SEINE RIVER FLOODS IN THE ILE-DE-FRANCE REGION

Historical analysis of the flood of 1910
and modeling reference scenarios

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March 2016

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In France, the natural disaster compensation scheme (hereafter the Nat Cat scheme), in effect since 1982, has undergone a certain number of changes, yet the underlying principles remain the same:

- the system is based upon a public-private partnership;
- there exists a principle of solidarity among insureds regardless of their level of exposure to natural events;
- the State participates in the Nat Cat scheme by providing unlimited coverage via CCR's non-compulsory public reinsurance offer;
- Nat Cat coverage may be triggered for relatively frequent events, for example once the 10-year return threshold has been reached for flood coverage.

The Law of July 13, 1982 provides a list neither of covered perils nor of excluded perils. Article 1 of this law only describes what is considered as being the effects of a natural disaster, namely "uninsurable direct material loss and/or damage the determining cause of which was the exceptional intensity of a natural element."

In practice, the perils coming within the scope of application of the Nat Cat scheme are as follows:

- floods (run-off flooding, overflow, rising of water table level, dam burst caused by a natural phenomenon);
- mudslides;
- earthquakes;
- landslides (including subsidence);
- subsidence caused by underground chambers and marl pits (excluding mines);
- tsunamis;
- avalanches;
- cyclonic winds (greater than average of 145 km/hour over 10 mins or gusts of 215 km/hour).

This list is not exhaustive.

The State reinsurance company (*Caisse Centrale de Réassurance - CCR*) is a French limited liability company wholly-owned by the State, with all State guarantees, that proposes unlimited reinsurance coverage to the French market for specialty insurance lines including natural disasters.

The CCR has therefore developed modeling tools to estimate the cost of an event several days after it occurs in order to:

- Establish provisions and financial reserves;
- Inform its stakeholder (the State) and insurance companies (ceding companies) that are reinsured by the CCR.

However, if only recent historic events covered by the Natural Disaster Scheme are analyzed, the assessment of the financial exposure of the State, the CCR, insurance companies and insured parties is incomplete. Among the most noteworthy events, the flood of the Seine in Paris in 1910 is often used as a reference. This involved the most heavily populated region of France (about 18.8% of the population lived in Ile-de-France) and also the most industrialized region (about 22% of insured business risks were located in Ile-de-France).

This report is an updated version of a study conducted by CCR in 2014 at the time of the 2016 *EU Sequana* simulation exercise held from March 7 to 18, 2016[1]. On the basis of its modeling tools, CCR provides an estimate of the cost of damages for two scenarios. Scenario 1 (S1), used in the 2016 *EU Sequana* simulation exercise, is the most extreme scenario with a flow 115% higher than that of January 1910 which corresponds to a height of 9.11 meters (30 ft.) at the Austerlitz bridge (S1). Scenario 2 (S2) applies the same flow as that of January 1910 with a height of 8.15 meters (27 ft.) at the Austerlitz bridge.

This report consists of two parts: the first focuses on the flood of January 1910 and the meteorological context that gave rise to the flood as well as the consequences on the population and the economy. The second part of this report focuses on the simulation results for different scenarios based on the flood model designed and developed by CCR enabling an understanding of the financial consequences on the insured property[2].

[1]For more information: http://www.prefecturedepolice.interieur.gouv.fr/Sequana/EU-Sequana-2016

[2]MONCOULON D., LABAT D., ARDON J., LEBLOIS E., ONFROY T., POULARD C., AJI S., REMY A., QUANTIN A., “Analysis of French insurance market exposure to floods : a stochastic model combining river overflow and surface runoff”, Natural Hazard and Earth System Science, 14, 2014, p. 1469-1485

PART I – CHRONOLOGY OF THE EVENTS OF 1910

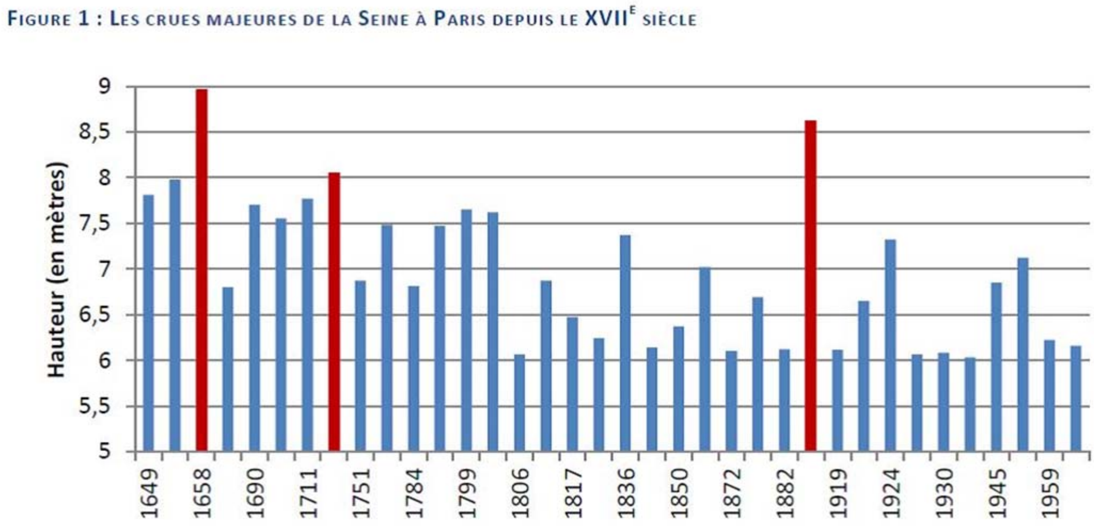
After a very wet winter, the rising water level of the Seine in the spring of 2013 caused fear of a major flood. This flood again raised the question of the vulnerability of the Ile-de-France region. More than a hundred years after 1910 and more than ten years after the last major flood of the Seine in 2001 [5.21 meters (17 ft.) on March 24], the possibility of another major event has prompted public authorities and those involved in aspects of risk to assess its potential consequences.

In the early 20th century, Paris was one of the "centers of the world". The Universal Exposition of 1900 enhanced the image of Paris as the capital city of industrial and technological progress. Hence, in many ways, the 1910 flood may be considered as one of the first floods to seriously jeopardize the agglomeration's resilience. It also illustrates the consequences that the development of society can have on risk exposure.

