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- FORESEE -

Future proofing strategies FOr RESilient transport networks against Extreme Events

– Deliverable 6.5 –

DE Case Study #4
Railway track 6185 (Oebisfelde-Berlin-Spandau).

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1. INTRODUCTION

This deliverable will consist in the test and validation of the project outcomes in Case Study (CS) #4 railway track 6185 (Oebisfelde-Berlin-Spandau) in order to select and design the best technical solutions before (preparation and preventive maintenance), during (event management and control center) and after a hazard event (predictive maintenance and emergency planning).

2. CASE STUDY #4 DESCRIPTION

The case study focusses on flooding hazards on railway tracks. This includes rising tides of rivers caused by heavy rainfall in the catchment area. Therefore, the German railway track no. 6185 between Oebisfelde and Berlin-Spandau was chosen, which is part of the high-speed railway (HSR) Hannover - Berlin.

2.1. INFRASTRUCTURE / NETWORK DESCRIPTION

The railway track 6185 corresponds to a section of the Hannover-Berlin high-speed railway line:

- 1730 (Hannover-Lehrte)
- 6107 (Lehrte - Oebisfelde)
- **6185 (Oebisfelde - Berlin-Spandau)**
- 6109 (Berlin-Spandau - Berlin Ostbf)

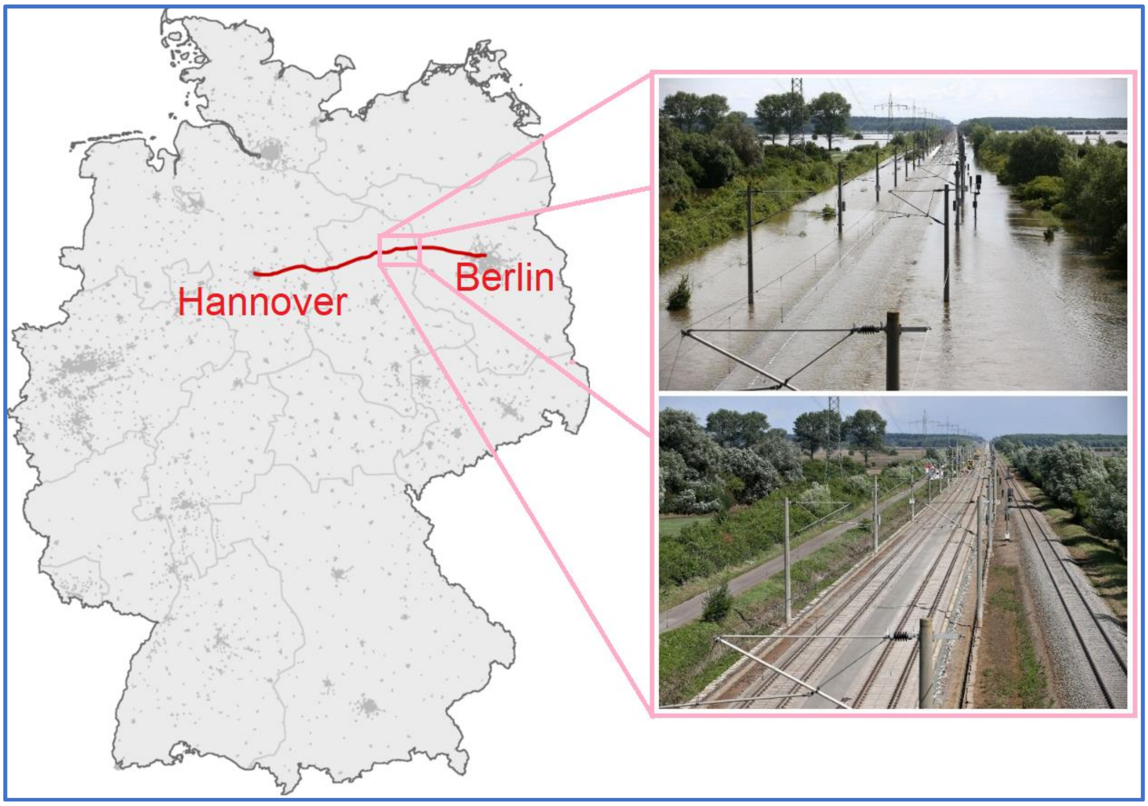


Figure 1. CS#4, The railwaytrack 6185 during and after the flood 2013 [Wikipedia / dpa].

The approx. 150 kilometres long track section between Oebisfelde (km 267,9) and Berlin-Spandau (km 112,7) is built as ballastless track with a maximum speed up to 250 km/h.

Between Oebisfelde and Berlin, the line runs largely parallel to the Lehrte line. The Track is part of the service area of the Deutsche Bahn AG (DB) – the passenger transport is managed by the resort "DB Personenverkehr" and the maintenance is performed by the resort "DB Netze".

In 2011, about 170 traffic and freight trains with approx. 10,000 passengers are on the track per day. The rail infrastructure has many bridges crossing the river Elbe (for example the Haemerten bridge near Schoenhausen) and several smaller rivers.

2.2 HAZARD DESCRIPTION

Due to former flooding events (especially the Elbe Flood in June 2013), there are data available regarding risks and damages caused by flooding. As a result of the Elbe flood in June 2013, the Haemerten bridge and an approximately 5 km long track section near Schoenhausen were closed due to flooding. Due to large-scale deviations, delays of one to two hours occurred. The DB introduced an interim timetable, which was later changed several times. Regular service was not resumed until months later in November 2013.
Due to the actuality, the available data and the impact as an extreme event, the Elbe flood 2013 is used in the following for validation and as a benchmark for evaluation the FORESEE tools.

3. SCENARIO CARD & VALIDATION CONDITIONS

3.1. SCENARIO CARD FOR CASE STUDY #4 RAILWAY TRACK 6185

As the railway track 6185 is an existing line, corresponding to the life cycle (LC) only the operating and maintenance phase is considered in the following.
The singular event or risk of flooding is attempted to be divided into the following cascading scenarios due to the different damage and operational effects:

- Heavy rain,
  Risk of moderate flooding.

- Heavy rain
  + river **flooding**,
  risk of fast and intense flooding.

CS#4	**scenario**	
LC phase	Operation & Maintenance,	**M**
risk	River Flooding,	**F**
transport	Railway Way,	**RW**
scale	National,	**N**
location	Germany,	**G**
	LC phase (M), risk (F), transport (RW), scale (N), location (G)	

Table 1. CS#4, Scenario card.

The main investigation topics regarding the considered operating and maintenance phase are flooding impacts on railway operations in combination with maintenance and contingency plans. Additionally, the effects of flooding to different railway track components in dependency of the water level are evaluated model-based.

- For the determination of input variables of the influences on railway operations in case of flooding, the case study consists on a traffic simulation model and an AI-based risk model, which takes former weather data and flooding events into account. The infrastructure and operations model is based on RailSys®[1] and includes all the traffic and infrastructure data of the railway track 6185. This also helps to evaluate the effects of different contingency plans to improve restauration works and select or design the best technical solutions for preventive maintenance. In particular, the influence of flooding-related speed restrictions can be analysed in the model.
  In addition, current guidelines, recommendations for action, procedures of the DB AG for major incident management (germ. "Großstörungsmanagement") are used here for the tool comparison. In this context, existing maintenance, operational and contingency plans (if any) are also analysed and compared.

- For the former weather data and risk assessment, information and models from national authorities and research institutions are used for analysis, for example the German Remote Sensing Data Center for Geo-Risks and Civil Security (ZKI[2]), Federal Institute of Hydrology (BAFG[3]), Flood control centre (HWZ[4]) and Saxony-Anhalt State Flood Protection and Water Management Agency (LHW[5]).

- In addition to the operational simulation, the influence of flooding on the individual track components is also studied on the basis of an own IVE Bridge Flooding Model[6] as a supplement to the other FORESEE tools. The study starts at the bottom of the embankment with risings tides of the nearby river. The water level will be increased in small steps and each step has to be analysed itself, because of influences of groundwater and structural stability of dams. Short before the water level reaches the top of the ballast, the electrical devices near the track will be damaged by water.

3.2. VALIDATION METHODOLOGY AND PROCEDURE

In the following, the input variables from the existing models and comparative data mentioned above will be comparatively validated with the output from the newly developed FORESEE tools in order to improve the resilience of the railway infrastructure in the event of hazards.

For this purpose, the Key Resilience Indicator (KRI) and Key Resilience Targets (KRT) are defined in the first step (see section 3.3) and used for the selection of the FORESEE tools for this CS#4 (see section 3.4) as well as an evaluation benchmark in the further procedure.

The following tool validation is adapted on DIN EN 50126[7] for railway applications according to the procedure in the V-model (also compare D.6.1). The linear approach in the V-Modell is basically divided into the phases of requirements analysis, implementation and validation. The selected FORESEE tools are additionally subdivided according to the time phase in which they are used (before, during or after an event) (see section 4).

The information regarding the requirements, modelling and output will be theoretically validated mainly on the basis of the deliverables of the individual FORESEE tools in the first step (see section 5). In the second step, the subsequent validation of the implementation of the requirements will start with a rating of the improvements via the selected FORESEE tools and also include a comparison with the current situation (see section 6.1 – 6.3). With the help of RAMSSHEEP and the resilience principles, a further qualitative validation is then performed, as well as a quantitative validation through a final net benefit analysis as a result of the possible tool implementation (see section 6.3 – 6.4).

In the final evaluation, possible suggestions for improvements for a real use and commercialization of the FORESEE tools are pointed out (see section 7) and the results of the validation of CS#4 are summarised once again as a conclusion (see section 8).

3.3. KEY RESILIENCE INDICATOR (KRI) AND TARGETS (KRT)

According to deliverable (D) 1.1 "Guideline to measure Levels of Service and resilience in infrastructures" and deliverable D.1.2 "Guideline to set target levels of service and resilience for infrastructures" the KRI and KRT are identified in preparation for the following validation of the FORESEE tools in phase 0 of the flow chart (see section 4, figure 2).

The KRI and KRT for CS#4 are determined with the help of an Excel file provided by ETH, which reflects the methodology from D.1.1 and D.1.2. The application and methodological correlations of the Excel file were taught by ETH in a "Resilience Index & Target Training Workshop on 24.03.2021.

In the first step, the input variables for measuring the service are defined. These are classified between event-independent (see annex 2.1) and event-dependent inputs (see annex 2.2).

The event-independent parameters include general theoretical data from the literature, real data and expert knowledge from the DB Netz infrastructure managers as well as the input-output data of the own traffic simulation model (see annex 1.1) based on RailSys® as an additional adjustment. The event-dependent inputs to measure the service are related to the hazard event of flooding for CS#4. The comparative data for the hazard assessment are provided here on the one hand by available practical cost and recover data from the Elbe flood in 2013. On the other hand, the estimation of the average delay per train after an event is again compared with the results of the own traffic simulation model based on RailSys®. For the "rough" estimation of the probability of damage, injury and death, the experiences of the own IVE Bridge Flooding Model (see annex 2.1) are also used in both input cases.

As a result of the first step, the determined inputs are combined or multiplied to represent the loss of service (LOS) after a flooding hazard in the form of a (maximum) cost value as a measured value. As shown in Table 2 (and annex 1.4), a distinction is made between intervention, travel time, accident and socio-economic costs.

CS#4	**LOS as a Cost Value [10^3€]**
Intervention	90 000
Travel Time	170 000
Accident	535 000
Socio-Economic	10 200

Table 2. CS#4, LOS as Cost Value.

In the second step of the KRI and KRT determination, the current condition state of the CS#4 railway infrastructure and hazard prevention strategies are estimated for the influencing variables provided by the ETH. The total of 27 indicators for measuring flood resilience (F) are categorised hierarchically into three levels of detail. At the top level "0", a distinction is made between infrastructure (F1), environmental (F2) and organisational (F2) indicators. In the lowest level, the current condition state and with it the optimisability is defined for each of the 27 indicators. For each indicator, a number of possible values are available as a scale. The measure for the current indicator state is defined in CS#4 based on expert knowledge together with the infrastructure manager DB Netz (see annex 1.5).

For the final analysis of the service and intervention costs with regard to the indicators and targets, two further factors are taken into account. On the one hand, the intervention, travel time, accident and socio-economic cost value presented in in Table 2 are only considered if an increase in the value of the resilience indicator is likely to lead to lower or higher expected costs - the case of same expected costs is not taken into account (see annex 1.6). In addition, on the other hand, the influence of the individual indicators on the service is assessed by using differentiated weights / percentages according to the expert knowledge of the infrastructure managers (see annex 1.7).
As an interim, the following Table 3 shows the evaluation of the LOS as a cost value, taking into account the two weighting factors and depending on the resilience indicators and targets.

CS#4		Costs [10^3€]				
ID	**Indicator**	**Intervention**	**Travel time**	**Accident**	**Socio-econ.**	**Total**
F.1.1.1	Age / Age of replacement of safe shut down system			267.500	5.100	272.600
F.1.1.2	Condition state of infrastructure	40.500	76.500	240.750	4.590	362.340
F.1.1.3	Condition state of protective structures/systems	43.772	82.680	260.198	4.961	391.610
F.1.1.4	After-event condition state of infrastructure	45.000	85.000	267.500	5.100	402.600
F.1.1.5	After-event condition state of protective structures/systems	493	932	2.932	56	4.413
F.1.2.1	The possibility of using another means to satisfy transport demand		126.759		7.606	134.364
F.1.2.2	The number of possible existing alternative ways to deviate trains		85.000		5.100	90.100
F.1.2.3	The presence of a safe shutdown system		56.925		3.415	60.340
F.1.3.1	Compliance with the current flooding design code	38.597	72.905	229.435	4.374	345.310
F.1.3.2	Strength of construction material used	80.695	152.424	479.688	9.145	721.952
F.1.3.3	Adequate systems to reduce flooding	64.289	121.435	382.164	7.286	575.175
F.2.1.1	Accessibility	9.102				9.102
F.2.1.2	Extent of past damages due to hazards	38.750				38.750
F.2.1.3	Hazard zone	83.443	157.615	496.023	9.457	746.537
F.2.1.4	Duration of past down time due to hazards	13.500				13.500
F.2.1.5	Budget availability	70.179	132.561	417.177	7.954	627.870
F.2.1.6	Traffic	45.218	85.411	268.793	5.125	404.546
F.2.1.7	Hazardous goods traffic			26.519		26.519
F.3.1.1	The presence of a monitoring strategy	34.918	65.957	207.570	3.957	312.403
F.3.1.2	The presence of a maintenance strategy	70.658	133.465	420.023	8.008	632.155
F.3.1.3	The extent of interventions executed prior to the event	82.221	155.307	488.760	9.318	735.606
F.3.2.1	The presence of an emergency plan		19.675		1.181	20.856
F.3.2.2	Practice of the emergency plan		89.566		5.374	94.940
F.3.2.3	Review/update of the emergency plan		167.229	526.280	10.034	703.543
F.3.2.4	Expected time for tendering	61.741	116.622		6.997	185.360
F.3.2.5	Expected time for demolition	13.500	25.500		1.530	40.530
F.3.2.6	Expected time for construction	13.500	25.500		1.530	40.530

Table 3. CS#4, LOS as weighted Cost Values for the resilience indicators.

In the third and final step, the resulting LOS cost values of the resilience indicators in the hazard event of flooding are compared with the necessary cost values for implementing the resilience targets. The comparative costs and targets are also based on the expert knowledge of the railway infrastructure manager and take into account (if necessary) legal requirements as a minimum target. In terms of a cost-benefit analysis, the resilience indicators and targets shown in Table 4 provide by far the maximum benefit and are consequently selected as key resilience indicators and targets for CS#4 (the complete comparison can be found in annex 1.8).

