JRC SCIENCE FOR POLICY REPORT

The benefit of continental flood early warning systems to reduce the impact of flood disasters

An assessment for Europe and an outlook for Africa

J. Thielen-del Pozo, V. Thiemig, F. Pappenberger, B. Revilla-Romero, P. Salamon, T. De Groeve and F. Hirpa

2015

Serbia and Bosnia and Herzegovina floods May 2014 © EC/ECHO/EEAS/EU Delegation BiH

EUR 27533 EN

This publication is a Science for Policy report by the Joint Research Centre, the European Commission's in-house science service. It aims to provide evidence-based scientific support to the European policy-making process.
The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

JRC Science Hub
https://ec.europa.eu/jrc

JRC97266

EUR 27533 EN

PDF	ISBN 978-92-79-52768-5	ISSN 1831-9424	doi:10.2788/46941	LB-NA-27533-EN-N
Print	ISBN 978-92-79-52767-8	ISSN 1018-5593	doi:10.2788/624063	LB-NA-27533-EN-C

© European Union, 2015

Reproduction is authorised provided the source is acknowledged.

How to cite: J. Thielen-del Pozo, V. Thiemig, F. Pappenberger, B. Revilla-Romero, P. Salamon, T. De Groeve and F. Hirpa; The benefit of continental flood early warning systems to reduce the impact of flood disasters; EUR 27533 EN; doi:10.2788/46941 (PDF)

All images © European Union 2015

Benefit of continental flood early warning systems to reduce the impact of flood disasters

- When flood events are extreme or affect regions of high vulnerability, they can become life threatening and devastating. They can also interrupt supply chains and cause significant socio-economic impacts worldwide.
- The EU has implemented a comprehensive policy framework to reduce flood impacts in the EU and worldwide.
- The JRC supports the EU policies on civil protection, disaster risk reduction and adaptation to climate change with state of the art European and global flood early warning systems. It manages the Copernicus Emergency Management Service.
- A study on the monetary benefit of flood early warning systems in Europe suggest major savings can be achieved.
- The recently launched Global Flood Partnership, co-chaired by JRC, fosters transfer of knowledge from the EU to developing countries and aid organisations.

This report summarises current European policies in place to deal with flooding in the different phases of the disaster management cycle. A description of the development of pan-European flood early warning capability (EFAS) is provided as well as how the system fits into the responsibility chain between national services and EU civil protection. An estimate of the potential monetary benefit of EFAS in Europe is clearly indicates the added value. It further addresses gaps of such systems in other regions such as Africa and demonstrates how methodology of EU systems could be transferred for better preparedness for flooding in vulnerable regions. The recently launched Global Flood Partnership shows great potential to facilitate such transfer.

Table of Contents

Acronyms

AFFS	African Flood Forecasting System
CECIS	Common Emergency Communication and Information System
Copernicus	EU Space programme
DFO	Dartmouth Flood Observatory
ECMWF	European Centre for Medium-Range Weather Forecasts
EFAS	European Flood Awareness System
EM-DAT	Emergency Events Database created and maintained by CRED
EMS	Emergency Management Service (of Copernicus)
ERCC	Emergency Response Coordination Centre
EERC	European Emergency Response Capacity
GFDS	Global Flood Detection System
GFP	Global Flood Partnership
GloFAS	Global Flood Awareness System
GRDC	Global Runoff Data Centre
HEPEX	The Hydrologic Ensemble Prediction Experiment
NHS	National Hydrological Services
UNISDR	United Nations International Strategy for Disaster Reduction
WFP	World Food Programme
WMO	World Meteorological Organisation

1. Executive Summary

Flooding is a natural phenomenon humans have to cope with since the first settlements. In regions with strong seasonal rainfall patterns, floods have often become an integral part of agricultural activity. But when the events become extreme or hit locations of high vulnerability, then floods can be life threatening and devastating. Important - and potentially long-lasting - socio-economic consequences can be felt at local, national but also international level as with increasing globalisation, interruptions in the supply chains anywhere in the world can propagate through entire production chains. The negative consequences of flooding can be tackled at different phases of the disaster risk management cycle – in the preparedness, preparation, crisis response, and recovery phase. Better coordination of actions along these phases on local, national and international level will contribute to a reduction of negative impacts of flood events.

Bakker (2009) has found that flooding in trans-national river basins globally account for about 30% of the casualties and almost 60% of all people affected. This report focuses on the impacts of flooding in Europe and Africa as representative examples of a developed and a developing continent being exposed to floods.

Europe is recurrently affected by severe flood events with trans-national events often being the most damaging ones. Over the past years, a comprehensive policy framework has been put in place to improve flood risk management holistically and to complement national and bi-lateral efforts to overall reduce the impact of flooding. The framework addresses prevention measures at basin scale, improved preparedness at national as well as EU level, coordinated crisis response across the EU, as well as solidarity across the EU in the recovery phase. Policies include the Floods Directive *(DIR 2007/60/EC)*, the EU Strategy on adaptation to climate change *(COM (2013) 216)*, the Union Civil Protection Mechanism *(DEC 1313/2013)*, the COPERNICUS programme *(REG 377/2014)*, and the EU Solidarity Fund *(REG 661/2014).*

One of the measures at European scale is the successful development and implementation of the European Flood Awareness System (EFAS) which was launched in 2003 (*COM2002/481*) as one of the instruments to improve preparedness for floods within the national services, as well as the European Civil Protection through pan-European monitoring and forecasting. EFAS is fully operational since 2012 as the first early warning system of the Copernicus Emergency Management Service.

The benefit of EFAS in conjunction with other EU mechanisms such as the Emergency Response Coordination Centre and the Copernicus Emergency Management Service – Mapping, as well as national flood forecasting services is illustrated at the example of the Balkan 2014 floods. The developments in Europe have shown that the combination of flood reduction policy, advanced early warning technology, and increased international collaboration have high potential to reduce flood risk and to improve disaster response. The monetary benefit of flood early warning in Europe has been assessed using EFAS as a reference system, taking into account different factors including different flood protection scenarios. Results show that flood early warning systems in Europe have the potential of reducing the costs of flood damages by about 25%, saving an estimated 30,000 million EUR over the next 20 years.

With EFAS, it has been demonstrated that operating continental flood forecasting systems is feasible and, more importantly, beneficial for national hydrological services, civil protection, and aid management at the same time. Based on methodologies and concepts developed for EFAS, the JRC has set-up and tested also an African Flood Forecasting System. Due to the limited availability of observational in situ data for setting up, running and validating the results both for historic or real-time data, satellite rainfall data have been used to test the performance of the African system. Applying the system in hindcast mode using the same weather prediction inputs as EFAS, the system has produced promising results.

Finally, since flooding is a global issue with many different facets to be dealt with on local, regional, national, and trans-national level and across various sectors, single authorities cannot tackle the complexity of flooding alone in sufficient detail. Therefore, the JRC initiated a *Global Flood Partnership* (GFP) as a multi-disciplinary group of scientists, operational agencies, and flood risk managers focused on developing efficient and effective tools applicable on global scale that can address these challenges. The GFP which has been launched in March 2014 (De Groeve et al, 2015) is briefly described and its potential demonstrated with a concrete example for the Malawi 2015 flood event.

2. Flooding – a shared problem and a problem for sharing

An analysis on flood records retrieved from various disaster archives, e.g. of the Dartmouth Flood Observatory (DFO)[1] or the EM-DAT International Disaster Database[2] shows that flooding is a global phenomenon which can take place almost anywhere in the world. The DFO archive recorded a total of 3713 large flood events worldwide from 1985 to 2010 (Figure 1), and it keeps actively reporting floods.

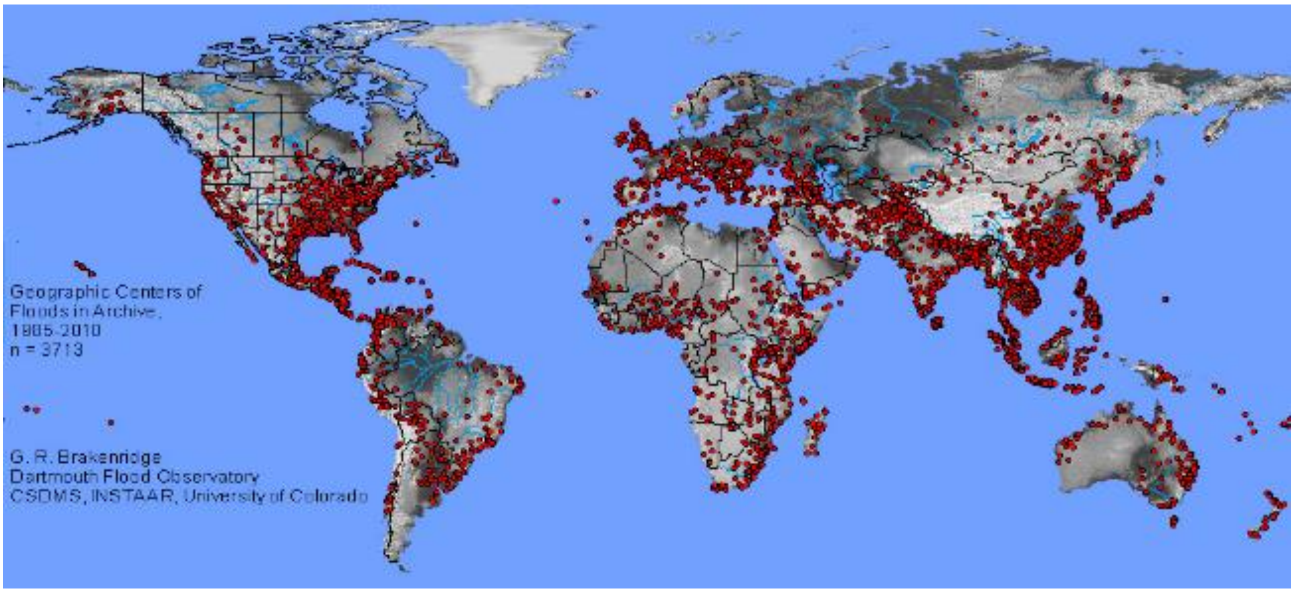


Figure 1: Geographic Centers of flooded areas in the Dartmouth Flood Archive GIS file covering the period from 1985-2010 [from G.R.Brakenridge, "Global Active Archive of Large Flood Events", Dartmouth Flood Observatory, University of Colorado, http://floodobservatory.colorado.edu/Archives/index.html]

Between 1980 and 2013, the EM-DAT database recorded 2369 riverine floods[3] worldwide with 2430 million people being affected, 117,000 dead and estimated economic damages to property, crops, and livestock of US$ 487 billion (Table 1). Of those riverine flood events, 328 and 542 occurred in Europe and Africa, respectively, and affected 8.4 and 50 million people causing an estimated economic damage of US$87 billion and US$6 billion.

Table 1 and **Error! Reference source not found.** illustrate how the **number of reported flood vents** has been developing over the last three decades (1980 to 2013). Although the increasing tendency may be partially explained by the higher number of reporting due to increasing availability of media, there is also some evidence that the actual number of events has augmented. According to an analysis of MunichRe in 2013[4], the "*frequency of flood events in Germany and central Europe has increased by a factor of two since 1980*". The same tendency has also been confirmed for the global scale, while Africa stands out with an increase by a factor of four. During

[1] *Dartmouth Flood Observatory, University of Colorado, http://floodobservatory.colorado.edu/Archives/index.html*
[2] http://www.emdat.be/
[3] Inland flooding in rivers excluding excluding flash floods, coastal floods and flooding due to dam failure. For a disaster to be recorded at least one of the following criteria must be fulfilled: Ten or more people reported killed; hundred or more people reported affected; declaration of a state of emergency and/or call for international assistance.
[4] http://www.munichre.com/en/media-relations/publications/press-releases/2013/2013-07-09-press-release/index.html

the time span, there has been a peak in occurrences from 2000 to 2010 globally, although with regional differences (**Error! Reference source not found.**).