The 1910 flood in the history of Paris floods

Paris has undergone a number of significant floods Among them, a total of 36 floods have been categorized as major floods, i.e. a height of over 6 meters (20 ft.) at the Austerlitz bridge, or one every 10 years since the great flood of 1649. Sixteen floods exceeded 7 meters (23 ft.) and are considered exceptional (Figure 1). Lastly, three floods exceeded 8 meters (26 ft.) in height; the flood of January 1658, of 1740 and of 1910.

FIGURE 1: MAJOR SEINE FLOODS IN PARIS SINCE THE 17TH CENTURY



FR	EN
Hauteur (en mètres)	Height (in meters)

The flood of 1658 was the result of a particularly harsh winter marked by heavy snowfall and a prolonged period of freezing temperatures that paralyzed the Seine. The flood began when the river started to thaw on February 18. On February 27, the flood reached its maximum high water level of 8.96 meters (29 ft.) at the Austerlitz bridge. The destruction of two pillars of the Pont-Marie bridge, that joins the Ile Saint-Louis to the rest of the agglomeration, stands out as one of the spectacular items of damage, as there were homes built in the bridge at the time.

The flood of December 1740 is well-known thanks to Philippe Buache, architect and member of the Royal Academy of Sciences who drew an accurate map of the inundated area at the flood's peak[3]. This flood began after a period of particularly heavy rains and the Parisians spent Christmas day 1740 in the flood waters.

The flood of January 1910 occurred 28 years after the last major flood [6.12 meters (20 ft.) in 1882] and almost 50 years after the last exceptional flood [7.02 meters (23 ft.) in 1861]. The period of its occurrence was marked by several other floods. The Seine flood occurred at the same moment as the floods of the Rhine and Rhone rivers. In June, the Rhine left its banks again causing floods in the east of France and the year ended with floods in the central area of the Loire river in December.

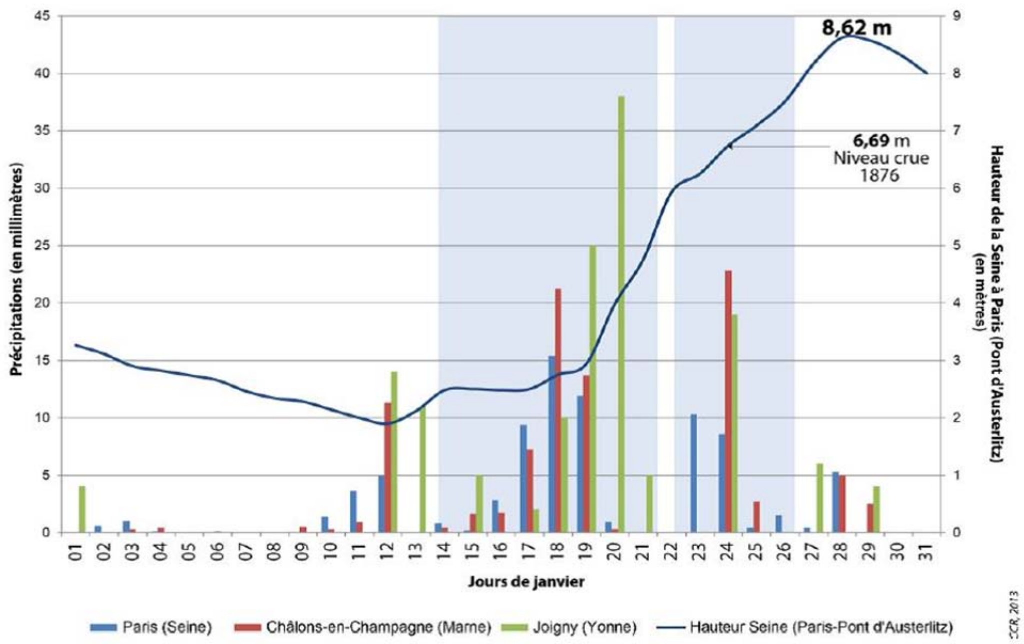
[3]BUACHE P. (in French), “Observations on the extent and height of the flood of December 1740”, History and Memoirs of the Royal Academy of Sciences, 1742, p. 336

The meteorological context

The flood of January 1910 resulted from a slow rise in water levels subsequent to excessive precipitations at the end of 1909 and the very beginning of 1910. The previous year was very wet, with monthly precipitations recorded by the Paris Montsouris Observatory at 96 mm in July and 105 mm in October. The total of 240 mm of rainfall in the last quarter of 1909 far exceeded the average of 170 mm in the period 1901-2001. This situation, that was encountered in the drainage basins of the Yonne, Marne and Seine rivers and their tributaries, would result in the saturation of the ground at the beginning of winter. Further deterioration in the month of January would therefore have immediate consequences on the levels of the watercourses. The observations at the Paris, Châlons-en-Champagne and Joigny monitoring stations suggest the importance of this additional precipitation (Figure 2).

FIGURE 2: PRECIPITATIONS IN JANUARY 1910 (SOURCE: CENTRAL OFFICE FOR METEOROLOGY)

FIGURE 2 : PRÉCIPITATIONS EN JANVIER 1910 (SOURCE : BUREAU CENTRAL DE MÉTÉOROLOGIE)



FR	EN
Précipitations (en millimètres)	Precipitation (millimeters)
Niveau cru 1876	1876 flood
Jours de janvier	Days in January
Hauteur Seine (Paris-Pont d'Austerlitz)	Height of Seine (Paris Austerlitz bridge)
Hauteur de la Seine à Paris (Pont d'Austerlitz) (en mètres)	Height of Seine in Paris (Austerlitz bridge) (in meters)

Between January 15 and 20, excessive rainfall affected a large part of Ile-de-France, with total precipitations of 40.6 mm in Paris, 45.7 mm in Châlons-en-Champagne (northeast of Paris) and 80 mm in Joigny (southeast of Paris). A second period occurred between January 23 and 29 with less precipitation but accompanied by heavy snowfall. The first alerts were issued on January 22, 1910 when the Seine reached its 1882 level [5.79 meters (19 ft.)] at the Tournelle bridge.

