Drought Stress Testing

Making Financial Institutions More Resilient to Environmental Risks

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DEUTSCHE ZUSAMMENARBEIT

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Natural Capital Finance Alliance
Finance sector leadership on natural capital

Secretariat:
UNEP FINANCE INITIATIVE
GCP GLOBAL CANOPY PROGRAMME

EMERGING MARKETS DIALOGUE ON FINANCE

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Under the umbrella of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), the Emerging Market Sustainability Dialogues (EMSD) provide a network of stakeholders and decision-makers from think tanks, multinational corporations, and the financial sector. The Emerging Markets Dialogue on Finance (EMDF) represents one of the three EMSD networks and brings together financial experts and practitioners from G20 emerging economies. It strives to enhance the capacity of financial institutions and government bodies in order to advance the development of sustainable financial systems. Jointly with our partners, we develop solutions for some of the most pressing challenges in the financial sector.

The goal of the EMDF is to redirect capital flows away from assets that deplete natural capital towards climate and eco-friendly investments to enable the transformation towards low-carbon, resource-efficient, sustainable economies. To achieve this, we work with financial institutions, investment firms, stock exchanges, central banks, ministries of finance, and international organizations from G20 economies to integrate environmental indicators in lending and investment decisions, product development and risk management.

About NCFA

The Natural Capital Financial Alliance (NCFA) was launched at the UN Conference on Sustainable Development (Rio+ 20 Earth Summit) in 2012 by UNEP FI and the UK-based non-governmental organisation, Global Canopy Programme (GCP). It is a worldwide finance led initiative to integrate natural capital considerations into financial products and services, and to work towards their inclusion in financial accounting, disclosure and reporting. Signatory financial institutions are working towards implementing the commitments in the Declaration through NCFA projects. These are overseen by a steering committee of signatories and supporters and supported by a secretariat formed of the UNEP FI and GCP.

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The Global Canopy Programme is a tropical forest think tank working to demonstrate the scientific, political and business case for safeguarding forests as natural capital that underpins water, food, energy, health and climate security for all. Our vision is a world where rainforest destruction has ended. Our mission is to accelerate the transition to a deforestation free economy.

About RMS

RMS is a leading provider of data, models and software that help insurance companies, financial institutions, their corporate clients, and government agencies assess and manage their exposure to extreme events across the globe. As the world's largest catastrophe risk modelling company, our clients include 85% of the top 40 reinsurance companies and 9 of the top 10 ILS funds globally. We provide a wide range of probabilistic risk models to our client base, including accumulation and loss models for many global climate and seismic hazards.

Acknowledgements and contact

Acknowledgements

We would like to thank the financial institution project partners and Expert Council members who dedicated time and resources to developing a methodology and tool to assess drought-related risk in corporate bond portfolios, participating in workshops and webinars, and testing an early version of the model to provide suggestions for improvement.

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Caveats
It should be noted that these findings are specific to the scenarios and the portfolios of loans used in the analysis and therefore do not necessarily represent standard industry sector impacts or country-wide risk assessments. The loan portfolios used are only a portion of the total loan portfolio of financial institutions, represented by the industry sectors that are in the scope of the study. Some of the scenarios analysed within the Tool are, by design, severe and represent catastrophic droughts in these countries. The Drought Stress Testing Tool is a prototype and the first step in the development of broader capabilities for financial institutions to quantify the environmental risks to their loan portfolios. As discussed in the Possible Project Extensions section of the accompanying report, a number of additional elements have been considered, which if included would enhance the accuracy of the drought risk assessment.

The Drought Stress Testing Tool rating model does not necessarily mirror financial institutions’ own rating model. The default rating model incorporated in the Tool is a financial metric-only based model and does not take into account certain important qualitative information. In addition, companies’ balance sheet could be more or less fragile due to recent economic conditions. The portfolio results detailed in this section should be viewed with this in mind and may not incorporate company, country or industry sector-specific mitigation measures which are outside of the scope of this Tool and report.

Foreword from BMZ

Natascha Beinker

Deputy Head of Division "Co-operation with the private sector/ sustainable economic policy" at the German Federal Ministry for Economic Cooperation and Development (BMZ). She is also G20 GPFI Troika Co-Chair and Co-Chair for the GPFI SME Finance Sub-group.

Environmental degradation and climate change are key global challenges of our times. The impacts on economic activity and human lives – for instance caused by extreme weather events such as droughts – are significant and will become more severe as global warming continues. The negative consequences for the financial sector, which provides companies and citizens with capital, have the potential to result in substantial material risks for financial stability and hence our economic system as a whole.

With the Paris Agreement on Climate Change, which Germany agreed upon jointly with 196 governments in 2015, a milestone was set in formulating a "global response to the threat of climate change". Our commitments now require action. To reach the ambitious goal, enormous investments in areas such as green technologies, low-carbon infrastructure and resource-friendly production methods are required.

Financial markets can play a pivotal role in accelerating this transformation towards a sustainable, greener future as lending and investment decisions direct the allocation of capital in our economic system. For the markets to assume this role, a key prerequisite is that participants understand the underlying risks imposed by climate change and environmental degradation. If we are to understand, adequately assess and price environmental risks to enable informed financial decision making, we need reliable data and methodologies.

The gaps in the environmental risk management capacity of financial institutions are increasingly recognized and are being addressed by international initiatives and fora such as the Financial Stability Board's Task Force on Climate-related Financial Disclosures (TCFD) and the G20 Green Finance Study Group (GFSG). To support such efforts in our ambition to make decision-making in the financial system more sustainable, the German Federal Ministry for Economic Co-operation and Development (BMZ) works with the financial sector to mainstream environmental considerations into lending and investment decisions. As part of this effort, the drought stress testing framework and Tool presented in this report were developed to enable banks to assess the exposure of their corporate loan portfolio to environmental risks, specifically drought.

As this is the first time drought risk has been assessed in this way, validation was key to the successful development of the Tool. Several banks from Brazil, China, Mexico and the United States advised on the model design and tested the purposefulness and compatibility of the Tool with their existing stress testing procedures, I would like to thank the contributing financial institutions along with Risk Management Solutions, the Natural Capital Finance Alliance and GIZ (Emerging Markets Sustainability Dialogues – Sustainable Finance Component (EMDF)) for the great partnership in developing this innovative framework and Tool.

Foreword from UNEP FI

Eric Usher

Head UN Environment Finance Initiative

Drought has affected Earth throughout recorded history. It inspires great ingenuity and engineering, while giving rise to despair, famine and war. Technologies such as weather mapping and precipitation modelling may have improved our ability to track and predict droughts, but they will still happen - with human-made climate change exacerbating their frequency and ferocity.

Banks may seem to be far removed from this theatre, but drought affects their clients and the setting in which they operate. If banks are better equipped to understand how a client may be at risk from drought and how drought can affect a sector or region, then a bank can choose to act on this knowledge. However, banks are often ill equipped to understand the impact of environment-related risks on their clients and portfolios.

To help address this, banks from different parts of the world have been brought together with advanced catastrophe risk modellers in a pioneering project to create a free, public tool that better equips banks to understand their clients' and their portfolios' vulnerability to extreme drought. There is obviously an element of self-interest in this – the banks can better incorporate a previously untreated risk. However, in acting on the information by supporting companies and people to be more resilient to drought or shifting finance to less vulnerable sectors and regions, economies can become more stable and resource efficient, better insulating them from the social and societal distress of possible economic collapse from drought. This also helps the planet as more resource efficient production in less vulnerable areas can produce healthier ecosystems better equipped to absorb shocks such as droughts.

The Natural Capital Finance Alliance (NCFA), a collaboration of UN Environment Programme Finance Initiative and Global Canopy Programme, has been instrumental in realizing this project. Founded at Rio+20 in 2012, the NCFA brings together financial institutions from around the world to provide tools and methodologies that bring natural capital considerations into the heart of mainstream finance. The Drought Stress Testing Tool is an excellent example of the NCFA's brand of collaborative engagement with the finance sector.

This pilot project has enabled nine banks in four countries with assets exceeding US$10 trillion to develop a tool that enhances their understanding of drought risks, while at the same time providing a tool for other banks in the four countries to adopt the innovation. This in itself will not change the world, but widespread adoption of the concept can. By developing a flexible and fully customizable platform for banks stress testing for drought where any country or region can be added, we have given power to the banks to change – and in doing so to contribute to a more resilient and sustainable world.

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Executive Summary

The global economy is highly interconnected and in recent years, we have seen how this interconnectivity can leave it exposed to systemic shocks, often because of a lack of awareness of potential sources of risk and subsequently, the ability to assess and quantify corresponding reverberations.

Natural hazards, and their associated environmental impacts on respective economies, are a set of such sources and due to their broad scope and magnitude, should be treated as potentially systemic risks to the financial system. As a result, financial institutions should account for environmental factors in their risk management assessments. However, the current level of awareness of such risks is low. In addition, financial institutions often lack the tools to enable robust quantification and assessment of these risks.

Water scarcity, or drought, is one environmental factor whose impact can be widely felt and observed throughout an economy. A recent drought in Venezuela, for example, has had severe economic repercussions including significant drought-induced shortages in power. Since about 70% of its electricity production comes from hydroelectric sources[1], Venezuela's power grid is highly reliant on regular precipitation. After three years of rainfall deficit, reservoir water levels were near critical[2], prompting the government to impose a two-day work week and restrict manufacturers' use of power[3] leading to supply chain shortages, productivity falls and, in certain cases, cessation of production.

Examples such as this illustrate how extreme environmental conditions can cause significant financial distress to corporations and as a result, affect the institutions that lend money to them. The work that underpins this report developed a framework to allow financial institutions to assess their exposure to environmental risks, specifically water scarcity or drought. The Drought Stress Testing Tool allows financial institutions to input their own high resolution loan data, and determine how drought scenario events change expected default rates.

The modular design of the Tool allows users to extract interim results and feed them into their own systems. In addition, the framework can be adapted to other environmental risks and is the first consistent approach to modelling environmental risks for the banking sector.

The Tool itself incorporates five drought scenarios for each of four countries (Brazil, China, Mexico, United States) to account for direct and indirect impacts of drought on 19 industry sectors. The Tool works by determining how a drought may change the revenue and operating costs for individual companies. These changes filter through the financial statements of the companies in a lending portfolio, translating into a revised credit rating and implying a new default probability as well as an updated expected loss for each company and the portfolio as a whole. Hence, the insights provided by the Tool inform banks how a company's financial statements could be affected by a drought, and how their likelihood of defaulting on their loans would change.

Since this is the first time that drought risk has been assessed in such a systematic and technical way, validation is key. By partnering with financial institutions the project was able to draw upon their expertise, validate the availability of market data and ensure that the Tool's outputs led to greater insight into their risk profile. Furthermore, the global coalition of banks involved in this project ensured that the ultimate result of this co-creation process, the framework and Tool, would be compatible with the standard systems of banks in order to reduce potential impediments to implementation.

1 http://data.worldbank.org/indicator/EG.ELC.HYRO.ZS?locations=VE

2 http://www.newyorker.com/tech/elements/the-electricity-crisis-in-venezuela-a-cautionary-tale

3 http://www.circleofblue.org/2016/world/venezuela-drought-aggravates-instability/

This work indicates that drought is a material risk for financial institutions in these four countries. The findings of this project show that losses from loan default could increase by an order of magnitude for particular portfolios under specific drought conditions. Although the scenarios were of varying levels of severity, in general most companies experienced some level of downgrade as a result of each scenario, and the nationwide negative economic impacts inflicted by drought conditions. These downgrades resulted in a wide variation of losses, although most scenarios outside of the US resulted in at least a doubling of expected losses to the loan portfolios.

Some of the industry sectors most affected were as expected – direct impacts drove losses to power generation in countries with a hydroelectric bias, along with water supply, agriculture and crop production. Sectors reliant on water-dependent inputs, for example the food and beverage manufacturing industry, also saw significant impacts due to reductions in availability of raw materials.

Industries less reliant on water availability, but strongly dependent upon general economic strength, also saw losses. Industries such as petroleum refining were seen to be significantly impacted by broad changes in economic conditions brought about by widespread drought and the resulting reduction in overall market demand.

However, one of the key findings of this project is that the biggest contributor to losses is not just the severity of the drought or the sector a company is in, but where a drought hits and how that interacts with the geographical concentration of business operations. Banks have not, to date, incorporated this aspect of risk into their diversification strategies, which mainly focus on sectoral diversification. To increase their resilience against environmental risks, a focus on geographical concentration should be an integral part of risk mitigation strategies.

Project Introduction

The environmental stress testing project was developed to foster and support the integration of environmental indicators into standard financial decision-making processes. The Natural Capital Financial Alliance (NCFA) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH designed a structure to enable the development of an analytical tool and framework that allows banks to quantify the risks that droughts pose to their corporate loan portfolio.

This pilot project follows on from a previous project, the Corporate Bonds Water Credit Risk Tool, which focused on individual debt instruments issued by power utility, beverage and mining companies and the risks posed to buyers of their bonds by water scarcity. While the previous project focused on the risks in individual company assets, feedback from users highlighted the need for and relevance of a tool that can be applied to a broader sectoral and portfolio level.

Against this backdrop, NCFA and GIZ contracted a consortium led by Risk Managements Solutions (RMS), the global leader in catastrophe risk modelling, in order to develop and design a modelling framework and methodology to assess how drought scenarios affect the corporate lending portfolios of financial institutions. The model looks at the impact of drought on at least eight industries in each of Brazil, China, Mexico and the US. The industry sectors were identified through a consultation process with the partner financial institutions.

A multi-disciplined 13-member Expert Council provided input on drought risk, hydro-climatic economic modelling, credit risk analysis and stress testing. The panel has provided independent technical advice on the methodology and framework development (see Appendix 2).

In order to make this Tool and framework as user-friendly as possible for financial institutions, it was crucial to integrate financial institutions from the respective regions into the development process. Nine financial institutions representing more than US$10 trillion in assets helped design the Tool by providing input, testing and validating the analytical framework developed by the consortium. The nine banks involved in the project are:

- Industrial and Commercial Bank of China (ICBC) Ltd;
- Caixa Econômica Federal;
- Itaú;
- Santander;
- Citi-Banamex;
- Banorte;
- Trust Funds for Rural Development (FIRA);
- Citigroup;
- UBS

A subset of these institutions then provided anonymized results based on samples from their own corporate lending portfolios. Analysis of the results and corresponding conclusions are shown at the end of this report.

“CAIXA is a public bank and the main financial agent for sanitation in Brazil, especially for water supply. The effects of climate change are already a significant socio-environmental risk to be considered in the analysis of project financing, especially in regions of great vulnerability. At the same time, they also represent an opportunity for new credit operations. Participation in the Drought Stress Testing project is an important step towards developing an effective technical tool that can be incorporated into CAIXA’s analysis and decision-making processes.”

– Jean Benevides, National Manager of Sustainabilty and Social-environmental Responsibility, Caixa Econômica Federal

Motivation for the Stress Testing Tool

It is increasingly recognized that environmental issues such as climate change, resource scarcity and water stress (including drought) can materially affect company performance and therefore the returns of the financial institutions that invest in these companies. Regulators and policymakers are acting to highlight the importance of these issues through initiatives such as the Financial Stability Board's Task Force on Climate-Related Disclosures and the G20's Green Finance Study Group. Consequently, it is becoming harder for companies and investors not to proactively engage with these issues and more important that they take action to mitigate their risks in this area.

Severe water stress affects much of the global population. In many areas, consumers and businesses withdraw more than 80% of the local available water supply, putting huge numbers of people at risk from even a marginal fall in rainfall. In many cases, droughts have caused severe social and economic problems, often well beyond the simple availability of water.

Between 2014 and 2016 Brazil saw one of the worst droughts in living memory. The drought was particularly intense in the metropolitan area of Sao Paulo, home to over 20 million people and one of Brazil's main production areas, with parts of the city without running water for days on end[4]. Chemicals firm Rhodia halted some of its operations due to low water levels, and Brazil's largest beef producer, JBS, had to make 800 redundancies[5]. Had the drought been even more severe or lasted longer, reservoir levels might have dropped to critical levels. Brazil relies upon hydroelectricity for 75% of its power generation capacity and as such, this would have led to large-scale brown-outs and black-outs.

Water scarcity and drought is not just an issue for emerging or middle income countries. The period between 2011 and 2015 was the driest ever recorded for California[6]. In December 2015 water levels in Lake Shasta, California's largest above-ground reservoir, were 29% of total capacity and total economic costs attributed to drought in 2015 were estimated at US$2.7 billion. Although this is small compared to California's GDP of US$2.3 trillion, climate change and depletion of subterranean water reserves means a higher risk of future, more serious events. Decades of over-pumping of California's aquifers have caused the water table to drop significantly and widespread subsidence described as "one of the single largest human alterations of the Earth's surface topography"[7]. This will affect the ability of agriculture and other water-dependent businesses in the region to adapt to drought conditions should even more severe drought events occur.

The above examples demonstrate how drought events can have wide economic implications for both high income and middle income countries, affecting companies across various industry sectors. Thus far, there has been little exploration of how large-scale drought events could affect the solvency of companies operating within the impacted region. It is possible that such an event would severely restrict production across many companies, which could significantly increase corporate default rates compared to normal economic conditions. Under severe scenarios, financial institutions that lend to corporates could face a drought-induced mass-default event, one which would not be identified during the more standard sector-based correlation analyses.

As droughts affect companies across a wide range of sectors, the Tool reveals that where a company is located is an important driver of systemic drought risk in lending portfolios. The Tool aims to support financial institutions to quantify their exposure to drought for a number of realistic scenarios. These stress tests provide quantitative insight into the likelihood of large drought events leading to numerous insolvencies, and hence large losses to lending books. Based on the output of this project, lenders may be forced to consider both 'hidden' correlations, and additional loss potential from the previously-unexplored exposure to drought risk in their risk management strategies.

4 https://www.nytimes.com/2015/02/17/world/americas/drought-pushes-sao-paulo-brazil-toward-water-crisis.html?_r=1

5 http://www.reuters.com/article/us-brazil-water-idUSKCN0VR1YJ

6 http://www.ppic.org/main/publication_show.asp?i=1087

7 http://water.usgs.gov/ogw/pubs/fs00165/

Purpose of the Project

Currently, very few banks use environmental stress testing and those that do employ a range of different techniques, data sources and analytical processes, which leads to inconsistencies of reporting between and even within institutions. One of the key purposes of the project was to develop a consistent framework for environmental stress testing that all banks agree would both support and enable modelling of these risks.

During initial workshops with the partner financial institutions, it was seen that there was strong appetite amongst all banks to manage environmental risk, but also an acknowledgement that some of the current techniques were neither sophisticated nor informative enough to be actionable. The institutions were eager for a standardised approach, and for a framework that gives confidence in results.

RMS built on the core ideas behind catastrophe risk modelling and adapted them to be appropriate for assessing financial institutions' lending portfolios. This involved two major tasks:

- Designing a model framework that achieves consensus amongst financial institutions and can be applied to a range of environmental risks
- Building an open source prototype tool that uses the model framework to stress test lending portfolios

Introducing a framework that is broadly accepted by a number of financial institutions creates an element of uniformity that can serve as the starting point for future development. By building on this framework, the prototype Tool demonstrates that the approach works and can provide a quantitative view of drought risk.

All of the components of the Tool are open and users can adjust them so that financial institutions that already use individual parts of the framework to incorporate their own knowledge and methodologies into the analysis. This is not a departure from having a uniform framework – it is important that financial institutions are encouraged to adopt their own view of risk where it differs from the consensus perspective.