Table 1: Occurrence of riverine floods and corresponding estimated damages

	Global		Europe		Africa	
	Occurrences	**Estimated damage** in million US$	**Occurrences**	**Estimated damage** in million US$	**Occurrences**	**Estimated damage** In million US$
1980-1989	129	10,955	13[5]	3086	20	785[6]
1990-1999	464	168,380	83	24,663	73	624[7]
2000-2010	1218	121,899	173	31,741	296	2499
1980-2010	1811	301,234	269	59,490	389	3908
1980-2013 inclusive	2369	486,940	328	87,403	542	5915

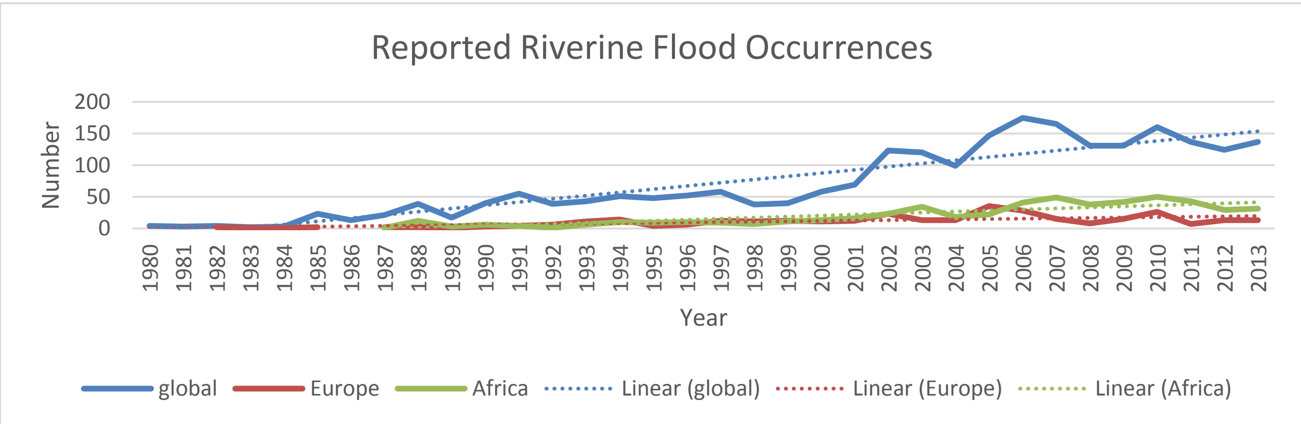


Figure 2 Number of reported riverine flood occurrences from 1980 to 2013 globally as well as for Europe and Africa

The increasing trend in number of occurrences has been additionally confirmed by the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2013) which suggests that due to climate change, heavy precipitation events have already increased in frequency and intensity, and in higher rainfall accumulations over land in the recent decades, and that this trend is likely to continue in mid-latitudes and over tropical regions.

According to the United Nations International Strategy for Disaster Reduction (UNISDR) and statistics from insurance companies, the **socio-economic impact** of floods has been increasing globally at a disturbing rate in the recent years.

[5] No data for 1981 and 1986
[6] Data records not complete with the years 1980-1984 and 1986 missing
[7] No data for 1991

Figure illustrates the annual costs of the flood events. Certain events appear particularly costly, with the highest costs having been reported within the last decade. However, JRC researchers have shown that damage reporting can differ considerably from country to country and agency to agency and therefore contains a lot of uncertainty (De Groeve et al., 2013). Therefore, it would have to be investigated further if there are hidden trends in the way damages are being reported before drawing conclusions from these numbers. Research findings from Jongman et al. (2014) for Europe suggests that effects of climate change could translate into extreme flood losses doubling in frequency by 2050 when taking into account the combined effects of climate change and socio-economic development.

The two main driving factors for this trend appear to be the increasing population and urbanization with subsequent changes in land use on the one hand, and changes in the frequency and intensity of events due to a changing climate on the other hand.

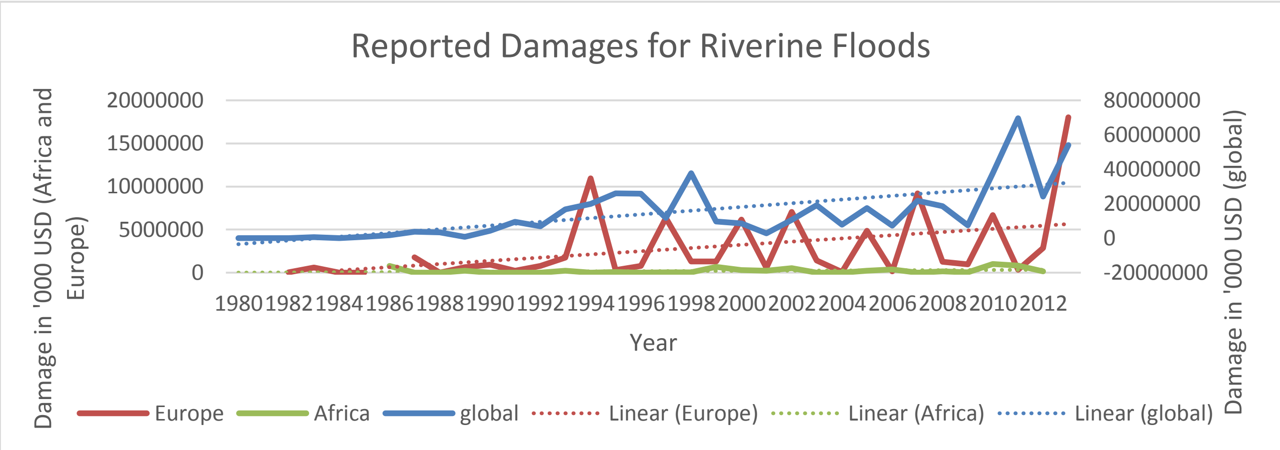


Figure 3: Total reported damage resulting from riverine floods from 1980 to 2014 as recorded in the EM-DAT data base. For each disaster, the number corresponds to the damage value at the moment of the event, i.e. the numbers correspond to the individual years.

2.1. Direct and indirect impacts

The direct and indirect impacts of natural disasters such as floods can be manifold and extend over various time scales. During the event human lives and properties are at risk, and civil protection measures primarily aim at protecting people, their homes, and critical infrastructure on the short term. Damage to transport networks, including harbours and airports as well as energy grid infrastructure, can produce medium- to long-term interruptions with negative consequences for the competitiveness of the local, regional, and national industries. Further, floods often overwhelm sewers as well as waste water treatment plants, causing the spillage of (partially) raw waters into the environment. This henceforth leads to the contamination of drinking water facilities, cutting many people during and after flood events off from clean drinking-water supplies, and creating preferable conditions for water- and vector-borne diseases, which cause most of the death toll of flooding. Furthermore, the release of toxic agents such as gasoline, pesticides, detergents and paints into the

environment peaks during flood events, causing contaminations with long-lasting adverse effects for the whole environment. Insurances can recover some of the costs caused by floods – if available and if coverage is sufficient.
As a further downstream effect with medium- to long-term consequences, the direct damages can result in lack of confidence of the markets with subsequent retreat of investors[8], and thus leading to considerable indirect damages. For example, following the Thailand flood in 2011 more than 13,000,000 people were affected, and several factories damaged by the flooding had to close down. This resulted in a rise in unemployment, subsequent reduction of investors, and retreat of insurance companies, all of which slowed down the recovery of the region considerably after the disaster. Furthermore, the negative effects on tourism, contributed to slowing down the recovery of the country as a whole[9].

In a globalised world where industries and businesses are interconnected across the globe, it is very likely that the impact of such major disasters does not remain restricted to local and national industries, infrastructures, and local communities, but that the effects can spread quickly to other parts of the world and interrupt business processes, supply chains, and resources with long-term effects[9]. Obtaining an overview on locations potentially threatened by major flooding within a time span that allows taking precautionary measures at corporate level is therefore not only important for those countries directly exposed to the risk of being flooded, and international aid organisations but all businesses and industries which may suffer from indirect consequences.

2.2. Trans-national river basins – more vulnerable than non-shared basins?

In a comprehensive analysis of floods statistics based on the EM-DAT and Dartmouth Flood Observatory databases for the years 1985 to 2005, Bakker (2009) has shown that 75% of countries affected by riverine flooding share this event with other countries, and that flooding in trans-national river basins globally account for about 30% of the casualties and almost 60% of all people affected. In particular, Bakker showed that "*Asia and Africa have seen the most trans-boundary floods, which resulted in the largest number of affected people. North America experienced the fewest number of trans-boundary floods and had the lowest scores for all three variables. Europe had the second highest quantity of trans-boundary floods, but the second lowest number of casualties"* (Bakker, 2009, p279).

One of the reasons may be that flood preparedness and prevention actions are rarely dealt with in terms of natural boundaries, i.e. river basin scale, but on administrative boundaries such as country, regional authorities, etc. However, floods are produced through processes taking place upstream, and measures introduced take effect downstream. It is therefore important that the entire river basin is considered when planning "hard flood prevention measures" such as reservoirs, retention areas, polders, dykes, or "soft flood adaptation measures" such as forecasting systems. Only if all information from upstream is included, crisis management and planning of aid can be done effectively and deployed where it is needed most.

2.3. What is the objective of this report?

[8] http://www.preventionweb.net/english/hyogo/gar/2013/en/home/GAR_2013/GAR_2013_2.html
[9] http://www.thaiwater.net/web/index.php/ourworks2554/379-2011flood-summary.html

The objective of this report is first to illustrate at the example of Europe which policy steps can be put in place to deal with flooding in a holistic way on basin-level. Second, it will be illustrated how the introduction of EU-wide policies as well as the development of an operational pan-European flood awareness system in addition to existing national systems has provided a framework for dealing with trans-national river basins and flooding in a more comprehensive way than would be possible on national level only. Improved coordination of aid on EU-level, establishment of dialogue amongst the national hydrological services, and increased preparedness on EU, national, and regional level has been the result with a potential of significantly reducing the monetary cost of damages on the long term. Third, with the illustration of the pan-European policies and systems, it is illustrated how a cascade of continental, national, and local flood monitoring and forecasting could be established to fill existing data and information gaps, and to contribute to faster and more efficient aid response for major flood disasters worldwide. An example for other continental systems is illustrated for Africa which is repeatedly affected by severe trans-national flood events (Bakker, 2009), but where gaps in national forecasting systems exist (Thiemig et al., 2011).

With flooding being a global issue, effective flood risk management may require not only continental but also global solutions which can be developed most effectively in partnerships allowing to work on different issues related to flood hazard, risk, and management across borders. The Global Flood Partnership has been specifically launched to close this gap and to bring science effectively into policy making (De Groeve et al., 2015).

3. Dealing with floods in a holistic way from a policy point of view

In order to protect our citizens, the environment, and ecosystems from any kind of adverse effects resulting from natural disasters, appropriate disaster risk reduction policies must be in place. Following the devastating floods affecting Europe in the 90's in the river basins of the Rhine (1993, 1995), the Oder (1997), and in particularly the Elbe and Danube (2002), Europe recognised the need for addressing floods - and natural disasters in general - in a comprehensive way (Figure) along the recognised phases of the disaster management cycle: prevention, preparedness, response, and recovery. Different policies were put in place to address the different phases. In 2009, the European Commission adopted a Communication on a *Community approach on the prevention of natural and man-made disasters (COM(2009)82)* proposing to reduce the impacts of disasters in general through appropriate disaster prevention measures.

In the following, the most relevant EU policies with regard to flood risk management are listed. The list may not be exhaustive and other sectorial policies may also be relevant.

3.1. Flood Prevention:

- *Directive 2007/60/EC*[10], the so called *Floods Directive* deals with the assessment and management of flood risk in the EU Member States. It foresees that the Member States assess both inland waters and coastal flood risk, map flood extent, assets, and humans at risk in these areas, and prepare full flood risk management plans including adequate and coordinated measures to reduce this flood risk. The flood risk management plans are to take into account long term drivers such as climate change and land use changes. In particular, EU Member States are requested to coordinate their flood risk management practices in shared river basins and not undertake measures that would increase the flood risk in neighboring countries. Actions under the *Floods Directive* are to be coordinated with the *Water framework directive (DIR 2000/60)*[11].
- The *EU Strategy on adaptation to climate change (COM (2013) 216)*[12] aims at making Europe more climate-resilient and enhance the preparedness and capacity of all governance levels to respond to the impacts of climate change. The keywords for adaptation actions include mainstreaming of climate change (mitigation and adaptation) into EU sector policies and funds. In particular, it promotes that climate change adaptation actions must be strongly coordinated with disaster risk management policies.
- *EU risk assessment guidelines (SEC(2010) 1626 final*[13]*)*, published in 2010, are a follow up of the communication on the Internal security strategy COM(2009)82 which addresses the need for an integrated approach between security and other policies.

[10] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32007L0060&from=EN
[11] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060
[12] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0216:FIN:EN:PDF
[13] http://ec.europa.eu/echo/files/about/COMM_PDF_SEC_2010_1626_F_staff_working_document_en.pdf

3.2. Flood Preparedness

- *The Communication on a solidarity based initiative (COM2002/481)*[14] was the EC's response to the Elbe and Danube flooding in 2002 launching the development of a pan-European early warning system for floods. Following the communication, the Joint Research Centre, in close collaboration with the Member States, started developing the European Flood Awareness System[15].
- *The Floods Directive (DIR 2007/60/EC)* specifically promotes flood forecasting and early warning systems as preparedness action to be integrated in the flood risk management plans.
- Decision (DEC 1313/2013)[16] on a Union Civil Protection Mechanism states that the Commission *"contributes to the development and better integration of transnational detection and early warning and alert systems of European interest in order to enable a rapid response, and to promote the inter-linkage between national early warning and alert systems, and their linkage to the ERCC and the CECIS. Those systems shall take into account and build upon existing and future information, monitoring and detection sources and systems".* Eligible prevention and preparedness actions *"contribute to the development of transnational detection, early warning and alert systems of European interest, in order to enable a rapid response as well as to promote the inter-linkage between national early warning and alert systems and their linkage to the ERCC and the CECIS".* And finally, the decision states that *"by contributing to the further development and better integration of transnational detection and early warning and alert systems of European interest, the Union should assist Member States in minimising the lead time to respond to disasters and to alert Union citizens."*
- Regulation 377/2014[17] has brought the Copernicus Programme from an initial operations phase (REG 911//2010, GIO[18]) to a full operational phase. The regulation enforces *emergency management and security* as one of the pillars of Copernicus. The role of the service is "*to provide information for emergency response in relation to different types of disasters, […] as well as the prevention, preparedness, response and recovery activities"*. In fact, the Emergency Management Service was the first Copernicus service becoming operational under GIO in 2012 with the European Flood Awareness System (EFAS). EFAS has been developed by the European Commission's Joint Research Centre with co-funding from DG ECHO, DG GROW[19], and the European Parliament.