CS#4 ID	Costs [10^3€]	Indicator	indicator state Actual / Target	Inter-vention [10^3€]	Travel time [10^3€]	Accident [10^3€]	Socio-econ. [10^3€]	Total [10^3€]	Net benefit [10^3€]
F.3.1.2		**The presence of a maintenance strategy**	Max	70.658	133.465	420.023	8.008	632.155	
	96.000		1 (Actual)	35.329	66.733	210.012	4.004	316.077	220.077
	128.000		2 (Target)	35.329	66.733	210.012	4.004	316.077	**408.155**
F.3.1.3		**The extent of interventions executed prior to the event**	Max	82.221	155.307	488.760	9.318	735.606	
	93.000		1 (Actual)	41.111	77.653	244.380	4.659	367.803	274.803
	100.000		2 (Target)	41.111	77.653	244.380	4.659	367.803	**542.606**
F.3.2.3		**Review/update of the emergency plan**	Max		167.229	526.280	10.034	703.543	
	25.000		1 (Actual)		83.615	263.140	5.017	351.772	326.772
	89.000		2 (Target)		83.615	263.140	5.017	351.772	**589.543**

Table 4. CS#4, Key Resilience Indicators, Condition State and Targets.

3.4. SELECTED FORESEE TOOLS AND ITS POSSIBLE CONNECTION WITH THE PREVIOUS KRI FOR CS#4

For the KRIs selected in the previous section 3.3., possible applications are now identified from the pool of developed FORESEE tools that support the implementation of the KRTs, which are also defined beforehand. In addition, the Flooding Bridge Model developed by the IVE is selected, presented and validated.

> It should be mentioned here that the majority of the ("available") FORESEE tools can only be analysed at the time of the present validation of CS#4 on the basis of the existing deliverables without practical application!

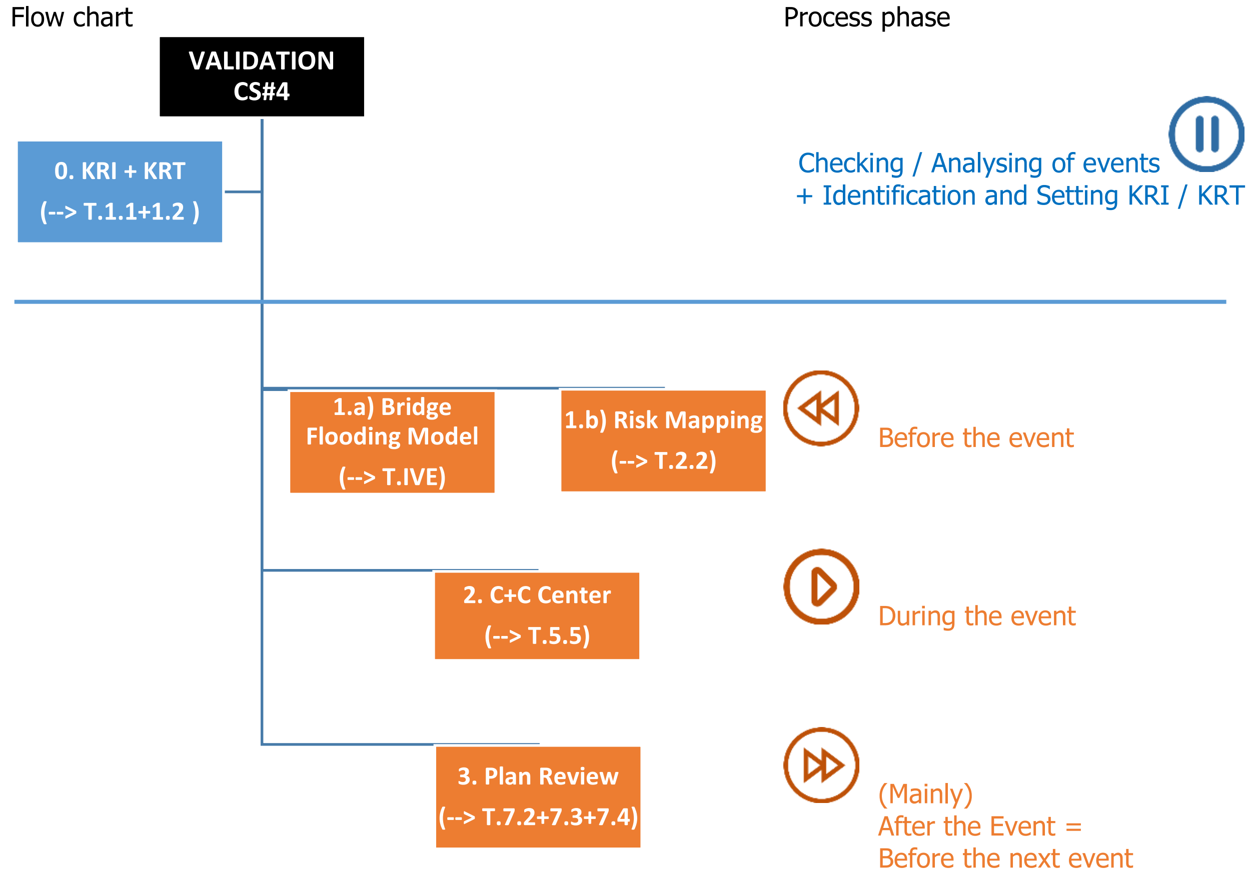
The FORESEE and IVE tools selected for CS#4 to improve the resilience of this railway infrastructure are the following:

Deliverable (D) / Tool (T)	Name	Developer	CS#4	
			Selected FORESEE tool	Corresponding KRI
T.IVE	Bridge Flooding Model	IVE	√	F.3.1.2 F.3.1.3 F.3.2.3
D.1.1	Resilience Guidelines to measure Level of Service & Resilience	ETHZ	→	*KRI Identification*
D.1.2	Set Targets	ETHZ	→	*KRI Identification*
D.1.3	Governance Module	UC		
D.2.5 / T.2.2	Risk Mapping	UC	√	F.3.1.2 F.3.1.3 F.3.2.3
D.2.4	Virtual modelling Platform	UEDIN		
D.2.5	Alerting SAS platform	TVUK		
D.3.4.1	Traffic Module	WSP		
D.3.4.2	Fragility and Vulnerability Analysis & Decision Support Module	RINA-C		
D.4.1	Flooding Methodology	IH		
D.4.4	Hybrid Data Fusion Framework	ETH		
D.5.1 / T.5.5	Command and Control Center	FRA	√	F.3.1.2 F.3.1.3 F.3.2.3
D.7.1 / T.7.1	Definition of framework: use cases, risk scenarios and analysis of impact	CEM	→	*Framework for T.7*
D.7.2 / T.7.2	Design, construction and remediation plans	CEM	√	F.3.1.2 F.3.1.3 F.3.2.3
D.7.3 / T.7.3	Operational and maintenance plans	TEC	√	F.3.1.2 F.3.1.3 F.3.2.3
D.7.4 / T.7.4	Management and contingency plans	ICC	√	F.3.1.2 F.3.1.3 F.3.2.3
Solutions catalogue				
D.4.2	Earthquake Platform	CEM		
D.3.3	Sustainable Drainage System	CEM		
D.4.7	Development of algorithms for the selection and definition of efficient and optimal actions	ETHZ/CEM		
D.3.5	New Family of PA-pavements	UC		
D.3.6	Smart & Integral slope stabilization system	UC		
D.4.4	SHM Algorithms	TEC		

Table 5. CS#4, FORESEE and IVE Tools incl. Solutions catalogue

4. SYSTEM VALIDATION IN CASE STUDY #4 BY CASE STUDY LEADER

The FORESEE tools selected in section 3.4 for resilience improvement are thematically clustered into the process phases before, during and after a possible flooding hazard.



Explanation

0. The infrastructure and event are digitized and identificated through Indicators, KRI and thresholds KRT as an evaluation benchmark

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1. a) The Tool "**Bridge Flooding Model**" analyses the condition of a railway track / -bridge model under the stress of flooding.
   b) The Tool "**Risk Mapping**" analyses the flooding hazard risks.
2. The Tool "**Command and Control (C+C) Center**" represents graphically the indicators and the thresholds.
3. *The Tool (or method) "Definition of framework" defines the use cases, risk scenarios and analysis of impact and potentials risks for*
   the Tool *(or method)* "**Plan Review**" which analyses, evaluates, updates and improves maintenance and contingency plans.

Figure 2. CS#4, FORESEE Tool Validation Flow chart and Process phase [IVE]

The tool validation is adapted on DIN EN 50126 for railway applications according to the procedure in the V-model. The linear approach in the V-Modell is basically divided into the phases of requirements analysis (**1.**), implementation (**2.**) and validation (**3.**).

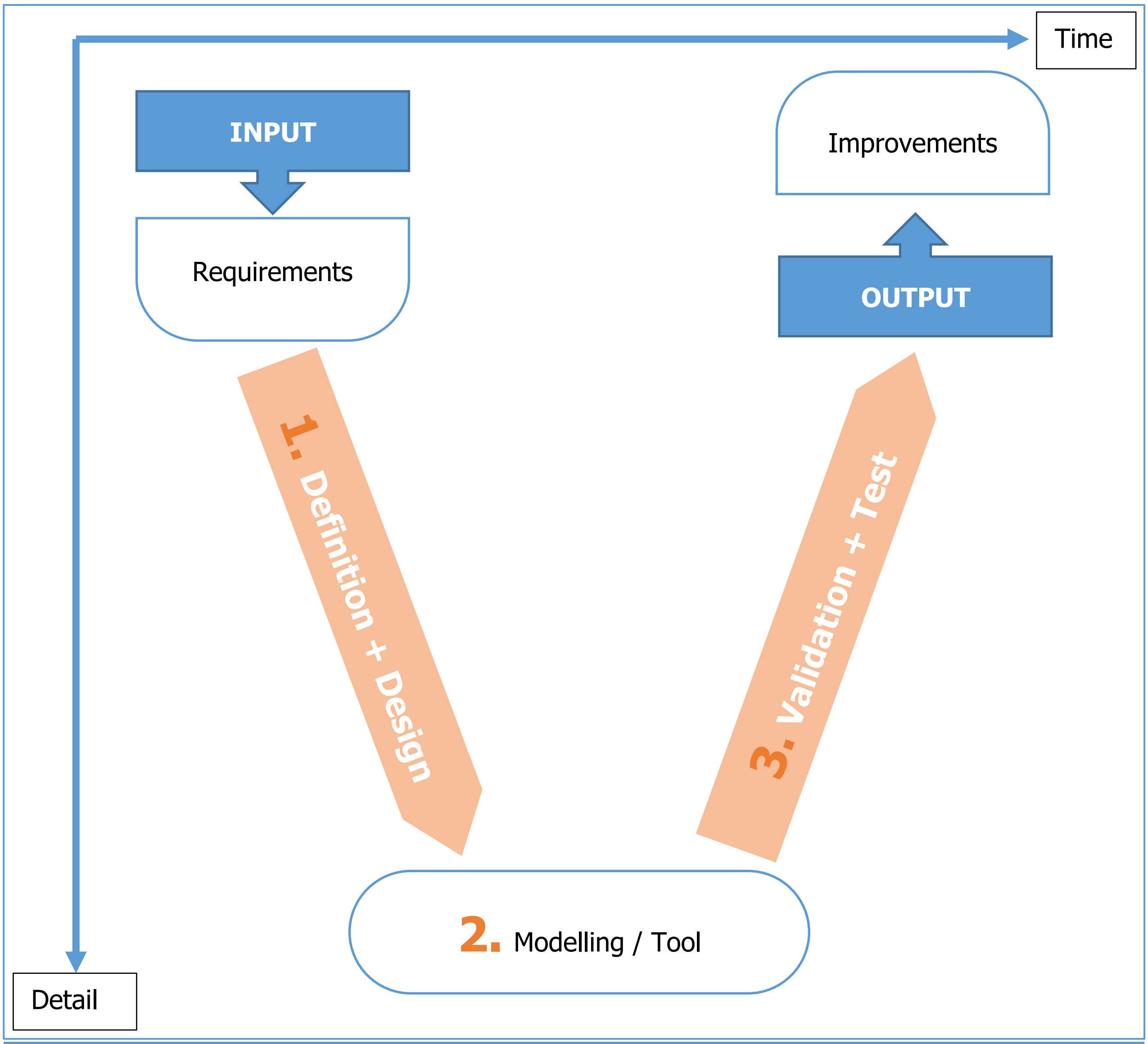


Figure 3. CS#4, FORESEE Tool Validation V-model [IVE]

In the following two sections, the FORESEE and IVE tools selected for resilience improvement in CS#4 are categorised according to the previously defined process phases and validated in accordance with the V-model. To this end, the input factors of the selected FORESEE and IVE tools are first described and clustered in section 5 in the form of a brief requirements analysis with an increasing level of detail. In the subsequent validation and test phase in section 6, the possible improvements through the selected FORESEE and IVE tools are determined. In this context, a comparison is also made with the current situation regarding hazard prevention and management plans from the infrastructure manager.

5. REQIREMENTS OF THE FORESEE TOOLS IN CS#4

As a basis for the subsequent validation and test phase, the selected FORESEE and IVE tools are briefly described below in the form of a requirements analysis as a comparable profile for each tool. All the information required for this is mainly taken from the deliverables provided. The subsequent validation and testing phase can therefore only be theoretical with a quantitative evaluation and not practical. For a clear structure, the tools are also assigned to their LC and process phases according to their future use.

In the following, additional indications for the requirements analysis of the individual tools are given. The summary of the comparative analysis of the collected requirements can be found in the subsequent Table 6.

5.1. Requirements of the IVE Tool "Bridge Flooding Model" (T.IVE)

The Bridge Flooding Model was developed at the University of Brunswick Institute of Transport, Railway Construction and Operation for the analysis of the condition of a railway track model under the stress of flooding in 2018[6].
The model focuses on the topic of flooding on railway bridges by using / re-modelling the example of the Elbe bridge Haemerten near Schoenhausen which was closed due to the Elbe floods in summer 2013. The target of the tool is to identify which damage is associated to which water level in order to develop measures which can reduce the probability or the intensity of the damage in the event of flooding. Various influences to damage predefined railway track components are used and assessed in this process.

5.2. Requirements of the FORESEE Tool "Risk Mapping" (T.2.2)

The requirements identified for the "Risk Mapping" tool only derive from the deliverable provided. The associated appendix shows that the tool provides specific outputs for the present CS#4 in the form of colour-coded risk and hazard maps (see annex 3.1).
These outputs are predefined by the tool developers and can therefore not be edited and applied independently for validation in this report for CS#4.

5.3. Requirements of the FORESEE Tool "Command and Control Center" (T.5.5)

The definition and design of the tool " Command and Control Center " are taken from the overall deliverable of the FORESEE toolkit, of which the Command and Control Center is an essential part. The actual outputs and deliverable of this tool are not yet available at the time of this validation, which complicates the subsequent requirements analysis and subsequent validation. In addition, the tool was demonstrated by the developers in a workshop on 18.11.2021 for the CSs involved and the individual presentations were handed out as a further basis of information.
For this CS#4, the tool developers have been provided with input data in the form of water levels for the river Elbe provided for the gauge stations Wittenberge, Tangermünde and Strombrücke in the period 1997 to 2018.

5.4. Requirements of the FORESEE Tools "Plan Review" (T.7.2, T.7.3, T.7.4)

The tools developed under T.7.x are grouped together for this validation, as the result is always an improvement and review of existing plans. For this tool collection, the most information is available in the framework of the requirements and input-output analysis compared to the other two selected FORESEE tools.
On the one hand, all individual deliverables are available for the theoretical part of the requirement definition. On the other hand, the T.7.2 tool is the only one of the selected tools that could be

tested in practice at the time of this validation. For this purpose, the tool developers provide form-based Excel tables, which the users (in this case the CS leaders) can fill with input values by their selves and determine the outputs independently (in this case Performance-based design resilience curves - see annex 3.2). In addition, the results were discussed together with the tool developers in a workshop on 21.07.2021 and the tool could be further improved.
In particular, the practical applicability compared to the purely theoretical analysis of the deliverable significantly increases the understanding of the tools and thus also the subsequent testability and rateability for real application and commercialisation.

