Methodology Note on the Global RApid post-disaster Damage Estimation (GRADE) approach

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Social, Urban, Rural & Resilience

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Cover: THE PHILIPPINES. November 2013, Typhoon Haiyan. Photo credit: © Dan Kitwood/Getty Images

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Notes: Fiscal year (FY) runs from July 1 to June 30; the financial contributions and expenditures reported are reflected up to June 30, 2017; all dollar amounts are in US dollars ($) unless otherwise indicated.

Design: Miki Fernández/ULTRAdesigns, Inc.

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Acknowledgments

This report was produced by a team led by Rashmin Gunasekera (Disaster Risk Management, World Bank) and Oscar Ishizawa (Senior Disaster Risk Management, World Bank) and comprising James Daniell (Consultant), Antonios Pomonis (Consultant), Rodrigo Andres Donoso Arias (Consultant), and Harriette Stone (Consultant).

The team is grateful to peer reviewers Krishna Vatsa (Regional Advisor, United Nations Development Programme), Stephane Hallegatte (Lead Economist, World Bank), and Josef Lloyd Leitmann (Lead Disaster Risk Management Specialist, Global Facility for Disaster Reduction and Recovery [GFDRR]). Their advice, comments, and feedback significantly improved this technical report.

The team is also thankful for the support and feedback of Moses Mung'oni (Disaster Risk Management Specialist, GFDRR), Niels Holm-Nielson (Lead Disaster Risk Management Specialist, World Bank), Mare Lo (Senior Disaster Risk Management Specialist, GFDRR), Keiko Saito (Disaster Risk Management Specialist, World Bank), Charlotte Lea Yaiche (Disaster Risk Management Analyst, GFDRR), Mary Boyer (Disaster Risk Management, World Bank), Xijie Lu (Consultant), and Matthew Foote (Argo-Global).

The team gratefully acknowledges funding support from the Africa Caribbean Pacific (ACP)-European Union (EU) Natural Disaster Risk Reduction (NDRR) program via GFDRR.

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Abbreviations and Acronyms

ACP	Africa Caribbean Pacific
AIR	AIR Worldwide
CDRP	Country Disaster Risk Profile
CEDIM	Center for Disaster Management and Risk Reduction Technology
CMU	Country Management Unit
D-RAS	Disaster-Resilience Analytics & Solutions
DALA	Damage and Loss Assessment
DRM	Disaster Risk Management
EEFIT	Earthquake Engineering Field Investigation Team
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GADM	Global Administrative Areas
GDACS	Global Disaster Alert and Coordination System
GDP	Gross Domestic Product
GFCF	Gross Fixed Capital Formation
GFDRR	Global Facility for Disaster Reduction and Recovery
GHSL	Global Human Settlement Layer
GIS	Geographic Information System
GRADE	Global RApid post-disaster Damage Estimation
GSURR	Global Practice for Social, Urban and Rural Development, and Resilience
HDI	Human Development Index
HRNA	Human Recovery Needs Assessment
IMF	International Monetary Fund
JRC	Joint Research Centre
KSB	Knowledge Silo Breaker
NDRR	Natural Disaster Risk Reduction
PAGER	Prompt Assessment of Global Earthquakes for Response
PDC	Pacific Data Center
PDNA	Post-Disaster Needs Assessment
PGA	Peak Ground Acceleration
RMS	Risk Management Solutions
SALB	Second Administrative Level Boundaries
TC	Tropical Cyclone
TTL	Task Team Leader
UAV	Unmanned Aerial Vehicle
UCL	University College London
UNDG	United Nations Development Group
USGS	U.S. Geological Survey

YOGYAKARTA, INDONESIA. Community mapping. Photo credit: World Bank

Executive Summary

1

This Methodology Note presents the Global RApid post-disaster Damage Estimation (GRADE) approach developed at the World Bank and conducted by the Global Practice for Social, Urban and Rural Development, and Resilience (GSURR) Disaster-Resilience Analytics & Solutions (D-RAS) Knowledge Silo Breaker (KSB). The Methodology Note explains the rationale behind GRADE's development that aims to address specific damage information needs in the first few weeks after a major disaster and how it complements the more comprehensive post-disaster needs assessment (PDNA) process.

In the aftermath of a disaster, governments are confronted with the challenge of determining the overall economic impact in order to gauge the magnitude of the event, identify priority sectors for reconstruction, understand differential geographic impacts, and comprehend relative public versus private damages. Time is clearly of the essence in assessment and response. Existing approaches and tools used for post-disaster damage assessment vary significantly in implementation time, the level of detail they deliver, and their level of accuracy.

Rapid post-disaster damage assessment approaches and tools can, within a short period of time, quantify the damage to physical assets and associated replacement costs. These approaches and tools aim to increase the efficiency and effectiveness of the post-disaster recovery effort and better inform reconstruction activities. To quantify damage to a higher level of detail, disaster risk modeling techniques, in combination with historical damage data and census and socioeconomic survey data, as well as satellite imagery, drone footage, and other media, are also being used.

These methods have been incorporated into the GRADE approach, which was developed by the World Bank[1] and supported by GFDRR. The GRADE approach can provide an initial rapid (within two weeks) estimation[2] of the physical post-disaster damage incurred by key sectors. The approach prioritizes the housing and infrastructure sectors, followed by other sectors, like agricultural production, as desired. The GRADE approach and outputs are intended to create an independent, credible sectoral quantification of the spatial extent and severity of a disaster's physical impact.

The GRADE approach has been successfully used after more than four disasters, including Madagascar (after Cyclone Enawo in March 2017), Haiti (after Hurricane Matthew in October 2016), Ecuador (after the earthquake on April 16, 2016), and Nepal (after the earthquake on April 25, 2015). GRADE was used to assess direct damages to property; direct damage estimations by economic sector; potential impacts on gross domestic product (GDP) and the economy; and, in the case of earthquakes, estimations of human casualties. Indirect losses due to reduced productivity, business interruption, and output loss are not at present addressed by GRADE. The approach complements other post-disaster damage and loss assessment approaches and processes, such as the PDNA adopted by the United Nations, the EU, and the World Bank in 2008.

This Methodology Note was prepared to inform governments and other key stakeholders who are involved in post-disaster damage assessment, relief, and recovery phases about the utility and outputs of

[1] GRADE is performed by the World Bank GSURR D-RAS KSB by a team of technical experts who carry out advisory and analytical services, including developing custom-built tools and solutions related to disaster risk management (DRM). The production of this report was supported by GFDRR.

[2] The GRADE method was used following four disasters that occurred between April 2015 and March 2017, with up to 90 percent of "like for like" field estimations accuracy (when compared with subsequent and more-detailed post-disaster analyses, such as the PDNA).

the GRADE approach. To prioritize and plan for overall reconstruction and specific interventions, stakeholders require approaches that provide a more in-depth assessment, with an engineering focus, than GRADE provides. However, before in-depth assessments are undertaken, it is critical to build the required sectoral baseline information for the design of rehabilitation and reconstruction plans. The GRADE approach provides this information, as it is based on an assessment of vulnerability and damage distribution of the affected infrastructure and assets.

The results of the GRADE approach could support the design of a short-term plan to re-establish affected services and to stabilize conditions of affected populations through temporary measures. GRADE can also provide information for investment plans and for intervention strategies for the recovery and reconstruction of damaged infrastructure. This includes not only the definition of physical interventions, but also the regulatory, financial, and institutional aspects that are required for implementation recovery efforts.

For example, after Cyclone Enawo in Madagascar (March 2017), the outputs from GRADE provided swift assessments that informed the preparation and implementation of disaster relief and emergency response strategies, improving the effectiveness of the response. Also, after Hurricane Matthew in Haiti (October 2016), the outputs helped develop the rapid PDNA, which, in turn, was used by the International Monetary Fund (IMF) to determine whether it should trigger its post-crisis mechanism for the country. (See Appendix A.3 for more details.)

This report presents the overall methodology approach in GRADE's four components—Hazard, Exposure, Vulnerability, and Loss Modeling—and discusses implications for World Bank staff, clients, and other stakeholders. The report closes with extended appendices that present the development team's experience using GRADE after four recent major disasters and a summary of other post-disaster damage assessment approaches.

Introduction

2

One of the immediate priorities after a disaster is to determine its direct impact, i.e., the costs associated with damage to property and infrastructure. Damage cost estimation enables governments to better strategize and mobilize resources for a resilient recovery. Post-disaster damage assessments are tackled around the world in many forms by various stakeholders, such as governments, private companies (mainly in the insurance/reinsurance industry), and international aid agencies. However, significant assessment gaps remain in terms of detail and timeliness. Traditional assessment approaches, particularly in data-scarce environments of the developing world, are often limited in geographic coverage and scope and/or are less accurate. More-detailed and accurate reports often require six to eight weeks to complete.

