Water Policy 17 (2015) 195–211

Integrated actions in the management of critical hydrologic events

Bruna Craveiro De Sá E Mendonça* and Mateus Monteiro De Abreu

Agência Nacional de Águas (ANA), Setor policial (SPO), Área 5, Quadra 3, Bloco M. 70610-200, Brasília, Brazil
**Corresponding author. E-mail: bruna.mendonca@ana.gov.br*

Abstract

Owing to the increase in urban populations, there has also been an increased incidence of critical events, especially those related to floods and landslides. Since the implementation of the National Civil Defense System in Brazil, a focus on disaster management is no longer the answer when assisting those affected; instead, the answer has become managing disaster risk, in addition to the response, including prevention and minimizing the effects of the critical event. This paper highlights the actions for modernization and expansion of the hydrological monitoring network, in particular the alert network, the completion of an atlas of vulnerability to floods and the deployment of Situation Rooms in the states, with a view to strengthening the role of these bodies in disaster risk management, and enabling greater responsiveness to these events and the use of the information gathered as a water resources management tool, allowing for better use of public resources.

Keywords: Critical hydrologic events; Flood vulnerability; Monitoring; Risk management; Situation Rooms

1. Introduction

Brazil's National Water Agency (Agência Nacional de Águas; ANA), created by Law No. 9984 on 17 July 2000, is an independent national regulatory body, with administrative and financial autonomy, under the Ministry of Environment. ANA is part of the National Water Resources Management System and is responsible for implementing the National Water Resources Policy which has, among its objectives, the prevention of and protection against critical hydrological events (droughts and floods) that occur naturally or as a result of inappropriate use of natural resources.

ANA has the following among its duties:

- Planning and promoting actions to prevent or minimize the effects of droughts and floods, within the National Water Resources Management System, in conjunction with the National Civil Defense and Protection System, to support the states and municipalities. These actions, when they involve the

doi: 10.2166/wp.2015.010

application of preventive rationing, may only be promoted observing criteria defined by federal decree, after consulting the respective river basin committees, if any.
- Setting and monitoring reservoir operation rules to be observed by public and private actors, in order to ensure multi-purpose water uses, according to the river basin master plans. The definition of the operation rules for the reservoirs of hydropower plants is to be carried out in conjunction with the Operador Nacional do Sistema Elétrico (ONS; the Electric System National Operator).
- Promoting the coordination of activities under the national hydrometeorological network in cooperation with agencies and with public or private bodies that comprise or are users of it.

ANA started to operate its Situation Room in November 2009. Through this facility, the agency monitors the hydrometeorological conditions of priority river basins and of the main reservoirs of the country, in order to support, in particular, decision-making to minimize the effects of droughts and floods. To do so, data from monitoring rainfall levels and river flows, the operation of the main reservoirs, weather forecasts and climate are used, as well as hydrological models and records of occurrences of emergency, or states of emergency, in the municipalities.

From the flood events which occurred in June 2010 in the states of Alagoas and Pernambuco, in the Mundaú, Paraíba, Una and Sirinhaém Capibaribe river basins, which resulted in the loss of human lives and properties as well as dozens of displaced and thousands of unsheltered families, the Agency decided to support the states in structuring their own situation rooms.

Similarly to ANA's, the State Situation Rooms carry out monitoring, but on a different spatial scale of analysis. The situation rooms act as a management center and subsidize the water resources state manager in critical situation decision making, identifying the possible occurrences of critical events (droughts and floods) by monitoring the hydrological conditions of the major river systems of the state and the meteorological data. Thus, they allow the adoption of preventive measures to mitigate the effects of droughts and floods.

To provide the State Situation Rooms with information, especially about floods, it was necessary to know the areas subject to floods and to verify the impact level and frequency of occurrence of those events.

The Flood Vulnerability Atlas was designed as a diagnostic tool, which resulted in the obtaining of information on the frequency of occurrence of floods and the impact levels associated with them. The intersection of these two pieces of information generated the classification of river stretches according to their vulnerability to flooding, on a scale of 1 to 1 million, in all Brazilian states, which allowed the definition of the warning hydrological network in the states.

2. The role of the National Water Agency

2.1. ANA Situation Room

Owing to its geological, geographical and climatological characteristics, floods, droughts, and landslides are the most common natural disasters in Brazil, and are strongly related to the occurrence of weather phenomena, in particular so-called 'extreme events'.

Floods and droughts have increasingly drawn the attention of society, since they cause significant economic and social impacts. The year of 2009, in particular, was marked by the occurrence of such events resulting in significant damages.

That same year, the ANA Situation Room was inaugurated with the basic function of monitoring the hydrological trends across the country. This task is accomplished by analyzing the evolution of rainfall levels and flow rates of rivers and reservoirs, and the weather and climate, as well as performing mathematical simulations that help in predicting extreme events (droughts and floods) across the country, in accordance with the assignments given to the Agency by Law No. 9.984/2000.

Operated jointly by the Superintendency for the Management of the Hydrometeorological Network and the Superintendency of Multiple Uses and Critical Events, the Situation Room performs the collection and validation of data and its analysis, aimed at producing reliable and timely information for decision-making by the ANA Board of Directors.

2.2. Process of coordination with federal agencies

Actions aimed at prevention of critical hydrological events carried out by ANA are part of a set of actions undertaken at the federal level, in the field of risk management and disaster response. In recent years, a growing concern regarding risk identification and prevention of natural disasters has been observed in Brazil, replacing the traditional treatment given to the subject, which focused predominantly on disaster response.

In this sense, institutions dedicated to gathering and networking relevant information to cope with extreme events were created, notably the National Center for Monitoring and Early Warning of Natural Disasters (CEMADEN) and the National Center for Risk and Disaster Management (CENAD). CEMADEN collects and produces information and systems for monitoring and alerts concerning the occurrence of natural disasters in susceptible areas throughout Brazil, while CENAD aims to manage strategic actions and disaster response, as shown in Figure 1. Within this structure, CEMADEN sends alerts of possible occurrences of disasters in mapped risk areas to CENAD. CENAD, in turn, transmits alerts to states, municipalities and other federal agencies and supports the disaster response actions.

