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# Flooding of industrial facilities - Vulnerability reduction in practice

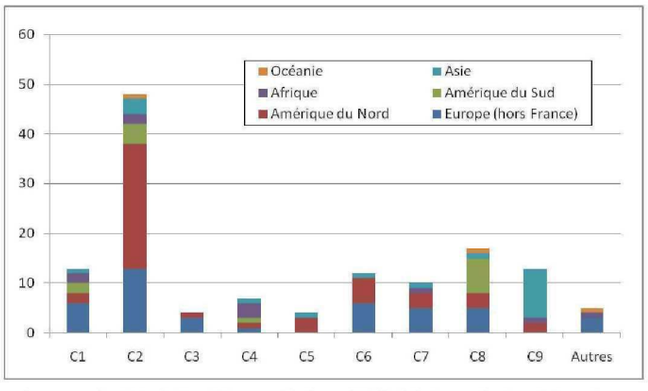
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## 1. Worldwide exposure of industrial plants to flooding

International databases such as OFDA and CRED show that floods accounted for more than half of disasters registered for the 1990-2001 period worldwide. With consequences of climate change largely unpredictable at local level, future statistics are not likely to show any improvement. As human activities historically developed in river areas and floodplains, industrial facilities are structurally exposed to flooding.

ARIA is a database maintained by BARPI, a service of the French Ministry of Ecology, reporting most of major industrial accidents occurring in the country - as well as a selection of accidents occurring abroad. In January 2008, the French Institute for Industrial Environment and Risks (INERIS) performed an analysis of ARIA data. Results show that less than 3 % of accidents (133 events out of 5050) were caused by one or more natural hazards (e.g. flooding, storm, earthquake...). At first glance the susceptibility of countries to experience natural-technological hazards (NaTech) appears, in average, rather low.

The figure below indicates the categories of failures, incidents or accidents triggered by natural hazards, and as reported in the ARIA database:




C1: Breaks of structures or equipments, due to the snow loads, wind or rain
C2: Fire or damage on electric equipments caused by storm and lightning
C3: Pollutions due to heavy rain
C4: Flooding of installations
C5: Chemical reactions initiated by contact with water
C6: Incidents caused by low ambient temperature
C7: Incidents caused by high ambient temperature
C8: Breaks of structures or equipments, due to landslides
C9: Accidents caused by earthquakes

Figure 1: Distribution of the 133 NaTech incidents and accidents reported worldwide

Even if the accidents caused by flooding form a statistically marginal group in terms of events, and when compared to other more frequent major accidents (technical problems, human errors...), it is clear that human, material and environmental consequences of NaTech events can be significant and should not be neglected.

When flooded, industrial facilities present the following two types of consequences:

- Direct consequences: damage to buildings, tanks, pipes, storage of raw materials and finished products, pumps, electrical, thermal and mechanical equipments...
  As shown by the analysis of past accidents, such direct damage may cause major accidents within industrial plants. These include release of hazardous material, soil or water pollutions by hazardous substances for the environment, fires, explosions, dispersion of toxic clouds...
- Indirect consequences: business interruption, temporary unemployment, rising of insurance premium in some countries...

Examples of industrial flooding are many. For instance, heavy rains feeding the El Maleh Oued (river) triggered the flooding of a refinery in Mohammedia (Morocco) on 25th November 2002. Many damages were reported. In particular, the roof of a tank was broken, while another cracked. Released oil products would then mix with the floodwaters. Oils, floating on the surface of the water, came into contact with hot parts of the units, causing a significant fire and a series of tanks, electrical equipments and pipes explosions. Human consequences of this accident counted two dead and four injuries. After the flood, the refinery was closed and its activities were suspended for several months for repair and cleaning.

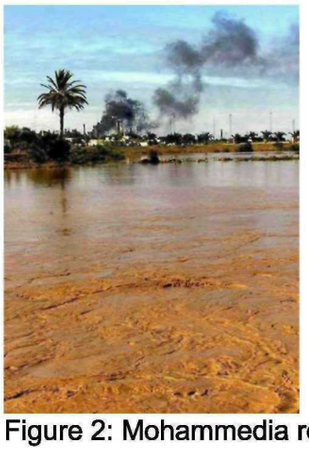


Figure 2: Mohammedia refinery fire (Morocco - 25th November 2002)

Another example is the flooding (caused by the Aisne river, France) of a building where pesticides and fertilizers were stored (Acy-Romance, 22nd December 1993). The water washed away containers and dissolved chemicals. As an emergency response measure, the door of the flooded building was sealed in order to contain the hazardous substances. The water within the plant was analyzed and eliminated by spreading of absorbent products.