Commercial catastrophe models have been developed over many years, incorporating the latest science and including numerous iterations of scrutiny, both internally and from insurance clients. While this Tool uses many of the approaches of insurance catastrophe models, it remains a prototype and the work presented here should be considered a first step towards achieving a fully-fledged environmental risk management model.

"We consider environmental risk management as an irreversible trend in the financial industry. Santander has a long-standing history of considering ESG in its risk assessments and of promoting sustainable business among its clients. Participating in this pilot was an excellent opportunity to further foster this agenda and to evolve our understanding of the possible impacts of droughts to our business. This tool will have immediate impact in terms of awareness raising and bringing the issue of environmental stress testing closer to mainstream risk management."

– Linda Murasawa, Sustainability Head, Santander Brazil

Model Methodology

The insurance catastrophe modelling framework was modified to make the Drought Stress Testing Tool both applicable to the peril of drought, and appropriate for use in assessment of financial credit risk.

Catastrophe Risk Model Framework

The basic components of a catastrophe model are displayed in figure 1:

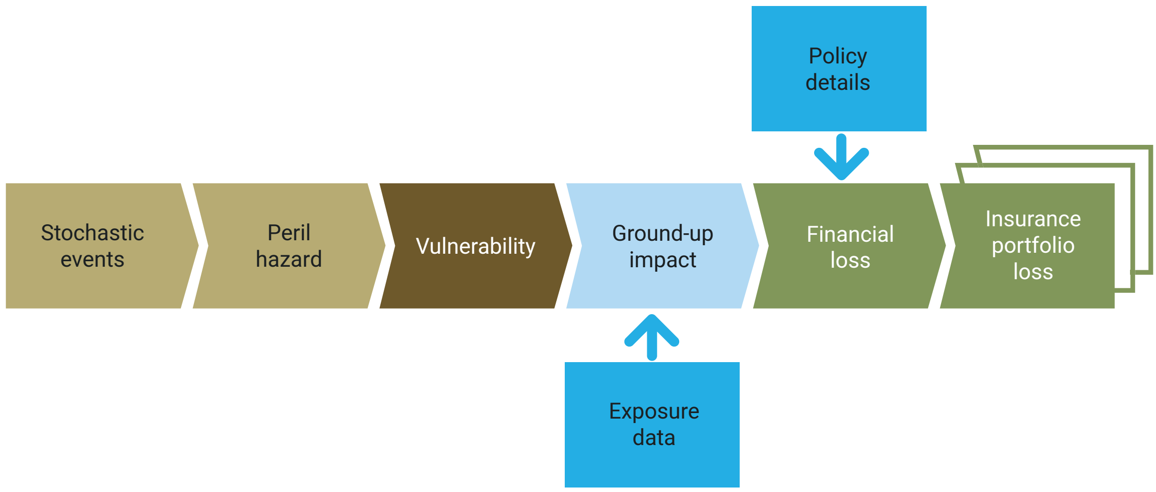


Figure 1: Schematic of traditional catastrophe risk modelling framework

Stochastic events

The first step is to develop a set of simulated, stochastic events to represent the physical systems driving the peril. This set aims to represent the physical characteristics of the peril, the likely severity and the associated probability of occurrence. The development of this event set is based upon the latest scientific understanding of the phenomenon and historical experience of where and how often it strikes. For fully-fledged probabilistic models, the count of stochastic events in an event set can number in the tens or hundreds of thousands.

Peril hazard

The second stage converts the stochastic event into a footprint to demonstrate the level of hazard at each geographic point impacted by the event. This hazard parameter is defined by the peril itself, such as 3-second peak gust wind speed for hurricanes, or spectral acceleration in the case of earthquake.

Vulnerability

Using understanding of building response and engineering data, models can determine how different levels of hazard would impact certain kinds of structure, in terms of where and how they have been constructed. Vulnerability can also include the potential for industries to shut down or reduce production, so-called Business Interruption.

Ground-Up Impact

Based on the severity of the hazard at a specified location, the exposure in the path of that hazard and the vulnerability of activity to business interruption, models can produce an expected 'ground-up' loss – the loss initially experienced by the risk holder. For insurance, the data entered into the model concerns details of what is insured – such as building and content characteristics and business activity.

Financial Loss

The final step is to apply the financial terms and conditions, including the value of the insured building or business activity, any deductibles or limits applied to an associated insurance policy. By aggregating all policy losses, the total loss to the re/insurer from each event can be determined. Insurers use the losses linked to each simulated event to calculate metrics for risk selection and pricing, outwards reinsurance decisions and capital requirements.

This methodology is now ubiquitous in the insurance industry, having been interrogated and validated by clients, rating agencies and governmental organizations, driving continual improvements in transparency and accuracy.

Drought Stress Testing Model Framework

Relative to insurance catastrophe loss models, the environmental risk models used within the corporate-banking sector are relatively underdeveloped. Insurance catastrophe risk models exist for several geological and climate-related perils based upon this event-driven framework. Water scarcity can also be represented by modelled events and the climatological understanding required to model drought hazard has much overlap with flood; with both perils involving extreme changes from ordinary rainfall levels, simply at opposite ends of the scale.

Once the drought hazard has been quantified, the model must then translate water scarcity into an impact to banks' expected loan defaults. The level of loss experienced by a financial institution depends on the characteristics of the borrower. Understanding each obligor's likelihood of default and hence its potential to cause a loss is akin to a vulnerability assessment, with the impact on the company's balance sheet replacing damage to an asset as would be seen in an insurance-driven model.

Although this translation to default-driven losses does require some adjustment to the catastrophe modelling methodology, this generic framework has demonstrated it is broadly applicable and as such serves as a practical starting point for developing the model. The key difference is to measure default risk as opposed to direct loss.

A schematic showing the adapted methodology is illustrated in Figure 2.

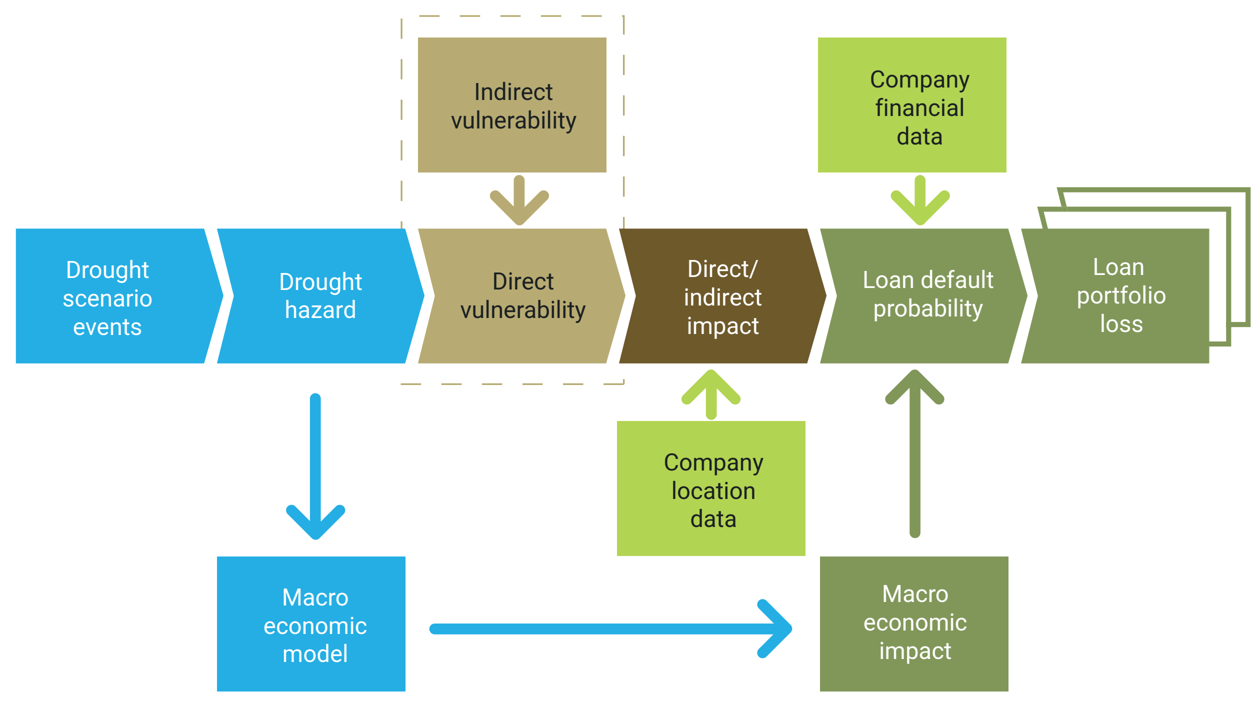


Figure 2: Schematic of drought stress testing model framework

This is the first time this methodology has been used to assess drought-driven default risk. As a first step towards obtaining a quantitative understanding of the risk, a set of five drought scenarios for each country was developed.

It is recognized that to develop a full quantitative risk view would require a larger and more complex stochastic event set. However, a limited number of scenarios can provide an extremely useful risk management tool to explore the impacts of an extreme environmental hazard. Within the insurance industry, scenarios are widely used to assess the impact of catastrophes. Lloyd's of London uses a series of regional realistic disaster scenario (RDS) events to stress test individual Lloyd's syndicates and assess the capital adequacy of the entire market[8].

Each drought scenario is represented by a time-evolving spatial grid, with each grid point presenting a value to show the deviation in rainfall levels from the historical norm. The time dependency element of this approach allows the model to assess and incorporate the evolution of drought conditions, which is essential as drought intensity varies significantly over time. The grid-point values are accumulated over each political state or province boundary and through time to determine a measure of total drought magnitude by state or province at each point in time.

Users of the Tool have to gather and input information about all outstanding loans in the bank's portfolio and the obligor companies themselves, including, where available, details about where individual operating sites are. To assess how these events could impact a company's likelihood of default, the vulnerability module is applied to each operating site.

The vulnerability module is split into a direct component and an indirect component. The direct component models the impacts to companies caused by having less water available to them. The indirect component assesses how power shortages and supply chain disruptions due to water scarcity can affect companies. A series of vulnerability factors determine how companies' revenues and costs can be expected to change due to drought conditions.

The vulnerability factors are applied to each site that contributes towards the company's revenue, allowing us to estimate how the scenarios will affect revenue and operating costs at each location. Revenue reductions and extra costs are then aggregated across the company's locations to develop a new company financial statement. For the Tool to provide a complete view of drought impact, the financial institutions would need to hold geographic and production information for all revenue-generating locations within each company to which they provide a loan.

During preliminary working sessions with financial institutions, it became apparent that in many cases such location information is either not collected, or is collected at point of underwriting but not available to the credit-modelling department. It was therefore important to be able to supplement these data with 'best inferred' information. The process described in the Archetype Generation Methodology section uses a logical process to populate 'best inferred' location information where the financial institutions do not hold the detailed data.

The updated revenue and cost of goods sold values from a company's financial statements data are input into a credit-rating model, which determines a new probability of default for the company. Clearly for this process to work financial institutions need financial statements for each company modelled. Again, in many cases these data are not available to the stress testing teams, so a similar Financial Archetype Methodology was developed to help fill any gaps. The resulting probability of default is independent of current macroeconomic conditions, and should be considered as a 'through the cycle' probability of default measure, hereby referred to as the "Base PD".

The broad model framework also includes a macroeconomic component that considers the impact of the drought on key macroeconomic variables. This uses a Global Vector Auto-Regressive method (GVAR) model with a measure of drought severity used as an exogenous variable. The macroeconomic model is linked to a probability of default model that modifies the Base PD to account for modelled macroeconomic conditions, giving an updated probability of default for each company that, when combined with loan details, provides an expected loss for the company. Expected losses are aggregated across all companies to determine the overall expected loss for a lending portfolio in each scenario.

The Tool has been designed to be modular and open source, so any user can replace any of the modules with their own internal modelling approach. This will allow the institutions to develop their own views of risk and make the Tool consistent with their other internal credit models.

Each of the steps within this model framework is described in more detail in the subsequent sections.

8 https://www.lloyds.com/the-market/tools-and-resources/research/exposure-management/realistic-disaster-scenarios

Drought Hazard

Analysis of Historical Data

Assessing drought intensity begins with the Standardized Precipitation Index value, which denotes the number of standard deviations from the expected level of precipitation. (SPI, McKee et al., 1993)[9]. SPI was selected by the World Meteorological Organization (WMO) as the most suitable internationally-recognized index of local drought conditions (Hayes et al., 2011)[10] .

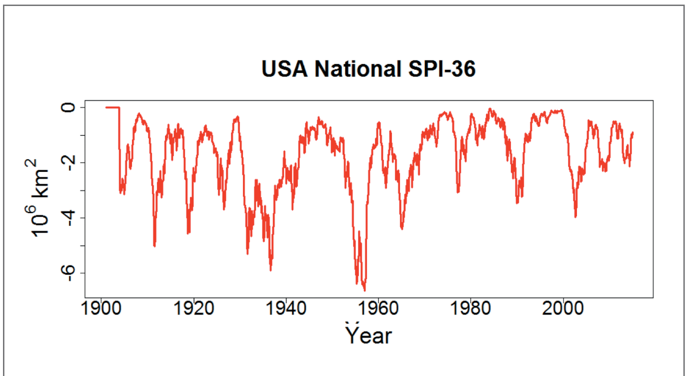


Figure 3: Rolling SPI-36 drought index for the U.S

The Drought Stress Testing Tool uses the SPI values from the CRU TS3.23 gridded precipitation dataset of the Climate Research Unit at University of East Anglia (Harris et al., 2014)[11]. This dataset records precipitation at 0.5°×0.5° resolution from 1901-2015. Developed using station observations, it has benefitted from many years of work on quality control, homogenization and feedback from a large pool of international researchers.

From this historical data, historical SPI maps were derived for droughts with time scales of 12 and 36 months, denoted SPI-12 and SPI-36, where the X in SPI-X indicates a deviation from average precipitation seen over an X-month period. For each country, a national index is obtained by spatially summing the grid-point indices where they are less than -1.0 (one standard deviation below normal) and where the annual mean precipitation is greater than 300mm. Figure 3 shows the national SPI-36 index for the USA. The deepest troughs in the time-series coincide with major recorded historical droughts in the US such as the Great Plains/Southwest drought in the 1940s/50s and 'Dustbowl' years of the 1930s.

Figure 4 shows the top four historical droughts in the US based on the national index SPI-36.

Drought Scenario Selection

The Drought Stress Testing Tool includes a selection of potential scenarios to provide a view of how droughts of different severity, duration and geographic distribution could affect a loan portfolio.

To do this, a large number of historical and theoretical drought events were generated. By referencing the historical data using the SPI metric, these were assigned an expected likelihood of occurrence. To reduce the scenario set down to five per country, some events were selected to match other banking stress tests, while others attempted to represent the extreme tail of the severity distribution, likely to occur once every 50 years, 100 years and 200 years, consistent with typical practice in catastrophe-exposed business. In certain cases, the intensity of historical events was adjusted to achieve the required level of severity. For example, in Figure 5, the USA scenario representing a 36-month drought of a severity that might be expected once every 200 years corresponds to a more severe version of the Rank 3 SPI-36 historical event in Figure 4.

For each country, the selected scenarios were selected to highlight varying durations, with two drought scenarios lasting two years and three drought scenarios lasting five years.

Information detailing each scenario is provided in Appendix 3.

9 McKee, T.B., Doesken, N.J., and Kleist, J. 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, Calif. 17– 22 January 1993. American Meteorological Society.

10 Hayes, M.J., Svoboda, M.D., Wall, N., and Widhalm, M. 2011. The Lincoln declaration on drought indices: universal meteorological drought index recommended. Bull. Amer. Meteorol. Soc. 92 (4): 485–488. doi:10.1175/2010BAMS3103.1

11 Harris, I., Jones, P.D., Osborn, T.J. and Lister, D.H. (2014), Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. Int. J. Climatol., 34: 623–642. doi:10.1002/joc.3711

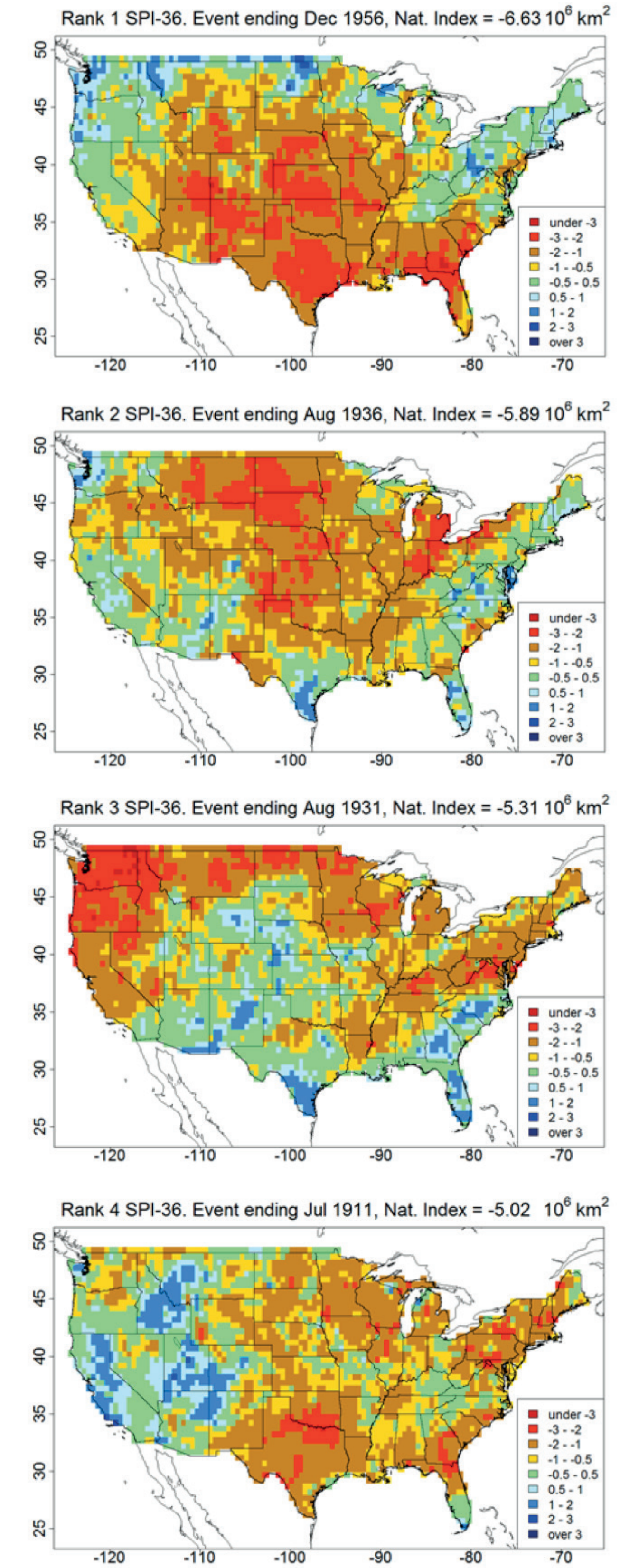


Figure 4: Top four historical droughts in the US based on SPI-36

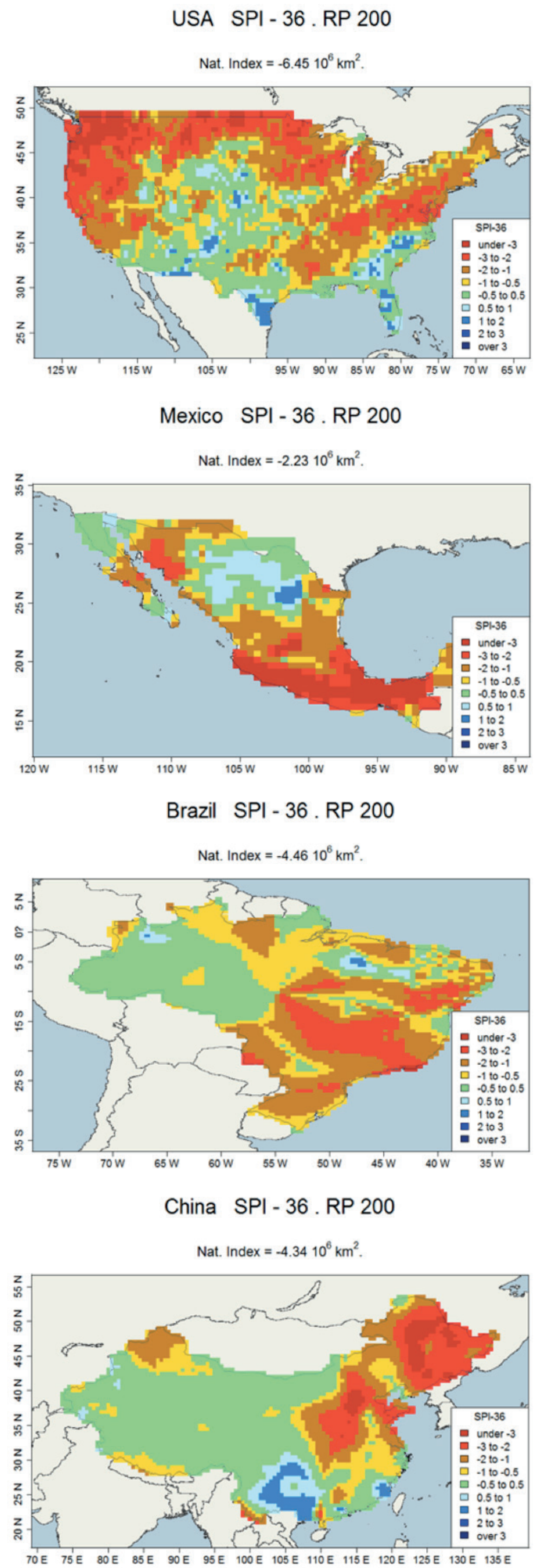


Figure 5: SPI maps at maximum intensity for scenarios for SPI-36 (200 year return period)

Hazard Footprint Generation

To translate rainfall levels to a metric more applicable to drought, the SPI is converted into a Total Drought Magnitude (TDM) for each state or province affected. This value is consistent with the Average Intensity (AI) measure defined by Jenkins (2011)[12], although in the case of this model aggregation is performed by state / province and not across the entire drought event.

