European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

Flood Management in Ireland

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Cover Image: Flooding River Shannon, Ireland, taken on 11 December 2015. Credit: Irish Defence Forces

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1 Introduction

1.1 The context of this study

The analysis of the *'Flooding in Ireland'* case study is carried out in the context of the 'The Sentinel Economic benefits Study' (SeBS). This 4-year study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

Each case study analysed in SEBS, focuses on products and services which use data coming from Sentinel satellites, measuring the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally-friendly operations, economic gains, improved quality of life, etc. The evaluated and demonstrated benefits can be used:

- By policy makers to justify the investments which have been made into the Copernicus programme,
- By space agencies to demonstrate that the technology for which they have public responsibility is capable of delivering strong, beneficial results,
- By other public agencies which are using EO data and services to meet their operational requirements e.g. European Environment Agency (EEA), European Maritime Safety Agency (EMSA), etc.,
- By the European Association of Remote Sensing Companies (EARSC) to promote the capabilities of the industry and the strong benefits which can result from the use of the services its members deliver,
- By companies to promote their capabilities and the power of their products and services.

In the framework of this project 20 case studies will be developed with reports to be published on each one. The study has started in March 2017 and will end in mid-2021.

1.2 What is this case study about

Flooding is one of the most devastating and frequently occurring natural hazards across the world. Each year it poses a significant risk to lives and property, causing people displacement and extensive damages in city infrastructure, road networks and agriculture. In addition to economic and social impacts, flooding can have severe environmental consequences, including the destruction of wetland areas and reduced biodiversity. In Europe, floods are the most frequent type of natural disaster accounting for the vast majority of natural disaster-related insurance claims. The average annual economic losses amount to approx. €5 billion in the EU and are expected to have a five-fold rise by 2050[1]. The causes of this projected increase have their roots in aspects of human activity. Thus, increased coastal and river flood risk is directly associated to climate change and its effects on sea level rise and increases in extreme rainfall[2]. This is further accentuated by a marked increase in the number of people and economic assets located in flood risk zones[3], and continued deforestation.

Whilst the root causes of floods are natural phenomena (sea level rise and rainfall) – and as such essentially uncontrollable – effective preparedness, response and risk reduction can be achieved through a well-coordinated disaster management approach. At political and legislative levels, a number of policies has been put in place towards improving flood prevention and organising risk management (e.g. the EU Floods Directive), and towards implementing a solid operational framework governing the different phases of crisis management (at EU level through the Civil Protection Mechanism and at Member State level through the corresponding procedures).

In this overall context, the availability of timely and reliable information enabling informed decisions for authorities involved in flood risk management, prevention and response is critical. To that end, satellite-derived information can be a valuable source for flood risk mapping (prevention), flood forecasting (preparedness and early warning phase) and for the crisis and post-crisis phases dealing with flood extent mapping and damage assessment. A prime example showcasing the value from the use of satellite data is given in the case of “Flooding in Ireland”. Starting with the record-breaking, country-wide floods during the winter of 2015-2016, the Irish authorities have incorporated satellite-derived maps as a valuable tool in response to large-scale flood events. Supplied through the Copernicus Emergency Management Service, these maps have enabled informed decision-making and produced significant economic and social benefits for all actors involved in flood management, from national coordination level down to individual citizens. This is what this case study is about.

[1] http://ec.europa.eu/environment/integration/research/newsalert/pdf/372na7_en.pdf

[2] See the IPCC report on Europe

[3] See for example the EC COM (2004)472 final on flood risk management

1.3 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders in Ireland. Not only did they warmly welcome us in Dublin, but they helped us navigate across the various aspects of disaster management, sharing the story of people who are doing their best to protect lives and property under such difficult circumstances. For that and for their overall openness we would like to sincerely thank:

- Paul Rock – National Directorate for Fire and Emergency Management
- Jim Casey – Office of Public Works
- Robert Ovington – National Directorate for Fire and Emergency Management, GIS Expert
- Tim McCarthy – Irish Representative at the Copernicus Committee
- John Keane – Chief Fire Officer in Roscommon County
- Brendan Cunningham – Managing Director of Pin Point Alerts-MapAlerter
- Domenico Grandoni – e-GEOS
- Lucia Luizetti – e-GEOS

2 Flood Management in Ireland

2.1 In the eye of the storm

Ireland is certainly no stranger to rain. Its geographical location ensures that it is regularly exposed to the influence of heavy storms from the North Atlantic, particularly in the winter. The storms originally form as hurricanes in the equatorial Atlantic, where the sea surface is warm enough to power them. The tail end of such hurricanes often affects Ireland; however, by the time these hit the island they have lost some of their devastating power[4]. Even if not in their full hurricane-level strength, such storms can have an enormous impact bringing heavy rainfall and causing considerable disruption from flooding.

2.1.1 The record-breaking Winter of 2015-16: Ireland hit by heavy storms

This was exactly the case of the winter of 2015/16, the wettest one ever recorded with rainfall totals 189% over the average (see figure 1).

Following an exceptionally wet month of November 2015, **the country was hit by a succession of Atlantic Storms which resulted in severe flooding across virtually the whole country**. The first to hit was Storm Desmond on December 4. It was followed by Eva on December 23 and Frank on December 29. The heavy rainfall associated with these storms exacerbated the ongoing flooding and gave rise to significant flooding in regions of the country which were previously relatively unscathed by floods. Thus, as the ground was fully saturated and with no capacity to absorb the continuous rain, several rivers and streams across the country swelled and burst their banks. In parallel, surface water flooding due to incessant rainfall was also occurring.

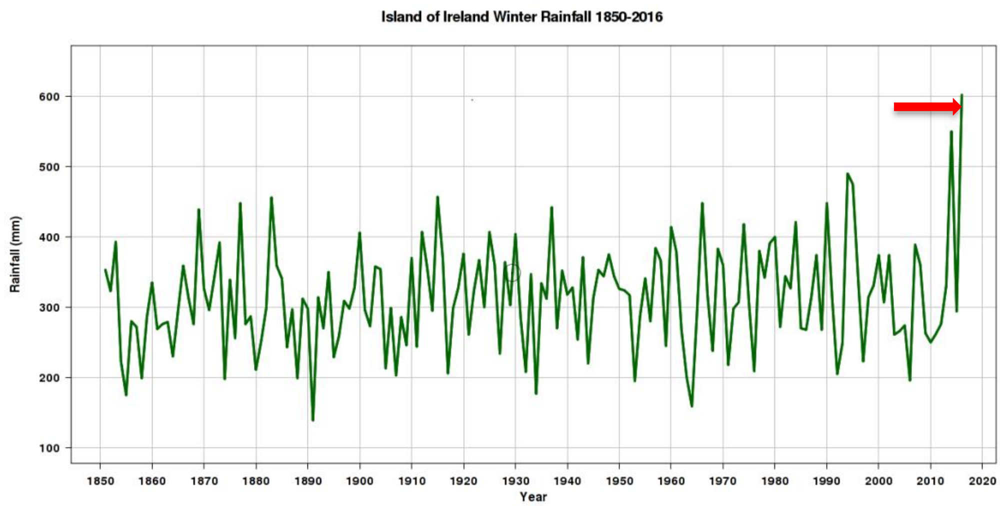

Figure 2-1: Time-series of winter rainfall covering the period from 1850 to 2015/16

[4] It is worth noting that [Ireland has been recently hit by Hurricane Ophelia] – providing strong evidence to current projections that [Europe will be hit in the future by more hurricanes].

Whilst the flooding impacted essentially the whole country – which makes this case already unique – the areas affected the most were the west, southwest, the whole area along the Shannon and its tributaries, and finally the southeast. The flooding persisted throughout the whole winter (even beyond March 2016 in certain areas), causing significant damage to homes and business, extensive disruption to the transport networks and heavily impacting the agricultural sector. As a result, many parts of the country were in a state of sustained flood emergency for almost two months. Before looking into the specific case of Winter 2015/16 it is instructive to gain a better understanding of the different types of impact that extreme flooding can bring.

2.2 Impacts of Flooding

Following a common practice amongst civil protection agencies across the globe, it is constructive to distinguish between **tangible** (i.e. readily measured in monetary terms and directly associated as a direct consequence of flooding) and **intangible** (i.e. not easily measurable in monetary terms and not clearly attributable to a flood event) impacts[5] caused by flooding.

2.2.1 Tangible impacts

Loss of lives and damage to property

The most immediate impacts of flooding include loss of human life, damage to private and public property, destruction of crops and loss of livestock, disruption of infrastructure, communications and the transportation network and deterioration of health condition owing to waterborne diseases. In the case of properties, flooding can affect both the buildings themselves and their contents. The associated impacts are typically value by the costs of building repair and contents replacement. Moreover, contamination of floodwaters by sewage, chemicals, etc. and the presence of seawater can greatly increase the damage caused by flooding.

Loss of livelihoods

Equally important is the effect on livelihoods for the affected communities. The disruption and damages on key infrastructure (e.g. power plants, roads and bridges) can bring economic activities to a standstill, resulting in the dysfunction of normal life for a period extending much beyond the duration of flooding. Loss of livelihoods is also strongly associated with the direct effect of flooding on production assets. Thus, the regular activity of farmers or industry is hindered over a longer period. This has often spill over effects on commercial activities in neighbouring to those that were flooded areas.

Decreased purchasing and production power

[5] It should be noted that the discussion of impacts here is not meant to be exhaustive. Several scientific or policy-related publications provide a detailed account. In the case of Ireland, we have closely consulted [OPW's Report of the Flood Policy Review Group]

Beyond the immediate impacts discussed above, damage to infrastructure can result in significant longer-term effects. This includes disruption related to the availability of clean water and the discontinuity of electricity supply and inhibited access to the transport and telecommunications networks. In addition, flooding can lead to reduction in purchasing power, depreciation of land value and, subsequently, increased economic vulnerability of the affected areas. Moreover, the significant costs associated with recovery and rehabilitation may divert the capital needed to maintain the normal levels of production and services.

2.2.2 Intangible impacts

Loss, stress and anxiety

Given their subjective nature, intangible impacts are harder to quantify, as they are often more personal to the victim and its relationship with the lost or damaged asset. This may include items of high emotional value including pets or memorabilia. Equally important to consider are intangible impacts related to trauma, post-event stress, or anxiety. These are often carrying on for a long period after the actual flooding, with owners of property in affected areas living with the ongoing fear of further flooding events.

Environmental Impacts

Flooding can have a direct impact on the environment and the ecosystems within the affected areas. Whilst some of these impacts are positive[6] (e.g. in terms of contributing to biological productivity and diversity in the flood plain), flooding can cause a series of negative impacts. This includes[7]

- Impacts on the **well-being of wildlife and livestock**, including negative short (e.g. flooding of ranching and farming habitats) and long-term (habitat potential, food availability) effects. Excessive flooding can lead to **loss of life and biodiversity** in the flooded region.
- **Riverbank erosion and sedimentation**: the sediments induce water pollution that may clog riverbeds and streams, as well as reduce the storage capacity for reservoirs and wetlands. In extreme cases water quality can be directly affected. In that regard, the Winter 2015/16 floods saw Irish Water placing over 23,000 customers on boil water notices (BWN). Ireland also faced sewage contamination and the flooding of wastewater treatment plants.
- **Pollution** associated with pollutants (bacteria, pesticides, chemicals from flooded plants) carried by flood water even to far distances.

Turloughs, Ireland's unique wetland ecosystems

Turloughs are a type of lakes (as big as 250ha), virtually unique to Ireland, which are "re-appearing" when flooding occurs. They are considered priority habitats in the EU Habitats Directive and support a variety of wet grassland and fen type vegetation. The Winter of 2015/16 saw the highest groundwater levels and resulted in record-level of turloughs. In this context, rural communities living around turloughs have been particularly affected by the floods.

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[6] See for example the "Environmental Aspects of Integrated Flood Management" by WMO, 2006

[7] We have consulted various sources for this brief overview. A nice summary is provided here.

The table below provides a summary of the different tangible and intangible impacts.

Tangible	Intangible
Loss of human life	Items of emotional value (pets, memorabilia)
Damage to properties: commercial, residential, industrial, agricultural	(Prolonged) stress and anxiety of affected people, incl. in view of potential future flooding
Welfare costs due to disruption of infrastructure incl. communications, transportation, electricity	Long-term health effects
Deterioration of public health, incl. due to contamination (sewage, chemicals, etc.)	Environmental impacts (loss of wildlife, erosion, pollution, damage to landscape and habitat, etc.)
Disruption of commercial activity	Reduction in personal capacity
Flood Response and Relief costs	Excessive appearance of turloughs (Irish case)
Alternative accommodation costs	
Decrease of property values (including agricultural land)	

Table 2-1: Summary of tangible and intangible impacts

The aftermath of the severe floods of 2009-2010

Unprecedented rainfall in late October and early November 2009 resulted in severe and prolonged flooding in many river catchments in Ireland. Houses, businesses and institutional premises were damaged with resulting displacement of people, disruption and loss. The financial toll reached 244M€ according to Insurance Ireland estimations. This was due – to a large extent – the flooding in the city of Cork (approx. 100M € damages) where the authorities were not able to issue adequate warnings alerting people at risk to the reality of what was coming. As the official report states: "*The main difficulty in this case was a disjoint between the meteorological and the hydrological system information, the failure to convert this into a coherent picture of what might happen, and then communicate this assertively to the relevant public as a specific flood warning*." This event made it clear that an integrated flood management approach is required, exploiting all available modern means of information.

As briefly discussed above for the case of the previously most severe flooding Ireland had faced (i.e. 2009-2010), the impacts of events of such magnitude can be truly devastating. The extraordinary case of the floods during the winter of 2015/16 – now considered the worst flooding in the history of Ireland – posed an enormous challenge to the Irish actors involved in the flood preparedness and response mechanism. It is therefore essential to understand how the mechanism is organised.

2.3 The Irish flood management mechanism

The actors involved in the Irish flood management mechanism are guided by a common goal: to prevent, reduce or mitigate the impacts of flooding. To do so they need to make informed decisions guiding their actions often in very stressful and complex conditions. In addition, when faced with **floods of such great scale as in Winter 2015/16, the successful implementation of flood management requires efficient coordination across numerous actors at national, regional and local level**. It is an intensive process that starts long before a major storm hits the country and continues long after its aftermath is fully realised. Firstly, it entails **preventive actions** proactively avoiding construction in flood-prone areas or taking measures (defences) to reduce the likelihood and impact of floods. It carries on with **preparedness,** i.e. the period closer to the occurrence of the flooding event, whereby authorities monitor the progress of the storm and issue warnings on the impeding flood risk. Following the outbreak of the actual flooding, **response** actions seek to contain its impact, protecting the lives of citizens and minimising damages to property. Finally, immediately after the flooding emergencies, the **recovery** process gets under way, with concerted rebuilding efforts and a transition back to normality.

In Ireland, the management of large-scale floods entails the effective collaboration of multiple actors. At **national level**, the co-ordination of the "Whole-of-Government" response to a flooding emergency falls to the Department of Housing, Planning, Community & Local Government, and in particular the National Directorate for Fire and Emergency Management (**NDFEM**). This is the designated "Lead Government Department" holding the responsibility to "*ensure that when adverse conditions arise, local authorities, in conjunction with other agencies, are able to respond promptly and effectively with the resources at their disposal to help offset the worst effects in relation to those aspects for which they have direct responsibility*". NDFEM works closely with OPW, Ireland's lead agency for flood risk management, and with other governmental departments forming the "National Emergency Coordination Group". In the case of winter floods of 2015/16 27 organisations were routinely involved in national response.

At **local and regional level**, the police force - An Garda Síochána, the Health Service Executive (HSE), the Local Authorities (LA) and their Principal Emergency Services (PES), have major emergency plans that can be activated in response to large scale emergencies. These are called the Principal Response Agencies (PRAs).

Other key actors involved in flood management are the Civil Defence (CD), Defence Forces, the Irish Coast Guard (when applicable), the Irish Meteorological Service (Met Éireann), multiple voluntary emergency services, community groups, specialised SMEs and, of course, the public at large.

The responsibilities of the different actors and the operational procedures governing their cooperation are described in:

- **The Multi-Agency Response to Flood Emergencies Protocol** and the **Guide to Flood Emergencies** – established in direct connection with the **Framework for Major Emergency Management** - provide guidelines concerned primarily with Emergency Response. Their stated aim is to "*assist the development and implementation of consistently effective flood* *emergency response and short-term recovery planning by the Principal Response Agencies and others, so as to minimise the impacts and damage caused by flood events in Ireland."*

- **The** **Catchment Flood Risk Assessment and Management** **(CFRAM)** Programme – overlooked by the Office of Public Works (OPW) – is the "*principal vehicle for implementing the Government's 2004 national policy on flood risk management*". Tightly connected to the 2007 EU Floods Directive, it provides recommendations/solutions to proactively manage flood risk in those areas at significant risk from fluvial and coastal flooding. This is documented and maintained in the 29 Flood Risk Management Plans (FRMPs).

Based on these key documents, we provide below a summary of the key activities in the different phases of the emergency management cycle.

2.3.1 Prevention

Flood prevention and protection requires that a combination of structural measures and preventive actions are put in place, ideally incorporated within an integrated, comprehensive, long term plan (of the order of decades). Such plans should be tailored for each river basin and cover all relevant aspects of water management, physical planning, land use, agriculture, transport and urban development, nature conservation at all levels (national, regional and local). Their elaboration should be a result of close cooperation between decision makers and practitioners at all levels as well as civil society.

In Ireland, the OPW oversees the implementation of actions strengthening the country's defences to future flooding. In doing so, OPW works in association with the relevant local authorities often funding them directly to undertake flood defence works. **Permanent flood defences** entail structural works incl. walls, weirs, dams and locks and non-structural works such as the establishment of wetlands and flood attenuation areas. In preventing and controlling the impact of flood events it is critical that such structural defences are regularly maintained, and any weak points are identified.

On top of this, OPW maintains the information portal identifying flood-related risks. Thus, through Flood Maps, the OPW raises the general awareness of citizens on the risk to property and possibly life from flooding in Ireland; it also provides developers, engineers and LA planners responsible for spatial planning and development management, with a robust picture of flood risk issues when assessing planning applications and when preparing spatial plans, such as (local) Development Plans.

Temporary defences include the deployment of sandbags and demountable barriers at known failure points and at flood pathways such as doorways and the entrances to basements and underground car parks. The effectiveness of such measures relies on timeliness; thus, they should be deployed before the floodwaters come pouring in. Protection against floods is a shared responsibility between agencies and householders. In that regard, OPW is giving advice to householders on how best to provide protection to individual properties through the www.flooding.ie portal.

The EU Floods Directive and its implementation in Ireland

The adoption in Ireland of the national flood risk policy direction is in line with the requirements of the EU Floods Directive, established in 2007. At its heart lies the protection of communities form the risk and impacts associated with flooding. This Directive requires Member States to assess if all watercourses and coast lines are at risk from flooding, to map the flood extent and assets at risk in these areas and to take adequate and co-ordinated measures to reduce this flood risk. Its implementation in Ireland, takes the form – among others of the following key activities:

- Development of a Preliminary Flood Risk Assessment (PFRA), to identify areas of existing or foreseeable future potentially significant flood risk (referred to as “Areas for Further Assessment”, or “AFAs”),
- Prepare flood hazard and risk maps for the AFAs
- Prepare Flood Risk Management Plans (FRMPs), setting objectives for managing the flood risk with the AFAs and prioritising measures towards achieving these objectives

The ‘Floods’ Directive was transposed into Irish law by the European Communities (Assessment and Management of Flood Risks) Regulations 2010, S.I. No. 122 of 2010 and amended by the European Communities (Assessment and Management of Flood Risks) (Amendment) Regulations 2015, S.I. No. 495 of 2015. The Regulations set out the responsibilities of the OPW and other public bodies in the implementation of the Directive, including public consultation, and details the process for implementation of the measures set out in the FRMPs. The implementation of the Directive is monitored by DG Environment of the European Commission.

