UrbanFlood

Early Warning Systems and the Mitigation of Climate Change Induced Disasters

Work Package 2 – D2.1

version 1.0, date 10/05/2010

May 2010
URBAN FLOOD

A project funded under the EU
Seventh Framework Programme
Theme ICT-2009.6.4a
ICT for Environmental Services and
Climate Change Adaption

Grant agreement no. 248767
Project start: December 1, 2009
Project finish: November 30, 2012

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DOCUMENT INFORMATION

<table>
<thead>
<tr>
<th>Title</th>
<th>Early Warning Systems and the Mitigation of Climate Change Induced Disasters (D2.1)</th>
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<tbody>
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</tbody>
</table>
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| Distribution | Public |
| Document Reference | UFD21v1.0.sto |

DOCUMENT HISTORY

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Prepared by</th>
<th>Organisation</th>
<th>Approved by</th>
<th>Notes</th>
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<tr>
<td>Feb 2010</td>
<td>v0.1.sto</td>
<td>Bob Pengel</td>
<td>STOWA</td>
<td></td>
<td>First framework</td>
</tr>
<tr>
<td>19/03/10</td>
<td>v0.6.sto</td>
<td>Bob Pengel / Sander Bakkenist</td>
<td>STOWA / BZ</td>
<td></td>
<td>Report on status in the Netherlands based on framework</td>
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<tr>
<td>24/04/10</td>
<td>V0.8.sto</td>
<td>Bob Pengel</td>
<td>STOWA</td>
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<td>Full Concept for partner review, including results Questionnaires</td>
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<tr>
<td>09/05/10</td>
<td>V0.9.sto</td>
<td>Bob Pengel</td>
<td>STOWA</td>
<td></td>
<td>Include suggestions by partners</td>
</tr>
<tr>
<td>10/05/10</td>
<td>V1.0.sto</td>
<td>Bob Pengel</td>
<td>STOWA</td>
<td>Nico Pals / Rob Meijer, TNO</td>
<td>Reviewed final version (living document)</td>
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ACKNOWLEDGEMENT

The work described in this publication was supported by the European Community’s Seventh Framework Programme through the grant to the budget of the Project UrbanFlood, Grant Agreement no. 248767.

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¹ BZ Innovation Management (BZ) is a Dutch firm of consulting engineers specialized in the field of innovation and development in the water safety and environment sector. BZ has a strong track record in projects and process management for monitoring of dikes, in the Netherlands and abroad.
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SUMMARY

This document presents the results of Task 2.2 of the UrbanFlood Project and describes the stakeholder analysis. It lists the demands and requirements for online Early Warning Systems and smart dikes.

The first step of the stakeholder analysis was to write down the known issues in an outline. Based on this a series of interviews was held in the Netherlands, verifying the outline and adding detail. Examples of ‘smart dike’ implementations were described.

The second part of the survey used questionnaires, sent in a targeted manner to international key resource persons. Out of 70+ questionnaires a somewhat meagre 12 responses were received by the time this report had to be completed. On the plus side 8 countries were represented, and the sometimes detailed reactions supported and added further detail to the draft. With this information the report was completed.

The report gives background on relevant policies, programmes and projects; it lists a number of example “smart dike” implementations, and it provides the reader with a listing of requirements for EWS and smart dikes based on the stakeholder analysis.

For Smart Dike EWS these requirements are subdivided in three classes. First are technical requirements of the system: those that must be met to ensure that the system actually works and a working prototype can be built. We also recognize non-technical requirements. These have mostly to do with the security, reliability and economics of the system. The third class of requirements deals with institutional issues – a system that is proven as a working prototype which is secure, reliable and economical still has to be accepted by the organisation that is going to implement it, and by the people who are going to work with it.

In the concluding chapter the first section is a justification for smart dikes and EWS, based on stakeholder responses. The second and last section presents several general conclusions.

Overall the responses were positive and helpful, and they provided clear and especially practical guidelines for the UrbanFlood EWS design. Most of the contacted stakeholders are interested in the UrbanFlood project and want to be involved and/or kept informed; some expressed their willingness to trial a sensor network for an online EWS. Task 2.3, which is to describe EWS requirements, builds upon the results in this report. This also implies that a certain degree of overlap between this report and the report for Task 2.3 is unavoidable.

Amersfoort
5 May 2010
### Acronyms and Abbreviations

<table>
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<th>Description</th>
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<tr>
<td>CRUE ERA-NET</td>
<td>EU funded project for cooperation in research on flooding - <a href="http://www.crue-eranet.net">www.crue-eranet.net</a></td>
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<tr>
<td>CYF, CY</td>
<td>Cyfronet AGH, Cracow, Poland – UrbanFlood partner</td>
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<td>Defra</td>
<td>Department for Environment, Food and Rural Affairs, UK</td>
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<td>DoW</td>
<td>Description of Work, annex to the UrbanFlood Grant Agreement</td>
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<td>EC</td>
<td>European Community</td>
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<td>EWS</td>
<td>Early Warning System</td>
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<tr>
<td>FloodProBE</td>
<td>EU research project providing solutions for flood risk reduction in urban areas</td>
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<td>FLOODsite</td>
<td>EU project: Integrated Flood Risk Analysis and Management Methodologies</td>
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<td>FRA</td>
<td>Flood Risk Assessment</td>
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<td>FRM</td>
<td>Flood Risk Management</td>
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<td>HRW</td>
<td>HR Wallingford</td>
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<td>ICOLD</td>
<td>International Commission of Large Dams</td>
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<td>ICT</td>
<td>Information and Communication Technology</td>
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<td>IJkdijk</td>
<td>IJkdijk Foundation, dike testing site in Groningen, the Netherlands</td>
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<td>LiveDijk</td>
<td>Test location for sensor technologies at Eemshaven, Groningen, the Netherlands</td>
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<td>SIE</td>
<td>Siemens, Germany. OOO Siemens in Russia is an UrbanFlood project partner</td>
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<td>TNO</td>
<td>Dutch organisation for Applied Research, The Netherlands – UF lead partner</td>
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<td>US, USA</td>
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<td>USACE</td>
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<td>UvA</td>
<td>University of Amsterdam</td>
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<td>WP</td>
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1 Introduction

1.1 UrbanFlood

UrbanFlood is a project investigating the use of sensors within flood embankments to support an online early warning system, real time emergency management and routine asset management. It is a project under the EU 7th framework Programme which started in December 2009 and will run for 3 years. Partners of UrbanFlood include TNO Information and Communication Technology, the University of Amsterdam and STOWA (Dutch acronym for the Foundation for Applied Water Research) from the Netherlands; HR Wallingford in the UK, ACC Cyfronet AGH in Poland and OOO Siemens in Russia.

Early Warning System Framework for European Cities

More than two thirds of European cities have to deal with flood risk management issues on a regular basis; these are issues which will worsen as climate change effects result in more extreme conditions. Early Warning Systems (EWS) can play a crucial role in mitigating flood risk by detecting conditions and predicting the onset of a catastrophe before the event occurs, and by providing real time information during an event. EWSs thus fulfil multiple roles as general information systems, decision support systems and alarm systems for multiple stakeholders including government, private companies and the general public.

The UrbanFlood Approach

The UrbanFlood project will create an internet based EWS service platform that can be used to link sensors via the Internet to predictive models and emergency warning systems. The data collected from the sensors will be interpreted to assess the condition and likelihood of failure; different models will be used to predict the failure mode and subsequent potential inundation in near real time. Through the Internet, additional computer resources required by the framework are made available on demand.

UrbanFlood will validate the EWS framework and method for implementation in the context of dike performance (failure) in an urban environment. A number of live pilot sites will be used to prove the methodology. Dikes will be equipped with sensor systems and the EWS service built up from a series of dike failure and flooding specific modules which include dike breach evolution and flood-spread models. UrbanFlood will investigate and show the feasibility to remotely monitor dikes and floods, whether from nearby offices or from other countries and continents through secure use of web based technologies.

For the development of flood mitigation scenarios and the training of personnel, the framework will also connect to a simulator that computes flood responses associated with failing dikes. UrbanFlood will make use of data from the induced failure of real dikes at the IJkdijk field laboratory to test and validate the overall EWS framework and individual modules.
Challenges

The challenges below are formulated in a generic manner but can be read as aimed at flood EWS aimed at monitoring flood defence structures – which is detailed in Challenge 5 and 6.

1. How to connect sensor infrastructures to an Internet-based Early Warning Systems (EWS), work with that EWS, and integrate this with existing EWS, with decision support, visualisation and public information systems?
2. How to monitor thousands of sensor streams?
3. How to create a common information space that allows easy integration, over the Internet with other EWSs, sensors and application programs for public information, decision support?
4. How to effectively host and manage multiple early warning systems? How can shared, Internet-based facilities for EWS adapt to a sudden (increase of) demand of computational resources? Can cloud computing resources be used for new EWS and keep investment in hardware low?
5. How to create an Internet-based EWS that monitors dikes and integrates that with simulations to measure dike strength and failure, and flood models, as well as with legacy EWS?
6. Is it feasible to monitor dikes on a European scale, from multiple locations?²

1.2 Partners

Partners in the UrbanFlood consortium are TNO Information and Communication Technology, the University of Amsterdam and STOWA (Foundation for Applied Water Research) from the Netherlands; HR Wallingford in the UK, ACC Cyfronet AGH in Poland and OOO Siemens in Russia.

TNO Information and Communication Technology is a unique centre of innovation in the Netherlands that brings together the IT and Telecom disciplines of TNO. The participating departments have years of experience in the research and development of online service platforms, data centres and sensor networks applications. TNO is a founding member of the IJkdijk field lab that develops sensor networks for dike failures.

HR Wallingford has a 60 year track record of achievement in applied research and specialist consultancy, working with the water environment. The company has a unique mix of know-how, assets and facilities including state of the art physical modelling laboratories, a full range of computational modelling tools and, above all expert staff with world-renowned skills and experience.

The Section Computational Science at the University of Amsterdam aims to be a worldwide key player in the school of thought on computational science in research and education. The

² The IJkdijk experience and business case prepared for FloodControl 2015 may be useful as an example.
section seeks to discover, through modelling and simulating, the way distributed information is being processed in complex information systems. The group focuses on cellular automata models. It addresses issues of how physical and biological problems can be formulated in this framework and how they can be mapped onto distributed computer architectures and grid systems.

**STOWA** (Dutch acronym for the Foundation for Applied Water Research) is a foundation that coordinates research for Dutch water authorities consisting of 26 water boards, all Dutch provinces and the Ministry of Transport, Public Works and Water Management. These authorities are responsible for ground and surface water management in rural and urban areas, as well as for domestic wastewater purification installations and dike and dam inspection. The water authorities avail themselves of STOWA’s facilities for the realisation of all kinds of applied technological, scientific, administrative-legal and social scientific research activities that may be of communal importance.

**ACC Cyfronet AGH** is one of the leading academic computer research institutions in Poland. The research unit of the Centre, together with Institute of Computer Science AGH, devotes its efforts to scalable distributed systems, cross-domain computations in loosely coupled environments, knowledge management and support for life sciences.

**OOO Siemens** is the Russian subsidiary of Siemens AG, a well-known German company. Its research centre in St. Petersburg focuses on topics related to the region and collaboration with local research institutes. The centre is the first research location within Siemens regarding the combination of machine learning and artificial intelligence, remote condition monitoring technologies, embedded systems software and infrastructure monitoring.

### 1.3 Target Groups - Stakeholders

The main stakeholder groups (audiences) as identified in the Communication and Dissemination Plan are given below:

1. Research Team, i.e. the UrbanFlood project team
2. Research Community, beyond UrbanFlood
3. Practitioners, including flood defence regulators, managers and operators, emergency planners and services
4. Policy makers, who set regulatory, legislative and other decision taking frameworks (and are separate from the FRM professionals who work within these frameworks). Policy makers are likely to be national, regional and local government authorities
5. Academic Community, which differs from the Research Community in its (additional) focus on teaching and training
   - Local Groups, including Non-governmental Organisations (NGOs), community groups, etc.
   - General Public
In this report a further detailing is used. The corresponding stakeholder group/audience is indicated between brackets.

For an UrbanFlood EWS the following main groups of potential end users were identified:

- Emergency response authorities; responsible for emergency management during high-water / flood events (3, 4)
- Public water management authorities; for day-to-day management and regular audits of flood protection infrastructure; also for emergency repairs and emergency flood management and dike strengthening measures (3, 4).
- Private management bodies; for day-to-day management of commissioned parts of civil infrastructure as result of Design-Build-Maintain (DBM) and Design-Build-Finance and Maintain (DBFM) contracts; with these contracts private parties are commissioned to maintain and manage the infrastructure after the building phase (3).
- The general public in areas that are at risk of flooding; they benefit from higher safety but they are not a direct partner in the project. Indirectly they are very important because the safety of the general public is the ultimate objective and the – perceived – improvement of safety will steer political and financial decisions regarding implementation of UrbanFlood based EWS’s (5).