In August 2012, the National Risk Management and Disaster Response Plan (Brazil Ministry of Planning, 2012) was launched with the goals of protecting lives, ensuring safety and minimizing damage resulting from disasters, and preserving the environment. The Plan articulates actions of different institutions, divided into four thematic axes – prevention, mapping, monitoring and alert, and disaster response.

2.2.1. Prevention axis. Prevention includes the infrastructure built as a result of the growth acceleration program (PAC) aimed at reducing the risk of natural disasters. Among the actions in this axis are slope stabilization work, urban drainage and flood control, and the construction of withdrawal, delivery and storage systems for drinking water in semi-arid regions to face the effects of drought.

2.2.2. Mapping axis. This axis provides the mapping of areas at high risk of slippage, landslides and floods in 821 priority municipalities. In these municipalities, intervention plans (which identify the vulnerability of houses and infrastructure within the risk areas and propose solutions to the problems encountered) will be prepared, in addition to supporting the preparation of geotechnical maps of urban fitness, to assist the municipalities in spatial planning. The development of the Flood Vulnerability Atlas is included in the 'hydrological risk' component.

2.2.3. Monitoring and alert axis. The actions under this axis aim to strength the monitoring and alert system, especially through the expansion of the observation network and the structuring of CEMADEN and CENAD. It also covers the implementation of the State Situation Rooms for hydrologic monitoring.

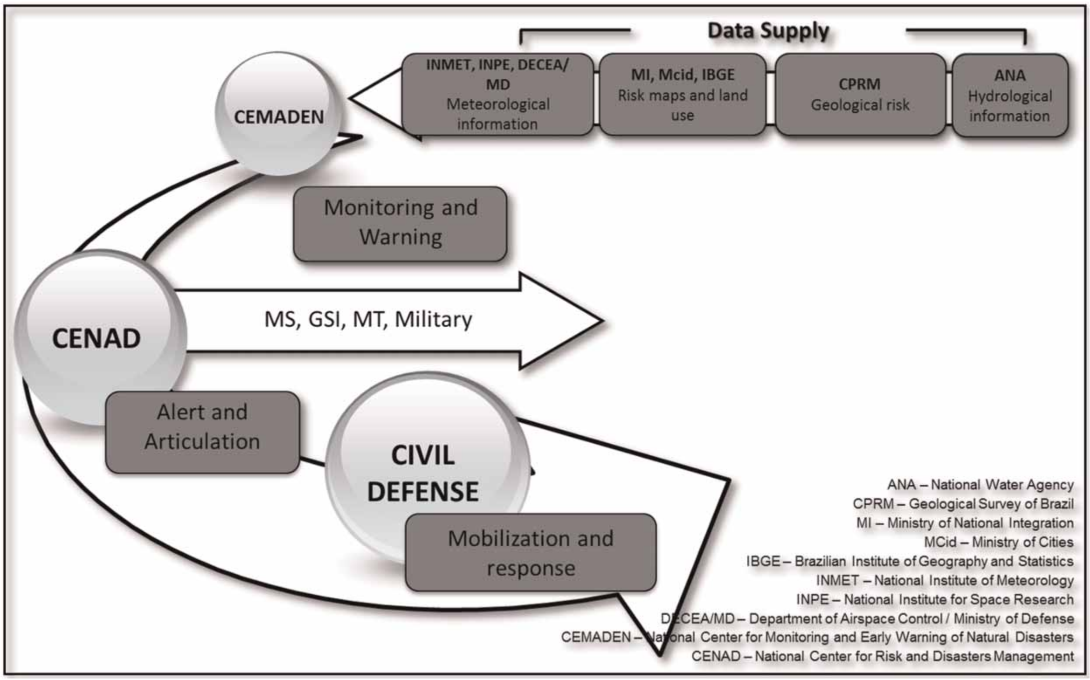

Fig. 1. Cycle of risk management and response to natural disasters.

2.2.4. Disaster response axis. This axis involves a set of actions which aim to increase the responsiveness of disasters occurrences, such as the creation of the National Emergency Force and the mobilization of National Security Forces to support the states and municipalities when major disasters occur, aiming to accelerate the implementation of recovery and relief actions.

The main role of ANA in this system, in accordance with Law No. 12,608, of 10 April 2012, is to continuously produce and forward to CEMADEN and CENAD reliable hydrological information with appropriate frequency and sufficiently in advance to allow adequate decision-making in a timely manner. In the case of the occurrence of critical flood events, a task force of geologists and hydrologists is temporarily mobilized in order to follow the event more closely. In parallel, ANA has elaborated its Flood Vulnerability Atlas, designed as a diagnostic tool of occurrence and impacts of gradual flooding in major rivers of the Brazilian basins. This project consisted of the identification of reaches of rivers where gradual flooding or plain flood occurs, the evaluation of the vulnerability of the affected regions and the definition of critical areas. Flood vulnerability maps have been made for each of the Brazilian states.

2.3. Process of coordination with the states

Following the flood events which occurred in June 2010 in the states of Alagoas and Pernambuco which resulted in the loss of human lives and material goods, as well as the displacement and a lack of shelter for tens of thousands of families, the agency decided to support the States in structuring their own Situation Rooms, following the existing ANA model and integrated with it.

These rooms are centers for managing critical situations related to water, with the aim of identifying possible occurrences of critical events and thus allowing the adoption of preventive and mitigatory measures that minimize the effects of droughts and floods. In addition to the state water resources management agency, State Situation Rooms typically rely on the presence of the local technical meteorological institute and the State Civil Defense. The working scale and the local knowledge gathered there allow the detection of and attention to regional events, unlike in ANA's Situation Room, which operates nationwide and on a macro scale.

Through technical cooperation agreements between ANA and the states, signed to set up the State Situation Rooms, the agency provides the necessary infrastructure for the rooms and data collection platforms (DCPs), to compose a monitoring and alert network in the major watersheds affected by floods, identified in the Flood Vulnerability Map. It also provides training and necessary software for their operation. The states, in turn, are committed to providing the physical space and furniture to deploy the rooms, as well as specific technical staff to perform the office and field activities necessary for their proper functioning.

Each technical cooperation agreement requires an annual basis work plan which provides the implementation of activities that contribute to the process of deployment and operation of the rooms and their integration with the Situation Rooms of ANA and other federal, state and municipal bodies. So far, ANA has helped establish Situation Rooms in all of the country's state capitals and in the Federal District.