It is therefore necessary that industrial plants managers improve their understanding of potential impact of flooding on their facility, and analyse major accidents or release of hazardous materials that may cause by such flooding. This holds true for governments as well, as the existence of an appropriate regulatory framework can be a strong impetus for reducing industrial vulnerability to flooding. Such framework should include prevention and protection features, as well as intervention measures against NaTech events.

This communication first presents how accident risk analysis helps in a) identifying flood-prone equipments or processes in facilities and b) devising appropriate safety barriers or measures. Second, good practices for vulnerability reduction, as applied by flood-prone

industry, are presented and discussed. Third a list of generic safety barriers against flood is proposed.

## 2. INERIS methodology integrating flood hazard in industrial safety assessment

The methodology for the integration of flood hazard in risk-reduction process for new or existing industrial facilities, proposed by INERIS, follows a sequence in 5 steps, as detailed below:

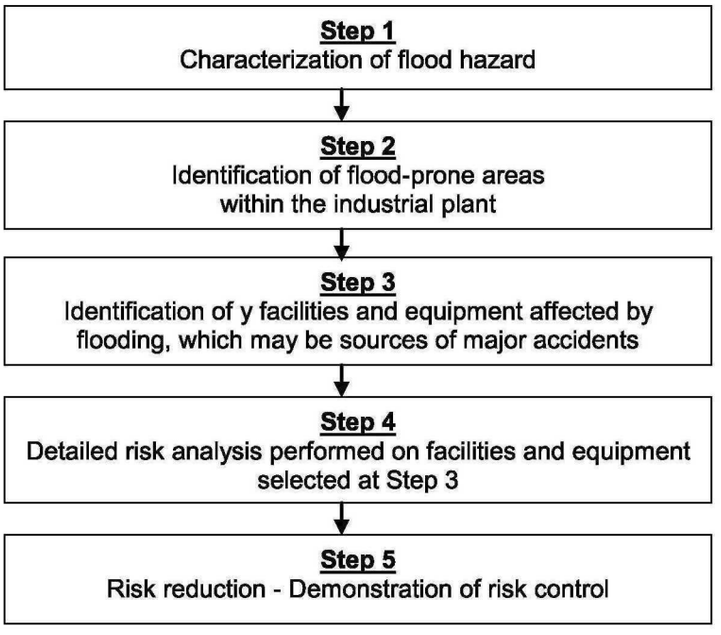



Figure 3 : Integration of flood hazard on industrial facilities - INERIS approach

### 2.1 Step 1: Characterization of flood hazard

This first step aims at determining whether the studied plant is located in a floodable area or not. If yes, data are needed to better understand the flooding, such as type of flooding (direct overflow of rivers, overflow indirectly by rise of water table in aquifer, excess runoff, tsunami...), water height, flow velocity, speed of water level rising, flooding duration, return period of floods...

This work could rely, for example, on documents and/or flood hazard maps (see the following figure), if any, produced or supervised by government and/or public administrations.

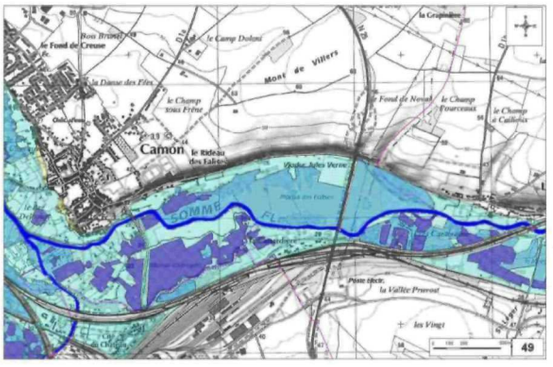



Figure 4: Example of flood hazard maps (Somme river - France)

2.2 Step 2: Identification of areas in the plant that may be affected by flooding

Based on information gathered in Step 1, the topography of the industrial plant, and the location of buildings and facilities within plant perimeter, areas which could be affected by flooding are identified.

