INRAE

Flood Risk

Research and expertise to understand, anticipate and protect

Flood of the River Rhone in December 2003 in Fourques (Gard, South France). The dykes protect the town. Copyright: Paul Royet

Flood risk represents the greatest natural hazard in France. One person in four is at risk[1], leaving 17 million inhabitants vulnerable.
The extreme flash flood events of October 2020 and October 2015 in South-East France, which led to more than 20 deaths, and the exceptional plain flood on Seine catchment of May-June 2016, when fewer lives were lost but considerable damage was caused to property and infrastructure, are a reminder of just how high the stakes are in terms of addressing this risk.
How should flood risk be managed?
Can flooding be predicted?
And how can we protect ourselves?

[1]*national flood risk assessment for 2011, French Ministry fot the Environment, Energy, and Sea (July 2012).*

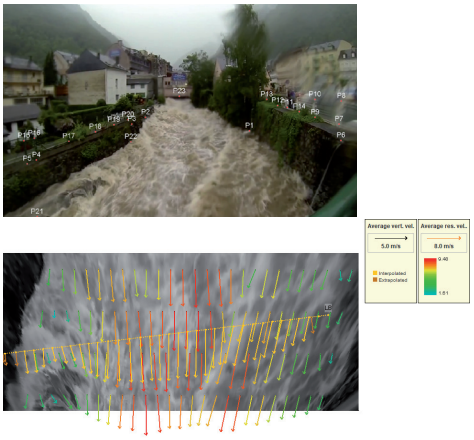
INRAE – the French National Research Institute for Agriculture, Food and Environment – has been an advisory body for the study and management of water-related risks for over 35 years, providing scientific expertise and support for French and European policy and strategy on flood-risk management. INRAE is also a national and world leader on the safety of hydraulic structures (levees and dams), and a major contributor to the works of both ICOLD (International Commission on Large Dams) and CFBR (the French Committee associated with ICOLD). The Institute owes this prominence as much to its targeted research activities as to its expert advice and support for public initiatives. The work of its hydrologists, hydraulics engineers and specialists in soil mechanics and civil engineering in Lyon, Grenoble, Aix-en-Provence and Antony focuses on understanding floods, risk control as well as prediction, and risk reduction and protection measures.

Understanding flood events in order to improve prediction

> In order to study and model flood events on different catchment scales, access to reliable, long-term data is required. Since 2013, scientists and practitioners have been able to access INRAE (formerly Irstea)'s hydrological and biogeochemical data from the long-term observatories it manages or is actively involved in, such as OTHU Yzeron, ORA-CLE, the Rhone Sediment Observatory and OHM-CV, Arc-Isere site of the ZABR (Zone Atelier du Bassin du Rhône/Rhone Basin Long Term Ecological Research Observatory) or Draix-Bleone observatory of IR OZCAR. This data is stored in the Hydrological Observatories Database (BDOH), a collaborative tool for open data sharing and management: https://bdoh.irstea.fr/.

> Using data provided by INRAE and Cerema (Centre for Studies and Expertise on Risks, the Environment, Mobility and Urban Planning), the BDHI (National Database on Historical Floods) keeps a record of exceptional floods that have occurred in France in previous centuries. It is updated with data from new flood events, providing a reference tool for all flood-risk managers. It has been available on line since March 2015: http://bdhi.fr. Another tool developed by Inrae is dedicated to sediment transport data https://en.bedloadweb.com/

> The study of flash floods, which can occur at any time in many places, including small unmonitored catchments, is a more complex matter, especially when there is little available data. INRAE's scientists have recently carried out a scientific assessment of the suitability and degree of measurement uncertainty of new remote-sensing techni-ques to measure flow. Such techniques are safer to use in flash floods and include portable speed radars and analysis of camera images and crowdsourced films posted on YouTube. Thanks to this unique set of data collected on the ground, it has been possible to validate tools for modelling flash flooding on scales ranging from a few km² to 2000 km².



An example of using a crowdsourced flood video to compute surface velocities and discharge using the Fudaa-LSPIV software (images of the Gave de Cauterets flood on 18 June 2013 found on YouTube)

> A further challenge lies in the prediction of extreme hydrological events (with a one in a thousand or even one in ten thousand chance of occurring in a given year) and their effects not only on the behaviour of watercourses but also, beyond these, on vulnerable local features (housing, industries, transport infrastructure, nuclear power stations, etc.). To compensate for the lack of long-term data, the Institute's researchers have developed software for simulating rainfall. The system, known as a rain generator, is based on observed rainfall statistics and generates long rainfall time series. When linked to a hydrological model, the rain-generator can produce flood scenarios to identify future risks. Several hydraulic and morphodynamic numerical models are being developed for real-time or ex-post simulation of flood propagation, sediment transport and bed evolution. This enables a better understanding of the potential risks of flooding in long-reach networks including dam management or locally.