2.3.2 Preparedness and early warning

Preparedness entails a set of actions that ensure a high level of readiness amongst flood management actors in view of an impending storm that is projected to cause significant flooding. Perhaps the most important among these actions are

- **Regular monitoring of water levels of rivers** in areas with high flooding risk. This is done by OPW monitoring the readings of water gauges in hydrometric stations placed in the Irish rivers, and supported by the information provided through the European Flood Awareness System (EFAS)[8]

[8] A detailed account of EFAS is given in chapter 3.2.2

- **Regular forecasts capturing the evolution of weather phenomena** and in particular the expected amount of rainfall. This is undertaken by Met Éireann and may give rise to severe weather warnings, in line with European best practices and in particular the [Meteoalarm](#) system. This system provides a colour-coded categorisation of weather warnings[9]:
  - **STATUS YELLOW** – Weather Alert – Be Aware
    The concept behind YELLOW level weather alerts is to notify those who are at risk because of their location and/or activity, and to allow them to take preventative action. It is implicit that YELLOW level weather alerts are for weather conditions that do not pose an immediate threat to the general population, but only to those exposed to risk by nature of their location and/or activity.
  - **STATUS ORANGE** – Weather Warning – Be Prepared
    This category of ORANGE level weather warnings is for weather conditions which have the capacity to impact significantly on people in the affected areas. The issue of an Orange level weather warning implies that all recipients in the affected areas should prepare themselves in an appropriate way for the anticipated conditions.
  - **STATUS RED** – Severe Weather Warning – Take Action
    The issue of RED level severe weather warnings should be a comparatively rare event and implies that recipients take action to protect themselves and/or their properties; this could be by moving their families out of the danger zone temporarily; by staying indoors; or by other specific actions aimed at mitigating the effects of the weather conditions.

  These weather warnings are issued as a function of weather elements (i.e. rain, wind, etc.) exceeding certain thresholds. Nevertheless, in certain occasions when the impacts of, for example heavy rain, are expected to be significant, weather warnings of a higher level (e.g. orange) may be issued even if the absolute numerical values are not meeting the given threshold. Weather warnings are disseminated to local authorities and the public using multiple means including television, radio, website/app and email notifications.

  It is worth underlining that the experience of the extraordinary floods of the Winter 2015/16 has led to the Government decision on the development of a "National Flood Forecast and Warning Service" as a unit within Met Éireann (in cooperation with OPW). It is expected that when this system becomes operational, it will substantially strengthen the flood forecasting capabilities of Ireland.

[9] The description of the different categories in the colour coding system is taken from https://www.met.ie/met-eireann-warning-system-explained

Naming of storms – an approach that helps to raise awareness

Starting in September 2015, the UK Met Office and Met Éireann have adopted an approach whereby wind storms forecast to cause substantial impacts over the UK and/or Ireland territory are given names. This "humanising" of storms makes it easier to relate to them by those affected and helps authorities to communicate on the impending severe weather – in unison – to the public, media and to other government agencies. The ultimate aim is to help increase public safety. When the scheme was announced, the Met offices used social media to collect potential names and then re-aligned the ones received with the US National Hurricane Centre approach. Today, following the positive reception of this approach, the naming of storms carries on, on the basis of well-defined guidelines and using online media to publicise it.

2.3.3 Response

The response phase entails a wide range of activities during the development, passage and abatement of a flood. **In Ireland, the activities during the response phase are coordinated through a combination of top-down and bottom-up approaches**. The former entails the actions undertaken at national level by the Department of the Housing, Planning, Community and Local Government and in particular the NDFEM, acting as the lead government agency during the response phase. The latter, concerns the decisions on response levels at local/regional level, taken by the Local Authorities (LAs) and in particular by the Severe Weather Assessment Teams. Thus, following the warnings issued by Met Éireann (see 2.3.2), these teams are entrusted with continuous monitoring and assessment of the ongoing flood event. It is their responsibility to decide the level of response required as shown in figure 2-2 below. Thus, depending on the magnitude and geographic scale of the flood event, major emergency may be declared and appropriate actions to set up local, regional or national emergency coordination groups may be taken (see "A guide to flood emergencies" for more details). These groups – each for the geographic scale[10] concerned – are responsible for the effective coordination of the different actors and the informed deployment of resources towards meeting the primary objectives of flood response[11]:

- Rescue persons in danger;
- Protect critical infrastructure (where possible);
- Minimise the impact of the water inundation on affected communities;
- Minimise the environmental impacts;
- Provide a place of safety;
- Ensure as far as practicable the safety and health of all responders;
- Facilitate speedy recovery and the return to normality for affected communities; and
- Maintain routine services to the wider community

[10] It is important to note that the National Emergency Coordination Group may be convened even if no major emergency is declared – this was the case in Winter 2015/16 too.
[11] These objectives are described in the "Protocol for Multi-Agency Response to Flood Emergencies"

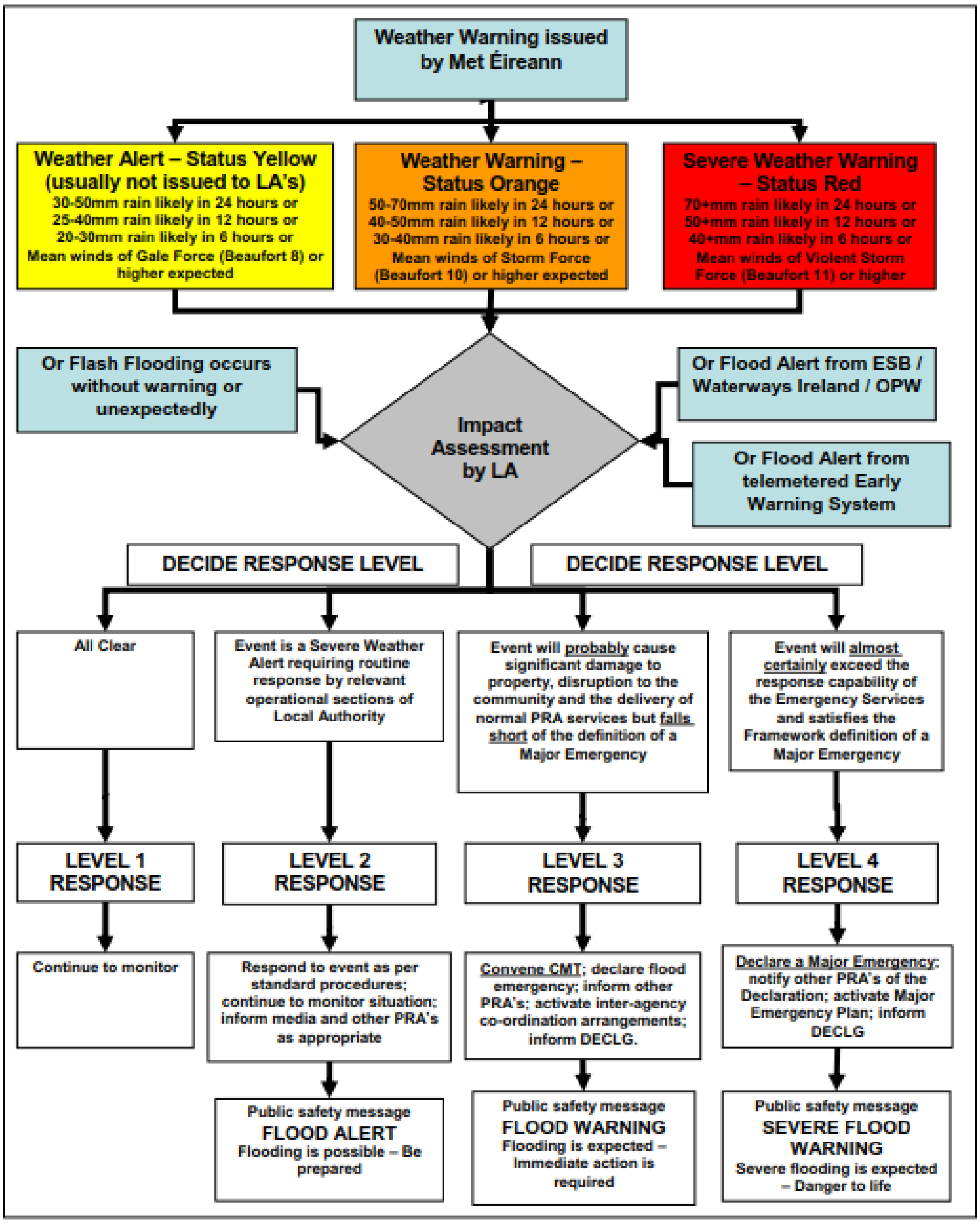

Figure 2-2: Response Action Levels following the different types of warning

Once the mechanism for response is triggered, a multitude of actors are striving to work in sync towards protecting the lives of citizens and minimising all other types of impact. A more detailed description of individual roles for the response phase is presented in Chapter 3.

2.3.4 Recovery

Recovery and response should not be seen as sequential phases but rather as an integrated system. This means practically that the achievement of the objectives set out for the response phase previously, carries on within the recovery phase. **Short-term recovery** includes actions taken to assess damage and achieve minimum operating standards for the various support systems. This entails the restoration of essential utilities such as power, fuel supplies and drinking water as soon as possible during the flooding event. It also concerns the execution of clean-up operations (removing debris); the provision of accommodation (either short term or more permanent) for displaced persons; and facilitating the provision of humanitarian assistance.

On the other hand, **long-term recovery** can extend for much longer periods (months or even years) as its aim is to address the enduring human, physical, environmental, social and economic consequences of emergencies. This process entails a preliminary (and then progressively more substantiated) assessment of damages and costs (incl. the ones incurred by responding agencies), the implementation of relief schemes for affected communities (e.g. for farmers, small businesses, etc.) and the subsequent execution of works/defences, whereby recovery essentially merges again with prevention. As with all other phases, effective recovery requires the smooth collaboration of multiple actors both at governmental level but also in the private sector and the communities themselves.

An overview of the high-level responsibilities projected at different operational levels and over the different phases is provided in the table below. In the context of a specific flood event, this gives rise to a "value chain", whereby actors rely on different types of information to take decisions and carry out actions which will help them reduce the impact of flooding to their respective activities. This value chain is presented in the next chapter.

	Prevention	Preparedness & EW	Response	Recovery
National	OPW	Dpt. of Housing OPW Met Éireann	NECG	OPW Dpt. of Housing
Regional	OPW	Met Éireann OPW PRAs	PRAs Defence Forces Civil Defence	OPW Local Authorities
Local	LAs (City Council, Fire Brigade) City Planners	LAs (City Council, Fire Brigade) SWA teams MapAlerter PRAs	LAs (City Council, Fire Brigade) SWA teams PRAs Voluntary Emergency Services Defence Forces and Civil Defence Citizens	Local Authorities

Table 2-2: Key roles across the actors involved in Flood Management in Ireland

2.4 Informed decisions, coordinated actions and effective interventions

Preventing, reducing and mitigating the impacts of floods with an intensity, duration and geographical spread as in the case of Ireland during the winter of 2015/16, requires that all actors work seamlessly together and that **all available sources of information are effectively used**. Thus, having the best possible situational awareness – i.e. **what is happening, where and when, is of utmost importance**. Before the winter of 2015/16 and especially in the wake of the previously most devasting flood event in Ireland – that of 2009-2010 – the Irish authorities have been using these information sources:

2.4.1 Historic Flood Data

Data concerning floods that have occurred across Ireland over the years is collected by OPW with the support of local authorities. This data – collated from reports, press articles or interviews with affected communities – includes

- Dates and relative magnitudes of historic flood events
- Depths, levels and duration of the flooding
- Maps of the flooded areas and relative extents
- Details of properties flooded or damaged
- Flood mechanisms

In Ireland, the OPW has noted the difficulty of collecting historic flood data, as they are often incomplete when compared to what is necessary for developing flood profiles and extent maps, as well for calibrating hydrological models. Therefore, in order to systematically collect such data, OPW has disseminated a flood data collection brochure (OPW, 2002), targeted primarily at local authorities. This provides instructions on the needed flood data and sets out the types of data required and methodologies for collection.

2.4.2 Hydrometric and Meteorological Data

Hydrometric and meteorological data are essential practically throughout the full emergency management cycle, from developing hydrometeorological models, to issuing timely warnings, and from monitoring the evolution of floods (and the storms producing them) to observing the progress of recovery works. Hydrometric data is provided in Ireland via www.opw.ie/hydro/index.asp and www.epa.ie. It is collected through a network of hydrometric stations gauging the flow of water and recording its levels. These stations are distributed across the rivers throughout the country.

The meteorological data is provided by Met Éireann, using weather stations distributed across Ireland and the information provided through international collaborations, most prominently the ECMWF.

Looking ahead, it is interesting to note that numerous publications, including "*Ireland's Climate, The Road Ahead*" published in 2013 by Met Éireann, present projections on the basis of climate-change models, that predict an increase in winter rainfall across much of Ireland, and an increase in the frequency of very wet winter days, as the levels of CO_2 in the global atmosphere increase.

2.4.3 Topographical surveys

Topographical surveys are conducted by surveyors either on foot or using aerial means (aircrafts or lately drones). By using of Light Detection and Ranging (LIDAR) techniques (or similar methods) one can construct the digital terrain model (DTM) which allows the modelling of the floodplain and the determination of property characteristics for the assessment of potential flood damage.

This type of “on-site” inspection carries on during the evolution of a flooding event by flood management authorities, civil protection staff or even volunteers reporting on the current state of flooding and potential damages. In the case of Ireland, the Severe Weather Assessment Teams are formed to help monitor the progress of flooding and support the decision-making process with regards to needed interventions (defences, resource allocation, etc.).

2.4.4 Limitations

Whilst these sources of information are very useful to flood management authorities, they are also bounded by certain limitations. These limitations give rise to important challenges faced by the authorities – especially in large scale flooding events such as Winter 2015/16:

- **Constructing a broader picture**: The ability to have a nationwide picture of the magnitude of flooding (and its impact) is crucial for the coordinated allocation of resources. Achieving this with the aforementioned resources is extremely difficult during the evolution of a flood; the topographical surveys are very localised and the information from the other sources cannot be easily transposed onto a map covering a wide area of interest.
- **Ensuring continuous monitoring**: Maintaining an accurate picture of the evolution of the flooding event in different areas of the country requires a very high degree of coordination and is particularly resource-intensive. Gaining access to tens of thousands of properties along each river is not possible in the demanding timeframe of emergency response. Similarly, whilst aerial surveying (flights with aircrafts or drones) can cover a large area, their operation is significantly affected by bad weather conditions.
- **Facilitating common understanding**: Communicating on the evolution and impacts of the flood is also very critical both between the responding agencies but also to the public, media and political hierarchy. This cannot be easily achieved with numbers (i.e. measurements of the gauges or meteorological data).

All these limitations can – to a very large extent – be addressed by the use of satellite data. Therefore, the Irish authorities entrusted with flood management have for the first time in Winter 2015/16 activated the Copernicus Emergency Management Service (CEMS) as tool to support them throughout their response activities.

We will look into this service in the next chapter, followed by a thorough account of how it was used by the different actors (chapter 4) and the concrete value it brought (chapter 5).

3 Satellite data for flood management

3.1 General introduction on the use of satellite data for flood mapping

In their efforts to devise and implement appropriate flood management actions, the actors presented in the previous chapter are faced with the challenge of responding to a dynamically changing – and thus very unpredictable, situation. It is therefore vital for them to have accurate and regularly updated information, allowing them to put in place defences, conduct drainage works or coordinate the relocation of people and assets. **This need for continuous and precise mapping and monitoring of the floods over large areas, is met by the use of satellite data**.

In the case of *Flood Management in Ireland* this need was addressed by using the maps provided through the Rapid Mapping component of the Copernicus EMS. Whilst this was the first time that Irish authorities sought to systematically use the satellite-based products of Copernicus EMS, it must be noted that satellite imagery has been used for many years across the globe and in several emergency contexts, including flooding[12],[13].

Therefore, before looking into the specifics of the Copernicus EMS and how it was used by the Irish actors, it is important to understand how satellites can capture changes on the surface of the Earth, allowing to construct accurate and regularly updated maps of flooding events.

3.1.1 How can satellites map and monitor flood events

Broadly speaking there are two main classes of Earth Observation satellites[14]:

- Those carrying **passive sensors** able to detect the sun's energy as it is reflected from the Earth's surface. These "optical" satellites are affected by cloud coverage (at it hinders solar radiation) and can only observe during day time. Typically used sensors in this category are radiometers (incl. imaging and spectro-radiometers) and spectrometers.
- Those carrying **active sensors** capable of emitting their own energy (in the form of electromagnetic radiation) to illuminate the scene (and objects therein) they observe. Such satellites send a pulse of energy from the sensor to the object and then receive the radiation that is reflected or backscattered from that object. Typically used sensors in this category are radar, scatterometers and lidar. Satellites carrying such sensors – for example Synthetic Aperture Radar (SAR) satellites – are unaffected by cloud coverage.

[12] Indicatively see http://www.eohandbook.com/eohb2015/ and https://disasterscharter.org/web/guest/home

[13] A very good overview is also provided in Voigt, et al. (2016). Global trends in satellite-based emergency mapping. Science. 353. 247-252. 10.1126/science.aad8728.

[14] A nice overview of passive and active instruments on board earth observation satellites is provided in https://earthobservatory.nasa.gov/Features/RemoteSensing/remote_08.php

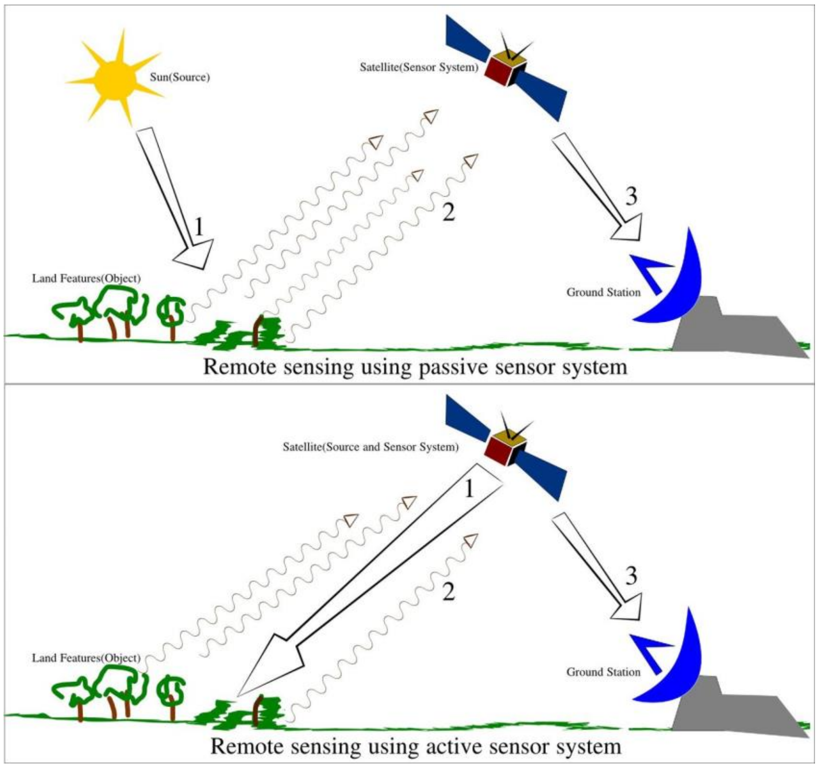

Figure 3-1: Illustration of passive vs. active remote sensing[15]

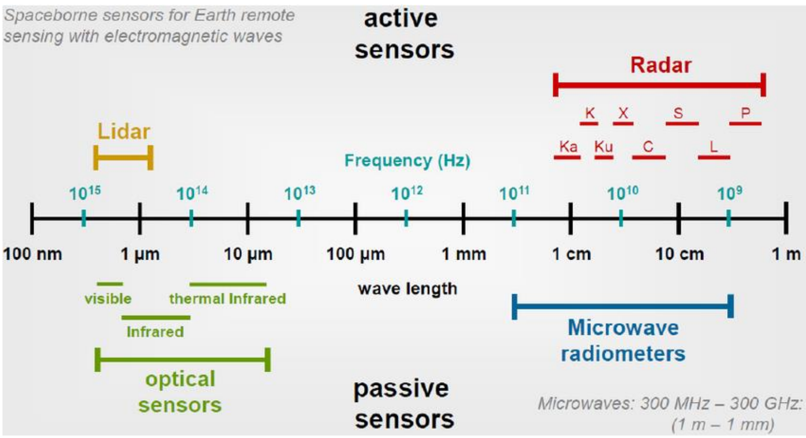

Figure 3-2: Active and passive sensors used for Remote Sensing[16] **in support to Emergency Management**

As seen in figure 3-1, active and passive sensors emit/collect electromagnetic signals of different wavelengths. In practice, different materials on the Earth's surface reflect electromagnetic waves in a different manner. These reflectance differences allow Earth Observation (EO) satellites to distinguish between grasslands, water surfaces, forests, buildings, etc. When more than two wavelengths are used, the separation among objects is even more evident. Thus, satellites equipped with multispectral sensors (i.e. utilising different bands of the spectrum) can provide data

[15] Graph taken from Dall (2017)

[16] Graph taken from Lefeuvre, F & Tanzi, Tullio. (2014). Radio Science Contribution to Emergency Disaster. Radio Science Bulletin. ISSN 1024-4530.. 37-46.

that allow the quantitative classification of different types of land cover in a given scene. Land cover classification can also be achieved using SAR satellites. Contrary to optical satellites – which essentially produce photographs, the SAR imagery is a measure of how much energy is scattered back to the sensor after being reflected on different types of materials.

