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Report on the validation of the vulnerability assessment methodology

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Executive Summary

The methodology developed in WP3 and WP4, which includes in-situ condition assessment and numerical modelling was demonstrated to professionals, CPAs and relevant authorities. The aim of the proposed methodology is to increase the information quality and reliability of the outputs from the numerical models, in order to decrease risk caused by flooding hazards. The methodology is demonstrated within two case study areas and the outcomes are integrated into flood prevention processes, during the hazard events by CPAs and within adaptation planning by owners. This deliverable is a report on the validation of the vulnerability assessment methodology from point of view of civil protection authority. This includes the assessment of integration of methodology results into existing civil protection systems.

Keywords: flood response measures, validation, flood prevention measures

Table of Contents

Project Information 2
Partner Information 2
Document Information 3
Executive Summary 4
Table of Contents 5
Abbreviations and Acronyms 6
1 Introduction 7
2 Vulnerability assessment methodology and output data 8
2.1 Vulnerability assessment methodology for embankments 8
2.2 Vulnerability assessment methodology for bridges 8
3 Civil protection agencies system of vulnerability assessment 10
3.1 Slovenian Civil Protection Agency 10
3.2 Croatian civil protection agency 15
3.3 Dutch civil protection agency 20
4 Integration of methodology into existing systems 23
4.1 Slovenia 23
4.2 Croatia 25
4.3 Netherlands 27
5 Conclusions 29
6 References 30

Abbreviations and Acronyms

ACPDR	Government of the Republic of Slovenia - Administration of the Republic of Slovenia for Civil Protection and Disaster Relief
BAG	Basic register addresses buildings
CI	Critical infrastructure
CPA	Civil protection authority
CORS	Slovenian national information centre
DARS	Slovenian motorway company
DEM	Company operating hydroelectric power plants on Drava river
DRSI	Slovenian Infrastructure Agency
GIS	Geographic Information System
HESS	Company operating hydroelectric power plants on lower Sava River
HPP	Hydroelectric power plants
KNMI	The Royal Netherlands Meteorological Institute
NAP	Amsterdam Ordnance Datum
LCO	National Coordination Committee Flood Threat
ReCO	Slovenian regional information centre – 112 call centre
RWS	Rijkswaterstaat - Ministry of Infrastructure and Water Management Netherlands
SENG	Company operating hydroelectric power plants on Soča river
ZARE	Autonomous Radio Communication System

1 Introduction

This deliverable is a report on validation of the vulnerability assessment methodology developed during WP4. The developed methodology is composed from two parts. First part of the methodology focuses on vulnerability assessment methodology of bridges subjected to flooding. The case study focused on two bridges in the area of City of Karlovac, Croatia. The second part of methodology focuses on vulnerability assessment methodology of embankments subjected to flooding. The methodology was used in both City of Karlovac case study area and in Oostmolendilk case study area in the Netherlands.

In the first part of the document, we will describe the vulnerability assessment methodology and its results. In the second part, we will introduce and outline the Slovenian, Croatian and Dutch civil protection systems. In the third part, we will assess the integration of vulnerability assessment methodology results into Slovenian, Croatian and Dutch national civil protection systems. The deliverable concludes with a summary of the most important findings.

2 Vulnerability assessment methodology and output data

2.1 Vulnerability assessment methodology for embankments

Vulnerability assessment methodology for embankments developed during project oVERFLOw is presented in detail in deliverable **D4.1 Report on Vulnerability Assessment Methodology - Fragility curves for embankments subjected to flooding**. Two areas have been chosen as pilot sites, for the deployment and demonstration of the technology developed within the oVERFLOw project. First case study area is the Oostmolendijk (dike rings 16 and 17) in vicinity of the city of Dordrecht in the Netherlands and the other case study area is in the city centre of Karlovac in Croatia.

The results of the methodology are fragility curves for assessing the likelihood of dyke, levee or riverbank failure. The fragility curves are calculated for one of five different mechanisms of failure:

- Global stability based on Limit equilibrium methods (Morgenstern and Price methods, 1965).
- Rapid drawdown – rapid reduction of riverside water level after the flood event whilst the soil in the slope remains fully saturated.
- Overtopping - water flows over the top of the embankment or levee.
- Piping - particles within or below the levee are eroded due to seepage. If seepage forces become large enough particles can get washed out of the soil, promoting increased flow which in turn can wash away larger particles and create a channel or a “pipe”.
- Seismic induced instability – embankment slope failure due to earthquake induced shaking.

Undrained soil shear strength was determined both using Cone penetration test (CPT) based N_{kt} factor approach and the SHANSEP approach adopted in normal Dutch practice for flood defence assessment. The N_{kt} approach was used to generate fragility curves as it allowed the in-situ variability to be measured and utilised, while the SHANSEP model just considers variability at critical state (used only at Oostmolendijk).

Calculated values of probability of failure for different scenarios provide the basis for the classification of the embankments and riverbanks, based on their vulnerability.

2.2 Vulnerability assessment methodology for bridges

Vulnerability assessment methodology for bridges developed during project oVERFLOw is presented in detail in deliverable **D4.2 Report on Vulnerability Assessment Methodology - Fragility curves for bridges subjected to flooding**. Two case study bridges have been chosen in the city centre of Karlovac in Croatia, for the deployment and demonstration of the technology developed within the oVERFLOw project. The case study bridges are Banija Bridge and Karlovac Bridge over Kupa river.

The performed study considers different flooding scenarios, including hydrodynamic loads, debris and scour. Several failure mechanisms were identified in relation to the considered flooding scenarios. Special attention was devoted to the explicit simulation of the effect of scouring on the distribution of forces in the structure. Several failure mechanisms are considered, and the most unfavourable mechanism for the given flooding scenario were identified. Before the vulnerability analysis, the numerical modelling approach was validated against the results of ambient vibration measurements applied on case study bridges. The vulnerability analysis was performed separately for the serviceability and ultimate limit state. Since both velocity and water height were found to be necessary for precise estimation of the bridge performance, the result of the vulnerability analysis is presented with fragility surfaces, which represent an extension of the classical fragility curve concept. In addition to hydrological data, geotechnical data from CPT investigations and boreholes was used.

