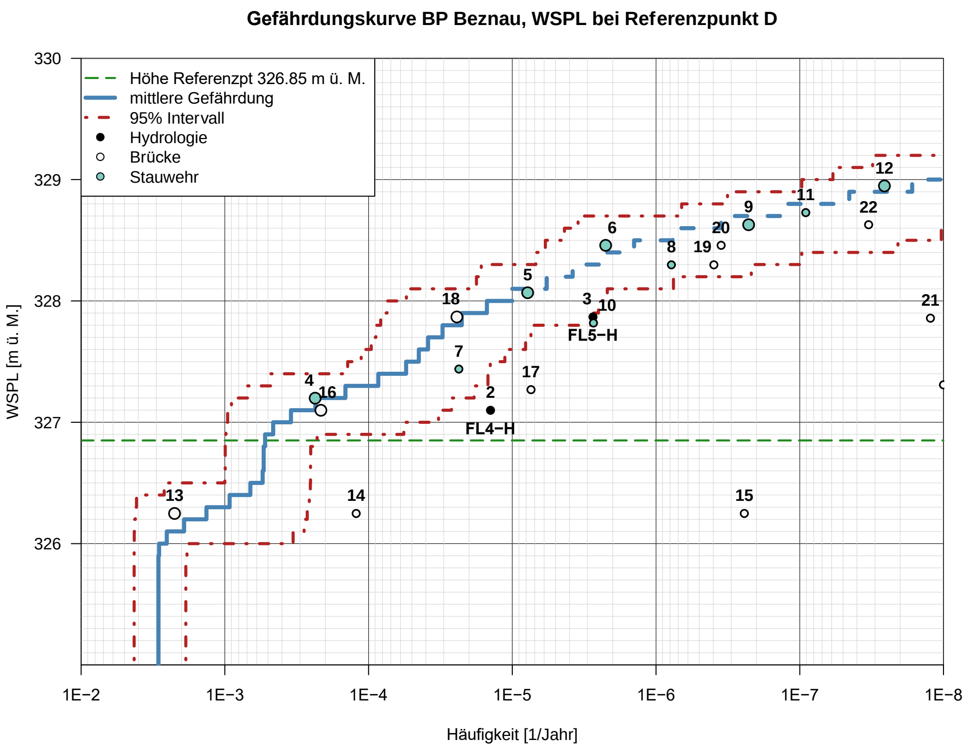


Figure 44: Hazard curve for BP Beznau, water level at reference point D. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 326.73 m.a.s.l. (Duplicate of Abbildung 81 in Hauptbericht.)

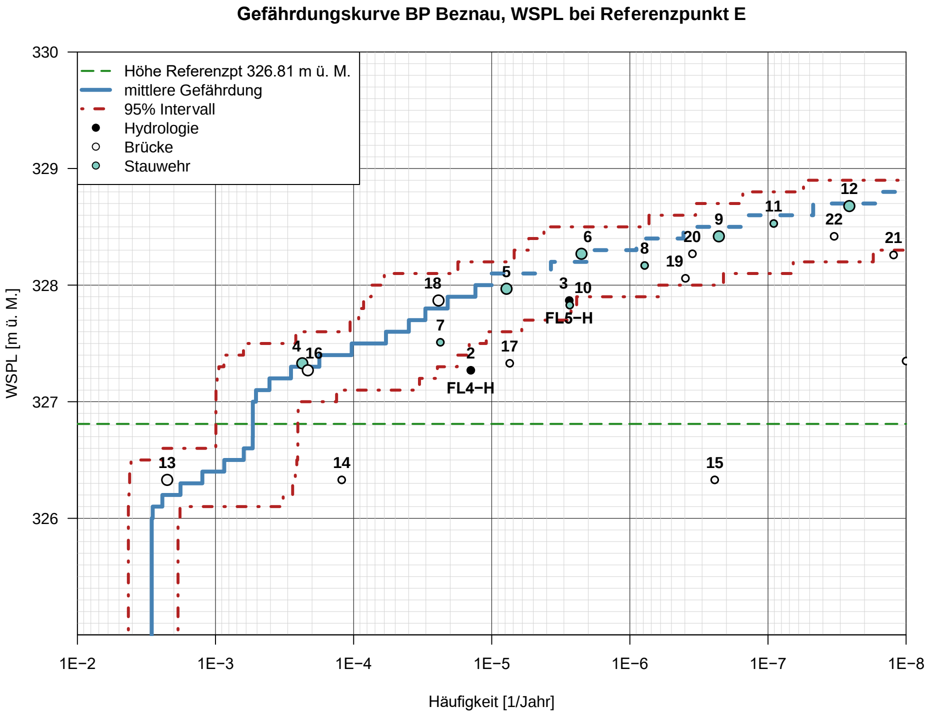


Figure 45: Hazard curve for BP Beznau, water level at reference point E. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 326.68 m.a.s.l.

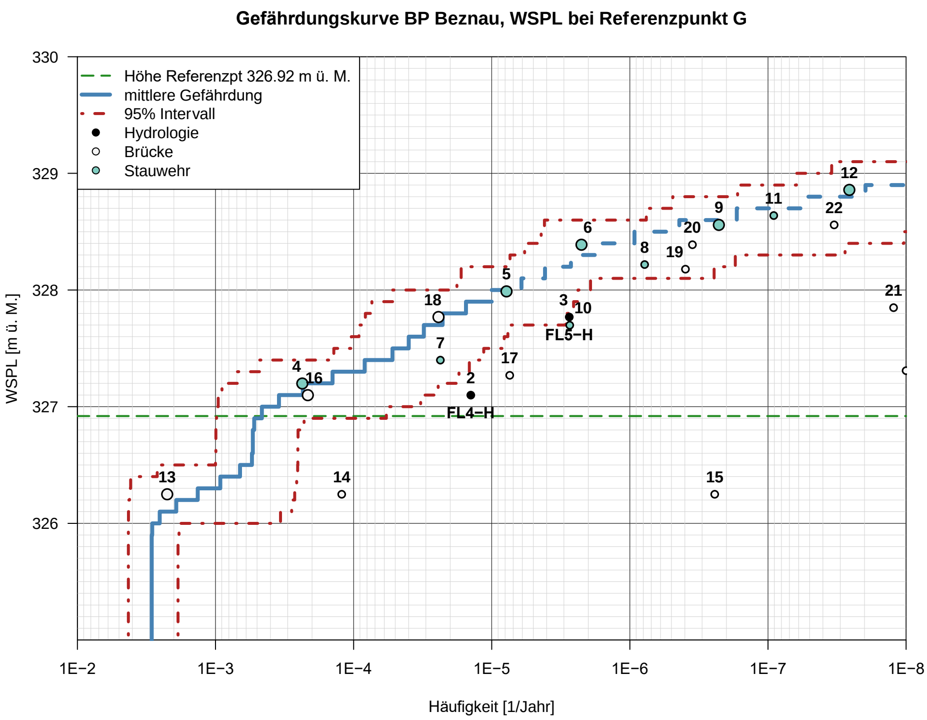


Figure 46: Hazard curve for BP Beznau, water level at reference point G. Points are scenarios that are plotted at their mean frequency (German: Häufigkeit) and water level (German: WSPL). Numbers on scenarios are used to identify them in the corresponding table of results and discussion of the results. The 95% interval is show in red. The reference elevation for the site is 326.92 m.a.s.l.

3.6.2 Site event trees

The event tree for BP Beznau focuses on the structures directly around the site, either in the Oberwasserkanal or Aare. A general structure is given in Figure 47.

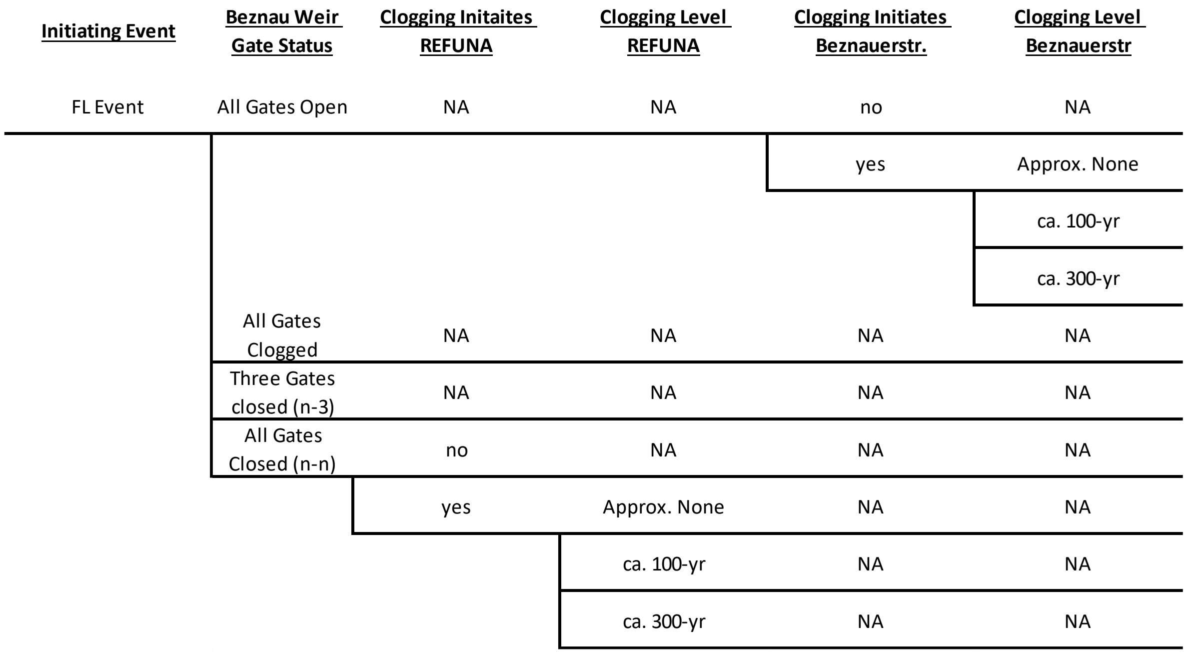


Figure 47: General event tree structure for BP Beznau.

The most difficult part of the event tree is the clogging of the bridges. Beznauerstrasse bridge can clog regardless of the status of the gates at Weir Beznau, but it was modelled as able to clog when all gates are open only. This is by far the most likely case for the gates and inclusion of clogging with other cases would not add much information because the frequencies of these scenarios would be much lower. REFUNA bridge can only clog when all the gates are closed at Weir Beznau. This leads to the branches out of the all gates closed (n-n) case.

The driftwood was divided between the Oberwasserkanal (OWK) and the Aare main channel based on the ratio of the flow to the peak flow of the hydrograph. This leads to probabilities of 300-year clogging at the OWK that are sufficiently small that the scenario frequency is generally less than 1E-8/a.

IE FL3	Beznau Weir Gate Status	Clogging Initiates REFUNA	Clogging Level REFUNA	Clogging Initiates Beznauerstr.	Clogging Level Beznauerstr	Mean Scenario Frequency [1/a]	Mean WSPL Ref. Pt. D	Mean WSPL Ref. Pt. E	Mean WSPL Ref. Pt. G	Sequence ID	Scenario ID
2.6E-3	9.1E-1 [all open]	1.0E+0	1.0E+0	0.0E+0	1.0E+0	0.0E+00	326.25	326.33	327.10	FL3-1	1
				1.0E+0	9.5E-1	2.2E-03	326.25	326.33	327.10	FL3-2	13
					[Ca. 100y] 5.2E-2	1.2E-04	326.25	326.33	327.27	FL3-3	14
					[Ca. 300y] 1.0E-4	2.4E-07	326.25	326.33	327.31	FL3-4	15
	[all clogged] 9.0E-2	1.0E+0	1.0E+0	1.0E+0	1.0E+0	2.4E-04	327.20	327.33	327.40	FL3-5	4
	[n-3] 3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	7.8E-06	328.07	327.97	328.22	FL3-6	5
	[n-n] 1.0E-3	8.6E-1	1.0E+0	1.0E+0	1.0E+0	2.2E-06	328.46	328.27	328.56	FL3-7	6
		1.4E-1	9.7E-1	1.0E+0	1.0E+0	3.5E-07	328.46	328.27	328.56	FL3-8	20
			[Ca. 100y] 3.4E-2	1.0E+0	1.0E+0	1.2E-08	327.86	328.26	327.96	FL3-9	21
			[Ca. 300y] 1.3E-4	1.0E+0	1.0E+0	4.9E-11	327.77	328.28	327.89	FL3-10	--