---

[14] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2002:0481:FIN:EN:PDF

[15] Previous "European Flood Alert System". The name was changed after francophone members of the GMES user committee voiced concerns that the word "alert" was too close to the French terminology D"alerte" which is issued as official warning of the national civil protection.

[16] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1313&from=EN

[17] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0377&from=EN

[18] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010R0911&from=EN

[19] DG ECHO was previously DG ENV and DG GROW previously DG ENTERPRISE

3.3. Flood Response

- Decision (DEC 1313/2013)[20] on a Union Civil Protection Mechanism states that coordinated response is ensured by "*a Union structure consisting of an Emergency Response Coordination Centre (ERCC), a European Emergency Response Capacity (EERC) in the form of a voluntary pool of pre-committed capacities from the Member States, trained experts, a Common Emergency Communication and Information System (CECIS) managed by the Commission and contact points in the Member States*." The development of transnational detection, early warning and alert systems of European interest are to be developed in order to "*enable a rapid response, and to promote the inter-linkage between national early warning and alert systems, and their linkage to the ERCC and the CECIS*."
- The COPERNICUS Emergency Management Service (see regulation 377/2014)[21] provides decision makers involved in the management of natural and human induced disasters with geospatial information derived from satellite remote sensing and completed by available in situ or open data sources.

3.4. Flood Recovery

- As a direct response to the 2002 flooding in Elbe and Danube, the concept of an EU Solidarity Fund (EUSF) was adopted in 2002[22] (REG 2012/2002) and revised again in 2014[23] to financially support countries which have suffered from major disasters. The Solidarity fund provides the European Union with an instrument to *"show solidarity, send a clear political signal and provide genuine assistance to citizens affected by major natural disasters that have serious repercussions on economic and social development."* From 2002 to 2014, the EUSF has been activated for more than 60 disasters including floods, forest fires, earthquakes, storms and droughts. 24 different European countries have been supported so far for an amount of over 3.7 billion EUR[24].

The different policies and mechanisms should not be seen as stand-alone applications as they often interact. For example, the European Flood Awareness System (EFAS) whose prime use is to strengthen the preparedness component of the EU Civil Protection mechanism also provides the modelling framework for simulating the effects and impacts of climate change on floods in Europe. It further enables the JRC to provide the ERCC with real-time information as well as scientific and analytical capacity during major flood crisis. It finally also allows the JRC to assess EU solidarity fund applications for consistency. Thus, a system such as EFAS, which has been developed primarily to strengthen the preparedness phase, has become an important instrument also for the other phases of the disaster management cycle as is illustrated in Figure .

[20] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D1313&from=EN
[21] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0377&from=EN
[22] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:311:0003:0008:EN:PDF
[23] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014R0661&from=EN
[24] http://ec.europa.eu/regional_policy/thefunds/solidarity/index_en.cfm#3

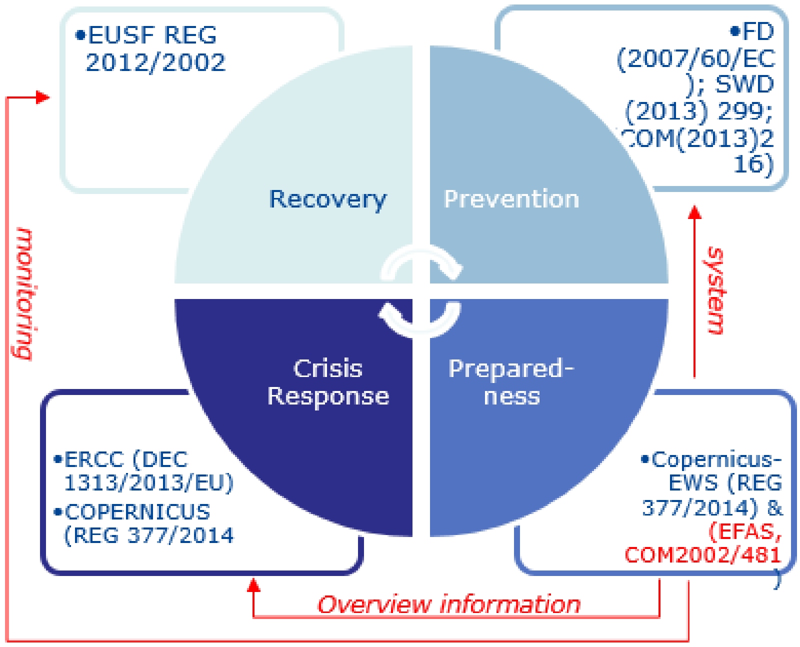


Figure 4: EU policies in support to effective flood risk management. Text and arrows in red indicate how the European Flood Awareness System, a preparedness tool, also contributes to the other different phases of the disaster management cycle.

In summary, in addition to national policies, over the past decade the EU has put in place important policies which contribute to improved disaster risk management throughout all steps of the management cycle including prevention, preparedness, crisis management, and recovery phase.

4. The European Flood Awareness Systems (EFAS)

4.1. State of the art, data and technology

Flood forecasting systems are a key element of effective flood preparedness strategies and can provide hydrological services, civil protection authorities and the public with useful information on upcoming events – provided that the information is sufficiently informative and accurate to take decisions/ action. A cascading information flow providing decision-makers with long-, medium- and short-term flood forecast information with increasing accuracy can contribute to improved planning and decision making for putting cost-effective preparedness measures into action at different levels and points in time. Both communication and preparedness measures need to be adapted to the lead time and the uncertainty. Monthly forecasts may result in increased attention in the forecasting centres only, 10-15 day forecasts in discussing scenarios, 5-8 days forecasts of verifying that local systems work, work schedules are adjusted, contingencies checked. Shorter term forecasts may finally result in discussion with civil protection and/or information of the public.

Since rainfall is the main driver for flooding, this also means that flood forecasting depends to a large degree on the accuracy of the meteorological forecasts. These have improved continuously in the past few years due to satellite and remote sensing technologies collecting observational data at very high spatial and temporal resolutions, both over land surfaces and oceans, which then can be assimilated into modern weather forecasting models. Nevertheless, the prediction of precipitation remains one of the biggest challenges. It has been a major achievement of science in the recent years that across different communities – scientists, decision makers, and policy makers – it has now been acknowledged that uncertainty in weather and flood forecasting exists and must not be ignored but quantified for better decision making[25,26]. By doing this, decision makers can be represented with a best guess forecast and the associated uncertainties. This is very useful since it avoids false "securities" and provides better scenarios of what might happen. Fortunately, as the events draw nearer the uncertainties greatly reduce allowing decision makers to refine decisions.

Uncertainties in weather and subsequent flood predictions can be quantified with so-called ensembles[27]. The use of ensembles has been internationally fostered by initiatives such as "The Hydrologic Ensemble Prediction Experiment" (HEPEX[28]), created with the aim to investigate how best to produce, communicate, and use hydrologic ensemble forecasts in hydrological short-, medium- und long-term prediction of hydrological processes[29]. Although the scientific community has clearly demonstrated the advantages of ensemble predictions over single, deterministic forecasts, the use of ensembles in operational flood forecasting is only slowly developing. For shorter lead-times when the uncertainties are smaller, many services still prefer relying on single deterministic forecasts. Other reasons for the slow transition from deterministic to ensemble forecasts could be computational and data availability constraints, lack of understanding and insufficient training of staff.

[25] Cloke, H.L., Pappenberger, F., 2009. Ensemble flood forecasting: A review. Journal of Hydrology, 375(3-4): 613-626
[26] www.hepex.org
[27] A number of model realisations which all provide equally possible predictions
[28] www.hepex.org
[29] Thielen, et al. 2008

4.2. *Effective transnational flood forecasting for EU and National services*

EFAS has been designed to close the gap of only partially existing probabilistic forecasting by providing Europe-wide forecasting information with lead times up to 10 days. Such extended lead times are particularly important for transnational river basins where coordination between different national authorities is needed, and therefore communication pathways may be longer than for national events (Bakker, 2006). The aim of the European system is therefore, first, to provide the EU's Emergency Response Coordination Centre (ERCC) with a unique and coherent overview on ongoing and forecasted floods across Europe, and second, to provide added value, basin-wide information to national hydrological services with the capacity to complement the national and local flood early warning systems.

EFAS development started in 2003 in close collaboration first with the national hydrological services and later with the European civil protection. In 2010, EFAS provided the ERCC[30,31] for the first time with an early warning for the Central European floods affecting in particular large parts of Poland. Having been alerted by EFAS, the ERCC was able to prepare for the event and deploy aid faster than would have been the case otherwise. Since 2010, EFAS has become a key tool for the ERCC with regard to floods in Europe and contributes since to improved preparedness for EU aid interventions under the Civil Protection Mechanism. It has been transferred to operations under the umbrella of the COPERNICUS Emergency Management Service in 2012.

EFAS is described in detail in Thielen et al., (2009) and Bartholmes et al., (2009), and its skill and performance documented in publications and bulletins[32]. Here the focus is to illustrate how EFAS has been inserted as added value system into the landscape of European operational hydrological and civil protection services.

The added value of EFAS can be summarised under four categories:

1. Increasing warning time: While national systems typically run short-term forecasts with 3-5 days lead times based on single weather forecast inputs, EFAS runs medium-range forecasts with 10-15 days lead times. Such long lead times can only be achieved by using multiple weather forecast inputs, obtaining probabilistic outputs. In other words, EFAS provides an estimate of the probability that flood events occur. The performance of the system will be dependent on the size and types of catchments. For very small, fast-responding catchments, it is unlikely that long lead times can be achieved, while for larger scale river basins, this might be easily achieved.

2. Providing complementary comparison data: Due to limited computing resources or other reasons, national services often use single weather forecast inputs which are often based on the national weather forecasts, e.g. in France the input data from Meteo France is used, in the UK from the UK Meteorological Office, and in Germany from the German Weather Service, etc. The dependence on a single weather forecast input can be limiting when, for example, a particular event is not captured correctly. In this case also the flood forecasting systems will not capture the event. EFAS uses multiple weather forecasts instead. In total, more than 130 weather forecasts are processed on a daily basis using inputs from three weather services, and at different spatial and temporal resolutions. Thus, through EFAS, the

[30] http://en.wikipedia.org/wiki/2010_Central_European_floods
[31] At the time still called MIC, the Monitoring and Information Centre
[32] See list on www.efas.eu

national hydrological services can assess if their forecasts are consistent with forecasts using different weather forecasts.

3. Providing information on river basin level: Except for the river Rhine, where an integrated flood forecasting system exists for all countries, in Europe flood forecasting is performed in administrative rather than river basin boundaries. Although bi-lateral exchanges exist between upstream and downstream countries, often authorities do not have the full overview of the flood situation upstream. This is particularly true for the river Danube which is shared between 19 countries. Through EFAS, the national authorities can monitor what is simulated and forecast for upstream areas.

4. Filling the gaps: In some countries national flood early warning systems do not exist, and then EFAS is the only source of early warning information in the medium-range covering also the short range. Furthermore, communication gaps between national authorities have been filled through an active partner network with annual meetings. To date more than 40 partner organisations have subscribed to EFAS. All partners are invited to annual meeting to discuss the development steps of the system, to define methodologies, colour codes, warning messages, etc. and to review new products. In return, the partner network provides EFAS with data and feedback.

4.3. EFAS information flow and interaction with Member State organisations

The schematic set-up of EFAS and its interactions with the Member State organisations is illustrated in Figure 5. EFAS consists of four centres which are outsourced to Member States, where they are operated by consortia of national authorities and private enterprises. Two centres are responsible for the collection of data, and therefore interact with the meteorological and hydrological data providers. The data are then passed on to the computational centre which calculates the forecasts. Finally, the outcome is then analysed by the EFAS dissemination centre which is run by operational hydrological services with experiences in communicating flood forecasting information to end users and which collect the feedback from the hydrological services.