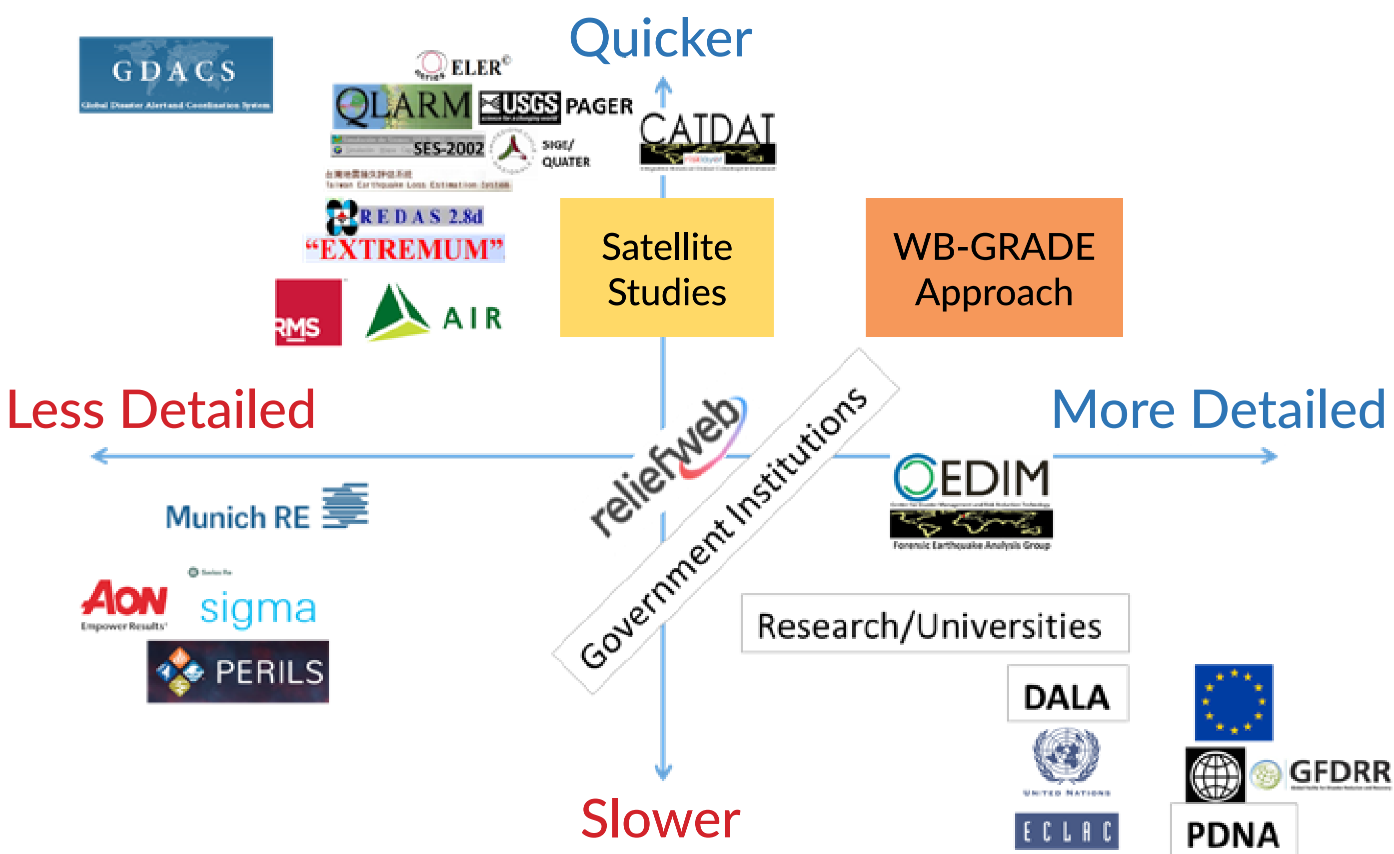
To address this gap, the World Bank developed a novel approach for rapid post-disaster damage assessment: GRADE. The GRADE approach introduces key risk modeling methodologies and processes into the early post-disaster response phase. This rapid direct damage estimation uses event footprint maps (i.e., scientifically sound spatial representations of the degree of hazard intensity in an affected area), modeling of exposed assets (e.g., the population, valuations of existing buildings and infrastructure), and their estimated vulnerability to the hazard to produce outputs that can aid relief agencies and governments during the crucial early period after a disaster. It complements other approaches of post-disaster needs assessments, such as the PDNA process, which have a significant focus on field-collected damage and loss data and on working with in-country partners to develop reliable sector-wide damage and loss assessments.

This capacity has been built on gradually evolving approaches during the past 10 years at the global level through the Prompt Assessment of Global Earthquakes for Response (PAGER), the Global Disaster Alert and Coordination System (GDACS), and the Center for Disaster Management and Risk Reduction Technology (CEDIM) at the Karlsruhe Institute of Technology, among others. Along with continuous developments, this technology is proving to be quite useful in reducing post-disaster uncertainties and providing higher confidence soon after severe disasters, especially disasters affecting very wide geographic areas or occurring in remote and harder-to-access parts of the world.

Figure 1 summarizes the key global stakeholders involved in producing post-disaster response information and their tools, quadri-sectored to show their relative level of detail and speed of output delivery. Rapid damage estimation model outputs by catastrophe modeling companies, such as AIR Worldwide (AIR) and Risk Management Solutions (RMS) are generally quick, but contain little in the way of underlying assumptions or sector-based details. These models usually cover disasters where there are significant insured exposures, with the developing countries not being a priority. In the insurance sector, insurance/reinsurance companies generally need to wait for loss adjusters and insurance penetration information to quantify their estimates, and they generally publish only aggregate estimates for certain sectors (lines of business).

In the public sector, the damage and loss assessment (DALA) framework, developed by the United Nation's Economic Commission for Latin America and the Caribbean, has been successfully implemented in many regional disasters, providing estimates of damage and loss by economic sector for the public and private sectors. Such detailed damage and loss analysis was nearly non-existent before the adoption of the DALA framework. In 2008, DALA was incorporated into the PDNA framework adopted by the United Nations Development Programme, the EU, and the World Bank. The PDNA framework is utilized globally and provides some of the best damage and loss assessments to date, sometimes surpassing reporting from disasters in the industrialized world, where information is often incomplete, fragmented, and restricted. The PDNA process is carried out by government institutions and, since 2008, has increasingly covered more events and countries. The PDNA reports cover all economic sectors, including estimation of private and public sector damages and losses, and are based on a transparent and detailed methodology (EU et al., 2013). However, the final estimates generally take more than a month to be released, due largely to the difficulty of synthesizing diverse data, reliance on completion of government damage surveys, administrative difficulties, and lack of access and sector-based loss determination. This temporal lag is critical; the faster a determination—or even an estimate—of costs related to property and infrastructure damage is made, the faster the needs are understood and resources can be acquired.

Figure 1. Global stakeholders providing various types of information or analytical services in the aftermath of natural disasters, categorized by level of detail and speed of delivery



What Is the GRADE Approach?

3

3.1 Description of the Approach

The GRADE approach is a remote, desk-based rapid damage assessment method deployed on request soon after a disaster, such as an earthquake or a tropical cyclone. The approach adopts evolving and innovative natural hazard risk modeling technology in order to rapidly fulfill post-event damage assessment requirements. It is an assessment of damages to housing and critical infrastructure sectors, derived by combining hazard parameters, exposure databases, extent of structural vulnerability, and relevant costs of repair and replacement. These components are overlaid on a geographic information system (GIS) platform, expert knowledge is applied, and results are produced within two weeks of major disasters. The method is applicable to modeling any type of natural hazard[3] for which reliable hazard, vulnerability, and risk model platforms exist, such as earthquake ground motion, earthquake-induced tsunamis, hurricanes and tropical cyclones, and other hazards, such as flooding and volcanic eruptions.

The assessment uses population layers (e.g., LandScan, Global Human Settlement Layer [GHSL], WorldPop), remotely sensed data for damage and consequences (e.g., UNOSAT, EU-Copernicus), social media updates, local situation reports, and other relief-related information flows, as well as pre-existing scientific, engineering, and socioeconomic datasets and loss-damage statistics, to identify the distribution of damage and to quantify sectoral damages and human casualties (particularly in the case of earthquakes in densely inhabited areas). The approach has been successfully deployed in four post-disaster analyses worldwide in the last three years. GRADE can also be adapted to different client priorities[4] and dataset availability, without compromising its swift delivery and accuracy. Inherent independence and scientific objectivity is also assured with the GRADE method because the analysis is based on open sources of information for each of the three main components (hazard, exposure, and vulnerability), is carried out by experienced researchers and practitioners, and is accompanied by a transparent summary report.

The innovative aspects of the GRADE approach incorporate information from a vast variety of datasets, continually verifying results and employing pioneering methods to achieve improved accuracy. The approach is time and resource intensive as it involves calculating:

