Accepted Manuscript

Geological Society, London, Special Publications

Climate change, water-related disasters, flood control and rainfall forecasting: a case study in river São Francisco, Brazil.

Julio Issao Kuwajima, Fernando Mainardi Fan, Dirk Schwanenberg, Alberto Assis dos Reis, André Niemann & Frederico Fábio Mauad

To cite this article, please follow the guidance at https://www.geolsoc.org.uk/onlinefirst#how-to-cite

Manuscript version: Accepted Manuscript

This is a PDF of an unedited manuscript that has been accepted for publication. The manuscript will undergo copyediting, typesetting and correction before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the book series pertain.

Although reasonable efforts have been made to obtain all necessary permissions from third parties to include their copyrighted content within this article, their full citation and copyright line may not be present in this Accepted Manuscript version. Before using any content from this article, please refer to the Version of Record once published for full citation and copyright details, as permissions may be required.

"Climate change, water related disasters, Flood Control and Rainfall Forecasting: a case study in river São Francisco, Brazil"

AUTHORS:

Julio Issao Kuwajima*, International Policy Centre for Inclusive Growth, Brazil (julio.kuwajima@usp.br)
Fernando Mainardi Fan, Federal University of Rio Grande Do Sul, Brazil (Fernando.fan@ufrgs.br)
Dirk Schwanenberg, Kisters, Germany (dirk.schwanenberg@kisters.de)
Alberto Assis Dos Reis, CEMIG, Brazil (betoreis@cemig.com.br)
André Niemann, University Duisburg-Essen, Germany (andre.niemann@uni-due.de)
Frederico Fábio Mauad, University of São Paulo, Brazil (mauadffm@sc.usp.br)

ABSTRACT:

Because of Climate-change, the frequency, intensity, and/or duration of extreme weather events such as floods, droughts, storms, and extreme temperatures is increasing. These events are often related to property, financial and human losses. Especially in poor and developing countries where there is no or poor disaster management due to social and financial difficulties or due to a lack of synergy between the mitigation actions taken. Negative impacts can be reduced, and losses can better coped with proper water management techniques. However these should not be handled solely with traditional management. The actual problem cannot be over simplified as merely a question of coping resources availability and demand. Therefore, the present paper aims to summarize and synthetize advances in weather forecasting and reservoir operation in the upper river São Francisco, strategic to Brazil because it provides water to the semi-arid region and energy for economically thriving Brazilian regions. Moreover, it discusses challenges, opportunities and improvement needed to implement these advances in the current national integrated water resources management. This is mainly focused in water-related disaster mitigation.

Keywords: Water-related disasters, reservoir, flood control, Water Resources management policy

Between 1990 and 2015, more than 1.6 million of deaths caused by natural disasters were recorded around the world. As this number continues to rise, regardless of recent progress on the implementation of disaster risk reduction strategies; stronger efforts are needed to build resilience and limit climate-related hazards and natural disasters. The full commitment of the Paris Agreement on Climate Change parties and signatories is required in order to mitigate climate change and its impacts (United Nations Economic and Social Council 2017). Water-related disasters (floods, windstorms, tidal wave and tsunami, droughts, and water-borne epidemics) are the most frequent natural, resulting in property damages and losses of life. Among these disasters, floods and windstorms are the deadliest, accounting for 88.5 % of the recorded deaths between 1900 and 2006. Even though water-related disaster fatalities are decreasing, their estimated economic loss is increasing, but both could be avoided with appropriate water-related management policies (Adikari & Yoshitani 2009).

As disasters resulted from extreme weather events (floods and droughts) pose severe negative social and economic threat to development and economic growth, managing the extremes in the hydrological cycle is critical to water resources management, therefore water-related disaster management should not be considered separately but part of integrated water resources management. In Gopalakrishnan (2013) current water disaster management policies are reviewed and five areas are identified to effectively meet future challenges: risk management, vulnerability assessment, capacity building and resilience, disaster risk reduction–development linkage, and institutional design.

The 2015 World Conference on Disaster Reduction introduced the Sendai Framework, a result of lessons learned, and gaps identified from its predecessors (Yokohama Strategy and Hyogo Framework). This 15-year, voluntary, non-binding agreement recognizes the State as the main actor on disaster risk reduction with shared responsibility with other stakeholders. It introduces innovations such as a strong emphasis on disaster risk management as opposed to disaster management. It also emphasizes tackling disaster risk reduction and climate change adaption when setting the Sustainable Development Goals, because the original Millennium Development Goals had an insufficient focus on risk reduction and resilience (United Nations 2015b).

Flood control techniques are important tools to reduce negative impacts and build resilience to destructive flash floods. These events are resulted from intense and often brief rainfall events and from potential water scarcity driven by harsher drought. Improved weather forecasting coupled with a decision support system (DSS) can be used as part of an early-warning system. It permits optimization of the storage of a hydropower dam; thus, predicting the occurrence of extreme weather events acting beforehand and, thus minimizing potential negative impacts. Besides that, apart from environmental obligations and flood protection purposes, water resources management enables to meet other objectives such as water supply, navigation and hydroelectricity generation. In this study we gathered demonstrations that, in the Upper São Francisco River in Brazil, with the implementation of enhanced weather forecasting and predictive control approach over a short-term forecast horizon, enabled to foresee stress conditions or peak flow events and support decision-makers to take actions before these events happen for minimizing their impacts.

1. Climate change, extreme weather and their implications to human development

Driven by natural and/or anthropogenic forces the climate is changing; i.e. increasing likelihood of occurrence and scale of extreme weather events (e.g. heatwaves, heavy precipitation and droughts). As this pattern worsens in the future, those events are likely to become more frequent and its consequences more significant (IPCC 2007; Marengo & Camargo 2008; Cubasch et al. 2013).

Recent IPCC report (2007) indicate that the occurrence and likelihood of extreme weather events is increasing. The return period of floods is likely to decrease as a result of changes in the runoff peak and volume caused by changes in the land use and land-cover, which will modify flood hazard classification. Areas previously regarded as low hazard may become high hazard zones (Hirabayashi et al. 2013; Zope et al. 2016).

As a result of long term droughts, higher evapotranspiration and increased air temperature; future climate-change scenarios suggest that extreme events in large portions of South America will become more common, this could eventually lead to biome and vegetation changes, such as tropical forest savannization in Amazonia (Salazar et al. 2007; Hirabayashi et al. 2013; Magrin et al. 2014). Extreme weather events can cause profound impacts on food production, economy, public health, energy production and transportation and are responsible for a disproportionately large part of climate-related damages (Kunkel et al. 1999; Easterling et al. 2000; Meehl et al. 2000; Rosenzweig et al. 2001; Patz et al. 2005; Koetse & Rietveld 2009).

2. Financial impacts and human losses caused by floods and water related disasters

Although floods have beneficial impacts on the environment by fertilizing the river bank's soil, recharging ground water and performing an important role for ecosystems; these events can pose threat to life, health, livelihoods and property, floods are responsible for affecting the life of around 65 million people between 1972 and 1996 (Green et al. 2000; World Comission on Dams 2000). Also Adikari & Yoshitani (2009) suggest that basin management plans should be executed, rather than city or town plans, on the basis of an increased understanding of disaster trends and foresightedness. Even though it is difficult to evaluate precisely the economic losses, the estimated figures resulted from such events are often astronomical. According to the Swiss Re database of natural catastrophes; the estimated loss due to extreme natural events between 1977 and 2017 is USD 4 trillion: USD 2.9 trillion were caused by climate-related events (windstorm, flood, drought, hail and bushfire) and 1.1 trillion USD caused by natural catastrophes (earthquake and tsunami). In the last decade (2007 to 2017) the average economic loss from natural disaster events is around USD 171 billion each year (Holzheu & Turner 2018).

A recent study by Gopalakrishnan (2013), found that water related disasters accounted for 90% of all-natural disasters during the period 2000–2010. The study found that droughts, floods and storms together accounted for 60% of the fatalities (estimated at 1.07 million) and 96% of the victims (estimated at 2.48 billion) in terms of human losses. Water-related disasters also accounted for 76% of economic damage from all-natural disasters, estimated at over $1 trillion.

The estimated financial loss caused by natural disasters in the 1970s was USD 75.5 billion, whereas the estimated loss during the period from 2000 to 2008 was USD 702.3 billion. According to Gokany (2009), the mortality rates and annual mortality of extreme weather events has declined in the last two decades despite of the increase of the probability of occurrence and population at risk, this is due to access to the capital and technology needed to prevent, protect and cope with the negative impacts. Therefore Risk-Assessment is vital to identify areas likely to be affected by such disasters and even thought flood protection structures are extremely expensive, these structures can alleviate financial impacts and reduce damage costs to rebuild and reconstruct damaged areas (Jongman et al. 2014b; Jongman et al. 2014a).

Developing countries are especially vulnerable to impacts resulting from climate change events. Their resilience is limited due to economic and social constraints, insufficient integration between different government administration levels (local, regional, national, etc.) and inability of policy makers to understand the interconnections and synergies between climate change management and other environmental and social benefits (Beg et al. 2002). In 2003, the estimated annual damage cost from natural disasters for developing countries was US$ 35 billion. To improve their ability to absorb the cost of disasters, these countries need to strengthen their adaptive capacity and incorporate economic and social impacts of extreme weather events analysis into their planning process (Mirza 2003).

a. Impacts and Consequences of Extreme Weather Events in Brazil

Even though Brazil possesses nearly one fifth of the world´s water reserves, they are unevenly distributed (spatially and seasonally) throughout its territory. As climate dictates the water availability in Brazil, especially during the summer, any changes in the pattern and precipitation

regime are likely to result in occurrence of floods and droughts with consequences to the agricultural and hydroelectric sector, resulting in impacts in the economy and population. These alterations can directly affect river flows. Current studies indicate that the river São Francisco will drastically decrease its discharge as result of rainfall reduction with severe consequences to irrigation and hydropower generation (Salazar et al. 2007; Nobre et al. 2016; Marengo et al. 2017a). Other factors that will aggravate water scarcity are environmental degradation, natural resources exploitation for economic growth and inadequate planning and management (Marengo et al. 2017a) In Brazil, from 1994 to 2015 the estimated economic loss caused by water-related disasters is BRL 182, 7 billion (Brazilian Real). Floods and mudslides correspond to 40% of this sum and 39% of the registered disasters. For the same period droughts and frosts represent 54% of the estimated damage and 48% of the registered events (UFSC 2016b) .In the last 30 years an analysis of the occurrence of high intensity rainfalls and historic droughts shows that they have become more recurrent; however current weather models have uncertainties because of low resolution grids and physical processes representations. Weather projections for South America indicate tendencies for increasing extremes in temperatures in the entire continent; in Brazil within the context of trends in extremes, it is projected rainfall reduction in eastern Amazonia and the Northeast and increasing rainfall trends in Southern Brazil (Marengo et al. 2009; Marengo 2014).A good example of this new dangerous trend is observed in the Amazonia. This region known for the vast water resources and watercourses, recently experienced successive severe droughts and floods events. The record flooding of 2009 was surpassed by the flood of 2012; and during the droughts of 2005 and 2010, the water levels dropped to an extent that navigation along sections of the Madeira River and Amazon River was not possible. These were the severest events in 45 years, moreover the Brazilian Water Agency (Agência Nacional de Águas – ANA), with data from the gauge station on the Negro river in Manaus, classifies these events as "once-in-a-century" seasonal extremes (Marengo et al. 2013a).