In 2012, the program designed to support the implementation of Situation Rooms joined the monitoring and alert axis of the National Risk Management and Disaster Response Plan, which had its implementation monitored by the Casa Civil (Office of the Chief of Staff of the Presidency). Moreover, CEMADEN will receive reports from the Situation Rooms and send notices to CENAD, following the example of interaction achieved between CENAD and the Pernambuco Situation Room.

The Flood Vulnerability Atlas also had the participation of states in its preparation, which assisted in the identification of vulnerable river stretches and in the estimation of the frequency and impact of gradual floods. From this information, the vulnerability of river stretches and critical basins within a state were defined. This study contributed to an indication of the need and location for additional telemetric hydrometeorological stations, which are monitored and maintained by State Situation Room staff.

In the long term, ANA will support states in developing flood hazard maps, flood risk maps, alert levels in rivers and reservoirs and the impact of dam breaks. Furthermore, ANA also supports the development or improvement of hydrological forecasting systems.

2.3.1. Spatial distribution of critical events related to water. First, it is important to note that the phenomena of drought and flood are distinguished in several ways: while floods affect cities located on the margin of rivers, hydrological droughts affect broader regions where there is insufficient water to meet demand. Moreover, floods generally are processed much more quickly than droughts, which are usually recorded after long periods of a negative precipitation anomaly. On the other hand, floods are usually associated with high rainfall sufficiently able to raise the level of a river beyond the limit supported by its channel, natural or artificial, which shows a close relationship between a weather event and urban occupation and the occurrence of a flooding event.

To synthesize the distribution throughout the Brazilian territory of critical hydrological events of floods and droughts monitored in ANA's Situation Room, the next items considered were the main results presented in the Brazilian Atlas of Natural Disaster (Brazil Ministry of National Integration & Federal University of Santa Catarina, 2012) published by the Ministry of National Integration, and shown in the maps and charts which follow.

2.3.1.1. Floods

The term 'flood' can be understood as the overflow of water from the normal channel of rivers, seas, lakes and reservoirs, or water accumulation by poor drainage in areas not normally submerged. Depending on their magnitude, floods are classified as exceptional, of high magnitude, normal or regular, or of small magnitude.

Gradual flooding includes floods where the gradual rise of the water level of a river, above its natural channel, occurs. The prediction of the occurrence of such events can be made with the use of ANA's river flows monitoring network. Thus, the monitoring developed in the Situation Room is more focused on the prediction of gradual flooding. To assist in understanding how such events are distributed over the Brazilian territory, they are presented below in Figures 2 and 3.

An analysis of Figure 3 shows that the southeast region has the highest number of recorded cases of gradual flooding in the country, followed by the northeast and south regions. Considering monthly distribution, there is a highlight in the peak occurrences in the southeast in January. The high number of occurrences in the north and northeast in April also stand out.

2.3.1.2. Flood Vulnerability Atlas

This Atlas is focused on gradual flooding or plain flooding events, which have the slow ascent and descent of river levels as their main characteristic. These events are seasonal almost all over the country, with the beginning of floods varying depending on the rainy season (Figure 4). In the basins of the

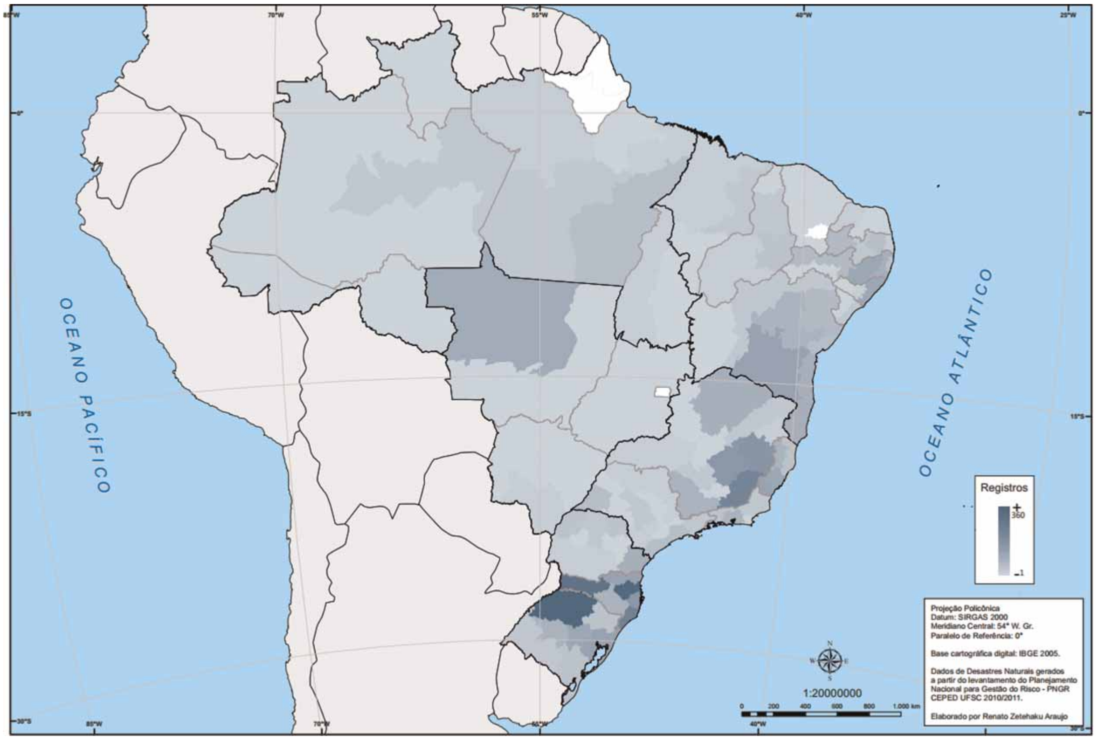

Fig. 2. Natural disasters caused by gradual flood in Brazil from 1991 to 2010 (Brazil Ministry of National Integration & Federal University of Santa Catarina, 2012).