As the river continued to swell, there were rumors in the capital that the Alma bridge would be razed to prevent the spread of ice jams in the capital. The water continued to rise unabated, reaching 8.62 meters (over 28 ft.) at the Austerlitz bridge on January 28, 1910 at noon[4]. This high water level was almost two meters (6½ ft.) higher than the historic flood of 1876.

Consequences on society

The city of Paris today is much unlike the Paris of 1910. However, an assessment of the damages caused by the flood of 1910 provides an example of the extent and chronology of the damages and malfunctions. The 1910 flood damaged approximately 20,000 buildings, directly affecting 200,000 people[5]. Damage increased as the flood waters rose, ranging from the interruption of communications to the destruction of homes[6].

Communications and energy supplies

Communications were the first victims of rising waters. The importance of river transport one century ago was such that the Seine was one of the major river transport arteries of the Parisian network. On January 23, the Tolbiac, Grenelle and Passy bridges could not be crossed and many businesses and industries were obliged to lay off personnel, with many activities coming to a standstill for 45 days. In addition to the telegraph, the telephone service was also affected and more and more subscribers found themselves without service as flooding progressed. On January 23, 2,653 subscribers among a total of 46,345 in Paris were without a telephone, increasing to 12,509 on January 28, 27% of the total number of users. Three days later, this number increased to 14,705.

The Paris Metro did not escape the effects of high water. Line 6 (between Nation and Place d'Italie) was interrupted starting on January 22. On January 25, the system was affected even more, as segments of lines 1, 3, 4 and 5 were interrupted. In addition, work underway on line 12 crossing the Seine was suspended; tramways and trains were also affected, making rail connections between Paris and its suburbs practically impossible. On the 26th, the Saint-Lazare station was inundated, suspending all trains.

[4]Nouailhac-Pioch (in French), Monograph of the flood of January-February-March 1910, Floods Commission, 1910, 94 p.

[5]Schneider (in French), "Meteorological characterization of the 1910 flood in the Paris region", *La Méteorologie*, No. 28, December 1999, p. 36

[6]See Appendix 2

The Metro was affected not only by water, but by numerous power outages. Power stations generating electricity were either shut down (Boulevard Richard-Lenoir, the Bercy warehouses and Palais Royal in Paris but also Saint-Ouen, Asnières and Issy-les-Moulineaux) or operation was interrupted (Puteaux, Saint-Denis, Levallois-Perret). The Saint-Ouen power station was shut down on January 22. Pumping operations permitted activity to resume five days later; the Asnières station was closed between January 28 and February 5.

Coal gas plants providing energy for street illumination in Paris were also affected in numerous places. Among the nine power stations operating in January 1910 (La Vilette, Passy, Vaugirard, Ivry, Saint-Mandé, Boulogne, Alfort, Clichy, Le Landy), only the Alfort and Passy stations were totally shut down due to the flooding of buildings[5]. On the other hand, coal deliveries to all stations stopped on January 23 due to the difficulty of procuring fuel. In addition to this damage, several gas mains ruptured and water filled about 120 kilometers (almost 200 miles) of gas mains, 7% of the total at the time[8].

Homes

In the entire Seine Department (currently Paris, Val-de-Marne, Hauts-de-Seine and Seine-Saint-Denis Departments), 15,600 homes and 20,000 buildings were flooded and 400 houses collapsed[9]. Data available on the municipalities in the Paris region point out local differences in terms of damage to homes and factories (Figure 3).

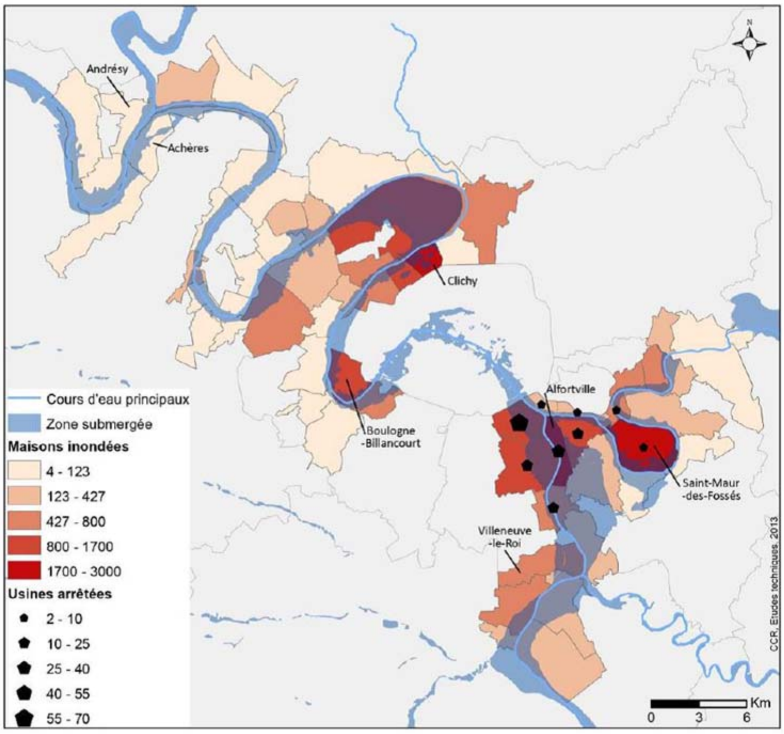
[7]Boreux (in French), "Distribution of lighting gas in Paris", Report to the Floods Commission, 1910.

[8]Ibid

[9]Ambroise-Rendu M (in French), "1910: The Seine in flood paralyses the capital", *La Houille Blanche*, No. 8, 1997, p. 41-44; Marti and Lepellettier (in French), "Hydrology of the 1910 flood and other major floods of the Seine basin", *La Houille Blanche*, No. 8, 1997, p. 33-39

FIGURE 3: DAMAGE IN THE ILE-DE-FRANCE REGION BY THE FLOOD OF JANUARY 1910

FIGURE 3 : DOMMAGES OCCASIONNÉS EN ÎLE-DE-FRANCE PAR L'INONDATION DE JANVIER 1910



FR	EN
Cours d'eaux principaux	Major watercourses
Zone submergée	Flooded zone
Maisons inondées	Flooded homes
Usines arrêtées	Factories shut

Upstream from Paris, the municipalities most heavily damaged were Saint-Maur-des-Fosses with 3,000 homes damaged, followed by Alfortville with 2,679. Alfortville was almost totally submerged by the Seine. Downstream, the municipalities of Clichy and Boulogne-Billancourt were the most heavily affected, with 2,130 and 1,700 homes damaged respectively.