> It is also possible to produce laboratory-based simulations of extreme flood events for different types of land use, and INRAE's platform at its Lyon Villeurbanne centre – the only one of its kind in Europe – is particularly useful in this respect (https://riverhydraulics.inrae.fr/en/tools/hydraulic-laboratory-hhlab/). Its facilities include a glazed 18-metre-long and 3-metre-wide flume with a set gradient for studing the effects of different types of flood-plain surface roughness (such as meadows, woodland and housing) on a river's flow. An urban flood model, built in 2017, can be used to study floods in a system of streets, with potential interaction with urban blocks and sewage systems. Using these experimental facilities, hydraulic modelling tools can be developed and validated to calculate the extent of flooding from rivers, urban systems, and failed hydraulic structures.
Hydraulic platforms dedicated to the experimental study of sediment transport and morphology of mountain streams and rivers, including debris-flow torrents, are also harnessed at INRAE Grenoble to predict flooding risks in mountain environments.

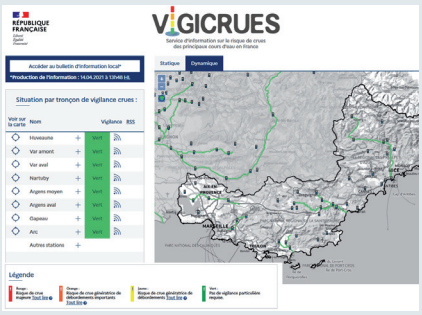
Simulation of extreme floods in the hydraulic laboratory at INRAE's Lyon centre. Copyright: Thierry Fournier

Practical tools for flood control and prediction

> Research data underpins the formulation of flood-control policies
Ways must be found to anticipate the measures required to mitigate the worst effects of flooding. INRAE has been developing innovative methods to assess flood risk in France. For example, the Institute has established a single standardised national database on flood flows (the SHYREG database). Used by the Ministry for Ecology and regionally-based state agencies, this database fills in gaps in the available data for certain areas, thereby helping to generate flood maps for Areas at High Risk of Flooding (TRIs) to comply with the EU Floods Directive.

> Innovating methods for producing flood discharge data
In partnership with river monitoring agencies in France and abroad, INRAE has developed new methods for safer, more accurate observation of flood discharges, and for quantifying the measurement uncertainty.
Such methods have been implemented in free software now commonly used by hydrological services and academics alike. The Fudaa-LSPIV free-software (https://riverhydraulics.inrae.fr/en/tools/measurement-software/fudaa-lspiv-2/) for video-based flow velocity and discharge measurement has been co-developed with EDF. Based on Bayesian inference of hydraulic equations, BaRatin (for Bayesian Rating curve) and its BaRatinAGE graphical environment (https://riverhydraulics.inrae.fr/en/tools/measurement-software/baratinmethod) are used to build stage-discharge rating curves and compute discharge hydrographs with quantified uncertainty. The OURSIN method for the uncertainty analysis of hydroacoustic profiler (ADCP) discharge measurements has also been implemented in the internationally-used QRevInt software (https://www.genesishydrotech.com/qrevint).

> On the monitored network: the Vigicrues service and the GRP model
In France, 21,000 km of rivers are monitored 24 hours a day by the Vigicrues network, coordinated by the national centre for flood forecasting (SCHAPI). Based on the flows measured in the rivers, this service produces a flood warning map, updated at least twice a day (https://www.vigicrues.gouv.fr/). It provides water levels in rivers, compares them to reference levels (historic floods), and forecasts their development over the next 24 hours. The GRP software (https://webgr.inrae.fr/en/software/grp/) developed by INRAE in Antony is among the tools most widely used by the regional flood forecasting services to produce their forecasts. This model calculates future flows and their associated uncertainty in real-time, based on observed rainfall and streamflow data and scenarios of future rainfall. It has proven invaluable to forecasters for anticipating flood events and is currently used by most regional flood forecasting services in France.