3 Civil protection agencies system of vulnerability assessment

3.1 Slovenian Civil Protection Agency

The Administration for Civil Protection and Disaster Relief is a body within the Ministry of Defence that carries out administrative and expert tasks regarding protection, rescue and disaster relief. The tasks pertain to the management, preparation and operation of the system for protection from natural and other disasters; the provision of assistance to affected local communities; monitoring, notification and warning; communications and the information system; the assessment of damage caused by natural and other disasters; fire protection and the operation of general rescue services; the organisation and operation of the Civil Protection Service and the preparation and operation of the Civil Protection Headquarters; the preparation and execution of national programmes in the field of protection from natural and other disasters; and disaster relief and post-disaster remediation.

3.1.1 Slovenian response to flooding events, stakeholders and vulnerability assessments

The system of Slovenian civil protection is based on responsibilities of the following stakeholders and parties involved:

- Citizens (individuals),
- Municipalities (mayors),
- Companies,
- Institutes and other organizations (directors) and finally,
- State (Government of the Republic of Slovenia - Administration of the Republic of Slovenia for Civil Protection and Disaster Relief - ACPDR).

National competence encompasses the management of the system, research and development work, drafting and implementing the national program, the elaboration of risk assessment and national emergency response plans, organization and equipment of national response units and services, on-site leadership of units and services in the event of a major disaster, organization of information and communication systems, damage assessment, assistance in reconstruction and recovery in order to prevent further damage and provide basic living conditions, drafting education and training program, inspections and international cooperation.

Local community competencies encompass: monitoring of danger and the provision of information and warnings in the event of danger, provision of communication means for local units and services, elaboration of local risk assessment and emergency response plans, implementation of protective measures in the event of a disaster, organization of individual and group protection for the population, organization and equipment of CP and other local response units and services, provision of emergency accommodations, training of local units and services, provision of on-site leadership for local units and services, disaster recovery efforts.

Enterprises that deal with hazardous substances or represent a disaster hazard have to, ensure conditions for the implementation of personal and group protection for their staff, develop a risk assessment and emergency response plan, ensure appropriate notification and warning systems for employees and the local population, organize response units and co-finance local community preparatory activities.

For the safety of the roads and their transportability, there are a few stakeholders responsible in Slovenia. For the state roads there is Ministry of infrastructure, for highways Slovenian motorway company (DARS) is responsible and for municipal roads local communities. State concessionaires are in charge for the maintenance of state roads.

Additionally, the dams and embankments are under the jurisdiction of Ministry of infrastructure, Ministry of environment and/or the owners/operators.

Slovenian environment agency is in charge of the national network of hydrological and weather stations.

Response units dealing with flooding events in Slovenia are mostly firefighters (local level) as first responders and regional/national high capacity pumping teams. Regional information centres in Slovenia for emergency are presented in Figure 1.

For flood hazard monitoring the ACPDR uses GIS application SMOK system for water monitoring. The application is used as a tool and support for decision makers in disaster response. In addition to the mentioned application, the hydrological warnings and reports compiled and published by Slovenian environment agency are used. These warnings and reports are published in written and graphic form, which show current hydrological situation and forecast for the current and the next day, including alarm levels for individual areas.

Parameters used are water level and flow. Both values are acquired form national network of hydrological stations maintained by Slovenian environment agency. Data is interpreted with Rules on methodology to define flood risk areas and erosion areas connected to floods and classification of plots into risk classes. Flood risk map, flood hazard map and map of areas of significant flood impact are also used.

Observation and early warning system in Slovenia is otherwise supported by:

- Geographic Information System (GIS),
- Autonomous Radio Communication System (ZARE),
- Public alarm system,
- Information Centres (CORS, ReCO).

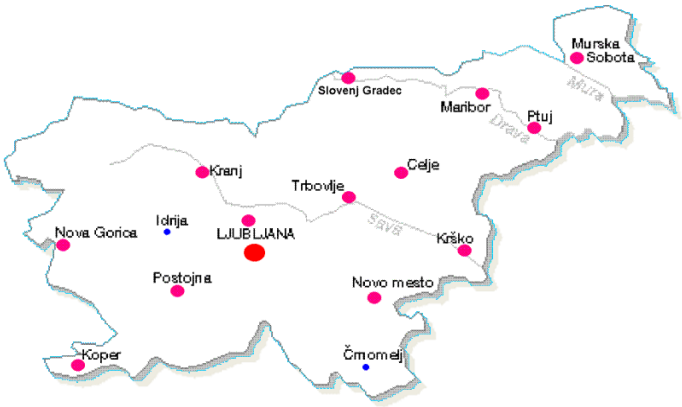

Figure 1: Regional information centres (112) in Slovenia

In the event of safety or operability issues of bridges and dykes the relevant municipal, regional or national Flood Protection and Rescue Plan is activated. Following this plan, forces and equipment for protection and assistance are gradually activated. The municipal forces and equipment are activated first, and then regional and national forces and equipment, if required. In the event of safety or operability issues of high hydroelectric barriers the municipal and specific plant Protection and Rescue Plans in the event of damage and demolition of high barriers are activated.