The following groups of stakeholders for realisation of an UrbanFlood EWS are identified:

- End Users: see above (3, 4 and 5)
- Private sector: parties that deliver goods and services to end-users for realisation of the EWS (3)
- Research partners: to provide know-how and credibility for the results produced by UrbanFlood (1, 2)
- Government: to provide financial incentives and judicial framework for further development bridging the gap between early adoption and main stream operation (4)

### 1.4 Objectives and Approach

This report, D2.1, is written under Work Package 2 (WP2): Stakeholder requirements. It should be considered together with UrbanFlood report D2.2 (Functionality & Architecture of Internet Based EWS and EWS Hosting Platforms). D2.2 is using the findings presented in this report; this means that some duplication is unavoidable.

The objective of this work package as stated in the Description of Works is:

*Identify typical capabilities, requirements and usage scenarios of the early warning system (EWS) from experts, authorities and citizens. Evaluate the UrbanFlood results.*

In more detail this means:

- to work with stakeholder organisations (responsible for flood risk management and emergency response, like water boards and local authorities) and experts
• to develop the specifications of the online early warning system, an agreed means of validation of the results and an agreed publicity strategy,
• to determine the requirements of urban flooding use cases
• to determine the impact on dike owning authorities and the public

This report is deliverable D2.1, the report titled “EWS and the mitigation of Climate Change Induced Disasters”. The report is the outcome of Task 2.2.

Task 2.2: Describe demand for online EWS and smart dikes. This task describes the current thinking and demands for EWSs. This forms an input for Task 2.3. Steps to be taken under task 2.2 are:

• Contact leading European and non European owners of EWSs. Find out their thinking on online EWS, using questionnaires.
• Contact leading European and non European authorities on flood protection. Find out their needs and or objections on smart dikes.
• Determine the impact on dike owning authorities and the public

For the Netherlands the method for data gathering was adjusted: because the discussion on ‘smart dikes’ has been ongoing for several years, and the Dutch water managers have recently been approached several times for surveys, it was decided to use the results of earlier surveys as the basis for the Dutch contribution. In a series of telephone interviews with selected water managers the UrbanFlood concept was explained and additional issues that are important to this concept were discussed. This prevented ‘questionnaire-fatigue’ and possible confusion. This approach was well-received and successful.

1.5 Structure of this Document

Main Report

Chapter 1 Introduction
Chapter 2 Related programmes, policies and projects
Chapter 3 Methodology
Chapter 4 Current experience with smart dike early warning systems
Chapter 5 Requirements for smart dike early warning systems
Chapter 6 Conclusions
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Annex 2 Relevant policies and programmes, projects and organisations
Annex 3  Experiences with early warning systems and smart dikes
Annex 4  Questionnaire
Annex 5  Short summaries of responses of questionnaires
2 Related Programmes, Policies and Projects

In this chapter an overview of programmes, policies and projects that have links with or are relevant to UrbanFlood are listed. Please note that the listing is not exhaustive and does not pretend to be complete. It is also mainly based on information from the Netherlands, where ‘smart dike’ projects are a bit further advanced than in other countries, and the UK, where UrbanFlood partner HR Wallingford is a main (international) authority on (flood) water management. Full details on these policies, programmes and projects can be found in Annex 2.

Europe

In Europe the guiding policy document is the European Directive on the assessment and management of flood risks.

This directive on the assessment and management of flood risks entered into force on 26 November 2007. It aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity, and requires Member States to identify the river basins and associated coastal areas at risk of flooding by 2011; draw up flood risk maps by 2013 and establish flood risk management plans focused on prevention, protection and preparedness by 2015.

The Joint Research Centre (JRC) provides policy support on flood issues, especially focused on cross-border river basins.

The Netherlands

In the Netherlands the relevant policies are the National Water Plan and the Delta Programme.

In December 2009, the Dutch Government approved the National Water Plan. This plan outlines the government policies for 2009 to 2015 in order to achieve sustainable water management. The National Water Plan focuses on both flood protection and an adequate water supply of sufficient quality. The measures set down in the Delta Programme contribute to a long-term realisation of the National Water Plan policy with regard to water safety and freshwater supply. The Delta Programme takes a longer view; its time horizon is 2100.

Relevant programmes and projects that were identified are the Program ‘Professionalisering Inspecties Waterkeringen’ (Improvement Inspection dikes), the programme Flood Control 2015, the IJkdijk foundation, LiveDijk, FLIWAS and the programme Sterkte en Belasting Waterkeringen (Strength and Load of Flood Defences).
The program ‘Professionalisering Inspecties Waterkeringen’ is an initiative of STOWA and Rijkswaterstaat Waterdienst. The program initiates projects to improve the operational practice of the inspection of dikes, resulting in a manual and an expert centre.

A group of Dutch companies and advisory firms is developing the application of monitoring technologies for flood management protection within the program Flood Control 2015. The aim is to develop a flood control room where water managers and emergency response authorities can make informed decisions based on relevant information. Partners collaborate internationally with SE Asia, Southern Europe and the USA.

One of the projects currently executed by the consortium is the MONSTER case (MONSTERCASE: MONitoring systeem STERkte CASEs), a business case for monitoring of dikes and carrying out further analysis of the IJkdijk datasets.

The IJkdijk is an international test site for new inspection and monitoring technologies for flood barriers. LiveDijk, the world’s first true sea dike equipped with sensors, is located at Seaport Eemshaven, Groningen as a project under IJkdijk.

FLIWAS is the acronym for FLood Information & WAning System, a web-based system which provides current information about imminent floods in major rivers to the right persons, at the right time, at the right location, to take the right decisions. It is the product of a multi-national EU project. In the Netherlands FLIWAS is recommended as the standard system for flood information exchange during flood related emergencies by Rijkswaterstaat (Ministry of Transport and Waterways).

The Program “Sterkte Belasting Waterkeringen” (SBW, Strength and Load of Flood Defences), carried out by Rijkswaterstaat and Deltares, aims to improve insight on actual strength of dikes in practical, realistic situations. Two sites are monitored and the data are used to improve experience based rules and models to calculate the strength of dikes.

The UK

In the UK Flood management is a devolved function in England, the Welsh Assembly, the Scottish government and the Northern Ireland Assembly.

Nationally the Department for Environment and Rural Affairs takes the lead on preparation of policy for England and Wales and the Environment Agency is the national executive authority in England and Wales. In low-lying areas (generally within 8m of mean sea level) the Internal Drainage Boards have responsibility for local water level management, both for floods and agricultural drainage. A revised Policy was published in 2004 called “Making Space for Water” which placed risk-based decision making as the core principle of flood management. In April 2010 a new Floods and Water Act passed through Parliament but its provisions have not yet been fully brought into force. This new Act gives responsibility for local flood management to local government within their administrative areas, with consultation across catchment boundaries.
Development planning is the responsibility of the Department of Community and Local Government which sets policy and regional and local authorities who develop spatial planning strategies and control development. A planning Policy Statement PPS 25 covers development and flood risk. Flood Risk Assessments (FRA) must be carried out at an appropriate scale to make “informed” and “sound” planning decisions.

The Environment Agency is the lead agency for management of flood emergencies with Local Authorities providing local facilities (e.g. evacuation centres) and the emergency services (police, fire, military) being engaged in the rescue. For large floods the emergency management is coordinated through the command levels of the Police service (Gold, Silver, Bronze) depending upon the scale of the emergency. At a national scale the Government COBRA committee may be convened to give direction from Government in wide scale and severe emergencies.

Research initiatives supported by Defra and the EA are: the Flood Risk Management Research Consortium (FRMRC I and FRMRC II); this interdisciplinary research Consortium focuses on some of the more recently identified strategic research investigating the prediction and management of flood risk and is the primary UK academic response to this challenge; and FLOODsite, an “Integrated Project” in the Global Change and Ecosystems priority of the Sixth Framework Programme of the European Commission. This project was coordinated by HR Wallingford in the UK, with the strong support of Defra and the Environment Agency. It’s extensive programme of research underpinned issues common to flood risk analysis and management practice across Europe.

Past and Parallel European Projects and International Initiatives

Over the past decade concerted efforts have been made to link research efforts nationally and internationally, to avoid duplication of effort and to facilitate greater collaboration and sharing of knowledge. CRUE ERA-NET aims to introduce structure within the area of European Flood Research by improving co-ordination between national programmes.

The UrbanFlood project straddles both the flood risk and ICT industries. From a flood risk perspective, the project builds upon knowledge of embankment failure modes, breaching and emergency management. This links through a number of European and International research projects including FLOODsite: specifically relating to outputs from Tasks 4, 6, 7 on flood defence failure modes, breach initiation and growth and reliability analysis. Within the IMPACT project a programme of research was undertaken to investigate breach processes and collate data with which to develop and validate breach models. The FloodProBE project addresses practical, near industry solutions for flood risk management in urban areas, covering impacts and solutions for buildings and the performance of defences.

UrbanFlood partner HR Wallingford has established strong links with international research relating to the performance of embankments, erosion and breach through collaboration on the ICOLD, USACE, USDA and USBR initiatives and additional initiatives such as the European working group on internal erosion and the CEATI facilitated Dam Safety Interest Group (DSIG) breach modelling project (performance evaluation for industry uptake). These links
help ensure that they (and hence the UrbanFlood project) remain aware of relevant research programmes implemented by US federal agencies such as USACE, USBR and USDA.
3 Methodology

3.1 Questionnaires

More than 70 questionnaires were sent to targeted individuals working at decision making and asset management level, who were considered key resource persons in important national institutions and organisations. Several of them work at international level. By the time this report had to be completed (end of April 2010) 12 of them have responded\(^3\). If the results from the Netherlands are included (see next section) responses were received from 8 countries\(^4\). Respondents had the choice to complete a more detailed list of questions if they had experience with (online) EWS for flood protection, or a shorter list if they had ideas on the subject but no direct experience with such systems. Three respondents completed the detailed list, while 9 completed the shorter list. The results from the Netherlands can be considered replies to the longer list. For the questionnaire see Annex 4; Annex 5 presents a short synopsis of the reactions of the respondents.

3.2 Approach for the Netherlands

In the period September 2009 – January 2010 an extensive survey on behalf of STOWA was conducted by (among others) BZ Innovation management\(^5\). The objective was to obtain the views and ideas of the Dutch water boards related to innovation in inspection and maintenance of dikes. This survey was part of the Dutch program ´Professionalisering Inspectie Waterkeringen’ (Improvement inspection methods flood defences), an approach to improve the quality of the inspection process of Dutch dikes sponsored by STOWA and Rijkswaterstaat Waterdienst, The Netherlands.

A short-list of organizations and individuals interested in application of sensor technologies to enhance their inspection capabilities was derived from this survey. From this list a selection of individuals and organisations were contacted by telephone to identify stakeholder needs for the UrbanFlood stakeholder analysis.

Based on the questionnaire used for the UrbanFlood stakeholder analysis survey, an abbreviated list of questions was derived. This list of questions was used during the telephone interviews.

\(^3\) This response is a bit low at fewer than 20%; typical response levels are 25%-35%. The low response may be due to the specific nature of the questionnaire and the relative lack of time for follow-up.

\(^4\) Germany (3); Ireland (2); the UK (2); Australia (1); Hungary (1); the USA (1); Canada (2) as well as the Netherlands (results from a significant number of interviews)

\(^5\) Dutch consulting firm active in the field of flood management and sensor technology – www.bzim.nl
The questions were:

- What is goal of the project?
- Where and how will project be realised?
- What are significant technical issues?
- What are the envisaged benefits?
- Can you comment on integration with decision-making within your organisation?
- Can you comment on system integration with other systems in your organisation?
- Is there enthusiasm for further application?
- What impact do you foresee on flood management / flood protection?
- What would be your advice for the UrbanFlood project?
- Do you have more detailed feedback?

General results were combined with results from earlier surveys, and the results of the Questionnaires. Some of the more detailed cases in which sensors are installed are presented in chapter Error! Reference source not found. and in more detail in Annex 3. Results are in chapter Error! Reference source not found. in the form of requirements, and conclusions are listed in chapter 6. Section 6.1 gives an overview of aspects that may justify application of smart dike technology. It is based on “Business Case IJkdijk, 2010-2012”, (internal document); “Leidraad toetsing regionale waterkeringen” (Guidance Audits Regional Dikes), with additional information from the results of the interviews and the questionnaires.
4 Current Experience with Smart Dike Early Warning Systems

An Early Warning System based on Smart Dikes for the protection of an urban area in the manner foreseen by the UrbanFlood project does not seem to exist yet. However, there are a number of projects, mostly in the Netherlands, where sensors are installed in dikes, and where some experience with such sensors has been gained. Early Warning Systems that are based on sensors are implemented for reservoir dams; the earliest examples are in the United States. The US Bureau of Reclamation dam safety program began in 1978, two years after the Grand Teton dam failed as it was being filled storage for the first time. It appears that the Army Corps of Engineers (USACE) have wired many sites but they admit that river levees are long overdue for monitoring.