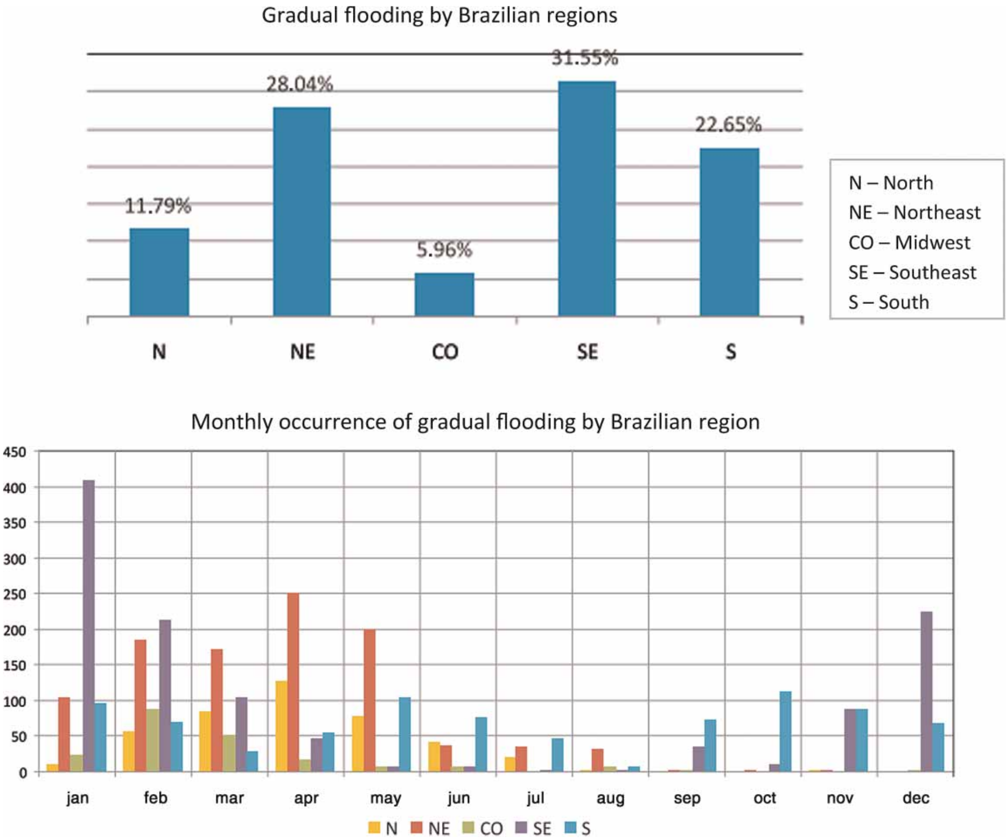

Fig. 3. Distribution of disaster caused by gradual floods in Brazil by region for the period from 1991 to 2010 (top) and the monthly occurrence of gradual flooding by region (bottom) (Brazil Ministry of National Integration & Federal University of Santa Catarina, 2012).

southeast, northeast and south regions, the flooding cycle is well defined, and the events generally occur at intervals of days or weeks and can repeat successively throughout the rainy season. In the north and midwest, large basins such as the Amazon and the Pantanal, have long cycles of floods, which last for months. They are also disasters with high economic loss in the affected areas, although the number of deaths is lower than in other water-related phenomena, such as torrents during heavy rains.

The flooding information was gathered in each state through meetings held during 2011 and 2012, in which the most relevant actors in tackling the issue were put together. All meetings were conducted by the state water resources management agency, with the participation of ANA. The involvement of the State Civil Defense is also highlighted. In each state there was a different composition of the participants, considering their involvement in the theme, region and the organizational structure of the State Government. The Geological Survey of Brazil (CPRM), the Hydroelectric Company of San Francisco (CHESF) and the National Department of Works Against Droughts (DNOCS)[1] also attended the meetings.

[1] CHESF and DNOCS attended the meetings held in their area of activity (basically, the Brazilian northeast).

Fig. 4. Critical periods for flood monitoring in the Brazilian regions.

To obtain the effective participation of states in preparing the maps, the first activities were the presentation of the objectives and methodology of the Atlas, through meetings in the states, which primarily involved the water resource management bodies and civil defense organizations. On these occasions, ANA presented preliminary maps from which each state could meet its set of information and records of flood events. Some states chose to hold several meetings in addition to the events organized in conjunction with ANA, as well as workshops to review the maps, which extended the deadline initially set.

The project was developed following the steps listed below, which have their own methodology and products:

(a) flooding stretches;
(b) vulnerability of flooding stretches;
(c) critical areas.

2.3.1.2.1. Flooding stretches. The purpose of this step was to identify the geographical distribution of the occurrences of floods in Brazil's major rivers, their frequency, magnitude and associated impacts, i.e. to gain a picture of events occurring in a given length of time.

The flooding stretches were identified by visits to the water resource management agencies and the states and the Federal District Civil Defense, in which the following issues were evaluated:

- where floods occur in the state;

- how often the river stretch flooded;
- what is the impact caused by flood in each stretch.

At this stage, a map of flooding stretches was consolidated for major rivers on a scale of 1 to 1 million, gathering the information collected in the states. The municipality boundaries and the municipality headquarters were also represented on the map in order to serve as a physical basis for signaling the flooding stretches. When working at the national level, the issue of scale becomes a relevant factor for the representation of information. The waterbase used today by ANA for application throughout Brazil is the so called 'Hintegrada', which is comprised of the graphical representation of the systematic mapping rivers at the scale of 1 to 1 million, as required by the Brazilian Institute of Geography and Statistics (IBGE), using the Otto Pfafstetter coding methodology. From ANA's basic hydrological data, a common period of daily rainfall data was determined for selected rainfall stations, to perform frequency analysis in order to identify the most recurrent extreme daily values, from which the occurrence of floods was estimated.

Even as a by-product, a map based on 'Otto' sub-basins was generated, which is useful for many other purposes at ANA, such as studies of grants of water, hydrologic modeling, identification of drainage areas of hydrological stations and alert systems.

2.3.1.2.2. Vulnerability of flooding stretches. The purpose of this step was to estimate the flooding stretches vulnerability in relation to the frequency of floods and their impacts. The vulnerability results from a qualitative assessment of the data gathered in the previous step, undertaken by classifying the frequency of occurrence and the level of impacts associated with flooding.