3.1.2 Monitoring and vulnerability assessments

The monitoring of bridges in national ownership is conducted by the Ministry of Infrastructure or companies with concessions, highway and motorway bridges by DARS d.d. (Slovenian motorway company). The Slovenian Infrastructure Agency (DRSI) of the Ministry of Infrastructure, carries out periodic inspections of bridging structures on state roads, and monitors and manages their condition in order to ensure traffic safety of these structures, in accordance with the applicable legislation and with instructions for carrying out periodic inspections of viaducts, bridges, overpasses, underpasses, galleries, tunnels, underpasses and footbridges on roads managed by the DRSI. Periodic inspections are carried out by authorized institutions or professionally trained technical staff. In accordance with the instructions for periodic inspections and the prescribed methodology, damage to elements of the bridging structure is recorded and classified, on the basis of which the structure is classified into a category that depends on the type and extent of the damage. Vulnerable bridging structures are thus included in the list of facilities in poor condition, on the basis of which further activities for their rehabilitation are then envisaged.

Responsibility for high hydroelectric barriers is under the jurisdiction of the Ministry of Infrastructure and their owners or operators. Responsibility for embankments and levees is under the jurisdiction of the Ministry of the Environment and Spatial Planning and their owners or operators.

In the case of inferior facilities under the jurisdiction of DRSI, which could indicate a potentially endangered load-bearing capacity and the related stability of the facility due to recorded damage, additional activities are carried out to determine whether the facility is still able to take the expected traffic load (a calculation analysis of the maximum allowable traffic load where the

safety of the facility will not be compromised). In the event that reduced carrying capacity is identified, it is necessary to consider the possibility of introducing alternative measures, such as the introduction of one-way alternating traffic, construction of a bypass road with a temporary bridging structure (Mabey), diversion of traffic to another road, etc.

During power plant operation the upstream river flow is monitored. The opening position of the hydro mechanical gates is guided by the measured flow data. This ensures the safe evacuation of excess water flow in the downstream river channel. A flood notification system has also been set up, which has been coordinated with the competent Ministries.

HESS is the company responsible for the safety/operability of the hydroelectric power plants (HPP) flow type accumulations, including their dykes and dams and for the four HPP on the Lower Sava river. Their system of response is represented in Protection and Rescue Plans for uncontrolled water spill from each HPP flow type accumulation. These activities are managed in cooperation with the Civil Protection forces (local/regional). Extra monitoring and visual supervision of the HPP flow type accumulations and their dykes are also carried out after high water levels/flows of the Sava river, in accordance with the Directions for Operation and Maintenance (Monitoring Programme).

Based on the implementation of periodic inspections, a list of recorded deficiencies in all bridging structures (BCP structures) is kept. The list contains basic information about the building and its damage rating. A list of facilities in poor condition is kept. Facilities in poor condition are monitored even more frequently; for example, the condition of an inferior facility may be monitored on the basis of monitoring the damage, checking its existing condition by calculation analysis of the maximum allowable traffic load where the safety of the facility will not be endangered, and so on.

DARS, d.d. is the operator of motorway bridges designed to the highest technical requirements, which also include high water safety. In addition, regular and extraordinary inspection of the condition of the bridge ensures its functionality and safety. Extraordinary inspections are also carried out when there are floods on individual parts of the network. In the event of damage, the necessary measures for traffic safety are immediately taken, together with, on the basis of an expert assessment, the necessary measures for the protection of the construction itself.

The safety of bridges and dykes is fairly well monitored, but it needs to be upgraded using new and proven technologies to get a better insight into the condition of these structures.

Safety dam monitoring on the Soča river is covered by a system of technical observation of dams. This includes required periodic monitoring of the basin area and dams of the following: vertical and horizontal displacements, seismic movements, water levels, precipitation and water temperature.

Dam spillways are equipped with hydro mechanical gate systems which ensure safe evacuation of the excess water. The hydro mechanical equipment is periodically checked and serviced to ensure its correct operation.

HESS believes that the existing HPP flow type accumulation dykes (and dams) under the company's jurisdiction are monitored appropriately and sufficiently.

According to the Rules on the Regular Maintenance of Public Roads, which is an executive part of the Roads Act, periodic inspections of road facilities are carried out by qualified experts, and visual inspections of road facilities by the inspection service of regular maintenance. Periodic inspections of road structures are carried out at least once every six years, with steel and wooden road structures being inspected at least once a year. In addition to the periodic inspections, visual inspections of road facilities are also carried out every three months by the inspection service of regular maintenance. In the event that a deterioration in the condition of the facilities is determined, a more detailed extraordinary inspection may be carried out, during which a check of the condition of the materials may also be carried out. DRSI considers that, on the basis of the described monitoring of the condition of roads and road structures, the progress of damage is established quickly enough to be able to take timely action.

DARS ensures quality control of the condition of bridges by systematically inspecting motorway bridges (daily inspections, periodic inspections, extraordinary inspections).

3.2 Croatian civil protection agency

3.2.1 Croatian response to flooding events, stakeholders and vulnerability assessments

In Croatia, the National Water Council is a Parliamentary body founded to consider systematic issues of water management, harmonize different needs and interests, and propose measures for development and improvement of the water system. The ministry responsible for all water management issues is the Ministry of Environment and Energy (Ministarstvo okoliša i energetike). Croatian Waters (Hrvatske vode) are a legal entity for water management (national agency), established for permanent and uninterrupted implementation of public services and other activities of water management within the framework of adopted plans. Organisational structure of Croatian Waters includes the Head Office (Directorate), water management departments, and water management branch offices. Croatian Waters are responsible for operational flood defence. Croatian Meteorological and Hydrological Service is competent for monitoring and forecasting of meteorological and hydrological events. National Protection and Rescue Directorate is responsible for disaster management (Sava Commission, 2019).

The operational management of flood risks and the immediate implementation of flood defence measures are determined by the State Plan for Flood Defence - adopted by the Government of the Republic of Croatia, and by the Main Implementation Plan for Flood Defence - adopted by Croatian waters (Hrvatske vode). All technical and other elements necessary for the management of regular and extraordinary flood defence are determined by the Main Implementation Plan of Flood Defence and the Implementation Plans of Flood Defense of Defended Areas. All these plans are publicly available on the website of Croatian waters. The national flood defence plan regulates: territorial units, levels of flood defence, measures (including preventive measures), operators, management (with obligations and rights of flood defence managers), content of flood defence implementation plans, notification and warning system and communication system, measures to protect against ice on watercourses.