Below are a number of practical examples of Smart Dikes in the Netherlands.

Vlaardingse Kade and Voorboezem Nootdorp - Hoogheemraadschap Delfland

The Vlaardingse Kade is a dike that is situated near residential areas of Schipluiden and Vlaardingen in the west of the Netherlands in the Rotterdam area. The Vlaardingse Kade protects a polder from flooding from the adjacent polder canal.

In 2008 a reconstruction of the Vlaardingse Kade was commissioned. Prior to this reconstruction part of the dike was monitored for deformation using sensor technology. The main reason to monitor this dike was to monitor the behaviour of the dike during reconstruction. The dike was known to have weak spots. The application of sensor technology was started as a test.

A total of 30 sensor modules were installed. The modules measured water pressures, temperature and movement. Modules were installed in ground layers up to a depth of 5 meters below sea level. Most important parameters were water levels and movement. From the measurements the phreatic layer was determined. Measurements were transmitted each minute with a regular internet connection to a central location. For this application Geobead sensors from Alert Solutions b.v. (www.alertsolutions.nl), Delft were used.

In March 2010 a new dike, the ‘voorboezem Nootdorp’, will be monitored using sensor technology. The monitoring of dike behaviour will be used to fine-tune the redesign of the dike. The objective of the sensors is to understand the behaviour of the dike. By linking the information to a soil model, the current stability of the dike can be calculated.

Although there is currently no connection with emergency management, an EWS could be used on known weak spots with an alarm going off when a threshold value is passed. The use of the system for the 5-yearly audit on dike safety is also good application. Finally the sensor system might be used to monitor dike safety in order to reduce the effort needed to strengthen the dike, but this is still controversial.
Relevant parameters are: water pressure (water levels), soil composition, temperature, movement and salinity. The latter could be used to monitor the origin of water flow. Information should be presented as understandable output, not a data stream that requires additional calculation first.

The installation of sensor probes is a point of attention. In the first application holes were drilled disturbing the soil around the sensor resulting in high initial transmissivity and settlement of the sensor. In the new application the sensors will be pushed into the ground.

It was stated that for application of sensor technologies as part of an EWS the reliability and costs should be comparable to conventional methods to successfully compete. Especially if the system is used for actual safety monitoring the power supply is a point of attention. In the first application at some point batteries went down. For the new installation a fixed power cable is used. In the future solar energy could be a sustainable and reliable solution. The reliability of data transmission is important under emergency circumstances. Since it currently depends on the GSM network, redundancy with for example satellite communication or a fixed fibre optic cable is preferred as backup.

**Smart Quay in Rotterdam Harbour**

In the Rotterdam Harbour in 2009 a quay wall was restored and widened by Ballast Nedam. As part of the works Inventec b.v. was commissioned to install a set of sensors over a length of 500m as part of a monitoring and warning system to detect any soil movements behind the quay wall. Since this is a design & construction work, no local authority was involved.

**Wilpse Klei Dike, Deventer - Waterschap Veluwe**

The Wilpse Klei Dike is a secondary dike along the River IJssel near the city of Deventer, in the eastern part of the Netherlands. Only during periods of high water the dikes have a function to withstand the river. Although the dike is currently stable, it has a history of flooding. During the winter floods of 1993 en 1995 the dike was overtopped, inundating the land behind. Although the local water board currently has no need to closely monitor the dike, it is willing to cooperate in installation of experimental sensor technology applications. The main reason for the water board to trial ‘smart dikes’ is to support innovation in this field; an adequate number of calibration sites are needed to provide proof-of-technology.

It was stated that application of technologies to provide early warning for flood management is important for dikes that are more critical, for example, sand dikes. The cost/benefit ratio is expected to be insufficient to implement the technology for secondary dikes. The highest benefits of an early warning system are to be expected during emergency situations. During the 1993 and 1995 flood events a decision to evacuate a part of the town of Deventer had to be made. At that time it was clear that there was an unmet demand for more in depth knowledge of dike behaviour and dike strength. A lot of external experts were consulted during these emergency events, both of which lasted more than a fortnight. During such events, although rare, a lot of knowledge can be gained from sensor and information systems that can inform on water pressure distribution, soil moisture...
distribution and deformation of the dike. The system should produce both quantitative output and a ‘red flag’ function. In addition a prediction of the situation in the dike for several days ahead given expected / forecast water levels is important.

**River Dike, Sleeuwijk – Waterschap Rivierenland**

The subject of discussion at water board Rivierenland is an idea to use existing geotechnical information from a national database (GeoTop) with laser altimetry measurements (from AHN2) to calculate the ‘opdrijfgevoeligheid’ (uplift sensitivity) of a primary dike near Sleeuwijk along the river Waal, in the centre of the Netherlands. This failure mechanism is relevant to all dikes in the western parts of the Netherlands constructed on top of ‘weak subsoil layers’, and water board Rivierenland is responsible for a significant part of these dikes.

The exercise should in principle enable a pre-calculation of uplift sensitivity for each of the dikes build on weak soils. The idea is in the conception phase. Ideally an approach on a river basin scale would be best suited and enable the use of existing connections between water management boards. The information could be used to audit the dikes on a more detailed level, in a more targeted way. During high water emergency events the information could provide insight in dike reaches that are more vulnerable to failure by uplift, given expected water levels. This makes this information an important part of an EWS.

An important technical aspect in the realisation of any application on a river basin management scale is a standardized data model. This should receive extra attention after initial steps which were taken in the Netherlands a few years ago.

There is collaboration with TNO Utrecht, The Netherlands to further develop the GeoTop model.

An EWS application is more than real-time measurements and status information delivery. There is also a need to realize a connection to existing databases containing risk-factors, pre-calculated scenarios and necessary background information. Only then can an EWS supply the responsible authorities with the necessary information to support decision making.

**New Westerholte Dike Near Stadshagen, Zwolle – Waterschap Groot-Salland**

Water board Groot-Salland is planning and designing a new dike along the river IJssel, near Stadshagen, Zwolle in the centre-north of the Netherlands. The dike will be completed in 2015 and have a total length of 2.2 kilometres. The new dike will be constructed on weak soil layers and there is interest in using sensor technologies to monitor the setting of the dike after construction.

In this planned application integration with decision making / early warning is not a main concern; the installation of sensors is perceived as part of studies to understand dike behaviour. Although extensive monitoring is always beneficial, the cost/benefit ratio should be kept in mind. If in the future an application of EWS is operational a ‘traffic light’ option is
required, with red to indicate (potential) emergency situations and green to indicate a normal, safe situation.

Integration with other systems is not a main issue. Relevant systems are DAM module (Dike Analysis Module) developed by STOWA and the Dutch water board geo information systems IRIS / INTWIS.

A recommendation for the EWS aspects of the UrbanFlood project is to focus on areas and countries where dike management may be less a national priority (compared to the Netherlands) and/or little information is available on dikes. The recent dike breaches in France are one example, but dike monitoring in developing countries may also be considered. The added value of an EWS can be maximized when applied in situations where flood probability is high.

Afsluitdijk – Rijkswaterstaat District IJsselmeergebied

Rijkswaterstaat, district IJsselmeergebied, monitors the Afsluitdijk, the closure dike of the IJsselmeer, the former Zuiderzee. The Afsluitdijk has a length of 32 kilometres and is situated in the north of the Netherlands. The Afsluitdijk separates the Waddenzee and the IJsselmeer (Lake IJssel). Monitoring of the Afsluitdijk with EWS could be of interest. The main perceived benefit of installing a sensor system is for regular inspection. It could also be useful during high water events. ‘You can see how the dike behaves, even when you’re in bed’.

The main technical concern is whether the entire dike can be covered using current sensor technology. The applications currently available were considered to be still in the test phase and not ready for large projects. Another aspect is the reliability of the data measured. The appropriate values need to be presented, but an alert based on the data should be accurate and meaningful. This requires more understanding and research.

Rijkswaterstaat IJsselmeer is interested to test new applications. At an earlier stage an invitation for a research plan was submitted to IJkdijk Foundation.
5 Requirements for Smart Dike Early Warning Systems

In the Netherlands there is strong demand for ‘dike strength’ calculation according to legal standards. Application in a flood early warning system has a (much) lower priority. For the UK and other countries the probability of dike failure is (much) higher than in the Netherlands, often because the risk (value at risk protected by the dikes) is less. This is also reflected in much higher standards for protection in the Netherlands. A breach in a primary dike in the Netherlands could mean an economical and humanitarian catastrophe of unprecedented scale (perhaps comparable with New Orleans – Katrina). A better understanding of the behaviour of dikes is expected to contribute significantly to flood security in the Netherlands as well as abroad.

Understanding dike behaviour is still under development. Dike managers consider it important to study actual dike behaviour to allow correct interpretation of the measured data. In addition, the use of existing databases and datasets to identify for example soil stratification is important. This type of data has to be available before a “Smart Dike EWS” can provide solid answers; therefore these works should be executed parallel to the development of an EWS.

The results of the study are subdivided into three groups: Technical, non-technical and institutional requirements. Technical requirements of the system are those that must be met to ensure that the system actually works; a working prototype can be built. We also recognize non-technical requirements. These have mostly to do with the security, reliability and economics of the system. The third class of requirements deals with institutional issues – a system that is proven as a working prototype which is secure, reliable and economical still has to be accepted by the organisation that is going to implement it, and by the people who are going to work with it.

5.1 Technical

Sensor technology

Should be proven and robust; the instruments should preferably last as long as the structure (flood barrier, dike, levee) or at least until the next maintenance cycle (on average around 50 years for dikes in the Netherlands). Currently sensors used in dikes rely on MEMS technology and have a life expectancy of (only) 10 years. When selecting a sensor it should thus last as long as possible to minimise replacement and possibly the need for recalibration, and of course to minimise disturbance and cost.

In this context we should realise that the development of sensor technology and communication does not stand still and we may very well want to replace sensors after 10 year with the technology available by then.
An issue is the reliability of the data produced by the sensors. A regular ‘health check’ or ‘heart beat signal’ ensures that the sensors will work when they are needed, even if events occur at long intervals (especially for sensors that ‘wake up’ after a threshold has been reached). Regular ‘sanity checks’ are needed to validate the sensor data. The frequency of data communication should be selected with care, and possibly pre-processing might be interesting at certain locations. Proper maintenance of the sensor network including the communication system is very important.

The use of IP camera technology, already widely deployed for road networks, should be considered as part of the sensor system as it will enable the asset manager to visually inspect key parts of the flood protection structures. Also, a check if movable flood defences are actually deployed when they should be is very important.

Communication with monitored structures
Reliability is essential for an EWS which is to be used and relied on during emergencies. Very often communication infrastructure is heavily burdened, damaged or disrupted during serious emergencies. A minimum constellation of data availability and options for processing the data into useful information should be available when (internet) communication fails. For practical reasons a secondary, fall-back data communication system which feeds a minimum acceptable amount of data to the (local) dike/asset manager should be considered to minimize dependence on the internet. Separate, dedicated/private IP infrastructure might be considered, especially if this is available in the form of national emergency support networks.

A second important consideration is the exchange formats and protocols; these should allow the broadest possible interchange of data (sets).

Computing Capacity
Reliability and availability of computing capacity in times of crisis should be ensured. As the availability of computer capacity is (almost) a commodity, priority access can be ensured by paying the right price. For processes that demand extremely high computing capacity, cloud computing can be an option. Note that during times of emergencies demand for cloud computing capacity does not necessarily go up; it may well go down.

Control of access to data was found to be an important issue for the water manager; preventing uncontrolled access (by the public) to stored data and reliability in times of emergencies requires special attention.

Models
The use of hydrological models for EWS is widespread and well accepted; mostly model results based on sensor data are considered very useful and beneficial. Most models used at present predict (maximum) water levels based on hydrological inputs and the state of the system. For an effective Smart Dike EWS geotechnical models of dike behaviour have to be
Models should be able to communicate with other models using an agreed, preferably common protocol. Data exchange between models should be possible at time-step basis if required. Existing models, both Open Source or other, can be easily prepared in such a way that they can be used within the UrbanFlood concept EWS (such adjustment should not take more than 2 weeks according to the DoW). Model performance should be good; the aim is real time calculation. Options to cooperate with existing parallel initiatives should be vigorously pursued in order to avoid competing systems and/or incompatible systems (for example: the planned Dike Data Support Centre in the Netherlands).

Interesting to note is that some respondents mention the usefulness of model generated predictions or even sensor readings to trigger pre-prepared action/response plans, sometimes automatically. The human factor is thus eliminated. Others may want to keep the human ‘in the loop’.