The frequency of floods is classified in the following ranges:

- High: floods occur within less than 5-year intervals;
- Average: floods occur between 5- and 10-year intervals;
- Low: floods only occur within intervals exceeding 10 years.

The level of impact was rated according to the criteria below (Figure 5):

Finally, the vulnerability was evaluated by performing the following combination of frequency and impact: high, when the impact is high for any frequency or when the impact is medium and the

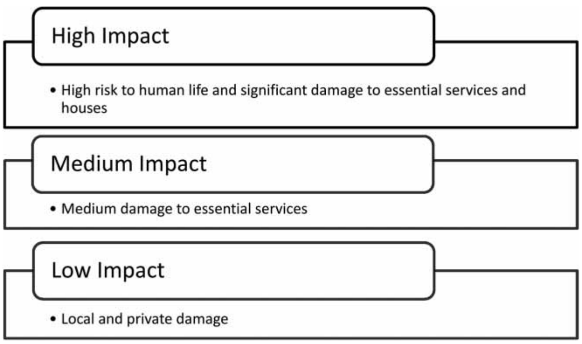

Fig. 5. Classes of impacts.

frequency is high; low when the impact is low and the frequency is medium or low; medium in all other cases, as shown in Figure 6.

The Annual Flood Occurrence Map serves to validate the results obtained in this step. Records of the occurrence of flooding and consequent damage to the population were determined by the National Secretariat of Civil Defense (SEDEC/MI) and IBGE, which were compiled and stored in a georeferenced database for application in the 1:1000000 scale.

The most significant disasters and areas of greatest frequency were identified and ranked by municipality, following the form of organization by the Civil Defense and IBGE. The National Secretariat of Civil Defense provides, in addition to recording when and where the event occurs, data on damage to people and property, by consulting reports submitted by the municipalities. IBGE has recently published the results of the National Survey on Sanitation (2008), in which the incidence of flooding in cities over the past 5 years was investigated. As a result it was found that 48.7% had no flood problems, 27.4% had floods or overflow problems and 23.9% had flooding or overflow issues due to bottlenecks. Also it was discovered that 60.7% of the municipalities had urban occupation in areas that are naturally subjected to flooding.

After the water management bodies and the states and Federal District Civil Defenses reviewed the results, the maps were drawn from the IBGE Continuous Cartographic Base of Brazil (BCIM) to the Millionth Scale. The hydrography follows the Otto Pfafstetter encoding to identify each river stretch, seeking their integration within the National Water Resources Information System (SNIRH). All information feeds a geographic information system, from which the maps are developed for each theme. Figure 7 summarizes the steps taken to build the Flood Vulnerability Atlas.

2.3.1.2.3. Critical areas. At this stage, from the data and maps produced in the previous steps, the critical areas for the occurrence of floods (either due to high exposure to events or a lack of preparation for dealing with them) were identified. From this summary, the preventive actions below were recommended, preferably in the form of nonstructural measures. These measures required the adequacy of the telemetric network of ANA, the states, National Institute of Meteorology (INMET) and National Institute for Space Research (INPE), and required the drafting of a reference manual providing guidance

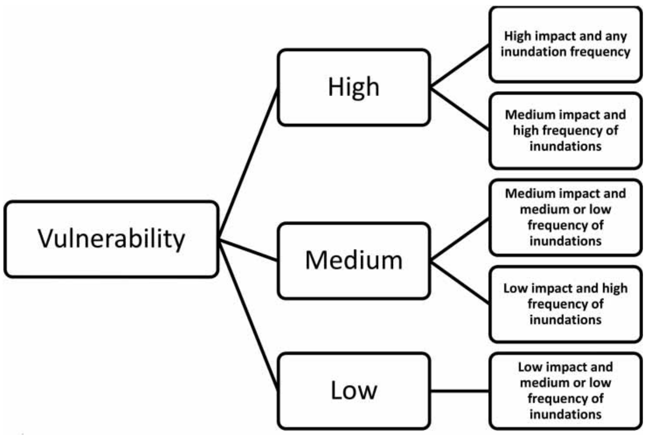

Fig. 6. Definition of the vulnerability level.

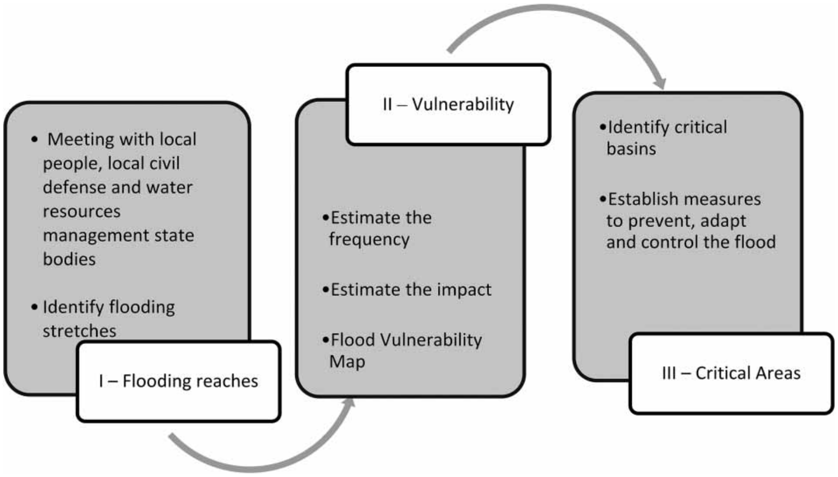

Fig. 7. Steps to build Flood Vulnerability Atlas.

on the technological and institutional options for coping with floods, involving nonstructural measures. According to the basin features, the following recommendations were made:

- Basins with elevated time of concentration:
  - stream flow forecasting models;
  - hydrologic warning systems.
- Basins with dense urban occupation:
  - charts of flood zones;
  - charts of flood risk.
- Basins with reduced time of concentration:
  - weather prediction systems.

As a final result, the Atlas presents maps showing the vulnerability of river stretches, such as the example shown in Figure 8.

The Flood Vulnerability Atlas identified 13,948 river stretches prone to flood in 2,780 rivers in the country, of which 4,111 stretches, or 30%, were considered highly vulnerable to gradual floods, 6,051 (43%) were of medium and 3,786 (27%) were of low vulnerability to such occurrences.

