FloodProBE: Technologies for improved safety of the built environment in relation to flood events

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ABSTRACT

The FloodProBE project started as a FP7 research project in November 2009. Floods, together with wind related storms, are considered the major natural hazard in the EU in terms of risk to people and assets. In order to adapt urban areas (in river and coastal zones) to prevent flooding or to be better prepared for floods, decision makers need to determine how to upgrade flood defences and increasing flood resilience of protected buildings and critical infrastructure (power supplies, communications, water, transport, etc) and assess the expected risk reduction from these measures.

The aim of the FloodProBE-project is to improve knowledge on flood resilience and flood protection performance for balancing investments in flood risk management in urban areas. To this end, technologies, methods and tools for assessment purposes and for the adaptation of new and existing buildings and critical infrastructure are developed, tested and disseminated.

Three priority areas are addressed by FloodProBE. These are: i) vulnerability of critical infrastructure and high-density value assets including direct and indirect damage, ii) the assessment and reliability of urban flood defences including the use of geophysical methods and remote sensing techniques and iii) concepts and technologies for upgrading weak links in flood defences as well as construction technologies for flood proofing buildings and infrastructure networks to increase the flood resilience of the urban system.

The primary impact of FloodProBE in advancing knowledge in these areas is an increase in the cost-effectiveness (i.e. performance) of new and existing flood protection structures and flood resilience measures.

1. Introduction

Floods, together with wind related storms, are considered the major natural hazard in the EU in terms of risk to people and assets (European Environment Agency, 2010). Between 2000 and 2009, Europe has witnessed some of the largest flooding events in its history. Recent major flooding events include the 2007 floods in the United Kingdom and the Elbe and Danube river floods during the summer of 2002. Over the

last 10 years, floods in Europe have killed more than 1,000 people and affected over 3.4 million others (Guha-Sapir et. al., 2010, EMDAT, 2010). Currently, more than 40 billion € per year is spent on flood mitigation and recovery (incl. compensation of flood damage) in the EU. More than 75 % of the damage caused by floods occurs in urban areas (Ashley et al, 2007). About 3 billion € per year is spent on large-scale flood defence structures alone.
Losses due to floods have increased in Europe over the last few decades. Population increase and increases in asset values in flood prone areas may contribute to this. (European Environment Agency, 2010). The ongoing urbanisation worldwide, as reflected by the growth of the number of megacities, also in deltaic areas, will thus require even more action in relation to this hazard. 70 % of the population will live in urban areas by 2050 (United Nations Population Division, 2008) and the economic values in these areas are constantly growing. Urban areas are mostly located in deltas close to rivers and the sea which are often subject to land subsidence. This means that flood risk in urban areas will increase disproportionately: flood damage figures in Europe could rise to 100 billion € per year by the end of the century (European Environment Agency, 2008).
Although there is no clear evidence that increased flood losses over the last decade are related to climate change, research on Flood Risk Management also has to address concerns coming from climate change scenarios regarding the likelihood of further increases in hydrologic flooding (Barredo, 2008, 2009; DEFRA, 2008; European Environment Agency, 2010). In addition to increased numbers of extreme weather events such as more frequent intensive precipitation, the increasing temperature has caused more melting water, particularly from polar ice. This causes the sea level to rise and expose coastal areas and cities to flooding during storms creating a more hazardous situation for the billions of people who live only few meters above or even below sea level. The increasing temperatures are likely to change weather patterns in many areas. Heavy rainfall increases the frequency of flash floods and more snow in wintertime causes serious floods during the snow melt periods.
Thus climate change and concentration of population and assets in urban areas are the main trends likely to affect flood related societal costs, risk to human life and loss of assets in the near future.
The problem owners for the issues outlined above are the public authorities responsible for flood protection and water management as well as other asset managers.
Urban flood defences comprise both soft soil embankments and hard structures that may stem from centuries ago and built from locally available materials. Due to this their status is often not fully know. Failures are very often caused by internal and /or external erosion processes, particularly at transitions between defence types. Complex combinations of defence types are typical in urban areas. Since flood defence systems are only as strong as the weakest links (“risk hotspots”), these have to be identified, assessed and strengthened.