**Visualisation**

Visualisation should be easy, intuitive and interactive; supporting a range of clients (multi-touch table, internet browser, hand-held PDA or mobile phone, perhaps even a TomTom / GPS unit). A ‘dashboard’ interface with clear and familiar parameters that users can understand and interpret immediately is an option presently pursued by the Dutch programme Flood Control 2015. End-users request both a representation of physical parameter in-depth analysis and a ‘red flag’ or ‘traffic light’ function (green: everything is stable, red: there is a problem) for instant overview. This can be supplied by enabling ‘drill-through menus’: on selecting a certain parameter successive levels of detail and complexity as well as functionality can be made available.

On this subject the concept of a ‘virtual sensor’ is interesting: data supplied by various sensors are transformed into a reading of the ‘virtual sensor’ that is then made available to the user. In this way different sensors or sets of sensors can be used to produce standardized values that users know how to interpret. For ‘smart dikes’ a standardized value (virtual sensor’, see 4.1) could be a standardized ‘strength indicator’\(^6\). Required are actual strength given the actual water level against the dike and prediction of the strength given the predicted water levels with a high level of accuracy and reliability.

\(^6\) Strength of a dike: a dike is meant to protect land against flooding by water. The capability of a certain stretch of dike to do this depends upon complex interaction of many aspects of the dike (such as grass cover, soil type, state etc.), which results in it’s overall resistance to failure. One way to express overall performance is to make use of fragility curves, which indicate the resistance of the dike to specific failure mechanisms. Fragility curves for different failure mechanisms may be combined into one overall fragility curve to reflect the predicted performance of a dike. If the dike can withstand a design (or norm) water level to an acceptable probability of failure, it can be considered strong enough.
The dashboard should also give access to functions that support inspection and audits, and to functions that support emergency management. A graphical / map / GIS representation of the flood defence system is expected by respondents; access to (detailed) GIS based maps is seen as essential to be able to assess the local situation. An overlay showing the progress of flooding in time would be extremely helpful.

Integration with (asset and/or water-) management and maintenance and functionality to optimize these is desirable.

**Compatibility with existing (EWS) systems**

This is strongly preferred, and should in practice be made possible by open interfacing with the components of the existing EWS. The use of open exchange protocols and formats and standards like OpenMI, and of course the need to use systems and formats that work over the Internet still will not ensure compatibility or even exchangeability, but make it more and more likely.

For the Dutch water boards the IRIS (IntWIS) system is widely used and contains all basic data of a dike.

**Local vs. centralised**

One of the respondents made a plea for local EWS; in a local EWS people generally know more about the background, and in case the system is down they also generally know better what to do and what to expect. In fact the UrbanFlood concept enables local water managers to build ‘their own EWS’ using generic tools.

**5.2 Non-technical**

**Security and access**

The system should be secure, meaning that the user has to be satisfied that the data are reliable and no-one can tamper with the data, the models and other aspects of the system. By restricting and controlling access to the system the integrity of the system will be ensured as much as possible. Restriction of access to results is also needed to prevent the spreading of inaccurate information; often an experienced operator / expert is needed to properly assess threat levels, even if the interface is intuitive and easy to use.

Of course computer systems should be shielded from any kind of tampering or hacking; the systems themselves should be safe (from flooding!) and have a secure or back-up electricity supply. The buildings should be accessible during floods and staff should be able to work there (think of heating, food, possibility to stay overnight, etc).

**Legal**

The legislation should allow the use of (all components of) the UrbanFlood EWS. While it will be exceptional that the use of (parts of) this EWS is not allowed, it will be much more
common that local laws prescribe a certain methodology or the use of specific data, obtained in a specific way.

If the use of an EWS is accepted it may be helpful if the procedures that lead to decisions based on the results of the EWS are codified in some way or other. This will facilitate decision making during emergencies, which are by definition times of high stress.

**Financial**

The case for online EWS should be made by showing that such systems do not only supply superior information, they also save money. An interesting idea here is to use sensors and online EWS to better monitor dikes and meet the requirements of the periodic audits of the dikes in the Netherlands more efficiently; it is argued that in this way investment in the regular dike improvement and maintenance can be lower and/or intervals can be longer; better monitoring can also limit the maintenance to only those exact locations that are weak.

The optimal use of different types or combinations of sensors needs to be studied; even when installation costs as compared to the costs of building the flood barrier are low the overall costs considering the length of flood barriers in most countries will be significant. In this respect it may be wise to prioritize and start with implementation in those locations where the value at risk and/or the danger to life is the highest, and in newly build or rebuild flood barriers (lower cost of installation).

For the Netherlands large scale implementation of ‘smart dike’ technology is depending on the cost/benefit ratio. Some argue that any cost can be explained in favour of public safety; while others ask ‘what is the appropriate price of safety?’ In the recently developed business case for a next phase of experiments and application with smart dikes it was argued that the total investment cost for realization and operation of monitoring systems in dikes should not exceed 2-5% of the costs for a new dike or approximately 5% of the current maintenance costs. This results in a price range of 50-150 k€ / km dike.

Communication cost was mentioned by one of the respondents; pre-processing and selecting appropriate communication intervals may be options to address this.

### 5.3 Institutional

**Human resources / training and acceptance**

The best system in the world is useless if it is not used and used properly. So it is critically important that the responsible experts are able to work with the system with a minimum of training. It is also important that the use of the EWS can easily be integrated in the emergency action procedures and decision processes without significant changes to these procedures. Since flood events are generally rare, the practical use of an EWS in an emergency situation should be part of regular emergency response drills; another option is to integrate the systems used for emergency and regular work (like asset management and
audits) as much as possible, so people are familiar with the systems. It is also possible to adapt and use the EWS for non-flood emergencies (multi-hazard) to ensure more frequent use.

**Obstacles to install sensor networks**

Almost every asset manager will want to have a guarantee that the installation of sensor systems will not weaken the structure. Even if the chances of weakening the structure are very small there has to be a clear advantage to gain permission. For example: A dike manager feels very unhappy about someone digging in his dike!

Another aspect is the distrust of the system: will it be as good as traditional methods; and will it eventually replace these methods (and the involved staff)? Acceptance of a Smart Dike EWS will be easiest if it is clear that the system is an addition and improvement on existing methods and systems, and not positioned to replace these (or the staff).

The possibility of vandalism should be looked into, and the system should be made as vandal-proof as possible. Normal use of the location (mowing of grass, other permitted agricultural use) should be possible without hindrance to the workers and without danger to the instruments and network cables.

**Risk management – need to use best available systems / methods**

If there are indications (audit results) that the safety level provided by a structure can no longer be considered sufficient, it may be prudent to install a monitoring / EW system, to more closely watch the structure. In this way asset managers may avoid or minimize legal problems and (financial) liability if the structure fails before it is brought back to the standard. This may also be a political argument: the best available methods have been deployed while the process of improving the flood protection structure runs its course.

**Reliability and trust of an (externally) hosted EWS**

This aspect was covered in the section about ‘Internet’ and ‘Cloud Computing’; the conclusion is that vital data delivery has to be ensured by redundant communication systems and it should be possible to carry out vital computations without access to the internet. Robustness is the key concept. In addition to the aspects mentioned before, the operation of the crisis team in a crisis situation has to be ensured. This means not only redundancy in communication but also in electricity supply, and possibly other necessities (food, water, accommodation and facilities to stay at or near the crisis centre). While these aspects are vitally important they are considered to be outside the scope of this report.

The avoidance of (too many) ‘false positives’ and ‘false negatives’ in flood early warning systems was mentioned as an important consideration. Too many false positives will erode the trust in the system and the authorities, while nobody wants to miss a real event.
Use of sensors owned by other organizations and citizens

At the trials for smart dikes in the Netherlands the sensor networks were installed and maintained by private companies. Such arrangements, which may include data (pre-)processing, can be looked into. One of the respondents in the Netherlands stated that the usefulness of an EWS for dike monitoring would be much higher if it was implemented on a river basin scale. This implies that the different water boards in this river basin will need to cooperate and share their sensor data. Implementation on a river basin scale is consistent with earlier EC research recommendations and with recent UK recommendations towards more effective emergency planning and management.

Using data from sensors operated by citizens may presently not be practical but may be in the future; such data is now used in meteorology. Standardizing and validation will then be very important.

Business model of a hosting platform for EWS

In fact, as the system is built based on internet technology, EWS can be offered as a service, and specialized organisations or companies may offer it as an online service. However, aspects mentioned before related to reliability and robustness may dictate that at least a minimal fall-back option is available at the responsible asset manager and/or the emergency response organisations. Here again the importance of this aspect is noted but the actual implementation of emergency communication systems and redundancy will be a responsibility of the relevant authorities.

At this moment implementation of ‘smart dikes’ in the Netherlands have all been in the form of a project, under the responsibility of either a regional water management organisation or a research foundation. For the Netherlands there may be a scope to involve public umbrella organisations for regional water managers in line with the appreciation that emergency response is a public responsibility; a possible candidate is ‘het Waterschapshuis’, the organisation that support the water boards in their ICT requirements (standards, software systems and datasets like the AHN – the Dutch digital terrain model).

Related to the IJKdijk experiment and LiveDijk Eemshaven experiment a proposal for initiation of a geo-spatial data centre IJKdijk is developed. This data centre is to host the infrastructure to collect and interpret data from smart dikes and make this information available to the relevant authorities. Respondents recommended integrating flood barrier sensor signals and water level gauge (sensor) signals into a single model data space; both for UrbanFlood and the DDSC this should be considered.

The business model for UrbanFlood is further elaborated in report D2.2: Functionality & Architecture of Internet Based EWS and EWS Hosting Platforms.

Intellectual Property Rights aspects

The UrbanFlood concept builds on ‘open exchange’, and explicitly does not exclude proprietary software and systems. It does have a preference for an open source approach.
Local governments and/or authorities may be legally bound to use only open source software or software of which they have access to the source code. This is the case for many if not all authorities in Germany, for example. If possible a working prototype of the UrbanFlood system should be made using open source components, which gives a minimum/acceptable performance.

Respondents to the questionnaire did not specifically mention IPR aspects. IPR aspects are different for sensor technology, models and ICT platforms.

IPR aspects are further elaborated in report D2.2: Functionality & Architecture of Internet Based EWS and EWS Hosting Platforms.
6 Conclusions

6.1 Justification for Smart Dikes and EWS

Smart dikes and EWS for urban flood management can support several important aspects of water management. Based on the questionnaires and the interviews the following aspects are addressed:

1. Good governance
2. Inspection and maintenance of dikes
3. Auditing dike safety
4. Emergency management
5. Reinforcing dikes

Good Governance

Although the risk of dike failure is low in the Netherlands, an actual failure can easily be disastrous because of expected damage and potential loss of life. The water management authorities will therefore do everything they can to prevent a dike failure and to ensure public safety from flooding. Senior water board managers have stated that application of an EWS for dikes is a useful measure in this respect because it is based on the best available technology. Considering the potential damage and danger there is a case that the best available methods should be used.

Inspection and Maintenance of Dikes

Currently dikes are visually inspected regularly by inspectors from the water board. They identify situations of damage and assess if the dike is still functional according to set and agreed standards. Since this inspection is mostly visual, no direct insight is gained of the situation within the dike. Application of a Smart Dike EWS allows for a better monitoring of geotechnical dike behaviour within the dike and will supplement visual monitoring by the inspectors. This view was shared by respondents from several countries.

Auditing Dike Safety

All primary dikes, 3400 km, in the Netherlands are audited by law for height, strength and stability on a 5-year basis. Currently an audit scheme for regional dikes, 14000 km, is being devised. For this audit information on the dikes needs to be collected. This is done through visual inspection and, if this is insufficient, through elaborate monitoring and testing. Application of electronic monitoring using a Smart Dike EWS will provide some of the information needed for auditing and may serve to support the audit findings. In the business case for large scale deployment of EWS for dikes in the Netherlands a cost reduction was envisaged for the application of EWS, as it may partly replace current data collection and audit efforts. This is doubly important for the planned audits for the secondary dikes, as funding and manpower are limited. While this is now a typically Dutch issue there is scope to
look at applicability in the rest of Europe and in other countries, as soon as more experience is gained in the Netherlands.

**Emergency Management**

During a flood / high water situation an emergency management team closely monitors the behaviour of the dikes in relation to predicted water levels. In 1993 and 1995 water levels in the Dutch rivers reached extremely high levels for extended periods of time. An evacuation was ordered, based on very limited information.

Application of a Smart Dike EWS can support the decision making process for emergency management by enabling the calculation of the actual remaining strength of a river embankment in relation to the measured and forecast water level. Water level forecasts and precipitation-runoff model predictions are very important inputs. A better understanding of dike behaviour during flood events will lead to better, fact based decisions regarding emergency measures and/or evacuation, and a more focused application of scarce resources and personnel, especially in an emergency. All respondents are positive about the use of EWS in emergency management for larger or more complex systems.