The regions that showed the highest proportion of stretches of rivers with high vulnerability to flooding are the midwest (45%) and the south (43%), while the others had less than 30% of their stretches with high vulnerability to gradual floods.

The north and northeast regions, although having significant gradual floods events, were the regions which were identified as having the fewest stretches being highly vulnerable to flooding. The north region has 82% of the sections identified with medium or low vulnerability to flooding and the northeast, 78%.

Owing to the large amount of maps obtained, it was necessary to simplify the presentation of the results, which was done in Table 1. This table shows, for each state, the main rivers with stretches of high vulnerability to flood. It is noteworthy that some critical sections which are smaller affluents are not listed, although several river stretches located in urban areas contribute to flood.

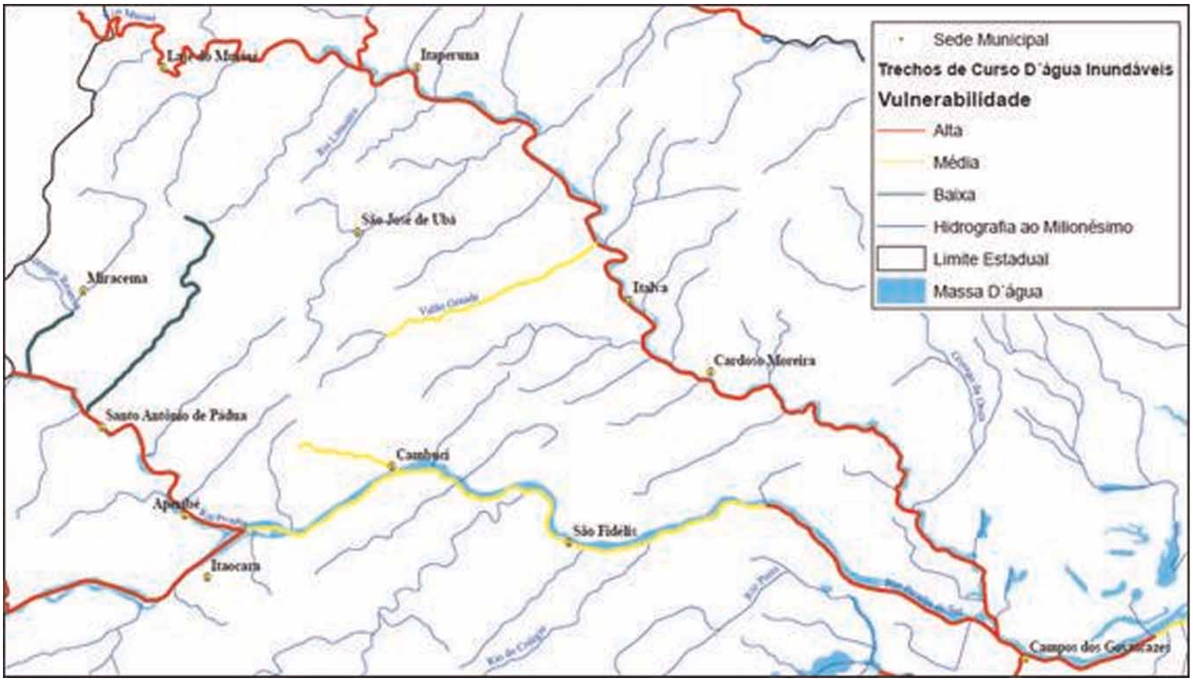

Fig. 8. Example of vulnerability map (Atlas of Vulnerability to Flooding).

As expected, the south and southeast regions are those with the largest number of rivers with vulnerability to flooding because their populations occupy a larger portion of the territory, settling in many cases in the lowland regions.

2.3.2. Priority watershed. The ANA Situation Room has some priority basins where there is frequent river level monitoring, especially in times of flooding, as in the case of the Doce, Mundaú and Acre rivers basins. The ANA Situation Room also monitors strategic basins for power generation, which is the case for the São Francisco, Large and Paraguay basins, or basins where important transpositions of flows occur, as in the cases of the Paraíba do Sul and Piracicaba rivers basins, among others.

As part of this monitoring, ANA issues daily or sporadic bulletins, depending on the hydrological situation set in the basin. The decision about the report period of a seasonal character bulletin is usually made based on the update of retention curves on existing stations in the basin, on the information available, and on the weather. To define new priority basins it is essential that Situation Room operators are guided by the results presented in the Flood Vulnerability Atlas.

2.4. Hydrometeorological stations

ANA is responsible for coordinating the activities carried out under the National Hydrometeorological Network, composed of more than 4,500 rainfall and river flow stations, where river level and river flow are monitored, as well as the amount of sediment and water quality. The rivers where monitoring

Table 1. Major rivers with stretches of high vulnerability to flooding.