In all cases, the data collected by EO satellites is transmitted via radio waves to properly equipped ground stations. There they are translated into a digital image that can be displayed on a computer screen. Each satellite image is composed of pixels and each of these pixels represents a square area on the image that is a measure of the sensor's ability to resolve (see) objects of different sizes. The higher the resolution the greater the ability of the sensor to discern smaller objects, but also the narrower the strip of land that can be surveyed by the satellite.

For the **mapping of floods** (whether with optical or with SAR and regardless the resolution), the basic process entails two steps:

- Extraction of the visible water extent from the post-event image (image 1 in the middle below)
- Subtraction from the visible water extent of the extent of water bodies in normal conditions (image 2 in the right below).

In this way, one is able to identify water areas which are a result of the flooding, or in other words to detect excessive water areas on top of the normal water bodies (i.e. rivers).

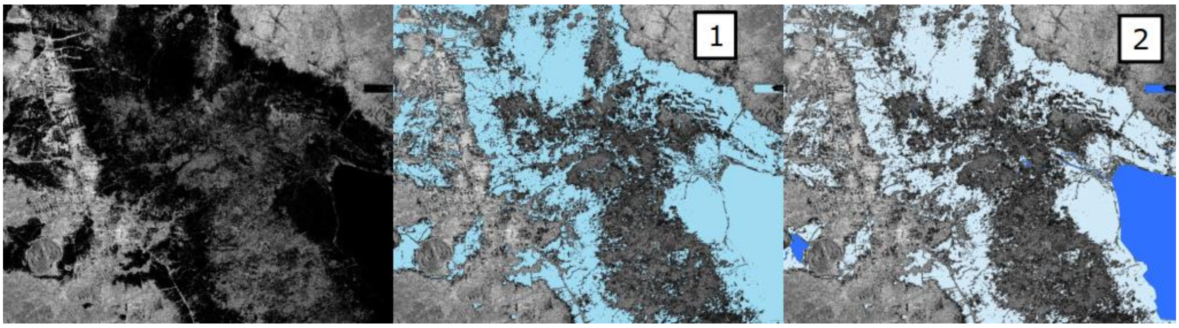

Figure 3-3: Flood mapping using satellite imagery (credit: e-GEOS)

This process is automated using smart algorithms that allow the translation of the information encapsulated in each pixel into **easily understandable maps** that highlight the extent (boundaries) of flooded areas (flood delineation maps) – see figure below. By collecting images of the same area on every new pass of the satellite (and usually combining different satellites), one can monitor the progress of the flood event. The revisit time depends on which satellite is used. For the Sentinel 1a and 1b constellation, the revisit time over Europe is – on average – 5 days.

Moreover, by using GIS techniques[17] one can add complementary layers of information (e.g. city maps) to derive damage assessments. Thus, satellite-derived maps are a highly valuable tool for flood management authorities, enhancing their situational awareness and enabling them to make informed decisions towards reducing the impact of the flood. All in all, remote sensing via satellites

[17] See for example Jochen Albrecht, Key Concepts and Techniques in GIS

has significant advantages when compared to more "conventional" methods but also specific limitations. These are described in the next section.

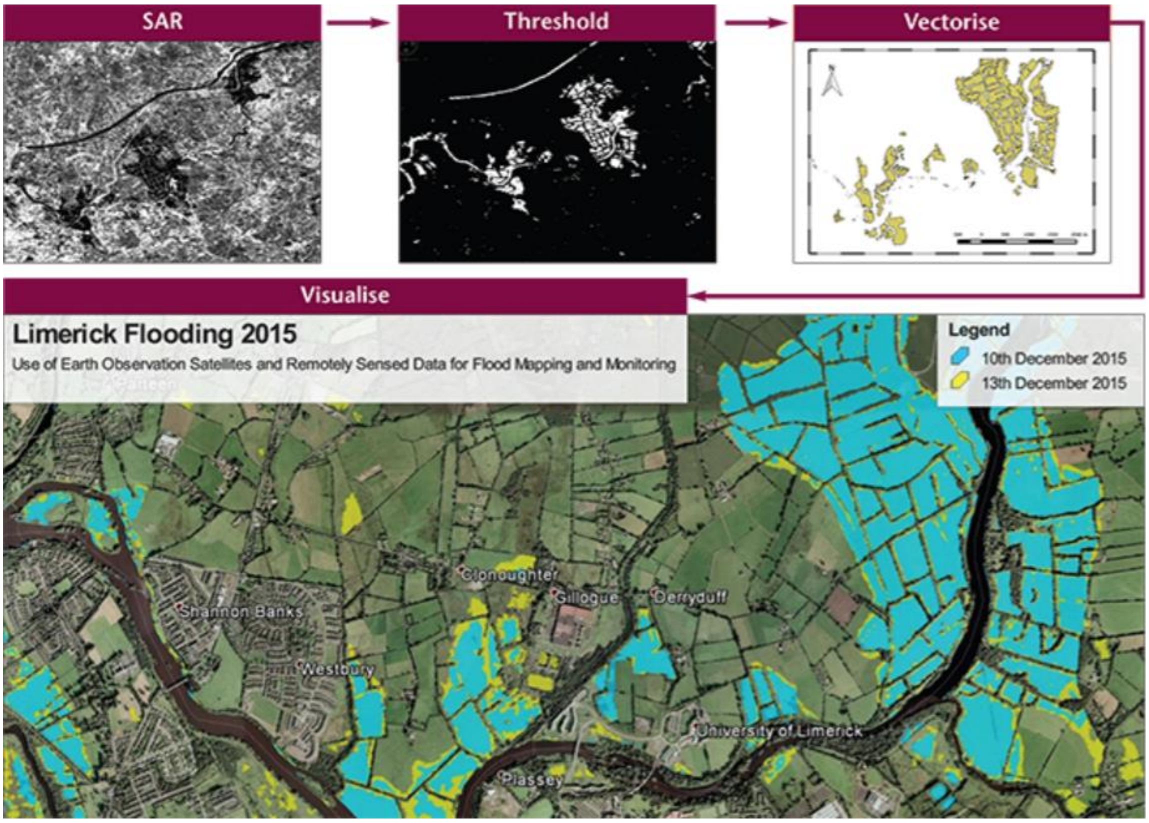

Figure 3-4: Using SAR imagery the flooding of Limerick in 2015 is visualised for December 10 (blue) and December 13 (yellow)[18]

3.1.2 Advantages

The most important advantages of satellite-based flood mapping include:

- The **capability to acquire data anywhere in the world** without any limitation by weather conditions (when combining optical and SAR) or the impact of the phenomenon itself. This capability is particularly relevant to countries with a climate like Ireland. Thus, contrary to in-situ sensors and communication systems which are prone to damage and/or failure when a disaster strikes, satellites offer a **robust source of near-real time information** to aid flood management. This is also extremely useful when considering inaccessible and hazardous areas which can be monitored without risk during all stages of flood management.
- The ability to generate **consistent, comparable and relatively objective** (i.e. not depending on individual interpretation/observation) information, **collected systematically on multiple scales, from local to regional to nation-wide**;

[18] Taken from Cahalane et al, A Flood of Images, Surveyors Journal, 2016

- The capability to supply **regular, detailed updates on the status of the flood** on a local, regional or national basis. By combining different satellites, this can be even done on a **daily basis** offering an invaluable resource to authorities dealing with flood response.
- Finally, whilst EO satellite data are a complementary data source to in-situ data (as well as airborne data, socio-economic data, and model outputs) in most countries, they **can be the only reliable source of information in countries lacking the ground infrastructure**.

3.1.3 Limitations

When compared to alternatives such as on-site or aerial surveys, satellite-based flood mapping presents the following limitations:

- The flood detection capability of SAR in urban and vegetated areas can be impaired due to resolution and active sensor limitations. Thus, in urban and forested areas, the detection of standing water can be disturbed by the presence of tree canopy or by double bouncing effects.
- Similarly, the flood detection capability of optical satellites is hindered in forested areas due to passive sensor limitations.

Until a few years back, another potential limitation was the cost of acquiring satellite data. That has changed with the advent of the Sentinel era – producing vast amounts of data under the Copernicus full, free and open data policy. This is further alleviated by the ability of countries experiencing large scale flooding to trigger the Copernicus Emergency Management Service at no extra cost. This service, triggered by the Irish flood management authorities for the first time in December 2015, is discussed in the next section.

	Satellite		Other alternatives	
	SAR	*Optical*	*Aerial survey*	*In field survey*
Reaction Time	Need to wait for the next pass	Need to wait for the next pass	Need to set up the flight plan and reach to AoI	Need to organize the in field team and reach the AoI
Acquisition frequency	2 times/day	1 time/day	It heavily depends on AoI size	Generally it is organized as a one shot survey
Clouds interference	Almost null	Blocking issue	Almost null (fly below clouds)	None
Other weather condition Interference	Almost null	Blocking issue	Might be a blocking issue if the airplane cannot fly	Might be a blocking issue for the teams mobility
Resolution (max)	0.5 m	0.5 m	0.1 m	0.01 m (GPS accuracy)
Thematic Accuracy	85% in open areas n.a. in urban and vegetated areas	85% in open areas n.a. in vegetated areas	90% in open areas n.a. in vegetated areas	100%
Coverage (range, in a single day)	100-40,000 kmq	100-40,000 kmq	10-2,500 kmq	Discrete sampling

Table 3-1: Comparative overview of observational features for satellites and other means

3.2 The Copernicus Emergency Management Service

The Copernicus Emergency Management Service (EMS) has been operational since April 2012 – the first Copernicus Service to do so. The objective of Copernicus EMS is to provide information for emergency response in relation to different types of disasters, including meteorological hazards, geophysical hazards, deliberate and accidental man-made disasters and other humanitarian disasters, as well as information for the prevention, preparedness, response and recovery activities of these disasters. The service has a global coverage. Copernicus EMS has two separate service components:

- The EMS on-demand Mapping with Rapid Mapping, Risk & Recovery Mapping, Validation
- The EMS Early Warning and Monitoring systems for floods, fires and droughts.

An overview of the full EMS service is shown below followed by additional details for the different components.

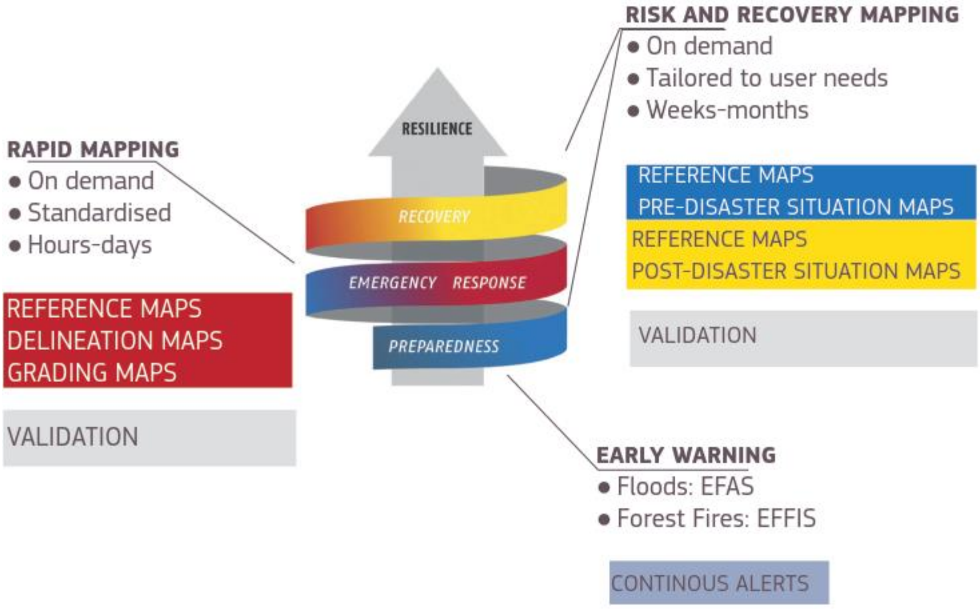

Figure 3-5: Overview of the different components of the Copernicus EMS[19]

3.2.1 Rapid Mapping

The Copernicus EMS Rapid Mapping module maintains an on-duty activity, available on a 24/7/365 basis, for the reception and handling of service requests by authorized users of the service.

Users are entities and organisations at regional, national, European and international level involved in crisis management within the EU Member States, the Participating States in the European Civil Protection Mechanism, the Commission's Directorates-General (DGs) and EU Agencies, the European External Action Service (EEAS), as well as international Humanitarian Aid organisations.

The users fall in three distinct categories:

- **Authorised Users** may trigger the service, by sending a Service Request Form (SRF) directly to the Emergency Response Coordination Centre (ERCC), operating within the European Commission's Civil Protection and Humanitarian Aid Operations department. Such users include National Focal Points (NFPs) in EU Member States and in most countries participating in the European Civil Protection Mechanism as well as European Commission Services (DGs) and the Situation Room of the EEAS.
- **Associated Users** must coordinate with and go through the Authorised Users to trigger the service. These include local, regional and other public entities; International Governmental Organisations (e.g. UN agencies, World Bank), and National & International Non-Governmental Organisations; entities and institutions within the EEAS sphere such as EU Delegations, the INTCEN, the EU Satellite Centre.

[19] Since 2018 the early warning and monitoring component also covers droughts. Graph copyright: Copernicus Emergency Management Service © 2012-2018, European Union.

- **General Public Users** are not authorised to trigger the service, but can be informed of an activation and access all available products through the web portal. Activations, for which sensitivity restrictions apply, are excluded.

The Rapid Mapping service generates (i) pre-emergency asset information in the areas affected by the emergency event, in particular on infrastructure, (ii) impact extent delineation, (iii) quantification and grading of damage caused by natural and man- made disasters, humanitarian crises (iv) information to follow the evolution of the emergency situation in the hours and days after the service activation request.

This information is provided to authorised users on-demand within hours-days following an activation. The actual delivery involves three distinct types of mapping products:

- **Reference maps** provide a quick updated knowledge on the territory and assets in consideration using data acquired before the occurrence of a disastrous event. The content consists of selected topographic features on the affected area, in particular exposed assets and other available information that can assist the users in their specific emergency management tasks. A reference map is normally based on a pre-event image captured as close as possible prior to the event.
- **Delineation maps** provide an assessment of the event extent (and of its evolution if requested). Delineation maps are derived from satellite post-disaster images. They vary depending on the disaster type and the delineation of the areas impacted by the disaster. In the case of flooding, this is the most common type of product offered, providing an accurate picture of the flood extent in the area of interest.
- **Grading maps** provide an assessment of the damage grade (and of its evolution if requested). Grading maps are derived from post-event satellite images. Grading maps include the extent, magnitude or damage grades specific to each disaster type. They may also provide relevant and up-to-date information which applies to the affected population and assets, e.g. settlements, transport networks, industry and utilities.

An extensive description of the different products can be found in the dedicated product portfolio.

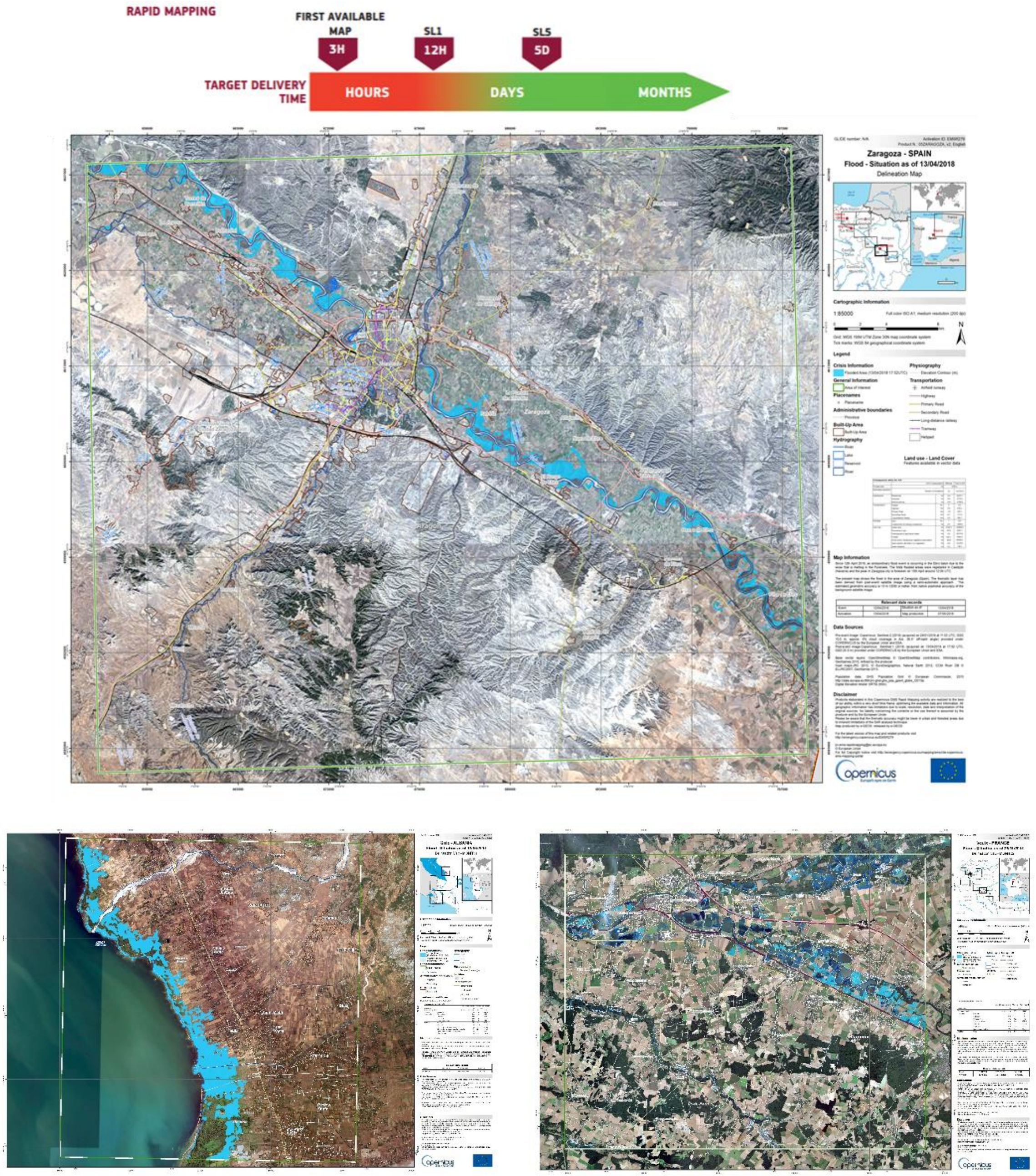

Figure 3-6: Examples of Flood Mapping products produced by CEMS[20]

Currently, the service foresees up to at least 60 rapid mapping activation requests per year. The service can be activated at any time of day and night, including weekends, public holidays and both within and outside normal working times. The maximum number of parallel serviceable activations is 8.

The simplified activation workflow is shown below:

[20] Delineation maps produced by CEMS (Copernicus Emergency Management Service © 2012-2018, European Union).