CS#4	REQUIREMENTS	LC + Process PHASE
T.IVE Bridge Flooding Model	0. Source of information: IVE Project / Master thesis "Analysis of the condition of a rail under the stress of flooding"[6] 1. Definition of requirements Identify which of the following six defined influences have the potential to damage the assessed railway track components depending on the water level that its serviceability is no longer given and it can no longer be operated without repair work: • Undercutting of foundations • Softening of earthworks • Overflow of electrical installations • Effects of faster flowing water • Positional changes of the superstructure • Input of foreign substances into railway track components 2. Design of the technical system Small-scale CAD model of a railway bridge over a river with earth dams in front and behind it and one DN 1000 mm culvert. 3. Implementation of the outputs Outputs of the bridge model as CAD-file with visualisation of the water level (see annex 2.1)	Life Cycle phase: Operation & Maintenance, M Process phase: Before the event
T.2.2 Risk Mapping	0. Source of information: Deliverable 2.5 "Datasets/maps hot spots, risks and impact ranking" 1. Definition of requirements Identification and prioritising of areas of high vulnerability of disruption caused by extreme natural events. The tool provides a risk occurrence assessment for the most significant natural disasters (floods, landslides, and earthquakes). 2. Design of the technical system (Arc-) GIS-based software application 3. Implementation of the outputs Colour-coded risk and hazard maps as tif-file (see annex 2.2)	

CS#4	***REQUIREMENTS***	***LC + Process PHASE***
T 5.5 C+C Center	0. Source of information: *Deliverable 5.1 "1st version of the FORESEE toolkit" **(*→ *D.5.3 unavailable at the validation date*)** 1. Definition of requirements Situation Awareness (SA) Organizing big data of hazard events and summarize it, so that a human operator can handle it. Anomaly / Outlier Detection: Finding potentially dangerous outliers and anomalies from the normal state in Big Data of hazard events 2. Design of the technical system Software application based on an individual model and its data for each CS by using machine learning techniques in neural networks. 3. Implementation of the outputs Issuing automatized alerts when a situation diverges from the normal state and potential danger is arising. ***(*→ Practical implementation only available from the workshop with the tool developers on 29.11.2021, see annex 2.3)***	Life Cycle phase: Operation & Maintenance, M Process phase: During the event

CS#4	REQUIREMENTS	LC + Process PHASE
T 7.2 **T 7.3** **T 7.4** Plan Review	0. Source of information: Deliverable 7.2 (for T.7.2) "Design, construction and remediation plans" Deliverable 7.3 (for T.7.3) "Operational and Maintenance Plans" Deliverable 7.4 (for T.7.4) "Management and contingency plans" 1. Definition of requirements Developing three different Resilience Plans, that aim to reduce the impact and consequences of extreme events as well as to increase the ability to recover from them. 2. Design of the technical system Software based tools by using Microsoft Excel to calculate the criticality (T.7.2) and risk assessment with net-benefit analysis (T.7.3). Online study to determine the warning conditions and crowd behaviours; computer aided models for evacuation and fire simulations (T.7.4) 3. Implementation of the outputs Design, construction, and remediation plans: These plans will include new design approaches based on performance-based design procedures in order to adapt and increase the LOS and resilience of existing and future infrastructures. (see annex 2.4) Operational and maintenance plans: These plans will provide a process to determine optimal intervention programs to increase the level of reliability and service of the infrastructures. These plans will also include methodologies, systems, procedures and materials to increase factors such as safety, efficiency or productivity. Management and contingency plans: These plans will develop new and more effective contingency and communication strategies in order to enhance the resilience of the transport system. Communication plans are key to mitigate the adverse consequences, by instigating the evacuation of users in a safe way, as well as by helping recover the normal service as quickly as possible.	Life Cycle phase: Operation & Maintenance, M Process phase: (Mainly) After the Event / Before the next event

Table 6. CS#4, Requirements of the selected Foresee Tools

6. VALIDATION OF THE FORESEE TOOLS IN CS#4

Based on the previous requirements analysis and the additional indications, the validation of the selected FORESEE tools for the improvement of the defined KRI and KRT in CS#4 can be evaluated as following.

As explained in the previous section, for most tools only descriptions of incoming requirements and outgoing outputs are available from the deliverables at the current time. As the newly developed tools can currently only be applied theoretically instead of practically, the validation is only qualitative by comparison with the current situation in the form of a tendential rating of the improvement.

The structural approach is similar to the previous requirements analysis. First of all, additional indications are pointed out regarding the improvements through the use of the selected FORESEE tools. The comparison of the identified improvements with the current situation and the tools used is summarised in Table 7 which follows.

Furthermore, the validation will be critically assessed by checking the RAMSSHEEP and Resilience Principles in section 6.4 and by performing a net benefit analysis in section and presenting the resilience factors after using the selected FORESEE and IVE tools in section 6.5.

6.1. Improvements via the IVE Tool "Bridge flooding model" (T.IVE)

At DB, the requirements for constructions are statically defined in guidelines (germ. "Richtlinien (Ril)"). With regard to railway bridges, the guideline catalogue Ril 836 sets requirements for earthworks including culverts (see below). The design flood level is also defined here, which appears with a very low probability (for example, only every 100 years) and ensures serviceability. As a result of climatic changes, previously selected design flood levels often no longer fulfil today's requirements.

In order to improve this situation, the Bridge flooding model developed by IVE provides information on the possible serviceability or damage of individual railway track components depending on different water levels in the form of a small-scale simulation. Based on this, measures can be developed that increase resistance and resilience to flooding or, in the event of damage, enable a quick and inexpensive repair of track components.

To validate the Bridge flooding model, the Elbe bridge at Haemerten is simulated. The situation around the Elbe bridge Haemerten is chosen because of the damage caused by the Elbe flood in 2013 (see annex 2.1). The model consists of the parts earthworks, railway overpass, superstructure and one culvert.
The earthworks were essentially designed in reference to Ril 836: The greatest danger for earthworks can be derived from percolating water and soaking of the dam construction material. With the floods, the groundwater level will also rise, so that the groundwater can affect the earthwork from below. In this case, a filter layer is installed to protect the structure from rising water. In order to prevent damage caused by rising water, a filter layer of 0.50 m to 1.00 m thickness made of non-cohesive soils should always be installed in earthworks according to Ril 836 in floodplains. A protective layer of 0.50 m thick protective layer can be assumed for this model. This ensures that no water can rise from the subsoil into the structure.

In the model, the water level can be increased step by step to find out which damages are associated with which water level. In the model, a design flood level of +7.50 m is assumed for the Haemerten Bridge as a 100-year event. The water level is assumed because the levels of the peak wave of the Elbe flood in 2013 had levels between approx. +7.00 m and +10.00 m. In the model, operation is no longer possible from a water level of +3.30 m, as the level of the track in front of and behind the bridge has been reached. From water level +5.00 m the culverts are flooded and from water level +11.75 m the bridge or railway overpass itself.

The analysis of the probability and intensity of damage to the route parameters in relation to the water level indicates that the regular arrangement of culverts at the level of the design flood level is the most effective strategy for increasing resilience in the event of flooding. In the rare case of an extreme flood, the additional culverts could channel the additional water through the earthworks and thus prevent the water level from rising above the design flood level.

Another sensitive point is the control and safety technology (germ. "Leit- und Sicherungstechnik (LST)"). The LST includes train protection systems on the one hand and control systems on the other. The LST facilities are installed in the direct proximity of the tracks and are therefore also threatened by flood events under certain circumstances. In general, the LST systems require electrical energy for operation, which means that water entry can cause malfunctions. Damage to the LST in particular caused the track closing for months during the Elbe floods in 2013 due to repair work, whereas the earthworks and bridges were almost undamaged. For this reason, the water-resistant installation of electrical systems is ensured by the use of IP68-standard technology, such as Eurobalises for train protection, as a further measure to improve resilience.

6.2. Improvements via the FORESEE Tool "Risk Mapping" (T.2.2)

For the Risk Mapping tool developed in T.2.2, no comparable systems are available from the infrastructure manager itself. But the sources freely available from the national authorities and research institutions provide similar results to the colour-coded risk and hazard maps of the FORESEE Risk Mapping.

Therefore, a possible improvement as a result of T.2.2 is rated as equal in total (- with a slight tendency towards the tools that are currently freely usable online and provide more detailed outputs for the CS#4 local area in Germany).

6.3. Improvements via the FORESEE Tool "Command and Control Center" (T.5.5)

Regarding the validation of the improvements due to the newly developed Command and Control Center in T.5.5, there is the following divergence:

On the one hand, the tool offers completely new functions for Big-Data-based automated and early hazard detection and prevention. Currently, only procedures for acute reaction in the event of a hazard are available in the form of major incident management (germ. "Großstörungs-management"), but no automated machine learning methods are provided for predictive warning. Such tools are urgently needed with regard to current flood events as the one in July 2021 in south-west Germany and would mean a significant improvement in disaster control. On the other hand, at the time of this validation, the descriptions and outputs for the Command and Control Center are unfortunately not yet fully available.

A limited form of validation was organised during the workshop on 29.10.2021 with the help of the tool developers. Here it was demonstrated which input and output data the Command and Control

Center uses for CS #4 (see annex 2.3): The input variables are historical water levels provided by the Waterways and Shipping Authority (germ.: "Wasserstraßen- und Schifffahrtsverwaltung (WSV)") from the (near) gauge stations of interest Wittenberge, Tangermünde and Strombrücke in the period 1997 to 2018 (see annex 2.3 Figure 21). This data was supplemented with precipitation data from the German Weather Service (germ.: "Deutscher Wetterdienst (DWD)". The Elbe floods in summer 2013 also serve as a validation example here. The example of the determined output data shows that the dam break at Fischbeck on 10 June 2013 (in the immediate vicinity of the Haemerten railway bridge) is recognised as an anomaly by the Command and Control itself with the aid of the Big Data analysis and could have generated an automated warning (see annex 2.3 Figure 22).

Unfortunately, no further (smaller) comparative events for validation could be identified by the infrastructure managers in the scope of CS#4 in relation to railway track 6185 - for example, the massive Elbe flooding in the summer of 2002 did not affect this track section.

Nevertheless, the Command and Control represents a clear improvement on the current situation as a validation result, as in response to infrastructure managers no comparable system is available for the Big Data analysis of historical flooding events and the derivation of automatic real-time warnings for future hazards.

6.4. Improvements via the FORESEE Tools "Plan Review" (T.7.2, T.7.3, T.7.4)

Within the present validation for CS#4, the FORESEE tools for the Plan Review grouped under T.7.x offer the greatest potential for improvement in a more qualitative rating. In the following comparison, the examined core issues represent the positive opposite of the current situation in all cases. On top of that, the three FORESEE tools from group T.7.x match quite closely to the improvement of the KRI and KRT identified in section 3.3 for resilience enhancement.

CS#4	Comparison		
	ACTUALY / CURRENT TOOLS		FORESEE TOOL
Hazard Assessment	- Design flood according to guidelines	T.IVE Bridge Flooding Model	✓ Water level dependent assessment of usability
	- historically based but possibly outdated design parameters		✓ Updatable and adaptable simulation model
	- Use of equipment standards depending on track category		✓ Track component related improvement measures
Rating	→ "Improvement!		
Hazard Assessment	- Risk and hazard maps freely available and editable online e. g. from LHW or BAFG (→ see annex 4.1)	T.2.2 Risk Mapping	✓ Risk and hazard maps prepared and predefined by the tool developers (→ see annex 3.1)
	- National standardised maps according to 2007/60/EC with detailed information only for Germany or only selected regions within Germany		✓ large scale rapid risk analysis based on past real extreme natural events occurred all over Europe for a general overview
Rating	= "Equal."		
Hazard Management	No comparable tool(s) available!	T.5.5 C+C Center	✓ Automatized alerts
			✓ Predictive risk prevention
			✓ AI-based hazard analysis
Rating	→ "Improvement!"		
Hazard Planning	- Subjective, based on Expert knowledge	T.7.2 T.7.3 T.7.4 Plan Review	✓ Objective, science-based
	- Static, based on Eu-wide and national regulations		✓ Dynamic, adapted to more variables and simulations
	- Incomparable and fixed, no reference or benchmark for possible optimisation available		✓ Comparable and scalable, monetize resilience / LoS to identify optimal investment decisions
Rating	→ "Improvement!"		

Table 7. CS#4, Improvements via the selected FORESEE Tools

CS#4	Main result validated			
	T.IVE Bridge Flooding Model	**T.2.2 Risk Mapping**	**T.5.5 C+C Center**	**T.7.2 / T.7.3 / T.7.4 Plan Review**
Was this type of analysis made before FORESEE? How it was made?	The requirements for constructions are statically defined in guidelines (Ril). With regard to railway bridges, the guideline catalogue Ril 836 sets requirements for earthworks including culverts. The design flood level is also defined here.	For the Risk Mapping tool developed, no comparable systems are available from the infrastructure manager itself. But the sources freely available from the national authorities and research institutions provide similar results to the colour-coded risk and hazard maps of the FORESEE tool.	-There are currently no comparable tools available.-	The current hazard planning is mainly based on subjective expert knowledge and static Eu-wide and national regulations.
How does FORESEE improve the results/analysis previously made?	Compared to the currently used guidelines, this tool enables a water level dependent assessment of usability by means of an updatable and adaptable simulation model to assess the best technical improvements of railway track components.	Compared to the national standardised maps according to 2007/60/EC with detailed information only for Germany or only selected regions within Germany, the FORESEE tool applies large scale rapid risk analysis based on past real extreme natural events occurred all over Europe for a general overview.	Since no comparable tools currently are available or can be described, the Command and Control Center offers completely new functions for Big-Data-based automated and early hazard detection and risk prevention.	Compared to the current incomparable and fixed procedures, the FORESEE tools provide dynamic science-and simulation-based guidelines for the design and review of hazard planning.
How does this result increase the resilience of your infrastructure?	This tool contributes to enhance the presence of a maintenance strategy and the extent of interventions executed prior to the event.	This tool contributes to enhance the extent of interventions executed prior to the event based on a software-supported risk assessment.	This tool contributes to enhance the operational management and monitoring during a hazard event as well as an ad hoc updating possibility of emergency plans in real time.	This tool contributes to enhance the review / update of the emergency plans due to newly developed guidelines after and based on the experience of previous events before the next event.
How does this FORESEE result improve your infrastructure's management?	The added value of the tool is to develop protective measures (such as pasassage of water through earthworks or the water-resistant installation of electrical systems) to optimize track components which can reduce the probability or the intensity of the damage in the event of flooding.	The main added value of the tool is identification and prioritising of areas of high vulnerability of disruption caused by extreme natural events.	The added value of the tool is the ability to automate decisions from previous events for the present and future. This type of situational awareness organises large amounts of data and summarises them that a human operator can process.	Developing three different resilience plans, that aim to reduce the impact and consequences of extreme events as well as to increase the ability to recover from them.
If it was not made, How does this FORESEE result improve your infrastructure's management?	The validation of the tool's adoption indicates in this case as a result that the arrangement of additional culverts and water-resistant installation of electrical control and safety systems (LST) have the most potential technical benefit.	The tool provides a GIS-based risk occurrence assessment for the most significant natural disasters - not only floods, as in this case, but also landslides and earthquakes.	Finding potentially dangerous outliers and anomalies from the normal state in Big Data of hazard events in real time to generate automated alerts indicates the most potential technical benefits after the tool is implemented.	These plans will include new design approaches based on performance-based design procedures in order to adapt and increase the resilience of existing and future infrastructures, determine optimal intervention programs to increase the level of reliability and will develop new and more effective contingency and communication strategies in order to enhance the resilience of the transport system.
What cost/resource efficiencies you expect these tools/results to have on your day-to-day business? (e.g. 10%-20% decrease in working hours over the first year; reduction of maintenance costs (20%-25%), Return on Investment (ROI) – 10-15%, increase in productivity 25-30%)	The Bridge Flooding Model can help to identify optimal solutions to reduce the probability or intensity of damage and thus directly the maintenance costs. This is not about a realistic and detailed planning of individual measures, but about the development of fundamental strategies to avoid a repetition of the consequences of flooding like the one in summer 2013 at the Elbe with total damage to the infrastructure in the amount of 150 million euros.	The partial implementation of the Risk Mapping can help to identify potential hot spots through hazard assessment and prepare for future events, thereby reducing future maintenance and restoration costs.	The positive expected effects of the Command and Control Center are essential for this case as it is the only tool with the possibility of an ad hoc (during the event) update of emergency plans. In addition to this new and important safety feature, the real-time automatic warning can also save working hours in manual operation monitoring and thus increase productivity.	The instruments of the Plan Review primarily influence the maintenance, safety and satisfaction of the transport system. These positive effects in terms of break- and downtime reduction as well as productivity increase can also be achieved retrospectively (after the event / before the next one) by reviewing the construction and maintenance plans by using the FORESEE applications.