**Reinforcing Dikes**

Many kilometres of dikes in the Netherlands will need reinforcement in the decade up to 2020. It is expected that a total of 7000 million Euro will have to be invested by the joint water management authorities to provide public safety in accordance with the current norms. It is believed by some senior water board managers that application of a Smart Dike EWS can help to better understand the behaviour of the dike and therefore allows for lower safety margins in the design. A more ‘lean and mean’ design of dikes could potentially save up to 5-10% of the total costs of reinforcement.

Alternatively, by both adhering to the current design norms and installing electronic sensors the real safety will be higher; safety margins included in the design to counter inaccurate knowledge of the behaviour of the dikes during an actual high water event may then provide real added safety. Tests on existing dikes and experience during extreme high water (in the main rivers) showed that they are consistently stronger than expected.

In addition to reinforcement due to land subsidence, expected sea level rise and expected higher peak flows of the big rivers in the Netherlands, another effect will reinforce the trend towards stronger dikes. Because of economic growth and the overall increase in number and value of houses and infrastructure at risk, the so-called ‘protection norm’ for primary dike rings and secondary embankments will eventually have to be upgraded to higher classes, requiring higher protection. It should be noted that a very large part of the population and the economic activity in the Netherlands are situated in areas at risk of flooding. This trend is not confined to the Netherlands but is also evident in many other countries.
6.2 General

The most important sensor readings for earthen dike management and monitoring that were mentioned in questionnaires and interviews are (internal) water pressure and movement. But in several cases ‘hard’ or movable flood defences are the main measures used in an urban flood protection system; in these cases internal water pressure is not relevant.

The mindset of the water managers in the Netherlands appears focused on the use of smart dikes and early warning systems as a means to prevent a dike failure. Quite literally they sometimes say that the investment for an early warning system to monitor for breaching only is not cost-effective. Application for emergency response alone is not a priority in the Netherlands although such an application may be possible in the future. Still the Netherlands appear to be ahead in application of state of the art sensor technology for monitoring flood defences; at several locations such systems have been installed or will be installed. The justification is often to gain a better understanding of the flood defence structure, in particular earthen dikes. Also, a timely warning may enable the dike manager to temporarily strengthen a given reach, in a much targeted manner.

All respondents are generally positive on the usefulness of EWS and sensor networks. EWS enable emergency response staff to react quickly and adequately, and a timely warning means that more options are possible, and more measures may be taken. Access to pre-calculated flooding scenarios supports emergency response personnel. Early warning of a threatening dike or flood wall failure can enable targeted responses by the authorities. Overall, EWS are seen to save lives and minimize economic disruption and damage.

It is critically important that the responsible experts are able to work with the system with a minimum of training. It is also important that the use of the EWS can easily be integrated in the emergency action procedures and decision processes without disruptive changes to these procedures. Since flood events are generally rare, the practical use of a Smart Dike EWS in an emergency situation should be part of regular emergency response drills; another option is to integrate the systems used for emergency and regular work (like asset management and audits) as much as possible, so people are familiar with the systems. It is also possible to adapt and use the EWS for non-flood emergencies (multi-hazard) to ensure more frequent use.

Integration of EWS with response plans or response planning systems and cell-broadcast or cell-phone warning systems is seen as helpful. Internet access makes relevant information available to both field workers and management. Data should be presented in a form that is useful to the particular user.

In general respondents are concerned about the cost-benefit ratio of installing sensors in dikes, considering the significant lengths of dikes that need to be monitored. Prioritizing installation at risk hot spots is often suggested.
Information on the physical environment is essential when setting up monitoring and EW systems. For flood control structures and dikes such information includes the subsoil, where soil composition and stratification are very important in determining the stability and strength. A linkage with the relevant information systems is desirable. Relevant systems for the Netherlands are INTWIS/IRIS and the DAM module.
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Website: www.livedijk.nl

Website: www.ijkdijk.nl

Website: www.floodsite.net

Website: www.impact-project.net

Website: www.floodrisk.org.uk

Website: www.crue-eranet.net
Annex 1  Scope and Place of this Report within the UrbanFlood Project

This report is written under Work Package 2 (WP2): Stakeholder requirements. This work package researches issues and benefits of the Internet based approach. Stakeholders and experts, some of them organised in an advisory board, are consulted to get a high quality and extensive list of requirements. This list, which will be completed in the early stages of the project, is a starting point of the design activities of WP 6. Furthermore, UrbanFlood bases a part of its dissemination strategy on these experts, as these should be influential people having impact on their organisations with regard to dike management.

The objective of this work package as stated in the Description of Works is:

*Identify typical capabilities, requirements and usage scenarios of the early warning system (EWS) from experts, authorities and citizens. Evaluate the UrbanFlood results.*

More in detail this means:

- to work with stakeholder organisations (responsible for flood risk management) and experts:
- to develop the specifications of the online early warning system, an agreed means of validation of the results and an agreed publicity strategy,
- to determine the requirements of urban flooding use cases
- to determine the impact on dike owning authorities and the public

WP2 is subdivided into the following tasks:

- Task 2.1 Describe the state of the art
- Task 2.2 Describe demand for online EWS and smart dikes
- Task 2.3 Describe EWS requirements
- Task 2.4 Determine evaluation criteria for impact analysis

This report is deliverable D2.1: EWS and the mitigation of Climate Change induced disasters. The report is the outcome of Task 2.2; it also includes aspects of Task 2.3.

**Task 2.2: Describe demand for online EWS and smart dikes**

This task describes the current thinking and demands for EWSs. This is input for Task 2.3.

- Contact leading European and non European owners of EWSs. Find out their thinking on online EWS, using questionnaires.
- Contact leading European and non European authorities on flood protection. Find out their needs and or objections on smart dikes.
- Determine the impact on dike owning authorities and the public
Annex 2  Relevant Policies, Programmes, Projects and Organisations

This annex provides an overview of relevant policies, programmes, projects and organizations that may be of interest or impact on the UrbanFlood project. The list is by no means complete, but is meant as background.

Europe

European Directive on the assessment and management of flood risks


Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. The Directive was first proposed by the European Commission on 18/01/2006, and was published in the Official Journal on 6 November 2007. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. The Directive was incorporated into national legislation in all EU Member States by the end of 2009.

The Directive requires Member States to first carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding. For such zones they would then need to draw up flood risk maps by 2013 and establish flood risk management plans focused on prevention, protection and preparedness by 2015. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU. The Directive also reinforces the rights of the public to access this information and to have a say in the planning process.

The links between the WFD (Directive 2007/60/EC) and the Floods Directive are fully recognised in the Floods Directive with the requirement to use the same boundaries and administrative structures wherever possible. An important overlap between the two Directives is in the subject of “hydromorphology” which already is the topic of another international working group of the WFD and covers the influence of human interventions in the river system. The European working group that is discussing the details of how the Directive will operate in practice is WG-F of the common implementation strategy of the WFD. The activities of WG-F have led to compilations of current practice on flood forecasting and flood mapping; an expert group on land-use and floods is also active. WG-F also has a responsibility to consider research and information exchange on flood risk management issues at a European level.
JRC - ISPRA

Besides the work of the development of an early warning system (EFAS (the European Flood Alert System), JRC carries out flood mitigation and forecasting case studies in the Elbe and Danube, flash floods and climate change effects and flood risk mapping.

http://natural-hazards.jrc.ec.europa.eu

The Netherlands

For the Netherlands the following related programs are identified:

National Water Plan

Source: http://www.deltacommissaris.nl/

In December 2009, the Dutch Government approved the National Water Plan. This plan outlines the policies the government will implement in the period from 2009 to 2015 in order to achieve sustainable water management. The National Water Plan focuses on both flood protection and an adequate water supply of sufficient quality and looks into various forms of water use. The measures to be taken in this regard are also set down. The National Water Plan is the successor of the Fourth National Policy Memorandum on Water Management of 1998 and replaces all previous water management policy memoranda.

Delta Programme

The measures set down in the Delta Programme contribute to a long-term realisation of the policy set down in the National Water Plan for the subjects of water safety and freshwater supply. The Delta Programme thus looks further ahead (until 2100).

Program Improvement Inspection Dikes

Source: www.inspectiewaterkeringen.nl

The program ‘Professionalisering Inspecties Waterkeringen’ is an initiative of STOWA and Rijkswaterstaat Waterdienst. The program initiates a number of projects with the aim to improve the operational practice of the inspection of dikes. The result of the programme of projects is a manual and an expertise centre.

Flood Control 2015

A group of Dutch companies and advisory firms is developing the application of monitoring technologies for flood management protection within the program Flood Control 2015. They focus on new monitoring technologies, real-time decision support programs and supporting infrastructure. The aim is to develop a flood control room where water managers and emergency response authorities can make informed decisions based on relevant
information. Partners within the program also organize congresses, training and education. Partners collaborate internationally with SE Asia, South EU and USA.

One of the projects currently executed by the consortium is the MONSTER case (MONSTERCASE: MONitoring systeem STERkte CASEs). The project develops a business case for monitoring of dikes and levees and carries out further analysis of the datasets collected during the IJkdijk experiment.

**IJkdijk and LiveDijk**

The IJkdijk is an international test site for new inspection and monitoring technologies for flood barriers. LiveDijk, the world’s first true sea dike equipped with sensors, was built at seaport Eemshaven, Groningen as a project under IJkdijk.

Source: [www.ijkdijk.eu](http://www.ijkdijk.eu)

**IJkdijk Test Site**

The IJkdijk is an international test site for new inspection and monitoring technologies for flood protection structures. The purpose of the IJkdijk is to study how new inspection and monitoring technologies can be used to improve the inspection of levees by obtaining a better understanding of their behaviour. The ultimate aim is to accurately assess the current and short term forecast strength of levees to enable the water management authorities in the Netherlands to intervene sooner and more targeted, should that prove necessary. The levee of the future is being designed and tested by the IJkdijk.

IJkdijk is an initiative of N.V. NOM, STOWA, Stichting IDL, Deltares and TNO and is situated in a small polder of Staatsbosbeheer (the National Forest Service in the Netherlands) to the south of Nieuweschans in the management area of Waterschap Hunze en Aa’s (Waterboard).

The IJkdijk has been built in a small polder to the south of Bellingwedde, in the management area of Waterschap Hunze en Aa’s.

**IJkdijk Experiments**

Macro stability experiment

A large-scale macro stability experiment was carried out by the IJkdijk foundation in partnership with Rijkswaterstaat in 2008. This experiment looks into the question of whether using measurement and sensor technologies form an addition to the regular visual inspection of levees and can thus predict stability problems in good time. On 27 September 2008 a controlled levee breach was brought about and the detailed results of the experiment are now available.
The test levee for the macro stability experiment was equipped with a wide range of measurement equipment. The analysis of the measurement results shows that movement and deformation in the levee are variables that predict a levee breach well in advance. Deformation took place as far as 42 hours prior to the actual breach of the test levee, precisely at the position where the levee actually collapsed. The sensors proved to support each other in the measurements carried out to detect premature subsidence in the levee. The IJkdijk foundation is convinced that sensor technology forms a valuable addition to regular levee inspections.

Further information:

IJkdijk foundation, PO Box 424, 9700 AK Groningen, The Netherlands

Contact: Wouter Zomer
Telephone number: +31 50 521 44 66 (NOM secretary)
E-mail: zomer@ijkdijk.nl

**Piping Experiment**

When water levels are high, the resulting pressure can force water to seep through the base of a dike. This water may take grains of sand with it, creating tubular openings (pipes) under the dike that get bigger and bigger, endangering the stability of the structure. This can weaken the dike and, in the worst case, cause it to collapse. The Netherlands Safety Map (VNK) study identified piping a few years ago as a potentially dangerous failure mechanism and recommended further research. The experiment at the Smart Dike location in Bellingwolde was the culmination of that research. The experiment was conducted in 2009.

To investigate "piping", a test dike was built specially, containing advanced monitoring equipment. The phenomenon was initiated in a controlled way, resulting in the collapse of the test dike. The experiment and the measurements show that piping is a failure mechanism that needs to be taken seriously.
The experiment took place in a section 4 m deep, 40 m long and 25 m wide. The subsurface in the section consisted of sand. Over the width of the section, there was a dike with high water on one side (more than 2.5 m) and low water on the other (0.1 m). The measuring equipment installed in advance acquired data about water pressure and the deformation of the dike. And heat-sensitive cameras recorded the piping process.

Further information:

IJkdijk association, Postbus 424, 9700 AK Groningen, The Netherlands

Contact: Wouter Zomer

Telephone number: +31 50 521 44 66 (NOM secretary)
E-mail: info@ijkdijk.nl

LiveDijk Eemshaven: Experiment Under Operational Conditions

The world's first true sea dike equipped with sensor technology has been built at seaport Eemshaven, Groningen in 2009. This 'LiveDijk' is equipped with measurement equipment that makes it possible to remotely monitor the condition of the dike on a continuous basis. Dike behaviour will be monitored for a period of 2 years (2009 – 2011). An evaluation will yield lessons learned. This experiment is conducted to show practical applicability of sensor technology and test its durability.