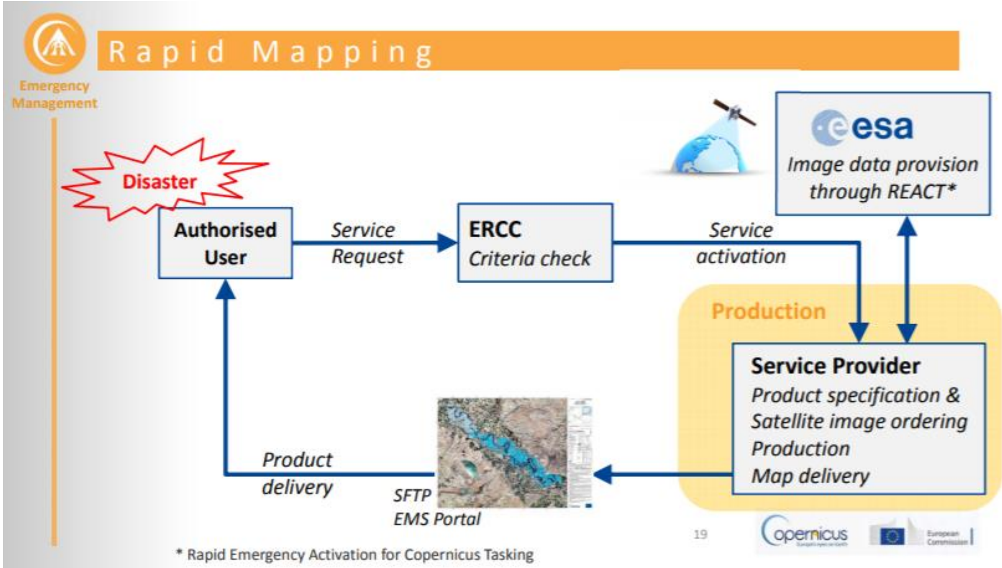

Figure 3-7: Overview of Rapid Mapping activation workflow[21]

The service is implemented by the European Commission's Joint Research Centre (JRC) through 4-year framework service contracts. The current contract (2015-2019) is with a consortium led by e-GEOS. More details on that are presented in 4.2.1.

3.2.2 EFAS

The **European Flood Awareness System (EFAS)** [22] **is the first operational European capacity for the monitoring and forecasting of floods across Europe.** It provides its partners - the National Hydrological Services and the Emergency Response and Coordination Centre (ERCC) – with probabilistic, early warning information on impending floods up to 10 days in advance. This information covers all European rivers and is supplied to National authorities twice-daily. The information generated by EFAS uses as input a combination of multiple weather forecasts and ensemble prediction systems (EPS). The basic architecture is shown in figure 3-8 below. The main interface for users to access the information is the EFAS website.

The development of EFAS was triggered in response to the devastating floods in Elbe and Danube rivers in 2002, whereby non-coherent flood warning information from different sources and of variable quality, complicated planning and organisation of aid. Its aim has been to increase the preparedness for floods in Europe. In practice, this means **providing actionable information to flood management authorities across Europe before major flood events strike their countries**. Following an extensive testing period (2005-2010), EFAS became part of the Emergency Management Service of the Copernicus Initial Operations in 2011 to support European Civil Protection. EFAS has been running in fully operational mode since autumn 2012 and today its operational components (see below) are run by Member State organisations.

[21] Credit: (Copernicus Emergency Management Service © 2012-2018, European Union)

[22] A similar capacity has been developed for Forest Fire Information under EFFIS. However, this is out of the scope of our study here.

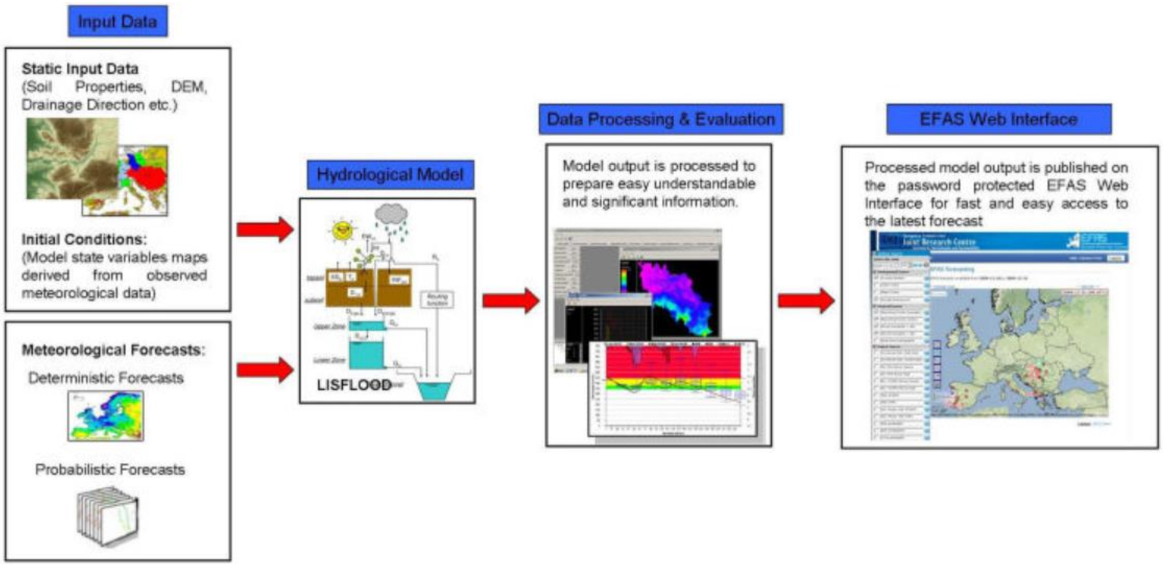

Figure 3-8: The fundamental concept behind the operation of EFAS

It is worth noting that the demonstrated value of EFAS information in the context of flood management during winter 2015/16 in Ireland, has led the Irish government to launch the development of a National Flood Forecasting and Warnings Service (NFFWS). This service, currently under development by Met Éireann and OPW – through a 3M€ budget, will provide accurate short range and detailed forecasts for fluvial and coastal floods. In this way it will complement EFAS, which has proven very useful for medium range and overview flooding forecasts. At the moment, Met Éireann is working together with contractors to review hydrological models and integrator systems for operational fluvial flood forecasting. The improved models should predict the actual peak flow to within +/- 10% and 6 hours of the actual peak at the gauged forecast points, and with a lead time of greater than 24 hours[23].

3.2.3 Risk and Recovery

This service consists of the on-demand provision of geospatial information in support of activities not related to the immediate emergency response phase. Instead it addresses prevention, preparedness, disaster risk reduction or recovery phases, with the products being delivered in the timeframe of weeks/months.

Given the wide variability of situations to be addressed, the user may request products in two ways:

- Choosing from a pre-defined set of detailed topographic features (for example infrastructure) and disaster risk information (hazard, exposure, risk). This allows having a standard base structure;
- Describing in free text the information needs specific to the given situation and type of product wanted. This allows including a wide range of optional information layers, depending on the user's needs.

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[23] For more information see here https://www.met.ie/review-of-hydrological-models

Three broad types of products are provided: (i) **Reference Maps** offering a comprehensive and updated knowledge of the territory and relevant assets in a disaster risk reduction context, (ii) **Pre-disaster situation maps** offering relevant and up-to-date thematic information that can help planning for contingencies on areas vulnerable to hazards, with the aim to minimise loss of life and damage, (iii) **Post-disaster situation maps** offering relevant and up-to-date thematic information for the needs of reconstruction planning and progress monitoring, mapping long-term impact, etc.

3.2.4 Validation

The **validation module** of Copernicus EMS is used for the verification of a sample of service outputs produced by the Rapid Mapping or Risk and Recovery Mapping services. It is therefore implemented independently of these two other services and follows a methodology developed by the Joint Research Centre (JRC). It is worth noting that the validation module was activated for the Irish case following the EMS Rapid Mapping activation of the Winter 2015/16.

3.3 How that data became available into the Irish setting

EFAS started sending out flood notifications at the very beginning of December, warning the Irish authorities (and their UK counterparts) of the high potential of severe flooding in the UK and Ireland for the weekend 5-6 December (associated to the arrival of Storm Desmond). A total of 19 EFAS Flood notifications were supplied to Irish authorities in the period between 3rd December and 6th January. On 4 and 5 December, the meteorological authorities in Ireland and the UK issued red warnings of extreme rainfall events in the west coast of Ireland, north-western England and south-western Scotland. Other parts of Ireland and the UK received amber, orange and red warnings, with some issuing flood warnings. Against this backdrop and following the convention of the National Emergency Coordination Group (NECG), **the Copernicus EMS – Rapid Mapping was activated by the NDFEM on the 8th of December 2015, at 22.12**.

The activation – with the code *EMSR149: Flood in Ireland* – produced a total of 107 flood delineation/extent maps, with the first product being delivered on December 10, 2015 and the last products being published on the 15th of January 2016. A wide range of radar satellites was used including Sentinel-1, COSMO SkyMed, RadarSat-2, and TerraSar-X. All products are available on the EMS Portal www.emergency.copernicus.eu/EMSR149.

Overall, 13 locations were monitored for varied periods and with multiple captures (see below).

Carrick-on-Shannon	(10 Dec – 10 Jan)	– 14 captures
Athlone	(11 Dec – 06 Jan)	– 11 captures
Limerick	(10 Dec – 10 Jan)	– 19 captures
Castleconnell	(14 Dec – 15 Jan)	– 16 captures
Ennis	(17 Dec – 09 Jan)	– 11 captures
Corofin	(17 Dec – 09 Jan)	– 11 captures
Enniscorthy	(02 Jan – 15 Jan)	– 8 captures
Gort	(10 Jan – 12 Jan)	– 3 captures
Roscommon	(10 Jan – 11 Jan)	– 3 captures
Belturbet	(10 Jan – 12 Jan)	– 3 captures
Claremorris	(11 Jan – 12 Jan)	– 2 captures
Ballinasloe	(10 Jan – 12 Jan)	– 3 captures
Portumna	(10 Jan – 12 Jan)	– 3 captures

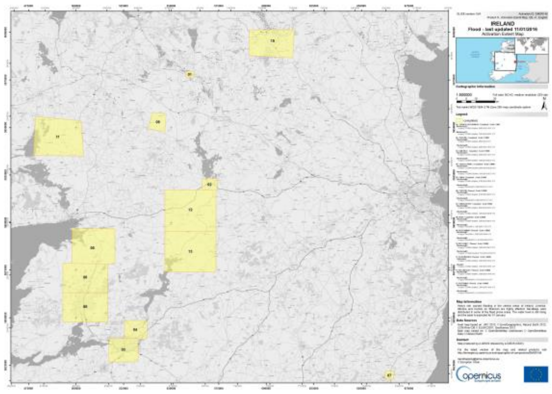
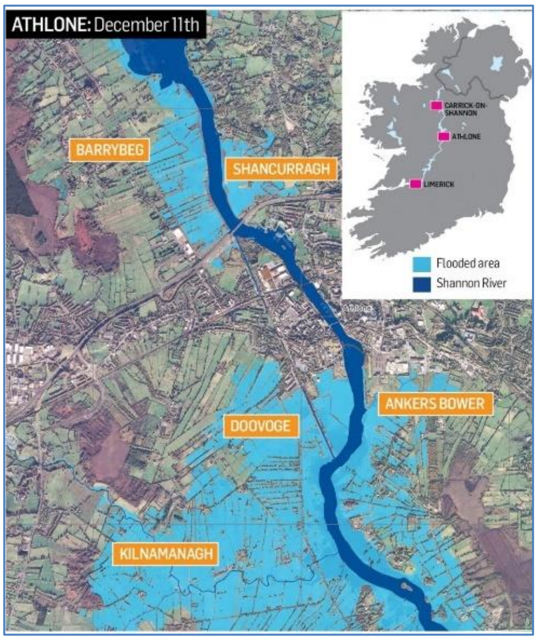


Figure 3-9: Overview of the areas covered by Copernicus EMS following activation EMSR149[24]

The produced flood delineation/extent maps were supplied to NDFEM in pdf and vector format on the EMS SFTP. NDFEM with the help of Robert Ovington set up an instance on ArcGIS online plotting the received maps and overlaying information from the Ordnance Survey of Ireland. The actors involved at local, regional and national level of flood response were given access to this web-service through generic user name and password. This allowed Local Authorities to access the flood maps rapidly and receive daily updates over the covered areas in a very timely manner.



It is important to note that the exact same products made available to flood management authorities were also uploaded on the EMS portal (15 min after they were uploaded on the EMS SFTP) and as such were openly accessible to the greater public (even via their smartphones) and the media. In fact, already as of the 11th of December 2015, the Irish media were using Copernicus Emergency Management Service maps to communicate with the public on the extent of devastation brought by the floods.

Figure 3-10: EMS maps showcased on the Irish Times just one day after they were made available to NDFEM

Thus, the Copernicus EMS flood delineation maps were now accessible to wide range of actors involved in flood response during the Winter of 2015/16. **The exact details on how these maps supported the different actors along the value chain to make informed decisions and take effective actions are presented in the next chapter**.

[24] (Copernicus Emergency Management Service © 2016 European Union, [EMSR149] Flood in Ireland: Activation Extent Map)

4 The use of satellite data across the value chain

4.1 The value chain related to the Winter floods of 2015/16

With the memories of the devastating floods of 2009-2010 still fresh, the National Emergency Coordination Group on Response to Severe Weather Emergencies was convened on December 3, 2015 by NFDEM – as the responsible entity within the Department of Housing, Planning, Community and Local Government. Having the latest data from weather forecasts provided by Met Éireann and the EFAS Flood Notifications[25] disseminated by OPW in hand, the NDFEM Department, chaired by Seán Hogan, brought together around the coordination table all the relevant governmental actors. Their aim was to assess the situation and the projected impacts by the imminent arrival of Storm Desmond, and to organise the response efforts at national to regional to local levels. This meeting essentially gave rise to a complete value chain, whereby actors active in each Tier were accessing and sharing different types of information enabling them to make informed decisions and proceed with targeted interventions to minimise the impact of the floods. This value chain is shown in figure 4-1.

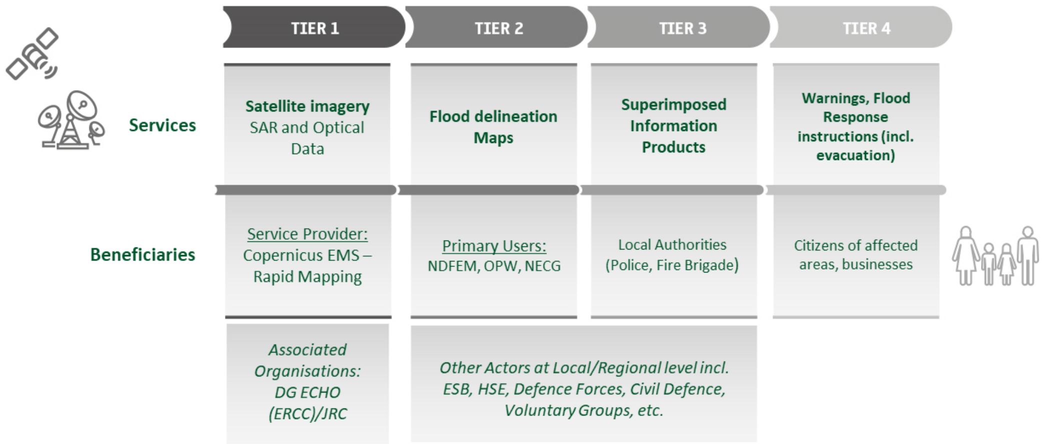


Figure 4-1: The value chain for Flood Management in Ireland

Details on the stakeholders' interests and responsibilities for each of the tiers are presented in the next section.

4.2 Stakeholders interests and responsibilities

As discussed in Chapter 2, the management of floods – especially of such great magnitude as in Winter 2015/16 in Ireland – is a very complex process. The actors involved at different coordination, tactical and operational intervention levels, need accurate and timely information on how the flooding evolves. To that end, and for the first time in Ireland, the use of conventional information sources (see 2.4) was complemented by the satellite-based flood delineation maps provided through the Copernicus EMS – Rapid Mapping. The use of these satellite-enabled maps has helped the various actors to carry out their responsibilities and address their challenges. Let us see how.

[25] A detailed account on EFAS is provided in Chapter 3.

4.2.1 Tier 1 – The satellite-based service: Copernicus Emergency Management Service

The Copernicus EMS – Rapid Mapping provides geospatial information and satellite maps of areas affected by emergencies, supplying the civil protection and the competent authorities of the countries of the Union and international humanitarian Organizations, with the data necessary for the management of catastrophic events. The EMS makes available to any authorised user anywhere in the world, within few hours of the onset of the emergency, also the pre-and post-event mapping, which facilitates the organisation and rescue operations. The Copernicus EMS – Rapid Mapping (see also 3.2) is available 24/7/365 and has a production capacity dedicated to crisis situations (floods, earthquakes, fires, technological disasters). At present, the service contract for the Rapid Mapping component of Copernicus EMS is with a European consortium formed by the Italian company e-GEOS (consortium lead), the German subsidiary GAF, the German Space Agency (DLR), the Italian company Ithaca and the French SIRS and SERTIT.

In the specific case of Winter 2015/16 floods in Ireland, e-GEOS was responsible for the production and delivery of the Copernicus EMS maps to the NDFEM. As discussed in section 3.3, the EMS readily responded to the activation request by the Irish authorities and produced a total of 107 maps over a period slightly longer than a month (08/12 to 15/01). In this process, the best available satellite data was used, including data from Copernicus Contributing Missions (i.e. COSMO SkyMed, RadarSat-2 and TerraSar-X) as well as the free and open Sentinel-1 data.

4.2.2 Tier 2 – The Primary users: Irish National Coordination Authorities

The actors in this Tier are concerned with the timely activation of the national emergency management mechanism and the continuous coordination of response efforts. To do so they are monitoring the evolution of the flooding event across the whole country and dispatching any available information to the involved agencies, governmental departments and other stakeholders.

The key entity in this tier is the **Department of Housing, Planning, Community and Local Government.** This department (and in particular the NDFEM therein) is the **lead Government Department for the response to severe weather emergencies**. Its role is to coordinate with all the involved agencies in a "whole of government" approach and facilitate – as much as possible – the mitigation of flood impacts.

When we discussed with NDFEM representative Paul Rock in Dublin – who was operationally involved throughout the flooding event – his message was clear: "*Life comes first"*. In other words, the top priority of flood response efforts was to protect lives; in fact, thanks to the response efforts only one casualty was reported in association to this event despite it being the worst in the history of Ireland.

With that in mind, Paul (as NCP) triggered the activation of Copernicus EMS – Rapid Mapping on the 8th of December. The aim was to rapidly acquire the best possible situational awareness over the areas worst hit by the floods. The EMS flood maps offered just that: an accurate overview of the extent of flooding in key areas and, thanks to their daily updates, an opportunity to continuously monitor the evolution of the flooding. In addition, as readily reported by Jim Casey of the OPW, the maps provided were very useful for validating CFRAM flood maps and for other flood-related research.

Figure 4-2: Flood delineation map over Limerick produced using Sentinel 1A[26]

But the satellite maps offered also something equally important: a **common framework of reference** allowing the NDFEM to communicate in an easily understandable manner with the political hierarchy, the response agencies, the media and the citizens alike. Thus, contrary for example to the previously worst flooding case of 2009/10, when Paul entered the **National Emergency Coordination Group for Flooding**, he was able to show all other participants the EMS maps, help them understand the scale and extent of the flooding and draw the strategic, tactical and operational decisions using the information they provided. Furthermore, the use of these maps helped the actors of this Tier to reduce the transmission of erroneous information to principal responders, the public and the media. The latter, as briefly discussed in section 3.3, were using these same satellite maps to illustrate the impact of the flooding in their news reports.

In parallel, by setting up a dedicated instance on ArcGIS Online (with the help of Robert Ovington) and adding complementary layers of information on top of the satellite imagery (i.e. city plans, road networks, etc.), the NDFEM offered access to added-value information products to the whole chain of command and, most importantly, to the actors responsible for local/regional intervention. This, as we will see in the next section, was crucial for the effective planning of response measures.

[26] (Copernicus Emergency Management Service © 2015, European Union, [EMSR149] Limerick: Delineation Map, Monitoring 7)

4.2.3 Tier 3 – The downstream users: the relevant local and regional Authorities

This tier is concerned with the operational level of intervention at local and regional level. The lead role in this case is held by the Local Authorities (LAs) – and in particular by the designated Principal Response Agency in each County. The responsibilities of the LAs include[27]:

- Coordinating an inter-agency response;
- Continuously monitoring forecasts/ alerts/ warnings to scale the appropriate response measures;
- Implementing flood response measures;
- Communicating with the Public in the affected areas.