Region	State	River
Midwest	Distrito Federal	Just small tributaries
	Goiás	Araguaia river, Ponte de Pedra river, Ribeirão Santa Maria river, Meia Ponte river, Paranã river and Vermelho river
	Mato Grosso	Cuiabá river and Araguaia river
	Mato Grosso do Sul	Paraguai river, Miranda river, Aquidauana river, Itiquira river, Apa river, Pardo river and Verde river
Northeast	Alagoas	Mundaú river, Paraíba river, Ipanema river, São Miguel river and Jacuípe river
	Bahia	São Francisco river, Itapicuru river, Jequirica river, Rio de Contas river, Cachoeira river, Almada river and Paraguaçu river
	Ceará	Acaraú river, Aracatiaçu river, Quixeramobim river, Cocó river and Jaguaribe river
	Maranhão	Itapicuru river, Mearim river, Munim river and Tocantins river
	Paraíba	Ingá river and Paraíba river
	Pernambuco	Una river, Pirangi river, Panelas river, Sirinhaém river, Jacuípe river, Mundaú river, Ipojuca river, Tapacurá river, Jaboatão river and Sirigi river
	Piauí	Parnaíba river and Gurguéia river
	Rio Grande do Norte	Apodi river, Piranhas-Açu river and Seridó river
	Sergipe	Caiçai river, Vaza-Barris river and Piautinga river
North	Acre	Juruá river, Tarauacá river, Envira river, Purus river, Iaco river and Acre river
	Amapá	Jari river, Araguari river and Amazonas river
	Amazonas	Solimões river, Negro river, Amazonas river, Madeira river, Purus river and Juruá river
	Pará	Amazonas river, Tapajós river, Xingu river and Tocantins river
	Rondônia	Madeira river, Mamoré river and Machado river
	Roraima	Branco river, Juaperi river, Igarapé Caracanã river and Igarapé Quitauaú river
	Tocantins	Araguaia river, Tocantins river, Manuel Alves Grande river, Lontra river, Ribeirão Tranqueira river and Formoso river
Southeast	Espírito Santo	São Domingos stream, Cricaré river, Cotaxé river, São Francisco river, São Mateus river, Doce river, São José river, Bananal river, Piraquê-Açu river, Fundão river, Guandu river, Santa Maria river, Jacu river, Santa Clara river, Castelo river, Itapemirim river, Muquiqui do Norte river, Muqui do Sul river, Rio do Veado river and Itabapoana river
	Minas Gerais	Guavinipã river, Paracatu, Mucuri river, São Nicolau river, Doce river, Piranga river, Xopotó river, Piracicaba river, Caratinga river, Matipó river, Mutum river, José Pedro river, São João river, Carangola river, Muriaé river, Turvo river, Maranhão river, Brumado river, Camapuã river, Paraopeba river, Jacaré river, Rio das Velhas river, Grande river and Rio das Mortes river
	Rio de Janeiro	Itabapoana river, Carangola river, river Muriaé, Pomba river, Paraíba do Sul river, Ururaí river, Canal da Andressa river, Macaé river, Preto river, Grande river, Preto river, Paquequer river, Capivari river, Tanguá river, Bananal river, Guandu river, Mambucaba river, Santana river and Sarapuí river
	São Paulo	Jacuí river, Jaguari river, Tietê river, Guanhanha river, Pariqueraçu river, Jacupiranga river and Ribeira do Igauapé river
South	Paraná	Tibaji river, Rio das Cinzas river, Pescaria river, Jaguaricatú river, Pitanga river, Nhundiaquara river, Atuba river, Belém river, Iguaçu river, Ribeirão dos Padilhas river, Barigui river, Rio da Várzea river, Negro river e Marrecas river

(*Continued.*)

Table 1. (*Continued.*)

Region	State	River
	Rio Grande do Sul	Uruguai river, Ijuizinho river, Ijuí river, Ligeiro river, Inhandava river, Carazinho river, Jacuí river, Soturno river, Vacacaí-Mirim river, Vacacaí river, São Sepé river, Arroio do Conde stream, Arroio dos Ratos stream, Pardo river, Zeferino stream, Taquari river, Santa Cruz stream, Caí river, Rolante river, Rio dos Sinos river, Gravataí river, Maquiné river, Camaquã river, Duro stream, Velhaco stream, Grande stream, Piratini river, Jaguarão river, Santa Maria river, Jaguari river, Ibicuí river, Ibiraputã river and Quaraí river
	Santa Catarina	Uruguai river, Rio das Almas river, Iraceminha river, Xanxerê river, Riacho Grande river, Santo Antônio river, Rio do Peixe river, Erval river, Canoas river, Guará river, Iguaçu river, Canoinhas river, Vermelho river, Pitanga river, Negrinho river, Cachoeira river, Texto river, Benedito river, Luís Alves river, Rio dos Índios river, Itajaí-açu river, Neise stream, Itajaí-mirim river, Taió river, Blumenau river, Itajaí do Oeste river, Itajaí do Sul river, Alto Braço river, Rio das Antas river, Cubatão river, Biguaçu river, Rio do Meio river, Braço do Norte river, Tubarão river, Mãe Luzia river, Manoel Alves river, Araranguá river, Sertão river and Mampituba river

occurs correspond to 2,176 of the 12,978 registered rivers in ANA's hydrological information system ANA[2].

This information is critical for both ANA's water resources management decision making as well as the development of projects in various sectors of the economy that are water users, such as agriculture, water transportation, hydroelectric power generation, sanitation and aquaculture.

In recent years, ANA has invested in the modernization of the hydrometeorological network, installing telemetric stations which, through the DCPs, carry out the automated acquisition of hydrologic data and transmit them to the Agency, where the data are processed, stored and made available online.

This type of equipment has several advantages, such as (i) it allows monitoring in areas of difficult access, (ii) it enables the monitoring in real time of critical hydrological events as well as the volume stored in reservoirs, (iii) it feeds water quality warning systems, and so on. For this reason, ANA began to adopt the telemetric stations as a reference in planning the expansion of the hydrometeorological network under its responsibility.

2.5. Reservoirs

Reservoirs are bodies of water, natural or artificial, used to store, regulate and control water resources. The basic purpose of storage is to retain excess water from the wet season to ensure water reserves in the dry season. Meanwhile, regularization corresponds to the quantity of water that a reservoir can provide in a given period of time.

The control of water resources is the operational aspect that concerns the way that water is used, as it can be stored or released, and how that should be achieved. The control is achieved by the operation of

[2] ANA provides data level, flow, sediment and water quality in Brazilian rivers and rainfall in the country at the following sites: HIDROWEB http://hidroweb.ana.gov.br/; hydrological monitoring system http://www.ana.gov.br/telemetria; and National Information System on Water Resources – SNIRH http://www.snirh.gov.br/.

the reservoir which relies on the definition of operating rules regarding the level of water that the dam must keep and flow rates to be flushed downstream. The level is directly associated with the stored water volume, which can be used for multiple purposes: human consumption, animal supply, irrigation, power generation, aquaculture, industrial use, flood control, etc. The flow released downstream may also be related to uses that may be downstream, including environmental water use to preserve the organisms that depend on it.

Regarding critical hydrological events, a high water level can cause backwater upstream, i.e., super-elevation of the water level of the river, flooding upstream regions. A low water level, in turn, reduces the ability to stabilize the reservoir, which can characterize a period of water shortage. Moreover, in the rainy season, it is possible to reserve part of the volume of the reservoir to retain a predicted flood wave.