A ‘dashboard’ which displays some of the sensor data can be seen at http://www.inspectiewaterkeringen.nl/content.asp?page=289

The experiment’s principal is water board Noorderzijlvest

An important aspect during installation was a proof of non-failure of the dike after installation. For installation of sensor technology in an existing sea-dike, a shallow ditch had to be made. The vegetation cover was removed with care and replaced after installation of the sensors. The water board officials from Noorderzijlvest made up an inspection round after installation to conclude that there was no ‘functional failure’ of the dike.

Further information:

Waterschap Noorderzijlvest, Stedumermaar 1, 9700 AA Groningen, the Netherlands

Contact: Christiaan Jacobs

Telephone number: +31 598 – 693 800
E-mail: c.jacobs@noorderzijlvest.nl
FLIWAS

Source: [www.fliwas.eu](http://www.fliwas.eu)

FLIWAS is the acronym for FLood Information & WArning System. FLIWAS is a web-based system and consist of different independently usable modules. FLIWAS provides current information about imminent floods in major rivers to the right persons, at the right time, at the right location, to take the right decisions. In this way better decisions can be made and professionals will have a better idea of the impact of their decisions. FLIWAS was developed in collaboration between EU water management partners. FLIWAS is recommended as the standard system for flood information exchange during flood related emergencies by Rijkswaterstaat (Ministry of Transport and Waterways). Implementation at the regional water management organisations is ongoing (March 2010).

Programma Sterkte Belasting Waterkeringen (SBW)

Source: [http://www.helpdeskwater.nl/waterkeren/sbw/](http://www.helpdeskwater.nl/waterkeren/sbw/) (Dutch)

This program (“Strength and Load of Flood Defences”) is conducted by Rijkswaterstaat and Deltares. The objective is to improve insight on actual strength of dikes in practical, realistic situations. Two sites are continually monitored (near Petten and the Waddensea). The information is used to improve experience based rules and models in order to calculate the strength of dikes.

Water Management Centre Nederland

The Water management Centre Netherlands is an information and knowledge hub for the Dutch water system. The centre collects and manages actual information for professional users of the water system on water levels, water quality and some other water related parameters. During emergency events the centre supplies available information to the emergency response organisations and authorities.

More information (in Dutch):
[http://www.rijkswaterstaat.nl/water/veiligheid/watermanagement/](http://www.rijkswaterstaat.nl/water/veiligheid/watermanagement/)

Het Waterschapshuis

‘Het Waterschapshuis’ is the support, management and implementation organisation for Information and Communication Technology (ICT) and manager of several important datasets (like the Dutch Digital Terrain Model AHN2) for the 26 Dutch district water boards. The objective is to promote the collaboration of the district water boards and other so called 'wet sector' government organisations on ICT.

Supported by Het Waterschapshuis the district water boards collaborate to improve the quality of digital services offered to the public and companies. An additional objective is the realisation of a considerable cost reduction on all ICT outlays.

More information: [www.hetwaterschapshuis.nl](http://www.hetwaterschapshuis.nl)
United Kingdom

In the UK Flood management is a devolved function in England, the Welsh Assembly, the Scottish government and the Northern Ireland Assembly.

Nationally the Department for Environment and Rural Affairs takes the lead on preparation of policy for England and Wales and the Environment Agency is the national executive authority in England and Wales. In low-lying areas (generally within 8m of mean sea level) the Internal Drainage Boards have responsibility for local water level management, both for floods and agricultural drainage. A revised Policy was published in 2004 called “Making Space for Water” which placed risk-based decision making as the core principle of flood management. In April 2010 a new Floods and Water Act passed through Parliament and but its provisions have not yet been fully brought into force. This new Act gives responsibility for local flood management to local government within their administrative areas, with consultation across catchment boundaries.

The principal flood risk management activities responsibilities of the Environment Agency are:

- Assessment of flood risks at a national scale
- Preparation of catchment flood management plans for each major river or subcatchment (over 60 across England and Wales)
- Planning and implementing flood management measures for main rivers and certain coastal cells
- Maintenance of flood management measures for main rivers and coastal defences under their authority
- Provision of flood warning through national and regional centres
- Collection, storage and distribution of data (hydrometric data; topographic survey; asset location, type and condition etc)
- Liaison with local Authorities for flood management on minor watercourses

The Environment Agency and Defra have a joint research programme which has developed a range of methods and guidance on flood risk management including

- FEH (Flood Estimation Handbook) for hydrological assessment of flows
- RASP (Risk Assessment (of flood and coastal defences) for Strategic Planning) (used for national scale risk mapping)
- MDSF (Modelling Decision Support Framework) (used for development of regional and catchment scale strategies)
- CES-AES (Conveyance Estimation System) a method for assessing the capacity of river chanens and other watercourses
- PAMS (Performance Based Asset Management) to assess condition and prioritise the maintenance of flood defence “assets”
- A new method is under development for investment appraisal
Development planning is the responsibility of the Department of Community and Local Government which sets policy and regional and local authorities who develop spatial planning strategies and control development. A planning Policy Statement PPS 25 covers development and flood risk. Flood Risk Assessments (FRA) must be carried out at an appropriate scale to make “informed” and “sound” planning decisions. Three levels of FRA are recognised with increasing levels of detail and analysis according to the decision and the degree of flood risk issues. The DCLG, the Environment Agency and the Construction Industry Research and Information Association have all issued guidance on the preparation of FRA documents.

The Environment Agency is the lead agency for management of flood emergencies with Local Authorities proving local facilities (e.g. evacuation centres) and the emergency services (police, fire, military) being engaged in the rescue. For large floods the emergency management is coordinated through the command levels of the Police service (Gold, Silver, Bronze) depending upon the scale of the emergency. At a national scale the Government COBRA committee may be convened to give direction from Government in wide scale and severe emergencies.

There have been a number of research initiatives over the past decade supported by Defra and the Environment Agency:

**Flood Risk Management Research Consortium (FRMRC I and FRMRC II)**

This interdisciplinary research Consortium focuses on some of the more recently identified strategic research investigating the prediction and management of flood risk and is the primary UK academic response to this challenge.

Sponsored by the Engineering and Physical Research Council (EPSRC) under Grant EP/F020511/1, with additional funding from the EA/Defra (Joint Defra/EA Flood and Coastal Erosion Management R&D Programme), the Northern Ireland Rivers Agency (DARDNI) and Office of Public Works (OPW), Dublin, it is the 2nd phase of the Flood Risk Management Research Consortium (FRMRC), the 1st phase of which was originally launched in February 2004. The concept lying behind this innovative joint funding arrangement is that it allows the Consortium to combine the strengths of fundamental and near-market researchers and research philosophies in a truly multi-disciplinary programme.

It has been formulated to address key issues in flood science and engineering and the portfolio of research includes the short-term delivery of tools and techniques to support more accurate flood forecasting and warning, improvements to flood management infrastructure and reduction of flood risk to people, property and the environment.

A particular feature of the 2nd phase is the concerted effort to focus on coastal and urban flooding. In addition, the Consortium continues to provide internationally leading research in the area of Land Use Management in the context of the generation of floods during extreme rainfall.
FLOODsite – Integrated Flood Risk Analysis and Management Methodologies

FLOODsite was an “Integrated Project” in the Global Change and Ecosystems priority of the Sixth Framework Programme of the European Commission. This project was coordinated by HR Wallingford in the UK, with the strong support of Defra and the Environment Agency. The extensive programme of research underpinned issues common to flood risk analysis and management practice across Europe.

FLOODsite commenced in 2004 and ran until 2009. The FLOODsite consortium included 37 of Europe’s leading institutes and universities and the project involved managers, researchers and practitioners from a range of government, commercial and research organisations, specialising in aspects of flood risk management.

FLOODsite covered the physical, environmental, ecological and socio-economic aspects of floods from rivers, estuaries and the sea. It considered flood risk as a combination of hazard sources, pathways and the consequences of flooding on the “receptors” – people, property and the environment. Flood risk management - the process which comprises pre-flood prevention, risk mitigation measures and preparedness, backed up by flood management actions during and after an event – was also addressed under this research programme.

Linking European and International Initiatives

Over the past decade concerted efforts have been made to link research efforts nationally and internationally. This helps to avoid duplication of effort and facilitates greater collaboration and sharing of knowledge.

CRUE-ERANET

CRUE ERA-NET aims to introduce structure within the area of European Flood Research by improving co-ordination between national programmes. The vision for the CRUE ERA-NET action on flooding is to develop strategic integration of research at the national funding and policy development levels within Europe to provide knowledge and understanding for the sustainable management of flood risks.

Building on Past and Parallel European Projects

The UrbanFlood project straddles both the flood risk and ICT industries. From a flood risk perspective, the project builds upon knowledge of embankment failure modes, breaching and emergency management. This links through a number of European and International research projects including:

FLOODsite – www.floodsite.net As detailed above, and specifically relating to outputs from Tasks 4, 6, 7 on flood defence failure modes, breach initiation and growth and reliability analysis. The Source-Path-Receptor framework used for flood risk analysis and management will be used within UrbanFlood.
IMPACT – www.impact-project.net

Within the IMPACT project a programme of research was undertaken to investigate breach processes and collate data with which to develop and validate breach models. This data was used to underpin more detailed breach model development within the FLOODsite project. This knowledge will be integrated into the UrbanFlood EWS framework.

FloodProBE – www.floodprobe.eu

The FloodProBE project is currently funded under the EC FP7 programme and runs from 1st November 2009 for 4 years. The project addresses practical, near industry solutions for flood risk management in urban areas, covering impacts and solutions for buildings and the performance of defences. This research has relevance to UrbanFlood through the understanding of failure modes and measurement of soil parameters.

ICOLD, USACE, USDA, USBR and CEATI Initiatives

Strong links with international research relating to the performance of embankments, erosion and breach have been established through collaboration on the projects mentioned above and additional initiatives such as:

(i) European working group on internal erosion
(ii) CEATI facilitated Dam Safety Interest Group (DSIG) breach modelling project (performance evaluation for industry uptake)

These links help ensure that we (and hence the UrbanFlood project) remain aware of relevant research programmes implemented by US federal agencies such as USACE, USBR and USDA.

**USA**

The USACE and BuRec has installed sensors in dams for monitoring purposes. The BuRec dam safety program began in 1978, two years after the Grand Teton dam failed as it was being filled storage for the first time. The USACE have wired many sites but admit that river levees are long overdue for monitoring. For more on State issues:


The USACE and BuRec operate most of the Federal dams, but the Tennessee Valley Authority is an important regional player, along with numerous privately owned dams around the country. Probably the single, most important organization is the American Society of Civil Engineers, whose membership includes representatives from the players above as well as Academia, civil engineering consulting firms, and some international counterparts. Moreover, whenever there is a civil engineering structural failure, concerns about failing water-supply and sewerage treatment facilities, concerns about decaying infrastructure, importance of stream gauging networks, and so on, the ASCE is almost always among the first to testify before Congress. Hence it has stature and provides a good framework for networking with people from various backgrounds.

The other potentially important player is the American Society of Testing and Material (ASTM), which is the US national standards organization and is the main US link to the International Standards Organization (ISO), which I am sure you are aware of. Typically when national programs are set up by the Congress (such as dam safety) standards of some sort of another have to be established so assure that every system meets minimum requirements for concrete, aggregates, clay cores of earthen dams, etc. I believe the USACE is responsible for making safety assessments of state dams, so there must be some sort of objective criteria that they probably use. There are hundreds of standards committees in ASTM and key players in dam safety will know if there are published standards.

Other key players are the State of California (which has a lot of very capable, water-oriented professionals), and BC Hydro, which is the Canadian entity that operates the upstream part of the Columbia River basin.

The USACE is the official agency to aggregate assessments of life and property losses due to floods in the US.
International

The World Bank has adopted a dam safety policy that comes into plan whenever a Bank project includes building a new dam or refurbishing an existing one. Dam safety seems to be an important issue for the World Bank.
Annex 3  

Experience with Early Warning Systems and Smart Dikes

An Early Warning System based on Smart Dikes for the protection of an urban area in the manner foreseen by the UrbanFlood project does not seem to exist yet. However, there are a number of projects, mostly in the Netherlands, where sensors are installed in dikes, and where some experience with such sensors has been gained. Early Warning Systems that are based on sensors are implemented for reservoir dams; the earliest examples are in the United States. The US Bureau of Reclamation dam safety program began in 1978, two years after the Grand Teton dam failed as it was being filled storage for the first time. It appears that the Army Corps of Engineers (USACE) have wired many sites but they admit that river levees are long overdue for monitoring.

A known application of smart dikes relates to the application of temperature measurements with a fibre optic cable near reservoir dams. These measurements are conducted to identify changes in temperature indicative for changes in subsurface water flows underneath the dams. The setup functions as early warning system to inform the reservoir dam manager for any potential problems related to dam stability. A system for these measurements is marketed (among others) by GTC Kappelmayer GMBH, Germany.