To carry out these activities, the Local Authorities mobilise all the available resources and tap into all sources of information in their disposal. A key partner in this process is the Office of Public Works (OPW) who holds the lead in relation to flood prevention and mitigation. In that regard, OPW acts as an interface between Tier 2 and Tier 3, providing regional updates to the national coordination level (NECG and political hierarchy) but also supporting on a full-time basis the deployment of defences, repairs of damage and clearing of debris. Equally important is the role of OPW as an information channel. In this regard, Jim Casey of the OPW has overseen the dissemination of flood notifications (from EFAS or national capacities) to the Local Authorities' Severe Weather Assessment Teams (SWAT), which together with weather alerts by Met Éireann, allowed the Local Coordination group to coordinate the appropriate response measures. These measures are often carried out in a 24/7 basis and under difficult conditions. They include

- the deployment of sandbag flood defences and pumping equipment to protect key sites (often with the help of the Fire Service, Defence Forces or the Civil Defence);
- liaison with the electricity operator (ESB) to ensure that the water levels of major catchments were managed to prevent flooding, where possible.
- Significant work by outdoor staff within local authorities to keep water courses clear and to remove fallen trees and debris.
- Flood rescue operations

The successful implementation of such interventions relies on the timely access to accurate information, presenting the current state of play of the flooding event as well as its dynamic evolution. Thus, alongside the on-site reports by local authority staff or volunteers, on-demand surveys with aerial means, and information from the hydrometeorological networks, the Local Authorities had for the first time ever access to the flood delineation maps powered by Sentinel 1A and other satellites. All this information was combined in the added-value information products made available through ArcGIS online by the NDFEM.

In this context, it is important to note that the initial activation of the Copernicus EMS was targeted at getting a rapid understanding of the situation in the Carrick-on-Shannon town in the Northwest of Ireland. When the first flood delineation maps for this area were delivered, the Local Authorities quickly realised that "*the provided information was gold!*". This stirred great interest amongst the

[27] More details on this can be found in the NDFEM Report on Flooding

other counties, leading to the submission of another 30 requests by different Local Authorities for satellite mapping of their areas. Eventually, 13 areas of Ireland were mapped until the 15th of January 2016.

As John Keane, the Chief Fire Officer and Head of Fire & Civil Protection Services in the Roscommon County Council, noted "*Coming from such a small county we would have never hoped to have access to such valuable information as that provided with the Copernicus Flood Maps*". John, operating like all other flood response managers at local level in a state of time pressure, and driven by a strong sense of responsibility, quickly realised the strength of the maps as a decision support tool.

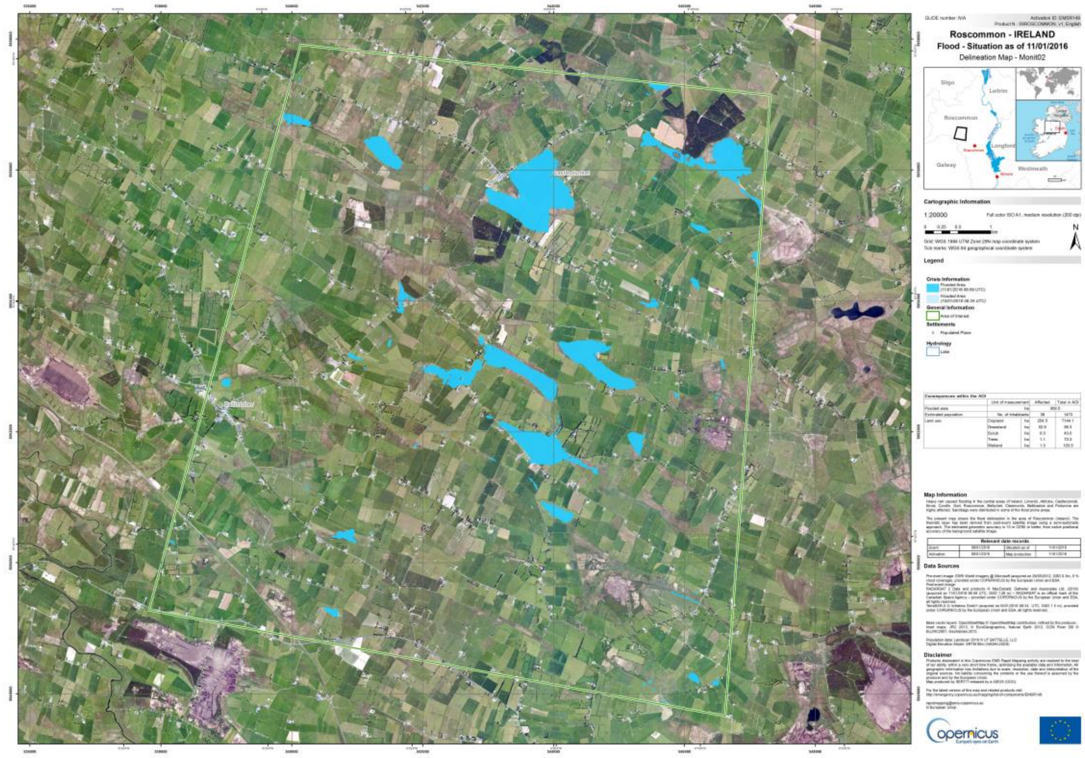


Figure 4-3: A Copernicus EMS Flood Delineation Map for Roscommon[28]

Maps such as the one showcased above were a significant complementary source of information, allowing John (and similarly the other LA's leads) to organise more targeted interventions, better allocate resources and – very importantly – communicate with both the political hierarchy at national level and the public in those affected areas.

4.2.4 Tier 4 – Citizens of affected Areas

This is the Tier where the impact of the flooding is felt most, in terms of threatened livelihoods of citizens and induced damages to their properties or business as a direct result of the floods. It is therefore very important – especially in a flooding event of such unprecedented magnitude, to have

[28] (Copernicus Emergency Management Service © 2016, European Union, [EMSR149] Roscommon: Delineation Map, Monitoring 2)

strong **community resilience**. In practice, the communities struck by the floods took action to protect their homes, businesses, vulnerable people and livestock. In this process, the individual citizens must work together with the Principal Response Agencies and voluntary emergency services, maintaining a good communication and avoiding duplication of effort. Having strong confidence to the instructions issued by the PRA's, allows the citizens to better protect themselves and their properties and to facilitate the work of flood responders. In that regard, satellite-enabled information plays an important role both directly and indirectly. In the former case, the availability of easily understandable flood maps – accessible to each individual either through the internet (the EMS portal) or through mainstream media, allows citizens to see for themselves the bigger picture and build stronger trust in the directions received by PRAs. In other words, seeing that the PRAs are using advanced tools to inform their decisions, allows the citizens to better heed their instructions and, subsequently to better protect their livelihoods and homes. In practice this means that evacuation plans can be executed in a more timely and smooth manner (e.g. moving livestock towards safety), flood prevention measures can be more targeted (e.g. placing sandbags where it matters most), and voluntary support can be more effective (e.g. in some cases supporting neighbouring towns). This aspect was unanimously underlined by the people we interviewed in the context of this study.

In the case of Ireland, this process is further facilitated by an innovative approach adopted by several LAs. The MapAlerter service developed by Pin Point Alerts – a small Irish SME – enables local councils to send geo-localised alerts to the subscribed citizens in their area using SMS, email, a smartphone app, or social media. Through the dedicated mode on "Severe Weather and Emergencies" the LAs can send tailored severe weather and flood alerts to the correct subset of the population of subscribers in their community. The MapAlerter is connected seamlessly to a large number of in-house Council data sources, including Met Éireann and ArcGIS online, allowing to send many alerts in a fully automated mode – i.e. no staff resources required. The effectiveness of the service has already been demonstrated in several emergencies. However, as Brendan Cunningham – the Managing Director of MapAlerter – underlined: "*There is great potential to further improve the service by linking to the open data provided by Copernicus EMS and in particular Sentinel-enabled maps*". Seeing the value of these maps in the context of Winter 2015/16 and subsequent activations, Brendan is certain that this improvement will have considerable impact and that it is technically feasible. This clearly underlines the impact of Sentinels on innovation.

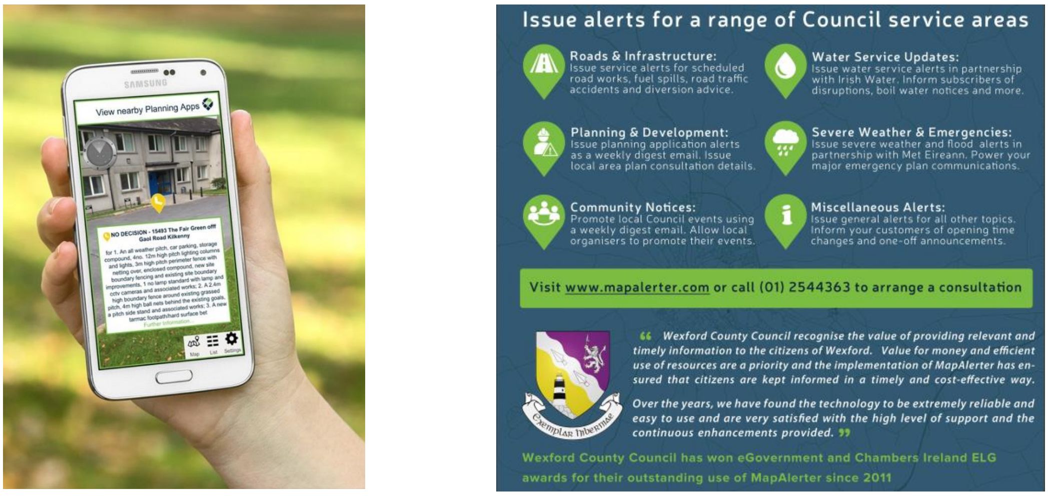


Figure 4-4: The MapAlerter application delivers geo-localised flood alerts to staff and citizens in the affected areas

4.3 Main take away for the next chapter

The common reference point for all the actors in the different tiers, is the use of flood delineation maps – produced using Sentinel 1A and other satellite data – as a key decision-support tool for effective flood management. Thus, in line with the previous cases we have analysed, the focus of our methodology lies on understanding the decisions made and actions taken across the different tiers of the value chain (see figure below) and on assessing the specific value provided by satellite data to make those decisions and actions more effective. This assessment is presented in the next chapter.

	Prevention	Preparedness & EW	Response	Recovery
National	Flood risk assessment tools Structural Measures Land Use Plans	River Level Monitoring EFAS or national forecasting Meteo Alerts Initiate Whole of Government	NECG meetings Triger national Mechanism Dissemination of all available information Monitor Big Picture	Flood Relief Schemes Nationwide damage assessment Improvement of procedures
Regional	Permanent flood defences River Basin Management Regional Risk Assessment	Cross-county Communication Activate Regional offices	Coordination among PRAs Regional Updates to NECG Response for Regional Infrastructure	Restoration of road network Defences implementation
Local	Permanent flood defences Informed Development Plans Temporary Defences	Setup of SWA teams Deployment of sandbags and pumps Issue Warnings	Inter-Agency Coordination Monitoring of Flood Evolution Flood Measures Implementation Comms with Public Community Resilience	Immediate damage assessment & repairs Utilities Restoration Defences implementation

Figure 4-5: Flood management activities in different phases and at different scales

5 Assessing the value of Satellite Data in Flood Management

Now that we know which effects the service is causing in the subsequent tiers of the value chain, we can establish the economic benefits that are sparked thereby: which financial value can we attribute to the availability of the service? That is the question we are addressing in this chapter. In this regard, it is useful to recall our value chain picture whilst adding the last two layers to it.

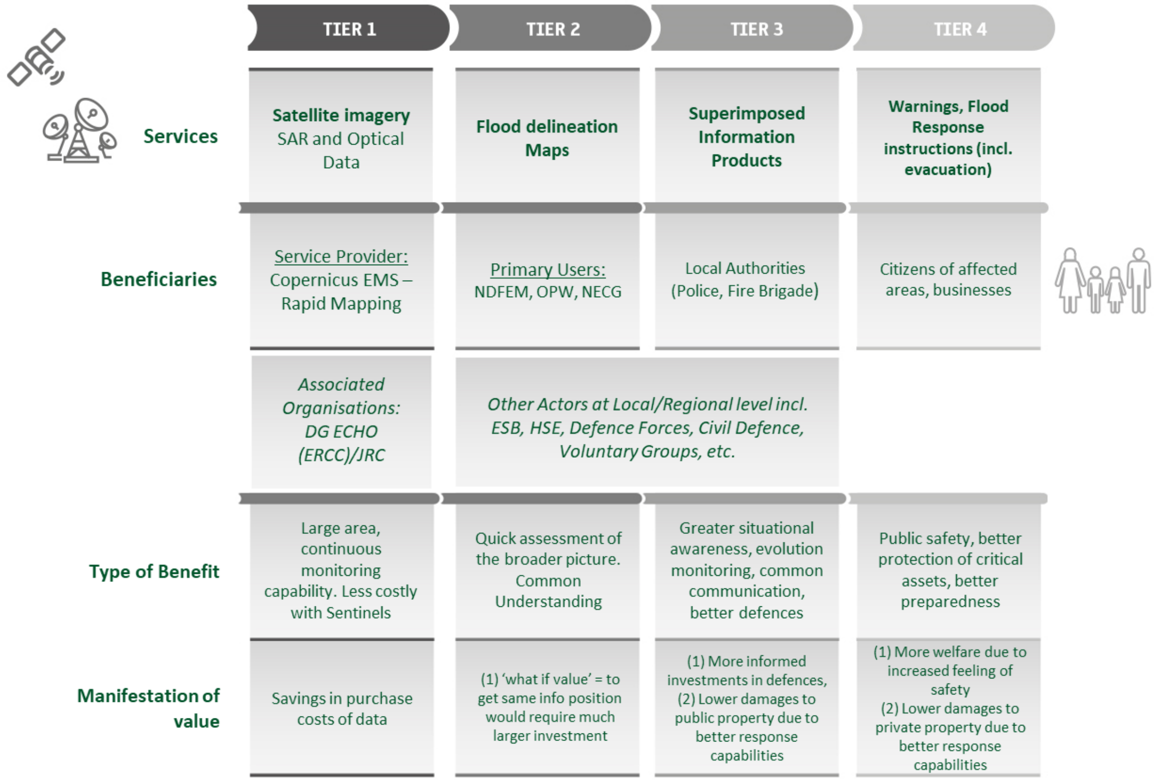


Figure 5-1: The type of benefit and manifestation of value for each Tier in the value chain

Before we go into the calculation of the benefits we should underline three key considerations:

1. The value arises from information extracted from satellite-based flood delineation maps

As discussed in the previous chapter, the information extracted from satellite-based flood delineation maps provided by Copernicus EMS – Rapid Mapping, enables actors in the different tiers to make better decisions and take more timely actions in response to the flooding event. In practice, once the Copernicus EMS was triggered it enabled regular monitoring of the flood event with a short latency and thus empowered early intervention for the flood management authorities. It must be noted that to ensure near-real time monitoring one must use all the satellite sources available, as each satellite constellation has a different frequency of passing over the same spot on the Earth. In other words, using a single satellite constellation would not suffice in such an operational context. Therefore, the quoted economic figures in the coming sections refer to the value arising from satellite-based flood delineation maps provided by Copernicus EMS and using data from Sentinels alongside commercial satellites' data. Thus, when we speak of benefits associated with "satellite data", in practice we refer to the satellite-based flood delineation maps.

In this context, the marginal value of Sentinels is presented in qualitative terms. That said, as we shall see below, Sentinels have become the satellite of choice for subsequent flood-related activations of the Copernicus EMS.

2. Focus on reduced damages

The bulk of the benefit from the use of satellite data in support of improved flood management is mostly felt in Tier 4; this includes the Irish citizens, companies and in fact also governmental organisations, benefitting from reduced tangible and intangible impacts caused by flooding in the Irish territory. The steps and actions (and the related information flows) taken by the preceding tiers are fully geared hereto. Accordingly, we will very much focus on calculating the monetary value of the benefit of the reduction of flood related damages in tier 4, which includes the value of feeling safer perceived by Irish citizens (section 5.2.4).

This being said, one should realize that there are also other benefits which are not discernible, not measurable and/or not monetizable. This applies for instance to the benefits associated with the better information position provided to the authorities, in particular those in tier 2 and 3, and which will generate efficiency gains, meaning the same results could be achieved by deploying less resources. However, in country-wide emergency situations such as the Winter 2015/16 floods, these gains were not cashed in (literally) but rather be invested elsewhere. In other words, regardless of the improved information position the authorities would ensure that "*all hands on deck*" applies, using the totality of resources in their disposal.

Similar considerations apply to the enhanced ability to prepare for future events. Thus, whilst the implementation of future works to reinforce the country's preparedness strongly benefits from the improved awareness of what actually happened, when and where (enabled by satellite maps), these benefits are placed in the future and depend on an event that may not - although likely will - occur (see more in paragraph 5.1.3). The same applies to other side benefits in the form of potential business opportunities being seized following the availability of the Sentinel data, which as mentioned above we will describe in a sort of anecdotal way but will not add a price tag to.

3. Winners and losers

In our study – as we did in previous ones and will do in future ones - we are concentrating on the positive economic effects brought about by the availability and subsequent usage of the Sentinel data in the value chain. That being said, one needs to realize: where there are winners, there must also be some losers. Put differently, innovation and subsequent economic benefits will partly come at expense of existing beneficiaries. However, recent studies demonstrate that 'on balance' and at macro level, there is a distinct positive effect. Annex 3 holds some further observations hereon.

All that said, the next section presents a systematic analysis of the economic value ("adding a price tag") arising from the use of satellite data (and in particular Sentinels) in each Tier.

5.1 Calculating the benefits

5.1.1 Tier 1: The satellite-based service: Copernicus Emergency Management Service

Qualitative Sentinel-related benefits

As discussed in section 3.2, the Rapid Mapping component of the Copernicus Emergency Management Service makes use of satellite data (either Sentinels or from the contributing missions from ESA, their Member States, EUMETSAT and other international third party missions) to produce flood delineation maps. These maps rely predominantly on the ability of satellites to capture and monitor the evolution of a flooding event, but they may also include additional layers of information such as cadastral plans at city level or, very rarely, aerial imagery captured by planes or drones. In this context, the availability – and by now operational maturity – **of Sentinel data presents a significant advantage for implementation of the service**: data continuity. In other words, commercial satellites do not take pictures of the same spot of the Earth continuously, unless they are tasked to do so. Therefore, when a disaster occurs it is highly unlikely that the area of interest will have been captured pre-event. Contrary to that, Sentinels take a picture of every spot of the Earth on every pass. This allows to construct a longer time series which helps a) to establish historic data of a certain region, b) identify changes that have occurred in a given area after an event using the same mapping qualities (resolution, geometry, etc.).

New business opportunities – an important side benefit enabled by Sentinel data

A significant, albeit side benefit associated with the availability of Sentinel data is directly felt by the contractors of the Copernicus EMS service – in this current case the consortium of e-GEOS, GAF, DLR, ITHACA, SIRS and SERTIT. The companies and institutions, through their role as service provider for EMS have developed strong competences that make their value proposition at a global scale very competitive if not unique. This type of benefit is perhaps best exemplified in the case of one of these companies (e-GEOS) being in the process of supplying the Australian government with an "EMS-like" service; to that effect e-GEOS is building on its track record in successfully delivering the Copernicus EMS Rapid Mapping. As a non-EU country, Australia does not contribute to the licensing agreements the EU has with commercial providers for the satellite data provided as part of the Copernicus Contributing missions. Thus, setting up an EMS-like service can only be feasible thanks to the availability of Sentinel data. In essence, the **free, full and open access to Sentinel data enables the business model for the provision of an EMS-like service by a European company (here e-GEOS) to a third-country (here Australia)**, thus creating a win-win scenario.

5.1.2 Tier 2: The Primary users: Irish National Coordination Authorities

Avoided costs

This Tier is concerned with National Coordination, for which maintenance of an accurate situational awareness is crucial. Powered by such awareness, the actors in this Tier – and in particular the National Directorate for Fire and Emergency Management (NDFEM) can better guide those in the next Tiers, eventually helping to reduce damages in Tier 4. As discussed in the previous chapter, this is significantly supported by the availability of flood delineation maps provided by Copernicus EMS using Sentinel and other satellite data.