The implementation plan also contains an overview of the territorial units for the direct implementation of flood defence measures (including the number and designation of sections and other necessary data) by defended areas of the sector and associated protective water structures where flood defence measures are implemented, i.e. flood defence measures against ice on watercourses, water levels at which a preparatory defence state begins on a particular section, regular or extraordinary flood defence and emergency state, legal entities and their managers and deputies registered for the implementation of flood defence, as well as flood defence managers from legal entities that manage dams and reservoirs. Obligations of the State Hydrometeorological Institute in collecting and delivering data, forecasts and warnings about hydrometeorological phenomena of significance for flood defence, instructions for creating reports on implemented measures, map representation of the boundaries of protected areas.

Flood defence is carried out on territorial units for flood defence - water areas, sectors, protected areas and sections. In this way, the Republic of Croatia is divided into 2 water areas, 6 sectors and 34 protected areas. The borders of water areas, sectors and protected areas are determined by the Law on Water, while the number and designation of individual sections is determined by the Main Implementation Plan for Flood Defence.

Sections are the lowest territorial units within the protected areas, where, in the event of a flood hazard, conditions are monitored and flood protection is directly carried out on protective water structures.

Flood protection can be preventive, regular and extraordinary. Preventive defence against floods consists of regular water maintenance works and protective water structures in order to reduce the risk of floods. Regular and extraordinary defence consists of measures taken immediately before the occurrence of the flooding hazard, during the hazard and immediately after the end of the hazard, with the aim of reducing possible damage from floods.

Immediate regular and extraordinary flood defence measures are:

- making forecasts of the size and time of the water wave
- frequent inspections of the condition of regulatory and protective water structures and structures for basic melioration drainage from the time of declaration of the preparatory state of flood defence until its revocation
- implementation of the necessary measures and actions on regulatory and protective water structures, as well as basic and, if necessary, detailed melioration drainage structures that can be used to receive and evacuate large amounts of water
- elimination of the causes that hinder the flow of water through the watercourse bed
- putting into operation the built facilities for the relief of large waters (loading channels, retention, reservoirs with retention space for the reception of large waters, constitutions, overflows, drainage tunnels etc.).

Effective defence against floods requires the cooperation of all competent bodies in the protection and rescue system, including local and regional self-government units, and the State Administration for Protection and Rescue, which is the holder of basic powers in the field of protection against disasters and major accidents, including and those due to floods.[1]

Roads in Croatia are operated on state, regional and local level. Croatian Motorways (Hrvatske autoceste) are responsible of motorways in Croatia while state roads are ran by Croatian Roads (Hrvatske ceste). On the regional and local level there is a company County roads (Županijske ceste) and municipalities.

3.2.2 Water level monitoring

In order to effectively implement operational defence against floods, Croatian waters have set up (in line with the State flood defence plan, NN 84/2010), an automated water level monitoring system, in which way real-time water level data is available to all flood defence centres. By establishing a network of automatic rain gauges and meteorological radars in cooperation with the State Hydrometeorological Institute and Croatian Waters have created the conditions for a more efficient operational defence against.

[1] https://www.voda.hr/hr/obrana-od-poplava-0

The current water levels at measuring stations, see Figure 2 and Figure 3, in the Republic of Croatia can be viewed in two basic ways;

1. Map of the Republic of Croatia showing the location of the stations, as well as the measures that are currently being conducted at a particular station
2. Displaying the list of stations, with the current state of the water level