For info: http://www.gtc-info.de/

Below are a number of practical examples of Smart Dikes in the Netherlands. Full details of the respondents are available with the UrbanFlood project management.

Vlaardingse Kade and Voorboezem Nootdorp

The Vlaardingse Kade is a dike that is situated near residential areas of Schipluiden and Vlaardingen in the west of the Netherlands in the Rotterdam area. The Vlaardingse Kade protects a polder from flooding from the adjacent polder canal.

In 2008 a reconstruction of the Vlaardingse Kade was commissioned. Prior to this reconstruction part of the dike was monitored for deformation using sensor technology. The main reason to monitor this dike was to monitor the behaviour of the dike during reconstruction. The dike was known to have weak spots. The application of sensor technology was started as a test.

A total of 30 sensor modules were installed. The modules measured water pressures, temperature and movement. Modules were installed in ground layers up to a depth of 5 meters below sea level. Most important parameters were water levels and movement. From the measurements the phreatic layer was determined. Measurements were transmitted each minute with a regular internet connection to a central location. For this application Geobeads sensors from Alert Solutions b.v. (www.alertsolutions.nl), Delft were used.

In March 2010 a new dike, the ‘voorboezem Nootdorp’, will be monitored using sensor technology. The monitored dike behaviour will be used to fine-tune the redesign of the dike.
The responsible team leader states that decision making is not influenced by EWS application since the determining parameters on height and slope of the dike are already set. The value of EWS application is to understand the behaviour of the dike. By linking the information to a ground model, the current stability of the dike can be calculated.

Although there is currently no connection with emergency management, he formulated some thoughts on the matter. An EWS could be used on known weak spots with an alarm going off when a threshold value is passed. The use of an EWS system for the 5-yearly audit on dike safety is also good application. Finally an EWS might be used to monitor dike safety in order to reduce the effort needed to strengthen the dike, but this is still a controversial point of view.

The team leader states that for application of sensor technologies as part of an EWS, the reliability should be similar to conventional methods and costs should also be comparable to existing methods to successfully compete.

Relevant parameters are: water pressure (water levels), soil composition, temperature, movement and salinity. The latter could be used to monitor the origin of water flow.

The installation of sensor probes is a point of attention. In the first application holes were drilled disturbing the soil around the sensor resulting in high initial transmissivity and settlement of the sensor. In the new application the sensors will be pushed into the ground.

The team leader notes that he prefers understandable output, not a data stream that requires additional calculation first. He now receives information in N.A.P. format.

Especially if the system is used for actual safety monitoring the power supply is a point of attention. In the first application at some point batteries went down. Currently a fixed power cable is used. In the future solar energy could be a sustainable and reliable solution.

Also the reliability of data transmission is important under emergency circumstances. Since it currently depends on the GSM network, redundancy with for example satellite communication or a fixed fibre optic cable is preferred as backup.

Hoogheemraadschap Delfland, Postbus 3061, 2601 DB Delft, the Netherlands

Smart Quay in Rotterdam Harbour

In the Rotterdam Harbour in 2009 a quay wall was restored and widened by Ballast Nedam. As part of the works Inventec b.v. was commissioned to install a set of sensors over a length of 500m by means of an EWS to detect any soil movements behind the quay wall. Since this is a design & construct work, no direct governing body was involved. Scope of the work relates to the project at hand.

Inventec b.v., Postbus 497, 8070 AL Nunspeet, The Netherlands
**Wilpse Klei Dike, Deventer**

The interview was held with the responsible policy worker for the water board Veluwe, Apeldoorn, The Netherlands. First the case of the Wilpse Klei dike is discussed.

The Wilpse Klei Dike is a secondary dike along the River IJssel near the city of Deventer, located in the eastern half of the Netherlands. Only during periods of high water the dikes have a function to withstand the river. Although the dike is currently stable, it has a history of flooding. During the winter floods of 1993 and 1995 the dike was overtopped, inundating the land behind the dike. Although the local water board currently has no need to closely monitor the dike, it is willing to cooperate to allow application of experimental sensor technology applications. An adequate number of calibration sites are needed to provide proof-of-technology. The main reason to trial ‘smart dikes’ is to support innovation in this field.

The application of technologies to provide early warning for flood management is important for dikes that are more critical, for example, sand dikes. He believes the cost/benefit ratio will not be sufficient to implement the technology for secondary dikes.

The highest benefits of an early warning system are to be expected during emergency situations. He recalls the 1993 and 1995 flood events when a decision to evacuate or not evacuate a part of Deventer had to be made. At that time it was clear that there was an unmet demand for more in depth knowledge of dike behaviour and dike strength. A lot of external experts were consulted during these emergency events, both of which lasted more than a fortnight. During these events, although rare, a lot of knowledge can be gained from information systems that can inform on water pressure distribution, soil moisture distribution and deformation of the dike. The system should produce both quantitative output and a ‘red flag’ function. Also a prediction of the situation in the dike for several days ahead given expected/forecast water levels is important.

Waterschap Veluwe, Postbus 4142, 7320 AC Apeldoorn

**River Dike, Sleeuwijk**

The subject of discussion with the responsible team leader from water board Rivierenland is an idea to use existing geotechnical information from a national database (GeoTop) with laser altimetry measurements (from AHN2) to calculate the ‘opdrijfgevoeligheid’ / uplift sensitivity of a primary dike near Sleeuwijk along the river Waal, in the centre of the Netherlands. This failure mechanism is relevant to all dikes in the western parts of the Netherlands constructed on top of ‘weak subsoil layers’, and water board Rivierenland is responsible for a significant part of these dikes.

The exercise should in principle enable a pre-calculation of uplift sensitivity for each of the dikes build on weak soils. The idea is in the conception phase. Ideally an approach on a river basin scale would be best suited and enable the use of existing connections between water management boards. The information could be used to audit the dikes on a more detailed
level, in a more targeted way. Also during high water emergency events the information could provide insight in dike reaches that are more vulnerable to failure by uplift, given expected water levels. This makes this information an important part of an EWS.

An important technical aspect in the realisation of any application on a river basin management scale is a standardized data model. This should receive extra attention after initial steps which were taken in the Netherlands a few years ago.

There is collaboration with TNO Utrecht, The Netherlands to further develop the GeoTop model.

Concluding note from the author: An EWS application is more than real-time measurements and status information delivery. There is also a need to realize a connection to existing databases containing risk-factors, pre-calculated scenarios and necessary background information. Only then can an EWS supply the responsible authorities with the necessary information to support decision making.

Waterschap Rivierenland, Postbus 599, 4000 AN Tiel, the Netherlands

New Westerholte Dike Near Stadshagen, Zwolle

Water board Groot-Salland is planning and designing a new dike along the river IJssel, near Stadshagen, Zwolle in the centre-north of the Netherlands. The dike will be complete in 2015 with a total length of 2.2 kilometres. The new dike will be constructed on weak soil layers and there is interest in monitoring the settling of the dike after construction using sensor technologies.

Integration with decision making is not a main concern; the installation of sensors is perceived as part of studies to understand dike behaviour. If in the future an application of EWS is operational. A ‘traffic light’ option is required, with red to indicate (potential) emergency situations and green to indicate a normal, safe situation.

Integration with other systems is not a main concern. Relevant systems are DAM module (Dijk Analysis Module) developed by STOWA and the Dutch water board geo information systems IRIS / INTWIS.

The main benefit of an EWS application is an understanding of behaviour of the dike. Although extensive monitoring is seen as always beneficial, the cost/benefit ratio should be kept in mind.

Finally: a recommendation for the UrbanFlood project is to focus on areas and countries where insufficient maintenance is done and/or little information is available on dikes. The added value of an EWS can be maximized when applied in these situations, where flood probability is high.

Waterschap Groot-Salland, Postbus 60, 8000 AB Zwolle, the Netherlands
Afsluitdijk

The Water District IJsselmeergebied of Rijkswaterstaat monitors the Afsluitdijk, the closure dike of the IJsselmeer, the former Zuiderzee. The Afsluitdijk has a length of 32 kilometres and is situated in the north of the Netherlands. The Afsluitdijk separates the Waddenzee and the IJsselmeer (Lake IJssel). Monitoring of the Afsluitdijk with an EWS could be of interest. The benefits for application is for both regular inspection and maybe also useful during high water events. The main benefit is that ‘you can see how the dike behaves, even when you’re in bed’.

The main technical issue expressed here is whether the entire dike can be covered using current sensor technology. The applications currently available are thought to be still in a test phase and not ready for large projects.

Another aspect for usage is the reliability of the data measured. The appropriate values need to be presented, but an alert based on the data should be accurate and meaningful. This requires more understanding and research.

The organisation is willing to test new applications. At an earlier stage an invitation for a research plan was submitted to IJkdijk Association.

Water district IJsselmeergebied, Postbus 600, 8200 AP Lelystad, the Netherlands
Introducing UrbanFlood

UrbanFlood is a European project investigating the use of sensors within flood embankments to support an online early warning system, real time emergency management and routine asset management.

Early Warning System Framework for European Cities

More than two thirds of European cities have to deal with flood risk management issues on a regular basis; these are issues which will worsen as climate change effects result in more extreme conditions. Early Warning Systems (EWS) can play a crucial role in mitigating flood risk by detecting conditions and predicting the onset of a catastrophe before the event occurs, and by providing real time information during an event. EWSs thus fulfil multiple roles as general information systems, decision support systems and alarm systems for multiple stakeholders including government, companies and the general public.

The UrbanFlood approach

The UrbanFlood project will create an EWS framework that can be used to link sensors via the Internet to predictive models and emergency warning systems. The data collected from the sensors will be interpreted to assess the condition and likelihood of failure; different models will be used to predict the failure mode and subsequent potential inundation in near real time. Through the Internet, additional computer resources required by the framework are made available on demand.

UrbanFlood will validate the EWS framework and method for implementation in the context of dike performance (failure) in an urban environment. A number of live pilot sites will be used to prove the methodology. Dikes will be equipped with sensor systems and the EWS service built up from a series of dike failure and flooding specific modules which include dike breach evolution and flood-spreading models. UrbanFlood will investigate and show the feasibility to remotely monitor dikes and floods, whether from nearby offices or from other countries and continents through secure use of web based technologies.

For the development of flood mitigation scenarios and the training of personnel, the framework will also connect to a simulator that computes flood responses associated with failing dikes. UrbanFlood will make use of data from the induced failure of real dikes at the IJkdijk field laboratory to test and validate the overall EWS framework and individual modules.

Challenges

1. How can professional organisations connect sensor infrastructures to an Internet-based Early Warning Systems (EWS), work with that EWS, and integrate this with existing EWS, with decision support, visualisation and public information systems?
2. How do we monitor thousands of sensor streams?
3. How do we create a common information space that allows easy integration, over the Internet with other EWSs, sensors and application programs for public information, decision support?
4. How do we effectively host and manage multiple early warning systems? How can shared, Internet-based facilities for EWS adapt to a sudden demand of computational resources? Can we beneficially use cloud computing resources to introduce new EWS and keep investment in hardware low?

5. How can we create an Internet-based EWS that monitors dikes and integrates that with simulations to measure dike strength and failure, and flood models, as well as with legacy EWS?

6. Is it feasible to monitor dikes on a European scale, from multiple locations?

The UrbanFlood Project

UrbanFlood is a project under the EU 7th framework Programme which started in December 2009 and will run for 3 years. Partners of UrbanFlood include TNO Information and Communication Technology, the University of Amsterdam and STOWA (Foundation for Applied Water Research) from the Netherlands; HR Wallingford in the UK, ACC Cyfronet AGH in Poland and OOO Siemens in Russia.

Dear <<<Name>>>.

You have been identified as an industry professional and/or potential stakeholder who might have experience in flood defence asset management, the use of sensors and early warning systems, and/or emergency management; you may also be interested in the research and application of methods proposed under the UrbanFlood project.

As such, your participation in a brief survey of the current position and future needs for the use of remote sensor systems and early warning systems would be very valuable and appreciated. In return for your input to this survey, we would be happy to share the overall findings of the review with you and also for you to participate more closely with the project should you be interested in doing so.

The feedback from this survey will be used to confirm the current state of the art and to define specific industry needs. These will then be used as criteria for the project team to address during the project.

After completing the questionnaire, please send it by email to Ms. Manuela Di Mauro, HR Wallingford at:

m.di.mauro@hrwallingford.co.uk

Questionnaire

Your name and contact details (please check)

Name : <<<name>>> 
Job title:
Email : <<<email address>>> 
Telephone : <<<telephone number including international access code>>>
We will not use your name in the report or any other publication. However, with your name and contact details we can follow up on issues you raise and, if you wish, keep you informed of relevant UrbanFlood news and results.