The TDM is defined as the cumulative SPI by state / province and time, and is calculated by accumulating the monthly average SPI by state / province.

$$TDM_T = \sum_{t=1}^{T} SPI_t$$

Equation 1

Figure 6 shows the time series of monthly average SPI and TDM in Arkansas for the 1934 drought in the US. Although the effect on rainfall became apparent from December 1933 onward, the drought magnitude does not become negative until June 1934. Likewise, although rainfall recovers from April 1935 onward, there is a delay until drought conditions begin to recede. TDM can account for the accumulation of low rainfall over time, meaning that the modelling considers both short, high-intensity periods and longer less intense periods of drought.

For each event scenario, the model uses TDM values by state or province and by point in time as the input for the vulnerability component of the model.

12 Jenkins, K. L., 2011. Modelling the Economic and Social Consequences of Drought under Future Projections of Climate Change. PhD thesis, Chapter 6.

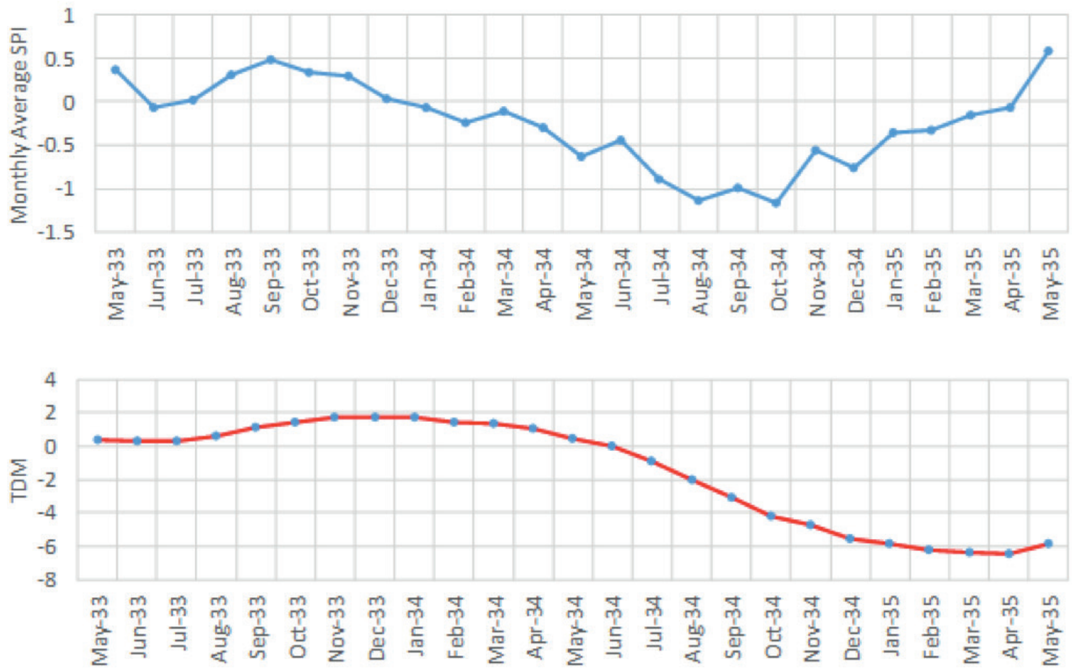


Figure 6: Time series of monthly average for Arkansas from the 1934 drought

Vulnerability Module Methodology

The vulnerability module converts the drought hazard footprint into an implied change in revenue and Cost of Goods Sold (COGS) at each company location. This is achieved through the assessment of three principal impact components:

- Direct impact on sector due to water deficit
- Indirect impact due to electric power shortage
- Indirect impact due to reduced material or labour supply

The water deficit and power shortage mechanisms consider a company's reliance upon these resources to generate revenue, and the extra operating costs created by reduced water availability during a drought. The indirect impact due to reduced material or labour supply is based on extensions to classical Input-Output (IO) methods looking at the 'trading' relationships between impacted and non-impacted states or provinces.

The ultimate financial impact, in the form of changes to revenue and operating costs considers the impact from each of the three mechanisms, as seen in Figure 7. A similar process is used to find the increase in company operating costs.

All of the vulnerability module components have been constructed and calibrated independently for each of the regions: Brazil, China, Mexico and US.

Ultimately, the vulnerability module provides a view by industry sector and by state/province for the impact on revenue and COGS for each of the five country scenarios. This allows the user to develop an intuitive understanding of how sensitive different industries and regions are to drought impact.

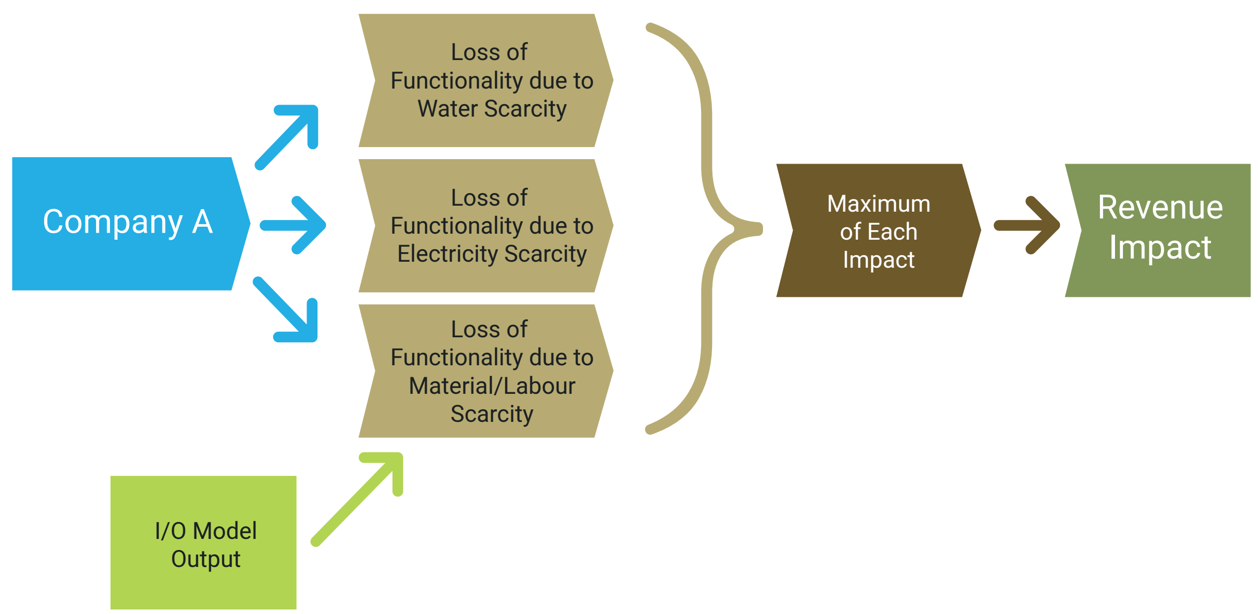


Figure 7: Framework of revenue impact model

Direct Vulnerability

Almost all industries rely on access to water at the locations that drive their revenue. The ultimate use of the water varies by industry, but the net result of a shortage of water can be to reduce production. The direct water scarcity component of the model looks at water deficit at key abstraction sources to assess falls in water availability at individual company sites and links this to a change in revenue and COGS.

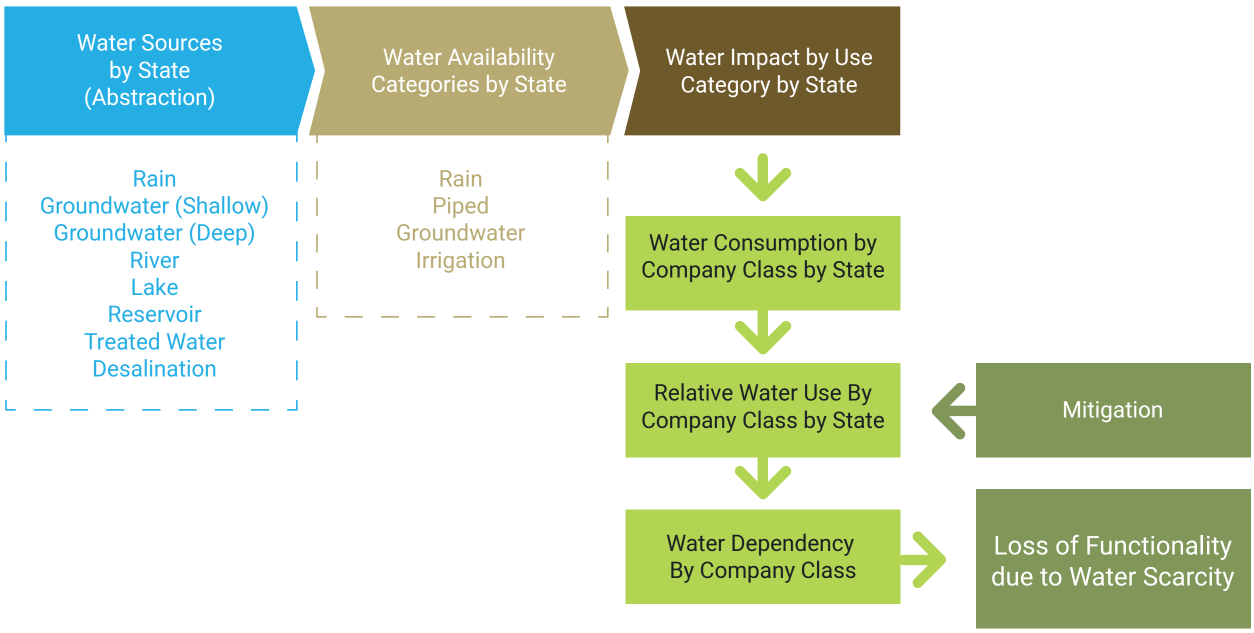


Figure 8: Schematic of methodology to determine loss of functionality due to direct water impact

"This tool can provide information that helps us to measure the potential risks associated with climate change; it offers a powerful and objective way to measure the impact of drought scenarios. We are already promoting changes in our management of water-related risks, but this tool offers information to better evaluate the most risky areas and industries, with clear, objective information to establish priorities. We are probably going to adjust our long-term investment strategies due to the results of this kind of analysis. In the near future, all banks are going to introduce climate modelling in their risk management methodologies, considering potential changes due to global warming. For us, this tool is the first step to do so in a formal way."

– Patricia Casillas, Specialist / Credit Department, Trust Funds for Rural Development (FIRA)

The model consider water abstracted from the following sources:

- Rainfall
- Shallow groundwater
- Deep groundwater
- River water
- Lakes
- Reservoirs
- Treated water (recycled water)
- Desalinization

Different geographic areas rely on different water sources, and the model assigns relative abstraction weights by state. Rainfall deficits will affect each source differently with shallow groundwater more immediately impacted by drought than reservoir levels. An impact function, as shown in Figure 9, links the drought magnitude to water availability from each water source.

In reality, most companies access water through distribution channels, which themselves source water from primary abstraction mechanisms. The model assumes that companies access water through one of the following:

- Rainfall (in this case the access channel is also the water abstraction source)
- Wells
- Pipelines
- Irrigation

The water distribution channels accessed at an individual company site depend both on the industry sector and on the geography in which the site is located. By propagating water from abstraction source to the distribution channel, the amount of water available to each business location can be determined.

The impact to a company location depends on its reliance on water for normal operations. By considering water availability and water dependency, it is possible to determine how much a company location will be affected and hence any changes to revenue and COGS.

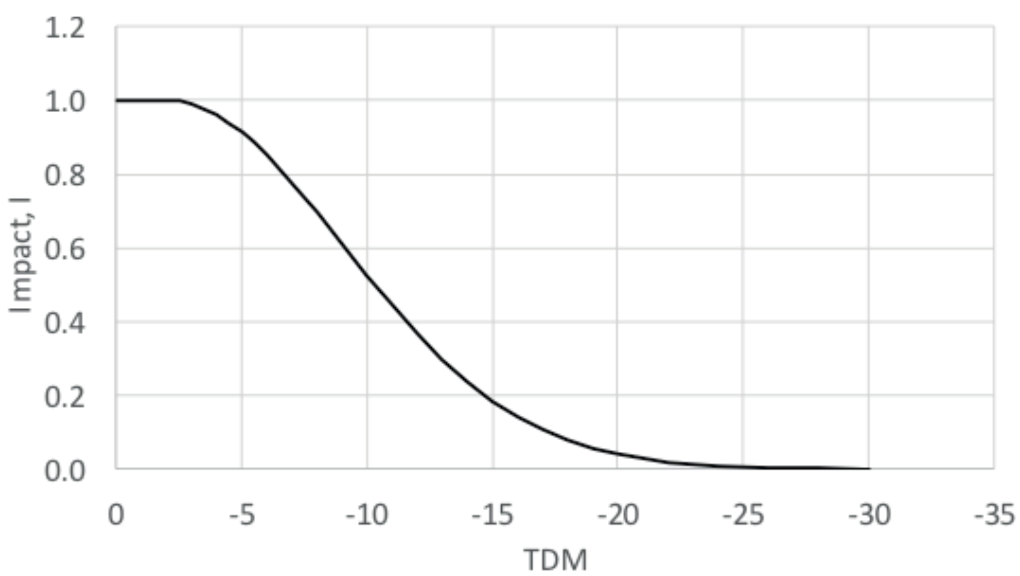


Figure 9: An example impact function for water availability at an abstraction source

Indirect Vulnerability from Reduced Material or Labour Supply

Drought, unlike many other natural hazards, rarely causes direct physical damage or loss outside of the agricultural sector. More commonly, a lack of water inhibits economic output in sectors with some degree of direct water dependence. Additionally, sectors that are not directly dependent on water can nevertheless be affected by reductions in output from other, directly affected sectors.

The indirect material/labour model uses a sectoral impact model adapted from a commonly used framework for modelling the economic impacts of natural disasters, the Adaptive Regional Input-Output (ARIO) model. The model assumes that an industry's output could suffer either because its own production capacity is insufficient, or because other industries cannot provide the necessary inputs in the production process. In addition, industries that produce less also demand less from their suppliers.

As with the other components of the vulnerability module, the output from this component is a change in revenue and COGS for each state/province and industry sector. These effects are then assessed alongside the other components as demonstrated in Figure 7.

"While climate change is a global phenomenon, its impacts will vary across geographies. This project explored unchartered territory by modelling the impact of drought scenarios on lending portfolios. It has helped us better understand the data requirements in quantifying drought-related risk and the challenges that will need to be addressed to further develop climate-related risk quantification methodologies."

– Liselotte Arni, Head Environmental and Social Risk, UBS

Macroeconomic Modelling Methodology

Incorporation of macroeconomic effects

The biggest impact on a company's finances is expected to come from the direct effect of a drought. However, severe droughts can last a long time and affect a wide area, so they can inflict significant damage on the broader economy.

As a result, the methodology accounts for the impact that a significant drought may have on the wider economy and how this might make it more likely that a company defaults on its loans.

The macroeconomic modelling approach uses a Global Vector Auto-Regressive (GVAR) model to analyse how drought shocks are transmitted through the global economy. The GVAR model uses a measure of drought as an exogenous variable, providing a way to model how the effects spread through the complex interactions in the global economy. The output from this process is a forecast of how a number of macroeconomic variables are affected.

The variables have been chosen based on both feedback from the financial institutions and the availability of reliable economic data. The economic dataset is taken from the GVAR toolbox[13] and runs from 1979 to 2013. Additional data extend the series up to the beginning of 2016.
The variables included are:

- Real gross domestic product (GDP)
- Consumer price index
- Equity price index
- Exchange rates
- Short-term interest rates
- Long-term interest rates
- Oil price index
- Agricultural raw material index
- Metals price index

Data are available for each of the countries included in the drought model as well as for other large global economies. This approach allows us to look at interactions between economies and provides a more complete view of drought impact than looking at countries in isolation.

Although the GVAR model can model droughts in multiple regions simultaneously, for clarity and simplicity each scenario is considered to occur independently, only affecting one country at a time. Other countries in the model are not considered to be directly affected by drought, but could be indirectly impacted through economic interactions with the affected country.

An important component of the model is the link between the severity of the drought and its macroeconomic impact, which is made through an SPI index used as an input to the GVAR model. The input is weighted by a state/province GDP measure, with the total value being equal to the sum over all states/ provinces. The weighting ensures that regions with a higher total GDP have a greater contribution to the drought impact.

13 https://sites.google.com/site/gvarmodelling/gvar-toolbox

Impact on Company Probability of Default and Expected Loss

The credit rating component of the model applies the changes in revenue and COGS implied by the vulnerability modelling, and adds in the modelled macroeconomic parameters to determine an updated probability of default for each company as a result of the drought impact.