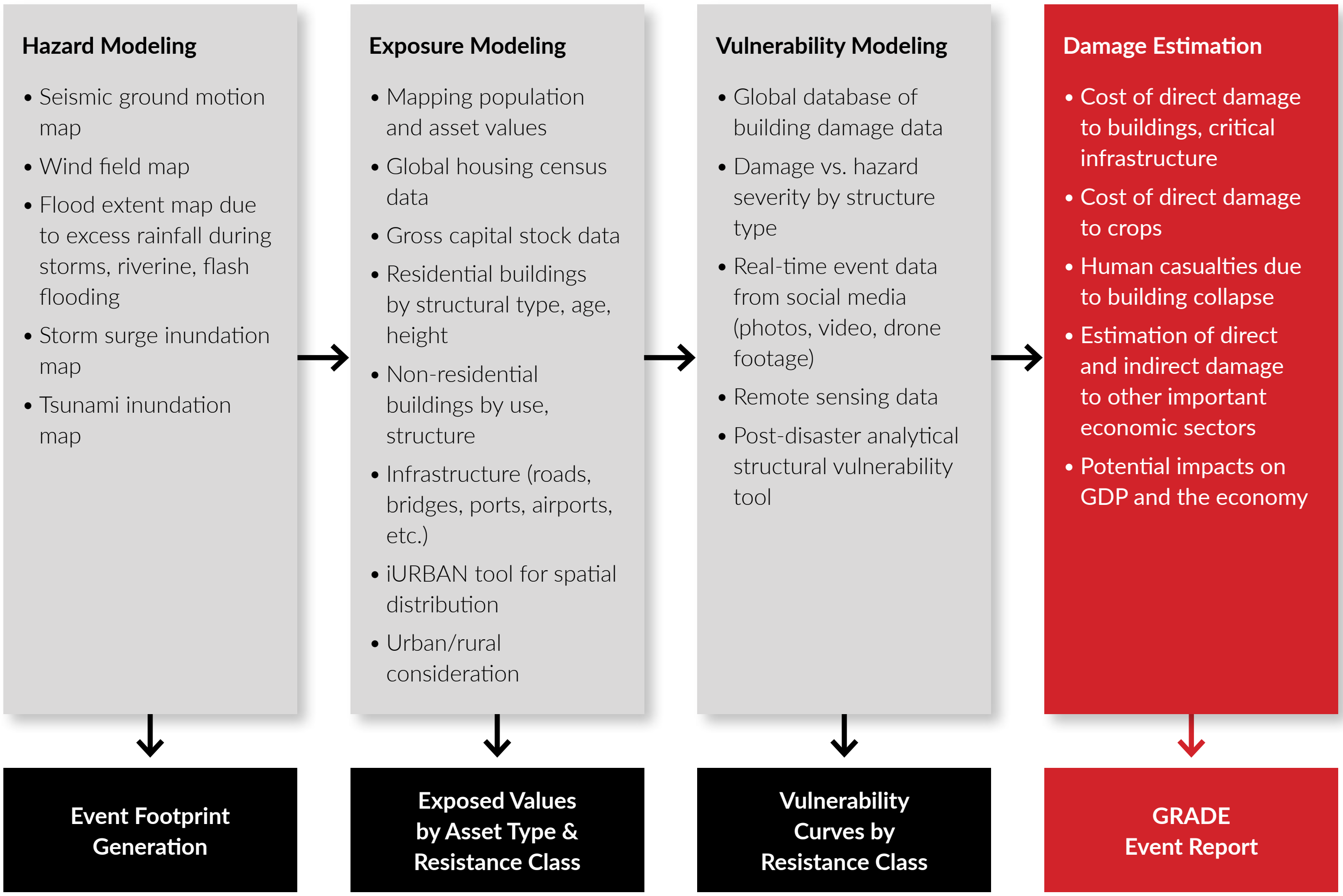
- Direct damages to property
- Direct damage estimations by economic sector
- Potential impacts on GDP and the economy
- Estimations of human casualties (for earthquakes)

Fundamentally, the product uses quantitative risk assessment methods adapted to the rapid post-event damage estimation needs, as highlighted in Figure 2.

[3] It must be kept in mind that some events can be long in duration (e.g., droughts, riverine flooding, and volcanic eruptions) and that the approach for these types of events must be conducted in relation to the optimal time for the overall damage assessment.

[4] For example, in the case of the 2015 earthquake in Nepal, emphasis was placed on rapid estimation of damage and human casualties due to building collapse and landslides; after the 2016 earthquake in Ecuador, emphasis was on assessing the vulnerability of widespread non-ductile reinforced concrete structures to more reliably estimate the damage.

Figure 2. The GRADE approach: Key components (top boxes) and outputs (bottom boxes)



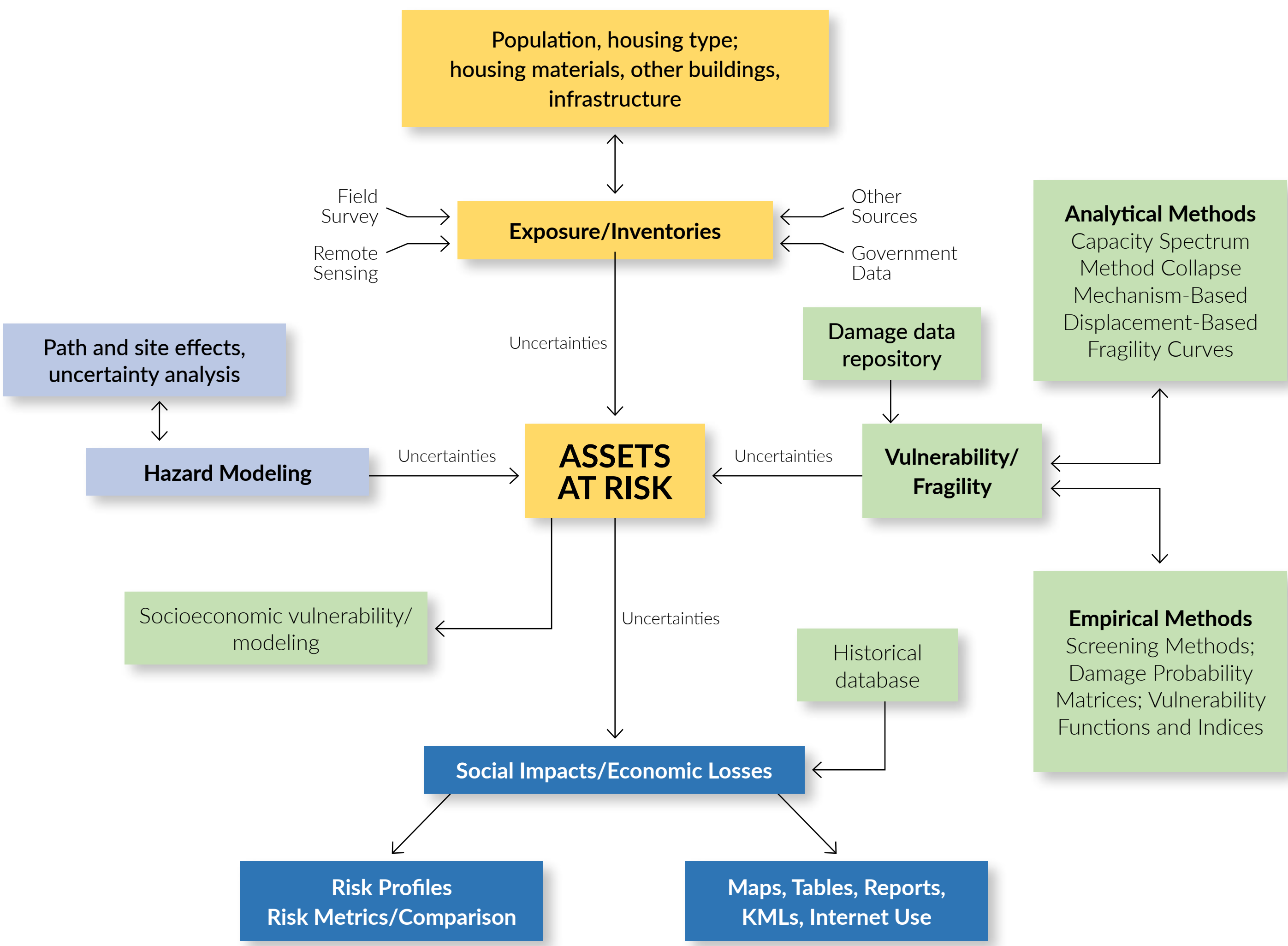
Disaster damage estimation generally uses four key components: hazard, exposure, vulnerability, and impact assessment. To adapt these components for rapid post-disaster assessments, the GRADE approach utilizes:

- Hazard modeling, including location and intensity of the disaster across the affected territories, also taking into account related datasets that can act as hazard modifiers, such as terrain, land use, soil type, and soil moisture
- An exposure value assessment, including population, housing by structural characteristics and related cost of construction, non-residential buildings, key infrastructure, gross capital stock, agricultural production, and regional GDP
- A vulnerability assessment of the various assets to the hazards, including use of early information from the relief communities for calibration-validation (e.g., remotely sensed damage, drone and other video footage, building safety assessment reports)
- A summary of impact, with priority given to the assessment of the likely costs associated with damage to property, critical infrastructure, and key production sectors, as well as social impacts, including fatalities (in the case of earthquakes), displaced people, and references to local reports of the socioeconomic impacts
- A summary of likely losses and consequences by economic sector calibrated against such data from previous comparable historical events

Figure 3 highlights the key steps in the GRADE approach, in its earthquake context, including all the various components and their interactions in the form of a flowchart. The hazard components are on the left, the exposure components are in the top middle, and the vulnerability components are on the right, with the outputs in the bottom middle.

The general concept is that, to quantify the damage potential arising from natural hazards, at first a very sound understanding of the fundamental science related to the particular hazard (e.g., seismology, meteorology) is needed to model how the simulated event propagates across a region (i.e., to generate a reliable event intensity footprint). A robust underlying model of exposure containing the latest assessment of population and building distribution by type of construction is also required. This exposure model should be developed so that it lends itself to the analysis of the vulnerability of the exposed assets to the various natural hazards. For example, for damage estimation to buildings and key infrastructure, detailed knowledge is needed on the types of buildings, infrastructure, assets, and sectoral stocks and flows that exist anywhere in the world and how these would be expected to perform when affected by a given hazard intensity. For effects on the population, such as human casualty estimations after earthquakes, the product employs collapse probability of building classes and other broad statistics of exposed population and resulting casualties in past earthquakes in the region, by time of day and day of week. For a more detailed consideration on exposure modeling, please refer to Gunasekera et al. (2015).

Figure 3. Flowchart of the GRADE earthquake damage estimation system



Source: Daniell (2014).

3.2 What Is the Added Value of the GRADE Approach and Why Is There Demand for It?

In the past, soon after a significant natural disaster, governments and institutions (such as the World Bank) needed—but had no access to—quantitatively measured information that would provide a reliable estimation of economic damages. This information is always urgently needed because it is used in stakeholders' strategies and decisions to form the initial response in an affected country. For the countries themselves, rapid loss estimation also assists in initial requests for funding from donors. However, until now, the process of *rapidly* obtaining these much-needed early economic estimates of damages has been ad hoc, macroeconomic based, time consuming, and costly, and sometimes utilized private companies' proprietary models, datasets, and assumptions.

The GRADE approach addresses this urgent need for sound and swift economic estimates, as it can use different and existent datasets and mechanisms to both rapidly—sooner than ever before—and reliably quantify the economic damages. The value of the GRADE's ability to offer quantitative, reliable estimates of economic damages cannot be overstated, facilitating far quicker response times and thus enabling the channeling of resources where they are most urgently needed.