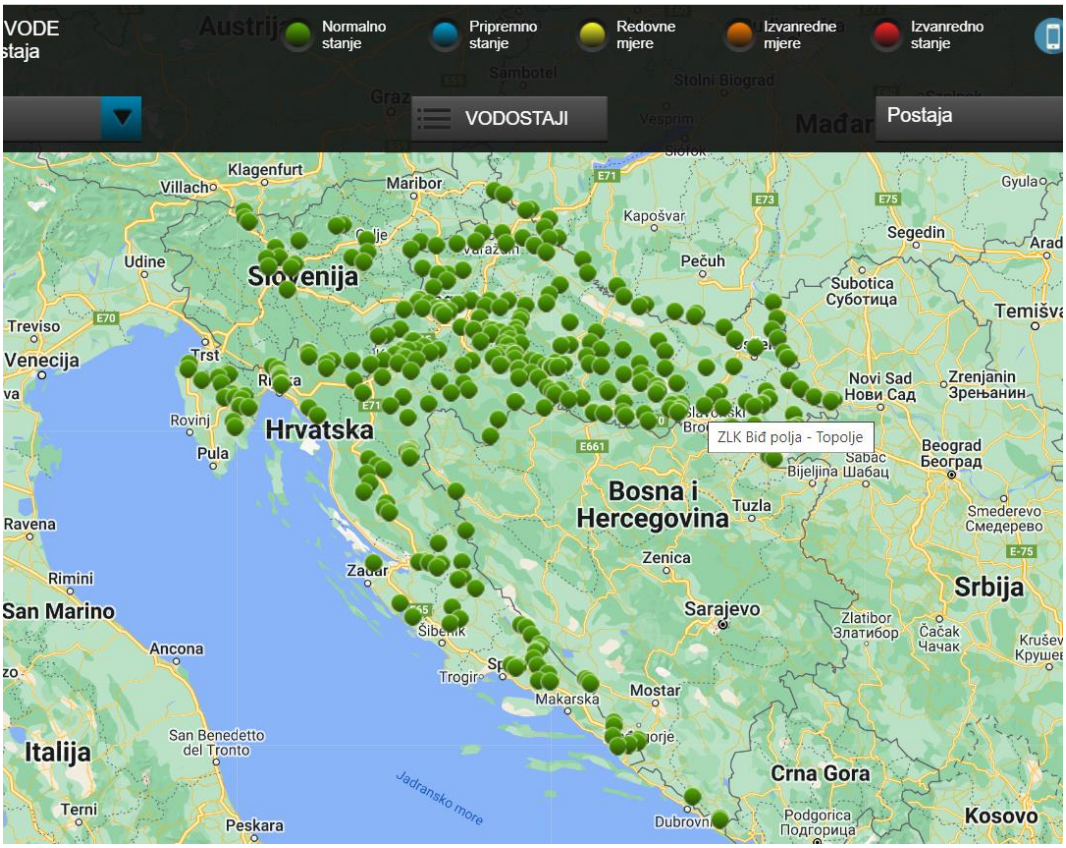

Figure 2 Water level measuring stations in Croatia

The stations are presented with circle on the map that, depending on the water level and the measures that apply to that station, change colour (normal state-green, preparatory state-blue, regular measures-yellow, extraordinary measures-orange, state of emergency-red). Information on the values of the last measured water level for each station is available. [2]

[2] http://vodostaji.voda.hr/

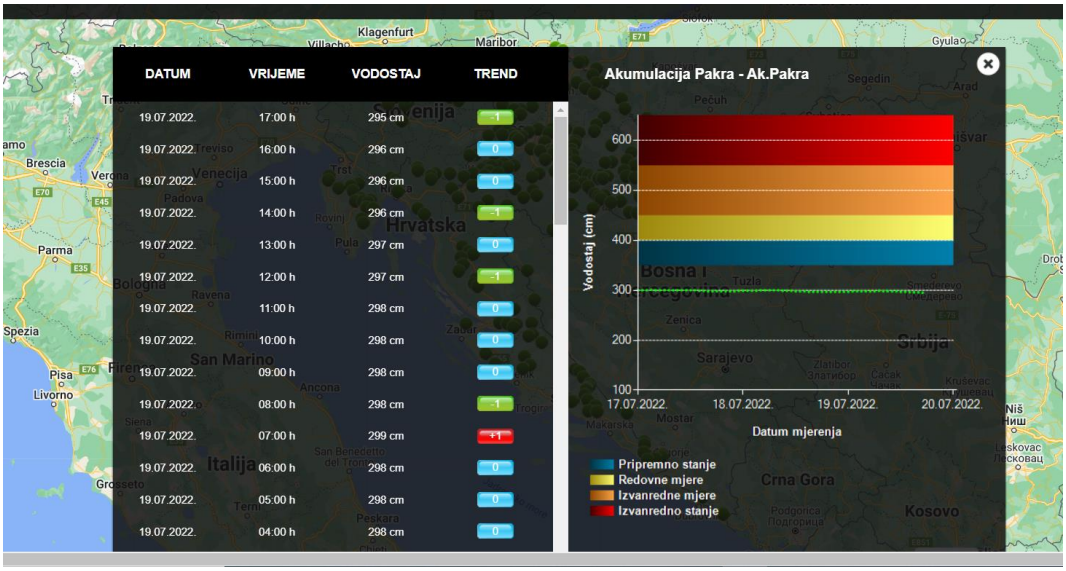

Figure 3 Real time water level chart with applied measures

3.2.3 Information management

There are two basic sources of alerting the operational forces of the civil protection system in the case of flooding (depending on the possible cause of flooding): i) State Hydrometeorological Institute and ii) Croatian waters. In case of flash floods caused by a large amount of precipitation the most authoritative source of warnings is the State Hydrometeorological Institute, which in its forecasts, issues warnings about dangerous weather phenomena, i.e. the possibility of torrential rains flooding in a certain area. Although it is not possible to specify exactly which part of the local areas will be in to be flooded in such situations, critical ones can be determined based on previous experiences points (e.g. flooding of underpasses - the possibility of closing traffic on certain road sections), and should be recorded by local authority. In such situations, the population is warned on a regular basis means (TV, radio). The local Civil Protection Headquarters are activated only if there is a torrential downpour and a larger area is threatened by floods, and the existing fire brigade does not have enough capacity for an adequate response.

The most authoritative source of warning in case of floods caused by high water level of the rivers are Croatian Waters, which regularly monitor the state of the water level and weather phenomena in neighbouring countries that can contribute to the rise in river water levels in Croatia. In the case of sudden events a situation like a dike bursting, citizens will be the first to report the situation and automatically after the notification of the County Centre 112 activates the Civil Protection Headquarters of the local units. Key information that needs to be submitted to the Civil Protection Headquarters in the case of embankment burst are:

- at which location did the embankment burst,
- which area of the city is most at risk due to water encroachment,
- what are the needs for manpower and machinery.

The civil protection headquarters then activates all available resources in accordance with the Plan, collects information from the County Center 112 and makes decisions on dealing with the goal stopping water intrusion based on the judgment of experts from Croatian waters. At the same time, it gives order to activate the capacity of legal entities of interest for civil protection and on the basis assessments of the situation on the ground exposed to flooding (location of vulnerable groups, locations hospital, school, etc.) defines priority zones for population evacuation. People in the Headquarters in charge of communication with the population through the Office for management in emergency situations, they warn the population and inform them, especially about the following:

- location of dike bursting,
- evacuation directions,
- handling in the event that flooding has already occurred and the water level is so high that self-evacuation impossible (switching off electricity and gas, escape to higher floors and buildings/roofs of houses until the arrival of civil protection forces),
- information about changes in the situation (flooding dynamics, actions taken for preventing water penetration, etc.).