Floods
In the last two decades severe flood events resulted in life loss, evacuation of people and property damage in different Brazilian regions (Table 1). The major examples of floods in Brazil are: the 2009 and 2012 floods in the Amazon river; the 2010 Santa Catarina State flood; the 2010 flood in the States of Alagoas and Pernambuco; the great flood of 2011 in Rio de Janeiro (World Bank 2012a, b, c, d; UFSC 2016a).Also the Itajaí Valley located at the state of Santa Catarina in Southern Brazil was stricken repeatedly by flood events in 2008, 2011, 2013, 2014, 2015, and again in 2017. From 2005 to 2012, the Amazon Basin shifted periods of extreme droughts to record breaking floods. According to Tomasella et al. (2010) this extreme discharge fluctuation results from side effects caused by alterations in the hydrodynamics of the basin rather than excess or deficit of precipitation, making it vulnerable to abrupt weather pattern changes despite of the sheer size of its rivers (Ning Zeng and Jin-Ho Yoon and Jose 2008; Tomasella et al. 2010).
In 2009 and 2012, the levels of the Solimões and Negro rivers, branches of the Amazon River, rose resulting in floods in urban and rural areas along the Peruvian, Colombian and Bolivian Amazonia (Marengo et al. 2012; Ordoñez and Raúl, Espinoza 2012; Marengo et al. 2013a). The 2009 flood impacted around 21 municipalities. The unpreparedness of the civil defence and lack of resiliency resulted in huge damage and cost. Solely in the state of Amazonas the housing sector reconstruction costs were estimated at USD 150 million and the estimated damages in the state of Acre at USD 15 million (Marengo et al. 2013a).
Therefore, the consequences of the 2012 flood were considered more severe than those of the 2009 flood. Due to chronic underinvestment in small-scale agriculture and rural development, the poorest population in the Amazon Region could not cope with the negative effects. The city of Manaus had 16 neighbourhoods, touristic attractions, local business, and the city centre and port facilities affected by the event and around 29,000 people are estimated to be impacted. This flood affected highways, roads and bridges; resulting in USD 100 million of damages in the state of Acre (Marengo et al. 2013a).

The most destructive and deadliest among those, despite divergences in the official statistics, was the event in 2008. The Civil Defence damage report presents more conservative numbers, estimating around 1.5 million people directly affected by the floods, the number of evacuees is in the order of 80 thousand; the number of damaged municipalities varies between 84 to 77; and the number of confirmed causalities varies between 110 to 135 (Sevegnani et al. 2009; World Bank 2012d; UFSC 2016b).

Even though some numbers are known, it is hard to make an accurate estimation of the total economic loss caused by the events in 2008. The estimations vary according to the source. According to a report from Comissão Técnica Tripartite Estadual de Meio Ambiente (2009) the infrastructure repair costs for bridges and roads were estimated at BRL 360 million; BRL 194 million were required for the city of Blumenau restoration. More than USD 340 million were the appraised loss resulted from shutting down the Itajaí Harbour during these events; and the emergency plan costed more USD 400 million to the Brazilian Federal Government (Stevaux et al. 2009). The damage assessment made by the World Bank (2012d), indicates BRL 4.75 billion in damages: BRL 1.46 billion for the infrastructure sector (transportation, telecommunications, water and sewage services and energy); BRL 1.43 billion in damages and losses in habitation; BRL 155 million for public health; and BRL 1.4 billion of damages and losses for the public sector (agriculture and industry and commerce).

In the following years (2011, 2013, 2014, 2017)the floods in the State of Santa Catarina and specially the Itajaí Valley received less public attention and were less documented compared to the 2008 event; the main source about them are articles from national and local press and local civil defence press releases.

In 2011 around 930,000 people in 80 municipalities were affected by another major flood event, which evicted more than 26,000 inhabitants from their homes and caused at least 5 casualties. A preliminary assessment estimated the losses at BRL 413,6 million (G1 2011; Secretaria de Estado da Agricultura e Política Rural 2011). In 2013 the effects of extreme precipitation were felt by more than 20,000 people in 72 municipalities, most them located within the Itajaí Valley (G1 SC 2013).

The 2014 flood was felt in 44 municipalities affecting around 47,000 people damaging and closing 20 state and interstate roads (G1 SC 2014). In 2015 the flood impacted 97 municipalities and around 30,000 people. The municipal authority in Rio do Oeste estimated that 70% of the municipality was destroyed causing an estimated loss of BRL 18 million, the major losses were in the agriculture sector (BRL 10 million) (G1 SC 2015; Silva 2015). According to data from the state of Santa Catarina civil defence reports, the most recent event in 2017 is estimated to have affected 99 municipalities and around 31,000 people. Even though the registered precipitation was higher than the event in 2008, there was no causalities due to the coordinated work of the civil defence and proper reservoir volume management (Defesa Civil de Santa Catarina 2017; Diário Catarinense 2017).

During June 2010, heavy precipitations caused floods in the State of Pernambuco and Alagoas, located in in North-eastern Brazil. In Pernambuco 70% of the monthly expected precipitation (180 mm) occurred between 18th and 19th June. Although a quick and organized response by the government and agencies avoided severer consequences, damages and losses were around BRL 3.4 billion, that represents 4% of Pernambuco´s GDP. There were also, 20 confirmed deaths as a result of flash floods in 77 municipalities (World Bank 2012c). In Alagoas the rainfall lasted from 17th to 19th June affecting approximately 270 thousand people: leaving 1.131 injured and 36 deaths. About 8% of the GDP from Alagoas, BRL 1.89 billion are the appraised costs from material losses and damages (World Bank 2012b).

Regarded as the deadliest water-related disaster of Brazilian History, the 2011 disaster in the Rio de Janeiro highlands region, was triggered by a torrential rain, from 11th to 16th, January 2011. 15 municipalities. Floods and mudslides that resulted were felt in 7 municipalities, affecting around 300 thousand people (42% of the region´s population), resulting in 662 people missing, 36,083 evacuated and between 905 and 910 dead (Ministério do Meio Ambiente 2011; World Bank 2012d).

The total costs estimated in losses in damages from this deadly disaster is around BRL 4.78 billion, 40 % of the Rio de Janeiro State GDP in 2009. About BRL 2.2 billion (46%) are related to direct damages

and losses and about BRL 2.6 billion to indirect damages and costs. The damages and property losses on transportation infrastructure were estimated at BRL 621 billion. Sanitation services damages and costs at BRL 457 million; BRL 214 million for agriculture sector; BRL 153.4 million for the industry; and BRL 469.2 million for commerce and services (Ministério do Meio Ambiente 2011; World Bank 2012d).

Droughts

Although droughts obey a different dynamic and pattern, they can be as potentially devastating as those caused from floods. The damages and losses resulted from long-lasting droughts result in deep consequences to agriculture, hydropower generation and human consumption. As this resource becomes scarcer, progress is hindered, and latent water-use inner conflicts are exposed.

Brazil has been also affected by droughts, particularly in the north-eastern portion of the Nation (Table 2). These two types of events might have a direct connection. A recent study indicated an essential correlation between the droughts of the austral summer of 2014, which resulted in the "Water Crisis" in the south-eastern Brazil with extreme rainfall events in western Amazonia. During the period of January 2014 to 2015 the rainfall over Acre in northern Brazil was intense in specific areas, 30.1 and 21% above average respectively for 2014 and 2015; and on the other hand, in SE Brazil, the intense deficit of rainfall was 61.2% in 2014 and 63.2% in 2015 below average (Cavalcanti et al. 2017). From 2013 to 2015, south-eastern Brazil, the most populated and economic active region of the country, struggled with the worst drought in 55 years, it resulted in impacts on water availability for human consumption, agriculture and hydropower production. Major Brazilian cities such as São Paulo, Rio de Janeiro and Belo Horizonte faced water shortages, affecting 40 million people (Coelho et al. 2016; Nobre et al. 2016). The so-called "Water Crisis" was a direct result of bellow average precipitations between 2013 and 2014 combined with high water demand because of the region´s economic importance and population density; which ultimately resulted in extreme stress to the SE Brazil reservoirs. The meteorological causes of this severe event are alterations to the regional atmospheric circulation during the rainy season over Southeast Brazil. The mid-troposphere blocking lasted 45 days and hindered the South Atlantic Convergence Zone (SACZ). As a result, the austral summer of 2014 was one of the warmest and driest since 1951 (Getirana 2015; Marengo & Alves 2015; Marengo et al. 2015; Seth et al. 2015; Coelho et al. 2016; Nobre et al. 2016).

The south-eastern Brazil drought from 2013 to 2015 had a direct impact in the population as schools, business and even hospitals had their operations limited due to water shortage, some regions in the State of São Paulo needed water-trucks to supply water between 2014 and 2015. The prices of products raised up to 30% due to the lower agriculture production during this period; and water and energy bills were also affected by a tariff adjustment during the summit of the "Water Crisis" (Nobre et al. 2016).

The loss estimate from this water crisis and its restrictions in the agricultural sector solely in 2014 is around BRL 20 million. A 6,7% reduction compared to the sector´s 2013 income (King et al. 2015; Nobre et al. 2016). According to reinsurer's annual damage reports the "Water Crisis" in SE Brazil had an overall loss estimated between USD 3 to USD 5 billion affecting more than 27 million people. One of the major losses event of the world in 2014 (Bevere et al. 2015; Jeworrek et al. 2015).

The Amazon region located in northern Brazil, usually associated with its rainforest and large rivers suffered a dramatic landscape change in 2005 and again in 2010, Espinoza et al.(2011) estimated that in 2010 the CO_2 release was around 8 billion tonnes and in 2005 around 5 billion tonnes, displacing the carbon absorbed by the rainforest. These extreme events, intercalated in a short period of time, are regarded as the worst droughts ever registered in that part of the nation resulting in great impacts on the population and ecosystems. Although droughts in the Amazon are thought to be rare and unusual, data from the Manaus gauge site on the Negro river, operating since 1902, indicates that these have become more severe and more frequent in the Amazon region. The first recorded drought was in 1911, but since 1964 the magnitude of the droughts has increased and

the interval between events has decreased, the events of 2005 and 2010 registered the lowest daily minimum since the beginning of recordings at the gauge site (Marengo et al. 2013a).

In 2005, because of low precipitation in the months that preceded the austral winter, the levels and discharges peaked their lower point between May and July. The rainfall reduction continued during this dry period, approximately 25 to 40% less than average. This dry condition caused fires in the Amazon (Marengo et al. 2008b). The 2005 drought caused negative impacts in several sectors including fisheries, transportation, health and agriculture. During this drought rivers, including the Madeira and upper and central Amazon River, became unnavigable. The water levels fell to extremely low levels, therefore communities reachable only by river transportation became isolated, hindering trade and commerce. As rivers dried up, the agricultural production decreased, impacting manioc and coffee crop production in 2006 and beans in 2005 (Marengo et al. 2008b; Anderson et al. 2011; Marengo et al. 2013a).