**How would you describe yourself (multiple answers are possible)**

- Concerned member of the public
- Asset Manager / Operations Manager
- Decision maker
- Emergency response coordinator / manager
- Other

*Other Description:*

**Below are two blocks of questions.**

- If you know about, **use or intend to use** online sensors for monitoring, including use as part of Early Warning Systems please fill in the questions of **Section A.**
- If you **do not use** or are not aware of online sensor systems and Early Warning Systems please fill in the questions of **Section B.**

**Section A: If you know about, already use or intend to use online sensor systems and/or early warning systems**

1. What systems do you use or are familiar with?

<table>
<thead>
<tr>
<th>System Name</th>
<th>General Description</th>
<th>Technical description</th>
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2. In what context are you familiar with online sensor or Early Warning Systems (EWS)? (i.e. flood embankments, dams etc; on rivers, lakes, reservoirs, estuaries, sea).

3. If you have direct experience of using / operating an online EWS would you be happy to provide more detailed feedback on technical issues and effectiveness in practice

☐ YES  ☐ NO

4. What are the suggested benefits of using such a system?
5. If you have actual experience with or knowledge of an online EWS, has the system provided the expected benefits? Please explain why it has or has not.

6. How does the system integrate with existing flood risk management / emergency management procedures? Were there any difficulties with integrating the system to start with? Are there any ongoing issues?
7. Do you think the EWS should be integrated or linked with flood protection asset management systems and/or inspection? Can you explain your answer?

☐ YES  ☐ NO

Why?

8. How does your system compare to the proposed UrbanFlood approach? What are the advantages / disadvantages of either system?

<table>
<thead>
<tr>
<th>Your System features</th>
<th>UrbanFlood System features</th>
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Advantages

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9. Please provide details on which parts of the proposed UrbanFlood system you would feel comfortable with, and which cause (some) doubt and why.


10. Based upon your experience to date, are you enthusiastic about the use of such systems or not? Please give reasons either way. In what environments can you envisage use of these systems?

[ ] YES  [ ] NO

Why?

Where would you use such systems?

11. What impact has the EWS had (or is the EWS expected to have) on your ability to manage flood risk?
12. What advice would you give to the UrbanFlood team based upon your experience?

i.e. Can you list any specific issues or requirements that an online sensor system or EWS needs to address or provide? (e.g. reliability, online security, form of data, uncertainty in data, public response etc)

13. Are you interested in participating more on this research project? Would you consider trialling an online EWS (or include aspects of the system that you did not yet use on a trial basis)?

14. Please indicate if you would like to receive a digital copy of the UrbanFlood Stakeholder Analysis report by email.

[ ] YES  [ ] NO
B: If you do not use or are not aware of online sensor or Early Warning Systems

1. Do you think that online sensor or Early Warning Systems (EWS) can provide a useful service? If yes or no, please explain why.

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<tr>
<th>YES</th>
<th>NO</th>
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</table>

Why?

2. What features do you think an online sensor or EWS should provide? Why?

3. What advantages do you think an online EWS would provide for flood risk and emergency management?
4. Can you envisage any issues or problems that implementing an online EWS might encounter?

5. Are you interested in participating more on this research project and perhaps trialling an online Early Warning System?
   - [ ] YES
   - [ ] NO

6. Please indicate if you would like to receive a digital copy of the UrbanFlood Stakeholder Analysis report by email.
   - [ ] YES
   - [ ] NO
Thank you for completing this questionnaire – we appreciate your feedback and will use this to help guide the research programme

Please send the completed questionnaire by email to Ms. Manuela Di Mauro, HR Wallingford at:

m.di.mauro@hrwallingford.co.uk

For further information on this questionnaire, the UrbanFlood project and the UrbanFlood system please contact Manuela Di Mauro or Mark Morris (HR Wallingford) or Bob Pengel (STOWA):

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Or visit the UrbanFlood website: www.urbanflood.eu

With Best Regards,

......................

On behalf of the UrbanFlood Project Team
Annex 5  

Short Summary of Responses of Questionnaires

Section A: If you know about, already use or intend to use online sensor systems and/or early warning systems

Three out of 12 respondents answered the Section A questions: one from Australia, with experience in applying sensors and systems mostly for reservoir dams, and two from Ireland, with experience with flood early warning systems. All three are interested in trialling the UrbanFlood concept / sensor network systems.

Full details of the respondents are available with the UrbanFlood project management.

Water Utility Company (Australia, international)
- Modeling of rainfall-runoff
- Models as warning
- Models useful
- Sensors in dams
- Use of IP cameras
- Warning if threshold is breached
- Heartbeat of sensors
- Ensure sensors work by proper maintenance – redundancy
- Communication redundancy (gsm fails in severe weather)
- No serious problems in data exchange and compatibility, usually easily resolved (one country)
- monitoring the condition of the asset from a safety/ageing/replacement
- UrbanFlood concept lower cost
- But reliance on Internet – could be unavailable in emergency situations
- Redundancy: private IP networks?
- Provide plenty of redundancy & backup
- Raw data how often – what is significant? Heartbeat data. Data Validation/Sanity Checks
- Analyse data locally, and send in resultant or summary info

Local Authority (Ireland)
- EWS used for warning and especially for triggering response (movable floodbarriers)
- Modeling of rainfall-runoff
- Models as warning
- Models useful, have proven their worth
- 800 km dikes – monitoring them some time in the future is seen as beneficial
- Ensure that infrastructure stays operational during a flood event
- Monitoring for asset management is seen as useful, in addition to EW function
- Preference for smaller local systems over a ‘big’ centralized system
- Implementation of sensors in embankments first where significant urban centres are to be protected
- Relative simplicity in output so local actors can act

Local Authority (Ireland)

- EWS used for warning and especially for triggering response
- Modeling of rainfall-runoff but also pumping systems, sewage flows – and coastal flooding
- Models as warning
- Greater integration between the capacity to forecast & the ability to warn & mobilise is required
- Manual
- System needs to be more comprehensive & inclusive of all organisations & public
- Asset management using sensor /EW systems: Yes because the integrity of the system can depend on knowing the state of the asset; the level of protection the asset is designed to afford and particularly if the asset is demountable or moveable (sea defence gates at the mouth of a canal) whether the defence is in place.
- Our sea gate is linked by telemetry to inform whether it is open or closed and has a tide gauge situated next to it to confirm the sea level it is dealing with.
- There appears to be a similarity of approach PARTICULARLY the UrbanFlood proposal to link sensors etc via internet.
- We see this as useful for a number of reasons.
  - If it can work with sensors it can work with gauges.
  - Useful information is available outside our administrative area but within our region which could be linked via such a proposals as UrbFS.
  - WE are already talking to our national Met Office about the potential to link rain gauges nationally to provide a means of ground proofing rainfall radar.
  - We have already linked our tide & some river gauges into a national network run by our Marine Institute.
- I would like more information please as I think this has a potential to go outside the linking of defence asset sensors only.
- If you recall our observations about FLIWAS under project NOAH there also seems to be scope for making the system multi-hazard not just for floods.
- Our experience has been if the system is multi-hazard the responder agencies will use it more frequently. The danger with single-hazard systems is that there can be long gaps between their being required and a lack of familiarity sets in.
- Impact of EWS:
Coastal EWS – Has given us the potential to manage risk in particular:
- Allowed us to appropriately activate our defences on a number of occasions and avoided much flood damage!
- Allowed us to Not activate on a large number of occasions and saved a lot of unnecessary overtime payment.
- Allowed us to tell the public that a particular scare (by others – media etc) was no cause for alarm thereby avoiding a lot of worry among the public.
- Advice: redundancy in the communication system so that should the main system fail in a crisis backup data is available

B: If you do not use or are not aware of online sensor or Early Warning Systems

A total of 9 respondents indicated that they belong to B. Responses came from Germany (3); the UK (2); Hungary (1); the USA (1); Canada (2);

Technical University (Germany)

- Fast warning in small catchments (flash flood aspect)
- Excluding human error
- Sensor network and EWS should be: Reliable, no negative or positive instrument errors, independent from the power supply network (e.g. with battery, solar panel), protected against vandalism
- Possible problems: Costs, responsibilities, accessibility to the catchment area, technical problems (instrument errors, power supply), possible vandalism

Local Flood Protection Authority (Germany)

- Access to information and data independent of location is important. Both the management as the field workers can have access to data if it is Internet-based.
- The monitoring of dikes and integration with other monitoring systems can deliver real-time data which may help assess actual danger.
- Modeling of flood scenarios will help preparations
- Features of an online EWS:
  - Real-time data availability
  - Graphical representation of situation of flood defence systems
  - GIS link to assess local situation graphically
  - Scenario calculations
  - Possibly action plans depending on specific warning levels or signals / thresholds
- Advantages:
  - Timely evacuation
  - More focused mobilisation of stabilising measures for threatened flood defences
  - Better information for field workers on location
  - Dike breach scenarios are very important to support emergency response organisations

- Issues
  - To be able to pinpoint problems in embankments the measurement/sensor network has to have a high resolution, resulting in a very large number of sensors
  - In Cologne the first flood defense is hard, not soft, so there is no need to monitor water levels in the dike
  - More interesting is monitoring of the stability of movable flood walls. Failure of these is the biggest risk for Cologne and this means they need to be monitored continuously when erected.

River Basin Association of local flood protection authorities (Germany)

- In general, hazard managers require information on upcoming threats and hazards as soon as possible in order to coordinate the counter measures needed at an early stage as preparation time may be short.
- In this context, online sensors or EWS may provide the possibility to initiate and perform proactive measures for flood mitigation and calamity management.
- Technical reliability of the system is needed to avoid wrong decisions. Here, systems have to check their operability themselves. In case of system errors, the status of system failure has to be sent.
- Additionally, there must exist the possibility to transfer the sensor results to the headquarters which coordinates the flood mitigation actions.
- External power supply (if needed) and online data transmission depends on working infrastructure which may fail during flood events

National Agency (UK)

- 9000 km of raised defences (fluvial and sea), the majority being earth or composite embankments. Although we have a programme of inspections and more detailed surveys, a remote tool would help us monitor our defences in real time.
- Real time assessment of asset “performance”, accessible by telemetry remotely
- Cheap to install and run
- Low carbon footprint (solar powered?)
- With the length of defences we have got we would have to prioritise any installation according to risk, even so there could be a significant cumulative cost.
- Reduced inspections during floods / high water bringing:
  - cost savings
  - better targeting of site visits
- Cost, especially in a tight financial climate where it would compete with other high priority work. The business case would have to be supported by a robust benefit / cost ratio and an early payback period.
- The length of embankments involved – we would need to prioritise
- The IT to run / monitor the sensors and its compatibility with our existing systems

**Regional Authority (UK)**

- Favourable to EWS.
- The real time data allows a better emergency response.
- Extra level on top of existing forecasting methods
- Issues:
  - Vandalism and access issues due to private land.
  - Needs relevant monitoring parameters, frequent samples, and the output should be easy to use.

**National Agency (Hungary)**

- Sensor systems and online EWS can provide extra and unbiased information about the state of the defences. It can avoid human mistakes or absentmindedness.
- More frequent checking of the key points than levee guards can do. The sensors can be on the spot and on duty 24 hrs/day.
- Issues or problems?
  - Maintenance (especially when we talk about hundreds or thousands of sensors). Protection against theft or impairment.
  - False alarms
  - Failure of power and internet
  - Surcharge of telecommunication lines (GSM) – costs of communication

**River Basin Authority (Canada)**

- **No need for online EWS**: We have sufficient lead time to our urban areas to use our current stream gauging system.
- Over-reliance on Online to the detriment of other modes of information dissemination. Other modes are fax, radio, TV, newspaper and verbal.

**Regional Authority (Canada)**

- Easy to use! The EWS should enable us to view the status of gauges easily and provide a warning alarm.
- It would make our work easier by having things on-line (right now, we are able to access gauges on-line or by phone, however, not all this info is real time).
National Department (USA)

- The obvious benefit of an online EW / sensor system is related to saving lives. It has been determined that the more warning time the more lives saved. It also may provide benefits to saving animals, property, transportation systems, water supplies, and environmental quality.

- Should provide continuous real-time feedback. It should be linked to a display system that can be checked on a minute by minute basis if need be but also provide daily information relative to the situation. It should be accessible to asset operations staff on a need to know basis. Should be linked to a cell phone feedback warning for those who need to know.

- Primarily in Urban environments in which EWS provide safety to life and economic return for safety to property. Obviously insurance companies are also very interested in EWS to cover the assets that they are providing policies for.

- EWS should be an integral part of operations and maintenance. EWS could and should play a part in prevention of accidents and catastrophic failures. These systems may help play a role in early prevention. The staff involved in asset management systems and/or inspection, because they are familiar with the flood protection system, could play a very important role in early warning.

- The EWS may also need periodic testing and validation. The staff of the flood protection asset management system may play a key role in testing, validation, and maintenance of the EWS.

- Issues would be related to maintaining the system and making sure that it is working properly even when it is not needed. The other issue is making sure that the people involved know how to use and react to the information the system provides.