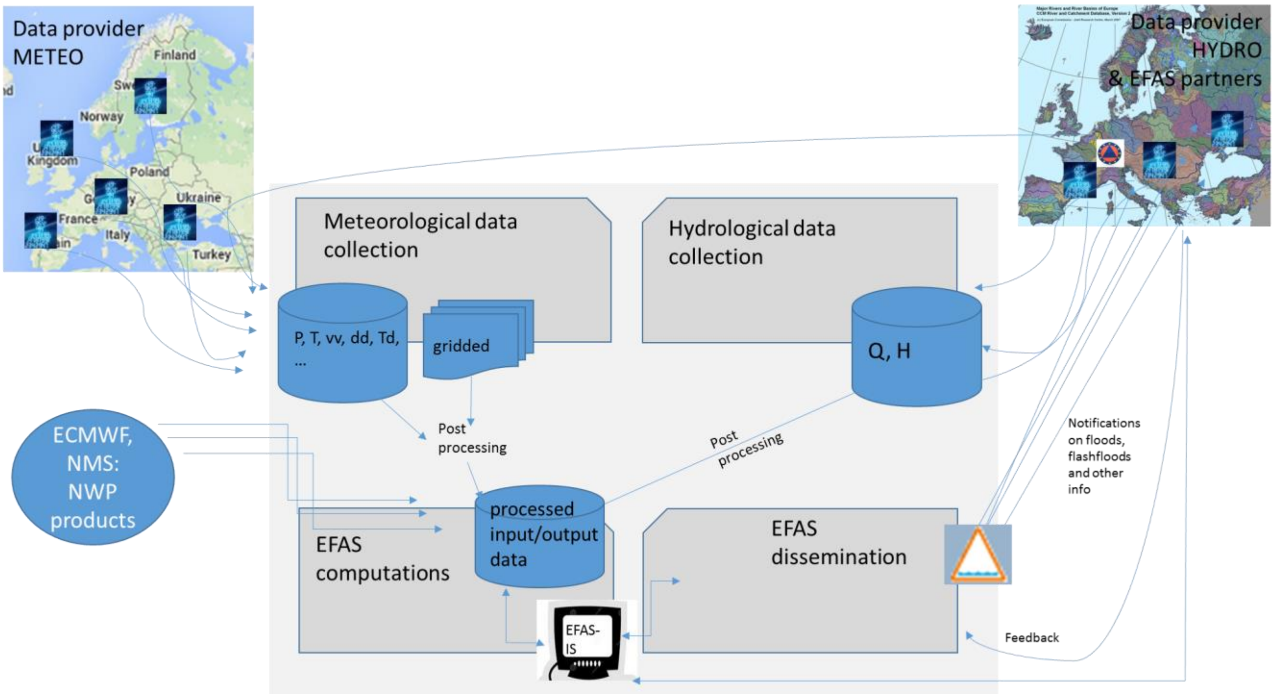


Figure 5: Schematic overview of the EFAS set-up and information flow between EFAS and the different networks of hydrological services and data providers of hydrological and meteorological data.

As operational service under the COPERNICUS Emergency Management Service (EMS), it must be ensured that EFAS does not interfere with national crisis management procedures at any time and that the national services remain the single authoritative voice[33] on weather and related disaster warnings within their respective countries. Thus, the information flow from EFAS to the Member States organisation and the European Commission services must be clear (Figure : EFAS sends information about upcoming flood events to those National Hydrological Services (NHS) which are members of the EFAS partner network, the EU Civil Protection Emergency Response Coordination Centre (ERCC), and the COPERNICUS rush mode mapping service. This is done both through the web platform which is accessible to all EFAS partners on a 24/7 basis (passive information flow) and through dedicated EFAS notifications which follow agreed procedures (active information flow).

[33] https://www.wmo.int/pages/prog/dra/eguides/index.php/en/5-functions/5-5-warnings-systems

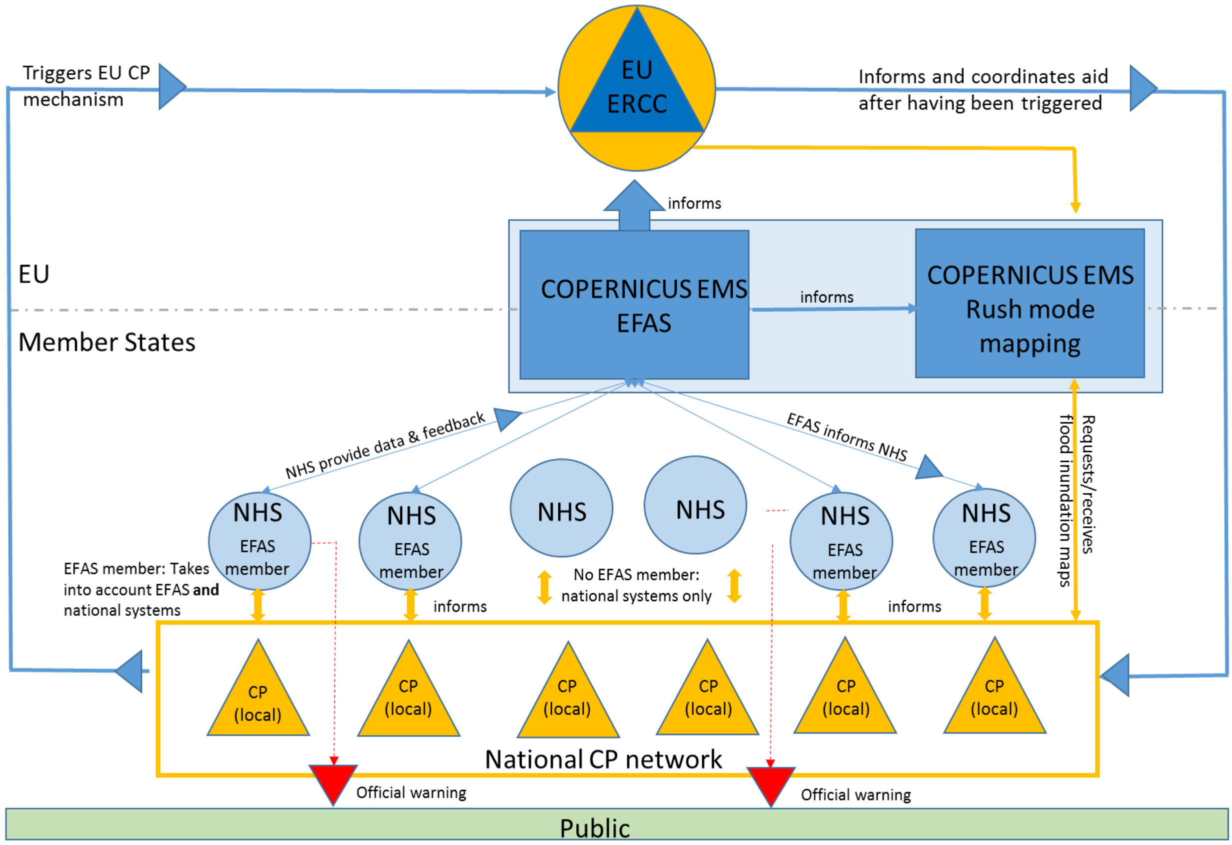


Figure 6: Schematic view of role of COPERNICUS Emergency Management Services (EMS) in relation to National services and the public

In the following a brief description of the role of the different actors in Figure is provided:

National Hydrological Services (NHS): EFAS provides real-time information only to a restricted partner network[34] which consists of i) NHS mandated to provide their country with flood forecasting information, ii) associated partners proposed by the NHS, and iii) the European Commission services, mostly the ERCC and COPERNICUS Emergency Management Service. Information is only distributed to those NHS which are member of the EFAS partner network and which have received training on the system. By restricting access to EFAS results in such a way, the single official voice principle for issuing warnings as requested by the Members of the World Meteorological Organisations[35] is respected. It further ensures that NHS not being informed and trained on EFAS products do not receive information that they may find confusing and difficult to interpret. NHS receive the EFAS information and use it in addition to their own national or local services. The NHS decide to inform their local, regional, or national civil protection based on the products they chose and according to their national protocols. In return, NHS provide EFAS with

[34] See www.efas.eu for list of EFAS partners. Currently the network has about 40 partners

[35] REVIEW OF THE RELEVANT DECISIONS OF CBS-EXT.(10) SIXTEENTH WORLD METEOROLOGICAL CONGRESS (CG-XVI), AND THE CBS/OPAG-PWS IMPLEMENTATION / COORDINATION (ICT/PWS) MEETING; CBS/OPAG-PWS/ET-SPI/Doc. 3, REV. 1 ; (27.VII.2012), https://www.wmo.int/pages/prog/amp/pwsp/documents/Doc_3_ET_SPI_REV1.doc

data and feedback on the system to improve its performance. Since most river basins are part of the EFAS network, all partners can discuss results based on EFAS without restriction and having reference information compared to their own local information.

European Commission services (ERCC and Copernicus EMS mapping): EFAS provides daily summaries of the ongoing and forecasted flood situation to the ERCC. Furthermore, the ERCC is in copy when flood alerts and watches are distributed to the NHS. Furthermore, EFAS information is distributed to the COPERNICUS EMS mapping activity which can be triggered by both the national authorities and the ERCC to obtain flood extent maps. The JRC is currently investigating how EFAS (or national flood forecasting information) can be used more systematically to trigger the COPERNICUS EMS mapping service to direct satellites towards the area of flooding before the event takes place, so that the maps can be available from the onset of the floods.

Civil Protection (CP): Local or national civil protection authorities are warned and kept informed about upcoming flood events through their local or National Hydrological Services within their own country. This ensures that they have the best information possible to act within their country. In case a disaster becomes too much for a country to cope with, the national civil protection services can trigger the EU Civil Protection mechanism, and request aid from other Member States through the ERCC. In order for Member States to be prepared for such requests, the ERCC shares high-level summary information of EFAS also with the National focal points for Civil Protection in the EU to raise their awareness of potentially critical flood events coming up in other countries.

Public: Official warnings or information on upcoming or ongoing flood events to the public is always informed provided by official national (or local) authorities. In some countries the NHS issue warnings to the public but in many countries it is the civil protection authorities which then decide to issue warnings to the public. Neither ERCC nor EFAS inform the public. The flood inundation maps provided by COPERNICUS EMS rush mode mapping service is public information - but then the event is already ongoing and the mapping information is not in conflict with disaster management procedures.

For the transfer of the experimental pan-European flood forecasting prototype to an operational system a strategy for secured financing and integration of the system into existing national structures as well as a wider Disaster Risk Management framework is crucial. For EFAS this has been achieved through the COPERNICUS programme.

In summary, the COPERNICUS emergency management service (EMS) includes pan-European early warning and mapping services providing unique overview information on floods within Europe to the European Civil Protection for improved aid management as well as providing added value information to the national services for improved flood risk management. The EU services respect the single voice warning principle and have clear entry points to national services for their information flow and therefore do not interfere with legal and national obligations. Formalised partner networks with the hydrological, civil protection, and COPERNICUS communities with clear rules are key to ensure the uptake of end-user needs.

4.4. The 2014 Balkan flood event - An example of EU services working hand in hand with national services

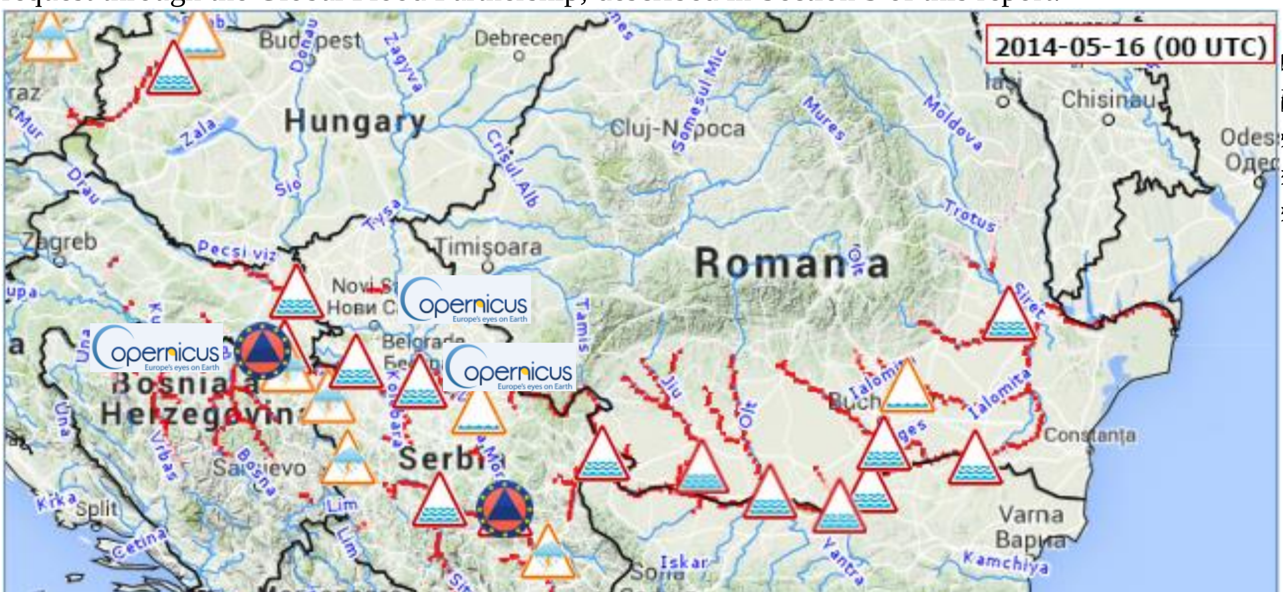
After weeks of persistent wet conditions, exceptionally intense rainfalls from 13 May 2014 onwards led to disastrous and widespread flooding in the Balkan Peninsula in south-eastern Europe, in particular Bosnia-Herzegovina and Serbia, as well as in other countries including southern Poland, Slovakia, and the Czech Republic. The events in Bosnia-Herzegovina and Serbia were estimated to be the worst in more than 100 years. 79 casualties were reported in Bosnia-Herzegovina, Serbia and Croatia, about 140,000 people displaced and an estimated 2.6 million people directly or indirectly affected[36]. Both Serbia and Bosnia-Herzegovina activated the EU Community Civil Protection Mechanism on 15 and 17 May respectively for assistance in their battle against the flooding.