The 2005 cumulative number of fire outbreaks in Amazonia rainforest increased significantly, 33% compared to the 1999 to 2005 mean; fire leaks induced by drought were responsible by deforestation and biome transformation, releasing huge amounts of greenhouse gases (Marengo et al. 2008a; Marengo et al. 2008b). Data from the health service of Acre indicate an increase of hospital admissions and expenses due to respiratory illnesses and waterborne diseases, they could be directly linked to soot from burnings and water quality deterioration resulting from reduced flow volumes (Marengo et al. 2008b; Tomasella et al. 2010).

Only five years after the 2005 event, the Amazon Region faced a more severe and longer dry spell. The 2010 drought affected large areas of the Amazon rainforest and water levels of major Amazon River tributaries set new low records. Again settlements reachable only by fluvial transportation, became isolated because these local streams, dried up. This drought resulted from El Niño effects during the austral summer and were intensified by the Tropical North Atlantic warming, which reduced humidity flux towards the Amazon Region. The result was the longest drought in 40 years and the lowest discharge ever registered in the Amazon river (8,300 m³/s) (Espinoza et al. 2011; Lewis et al. 2011; Marengo et al. 2011; Espinoza et al. 2012).

The severity of this drought and their negative consequences on fresh water supply, navigation is related to its longer duration. The combination of higher air temperatures, dry air and low water levels and discharge during the austral spring and winter increased forest fires in 200% (Marengo et al. 2011; Xu et al. 2011). According to local authorities and reports from government agencies around 62,000 families were affected by the 2010 drought; the aftermath of lack of sanitation and water quality deterioration in rural regions was waterborne diseases outbreak. The Brazilian government had to provide water pumping and treatment, food deliveries as an emergency measure, costing USD 13.5 million (Lewis et al. 2011).

Unlike the last two examples in Southeast and North Brazil, the Northeast Brazil, is a region historically prone to drought, since the XVII century 45 drought events were recorded. The War of Canudos regarded as deadliest civil war in Brazilian history can trace its origins in the social unrest and economic problems resulted from the droughts of 1896 to 1897. Due to the vulnerability and susceptibility to droughts of this region, since the 1950s, the government has employed structural measures such as reservoirs and channels, as well as social programs. The results are partially successful. Even though deaths caused by drought are not registered since the 1970s, population exodus from the semiarid region during droughts has not stopped (Marengo et al. 2013b).

The current ongoing drought can trace its beginnings back in 2012, the intensity of the 2012 drought was higher than the previous record holder that occurred in an El Niño year in 1998. Unusual warmer temperatures in the Tropical North Atlantic Ocean favoured an anomalous position of the ITCZ (Inter Tropical Convergence Zone). Thus, hindering rainfall in Northeast Brazil and is believed to be the cause of the floods in Amazonia that year. Contradicting recent studies that associate La Niña with more precipitation, between 2012 and 2013 in this region, the phenomenona did not alleviate the drought conditions (Marengo et al. 2013b; Marengo et al. 2016; Marengo et al. 2017b). This drought persisted in the following years with two peaks of higher intensity, from 2012 to 2013 and

after the El Niño in 2015. Even though studies of damages and losses are scarce, until 2017 this long event was estimated to have caused around USD 30 million in losses, affecting around 33.4 million people in more than 1100 municipalities. 997 of these municipalities have declared state of emergency due to severe drought and social unrest was reported in rural areas. (Marengo et al. 2016; Marengo et al. 2017b).

Governmental investments to mitigate the impacts (special credit lines for small farmers and emergency water distribution by trucks) proved to be insufficient to cope with the impacts of this long drought. On the other hand, this crisis sparked the need of discussion and improvement. Efforts were made at Federal and state management level to handle the socio-economic and environmental problems caused by the event. Integrating scientific knowledge and technology of The Drought Monitor of the Brazilian Water Agency (ANA) with the Monitoring Program of Drought in Semiarid of the National Centre for Natural Disaster Monitoring and Alert (CEMADEN), it was possible to create indicators for drought monitoring and forecasting to approach these issues with focus on vulnerability reduction and resilience building (Marengo et al. 2017b).

3. Addressing weather uncertainty with weather forecasting techniques and early warning systems

The Brazilian energy sector is highly dependent on hydroelectricity. 68% of Brazil's electricity supply comes from hydroelectric power. In 2016 the total hydroelectric capacity installed was 96.925 MW, generating 380.911 GWh (Brasil et al. 2015; Empresa de Pesquisa Energética (Brasil) 2017). However, most of the electric installed capacity is concentrated in the south, southeast and central-west regions of the country. Making Brazil vulnerable to precipitation and hydrological pattern changes. An example of this was the severe drought of 2001 that resulted in blackouts and energy shortages, in the aftermath both the energy and the water resources sectors went to a restructuration to improve the planning, operation and management.

Whenever there is water scarcity, it is required to produce a larger than usual amount of electricity through thermal plants that burn fossil fuels to compensate the reduction of production with hydropower sources. However, the energy generated by fossil fuels is more expensive, and expels more greenhouse gases. During the "Water Crisis" of 2014 in Southeast Brazil, the reservoirs supplying this power generation were almost dry. Hydropower dams were not able to provide enough energy and thermoelectric power stations were used to make up the energy demand. This resulted in increased energy generation prices and tariffs in 2015 (Nobre et al. 2016). In contrast, artificial reservoirs can also be used as detention basins using their storage capacity to reduce the peak of downstream floods and related hazards (Green et al. 2000). Hence, reservoirs originally created to meet the needs of human activities such as irrigation, water supply, navigation, fish production, recreation and electricity production, arise as important players to mitigate environmental impacts of droughts and flood events. However, to operate these structures as efficiently as possible, non-structural measures may contribute significant value. This includes the monitoring of precipitation, river and reservoir stages as well as flow measurements, hydrological forecasting, early warning systems, to the implementation of offline and online management strategies.

Climate variability, particularly over the vastly populated region of Brazil here investigated, has an important impact in governmental actions. Therefore, understanding the observed climate variability and explaining the causes of droughts in these regions is fundamental to support strategic government decisions (Coelho et al. 2016). Understanding this variability itself is a challenge; extreme events scales range from days to millennia; and besides that, regarding weather uncertainty and weather forecasting, it is important to understand whether their likelihood and frequency is changing and to be able to better predict their severity and intensity.

Since the 1970s, driven by technological advancements in computational power, numerical models for weather simulation have been continuously enhanced and perfected. According to Marengo et al. (2009) and Bony et al. (2015), although current Global Climate Models (GCMs) allow better

scientific understanding of anthropogenic global climate change, , it is still required to obtain targeted projections of regional climate change. Current regional projections usually have coarse resolution and limited skill and accuracy for local climates simulations. They are largely derived from GCMs, which are designed for different model skills and climate predictability. The development of regional climate change projections is key to move toward integrated assessment and skipping from mitigation to adaptation-based solutions for reducing vulnerability.

The use of hydrological models with the inclusion of precipitation forecasts is the main type of short-term runoff forecast generation for lead-times superior to the time of concentration of a basin. This enables operators to improve water storage management. Through this technique, operators can allocate additional storage before the flood event by pre-releasing water from a reservoir in order to mitigate damages at downstream rivers. It also prevents risks of dam structure over-topping and uncontrolled spillages. Furthermore, in case of droughts, optimized water level management can help reservoir sustain water storage; avoiding drastic level dwindling and thus guaranteeing and optimizing water supply. For this purpose, a robust and fast routing model is required to obtain quick and reliable estimates of downstream flow conditions related to release changes of the reservoir (Kuwajima et al. 2014).

Usually in this kind of system, one source rainfall forecasts are the standard (only one run of a meteorological model), resulting in only one possible trajectory for the future. This characterizes a deterministic runoff forecast. These deterministic hydrological forecasts quite often result in future runoffs that are very distinct from reality. The forecast system contains several uncertainties, such as imperfections in the hydrological and meteorological models or insufficient observed data (TAYLOR & BUIZZA 2003; Pappenberger et al. 2013). One of the main uncertainties in this procedure is the initial condition of the chosen meteorological model. Weather forecasting models are very sensitive to initial conditions of the atmosphere; at the initial forecast calculation, slightly different initial conditions, can result in a completely different state of the atmosphere (Lorenz 1969).

Even if the weather forecast numerical models were perfect, this dependence on the initial conditions would still exist, and small errors in the estimation of the initial conditions could lead to significant errors in the forecast. To deal with this problem, the concept of ensemble forecast arose in Meteorology. This technique that allows for the exploration of uncertainties associated with the initial conditions and/or the structural deficiencies of the meteorological models (Georgakakos & Krzysztofowicz 2001). In an ensemble forecast, different meteorological models or different initial conditions of a single model are used to generate a forecast ensemble, where each of the forecast members represent a possible trajectory of atmospheric processes across the forecast horizon. Recently this incorporation of uncertainty concept by means of short term ensemble forecasts has also been adopted in Hydrology, particularly by applying ensemble forecast results of meteorological variables in a rainfall-runoff hydrological model to obtain, in the same way, an ensemble of runoff forecasts (Cloke & Pappenberger 2009).

Michaels (2015) acknowledges advancements of flood risk estimation, by implementing probabilistic weather forecasting techniques, notably ensemble prediction systems as components of decision making under uncertainty in an evolving policy landscape and advancements on flood risk management . Compared to deterministic forecasts, these applications have demonstrated benefits in terms of forecast quality: a better understanding of the uncertainties associated with prognostics; better operational decisions; amongst others, motivating the development of several operational systems of hydrological ensemble forecasts around the world (Pagano et al. 2013; Pappenberger et al. 2013).

a. Brazilian hydropower operation and disaster risk management

In Brazil, the ONS (Operador Nacional do Sistema Elétrico) is responsible for the short-term and long-term operation of the Brazilian electric system and coordination of flood control. The ONS was created to manage the generation and distribution of electric energy. Because around 142,042 MW of the 150,338 MW of the Brazil´s total installed capacity is currently interconnected to the SIN

(Sistema Interligado Nacional), making it possible to transfer energy produced in one region to another (ONS 2009; EPE 2016, 2017).

This centralized coordination aims to optimize the SIN system as whole and not each Dam individually. For daily operations, ONS uses short-term forecasts (up to 15 days) to set the operation at each Hydro Power Plant (HPP). If the forecasting systems are displaying situations of flood occurrence, the control of the dam is changed to the *in-situ* operator, to avoid safety-related problems (ONS 2009, 2016f, d, c, b).