Table 8. CS#4, Main result validated

ADVA

6.3. RAMSSHEEP AND RESILIENCE PRINCIPLES FOR CS#4

The implementation of the selected FORESEE and IVE tools should make the infrastructure (more) resilient. In addition to the improvement rating described in the previous sections, the terms of RAMSSHEEP[8] and resilience principles[9] are introduced to validate resilience in an also qualitative but structured method.

Within the FORESEE project, resilience has been defined as the ability to continue to provide service if a hazard event occurs (compare D.1.1).

The well-known RAMS analysis (compare also DIN EN 50126[7]) can be seen as a risk concept that describes the primary performance and resilience of all the functions of a system. In comparison to a basic RAMS analysis, the new extended RAMSSHEEP analysis also takes more social, ecology and economy aspects into account. In this project resilience consists of four outcome-focused abilities which are described as resilience principles in the following. Since infrastructure resilience relies on these four concepts, improving any of them improves the overall resilience of the infrastructure (compare D.7.1).

In the following, it is qualitatively validated whether the FORESEE and IVE tools selected in CS#4 affect the RAMSSHEEP and resilience principles. In the summary Table 9, it is already obvious that there are only slight subtractions in the Risk Mapping Tool T.2.2, because in the form of the risk and hazard maps, it is primarily the process phase before the event that is influenced and not the event itself during the hazard.

CS#4 *TOOL*	*OUTPUT*												
	RAMSHEEP									RESILIENCE PRINCIPLES			
	R	A	M	S	S	H	E	E	P	*Robust-nes*	*Resources-fulness*	*Rapid-Recovery*	*Adaptability*
T.IVE Bridge Flooding Model	√	√	√	√	√	√	√	√	√	√	√	√	√
T.2.2 Risk Mapping	-	-	-	√	√	-	√	√	√	-	-	-	√
T.5.5 C+C Center	√	√	√	√	√	√	√	√	√	√	√	√	√
T.7.2 **T.7.3** **T.7.4** Plan Review	√	√	√	√	√	√	√	√	√	√	√	√	√

Table 9. CS#4, RAMSHEEP & Resilience Principles

For a better understanding, the terms and components of the RAMSHEEP and resilience principles are described again afterwards.

The acronym of **RAMSSHEEP** stands for [extracted from [8]]:

- **R**eliability:
  The probability that a system/structure will fulfil its function under certain circumstances and during a specific time interval.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **A**vailability:
  The probability that a system/structure can fulfil its function at any random moment under certain circumstances.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **M**aintainability:
  The probability that a system/structure fulfils its function under certain circumstances during maintenance within the established time frame.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **S**afety:
  The absence of unacceptable risks in the system/structure in terms of human injuries.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.2.2 Risk Mapping, T.7.x Plan Review**

- **S**ecurity:
  The guarantee of a safe system/structure with respect to vandalism, terrorism and human errors (including all kinds of sabotage of the system).
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.2.2 Risk Mapping, T.7.x Plan Review**

- **H**ealth:
  The feeling of good health with respect to the physical, mental and societal views. This does not implement if an individual is feeling well or not (subjective argument).
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **E**nvironment:
  To meet certain requirements which have been secured in Environmental Acts one suffices the rules of a good and clean environment. The environment can be seen as a physical environment wherein human life is even possible.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.2.2 Risk Mapping, T.7.x Plan Review**

- **E**conomics:
  The Cost-Benefit will form a central position in the aspect of Economy. The increase the performance of the RAMS aspects will lead also to an increase of the direct costs. A serious reflection in terms of a Cost-Benefit Analysis must be made to provide more insight for an economical choice.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.2.2 Risk Mapping, T.7.x Plan Review**

- **P**olitics:
  A rational decision has to be made based on the aspects above, including also some political aspects.
  ➔ **T.IVE BFM, T.5.5 C+C Center, T.2.2 Risk Mapping, T.7.x Plan Review**

The **Resilience Principles** stand for [extracted from D.7.1]:

- **Robustness:**
  This concept refers to the ability for transport infrastructure to overcome and absorb disruptive event shocks and continue operating. This concept is mainly oriented toward the physical parts of the infrastructure. At first sight, robustness could be misunderstood if it is assimilated simply as "resistance" and only translated into designing structures that are strong enough to resist a shock. Nevertheless, this concept goes beyond being able to stand the hazard's punch; robustness could also be translated to redundant systems, so if something important stops working there is a substitute or an alternative path that would allow to keep operating. Robustness also relates to reliability: the capability to operate under a range of conditions. Finally, robustness also entails investing and maintaining elements of critical infrastructures.
  - ➔ **T. IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **Resourcefulness:**
  This concept refers to the ability to skilfully manage a disruption as it unfolds. Resourcefulness might depend on the resources available to overcome difficulties, but it is primarily people oriented as it is related for example to prioritizing what should be done, how to communicate an emergency message, how to manage people to evacuate the network, etc. This includes financial, social, physical, technological, information and environmental resources. This ability relies more on people, rather than on the infrastructure itself.
  - ➔ **T. IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **Rapid recovery:**
  This concept refers to the ability to get "back to normal" as quickly as possible after a disruption. It is oriented towards people as well as towards the infrastructure. With regards to people, this concept entails to carefully develop contingency plans, emergency plans, and counting with the right people and resources at the right place. With regards to the infrastructure orientation, it entails designs and constructions that provide the ability to recover from disruptions (e.g.: modular infrastructures that enables single components to be easily replaced, minimising the disruption or the loss of service, or flexible designs, such as bidirectional roads, that enable operators to temporarily adapt better to the required recuperation restrictions).
  - ➔ **T. IVE BFM, T.5.5 C+C Center, T.7.x Plan Review**

- **Adaptability:**
  More than the quality of being able to adjust to new conditions, which is already included in the rapid recovery ability, this concept refers to the ability to absorb new lessons that can be drawn from past events to improve resilience. Engineers, emergency planners, transport operators, owners, etc. are able to learn from experience and past failures. This concept is oriented towards people as it involves revising plans, procedures, and introducing new tools and technologies to improve the other three resilience concepts (robustness, resourcefulness, and rapid recovery). Learning from the past will allow to be better prepared for the next crisis.
  - ➔ **T. IVE BFM, T.2.2 Risk Mapping T.5.5 C+C Center, T.7.x Plan Review**

6.4. NET BENEFIT ANALYSIS AND RESILIENCE VALIDATION IN CS#4

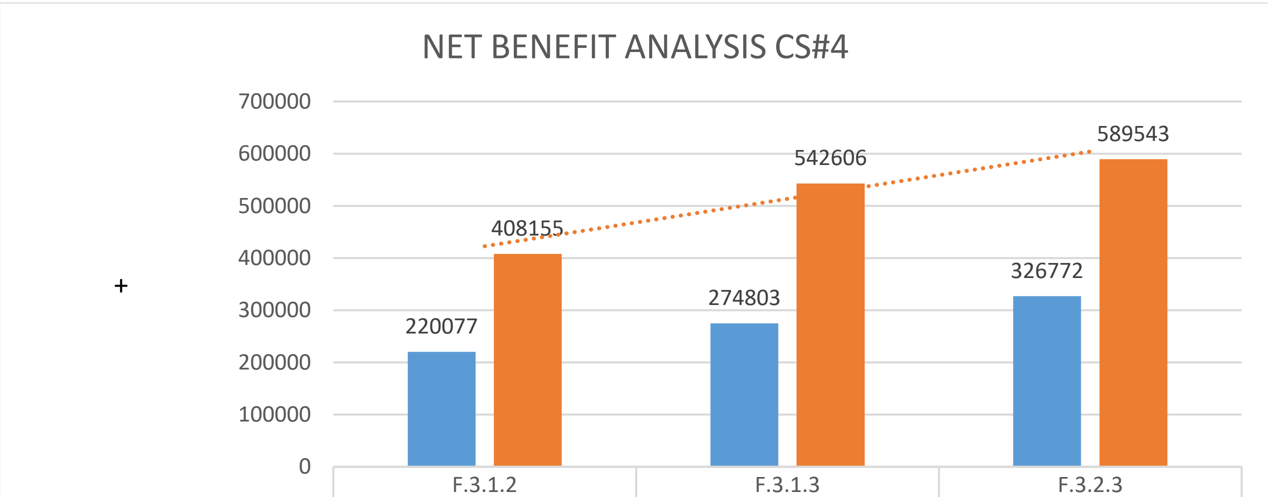
After the possible improvements of the current situation and resilience of the infrastructure are presented qualitatively in the previous sections, a quantitative validation will now also be conducted.

For this purpose, the monetisation of the resilience indicators and targets in the form of the LoS as a Cost Value from Section 3.3, Table 4 is used again and validated by analysing the net benefit costs. It is assumed that for the identified **key resilience indicators**

- **F.3.1.2** **The presence of a maintenance strategy**
- **F.3.1.3** **The extent of interventions executed prior to the event**
- **F.3.2.3** **Review/update of the emergency plan**

the key resilience targets (increase by one stage in each case) will be achieved in CS#4 through the use of the selected **FORESEE and IVE tools**

- **T.IVE** **Bridge Flooding Model**
- **T.2.2** **Risk Mapping**
- **T.5.5** **Command and Control Center**
- **T.7.2.** **Design, construction and remediation plans**
- **T.7.3.** **Operational and maintenance plans**
- **T.7.4.** **Management and contingency plans**



	F.3.1.2	F.3.1.3	F.3.2.3
Net benefit (Actual) [1k €]	220077	274803	326772
Net benefit (Target) [1k €]	408155	542606	589543

Figure 4. CS#4, Net benefit analysis [IVE]

Figure 4 demonstrates that the net benefit of LoS costs and thus the resilience of the infrastructure to hazards can be almost **doubled** in total compared to the current state if the set resilience targets are fulfilled.

7. POTENTIAL IMPROVEMENTS OF THE FORESEE TOOLS FOR REAL COMMERCIALISATION

After the initial qualitative review based on the V-model and the subsequent quantitative review with regard to a net benefit analysis, the last step of the validation will be to estimate and evaluate possible improvements of the FORESEE and IVE tools for a real commercialisation. The necessary boundary conditions and comparative values are determined by the use of D.8.6.
The following values are estimations and have been determined by expert knowledge in cooperation with infrastructure managers. The actual comparison of the improvements as a result of the selected FORESEE tools described in section 6 shows that in CS#4 the most significant potential for optimisation at the time of the study is provided by the Plan Review applications in T.7.x. These instruments of the Plan Review primarily influence the maintenance, safety and satisfaction of the transport system (see Table 10)

	FORESEE ESTIMATED POSITIVE IMPACTS	CS#4 RATING
Return of the investment	6 – 9 %	√
Reduction of maintenance costs	15 – 20 %	√
Breakdowns reductions	65 – 70 %	-
Increase in productivity	25 – 30 %	-
Downtime reduction	20 – 30 %	-
Significant User Safety and satisfaction of the transport system		√

Table 10. CS#4, FORESEE Estimated Positive Impacts.

The positive effects in terms of break- and downtime reduction as well as productivity increase can also be achieved retrospectively (after the event / before the next one) by reviewing the construction and maintenance plans by using the applications of T.7.x. However, the Command and Control Center specified in T.5.5 would be essential for this cases during the event. Unfortunately, too less information is available on T.5.5 according to section 6 for a validation at the current time of the investigation. Last but not least, the Bridge Flooding Model in T.IVE can help to identify optimal solutions to reduce the probability or intensity of damage and thus directly the maintenance costs. This is not about a realistic and detailed planning of individual measures, but about the development of fundamental strategies to avoid a repetition of the consequences of flooding like the one in summer 2013 at the Elbe in the examination area of CS#4.

In any case, the FORESEE and IVE tools for a real use in CS#4 would have to be adapted even more to the special boundary conditions of railway infrastructure compared to other modes of transport. With regard to a plan review, the specific needs of the infrastructure manager must be taken into account even more. Therefore, a tailor-made implementation of the FORESEE and IVE tools is necessary.

FORESEE SOLUTIONS IMPLEMENTATION-LEVEL	INVESTMENT COST RANGE	CS#4 RATING
Full implementation	€120,000 - €200,000	-
Partial implementation	€50,000 - €95,000	-
Tailored implementation	€70,000 - €150,000	√

Table 11. CS#4, FORESEE solutions implementations-level.

8. CONCLUSION

The present validation concludes that an implementation of selected FORESEE tools can increase the resilience of the railway infrastructure considered in CS#4 and that a real implementation could be beneficial. This is clarified in the present deliverables as follows:

By defining the LoS in section 3.3, the current state of the infrastructure studied in CS#4 can be monetised. On this base the optimal indicators (KRI) and targets (KRT) for improvement can be found. For the possible achievement of the set targets, various software and process tools newly developed in the FORESEE project are presented in section 3.4., of which the tools for the Bridge Flooding Model T.IVE, Risk mapping T.2.2, Command and Control Center T.5.5 and Plan Review (T.7.x) are most correspondable for the present case.

The system validation described structurally in section 4 based on a V-model in the form of a requirements analysis of the inputs in section 5 and validation of the improvements through the outputs in section 6 identifies the most significant issue of the present study:

Most of the (selected) FORESEE tools can only be evaluated theoretically on the basis of the existing deliverables. The practical application, which is essential for a better understanding of the tools, can only be carried out to a very limited extent at the present status (e. g. only with T.7.2), which complicates the comprehension of the outputs and improvements of the developed tools. Therefore, only a qualitative form of validation is possible. Here, the Plan Review tools in T.7.x overall provide the most potential for improvement for CS#4. If there is too little information available, as in the case of the Command and Control Center in T.5.5, unfortunately no profound validation can be performed at all.

Assuming that the selected FORESEE tools can help to achieve the defined improvements of the indicator state one level up, the consideration of RAMSHEEP and resilience principles in section 6.3 as well as the net benefit analysis of the LoS in section 6.4 show that the resilience of the infrastructure considered in CS#4 can be increased by using the selected FORESEE and IVE tools in general.

As a recommendation, the present validation should be repeated or supplemented when sufficient information is available on all FORESEE and IVE tools so that they can be tested more practically with own use cases and input data. This would probably increase the benefit and the potential for a real commercialisation in section 7 but especially the understanding of the newly developed FORESEE and IVE tools considerably.