Figure 48: BP Beznau FL3 event tree with point estimates for initiating events and conditional probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL4	Beznau Weir Gate Status	Clogging Initiates REFUNA	Clogging Level REFUNA	Clogging Initiates Beznauerstr.	Clogging Level Beznauerstr	Mean Scenario Frequency [1/a]	Mean WSPL Ref. Pt. D	Mean WSPL Ref. Pt. E	Mean WSPL Ref. Pt. G	Sequence ID	Scenario ID
2.6E-4	9.1E-1 [all open]	1.0E+0	1.0E+0	6.0E-2	1.0E+0	1.4E-05	327.10	327.27	327.57	FL4-1	2
				9.4E-1	9.7E-1	2.1E-04	327.10	327.27	327.57	FL4-2	16
					[Ca. 100y] 3.4E-2	7.4E-06	327.27	327.33	327.70	FL4-3	17
					[Ca. 300y] 4.5E-5	1.0E-08	327.31	327.35	327.81	FL4-4	--
	[all clogged] 9.0E-2	1.0E+0	1.0E+0	1.0E+0	1.0E+0	2.4E-05	327.44	327.51	327.84	FL4-5	7
	[n-3] 3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	7.8E-07	328.30	328.17	328.37	FL4-6	8
	[n-n] 1.0E-3	8.7E-1	1.0E+0	1.0E+0	1.0E+0	2.3E-07	328.63	328.42	328.70	FL4-7	9
		1.3E-1	9.8E-1	1.0E+0	1.0E+0	3.3E-08	328.63	328.42	328.70	FL4-8	22
			[Ca. 100y] 2.1E-2	1.0E+0	1.0E+0	7.2E-10	327.97	328.37	328.11	FL4-9	--
			[Ca. 300y] 6.0E-5	1.0E+0	1.0E+0	2.0E-12	327.88	328.40	328.04	FL4-10	--

Figure 49: BP Beznau FL4 event tree with point estimates for initiating events and conditional probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

IE FL5	Beznau Weir Gate Status	Clogging Initiates REFUNA	Clogging Level REFUNA	Clogging Initiates Beznauerstr.	Clogging Level Beznauerstr	Mean Scnenario Frequency [1/a]	Mean WSPL Ref. Pt. D	Mean WSPL Ref. Pt. E	Mean WSPL Ref. Pt. G	Sequence ID	Scenario ID
3.0E-5	9.1E-1 [all open]	1.0E+0	1.0E+0	1.0E-1	1.0E+0	2.7E-06	327.87	327.87	327.77	FL5-1	3
				9.0E-1	9.8E-1	2.4E-05	327.87	327.87	327.77	FL5-2	18
					[Ca. 100y] 1.6E-2	4.0E-07	328.30	328.06	328.18	FL5-3	19
					[Ca. 300y] 1.2E-5	3.0E-10	328.34	328.10	328.22	FL5-4	--
	[all clogged] 9.0E-2	1.0E+0	1.0E+0	1.0E+0	1.0E+0	2.7E-06	327.82	327.83	327.70	FL5-5	10
	[n-3] 3.0E-3	1.0E+0	1.0E+0	1.0E+0	1.0E+0	9.1E-08	328.73	328.53	328.64	FL5-6	11
	[n-n] 1.0E-3	8.5E-1	1.0E+0	1.0E+0	1.0E+0	2.6E-08	328.95	328.68	328.86	FL5-7	12
		1.5E-1	9.9E-1	1.0E+0	1.0E+0	4.5E-09	328.95	328.68	328.86	FL5-8	--
			[Ca. 100y] 9.7E-3	1.0E+0	1.0E+0	4.4E-11	328.19	328.61	328.18	FL5-9	--
			[Ca. 300y] 1.6E-5	1.0E+0	1.0E+0	7.3E-14	328.08	328.62	328.08	FL5-10	--

Figure 50: BP Beznau FL5 event tree with point estimates for initiating event end conditional probabilities. Mean scenario frequency is the mean of the sampled distribution of the scenario frequency.

3.6.3 Initiating events and their frequencies

The same initiating events are used as for BP PSI and the values are summarized in Table 18. It is repeated in Table 20 for the convenience of the reader.

Table 20: Summary statistics of flood initiating events for BP PSI and BP Beznau. The statistics are calculated on the real-space values, not the logarithmic transformation. Pearson linear correlation is cor(.,.). (Duplicate of Table 18.)

Initiating Event (flow range)	Low Set	Median Set	High Set
FL3 (3358-4081)	cor(FL3, FL4) = 0.011 cor(FL3,FL5)= -0.006 mean = 1.80E-3 std. dev. = 7.77E-5	cor(FL3, FL4) = -0.002 cor(FL3,FL5) = 0.007 mean = 2.35E-3 std. dev. = 9.02E-5	cor(FL3, FL4)= -0.020 cor(FL3,FL5)= -0.022 mean = 3.65E-3 std. dev. = 1.09E-4
FL4 (4081-4814)	cor(FL4, FL5)= 0.034 mean = 1.66E-4 std. dev. = 2.44E-5	cor(FL4, FL5) = -0.058 mean= 2.14E-4 std. dev.=2.71E-5	cor(FL4, FL5)= -0.019 mean = 4.02E-4 std. dev. = 3.79E-5
FL5 (4814-6000)	Mean= 1.42E-5 std. dev.= 6.99E-6	Mean=2.11E-5 std. dev.=8.42E-6	Mean=5.58E-5 std. dev.= 1.40E-5

3.6.4 Top events and their probabilities

3.6.4.1 Weir Beznau Gates (*GEWISSkm* 8.737)

Closed gates leads to increased water levels at the site. Both all gates closed (n-n) and Three Gates Closed (n-3) are considered. The following cases are used for the gates:

- All gates open
- Three Gates Closed (n-3)
- All Gates Closed (n-n)
- Gates Clogged

Additionally, clogging at the structure is considered. The increases between this and the hydrologic scenarios varies among the reference points at the site. The driftwood volume are listed in Table 5 above while other relevant parameters are shown in Table 21 below. The driftwood is stochastically partitioned between the Aare main channel and Oberwasserkanal (as represented by parameter ‘r’ in Table 21). The flow for the OWK is taken as a constant 418 m^3/s. This results in around 7-11% of the driftwood being attributed to the OWK, and the remainder on the Aare. This results in a high likelihood of reaching the 350 m^3 of driftwood to clog Weir Beznau.

3.6.4.2 Bridge REFUNA Clogging (*GEWISSkm* 8.842)

This bridge can only clog when there are all gates closed (n-n) at Weir Beznau (*Resultatmappe3*, BPB, Section 5.4. III). The impact that the site varies, from increases compared to the n-n gates case to decreases. This is included as a top event.

3.6.4.3 Bridge Beznauerstrasse Clogging (*GEWISSkm* 7.995)

Clogging at this structure can substantially increase the water level at the site. The probability that clogging initiates is relatively high (*Resultatmappe 3*, BPB, Chapter 5.4 V). The partitioning of the driftwood means that the total probability of clogging remains relatively low for 100-year and 300-year scenarios (in Table 21, 'r' models the driftwood split between the Aare and the OWK).

Table 21: Summary of probabilities used for top events at BP Beznau. Distributions are defined with their parameterization in Appendix G-1

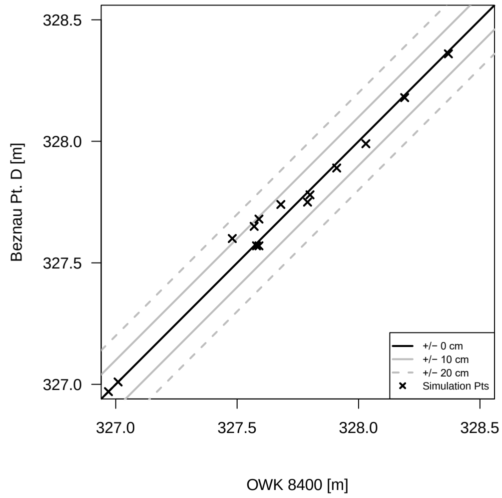
Structure	Top Event	Conditions	Probability Model	Comment
Weir Beznau	All Gates Closed	Independent	1E-3	Scoping value
	Three Gates Closed	Independent	3E-3	
	All Gates Open	Independent	9.96E-1	Complement of other cases
	Clogging Initiates at Gates	Independent	p_H ~ Uniform(0.03,0.15)	*Resultatmappe 3, BPB, Section 5.4 II*
	Clogging Volume at Gates	FL3	P_w ~ 1- Φ ($\ln(c_2)$,μ,σ) μ ~ 7.862 + ln(1-r) r ~ beta(2,2,0.5R,1.5R) R = 0.111 σ = 0.800 c_2 = 350	*Detailbericht C* for driftwood background.
		FL4	P_w ~ 1- Φ ($\ln(c_2)$,μ,σ) μ ~ 7.862 + ln(1-r) r ~ beta(2,2,0.5R,1.5R) R = 0.095 σ = 0.800 c_2 = 350	
		FL5	P_w ~ 1- Φ ($\ln(c_2)$,μ,σ) μ ~ 7.862 + ln(1-r) r ~ beta(2,2,0.5R,1.5R) R = 0.074 σ = 0.800 c_2 = 350	

Structure	Top Event	Conditions	Probability Model	Comment
Beznauerstrasse Bridge (007995)	Clogging Initiates	FL3	$p_H = 1.0$	*Resultatmappe 3,* BPB, Section 5.4 V
	Clogging Initiates	FL4	$p_H = 9.4E\text{-}1$	
	Clogging Initiates	FL5	$p_H = 9.0E\text{-}1$	
	ca. 100y Driftwood	FL3	$P_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.111$ $\sigma = 0.800$ c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for driftwood background.
	ca. 300y Driftwood	FL3	$P_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.111$ $\sigma = 0.800$ c_2 = 100y upper value	
	ca. 100y Driftwood	FL4	$P_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.095$ $\sigma = 0.800$ c_1 = 100y lower value c_2 = 100y upper value	
	ca. 300y Driftwood	FL4	$P_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.095$ $\sigma = 0.800$ c_2 = 100y upper value	
	ca. 100y Driftwood	FL5	$P_W \sim \Phi(\ln(c_2),\mu,\sigma) - \Phi(\ln(c_1),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.074$ $\sigma = 0.800$ c_1 = 100y lower value c_2 = 100y upper value	
	ca. 300y Driftwood	FL5	$P_W \sim 1-\Phi(\ln(c_2),\mu,\sigma)$ $\mu \sim 7.862 + \ln(r)$ $r \sim 1\text{-beta}(2,2,0.5R,1.5R)$ $R = 0.074$ $\sigma = 0.800$ c_2 = 100y upper value	

Structure	Top Event	Conditions	Probability Model	Comment
REFUNA Bridge (008842)	Clogging Initiates, p_H	n-n Beznau; FL3	p_H = 1.4E-1	*Resultatmappe 3,* BPB, Section 5.4 V
	Clogging Initiates, p_H	n-n Beznau; FL4	p_H = 1.3E-1	
	Clogging Initiates, p_H	n-n Beznau; FL5	p_H = 1.5E-1	
	ca. 100y Driftwood	FL3	P ~ Φ (ln(c_2),μ,σ)- Φ (ln(c_1),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.111 σ = 0.800 c_1 = 100y lower value c_2 = 100y upper value	*Detailbericht C* for driftwood background. Volume distribution summarized in Table 5
	ca. 300y Driftwood	FL3	P ~ 1-Φ(ln(c_2),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.111 σ = 0.800 c_2 = 100y upper value	
	ca. 100y Driftwood	FL4	P ~ Φ (ln(c_2),μ,σ)- Φ (ln(c_1),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.095 σ = 0.800 c_1 = 100y lower value c_2 = 100y upper value	
	ca. 300y Driftwood	FL4	P ~ 1-Φ(ln(c_2),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.095 σ = 0.800 c_2 = 100y upper value	
	ca. 100y Driftwood	FL5	P ~ Φ (ln(c_2),μ,σ)- Φ (ln(c_1),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.074 σ = 0.800 c_1 = 100y lower value c_2 = 100y upper value	
	ca. 300y Driftwood	FL5	P ~ 1-Φ(ln(c_2),μ,σ) μ ~ 7.862+ ln(r) r ~ 1-beta(2,2,0.5R,1.5R) R = 0.074 σ = 0.800 c_2 = 100y upper value	

3.6.5 Notes on the use of reach simulation results for BPB scenario outcomes

There are three reference points at the site: D, E, and G (map in *Hauptbericht, Abbildung* 64). For some of the FL3 scenarios, these points are not wetted. In those cases, a pseudo water elevation is used as



listed in Table 22.