The Operating Rules for Flood Control Policies are based on scenarios created using historical discharges, hydrological synthetic series, resulting in an offline guideline document containing a table describing different operating restrictions regarding different flood risk conditions (ONS 2016a, b) The flood risk conditions are divided into four categories regarding higher or lesser risk of flood events; maximum discharge violation; and allowed dam storage by the Operating Rules for Flood Control Policies. In a "Normal" flood risk condition, there is no risk of a flood event nor violation of discharge or storage; the "Attention" condition implies risk of a flood event or that the storage is full, but there is no indication of maximum discharge violation; the "Alert" condition is characterized by flood risk event while the storage is full and with indicative of maximum discharge violation; and the "Emergency" condition means that there is flood risk event with full storage and maximum discharge violation. Aside from Normal and Attention conditions, operators have little or no operational freedom. The only situation when operators can set and decide target values for spillway and turbine discharge are under Alert and Emergency conditions (ONS 2016a).

Aside from ONS and Hydropower operators there are other institutions with shared responsibilities on disaster risk reduction. Meteorological data and river monitoring data is provided by the Companhia de Pesquisa de Recursos Minerais – CPRM (Geological Survey of Brazil), Instituto Nacional de Meteorologia - INMET (National Institute of Meteorology), Centro de Previsão de Tempo e Estudos Climáticos Studies - CPTEC (Center for Weather Forecasting and Climate), Instituto Nacional de Pesquisas Espaciais - INPE (National Institute for Space Research) and Agência Nacional de Águas - ANA (National Water Agency). The mitigation actions and planning are done by the Ministério de Integração Nacional (Ministry of National Integration) and its Secretaria Nacional de Proteção (National Secretary of Protection), Defesa Civil (Civil Defence), Centro Nacional de Monitoramento e Alerta de Desastres Naturais - CEMADEN (Centre for Monitoring and Alert of Natural Disasters) and Centro Nacional de Gerenciamento de Riscos e Desastres - CENAD (National Center for Risk and Disaster Management).

The transition towards a probabilistic risk management requires further institutional capacity development and integration of actions between the several institutions involved in this subject (Thompson & Graham 1996; Pahl-Wostl 2007; Haasnoot et al. 2011). New developments for longer forecasting lead times, advances in decision making aids, and inclusion of probabilistic forecasting in hazard mitigation need to be made to meet different needs of users and sectors.

Based on such a scenario, recent studies have looked for the performance of forecasting techniques in large tropical basins, as in the case of the basins in the main hydroelectric Brazilian reservoirs, and the potential benefits they could offer in terms of quality and persistence of runoff forecasts for them. As examples, the studies of Fan et al. (2014; 2015c; 2015a; 2015b) showed results of short-term hydrologic ensemble forecasts evaluation for large basins in Brazil, and concluded that, based on performance metrics, the use of ensembles have a series of advantages in comparison to single deterministic forecasts. Among the evaluated datasets, the ones produced from the ECMWF (European Center for Medium Range Weather Forecasts) were featured. After these and others recent studies the ONS is starting to include the use of short-term ensembles in its methodologies. And, other very important hydropower plants (HPPs), such as the Itaipu Dam, the largest Brazilian Dam, started to adopt hydrologic ensemble forecasting (Lisboa et al. 2015; Fan et al. 2017). As ensemble forecasting techniques become more accurate their use of could be extended to higher lead time applications, where deterministic predictions have been traditionally applied in the last two decades. The use of persistence information from deterministic streamflow forecasts, as an

uncertainty measurement for decision-making, appears to be an interesting strategy with advantages in medium-range lead times for anticipation of hydrological events compared to single deterministic forecasts (Fan et al. 2016).

4. Weather forecasting for operation optimization in Três Marias waterpower dam

Due to its location and significant size, the São Francisco River is one of the most important Brazilian rivers. It is the most important river of the drought prone Northeast Brazil and strategic to the important Government's inter-basin water transfer project designed to increase water availability and mitigate the frequent droughts affecting the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco. The "Velho Chico", as it is called by the locals, also has huge cultural significance. Its surrounding areas are filled of architectural, archaeological and heritage sites (Santos 2003).

Located in the Upper São Francisco River Region in the centre of the state of Minas Gerais between the municipalities of São Gonçalo do Abaeté, Felixlândia, Morada Nova de Minas, Biquinhas, Paineiras, Pompéu, Abaeté e Três Marias (Figure 1), the Três Marias reservoir, also known as UHE Bernardo Mascarenhas, is one of the 9 reservoirs built for hydroelectric purposes in the São Francisco river (Três Marias, Sobradinho, Luiz Gonzaga (Itaparica), Apolônio Sales (Moxotó), Xingó, Paulo Afonso I, Paulo Afonso II and Paulo Afonso III).

The CVSF (Comissão do Vale São Francisco) started the dam construction in 1958. In 1962 at the time of its inauguration, the Três Marias Hydropower Dam was the biggest Brazilian hydropower dam. Its dimensions are 2,700 m width and 75 m height, with a gate-controlled spillway. The reservoir has maximum surface area of around 1,090 km² and a maximum storage of 19,528 hm³. With six 66 MW generators powered by Kaplan turbines, the total installed capacity is 396 MW. The dam is integrated into the SIN and is currently administrated by CEMIG (Companhia Energética de Minas Gerais) with operation coordination by the ONS.

The historical total daily release of the Três Marias dam from 1931 to 2011 ranged between 42 to 7,245 m³/s with an average discharge of 689 m³/s. The dam´s discharge prediction is relevant to the operational process of the subsequent downstream reservoirs at the São Francisco river, since it is responsible for about 26% of the total river discharge, and therefore significantly affects the northeast energy strategy (ONS 2009). The dam is important in the SIN operation and regarded as strategic due to its scale, hydraulic and energetic relevance, and its role in the network security. This implies that Três Marias is vital for the grid stability and has impacts on the ONS centralized hydraulic operations and network security. Therefore, the ONS is responsible for scheduling the target values on monthly, weekly, daily and in real-time basis (ONS 2016b, e, 2017).

The dam must operate under several operational discharge restrictions regarding flood downstream, discharges above 2,000 m³/s released at the reservoir will inundate islands populated by communities located downstream and discharges above 4,000 m³/s will cause severe floods in the city of Pirapora, located about 130 km from the dam. If the discharges of the dam and from the incremental basins reach the order of 8,000 m³/s, the flooding inundation may extend to regions located in the state of Bahia at the middle and lower Sao Francisco basin, about 700 km away from the dam. The operational dam management is further limited by environmental restrictions. The discharge can only be reduced to values lower than 460 m³/s after ichthyofauna monitoring to avoid fish detention. The same rule is applied to the spillway closing. A minimum discharge equal or greater than 420 m³/s must be always ensured for environmental flow purposes. The flow variation should always be shifted slowly at the rate of 150 m³/s per 30 minutes (ONS 2018b, a).

The Três Marias is a well-documented case researched by several authors regarding short-term forecasts at the dam. Moreover, all these studies used short-term ensemble forecasts to consider uncertainty.

Fan et al. (2014), showed experiments of ensemble forecasting applied to the HPP Results showing some benefits in the use of ensembles. Particularly for the reservoir inflow on flooding events, in comparison to the deterministic values given by the control member of the ensemble and by the ensemble mean. Despite the necessary improvements mentioned for the system, the results suggest

that benefits can also result from the application of ensemble forecasts for hydropower plants with large basins within the Brazilian energy system. Fan et al. (2015b) undertook a verification of inflow into hydropower reservoirs using ensemble forecasts of the "The International Grand Global Ensemble" (TIGGE) database for large scale basins in Brazil, including the Três Marias Dam. The work presents one of the first extensive efforts to evaluate ensemble fore-casts for large-scale basins in South America using TIGGE archive data. According to the authors, results from these evaluations confirm that ensemble forecasts depend on the particular model used to run the hydrological model and suggested the better performance of European Centre for Medium-Range Weather Forecasts (ECMWF) model at the basin. These conclusions motivated the use of this particular weather forecasting model in the further studies conducted at the basin. In a continuation of the studies, Schwanenberg et al. (2015) demonstrated the development of a state-of-the-art applications of short-term reservoir management system, which integrate several advanced components, namely hydrological modelling and data assimilation techniques for predicting streamflow; optimization-based techniques for decision-making on the reservoir operation and the technical framework for integrating these components with data feeds from gauging networks, remote sensing data and meteorological weather predictions.

The basis for the anticipatory short-term management of the reservoir over a forecast horizon of up to 15 days are the streamflow predictions of the "Modelo de Grandes Bacias", also known as MGB hydrological model, the same firstly developed by Fan et al.(2014). The novel short-term optimization approach consisted in the reduction of the ensemble forecasts into scenario trees as an input of a multi-stage stochastic optimization. The authors showed that this approach has several advantages over commonly used deterministic methods which neglect forecast uncertainty in the short-term decision-making. First, the probabilistic forecasts have longer forecast horizons that allow an earlier and therefore better anticipation of critical flood events. Second, the stochastic optimization leads to more robust decisions than deterministic procedures which consider only a single future trajectory. Third, the stochastic optimization permits to introduce advanced chance constraints for refining the system operation. These same scenario optimization techniques were further developed and implemented by Naumann et al. (2015) to dams in the USA.

Closing the block of short-term ensemble forecasts for the Três Marias optimization, Fan et al., (2016) introduced a novel, mass conservative scenario tree reduction in combination with a detailed hindcasting and closed-loop control experiments for a Três Marias, operating with two main objectives: (i) hydroelectricity generation and (ii) flood control downstream. In the experiments, precipitation forecasts based on observed data, deterministic and probabilistic forecasts were used to generate streamflow forecasts in a hydrological model over a period of 2 years. According to authors, results for a perfect forecast show the potential benefit of the online optimization and indicate a desired forecast lead time of 30 days. In comparison, the use of actual forecasts of up to 15 days shows the practical benefit of operational forecasts, where stochastic optimization (15 days lead time) outperforms the deterministic version (10 days lead time) significantly. The range of the energy production rate between the different approaches is relatively small, between 78% and 80%, suggesting that the use of stochastic optimization combined with ensemble forecasts leads to a significantly higher level of flood protection without compromising the energy production

Due the fact that the São Francisco River catchment has a vital role in the current Brazilian drought impact mitigation policy for the Northeast semi-arid part of the country, and to the development an impoverished and underdeveloped region, a broader problem approach is required to evaluate the dynamic iterations between floods, droughts and society. Improvements in the current Water Disaster Management Policies are also required: development of more early-warning systems; development of resilience enhance measures; comprehensive disaster risk assessment policies and improved mechanisms for vulnerability assessment and reduction.

5. Creating synergy between weather forecast techniques and better disaster reduction policies.

Since the mid-1990s, World Conferences on Disaster Risk Reduction (WCDRs) are being held to promote discussions between governmental institutions and other stakeholders (NGOs, private sector, civil society organizations and local governments) on disaster risk reduction and building disaster resilience.

At each WCDRs new and improved disaster risk reduction guidelines and strategies are introduced. In 1994, at the first WCDR hosted in Yokohama, Japan the Yokohama Strategy for a Safer World was adopted. During 2005 at the second WCDR conference held in Kobe, the Hyogo Framework for Action (2005-2015) was introduced; which would be replaced in 2015 at the third WCDR by the Sendai Framework for Disaster reduction (2015-2030).