Traditionally, flood management practices have focused on defensive practices. In the past two decades, due to the realization that risk could and should be actively managed, a shift has been observed from predominantly defensive actions to the wider focus of pro-active management of risk. Land use is possibly the most significant aspect of flood risk management, hence it is essential to ensure that this is an integrated process. The key messages from the update of the UK 2004 Foresight Future Flooding study (Evans et al, 2004, 2008) are that (i) river and coastal defences

have the greatest potential impact for reducing overall flood risk, (ii) better land use planning and the flood-proofing of buildings still appears among the most important risk reducers, (iii) finding the space in urban areas to accommodate increased overland flows is one of the most important responses.
This rethinking and substantial change in the traditional approach to flood risk management has to be developed within an appropriate regulatory framework. Necessary restrictions in the land use planning in areas prone to flooding have to be included in development plans for all types of flooding. Flood preparedness will be mainly influenced by increasing the resilience of the built environment (in the widest sense). In parallel, contingency planning encompasses all activities and resources in case of a hazard event that include emergency response; emergency infrastructure; financial preparedness and recovery plans.

It follows from the above that traditional flood risk management approaches omit important ways of dealing with floods pro-actively at city level, and of building on bottom-up responses that reduce their impact and enhance recovery.

2. Project objectives

The project FloodProBE is funded under the Seventh Framework Programme from the European Union starting November 1st 2009 and running for four years. The principal aim of the project is to provide cost-effective means for flood risk reduction in urban areas. To this end, FloodProBE will develop technologies, methods, concepts and tools for enhanced assessment and adaptation of urban systems related to floods. Major bottlenecks that hamper the adoption and wide spread uptake of these technologies are amongst others (i) lack of understanding of current and future risks (ii) lack of long-term planning, poorly integrated and comprehensive planning, (iii) lack of understanding of the effectiveness of these technologies, and (iv) inadequate controlling roles of local and regional authorities, and lack of formal guidance and policies for implementation.
The current research will build up on the results of key initiatives such as the European FLOODsite (www.floodsite.net) and ComCoast projects and national/regional projects such as FRMRC (UK), RIMAX (DE), NOAH/FLIWAS (NL, DE), FloodControl2015, SBW (NL), Criterre and ERINOH (FR). Priority issues for urban flood risk management are subject of research in FloodProBE.
The specific project objectives are:

1. To improve methods for assessing the vulnerability of the urban environment related to floods, especially by extending conventional methods with the ability to assess indirect impacts of damage to critical networks and assets with a high value density.
2. To improve the understanding and assessment of urban flood defence performance, in order to develop suitable protection measures and to increase the cost-effectiveness of future investments.
3. To develop and test construction technologies and concepts to improve the performance of existing and new flood defences and for flood-proofing of the urban environment.
4. To integrate the knowledge developed in the project on assessment of vulnerability of urban areas and flood defences as well as the newly developed

construction technologies and concepts to support holistic flood risk management strategies. This implies that optimal solutions require the joint consideration of flood defences and adaptation of the vulnerable assets.

5. To contribute to harmonisation of guidance in flood risk assessment and flood management in the urban context, and thereby support the implementation of the EU Flood Directive**.**

By integrating the knowledge to be developed in the project within existing flood risk management strategies, the end-users, mainly responsible public authorities and asset managers, will be enabled to manage flood risk using more holistic approaches.

3. Science-policy-practice interfaces

In the FloodProBE-project the development and uptake of knowledge is organized along four interlinking routes. The first dissemination route is research and development contributing to existing decision support systems in European countries. The second route is guidance developed on how to use the new knowledge in engineering practice. The third route is aimed at involving stakeholders by direct interaction and applications in pilot cities. Finally a policy brief will be drafted to inform policy makers in general. In the following paragraphs each dissemination route is considered in more detail.

3.1 Decision support

Modern urban flood risk management in developed countries requires Decision Support Systems (DSS). These can be based on source-pathway-receptor concepts. The hazard is depicted by the source, whilst the pathway commonly represents the flood defence system and the receptor is the representation of the values at stake, including economic and societal value as well as people at risk (Samuels et al, 2008). FloodProBE focuses on urban flood risk identification and assessment and upon offering cost-effective solutions for the most important risk contributors, such as assets of high value like critical infrastructure networks, and weak links in flood defence systems. The project develops solutions through easily accessible technologies, concepts, methods and tools, for practical application by public authorities, asset managers and their consultants.