The GRADE reports for events are custom-built and incorporate the needs of the affected countries. The reports and underlying analysis make use of and summarize key information on the hazards (e.g., wind, accumulated rain, flooding) and existing exposures, and examine the vulnerability of the various assets to the hazards. All this work culminates in the damage assessment report, which is intended to disseminate information on the disaster's impacts, direct economic consequences, and any uncertainties related to the assessment. This allows users to gain an appreciation of the results and how they were calculated, but also to take appropriate action and mobilize resources to the sector or geographic area where they are needed most.

Given the short time frame for delivery of the products, targeted, dedicated searches of disaster location data, including geocoded and non-geocoded government sources, are assessed. State-of-the-art, multi-language disaster information—considering the data archives of more than 1,000 globally linked disaster impact sources on the websites of governments, provinces, and other administrative levels—is also assessed.

The GRADE approach offers flexibility to respond to stakeholder needs through its composition of various sub-products to inform the final assessment. The method can be adapted according to the disaster, the country context, and the available data. However, in general, key steps of the GRADE approach are listed below, along with their associated added value. These steps also represent stand-alone products, adding value to the final assessment or further government studies.

1. A scientifically sound event intensity footprint map is created using key hazard parameter information related to the disaster and assessments by experts in seismology, hydrometeorology, volcanology, etc. as applicable. *Added value: The GRADE approach evaluates the scientific rigor of the event intensity footprint and applies the result to risk assessment.*

2. Datasets that include the latest socioeconomic, demographic, and geospatial data are examined to assess exposure (residential, non-residential, and critical infrastructure) in the affected region. Other global datasets, such as night-light intensity, as well as any preexisting building footprint datasets, are used to estimate the spatial distribution of the residential and non-residential exposure. *Added value: This includes a review of the latest global population databases to assess their accuracy relative to the nearest census at the regional level. Labor statistics and other socioeconomic surveys are assessed to estimate the non-residential exposure by key use class, as these are not included in the census.*

3. The buildings exposure database groups residential buildings into classes differentiated by type of construction. A country and/or region-level exposure database includes differentiation between urban and rural areas and quantifies the exposed values in terms of vulnerability to both seismic and meteorological hazards. These estimates are adjusted to the best estimates of the

gross capital stock in the affected region. *Added value: Such exposure datasets are valuable not only for the purposes of GRADE but also for studies on country or region-level risk assessment and financing.*

4. The GRADE approach links to up-to-date ground-based datasets. *Added value: Post-disaster damage photos, on-the-ground videos, drone footage, and remote sensing grading assessments are compared to the abovementioned datasets for validation and analyzed for conclusions on the severity of the damage and the vulnerability of the buildings.*

5. *Added value: The structural vulnerability of groups of physical assets or critical infrastructure is evaluated using cutting-edge engineering knowledge and research.*

6. *Added value: GRADE researchers also interpret and evaluate rapid disaster loss estimates published by other global, regional, and local agencies.*

Appendix A of this report highlights four case studies that exhibit the capabilities of the GRADE approach and details of results achieved. These case studies are the April 2015 earthquake in Nepal (Appendix A.1), the April 2016 earthquake in Ecuador (Appendix A.2), the impact of Hurricane Matthew on Haiti in October 2016 (Appendix A.3), and the impact of Cyclone Enawo on Madagascar in March 2017 (Appendix A.4). The appendix also highlights feedback from World Bank Task Team Leaders (TTLs) who used the product. It also reflects client needs and response. Their feedback offers stakeholder insight and value-added perspective and reinforces the need for approaches such as GRADE for deployment in post-disaster situations.

The appendix also highlights the flexibility needed (to meet different client priorities) and the different emphases of products such as GRADE using four different examples.

1. In the case of the April 25, 2015 earthquake in Nepal, emphasis was initially placed on estimation of human casualties due to building collapse and landslides, followed by economic damage assessment in the housing sector. Existing post-earthquake scenario studies and other stakeholders (e.g., PAGER, QLARM) suggested potential for great loss of life (e.g., in the first nine days after the event, PAGER estimated a 32 percent probability of 1,000–10,000 deaths and a 33 percent probability of 10,000–100,000 deaths). GRADE estimated 7,000–10,000 deaths by the fifth day. The death toll stood at 8,857 on August 8, 2015, according to Nepal's National Emergency Operations Center.

2. For the April 16, 2016 earthquake in Ecuador, emphasis was placed on assessing the vulnerability of widespread non-ductile reinforced concrete structures to more reliably estimate the damage. Within the first couple of days of the event, it was evident that reinforced concrete structures in the region had performed poorly across a very wide zone. This was due to poor adherence to earthquake design principles in the country's building code. However, it was not clear how widespread was the collapse or partial structural failure of concrete and other structural types in the region (e.g., various types of concrete block construction). It was thus crucial to assess the fragility of these structures and their relative contribution to the overall exposure. Various comparative approaches were employed, including study of the performance of buildings in the 1998 Bahia de Caraquez earthquake, inspection of hundreds of photos from digital media, use of satellite-based damage grading maps (which became available during the second week), and compilation of damage information from the twice-daily Situation Reports of the Ecuador government. Human casualty data were also employed in conjunction with building collapse casualty models and assessment of existing buildings.

3. In Haiti, immediately after Hurricane Matthew in October 2016, emphasis was put on more accurately assessing damage to buildings with the use of unmanned aerial vehicle (UAV) footage and other social media to adjust the theoretical wind vulnerability model to the conditions of the built-environment in southern Haiti. This technique showed the performance of engineered structures with flat reinforced concrete slabs was much better than the buildings with pitched roofs, making it possible to gauge relative damage in different

locations (e.g., Jeremie versus smaller settlements).

4. For Cyclone Enawo in March 2017 in Madagascar, emphasis was on estimation of damages to agricultural production due to wind and flooding, including effects on the valuable vanilla crop.

3.3 Complementing Other Post-Disaster Damage Assessments with the GRADE Approach

There are several post-disaster damage assessment approaches used by both the private and the public sectors. We have assessed their capabilities, delivery time frame, cost, type of outputs, data needs, resolution, and limitations (see Appendix B). Appendix B details the complementarity of these approaches and tools in comparison to the GRADE approach. In the private sector, the insurance/reinsurance industry and insured risk modeling companies publish rapid assessments of economic losses associated with damages, which are more descriptive than detailed by sector (e.g., Munich Re, RMS, AIR). There are also more highly detailed assessments conducted for European windstorms by institutions like PERILS AG[5] (see Appendix B), but these are generally published several months after an event, with successive updates following for up to a year after an event. (Complementarity with the PDNA and disaster recovery framework is discussed in Section 5.2.)

Another advantage of the GRADE approach is that it allows for the identification of limitations and gaps in data. The GRADE approach has evolved from the collective experience of world-class natural hazards risk engineers with decades of experience in post-disaster assessment, who have been responsible for the creation of some of the best disaster damage, risk, and socioeconomic databases to date, such as CATDAT (http://www.catdat.de), GEMECD (https://gemecd.org/), and CEQID (http://www.ceqid.org/CEQID/Home.aspx), and who continue to maintain and update their datasets and lead or participate in post-disaster field surveys, such as those carried out by the United Kingdom's Earthquake Engineering Field Investigation Team (EEFIT) (https://www.istructe.org/resources-centre/technical-topic-areas/eefit).

[5] PERILS AG is a company that provides post-disaster insurance market data directly collected from insurance companies in Europe. It offers a PERILS industry exposure and loss database on windstorms and ensuing perils.

Guidance on Datasets to Use and the GRADE Method in Brief

4

4.1 Introduction

This section provides some guidance for disaster response stakeholders interested in understanding the datasets required to conduct a GRADE assessment and the methodological steps involved. As highlighted in Section 3.1, the method incorporates hazard, exposure, and vulnerability components that collectively quantify the post-disaster impact.

4.2 The Hazard Component

To estimate a loss, the hazard component requires that the collected metrics be compatible with preexisting vulnerability functions of the elements at risk. As empirical data are required for the historical loss functions to check the loss estimation, metrics that have been collected from past disasters should be used. Local sources and hazard measurement station data are preferred (when available and accessible) over modeled estimates from global databases, but both should be assessed as part of the collection process.

Table 1. Examples of hazard data required for the GRADE approach

Disaster type	Hazard parameters	Number of major damaging events per year	Source (outside of research institutions)
Flood, storm surge, tsunami	Water depth (m), flow velocity (m/s), and energy	600+	Local flood departments, MODIS data, Joint Research Centre (JRC), Pacific Tsunami Warning Center
Earthquake	Intensity and shaking footprint; ground motion (Sa, Sv, Sd)	250–300	Local seismological agencies, U.S. Geological Survey (USGS), European-Mediterranean Seismological Centre, German Research Centre for Geosciences
Landslide	Debris volume, displacement	150	Local agency, satellite imagery
Volcano	Tephra quantity (kPa, thickness), pyroclastic flow or surge, pyroclastic falls, lahar flow, ground shaking	50	Volcanic Ash Advisory Centre, seismological agencies, volcanological agencies, Smithsonian
Wind, typhoon, tornado, hail	Wind speed (sustained or gust), wind pressure, tornado track, hail track and hail size (mm), reflectivity (dBz), kinetic energy, Saffir-Simpson scale	800+	Local meteorological departments, systems, weather stations, satellites
Extreme temperature, bushfire, drought	Temperature, wind speed, heat output, and energy	100 (where measured)	Fire agencies, satellites, meteorological agencies

A hazard footprint is then synthesized, modeled using the various hazard metrics and converted into a GIS environment. Where uncertainties exist and/or accurate station data are not available, multiple scenarios are produced and weighted using expert judgment for use as part of the analysis.