Credit Rating Model

Credit Rating Model methodology

A credit rating model was built using an ordinary least squares (OLS) regression model to link financial ratios to a Standard and Poor's (S&P) credit rating score. The model uses over 1,800 sample companies, each with either an S&P or a Moody's rating. The Moody's ratings are mapped to their S&P equivalent rating, and then all ratings are mapped to a probability of default (PD) value equal to the historical average annual PD for each rating between 1982 and 2015. The resulting PD values are assumed to be independent of macroeconomic conditions. This credit model does not explicitly include any influence from drought conditions.

The variables used for the model were determined by considering which values drive the credit-worthiness of borrowers, and which are typically available to financial institutions. We also ensured that none of the chosen financial metrics are highly correlated. The final set of variables chosen are:

- Log of total assets
- EBITDA to net debt ratio
- Return on assets
- EBIT to interest expense ratio
- Liabilities to assets ratio

The S&P sovereign credit rating of the issuer's country of domicile was incorporated into the model to account for the variability of credit ratings by country, without imposing a strict country risk ceiling. The industry sector of the issuer is also included as a fixed effect for each industry. The resulting credit-rating model returns the companies' macroeconomic independent PD value as an output. This value is referred to as the "Base PD".

Credit Rating Model Validation

Several tests were performed to ensure the validity of the model, comparing the implied credit rating from the model with the actual credit rating from S&P or Moody's. In about 89% of cases, the model-implied credit rating is within three sub-notches (a sub-notch being +/- on the letter) of the rating agency rating, providing good confidence that this model works.

Figure 11 shows the rating distributions from the credit rating model and the rating agencies. While there is broad agreement, the model produces a higher concentration of companies in the portion of the distribution between BBB+ and BB, and a lower concentration of companies on the edges of the total distribution.

Finally, stability tests were run on the model to ensure that the methodology performs well out of sample. This involved randomly sampling subsets of half of the companies to re-estimate the model, and then testing the model on the out-of-sample companies. The process was repeated several times and we found that the model is consistently stable, with only small deviations observed between samples.

The modular nature of the Drought Stress Testing Tool allows financial institutions, to substitute their own credit models in place of the model provided in order to enable and encourage adoption.

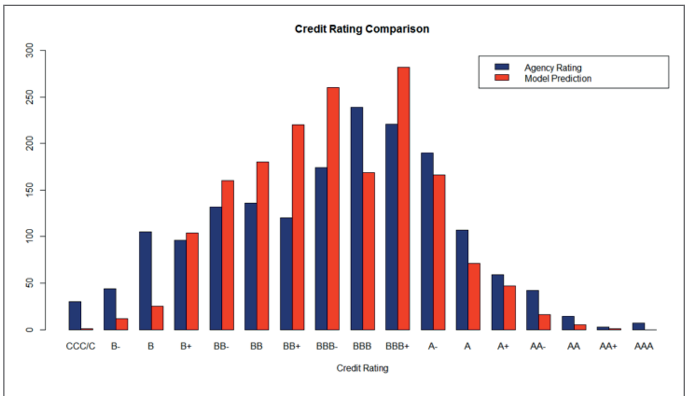


Figure 11: Rating distributions for agency ratings and the credit rating model

Financial Statement Modelling

The impacts of a company's vulnerability on revenue and COGS are applied to the appropriate values at each of a company's locations. This gives updated revenues and COGS for each modelled location, which are then aggregated across all locations to determine the updated company-wide values. These updated values flow through the company's income statement, implying new financial statements, and thus new financial ratios, for each company.

The updated financial ratios are fed into the credit rating model, determining a drought-impacted Updated PD for each company. Note that the Updated PD value may or may not imply a change in the credit rating.

Link Between Financial Statement and Macroeconomic Model

The determination of the Updated PD is independent of macroeconomic conditions and so, to incorporate the macroeconomic impact, the model modifies the probability of PD value ranges for a given credit rating.

A satellite model linking change in GDP to default rates was built using historical default data. The model fits historical company defaults by year and annual change in GDP for the year time series and is used to forecast future total PD values given the modelled evolution of GDP.

The total PD value is then split out to find the implied PDs for individual credit rating letters. The model also ensures that the worse a letter score, the higher the probability of default. Factors built using these default rates can then modify Updated PD rating to a Final PD that takes into account macroeconomic conditions.

The Final PD value is then multiplied by the loss-given-default amount to give an estimate of how much a default will cost the lender. As prescribed by Bank of International Settlements, the loss-given-default amount is 45% for senior unsecured loans and 75% for all subordinated loans[14]. Expected losses are then aggregated across all companies within the portfolio to get to the overall expected loss for each scenario.

14 http://www.bis.org/bcbs/publ/d362.pdf

"The quantification of financial impacts arising from environmental risks, particularly those related to climate change, is an important step in the evolution of environmental and social risk management. The focus on drought, a physical risk arising from climate change, is an important addition to the body of work related to stress testing, carbon emissions and climate change.

"The development of the tool is timely, as it will inform how institutions can conduct scenario analysis on climate change risks in alignment with the expected guidance from the Taskforce on Climate-Related Financial Disclosures."

– Courtney Lowrance, Global Head of Environmental and Social Risk Management, Citi

Archetype Generation Methodology

The model framework requires financial statement and location data to be input for each company in the analysis. In many cases the financial institutions will not have all the data they need to most accurately stress test their portfolios. Therefore, the model allows archetypal data to be generated as a proxy where this is the case. In all cases, using real data will yield more representative portfolio results.

Financial Archetype Methodology

The financial information used for a company is determined by the company's industry, size and the country of domicile. The financial data used for the archetypes were determined by analysing financial statements from approximately 20,000 global companies.

Location Archetype Methodology

The location data used in the archetypes are determined via a random sampling process based on how actual production for the relevant industry sector is distributed across a company's country of domicile. This method best reflects loss correlations that would be expected across an industry portfolio, although the representative locations generated will very likely differ from the company's actual locations.

The method first determines in how many states/provinces the company is likely to have locations. Small companies may only have locations in one state/province, whereas medium and large companies will be assumed to have exposure across multiple states provinces.

A defined state/province is assigned to each location by sampling the geographic industry distribution for the relevant country. Locations are more likely to be in areas with high economic activity for the specified industry sector. For example, oil and gas companies in the US are much more likely to be in Texas, where around 30% of US oil GDP is generated, than Florida, where less than 0.1% of US oil GDP is generated (US Energy Information Administration 2014 data[15]).

The final stage is to determine the amount of production at each location by resampling the geographic industry distribution for the country and industry of the company, so that locations in states with a large percentage of total output are likely to be attributed with larger production.

15 https://www.eia.gov/dnav/ng/ng_prod_sum_a_EPG0_FGW_mmcf_a.htm

Calibrating scenario modelling to reflect how external environmental shocks could affect the credit quality of certain industries will be useful for stress testing."

– Jorge Sobehart, Managing Director Risk Architecture, Citi

Analysis of financial institution loan portfolio data

Introduction

We partnered with a number of financial institutions to analyse certain loans and compile insights into how the drought scenarios would affect modelled default rates of loans in their portfolios. The data used was real loan data representing limited subsets of these specific financial institutions' portfolios, and were selected to show a range of impact that could be experienced.

We have appropriately aggregated, summarised and anonymised the data to prevent disclosure of proprietary or confidential information. The findings strongly support the notion that drought is a tangible and material risk for many industries and that it should be considered when assessing loan default rates.

Caveats

These findings are specific to the scenarios and portfolios of loans used in the analysis and so do not necessarily represent standard industry sector impacts or country-wide risk assessments. The portfolios used are only a portion of the total loan portfolio of participating financial institutions, represented by the industry sectors within the scope of the study. Some of the scenarios analysed are, by design, severe and represent catastrophic droughts in these countries.

Additionally, the Drought Stress Testing Tool is a prototype and the first step in the development of broader capabilities for financial institutions to quantify the environmental risks to their loan portfolios. As discussed in later sections of this report, a number of additional elements have been considered, which would enhance the accuracy of the drought risk assessment if they were included.

The Drought Stress Testing Tool rating model does not necessarily mirror financial institutions' own rating model. The default rating model incorporated in the Tool is a model based on financial metrics only and does not take into account certain important qualitative information. In addition, companies' balance sheets could be more or less fragile due to recent economic conditions. Also, the portfolio results detailed in this section may not incorporate company–, country– or industry sector-specific mitigation measures that may be in place but are outside of the scope of this Tool and report.

"Water-related risks have become increasingly serious all over the world. As one of the biggest commercial banks in the world, ICBC has spent many years in protecting our portfolios against environmental risk; water risk is one of the most important. We actively participated in this project on water risk as it provides a useful tool to all financial institutions, and will encourage other commercial banks to focus on this risk."

– Dr. Yin Hong, Deputy Director of Urban Finance Research Institute, ICBC

Brazil

Brazil – Portfolio 1

General

- The portfolio contains companies across eight different industry sectors, ranging from beverage and tobacco manufacturing to oil and gas extraction to water supply and irrigation, which the participant banks considered to be more sensitive to droughts.
- Depending on the drought scenario, 65%-70% of obligor companies' credit ratings were downgraded. This shows that drought events of this magnitude could be highly impactful to these sectors in Brazil.
- Drought increased the portfolio losses due to default by between 1.5x and 2x depending upon the drought scenario applied, compared to expected default rates.
- Severe drought events are expected to have a large impact in Brazil due to the country's heavy reliance on hydroelectric power. Around 75% of Brazil's electricity supply comes from hydropower, with power output dependent on reservoir water levels.

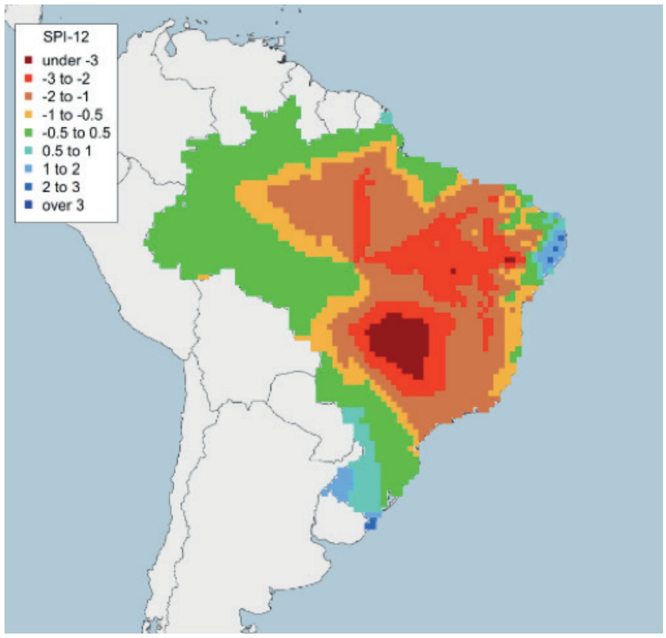


Figure 13: Brazil scenario 5. It can be seen that the important economic region that encompasses Sao Paulo, Minas Gerais and Rio de Janeiro is heavily affected.

Scenario impact

- All five scenarios significantly reduce company revenues and increase overall operating costs.
- Scenario 5, affecting the main production areas of Brazil, Sao Paulo, Rio de Janeiro and Minas Gerais, is the most impactful because it is concentrated in regions with high industrialisation and production, but all scenarios result in significantly higher expected losses compared with the non-drought scenario.
- Scenario 1 has the highest hazard return period; however, this scenario is spread broadly across the country, impacting regions with relatively low production as well as the main economic areas.

Company profile impact

- Food manufacturing and crop production drive losses to the portfolio because they are highly dependent on water to maintain production levels and the portfolio is relatively highly exposed to these industries.
- The most vulnerable sectors to drought are water supply and irrigation systems and crop production since they depend directly on water availability in order to generate revenue.
- Within this portfolio, there is no significant difference in impact between small, medium and large companies, probably because the affected industries are highly geographically concentrated.

Brazil – Portfolio 2

General

- The portfolio covers a broad range of industry sectors. The largest individual contribution comes from crop production, but there is also notable exposure to electric power generation, food manufacturing, and oil and gas extraction.
- Due to limited availability of location data, the Tool's archetype data was used to supplement the portfolio. Although this includes certain assumptions, this approach yields solid insights given the real-world loan terms and values.
- For the most severe scenario almost 90% of companies were downgraded, implying that drought events in Brazil can severely affect companies, both directly or indirectly.
- Expected losses to the portfolio are driven by crop production, which is heavily reliant on either direct rainfall or irrigation networks to maintain production levels. In the worst-case scenario, expected losses for this sector increase by an order of magnitude.
- Compared to the reference view, expected losses grow by between 4x and 9x, depending on the scenario due to the high level of exposure to the agricultural sectors, which use water highly intensively.

Scenario impact

- All five scenarios have a big impact on the portfolio, leading to lower revenues for the obligor companies and hence increased probability of default.
- Scenario 2, a highly intense five-year drought, is marginally the most impactful scenario. This event is particularly strong in some of the country's most important agricultural regions, Paraná, Rio Grande do Sul and Goiás. It leads to expected losses increasing 13x in crop production, with overall expected losses increasing nine times relative to the no-drought reference scenario.
- Scenario 1, the most intense drought scenario, lasting five years, has the highest hazard and big impacts on the portfolio. This scenario has a significant effect on key agricultural areas, but is slightly less concentrated than Scenario 2, hence the marginally lower expected losses as compared with Scenario 2.

Company profile impact

- Losses to the portfolio are driven by crop production due to the portfolio's weighting towards this sector and agriculture's high reliance on direct access to water.
- Electric power generation companies are also greatly affected, with expected losses increasing up to 6x relative to the reference scenario, due to Brazil's heavy reliance on hydroelectric power.
- The most directly vulnerable sectors to drought are water supply and irrigation systems and crop production due to reliance on water availability in order to generate revenue.

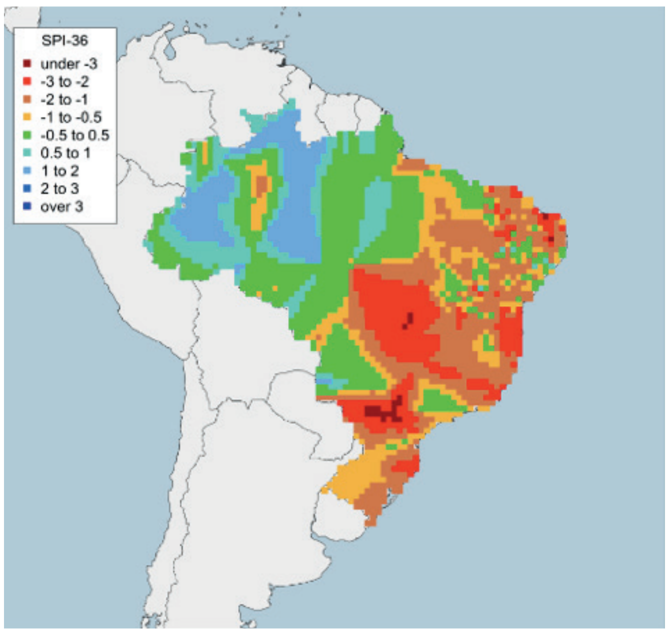


Figure 14: Brazil scenario 2. It can be seen that the drought impacts important agricultural regions of the country such as Paraná, Rio Grande do Sul and Goiás.

China

China – Portfolio 1

General

- The portfolio contains around 2,500 companies, spread across 11 different industries including manufacturing, construction, power-generation, retail, transport and water distribution.
- Depending on the scenario, drought has a moderate impact on the credit portfolio assets in most affected regions. However, drought is a material risk for individual companies, and could represent a systemic risk to corporate lenders.

Scenario impact

- All scenarios significantly affected company revenues and overall operating costs.
- Although it was not the most severe in terms of overall hazard for China, Scenario 2 is the most impactful scenario due to its effect on the highly-industrialised regions surrounding Beijing, Tianjin and Shanghai. This highlights the fact that although the intensity of a drought is a key driver with respect to impact, understanding the geographic spread of companies is also critical to understanding potential losses.

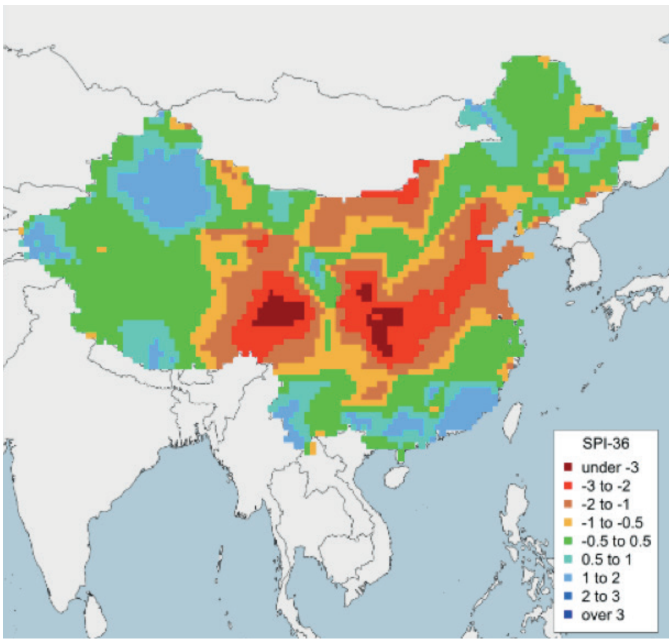


Figure 12: China scenario 2. It can be seen that many of the important economic regions on the east coast are affected.

Company profile impact

- In general, electric power generation, manufacturing, beverage, tobacco product manufacturing power is second only to coal in China in terms of power generation and is critically reliant on water availability. The food, beverage and tobacco sectors are highly reliant on primary output from the agricultural sector, which is significantly curtailed by large drought events.
- Small and medium sized firms are more affected by drought events than large firms, for two reasons:
  - Large companies typically have larger, more stable balance sheets enabling them to survive periods of financial turbulence. Smaller companies are more sensitive to reductions in revenue or hikes in their cost base.
  - Large companies typically have more operating sites that are widely spread across the country. Given that drought is a regional event, proportionally fewer locations are affected by the scenario, leading to a lower overall impact to the company's finances. Smaller companies are generally more geographically concentrated with fewer operating sites and, as a result, a large drought can potentially affect a greater proportion of overall company revenue.

Mexico

Mexico – Portfolio 1

General

- The portfolio is weighted towards construction and agriculture, but there is also exposure to the manufacturing, power generation and oil extraction industries.
- Due to limited availability of location and balance sheet data, the Tool's financial and location archetype data was used to supplement the portfolio. Although as a result, this includes certain assumptions, this approach yields solid insights given the real-world loan terms and values as the archetype data should be representative of the "true" portfolio data.
- Depending on the scenario, between 90% and 100% of companies analysed see their credit ratings fall due to the drought scenario. These segments in Mexico appear vulnerable to large drought events, and the events have a significant impact on implied credit-worthiness.
- In general, the base expected loss for the portfolio is very low because the largest loan values are to companies with relatively good credit ratings. As a result, although these companies are affected by the drought events, there is only a small chance of their likelihood of default increasing.
- The expected loss for the base scenario is 0.07%, growing to between 0.3% and 0.7% depending on the drought scenario. This represents up to a tenfold increase in overall expected loss due to drought events.