FloodProBE will elaborate the results of its activities in the form of modules or methods that can be integrated within the different national or organisational DSS and methods for flood risk management. New insights, methods and tools will be integrated and tested at pilot locations to illustrate the impact of the newly developed knowledge and technologies.

There are many commonalities between models and concepts used for supporting decision-making in different countries and there is a common underlying need for improved science and methods. The work within FloodProBE aims to meet those common needs. Current decision support systems from different partners will be further developed through the integration of new generic modules, methods or information based on the insights and methods developed in FloodProBE. These are discussed in more detail later in this paper. Where possible, the new modules will be developed in close liaison with pilot study activities.

The overarching result will be recommendations on how to integrate and use FloodProBE models for different types of decision support related to urban flood risks. Decision support for maintenance, policy making and dealing with calamities will be considered.

As an initial list (figure 1), the following methods or results have been identified as examples of tools or methods that should be considered in relation to existing DSS and practice:

- infrastructure network analysis for improved damage estimation and prioritization of protection measures to identified "risk hotspots"
- damage estimation module on building level for high resolution analysis
- new or adapted failure modes for reliability analysis of erosion mechanisms in urban flood defences
- data acquisition and processing of geophysical and remote sensing data
- combining data from different sources to improve reliability analysis for flood defences
- retrofit timing and application of flood-proofing measures based on the new technologies and concepts

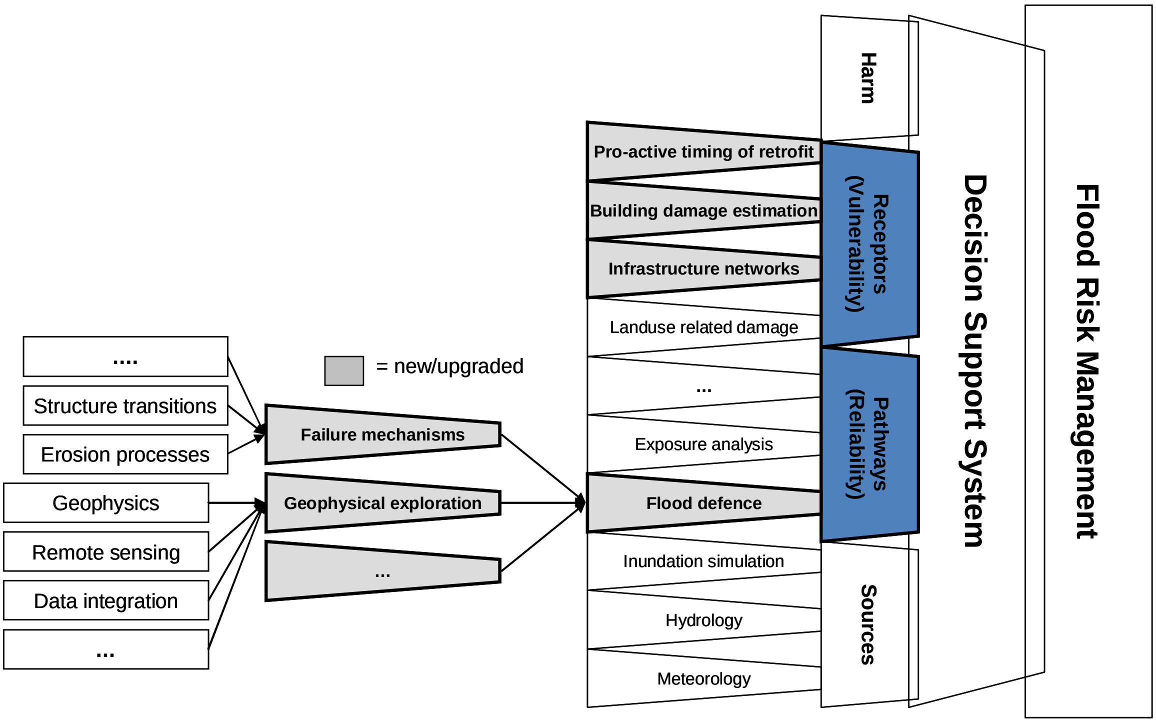

Figure 1. Specific areas of knowledge development in FloodProBE (indicated in grey as new/upgraded)

It should be stressed that FloodProBE is focussed upon ensuring that new models and methods can be integrated with existing decision support systems or methods; the project will not produce new DSS. This approach is being taken because it is more effective in terms of science uptake to provide something which meshes easily with an existing DSS model or method than to try and encourage complete replacement of a DSS by many different end user organisations.