The Yokohama Strategy identified that a more pro-active approach towards informing, motivating and involving people in all aspects of disaster risk reduction was needed and highlighted scarcity of resources for the realization of risk reduction objectives; whereas the Hyogo Framework is a detailed guideline for the coordination of different sector and actors on disaster loss reduction (United Nations 2007, 2015a).

Water related disaster risk management and integration of policies and coordination of stakeholders are also approached by the Agenda 2030 and its 17 Sustainable Development Goals (SDGs), introduced at the United Nations (UN) Rio+20 summit in Brazil in 2012. The SDGs were integrated into the follow-up to the Millennium Development Goals (MDGs), stablished in 2000s, after their deadline in 2015 (United Nations 2015b). Griggs et al.(2013), suggested that these new goals should be more embracing than the MDGs, as they should not only focus on extreme poverty reduction in developing countries, but also to make the transition to sustainable lifestyles in every nation around the globe.

This new framework also approaches Integrated Water Management and Water-Disasters mitigation as the goals 6, 7, 11 and 13, respectively "Ensure availability and sustainable management of water and sanitation for all", "Ensure access to affordable, reliable and modern energy for all", "Make cities and human settlements inclusive, safe resilient and sustainable" and "Take urgent action to combat climate change and its impacts". They all have targets and indicators directly or indirectly related to water resources management implementation, water-related disasters risk reduction and resilience, mitigation and adaptation to climate change and early warning (United Nations 2015b).

Analysing the integration and effectiveness from the SDGs, both Le Blanc (2015) and Stafford-Smith (2016) agreed that they were indeed broader and more integrated than their predecessors by linking social, economic, and environmental aspects through a set of transversal goals. But also indicated that more integration across sectors in terms of strategies, policies and implementation is desirable. It was also emphasized that the success of the SDGs depends of a multi-stakeholder effort, involving different levels of national and local governments but also from collaboration of other organizations such as private sectors, philanthropic organizations and international organizations.

In recent years cross-disciplinary integration with social resilience concepts have also been highlighted as an important step towards adaptive planning for climate change in vulnerable regions (Dale et al. 2015). Sivapalan (2015) presents an interesting paradigm to this broader problematic through a coupled socio-hydrology-flood model which allows exploration of the resulting coevolution of floods and societies, with a focus on estimation of emergent flood risk. In contrast to the current and traditional approach, where for a chosen design period, flood risk is estimated as a combination of flooding probability and its potential damages. This new approach permits analysis of the dynamic interactions and feedbacks between floods and societies making better long-term strategic water management plans, thereby avoiding long-term dynamics misunderstandings.

Alongside structuration and structuring actions natural protection have also positive impacts in flood mitigation. In a historical examination on benefits and costs of Natural Valley Storage Protection, Kousky (2015) highlighted benefits of the economics and politics of "green" flood control. The cost

of large-scale land acquisition outweighed the sole benefits of avoided flood damage, indicating land use regulation as a cheaper alternative to land purchase.

However, due to political and economic factors the Agenda 2030 and Hyogo framework are at risk in Brazil. The official discussion about ways to implement and monitor the SDGs at National Government level started late in2016 with the establishment of the SDG National Commission (Brazil 2016a). As of late 2018, the progress of the SDGs in Brazil were not fully implemented with ongoing discussions on goal and indicators revision (Ipea 2018).

According to Brazil (2018), the budget for natural disasters mitigation actions has decreased since 2014: Expenditures with the national programme for natural disasters and with CEMADEN (monitoring and implementation) diminished from BRL 45,75 million in 2014 to BRL 8 million in 2018 (Table 3).

In addition, a Federal budget cut for next 20 years passed in 2016, compelling further budget costs to an area already lacking of financial resources, this context is likely to jeopardise new improvements in the given governance and structure (Brazil 2016b; Mariano 2017; Vairão Junior & Alves 2017). These are also clear indications of lack of governmental commitment not only the current water risk reduction structure, but also the needed integration of water risk reduction policies at all levels, which are likely to inhibit the success of mitigation action in the long term (Lassa et al. 2018) .

6. Conclusions

Climate change is likely to enhance the uncertainty and magnitude of extreme weather events in Brazil, causing longer and severe droughts and higher peak flows in wet seasons. As these extreme phenomena become more frequent, impacts on important human activities such as agriculture, water supply and hydropower generation will have to be addressed on a regular basis.

As agriculture is one of Brazil´s most important productive sector, and one of the most vulnerable to weather disturbances, the consequences of an increased likelihood of extreme precipitations and longer dry spells, may result in negative impacts to the Country´s economic growth; rural exodus; an increase in regional differences and higher pressure on public services in urban centres. Therefore, better understanding of the local weather and hydrology is required, thus better weather forecasting and predictive models are essential tools to mitigate and diminish negative impacts of droughts and floods.

In all recent major extreme-weather events in Brazil the impacts on local vulnerable population had severe impacts and losses especially on vulnerable populations, indicating governmental agencies unpreparedness to efficiently make disaster risk reduction and implement adaptation strategies that cope with negative impacts of these events. Thus, it is imperative to develop tools to help improve preparedness to extreme events as early-warning systems and high-resolution climate scenarios for impacts and adaptation studies.

The current drought and flood policies are not focused in vulnerability reduction but instead are centred on impact mitigation. Budget cuts and demobilization of institutions and agencies responsible for early-warning systems and disaster risk reduction hinder vulnerability reduction required to understand and practice climate-change adaptation.

Advancements in climate and hydrology monitoring and the improvement of regional and local weather forecast models can have a vital role in extreme weather adaptation and resilience, as they serve as tools for policymakers to implement adaptation strategies to cope with climatic hazards. The further development and dissemination of these technique have the potential to improve the Integrated Water Resources Management in all levels of users.

It is important to stress that the full success of the techniques and policies currently being applied to assess how droughts and floods impacts the health and livelihoods of people living in these regions, it is imperative to implement other measures that would greatly improve the flood control and water-disasters resilience. These include well-suited government policies aimed for adaptation and

vulnerability assessments for the population. The Agenda 2030 should be used as catalyst to this change, integrating policies, strategies and sectors to social, economic and environmental goals.

7. Acknowledgements

8. Tables and Captions

Table 1 – *Recent Extreme Flood Events in Brazil.*

Year	Region	Estimated damages and impacted population
2008	Itajaí Valley (Santa Catarina)	Impacted at least 84 municipalities Affected 1.5 million people, 80,000 evacuees and at least 110 deaths BRL 4.75 billion in damages
2009	Amazon River	USD 165 million in damages(21 municipalities in Acre and Amazonas)
2010	Alagoas and Pernanbuco	BRL 5,29 billion in damages (3,4 billion in Pernanbuco and 1,89 billion in Alagoas) 56 deaths (20 in Pernanbuco and 36 in Alagoas)
2011	Rio de Janeiro	BRL 4.78 billion in damages 15 municipalities Affected 300,000 people with at least 905 deaths
2011	Santa Catarina	80 municipalities Affected930,000 people At least 9 deaths BRL 413,6 million
2012	Amazon River	Affected 29,000 people in Manaus and USD 100 million damages in Acre
2013	Santa Catarina	Affected 20,000 people 72 municipalities
2014	Santa Catarina	Affected 47,000 people 44 municipalities
2015	Santa Catarina	Affected 31,000 people 99 municipalities BRL 18 million in damages

Table 2 – *Recent Extreme Drought Events in Brazil.*

Year	Region	Estimated damages and impacted population
2005	Amazon Region	Impacted agricultural production Transportation Forest fires

2010	Amazon Region	62,000 families Outbreak of waterborne diseases USD 13.5 million
2012 (ongoing)	Northeast Brazil	USD 30 million in losses 11000 municipalities
2014	South-Eastern Brazil	At least USD 5 billion in losses Affected around 27 million people

Table 3 – *Brazil´s expenditures with natural disasters mitigation action (2014-2018)*

| Year	Natural Disasters National Programme (BRL)	Cemaden - Monitoring (BRL)	Cemaden – Implementation (BRL)	Total (BRL)
2014	24.366.250,27	7.166.852,82	14.215.883,53	45.748.986,62
2015	14.962.942,06	6.965.929,76	7.466.568,99	29.395.440,81
2016	1.924.363,15	11.117.196,96	0,00	13.041.560,11
2017	598.464,01	8.852.297,25	0,00	9.450.761,26
2018	78.843,23	7.957.422,21	0,00	8.036.265,44
Total	41.930.862,72	42.059.699,00	21.682.452,52	105.673.014,24

9. Figures Captions
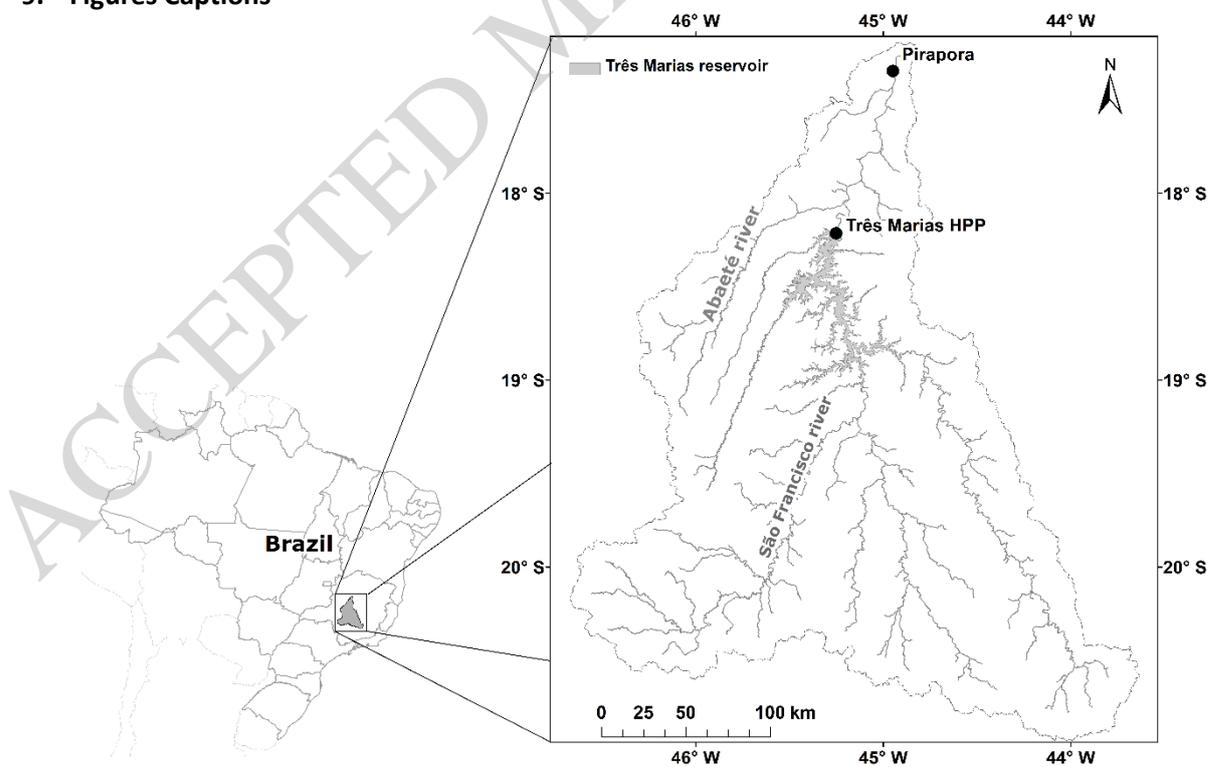
Figure 1 – *Location of the Upper São Francisco Basin and Três Marias HPP.*

10. References

Adikari, Y. & Yoshitani, J. 2009. *Global Trends in Water-Related Disaster: An insight for policymakers.* International Centre for Water Hazard and Risk Management (ICHARM) and UNESCO.