According to the report issued by Mr. Alexandre, Inspector General with the authority for bridges and roadways (*Ponts-et-Chaussées*), all flooded homes had to be evacuated in several municipalities[10]. Five hundred homes were abandoned in Achères, Andresy and Villeneuve-le-Roi, even though not all were subjected to extensive damage. On average for the municipalities concerned, approximately 1% of flooded homes required repairs after the flood, whereas this figure exceeded 10% in "blue collar" towns such as Alfortville and Puteaux.

[10]Alexandre P. (in French), "Suburban municipalities", Report to the Floods Commission, 1910

Witness accounts in the press or in reports issued told of the serious problems affecting blue collar families during the flood: in addition to their homes being flooded, they were laid off because their factories were shut down.

Damage to businesses

Much like the plants that supply energy, the various businesses of the Ile-de-France region also suffered from the direct and indirect effects of the flooding. Some were flooded, making work impossible, while others suffered electric power outages due to the problems energy suppliers were encountering. Upstream from Paris, in today's Val-de-Marne Department, the most seriously affected municipalities were Ivry-sur-Seine with 67 establishments impacted, followed by Alfortville with 28 and Maisons-Alfort with 15.

The closing of the factories meant that workers could no longer perform their jobs. As a consequence, 8,000 workers were laid off without wages in Corbeil-Essonnes as well as 3,500 in Puteaux. Water also caused short circuits that in many cases had serious consequences. In Ivry, the *Pagès* vinegar plant was an island surrounded by water on January 25. It was probably a short circuit that caused the explosion of the building and the fire fed by almost 10,000 liters of methyl alcohol[11].

From crisis management to risk management

Between prevention and help: How the authorities responded to the flood

In the absence of flood risk prevention measures – the first prevention plan saw the light of day only in 1935 with the Submersible Surface Plan – the prevention and alert system for the Seine basin in 1910 was essentially based on the flood warning system implemented in 1854 by Belgrand. The observation service of this system used readings taken at different gauging stations and examined earlier floods in order to provide a flood estimation (high water level, time) to the authorities concerned. The system appears to have operated correctly in January 1910: examination of the official municipal bulletin of Paris shows that authorities were warned of the flood in advance.

[11] *L'Humanité*, Edition of January 26, 1910

On January 22, weather services stated that the flood would be similar to that of 1882-1883. The next day, after water had risen to a height of 5.93 meters (19½ ft.) at the Austerlitz bridge the evening before, weather services indicated that the city should prepared for a flood similar to that of 1876 [6.69 meters (22 ft.)].

In spite of these warnings, the official municipal bulletin containing the decisions made by the authorities contained no decision concerning the flood. The municipal by-law of April 5, 1884 required local elected officials to take all necessary measures to prevent risks from natural hazards[12]. The question was addressed only on the 26th, when the Prefect of the Seine instructed them by means of an order (*arrêté*) to meet in special session. Emmanuel Evain, a disillusioned municipal counselor of Paris, declared on January 26: "What did we do to prevent [the flood] epidemic or contagious diseases, epizootics, if necessary by requesting the intervention of a higher authority that threatened such and such zones in a district? Nothing was done"[13]. He and his colleagues called for a genuine overhaul of the prevention policy implemented by both the municipality and the Prefecture. The chief of police, Mr. Lepine, even confessed that he did not know of the needs faced by the authorities, but this admission of failure and remorse did not deter the determination of the authorities. Although they admitted a share of responsibility for the absence of protection of the population, they adopted a series of measures to prevent the situation from escalating into a social and political crisis. A credit of 100,000 francs (a substantial sum at the time) was voted to enable victims to cope with the emergency. Following this, in neighborhoods where flood waters were not excessively high, walkways were installed over a total length of almost 39 kilometers (62 miles) in the space of several days to enable people to access their homes.

The chief of police, Mr. Lepine, proposed organizing a security service to protect persons and property. Not only did floodwaters inundate homes, but currents also eroded many foundations. The City Council decided to extend the evacuation of the most highly threatened buildings after consulting with architects. On January 27, 2,500 residents of the avenue Ledru-Rollin (11th arrondissement of Paris) were asked to leave their homes[14]. In cases of refusal, as was the case in Courbevoie, the authorities called on the police to force residents to leave their homes. As a result, the authorities had to find temporary shelter for several thousand people, although the local officers had already sent many of these people to hotels.

[12]Municipal by-law of April 5, 1884, Art. 97-6 (in French) "Prevention by suitable precautions, and that of distributing required assistance to put a stop to accidents and calamities such as fires, floods, epidemic or contagious diseases, epizootics, if necessary by requesting the intervention of a higher authority".

[13]Report of the session of January 26, 1910, Official municipal bulletin, February 6, 1910

[14]*L'Humanité*, Edition of Saturday, January 29, 1910

The number of people involved was augmented by inhabitants of neighboring municipalities who sought shelter in the capital.

During the night of January 24 to 25, 1910, almost 2,000 inhabitants of Maisons-Alfort tried to find refuge in Paris. The authorities then decided to requisition public buildings that could temporarily accommodate the victims, but implementing these measures required additional personnel unavailable to the city. Mr. Lepine decided to summon the army to make up for this shortfall. Five days later during a special session of the General Council of the Seine Department, he provided a list of troops and equipment he had obtained from the Minister of the Navy and the military governor of Paris[15]. A total of 47 battalions of infantry, 16 squadrons of cavalry, 18 companies of engineers, 3,700 horses, 200 boats, 290 dinghies and 23 barges were deployed in the Ile-de-France region. During the same General Council session, the parties involved defined all measures to be taken at the level of the department. Although floodwaters began to recede on January 28, the authorities remained preoccupied with health risks (water pollution, development of disease, etc.). The first measure taken was therefore to disinfect flooded buildings and to ask the population to aerate their homes.