In these critical situations of floods and shortage of water, the reservoir also has significant relevance to downstream areas. Flows released can soften the impact of floods, in that they reduce the natural flow spillover to the limit of the river channel, or relieve the pressures on water resources. On the other hand, it can increase the water supply by releasing higher flow during the drought season.

In this context, ANA has an important role, since it has, as one of its tasks, to define and monitor the conditions of operation of reservoirs by public and private actors, to ensure multiple use of water resources (as established in the resource water plans in their basins). In hydropower exploitations, ANA negotiates the definition of reservoir operating conditions with ONS.

ONS annually consolidates and offers an 'inventory of operative constraints of hydroelectric drain' on its homepage, providing information about hydraulic operational constraints originating from surveys conducted in the past and periodically, relative to the minimum and maximum flows sections and river stretches, limitations of maximum and minimum flows in exploitations, maximum and minimum reservoir levels, maximum rates of change of hydraulic flows, and other restrictions. This inventory also shows a schematic diagram of the power plants of the National interconnected system (SIN), classifying by basin.

ONS also annually prepares and provides an 'annual flood prevention plan', which contains the results of the studies conducted to define the volumes expected to be maintained in the associated reservoirs with different hydrological scenarios grouped by basin. The flood-control volume corresponds to the portion of the net volume of the dam to be maintained during the period when aiming to retain part of its volume, protecting downstream areas because the river flow can be reduced.

2.5.1. Definition of reservoirs for critical events monitoring. The definition of the reservoirs must take into account hydrological peculiarities of the region and the relative importance that they have: in times of shortage, regulating reservoirs are strategic to meet water demands; in the wet seasons, reservoirs with a flood-control volume and the damping capacity of the flow should be considered in controlling floods.

Run-of-the-rivers reservoirs are those which make little alteration of natural river flows, with less relevant flood control. However, knowledge of the characteristics of the operation and monitoring of these are needed, since these are constructions that interfere with the natural flow.

Table 2 lists the main features to be observed in defining reservoirs to monitor the activity of critical hydrological events, monitoring scarcity of water and flooding. Moreover, it presents some important issues to be monitored if there is available information.

In general, the larger reservoirs in a basin are used both in ensuring water supply in times of scarcity and in flood control. In Brazil, only the reservoirs linked to the SIN hold most of the information in a

Table 2. Definition of reservoirs for critical events monitoring.

Period	Main characteristic	Relevant information
Dry	Storage capacity; Regularization capacity;	Storage volume; Target volume of the period; Minimum flow released downstream; Maximum water withdrawals for the period; Climate forecast.
Wet	Total hold volume; Cushioning capacity of flood flows;	Reservoir level; Target level of flood control storage volume; Expected inflow; Predicted outflow; Maximum outflow; Weather forecast.

systematic way. This means that in most reservoirs for multipurpose uses that are not required for the generation of hydropower, information has to be raised from various sources or generated from specific studies.

The National Electric Energy Agency provides the georeferenced information system for the electricity sector where data about the exploitations of the power sector can be obtained. In addition, some other data can be obtained from the websites of State Water Resources Managers Agencies.

2.5.2. Characterization of reservoir operation situations. The characterization of reservoir operation for flood control should consider the occupation of flood control storage, the forecasted inflow and outflow and maximum outflow, which is usually associated with the flow limit supported by the riverbed at critical points downstream.

The main differences in the characterization of scarcity in relation to flooding is that the length of the first is longer, typically in the order of months, and its onset occurs when water scarcity compromises the burden of water demands, especially of water supply systems. Thus, scarcity is characterized from the average inflow, the reservoir level (which is associated with a storage volume) and the planned rate of withdrawal flow.

It is noteworthy that the operating rules may be disregarded in emergency situations, when there is characterized imminent risk to the health of the population, the environment and hydraulic structures due to accidents or floods. In these cases, it is recommended that the system operations are carried out by the operator, with the accompaniment of the bodies involved – management agency, committee and so on.

3. Situation Room Action Plan

An annual Situation Room Action Plan should be prepared to guide its operation, indicating minimally:

- regions or priority basins to be monitored during the period of the Plan, considering the critical event;
- actions in the Situation Room to be developed by region or basin and its stage in the development of each action;

- staff available and the allocation of activities among its members, considering the technological resources available.

In general, the Situation Room Action Plan translates into the generation and dissemination of information on critical hydrological events.

4. Final considerations

Since the implementation of the National Civil Defense System in Brazil in 1988, the focus on disaster management is no longer the response when assisting those affected; it has now become managing disaster risk, in addition to the response, including prevention and minimizing the effects of the critical event.

ANA, established in 2000, has been engaging in risk management, with the pillars of hydrological monitoring, mapping risk areas and improved responsiveness to the occurrence of extreme flood and drought events.

In this context, we highlight the actions for modernization and expansion of the hydrological monitoring network, in particular the alert network, the completion of the Flood Vulnerability Atlas and deployment of Situation Rooms in the states, with a view to strengthening the role of these bodies in disaster risk management and providing them with greater capacity to respond to such events.

In recent years, a growing concern regarding risk identification and prevention of natural disasters has been observed in Brazil. In 2013, 273 emergency decrees (SE) were published or states of emergency (ECP) declared due to the occurrence of floods in 262 municipalities (for approximately 4.7% of all municipalities in the country, the issuing of decrees related to these types of events has been decreasing since 2009 and, in 2013, the number of decrees issued was registered as the fourth smallest value in a series of eleven). Although it may mean that the events are more localized, this information also reflects the effectiveness of the actions that have been implemented by the bodies in the National System of Civil Protection and Defense, among them the ANA. Certainly, the impacts of extreme weather events cannot be eliminated but, through prevention, forecasting and warning, it is possible to reduce the damage to property and infrastructure, and the loss of human lives.

References

Brazil Ministry of National Integration & Federal University of Santa Catarina (2012). *Brazilian Atlas of Natural Disaster: 1991–2010*. Volume: Brazil. Ministry of National Integration & Universidade Federal de Santa Catarina (UFSC), Florianópolis.

Brazil Ministry of Planning (2012). National Risk Management and Disaster Response Plan: 2012, 2014 - Presentation. http://www.planejamento.gov.br/secretarias/upload/Arquivos/pronunciamentos/apresentacaoes/2012/120808_Plano_Nac_Risco_2.pdf.