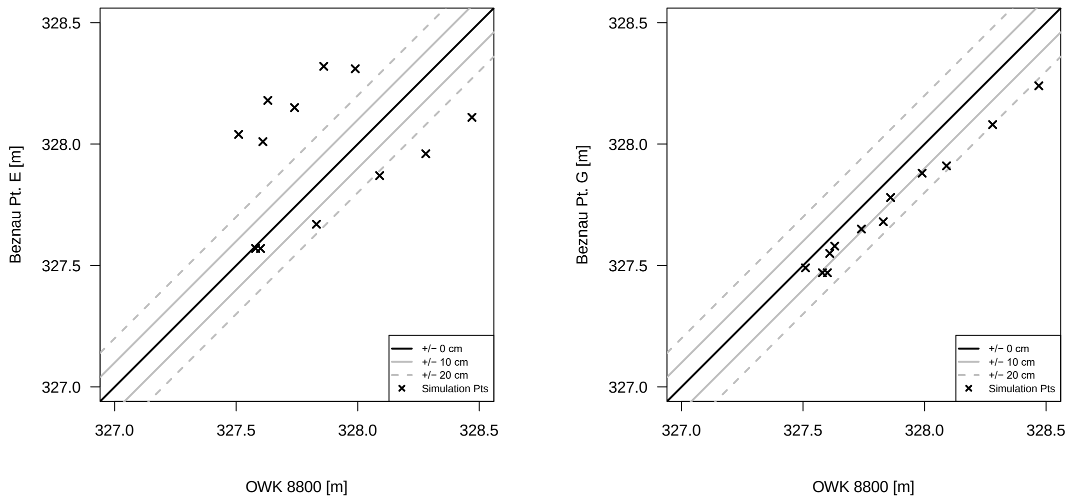


Figure 51 shows that in most cases the differences are within +/- 0.1 m of each other for the FL3 and FL4 wetting scenarios. Beznau E shows less agreement, but the used point is conservative and agreement is better for the lower water levels.

The morphology and hydraulic model uncertainties are listed in Appendices G-2 and G-3, respectively.

Table 22: Reference points, elevations, and pseudo point for dry scenarios used for BP Beznau.

Reference Point	Reference Elevation [m ü. M.]	Pseudo Point used when Reference Dry
D	326.73	OWK_008400
E	326.68	OWK_008800
G	326.92	OWK_008800

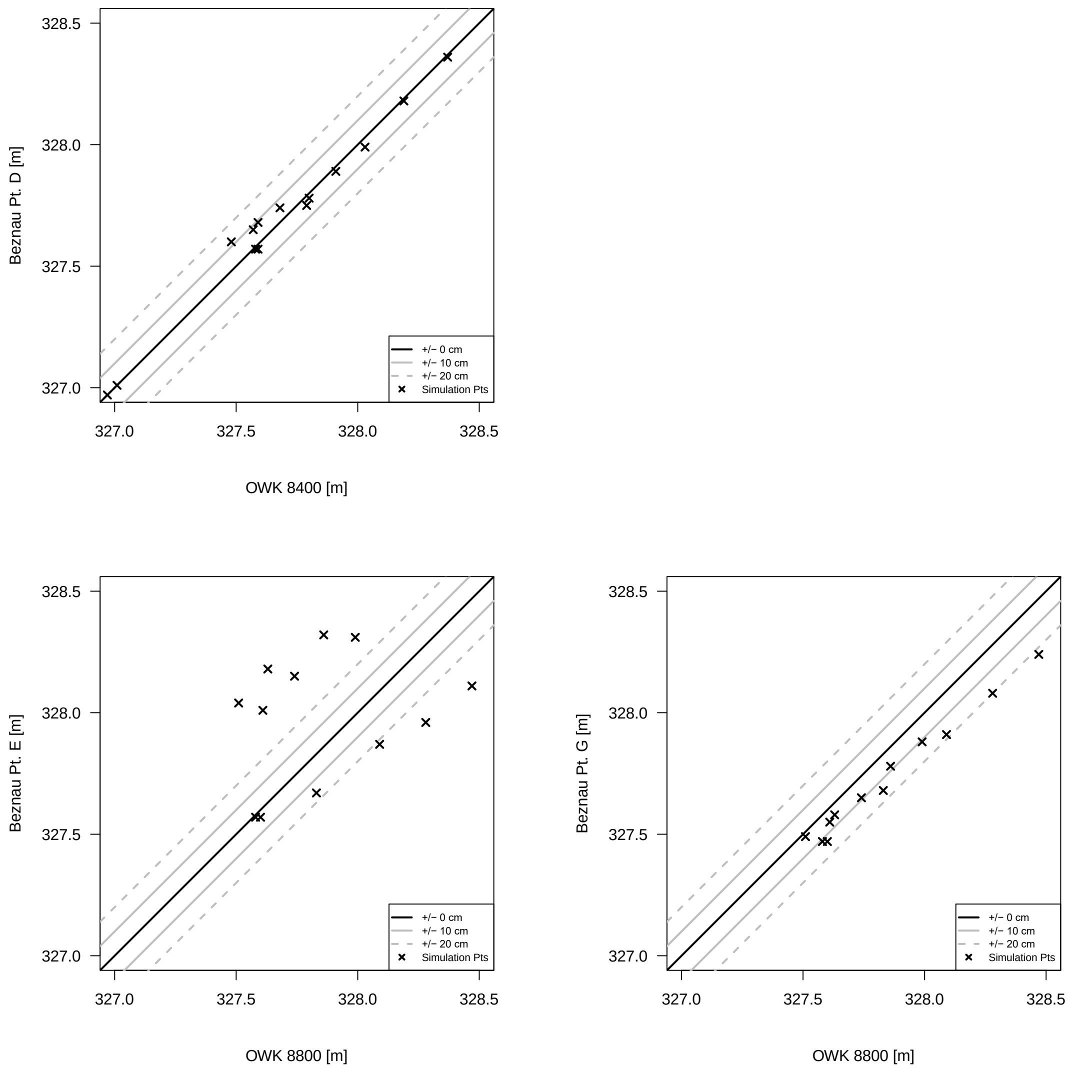


Figure 51: Comparison of wetted scenarios for pseudo point elevations used at BP Beznau.

Three types of clogging scenarios are modelled: “small volume with minor impact on hazard”, 100-yr, and 300-yr volumes. The case “small volume with minor impact” is defined on the basis of the clogging backwater relationship and approximated by the simulation run without clogging. For instance, Scenario 13 is approximated with Scenario 1, which is the pure hydrological scenario. The rationale for treating Scenario 13 and analogous scenarios as separate scenarios is related to probabilistic scenario delineation. See Section 2.3.5 for a general discussion on the probabilistic modelling of clogging. The scenarios impacted by this approximation are 13, 16, and 18. The analogous approximation for n-n weir gates at Beznau and REFUNA clogging applies to scenarios 20, 22, and a sequence FL5-8 (mean frequency below 1E-8/a).

The n-3 and clogged gates cases with FL5 (scenarios 10 and 11) were not simulated. In each case a simulated value was offset by some amount which reflected the approximate difference of the related scenarios from the FL4 event tree. In the case of Scenario 10, the offset was calculated as the approximate difference between the hydrologic scenario (Scenario 2, FL3-H) and clogged gates cases (Scenario 7). In the case of Scenario 11, the offset was calculated as the approximate difference between the n-3 (Scenario 8) and n-n gate cases (Scenario 9). The uncertainties of these approximations are expected to be well within the uncertainty range at the site.

Clogging of Beznauerstrasse with 100-year and 300-year volumes with FL5 was not simulated (Scenarios 19 and Sequence FL5-4). Results from FL3 and FL4 simulation of the similar scenarios show that the REFUNA clogging cases yield higher water levels (e.g. Sequence FL5-9). These were used as bounding or approximate value.

Villigen PSI, 5.02.2021

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Appendix G-1 Definition of Probability Distributions

The following probability distributions are used directly in sampling or are an underlying assumption used in the calculation of probabilities. All distributions are sampled using R base software (R Core Team, 2019) and the “triangle” package (Carnell, 2019). The list of applications of the distributions is not necessarily complete.

Table 23: Summary of probability distributions and their parameterizations. The list of applications is not complete for the report.

Distribution	Parameters	Example Application
Triangular(a,b,c)	a = minimum b = maximum c = mode (most likely)	Morphology
Log-triangular(a,b,c)	a = minimum b = maximum c = mode (most likely)	Failure of Structures [equivalent to logarithm of value distributed Triangular]
Uniform(a,b)	a = minimum b = maximum	Percentile of distribution for epistemic uncertainties
Normal(μ,σ)	μ = mean σ = standard deviation	Hydraulic Model Uncertainty
Lognormal(μ,σ)	μ = log-space mean σ = log-space standard deviation	Driftwood volume analytical assumption
Beta(α,β,a,b)	α = first shape parameter β = second shape parameter a = lower bound b = upper bound	Driftwood split between Aare and OWK by BP Gösgen
Monte Carlo(v)	v = vector of sampled values from which statistics can be computed	Initiating Event Frequency

Appendix G-2 Hydraulic Model Uncertainty for Points

Table 24: Summary of normal distributions used in uncertainty propagation from hydraulic parameters. The mean and standard deviation of the normal distribution parameters were calculated based on the 95th and 5th percentiles of the distributions. All units are in meters.

BP	Point ID	Overland Flow				Channel Flow			
		Quantiles		Distribution Parameters		Quantiles		Distribution Parameters	
		95th	5th	Mean (µ)	Std. Dev. (σ)	95th	5th	Mean (µ)	Std. Dev. (σ)
Mühleberg	AAR_155170	0.102	-0.097	0.003	0.060	0.144	-0.139	0.002	0.086
	KKM A	0.097	-0.090	0.003	0.057	0.144	-0.139	0.002	0.086
	KKM B	0.094	-0.089	0.003	0.056	0.144	-0.139	0.002	0.086
	KKM C	0.097	-0.092	0.003	0.057	0.144	-0.139	0.002	0.086
	KKM D	0.096	-0.090	0.003	0.056	0.144	-0.139	0.002	0.086
	KKM E	0.095	-0.090	0.003	0.056	0.144	-0.139	0.002	0.086
	KKM F	0.093	-0.087	0.003	0.055	0.139	-0.134	0.002	0.083
	KKM G	0.094	-0.089	0.002	0.056	0.144	-0.139	0.002	0.086
	KKM H	0.068	-0.063	0.002	0.040	0.125	-0.124	0.001	0.076
	KKM I	0.068	-0.063	0.002	0.040	0.125	-0.124	0.001	0.076
Olten	AAR_055379	0.448	-0.426	0.011	0.265	0.409	-0.392	0.008	0.243
	AAR_054858	0.397	-0.372	0.012	0.234	0.361	-0.337	0.012	0.212
	OLT A	0.448	-0.426	0.011	0.265	0.409	-0.392	0.008	0.243
	OLT B	0.397	-0.372	0.012	0.234	0.361	-0.337	0.012	0.212
	OLT C	0.397	-0.372	0.012	0.234	0.361	-0.337	0.012	0.212
	OLT D	0.397	-0.372	0.012	0.234	0.361	-0.337	0.012	0.212
Gösgen	AAR_047387	0.371	-0.121	0.125	0.150	0.406	-0.167	0.119	0.174
	KKG A	0.412	-0.142	0.135	0.168	0.442	-0.178	0.132	0.188
	KKG B	0.009	-0.059	-0.025	0.021	0.072	-0.218	-0.073	0.088
	KKG C	0.141	-0.080	0.030	0.067	0.406	-0.167	0.119	0.174
	KKG D	0.243	-0.113	0.065	0.108	0.406	-0.167	0.119	0.174
	KKG E	0.228	-0.108	0.060	0.102	0.406	-0.167	0.119	0.174
	KKG F	0.150	-0.089	0.031	0.073	0.406	-0.167	0.119	0.174
	KKG G	0.214	-0.152	0.031	0.111	0.170	-0.173	-0.002	0.104
PSI	AAR_010470	0.314	-0.287	0.013	0.183	0.255	-0.242	0.007	0.151
	PSI A	0.211	-0.194	0.008	0.123	0.175	-0.169	0.003	0.105
	PSI B	0.314	-0.287	0.013	0.183	0.255	-0.242	0.007	0.151
Beznau	AAR_009830	0.211	-0.194	0.008	0.123	0.175	-0.169	0.003	0.105
	KKB A	0.077	-0.072	0.003	0.045	0.088	-0.095	-0.003	0.055
	KKB B	0.122	-0.100	0.011	0.068	0.067	-0.072	-0.003	0.042
	KKB C	0.159	-0.143	0.008	0.092	0.278	-0.272	0.003	0.167
	KKB D	0.107	-0.093	0.007	0.061	0.042	-0.045	-0.002	0.027
	KKB E	0.136	-0.121	0.007	0.078	0.030	-0.032	-0.001	0.019
	KKB F	0.164	-0.144	0.010	0.094	0.012	-0.012	0.000	0.007
	KKB G	0.103	-0.089	0.007	0.058	0.040	-0.043	-0.001	0.025
	KKB H	0.120	-0.100	0.010	0.067	0.022	-0.024	-0.001	0.014
	KKB J	0.107	-0.093	0.007	0.061	0.042	-0.045	-0.002	0.027
	KKB K	0.145	-0.121	0.012	0.081	0.017	-0.018	-0.001	0.011