[15]Report of the session of the General Council of the Seine Department of January 31, 1910, Official municipal bulletin, February 7, 1910

Protection measures subsequent to 1910

After the 1910 flood, a commission chaired by Alfred Picard was tasked to "consider the future", in other words, propose measures to prevent a repetition of this type of event[16]. Several reports were drafted in order to describe the damage caused and the planned prevention systems. In 1924, in the wake of a serious river crisis (drought and flooding) the Dusuzeau commission also proposed a series of measures. Throughout the 20th century and depending on the whims of the river, many steps were taken to reduce the region's vulnerability.

Elevation of flood walls

The elevation of defense works (dikes, levees, flood walls) has long been based on risk management[17]. From the disastrous floods of the Loire river (1846, 1856 and 1866) until just after the recent Xynthia storm, these defense works constitute an inevitable response to adverse flood conditions. However, these works increase the vulnerability to flooding due to the risk of rupture and the modification of downstream water flows[18]. Today in Paris, the present flood walls are at the level of the flood of 1910. In the Val-de-Marne and Seine-Saint-Denis, the flood walls provide protection against floods with a return period of up to 50 years[19].

Works performed on the bed of the seine

Dredging the bed of the Seine has been practiced for a long time. After the flood of 1876, the arms of the Ile Saint-Louis and Ile de la Cité were dredged to lower the water line[20]; additional work was carried out in 1924.

[16]Floods Commission. Various reports and documents, Paris, Imprimerie Nationale, 1910

[17]Desarthe J. (in French), The weather of seasons, climate, extreme events societies in the west of France, Paris, Hermann, 2013, 338 p.

[18]SETEC, IIBRBS (in French), System for local protection in the Paris region. Hydraulic assessment and needs for reinforcement, 1998, Cited by Reghezza-Zitt M., Is Paris sinking? Paris, Fayard, 2012, p. 170

[19]Reghezza-Zitt M. (in French), Is Paris sinking? Paris, Fayard, 2012, p. 169

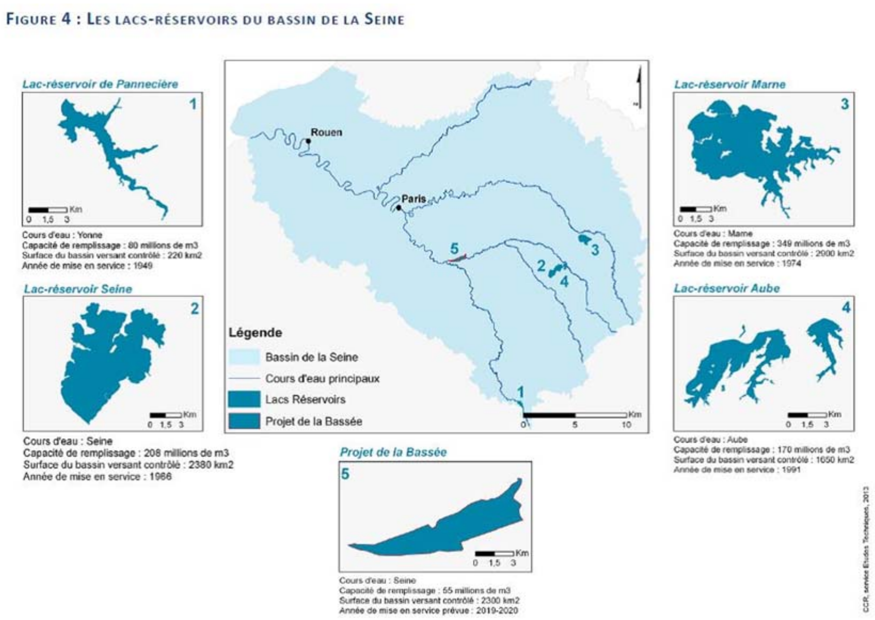
[20]Reghezza-Zitt M. (in French), Is Paris sinking? Paris, Fayard, 2012, p. 171

In parallel, other improvements were conducted, such as reconstructing bridges or renovating dams and locks.

Reservoir lakes

After the drought of 1920 and the flood of 1924, the Ministry of Public Works approved the construction of dams to create a reserve of a billion cubic meters to be used for retention during floods and as a water supply during low water periods. This was intended to maintain the Seine at an optimal level to meet domestic and industrial needs. These large scale projects were progressively implemented during the second half of the 20^{th} century and today, four reservoir lakes with a total capacity of 807 million cubic meters control the upstream basin of the Seine (Figure 3)[21]. The "*La Bassée*" project will augment this capacity to 862 million m^3 by 2020.

FIGURE 4: RESERVOIR LAKES OF THE SEINE BASIN



FR	EN
Lac-Résevoir de Pannecière	**Pannecière Reservoir Lake**
Cours d'eau : Yonne	Watercourse Yonne
Capacité de remplissage : 80 millions de m3	Filling capacity 80 million m^3
Surface du bassin versant contrôlé : 220 km2	Surface of controlled drainage basin 220 km^2
Année de mis en service : 1949	Year of commissioning 1949
Lac-réservoir Seine	**Seine reservoir lake**
Projet de la Bassée	**"La Bassée" project**
Lac-réservoir Marne	**Marne reservoir lake**
Lac-réservoir Aube	**Aube reservoir lake**
Légende	**Legend**
Bassin de la Seine	Seine bassin
Cours d'eau principaux	Major watercourses
Lacs Réservoirs	Reservoir lakes

[21]Data taken from the Website of *EPTB Seine Grands Lacs*, http://www.seinegrandslacs.fr/

PART II – SEINE FLOODS TODAY: MODELING, LOSS AND DAMAGE

For the past decade, the CCR has managed a number of projects leading to the creation of:

- a database on prior decrees declaring a state of natural disaster;
- an insurance database geolocalized at different degrees of accuracy (exact address, street, municipality) and natural disaster claims, created in the context of bilateral and confidential relations between the CCR and its clients;
- a flood model to estimate the damages arising from a given flood.