EFAS started predicting increasing probabilities for flooding in the Balkan region on the 7th May, in particular in the Sava River, and the first flood peak was predicted on the 15-16th May. However, the forecasts also exhibited a high degree of uncertainty. The Serbian hydrological service and ERCC were informed accordingly with a flood watch and asked to follow the situation on the EFAS web-portal. Since Bosnia-Herzegovina is not an EFAS partner, the authorities could not be directly informed. The ERCC was updated thereafter on a daily basis with EFAS information as well as a summary of what was reported on national websites. For Bosnia-Herzegovina national information could not be found and therefore the EFAS represented the only source of information for the ERCC and possibly also for neighbouring countries.

After the first notifications of 7th May an official EFAS flood alert was issued on the 11th May. From 11-18 May, a total of 15 flood alerts and 8 flood watches were distributed to the National hydrological services that are member of the EFAS network. In addition, the JRC´s expert teams provided the ERCC with in-depth information and daily situation reports and maps, integrating EFAS information, scientific data with impact information into products tailored for civil protection, thus contributing to coordinated actions to mitigate further potential damage in the countries and across borders.

Furthermore, the COPERNICUS Emergency Mapping Service (EMS) was able to prepare activations based on EFAS. EMS mapping was triggered by the ERCC on 16 May, first for Bosnia-Herzegovina and then for Serbia, followed by a request from Croatia the next day. The first post-disaster map with flood delineation was delivered on 18 May. Reference maps and flood delineation maps were delivered during subsequent days and they are available at http://emergency.copernicus.eu.

Figure illustrates the different EU mechanism which worked hand in hand during the preparedness and crisis response phase. The red (orange) triangles illustrate EFAS alerts (watches) which were sent to the national hydrological services which are members of EFAS. Bosnia-Herzegovina is not yet member of the EFAS partner network and therefore did not receive the early warning information. The ERCC was activated for Bosnia-Herzegovina and Serbia (civil protection symbol with blue circle and triangle). Also the Copernicus rapid mapping was activated for those countries. EFAS informed the national services, the ERCC and the Copernicus emergency management mapping service. Furthermore, information was also shared with the World Food Programme on request through the Global Flood Partnership, described in Section 5 of this report.



4.5. An estimation of the monetary benefit of flood early warning in Europe

In Europe, most countries have national or local flood forecasting systems in place. Often different hydrological models with different strengths and capabilities are used for different river basins[37]. Flood forecasting systems can be based on observations, e.g. river levels, observed rainfalls, and weather forecasts. Many systems are still based on observations or single (deterministic) weather forecasts but there is also an increasing number of services using multiple (ensemble) weather forecasts to drive the flood forecasting systems[38]. Although strongly promoted by the Floods Directive, a basin-wide flood forecasting system exists only in a few river basins in Europe, e.g. for the river Rhine[39, 40].

Exactly how much loss and damage costs can be avoided through early warning is important information for decision makers and donors, but unfortunately it is difficult to quantify. How to assess a reduction in damage if the damage without early warning is not known? How to assess the benefit of a pan-European early flood warning system in addition to a national system based on short-term weather forecast? Some studies exist, e.g. the International Commission for the Protection of the Rhine has estimated that flood warnings can help businesses avoid 50-75% of flood losses (International Commission For The Protection Of the Rhine, 2002).

However, in order to estimate the monetary benefit of avoided damages of early warning systems across Europe correctly, detailed case studies of damage would be required for the different flood events, the different forecasting systems and models involved, the response in each country and many other sources of information. Such a study would require considerable resources and time, if feasible at all. Instead, as a first guess, the potential benefit has been assessed using the European Flood Awareness System (EFAS) as a reference to calculate the potential monetary benefit of avoided damages through early flood warnings in Europe (Pappenberger et al., 2015). One of the advantages of using EFAS is that the results are comparable across Europe. However, the drawback is that results remain indicative, and the study is a theoretical exercise[41]. In order to execute the study, the estimates of i) the cost of early warning systems including development, set-up and operational running, ii) flood damage data and iii) damage reduction through early warning are required.

i) Cost of early warning systems:

For this study, the costs of developing and running EFAS have been used as a basis. The development of EFAS over a period of 10 years including costs for data collection on EU scale, IT, development of the systems, establishing and maintaining a partner network, as well as associated operational and fundamental research to achieve a state of the art system has been estimated to 20 million Euro over a time period of 10 years. The operational running cost of the system including operational development as in 2012 are estimated as 1.8 million Euro. These values have been extrapolated over the next 20 years taking into account a discount factor, amongst others including

---

[37] For more information on national hydrological services and their flood forecasting systems see http://floods.jrc.ec.europa.eu/national-water-level-information.html

[38] Cloke, H. L.; Pappenberger, F. Ensemble flood forecasting: A review. In: JOURNAL OF HYDROLOGY, Vol. 375, No. 3-4, p. 613-626

[39] See http://www.iksr.org/

[40] Renner M, M.G.F. Werner, S. Rademacher, E. Sprokkereef .: 2009, Verification of ensemble flow forecasts for the River Rhine, Journal of Hydrology, 376

[41] Pappenberger F., H.L. Cloke, F. Wetterhall, D. J. Parker, D. Richardson, J. Thielen., 2014, The Financial Benefit of Early Flood Warnings in Europe, submitted to ENVIRONMENTAL SCIENCE & POLICY

inflation rate, which has been assumed to be 5%. On this basis, over a time of 20 years, the *corrected* cost of EFAS has been extrapolated to amount to approximately 63,500,000 Euro.

ii) Flood damage data

One of the difficulties for executing such a study is to obtain detailed data on flood damage which are often confidential and not released by the authorities. For this study, data from the EM-DAT[42] emergency events database has been used, and where applicable, complemented with public information from the European Solidarity fund applications[43]. In addition, the flood damage map of Barredo. (2009), assuming that flood defence measures are not in place, has been used. The map has been modified by aggregating to river catchment scale and by rescaling the potential damage to annual average damages based on 5 year return periods (Figure).

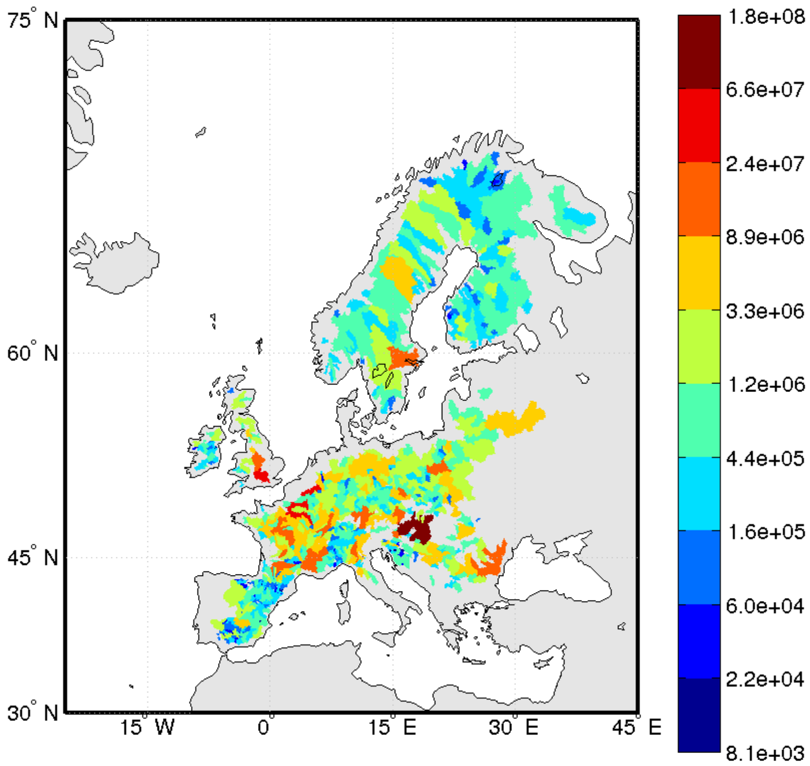


Figure 8: Potential Flood Damage aggregated on EFAS sub catchments in Europe and standardised on 2012 in Euro [based on Barredo, 2009].

From the EM-DAT database the number of flood events, and the financial costs have been extracted for Europe. The costs have been adjusted using average inflation in Europe to 2012 costs and the US dollars converted into Euro with an exchange rate of 0.72.

iii) Damage reduction through early warning

First, to estimate the financial benefit of early warning, the skill in the forecasting system needs to be assessed – if there is no skill, there is no reduction as the response would be random whereas a perfect system would result in maximum reduction. The estimate of EFAS skill has been based on

[42] www.emdat.be/database

[43] http://ec.europa.eu/regional_policy/thefunds/doc/interventions_since_2002.pdf.

EFAS hits, false alarms and misses, which were then combined with Barredo's (2009) modified flood damage map for Europe (Figure). Then the EM-DAT database for the period 2000-2013 has been used and combined with the average warning performance from a 2-year reforecast study with EFAS for entire Europe.

Second, an assumption needs to be made about actions following the early warning. Here it has been assumed that each flood early warning has resulted in preparedness actions (of some kind) both in the national services and at the EU level. The benefit of such actions have been estimated based on literature and case studies and then compared with the system installation and running costs. The difference between cost and benefit is calculated to be the relative benefit of the EFAS as the return on 1 Euro investment in the EFAS system. These estimates have been modified using different standards of protection, and tested for other sensitivity factors to account for the uncertainties in the methodology to provide an envelope of likely benefit values.

Parker et al (2008, 2007a, b) have estimated damage reduction factors for different actions in response to flood warnings. By far the largest reduction can be obtained by operating (flexible) flood defences according to the flood warnings (~30%). Damages are reduced to a much lower extent by moving and evacuating property content (~6%). Actions such as water course maintenance of community level defences amount to less than 1%.

A sensitivity analysis has shown that in the calculation of cost-benefit analysis the damage reduction factor introduces the largest uncertainty and the estimation of the actual damage introduces the second largest variation in the results followed by the potential impact of future improvements in the early warning systems.

Results of the study are summarised in Table 2 as a function of the level of flood protection where two extreme assumptions for Europe are presented – no flood protection at all and all rivers are protected against a 100 year flood. For European rivers the flood protection level will be somewhere in between these two envelops. Further 19 scenarios with different early warning performances, discount rates and damage data have been calculated. Of these 19 scenarios, the result of the most conservative estimation as well as the medium best guess estimation are included in Table 2 which provides the ratio of damage reduction for each Euro invested in early warning as well as the overall financial benefit based on the development and running cost of EFAS over a time span of 20 years (see section on *Cost of early warning system* above).

Table 2 Cost-benefit of flood early warning as a function of different protection scenarios.

Assumption scenario	**No flood protection**	**100 year flood protection**	**Conservative estimation**	**Medium best guess estimation**
Ratio benefit for 20 years	1:988	1:13	1:159	1:480
Benefit after 20 years in million Euro	62,850	830	10,115	30,540

For comparison, the EU Solidarity Fund received applications for flood related disasters from 2002 to 2013 with an estimated amount of damages of 43,500 million Euro (values not corrected for 2012), thus an average of 3,600 million Euro per year. Extrapolating this value over the next 20 years taking into account the same discount factor as for the cost estimation of EFAS, and not taking into account the effects of climate change, then this amounts to a total of about 120,000 million Euro. Thus, assuming the medium best guess scenario, about 25% of the expected damage costs could be saved through early warning.

The study has also performed a sensitivity analysis as to which factors are the most crucial ones. There is a considerable range in the estimated relative financial benefit with the damage reduction factor introducing the largest uncertainty. The estimation of the actual damage introduces the second largest variation in the results followed by the potential system improvement in the future.

Thus, flood early warning systems in Europe have the potential to reduce the costs of flood damages by about 25%, saving an estimated 30,000 million EUR over the next 20 years. It would be very interesting to identify to what extent trans-national forecasting enhances the monetary benefit in contrast to national forecasting capacities only. However, this would require detailed in depth case studies, which was beyond the scope of the study.

5. Partnerships – key for sharing knowledge on flood risk management

5.1. The EU-Africa Strategic Partnership

According to the analysis of Bakker (2009), African countries are a particularly vulnerable for severe flooding in trans-national river basins with a high number of casualties and high socio-economic impact. In fact, a comprehensive review of the status on flood forecasting and early warning systems in Africa by Thiemig et al. (2011) showed that a large number of flood risk management initiatives are ongoing and flood forecasting systems exist. For the study, more than 500 questionnaires were sent to national and international authorities and organisations dealing with flood management for Africa. Overall, 65 questionnaires were returned from 56 different institutions of which 47 were African and 9 non-African organisations representing 24 different river basins including major basins such as Nile, Congo, Niger, Orange, Zambesi, and Limpopo (Figure [44]). Governmental and non-governmental, river basin authorities and research organisations filled out the questionnaire.