4.3 The Exposure Component

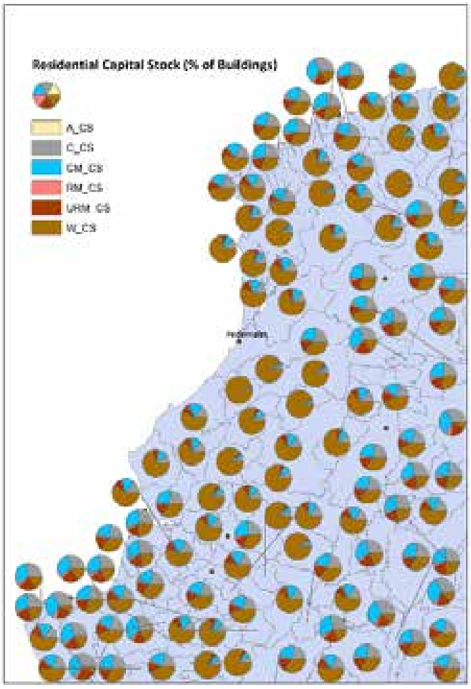
The exposure component requires information on the population (disaggregated), capital stock, and the flows (production through GDP) of the affected region. This is much like the PDNA method, but with an additional spatial component. Depending on the country affected, the baseline data are collected from the national statistical office (census, custom surveys for specific sectors, etc.). In many cases, these data are available on a provincial (administrative level 2) or district (administrative level 3) level. Until recently, in most cases, the exposure data were not geocoded with the administrative boundaries data in the GIS layer of the particular country. Global datasets, such as Global Administrative Areas (GADM), Second Administrative Level Boundaries (SALB), and other sources, are used for the boundaries' GIS shape files. The smallest administrative zone can then be downscaled or split into 1 km or 100 m resolution cells, depending on the data available. If census data are used, a regression or projection estimation is required using population growth to convert data from the census date to the date of the disaster. The global population data can be sourced from WorldPop (www.worldpop.org), LandScan (where available), GHSL (https://ec.europa.eu/jrc/en/global-human-settlement-layer), or various Geonodes. It is advised that these global datasets are assessed against the nearest census and national population projections at an appropriate level of resolution, such as the province or the district.

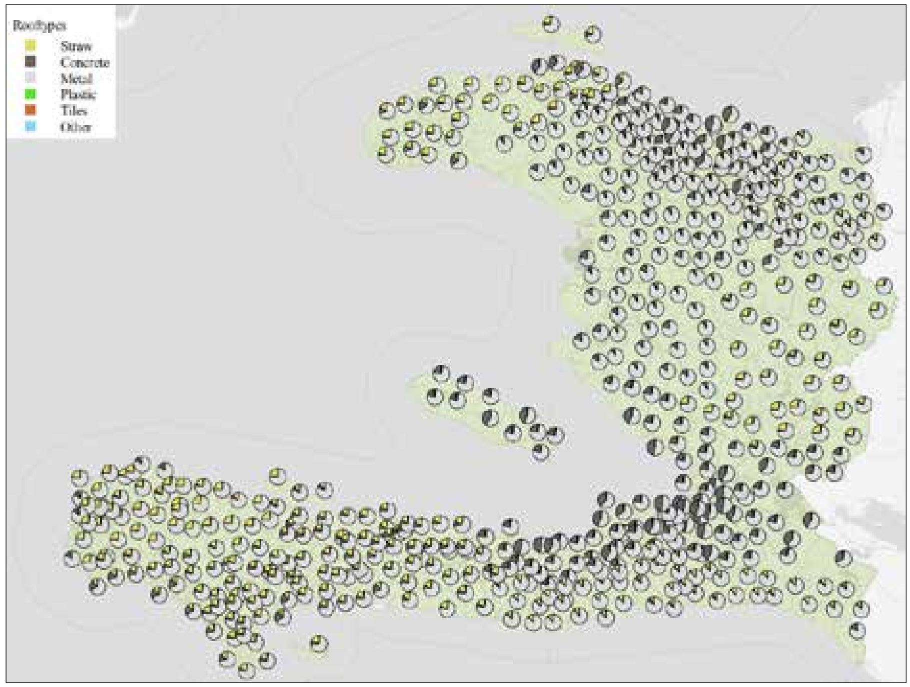
For the capital stock component, estimation is made, as discussed in Gunasekera et al. (2015), resolving replacement cost data from a size estimation of infrastructure multiplied by a per-unit estimation of construction cost and gross capital stock estimated via appropriate service lives of the built assets and the national investment in those assets, usually in the form of gross fixed capital formation (GFCF). The investment data are usually available as part of the national accounts or bank data of the country, for the most part from the national statistics bureaus or the Ministry of Economy or Finance.

Inclusion of building typology information in the method provides additional information and complementarity to the PDNA method. This is highlighted in Figure 4, which shows the distribution of the building typologies in Ecuador and Haiti that were crucial to identifying the building damage distribution at the subnational scale. Construction data come either from official sources, such as the Ministry of Development, or from central statistics bureaus in the relevant country, in the form of annual series of construction statistics of built value, built floor area, and built volume, by asset type, per region or province. These mostly refer to the formal construction sector; additional information and assessments are needed for the informal sector in regions and/or countries where this is important. In the absence of data, reports are often available for the construction of individual assets within a country, as well as construction manuals with official unit costs of construction values for specific building types and projects. Common international housing data repositories, such as the World Housing Encyclopedia (http://www.world-housing.net/), are also quite useful, particularly in countries exposed to earthquake risk. In some cases, these data need to be estimated from existing information in other locations and/or through consultation with local experts. The split of public and private assets along the lines of capital investment form one such important dataset.

For GDP or sectoral information, these data are often available from the relevant government ministry and/or bureau of statistics. Where detailed data for production are not available at the subnational unit of the country, proxies, such as the number of establishments or the output of a particular product, may need to be used. Global databases, such as those of the World Bank (Income) Group, the IMF, and the Food and Agriculture Organization of the United Nations (FAO) can be used for the national-level estimate, but these data are usually available at higher resolution from the relevant location.

Figure 4. Example of capital stock and construction type of different roof types in Ecuador (left) and Haiti (right)





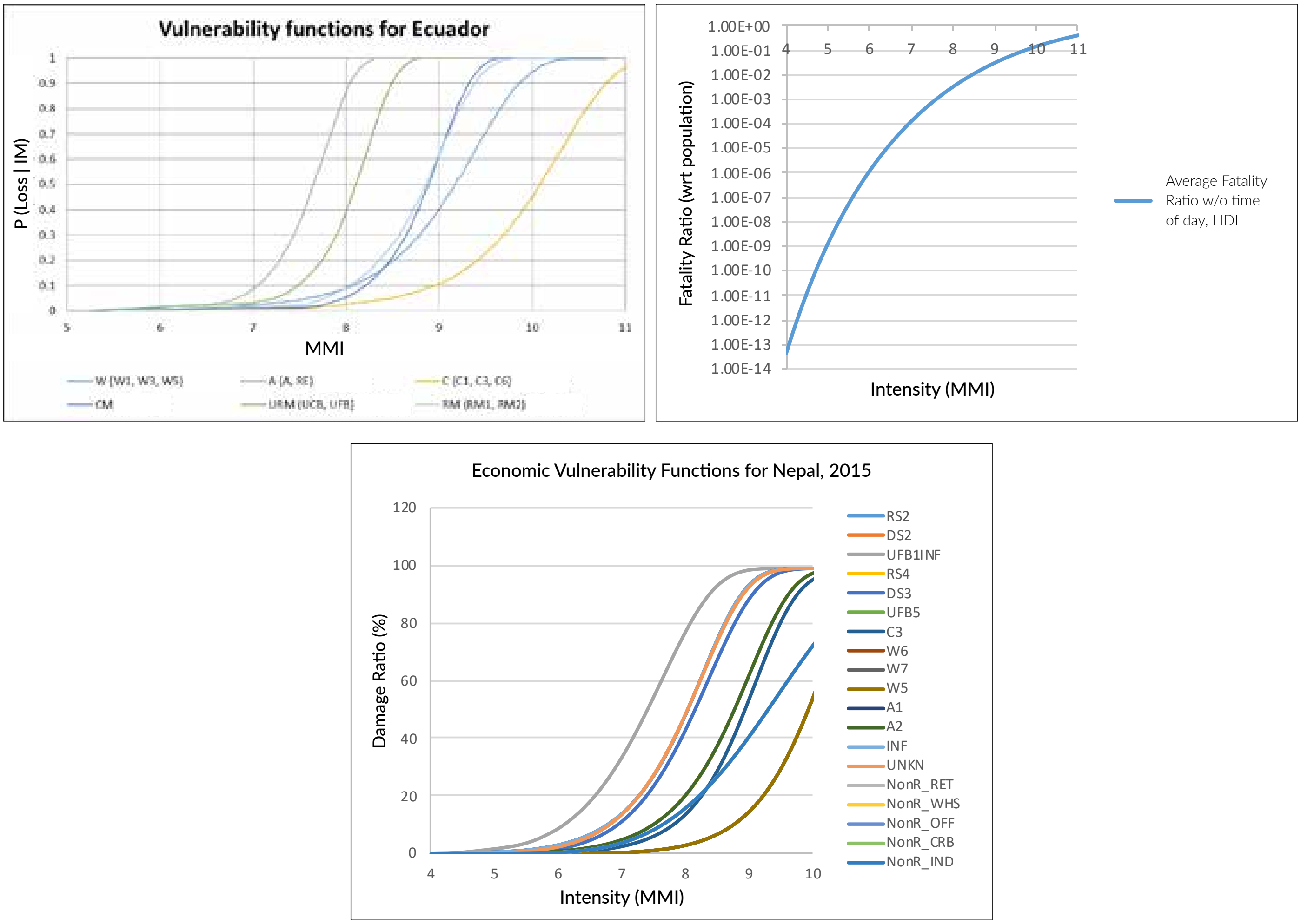
4.4 The Vulnerability Component

Understanding the building stock and using a method to group similar building typologies appropriate in detail and scale is important. The PAGER (Jaiswal et al., 2012) taxonomy of building structures is widely regarded as being comprehensive enough for global application and can be employed at two different levels of detail. With building typology proportions of PAGER classes, the vulnerability of groups of structures can be considered for any region in the world.