Maps of flooded areas in the plant, for different water heights, can be drawn (see figure below):

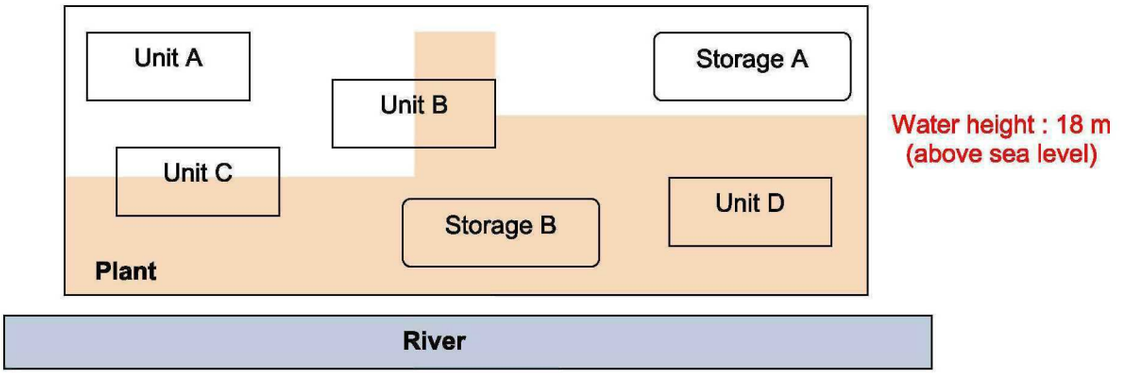



Figure 5: Potentially flooded areas on the industrial site

2.3 Step 3: Identification of flood-prone facilities and equipment likely to cause major accidents

The objective of this step is, in the areas which may be flooded, to identify facilities and equipments potential sources of major technological accidents.

Selecting items vulnerable to flooding is based on:

- an analysis of hazardous properties of substances and preparations contained in the facilities and equipements (Material Safety Data Sheets), with attention given to the *incompatibility* of these products with water,
- a *flotation* study for the tanks,
- an analysis of *lessons learned* from floods that have already occurred on the studied plant or on similar industrial facilities.

2.4 Step 4: Detailed risk analysis on facilities and equipments affected by flooding, which can be sources of major accidents

For each facility and equipment identified in Step 3, the flood hazard should be considered as an external aggression and/or as a hindrance to the functioning of safety barriers.

A systematic risk analysis (Preliminary Risk Assessment - PRA, HAZOP, "bow-tie approach"...) is conducted. The accidental sequences leading to dangerous phenomena (fire, explosion, toxic cloud dispersion, BLEVE, pollution...) are elicited, while existing safety barriers are highlighted. See table below for an example of the type of accident sequence derived from the risk analysis process.

Table 1: Extract of Preliminary Risk Assessment - Storage tank containing flammable liquid

| Initiating events | Critical event | Dangerous phenomena | Safety barriers |
|---|---|---|---|
| Ripple effect (for torrential floods) | Significant breach in the tank | - Soil and water pollution<br>- If ignition, fire and explosion | - Attach the bottom of the tank<br>- Drain the tank in case of flood warning |
| Collisions with floating objects | | | |
| ... | ... | ... | ... |

2.5 Step 5: Risk reduction - Demonstration of risk control

An analysis of the safety barriers performance is achieved. The aim is to minimize accident risk at the plant level, making existing technical and human safety barriers more robust and / or by installing additional barriers. While doing so, stability of (acceptable) risk level must be demonstrated by the operator (by testing robustness of safety chains, by improving staff training...).

French regulation makes it compulsory to conduct this above analysis as part of safety reports that are mandatory for any high-risk industrial facility.

It should be noted that the management of NaTech accident is not limited at reducing the accident risk at source, but others tools such as river basin management, land-use planning and emergency plans, prepared by authorities, may also limit the number of people exposed in the surroundings.

## 3. Good practice for the mitigation of flood impacts on industrial facilities

As an agency placed under supervision of the French Ministry of Ecology, INERIS plays a lead role in advising competent authorities on matters pertaining to industrial safety. In particular, INERIS collects good practices - in France and aboard - for mitigation accident risks triggered by natural hazards. The present section provides an overview of these lessons learned.

3.1 Presentation of two case studies in France

a) A SEVESO-classified type of industry, specialised in manufacturing of aeronautic and aerospace equipment and riparian to the Seine River, has established a flood emergency plan.

Three types of flooding have been found to potentially impact the plant : overflow of the Seine river, water table rising (alluvial aquifer) and flooding by public sewerage.

The reference event chosen for designing the emergency plan was a water level higher than the maximum ever recorded historically (1910 catastrophic flood). Several intermediate levels were defined for progressive warning purposes. Derived actions include:

- monitoring the flooding with graduated scale and piezometers,
- setting up a crisis team,
- building walls to isolate some critical major equipments (protection of the production tools, ensure safety) like gas valve, telecommunications equipments, archives room...
- emptying acids tanks located underground,
- entering in connection with electricity and natural gas networks operators,
- managing the return to normal situation when the water level begins to decline, including cleaning and pumping operations, restart of facilities...

b) Ruptures of dikes along the Rhône river could cause flooding of a warehouse storing agrochemicals. An emergency plan has been prepared for this storage. But the risk reduction was also made through permanent preventive measures such as:

- modification of storage management in order to store at a higher altitude the products most sensitive to moisture,
- installation of electrical equipment above the highest water level already observed in the past,
- increasing of the impermeability of ground and walls by applying resins.