Scenario impact

- Scenario 5, a once-in-100 years drought lasting two years, has the highest impact of the five drought scenario events in the first year, with an expected loss of 0.7%, 7x higher than the base expected loss. This scenario affects the important industrial regions of Ciudad de México and México state, as well as the important agricultural region of Jalisco.
- In Scenario 5, oil and gas extraction contributes the largest proportion of losses, followed by food manufacturing, because of the importance of water availability to food output and the ability to extract oil.
- Although less severe than Scenario 5 at its peak, Scenario 2, another one-in-100 years event, but lasting five years, has the greatest impact over the full five-year period, with over 1% expected loss. This scenario again affects the important industrial regions of Ciudad de Mexico, Mexico, and Jalisco.

Company profile impact

- Within the model, the most vulnerable sector to changes in revenue is crop production even though losses for this portfolio are being driven by oil and gas extraction and food manufacturing. The food manufacturing sector is highly dependent on agricultural produce, and the oil sector is dependent on water for extraction. Although the impact on revenue for these industries is smaller than for agriculture, the impact on the credit rating is higher due to the financial characteristics of companies in these sectors.

Mexico – Portfolio 2

General

- The portfolio is predominantly related to energy industries (oil and gas, related services).
- Due to limited availability of location data, the Tool's archetype data was used to supplement the portfolio. Although as a result, this includes certain assumptions, this approach can yield solid insights given the real-world loan terms and values which were used.
- We accounted for differences in individual companies' water efficiency practices using the water impact modification factor functionality, based upon the bank's understanding of individual companies' water practices. The modification factors used were all within the range between 0.9 and 1.1, resulting in only modest changes to drought impacts.
- Depending on the scenario, between 65% and 90% of credit ratings are downgraded due to the drought scenario.
- Compared to the reference scenario, the introduction of drought increased portfolio losses by up to 150%, depending upon the scenario applied. This is once again relative to a low base default rate.

Scenario impact

- All five Scenarios have a high impact on overall expected losses during the first two years, with 85%-95% of overall losses coming in this period. This shows that the impact of drought becomes apparent quickly after the onset of the event.
- The most impactful event is Scenario 5. This scenario is a highly severe, two-year drought. It severely affects the Mexican Gulf region (Tamaulipas, Veracruz and Tabasco), where much of the country's oil and gas industry is located.

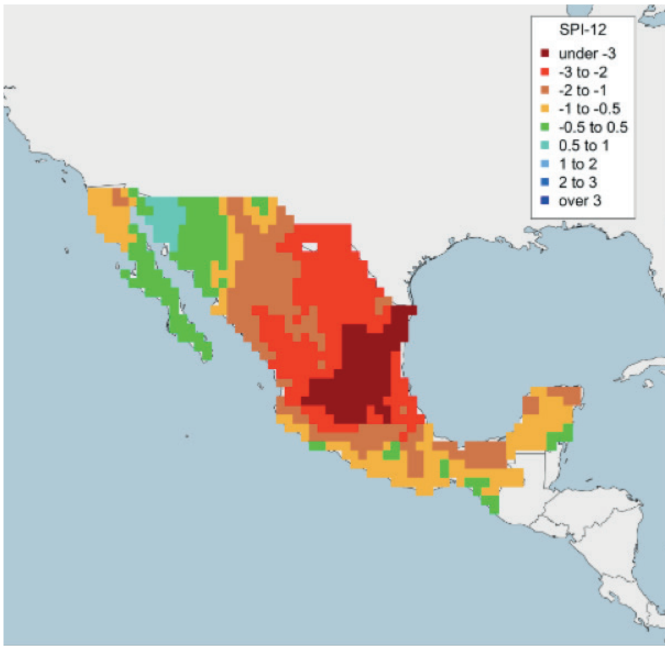


Figure 16: Mexico Scenario 5. It can be seen that the central region of Mexico experiences intense drought conditions.

United States

United States – Portfolio 1

General

- The portfolio focused on power generation and petroleum industries. It is representative of an industry portfolio and due to limited availability of location and balance sheet data, the Tool's archetype data was used to supplement the portfolio.
- The use of financial archetype data implies the use of certain assumptions, and although this approach yields solid insights, it results in a portfolio that is potentially more highly internally-correlated than might occur in reality.
- Depending on the scenario, between 70% and 100% of companies analysed see their credit rating fall due to the drought scenario, highlighting the systemic risk posed by drought events.
- Compared to the expected default rate, the introduction of drought increased portfolio losses due to default by up to 30x for the worst-case scenario, but this is relative to the archetype portfolio's extremely low base default rate.
- The high level of correlation in the portfolio, the use of financial and location archetypes, and the geographic concentration of the industries being assessed results in large variations between scenario losses.
- The main losses to this portfolio come from the indirect impact of drought, demonstrating the importance of understanding the interrelation between industries.

Scenario impact

- All but one of the scenarios have a low impact on overall expected losses, suggesting that US power generation and petroleum companies are relatively resilient to the direct impacts of drought. Even though these scenarios might affect areas with high production, the overall impact on default rates is low.
- Scenario 4 represents a highly severe, geographically broad 2-year drought. This scenario causes expected losses of over 6% of the entire portfolio value.
- While this scenario has a relatively low direct impact on the main oil-producing regions of the US, like Texas, it has large direct impact on both East and West coasts, which are both heavy consumers of energy and refined petroleum products.
- The expected losses are driven by the East and West coast drought impacts that reduce demand for Texan energy products, resulting in reduced revenues in Texas, even though the drought hazard is relatively low there.

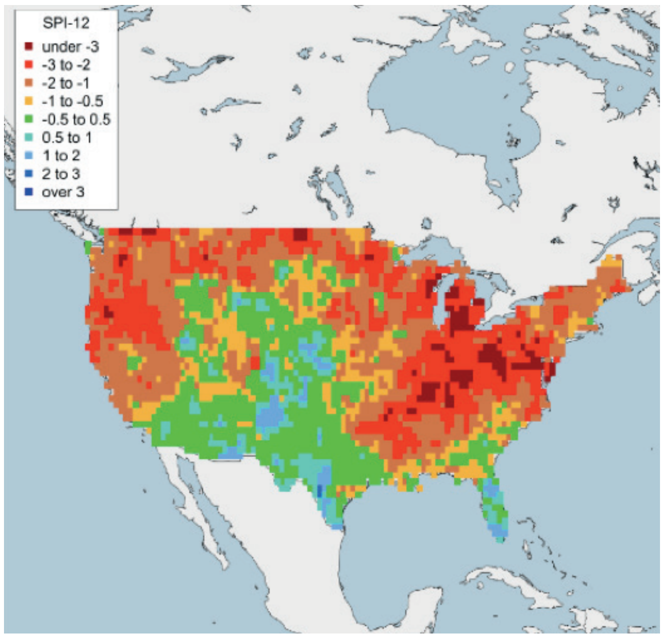


Figure 15: US Scenario 4. It can be seen that both the east and west coasts are heavily impacted by the drought event

Company profile impact

- In scenario 4, petroleum refinery companies are driving most losses due to the large indirect drought impact across this sector.
- Across all scenarios, water supply and irrigation companies are most vulnerable to drought, followed by electric power generation companies because of their high dependency on water abstraction.
- Due to the petroleum-focused nature of the portfolio, the number of small and medium sized companies in it is very low. As a result, it is not possible to determine relative vulnerability by company size.

United States – Portfolio 2

General

- The portfolio focused on the water utility and petroleum Refining industries.
- Across a five-year period, the overall default probability for the water utility portfolio increased by about 0.5% between the reference year and the five drought scenarios.
- Certain scenarios imply a potential drop of 75% in revenue and 20% increase in COGS for California water utilities, showing a significant impact due to drought. The impact on the default rate was, however, relatively low, indicating that these companies are able to withstand severe reductions in revenue.
- Over five years the overall default probability for the petroleum refining portfolio increased from 0.29% in the reference year to an average of 0.31% across the five drought scenarios – a nominal increase of 7%. The change in default rate increased losses between 2% and 14% depending on the scenario.
- For water utilities, compared to the reference scenario, the drought increased portfolio losses by between 0.5% and 5% depending on the scenario. The relatively moderate impact on defaults, even though the drought causes significant falls in revenues, is in part because the credit model includes implied guarantees or some level of government support for utilities.

Scenario impact

- Scenarios 1, 2 and 3, (all five-year drought scenarios) have a moderate to severe impact on overall expected losses, with overall losses increasing between 2.5% and 5% for water utilities, and 7%-15%, for petroleum refineries. This suggests that water utilities are relatively resilient, even to long-term droughts despite experiencing significant reductions in revenues.
- Scenarios 4 and 5 (both two-year drought scenarios) show minimal impact on overall expected losses, with losses increasing by 0.7% for water utilities, and 2% for petroleum refineries. This shows the relative resilience of US companies to shorter drought scenarios.

"The world is facing a changing climate. Brazil's water crisis in 2015 made us more aware about the impacts and possible loss to companies, the economy and environment. We at Itaú Unibanco are proud to participate in the Drought Stress Testing Tool as we can now measure the effects of water-related crises to our portfolios. Knowledge of the risks is the best way to mitigate them. The project is bringing us insights to become even better at socio-environmental risk management in our portfolio."

– Denise Hills, Head of Sustainability and Inclusive Business, Itau Unibanco

Actionable Insights

Stress testing processes provide a wealth of information to inform lending decisions and manage capital requirements based upon the whole-portfolio risk profile.

This section explores how this additional insight could be used, and further steps financial institutions may take to obtain more representative results around drought impact. The two overarching areas addressed are:

- How financial institution risk management and lending strategies might be informed by the model output
- How financial institutions might collaborate with their borrowers to obtain detailed information for more accurate assessments.

Risk Management Adaptation

A solid understanding of the risk to which an organisation is exposed is essential to sound risk management. Modelling forms a central part of developing this understanding and assessing the associated risk management options. Risk management practices can take a number of forms both in terms of responding after the event and developing resilience pre-event.

These risk management practices can be broken down into three main categories:

- Risk retention
- Risk mitigation
- Risk transfer

These strategies are used across all industries, including financial services.

Risk Retention

Risk retention is where an organization consciously elects to absorb losses up to a certain level. Almost all risk management strategies include at least some degree of risk retention. Typically, risk retention is used to cover more frequent, less extreme losses that are less efficiently managed through insurance structures.

Running the Drought Stress Testing Tool gives financial institutions a quantitative value for the expected loss from each scenario. Looking at this figure in the context of its risk appetite allows the institution to determine if the loss can be comfortably absorbed (and thus risk retention would be appropriate), whether it would threaten profitability, or if it could threaten the viability of a loan portfolio.

Risk Mitigation

Risk mitigation practices aim to reduce the threat or impact of a given peril. Even when exposed to large climatological events such as droughts, financial institutions have many options to materially reduce their risk.

Increasing obligor resilience
Better understanding of specific sectoral sensitivities to drought will enable financial institutions to work with individual borrowers or business associations to improve their water risk resilience strategies. They will also be better served by increased knowledge of individual companies' water management strategies and preparedness. During an event, water management can help the long-term profitability of companies. More efficient water use could be encouraged, and institutions could give financial incentives, such as lower loan costs via more favourable interest rates if a borrower has access to alternative water sources or has implemented more sophisticated and advanced water management measures.

Due to the threat of electricity shortages in certain regions, the availability of backup power sources would also reduce risk. Similar incentives could be applied to companies that can show greater power supply independence during a drought.

Stricter acceptance criteria
Another possible mitigation measure would be to restrict, or stop, lending to sectors shown to be highly vulnerable to water scarcity in areas that are prone to intense droughts and where, as a result, companies may require additional capital to deal with droughts. While this would reduce the overall risk to banks from drought, it would also reduce the business available to them. Nonetheless, it may be appropriate, particularly where mitigation measures are challenging.

Geographic accumulation management
The Tool revealed that loan portfolios can be most severely affected by being geographically concentrated in drought-hit areas that are highly industrialized. Banks could moderate the overall impact from drought events by diversifying their lending portfolios and managing geographic and sectoral accumulations.

Although drought events are very large spatially, over large countries, it is rare that even the most severe drought impacts all of the country. Companies with diffusely distributed operating locations are highly unlikely to see all operations hit by the same drought. However, companies with more concentrated exposure could see water scarcity at all operating locations, as was illustrated in the scenarios affecting Brazil, China and Mexico outlined in the report. The financial implications will thus be more severe for those companies with specific concentrations within the affected area and loan pricing should reflect levels of geographic concentration.

At the portfolio level, institutions could engineer their portfolio so that geographic concentrations of exposures do not exceed pre-determined threshold amounts. The threshold values would be determined by overall risk appetite and can be informed by the Tool's outputs.

Risk Transfer

If the risk cannot be mitigated or avoided by not lending, and the resulting risk levels exceed risk appetite, then risk transfer mechanisms can move drought risk away from the lender. Risk transfer can occur at two levels, for individual obligors, and for the financial institutions themselves. Either form of risk transfer will benefit financial institutions and will lower overall losses attributed to drought.

A widespread example for risk transfer on the obligor level is agricultural insurance. In the US, heavily subsidized agricultural insurance protects farmers from the most severe drought events[16]. In China,[17] parametric insurance schemes have been developed to protect farming families in Heilongjiang Province.

Similar products could be developed for other industries directly affected by water scarcity. The expected recovery from the insurance scheme could be modelled on a company's income statement, and would reduce the impact of the drought on company revenues, reducing default risk and hence credit terms.

Risk transfer products purchased directly by financial institutions would also reduce their risk. These could be based upon parametric indices that pay out when drought conditions reach certain levels or where default during a drought period exceeds a defined threshold.

Improved Data Quality

Aside from direct risk management strategies, banks can improve the resilience of their portfolios by improving the quality of their data. The quality of the Tool output and consequently the confidence in the results which are used to inform risk management decisions is heavily dependent on the accuracy of the data used. In many cases, financial institutions do not have access to all their clients' financial statement data, or the location data required for the Tool to return the most accurate results.

While this Tool does contain archetype functionality that can be used in place of real data, these archetype data may not reflect the true financial performance of the company. Using real data will always produce more reliable and accurate results, more closely reflecting a company's true financial performance. Financial institutions would benefit from working with their clients to improve access to these data. Similarly using real geographical data will lead to more representative drought impacts for each company, giving more accurate overall losses.

The financial institutions could also work more closely with obligors to understand their water scarcity resilience strategies and any mitigation or adaptation measures companies have in place or are planning. This knowledge would allow financial institutions to use the Tool's in-built water impact modification factor functionality[18] to give more accurate modelling results.

These data are either not collected by financial institutions, or if they are, not stored in such a way that gives the credit modelling teams access. Where the data are not collected, the financial institutions would have to introduce extra data requirements at the point of underwriting. For cases where the data are collected, but not made available, the financial institutions would have to change their internal data management systems to allow these data to become more widely available. Access to these data would immediately benefit the financial institutions as they could immediately be used within the Tool.

16 https://www.bloomberg.com/news/articles/2013-09-09/farmers-boost-revenue-sowing-subsidies-for-crop-insurance

17 http://www.swissre.com/media/news_releases/nr_20160803_chinaparametric.html

18 The stress testing tool allows a user to enter a "Water Impact Modification Factor" that accounts for the water resiliency of company locations. The factor linearly scales the difference between non-drought and drought impacted levels of income and costs for the location modelled.

Possible Project Extensions

The current version of the Drought Stress Testing Tool is a prototype. However, the framework that has been built is highly versatile, and there are many possible options for extension. Additional features could be added to improve usability, accuracy and to expand the model's scope. There are three main categories where extension is possible:

- Extending the scope of the Tool within the current framework
- Expanding the Tool framework
- Applying the framework to other environmental, social and governance risks

It should be noted that this framework has been designed to look at risk to organizations over the medium term (one to five years) for events with relatively sudden (of the order of months) onset. The framework has not been developed to accommodate long-term modelling of events with gradual changes in conditions, such as adaptation to staggered climate legislation.

In the following section, we discuss potential enhancements to the model framework and the Tool itself.

Extension of the Scope of the Tool Within the Current Framework

The changes discussed in this section relate to additional features that could be modelled without major adaptations to the current model framework.

Additional Countries

The four countries modelled as part of this project were chosen as they are geographies covered by the partner financial institutions. Many other countries are highly susceptible to drought events where a similar modelling approach could prove useful for other financial institutions. New data could be added to the Tool to enable new countries to be included. A new set of hazard scenarios would be needed, the vulnerability of the industries would need to be understood, and new macroeconomic modelling would need to be performed. This would result in a new set of impact factors, and new macroeconomic modelling that would be accessed through the Tool.

Additional Industry Sectors

Currently the Tool supports approximately 10 industry sectors for each modelled country. Additional water-vulnerable industry sectors could also be included. This would allow financial institutions to model more of their portfolios against drought risk and would increase the utility and applicability of the Tool by widening its scope.

Multi-Country Scenarios

El Niño and La Niña events significantly influence the location and amount of rainfall across many regions and can lead to concurrent drought conditions across multiple countries. The scenarios currently considered exclusively impact one country, implying that the drought scenarios across countries are independent of each other and no correlations between countries are considered. The Tool could be extended to include multi-country scenarios, with additional correlations potentially implying greater losses to financial institutions from drought events.

Expanding the Tool Framework

It is acknowledged that this version of the Tool represents the first step in environmental risk modelling. The model presented is in many ways much simpler than a standard insurance catastrophe risk model. However, there is potential to build this into a much more sophisticated model.

Water management practices – quality assessment

Expanding the assessment of the water management practices companies have in place is one of the most important ways of adding value to the Tool. Sound water management is essential to reduce the impact of drought on business operations. In the same way that financial institutions should incorporate a company's high-level exposure to drought risk into their loan rates, they should also consider any additional mitigation or adaptation measures that companies have in place. The current model only incorporates a linear factor to differentiate between water management practices. Being able to account for specific activities and mechanisms would also help financial institutions to promote positive practices through relevant financial incentives.

Introducing Verification Functionality

Within the financial services sector, back-testing is frequently used to determine the performance of a model or a strategy. Similarly, when building catastrophe risk models, comparing losses for the modelled version of an event and actual historical losses from the event verifies the accuracy of the model. One key limitation of back-testing is that the verification process requires detailed historical data. Currently there are no data sets that link actual company defaults to environmental conditions. Should this data begin to be collected, financial institutions will be able to back-test the model, allowing them to alter key modelling assumptions and determine how changes to these assumptions affect the accuracy of model predictions.

Developing a Stochastic Event Set

The core of catastrophe risk models is a stochastic event set that include tens of thousands of events, each with a probability of occurrence. These event sets allow the full range of potential event outcomes to be modelled, enabling metrics such as probable Average Annual Loss (AAL) and Value at Risk (VAR) to be calculated. The Drought Stress Testing Tool has only five scenarios for each country, so these probabilistic metrics cannot be determined. The Tool framework could be adapted to consider a full stochastic set of drought events instead of the five scenarios. A full stochastic catalogue of drought events, encompassing tens of thousands of drought patterns, would be developed, each with a probability of occurrence. Loss estimates could be calculated for each of these events, enabling banks to understand the frequency of highly severe drought events.

Quantifying Uncertainty

Uncertainty around the model output has not been developed for this prototype version of the Tool. The development of uncertainty relations is a large undertaking, involving the propagation of error terms through all aspects of modelling. For the current iteration of the Tool the RMS vulnerability team concentrated on developing reliable and accurate impact factors. The importance of quantifying uncertainty around loss values is fully understood and developing quantification of uncertainty is seen as an important step for subsequent versions of the Tool.