Standard operation of the model enables the simulation of the most frequent and most costly floods, i.e. flooding by overflow and by runoff. Flooding caused by rising water table levels is excluded from the simulation. The deterministic model is a distributed model that simulates continuous water flows using a digital elevation model (DEM). This model was designed to include the principal hydrological processes that could cause a flood resulting in damages: transformation of rain into flow-rates, infiltration, water flow, watercourse hydrology, overflows.

Description of hazard modeling

The model uses the following input data that are independent of events:

- A digital elevation model (DEM) in matrix format (Altitude DB® at 50 m);
- A hydrographic system (DB Carthage®);
- Land use (from Corine Land Cover).

The following input data depend on each event:

- Evapotranspiration (ET), daily and hourly rainfall;
- Daily water flows during the period;
- Maximum monthly flows during the month(s) of the event.

[22] MONCOULON D., LABAT D., ARDON J., LEBLOIS E., ONFROY T., POULARD C., AJI S., REMY A., QUANTIN A., “Analysis of French insurance market exposure to floods : a stochastic model combining river overflow and surface runoff”, Natural Hazard and Earth System Science, 14, 2014, p. 1469-1485

The first three data sets are provided by *Météo France* and the last two are from Hydro, a database administered by the Central Hydrometeorology Bureau and Support for Flood Predictions (*SCHAPI*), a section of the Ministry of the Environment, Energy, and the Sea (*MEEM*).

Modeling the hazard is simplified when a scenario similar to Paris 1910 is simulated. In this case, flow values measured at the hydrographic system stations are used in place of rainfall values. The model is used to:

- Propagate flow-rates along the entire hydrographic system;
- Transform flow-rates into water level heights;
- Determine the occurrence of spillover if thresholds are exceeded (corresponding to flood walls and dikes along the Seine or to decade flows);
- Calculate the extension of the flood zone and water levels at each point.

The model employs several simplifying hypotheses, in particular concerning the impact of saturation of urban drainage systems, conduits, karstic geology, etc. that have the potential of aggravating the total loss experience. Table 1 presents the two scenarios used for an as-if damage model:

TABLE 1: DESCRIPTION OF SIMULATED FLOOD SCENARIOS

Scenario	Description
S1	9.11 m (30 ft.) at the Austerlitz bridge in Paris (January 1910 flows multiplied by 1.15)
S2	8.15 m (27 ft.) at the Austerlitz bridge in Paris (flows equivalent to January 1910)

Damage modeling

The cost of an event is estimated on the basis of the portfolio of geolocalized insured risks superimposed on the simulated hazard for the event. For each risk located inside hazard zones, the model calculates a claim frequency (or a claim probability) as well as costs incurred in the event of loss/damage, by applying a destruction rate to the insured property.

The claim probability is calculated by differentiating the following types of risks:

- House: owner-occupier or tenant
- Apartment: owner-occupier or tenant
- Absentee owner and condominium ownership
- Professional risks (agricultural, industrial, other professional risks)

The variables used to estimate the probability of damage are primarily:

- The height of spillover;
- Runoff flow-rate;
- The probability of being on the ground floor of apartment buildings (estimated using data on the number of stories per building provided by the *INSEE*, French National Statistics Bureau).

The function used to determine the claim probability based on hazard and vulnerability variables is calculated on the basis of risks covered and past claims.

In order to estimate the cost in the event of a disaster, risks in the runoff zone and policies in the spillover zone are considered separately. The variables used to estimate the cost in the event of a disaster are the type of risks, values insured, runoff flow rates or spillover heights.

An estimation of the amount remaining to be paid by insured parties is given in this ratio. This refers to the deductible under private and business policies (10%), considered to be a standard deductible (excluding any doubled deductible in case of repeated claims).

Calibrating and validating the model

This model was initially developed to simulate all type of events (floods in plains, mountains, and the Cévennes region) encountered in continental France. As its modeling of groundwater aquifers is highly simplified. It is better suited to floods with rapid flows, floods in mountains and those of the Cévennes region, although a limitation for mountainous regions is that snow melt offs are not taken into account. One of the main advantages of this model is that it can be used to simulate every meteorological and/or hydrological event occurring over a variable surface and for a variable duration, within the calculation capacity limits of the CCR. It can therefore be used for the entire land mass of continental France and in particular has been tested and calibrated for the most important events occurring during the past decade: the Rhone flood in December 2003, the Gard river flood in September 2002, the Aude river flood in November 1999 and that in southeast France in November 2008, to mention only the most costly. The prime reason for calibration is not only to obtain a correct simulation of maximum water flows observed in different watercourse segments during a previous flood, but above all to model the perimeter of the flooded zone in order to best estimate the loss caused by an event. All parameters of the model are adjusted on the basis of the damage modeling for each representational historical events catalog. Some of the simplifying choices made in the modeling of physical phenomena are justified by their low impact on the cost of an event as delivered by the model. The following table lists several simulation results of past events (Table 2).

TABLE 2: COMPARISON OF REAL COSTS (SOURCE: CCR) AND COSTS SIMULATED (EXCLUDING MOTOR) BY THE DETERMINISTIC MODEL FOR THE INSURANCE SECTOR (FIGURES IN € M FOR THE YEAR)

Event	Real cost (M€)	Simulated cost (M€) [10-90 centiles]
Aude (November 1999)	330	[277-416]
Gard (September 2002)	600	[361-555]
Rhône (December 2003)	730	[516-913]
Gard (September 2005)	77	[174-277]
East Center (November 2008)	130	[127-166]

The damage model was calibrated using the historical loss experience. Certain prevention measures implemented in the exposed zones are not taken into consideration in the damage model.

Results of modeling

Table 3 lists the results of loss simulation in different flood scenarios in terms of total cost (mathematical expectation of the distribution of simulated costs) and 10% and 90% confidence intervals (CI). Amounts listed are in billions of 2015 euros (€ b).

TABLE 3: RESULTS OF SIMULATION WITH THE CCR MODEL (IN 2015 € B)

Scenario	Total cost (€ b)	10% CI	90% CI	Amount paid by insured parties (deductible)
S1	13.3	8.8	23.9	1
S2	5.1	3.5	9.1	0.4

The amount of the deductible (amount of loss borne by the insured party) is added to the amounts paid out by insurance companies. Its calculation is performed on the basis of the number of claims by individuals (a deductible of € 380) and the amount of business claims (deductible of 10% of the amount). For the purposes of this report, a standard deductible is used for all municipalities.