The vulnerability component, in the interest of rapid results, is undertaken using preexisting structural vulnerability functions, where available. Existing structural vulnerability functions are selected to represent the vulnerability of assets to the hazards. Finding a balance between time and accuracy, the GRADE approach selects existing functions from global sources aggregated within large databases from CATDAT in Karlsruhe and at University College London (UCL), in collaboration with the World Bank Group. All sources of existing functions are collated in these datasets, including theses from local institutions, local reports, and research articles. The selection of these structural vulnerability functions forms one part of the vulnerability component; there is also a need for calibration with empirical data from disasters that have occurred in contexts similar to the affected region. Preferably, the structural vulnerability functions should have not only the building type and its damageability as functions of the hazard intensity, but also the probability distribution around the median.

The process of selection is innovative and employs an algorithm developed at UCL that searches through a large database of structural vulnerability functions to select the most relevant and quality functions for each group of buildings (Stone et al., 2017). These vulnerability functions are then calibrated using expert judgment, where required, to best fit the nature of the event, using engineering information, reports of damage from the ground, and existing damage data from past earthquakes. This step is particularly important if structural vulnerability studies for that specific region or for a particular building type are scarce. As more information from the affected region becomes available, the structural vulnerability functions are updated accordingly.

Figure 5. Examples of structural vulnerability functions and fatality rate against macroseismic intensity (MMI)



For each hazard metric, there are a multitude of existing global vulnerability and fragility functions,[6] and testing versus the initial damage data from the affected region is required to ensure that the functions used relate well with initial damage reports and are ground-truthed using remote-sensed damage reports. Drone-sourced imagery is also becoming more readily available and is included in the assessment and validation process where available. Multiple settlements in multiple hazard intensities should be checked to gain a better understanding of the structural vulnerability of various types of assets across the spectrum of intensities. In the absence of detailed information on the built assets, aggregated structural vulnerability functions should be used in preference to disaggregated structural vulnerability functions in order to reduce the overall uncertainty of the analysis.

Parameters such as load-bearing structure type, outer-wall type, roof cover and roof structure type, story height, building age, condition of maintenance, and building code adherence often play a major role and should be incorporated wherever possible into the structural vulnerability analysis.

4.5 The Damage Modeling Component

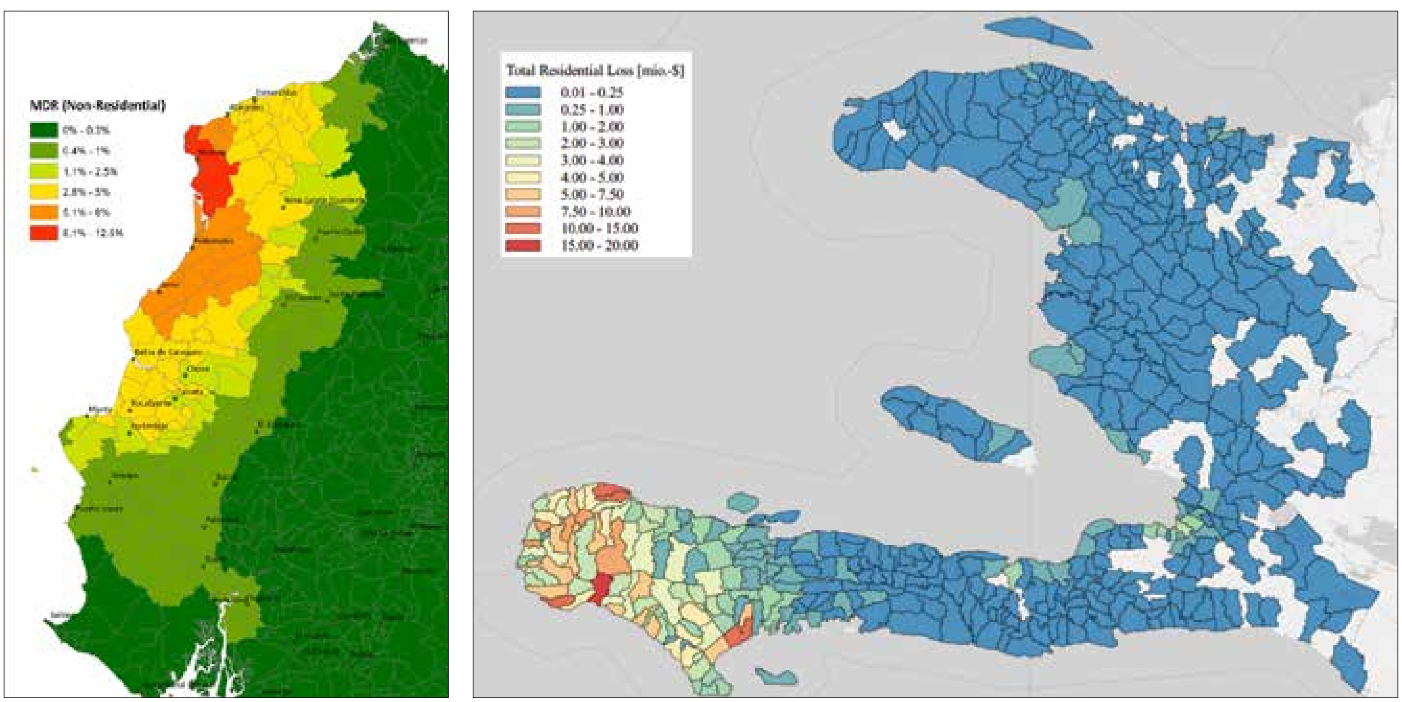
The overall damage estimate is formed by combining the three components of risk (hazard, exposure, and vulnerability). These components need to be incorporated into a GIS environment to allow easy interfacing with incoming ground-based data and to understand the spatial interaction of the disaster event. Where uncertainties exist in the data, they should be

[6] Fragility functions show the probability of exceeding distinct levels of damage severity against hazard intensity; vulnerability functions show the probability of exceeding a loss expressed as a ratio of the "as is" replacement value of the asset against hazard intensity (Pomonis et al., 2014).

recorded, but a best estimate should be made based either on the median estimate or on a tailored estimate of the observed damage. Relevant loss parameters include replacement cost of the housing sector, reconstruction cost of public assets, infrastructure losses, and sectoral disaggregation of production losses. Currently, this has been produced in a spatial form with disaggregation based on the administrative boundary units of the respective country. This should be developed in line with what is needed for the relevant government.

In most cases, the optimal time after an event for the issuing of a first-level rapid DALA is around two weeks, during which reassessments of the damage and the hazard intensity can be examined. By sampling the damage ratio in the towns and locations affected by the disaster, in combination with knowledge about the predominant building classes per location, the preexisting structural vulnerability functions can be calibrated in real-time versus initial assumptions. This can also be aided and improved via the ever-increasing post-disaster drone footage and satellite imagery available, as well as with video evidence and images from social media. Ground-based accounts (e.g., damage surveys) can also be a useful tool in this "Bayesian" or information-based updating process. This allows for an updating of the economic losses and a better damage assessment over time after a disaster. However, it is also important to remember that for particular disasters, such as riverine floods, wildfires, cold and heat waves, and droughts, the event duration is usually longer and thus different approaches are needed. Similarly, in the case of earthquakes, significant aftershocks or secondary effects (tsunamis, liquefaction, landslides, etc.) can aggravate the losses, while volcanic eruptions can have several eruption phases over a significantly longer period of time.

Figure 6. Example of damage product showing mean damage distribution for the 2016 earthquake in Ecuador (left) and Hurricane Matthew in 2016 in Haiti (right)



5 Implications for Clients

5.1 Limitations and Implications

The GRADE approach can provide estimates to stakeholders so that they are quickly informed of the potential extent of economic losses, the distribution of damage, and other associated impacts. These assessments should be interpreted as first-order direct damage estimations, albeit with a significant degree of reliability.[7] However, GRADE's outputs are still estimates, remote-based calculations that are influenced and updated from available ground-based data. While there is confidence in the overall economic estimates and distribution of damage, the confidence level at the individual asset level is very low. The results are based on projections from the latest census data (which in some cases may have been conducted more than 10 years earlier) that also require assembly of data (e.g., number of people per housing unit, including vacant units that in some locations form a significant part of the exposure) from previous censuses, as well as official population projections for the various districts that take into account the recent socioeconomic conditions in the affected country. The accuracy of the exposure model (i.e., the estimated replacement value of the building stock in the affected region distributed appropriately into relevant vulnerability classes) for the current year depends largely on the comprehensiveness of these data.

Due to the dynamic nature of exposure, even the baseline exposure data (on which structural vulnerability and loss estimations are based) are estimates, and it is understood that the confidence levels of the GRADE results are influenced by availability, accuracy, vintage, socioeconomic/political sensitivities of baseline exposure, and the flow of damage data during the early post-disaster period. Further, as discussed in Section 4.5, the spatial damage distribution could be considered indicative for identifying damage hot spots and highlighting the relative magnitude of the disaster and its regional context. For example, for capital stock loss estimation in Haiti after Hurricane Matthew in October 2016, a hybrid approach was used, with a check from the rebuilding costs after the 2010 earthquake and other urban/rural costs to compare against the capital investment data approach. These loss estimates were then apportioned to the urban and rural residential and non-residential sectors. Finally, the GRADE approach does not calculate economic productivity losses or recovery financing needs (which are key outputs of the PDNA process).