Twenty-four institutions reported that they were involved in flood forecasting activities at the time of filling out the questionnaire. The study showed that most institutions work with forecasting systems based on rainfall – runoff modelling, closely followed by the statistical models and analysis *(*Thiemig et al., 2011*).* The majority of these systems addressed the short-range up to three days, four covered the forecasting range 5-14 days, and three 15 days and more. The forecasting range 8-13 days was not covered at all, although skill has been demonstrated in both weather and flood forecasts at these lead times for larger catchments and in particular when using ensemble prediction systems. Furthermore, forecasting information at this range can be crucial for reducing flood-related losses as they provide more time for preparation and decision-making (Thielen et al., 2009). Seasonal forecasting was not specifically reported.

Figure 9: River basins in Africa for which questionnaires on flood risk management were returned shown in blue. For catchments only outlined but not filled information was not provided

http://search.aol.com/aol/imageDetails?s_it=imageDetails&q=basins+of+africa&v_t=comsearch51&host=http://darrenthorpe.com/photoktsj/basins-of-africa&google.com&thumbUrl=http://t1.gstatic.com/images?q=tbn:ANd9GcSuw3nM1sCUIQVo229gwuc3LTMarhmT71eElhXd76YvopKZ0h77wjCPUJ4h adapted

The survey results show that not all countries have comprehensive flood forecasting systems in place, and that a gap exists in medium-range flood forecasting as well as trans-border forecasting systems in Africa. Thus the question arises if – similar to the development in Europe – a skillful pan-African flood awareness system could be developed and operated.

Thiemig et al. (2010, 2015) have developed a prototype of an African Flood Forecasting System (AFFS) in analogy to EFAS, producing probabilistic, medium-ranged flood forecast information at the pan-African scale with lead times up to 10–15 days in advance. While the African system has been set-up with similar components and methodologies as in EFAS there are a few differences to the European version:

a) **Hydrological model**: models designed for Europe cannot readily be transferred to African river basins. The modelling framework needed to be adapted to account for the different climate zones, soil characteristics and water management operations that alter the hydrological response in African river basins.

b) **Data availability**: While for Europe dense station networks for both meteorological and hydrological data exist and data is made available for EFAS in near real-time, this is currently not the case for Africa. Up to date, a number of national hydrological services such as the Ethiopian Ministry of Water and Energy, the GLOWA Volta Project, FAO Somalia Water and Land Information Management, the Global Runoff Data Centre (GRDC) and the South African Department of Water Affairs and Forestry (DWAF) provided the JRC with historical hydrological observations to support the development of AFFS by enabling model calibration and verification studies. The JRC has also made use of numerous satellite-based rainfall data as well as re-analysis products from various sources such as the European Centre for Medium-Range Weather Forecasts or NASA.

c) **Alert thresholds**: Alert thresholds are calculated from long-term simulations based on observed data and by applying extreme value statistics to the simulated time series. These thresholds are then applied to the hydrological forecasting ensemble. A hydrological situation is considered as potential flood situation, if a certain number of individual hydrological forecasts exceed the predefined critical thresholds. For rivers in Africa thresholds of 2, 5 and 20-years return period are used.

Figure illustrates schematically how the African Flood Forecasting System is designed. The driving weather forecasts are the global ensemble prediction system weather forecasts from the European Centre for Medium-Range Weather Forecasts (ECWMF), but any other regional or local weather forecast could be integrated. In absence of sufficient real-time weather observations, here the first 24 hour ECMWF data are used to calculate the initial conditions in case satellite data are not available, while the 15-day ECMWF-ENS drive the flood forecasting model. Using the output of the model together with the previously calculated critical thresholds, the system can provide both spatial and temporal information on the development of flooding within the forecasting range (up to 15 days).

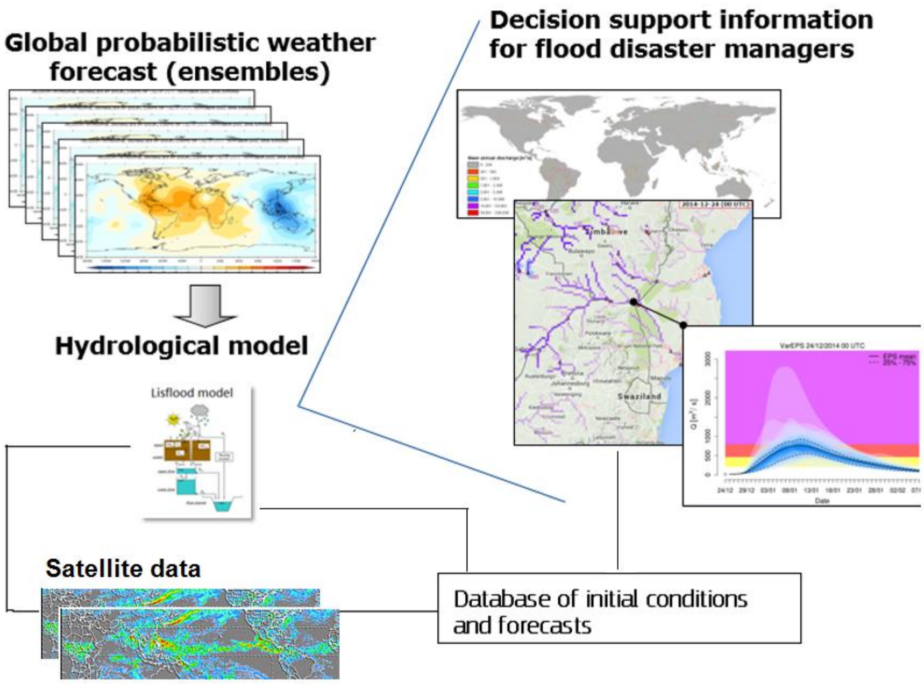


Figure 10: Schematic view of the African Flood Forecasting System

AFFS has been set-up on pan-African scale and its performance tested for the year 2003. In order to do this, a reference of reported flood events for 2003 has been created by extracting information from various disaster databases such as Dartmouth Flood Observatory, Emergency Events Database EM-DAT, NASA Earth Observatory, and ReliefWeb. From these sources, a total of 39 medium- to large scale flood events were identified. Together with information about location, time-period of these events and outline of the affected area these were compiled into a database. This reference data base was then used to compare AFFS flood signals against reported flood events to determine hit and false alarm rate as well as to present an AFFS forecast of a flood event in an ungauged basin.

For 2003, AFFS forecasted 40 flood events in Africa. Cross-comparing those against the reference data base, yield that 27 of the forecasted flood events were also reported, while 11 events that were forecasted by AFFS were not reported and 12 events that were reported were not forecasted. This results in a *Probability of Detection* of 69 %, a *False Alarm Ratio* of 29 % and a *Critical Success Index* of 54 %. Further investigations showed that the system showed particular strength in predicting riverine flood event of long duration (> 1 week) and large affected areas (> 10,000 km^2).

Figure 3 illustrates an example of a flood forecast calculated with AFFS. It shows the forecasted temporal and spatial development of a flood event in the Sabi Basin in Zimbabwe. Based on AFFS the onset of the flood event is forecasted with a lead time of 8 days for the 5^{th} of March, which coincides perfectly with information given by the Dartmouth Flood Observatory who reported flooding in the Sabi River Basin between 5^{th} and16^{th} March 2003. Also the forecasted flood magnitude agrees with the severity classification of the observed event.

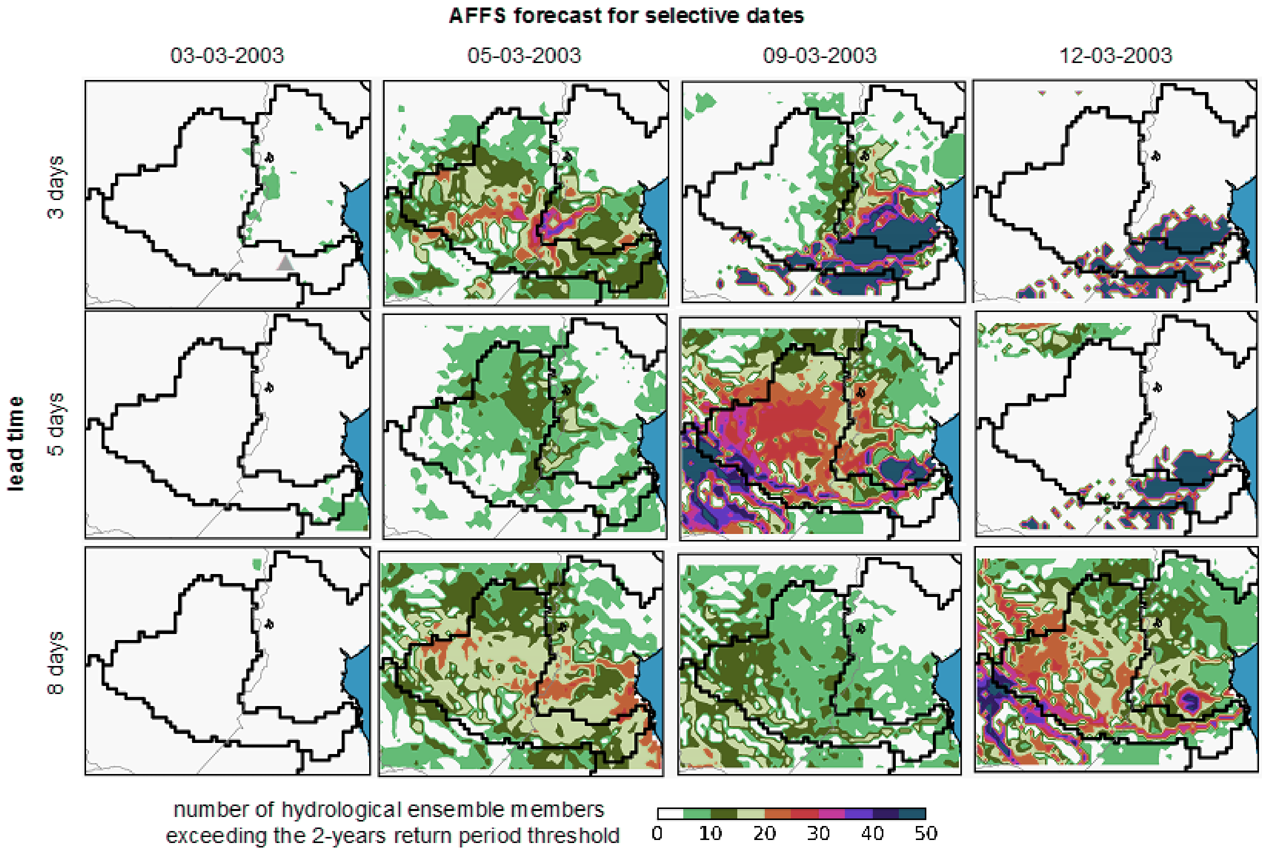


Figure 31: AFFS forecast of the flood event in the Sabi River Basin in March 2003. The different panels show the development of the exceedance of hydrological threshold over space considering 3, 5, and 8 days of lead time.

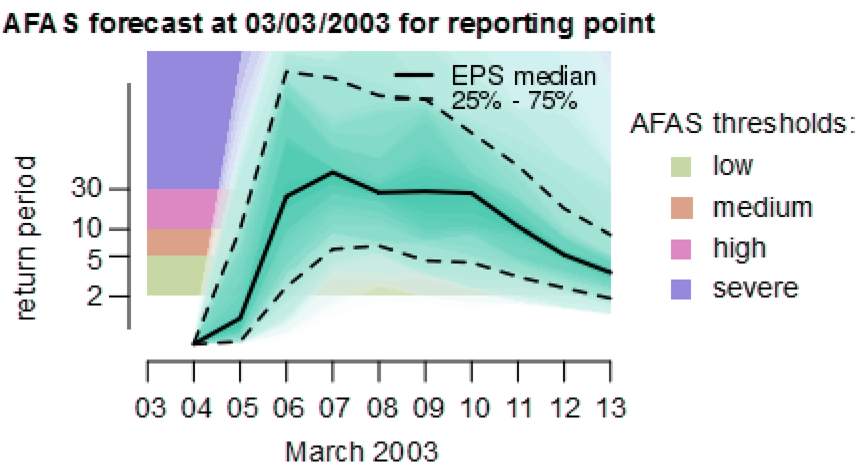


Figure 42: AFFS forecast of the flood event in the Sabi River Basin in March 2003. The quantile plot shows the temporal development of the flood forecast at a particular location (marked with a grey triangle in Figure 3).

Thus, from a technical point of view it would be feasible to operate a pan-African Flood Awareness System and to further complement its information with a flood detection system. Clearly, further improvements of the system based on more detailed observed data and local or regional weather forecasts would be needed before such a system could provide added value to the authorities already operating local flood forecasting systems.