The two above-mentioned changes would both result in a much more sophisticated model, requiring more computational power to deliver results. An Excel-based tool would no longer suffice to deliver the model, so enterprise software would need to be built to deliver this functionality.

Application of Framework for Other Environmental, Social and Governance Issues

As the framework employed here is highly flexible, it could be adapted to assess default risk due to other environmental, social, and governance issues. The framework is ideally suited to capture the risk of relatively sudden (over a timeframe of approximately one year) changes to a company's financial statement, and any change that affects a company's revenues and costs can be modelled.

Other Natural Catastrophe Perils

The Tool could be adapted to model scenarios from additional natural catastrophe perils - such as hurricanes, convective storms, earthquakes, floods and terrorism - as well as modelling drought. The general framework of the Tool would not need to change; however, due to the spatial hazard gradient of these perils, geographic information would be needed at a more granular level to capture the true vulnerability of locations. Therefore, for such models to be useful, financial institutions would need better data collection and storage procedures.

Legislative Risk

Any legislation that imposes immediate restrictions on a company's ability to drive revenue, or its operating costs will affect the company's probability of insolvency. An example of legislative risk is government-imposed regulation of tobacco advertising. This would likely result in a reduction in revenue for tobacco companies, translating to an increase in the default probability for the industry. This kind of impact could be modelled through the Tool framework, allowing financial institutions to assess the overall impact of a legislative change on their overall portfolio.

Carbon Risk

Another form of risk that faces financial institutions is carbon risk. For corporate lenders, the risk is that companies with a high reliance on carbon will be unable to generate revenue should strong regulation or other pressure around carbon use be widespread, leading to increase in company default rates. Much of the work in this field so far has focused on value reduction through asset stranding over the long-term. The Tool framework could model the impact of the sudden introduction of carbon regulation, and thus could be used in sensitivity testing for financial institutions.

Application to Other Types of Risk

Further modification to the framework could even enable assessment of other types of financial risk, such as equity price volatility and infrastructure finance risk. Using impact factors to assess changes to revenues and costs of companies would be relevant to all types of financial analysis. However other aspects of the proposed framework would need to be adapted to accommodate different types of financial analysis.

“Social and Environmental Risk Management is one of the pillars of our corporate sustainability strategy. The challenges that climate change brings about, such as drought in Mexico, requires us to be prepared as a financial institution. The great value of this initiative lies in the use of valuable local information to face a global issue.”

– Andrés Albo, Social Commitment Director, Citibanamex

Conclusion

This report outlines how financial institutions can stress test their corporate loan portfolios for the impact of drought, using a tool developed as part of a framework designed by the Natural Capital Financial Alliance and GIZ. The Drought Stress Testing Tool, developed by a consortium led by RMS, was used to assess the impact of five drought scenarios on a range of industries in China, Brazil, Mexico and the US. With input from nine banks, the Tool examined the impact on a set of sample portfolios representing examples of the type of portfolio that banks in the respective countries might hold.

In general, the results of the study reveal that there was significant variation in how different countries and sectors were affected by each set of scenarios.

In the US, most industries were relatively resilient to the direct impacts of drought. The limited reliance upon hydroelectric power and relatively robust local and national government support is expected to prevent severe direct impacts in most cases. However, where scenarios cause widespread interruption to economic activities, there is marked fragility for industry sectors such as petroleum refineries and production, whose reliance upon the broader economy can greatly affect revenues and hence loan default rates.

Brazil, Mexico and China show greater, more consistent susceptibility to water scarcity, with default rates more than doubling in multiple scenarios. These increases, and the resulting financial losses, were generally driven by direct impacts of drought on industry sectors that one would intuitively expect to be reliant on water, such as power generation (in regions with higher hydroelectric power reliance), water distribution, agriculture and water-intensive manufacturing industries.

It is worth noting, however, that across all countries, in almost all scenarios, most companies saw an increase in probability of default and subsequent reduction of their credit rating. While defaults may not have directly increased as a result, lower revenue will undoubtedly affect financial performance and companies' shareholders.

The analysis shows that while some less severe scenarios had little impact on default-driven losses, severe droughts could cause significant, and in extreme cases, critical effects on a loan portfolio. Although instinct may drive focus onto heavily water-dependent industry sectors, defaults and losses can also come from industries that are indirectly impacted by drought such as the petroleum industry – and that these losses can be driven not by the direct impact of drought on those industries but by the effect on their customers, often elsewhere in the country.

To completely understand drought risk financial institutions will need to take a more holistic assessment approach, incorporating both secondary and macroeconomic impacts. But it is apparent that drought, and water scarcity in general, is a risk financial institutions should seek to better understand, both to differentiate between companies seeking loans and to identify critical concentrations of risks that could drive significant defaults and losses.

The insights provided by the Tool enable lenders to make better-informed decisions on lending and capital requirements, including whether to retain, mitigate or transfer risk. The Tool gives banks transparency on whether it is appropriate to retain certain levels of risk, given the expected loss from the various drought scenarios.

Risk mitigation measures could include working with borrowers to improve their water resilience, imposing stricter acceptance criteria and diversifying portfolios both geographically and in terms of sectoral balance.

Risk transfer could take the form of insurance against drought risk, for individual companies or financial institutions themselves.

The Tool's efficacy is improved through access to better quality data. During the production of the scenarios, it emerged that lenders do not always have access to all the financial or location data they need for the Tool to give the most accurate results. Although the Tool is designed to allow archetype functionality that can be used in place of real data, real data will always produce more reliable and accurate results. Financial institutions would benefit from working with clients to improve access to data and to understand how they are tackling water stress.

The environmental stress testing framework is highly versatile and could be extended in a number of ways. Within the current framework, additional countries or industry sectors could be considered and it could also examine multi-country scenarios where drought affects multiple countries.

The Tool could also be made much more sophisticated, incorporating a quality assessment of water management practices, for example, as well as developing uncertainty relations and expanding the stochastic event set. In addition, the framework can be applied to other environmental and social issues, including other natural catastrophes such as flood and earthquake; legislative risk and carbon risk.

Appendix 1: Climate Change Assessment

In this appendix, we present additional work that is separate to the core content of this report. The analysis and results presented are purely to provide context around the impact of climate change-driven evapotranspiration. This analysis has no further bearing on the research or the model results presented in the main body of the report.

As an extension of hazard development, we performed additional analysis to determine the impact that climate change would have on drought frequency and severity. It should be noted that the outcomes of this additional analysis are not included within the Tool.

The IPCC AR5 report has reviewed the scientific literature on global and regional changes of precipitation, evapotranspiration and drought occurrence over the past century. Conclusions are that confidence in trends, either positive or negative, are low to medium on most landmasses. Low levels of confidence are due to the difficulty of discerning natural variability from climate change, to the quality and availability of the data and to the lack of ad-hoc methodologies. The table shown in Figure 17 (last column) summarizes the IPCC review of literature.

Region	Warm Days (e.g., TX90p[a])	Cold Days (e.g., TX10p[a])	Warm Nights (e.g., TN90p[a], TR[a])	Cold Nights/Frosts (e.g., TN10p[a], FD[a])	Heat Waves / Warm Spells[g]	Extreme Precipitation (e.g., RX1day[a], R95p[a], R99p[a])	Dryness (e.g,. CDD[a]) / Drought[h]
North America and Central America	*High confidence*: *Likely* overall increase but spatially varying trends[1,2]	*High confidence*: *Likely* overall decrease but with spatially varying trends[1,2]	*High confidence*: *Likely* overall increase[1,2]	*High confidence*: *Likely* overall decrease[1,2]	*Medium confidence*: increases in more regions than decreases[1,3] but 1930s dominates longer term trends in the USA[4]	*High confidence*: *Likely* overall increase[1,2,5] but some spatial variation *High confidence*: *Very likely* increase central North America[6,7]	*Medium confidence*: decrease[1] but spatially varying trends ***High confidence[b]*: *Likely* decrease central North America[4]**
South America	***Medium confidence[b]*: Overall increase[8]**	***Medium confidence[b]*: Overall decrease[8]**	***Medium confidence[b]*: Overall increase[8]**	***Medium confidence[b]*: Overall decrease[8]**	*Low confidence*: insufficient evidence (lack of literature) and spatially varying trends but some evidence of increases in more areas than decreases[8]	***Medium confidence[b]*: Increases in more regions than decreases[8,9] but spatially varying trends**	*Low confidence*: limited literature and spatially varying trends[8]
Europe and Mediterranean	*High confidence*: *Likely* overall increase[10,11,12]	*High confidence*: *Likely* overall decrease[11,12]	*High confidence*: *Likely* overall increase[11,12]	*High confidence*: *Likely* overall decrease[10,11,12]	***High confidence[b]*: *Likely* increases in most regions[3,13]**	***High confidence[b,c]*: *Likely* increases in more regions than decreases[5,15,16] but regional and seasonal variation**	*Medium confidence*: spatially varying trends ***High confidence[b]*: *Likely* increase in Mediterranean[17,18]**
Africa and Middle East	***Low to medium confidence[b,d]*: limited data in many regions but increases in most regions assessed** ***Medium confidence[b]*: increase North Africa and Middle East[19,20]** ***High confidence[b]*: *Likely* increase southern Africa[21,22,23]**	***Low to medium confidence[b,d]*: limited data in many regions but decreases in most regions assessed** ***Medium confidence[b]*: decrease North Africa and Middle East[19,20]** ***High confidence[b]*: *Likely* decrease southern Africa[21,22,23]**	***Medium confidence[b,d]*: limited data in many regions but increases in most regions assessed** ***Medium confidence[b]*: increase North Africa and Middle East[19,20]** ***High confidence[b]*: *Likely* increase southern Africa[21,22,23]**	***Medium confidence[b,d]*: limited data in many regions but decreases in most regions assessed** ***Medium confidence[b]*: decrease North Africa and Middle East[19,20]** ***High confidence[b]*: *Likely* decrease southern Africa[21,22,23]**	*Low confidence[d]*: insufficient evidence (lack of literature) *Medium confidence*: increase in North Africa and Middle East and southern Africa[3,19,21,22]	*Low confidence[d]*: insufficient evidence and spatially varying trends ***Medium confidence[b]*: increases in more regions than decreases in southern Africa but spatially varying trends depending on index[5,21,22]**	*Medium confidence[d]*: increase[19,22,24] ***High confidence[b]*: *Likely* increase in West Africa[25,26] although 1970s Sahel drought dominates the trend**
Asia (excluding South-east Asia)	***High confidence[b,e]*: *Likely* overall increase[27,28,29,30,31,32]**	***High confidence[b,e]*: *Likely* overall decrease[27,28,29,30,31,32]**	***High confidence[b,e]*: *Likely* overall increase[27,28,29,30,31,32]**	***High confidence[b,e]*: *Likely* overall increase[27,28,29,30,31,32]**	***Medium confidence[b,e]*: Spatially varying trends and insufficient data in some regions** ***High confidence[b,c]*: *Likely* more areas of increases than decreases[3,28,33]**	***Low to medium confidence[b,e]*:** ***Low confidence* due to insufficient evidence or spatially varying trends.** ***Medium confidence*: increases in more regions than decreases[5,34,35,36]**	***Low to medium confidence[b,e]*** ***Medium confidence*: Increase in eastern Asia[36,37]**
South-east Asia and Oceania	***High confidence[b,f]*: *Likely* overall increase[27,38,39,40]**	***High confidence[b,f]*: *Likely* overall decrease[27,38,39]**	***High confidence[b,f]*: *Likely* overall increase[27,38,39,40]**	***High confidence[b,f]*: *Likely* overall decrease[27,38,39]**	***Low confidence* (due lack of literature) to *high confidence[b,f]* depending on region** ***High confidence[3]*: *Likely* overall increase in Australia[3,14,41]**	***Low confidence* (lack of literature) to *high confidence[b,f]*** *High confidence*: *Likely* decrease in southern Australia[42,43] but index and season dependent	***Low to medium confidence[b,f]*: inconsistent trends between studies in SE Asia. Overall increase in dryness in southern and eastern Australia** ***High confidence[b]*: *Likely* decrease northwest Australia[25,26,44]**

Figure 17: Regional observed changes in a range of climate indices since the middle of the 20th century. From the IPCC fifth assessment report (2013).

Nevertheless, modelling and theory point toward possible important changes in the hydrological cycle with climate change, possibly significantly affecting drought patterns and severity. An important driver of these changes is the faster surface warming of continents compared to oceans (surface warming for the period 1901-2014 is shown in Figure 18). This would cause evapotranspiration to increase faster than precipitation on land, leading to drier conditions. The effects of both temperature and evapotranspiration can be captured in the standardized precipitation and evapotranspiration index (SPEI).

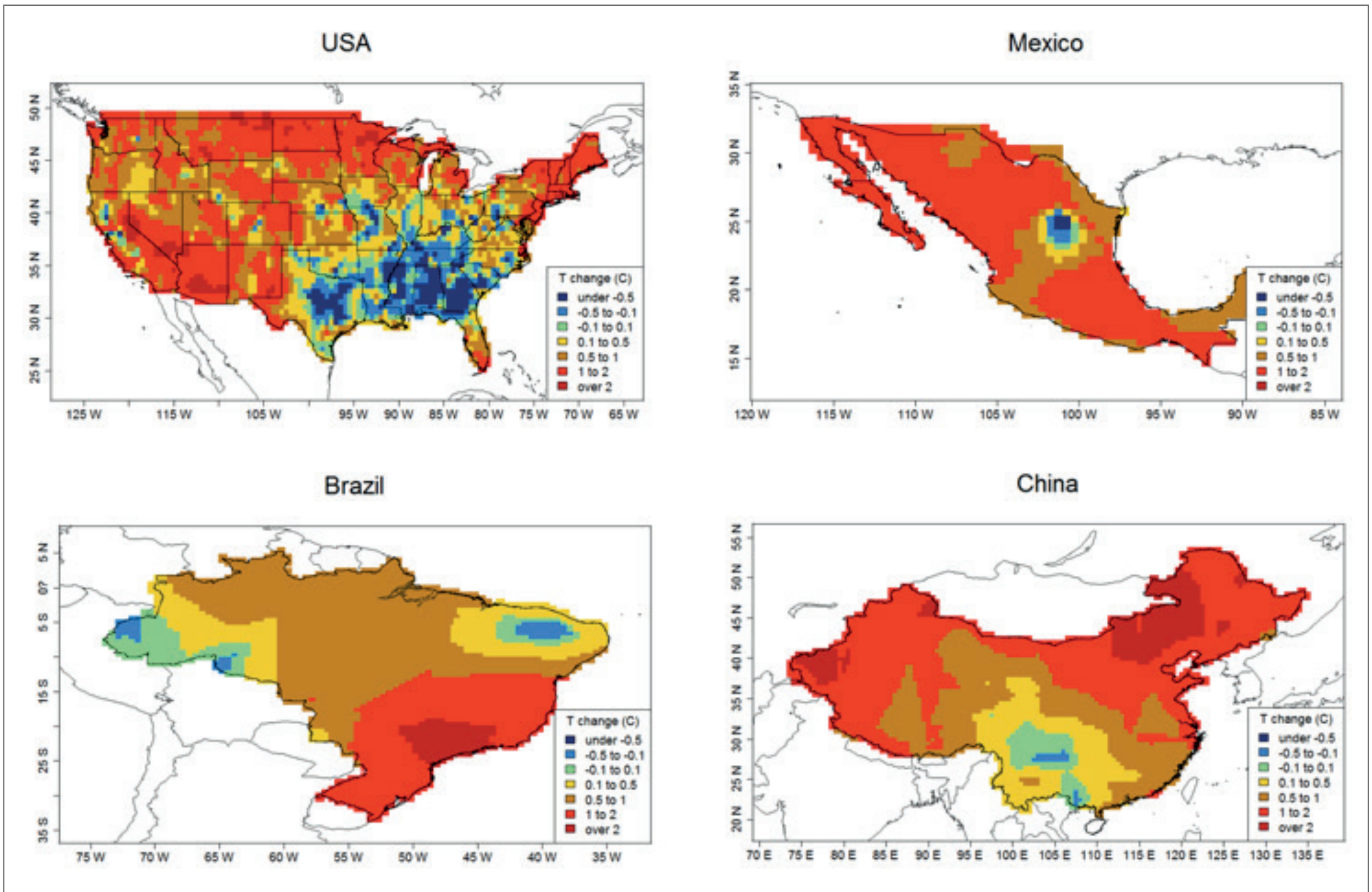


Figure 18: Temperature surface warming from 1901 to 2014 (CRU data set)

To assess the effect of present climate change on drought magnitude and return periods, we looked at how past droughts might have looked in the present climate. We calculated precipitation and potential evapotranspiration trends for each grid point covering the four countries between 1901 and 2014. Figure 18 shows the change in the difference between precipitation and potential evapotranspiration from 1901 to 2014. We then define an “effective precipitation” by subtracting from the de-trended precipitation the difference between de-trended and historical potential evapotranspiration. This “effective precipitation” is essentially past precipitation corrected for long-term trends in precipitation and evapotranspiration. For example, if in a particular location precipitation and evapotranspiration have both increased, we obtain the “effective precipitation” in year 19XX by adding the increase in precipitation from 19XX to present and by subtracting the increase in evapotranspiration from 19XX to present. To derive a record of what past droughts might have looked in the present climate, we run the same SPI analysis as described previously but on this “effective precipitation”.

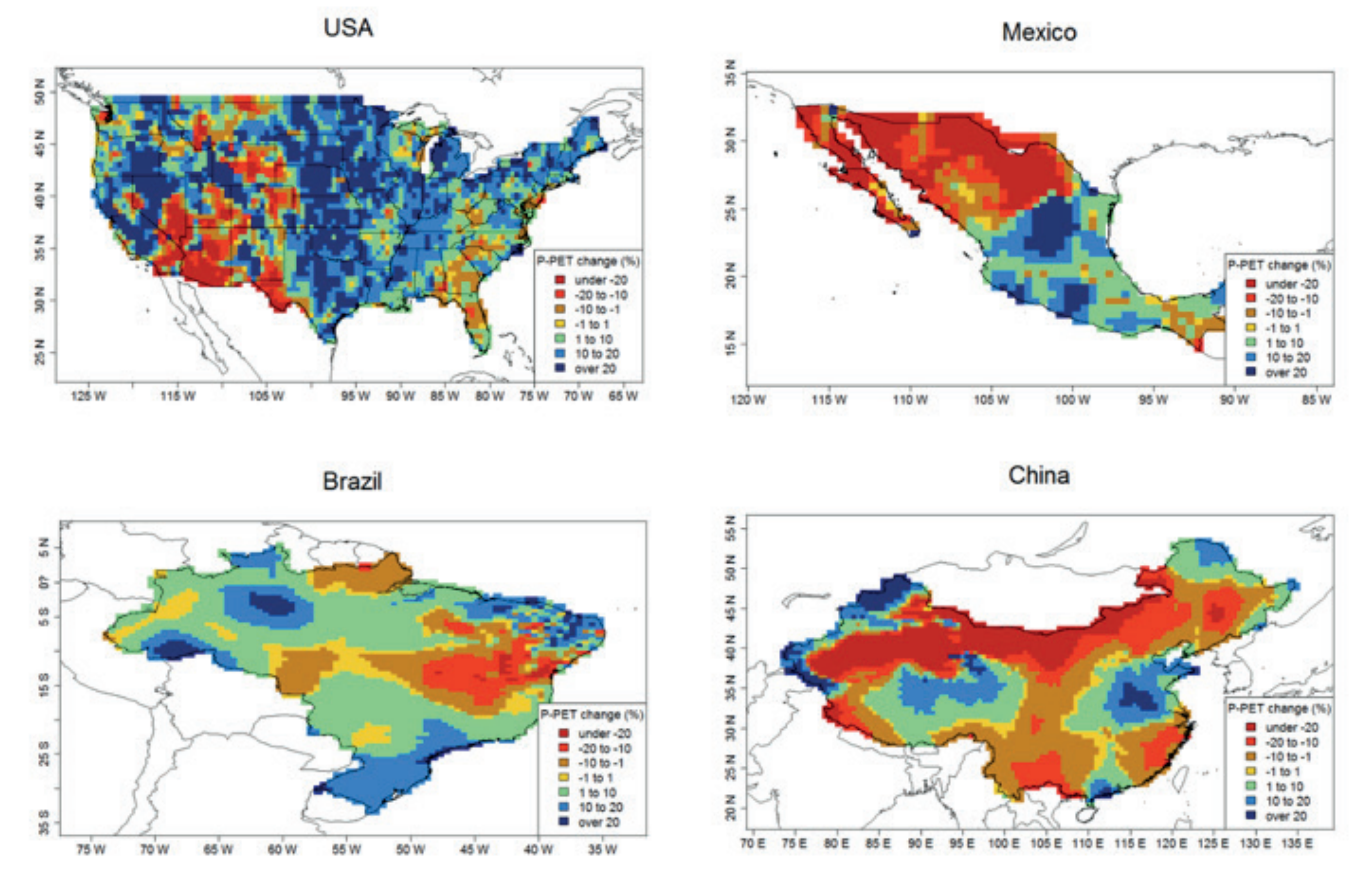


Figure 19: Long-term change between 1901 and 2014 in the difference between precipitation and potential evapotranspiration (P-PET). P-PET is normalized with the mean precipitation and shown in %. Red indicates drying and blue indicates moistening.