Vigicrues map 14/04/2021, Provence-Alpes-Côte d'Azur

> Outside the monitored network: the Vigicrues Flash service and the AIGA method
More than 100,000 km of rivers remain "unmonitored", however. To plug this gap, the state has also set up the Vigicrues Flash service, with the help of scientists from INRAE Aix-en-Provence who have developed the AIGA method (Adaptation of Geographic Information for Flood Warning). Designed as a support tool for decision-makers and managers in crisis situations, the AIGA method does not provide the value of the phenomenon (amount of rainfall or predicted flow rate, as with the GRP model), but simply displays whether it is unusual. For this purpose, the only real-time data needed concerns the radar rainfalls which are then transformed into modelled flows. The results are expressed as return periods. For example, a flood with a return period of 10 years means a flood that has a 1 in 10 chance of occurring each year. Thus, the state services are informed of the rarity of the current flood, even for rivers that do not have real-time measurements.

> For steeply-sloping mountain areas, INRAE and Meteo France now offer an innovative risk management and warning service using a network of radars adapted to cope with rugged terrain. The data they provide is processed using hydrological models so that local authorities can be warned via the RHyTMME web-based platform when there are risks of torrential flooding, mud flows or debris flows and appropriate safety measures can be taken. With three radars installed between 2011 and 2015, the forecasting platform has been tested on the ground by local authorities, national agencies and other risk managers and has demonstrated its effectiveness. It has been in operation in the Hautes-Alpes since January 2016.

An X-band hydrometeorological radar installed at the summit of Mont-Colombis in the Hautes-Alpes. Copyright: Alix Guillot

> Radar technology is now being exported to Sao Paulo in Brazil where intensive rainfall, especially in January and February, causes torrential flooding and landslides. In a joint project with the Novimet company, INRAE's scientists have adapted their models to the urban environment and subtropical climate of the area. In particular, predictions are now updated every 10 minutes rather than every hour (the default pattern for many French flood forecasting services) and the model has been extended to include retention basins designed to attenuate peak flows in urban areas.

Ensuring the safety of levees and dams

Natural risks in mountains and hydraulic structures: INRAE's expertise system certified ISO 9001

In an ever-changing world, research contributions are eagerly awaited and must be commensurate with the challenges to be met . In light of society's expectations in terms of agriculture, food and the environment, INRAE's ability, as a public research establishment, to ensure a "research-expertis" continuum is essential. It is within this framework that the INRAE's Expertise and Public Policy Support Department has been committed, since the Institute's creation in 2020, to the consolidation and external recognition of its expertise and public policy support missions.
Thus, at the beginning of February 2021, INRAE was newly awarded the ISO 9001 certification for the whole of its expertise quality system related to the management of gravity risks in the mountains (snow avalanches, rock falls, debris flows, etc.) and hydraulic structures (dams, dykes, etc.).
This certification confirms the sound reliability of INRAE's expertise in these areas of high concern for public safety.

Breach on the Vigueirat dykes in December 2003 Copyright: Rémy Tourment

> Levees, dykes, or floodbanks, are designed to protect people and property from flooding. However, the exceptional floods of the past thirty years in France – Camargue in 1993 and 1994, Aude in 1999, Gard in 2002, Rhone in 2003 and Cyclone Xynthia in 2010 – have revealed a set of structures that are poorly recorded, insufficiently maintained and neither fully managed nor fully regulated.

Experts inspect emergency repair work carried out following Cyclone Xynthia. Copyright: Rémy Tourment

> Monitoring the condition of every single part of a levee is a challenge for supervisors and managers alike, given that such structures can extend over many dozens of kilometres. INRAE's specialists in levees, in partnership with other research teams (such as Université Gustave Eiffel, Cerema, IGN and EDF) and specialist companies (such as Geomatys, Fugro-Geoid, Tencate, Survey Copter and Sintegra), have developed high-return methods of data collection for the assessment of structures. These rely on the use of airborne Lidar technology (using helicopters and drones) and enables the collection of affordable, high-precision data for embankments ranging from 10 to 50 km in length.
In a recently published book, INRAE describes the first integrated method in France for conducting a risk analysis of levee systems: the culmination of years of development based on actual analyses on real levee systems.

> Most levees are made of earth and their principal cause of failure is internal erosion. INRAE's soil-mechanics experts have developed an experimental device using the Hole Erosion Test (HET) to measure a levee's resistance to erosion. This makes it possible to estimate the probable timespan from the onset of the erosion process to the failure of the structure, which can be a matter of hours, days, or longer. Thanks to the HET, appraisal work can be carried out for industrial partners such as EDF which owns a considerable number of hydraulic structures in France. The experimental apparatus has been handed over to two companies who are helping managers to assess their structures: GeophyConsult since 2012 and Sol Solution since 2014.