Appendix G-3 Morphology Uncertainty

Table 25: List of morphology distributions used by site. An iterative program was used to solve for the bounds of the distribution so that the 5th and 95th percentiles of the distribution matched the reported value. The best estimate is taken as the most probable value (peak of triangular distribution). Discussion of morphology is in **Detailbericht F.** ***All units are in meters.***

BP	Relevant Scenarios	Best Estimate [m]	5th Percentile [m]	95th Percentile [m]	Triangular Distribution Parameters
Mühleberg	Landslide Brättele	+0.4	+0.35	+0.55	a=0.315 b=0.604 c=0.400
	Toppling Weir Mühleberg	0.0	-0.05	+0.15	a=-0.085 b=0.204 c=0.000
	Breach Weir Mühleberg	+0.2	+0.05	+0.25	a=-0.004 b=0.285 c=0.200
	All Others	+0.2	+0.15	+0.35	a=0.115 b=4.04 c=0.200
Olten	Not Relevant	--	--	--	--
Gösgen	Points on Aare (reference points A and C)	-0.4	-0.6	-0.35	a=-0.670 b=-0.310 c=-0.400
	Points on the Oberwasserkanal (reference point B)	0.0	0.0	0.05	a=-0.003 b=0.065 c=0.000
PSI	All Scenarios	-0.2	-0.3	+0.1	a=-0.370 b=0.209 c=0.200
Beznau	Points upstream of Weir Beznau (reference points D, E, and G)	+0.2	+0.1	+0.55	a=0.024 b=0.674 c=0.200
	Points downstream of Weir Beznau (scenario points C and K)	+0.2	-0.1	+0.3	a=-0.209 b=0.370 c=0.200

Appendix G-4 Driftwood Sensitivity Cases

Case 1: Uncertainty of Clogging

The analysis of driftwood clogging probabilities did not treat epistemic uncertainty. This appendix uses BP Gösgen C as an example to illustrate the sensitivity, or rather insensitivity, of the results to the inclusion or exclusion of this source of uncertainty. Two components compose the clogging probability, p_c, and each was assigned an uncertainty.

Uncertainty in the probability of the delivered driftwood volume (p_w) was calculated based on an assumed 20% uncertainty in the backwater-driftwood volume relationship. The simulations are assumed to apply to the same range of the backwater values, but the uncertainty on the backwater-volume relationship translates into an uncertainty on the volume of the driftwood for each nominal backwater value. The distribution of the driftwood remains the same, it is only the volume that changes. The backwater-volume relationship uncertainty is considered epistemic at a bridge, but independent between the two bridges.

Figure 52 is histograms of the sampled $p_{w,100}$ and $p_{w,300}$ values used in this sensitivity case. The $p_{w,100}$ values range from approximately 0.5 to 0.7 and the $p_{w,300}$ values range from approximately 0.02 to 0.35.

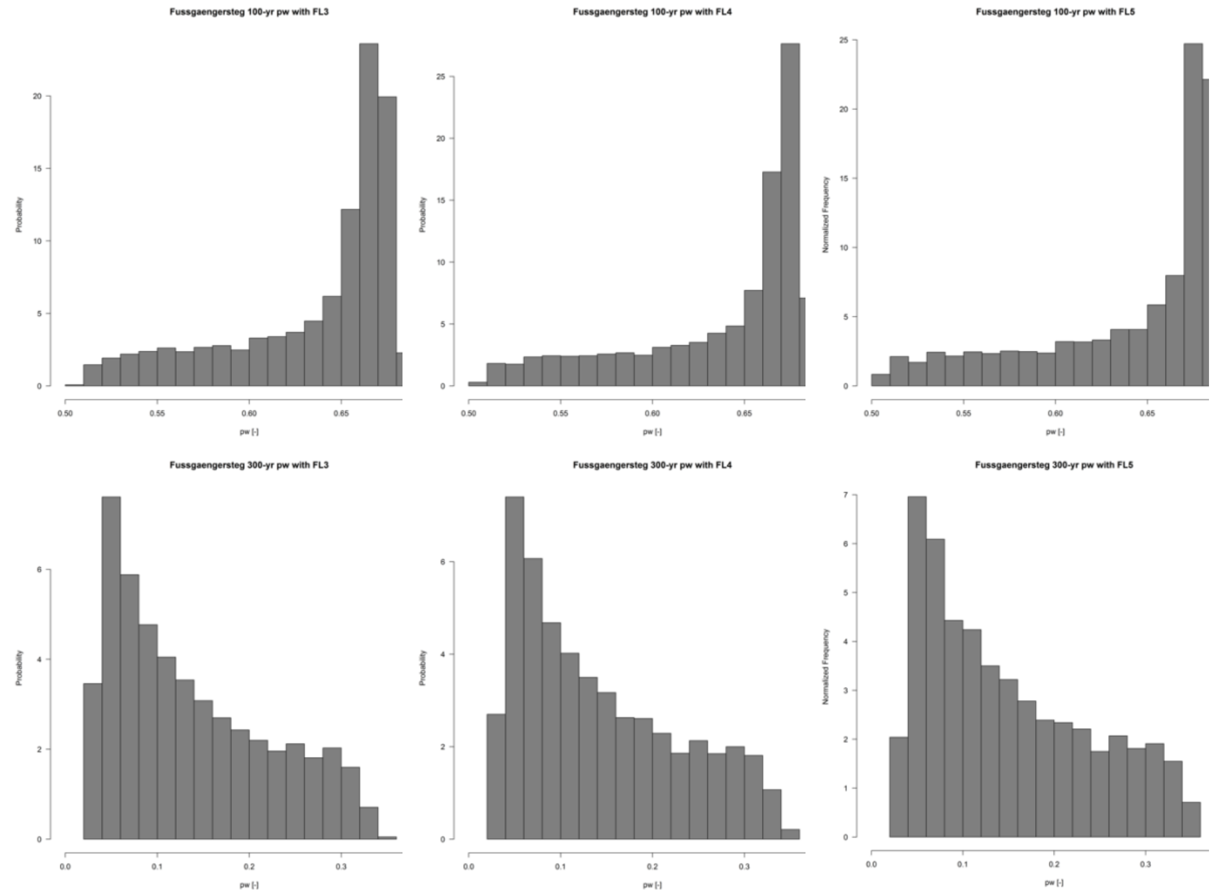

Figure 52: Histograms of sampled pw values for Fussgängersteg. Top row 100-year clogging, bottom row 300-year clogging. FL3 left, FL4 center, FL5 right.

The probability that clogging initiates (p_H) is assigned a range of +/- 0.2. For a point estimate probability of 0.5, the range would be sampled uniformly between 0.3 and 0.7. The range is truncated at 0.0 and 1.0, as necessary. For instance, a point estimate probability of 0.9 would be sampled uniformly between 0.7 and 1.0 with no additional mass at 1.0.

Figure 53 compares the hazard curves when the point estimate of the clogging probabilities are used versus the distributions described above. It seems that mean is the same or slightly higher over the domain and the uncertainty is only very slightly different. For instance, the interval at 382 m changes from roughly 4.2E-2—2.5E-4/a.

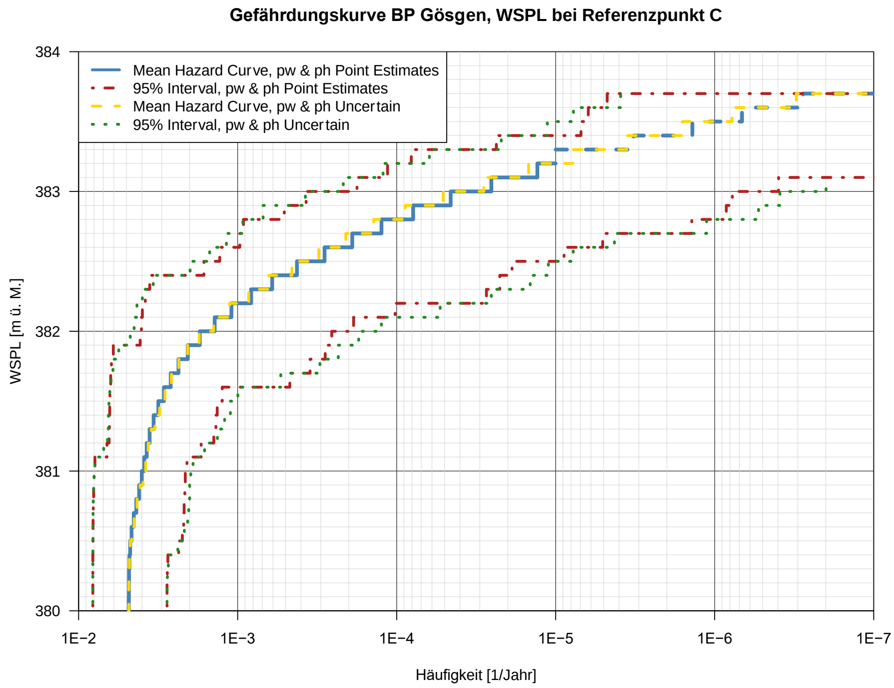

Figure 53: Comparison of BP Gösgen hazard curves with and without driftwood probability uncertainties.

Although the changes in the hazard curve and intervals are negligible, individual scenario frequencies have more substantial changes, but still relatively minor. Figure 54 illustrates that the changes in frequencies are all less than a factor of two and more scenarios have increased frequencies than decreased. The hydrologic scenarios (FL3-H, FL4-H, and FL5-H or numbered scenarios 1, 2, and 3) have a relatively higher frequency and typically show the largest relative change of any scenario in the event tree.

The clogging of Fussgängersteg, which are scenarios FL3-6, FL3-7, FL4-6, FL4-7, and FL5-5, FL5-6 in the event trees, generally have a decrease in the probability of the 100-year clogging event and an increase in the 300-year clogging event when considering this uncertainty. The 100-year clogging cases decrease by a factor of about 0.95 and the 300-year clogging cases increase by a factor of about 1.2. As was illustrated on the hazard curve, the hazard curve at the site and its uncertainty do not change substantially. Moreover, the change in individual scenario frequencies is minor.

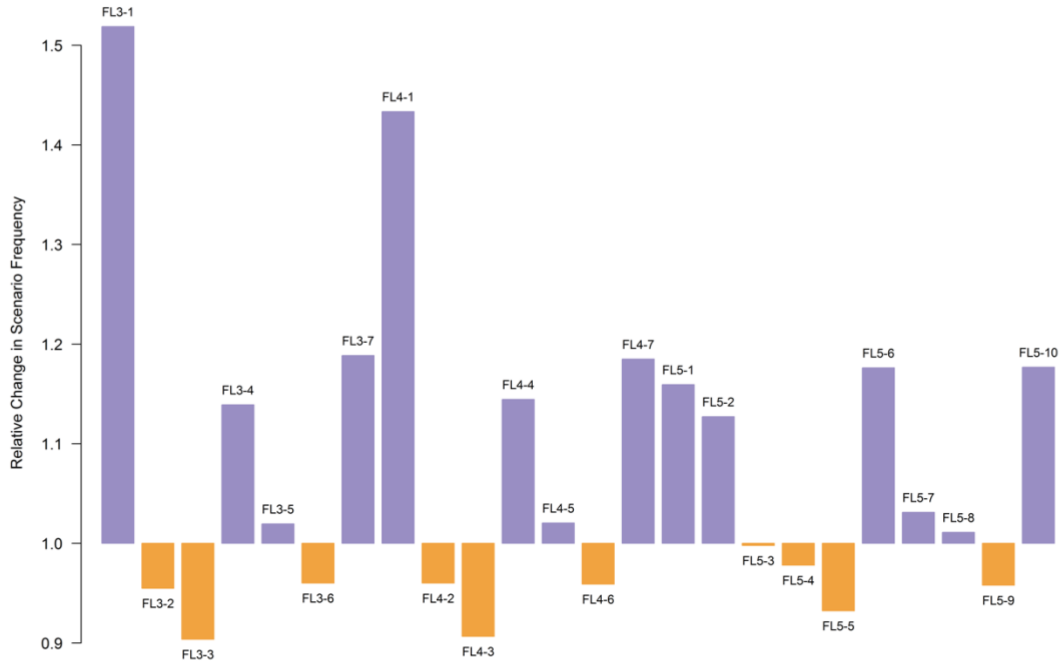

Figure 54: Changes in scenario frequency with and without driftwood probability uncertainty. Bars above 1.0 indicate the scenario frequency increased when driftwood probability uncertainty was included. Each bar is labelled for reference in the event trees. Relative frequencies.