Recommendations for application and schematization related to FloodProBE models and modules will be refined through the experience gained from application during the execution of the pilot study areas.

3.2 Providing guidance

The new knowledge produced by FloodProBE will also lead to amendment of existing and the creation of new guidance documents. Areas addressed are vulnerability assessment, flood defence assessment, protection, and flood proofing measures for the urban environment. Guidance provided will be structured so that it is easy to integrate into existing flood risk management decision support that is provided mainly on a national or regional level. This will contribute to harmonisation of approaches and guidance throughout Europe and form an essential contribution to the implementation of the EU Flood Directive.

Use of the guidance will enable the problem-owners to increase the effectiveness of their investments in flood protection and flood-proofing, by identification and targeted improvement of “risk hotspots”, as well as by utilisation of the newly developed cost-effective technologies and concepts. The final impact is a significant saving on the costs of flood damage and protection in Europe. The developed solutions will be generic and applicable in urban areas across the EU and worldwide.

3.3 Stakeholder involvement

In order to achieve the expected impact described above, the FloodProBE consortium recognizes the need for effective stakeholder involvement in order to develop solutions that meet the end-users needs and that can be applied in practice. The third dissemination route is therefore learning, testing and developing through pilot sites (figure 2), strengthening the link between research and practice. The associate program that is maintained also ensures stakeholder participation to obtain relevant and practicable results in terms of guidance and enhanced decision support tools.

Figure 2. Pilot locations FloodProBE-project

Finally FloodProBE will write a policy brief to inform policymakers about the outcomes and on how implementation of the science and strategies into policy making processes could be undertaken.

4. Science and development in FloodProBE

Uncertainties about climate change scenarios and autonomous economic and social developments make it difficult to determine optimal strategies for urban flood risk management. It is likely that a combination of flood prevention and flood resilience would offer a robust strategy. Making an urban environment more flood resilient means, amongst other aspects, to make it less susceptible to flooding and to increase its recovery capacity after flooding has occurred. The following subsections describe the progress beyond the state-of-the-art on:

- Vulnerability of urban systems
- Reliability of urban flood defences
- Construction technologies and concepts for flood protection and building flood resilience
- Urban flood management in an integrated framework

4.1 Vulnerability of urban systems

Urban systems contain assets of high value and complex and interdependent critical infrastructure networks (i.e. power supplies, communications, water, transport etc.). The infrastructure networks are critical for the continuity of economic activities as well as for the people's basic living needs. Their availability is also required for fast and effective recovery after flood disasters. The severity of flood damage therefore largely depends on the degree that both high value assets and critical urban infrastructure are affected, either directly or indirectly. In the summer of 2007 floods caused half a

million people to loose access to water supply and electricity in the UK. In Gloucestershire 350 000 people did not have their water supply restored until 17 days after the event. The insured costs of EUR 2.4 billion made it one of the costliest disasters in UK history (European Environment Agency, 2010).
Critical urban infrastructure, comprising networks and their associated buildings, such as transport, water and electricity supplies and telecommunications are considered as lifelines. These networks play a fundamental role in modern society and cause tremendous direct and indirect consequences when they suffer downtime (figure 3). The functions of these lifelines are interdependent, and damage to one can cascade rapidly into all the connected systems.

Figure 3. Flooding in the city of Prague, 2002 (Photo courtesy REC CZ)

Although the disaster was not caused by floods, but was mainly due to heavy rain and wind, the interdependency between networks and consequences of a breakdown of critical infrastructure can be seen in the following example.