The results of this analysis vary by geography. In the US, the results point toward drought intensity decreasing over the past century. However, the response is regional, with the south-west US drying significantly and the plains becoming much wetter. Our analysis showed that at the national level the intensity of drought decreased by about 5% to 10% for any given return period.

The analysis suggests that the dry regions of northern Mexico became drier due to higher evapotranspiration and, to a lesser extent, due to lower precipitation. The highlands of central Mexico have become wetter because the increase in precipitation is outweighing the increase in evapotranspiration. Southern tropical regions are slightly drier mainly due to more evapotranspiration. At the national level, for a given return period, the intensity of droughts has increased by 5%-10%. The analysis showed that the return periods of drought events of specified severity reduced from 200 to 150 years, from 100 to 80 years and from 50 to 40 years respectively. Northern regions dominate these national trends, while the central and southern parts of Mexico, where populations are more densely concentrated, tend to become wetter.

Some regions in Brazil, notably large parts of the north-east, have dried significantly over the past century. Other regions, like the south, are becoming wetter because the increase in rainfall is larger than the increase in evapotranspiration. At the national level, our results cannot point towards any significant change in drought intensity over the past century.

China appears to have become drier over time, with more severe impact from climate change causing the intensity of droughts to increase by about 20%. This analysis showed that the return periods of drought events of specified severity reduced from 200 to 100 years, from 100 to 50 years and from 50 to 30 years respectively.

Limitations and Caveats

The results presented in this climate change analysis must be interpreted with caution for reasons due to the quality of the data and the methodology. Moreover, these results have no predictive value; if the climate dried or moistened in any particular region over the past century, that does not mean that the trend will continue in the future.

A few important caveats are:

- We considered potential evapotranspiration, the evapotranspiration that would occur with an infinite reservoir of water. Actual evapotranspiration, which is very difficult to estimate, is smaller. Hence, our analysis is biased toward drying and overestimates drought intensity change over the past century.
- We have considered change in the mean climate but not change in its variance. Drought can become more important even if the climate moistens, for example if the annual or inter-annual variability of precipitation changes.
- Other important meteorological data not considered in this analysis can significantly affect drought impact. For example, the ratio of snow to rain in mountains greatly affects drought intensity in the western states of the US.

Appendix 2: Expert Council Members

The Expert Council includes 13 members to provide independent input in drought risk, hydro-climatic economic modelling, credit risk analysis and stress testing.

- Dr. Andrien Nguyen-Huu, Ecole Polytechnique
- Antônio Félix Domingues, National Water Agency (ANA)
- Dr. Arnoldo Matus Kramer, Chief Resilience Officer for Mexico City
- Beibei Jiang, Green Finance Consultant and Analyst, Central University of Finance and Economics
- Brazilian Business Council for Sustainable Development (CEBDS)
- Butch Bacani, Programme Leader, The UNEP FI Principles for Sustainable Insurance Initiative
- Cyrus Loftipour, Vice-President, MSCI Environmental, Social and Governance (ESG) Research
- Greg Elders, Senior Analyst, ESG, Bloomberg Intelligence
- Johannes Ruf, Senior Lecturer, Department of Mathematics, University College London
- Karen Lockridge, Principal, Pension actuary & sustainability champion, Mercer
- Marwa Hammam, Executive Director, Master of Finance Programme, Cambridge Judge Business School
- Mike Wilkins, Global Head of Environmental and Climate Risk Research at Standard & Poor's Ratings Services and FSB Climate-related Finance Disclosure Task Force member
- Professor Minjun Shi, Chinese Academy of Sciences
- Nick Robins, UNEP Inquiry Co-Director
- Paul Reig, World Resources Institute (WRI)
- Dr. Roger Pulwarty PhD, Senior Advisor for Climate Research, and Director, National Integrated Drought Information System, National Oceanic and Atmospheric Administration, U.S,
- Samantha Sutcliffe, Principal Green Bonds Asia & Middle East, Skandinaviska Enskilda Banken AB (SEB)
- Dr. Yusuke Kuwayama, Fellow, Resources for the Future

Appendix 3: Hazard Scenarios

Five scenarios have been selected for each country modelled within the Tool. The scenarios are a mixture of two-year drought events and five-year drought events. The drought patterns were found by looking at historical drought events over the past 114-year period by studying the UEA CRU time-series precipitation data. For the drought events with a return period equal to 200 years, we have studied previous historical events and increased the intensity to match what we would expect to see for a longer return period event.

To understand the images, each grid-square has a value on an SPI-x (where x is equal to either 12 or 36) index, which compares the volume of rainfall experienced over the preceding x months, relative to the mean rainfall for that grid square, as measure across the historical catalogue. It is expressed in terms of standard deviation – so an SPI-12 value of -2 means there are 2 standard deviations less rainfall than usually experienced at that grid cell over the previous 12 months. The two-year droughts use SPI-12 and the five-year droughts use SPI-36.

The national index is found by taking only the grid cells with an index of less than minus 1.5 to identify cells experiencing a drought. This value is then multiplied by the area of their grid cell and summed nationally. This methodology will allow both locally-intense events and wide-reaching, though less severe, events to be recognized as severe drought events.

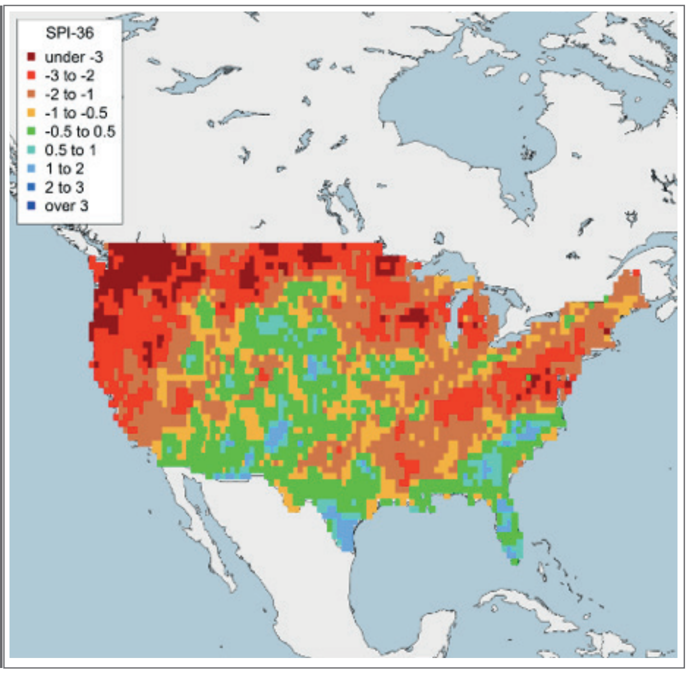
Each of the images shown in this section display the spatial footprint of the SPI measurements recorded at the most intense measurement of national level SPI (either SPI-12 or SPI-36 depending on the scenario length) within the entirety of the drought scenario. It should be noted that while these images show the peak drought, the modelling within the Tool considers the full time-series evolution of each drought event. Dark red colours represent areas with highly intense drought conditions, while blue colours show areas receiving more precipitation than usual.

Included here is also a reference to the historical drought that inspired this scenario. Most scenarios are not direct copies of these historical events, but while the intensity has been adjusted to achieve the desired severity targets, the geographic spread and duration have been used to influence the scenario characteristics.

US SCENARIOS

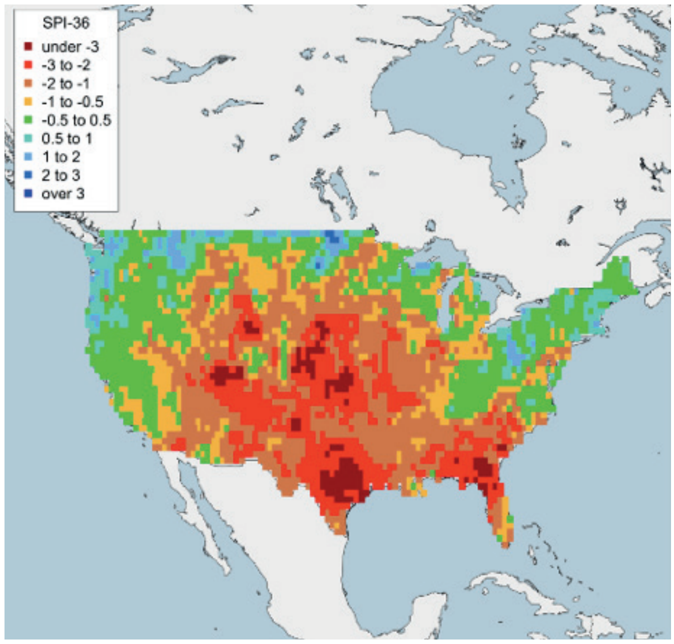
US SCENARIO 1

Scenario return period:	200 years
Scenario duration:	5 years
National SPI-36 Index:	-7.065 × 106 km2
Related historical date	August 1931



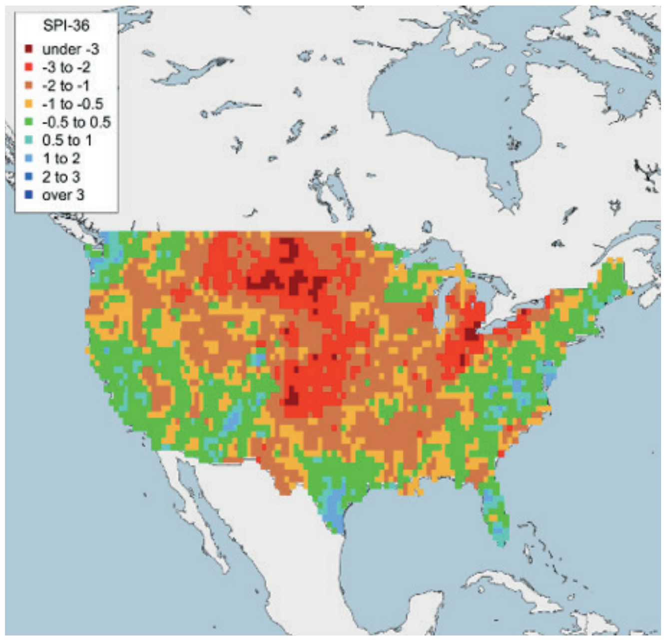
US SCENARIO 2

Scenario return period:	100 years
Scenario duration:	5 years
National SPI-36 Index:	-5.862 × 106 km2
Related historical date	September 1956



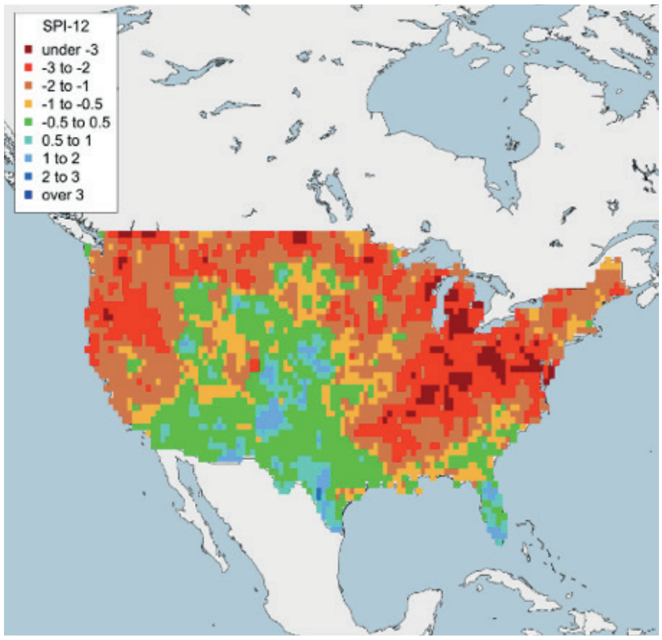
US SCENARIO 3

Scenario return period:	50 years
Scenario duration:	5 years
National SPI-36 Index:	-4.672 × 106 km2
Related historical date	August 1936



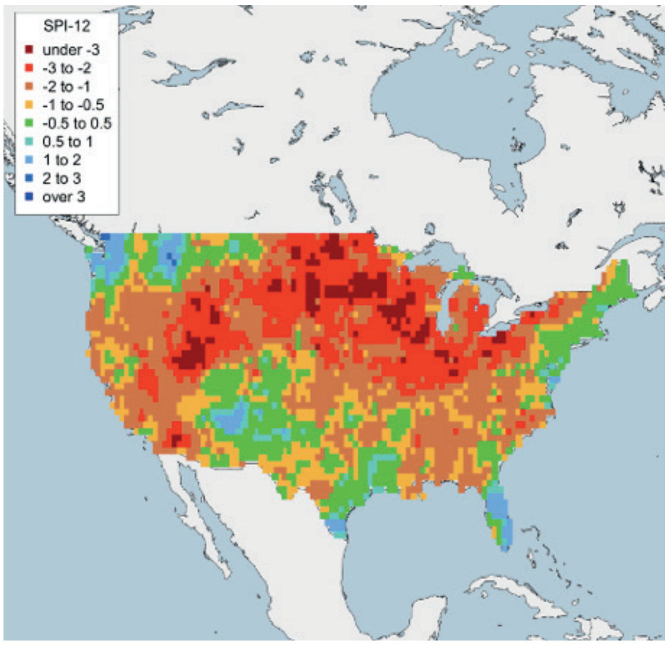
US SCENARIO 4

Scenario return period:	200 years
Scenario duration:	2 years
National SPI-12 Index:	-7.064 × 106 km2
Related historical date	May 1931



US SCENARIO 5

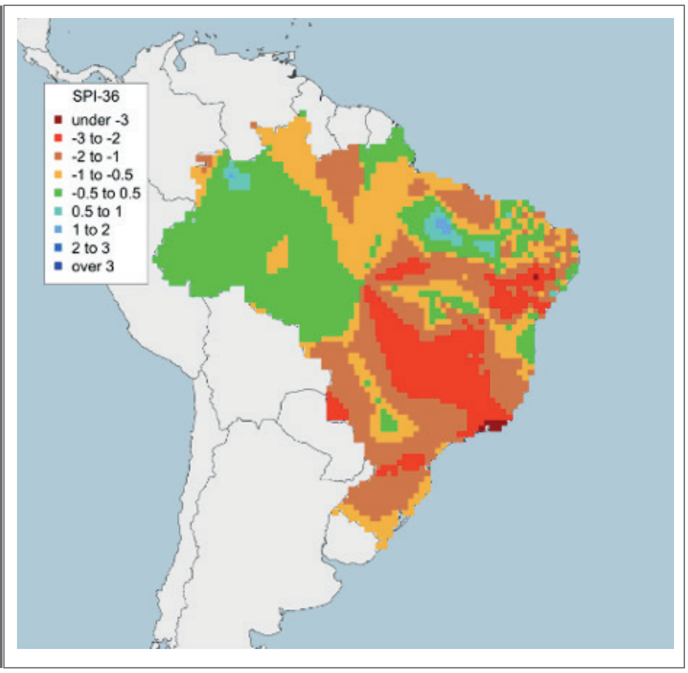
Scenario return period:	100 years
Scenario duration:	2 years
National SPI-12 Index:	-6.198 × 106 km2
Related historical date	May 1934



BRAZIL SCENARIOS

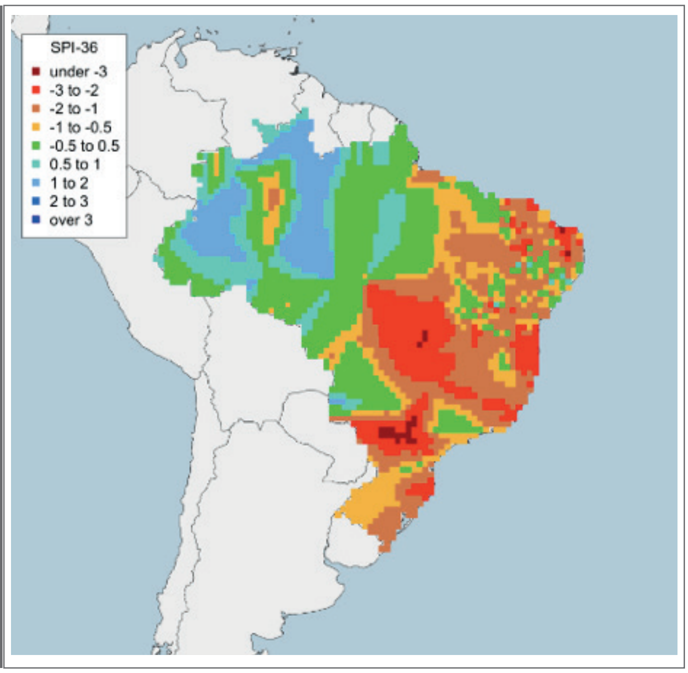
BRAZIL SCENARIO 1

Scenario return period: 200 years
Scenario duration: 5 years
National SPI-36 Index: -4.628 × 106 km2
Related historical date November 1934



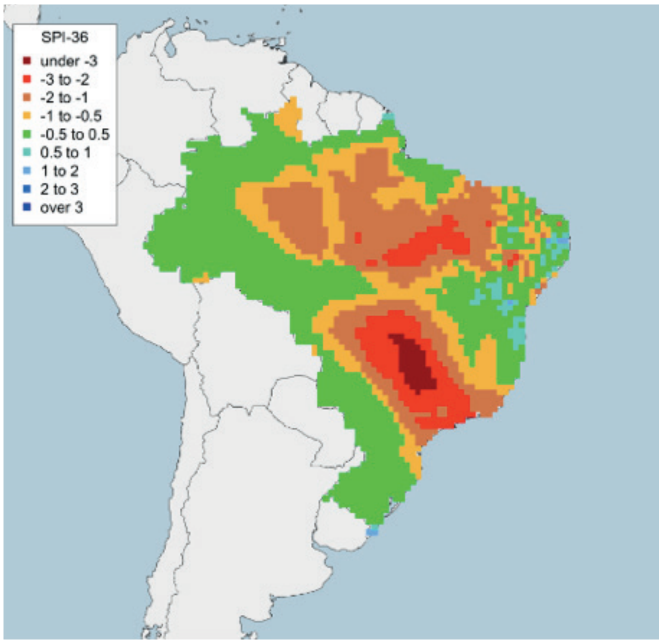
BRAZIL SCENARIO 2

Scenario return period: 100 years
Scenario duration: 5 years
National SPI-36 Index: -3.815 × 106 km2
Related historical date March 1954