Case 2: Driftwood Volume Uncertainty

The volumes of driftwood is inherently uncertain because it is based on the estimated 30-year and 300-year driftwood volumes. This section explores the impact of increasing those driftwood volumes for the decisive scenarios at BP Gösgen. Generally, decreasing the volumes would lead to lower hazard because of the clogging cases are associated with such a higher risk.

The impact on the decisive scenario frequencies was assessed by increasing the driftwood distribution by a factors of 2, 5, 10, and 20 compared to the base case assumption outlined in Section 2.3.5. This increase in the driftwood volume only impacts the probability of driftwood delivered, p_w, values. As the volume increases, the probability of 300-year volumes increases and the probability of 100-year volumes decreases. These volumes are assigned based on the base distribution and the distribution is shifting farther and farther to the right of them. The probability of clogging initiating remains the same as the base case.

There is a clear pattern from the results in Figure 54. If the driftwood volume is roughly twice that which was assumed, the 100-year scenarios have nearly the same frequency and the 300-year scenarios have approximately half an order of magnitude increase in the frequency. In the hazard curve, most of the Fussgängersteg clogging scenarios are roughly on the same line and they are both decisive (German: Massgebend); however, if the driftwood distribution roughly doubles it is likely that the 300-year scenarios would be the only decisive ones.

As the volume increases, it quickly reaches the limiting state where there is essentially only a 300-year clogging case at nearly an order of magnitude higher frequency than in the base case. For practical purposes, driftwood volume distributions five times the base case estimate are close to the limiting value and ten times are at the limiting value.

These results illustrate the importance of further research into the driftwood volumes that can be expected from such extreme events and the dynamics of the arrival of the driftwood, formation of the clog, and possible collapse of the clog.

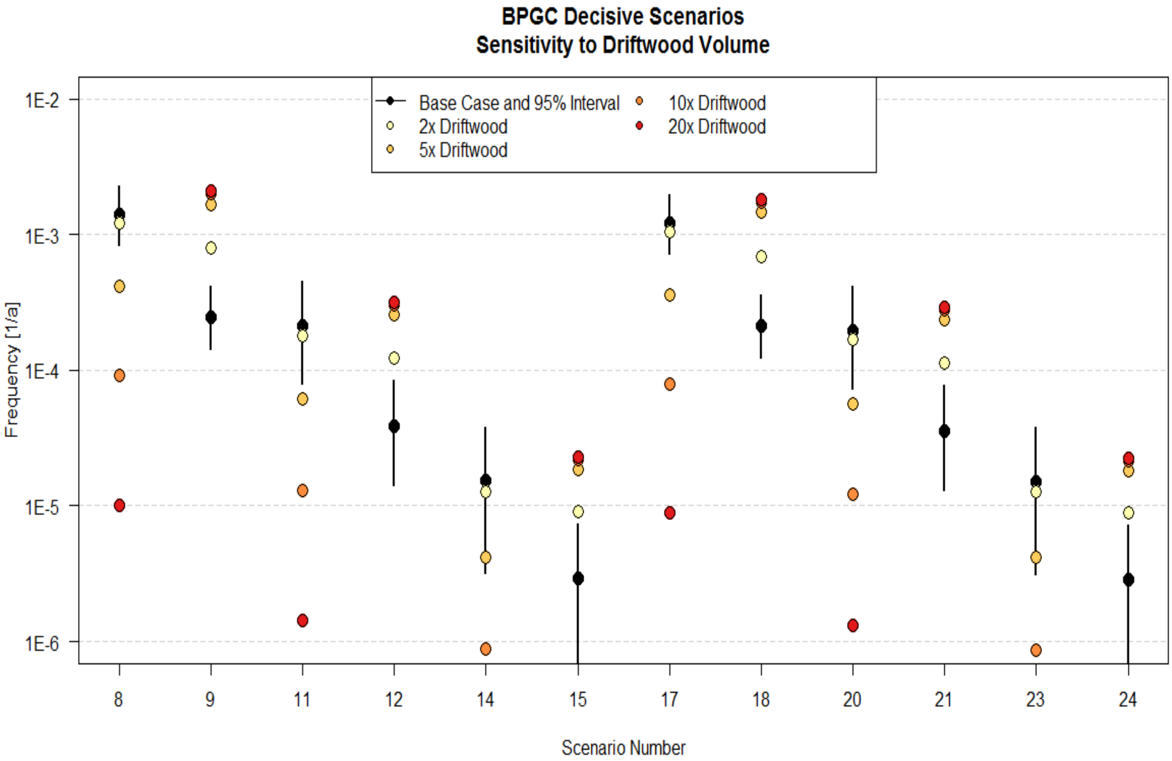

Figure 55: BP Gösgen point C clogging scenarios (100-yr and 300-yr) under different driftwood distribution volume assumptions relative to the base case. Dots that are redder are higher volumes relative to the base case. The black dots and line represent the mean scenario frequency and the 95% interval from the base case. Scenarios 8-15 are for the Fussgängersteg, most of which are decisive in the original hazard curve, and Scenarios 17-24 are for Sandackerstrasse, not decisive scenarios but ones that dominate the pure hydrologic events. Scenario numbers are specified in the hazard curve.

Appendix G-5 Calculation of Seismic Scenario Frequencies

This appendix describes how the frequency of the seismic scenarios resulting in dam failures is calculated from the information on the fragility of the structures and on the seismic load, i.e. the frequency of exceedance of seismic accelerations. In addition, it documents the uncertainty analysis.

Data Sources for Fragility and Seismic Load

The fragilities for the relevant dams are obtained from [BKW, 2018]. The seismic load was provided by BAFU to the EXAR project [BAFU, 2019].

Seismic exceedance information was provided in in tabular and graphical form. Tables were used in the following analysis.

Fragility

The fragility curve of a dam provides the dam's failure probability for a given peak ground acceleration (PGA). The fragility curve is modelled as a lognormal distribution, which can be defined in terms of two parameters. These are the median A_m and the log-space standard deviation β.

The parameter β can be divided into its component parts of aleatory uncertainty (β_r) and epistemic uncertainty (β_u). The combination of aleatory and epistemic uncertainty is β_c = sqrt(β_r^2+ β_u^2).

Note that the error factor (EF), defined as the square root of the ratio of the 95th and 5th percentiles, is directly a function of β for the lognormal distribution. The relationship is EF = exp(1.645 β).

Uncertainty on the fragility was calculated by separating the β_u component and applying that to the uncertainty of A_m, which was modelled with a lognormal distribution with median value A_m^* and a log-space standard deviation of β_u. This is discussed in more detail in a following section and in [ABSG, 2003].

The estimated fragilities for the structures are summarized in Table 26.

Table 26: Fragility curve parameters for the dams at Mühleberg and Schiffenen.

Parameter	Mühleberg	Schiffenen
A_m	1.47	2.088
β_r	0.207	0.400
β_u	0.400	0.15

Seismic Load (Exceedance frequencies)

The frequency that a given spectral acceleration (SA) is exceeded is provided in several curves (and tables) representing the 5th, 16th, 50th, 84th, and 95th percentiles and the mean estimate. In uncertainty propagation, the percentile curves are used to represent epistemic uncertainty on the seismic exceedance model.

Values of exceedance are provided for discrete values of SA. In the numerical approximation, the frequency of each interval is calculated by the difference in exceedance frequency at the two ends of the interval. This give a frequency of a range of SAs.

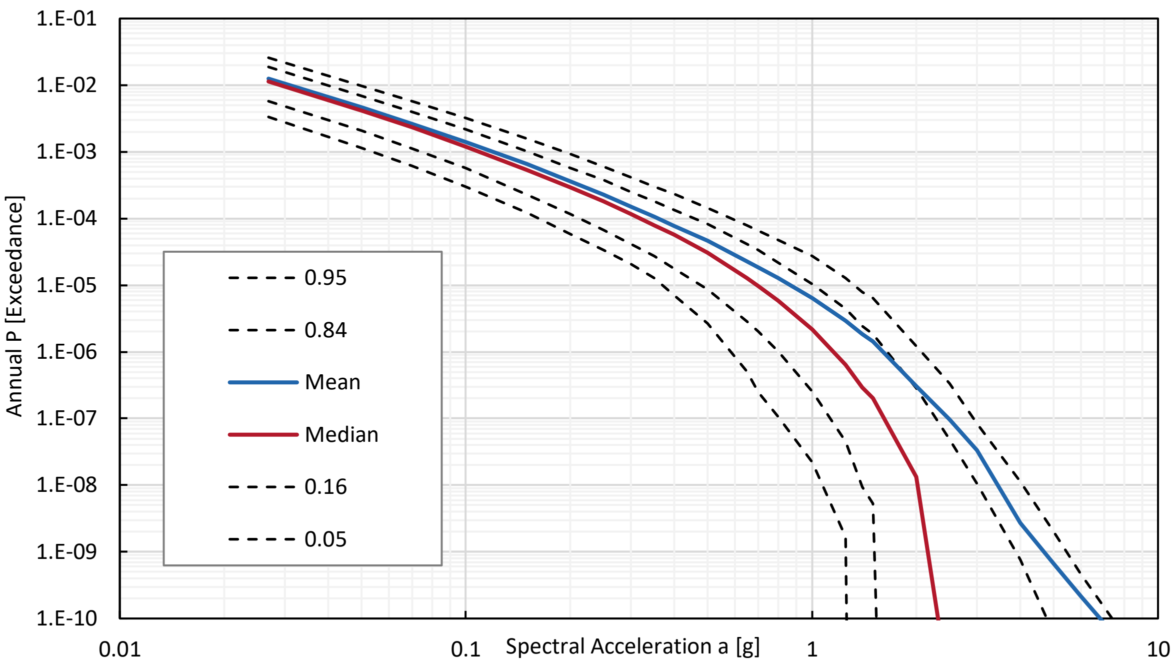

Figure 56: Seismic exceedance curves for Mühleberg. Lighter and thinner lines are more extreme percentiles of the exceedance curve.

Scenario Frequency

For a given fragility curve and the frequency of exceedance for seismic accelerations, the scenario frequency is calculated as the integral of the product of fragility for a given acceleration and the frequency of this seismic acceleration. This integral is approximated numerically as a summation. The equations are provided below. The term *Freq(a)* is the negative of the derivative of the seismic exceedance curve, which is equivalent to differentiating the cumulative distribution function (CDF) to obtain a probability density.

$$Freq(scen) = \int_{-\infty}^{\infty} Pf(\,dam \mid a) Freq(a)\, da$$

$$\cong \sum_{j=2}^{n} Pf(dam \mid \tfrac{a_{j-1}+a_j}{2}) [F_{exc}(a_{j-1}) - F_{exc}(a_j)]$$

Where *Freq(.)* is the frequency,

Fexc(.) is the exceedance frequency,

Pf(dam | a) is the probability of failure given ground acceleration *a*,

a is the seismic acceleration, and

j is the index for the values of SA/PGA where exceedance frequency are known.

It can be seen that the fragility is defined in terms of peak ground acceleration while the seismic load is described as the frequency of exceedance of a spectral acceleration. For the purpose of this calculation, an equivalence between the PGA and SA is assumed. Note also that for the numerical integration, the probability of failure at the mean of the interval is used rather than the mean probability of failure over the interval (trapezoidal approximation).

Uncertainty Propagation

The uncertainty propagation accounts for uncertainty in both the fragility and the seismic exceedance. The uncertainty analysis of the fragility curves performed using the method reported in [ABSG, 2003], which is combined with the seismic load uncertainty mentioned above. The method is as follows:

1. A parameter of the A_m fragility curve is sampled according to the specified lognormal distribution.
2. One of the five seismic fragility curve percentiles is sampled with specified weight.
3. The numerical integral is evaluated to give the scenario frequency.
4. Steps 1-3 are repeated 5000 times. This number is chosen to be the same size used in the uncertainty propagation performed for the hydrologic initiating events.

The scenario frequencies for Schiffenen and Mühleberg are desired. Because the frequencies of the seismic failures of the dams result from the full range of accelerations, i.e. they account for numerous seismic events, the correlation of the seismic loads do not need to be considered.

The weights for the sampling of the seismic fragility percentile curves are defined so as to preserve the distributional properties of the underlying continuous distribution. In this case, this corresponds to preserving the variance a normal of distribution when it is approximated by the 5^{th}, 16^{th}, 50^{th}, 84^{th}, and 95^{th} percentile values. Multiple sets of weights satisfy this constraint; consequently, the selected weights are derived as the middle of the range of each weight that meets the constraint. The probability of sampling the 5^{th} and 95^{th} quantiles are 0.1093 each, the probability of sampling the 16^{th} and 84^{th} quantiles are 0.2066 each, and the remainder of the probability (0.3682) is applied to the median curve.