The information from the forecasting system could be complemented with satellite based flood detection systems such as the Global Flood Detection System (GFDS). GFDS was developed and is maintained at the European Commission Joint Research Centre in collaboration with the Dartmouth Flood Observatory[45]. It uses passive microwave sensors so that cloud cover is not an obstacle, a clear advantage over optical sensors. On the basis of lack of up-to-date and near-near time availability of *in situ* measurements of river flow in many regions of the world, satellite products could be used to enhance the skill of hydrological, being complementary or an alternative of *in situ* measurements. The impact of using GFDS data for hydrological modelling have been tested for different applications such as the estimation of streamflow measurements[46], river discharge now-casting and forecasting[47], calibration of the hydrological model within GloFAS[48], and data assimilation to update simulated discharge values based on the detected satellite signal[49]. Other solutions for flood detection with higher resolution sensors exist but may not have a continuous data stream and must be tasked to have images[50].

More importantly, a framework or partnership is needed to embed the work for effective transfer of knowledge and provide African authorities with ownership for system, development, and output. The EU-Africa Strategic Partnership on “Science, Information Society and Space” for further development” is currently being discussed as a possible framework to achieve this. It would facilitate, as was seen crucial for EFAS, to build an active network of national hydrological services prepared to i) collaborate with the developer team to build a joint system and ii) to have the system transferred to one or several partner authorities after an initial development stage. Only with local knowledge and competent feedback such a system can be shaped to respond to the needs of the end-users. Furthermore, experience with EFAS has shown that services feeling part of the development of the continental system are more likely to take ownership and therefore more easily inserted continental system information into their flood warning procedures.

It is therefore to be explored if within the framework of the EU-Africa Strategic Partnership on “Science, Information Society and Space”, the GMES-Africa initiative could provide the platform for African scientists and authorities to collaborate with Europe to develop the required capacity and infrastructure for a pan-African flood early warning and detection system in the near future. A study on the monetary benefit of such a system, similar to the one described in Section 3.5, is envisaged as future research study.

[45] www.gdacs.org/flooddetection/, http://www.dartmouth.edu/~floods/GlobalFloodDetectionSystem.pdf
[46] Revilla-Romero et al. 2014
[47] Hirpa et al., 2013
[48] Revilla-Romero, et al., 2015
[49] Revilla-Romero, et al., in preparation
[50] See PUBSY JRC80255 by de Groeve et al. (2013)

5.2. Bridging between science, policy and stakeholders - the Global Flood Partnership

5.2.1. Joining forces

As illustrated at the beginning of this report, flooding is a global issue with many different facets to be dealt with on local, national, and trans-national level and across various sectors. Single authorities cannot tackle the complexity of flooding alone in sufficient detail. While there is a wealth of data, tools, and research in specific areas, effective production and sharing of knowledge is key to avoid fragmentation of knowledge. Mechanisms are needed for the increased use of knowledge in flood disaster risk management and climate change adaptation for achieving positive exchange between scientists,, policy makers and practitioners (Spiekermann et al., 2015).

Therefore the JRC initiated a *Global Flood Working Group* as a multi-disciplinary group of scientists, operational agencies and flood risk managers focused on developing efficient and effective global flood management tools that can address these challenges. The group has been established in 2011 and hosted annual meetings. The goals of the group are (1) to develop and improve global flood forecasting and monitoring systems, (2) to deploy these systems in a global flood observatory tracking floods in near real-time, (3) to build a global flood record suitable for flood risk assessment, and (4) to make these tools available to organizations and countries that need them. Following conclusions from the 2013 meeting in Maryland, Boulder[51], the Global Flood Working Group decided to create a larger framework for the initiative and launched the *Global Flood Partnership* in 2014[52]. A concept paper was established, distributed prior to the meeting and discussed during the 2014 workshop[53] (De Groeve et al., 2015).

Around 50 partners were presented during the launch event. Apart from the JRC and the Dartmouth Flood Observatory, key partners are the European Commission Humanitarian Aid and Civil Protection (DG ECHO), the World Bank, UN organisations such as the World Meteorological Organisation (WMO), the World Food Programme (WFP), and the Office for Disaster Risk Reduction (UNISDR) as well as the European Centre for Medium-Range Weather Forecast, National Weather services such as the UK Met office, and a large scientific community.

Formalising the current collaboration shall provide tangible results in the following areas:

- Global flood forecasting and monitoring systems complementary to national and regional capacities,
- global sharing of hydro-meteorological data and information,
- national and cross-border country capacity building, and
- improved flood risk management platforms and information products.

The JRC has developed two global systems which are included in the operational services of the Global Flood Partnership, the Global Flood Awareness System (GloFAS)[54] and the Global Flood Detection System (GFDS)[55]. Both systems run daily in experimental mode and are made available

---

[51] http://portal.gdacs.org/Expert-working-groups/Global-Flood-Working-Group/2013-Workshop
[52] http://portal.gdacs.org/2014-Flood-Workshop
[53] http://portal.gdacs.org/Portals/0/GFP/Concept%20Paper%20Global%20Flood%20Partnership%20v4.3.pdf
[54] http://www.hydrol-earth-syst-sci.net/17/1161/2013/hess-17-1161-2013.html
[55] http://www.dartmouth.edu/~floods/GlobalFloodDetectionSystem.pdf

within the Global Flood Partnership. However, in order to respect the one voice warning principle, GloFAS results are only made available upon registration and are shared within the Partnership during events and on request.

5.2.2. Sharing information – the Malawi case study

The benefit of the Global Flood Partnership has been demonstrated already during several flood events including the Balkan region in 2014, Malawi in January 2015 as well as in Myanmar in August 2015.

In the case of Malawi, heavy rainfalls affected parts of Mozambique and Malawi from 12-17 January 2015 with highest impact on the river discharges in the Zambezi River Basin. With serious flooding having taken place on recently and faced with further ongoing heavy rainfalls, the President of Malawi declared a State of Emergency on 13 January 2015 for 15 districts. Immediately a number of humanitarian aid organisations started acting to provide assistance to the affected population.

Initially, the heavy rains were well forecast by the numerical weather predictions (Figure 5) which coincided well with later observations. Figure 14 illustrates the corresponding GloFAS flood forecast of 10 January 2015, and the flood delineation map produced by the Copernicus emergency management mapping service of 17 January for the area of Malawi bordering with Mozambique.

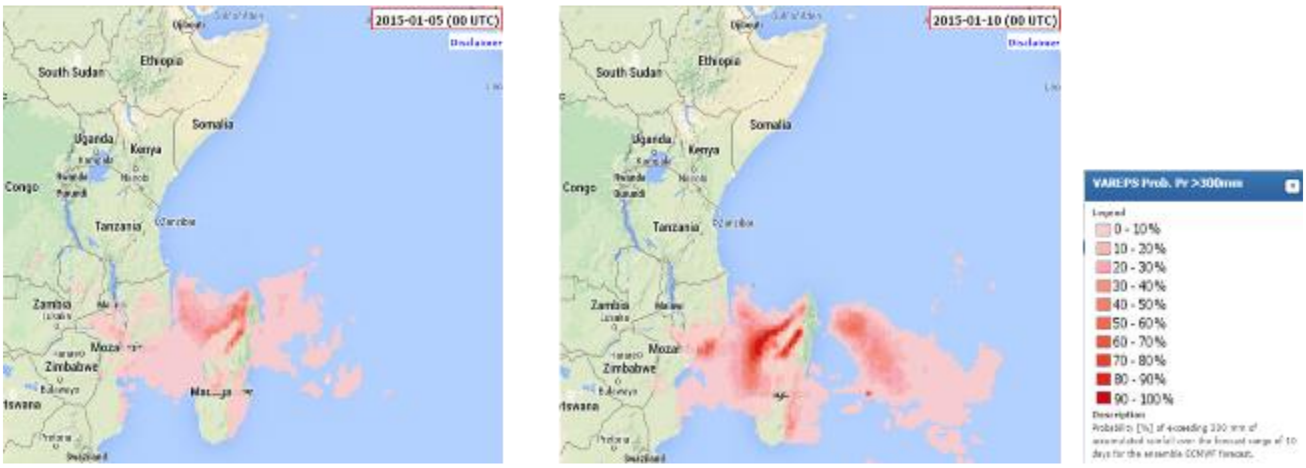


Figure 5 Probabilities of exceeding 300 mm over a 10 day forecast for the time period of 5-15 January (left) and 10-20 January 2015 (right) in Southeast Africa based on the Numerical Weather Prediction from the European Centre of Medium-Range Weather Forecast (ECMWF).

GloFAS predicted an increased probability for flooding along many river stretches in Malawi and Mozambique. However, in subsequent forecasts the predicted rainfalls shifted out of the area which resulted in flood forecasts with too low probabilities for flooding compared to the observed large spread flooding in subsequent days. Furthermore, it appears that the hydrological processes in the swamp and lake area in the surroundings of Bangula have not been fully captured by the model which is to date essentially uncalibrated. This highlights the importance of combining flood forecasting with various flood detection information, e.g. satellite imagery or GFDS, for a comprehensive coverage of flood situations as well as the need of feedback and local information to achieve more robust results.

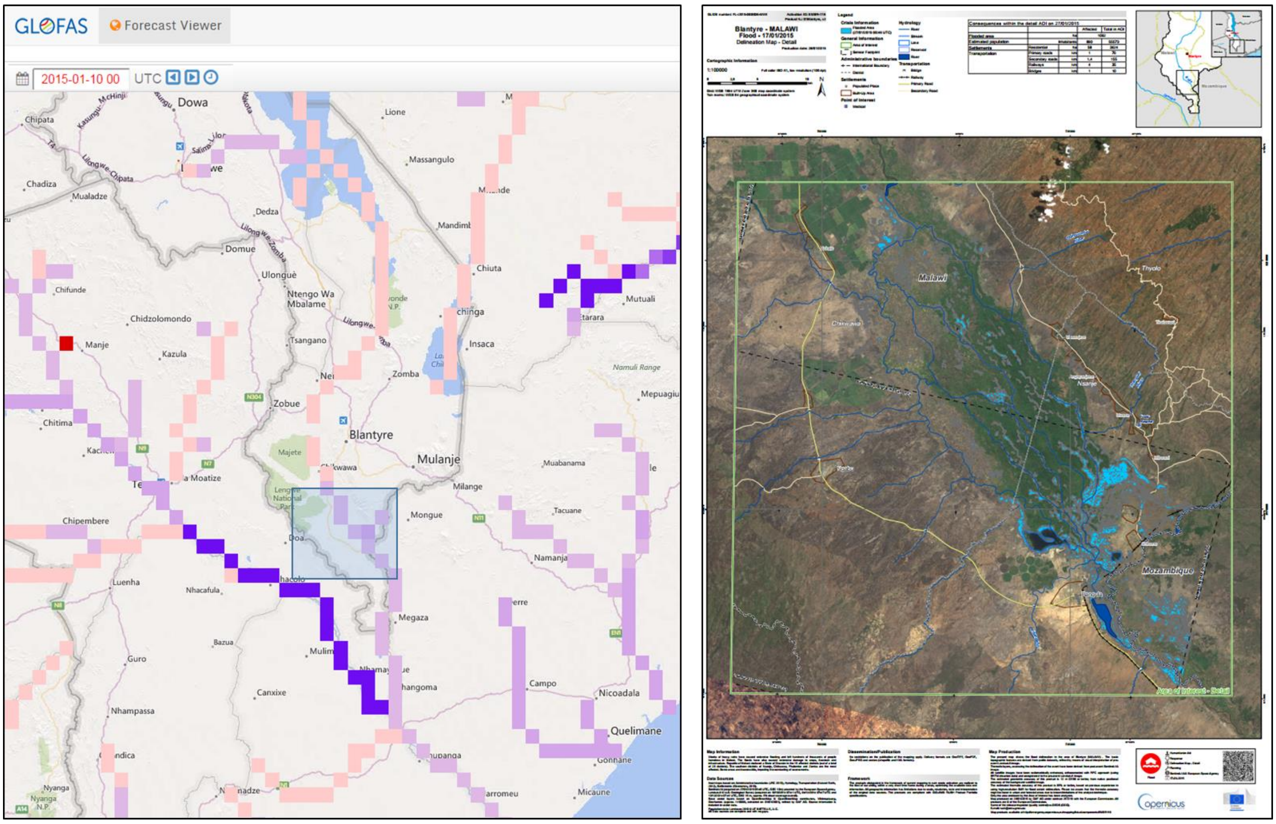


Figure 14 Malawi flood in January 2015. On the left: GloFAS forecast of 10 Jan 2015 highlighting river pixels where the 20 year (5 year) return period threshold is predicted to be exceeded in purple (red). The probability of exceedances is shown in monochromatic scales with light colours illustrating low probabilities and intense colours high probabilities. On the right: the flood delineation information of Copernicus mapping service for 17 Jan 2015 [http://emergency.copernicus.eu/mapping/system/files/components/EMSR116_01BLANTYRE_DELINEATION_DETAIL01_v2_100dpi.pdf]

The Global Flood Partnership played an important role in distributing and sharing information between the members of the group service providers and aid organisations:

On 14 January the *World Food Programme* posted a request to the Partnership for more information. On the same day the World Food Programme received overview information from GloFAS on the meteorological and hydrological situation and the publicly available information from the ERCC was shared. In the following days different products including satellite detection maps and extreme rainfall assessment were shared within the community. Also, importantly, questions and answers for clarification requests were dealt with almost instantaneously by the members of the group providing information from different angles and sources of information.