In November 2009, a failure in the electricity network of the second biggest hydropower plant in the world, located between Paraguay and Brasilia, caused an electrical breakdown. The consequence was that Sao Paulo and Rio de Janeiro stayed without electricity for several hours which triggered a chain reaction. The lack of electricity caused the shutdown of several airports and people were trapped in the subway, affecting the entire transport infrastructure. People trapped in the underground railways had to leave the trains and walk along the tracks out of the tunnels. Due to the failure of traffic lights, the entire traffic network collapsed. 40 million people stayed without electricity until the next morning. An increased police presence was needed to maintain security during the night without lighting.
The example shows that natural hazards can cause disastrous situations for human life, property and infrastructure. Imagine what would have happened if this was due to, and

combined with, a flood event. In order to be prepared to avoid and manage hazardous flood situations it is essential to understand and analyze the vulnerability of infrastructure and associated buildings. In addition, there is a need to assess interconnected infrastructures and the built environment on which society depends in order to understand interdependencies and indirect consequences. Current flood risk management and research mainly use the susceptibility and value of the protected assets (expected damage to buildings and inventory) to assess their vulnerability, i.e. the potential direct damage. Risk and vulnerability analyses (RVA) which were originally developed for technological operations were modified for different sectors and are commonly in use. However, existing vulnerability assessment methodologies are not sufficient in the sense of assessing the interaction of different infrastructure and damage estimations for the most vulnerable components and buildings. Improving the assessment of potential indirect damage to the entire urban system caused by flood-induced failure of particular components is of great value. It allows decision-makers to focus their investments on such “risk hotspots”, i.e. particularly vulnerable elements of the urban system. This will considerably increase the cost-effectiveness of their investments.

Therefore, FloodProBE will further develop the state-of-the art vulnerability analysis methods on a more detailed urban level to identify, assess and rank the most vulnerable assets and elements. FloodProBE will especially advance knowledge on the susceptibility of different types of buildings by developing more detailed assessment methods. These will include the pathways at a building level (how does the water lead to damage) and the building functions that are affected. The results will particularly enable the development of flood-proofing concepts and technologies for increasing building flood resilience, thus decreasing their susceptibility to floods and / or increase their capacity to recover from flood damage. This is particularly relevant for critical buildings, i.e. those that need to remain operational during flood events, such as hospitals, fire stations, water supply and treatment works, and energy generating and communication stations. FloodProBE will furthermore refine existing damage models, by research into the expected costs of repair of damaged assets, particularly buildings with public, commercial and industrial use with high concentration of persons and values.

For the purpose of improved vulnerability assessment, FloodProBE will develop methods and tools for assessing the indirect damage to the urban system by failure of infrastructure networks. This research includes assessment of network reliability and failure mode and effect analysis (FMEA), focussed on indirect damage expected from flooding. The outcomes of such analyses that include indirect costs might lead to significantly different conclusions regarding protection measures compared to decisions based on the expected direct damage costs only.

4.2 Reliability of urban flood defences

The main uncertainties affecting the reliability of urban flood defences are related to the foundations and the soil used as construction material. Urban flood defences comprise both soft soil embankments and hard structures. Failures are often caused by internal and / or external erosion processes, particularly at transitions between defence types. Complex combinations of defence types are typical in urban areas. Since flood defence systems are only as strong as the weakest links (“risk hotspots”) these weak spots need to be identified, assessed and strengthened. Improved identification and

upgrading of weak links in flood defence systems will increase the cost-effectiveness of flood protection investments significantly.
There is a need for improved understanding and clear guidance on assessing erosion processes, internal and surface erosion and erosion around transitions associated with embankments, in particular against hard structures. These potential failure locations have proven to be particularly problematic for urban flood defences (USACE, 2007). This requires attention for the development of suitable detection, prevention and repair technologies.

Conventional site investigation techniques for assessing geotechnical properties assess soil properties at specific locations quite accurately, however, determining the soil properties over longer lengths of embankment is less precise and in between measured points values have to be interpreted or interpolated, introducing large uncertainties. More recently, the use of geophysical methods and remote sensing is becoming popular for assessing large areas, even though this entails a lower degree of accuracy. However, there are quite different national approaches to the application of these techniques. Furthermore, classical and innovative methods generate different types of data. These approaches are not yet routinely combined with assessment methods and tools, but only used in engineering judgement.