3.3 Dutch civil protection agency

3.3.1 Dutch response to flooding events, stakeholders and vulnerability assessments

Main responsibility for safety and security, and risk management policies in the Netherlands, is dedicated to the municipalities and secondary to the 12 provinces. The municipalities are responsible for firefighting, police and security, risk management and disaster preparedness. The provinces are responsible for risk policies only concerning issues that transcend the level of the municipalities. While the formal responsibilities for safety and security are mainly concentrated in the 344 municipalities, effectively the main government authorities for safety and security are, however, organized on the level of 25 regions, see Figure 4.

Figure 4 The official map of the 25 Safety Regions (in Dutch Veiligheidsregio's) in the Netherlands (Boersma et al., 2012)

The 25 Safety Regions are, on behalf of the municipalities, responsible for the fire services, the medical emergency management, the joint emergency room of police, fire services and ambulance services (112), and the disaster preparedness and response. Furthermore, the Safety Regions give

advice to the municipalities and provinces on risk reduction policies. Implementation of risk reduction policies, however, effectively remains a responsibility of the municipalities and provinces itself.

Also, The Netherlands is divided into 26 Regional Water Authorities, the eldest form of Dutch government administration, because of the significant risk of flooding. They are responsible for the management of water barriers, waterways, water quantity (ensuring a correct water level) and water quality. The borders of the 26 Regional Water Authorities follow the dimensions of the water risk areas (water basins). This means they are completely different from the borders of the 25 Safety Regions.

In the event of a flood threat, different action perspectives are possible. Depending on, among other things, the impact of the expected flood, there are several options. It comes down to 'staying' or 'leaving' from the endangered area. This can be the case before, during or after a flood, as seen in Figure 5.

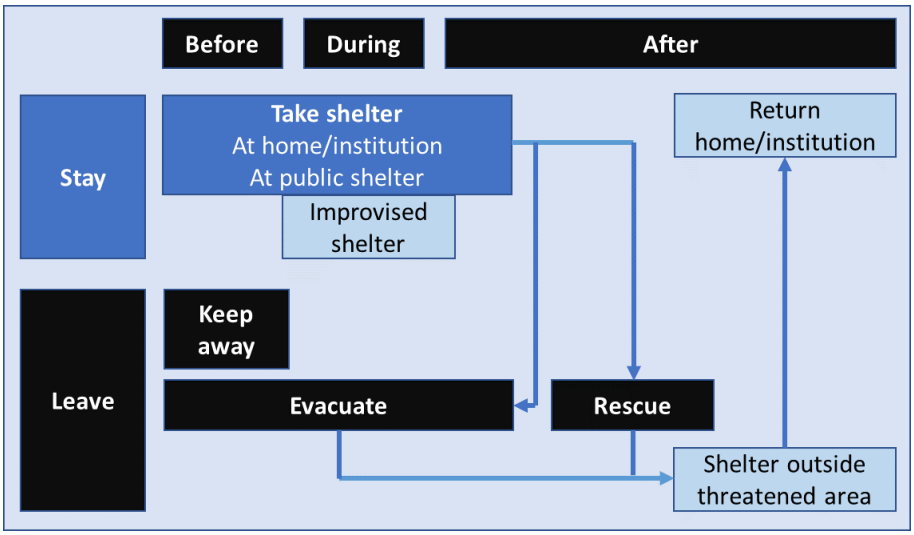

Figure 5 Perspectives for action in the event of (imminent) flooding (VRZHZ, 2021)

3.3.2 Water level monitoring and vulnerability assessment

Real-time water levels are maintained by the governmental body for infrastructure Rijkswaterstaat (RWS), which also provides publicly available predictions of the water levels for the following six days[3]. The same body is responsible for the development of Countrywide Information System Water and Floods (LIWO platform in Dutch)[4]. This system includes maps of the simulated flooded area if a breach happens for each dyke section in the entire country. Evacuation scenarios are typically planned for the worst-case scenario, as presented in LIWO platform and includes an evacuation map in case of any dyke breaches. In the Netherlands four different failure mechanisms are considered when assessing dykes, namely; global stability, overtopping, piping and rapid drawdown. In Deliverable 4.1 the mechanisms are described and a methodology for combining them in a systems approach is described.

[3] https://rijkswaterstaat.github.io/wm-ws-dl/?python#onlinewaarnemingenservice
[4] https://basisinformatie-overstromingen.nl/#/maps

The basic register addresses buildings (BAG) 56 of the Netherlands is a spatial register of all buildings in the Netherlands and includes information about the height of each building. The existing height information is based on the Amsterdam Ordnance Datum (NAP) and contains the roof height as well as the ground level. In the LIWO, the number of floors above ground level (F) of each building is calculated. The flooding scenarios from the LIWO site are overlaid on the buildings of the BAG layer. The maximum height of a flooding scenario at the location of each building reveals whether a building contains dry floors. Based on this data Civil Protection Agency plans population evacuation in certain area.

3.3.3 Information management

Information about the expected water levels and about areas threatened with flooding is provided by RWS and the Water Boards. In addition, municipalities provide information about local flood control. RWS provides information about current and expected water levels in the main water system (coast and rivers) and about the storm surge barriers.

From the Water Management Centrum Nederland (WMCN) or the National Coordination Committee Flood Threat (LCO) regional or from D-7 national (pre)warnings or alarms for high water and flood threats are given. In addition, the KNMI can issue national weather warnings or alarms. The water boards (regional water authorities) provide information about flood threats or danger at primary and regional flood defences and thereby endangered areas, possible flooding from regional water systems, and their effects on roads and sewage treatment plants managed by the water boards.

[5] https://docs.geostandaarden.nl/3dbv/prod/#inhoud-van-de-3d-basisvoorziening
[6] https://www.kadaster.nl/zakelijk/producten/geo-informatie/3d-producten/3d-basisvoorziening

4 Integration of methodology into existing systems

4.1 Slovenia

Bridges and embankments in Slovenia are periodically surveyed by its owners or operators as is demanded by Slovenian legislation. The surveys are conducted by technical specialist employed by owners or operators. And identified damage is classified and catalogued. Depending on the type and extent of damage, further measures are taken to ensure the safety of the structure.