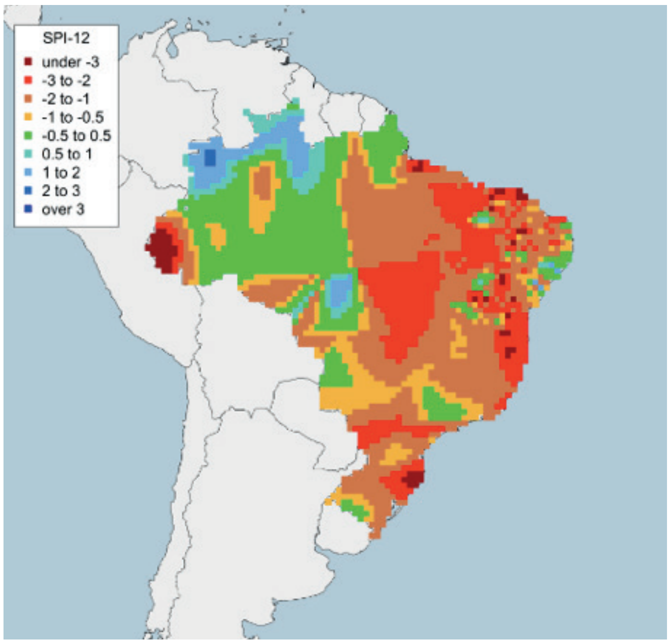
BRAZIL SCENARIO 3

Scenario return period:	50 years
Scenario duration:	5 years
National SPI-36 Index:	-2.784 × 106 km2
Related historical date	February 1916



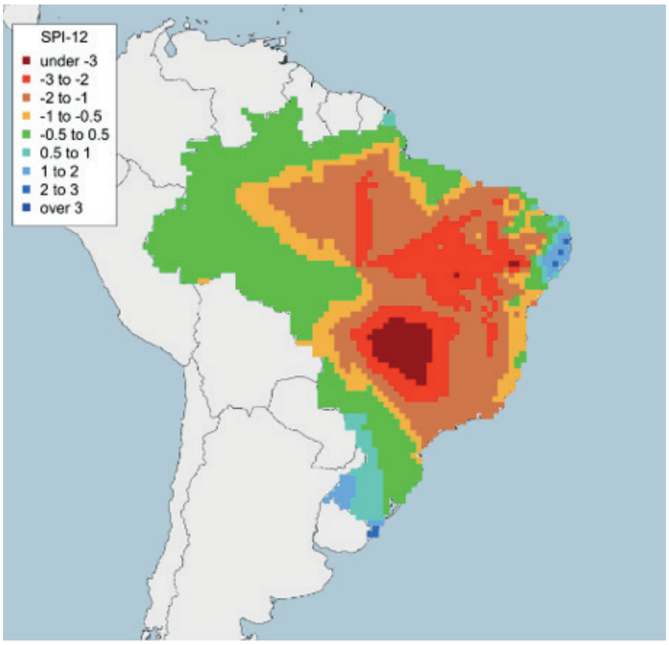
BRAZIL SCENARIO 4

Scenario return period:	200 years
Scenario duration:	2 years
National SPI-12 Index:	-6.752 × 106 km2
Related historical date	January 1952



BRAZIL SCENARIO 5

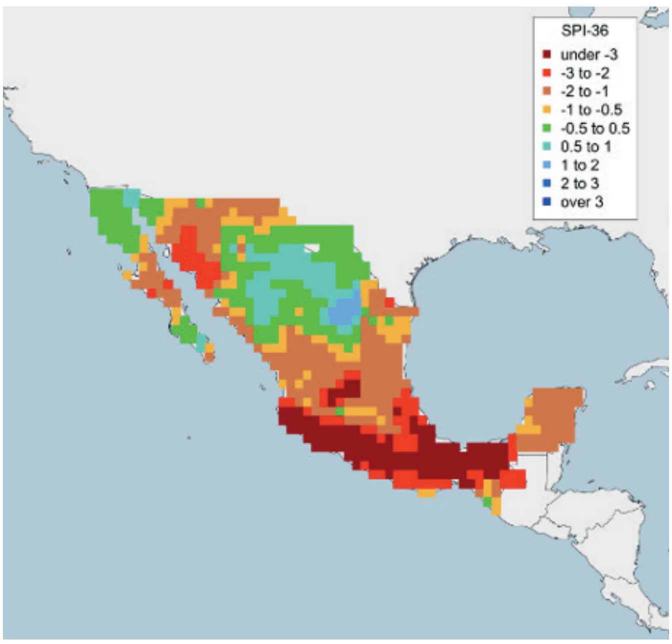
Scenario return period:	100 years
Scenario duration:	2 years
National SPI-36 Index:	-5.405 × 106 km2
Related historical date	February 1915



MEXICO SCENARIOS

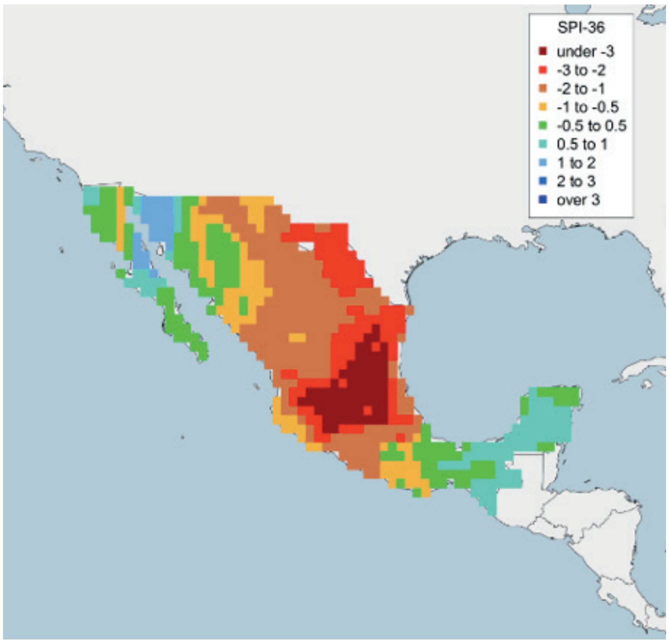
MEXICO SCENARIO 1

Scenario return period:	200 years
Scenario duration:	5 years
National SPI-36 Index:	-2.231 × 106 km2
Related historical date	October 1940



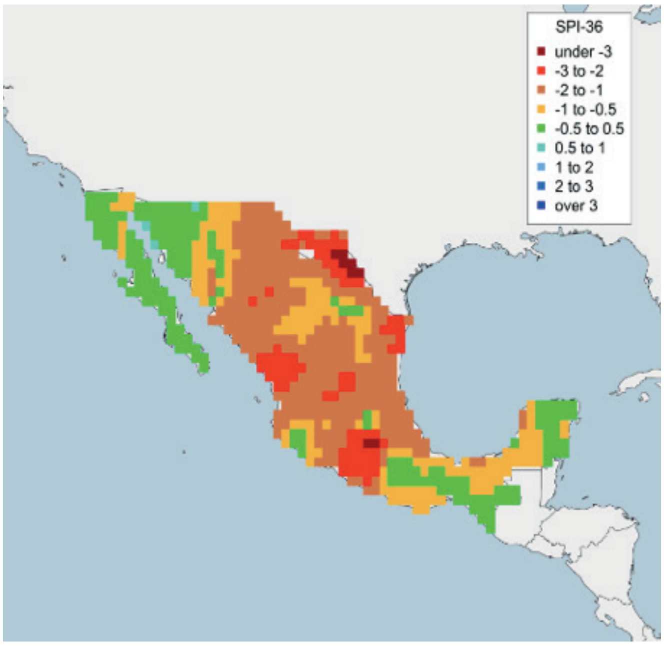
MEXICO SCENARIO 2

Scenario return period:	100 years
Scenario duration:	5 years
National SPI-36 Index:	-1.670 × 106 km2
Related historical date	October 1918



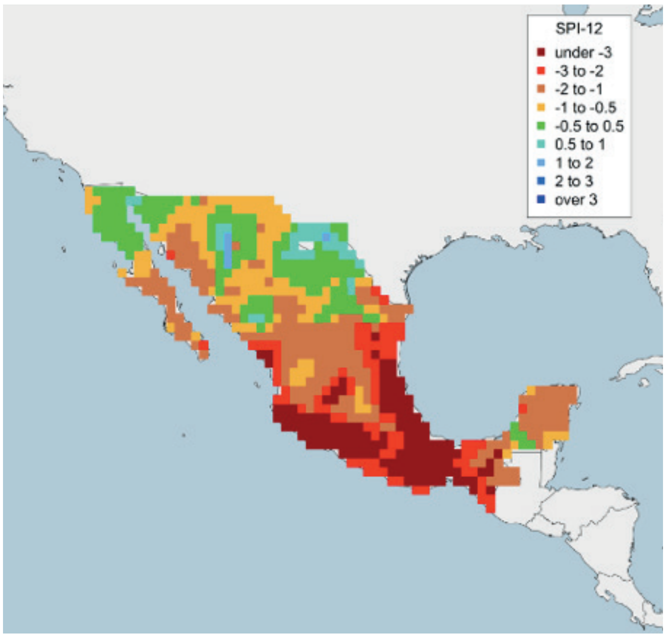
MEXICO SCENARIO 3

Scenario return period:	50 years
Scenario duration:	5 years
National SPI-36 Index:	-1.241 × 106 km2
Related historical date	September 1911



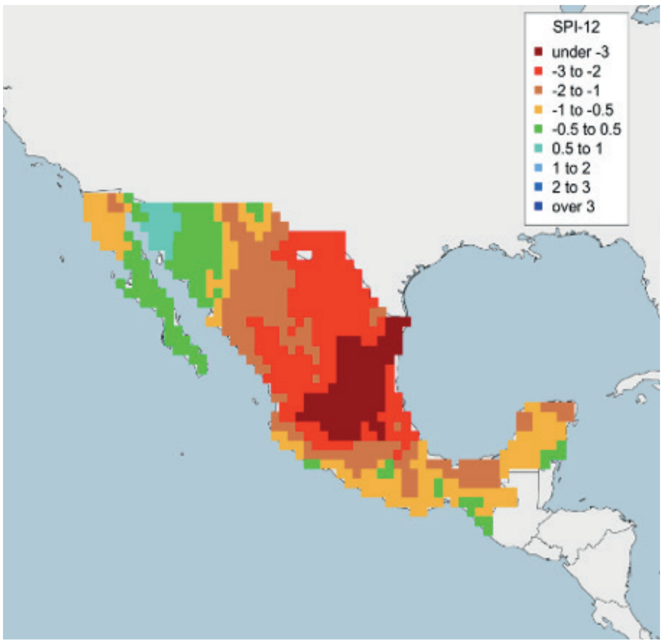
MEXICO SCENARIO 4

Scenario return period:	200 years
Scenario duration:	2 years
National SPI-12 Index:	-2.508 × 106 km2
Related historical date	October 1940



MEXICO SCENARIO 5

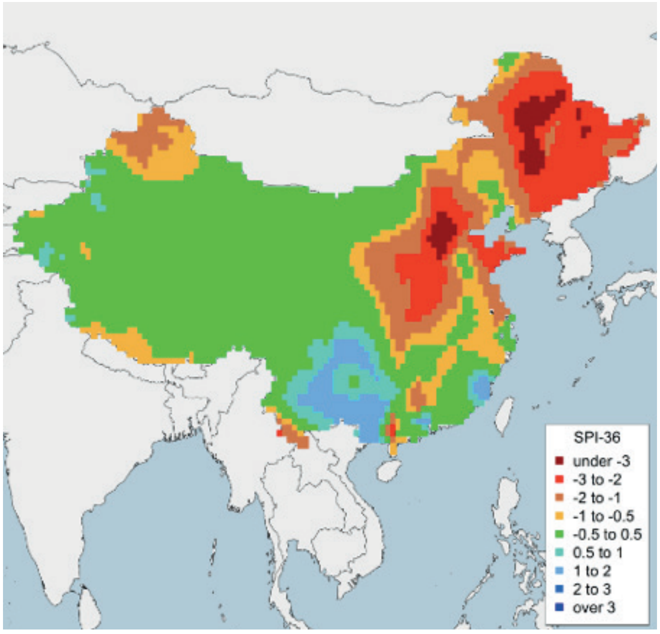
Scenario return period:	100 years
Scenario duration:	2 years
National SPI-12 Index:	-2.157 × 106 km2
Related historical date	February 1918



CHINA SCENARIOS

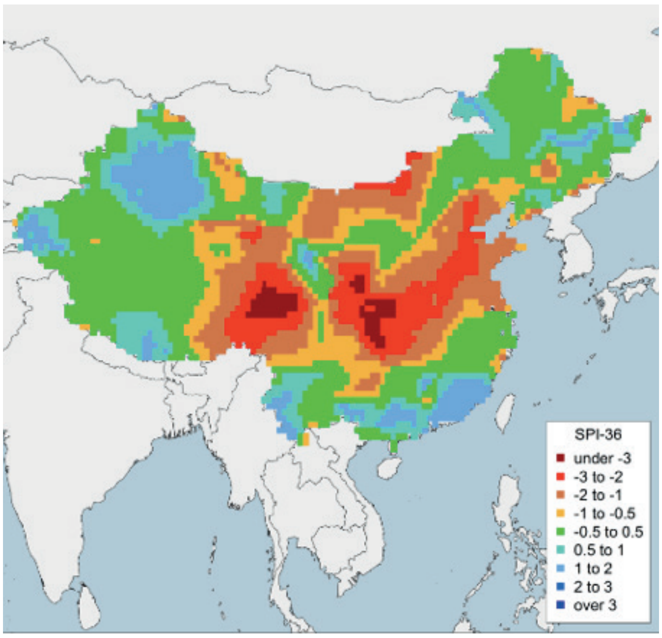
CHINA SCENARIO 1

Scenario return period:	200 years
Scenario duration:	5 years
National SPI-36 Index:	-3.900 × 106 km2
Related historical date	June 1922



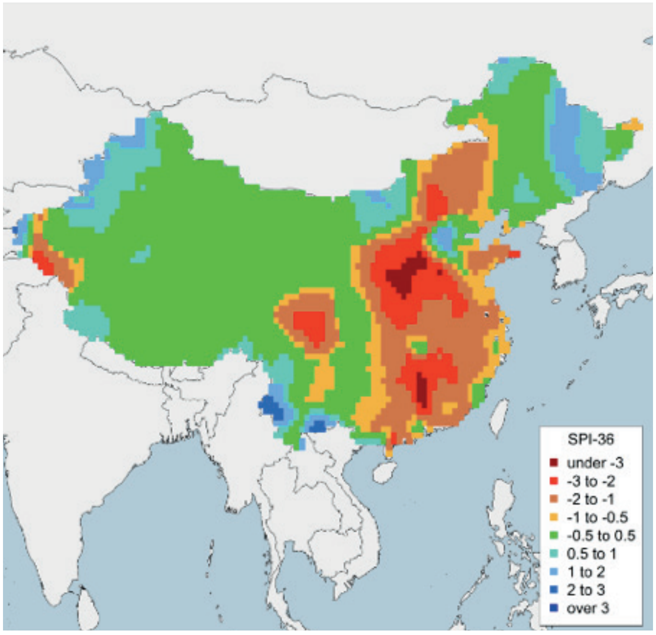
CHINA SCENARIO 2

Scenario return period:	100 years
Scenario duration:	5 years
National SPI-36 Index:	-3.477 × 106 km2
Related historical date	February 1943



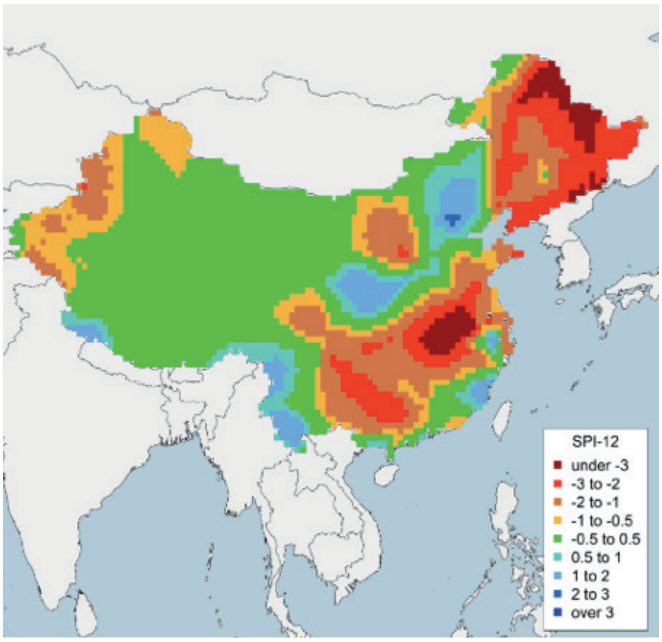
CHINA SCENARIO 3

Scenario return period:	50 years
Scenario duration:	5 years
National SPI-36 Index:	-3.054 × 106 km2
Related historical date	July 1930



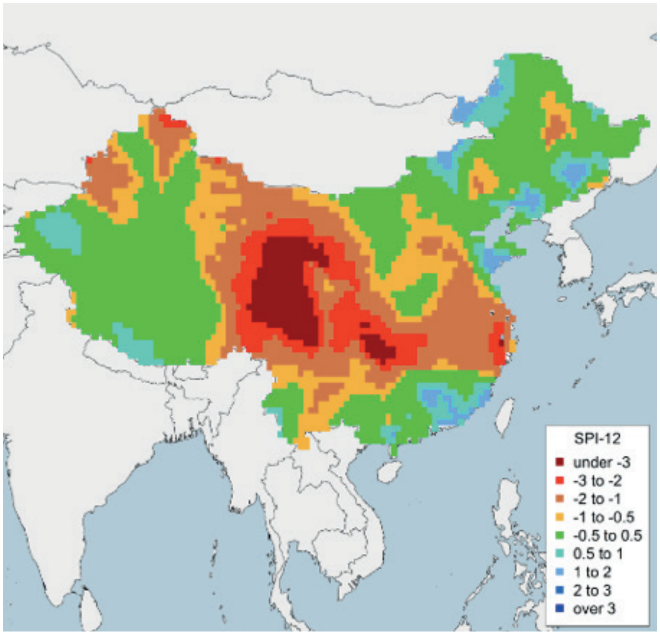
CHINA SCENARIO 4

Scenario return period:	200 years
Scenario duration:	2 years
National SPI-12 Index:	-4.686 × 106 km2
Related historical date	July 1925



CHINA SCENARIO 5

Scenario return period:	100 years
Scenario duration:	2 years
National SPI-12 Index:	-4.227 × 106 km2
Related historical date	July 1940



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