For the purposes of this exercise, it was assumed that the underlying distribution is normal and that the weights should result in the same variance of the distribution. Without loss of generality, the weights for the standard normal distribution can be used. The problem is formulated as follows.

$$\min_{w_1,w_2} abs\,|2w_1 z_{0.95}^2 + 2w_2 q_{0.84}^2 - 1|$$

Subject to:

$$0.05 \leq w_1 < 0.16$$

$$0.16 \leq w_1 + w_2 < 0.5$$

$$w_1 < w_2$$

$$2w_1 + 3w_2 < 1$$

The first two constraints ensure that the “jumps” in the CDFs occur to coincide with the given quantiles. The next two constraints specify higher weight is given to the quantiles towards the center of the distribution than at the extremes. The normal distribution itself has much higher density towards the center than the extremes. The result is that w_1 (weight for 5^{th} and 95^{th} percentiles) and w_2 (weight for 16^{th} and 84^{th} percentiles) can be satisfied by a range of weights. W_1 ranges from 0.0833 to 0.1353, and this specifies values of w_2 as between 0.2778 to 0.1353. Based on these criteria alone, there is no justification for one set of weights versus any other on that continuum. Therefore, we used the average value (center) over that range for each weight and report the differences in the resulting mean frequency and error factor of the distribution.

Seismic Scenario Frequencies

The result of the calculations are summarized in Table 27. Several statistics of the sampled distribution are reported for the two earthquake scenarios. The impact of these scenarios are discussed in the *Hauptbericht*, Section 12.3.3.

Table 27: Summary statistics of seismic scenario frequencies for Schiffenen and Mühleberg accounting for fragility and seismic load uncertainty.

Frequency Distribution Statistics [1/a]	Mühleberg	Schiffenen
2.5%	2.0E-11	6.9E-9
Median	5.2E-10	2.2E-7
Mean	4.7E-6	4.9E-7
97.5%	3.8E-5	2.6E-6

The results used the mean values of the weights that satisfy all the constraints. Figures 58 and 59 plot the results of the mean and the error factors for the full range of weights that satisfy the constraints. The mean values change relatively minimally compared to the uncertainty of the estimated values. Moreover, these changes would not be sufficient to change the analysis of the risk at the site.

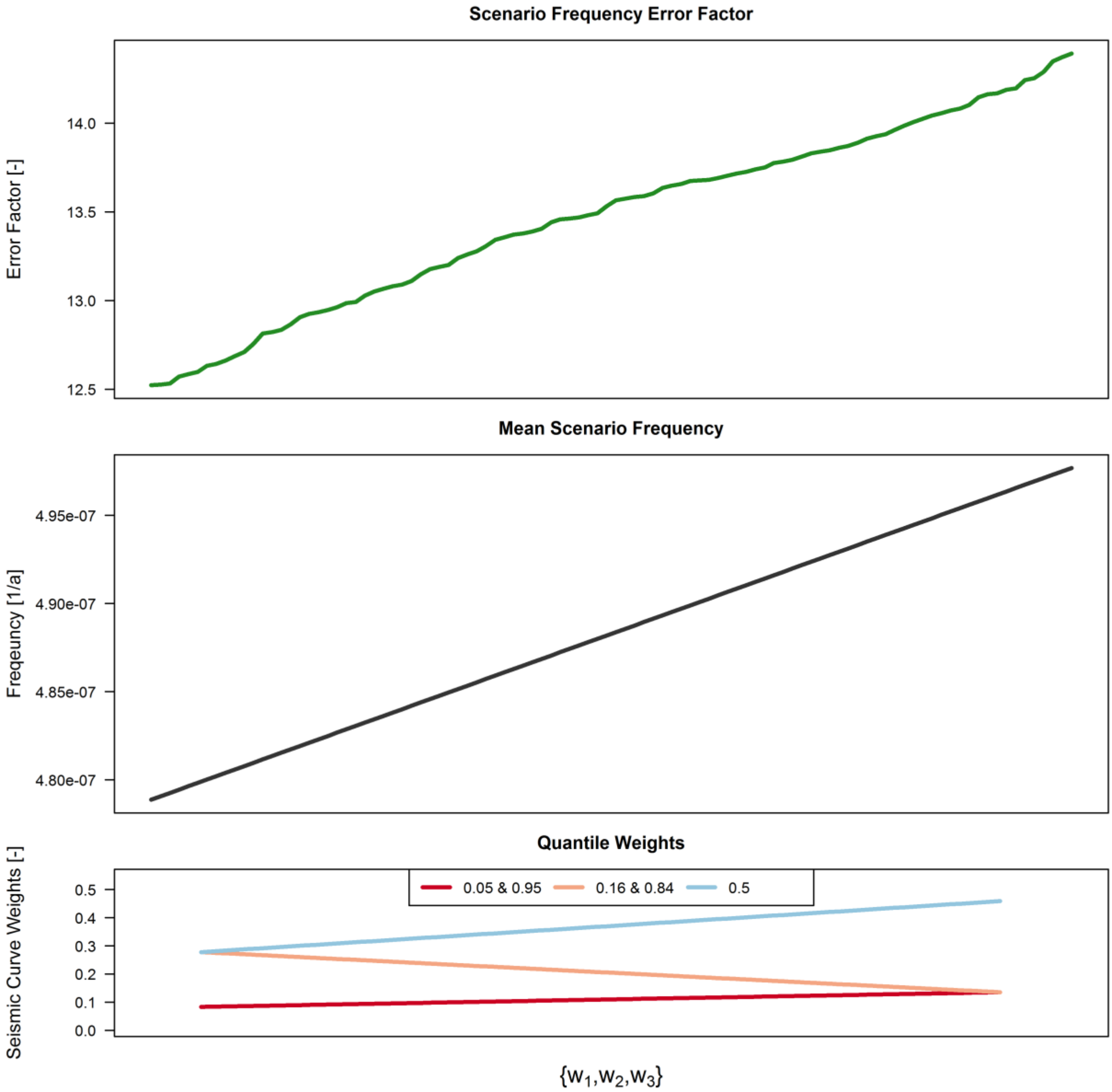

Figure 57: Sensitivity of scenario frequency and uncertainty due to assumption of weights of the different seismic exceedance curves for dam Schiffenen. Any vertical line through the sets of plots defines a set of weights, the mean scenario frequency, and the error factor of the scenario frequency.

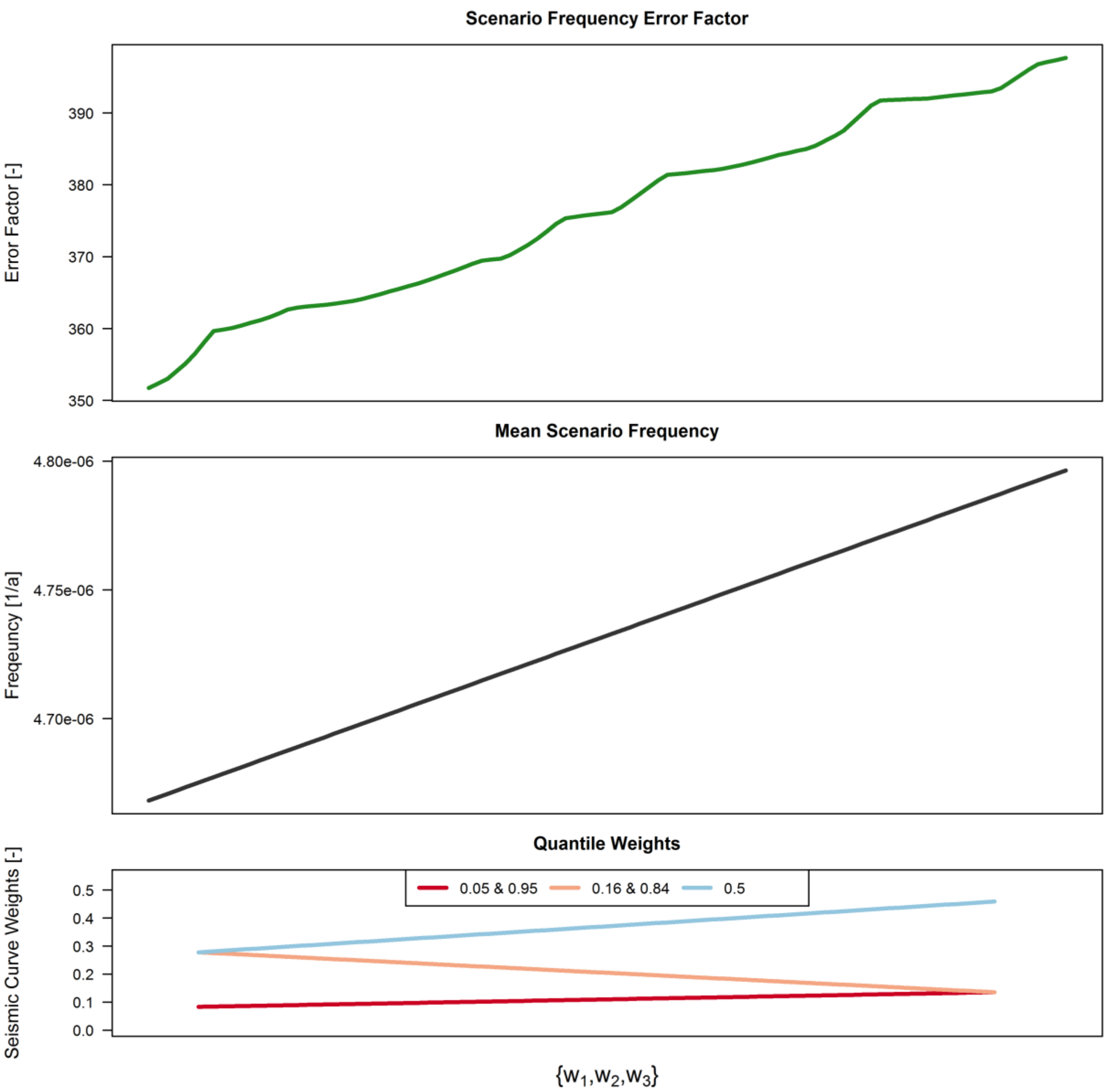

Figure 58: Sensitivity of scenario frequency and uncertainty due to assumption of weights of the different seismic exceedance curves for dam Mühleberg. Any vertical line through the sets of plots defines a set of weights, the mean scenario frequency, and the error factor of the scenario frequency.

References.

[BAFU, 2019] "Weitergabe von Dokumenten an das Projekt EXAR", BAFU to the EXAR Project, Memorandum dated 28 Juni 2019

[BKW, 2018] BKW (2018). MUSA2018 Mühleberg Safety Analysis, Appendix: KKM Seismic PSA Fragility Modeling Notebook, pp. 17-18.

[ABSG, 2003] ABSG Consulting Inc. (2003). "Seismic Probabilistic Risk Assessment Implementation Guide". Appendix B. Technical Report prepared for EPRI.

Appendix G-6 Event Tree Scenario Tables

The tables in this appendix list the mean frequencies, mean water levels (WSPLs), and additional information for all scenarios included in the event trees. The mean frequencies are the mean of the propagated frequency and probability uncertainty (mean of multiplication of the distributions of those frequencies and probabilities used to define the scenario). The mean WSPL (water level) is the simulated water level plus the mean of the hydraulic model uncertainty distribution plus the mean of the morphology uncertainty distribution.