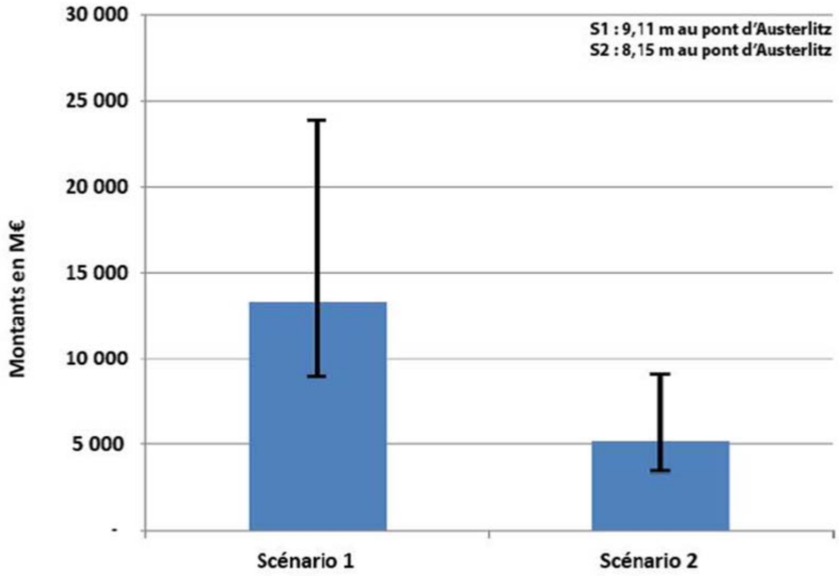
In the case of scenario 1 (S1), the insurers and the private reinsurance market will pay 23% of the total estimated cost. The remaining amount will be covered by CCR's reinsurance treaties. In the case of this extreme scenario, a portion of the losses will be paid under the State guarantee as the intervention threshold has been exceeded.

In the case of scenario 2 (S2), the insurers and the private reinsurance market will pay 43% of the total cost. CCR will cover the remaining losses without calling into play the State guarantee.

Figure 5 shows simulated loss amounts as a function of the flood scenario modeled.

FIGURE 5: RESULTS OF THE SIMULATION OF TWO SCENARIOS (SIMULATED MEAN COST WITH 10-90% CONFIDENCE INTERVAL)

FIGURE 5 : RÉSULTATS DE SIMULATION DES DEUX SCÉNARIOS (COÛT MOYEN SIMULÉ – INTERVALLE DE CONFIANCE 10-90)

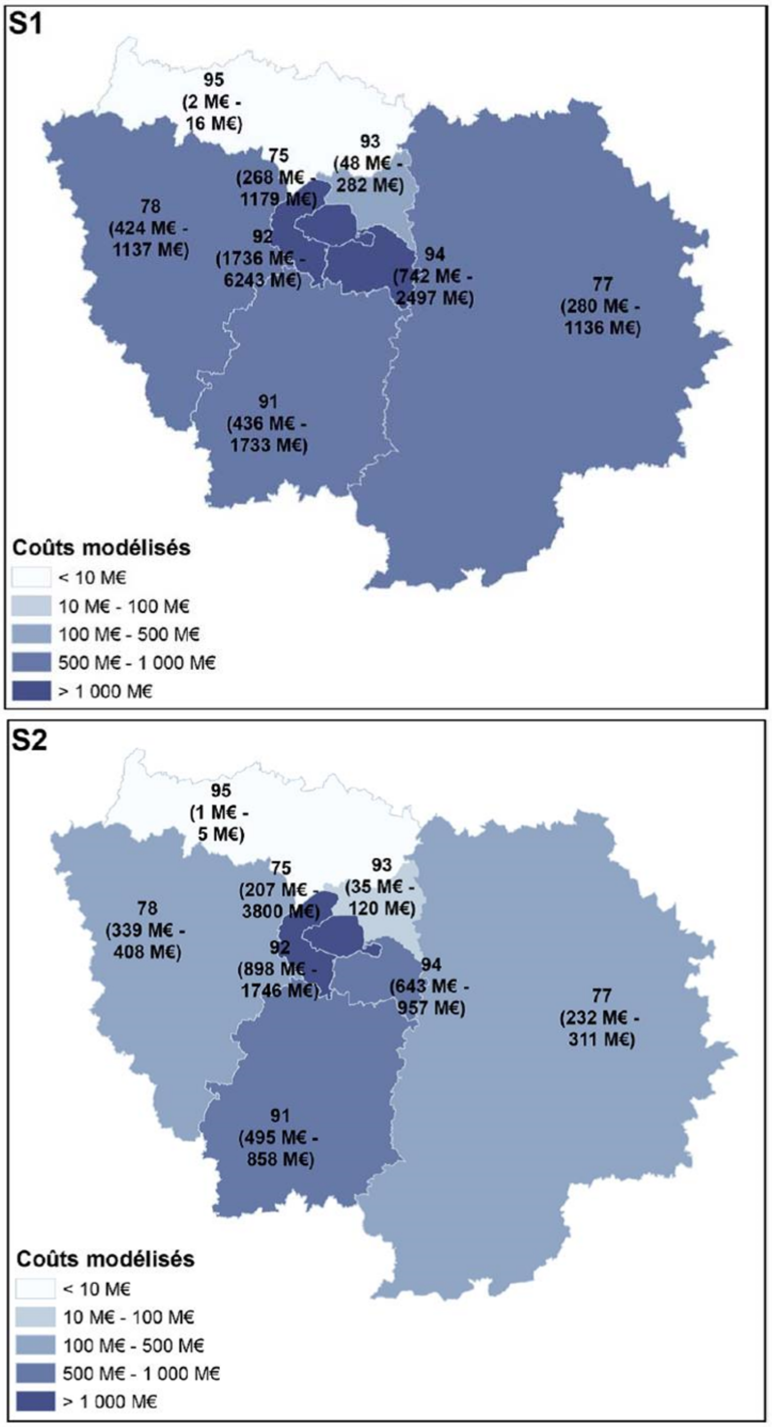


FR	EN
Montants en M€	Amounts in € m
S1 : 9,11 m au pont d'Austerlitz	S1: 9.11 meters (30 ft.) at the Austerlitz bridge
S2 : 8,15 m au pont d'Austerlitz	S2: 8.15 meters (27 ft.) at the Austerlitz bridge
Scénario 1	Scenario 1
Scénario 2	Scenario 2

Figure 6 is a map of the geographic distribution of loss throughout the greater Paris region as a function of the simulated flood scenario.