4.2.1 Erosion

Soil erosion is the cause of failure of the majority of dikes and composite flood defence structures, whether through internal erosion, wave overtopping, overflow or contact erosion. For structure failure modes in general, definitions are given in the FLOODsite Report T04-06-01 (Allsop et al., 2007) as a starting point. However, for internal erosion, later definitions of the ICOLD European Working Group on Internal Erosion of Embankment Dams (Granada, 2010) are followed, stating that internal erosion is the “downstream transport of soil particles within an embankment dam or its foundation by seepage flow”. This includes 4 mechanisms:
(a) concentrated leakage erosion through a pre-existing path in the embankment or foundation,
(b), piping, or backward erosion leading to a tunnel in the embankment or foundation,
(c) suffusion, or suffosion, involving selective erosion of the fine particles from the matrix of coarse particles or
(d) soil contact erosion, or external suffusion, involving selective erosion of fine particles from the contact with a coarser layer.
The FloodProBE project research focuses on all of these mechanisms except suffusion, since these types of erosion are known to be dominant for the urban areas in France, Great Britain and the Netherlands. The dominant internal erosion mode is predominately dependent upon the characteristics (or configuration) of the soil layer, especially grain size distribution and compaction.

4.2.2 Transitions

Analysis of recent flood events such as at Arles (France) and New Orleans (USA) have demonstrated the weaknesses in urban flood defences that can occur at transitions between structure types or at specific locations. In particular, as had been seen in many cases, the contact zone can be a preferred seepage path, where erosion can be initiated or can develop. Those transitions create weak points within a defence, and undermine the performance of the overall system of flood defences. Since the performance of

transitions is typically not included within system risk models, such transitions also undermine the accuracy of overall system risk prediction. This issue was identified in the European FLOODsite project (Allsop et al., 2007).
The broad aim of the work in FloodProBE is to identify typical weak designs for structure transitions and specific points and provide guidance on repair or retrofit solutions (figure 4 and 5). In particular, internal erosion processes at structure transitions, or below historical structures such as sluices, are poorly understood, since information on the current state of the subterranean part of the structure (e.g. foundation or sheet pile cut-offs) is often lacking (figure 6).

Figure 4. A house in a levee (Photo courtesy Cemagref)

Figure 5. A culvert through a levee (Photo courtesy Cemagref)

There is a need for better methods for safety assessment of those structures, being preferably fast, cost-effective and non-destructive methods, as well as a clear understanding of the erosion processes that lead to inundation failure. FloodProBE will build upon the state-of-the-art to advance the fundamental knowledge on soil erosion along structures and at structure transitions. This new knowledge will be used to extend or introduce failure mode descriptions for the risk analysis of urban flood defences in particular. FloodProBE will also deliver guidance on taking decisions on design, repair and upgrading of urban flood defences, in particular the design of transitions between embankments and structures.

Figure 6. Structure transition in flood defence (Photo courtesy HR Wallingford)

4.2.3 Vegetation cover

Performance of vegetation during flooding is also an important aspect. There is an increasing realisation that overflowing and wave overtopping of flood embankments needs to be an accepted part of flood embankment performance for more extreme flood events (figure 7).

Figure 7. Overtopping grass covered flood defence (Photo courtesy HR Wallingford)

Climate change effects appear to be leading towards more extreme conditions for both hydraulic loading (magnitude of flood event) and climatic conditions (prolonged wet and dry periods). These changes pose an increasing load upon the performance of grass cover on embankments. Variations in climatic conditions mean that the condition of grass cover may vary more widely, whilst an increase in hydraulic loading means greater durations, depths and velocity of overflowing water. Existing design guidance on the performance of grass on dikes, such as the CIRIA Report 116 (Hewlett et al., 1987), is limited and based upon data and analyses from the 1980s (Young, 2005). The data sets used are fairly limited, and also appear to contain in built factors of safety which, whilst maybe appropriate for use in design methods, cause problems when the performance curves are used for reliability analysis (Morris et al., 2009, Morris et al., 2010). The broad aim of this research action is the development of extended or revised guidance based upon a review of international research results and existing grass performance data from the last 25 years. FloodProBE will deliver new or extended guidance (good practice) on efficient acquisition and use of distributed data for reliability assessment of urban flood defence performance, thus also contributing to harmonisation of good practice. Developing methods and tools for combining data from different sources (site investigation, geology, remote sensing and geophysical techniques) will lead to effective and complementary use of existing data and knowledge.