Anderson, L.O., Trivedi, M., Queiroz, J., Aragão, L., Marengo, J., Young, C. & Meir, P. 2011. *Counting the Costs of the 2005 Amazon Drought: A preliminary Assessment.* Global Canopy Programme and University of Edinburgh.

Beg, N., Morlot, J.C., Davidson, O., Afrane-Okesse, Y., Tyani, L., Denton, F., Sokona, Y., Thomas, J.P.*, et al.* 2002. Linkages between climate change and sustainable development. *Climate Policy*, **2**, 129-144, http://doi.org/10.3763/cpol.2002.0216.

Bevere, L., Orwig, K., Sharan, R. & Ronke, P. 2015. *Natural catastrophes and man-made disasters in 2014: convective and winter stomrs generate mos losses.* Swiss Re.

Bony, S., Stevens, B., Frierson, D.M.W., Jakob, C., Kageyama, M., Pincus, R., Shepherd, T.G., Sherwood, S.C.*, et al.* 2015. Clouds, circulation and climate sensitivity. *Nature Geoscience*, **8**, 261, http://doi.org/10.1038/ngeo2398.

Brasil, Ministério de Minas e Energia & Empresa de Pesquisa Energética. 2015. *Plano Decenal de Expansão de Energia 2024.* Ministério de Minas e Energia. Empresa de Pesquisa Energética.

Brazil. 2016a. Decreto N º 8.892, de 27 de outubro de 2016. *In*: República, P.d. (ed.), Brasília, DF.

Brazil. 2016b. Emenda Constitucional Nº95, de 15 de Dezembro de 2016. *In*: República, P.d. (ed.), Brasília-DF.

Brazil. 2018. Portal da Transparência. *In*: União, M.d.T.e.C.-G.d. (ed.), Brasília, DF.

Cavalcanti, I.F.d.A., Marengo, J.A., Alves, L.M. & Costa, D.F. 2017. On the opposite relation between extreme precipitation over west Amazon and southeastern Brazil: observations and model simulations. *International Journal of Climatology*, **37**, 3606-3618, http://doi.org/10.1002/joc.4942.

Cloke, H.L. & Pappenberger, F. 2009. Ensemble flood forecasting: A review. *Journal of Hydrology*, **375**, 613-626, http://doi.org/https://doi.org/10.1016/j.jhydrol.2009.06.005.

Coelho, C.A.S., de Oliveira, C.P., Ambrizzi, T., Reboita, M.S., Carpenedo, C.B., Campos, J.L.P.S., Tomaziello, A.C.N., Pampuch, L.A.*, et al.* 2016. The 2014 southeast Brazil austral summer drought: regional scale mechanisms and teleconnections. *Climate Dynamics*, **46**, 3737-3752, http://doi.org/10.1007/s00382-015-2800-1.

Comissão Técnica Tripartite Estadual de Meio Ambiente. 2009. *Caminhos da recuperação : orientações para a recuperação ambiental dos municípos atingidos pelo desastre ambiental de novembro de 2008 em Santa Catarina.* Comissão Técnica Tripartite Estadual de Meio Ambiente - CTTEMA/SC.

Cubasch, U., Wuebbles, D., Chen, D., Facchini, M.C., Frame, D., Mahowald, N. & Winther, J.-G. 2013. Introduction. *In*: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A.*, et al.* (eds) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* Intergovernmental Panel on Climate Change (IPCC), Cambridge, United Kingdom and New York, NY, USA.

Dale, A., Vella, K.J. & Cottrell, A. 2015. Can social resilience inform SA/SIA for adaptive planning for climate change in vulnerable regions? *Journal of Natural Resources Policy Research*, **7**, 93-104, http://doi.org/10.1080/19390459.2014.963371.

Defesa Civil de Santa Catarina 2017. Sobrelevação das barragens e trabalho preventivo da Defesa Civil minimizam impactos das enchentes de 2017. http://www.sdc.sc.gov.br/index.php/ultimas-noticias/4860-sobrelevacao-das-barragens-e-trabalho-preventivo-da-defesa-civil-minimizam-impactos-das-enchentes-de-2017.html.

Diário Catarinense 2017. Após chuva, famílias atingidas por enchentes e deslizamentos retornam para as casas em SC. http://dc.clicrbs.com.br/sc/estilo-de-vida/noticia/2017/06/apos-chuva-familias-atingidas-por-enchentes-e-deslizamentos-retornam-para-as-casas-em-sc-9813321.html.

Easterling, D.R., Meehl, G.A., Parmesan, C., Changnon, S.A., Karl, T.R. & Mearns, L.O. 2000. Climate Extremes: Observations, Modeling, and Impacts. *Science*, **289**, 2068.

Empresa de Pesquisa Energética (Brasil). 2017. *Balanço Energético Nacional 2017: Ano base 2016.* Empresa de Pesquisa Energética.

EPE. 2016. *Demanda de Energia 2050.* Ministério de Minas e Energia (MME) & Empresa de Pesquisa Energética (EPE).

EPE. 2017. *Anuário Estatístico de Energia Elétrica 2017: ano base 2016.* Ministério de Minas e Energia (MME) & Empresa de Pesquis Energética (EPE).

Espinoza, J.C., Ronchail, J., Guyot, J.L., Junquas, C., Vauchel, P., Lavado, W., Drapeau, G. & Pombosa, R. 2011. Climate variability and extreme drought in the upper Solimões River (western Amazon Basin): Understanding the exceptional 2010 drought. *Geophysical Research Letters*, **38**, http://doi.org/doi:10.1029/2011GL047862.

Espinoza, J.C., Ronchail, J., Guyot, J.L., Junquas, C., Drapeau, G., Martinez, J.M., Santini, W., Vauchel, P*., et al.* 2012. From drought to flooding: understanding the abrupt 2010–11 hydrological annual cycle in the Amazonas River and tributaries. *Environmental Research Letters*, **7**, 024008.

Fan, F.M., Ramos, M.-H. & Collischonn, W. 2015a. Sobre o uso de previsões hidrológicas probabilísticas para tomada de decisão /On the use of probabilistic hydrological forecasts for decision making. *Revista Brasileira de Recursos Hídricos*, **20**, 914-926, http://doi.org/http://dx.doi.org/10.21168/rbrh.v20n4.p914-926.

Fan, F.M., Collischonn, W., Meller, A. & Botelho, L.C.M. 2014. Ensemble streamflow forecasting experiments in a tropical basin: The São Francisco river case study. *Journal of Hydrology*, **519**, 2906-2919, http://doi.org/https://doi.org/10.1016/j.jhydrol.2014.04.038.

Fan, F.M., Schwanenberg, D., Collischonn, W. & Weerts, A. 2015b. Verification of inflow into hydropower reservoirs using ensemble forecasts of the TIGGE database for large scale basins in Brazil. *Journal of Hydrology: Regional Studies*, **4**, 196-227, http://doi.org/https://doi.org/10.1016/j.ejrh.2015.05.012.

Fan, F.M., Collischonn, W., Quiroz, K.J., Sorribas, M.V., Buarque, D.C. & Siqueira, V.A. 2015c. Flood forecasting on the Tocantins River using ensemble rainfall forecasts and real-time satellite rainfall estimates. *Journal of Flood Risk Management*, **9**, 278-288, http://doi.org/10.1111/jfr3.12177.

Fan, F.M., Schwanenberg, D., Alvarado, R., Assis dos Reis, A., Collischonn, W. & Naumman, S. 2016. Performance of Deterministic and Probabilistic Hydrological Forecasts for the Short-Term Optimization of a Tropical Hydropower Reservoir. *Water Resources Management*, **30**, 3609-3625, http://doi.org/10.1007/s11269-016-1377-8.

Fan, F.M., Lisboa, A.M.V., Trinidad, G.G.V., Pontes, P.R.M., Collischonn, W., Tucci, C. & Buarque, D.C. 2017. First Assessment of Itaipu Dam Ensemble Inflow Forecasting System. *Geophysical Research Abstracts*, **19**, 8606.

G1 2011. Sobe para 70 número de cidades em emergência pela chuva em SC. http://g1.globo.com/brasil/noticia/2011/01/sobe-para-70-numero-de-cidades-em-emergencia-pela-chuva-em-sc.html.

G1 SC 2013. Chuvas em SC atingem ao menos 72 cidades e ainda há risco de inundação. http://g1.globo.com/sc/santa-catarina/noticia/2013/09/chuvas-em-sc-atingem-ao-menos-72-cidades-e-ainda-ha-risco-de-inundacao.html.

G1 SC 2014. SC tem 45 mil atingidos pelas chuvas e 23 municípios em emergência. http://g1.globo.com/sc/santa-catarina/noticia/2014/06/sc-tem-45-mil-atingidos-pelas-chuvas-e-23-municipios-em-emergencia.html.

G1 SC 2015. Enchente causa prejuízos de R$ 18 milhões em Rio do Oeste, SC. http://g1.globo.com/sc/santa-catarina/noticia/2015/11/enchente-causa-prejuizos-de-r-18-milhoes-em-rio-do-oeste-sc.html.

Georgakakos, K.P. & Krzysztofowicz, R. 2001. Probabilistic and ensemble forecasting. *Journal of Hydrology*, **249**, 1, http://doi.org/https://doi.org/10.1016/S0022-1694(01)00455-3.

Getirana, A. 2015. Extreme Water Deficit in Brazil Detected from Space. *Journal of Hydrometeorology*, **17**, 591-599, http://doi.org/10.1175/JHM-D-15-0096.1.

Gokany, I.M. 2009. Deaths and Death Rates from Extreme Weather Events: 1900-2008. *Journal of American Physicians and Surgeons*, **14**, 8.

Gopalakrishnan, C. 2013. Water and disasters: a review and analysis of policy aspects. *International Journal of Water Resources Development*, **29**, 250-271, http://doi.org/10.1080/07900627.2012.756133.

Green, C.H., Parker, D.J. & Tunstall, S.M. 2000. Assessment of Flood Control and Management Options. *Thematic Review IV.4 prepared as an input to the World Commission on Dams*. Secreriat of the World Commission on Dams, Cape Town, 183.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockstrom, J., Ohman, M.C., Shyamsundar, P., Steffen, W., Glaser, G*., et al.* 2013. Policy: Sustainable development goals for people and planet. *Nature*, **495**, 305-307, http://doi.org/http://www.nature.com/nature/journal/v495/n7441/abs/495305a.html#supplementary-information.