ANNEX 1. IDENTIFICATION OF KRI AND KRT

1.1 Extracts from the RailSys® traffic simulation model as comparatives

					Berlin Spandau - Oebisfelde (Tr. 1)				Oebisfelde - Berlin Spandau (Tr. 2)				Spandau-Oebisfelde (Tr. 1)				Oebisfelde-Spandau (Tr. 2)			
Scenario	Max. Speed Infra Track 1 [km/h]	Max. Speed Infra Track 2 [km/h]	Max. Speed PT [km/h]	Max. Speed FT [km/h]	Travel time PT [s]	Travel time PT [hh:mm:ss]	Travel time FT [s]	Travel time FT [hh:mm:ss]	Travel time PT [s]	Travel time PT [hh:mm:ss]	Travel time FT [s]	Travel time FT [hh:mm:ss]	Number of PT Trains [N]	Number of FT Trains [N]	Interlinked level of occupation [%]	average headway [s]	Number of PT Trains [N]	Number of FT Trains [N]	Interlinked level of occupation [%]	average headway [s]
1	250	250	250	100	2436	0:40:36	5658	1:34:18	2400	0:40:00	5658	1:34:18	30	18	63,2	414	30	18	64,7	424
2	160	160	160	100	2501	0:41:41	5658	1:34:18	2465	0:41:05	5658	1:34:18	30	18	62,2	407	30	18	63,4	415
3	160	80	160/80	100/80	2501	0:41:41	5658	1:34:18	2588	0:43:08	5695	1:34:55	30	18	62,3	408	30	18	62,8	411
4	120	80	120/80	100/80	2550	0:42:30	5658	1:34:18	2588	0:43:08	5695	1:34:55	30	18	62,1	406	30	18	62,8	411
5	80	80	80	80	2624	0:43:44	5696	1:34:56	2588	0:43:08	5695	1:34:55	30	18	62,6	410	30	18	62,8	411
6	80	0	80/0	80/0	2624	0:43:44	5696	1:34:56	2588	0:43:08	5695	1:34:55	60	36	118,1	447	-	-	-	-
7	60	60	60	60	2686	0:44:46	5766	1:36:06	2650	0:44:10	5762	1:36:02	30	18	64,5	423	30	18	63,3	414
8	60	0	60/0	60/0	2686	0:44:46	5766	1:36:06	2718	0:45:18	5762	1:36:02	60	36	129,4	491	-	-	-	-
9	20	20	20	20	3102	0:51:42	6234	1:43:54	3066	0:51:06	6227	1:43:47	30	18	91,6	600	30	18	86,1	564
10	20	0	20/0	20/0	3102	0:51:42	6234	1:43:54	3131	0:52:11	6227	1:43:47	60	36	197,9	750	-	-	-	-

Data set by IVE for different scenarios

Data from railway operations model

Figure 5. CS#4, Extracts from the traffic simulation model [IVE]

1.2 Event-independent inputs to measure the service

Inputs	Symbol	Value
Annual cost of regular maintenance [€/m]	Cm	5
Length of the infrastructure [m]*	Li	150000
N. of people traveling per day	P	10000
N. of people traveling per work in a day	Pw	7000
N. of people traveling per leisure in a day	Pl	3000
Goods travelling per day [trains]	G	10
Cost of work time [€/min]	Cwt	2
Cost of leasure time [€/min]	Clt	1
Socio economic costs per person [€/p.p.]	SECp	0
Socio economic costs for goods [€/train]	SECg	2
Impact of injuries per person [10^3€/p.p.]	Ip	10
Impact of death per person [10^3€/p.p.]	Dp	5000
Speed limit (average between weather condition) [km/h]*	Sl	125
Delay per person per day with no hazard event [min/p.u.]	Dpud_0	5
Delay per freight train per day with no hazard event [min/p.u.]	Dfud_0	5
Property damage probability with no hazard event [%]	Ppd_0	1
Injury probability with no hazard event [%]	Pi_0	1
Death probability with no hazard event [%]	Pd_0	0,01
Property damage per person in case of accident [10^3€/p.p.]	PDp_0	0,5
*Real Data		

Figure 6. CS#4, Event-independent inputs to measure the service [ETH / IVE]

1.3 Event-dependent inputs to measure the service

Inputs	Symbol	Flooding [_f]
Cost of intervention after the event [€/m]	Ci	600
Delay per person per day after an event [min/p.u.]	Dpud	100
Delay per freight train per day after an event [min/p.u.]	Dfud	100
Days to recover in case of accident	D	100
Property damage probability per event [%]	Ppd	50
Injury probability per event [%]	Pi	10
Death probability per event [%]	Pd	1
Property damage per person in case of accident [10^3€/p.p.]	PDp	5

Figure 7. CS#4, Event-dependent inputs to measure the service [ETH / IVE]

1.4 Loss of Service after a flooding hazard as a cost value

Impact level 1	Symbol	Description	Impact level 2	Symbol	Costs [10^3€]			
					Estimate	Computation	Estimate	Computation
Interventions	Ii_f	The impact of executing interventions			90000	(Ci_f*Li)	90000	(Ii_f)
Travel time	Itt_f	The impact of the additional travel time on passengers	Work	Itt.w_f	140000	(Pw*Dppd_f*Cwt*D_f)	170000	(Itt.w_f+Itt.l_f)
			Leisure	Itt.l_f	30000	(Pw*Dppd_f*Clt*D_f)		
Safety	Is_f	The impact on the users and affected public due to the user being involved in an accident	Property damage	Is.pd_f	25000	((Ppd_f/100)*PDp_f*P)	535000	(Is.pd_f+Is.i_f+Is.d_f)
			Injury	Is.i_f	10000	((Ppd_f/100)*Ip_f*P)		
			Death	Is.d_f	500000	((Ppd_f/100)*Dpp_f*P)		
Socio-economic activities	Ise_f	The contribution of the road operation to socio-economic development, i.e. the socio and economical costs of people and goods not being able to travel	Persons	Ise.p_f	10000	(P*Dppd_f*D_f*SECp)	10200	(Ise.p_f+Ise.g_f)
			Goods	Ise.g_f	200	(P*Dppd_f*D_f*SECg)		
Total					805200	(Ii_f+Itt_f+Is_f+Ise_f)		

Figure 8. CS#4, Loss of Service after a flooding hazard as a cost value [ETH / IVE]

1.5 Scale and measures of resilience indicators for flooding

ID	Level 0	ID	Level 1	ID	Indicator	Scale	Measure	Impact				Meaning of the measured Value for the current indicator state
								Intervention	Travel time	Accident	Socio-econ.	
F.1	Infrastructure	F.1.1	CS of the infrastructure	F.1.1.1	Age / Age of replacement of safe shut down system	3	1			X	X	1 of 3 = "> 50%, < 80% of expected life time achieved"
				F.1.1.2	Condition state of infrastructure	5	1	X	X	X	X	1 of 5 = "Not known. No information is available on the condition state of the infrastructure."
				F.1.1.3	Condition state of protective structures/systems	5	3	X	X	X	X	3 of 5 = "Good (A condition in which it is unlikely that the protective structures/systems would collapse under normal traffic loads over the next 20 years)"
				F.1.1.4	After-event condition state of infrastructure	3	3	X	X	X	X	3 of 3 = "In service and no repairs necessary"
				F.1.1.5	After-event condition state of protective structures/systems	3	1	X	X	X	X	1 of 3 = "Out of service, requires repair/rebuilding"
		F.1.2	Protection measures	F.1.2.1	The possibility of using another means to satisfy transport demand	2	2		X		X	2 of 2 = "Multiple alternative means"
				F.1.2.2	The number of possible existing alternative ways to deviate trains	2	2		X		X	2 of 2 = "Multiple alternative ways"
				F.1.2.3	The presence of a safe shutdown system	1	1		X		X	1 of 1 = "Safe shut down"
		F.1.3	Preventive measures	F.1.3.1	Compliance with the current flooding design code	2	2	X	X	X	X	2 of 2 = "Above current regulation "
				F.1.3.2	Strength of construction material used	3	1	X	X	X	X	1 of 3 = "Resistance C"
				F.1.3.3	Adequate systems to reduce flooding	1	0	X	X	X	X	0 of 1 = "Absence of the system"
F.2	Environment	F.2.1	Context	F.2.1.1	Accessibility	3	1	X				1 of 3 = "Accessible with truck mounted crane"
				F.2.1.2	Extent of past damages due to hazards	3	1	X				1 of 3 = "Serious damage"
				F.2.1.3	Hazard zone	3	0	X	X	X	X	0 of 3 = "High"
				F.2.1.4	Duration of past down time due to hazards	2	1	X				1 of 2 = "1-2 weeks"
				F.2.1.5	Budget availability	2	1	X	X	X	X	1 of 2 = "Enough for >50%, <100% of the intervention"
				F.2.1.6	Traffic	3	1	X	X	X	X	1 of 3 = ">20%, <50% of capacity "
				F.2.1.7	Hazardous goods traffic	2	1			X		1 of 2 = "Rare dangerous goods"
F.3	Organization	F.3.1	Pre-event activities	F.3.1.1	The presence of a monitoring strategy	2	1	X	X	X	X	1 of 2 = "Periodic monitoring of the condition state"
				F.3.1.2	The presence of an maintenance strategy	2	1	X	X	X	X	1 of 2 = "Only responsive interventions conducted"
				F.3.1.3	The extent of interventions executed prior to the event	2	1	X	X	X	X	1 of 2 = ">50%, <80% of the benchmark budget"
		F.3.2	Post event activities	F.3.2.1	The presence of an emergency plan	2	1		X		X	1 of 2 = "Generic plan"
				F.3.2.2	Practice of the emergency plan	4	1		X		X	1 of 4 = "1 exercise every > than 2 years"
				F.3.2.3	Review/update of the emergency plan	2	1		X	X	X	1 of 2 = "<5 years ago"
				F.3.2.4	Expected time for tendering	3	0	X	X		X	0 of 3 = "> 1 year"
				F.3.2.5	Expected time for demolition	3	1	X	X		X	1 of 3 = "> 8 months and < 1 year"
				F.3.2.6	Expecetd time for construction	3	1	X	X		X	1 of 3 = "> 1 year and < 1.5 year"
						71	31					

Figure 9. CS#4, Scale and measures of resilience indicators for flooding [ETH / IVE]

1.6 Impact factor for Increasing the value of the resilience indicator

ID	Level 0	ID	Level 1	ID	Indicator	Motivation (i..e the indicator is selected for the case study because...)	Likely effect on measures of service and intervention costs An increase in the value of the resilience indicator it is likely to result in ... expected costs				The... the resilience
							Intervention	Travel time	Accidents	Socio-econ. activities	
F.1	Infrastructure	F.1.1	CS of the infrastructure	F.1.1.1	Age / Age of replacement of safe shut down system	The older the safe shut down system, the more obsolete their performances and therefore the higher is the probability of accidents due to a lack of stopping the traffic in case of a flooding	*the same*	*the same*	**higher**	**higher**	lower
				F.1.1.2	Condition state of infrastructure	The better the condition state of the infrastructure, the lower is the probability of the infrastructure to be damaged following up with a flooding event and the lower the consequences are in case it occurs.	**lower**	**lower**	**lower**	**lower**	higher
				F.1.1.3	Condition state of protective structures/systems	The more deteriorated the protection barriers, the lower is the probability that it can provide the LOS for which it was designed, and the higher the expected consequences are in case a flooding event	**lower**	**lower**	**lower**	**lower**	higher
				F.1.1.4	After-event condition state of infrastructure	The expected condition of the infrastructure after an event, is an indication of its ability to withstand the floodig and, therefore, of higher resiliency.	**lower**	**lower**	**lower**	**lower**	higher
				F.1.1.5	After-event condition state of protective structures/systems	The expected condition of the protective structures/systems after an event, is an indication of its ability to withstand the floodig and, therefore, of higher resiliency.	**lower**	**lower**	**lower**	**lower**	higher
		F.1.2	Protection measures	F.1.2.1	The possibility of using another means to satisfy transport demand	The possibility of re-routing people and goods using temporary means reduces the consequences of an infrastructure being out of service.	*the same*	**lower**	*the same*	**lower**	higher
				F.1.2.2	The number of possible existing alternative ways to deviate trains	The possibility of re-routing the train traffic through other existing paths reduces the consequences of an infrastructure being out of service after a flooding event.	*the same*	**lower**	*the same*	**lower**	higher
				F.1.2.3	The presence of a safe shutdown system	The presence of a safe shut down system reduces the consequence of a flooding event.	*the same*	**lower**	*the same*	**lower**	higher
		F.1.3	Preventive measures	F.1.3.1	Compliance with the current flooding design code	The more recent the flooding regulation's level of compliance, the lower the impact of a flooding event on the infrastructure.	**lower**	**lower**	**lower**	**lower**	higher
				F.1.3.2	Strength of construction material used	The stronger the construction material of an infrastructure, the higher ist ability to withstand the effect of an a flooding event.	**lower**	**lower**	**lower**	**lower**	higher
				F.1.3.3	Adequate systems to reduce flooding	The adequate functioning of systems to reduce flooding effects prevent the rail section to be hit in case of flooding.	**lower**	**lower**	**lower**	**lower**	higher
F.2	Environment	F.2.1	Context	F.2.1.1	Accessibility	The more the rail is accessible, the less expensive it is to conduct the intervention on it.	**lower**	*the same*	*the same*	*the same*	higher
				F.2.1.2	Extent of past damages due to hazards	The higher the past damages connected to earthquakes, the higher is its probability of suffering strong events also in the future.	**higher**	*the same*	*the same*	*the same*	lower
				F.2.1.3	Hazard zone	The more the rail is in a zone exposed to frequent and high magnitude floodings, the higher is its probability of being hit.	**higher**	**higher**	**higher**	**higher**	lower
				F.2.1.4	Duration of past down time due to hazards	The highest the number of days per year that earthquakes have interrupted the service, the higher is its probability of suffering interruptions also in future.	**higher**	*the same*	*the same*	*the same*	lower
				F.2.1.5	Budget availability	The higher the budget availability is, the higher is the probability and effectiveness of the executing the interventions to recover the disruption of a flooding event.	**lower**	**lower**	**lower**	**lower**	higher
				F.2.1.6	Traffic	The more traffic is on a rail the higher is the exposition to consequences in case a flooding event occurs.	**higher**	**higher**	**higher**	**higher**	lower
				F.2.1.7	Hazardous goods traffic	The presence of dangerous goods transported on the rail raises the consequences in case of accident.	*the same*	*the same*	**higher**	*the same*	lower
F.3	Organization	F.3.1	Pre-event activities	F.3.1.1	The presence of a monitoring strategy	The presence of a monitoring plan raises the awareness of the IM on the state of the rail line and his preparedness to react when necessary. A prepared IM is trusted to be more reactive and reduces the consequences of a flooding event on traffic.	**lower**	**lower**	**lower**	**lower**	higher
				F.3.1.2	The presence of an maintenance strategy	The presence of an intervention strategy lowers the probability that an infrastructure ends up in a deteriorated state.	**lower**	**lower**	**lower**	**lower**	higher
				F.3.1.3	The extent of interventions executed prior to the event	The more it is spent on regular maintenance before the event, the lower is the probability that the infrastructure will suffer a drop in LOS following up with a flooding event.	**higher**	**higher**	**higher**	**higher**	lower
		F.3.2	Post event activities	F.3.2.1	The presence of an emergency plan	The presence of an emergency plan reduces the time between the occurrence of a flooding event and the moment an IM reacts.	*the same*	**lower**	*the same*	**lower**	higher
				F.3.2.2	Practice of the emergency plan	The regular exercise of the emergency plan raises the ability of the IM to apply it when needed, reducing the time for execution and the risk of failure.	*the same*	**lower**	*the same*	**lower**	higher
				F.3.2.3	Review/update of the emergency plan	The longer the time since the last review/update of the emergency plan the less the plan is trusted to be effective.	*the same*	**higher**	**higher**	**higher**	lower
				F.3.2.4	Expected time for tendering	The longer the time for the for public tender the longer the infrastructure stays out of service.	**higher**	**higher**	*the same*	**higher**	lower
				F.3.2.5	Expected time for demolition	The longer the time for demolition the longer the infrastructure stay out of service.	**higher**	**higher**	*the same*	**higher**	lower
				F.3.2.6	Expecetd time for construction	The longer the time for construction the longer the infrastructure stay out of service.	**higher**	**higher**	*the same*	**higher**	lower

Figure 10. CS#4, Impact factor for Increasing the value of the resilience indicator [ETH / IVE]