In order to add a price tag on this benefit, we can ask what cost the Irish Government would have to incur (during the 2015/16 flooding) to establish an information position that is equal to that resulting from satellite-based maps. To do so we can calculate the cost of deploying aircrafts producing aerial photogrammetry maps yielding an equivalent information position.[29] This comparison is meaningful since the thematic accuracy of remote sensing by satellites is comparable to that of aerial surveys even in urban or vegetated areas (85% vs 90%)[30].

To achieve this, we follow the steps presented below.

Calculating the "equivalent" using aircraft

For this comparison we have chosen Beechcraft's King Air 350, a representative aircraft model used by the US NOAA[31] for the purpose of flood mapping and monitoring. Other models such as different types of CESSNA have similar price components. To allow for a meaningful comparison we must draw boundaries with regards to the duration and geographic coverage achieved by satellites and then translate that in terms of the equivalent needs and associated costs for the aircraft. Thus, first we must note that EMS was activated for a total of 38 days during the Winter 2015/16 period. In addition, the maximum coverage/range of SAR satellite imagery in a single day (on SM mode[32]) is 32,000 km^2. However, the actual overall area[33] that is applicable in this case is approx. 15,000 km^2. Therefore, this will be our baseline for the comparison.

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[29] Of course it would have been the question whether, given the level of resources needed, the Irish government would have been prepared to spend such an amount for this purpose, but that is beside the point: what we are doing is trying to put a price tag on the fact that through the availability of satellite data this information position can be established now and compare that with the scenario that the Irish government would have decided that it needed to reach that same position, whatever the resources needed.

[30] Grandoni, Advantages and Limitations of using satellite images for flood mapping, 2013

[31] See here https://www.omao.noaa.gov/find/media/articles/2016-01-18/noaa-aircraft-collect-aerial-imagery-midwest-floods

[32] See details here https://sentinel.esa.int/web/sentinel/user-guides/sentinel-1-sar/revisit-and-coverage

[33] This can be easily calculated on the basis of the overview map found here http://cdn-c.copernicus-ems.eu/mapping/sites/default/files/thumbnails/EMSR149-AEM-1452614313-r29-v1.jpg. We have assumed double the area of the yellow patches in this map as floods could have occurred in other parts of the rivers.

Taking these elements into account we can construct the table below showing the cost to use aircraft for the purpose of acquiring the same information position as with satellites. It must be noted that we have validated our basic assumptions and the calculation of the costs with EUROSENSE, a company specialising in airborne campaigns.

Purchase cost[34] [second-handed]	3,900,000 €
Average cost per hour (incl. depreciation)	2,640 €
Average cost per day (assuming 6 hours of operation in the Winter)	15,840 €
Coverage/range in a single day for one aircraft (max)	2,500 km^2
Cost to cover same area per day	95,040 €
Cost for 38 days	3,611,520 €

Table 5-1: Estimated costs in relation to aircraft operation

Analysing this table, it becomes quickly evident that the cost of operating aircrafts **to cover the same area that EMS can cover over the same period would be approx. 3.6M €.** If we were to add the capital cost for acquiring an adequate number of aircrafts to perform this – because one aircraft cannot in practice cover the needed area per day – the total number would be 6-fold higher.

Clearly this is an upper limit, as the Irish Authorities may have found (partly) other alternatives or may have decided to deploy the aircrafts for a shorter period and more focused on the truly problematic areas.[35] It must be furthermore noted that in this calculation we have not added costs for the digitisation of the imagery acquired by aircrafts, the cost of specialised personnel to perform photogrammetric passes and the cost of purchasing the needed cameras.

This comparison can be extended to drones – where the results are even more favourable towards the use of satellites. One can see that even drone-driven media are reaching this conclusion.

5.1.3 Tier 3: Office of Public Works and Local Authorities

Introductory Observations

As highlighted earlier, the satellite-based flood delineation maps offer an increased accuracy in monitoring the flood events and their evolution. The authorities have better awareness of what is happening in given locations over time. This not only allows to take more informed actions in the response phase, it also enables authorities to spend money in a wiser way towards deploying defences in the recovery phase (which spills over into preparedness for future events), drafting

[34] See here https://www.sherpareport.com/aircraft/costs-king-air-350.html

[35] Actually, between 5 December 2015 and 5 January 2016 the Irish Air Corps took some 6.000 aerial photos of the flooding in the west and along the Shannon. Unfortunately, the pictures were not georeferenced at the time of capture. Therefore, the process of assigning coordinates to each photo was very time consuming, and as a result, digitising the images into flood outline maps is difficult. Also, very locally, swarms of drones were applied.

better emergency response plans and supporting increased resilience of infrastructure. Therefore, the challenge we are faced with when attempting to calculate the benefits here, is that of associating the value of information extracted from satellite-based flood delineation maps with better future investments in preparedness works. In this effort, we have carried out very extensive literature research to build a "baseline" around Return on Investment associated with improved preparedness capacity. Unfortunately, no sources exist in the publicly available literature whereby such baseline is associated to the availability of satellite imagery. In light of this, we had to resort to scientific and economic analyses around the impact of early warning systems in this context. We consider this "leap" to be well justified because of the following observation:

- **Early warning systems** (relying primarily on hydrometeorological data[36]) allow the intervention of authorities just prior to a flood event; authorities can warn the local population of the impeding event, can deploy sandbags and other defences to reduce its immediate impact and can in general improve the overall preparedness just before the storms strike and the rivers flood.
- **Early intervention systems** (relying primarily on satellite data) allow the intervention of authorities just after a flood event and throughout its evolution. In this regard, having the access to accurate map the current status and evolution of flooding (e.g. in regions higher upstream) allows authorities to warn local population further downstream, deploy sandbags and other defences more effectively and minimise the impacts of the event.
- The eventual impact of information provided by early warning towards reduced damages is certainly higher than that of "early intervention" information. On the other hand, the impact on future preparedness is certainly comparable between the two, as they both inform authorities on where defences or resilience supporting measures may be mostly needed for future events.

Based on these observations, we proceed below with the discussion of the benefits associated with improved future preparedness.

Improved Preparedness

Just like in the case of Tier 2, the actors active in Tier 3 are fully focused on the benefits that will ultimately materialise in the form of reduced damages in tier 4[37]. However, there is an actual benefit accruing with the OPW (and to some extent also with the local authorities) in the form of the enhanced ability to take better investment decisions.

And those investments are substantial. In 2016, under the OPW Capital Programme and Minor Works Scheme, 430 million € was allocated for a period of five years. On top of that, in May 2018 the Minister of State for the Office of Public Works & Flood Relief, announced that the government had adopted an additional 10-year €1 billion programme of investment in flood relief measures.

[36] It must be noted that satellite data is also used in conjunction with in situ data for hydrometeorological modelling purposes
[37] As mentioned above, OPW (and also the local authorities) will enjoy efficiency benefits as well, but these resources will immediately be converted into other activities aimed at addressing the flooding, so these benefits will sort of carry over to the benefits created in tier 4.

Put differently, as of 2016, the Irish government, through the OPW, will be spending close to 1.5B€ on flood relief schemes.[38]

So what value can we associate to this in connection to the availability of satellite-based flood delineation maps? First, we need to realize that the enhanced ability to make better investment decisions – spending this 1.5B€ over the period 2016 up to 2030 – is caused not only by the availability of satellite imagery, but a big mix of data sources and experiences from past events and future innovations, including those where imagery has played and will play a role. Secondly, we must be aware that these resources will be spent on a wide array of measures – see table 5-2 for the possible responses to flood warning[39] – ranging from investment in structural flood defence systems to awareness raising. Some of these measures will have a much higher 'Satellite sensitivity factor' than others, where the availability of these data will have no impact whatsoever.[40] Last but not least, the details of the investments are currently largely unknown and may actually change over time and in fact the various measures may have cross over synergetic effects.

Flood warning response	Examples
1. Flood defence operation (FDO)	- Closure of a flood barrier Diversion of flood flows into a flood diversion channel - Opening of flood detention of flood storage areas - Use of flood storage capacity in flood dams and river regulation Emergency repair of failing flood defences - Making breaches in secondary flood banks and informal defences to lower flood levels
2. Operation of community-based options (CBO)	- Mountable/demountable flood defences provided for a community, neighbourhood or road - Community pumping schemes

[38] On 4 May 2018 the Minister of State for the Office of Public Works & Flood Relief said: "*Progressing these initial 50 new flood relief schemes, together with those 75 schemes already complete and underway, will protect 80% of the 34,500 properties assessed at having a 1% chance of experiencing a significant flood event in any year (1 in 100 year flood event). Evidence from the CFRAM Programme has pointed to the feasibility for Government to invest in a total of 118 flood relief schemes over the coming decade which will provide protection to 95% of those properties assessed to be at significant flood risk. While work on all of these has started through the CFRAM Programme, progressing 50 of these schemes from today to detailed design is being expedited by procurement frameworks that have been put in place and, overall, means we are tackling the greatest risk nationally*" (http://floodlist.com/europe/ireland-e1-billion-flood-risk-management-plan-announced).

[39] Sally J. Priest , Dennis J. Parker & Sue M. Tapsell (2011) Modelling the potential damage-reducing benefits of flood warnings using European cases, Environmental Hazards, 10:2, 101-120, DOI: 10.1080/17477891.2011.579335

[40] Quite illustrative is the 2015 Pappenberger study mentioned above, analysing the benefits of a continental scale early flood warning system coming up with a range of estimates of potential avoided flood damages applying a detailed sensitivity analysis of the avoided damages factor, the forecast performance, the impact of discount factors and the uncertainty of the damage datasets. For example, the study estimates that if the pathway of action due to an early warning comprises only water course maintenance, then the ROI (after 20 years) would reduce to 1:4 and, in contrast, improved forecast performance could lead to a ROI of 1:202 (after 20 years).

3. Contingent resilience measures (CRM) 4. Contents moved or evacuated (CME)	- Use of property-level temporary resilience measures - Moving possessions within properties to a higher level, or moving possessions to another location
5. Watercourse capacity maintenance (WCM)	- Remove blockages from watercourses - Clear debris screens - Weed and tree clearance from channels
6. Business continuity planning (BCP)	- Deployment of business continuity plans to reduce direct and indirect flood damages to businesses

Table 5-2: Measures aimed at reducing flood damages or human losses

Putting a price tag on the investments to be made

Briefly put, assessing the impact of the availability of the Satellite data on the investments to be made by the Irish government is in fact an equation with a lot of variables, unknown input data and correlation factors and, ultimately, leads to partly subjective attribution.

That being said, the stakeholders we interviewed have confirmed that there is an impact, so we will have to make assumptions and guestimates.

The first question then is how much of (the value of) the investment decisions to be made are influenceable by the availability of satellite data. We do not have this information and therefore we take a conservative approach **assuming** that only 50% will be 'Satellite sensitive'.

We then get to the assessment of the return of investment (ROI). As noted in the introductory observations, we have not come across any assessments specifically on the impact of Satellite data on flooding prevention investment decisions. However, we can take a number from the Flood Risk Management Plan announced by the Minister of State for the Office of Public Works & Flood Relief on 4 May 2018, where he estimated that the 42 major flood relief schemes set up around the country since 1995 are providing protection to 9,500 properties and deliver an economic benefit to the State in damage and losses avoided of €1.9 billion. As the new investments are to protect another 18,100 properties (assessed at having a 1% chance of experiencing a significant flood event in any year (1 in 100 year flood event)) and if we **assume** that estimated avoided damages and losses per property can be applied on the new investments we end up with a **ROI of 2.4** (meaning that each euro spent will generate a return of 2.4 euro).[41]

Then the question is for what period can we apply this ROI. The statement of the Minister does not clarify this point, and therefore we have relied on the ROI from the Pappenberger study, which is based on a payback period of 20 years. Accordingly, we have done the calculations for the period 2016 – 2048 (being the last year of the payback period, where the investment made in 2029 will yield its last returns, given this ROI period of 20 years).[42]

[41] 9.500 properties yield a benefit of 1.9 B€, corresponding with a benefit of 200,000 € per property. As the new investments are to protect another 18.100 properties, this will lead to a benefit of 3.62 B€. Based on the commitment to invest 1.5 B€ this would imply a ROI of 2,4

[42] Obviously, in practice it may well be that the ROI period of some of the investments will last longer, particularly where it concerns investments in physical infrastructure.

Furthermore, as knowledge on flood prevention will likely increase, we **assume** that throughout the current investment period foreseen, this ROI will grow gradually and steadily. We therefore assume a growth rate of 2% each year until 2029.

Finally, we need to know the incremental value of having the Satellite data, and the subsequent knowledge based thereon. As indicated above, we have not found any specific data to that effect. That being said, clearly, satellite data form an input into the knowledge base where the investment measures are based upon and, furthermore, it is safe to assume that satellite data will be an input of increasing importance. Again, taking a conservative stance we **assume** that the continued longitudinal availability of satellite data will increase the quality of decision making over time – starting with 0.1% in 2016 (the year the first investment program started) and adding 0.1% on top of this each year[43] (base year 2016) leading up to 1.4% 'Satellite related better decision making' in 2029.[44]

This then allows us to calculate the Satellite related benefits that will kick in as the investments are made by the Irish government, as detailed in table 5-3 below. [45]

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[43] It must be noted that the attribution of "annual" benefits may look artificial, however it is a convenient convention that allows us to project into the future. It may well be that in a certain year no major flooding event happens and thus no associated benefits are felt. But whether we look at it from an average point of view or from the recent historical data, it seems that if anything more than one major events are happening per year.

[44] So this increase is related to the relative importance of Sentinel data (in relation to other information sources) which we assume to be increasing over time. This is why this is a separate factor and is not covered by the increase of 2% per year in the ROI we have applied.

[45] Taking 2016 as the base year for calculating the benefits, theoretically, the benefits of the future years should be discounted using cost of capital to give their net present value. As the difference would be fairly insignificant, and as the point being made here is not in the exact value, we have refrained from doing so.

	Investments made in Meuro	proportion of 'satellite sensitive' investments in Meuro	ROI over a period of 20 years in euro	total ROI on satellite sensitive investments over period of 20 years in Meuro	% better decision making attributable to satellite data	total return due to better decision making attributable to satellite data over a period 20 years	total return due to better decision making attributable to satellite data per year in Meuro	total return per year due to better decision making attributable to satellite data per year in Meuro	total cummulative return per year due to better decision making attributable to satellite data in Meuro
source	Irish government	assumption study team	estimate from the from the Flood Risk Management Plan		assumption study team				
value		50%	2.4		0.1				
increase			2%		0.1				
year									
2016	86	43.0	2.4	103.2	0.1	0.1	0.0	0.0	0.0
2017	86	43.0	2.4	105.3	0.2	0.2	0.0	0.0	0.0
2018	86	43.0	2.5	107.4	0.3	0.3	0.0	0.0	0.1
2019	86	43.0	2.5	109.5	0.4	0.4	0.0	0.1	0.1
2020	86	43.0	2.6	111.7	0.5	0.6	0.0	0.1	0.2
2021	150	75.0	2.6	198.7	0.6	1.2	0.1	0.1	0.3
2022	150	75.0	2.7	202.7	0.7	1.4	0.1	0.2	0.5
2023	150	75.0	2.8	206.8	0.8	1.7	0.1	0.3	0.8
2024	150	75.0	2.8	210.9	0.9	1.9	0.1	0.4	1.2
2025	150	75.0	2.9	215.1	1.0	2.2	0.1	0.5	1.7
2026	150	75.0	2.9	219.4	1.1	2.4	0.1	0.6	2.3
2027	150	75.0	3.0	223.8	1.2	2.7	0.1	0.8	3.1
2028	150	75.0	3.0	228.3	1.3	3.0	0.1	0.9	4.0
2029	150	75.0	3.1	232.8	1.4	3.3	0.2	1.1	5.1
2030								1.1	6.1
2031								1.1	7.2
2032								1.1	8.2
2033								1.1	9.3
2034								1.1	10.4
2035								1.1	11.4
2036								1.0	12.5
2037								1.0	13.5
2038								1.0	14.5
2039	no investments made (under the 2018 Flood Risk Management Plan)							1.0	15.5
2040								0.9	16.4
2041								0.9	17.3
2042								0.8	18.1
2043								0.7	18.7
2044								0.6	19.3
2045								0.4	19.7
2046								0.3	20.0
2047								0.2	20.2
2048								0.0	20.2

Table 5-3: Assessment of benefits stemming from Sentinel-related better investment decisions

It should be kept in mind that the ultimate cumulative amount of 20.2 M€ (that will have been yielded in 2048) will be embedded in and disguised as future damages not incurred, which means they will never be visible let alone tangible. This being said, the point is that the availability of the satellite data will serve as a significant multiplier on the investments to be made by the Irish government in the years to come and which will pay off nicely in the future. So, if we take this number and divide it over the number of years in which it will be generated, we end up with an average yearly benefit resulting from the availability of satellite data; this leads up to **better decision making of 0.61 M€ per year** (being 20.2 M€ divided by 33 years).

5.1.4 Tier 4: Irish citizens, businesses and public sector bodies

Clearly, the last tier is where most of the benefits accumulate, largely in the form of reduced damages. Next to that there are distinct, although intangible, benefits in the form of enhanced feeling of safety of citizens, higher trust in the efforts of authorities thanks to easier-to-understand communication and better environmental protection. Finally, we will also see that the specific availability of Sentinel data also sparks business opportunities.

Reduced damages

Introductory observations

In search of identifying and isolating the incremental value of the availability of the satellite data, ideally, we would like to compare the 'ex post situation' with 'the ex-ante situation'. Therefore, in an ideal world we would compare the impact of the 2015/16 flooding (where flood delineation maps using Sentinel and other satellite data were used) with the impact of the floods before that and particularly the recent ones, so those of 2013/14, 2011 and 2009 – where satellite data was not used. For this comparison to hold, we would need to have access to the same information for each of these events as well as the ability to develop a sort of 'standard unit' that would allow us to insert the different input variables into the equation, like: amount of rain per square hectare, per day, per catchment area. This would allow us to calculate the expected damage for the 2015/16 event, compare it with the actual damage observed and, subsequently, connect the reduced damages (in practice a percentage thereof) to the availability of the satellite data (whilst other variables may have an influence as well). This would ultimately leave us with the difference – so reduced damages, deducting 2015/16 'actual' from 2015/16 'expected without satellites'.[46]

Unfortunately, we do not live in this ideal world. Firstly, there is a lack of comparable data. The table 5-4 below presents the data we have been able to retrieve after a very extensive study of available documentation on the Irish floods. Unfortunately, quite some cells have remained empty. Moreover, estimating the benefits of flood forecasting systems is limited not only by the underlying data but also by many other uncertainties including the methods employed to estimate damages and reduced damages[47]. But, even if data are available, the classification thereof is not consistent over time, which does not help either. Comparing 2015/16 with 2013/14 already requires us to merge damage categories (partly based on assumptions)[48].

[46] Merz et al. (2010), give a thorough review of flood damage assessment categories and methods and point out that absence of data and uncertainty are two major factors to take into account. (B. Merz, H. Kreibich, R. Schwarze, A. Thieken, Assessment of economic flood damage Nat. Hazards Earth Syst. Sci., 10 (2010), pp. 1697-1724.)

[47] Florian Pappenberger, Hannah L.Cloke, Dennis J.Parker, Fredrik Wetterhall, David S.Richardson, Jutta Thielen, The monetary benefit of early flood warnings in Europe, Environmental Science & Policy Volume 51, August 2015, pages 278-291

[48] Actually, the national report on the 2013/14 flooding explicitly calls for such 'consistent methodology to measure the economic impact of emergencies and the implications for the Exchequer in terms of capital and current cash-flows.' NDFEM, report on severe weather from 13 December 2013 to 17 February 2014, 11 November 2014, p. 58.

Comparing this with the data available in the United Kingdom, we can only underline that the numbers published there are more detailed as well as more consistent over time[49] [50].

Secondly, even if we would have been able to fill all cells consistently, the next big challenge is the modelling. The relation between the input variables - duration and intensity of the rainfall, in particular, as well as other relevant situational circumstances, like size, topography and geology of the catchment, land use and previous weather conditions, tying in with the saturation level of the soil - and the variables determining the output – like density of population, presence of immovable assets, public infrastructure included, risk enhancing circumstances (like sewage water surfacing, electricity transport cables) - is extremely complicated and possibly even chaotic. However, many facts feed into the assumption that the availability of the satellite-based flood maps has led to significant benefits in the form of reduced damages.