In the Slovenian civil protection system, safety/operability of bridges, dikes, dams and embankments is represented mostly at the local level and tackled in the municipal protection and rescue plans or protection and rescue plans in other organisations, where the owners usually closely cooperate with local authorities about the risk they are presenting in an area. If a region is more at risk of a dam/dike/bridge/embankment failure due to its characteristics, a regional protection and rescue plan is made alongside a protection and rescue plan against flooding. Next, some regions have protection and rescue plans also for notification, warning and alarming the public about the high water levels.

The safety of bridges and dikes is therefore fairly well monitored, but it needs to be upgraded using new and proven technologies to get a better insight into the condition of these structures. Safety dam monitoring on the Soča river is covered by a system of technical observation of dams. This includes required periodic monitoring of the basin area and dams of the following: vertical and horizontal displacements, seismic movements, water levels, precipitation and water temperature.

Dam spillways are equipped with hydro mechanical gate systems which ensure safe evacuation of the excess water. The hydro mechanical equipment is periodically checked and serviced to ensure its correct operation. HESS believes that the existing HPP flow type accumulation dykes (and dams) under the company's jurisdiction are monitored appropriately and sufficiently. DEM (company operating hydroelectric power plants on Drava river) suggests that the current system could be improved by using new and proven technologies, such as the use of drones to inspect the condition of the surface of structures in inaccessible locations, the use of laser scanning to monitor eventual deformations of these structures, the use of optical fibres to monitor eventual water seepage through dykes (dyke leakage), and also to monitor eventual deformations. Technical monitoring of the dams on the Soča river has been carried out from the beginning of their operation. The technical observation system is continually being adapted to meet the necessary improvements that have been identified. HESS believes that current experience, existing procedures, and methods can be further improved by simulations of such events followed by additional staff training, implementation of additional exercises, and potentially by new and improved procedures and methods. DARS, d.d., the motorway network operator, has begun to introduce remote monitoring of the condition of some motorway facilities. In the future, it plans to increase the number of key facilities on which equipment for remote monitoring of the condition and possible critical damage will be installed. SENG (company operating hydroelectric power plants on Soča river) is currently preparing a project to improve the technical observation of dams. The whole concept of improving the existing system is in providing as many automated measurements as possible. For every measurement limit, values are defined, and with an

automated system in place, an appropriate response can be initiated when those values are reached. DEM believes that the current system covers both the necessary measurements (i.e. deformation, groundwater, external loads, etc.) and the necessary visual inspections which must complement the measurement system.

DRSI believes that the system of monitoring roads and road facilities is legally adequately regulated. In the event of a deteriorating condition of road facilities managed by a certain operator, it makes sense for this operator to prescribe more frequent periodic inspections.

To summarize, possible challenges about integrating vulnerability assessment methodologies developed through oVERFLOw project are following :

- when to apply additional monitoring and vulnerability assessment, besides to the existing system;
- how useful/efficient is the methodology in comparison to the measures already taken;
- since there are many stakeholders in the system of operators/owners and the system of CP works as an entity, applying certain CP measures is feasible only if the monitoring/vulnerability assessment is implemented widely.

4.2 Croatia

For the case study area in Croatia the city of Karlovac three different flood scenarios have been analysed and compared. Flood scenarios are based on Croatian Waters flood hazard maps with three different probabilities of occurrence related to three different return periods:

- high probability (HP) of occurrence with return period 25 years,
- medium probability (MP) of occurrence with return period 100 years and
- low probability (LP) of occurrence with return period of 1000 years.

Water depths are grouped into four categories: < 0.5 m, 0.5 – 1.5 m, 1.5 – 2.5 m and > 2.5 m (Croatian Waters, 2019).

In order to develop GIS based risk forecasting tool the following input data (Skaric&Stipanovic,2022) are used:

- Number of endangered population by settlements (up to 100, from 100 to 1,000, more than 1,000) – source Central Bureau of Statistics and database from City of Karlovac (population density per city district).
- Data on land use from City of Karlovac in line with urban planning for City of Karlovac.
- Transport infrastructure data taken from Open Street Map.
- Data on cultural heritage taken from the competent institutions (UNESCO sites). (http://korp.voda.hr/)

Based on the performed analysis, following information is provided in the form of GIS based risk forecasting tool, to be used by CPAs in a case of a flood event:

- Which evacuation routes are safe and available:
    a. Flooded roads – roads that can and cannot be used due to the flooding;
    b. Which critical infrastructure with the focus on embankments and bridges are safe or not safe to be used due to the flooding;
- How many people need to be evacuated and in which parts of the affected area they are located;
- Which critical objects are affected by flood (buildings with people without self-sufficiency – hospitals, preschools, schools, old-people homes etc.);
- Which shelters for evacuation are available or flooded.