The following list details the different transfers of knowledge shared with WFP and the rest of the global flood partnership within a time span of 2 days.

14 January	Request for more information by UN World Food Programme
14 January	Overview report with results from the Global Flood Awareness System. Overall the system predicted high probabilities for flooding in the region, but the severity of flooding for Malawi was underestimated.
14 January	Information from the ERCC portal was shared with WFP http://erccportal.jrc.ec.europa.eu/About-us/Full-Text-Search?Search=malawi with information on the flooding starting on 13 Jan
15 January	ITHACA [56] provided an EXTREME RAINFALL ASSESSMENT for Malawi 15/01/2015
15 January	Vienna University of Technology communicates that satellite-based flood maps available based on TerraSAR-X from the German Aerospace Centre (DLR). WFP communicated that maps were shared with the country offices
15 January	Communication that GFDRR[57] is getting involved
16 January	Dartmouth flood observatory[58] communicates that the floods are mapped manually
16 January	NASA communicates that the charter has been activated for Mozambique but not yet Malawi. Communication that satellite imagery does not yet show flooding at the mouth of the Zambezi
16 January	Upon a request for clarification if the charter has been activated, UNOSAT confirms that the Charter has been activated for Malawi
20 January	Malawi Floods - ECHO Civil Protection Message no.1 which contains an update on the situation is distributed

This impressive list illustrates clearly how information flow can be enhanced, relevant content shared, and knowledge increased through the partnership.

In summary, the Global Floods Partnership aims at developing and aligning efforts, technologies, and capabilities nationally, across borders, regionally and globally as well as across sectors and disciplines, and therefore bridges the gaps between science, policy, and decision makers. Such a new formal partnership also allows for a more efficient use of financial resources and capacities at the global level. The coordinated flow of information during flood events such as the Malawi floods beginning of 2015 clearly highlight the potential for improved aid management for developing countries. The GFP also directly contributes to the JRC's newly launched Disaster Risk Management Knowledge Centre (DRMKC).

56 www.ithacaweb.org
57 https://www.gfdrr.org/
58 www.dartmouth.edu/~floods

In particular for Africa where hydro-meteorological observational data can be scarce (Revilla et al., 2014), medium-range probabilistic forecasting systems are not yet well established (Thiemig et al., 2011), and many major trans-national river basins exist (figure 9), authorities can benefit from global solutions and competences accessible through the partnership.

6. Conclusions

Flooding is a natural phenomenon with global dimensions which disproportionally affects vulnerable societies. Important - and potentially long-lasting - socio-economic consequences can be felt at local, national but also international level as with increasing globalisation, interruptions in the supply chains anywhere in the world can propagate through entire production chains. While developed countries may have sufficient coping capacity to recover fully from major flooding or even become more resilient for future events, this is often not the case for developing countries.

The negative consequences of flooding can be addressed through different phases of the disaster risk management cycle – in the preparedness, preparation, crisis response, and recovery phase. The better the actions along the phases are coordinated and going hand in hand on local, national but also international level, the more the negative impacts of flooding can be reduced. In particular for trans-national river basins where the origin of the flooding may be in a different country than where the impacts are largest, calling for river-basin-wide solutions in forecasting and detection systems for effective sharing of information.

Over the past 10 years, the European Commission has put in place a comprehensive policy framework for reducing the impact of flood disasters in Europe and increasing the resilience against such events. Policies are effective throughout the different phases of the policy cycle. With the development of the European Flood Awareness System and its uptake in the Copernicus Emergency Management Service, an operational pan-European early warning system has been established to improve preparedness and crisis management in particular for cross-border events where coordination of aid requires transparent overviews of both ongoing and upcoming flood situation for decision makers. A recent study on the monetary benefit of continental early warning systems suggests that important savings of the order 25% can be achieved with effective forecasting system in Europe. A transfer of the European system to other continents, i.e. Africa, or even global scale is currently ongoing.

With the development of continental to global flood early warning and detection the JRC has laid important foundations for actions to effectively reduce the socio-economic impact of floods in the EU and worldwide. The recently launched *Global Flood Partnership (GFP)* co-chaired by JRC and the Dartmouth Flood Observatory facilitates in an effective way the sharing of information and potential coordination of actions by bringing knowledge from scientific communities to decision makers, including national and regional water authorities, water resource managers, civil protection and first line responders, and international humanitarian aid organisations while at the same time respecting the single official voice principle for warnings and not interfering with national civil protection actions. The Global Flood Partnership also directly contributes to the JRC’s Disaster Risk Management Knowledge Centre (DRMKC).

This report illustrates that transfer of knowledge between Europe and authorities in other continents such as Africa is possible and how networks such as the EU-Africa Strategic Partnership on “Science, Information Society and Space” could be useful to achieve this goal. Finally, it is shown that the JRC can provide the EU with the instruments for contributing to the goals of the Sendai Framework for Disaster Risk Reduction 2015-2030[59] by providing global input to multi-risk early warning systems as part of effective disaster risk reduction at all levels and promote strengthening

[59] www.wcdrr.org/preparatory/post2015

partnerships as a vehicle to achieve effective and global solutions for the reduction of impact of flood disasters in vulnerable countries and worldwide.

Acknowledgements

The authors would like to acknowledge the support of JRC colleagues in the *FLOODS* team, the Water Unit of IES and the Critech team of IPSC who have contributed to the work on European and global flood forecasting and detection and the establishment of the Global Flood Partnership, in particular L. Alfieri, B. Bisselink, H. Beck, P. Burek, A. de Roo, J. Disperati, F. Dottori, G. Gomes, M. Kalas, V. Lorini, D. Muraro, V. Ntegeka, H. Sint, and Z. Zajac as well as D. Ad Khudairy and Frank Raes. Furthermore, the authors acknowledge the staff of ECMWF who are continuously contributing to the development of GloFAS, in particular B. Krzeminski, F. Wetterhall, and E. Zsoter. The HEPEX community and in particular M.H. Ramos is thanked for scientific stimulus on probabilistic flood forecasting, Prof. H. Cloke and L. Stephens from University of Reading for research input on communication of flood early warning to humanitarian aid. The authors acknowledge the support of the COPERNICUS programme not only for funding but also for providing a long missing coherent framework for emergency management services within and outside Europe. The staff of the Emergency Response Coordination Centre of DG ECHO, the World Food Programme, the Dartmouth flood observatory, and the EFAS partners and data providers are thanked for their trust in our systems and developments as well as their invaluable feedback to improve the systems further. Finally, I would like to thank A. Annunziato and T. Thielen for revision of the manuscript and feedback on disaster risk management.

7. References

Bakker, M. H. N., 2006: Transboundary River Floods: Vulnerability of Continents, International River Basins and Countries. PhD Dissertation, Oregon State University, Corvallis.

Bakker, M.H.N., 2009: Transboundary river floods: examining countries, international river basins and continents, Water Policy 11 (2009) 269–288

Barredo, J.I., 2009: Normalised flood losses in Europe: 1970–2006. Nat. Hazards Earth Syst. Sci., 9(1): 97-10

Bartholmes, J. C., J. Thielen, M. H. Ramos, and S. Gentilini (2009) The European Flood Alert System EFAS - Part 2: Statistical skill assessment of probabilistic and deterministic operational forecasts; Hydrology and Earth System Sciences, 13, 141-153, 2009

De Groeve T., Polnjansek K., Ehrlich D. (2013) Recording data losses, JRC Scientific and Policy Report, European Commission, EUR 26111 EN, 2013

De Groeve, T., J. Thielen, R. Brakenridge et al., 2015: Joining Forces in a Global Flood Partnership, Bulletin of the American Meteorological Society 2014, doi: http://dx.doi.org/10.1175/BAMS-D-14-00147.1

Hirpa, F.A., Hopson, T.M., De Groeve, T., Brakenridge, G.R., Gebremichael, M., Restrepo, P.J., 2013. Upstream satellite remote sensing for river discharge forecasting: Application to major rivers in South Asia. Remote Sens. Environ. 131, 140–151. doi:10.1016/j.rse.2012.11.013

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jongman B., S. Hochrainer-Stigler, L. Feyen, J. C. J. H. Aerts, R. Mechler, W. J. Wouter Botzen, L. M. Bouwer, G.Pflug, R. Rojas & P. J. Ward, 2014: Increasing stress on disaster-risk finance due to large floods, Nature Climate Change, 4, 264–268, doi:10.1038/nclimate2124

Pappenberger F., Cloke H.L., Parker D.J., Wetterhall F., Richardson D.S., Thielen J (2015) The monetary benefit of early flood warnings in Europe, *Environmental Science and Policy*, Vol. 51, p 278-291

Parker, D.J., Tunstall, S.M., McCarthy, S., 2007a: New insights into the benefits of flood warnings: Results from a household survey in England and Wales. Advances and challenges in flash flood warnings, 7(3): 193-210.

Parker, D.J., Tunstall, S.M., McCarthy, S.N.i.i.t.b.o.f.w.R.f.a.h.s.i.E.a.W., 2007b: New insights into the benefits of flood warnings: Results from a household survey in England and Wales. Environmental Hazards-Human and Policy Dimensions, 7(7): 193-210.

Parker, D.J., Priest, S.J., Schildt, A., Handmer, J.W., 2008: Modelling the damage reducing effects of flood warnings, FLOODsite Report No. T10-07-12, HR Wallingford, Wallingford, UK.

Revilla-Romero, B., Thielen, J., Salamon, P., De Groeve, T., and Brakenridge, G. R.: Evaluation of the satellite-based Global Flood Detection System for measuring river discharge: influence of local factors, Hydrol. Earth Syst. Sci., 18, 4467-4484, doi:10.5194/hess-18-4467-2014, 2014

Revilla-Romero, B., Beck, H.E., Burek, P., Salamon, P., De Roo, A., Thielen, J., 2015. Filling the gaps - calibrating a rainfall-runoff model using satellite-derived surface water extent. Remote Sensing of Environment.

Revilla-Romero, B., Wanders, N., Burek, P., Salamon, P., De Roo, A., n.d. Integrating remotely sensed surface water extent into continental scale flood forecasting. In preparation.

Spiekermann R., Kienberger S., Norton J., Briones F., and Weichselgartner J. (2015) The Disaster-Knowledge Matrix – Reframing and evaluating the knowledge challenges in disaster risk reduction; Int.l Disaster Risk Reduction 13(2015) 96–108

Thielen, et al. 2008. Aims, challenges and progress of the Hydrological Ensemble Prediction Experiment (HEPEX) following the third HEPEX workshop held in Stresa 27 to 29 June 2007, Atmos. Sci. Let. 9: 29–35

Thielen-del Pozo, J., J. Bartholmes, M.-H. Ramos, and A. de Roo (2009) The European Flood Alert System. Part 1: Concept and development, Hydrology and Earth System Sciences, 13, 125-140, 2009

Thiemig, V., Bisselink, B., Pappenberger, F., and Thielen, J.: A pan-African medium-range ensemble flood forecast system, Hydrol. Earth Syst. Sci., 19, 3365-3385, doi:10.5194/hess-19-3365-2015

Thiemig V, Ad de Roo & Hussein Gadain (2011) Current status on flood forecasting and early warning in Africa, International Journal of River Basin Management, 9:1, 63-78

Thiemig, V., Pappenberger, F., Thielen, J., Gadain, H., de Roo, A., Bodis, K., Del Medico, M. and Muthusi, F. (2010), Ensemble flood forecasting in Africa: a feasibility study in the Juba–Shabelle river basin. Atmosph. Sci. Lett., 11: 123–131.

UNISDR: 2005: Hyogo Framework for Action 2005-2015: Bulding the Resilience of Nations and Comminities to disasters, United Nations International Strategy for Disaster Reduciton, http://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf (last acess: February 3, 2015)

8. Links

COPERNICUS	www.copernicus.eu
COPERNICUS EMS	http://emergency.copernicus.eu/
ECMWF	www.ecmwf.int
EFAS	www.efas.eu
DG ECHO	ec.europa.eu/echo/
DG GROW	ec.europa.eu/enterprise/dg
GFDS	http://www.gdacs.org/flooddetection
GFP	portal.gdacs.org/Global-Flood-Partnership
GloFAS	http://www.globalfloods.eu/en/

Europe Direct is a service to help you find answers to your questions about the European Union
Free phone number (*): 00 800 6 7 8 9 10 11
(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server http://europa.eu

How to obtain EU publications

Our publications are available from EU Bookshop (http://publications.europa.eu/howto/index_en.htm),
where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents.
You can obtain their contact details by sending a fax to (352) 29 29-42758.

LB-NA-27533-EN-N

JRC Mission

As the Commission's
in-house science service,
the Joint Research Centre's
mission is to provide EU
policies with independent,
evidence-based scientific
and technical support
throughout the whole
policy cycle.

Working in close
cooperation with policy
Directorates-General,
the JRC addresses key
societal challenges while
stimulating innovation
through developing
new methods, tools
and standards, and sharing
its know-how with
the Member States,
the scientific community
and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office

doi:10.2788/46941

ISBN 978-92-79-52768-5