Circumstantial evidence of benefits

Experiences from the past flooding events are well documented by the Irish authorities and lessons learnt driven to improve the related activities for the future events. We analysed reports available for the 2009-2010, 2013-2014 and 2015-2016 events (see hyperlinks) to find elements that may be relevant for evaluating the impact of the use of satellite-based flood delineation maps. We summarise them in the Table below (the texts in the cells have been directly copied from the original reports).

[49] UK Environment Agency, Estimating the economic costs of the 2015 to 2016 winter floods, January 2018, page 48.
[50] In Ireland the relative inaccessibility to robust data may also be due to the ongoing discussions between the main Irish stakeholders – essentially the government and the insurance companies – as to who should pick up the bill for the necessary investments in defences to be done in the near future. In this context, a recent policy paper calls for a new approach which is to be backed up by a transparent data policy.

Year	2009	2014	2015 - 16
Duration	19 November - 10 December 2009	27 January – 17 February 2014 (floods)	4 December 2015 – 13 January 2016
Estimated damages	Private sector: 244 M€ claimed under insurance Public sector: unknown	Private sector: 170,4 M€ claimed under insurance Public sector: 44,3 M€ reported	Private sector: 70 M€ claimed under insurance Public sector: 133,3 M€ reported
Description of event	The flooding emergency started on Thursday, 19 November 2009. The proximate cause of the flooding was the levels of rainfall that occurred during the months of October and November, in combination with the wet summer of 2009, already affecting the normal capacity in catchments to soak up the rain. Rain fell in many areas from the 16 November, and in the 48 hour period of 18/19 November many areas of the southwest experienced over 100mm of rain. The higher/ mountainous areas experienced even higher total levels of rainfall (up to 125mm) in this 48 hour period. The flooding which occurred on the 19 November was sustained by further intermittent rainfall until the 24 November 2009 in many parts of the country.	During the period from 13 December 2013 to 6 January 2014 there were storms in or around Ireland roughly once every three days. In addition to the very strong winds there were periods of extremely heavy rain (most of them rather short- lived) and a lot of thunderstorm activity. These storms coincided with high tides and created severe conditions in a number of coastal areas. After a respite period of around three weeks the country was subjected to a second series of severe storms commencing on 27 January. This second spell of severe weather persisted until 17 February and included the extreme and highly destructive storm event of 12 February 2014. There was a constant threat in	Following an exceptionally wet month of November 2015, severe flooding occurred in many parts of the country as a result of a series of Atlantic Storms beginning on 4 December 2015 with Storm Desmond. Further significant and extensive flooding occurred in the wake of Storm Eva that impacted the country on 23 December. This flooding primarily affected the midlands and west of the country. The heavy rainfall associated with this storm exacerbated existing flooding and gave rise to serious flooding in parts of the country that had previously escaped relatively unscathed. With the ground fully saturated and with no capacity to absorb any more water, rivers and streams around the country swelled and overtopped their banks. Surface water flooding due to

	At the end of the month of November, further rainfall, this time in the east of the country, again led to flooding. The wet weather continued into December, and added to and prolonged the flooding, especially in the West of the country. It was only on the 10 December that the weather situation changed, and that change was to bring its own, different set of difficulties. The area where most damage was done during the flooding was in Cork on the night of Thursday 19 November 2009. The River Lee burst its banks as it entered the western city suburbs and caused extensive damage to property to the order of 141 M€ (insurance estimates).	a number of river catchments of severe flooding arising from the rainfall.	pluvial factors i.e. resulting directly from intense and prolonged rainfall also occurred. Storm Frank on 29 December brought yet more rain with the worst of the resultant flooding occurring in the South East with Carlow, Kilkenny, Waterford and Wexford seriously affected. Graignamanagh was flooded twice in four days and the Quays and other parts of Enniscorthy were inundated when the River Slaney broke its banks. In the case of the River Shannon, the continued and sustained rainfall worsened already severe flooding along that river and its tributaries, flooding a number of homes and leaving many others cut off as roads became submerged. The huge volumes of water discharged through the extensive Shannon catchment caused flooding in the lower reaches also, below the Parteen Weir. Rainfall over the period was 189% of normal, making it the wettest winter ever recorded. Met Éireann measured 602mm total average rainfall for the country during this time.

Observations and recommendations in reports relevant to availability of satellite data	While some individuals were notified of the possibility of flooding**, the general flood warnings which were broadcast for the Cork area on the evening of the 19 November were not sufficiently specific to alert many of the people who were at risk**. It should be noted that three towns in Ireland (Mallow, Clonmel and Kilkenny) had fluvial flood forecasting and warning systems in November 2009, and there was not a specific flood forecasting system in operation on the River Lee in November 2009. The evidence is that both ESB and Cork City Council issued specific warnings to people affected by the flood, and the media carried severe weather warnings. **However, these more general warnings did not alert people at risk to the reality of what was coming. The main difficulty in this case was a disjoint between the meteorological and the hydrological system information, the failure to convert this into a coherent picture of what might happen, and then communicate this**	Sector-specific and general public communications need to be further developed to improve emergency messaging and resilience. **The mechanisms for issuing effective and timely public warnings and information in cases of fast moving/ developing emergency situations, such as the severe storm of 12 February 2014, need to be further developed also. A key element of this is ensuring accurate and up to date situation reports between local co-ordination level and national level (National Co-ordination Group). This would allow for appropriate consideration and decision-making and so that appropriate public messages can issue effectively and in a timely manner.** Previous reports on Severe Weather Emergencies have suggested that there is a need for a consistent methodology to measure the economic impact of emergencies and the implications for the Exchequer in terms of capital and current cash-flows. The events associated with this severe weather, which is by no means an extreme situation, underline again	The severity and spatial distribution of flooding in the winter of 2015/2016 was greater than that of 2009. **However, it has been reported that many areas suffered less damage to property compared to the 2009 event. This could possibly be due to improved awareness and preparedness amongst the local authorities, first responders and residents in those areas. The improvement in preparedness could also be attributed to the fact that it was only 6 years since the last major flooding event in Ireland, and it was fresh in the minds of those involved in the previous response effort. The improvement in preparedness may also be as a result of the work of the National Directorate for Fire and Emergency to publicise the Major Emergency Management Framework documents and the associated Guide to Flood Emergencies amongst the primary response agencies.** **The winter of 2015/2016 was the first widespread activation of the Copernicus EMS in Ireland. The outputs from the Copernicus EMS are being used for a number of post-event**

	assertively to the relevant public as a specific flood warning. **The terms of the warnings that were issued were limited because of this un-coordinated approach to flood forecasting and warning for the areas which were to be affected.** While some excellent hazard identification work had been done within individual agencies, **the available information from the different agencies had not been joined into a comprehensive risk assessment (and flood response plan) which could have indicated with greater clarity the areas likely to be affected by the floods.**	the need for a common and widely understood methodology to gather economic impact information. This would facilitate Government decision-making in relation to funding the response and assessing appropriate recovery programmes, as well as consideration of future investment in prevention and mitigation works.	**activities. The maps are being used to assess the extent of flood damage to land** **and properties in the aftermath of the flooding and are clearly a valuable resource for Irish government departments. It is also being used in the CFRAM Programme to** **validate much of the predictive flood mapping that has been produced for the selected study areas. Furthermore, the outputs from the EMS are also being used as the main source of information for research in some of the third level Irish institutions. Seeing as the winter of 2015 was the first activation of the Copernicus EMS for Ireland, it is now clear that there may be further uses of the Copernicus EMS for flood related studies and research, in Ireland and that Ireland as a partner should encourage the further improvement of the service.**

Table 5-4: Characteristics of 2009-2010, 2013-2014 and 2015-2016 and analyses the relevant findings and recommendations.[51]

[51] The table compares the characteristics of the flooding in 2009-2010, 2013-2014 and 2015-2016 based on the corresponding reports (see hyperlinks).

First of all, we note that reports on the past flooding events concur about the fact that non-negligible benefits were triggered by the availability of the Copernicus data and information. This is best exemplified in the 2015/16 NDFEM report, whereby: *"The Copernicus EMS activation was a considerable additional asset in formulating a real time overview of the extent of the flooding, which could be mapped over time."* Similarly, Jim Casey of the OPW underlined that "*It proved very useful for improved awareness and preparedness amongst the LAs, principal responders, and the public helping to mitigate the impacts of the flooding*".

This was also confirmed by our interviewees who were involved in the actual operations during the events. They helped us produce the table below, comparing the 2015/16 flooding experience with the past ones and identifying, across all phases and levels of competent authorities, the benefits that they think are related to the availability of the satellite data.

	Prevention	Preparedness & EW	Response	Recovery
National	Embedded lessons learned in plans Improved investment	Enhanced confidence and clarity on upcoming event EFAS-calibration of models Timely trigger of national mechanism	Delineation of flood extent and continuous monitoring Enhanced quality of NECG meetings Prioritisation of critical infrastructure	Informed Flood Relief Schemes Cost-effective Nationwide damage assessment Embedding Sat data in operational procedures
Regional	More informed defences Trigger of small catchment prediction Enriched risk assessment based on observations	Common reference for communication Regional scale of monitoring, applicable for disruption minimisation	Update of regional picture Targeted Response for Regional Infrastructure	Validation of forecasts and models Informed defences implementation
Local	More informed defences Informed Development Plans	Timely Setup of SWA teams Resource Preparation EFAS warnings	Delineation of flood extent and continuous monitoring Informed Impact Minimisation Measures Improved communication with all stakeholders Community Trust	Improved positioning for Immediate damage assessment & repairs Common reference for Utilities Restoration Increased confidence for future events

Table 5-5: Examples of benefits from Copernicus EMS in different phases and scales

So, on the basis of the reports compared and the interviews done, we think it is safe to conclude that the availability of the satellite imagery has contributed significantly to the lower level of damages even if the 2015/16 flooding was more severe in terms of volume and duration when compared to the previous events. A major factor contributing to the (relatively large) damages in 2009 and 2014 appears to be a lack of a common point of reference – 'something connecting the dots' - to optimise coordination, particularly at local level. This is best summarised in the case of the extensive flooding in Cork in 2009 whereby, according to the official report, "*The more general warnings did not alert people at risk to the reality of what was coming. The main difficulty in this case was a disjoint between the meteorological and the hydrological system information, the failure to convert this into a coherent picture of what might happen, and then communicate this assertively to the relevant public as a specific flood warning.*"

Accordingly, our take away is – which is confirmed by the Irish interviewees - that the availability of the satellite-based flood delineation maps allowed not only for an integration of the existing information sources (hydrological, meteorological, elevation etc.) enabling early intervention but also, and even more importantly, for a 'near real time contextualisation' of all information available, including feedback loops from the operational people on the ground, allowing for a much better coordinated response and a better capability to intervene.

Adding a price tag to the benefits

Given this role of the satellite data, the question is what value to connect to it. First and foremost: no data hereon exist, meaning we shall have to rely on numbers from studies that are comparable and then apply a sort of 'satellite conversion factor' to those (see more in the introductory observations at the beginning of this chapter).

Actual damage estimations are available from the official Irish sources for the events of 2009, 2014 and 2015/16 and summarised in the Table below, distinguishing between damages to public sector and to private sector.

<table>
<tr><th rowspan="2"></th><th colspan="2">Dec 2015 - Jan 2016</th><th colspan="2">Jan 2014 - Feb 2014</th><th colspan="2">Nov 2009</th></tr>
<tr><th>actual damages in M€</th><th>% of total cost</th><th>actual damages in M€</th><th>% of total cost</th><th>actual damages in M€</th><th>%</th></tr>
<tr><td colspan="7">public sector</td></tr>
<tr><td>Roads Repair</td><td rowspan="6">102</td><td rowspan="6">50%</td><td>11.7</td><td rowspan="6">17%</td><td rowspan="8">unknown</td><td></td></tr>
<tr><td>Repair of Existing Coastal Protection Works</td><td>10.9</td><td></td></tr>
<tr><td>Tourism facilities</td><td>1.9</td><td></td></tr>
<tr><td>Piers and Harbours</td><td>2.3</td><td></td></tr>
<tr><td>Local Authority Infrastructure</td><td>10</td><td></td></tr>
<tr><td>Community and Miscellaneous Infrastructure</td><td></td><td></td></tr>
<tr><td>Response, Clean-up and necessary immediate works</td><td>23.3</td><td>11%</td><td>5.2</td><td>2%</td><td></td></tr>
<tr><td>Irish Rail damage</td><td>8</td><td>4%</td><td>1.8</td><td>1%</td><td></td></tr>
</table>

OPW Historic Properties			0.5	0%		
OPW Infrastructure				0%		
Total public sector	*133.3*		*44.3*	*21%*		
private sector						
private properties	29	14%	109.9	51%		
commercial properties	33	16%	60.5	28%	244	
other	8	4%		0%		
Total private sector	*70*		*170.4*		*244*	
grand total	**203.3**	**100%**	**214.7**	**100%**		

Table 5-6: Overview of damages reported of the 2015/16 floods with those from 2014 and 2009[52]

From the Tables one can see how properties owned by companies and businesses seem to benefit more than public sector infrastructure. Accordingly, it seems justified to create two levels of impact, distinguishing between public and private sector assets.

One can notice that, despite the 2015/16 event being particularly strong (see paragraph 2.1.1 and table 5-4 above), the overall damages to the private sector were declining sharply. The differences could be related to different factors such as the strength and intensity of the flood, but also the overall enhanced capabilities of the Irish authorities to deal with flooding thanks to e.g. the establishment of additional flood defences, better communication technology etc. A main difference is also that in 2015/2016 the EMS was triggered and provided satellite flood maps that allowed enhanced situational awareness.

But how much value can be attributed to the availability of the EMS maps? There are no existing data in this respect. However, there are quite a number of publications on avoided damages following the implementation and usage of systems that enable early warning. As expected and in line with the wide variety of influencing factors the outcomes differ quite significantly. The table below gives a (non-exhaustive) overview of interesting publications and the main numbers mentioned therein.

[52] NDFEM, Towards integrated emergency management – a report on the review of the response to exceptional severe weather events of 2009 – 2010; NDFEM, Report on severe weather from 13 December 2013 to 17 February 2014, November 2014; NDFEM, Report on Flooding December 4 2015 – January 2016, November 2016.

Source and year of publication	Estimate of damages avoided
Smith, D. I., 1981[53]	residents in the city of Lismore (Australia) in 1974 were able to reduce residential damages from riverine flooding by 48 % of the potential damages. This reduction was attributed to the experience of the community, preparedness of residents and sufficient warning lead time
Wind et al., 1999[54]	flood damages from the Meuse floods in the Netherlands in 1995 were 35% lower than those experienced in 1993 when similar areas were affected by floods of comparable discharge. It is argued that in this case the differences in damages can be attributed to both increased flood experience and an increase in warning lead time.
International Commission For The Protection Of the Rhine, 2002[55]	flood warnings can help businesses avoid 50-75% of flood losses
Carsell et.al, 2004[56]	estimates of potential avoided flood damages for flood warnings 48 h ahead range from 4 to 40%
Tunstall, et al., 2005[57]	21 % of the total potential damages could ever be influenced by the provision of a flood warning and that a warning with a lead time of 8 hours would save in the region of 6%.
Parker et al., 2007 and 2008[58]	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%).

53 Smith, D. I., 1981. Actual and potential flood damage: a case study for urban Lismore. NSW, Australia, Applied Geography, 1. 31–39.

54 Wind, H. G., Nierop, T. M., de Blois, C. J. and de Kok, J. L., 1999. Analysis of flood damages from the 1993 and 1995 Meuse floods. Water Resources Research, 35(11). 3459–3465.

55 International Commission For The Protection Of the Rhine, Non Structural Flood Plain Management Measures and their Effectiveness, 2002

56 Kim M. Carsell, Nathan D. Pingel, P.E., David T. Ford, P.E., Quantifying the Benefit of a Flood Warning System, Natural hazards review, 2004

57 Tunstall, S. M., Tapsell, S. M. and Fernandez-Bilbao, A., 2005. The Damage Reducing Effects of Flood Warnings: Results from New Data Collection. Flood Hazard Research Centre, Middlesex University, London.

58 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. and 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.

	Actions such as water course maintenance of community level defences amount to less than 1%.
Sniffer (2006-2009)[59]	Specifically considering domestic properties estimates that flood warnings result in 7,3% avoided flood damages
J. Thielen-del Pozo, et al., 2015[60]	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.

Table 5-7: Overview of research on flooding related avoided damages

These numbers relate by and large to the benefits of **early warning systems**, but as discussed in Section 5.1.3 it is the *seamless integration* of the existing 'traditional' data with the satellite-based maps which allows for the leap in the information position, both in terms of timing and quality. **Without doubt, and as discussed in the previous chapters, systems which can trigger increased awareness at the early stages of the evolution of a flooding event have a positive impact on reducing damages**. Accordingly, we have used the numbers above as a baseline measurement for our assessment by taking the highest and lowest values and subsequently contributing a part thereof to the availability of the satellite data (as this data will further enhance the early warning benefits) to make an assessment of the reduced damages derived from 'satellite related' early interventions. Thus, we get two scenarios, reflecting a minimum and maximum value and a likely interval where the value of the 2015/16 avoided damages lies in, as the table below demonstrates.

	Dec 2015 - Jan 2016 damages[61]	**Baseline estimate of % of avoided damage based on studies in table 5-2**		**Assumed satellite-related contribution (%) to avoided damages**		**assessment of satellite related avoided damage in M €**		
		low	high	low	high	low	medium	high
public sector	133.3	5%	25%	10%	25%	0.67	4.50	8.33
private sector	70	20%	50%	10%	25%	1.40	5.08	8.75
grand total	**203.3**					**2.07**	**9.58**	**17.08**

[59] Sniffer (2006-2009) Assessing the Benefits of Flood Warning (UKCC10, UKCC10A, UKCC10B), 2009

[60] 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

[61] These numbers are taken from table 10.

Table 5-8: Assessment of reduction in damage derived from satellite-enabled early mapping

So applying the low and high percentages from the baseline studies on early intervention benefits (column 'Baseline estimate of % of avoided damage % based on studies' in table 5-2) on the 2015-2016 damages measured and subsequently applying our guestimate, being a high and low scenario (column 'Assumed satellite-related contribution (%) to avoided damages') leaves us with a low and high scenario assessment of the satellite related avoided damages.

Accordingly, we estimate that the avoided damages related to the availability of the flood delineation maps powered by Sentinel (and other satellites') data is at least 2 M€, possibly up to 17 M€, and likely around 10 M€.

Other benefits

As we demonstrated above, the range of benefits is much broader than the avoided damages, although we do expect that this constitutes a large proportion thereof. By means of illustration we mention two other main benefits: the savings from reduced disruption and the value of feeling safer and more secure.

Reduced Disruption

In addition to the direct costs for clean-up and repair of damaged roads, there are **direct and indirect impacts relating to losses in utility from the disruption of the road network**, also referred to as welfare costs. In principle, they can be significant: **road networks underpin economic and social activity** by enabling the movement of goods and people. The size of these cost differs in accordance with the specific context of the flooding event (i.e. population density, existence of alternative routes, whether it is a main road or highway in question, local economic activity, etc.) and the extent of its damage. For main thoroughfares, costs from road disruptions can run up to 120,000 EUR per hour[62].

A wide range of impacts are considered[63,64,65]. Local people, businesses and public services are forced to make detours around roads that are out of service and might experience increased congestion on roads (e.g. damaged lanes are closed, redirections) with cars having to slow down or stay stuck in traffic – in turn resulting in higher fuel usage, longer travel time, higher greenhouse

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[62] E. Hooper, L. Chapman, A. Quinn (2014) Investigating the impact of precipitation on vehicle speeds on UK motorways, Meteorological Applications, 21:2, 194-201, DOI: 10.1002/met.1348

[63] M. Pregnolato, A. Ford, S.M. Wilkinson, R.J. Dawson (2017) The impact of flooding on road transport: A depth-disruption function, Transportation Research Part D: Transport and Environment, 55, 67-81, DOI: 10.1016/j.trd.2016.06.020

[64] M.G. Winter, B. Shearer, D. Palmer, D. Peeling, C. Harmer, J. Sharpe (2016) The economic impact of landslides and floods on the road network, Procedia Engineering, 143, 1425-1434, DOI: 10.1016/j.proeng.2016.06.168

[65] M.G. Winter, E.N. Bromhead (2012) Landslide risk: Some issues that determine societal acceptance, Natural Hazards, 62, 169-187

gas emissions, traffic-related stress, etc. Furthermore, road disruptions sever access to and from communities. As such, access to markets, employment, health and educational services, social activities, etc. is curtailed or blocked. Costs borne in the long-term can also sometimes be relevant. For example, the extended closure of a road and perceived future risk of damage can affect local business confidence[64].