Therefore, the implications of GRADE are that:

- There is merit and benefit in developing ex ante disaster loss estimation and risk models, to help improve not only disaster risk management (DRM) and risk transfer strategies, but also post-disaster response.
- GRADE's two-week outcome release target (or shorter if circumstances/preexisting data allow) bridges a big gap that currently prevails in the post-disaster response community, where the earliest detailed and reliable results via the PDNA process are derived around six to eight weeks after the event.
- The four-to-six week gain may facilitate more-rapid and effective fundraising for reconstruction, necessary for in-country budget reallocation toward the worst affected provinces (usually a time-consuming process).
- The estimated sectoral losses are an additional tool for the World Bank and governments to "improve the speed and efficiency associated with efforts to estimate the impact of severe events, thereby hopefully improving the speed and efficiency of response."[8]
- The two-week time frame can be shortened when

[7] For example, after the earthquake in Nepal in April 2015, the GRADE economic damage estimated within two weeks of the disaster for the event was accurate to more than 60 percent of the PDNA results released eight weeks after the event.

[8] See: http://www.primature.gov.mg/cpgu/wp-content/uploads/2017/03/MG-Report-on-the-Estimation-of-Economic-Losses.pdf.

affected territories are small and relatively uniform or where D-RAS team has already developed fully probabilistic risk assessment models (e.g., the D-RAS team response to Cyclone Ava in January 2018 delivered GRADE results within 10 days of request). These models include precompiled stochastic event sets, and the most appropriate modeled event can be selected. Access to post-disaster aerial footage (as used by D-RAS team in the case of Hurricane Maria in Dominica in 2017) can also help speed up the assessment of damage in particular following destructive hurricanes.

5.2 How the GRADE Approach Complements the PDNA and Recovery Planning Framework

The PDNA process consists of a set of established methods for damage and loss estimation that allow governments to assess the impact of a disaster on the population, society, and key economic sectors. The standard procedure is for government ministries to collect data in the field, supplementing it with additional information, which is then organized and analyzed according to the established and comprehensive PDNA method. For the societal impacts, the United Nation's Human Recovery Needs Assessment (HRNA) method is also used, as it has been integrated into the PDNA process.

Like the PDNA process, the GRADE approach uses many forms of government and auxiliary datasets. However, the GRADE approach, being a remote assessment in the early post-disaster weeks, combines government-collected damage data with global detailed damage databases, insurance/reinsurance global loss databases, and analytical studies and literature on structural fragility and vulnerability, as well as more recent data provided by remote sensing observations (EU-Copernicus, UNOSAT, Pacific Data Center [PDC], etc.) and information from drone and video footage in social media. The augmentation of these different datasets enables a more comprehensive view of the likely effects on buildings and the associated losses. In addition, the method outlined in Gunasekera et al. (2015) and other specialized tools (e.g., iURBAN [Aubrecht and Torres, 2016]) results in the rapid generation of country exposure base datasets. For more details please also refer to the comparison in Appendix B.

In conclusion, rapid post-disaster damage and economic loss estimation methods complement the PDNA process that addresses sectoral loss estimates in more detail. Therefore, **GRADE should not be viewed as a replacement for the extremely important PDNA efforts**. GRADE is carried out to provide a useful swift, initial estimate of the likely damages and related aspects of a disaster, such as estimation of human casualties after an earthquake or tsunami or other rapid-onset disasters that did not allow for evacuations and sheltering. The GRADE outputs can also be used as reference data during the PDNA process. GRADE has also allowed the World Bank to respond to the demand from clients in a more targeted manner, as well as providing independent, science- and engineering-based evidence for strategies in responding to disasters.

5.3 How Can These Results Be Used by Stakeholders?

Key outcomes of the rapid post-disaster analyses are meant to strengthen the action plans and strategies developed to respond to disaster events. Specifically, the outcomes include:

- Early dissemination of damage estimates and/or human casualty assessments
- Provision of key baseline data for national and subnational authorities
- Independent evaluation of scientific data on the spatial distribution of the hazard
- Assistance in preparation and implementation of disaster relief and response strategies
- Long-term integration of disaster risk reduction issues and practices into national and local government plans and programs

If or when a reconstruction plan is decided on, government agencies could manage the transition from analysis to planning. The reconstruction plan could potentially be influenced by the risk assessment results, such as was done after Hurricane Matthew in 2016. This influence could extend to assessing which sectors are most affected, how a plan will be implemented, resource management, and prioritization.

The outcomes of this early diagnosis allow governments to strengthen the action plans and strategies developed to respond to disasters, recognize early post-disaster requirements to keep the population informed and to manage expectations, understand and manage the immediate multi-donor environment, and complement traditional PDNAs with strong data and analysis to build stronger baseline data. Each of these is clarified below.

1. **Informing the reconstruction plans and strategies developed following a disaster event.** GRADE's outputs can assist governments in informing the preparation and implementation of disaster relief and response strategies. Following a disaster, the aim of the emergency response and short-term action plans is to provide immediate assistance to maintain life and support the affected population. These data are fundamental in supporting the process of identifying initial interventions and in informing the government's or humanitarian community's emergency response and short-term action plans. This initial diagnosis provides an opportunity to contribute to and inform the initial action plan by identifying early intervention requirements and priorities. Having a well-designed and coordinated short-term action plan contributes to facilitating the design of the intervention strategy, which should be able to estimate the investment needed for the recovery and reconstruction of each affected sector.

2. **Recognizing early post-disaster requirements to keep the population informed and to manage expectations for governments.** Having rapid and good quality data is an essential input to promptly recognize initial demands and to control the disturbance generated by the disaster. It is critical for governments and public agencies to be able to provide good information and maintain clear and consistent communication after a disaster. Time scales are accelerated in the post-disaster context and actions need to be taken promptly. In particular, in the earlier stages of the recovery process, timely presentation of data takes precedence over exhaustive analytical precision. The more detailed work can be carried out at later stages. Following a disaster, the context is changing on a weekly, daily, or even hourly basis. Information that is released too late may simply no longer be relevant, accurate, or useful.

3. **Understanding and managing the immediate multi-donor environment.** Governments can also refer to GRADE's outputs to manage the multi-donor and agency post-disaster environment. It is widely recognized that governments must lead recovery and reconstruction efforts, but also that the direct and indirect impacts of the disaster may compromise government capacity to lead such efforts and support; leadership from the international community may be required. Having good-quality information contributes to the credibility of the request for assistance from the government and the accelerated mobilization of resources through the inclusion of early recovery requirements and reconstruction in humanitarian appeals and the establishment of funding mechanisms, such as multi-donor trust funds.

4. **Supplying the PDNA process with strong quantitative data and analysis to build stronger baseline data.** The GRADE approach provides a scientific and comprehensive picture of catastrophe impacts; it specifically disseminates early knowledge of economic loss and/or human casualty assessments and provides key standard data for national and subnational authorities. Governments can use this information as a basis to inform themselves prior to subsequent and more-detailed intersectoral PDNAs and future conditions evaluations to facilitate stronger baseline data in the shortest time possible, and to then define the recovery framework. Considering that governments are seldom well prepared for strong data collection in the wake of a disaster, having a strong baseline is even more crucial if governments are to accurately define the recovery strategy, prioritize actions, and fine-tune planning.

Conclusions

6

Following a disaster, governments and other stakeholders need to determine the impact of the disaster, i.e., the extent of human casualties and economic loss due to property and infrastructure damage. Within this framework, innovative methods developed and employed by the experts in the World Bank GSURR D-RAS team use the GRADE approach, which allows for a desk-based, rapid, lower-cost, and accurate post-disaster damage assessment that can be conducted within just two weeks of a request following a disaster. The analysis employs key information on the hazards, exposures, and vulnerabilities of the various assets, taking into account modeling uncertainties and reporting damages and losses, along with their associated ranges.

The GRADE results enable stakeholders to more rapidly comprehend the extent of economic losses and the spatial distribution of damage and to be empowered to mobilize, strategize, and determine appropriate, timely, and efficient courses of action in response to a country's government demand. Outputs of post-disaster assessment approaches need to be flexible to respond directly to the needs of the affected countries and stakeholders. Within the GRADE approach, to improve accuracy, both inputs and outputs are validated extensively using data from historical events and data reported from the affected area. (However, it needs to be noted that, although results are presented spatially, they do not extend to individual buildings or sectoral losses on the microscale.) Table 2 is a quick summary of the GRADE's requirements in resources and time and the expected accuracy of its output content.

Appendix A highlights a number of real-world case studies that illustrate the capabilities of the GRADE approach and the range and extent of results achieved. Feedback from World Bank TTLs are also included; they offer insights into client demand and how the GRADE approach has been successfully deployed in post-disaster situations.

The effectiveness of post-disaster rapid damage assessment approaches such as GRADE is dependent on the quality of data available. This issue is exacerbated in data-scarce countries, as the accuracy of analysis and the scope of application of GRADE's innovative methods are reliant on each country's available data. This type of analysis is also dependent on the availability of experts. For example, a GRADE approach requires 3–5 core experts working nearly full-time for a two-week period.

GRADE has been applied, with great success, to earthquakes and tropical cyclones. However, it would be tremendously exciting to extend the GRADE approach to multi-hazards and cascading disasters as well, as the obvious next step in GRADE's development. GRADE still has much potential to be exploited in the service of ever more rapid and accurate post-disaster assessments.

Table 2. The GRADE approach key information

Resources	Speed	Information Content	Reliability	Accuracy
10 days each of at least five consultants; data resources vary depending on region/country	Approximately 2 weeks per country/event	Economic loss estimation report and analytical tables and maps relating to physical damage (of key sectors, such as housing)	Calibrated against inflow of consequence data (remote sensing, drone footage, social media video, crowd-sourced information, early government assessments)	More than 60% vis-à-vis the detailed PDNA damage assessment (but in less than a third of the time).