1.7 Impact factor for using differentiated resilience weights

Impact on the service per indicator			Costs [10^3€]				
Impact on the service	ID	Indicator	Intervention	Travel time	Accident	Socio-econ.	Total
50%	F.1.1.1	Age / Age of replacement of safe shut down system	45.000	85.000	267.500	5.100	402.600
45%	F.1.1.2	Condition state of infrastructure	40.500	76.500	240.750	4.590	362.340
49%	F.1.1.3	Condition state of protective structures/systems	43.772	82.680	260.198	4.961	391.610
50%	F.1.1.4	After-event condition state of infrastructure	45.000	85.000	267.500	5.100	402.600
1%	F.1.1.5	After-event condition state of protective structures/systems	493	932	2.932	56	4.413
75%	F.1.2.1	The possibility of using another means to satisfy transport demand	67.108	126.759	398.917	7.606	600.389
50%	F.1.2.2	The number of possible existing alternative ways to deviate trains	45.000	85.000	267.500	5.100	402.600
33%	F.1.2.3	The presence of a safe shutdown system	30.137	56.925	179.146	3.415	269.623
43%	F.1.3.1	Compliance with the current flooding design code	38.597	72.905	229.435	4.374	345.310
90%	F.1.3.2	Strength of construction material used	80.695	152.424	479.688	9.145	721.952
71%	F.1.3.3	Adequate systems to reduce flooding	64.289	121.435	382.164	7.286	575.175
10%	F.2.1.1	Accessibility	9.102	17.193	54.106	1.032	81.432
43%	F.2.1.2	Extent of past damages due to hazards	38.750	73.195	230.348	4.392	346.684
93%	F.2.1.3	Hazard zone	83.443	157.615	496.023	9.457	746.537
15%	F.2.1.4	Duration of past down time due to hazards	13.500	25.500	80.250	1.530	120.780
78%	F.2.1.5	Budget availability	70.179	132.561	417.177	7.954	627.870
50%	F.2.1.6	Traffic	45.218	85.411	268.793	5.125	404.546
5%	F.2.1.7	Hazardous goods traffic	4.461	8.427	26.519	506	39.912
39%	F.3.1.1	The presence of a monitoring strategy	34.918	65.957	207.570	3.957	312.403
79%	**F.3.1.2**	The presence of an maintenance strategy	70.658	133.465	420.023	8.008	632.155
91%	**F.3.1.3**	The extent of interventions executed prior to the event	82.221	155.307	488.760	9.318	735.606
12%	F.3.2.1	The presence of an emergency plan	10.416	19.675	61.919	1.181	93.192
53%	F.3.2.2	Practice of the emergency plan	47.417	89.566	281.868	5.374	424.225
98%	**F.3.2.3**	Review/update of the emergency plan	88.533	167.229	526.280	10.034	792.077
69%	F.3.2.4	Expected time for tendering	61.741	116.622	367.015	6.997	552.375
15%	F.3.2.5	Expected time for demolition	13.500	25.500	80.250	1.530	120.780
15%	F.3.2.6	Expecetd time for construction	13.500	25.500	80.250	1.530	120.780

Figure 11. CS#4, Impact factor for using differentiated resilience weights [ETH / IVE]

1.8 Key Resilience Indicators and Targets

ID	N possible values	Value	Legal requirement	Possible values	Costs	Unconstrained target	Indicator	Target	Max/ actual	Intervention	Travel time	Accident	Socio-econ.	Total	B/C	Net benefit
F.1.1.1	3	1				2	Age / Age of replacement of safe shut down system	2	Max			267.500	5.100	272.600		
				0	0				0			0	0	0	0,00	-
				1	80000				1			89.167	1.700	90.867	1,14	10.867
				2	70000				2			89.167	1.700	90.867	1,30	31.733
				3	93000				3			89.167	1.700	90.867	0,98	29.600
F.1.1.2	5	4				3	Condition state of infrastructure	3	Max	40.500	76.500	240.750	4.590	362.340		
				0	0				0	0	0	0	0	0	0,00	-
				1	60000				1	8.100	15.300	48.150	918	72.468	1,21	12.468
				2	63000				2	8.100	15.300	48.150	918	72.468	1,15	21.936
				3	72000				3	8.100	15.300	48.150	918	72.468	1,01	22.404
				4	84000				4	8.100	15.300	48.150	918	72.468	0,86	10.872
				5	86000				5	8.100	15.300	48.150	918	72.468	0,84	-2.660
F.1.1.3	5	3	3			3	Condition state of protective structures/systems	3	Max	43.772	82.680	260.198	4.961	391.610		
				0	0				0	0	0	0	0	0	0,00	-
				1	60000				1	8.754	16.536	52.040	992	78.322	1,31	18.322
				2	63000				2	8.754	16.536	52.040	992	78.322	1,24	33.644
				3	72000				3	8.754	16.536	52.040	992	78.322	1,09	39.966
				4	84000				4	8.754	16.536	52.040	992	78.322	0,93	34.288
				5	86000				5	8.754	16.536	52.040	992	78.322	0,91	26.610
F.1.1.4	3	3	2			3	After-event condition state of infrastructure	3	Max	45.000	85.000	267.500	5.100	402.600		
				0	0				0	0	0	0	0	0	0,00	-
				1	60000				1	15.000	28.333	89.167	1.700	134.200	2,24	74.200
				2	71000				2	15.000	28.333	89.167	1.700	134.200	1,89	137.400
				3	93000				3	15.000	28.333	89.167	1.700	134.200	1,44	178.600
F.1.1.5	3	1				2	After-event condition state of protective structures/systems	2	Max	493	932	2.932	56	4.413		
				0	0				0	0	0	0	0	0	0,00	-
				1	1200				1	164	311	977	19	1.471	1,23	271
				2	1400				2	164	311	977	19	1.471	1,05	342
				3	1600				3	164	311	977	19	1.471	0,92	213
F.1.2.1	2	2				1	The possibility of using another means to satisfy transport demand	1	Max		126.759		7.606	134.364		
				0	0				0		0		0	0	0,00	-
				1	60000				1		63.379		3.803	67.182	1,12	7.182
				2	68000				2		63.379		3.803	67.182	0,99	6.364
F.1.2.2	2	2				1	The number of possible existing alternative ways to deviate trains	1	Max		85.000		5.100	90.100		
				0	0				0		0		0	0	0,00	-
				1	30000				1		42.500		2.550	45.050	1,50	15.050
				2	55000				2		42.500		2.550	45.050	0,82	5.100
F.1.2.3	1	1				1	The presence of a safe shutdown system	1	Max		56.925		3.415	60.340		
				0	0				0		0		0	0	0,00	-
				1	18000				1		56.925		3.415	60.340	3,35	42.340
F.1.3.1	2	2				2	Compliance with the current flooding design code	2	Max	38.597	72.905	229.435	4.374	345.310		
				0	0				0	0	0	0	0	0	0,00	-
				1	120000				1	19.298	36.452	114.717	2.187	172.655	1,44	52.655
				2	140000				2	19.298	36.452	114.717	2.187	172.655	1,23	85.310
F.1.3.2	3	1				2	Strength of construction material used	2	Max	80.695	152.424	479.688	9.145	721.952		
				0	0				0	0	0	0	0	0	0,00	-
				1	230000				1	26.898	50.808	159.896	3.048	240.651	1,05	10.651
				2	235000				2	26.898	50.808	159.896	3.048	240.651	1,02	16.302
				3	250000				3	26.898	50.808	159.896	3.048	240.651	0,96	6.952
F.1.3.3	1	0				1	Adequate systems to reduce flooding	1	Max	64.289	121.435	382.164	7.286	575.175		
				0	0				0	0	0	0	0	0	0,00	-
				1	540000				1	64.289	121.435	382.164	7.286	575.175	1,07	35.175
F.2.1.1	3	1				2	Accessibility	2	Max	9.102				9.102		
				0	0				0	0				0	0,00	-
				1	2000				1	3.034				3.034	1,52	1.034
				2	2200				2	3.034				3.034	1,38	1.868
				3	8000				3	3.034				3.034	0,38	-3.098
F.2.1.2	3	1				0	Extent of past damages due to hazards	0	Max	38.750				38.750		
				0	0				0	0				0	0,00	-
				1	16000				1	12.917				12.917	0,81	-3.083
				2	18000				2	12.917				12.917	0,72	-8.167
				3	20000				3	12.917				12.917	0,65	-15.250
F.2.1.3	3	0				0	Hazard zone	0	Max	83.443	157.615	496.023	9.457	746.537		
				0	0				0	0	0	0	0	0	0,00	-
				1	255000				1	27.814	52.538	165.341	3.152	248.846	0,98	-6.154
				2	380000				2	27.814	52.538	165.341	3.152	248.846	0,65	-137.309
				3	420000				3	27.814	52.538	165.341	3.152	248.846	0,59	-308.463
F.2.1.4	2	1				2	Duration of past down time due to hazards	2	Max	13.500				13.500		
				0	0				0	0				0	0,00	-
				1	5000				1	6.750				6.750	1,35	1.750
				2	4000				2	6.750				6.750	1,69	4.500
F.2.1.5	2		1			2	Budget availability	2	Max	70.179	132.561	417.177	7.954	627.870		
				0	0				0	0	0	0	0	0	0,00	-
				1	260000				1	35.090	66.280	208.588	3.977	313.935	1,21	53.935
				2	310000				2	35.090	66.280	208.588	3.977	313.935	1,01	57.870
F.2.1.6	2	1				2	Traffic	2	Max	45.218	85.411	268.793	5.125	404.546		
				0	0				0	0	0	0	0	0	0,00	-
				1	133000				1	22.609	42.705	134.396	2.562	202.273	1,52	69.273
				2	140000				2	22.609	42.705	134.396	2.562	202.273	1,44	131.546
F.2.1.7	2	1				1	Hazardous goods traffic	1	Max			26.519		26.519		
				0	0				0			0		0	0,00	-
				1	9000				1			13.259		13.259	1,47	4.259
				2	15000				2			13.259		13.259	0,88	2.519
F.3.1.1	2	1				2	The presence of a monitoring strategy	2	Max	34.918	65.957	207.570	3.957	312.403		
				0	0				0	0	0	0	0	0	0,00	-
				1	52000				1	17.459	32.978	103.785	1.979	156.201	3,00	104.201
				2	60000				2	17.459	32.978	103.785	1.979	156.201	2,60	200.403
F.3.1.2	**2**	**1**	**1**			**2**	**The presence of an maintenance strategy**	**2**	**Max**	**70.658**	**133.465**	**420.023**	**8.008**	**632.155**		
				0	**0**											
				1	**96000**				**1**	**35.329**	**66.733**	**210.012**	**4.004**	**316.077**	**3,29**	**220.077**
				2	**128000**				**2**	**35.329**	**66.733**	**210.012**	**4.004**	**316.077**	**2,47**	**408.155**
F.3.1.3	**2**	**1**				**2**	**The extent of interventions executed prior to the event**	**2**	**Max**	**82.221**	**155.307**	**488.760**	**9.318**	**735.606**		
				0	**0**											
				1	**93000**				**1**	**41.111**	**77.653**	**244.380**	**4.659**	**367.803**	**3,95**	**274.803**
				2	**100000**				**2**	**41.111**	**77.653**	**244.380**	**4.659**	**367.803**	**3,68**	**542.606**
F.3.2.1	2	1	1			1	The presence of an emergency plan	1	Max		19.675		1.181	20.856		
				0	0				0		0		0	0	0,00	-
				1	10000				1		9.838		590	10.428	1,04	428
				2	18000				2		9.838		590	10.428	0,58	-7.144
F.3.2.2	4	1				4	Practice of the emergency plan	4	Max		89.566		5.374	94.940		
				0	0				0		0		0	0	0,00	-
				1	12000				1		22.391		1.343	23.735	1,98	11.735
				2	13000				2		22.391		1.343	23.735	1,83	22.470
				3	15000				3		22.391		1.343	23.735	1,58	31.205
				4	17000				4		22.391		1.343	23.735	1,40	37.940
F.3.2.3	**2**	**1**				**2**	**Review/update of the emergency plan**	**2**	**Max**		**167.229**	**526.280**	**10.034**	**703.543**		
				0	**0**											
				1	**25000**				**1**		**83.615**	**263.140**	**5.017**	**351.772**	**14,07**	**326.772**
				2	**89000**				**2**		**83.615**	**263.140**	**5.017**	**351.772**	**3,95**	**589.543**
F.3.2.4	3	0				3	Expected time for tendering	3	Max	61.741	116.622		6.997	185.360		
				0	0				0	0	0		0	0	0,00	-
				1	26000				1	20.580	38.874		2.332	61.787	2,38	35.787
				2	28500				2	20.580	38.874		2.332	61.787	2,17	69.073
				3	30000				3	20.580	38.874		2.332	61.787	2,06	100.860
F.3.2.5	3	1				3	Expected time for demolition	3	Max	13.500	25.500		1.530	40.530		
				0	0				0	0	0		0	0	0,00	-
				1	4000				1	4.500	8.500		510	13.510	3,38	9.510
				2	6000				2	4.500	8.500		510	13.510	2,25	17.020
				3	11200				3	4.500	8.500		510	13.510	1,21	19.330
F.3.2.6	3	1				1	Expecetd time for construction	1	Max	13.500	25.500		1.530	40.530		
				0	0				0	0	0		0	0	0,00	-
				1	11000				1	4.500	8.500		510	13.510	1,23	2.510
				2	18000				2	4.500	8.500		510	13.510	0,75	-1.980
				3	20000				3	4.500	8.500		510	13.510	0,68	-8.470

Figure 12. CS#4, Key Resilience Indicators and Targets [ETH / IVE]

ANNEX 2. FORESEE TOOL VALIDATION

2.1 Outputs from the Tool IVE "Bridge Flooding Model"

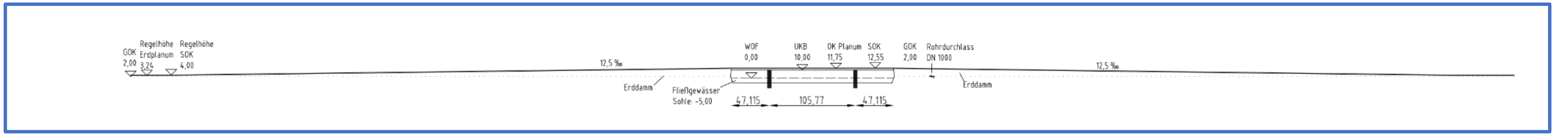


Figure 13. CS#4, Bridge Flooding Model (T.IVE) – longitudinal section (full scale) [IVE]

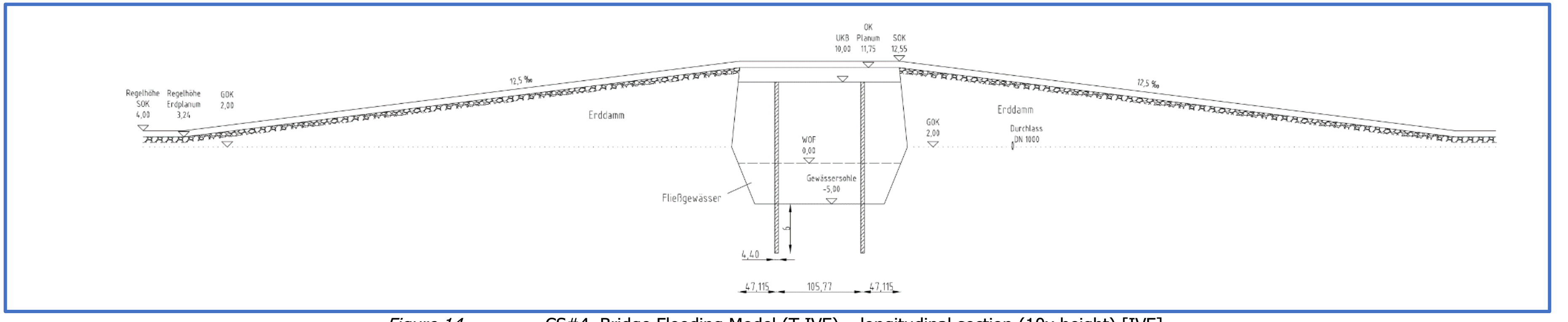


Figure 14. CS#4, Bridge Flooding Model (T.IVE) – longitudinal section (10x height) [IVE]