> The repair and reinforcement of levees is a further research priority. The reality is that most are old and 65% are in a state of disrepair. Together with ISL Ingenierie, INRAE is looking into the addition of lime to strengthen river embankments. As a stronger and cheaper option for the construction and repair of these structures, this method significantly bolsters resistance to internal erosion and cuts down on the transport of materials. Full-scale tests are now in progress to assess the resistance of a lime-treated soil embankment to surface erosion.

An aerial view of the soil-lime experimental embankment under construction. DigueElite project. Copyright: Dronimages

> INRAE's provision of scientific and technical support for the inspection of embankments on behalf of the Ministry of Ecology includes published reference materials such as the "Réferentiel technique sur les digues maritimes et fluviales" (Technical Guide on River Embankments and Seawalls) and the International Levee Handbook. The Institute has also created a digital platform, WikiBarDig, which brings together comprehensive information on the design and construction of hydraulic structures (embankments and dams) and the processes that cause them to fail or deteriorate with age.
The Institute is tasked with providing expert advice to the Government and lends advice during emergencies (Rhone 2003, Agly 2013, Aude 2014). The extention of its original specialism in river embankments to include seawalls was recognised and put to good use in 2010 in the aftermath of Cyclone Xynthia.

Creating the management strategies of tomorrow

> Improving our future readiness requires us to foster memories of past events. Various databases providing information on historical flood events from across the country (see above, BDHI) have been created by INRAE. Available to local authorities and groups and, in some cases, incorporating information provided by members of the public, these are intended to encourage the pooling of knowledge and wisdom in order to create a risk culture that is shared by all.

> On the basis of this historical data, combined with the national evaluation of possible consequences of flooding (EPRI, Preliminary Flood Risk Assessment), the 122 areas at High Risk of Flooding (TRIs) in France and its overseas *Departments* have been identified. Flood-risk maps have been generated for these in accordance with the EU Floods Directive. Local Flood Risk Management Strategies (SLGRIs) must be produced within the next six years. In addition, each major catchment now has a Flood Risk Management Plan (PGRI). INRAE has been involved in each of these steps to define and implement the French objectives and measures called for by the Directive.

INRAE's flood research also includes new projects to address the economics and sociology of flood management.
In Montpellier, the Institute is analysing the viability of the various management and protective solutions, while in Bordeaux it is investigating how governance needs to adapt to current challenges in flood-risk management.

INRAE: providing support for local authorities

Since 1 January 2018, new responsibilities have been devolved to towns and their authorities concerning the management of aquatic environments and flood control (GEMAPI). Not only is INRAE making available the tools and methods it has developed, but its experts are also providing training, giving talks and setting up partnership projects to assist elected representatives and their staff in their new role.
INRAE (Aix and Antony) also contributes to the PICS project (coord. Univ. Gustave Eiffel, https://pics.ifsttar.fr/en/), aimed at developing a new generation of integrated modelling chains to forecast flash-flood impacts. With reaction times of less than 6 hours, these events can cause extensive damage with many casualties, especially in the Mediterranean region where extreme flood events are expected to increase in the context of climate change.

> Link between floods and climate change

When a major new flood event occurs, the link between the event and climate change is debated, especially as damage caused by floods has increased significantly in recent decades. The temptation is to interpret them as warning signs of the impact of climate change, calling into question flood control measures. INRAE was involved in two pan-European stationarity analyses on flood characteristics recently published in Nature and Science. More than 3,700 gauging stations with discharge data available over a 50-year period (1960-2010) were examined. The results show no consensus on observed trends in floods, which may be shared on a large scale, whether in terms of severity or seasonality of events. Europe displays trends, both increasing and decreasing, in the intensity of floods: over the five decades, the changes range from a decrease in peak floods of -23% in Eastern Europe to an increase of +11% in Northwestern Europe. Warmer temperatures have led to earlier spring snowmelt floods throughout Northeastern Europe, while later winter floods around some sectors of the Mediterranean coast could be due to a change in atmospheric circulation patterns. The fact that no generalised trend appears on the flood regime is related to the complexity of the physical processes that cause runoff. They depend both on climatic evolutions acting on different regional scales and, in an area with a lot of human involvement, on human activity – often flood control and land use change – which can either compoud climate changes or, conversely, compensate its effects. Furthermore, the variability in discharge time series is generally very large, especially where extreme events are concerned, which makes it difficult to detect trends.

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