Haasnoot, M., Middelkoop, H., van Beek, E. & van Deursen, W.P.A. 2011. A method to develop sustainable water management strategies for an uncertain future. *Sustainable Development*, **19**, 369-381, http://doi.org/10.1002/sd.438.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H. & Kanae, S. 2013. Global flood risk under climate change. *Nature Clim. Change*, **3**, 816-821, http://doi.org/10.1038/nclimate1911

http://www.nature.com/nclimate/journal/v3/n9/abs/nclimate1911.html#supplementary-information.

Holzheu, T. & Turner, G. 2018. The Natural Catastrophe Protection Gap: Measurement, Root Causes and Ways of Addressing Underinsurance for Extreme Events†. *The Geneva Papers on Risk and Insurance - Issues and Practice*, **43**, 37-71, http://doi.org/10.1057/s41288-017-0075-y.

IPCC 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ipea. 2018. *ODS - Metas Nacionais dos Objetivos de Desenvolvimento Sustentável: Proposta de Adequação.* Instituto de Pesquisa Econômica Aplicada (Ipea).

Jeworrek, T., Hinz, S., Bove, M., faust, E., Ellenrieder, T., Kron, W., Moore, A., Anwender, D*., et al.* 2015. *Natural catastrophes 2014: Analyses, assessments, positions.* Munich Re.

Jongman, B., Koks, E.E., Husby, T.G. & Ward, P.J. 2014a. Increasing flood exposure in the Netherlands: implications for risk financing. *Nat. Hazards Earth Syst. Sci.*, **14**, 1245-1255, http://doi.org/10.5194/nhess-14-1245-2014.

Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J.C.J.H., Mechler, R., Botzen, W.J.W., Bouwer, L.M., Pflug, G*., et al.* 2014b. Increasing stress on disaster-risk finance due to large floods. *Nature Clim. Change*, **4**, 264-268, http://doi.org/10.1038/nclimate2124

http://www.nature.com/nclimate/journal/v4/n4/abs/nclimate2124.html#supplementary-information.

King, D., Schrag, D.P., Dadi, Z., Ye, Q. & Gosh, A. 2015. Systemic Risks. *In*: Hynard, J. & Rodger, T. (eds) *Climate Change: A Risk Assessment*. Centre for Science and Policy (CSaP), London, UK, 109-120.

Koetse, M.J. & Rietveld, P. 2009. The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research Part D: Transport and Environment*, **14**, 205-221, http://doi.org/https://doi.org/10.1016/j.trd.2008.12.004.

Kousky, C. 2015. A historical examination of the Corps of Engineers and natural valley storage protection: the economics and politics of 'green' flood control. *Journal of Natural Resources Policy Research*, **7**, 23-40, http://doi.org/10.1080/19390459.2014.963372.

Kunkel, K.E., Pielke, R.A. & Changnon, S.A. 1999. Temporal Fluctuations in Weather and Climate Extremes That Cause Economic and Human Health Impacts: A Review. *Bulletin of the American Meteorological Society*, **80**, 1077-1098, http://doi.org/10.1175/1520-0477(1999)080<1077:TFIWAC>2.0.CO;2.

Kuwajima, J.I., Schwanenberg, D., Montero, R.A., Fan, F.M. & Reis, A.A.d. 2014. Trade-off Assessment of Simplified Routing Models for Short-Term Hydropower Reservoir Optimization. *Geophysical Research Abstracts*, **16**, 1.

Lassa, J.A., Surjan, A., Caballero-Anthony, M. & Fisher, R. 2018. Measuring political will: An index of commitment to disaster risk reduction. *International Journal of Disaster Risk Reduction*, http://doi.org/https://doi.org/10.1016/j.ijdrr.2018.11.006.

Le Blanc, D. 2015. Towards Integration at Last? The Sustainable Development Goals as a Network of Targets. *Sustainable Development*, **23**, 176-187, http://doi.org/10.1002/sd.1582.

Lewis, S.L., Brando, P.M., Phillips, O.L., van der Heijden, G.M.F. & Nepstad, D. 2011. The 2010 Amazon Drought. *Science*, **331**, 554.

Lisboa, A.M.V., Gomes, V.T.G., Fan, F.M., Collischonn, W. & Tucci, C.E.M. 2015. Uso del modelo MGB en la predicción de caudales en Itaipú. *Revista de la Sociedad Científica del Paraguay*, **20**, 189-203.

Lorenz, E.N. 1969. The predictability of a flow which possesses many scales of motion. *Tellus*, **21**, 289-307, http://doi.org/10.1111/j.2153-3490.1969.tb00444.x.

Magrin, G.O., Marengo, J.A., Boulanger, J.P., Buckeridge, M.S., Castellanos, E., Poveda, G., Scarano, F.R. & Vicuña, S. 2014. Central and South America. *In*: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M*., et al.* (eds) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1499-1566.

Marengo, J.A. 2014. O futuro clima do Brasil. *Revista USP; n. 103 (2014): Dossiê ClimaDO - 10.11606/issn.2316-9036.v0i103p25-32*.

Marengo, J.A. & Camargo, C.C. 2008. Surface air temperature trends in Southern Brazil for 1960–2002. *International Journal of Climatology*, **28**, 893-904, http://doi.org/10.1002/joc.1584.

Marengo, J.A. & Alves, L.M. 2015. Crise Hídrica em São Paulo em 2014: Seca e Desmatamento. *GEOUSP: Espaço e Tempo (Online); v. 19, n. 3 (2015): Dossiê: A crise hídrica no Estado de São PauloDO - 10.11606/issn.2179-0892.geousp.2015.100879*.

Marengo, J.A., Torres, R.R. & Alves, L.M. 2016. Drought in Northeast Brazil—past, present, and future. *Theoretical and Applied Climatology*, **129**, 1189-1200, http://doi.org/10.1007/s00704-016-1840-8.

Marengo, J.A., Tomasella, J. & Nobre, C.A. 2017a. Climate Change and Water Resources. *In*: de Mattos Bicudo, C.E., Galizia Tundisi, J. & Cortesão Barnsley Scheuenstuhl, M. (eds) *Waters of Brazil: Strategic Analysis*. Springer International Publishing, Cham, 171-186.

Marengo, J.A., Jones, R., Alves, L.M. & Valverde, M.C. 2009. Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. *International Journal of Climatology*, **29**, 2241-2255, http://doi.org/10.1002/joc.1863.

Marengo, J.A., Nobre, C.A., Tomasella, J., Cardoso, M.F. & Oyama, M.D. 2008a. Hydro-climatic and ecological behaviour of the drought of Amazonia in 2005. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **363**, 1773.

Marengo, J.A., Tomasella, J., Alves, L.M., Soares, W.R. & Rodriguez, D.A. 2011. The drought of 2010 in the context of historical droughts in the Amazon region. *Geophysical Research Letters*, **38**, n/a-n/a, http://doi.org/10.1029/2011GL047436.

Marengo, J.A., Tomasella, J., Soares, W.R., Alves, L.M. & Nobre, C.A. 2012. Extreme climatic events in the Amazon basin. *Theoretical and Applied Climatology*, **107**, 73-85, http://doi.org/10.1007/s00704-011-0465-1.

Marengo, J.A., Borma, L.S., Rodriguez, D.A., Pinho, P.c., Soares, W.R. & Alves, L.M. 2013a. Recent Extremes of Drought and Flooding in Amazonia: Vulnerabilities and Human Adaptation. *American Journal of Climate Change*, **Vol.02No.02**, 910, http://doi.org/10.4236/ajcc.2013.22009.

Marengo, J.A., Alves, L.M., Aalvala, R.C.S., Cunha, A.P., Brito, S. & Moraes, O.L.L. 2017b. Climatic characteristics of the 2010-2016 drought in the semiarid Northeast Brazil region. *Anais da Academia Brasileira de Ciências*, 0-0.

Marengo, J.A., Alves, L.M., Soares, W.R., Rodriguez, D.A., Camargo, H., Riveros, M.P. & Pabló, A.D. 2013b. Two Contrasting Severe Seasonal Extremes in Tropical South America in 2012: Flood in Amazonia and Drought in Northeast Brazil. *Journal of Climate*, **26**, 9137-9154, http://doi.org/10.1175/JCLI-D-12-00642.1.

Marengo, J.A., Nobre, C.A., Seluchi, M.E., Cuartas, A., Alves, L.M., Mendiondo, E.M., Obregón, G. & Sampaio, G. 2015. A seca e a crise hídrica de 2014-2015 em São Paulo. *Revista USP; n. 106 (2015): Crise HídricaDO - 10.11606/issn.2316-9036.v0i106p31-44*.

Marengo, J.A., Nobre, C.A., Tomasella, J., Oyama, M.D., Sampaio de Oliveira, G., de Oliveira, R., Camargo, H., Alves, L.M*., et al.* 2008b. The Drought of Amazonia in 2005. *Journal of Climate*, **21**, 495-516, http://doi.org/10.1175/2007JCLI1600.1.

Mariano, C.M. 2017. Emenda constitucional 95/2016 e o teto dos gastos públicos: Brasil de volta ao estado de exceção econômico e ao capitalismo do desastre. *Revista de investigações constitucionais*, **v.4**, 259-281, http://doi.org/http://dx.doi.org/10.5380/rinc.v4i1.50289.

Meehl, G.A., Karl, T., Easterling, D.R., Changnon, S., Pielke, R., Changnon, D., Evans, J., Groisman, P.Y*., et al.* 2000. An Introduction to Trends in Extreme Weather and Climate Events: Observations, Socioeconomic Impacts, Terrestrial Ecological Impacts, and Model Projections. *Bulletin of the American Meteorological Society*, **81**, 413-416, http://doi.org/10.1175/1520-0477(2000)081<0413:AITTIE>2.3.CO;2.

Michaels, S. 2015. Probabilistic forecasting and the reshaping of flood risk management. *Journal of Natural Resources Policy Research*, **7**, 41-51, http://doi.org/10.1080/19390459.2014.970800.

Ministério do Meio Ambiente. 2011. *Relatório de Inspeção: Área atingida pela tragédia das chuvas na Região Serrana do Rio de Janeiro.* Ministério do Meio Ambiente - Secretaria de Biodiversidade e Florestas.

Mirza, M.M.Q. 2003. Climate change and extreme weather events: can developing countries adapt? *Climate Policy*, **3**, 233-248, http://doi.org/10.3763/cpol.2003.0330.

Naumann, S., Schwanenberg, D., Karimanzira, D., Fan, F. & Allen, C. 2015. Short-term management of hydropower reservoirs under meteorological uncertainty by means of multi-stage optimization. *at - Automatisierungstechnik*, **63**, 535, http://doi.org/10.1515/auto-2014-1168.

Ning Zeng and Jin-Ho Yoon and Jose, A.M.a.A.S.a.C.A.N.a.A.M.a.J.D.N. 2008. Causes and impacts of the 2005 Amazon drought. *Environmental Research Letters*, **3**, 014002.