There are established methodologies to estimate welfare costs[64]. They take into account the structure and length of the road network, average traffic volumes, bottlenecks and blockages and how long it takes for the road network to return to normal, deriving resultant loses in utility. For example, a shutdown in a road resulting in 10 km longer journeys for a traffic flow of 250 cars per day will result in extra 2500 km driven, with derivative calculations for the increased fuel costs, time costs and carbon emissions. However, this level of granularity is beyond the scope of this study.

To derive an estimate for welfare costs, this study applies an empirical estimate. It is based on the causal correlation between the degree to which a road network is damaged and the resulting disruption. That is, disruption is directly proportional to road damage, the latter of which is directly measured through the total repair costs of a road network. This approach was used by the Environment Agency to estimate welfare costs from road disruption for the 2015-2016 winter floods in England and Wales[66] - i.e. for the exact same event (Storms Desmond, Frank and Eva).

However, as was noted before, disruption also depends on a variety of other parameters that are highly variable between flooding events. Consulting the available literature, we have defined the high and low scenarios for this case:

- For the 2013-2014 winter floods[67], the Environment Agency estimated welfare costs from road disruption at around 1% of repair costs.
- For the 2015-2016 winter floods, the Environment Agency estimated welfare costs at 50% of road repair costs.

For the purposes of this study, we feel that the upper limit is too high for the high scenario and have revised this parameter to reflect a more modest approach: welfare costs are 30% of repair costs. These parameters are reflected in the table below.

Satellite data (including from Sentinels) can be used to avoid road damage – or quickly act to minimise the disruption from it – and thus the associated welfare costs. By making a daily update in flood delineation maps available, emergency responders can send resources and take measures to protect critical arteries under the threat of damage, wherein it is feasible. Satellite pictures are particularly suitable for this use. The coverage is sufficiently broad to provide a holistic picture of the road network over a vast area, providing an appropriate scale for analysis. In addition, satellite imagery is cost-effective in comparison to drone and aerial imagery (see earlier discussion). As such,

[66] Environment Agency (2018) Estimating the economic costs of the 2015 to 2016 winter floods
[67] Environment Agency (2016) The costs and impacts of the winter 2013 to 2014 floods report

our study reflects the contribution of satellite imagery to avoiding road damage and reducing the welfare costs from the consequent disruptions.

	Dec 2015 - Jan 2016 damages to road (M€)	welfare costs % assessment based on studies		satellite related contribution to avoided damage %		assessment satellite related avoided damage (M€)		
		low	high	low	high	low	medium	high
Total	102	1%	30%	10%	25%	**0.1**	**3.9**	**7.7**

Table 5-9: Assessment of satellite-related avoided welfare-costs from road disruptions

Thus, for the specific case of Ireland winter flooding in 2015/16, an avoided welfare cost of about 3.9M can be estimated.

The value of feeling safer and more secure

Clearly experiencing a flooding will have a significant impact on people's personal lives. The prospect of losing property and even worse will be very stressful, in particular for those people living flood risk areas.

Monetizing the potential impact of the availability of the imagery on the wellbeing of the Irish citizens is of course tricky: not only is the correlation between the usage and the effects unknown but also how does one value 20% more security? Then again, likely any person on the street would confirm such improved safety would have a value. It is important to realize that calculating these benefits is not about actual (avoided) damages: it is about a lower stress level, more confidence so about perceived well-being. Here we should underline that the people we interviewed underlined on several occasions that the use of Copernicus EMS maps helped significantly to build stronger trust among the citizens on the authorities' ability to handle the situation. This was further materialised through the media, where reporters were using the flood delineation maps in their news stories.

Many major settlements in Ireland are situated on estuaries. This includes Dublin (1.8 million people), Cork (0.3 million people), Limerick (0.1 million people), Galway (0.08 million people), Waterford (0.05 million people) and Drogheda (0.04 million people). A recent study shows that Dublin and Cork are listed as high-risk areas for future flooding.[68]

Adding everything up, it would be safe to say that out of the 4.8 million people living in Ireland, at least 50% could be directly affected and will likely suffer from fear for flooding, which gives as an amount of 2.4 million people. The next question would be how much these people would be willing

[68] https://www.irishtimes.com/news/environment/which-irish-cities-will-be-hardest-hit-by-flooding-in-the-future-1.3402451

to pay for a reduction in the risk of the impact of flooding and then to attribute a proportion of that reduction to the availability of the satellite data. At this point we should recall that the economic benefit from avoided damages and reduced disruption is between 2-20 M€ for the case of winter 2015/16 flooding (total damages 203€M). Therefore, we are looking at a low (1%) and high (10%) reduction scenario as shown in the table below.

		Reduction of risk of impact due to satellite data		Range of perceived value in M€ per year
		1%	10%	* 2.4 million people
Willingness to pay per citizen in euros per year	Low	0.01	0.1	0.024 – 0.24
	High	0.1	1	0.24 – 2.4

Table 5-10: Willingness to pay for reduced risk of impact

Clearly, this is a bit of 'gut feeling economics', but it demonstrates the significant multiplier of the impact of the availability of the satellite data, and in particular if this will reduce the risk of impact with higher probability. In fact, it may well be that in the 10% scenario, the willingness to pay will increase progressively rather than proportionally (as we have done in the table). The large number of people involved establishes the big leap in the value.

The value of communicating based on a common framework of reference

Whilst it is not easy to add a price tag to it, we should not overlook the importance of communicating based on a common framework of reference. Thus, contrary to the paradigm of previous flooding events that relied on simply communicating on the basis of numbers (e.g. gauge measurements, weather data), in 2015/16 the satellite-based maps allowed the competent authorities to pass key messages to people on the field, the public but also media. This aspect has been underlined by the interviewed stakeholders time and again as being critical towards facilitating the smooth execution of flood management. In fact, the communicative power of the satellite-based flood maps to convey the scale and extent of the flooding has proven to be invaluable. Furthermore, the use of these maps enabled both the principal responders and the media to convey instructions accompanied by easily understandable visuals, thus reducing the transmission of erroneous or "non-actionable" information. As discussed in section 3.3, almost from the get-go of the event, the media were using the same satellite maps to illustrate the impact of the flooding in their news reports.

5.2 Wrap up and conclusions

Tier	Benefits identified	Economic value stemming from the use of satellite-based flood delineation maps (M€)		
		Low	Medium	High
Tier 2	Savings in the context of establishing same level of situational awareness for the same area and over the same period as Copernicus EMS (comparison with aerial surveying)	**3.61**		
Tier 3	Avoided potential future damages due to better decision making in relation to investments into measures for better future preparedness	**0.61** per year adding up to a cumulative amount of 20.2 M€ by 2048		
Tier 4	Avoided welfare costs	0.1	3.9	7.7
	Avoided damage	2.07	9.58	17.08
	Willingness to pay for reduced risk of impact	0.1 per year	0.7 per year	1.3 per year
	Communicating on the basis of a common framework of reference	NA		
Total in M€		**5.8 + 0.7 per year**	**17.1 + 1.1 per year**	**28.4 + 1.9 per year**

Table 5-11: Overview of economic value from the use of satellite-based flood maps

Looking at the "medium" scenario, we conclude that the use of Copernicus EMS flood delineation maps produced using Sentinel (and other satellites) resulted in an economic benefit for the case of "*Flood Management in Ireland*" of the order of 17.1M€ plus an ongoing benefit of 1.1 M€ per year from 2016 up to 2048.

6 Summary of Findings & Conclusions

This case study, analysing the economic benefits from the use of satellite-based flood maps in Ireland, has given us a strong insight on a prominent, intrinsic contrast.

On one hand **all the actors we interviewed (active at national, regional and local flood management level) were unequivocally convinced about the great value of using flood delineation maps produced with Sentinel 1 or other satellite data**; the enhanced situational awareness, the ability to maintain a continuous monitoring of the flooding situation at such wide scales and the unique opportunity to communicate on the same basis with a wide range of stakeholders (public, flood management staff, politicians, media) makes these satellite-based maps an invaluable, decision-support tool.

On the other hand, the **complexity of flood management** – involving the decisions of multiple actors at different spatial and temporal scales and being influenced by multiple parameters (quality of flood defences, severity of rainfall, topography, catchment characteristics, etc.) – **makes the economic calculations particularly difficult**. Nonetheless, we have attempted – based on established methodologies and well-defined assumptions, to put a price tag on the major categories of identified benefits.

Beyond the quantitative benefits that have been calculated and presented in this report, we have also shed light on some side benefits. These entail the new horizons for business and innovation opened in particular by the availability of Sentinel data in full, free and open manner. e-GEOS, the prime contractor of Copernicus EMS Rapid Mapping, has been able to propose EMS-like services to the Australian government in a case enabled by the access to Sentinel (and other Copernicus) data. Similarly, the SME MapAlerter, already operationally supporting emergency management in Ireland, could strongly benefit from the availability of both the Sentinel data and the flood delineation maps to provide added value services to local authorities in and, why not, beyond Ireland.

We hope that this analysis not only underlines the benefit for Ireland but also opens up a window for follow-up or comparative studies in other countries. We conclude our report by presenting some additional observations on these two last points.

6.1 Benefit to Ireland

Increased resilience. Better preparedness. Enhanced capacity to respond. Following the 2015/16 floods, Ireland has systematically sought to build on the experience gained through the first ever activation of Copernicus EMS – Rapid Mapping and realise these three major benefits. Perhaps the most telling fact about the value of the satellite data and how this has been exploited in subsequent years, is that Ireland has activated EMS another 4 times since.

Secondly, this seminal event, has forged the firm intention of NDFEM to incorporate the possibility to activate Copernicus EMS as an integral tool in the Irish flood management framework/protocol which is currently under revision. In that sense, this is truly and in equal part an Irish and EU success story.

6.2 Scalability

This analysis concerns the specific case of Ireland in the context of the Winter 2015/16 floods. As it happens, the same storms that hit Ireland have caused massive damages in the UK too. According to the UK Environment Agency, the estimated damages of the floods in 2015/16 amounted to £1.6 billion. The same practically applies to all previous and future large-magnitude floods associated with heavy rain caused by Atlantic storms. Moreover, whilst continental Europe is not affected so much by Atlantic storms, the impact of river flooding is still enormous. According to the analysis done in the FP7 ClimateCost project, approximately 170,000 people are affected by flooding in the EU27 annually, with this number rising to 290,000 by 2050. The associated annual cost from flood-related damages is estimated to reach 25-50bn by 2050[69].

The increased impact of flooding can be attributed to socio-economic change and climate change alike. For the latter, climate models suggest that "*in the coming decades, climate change will intensify the hydrological cycle, and increase the magnitude and frequency of intense precipitation events in many parts of Europe*".

Against this backdrop, it is important to consider whether the analysis we have performed here and the projected benefits stemming from the use of satellite data delivered by Copernicus EMS (and the marginal effect of Sentinels in particular) can be effectively extrapolated to other countries or even at a pan-EU level. To that end we can make the following observations:

- **Each flooding event has its own specificities** associated primarily with the intensity and duration of the rainfall but also with the vulnerability of the affected area. Also important are the preparedness and response readiness of the authorities and the public especially in terms of reducing the impact of the floods.
- **The impact of fluvial (i.e. river) floods can be significantly different in terms of total costs** if urban areas are heavily affected. This was particularly underlined in the case of the 2009 floods in Ireland where the city of Cork flooded, raising the total damages significantly higher than those of 2015/16 despite the latter event being considerably more severe.
- Whilst the **value of using satellite data for flood management is increasingly recognised**, **its use is, so far, constrained only to events over a certain magnitude**[70]. An indicator for this increased recognition – at minima within the emergency management community in

[69] See for here http://ec.europa.eu/environment/integration/research/newsalert/pdf/372na7_en.pdf
[70] This refers to the threshold over which the Copernicus EMS is activated. Scales for flood magnitude do exist – see for example here

Europe, is the increased total number of flood-related activations of the Copernicus EMS over time.

- Even if the particular case of Winter 2015/16 involved only a few products using only Sentinel 1 satellites it marks the beginning of a new era. In other words, there is a **strong trend of increasing use of Sentinel 1 data** for flood-related activations of EMS Rapid Mapping. Indicatively, before Ireland 2015/16 only 17 Sentinel products were generated for 3 cases (Umbria – same storms as Ireland; Myanmar and Croatia). Since then 286 Sentinel 1 products have been produced, making it the satellite of choice!
- The value of the satellite-based flood delineation maps is further demonstrated by the request of several civil protection authorities (incl. the Irish) for a **more direct access to the products** not only for the primary user but also for the community of responders. This is being considered within the evolution of the service.
- **Many of the benefits brought by the use of satellite data are very strongly felt by the flood management actors but are also very difficult to monetize**. This is to a large extent because the response agencies will "throw all they have" in their efforts to quickly and effectively respond to a massive flooding event regardless of the improved situational awareness position enabled by Sentinels/satellite data. For example, whilst one can certainly claim that better allocation of resources is accomplished thanks to these maps, the Local Authorities will still use all their available personnel – i.e. no "cost savings" in that sense.

Considering all these observations together, we can conclude that the scalability/extrapolation potential of this case study is very high. It could include at minima other cases in which Copernicus EMS has been activated whereby the relative specificities compared to the Irish case could be highlighted.

Whilst such extrapolation is not in the scope of this study it may well be that we perform it in the form of a dedicated "extrapolation report" in the next years of this contract. Strong synergies could then be established with the European Commission's JRC and potentially EEA, to construct a bigger picture and cross-analyse different methodologies and studies[71].

[71] For example in conjunction to the recent book co-authored by JRC and EMS contractors.

Annex 1: References and Sources

The list below covers only the main sources used extensively throughout the study. The reader can find more references in the form of footnotes or hyperlinks throughout the text.

1. NDFEM, Report on Flooding December 4 2015 – January 2016, November 2016: Link
2. NDFEM, A Framework for Major Emergency Management - Guide to Flood Emergencies, July 2013: Link
3. NDFEM, Towards integrated emergency management – a report on the review of the response to exceptional severe weather events of 2009 – 2010: Link
4. NDFEM, A Framework for Major Emergency Management - Multi-agency response to flood emergencies, November 2016; Link
5. NDFEM, Towards integrated emergency management – a report on the review of the response to exceptional severe weather events of 2009 – 2010, June 2011: Link
6. NDFEM, Report on severe weather from 13 December 2013 to 17 February 2014, November 2014: Link
7. OPW, Report of the Flood Policy Review Group, 2004: Link
8. UK Environment Agency, Estimating the economic costs of the 2015 to 2016 winter floods, January 2018: Link
9. Feyen, L. and Watkiss, P., The Impacts and Economic Costs of River Floods in Europe, and the Costs and Benefits of Adaptation - Results from the EC RTD ClimateCost Project, 2011: Link
10. Florian Pappenberger *et al*, The monetary benefit of early flood warnings in Europe, Environmental Science & Policy Volume 51, August 2015, Link
11. The State and Health of the European EO Services Industry; EARSC 2017. Link

Annex 2: General Approach and Methodology

This is the second case of a new set to be analysed following the 1st 3 cases published in 2015/16. It follows the same basic methodology[72] based on establishing a value chain for the use of a single EO service with the addition of an analysis of the environmental impacts.

For each new case, a comparison of the methodology which has been used will update our perspective on the overall methodology to be used for future cases. What have we learned from this case?

In this case the following points stand out:

- The value chain is fully described but the large majority of the economic value is felt in Tier 4 in association with reduced impacts of the flooding. Thus, whilst the decisions and actions leading to reduced impacts are taken in Tier 2 and 3, the results of those decisions and actions – and thus the economic benefit associated to them – materialises mostly in Tier 4.
- The value-chain is to a large extent "agnostic". In other words, the same actors operating in Tier 2, 3 and 4 would still be processing different sources of information to guide their flood response activities regardless of the availability of satellite data. In other words, even if 2015/16 was the first occasion in which Irish authorities triggered the use of satellite data, the composition of the value chain has not changed.
- The case is based on a specific event rather than computing an average annual benefit. Given that the events are quite infrequent (fortunately) it has not been considered worthwhile to try to convert this into an annual benefit which would require assessing the frequency of floods as well as introducing a factor for their severity. It is the first case to be treated in this way but there will surely be more in the future.

[72] SeBS Methodology; June 2017.

Annex 3: Winners… and losers?

The creation and subsequent usage of Sentinel data down the value chain has a significant economic impact. Quite prominently, product and process innovation based on the availability and subsequent application of the data, lead to positive effects where new products and services emerge, and existing processes can be run more effectively and efficiently. Conversely of course, there are also 'negative' consequences as jobs are displaced and sometimes even destroyed, creating technological unemployment.

> As we have shown in our study 'Winter navigation in the Baltics' as the captains on the icebreakers in the Baltics could suddenly rely on Sentinel based ice charts providing a fully synoptic picture of the ice, the helicopter pilots they traditionally relied upon, became abundant.[73] Similarly, in our study 'Forest Management in Sweden' the Swedish Forest Agency could reduce the number of forest inspectors, as Sentinel data allowed for a reduction of in situ inspections.[74]

How technological progress and innovation are related to employment has been an area of fierce debate for centuries. From fairly recent studies appear that product innovation spark new economic activities, creating new sectors, more jobs, whereas process innovation[75] is more job destroying, although market mechanisms can sometimes largely compensate for the direct job losses, mitigating the ultimate impact on demand for labour. Such price and income compensations can derive from a decrease in wages, leading to an increase in demand for labour or the effects of new investments (enabled by accumulated savings) creating new jobs elsewhere. Obviously, the speed and impact of such effects are highly dependent on the flexibility of markets, the level of competition, demand elasticity, the extent of substitutability between capital and labour and, of course, possible institutional rigidity.[76]

> A German study on the co-evolution of R&D expenditures, patents, and employment in four manufacturing sectors concluded that patents and employment are positively and significantly correlated in two high-tech sectors (medical and optical equipment and electrics and electronics) but not in the other two more traditional sectors (chemicals and transport equipment).[77] Similarly,

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[73] Sawyer, G. and De Vries, M. "Winter navigation in the Baltics." Copernicus Sentinels' Products Economic Value: A Case Study (2015)
[74] Sawyer, G. and De Vries, M. "Forest Management in Sweden." Copernicus Sentinels' Products Economic Value: A Case Study (2016)
[75] As process innovation is defined as producing the same amount of output with less labour (and sometimes other) inputs, logically the direct impact of process innovation is job destruction when output is fixed.
[76] Vivarelli, M. "Innovation and employment: Technological unemployment is not inevitable—some innovation creates jobs, and some job destruction can be avoided." IZA World of Labor 2015: 154

[77] Buerger, M., T. Broekel, and A. Coad. "Regional dynamics of innovation: Investigating the coevolution of patents, research and development (R&D), and employment." Regional Studies 46:5 (2012): 565–582.

a study using a panel database covering 677 European manufacturing and service firms over 19 years (1990–2008) detected a positive and significant employment impact of R&D expenditures only in services and high-tech manufacturing but not in the more traditional manufacturing sectors.[78] Another study found a small but significant positive link between a firm's gross investment in innovation and its employment based on longitudinal data set of 575 Italian manufacturing firms over 1992–1997.[79]

Clearly, this tells us that the ultimate 'net' impact of innovation – both at product and process level - brought about by the availability of new technology, such as Sentinel data, will be closely related to the market and institutional settings in which they become effective. However, on the whole the conclusion seems justified that the 'negative' effects, in the form of possible loss of employment, is largely outweighed by the positive economic effects throughout the value chain.

Accordingly, in this study – and likewise for the past and future ones - we will concentrate on the positive effects brought about by the availability of the Sentinel data throughout the value chain. That there are also (temporary) 'negative' impacts is a given, but the net effect at macro level will always be positive.

[78] Bogliacino, F., M. Piva, and M. Vivarelli. "R&D and employment: An application of the LSDVC estimator using European data." Economics Letters 116:1 (2012): 56–59.

[79] Vivarelli, M. "Innovation, employment, and skills in advanced and developing countries: A survey of the economic literature." Journal of Economic Issues 48:1 (2014): 123–154 as well as "Technology, employment, and skills: An interpretative framework." Eurasian Business Review 3:1 (2013): 66–89.

Annex 4: About the Authors

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