4.2.4 Combination of information sources

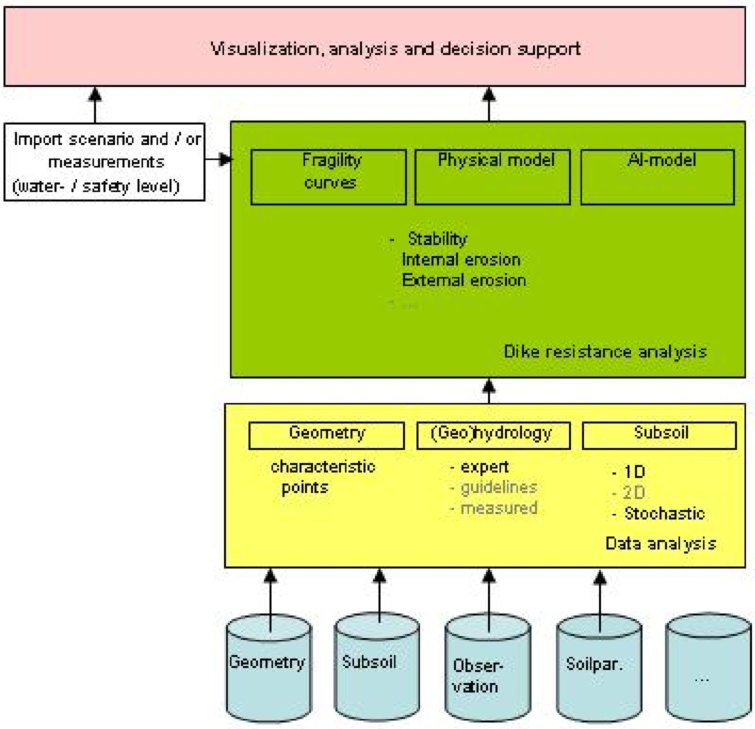

Figure 8. Example of modular approach to the reliability assessment of flood defences

FloodProBE will investigate the combination of information sources for dike diagnosis (figure 8). The impact will be to develop structured approaches and formalized procedures for combining data from different information sources for the purpose of improving reliability assessment. The outcomes will lead towards European harmonisation of guidance for a larger community of potential users. This will help to create uniformity in the risk assessments within the EU Flood Directive.

4.3 Construction technologies and concepts for flood protection and flood proofing the built environment

4.3.1. Multifunction flood defences

The ongoing growth of cities is reflected in a trend towards higher density urban areas. Various functions such as flood defence, housing, and transport compete for space. There is an increasing need to combine flood defence functionality with other functions in a new type of flood defence system and thereby make better use of the available space. FloodProBE will further develop state-of-the art design concepts for multifunctional flood defences. By developing construction concepts that integrate other commercial or industrial functions into flood defences, the investment in flood protection can be made more cost-effective. Innovative integrative solutions allow an optimal use of the available space. Examples are car parking and (temporary) water storage or integration of houses into flood defence structures (see Figure 9). Based on initial work on the integration of different functions, a range of functions will be explored for potential integration. Based on stakeholder input (workshops), the most promising concepts will be detailed. The applicability of concepts will be illustrated through pilot studies.

Figure 9. An artist impression of a multi-functional flood defence system (Rotterdam Dakpark, The Netherlands). This structure combines three functions: flood defence, a green roof and recreational park and commercial properties (courtesy DuraVermeer).

FloodProBE will build upon state of the art science and technology to further advance concepts and technologies that reduce the impact of flooding to cities in terms of casualties and (indirect) damage as part of a package of an integrated flood risk management scheme including flood prevention, protection and preparedness (e.g. awareness, warning and emergency planning). It will also develop guidelines on how to select, implement and operate these technologies and concepts. FloodProBe will focus on flood proofing[1] of existing and new vulnerable critical assets (risk hot spots) and infrastructure and smart shelters. Examples of hot spot buildings are power stations, communication and data hubs, water treatment plants, hospitals, and fire fighting stations. These assets are high value nodes in critical infrastructure. Events such as flooding by hurricane Katrina have demonstrated that "shelter in place" strategies have benefits over large scale evacuation. The aim here is to develop technologies that are smart in the sense that they integrate a shelter function in various building types in urban areas, such as high-rise or (semi-)public buildings such as sport stadiums. The benefits include (cost) effectiveness by function integration, and reduction of loss of life by offering a safe alternative to evacuation. FloodProBE will also consider integrated vertical evacuation and shelter functions in utility and high-rise buildings, in order to provide alternatives to horizontal evacuation strategies.