Nobre, C.A., Marengo, J.A., Seluchi, M.E., Adriana Cuartas, L. & Alves, L.M. 2016. Some Characteristics and Impacts of the Drought and Water Crisis in Southeastern Brazil during 2014 and 2015. *Journal of Water Resouce and Protection*, **Vol. 8**, 10, http://doi.org/10.4236/jwarp.2016.82022.

ONS. 2009. Submódulo 1.1 O Operador Nacional do Sistema Elétrico e os Procedimentos de Rede: visão geral. *Módulo 1 - O Operador Nacional do Sistema Elétrico e os Procedimentos de Rede*. Operador Nacional do Sistema Elétrico (ONS), 23.

ONS. 2016a. Submódulo 9.4 - Estabelecimento das regras para operação de controle de cheias. *Módulo 9 - Recursos hídricos e meteorologia*. Operador Nacional do Sistema Elétrico (ONS), 11.

ONS. 2016b. Submódulo 26.2 - Critérios para classificação da modalidade de operação de usinas. *Módulo 26 - Modalidade de operação de usinas*. Operador Nacional do Sistema Elétrico (ONS), 14.

ONS. 2016c. Submódulo 18.2 - Relação dos Sistemas e modelos computacionais. *Módulo 18 - Sistemas e modelos computacionais*. Operador Nacional do Sistema Elétrico (ONS), 33.

ONS. 2016d. Submódulo 9.6 - Acompanhamentoe previsão meteorológica e climática. *Módulo 9 - Recursos Hídricos e meteorologia*. Operador Nacional do Sistema Elétrico (PNS), 8.

ONS. 2016e. Submódulo 23.6 - Critérios para identificação estratégicas do Sistema Interligado Nacional. *Módulo 23 - Critérios para estudos*. Operador Nacional do Sistema Elétrico (ONS), 6.

ONS. 2016f. Submódulo 9.5 - Previsão de vazões e geração de cenários de afluências. *Módulo 9 - Recursos Hídricos e meteorologia*. Operador Nacional do Sistema Elétrico (ONS), 9.

ONS. 2017. Submódulo 10.18 - Cadastro de Informações Operacionais: Instalações e equipamentos Estratégicos do Sistema Interligado Nacional. *Módulo 10 - Manual de Procedimentos da Operação*. Operador Nacional do Sistema Elétrico (ONS), 29.

ONS. 2018a. Submódulo 10.21 - Controle dos Reservatórios da Região Hidrográfica do São Francisco - Bacia do Rio São Francisco. *Módulo 10 - Manual de Procedimentos da Operação*. Operador Nacional do Sistema Elétrico (ONS), 63.

ONS. 2018b. Cadastro de Informações Operacionais - Cadastro de Informações Operacionais Hidráulicas da Bacia do Rio São Francisco. *Módulo 10 - Manual de Procedimentos da Operação*. Operador Nacional do Sistema Elétrico (ONS), 88.

Ordoñez and Raúl, Espinoza, J.C.E.a.J.R.a.J.L.G.a.C.J.a.G.D.a.J.M.M.a.W.S.a.P.V.a.W.L.a.J. 2012. From drought to flooding: understanding the abrupt 2010–11 hydrological annual cycle in the Amazonas River and tributaries. *Environmental Research Letters*, **7**, 024008.

Pagano, T.C., Shrestha, D.L., Wang, Q.J., Robertson, D. & Hapuarachchi, P. 2013. Ensemble dressing for hydrological applications. *Hydrological Processes*, **27**, 106-116, http://doi.org/10.1002/hyp.9313.

Pahl-Wostl, C. 2007. The implications of complexity for integrated resources management. *Environmental Modelling & Software*, **22**, 561-569, http://doi.org/https://doi.org/10.1016/j.envsoft.2005.12.024.

Pappenberger, F., Stephens, E., Thielen, J., Salamon, P., Demeritt, D., Andel, S.J., Wetterhall, F. & Alfieri, L. 2013. Visualizing probabilistic flood forecast information: expert preferences and perceptions of best practice in uncertainty communication. *Hydrological Processes*, **27**, 132-146, http://doi.org/10.1002/hyp.9253.

Patz, J.A., Campbell-Lendrum, D., Holloway, T. & Foley, J.A. 2005. Impact of regional climate change on human health. *Nature*, **438**, 310, http://doi.org/10.1038/nature04188.

Rosenzweig, C., Iglesias, A., Yang, X.B., Epstein, P.R. & Chivian, E. 2001. Climate Change and Extreme Weather Events; Implications for Food Production, Plant Diseases, and Pests. *Global Change and Human Health*, **2**, 90-104, http://doi.org/10.1023/A:1015086831467.

Salazar, L.F., Nobre, C.A. & Oyama, M.D. 2007. Climate change consequences on the biome distribution in tropical South America. *Geophysical Research Letters*, **34**, n/a-n/a, http://doi.org/10.1029/2007GL029695.

Santos, M.R.A.d. 2003. *Rio São Francisco : patrimônio cultural e natural*. Assembleia Legislativa do Estado de Minas Gerais (ALMG), Belo Horizonte, MG.

Schwanenberg, D., Fan, F.M., Naumann, S., Kuwajima, J.I., Montero, R.A. & Assis dos Reis, A. 2015. Short-Term Reservoir Optimization for Flood Mitigation under Meteorological and Hydrological Forecast Uncertainty. *Water Resources Management*, **29**, 1635-1651, http://doi.org/10.1007/s11269-014-0899-1.

Secretaria de Estado da Agricultura e Política Rural 2011. Secretaria de Estado da Agricultura e Política Rural. http://webimprensa.sc.gov.br/paginas/index.asp?codigon=63447.

Seth, A., Fernandes, K. & Camargo, S.J. 2015. Two summers of São Paulo drought: Origins in the western tropical Pacific. *Geophysical Research Letters*, **42**, 10,816-810,823, http://doi.org/10.1002/2015GL066314.

Sevegnani, L., Frank, B., Negredo, J.C., Soares, M.V. & Keim, E.J. 2009. Gente socorrendo gente. *In*: Frank, B. & Sevegnani, L. (eds) *Desastre de 2008 no Vale do Itajaí: água, gente e política*. Fundação Agência de Água Comitê do Itajaí (AACI) & Universidade Regional de Blumenau (FURB), Blumenau.

Silva, R.d. 2015. Enchentes afetam 30 mil pessoas em Santa Catarina. https://noticias.uol.com.br/cotidiano/ultimas-noticias/2015/10/23/enchentes-afetam-30-mil-pessas-em-santa-catarina.htm.

Sivapalan, M. 2015. Debates—Perspectives on socio-hydrology: Changing water systems and the "tyranny of small problems"—Socio-hydrology. *Water Resources Research*, **51**, 4795-4805, http://doi.org/10.1002/2015WR017080.

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., Stigson, B., Shrivastava, P., *et al.* 2016. Integration: the key to implementing the Sustainable Development Goals. *Sustainability Science*, http://doi.org/10.1007/s11625-016-0383-3.

Stevaux, J.C., Latrubesse, E.M., Hermann, M.L.d.P. & Aquino, S. 2009. Floods in Urban Areas of Brazil. *In*: Latrubesse, E.M. (ed) *Developments in Earth Surface Processes*. Elsevier, **13**, 245-266.

TAYLOR, J.W. & BUIZZA, R. 2003. Using weather ensemble predicitons in eletric demand forecast. *International Journal of Forecasting*.

Thompson, K.M. & Graham, J.D. 1996. Going beyond the single number: Using probabilistic risk assessment to improve risk management. *Human and Ecological Risk Assessment: An International Journal*, **2**, 1008-1034, http://doi.org/10.1080/10807039609383660.

Tomasella, J., Borma Laura, S., Marengo José, A., Rodriguez Daniel, A., Cuartas Luz, A., Carlos, A.N. & Prado Maria, C.R. 2010. The droughts of 1996–1997 and 2004–2005 in Amazonia: hydrological response in the river main-stem. *Hydrological Processes*, **25**, 1228-1242, http://doi.org/10.1002/hyp.7889.

UFSC. 2016a. *Relatório dos danos materiais e prejuízos decorrentes de desastres naturais em Santa Catarina:1995-2014.* Universidade Federal de Santa Catarina - Centro Universitário de Estudos e Pesquisas sobre Desastres & World Bank.

UFSC. 2016b. *Relatório de danos materiais e prejuízos decorrentes de desastres naturais no Brasil:1995-2014.* Universidade Federal de Santa Catarina - Centro Universitário de Estudos e Pesquisas sobre Desastres & World Bank.

United Nations. 2007. Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters. *Extract from the fnal report of the World Conference on Disaster Reduction (A/CONF.206/6)*. United Nations: International Strategy for Disaster Reduction, Geneva, Switzerland, 28.

United Nations. 2015a. Sendai Framework for Disaster risk Reduction 2015-2030. United Nations Office for Disaster Risk Reduction (UNISDR), 32.

United Nations. 2015b. Seventh Session: Agenda item 15 and 116. *In*: Assembly, U.G. (ed.) *Transforming our world: the 2030 Agenda for Sustainable Development*. United Nations, 35.

United Nations Economic and Social Council. 2017. Report of the Secretary-General: Progress towards the Sustainable Development Goals. *In*: Nations, U. (ed.) *E /2017/66*. United Nations Economic and Soucial Council, 19.

Vairão Junior, N.S. & Alves, F.J.d.S. 2017. The constitutional amendment 95 and it´s effects. *Revista de Contabilidade do Mestrado em Ciências Contábeis*, **22**, 54-75.

World Bank. 2012a. Avaliação de Perdas e Danos: Inundações Bruscas em Santa Catarina - Novembro de 2008. Banco Mundial, Brasília-DF, 67.

World Bank. 2012b. Avaliação de Perdas e Danos: Inundações Bruscas em Alagoas - Junho de 2010. Banco Mundial, Brasília - DF, 59.

World Bank. 2012c. Avaliação de Perdas e Danos: Inundações Bruscas em Pernambuco - Junho de 2010. Banco Mundial, 71.

World Bank. 2012d. Avaliação de Perdas e Danos: Inundações e deslizamentos na Região Serrana do Rio de Janeiro - Janeiro de 2011. Banco Mundial, Brasília-DF, 63.

World Comission on Dams. 2000. *Dams and Development: A new Framework for Decision-Making.* World Comission on Dams (WCD).

Xu, L., Samanta, A., Costa Marcos, H., Ganguly, S., Nemani Ramakrishna, R. & Myneni Ranga, B. 2011. Widespread decline in greenness of Amazonian vegetation due to the 2010 drought. *Geophysical Research Letters*, **38**, http://doi.org/10.1029/2011GL046824.

Zope, P.E., Eldho, T.I. & Jothiprakash, V. 2016. Impacts of land use–land cover change and urbanization on flooding: A case study of Oshiwara River Basin in Mumbai, India. *CATENA*, **145**, 142-154, http://doi.org/https://doi.org/10.1016/j.catena.2016.06.009.