FIGURE 6: RESULTS OF THE SIMULATION OF SEVERAL SCENARIOS (WITH 10-90% CONFIDENCE INTERVAL)

FIGURE 6 : RÉSULTATS DE SIMULATION DES SCÉNARIOS AVEC LES INTERVALLES DE CONFIANCE À 10 ET 90%



FR	EN
Coûts modélisés	Modeled cost

The losses modeled are limited to the scope of claims covered by the Nat Cat scheme. The amounts shown therefore concern:

- Claims excluding motor coverage, involving policies insuring residential agricultural, industrial or commercial properties;
- Direct losses;
- Business interruption resulting from direct damages for practitioner's or business risks;
- A proportion corresponding to motor claims, estimated at 5.7% of non-motor claims (average rate observed for previous flood events).

The insurance portfolio uses the *SIRENE* (French corporate classification system) classification for industrial risks. Natural disaster losses concern only municipalities that applied for a state of natural disaster to be declared when this was approved by the Interministerial Commission. For the purpose of this report and due to the extreme nature of this event, we consider that all municipalities are recognized as being affected by a natural disaster once they are affected by at least one damaging event.

These scenarios do not consider several factors. First, the effects of runoff resulting from heavy rains in urban areas are not included in this approach that is based only on watercourse flow-rates. Similarly, except for the Seine, the inventory of protective works (flood walls, dikes) in other watercourses of the region is only partial. Finally, operating losses in the framework of business risks are difficult to assess. The effect of rising groundwater in contact with the Seine on underground works not totally watertight is not considered but could have a significant impact on infrastructures (electricity, drinking water, transport).

CONCLUSION

The magnitude of the 1910 flood had a significant effect on the mind-set of populations at the time. Despite policies aimed at augmenting awareness, however, a large part of the population still does not feel concerned by the risk of flooding[23]. The simulations conducted with different scenarios provide an indication of the extent of the damage and loss if risk becomes reality in the drainage basin of the Seine and of the Departments of the Ile-de-France “economic basin”.

Scenario S1, the more extreme of the two, with a flow 1.15 times that of 1910, would generate moderate insured damages covered by the Nat Cat scheme of approximately € 13 billion according to the model (with high uncertainty generating an interval of confidence of 8.8 at € 23,9 billion). Scenario S2, with a flow equivalent to that in 1910 would produce a height of 8.15 meters (26 ft.) at the Austerlitz bridge and would generate losses of over € 5 billion for the Nat Cat scheme (between € 3.5 and € 9.1 billion). For purposes of comparison, the cost of natural disaster claims to the insurance industry resulting from the Xynthia storm that ravaged the Atlantic coast in February 2010 is estimated to have caused € 710 million in damages.

As the Nat Cat scheme covers only direct damages and business interruption losses for insured property, it is necessary to take into account all uninsured damages to estimate the impact of the Seine flood on the economy as a whole. Damages to infrastructures, to works of art, or to property belonging to the State are not covered and certainly comprise a significant portion of the damages resulting from a flood of this type.

Given the estimated amounts of damage, the natural disaster compensation scheme could cope with an event of this magnitude. The State would inevitably need to intervene for the more severe scenarios.

However, much skepticism persists in modeling this type of catastrophe. Even when considering insured losses, the simulated direct damages undoubtedly represent only a part of the reality. This is because the models are calibrated using only recent events, for which data are available, and none of these events have reached the magnitude of the catastrophe of January 1910.

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APPENDIX

APPENDIX 1: HOW THE NAT CAT SCHEME WORKS

[Graphique à inséré depuis le site Internet de CCR]

APPENDIX 2: CHRONOLOGY OF THE FLOOD OF JANUARY 1910

Date	Flood height in meters (feet)	Effects
January 22	5.93 (19 ft.)	Paris: Metro power station at the Quai de la Rapée flooded Paris: Metro lines 1 and 6 paralyzed Vitry: Power plant on the Quai du Pont flooded Versailles: Access to drinking water compromised
January 23	6.25 (19 ft.)	Quai d'Auteuil evacuated
January 24	6.74 (19 ft.)	Paris: 1.80 meters (6 ft.) of water over the Quai de la Gare and Quai de la Rapée. Surrounding buildings evacuated Alfortville: homes abandoned Saint-Germain en Laye: factories flooded Hygiene measures given by authorities (boil water, etc.)
January 25	7.09 (19 ft.)	Corbeil, Vitry, Choisy and Ivry: factories flooded, workers laid off Paris: partial interruption of the Metro; the rumor that the Pont de l'Alma will be razed circulates around the city Andresy: gas plant for urban illumination no longer operational Choisy-le-Roi: water pumping plant closed
January 26	7.51 (19 ft.)	Paris: collapse of the Bercy Metro station tunnel (line 6) Puteaux: factories closed Paris: rupture of sewer lines in the rue du Havre and the rue Saint-Lazare Paris: protection measures for buildings at risk of collapse Villeneuve-Triage, Nanterre: evacuation of inhabitants threatened by rising waters
January 27	8.16 (19 ft.)	Paris: The zoo tries to evacuate its elephants
January 28	8.62 (19 ft.)	Paris: 2,500 inhabitants of the avenue Ledru-Rollin leave their homes Paris: 1.5 meters (5 ft.) of water in the basement of city hall Gennevilliers: rupture of the dike
January 29	8.57 (19 ft.)	Paris: evacuation of buildings at the risk of collapse
January 30	8.34 (19 ft.)	Saint-Mandé: 500 displaced persons given shelter
January 31	8 (19 ft.)	Alfortville: army troops deployed to prevent civil disturbance and looting

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