Low rise buildings (ground and first floor) are highlighted on maps and combined with the data on number of residents living in these buildings. Presumption is that these residents should be prioritised for the evacuation due to the fact that the water can reach their top floors. Maps with flooded area with associated water depths[7] for three different flood probabilities of occurrence, highlighted low rise buildings and number of people in these buildings

Municipalities in Croatia need to develop their own civil protection action plan which defines actions in case of different hazardous events including floods. It includes early warning operating system, preparedness of operational forces, mobilisation of the forces of the civil protection system and evacuation of population. Civil Protection Action Plan of the city of Karlovac (DLS,

[7] http://korp.voda.hr/

2021) contains the measures regarding population evacuation from certain areas in case of different hazardous events. The plan defines locations of the shelters for the evacuated population in stationary facilities in the area of the City of Karlovac. These locations are overlapped with flood maps from Croatian Waters showing that a lot of these locations are under water in case of all three flood scenarios. The same map also shows critical infrastructure which needs to be highlighted for CPAs regarding prioritization of evacuation or other actions, such as schools, kindergartens, health care institutions, as well as possible pollutants as landfills and wastewater treatment plants,

The safe evacuation routes are established based on reaching the nearest safe place within building, building blocks and city district with areas with higher buildings which are safer in case of a flood hazard,. The main constraints for the safe evacuation routes are associated with the vulnerabilities of the structures along evacuation routes during the hazard event, such as potential scour of the bridge pier due to the high water level and water flow, uncertain safety of the flood protection system also with roads on top of it or behind, uncertain road conditions due to the roads under water, road blockage, etc. Optimal evacuation alternatives in the form of safest and most efficient routes for the evacuation of population from the affected region are determined based on the results of vulnerability assessment of bridges and embankments. Results of the vulnerability analysis of embankments and bridges are categorized based on the developed fragility curves presented in D4.1 and D4.2. Once the probabilities of failures are calculated for pre-defined loads, an asset classification follows.

Depending on the water height, certain parts of road that is on the top of the embankments are not safe for usage meaning that this evacuation route cannot be used in a case of flood. Probability of failure for embankments, which are linear structures, is shown on the map with certain length of the embankment belonging into one of the eight categories from high expected performance to hazardous expected performance.

Bridges, presented on the map as point structures, are associated with a traffic light green, yellow or red, depending on the water level and fragility curves developed in D4.1 (Kosič & Anžlin, 2022). Red light means that a bridge cannot be used, yellow that it can be used but with caution and restrictions, and green light means that it is safe for use.

Roads or parts of roads are under water when a flood occurs leaving them unavailable for use. The information on roads that are flooded provides CPAs necessary data to redirect their actions to available evacuation routes.

4.3 Netherlands

The aim of the case study in the Netherlands was to improve the vulnerability assessment methodology and to integrate it into the current flood risk assessment methodology, focusing on the response and preparedness activities performed by CPA. Vulnerability assessment of dykes included development of fragility curves which are showing dependency of likelihood of embankment failure to the water levels. The methodology considered embankment and riverbank failure through global stability (in static and dynamic loading condition), piping, overtopping and rapid drawdown. In the Netherlands where a failure of the dyke would lead directly to flooding, an event tree was used to link the different failure mechanisms while also providing a consistent methodology linking flood return periods to embankment failure. Since the fragility curves are linked to the water levels of inland waterways and Rijkswaterstaat is providing water level predictions for the following six days, we are proposing real-time data driven approach for the development of the evacuation plans. Based on the information of the dyke vulnerability, it is possible to determine the location which is most probable to fail. When updating the potential location of the breach, it is also possible to update the evacuation predictions. Currently only the worst-case flooding scenario is developed into an evacuation plan. Moreover, this evacuation plan integrates all possible flooding scenarios of dyke breaches. The plan is not an accurate reflection of the current situation, as the worst-case scenario with a return time of 1:400,000 is not only very unlikely to happen, it is also unlikely to happen at all dykes simultaneously. In Table 1 it can be seen that when applying the breach at one location or when knowing the more accurate location of the dyke failure, the number of buildings which need to be evacuated is significantly lower, actually for almost 90%. The reason why some buildings are meant to be evacuated in LIWO, but not in this research is most likely because the LIWO takes dyke overtopping at all locations into account at the same time, while in this case only one dyke is taken into account, where the most probably the breach would occur.

Table 1: Comparison of real-time evacuation predictions with the current LIWO dataset

	Real-time water level evacuation prediction	LIWO model	Overlap
Evacuation	439	3,806	421
No evacuation	32,527	29,160	29,141
Total	32,966	32,966	

This research tried to develop an evacuation plan that integrates multiple possible scenarios of one dyke breach location. It aimed to assist in better informed decision making for first responders, if such a situation should happen. Predicted water levels, that are validated with real-time sensor data, have been combined with the 3D building registry and three flooding maps with varying return periods. It has been found that, in the case of a dyke breach at the highest return period (1:4,000), only 20 buildings need to be evacuated, compared to 372 on a return period of

1:40,000 and 439 on a return period of 1:400,000, which represent only 11% comparing to the current evacuation map, where 3,806 buildings need to be evacuated.

All-in-all, decision making in case of evacuation is improved by a better prediction of the flooding depth, due to the inclusion of water level. It is also improved by a more granular approach to dyke breaches, by not aggregating all breaches into one. This method greatly reduces stress for the civil protection agencies and enables them to prioritize evacuation while large number of residents can stay in the relative comfort of their own home (Skaric&Stipanovic, 2022).

5 Conclusions

To conclude, to be practically applied on Slovenian infrastructure, vulnerability assessment methods for bridges and embankments, both developed through oVERFLOw could prove themselves useful, possibly as an addition to existing monitoring and measurements taken by the infrastructure and flood protection system owners and operators. We suggest beforehand tests on individual objects, which are part of national infrastructure networks.

Risk forecasting tool model developed in the oVERFLOw project was presented and validated for two case studies, City of Karlovac in Croatia and Oostmolendijk in the Netherlands. In both cases we have shown the benefits of the integration of newly developed methodology into the existing tools and procedures, thus revealing the information about the areas with the highest potential risk enabling prioritization of the investments and evacuation planning. Mapping of vulnerability of critical infrastructure, flood water levels and population density in the affected area, gives the insights into the safe evacuation routes and the number of people who need to be evacuated. This information is especially important for CPAs and first responders about the endangered population, areas with low rise buildings or buildings with people without self-sufficiency (preschools, schools, old-people homes etc.) where their immediate attention is needed. It also provides the information about safety evacuation routes so they can reach certain areas without delay or endangerment.

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