4.3.2. Flood-proofing road infrastructure

Infrastructure is often at risk due to its location in hazard prone areas; flood water disrupts communication links and inundates large settlement and urban areas. Frequently the location and structure combine to increase the vulnerability. Road infrastructure forms a lifeline for inhabitants in a flood prone area, allowing evacuation as well as access for emergency response services to affected areas. Access is fundamental for the continued provision of essential services such as the supply of food, bottled water and the maintenance of communications. Flood proof structures are therefore required in circumstances of flooding and post-flooding, for interoperability and connection. Hence the need to develop new technologies that can be applied to road infrastructure providing flood proofing solutions (Permanent measures, Contingent measures, Emergency measures). A specific focus of the research lies in activities related to bridges, where two main actions will investigate light weight bridge technology applied for both footbridge and vehicular bridges, and the search for a solution that could significantly reduce the operative, logistic costs and lost profits from flooding.

4.3.3 Biotechnical treatment of flood defences

In FloodProBE the application of biotechnological methods (BioGrout technology) will be developed and tested for the prevention, retrofit and repair of geotechnical failure mechanisms within flood defences, focussing upon erosion failure processes.

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[1] The definition of flood proofing used here comprises measures that aim to prevent flood water reaching the inside of properties or minimise damage caused by floods enter property.

BioGrout is an innovative biotechnology based on Microbial In situ Carbonate Precipitation (MICP) for the improvement of sandy soils in terms of strength and stiffness. A PhD study at Murdoch University in Australia (Whiffin 2004) has proven the feasibility of the in situ strengthening of sand. Deltares (NL) has developed this technology further in terms of knowledge on up-scaling the process from laboratory to field scale and testing the applicability of the process. Two different methods for MICP can currently be identified, called first and second generation. Principles and production for first and second generation BioGrout are described in (Van Paassen, 2009). With BioGrout first generation, carbonate is produced through the hydrolysis of urea. Sporosarcina pasteurii, an ureolytic bacterium able to produce large amounts of the intracellular enzyme urease, hydrolyzes urea, producing carbonate and ammonium ions:

$$CO(NH_2)_2 + 2H_2O \rightarrow CO_3^{2-} + 2NH^{4+}$$

In the presence of calcium, the carbonate precipitates according to its chemical solubility product (K_{sp} = 3.36 x 10-9 at 25°C), to form calcium carbonate crystals which bond the sand particles together.

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_{3(s)}$$

The result of this process is an increase in mechanical strength of the soil by increasing the cohesion between the soil grains, whilst keeping a significant portion of the original materials' permeability.
Being able to modify ground strength or permeability holds significant potential for failure prevention, non-destructive retrofit and repair of flood defences. The technology might prevent the need for structural upgrades or renovation through the application of a low disturbance, in situ process that does not leave harmful residuals. The main characteristics in comparison to conventional flood defence improvement technologies are: (a) it is a non-destructive retrofit technology, (b) it causes less disruption of urban activities, does not require any additional space to be occupied by the flood defence and does not change the visual appearance of the structure and (c) it repairs flaws or improves weak spots without creating new weak elements (e.g. transitions with hard structures). FloodProbe will specifically advance this technology in the field application to internal erosion. The potential to reduce the risk of erosion will be tested at lab scale to large scale specimen to validate its applicability in flood defence strengthening.

5. Conclusions

FloodProBE will contribute significantly to the implementation of the EU-Flood Directive. Results will support risk management and reduction measures for urban areas caused by flooding in general and autonomous developments in terms of growing urbanisation and climate change. The focus of the developments are on the main contributors to direct and indirect potential flood damage, the infrastructure networks and high-density value assets. Especially long disruption to public services, like critical infrastructure networks, cause major indirect damage after flood disasters.
The project communication process is strongly web based and is focused at sharing information internally and dissemination through e-Zines and direct cooperation in pilot projects with different stakeholders.

The collaboration with end-users (urban planners, public authorities, constructors, architects) is achieved in particular through a series of integrated pilots. Furthermore guidance will be produced based upon the outcome of the research activities organised in separate work packages and will be integrated into a *handbook for practical application in urban flood management*.

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