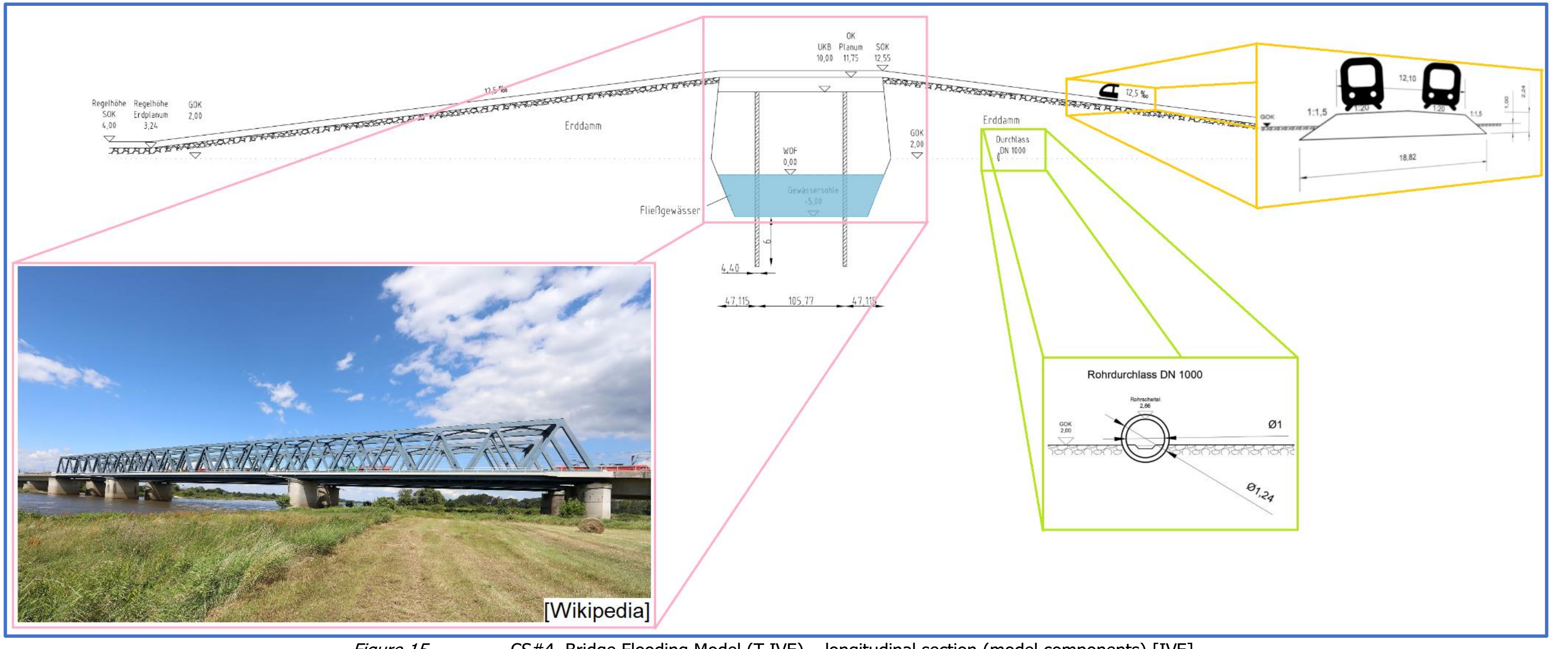


Figure 15. CS#4, Bridge Flooding Model (T.IVE) – longitudinal section (model components) [IVE]

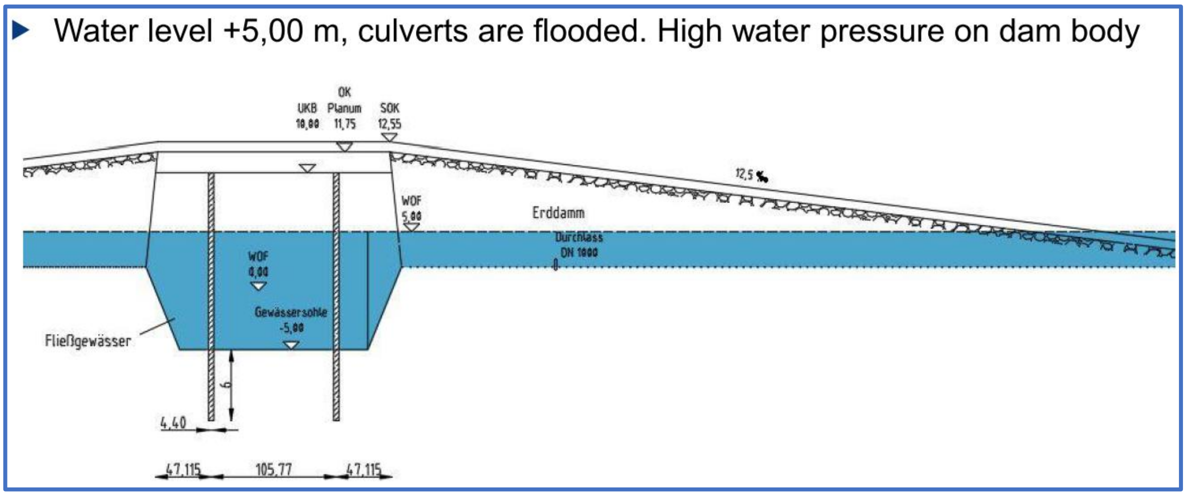


Figure 16. CS#4, Outputs from Bridge Flooding Model (T.IVE) – water level +5,00 m [IVE]

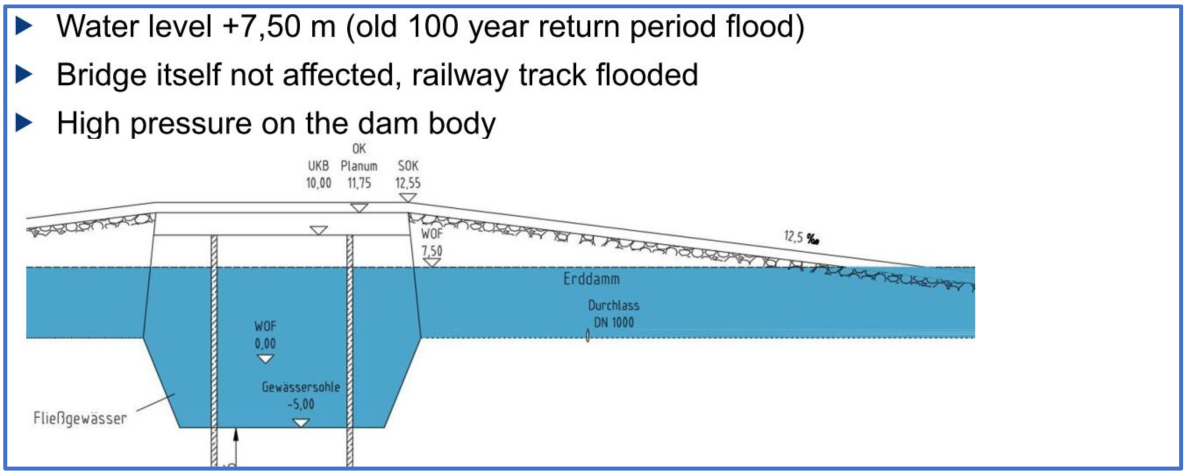


Figure 17. CS#4, Outputs from Bridge Flooding Model (T.IVE) – water level +7,50 m [IVE]

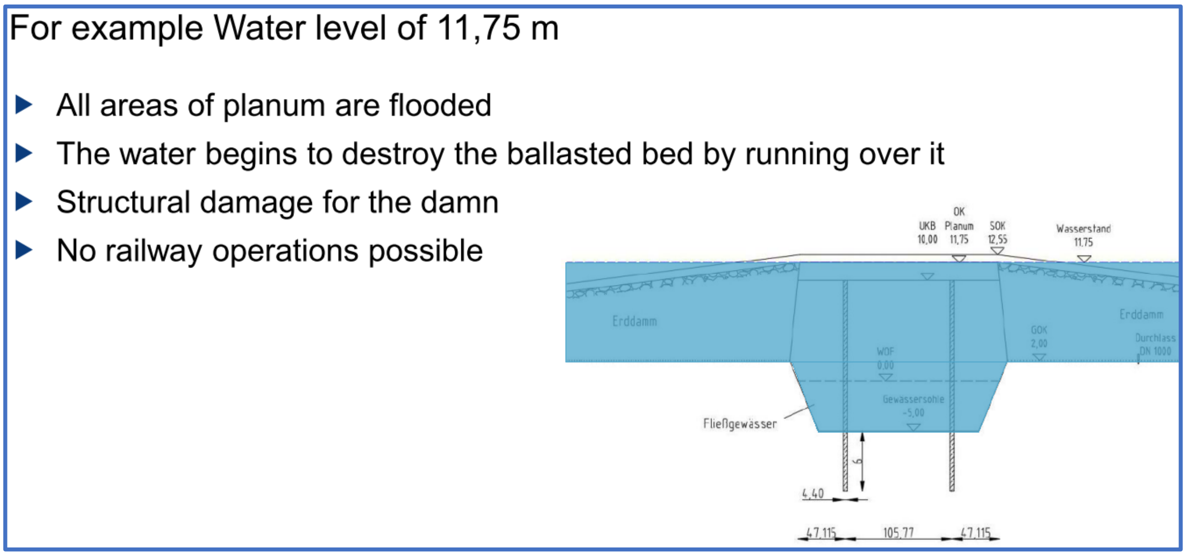


Figure 18. CS#4, Outputs from Bridge Flooding Model (T.IVE) – water level +11,75 m [IVE]

2.2 Outputs from the FORESEE Tool 2.2 "Risk Mapping"

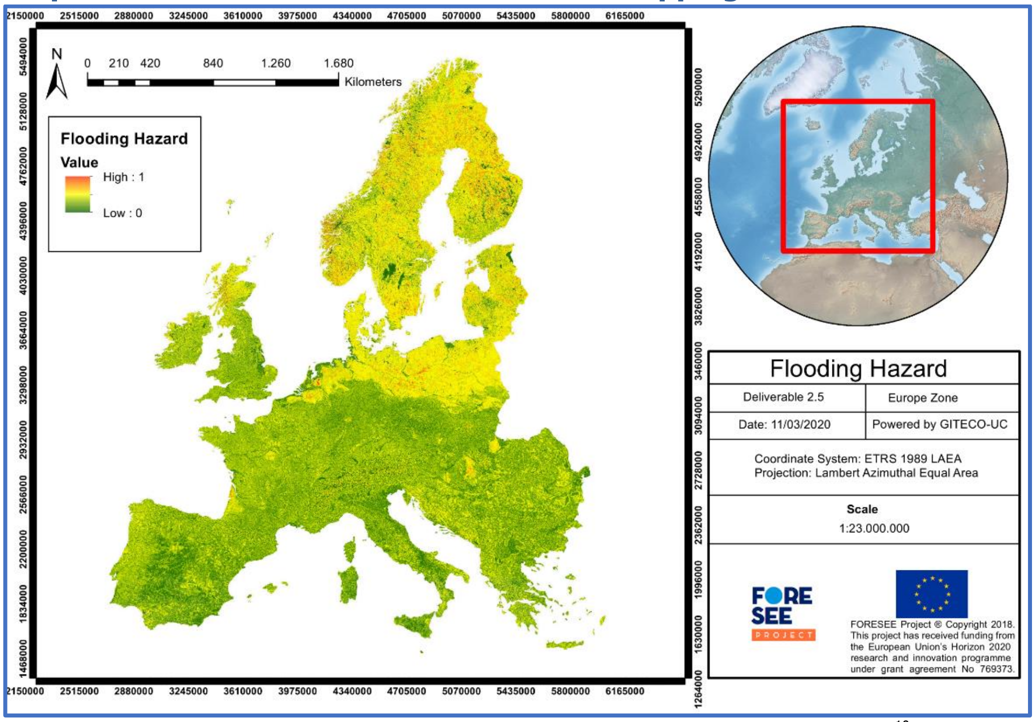


Figure 19. CS#4, Hazard map output from FORESEE Tool 2.2 [UC / D 2.5[10]]

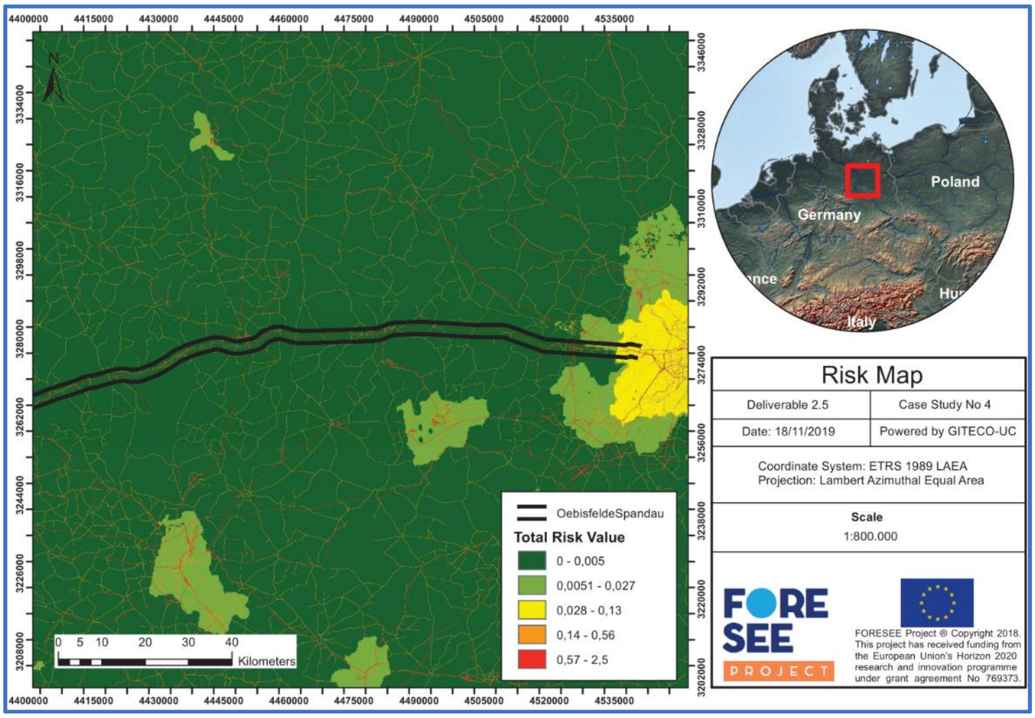


Figure 20. CS#4, Risk map output from FORESEE Tool 2.2 [UC / D 2.5]

2.3 Outputs from the FORESEE Tool 5.5 "Command and Control Center"

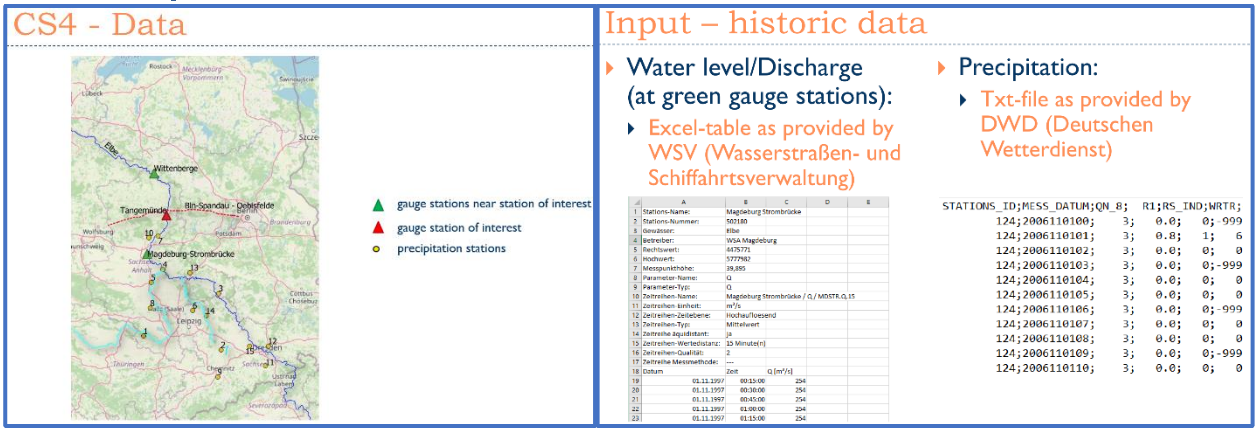


Figure 21. CS#4, Input Data for FORESEE Tool 5.5 [FRA]