Table G-6-1 Scenario table for BPM

Table G-6-1. Detailed results for BP Mühleberg including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. Hydraulic and morphology uncertainty distributions are defined in Appendices G-2 and G-3.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M.]			Hydraulic Uncertainty	Morphology ΔH	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. A	Ref. Pt. B	Ref. Pt. E					
1	FL3-1	1.5E-3	465.62	465.62	465.63	Channel	0.2	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	1.8E-4	465.99	465.99	466.00	Channel	0.2	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	1.1E-5	466.80	466.78	466.81	Overland	0.2	FL5; ohne Bauwerksversagen	√ C	--
4	FL3-4	3.6E-3	465.62	465.62	465.63	Channel	0.2	FL3; Verklausung Stauwehr Mühleberg (volumenunabhängig)	A*	Approximation
5	FL3-8	1.5E-5	465.62	465.62	465.63	Channel	0.2	FL3; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3)	√	--
6	FL3-12	5.1E-6	465.62	465.62	465.63	Channel	0.2	FL3; Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n)	√	--
7	FL4-4	4.1E-4	465.99	465.99	466.00	Channel	0.2	FL4; Verklausung Stauwehr Mühleberg (volumenunabhängig)	√	--
8	FL4-8	1.8E-6	465.99	465.99	466.00	Channel	0.2	FL4; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3)	√	--
9	FL4-12	5.9E-7	465.99	465.99	466.00	Channel	0.2	FL4; Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n)	√	--
10	FL5-4	2.6E-5	466.80	466.78	466.81	Overland	0.2	FL5; Verklausung Stauwehr Mühleberg (volumenunabhängig)	C*	Approximation
11	FL5-8	1.1E-7	466.80	466.78	466.81	Overland	0.2	FL5; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3)	√	--
12	FL5-12	3.7E-8	466.80	466.78	466.81	Overland	0.2	FL5; Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n)	√	--
13	FL3-6	1.4E-6	466.47	466.41	465.81	Channel	0.4	FL3; Verklausung Stauwehr Mühleberg (volumenunabhängig) & Rutschung Brättele	D*	Approximation
14	FL3-3	5.8E-7	466.47	466.41	465.81	Channel	0.4	FL3; Rutschung Brättele	√ D	--
15	FL4-6	1.6E-7	466.57	466.46	466.18	Overland	0.4	FL4; Verklausung Stauwehr Mühleberg (volumenunabhängig) & Rutschung Brättele	E*	Approximation
16	FL4-3	6.8E-8	466.57	466.46	466.18	Overland	0.4	FL4; Rutschung Brättele	√ E	--
17	FL5-6	1.0E-8	467.03	466.99	466.96	Overland	0.4	FL5; Verklausung Stauwehr Mühleberg (volumenunabhängig) & Rutschung Brättele	G*	--
			Mean WSPL [m ü. M.]					Scenario Description		Comment

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Ref. Pt. A	Ref. Pt. B	Ref. Pt. E	Hydraulic Uncertainty	Morphology ΔH		Sim. Ref.[3]	
18	FL3-5	4.7E-7	465.98	465.98	465.99	Channel	0.2	FL3; Verklausung Stauwehr Mühleberg (volumenunabhängig) & Rutschung Runtigenflue	F*	--
19	FL3-2	2.0E-7	465.98	465.98	465.99	Channel	0.2	FL3; Rutschung Runtigenflue	√ F	--
20	FL4-5	5.4E-8	466.22	466.21	466.24	Channel	0.2	FL4; Verklausung Stauwehr Mühleberg (volumenunabhängig) & Rutschung Runtigenflue	H*	Approximation
21	FL4-2	2.3E-8	466.22	466.21	466.24	Channel	0.2	FL4; Rutschung Runtigenflue	√ H	--
--	FL3-7	8.3E-22	467.24	466.94	467.1	Overland	0	FL3; Verklausung Stauwehr Mühleberg; Kippen Stauwehr Mühleberg	√ I	--
--	FL3-9	2.0E-9	465.98	465.98	465.99	Channel	0.2	FL3; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Runtigenflue	F*	--
--	FL3-10	5.9E-9	466.47	466.41	465.81	Channel	0.4	FL3; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Brättele	D*	Approximation
--	FL3-11	1.6E-26	468.80	468.14	468.35	Overland	0	FL3; Verklausung Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-3), Kippen Stauwehr Mühleberg	K*	Bounding values of n-n gates closed toppling case
--	FL3-13	6.7E-10	465.98	465.98	465.99	Channel	0.2	FL3; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Runtigenflue	F*	--
--	FL3-14	2.0E-9	466.47	466.41	465.81	Channel	0.4	FL3; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Brättele	D*	Approximation
--	FL3-15	1.1E-18	468.80	468.14	468.35	Overland	0	FL3; Verklausung Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n), Kippen Stauwehr Mühleberg	√ K	--
--	FL4-7	9.7E-23	467.24	466.94	467.10	Overland	0	FL4; Verklausung Stauwehr Mühleberg; Kippen Stauwehr Mühleberg	I*	Approximation. Wohlensee levels same and hazard equal for all Clogging+Toppling.
--	FL4-9	2.3E-10	466.22	466.21	466.24	Channel	0.2	FL4; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Runtigenflue	H*	Approximation
--	FL4-10	6.8E-10	466.57	466.46	466.18	Overland	0.4	FL4; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Brättele	E*	Approximation
--	FL4-11	1.3E-22	469.40	468.66	468.87	Overland	0	FL4; Verklausung Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-3), Kippen Stauwehr Mühleberg	L*	Bounding value of n-n gate toppling case
--	FL4-13	7.7E-11	466.22	466.21	466.24	Channel	0.2	FL4; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Runtigenflue	H*	Approximation

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M.]			Hydraulic Uncertainty	Morphology ΔH	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. A	Ref. Pt. B	Ref. Pt. E					
--	FL4-14	2.3E-10	466.57	466.46	466.18	Overland	0.4	FL4; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Brättele	E*	Approximation
--	FL4-15	8.3E-18	469.40	468.66	468.87	Overland	0	FL5; Verklausung Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n), Kippen Stauwehr Mühleberg	√ L	--
--	FL5-2	1.4E-9	466.89	466.87	466.89	Overland	0.2	FL5; Rutschung Runtigenflue	√ J	--
--	FL5-3	4.2E-9	467.03	466.99	466.96	Overland	0.4	FL5; Rutschung Brättele	√ G	--
--	FL5-5	3.4E-9	466.89	466.87	466.89	Overland	0.2	FL5; Verklausung Stauwehr Mühleberg; Rutschung Runtigenflue	J*	--
--	FL5-7	4.8E-24	467.24	466.94	467.10	Overland	0	FL5; Verklausung Stauwehr Mühleberg; Kippen Stauwehr Mühleberg	I*	Approximation. Wohlensee levels same for all clogging leading to toppling cases.
--	FL5-9	1.4E-11	466.89	466.87	466.89	Overland	0.2	FL5; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Runtigenflue	F*	Approximation
--	FL5-10	4.3E-11	467.03	466.99	466.96	Overland	0.4	FL5; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-3); Rutschung Brättele	G*	Approximation
--	FL5-11	3.1E-22	469.40	468.66	468.87	Overland	0	FL5; Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-3), Kippen Stauwehr Mühleberg	L*	Bounding value from FL4; n-n; toppling. Simulation showed higher hazard for that scenario.
--	FL5-13	4.8E-12	466.89	466.87	466.89	Overland	0.2	FL5; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Runtigenflue	F*	Approximation
--	FL5-14	1.4E-11	467.03	466.99	466.96	Overland	0.4	FL5; Stauwehr Mühleberg, 3 Wehrklappen geschlossen (n-n); Rutschung Brättele	G*	Approximation
--	FL5-15	1.1E-17	469.40	468.66	468.87	Overland	0	FL5; Verklausung Stauwehr Mühleberg, HW-Entlastung ausser Betrieb (n-n), Kippen Stauwehr Mühleberg	L*	Bounding value from FL4; n-n; toppling. Simulation showed higher hazard for that scenario.

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.

Table G-6-2 Scenario table for BPO

Table G-6-2. Detailed results for BP Olten including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. All scenarios were classified as having channel hydraulic uncertainty. Morphology was not considered at this site. The distribution of the hydraulic uncertainty is summarized in Appendix G-2.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M]			Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. A	Ref. Pt. B	Ref. Pt. C			
1	FL3-1	4.7E-4	391.81	391.39	391.40	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	7.7E-5	392.49	392.06	392.07	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	6.4E-6	393.87	393.38	393.39	FL5; ohne Bauwerksversagen	√ C	--
4	FL3-3	3.9E-4	391.81	391.39	391.40	FL3; Verklausung Bahnhofbrücke mit kleinem Holzvolumen ohne signifikante Auswirkung	A*	Approximation
5	FL3-4	1.4E-3	393.42	391.40	391.41	FL3; Verklausung Bahnhofbrücke (100-jährliches Holzvolumen)	√	--
6	FL3-5	3.0E-4	394.30	391.40	391.41	FL3; Verklausung Bahnhofbrücke (300-jährliches Holzvolumen)	√	--
7	FL4-3	5.9E-5	392.49	392.06	392.07	FL4; Verklausung Bahnhofbrücke mit kleinem Holzvolumen ohne signifikante Auswirkung	B*	Approximation
8	FL4-4	2.1E-4	394.27	392.04	392.05	FL4; Verklausung Bahnhofbrücke (100-jährliches Holzvolumen)	√	--
9	FL4-5	4.5E-5	395.24	392.04	392.05	FL4; Verklausung Bahnhofbrücke (300-jährliches Holzvolumen)	√	--
10	FL5-3	4.2E-6	393.87	393.38	393.39	FL5; Verklausung Bahnhofbrücke mit kleinem Holzvolumen ohne signifikante Auswirkung	C*	Approximation
11	FL5-4	1.5E-5	396.01	393.39	393.40	FL5; Verklausung der Bahnhofbrücke (100-jährliches Holzvolumen)	√	--
12	FL5-5	3.2E-6	397.04	396.44	393.39	FL5; Verklausung der Bahnhofbrücke (300-jährliches Holzvolumen)	√	--
13	FL3-2	1.6E-3	392.46	392.19	392.20	FL3; Verklausung Trimbacherbrücke (>400 m^3 solid)	√	--
14	FL4-2	2.5E-4	393.54	393.30	393.31	FL4; Verklausung Trimbacherbrücke (>400 m^3 solid)	√	--
15	FL5-2	2.1E-5	398.31	397.75	398.33	FL5; Verklausung Trimbacherbrücke (>400 m^3 solid)	√	--

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.

Table G-6-3 Scenario table for BPG Aare A&C

Table G-6-3. Detailed results for BP Gösgen Aare (Points A and C) including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. All scenarios were classified as having channel hydraulic uncertainty. Morphology was not considered at this site. The hydraulic model uncertainties are summarized in Appendix G-2. All scenarios were assigned the same morphology uncertainty summarized in Appendix G-3.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M]		Hydraulic Uncertainty	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. A	Ref. Pt. C				
1	FL3-1	2.0E-4	380.84	380.83	Channel	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	3.6E-5	381.57	381.56	Channel	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	1.9E-6	382.83	382.01	Overland	FL5; ohne Bauwerksversagen	√ C	--
4	FL5-8	2.7E-6	383.10	382.15	Channel	FL5; Verklausung Fussgängersteg KKG mit kleinem Holzvolumen ohne signifikante Auswirkung; Bruch OWK Seitendamm in der Nähe von Brücke 4 (Schachenstrasse)	√	--
5	FL5-4	2.6E-6	383.10	382.15	Channel	FL5; Verklausung Brücke Sandackerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung; Bruch OWK Seitendamm in der Nähe von Brücke 4 (Schachenstrasse)	√	--
6	FL5-2	2.4E-6	383.10	382.15	Channel	FL5; Bruch OWK Seitendamm in der Nähe von Brücke 4 (Schachenstrasse)	√	--
7	FL3-5	4.7E-4	380.84	380.83	Channel	FL3; Verklausung Fussgängersteg KKG mit kleinem Holzvolumen ohne signifikante Auswirkung	A*	Approximation
8	FL3-6	1.4E-3	382.56	382.10	Channel	FL3; Verklausung Fussgängersteg KKG (100-jährliches Holzvolumen)	√	--
9	FL3-7	2.5E-4	383.10	382.63	Channel	FL3; Verklausung Fussgängersteg KKG (300-jährliches Holzvolumen)	√	--
10	FL4-5	6.8E-5	381.57	381.56	Channel	FL4; Verklausung Fussgängersteg KKG mit kleinem Holzvolumen ohne signifikante Auswirkung	B*	Approximation
11	FL4-6	2.1E-4	383.06	382.46	Channel	FL4; Verklausung Fussgängersteg KKG (100-jährliches Holzvolumen)	√	--
12	FL4-7	3.8E-5	383.42	382.94	Channel	FL4; Verklausung Fussgängersteg KKG (300-jährliches Holzvolumen)	√	--
13	FL5-7	2.1E-6	382.83	382.01	Channel	FL5; Verklausung Fussgängersteg KKG mit kleinem Holzvolumen ohne signifikante Auswirkung	C*	Approximation
14	FL5-9	1.5E-5	383.69	383.04	Overland	FL5; Verklausung Fussgängersteg KKG (100-jährliches Holzvolumen)	√	--
15	FL5-10	2.9E-6	384.00	383.44	Overland	FL5; Verklausung Fussgängersteg KKG (300-jährliches Holzvolumen)	√	--

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M]		Hydraulic Uncertainty	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. A	Ref. Pt. C				
16	FL3-2	4.0E-4	380.84	380.83	Channel	FL3; Verklausung Brücke Sandackerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	A*	Approximation
17	FL3-3	1.2E-3	381.56	381.55	Channel	FL3; Verklausung Brücke Sandackerstrasse (100-jährliches Holzvolumen)	√	--
18	FL3-4	2.1E-4	381.94	381.93	Channel	FL3; Verklausung Brücke Sandackerstrasse (300-jährliches Holzvolumen)	√	--
19	FL4-2	6.3E-5	381.57	381.56	Channel	FL4; Verklausung Brücke Sandackerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	B*	Approximation
20	FL4-3	2.0-4	382.20	382.19	Channel	FL4; Verklausung Brücke Sandackerstrasse (100-jährliches Holzvolumen)	√	--
21	FL4-4	3.6E-5	382.53	381.95	Channel	FL4; Verklausung Brücke Sandackerstrasse (300-jährliches Holzvolumen)	√	--
22	FL5-3	2.0E-6	382.83	382.01	Channel	FL5; Verklausung Brücke Sandackerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	C*	Approximation
23	FL5-5	1.5E-5	383.30	382.43	Channel	FL5; Verklausung Brücke Sandackerstrasse (100-jährliches Holzvolumen)	D*	Bounding value 300-year clogging
24	FL5-6	2.9E-6	383.30	382.43	Overland	FL5; Verklausung Brücke Sandackerstrasse (300-jährliches Holzvolumen)	√ D	--

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.