3.2 List of possible measures to reduce vulnerability to flooding

An indicative list of possible measures to reduce the vulnerability of industrial facilities to flooding is proposed (may vary depending on the configuration of the plant):

- Build dikes and levees for protection around the plant,
- Build walls around the critical equipments, those which are the most important for operation and safety / Close certain openings,
- Control, and if necessary strengthen tanks attachment,
- Move storage to areas that are not likely to be flooded,
- Move equipment, sensors, networks (electricity, gas, water, telecommunications, computer system...) above the highest past flooding water height,
- Install systems to cut automatically power and gas supplies,
- Provide pathways which cannot be flooded to make intervention easier, and refuge area outside water for staff

An emergency plan must detailed driving to follow in case of possible flooding and precautions to be taken depending on the nature of concerned products and processes. Generic features of such plan include:

- Definition of the emergency plan implementation threshold,
- Presentation of means to be informed of the water rising : maps / newsletters written by the agencies responsible of climate / flooding forecasting and monitoring, graduated scales located in the plant or in a nearby point, piezometers to measure the groundwater level, regular monitoring and surveys conducted by employees...,
- Description of the organization during the flood (members of the crisis team, operations manager...),
- Mapping of areas in the plant that could be flooded,
- List of critical units and equipments,
- List of temporary actions to be undertaken and the people involved to make them (priority, sequence, decision tools...)
    - Build provisional containments, walls...
    - Close doors and windows with blocking devices (mobile panels...)
    - Move vehicles and non-essential objects out of the plant
    - Attach objects that may move in order to avoid collision and break of pipe or tank
    - Empty tanks (raw materials, manufactured products, solid and liquid waste...)
    - Fill the tanks (over and underground) that may float, provided that the stored products are compatible with water
    - Put facilities in a safe position (isolate tanks, stop product transfers, stop production...)
- Inventory of equipment (pumps, generators, lifeboat, workers protection...) to use
- List of contacts (agencies responsible of climate / flooding forecasting and monitoring, local and national authorities, rescue services, subcontractors...)

During the establishment of this emergency plan, it is important not to forget to include the management of the post-flooding period and the return to normal operating.

Two important points must be seriously considered for assessing available human and material resources:

- Some employees might not be available to make the planned actions (their own houses could be affected by flooding, dead or injured persons in their families, access to the plant impossible...),
- The external rescue services may not help necessarily the crisis team, because they will provide assistance to the population in priority.

Finally exercises must be performed periodically to ensure the effectiveness of this emergency plan.

**4. Flooding vulnerability reduction: difficulties and challenges**

The reduction of the vulnerability to flooding of industrial facilities, as explained in paragraphs 2 and 3, may still face some difficulties in its implementation.

Most countries have initiated policies to reduce impact of natural disasters, and have produced flooding maps. This work taking a long time, all data on floods are not yet available in all areas potentially affected in the world. Without information on this natural hazard,

owners of industrial facilities can not know if their plants are concerned and if measures are necessary.

It should be noted that the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks requires Member States to identify (end of 2011) and map river basin districts and coastal areas at risk (end of 2013), and develop management plans (end of 2015).

Although there exist regulations, rules and/or guidelines for natural disasters on one hand and technological major accidents on the other hand, too few similar documents exist for NaTech accidents management. The need to have guidelines is real for all stakeholders; industrials, authorities responsible of the control, rescue services, insurers... would all be interested.

Authorities and emergency services are not most of the time equipped and prepared to manage multi-hazards disaster such as a major technological accident due to a natural hazard event. Multi-hazards approaches for land-use planning and management of emergencies should eventually be developed.

When a plant is flooded, hazardous substances and preparations may be driven by water and deposited on the soil after the natural phenomenon. It seems that assessment of the short time and long time impacts of this pollution to human health and environment should be further investigated. Experts have to progress in this field.

Post-accidental investigations are essential to improve NaTech related knowledge, extend the list of good practice measures in prevention, protection and intervention, and contribute to improve NaTech risk management.

Working groups with representatives of governments and NaTech experts have been created by the European Commission (Joint Reseach Center - Ispra, Italy) and by the Organisation for Economic Co-operation and Development (OECD) to provide answers to these still outstanding questions.

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