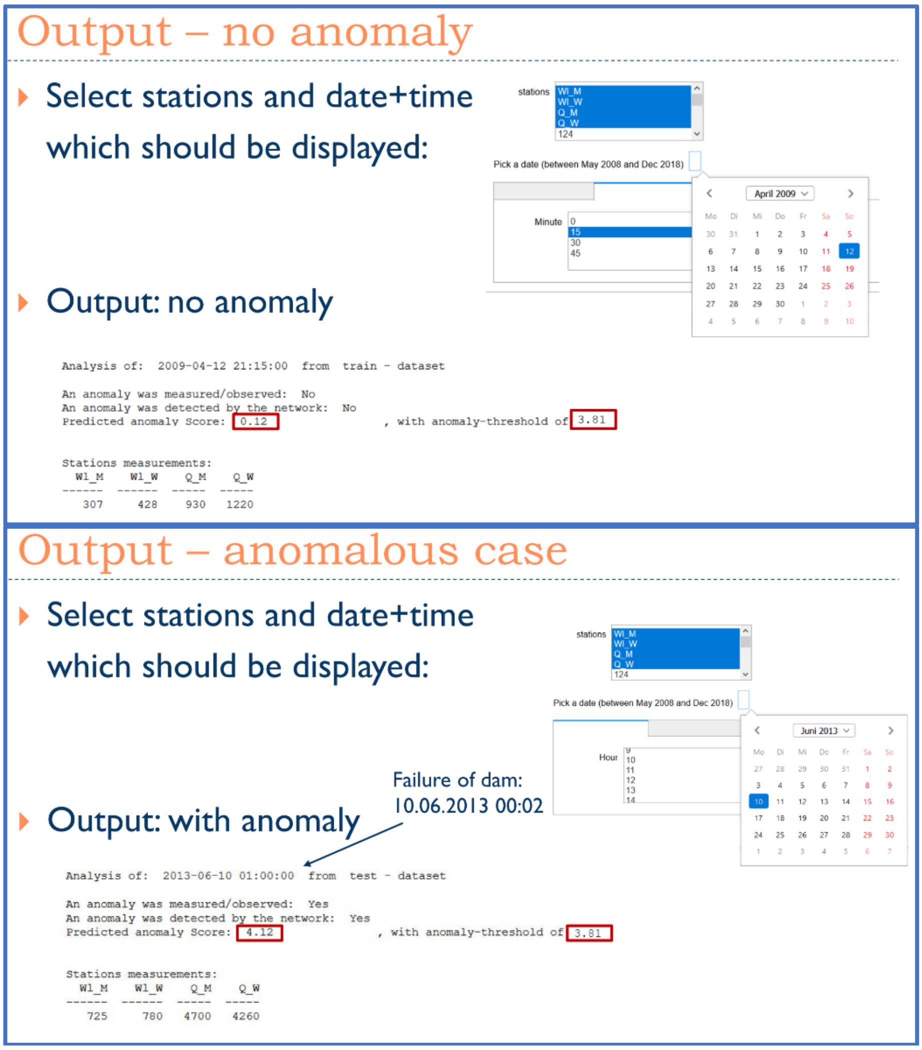


Figure 22. CS#4, Output Data for FORESEE Tool 5.5 [FRA]

2.4 Output from the FORESEE Tool 7.2 "Plan Review"

PERFORMANCE-BASED DESIGN - RESILIENCE CURVE

HAZARD

Hazard Type	**FLOODING**
Hazard Level	**Extreme**

Return Period of the event (years) 500

Probabiilty of being exceeded in 50 years (%) 9,53

PERFORMANCE OBJECTIVES

TRANSPORT INFRASTRUCTURE		DESIRED PERFORMANCE LEVELS								
		Short-term			Intermediate			Long-term		
		Days			Weeks			Months		
Description	**Category**	**0-12h**	**1 d**	**1-3 d**	**1-4**	**4-8**	**8-12**	**4**	**4-24**	**24+**
Track (incl. catenary, control and safety systems, etc.) Hazard: EXTREME Level	III	0%	0%	0%	0%	0%	0%	0%	100%	
Track (incl. catenary, control and safety systems, etc.) Hazard: DESIGN Level		0%	0%	0%	50%	50%	100%			
Track (incl. catenary, control and safety systems, etc.) Hazard: ROUTINE Level		0%	0%	50%	100%					

RESILIENCE CURVE

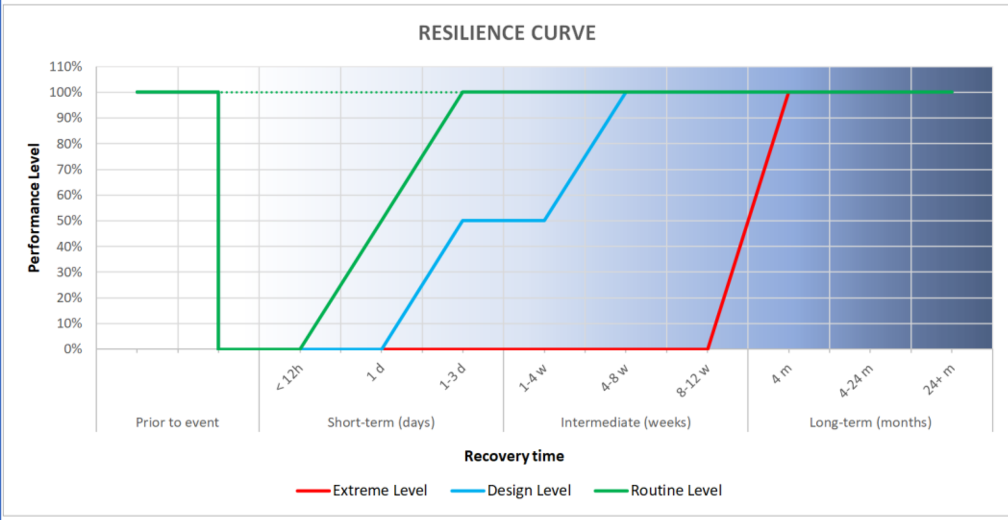


Figure 23. CS#4, Performance-based design resilience curve from FORESEE Tool 7.2 [CEM / IVE]

ANNEX 3. COMPARISON DATA

3.1 Outputs from comparison tools for the "Risk Mapping"

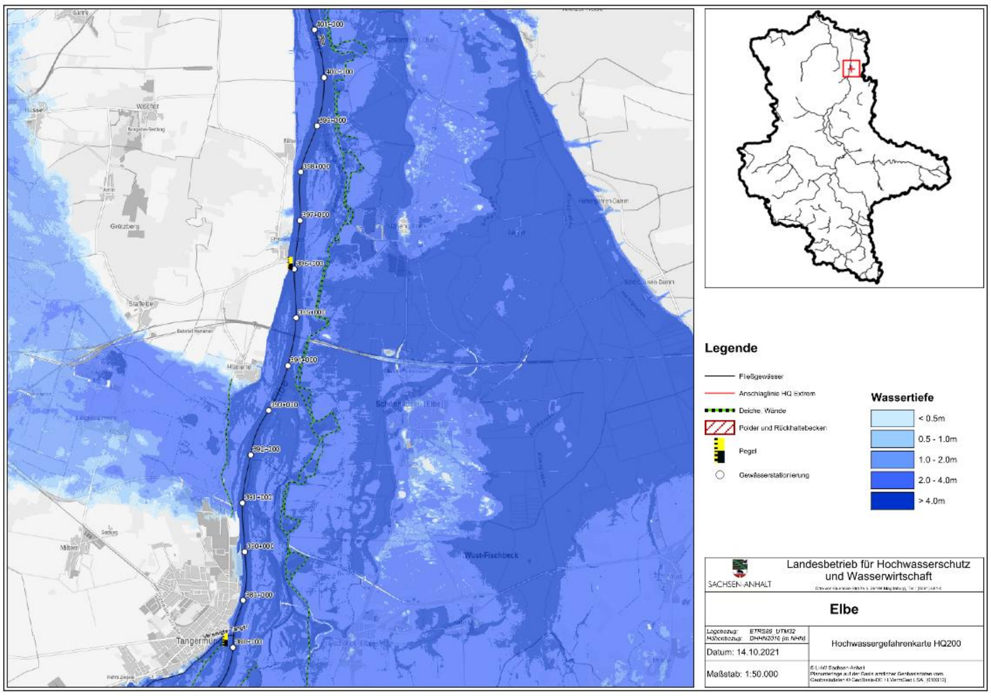


Figure 24. CS#4, Hazard map output from LHW [www.geofachdatenserver.de]

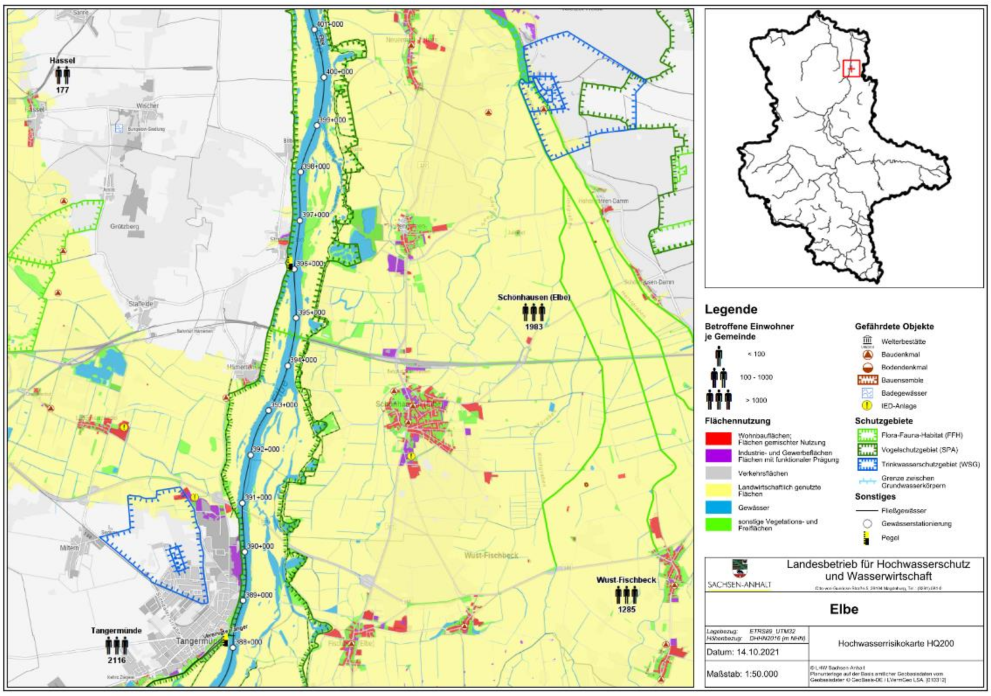


Figure 25. CS#4, Risk map output from LHW [www.geofachdatenserver.de]

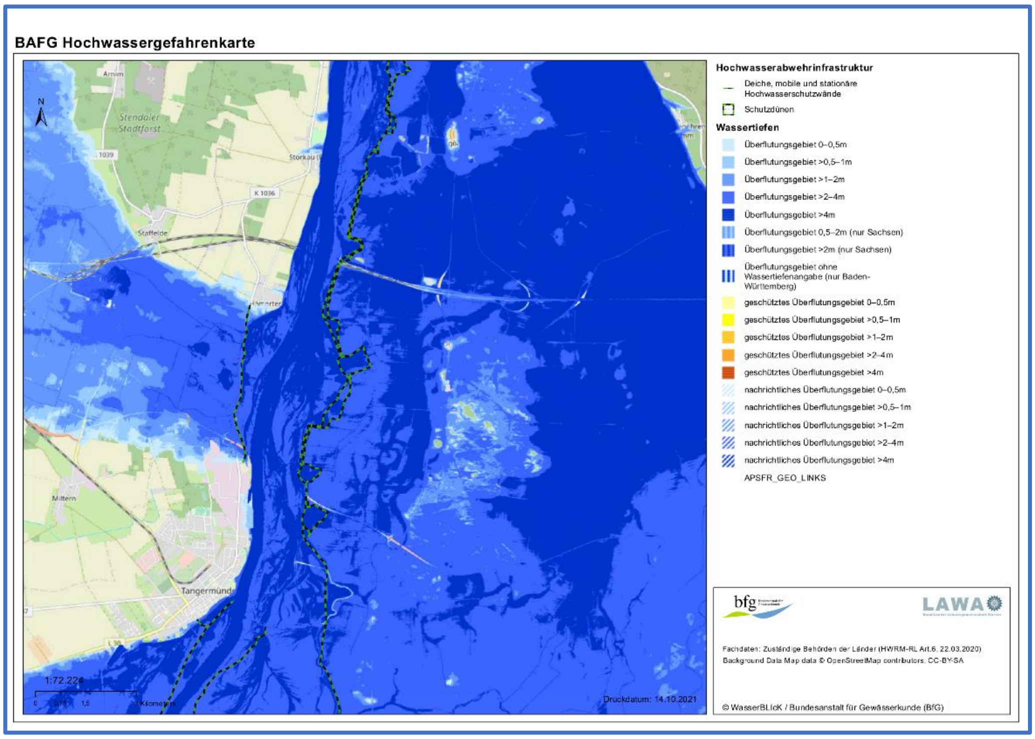


Figure 26. CS#4, Hazard map output from BAFG [geoportal.bafg.de]

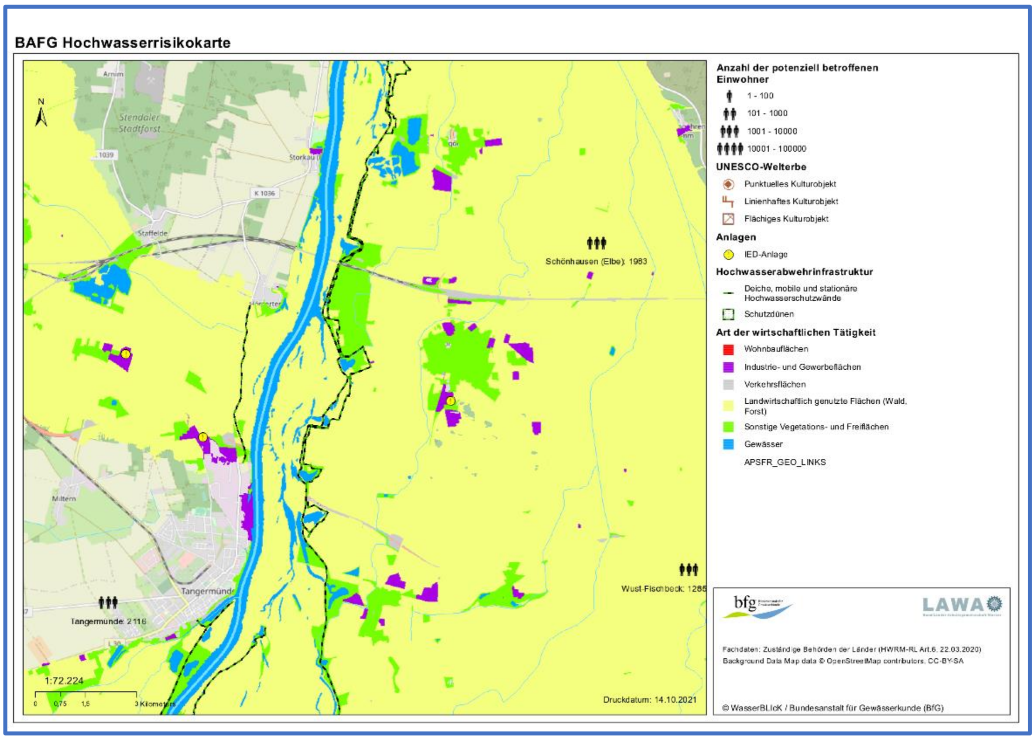


Figure 27. CS#4, Risk map output from BAFG [geoportal.bafg.de]

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[1] [https://www.rmcon-int.de/railsys-en/railsys-suite/]
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[4] [https://www.hochwasserzentralen.info/]
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[6] Jan Michael Köchy, *Analysis of the condition of a railway model under the stress of floods*, Master thesis, 2018 [IVE]
[7] DIN EN 50126, *Railway Application – The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)*
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