Table G-6-4 Scenario table for BPG Oberwasserkanal B

Table G-6-4. Detailed results for BP Gösgen Oberwasserkanal (Point B) including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. All scenarios were classified as having channel hydraulic uncertainty. Morphology was not considered at this site. All scenarios were assigned channel hydraulic model uncertainty. All scenarios were assigned the same morphology uncertainty. These distributions are summarized in Appendices G-2 and G-3.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M] Ref. Pt. B	Scenario Description	Sim. Ref.[3]	Comment
1	FL3-1	1.0E-4	387.99	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	1.3E-5	388.97	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	2.0E-6	389.37	FL5; ohne Bauwerksversagen	√ C	--
4	FL3-8	1.2E-5	389.12	FL3; Weir Winznau 2 gates closed (n-2)	√	--
5	FL3-9	4.1E-6	389.37	FL3; Weir Winznau 4 gates closed (n-n)	√	--
6	FL4-8	1.9E-6	389.38	FL4; Weir Winznau 2 gates closed (n-2)	√	--
7	FL4-9	6.5E-7	389.72	FL4; Weir Winznau 4 gates closed (n-n)	√	--
8	FL5-8	1.5E-7	389.92	FL5; Weir Winznau 2 gates closed (n-2)	D*	Bounding value n-n gate case
9	FL5-9	5.0E-8	389.92	FL5; Weir Winznau 4 gates closed (n-n)	√ D	--
10	FL3-5	3.6E-3	387.99	FL3; Clogging Giessenstr. Bridge with small volume with no impact	A*	Approximation
11	FL3-6	7.2E-5	387.1	FL3; Clogging Giessenstr. Bridge with 100-year volume	√	--
12	FL3-7	2.0E-7	387.1	FL3; Clogging Giessenstr. Bridge with 300-year volume	√	--
13	FL4-5	5.7E-4	388.97	FL4; Clogging Giessenstr. Bridge with small volume with no impact	B*	Approximation
14	FL4-6	6.2E-6	389.07	FL4; Clogging Giessenstr. Bridge with 100-year volume	√	--
15	FL4-7	1.2E-8	389.07	FL4; Clogging Giessenstr. Bridge with 300-year volume	√	--
16	FL5-5	4.0E-5	389.37	FL5; Clogging Giessenstr. Bridge with small volume with no impact	C*	Approximation
17	FL5-6	1.2E-7	389.92	FL5; Clogging Giessenstr. Bridge with 100-year volume	D*	Bounding value
18	FL3-2	3.8E-4	387.99	FL3; Clogging Schachenstr. Bridge with small volume with no impact	A*	Approximation
19	FL3-3	7.8E-6	387.07	FL3; Clogging Schachenstr. Bridge with 100-year volume	√	--
20	FL3-4	1.5E-8	387.06	FL3; Clogging Schachenstr. Bridge with 300-year volume	√	--

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M]	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. B			
21	FL4-2	5.7E-5	388.97	FL4; Clogging Schachenstr. Bridge with small volume with no impact	B*	Approximation
22	FL4-3	6.2E-7	388.96	FL4; Clogging Schachenstr. Bridge with 100-year volume	√	--
23	FL5-2	7.9E-6	389.37	FL5; Clogging Schachenstr. Bridge with small volume with no impact	C*	Approximation
24	FL5-3	2.5E-8	389.37	FL5; Clogging Schachenstr. Bridge with 100-year volume	√ E	--
--	FL4-4	7.6E-10	388.96	FL4; Clogging Schachenstr. Bridge with 300-year volume	√	--
--	FL5-4	1.4E-11	389.37	FL5; Clogging Schachenstr. Bridge with 300-year volume	E*	Approximation [no difference in WSPL at FL4]
--	FL5-7	1.1E-10	389.92	FL4; Clogging Giessenstr. Bridge with 300-year volume	D*	Bounding value

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.

Table G-6-5 Scenario table for BPP

Table G-6-5. Detailed results for BP PSI including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. All scenarios were classified as having channel hydraulic uncertainty. Morphology uncertainty was the same for all scenarios. Distributions of these are summarized in Appendices G-2 and G-3.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m ü. M] Ref. Pt. A	Scenario Description	Sim. Ref.[3]	Comment
1	FL3-1	1.2E-3	327.72	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	1.3E-4	328.44	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	1.5E-5	329.63	FL5; ohne Bauwerksversagen	√ C	--
4	FL3-3	2.7E-4	327.72	FL3; Verklausung PSI Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	A*	Approximation
5	FL3-4	9.4E-4	327.72	FL3; Verklausung PSI Brücke (100-jährliches Holzvolumen)	√	--
6	FL3-5	2.0E-4	327.72	FL3; Verklausung PSI Brücke (300-jährliches Holzvolumen)	√	--
7	FL4-3	2.6E-5	328.44	FL4; Verklausung PSI Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	B*	Approximation
8	FL4-4	9.0E-5	328.44	FL4; Verklausung PSI Brücke (100-jährliches Holzvolumen)	√	--
9	FL4-5	1.9E-5	328.44	FL4; Verklausung PSI Brücke (300-jährliches Holzvolumen)	√	--
10	FL5-3	2.9E-6	329.63	FL5; Verklausung PSI Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	C*	Approximation
11	FL5-4	9.9E-6	332.57	FL5; Verklausung PSI Brücke (100-jährliches Holzvolumen)	D*	Bounding value
12	FL5-5	2.1E-6	332.57	FL5; Verklausung PSI Brücke (300-jährliches Holzvolumen)	√ D	--
13	FL3-2	1.2E-6	329.36	FL3; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√	--
14	FL4-2	1.3E-7	329.84	FL4; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√	--
15	FL5-2	1.5E-8	330.76	FL5; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√	--

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.

Table G-6-6 Scenario table for BPB

Table G-6-6. Detailed results for BP Beznau including mean frequencies, mean water levels, sequence IDs, scenario IDs (used in hazard curve figures), scenario descriptions, and scenarios that were approximated or bounded. The hydraulic model uncertainty distributions are summarized in Appendix G-2. Morphology uncertainty was the same for all scenarios at these reference points and is summarized in Appendix G-3.

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m. ü. M.]			Hydraulic Uncertainty	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. D	Ref. Pt. E	Ref. Pt. G				
1	FL3-1	0.0E+0	326.25	326.33	327.10	Channel	FL3; ohne Bauwerksversagen	√ A	--
2	FL4-1	1.4E-5	327.10	327.27	327.57	Channel	FL4; ohne Bauwerksversagen	√ B	--
3	FL5-1	2.7E-6	327.87	327.87	327.77	Overland	FL5; ohne Bauwerksversagen	√ C	--
4	FL3-5	2.4E-4	327.20	327.33	327.40	Overland	FL3; Stauwehr Beznau, Verklausung	√	--
5	FL3-6	7.8E-6	328.07	327.97	328.22	Overland	FL3; Stauwehr Beznau, 3 Wehrklappen geschlossen (n-3)	√	--
6	FL3-7	2.2E-6	328.46	328.27	328.56	Overland	FL3; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√ D	--
7	FL4-5	2.4E-5	327.44	327.51	327.84	Channel	FL4; Stauwehr Beznau, Verklausung	√	--
8	FL4-6	7.8E-7	328.30	328.17	328.37	Overland	FL4; Stauwehr Beznau, 3 Wehrklappen geschlossen (n-3)	√	--
9	FL4-7	2.3E-7	328.63	328.42	328.70	Overland	FL4; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√ E	--
10	FL5-5	2.7E-6	327.82	327.83	327.70	Overland	FL5; StauwehrBeznau, Verklausung	√	--
11	FL5-6	9.1E-8	328.73	328.53	328.64	Overland	FL5; Stauwehr Beznau, 3 Wehrklappen geschlossen (n-3)	√	--
12	FL5-7	2.6E-8	328.95	328.68	328.86	Overland	FL5; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n)	√ F	--
13	FL3-2	2.2E-3	326.25	326.33	327.10	Channel	FL3; Verklausung Brücke Beznauerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	A*	Approximation
14	FL3-3	1.2E-4	326.25	326.33	327.27	Channel	FL3; Verklausung Brücke Beznauerstrasse (100-jährliches Holzvolumen)	√	--
15	FL3-4	2.4E-7	326.25	326.33	327.31	Channel	FL3; Verklausung Brücke Beznauerstrasse (300-jährliches Holzvolumen)	√	--
16	FL4-2	2.1E-4	327.10	327.27	327.57	Overland	FL4; Verklausung Brücke Beznauerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	B*	Approximation
17	FL4-3	7.4E-6	327.27	327.33	327.70	Channel	FL4; Verklausung Brücke Beznauerstrasse (100-jährliches Holzvolumen)	√	--
18	FL5-2	2.4E-5	327.87	327.87	327.77	Overland	FL5; Verklausung Brücke Beznauerstrasse mit kleinem Holzvolumen ohne signifikante Auswirkung	C*	Approximation

Scenario ID[1]	Sequence ID[2]	Mean Frequency [1/a]	Mean WSPL [m. ü. M.]			Hydraulic Uncertainty	Scenario Description	Sim. Ref.[3]	Comment
			Ref. Pt. D	Ref. Pt. E	Ref. Pt. G				
19	FL5-3	4.0E-7	328.30	328.06	328.18	Overland	FL5; Verklausung Brücke Beznauerstrasse (100-jährliches Holzvolumen)	G*	Estimated based on REFUNA and Beznauerstr. Clogging and trends from FL4 between scenarios
20	FL3-8	3.5E-7	328.46	328.27	328.56	Overland	FL3; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	D*	Approximation
21	FL3-9	1.2E-8	327.86	328.26	327.96	Overland	FL3; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (100-jährliches Holzvolumen)	√	--
22	FL4-8	3.3E-8	328.63	328.42	328.70	Overland	FL4; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	E*	Approximation
--	FL3-10	4.9E-11	327.77	328.28	327.89	Overland	FL3; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (300-jährliches Holzvolumen)	√	--
--	FL4-4	1.0E-8	327.31	327.35	327.81	Channel	FL4; Verklausung Brücke Beznauerstrasse (300-jährliches Holzvolumen)	√	--
--	FL4-9	7.2E-10	327.97	328.37	328.11	Overland	FL4; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (100-jährliches Holzvolumen)	√	--
--	FL4-10	2.0E-12	327.88	328.40	328.04	Overland	FL4; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (300-jährliches Holzvolumen)	√	--
--	FL5-4	3.0E-10	328.34	328.10	328.22	Overland	FL5; Verklausung Brücke Beznauerstrasse (300-jährliches Holzvolumen)	G*	Estimated based on REFUNA and Beznauerstr. Clogging and trends from FL4 between scenarios
--	FL5-8	4.5E-9	328.95	328.68	328.86	Overland	FL5; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke mit kleinem Holzvolumen ohne signifikante Auswirkung	F*	Approximation
--	FL5-9	4.4E-11	328.19	328.61	328.18	Overland	FL5; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (100-jährliches Holzvolumen)	√ G	--
--	FL5-10	7.3E-14	328.08	328.62	328.08	Overland	FL5; Stauwehr Beznau, HW-Entlastung ausser Betrieb (n-n); Verklausung REFUNA Brücke (300-jährliches Holzvolumen)	√	--

[1] Labels for scenarios in the hazard curve figures.

[2] Labels for scenarios in the event tree. The first part of the identifier is the flood initiating event and the second part is the sequence number within the tree.

[3] Scenarios with a simulated are denoted with a '√'. Scenarios with a simulation used in the approximation, bounding, etc., of another scenario are assigned a letter. Bounded, approximated, etc., scenarios refer to the letter of the referenced scenario with an additional '*'.