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Appendix A. GRADE Case Studies

A.1 April 2015 Earthquake in Nepal

On April 25, 2015, at 11:56 local time, a magnitude 7.8 earthquake of 15 km focal depth occurred in the Gorkha district of central Nepal, approximately 80 km to the northwest of the capital, Kathmandu. This was Nepal's largest magnitude and most lethal earthquake since 1934 and the most costly since at least the August 1988 magnitude 6.8 earthquake in the eastern part of the country on the border with India. The earthquake affected 35 of Nepal's 75 districts in the Western and Central regions, including the Kathmandu Valley. The affected area included mountain and hilly areas where rural populations are dispersed, as well as some very densely populated districts and Nepal's two largest cities: Kathmandu and Pokhara. Worst affected were the districts of Sindulpalchok, Kavrepalanchok, Nuwakot, Rasuwa, Dolakha, and Kathmandu in the Central Region and Kaski, Gorkha, and Lamjung in the Western Region, with a combined population of 3.85 million people (14.5 percent of the country's population [2011 census]), where 20.3 percent of Nepal's 2013 GDP was produced.

The earthquake caused extensive loss of life in Nepal (8,962 dead), as well as in India (130 dead), China (27 dead and 3 missing), and Bangladesh (4 dead), while around 20,700 across the region suffered serious injuries and 83,300 had minor injuries. Damage to Nepal's housing stock was extensive, with 512,054 houses destroyed and 280,730 damaged (combined damage from the main shock, the magnitude 7.3 aftershock of May 12, and numerous other damaging aftershocks). Landslides occurred and roads and power lines were also damaged in Nepal.

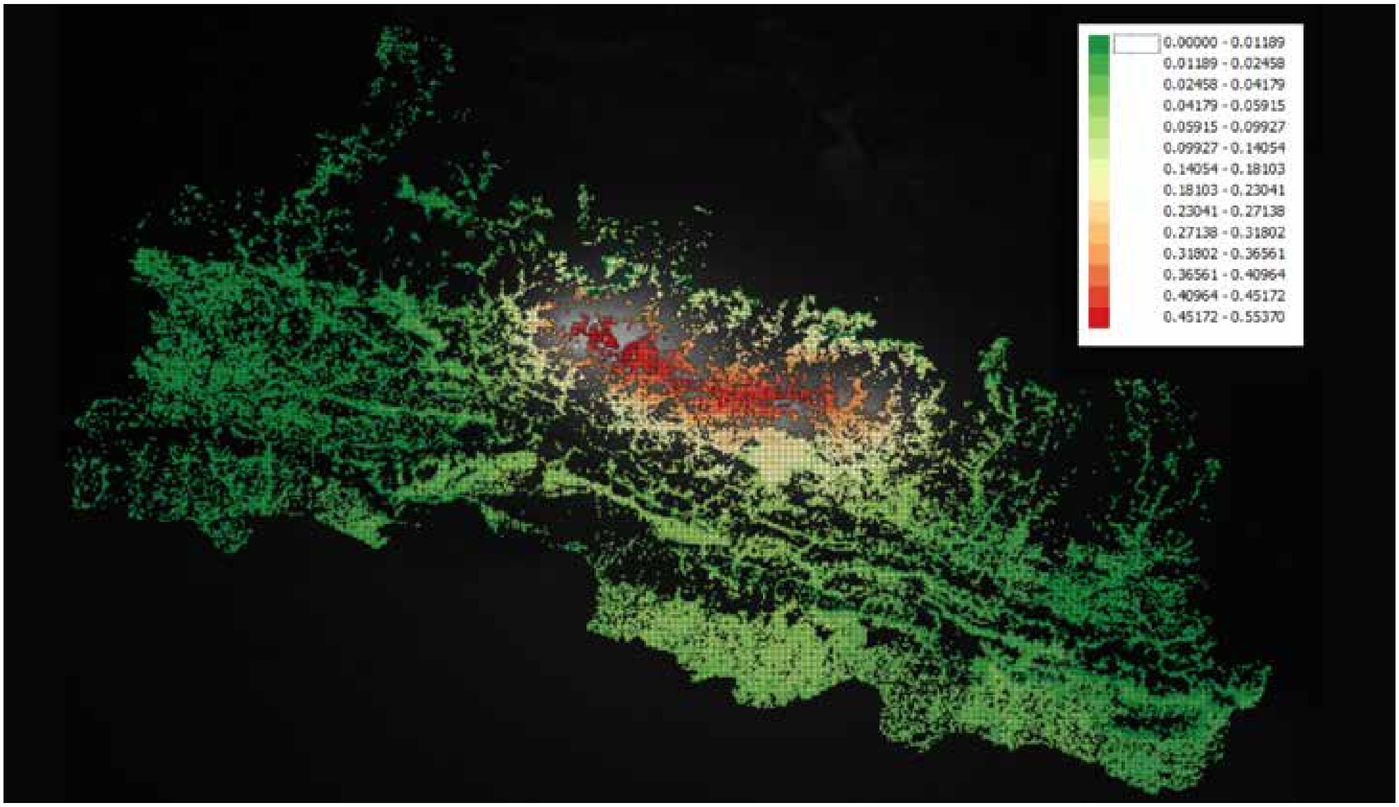
Soon after the earthquake, GSURR D-RAS team worked for two weeks to derive an initial estimate of the losses. The GSURR D-RAS KSB team set out to solve a few issues, including the fact that there was initially great concern that this event would result in a great number of fatalities, with some entities estimating potential loss of life of around 50,000, bringing the scale of the disaster into question. The World Bank and the client needed more confidence in the loss estimates to adequately assess the impact. Initially, the GSURR D-RAS team's focused on the estimation of the number of fatalities. A reliable estimate required good building stock data and associated population data. Data scarcity and much uncertainty were present in each of the three risk model components (hazard, exposure, and vulnerability), with a lack of credible sources and many disparities on key parameters between sources, as well as language issues, with many data reports being in Nepali.

Hazard information was derived from international (USGS, GEOFON, etc.) and local networks. A ground motion map was produced as part of the study, fitting the available data, while macroseismic intensity prediction equations based on historic earthquakes in Nepal were used to derive the intensity map. Such post-disaster hazard information is often difficult to collect and thus the GSURR D-RAS team relied on the work created within CATDAT (Daniell et al., 2012) and other studies. The attenuation function used for the generation of the peak ground acceleration (PGA) map was calibrated to the local station data. In the absence of additional information, two complementary maps were needed to examine the differences.

The ward-level census data of 2011, available from the Nepal Central Bureau of Statistics, were collected, with the number of households and housing units. These data allowed us to estimate spatially detailed exposure of the housing sector using gridded population data (LandScan 2012) and also to calculate using ward-level centroids. Furthermore, the 2011 Nepal Population and Housing Census provided useful information on the residential building stock (housing units), with data on outer wall and roof cover typologies being quite useful for the characterization of the seismic vulnerability. The region's housing stock was thus described in terms of 12 structural-building typologies. The data were assembled at the district level and digitized.

The non-residential exposure was estimated through the distribution of the built floor area into five broad building use classes (commercial-retail; commercial-warehouse; commercial offices, including administration and hotels; and industrial and critical facilities). This was done by analyzing the labor statistics of Nepal in its urban and rural areas, plus other information gathered for validation (particularly for the critical buildings).

Figure 7. Spatial distribution of direct loss ratio to residential buildings released by GSURR DRAS team on May 2, 2015



The weight of the non-residential sector relative to the residential sector was derived looking at the non-agricultural labor, showing the need for detailed digitized indicator data as part of this PDNA method. The economic value of the building stock was calculated using two methods, resulting in better reliability: a capital stock method from investment data and a unit cost of construction by vulnerability class and building size.

For the structural vulnerability component, the reference functions used were based on historic earthquake losses in Nepal and other similar events in the broader region, with the vulnerability derived for both economic losses and fatalities. This was then updated over the next few days when additional building damage data were collected. Eventually, broad structural vulnerability classes were used for the building stock in Nepal. The original loss function from Daniell (2014) was used, but it was updated not only via the human development index (HDI) of the location (a proxy for building quality and engineering), but also with the building typologies within each district in order to examine the differentiation of the built stock. Similarly, the average fatality function was created (differentiation based on HDI and vulnerability) as per work from Daniell and Wenzel (2014) on previous casualty studies in earthquakes. Thus, an aggregated loss per ward was derived and summed to provide the fatality and economic loss estimate in each affected district.

An important achievement of this work was the quick output of losses and the building of datasets of exposure and loss information, in the absence of much information on socioeconomic stock before the disaster. The GRADE estimate, released on May 7, 2015, reported the likely number of fatalities in Nepal at 9,757, which was just 9 percent higher than the final toll reported, as of 2017. This early assessment helped alleviate fears that an excessively large loss of life could have taken place (as had been initially estimated by some). In terms of direct losses to the residential and non-residential building stock, the GRADE estimate was US$2.75 billion, which tallied very well compared to the PDNA released at the end of May 2015. The populated cell-level estimated loss map is shown in Figure 7.

A.2 April 2016 Earthquake in Ecuador

On April 16, 2016, at 18:58 local time, a magnitude 7.8 earthquake of 19 km focal depth occurred off the west coast of Ecuador, seriously affecting the coastal zone between Esmeraldas in the north and Guayaquil in the south (a distance of 400 km separating these two locations). This was Ecuador's largest magnitude earthquake since 1942 and the most lethal since 1949. In addition to the worst affected provinces of Manabí and Esmeraldas (where 13 percent of the population resides), the earthquake caused some damage in the Santo Domingo de los Tsáchilas, Guayas, Los Rios, Santa Elena, and Pichincha provinces (where an additional 53 percent of Ecuador's inhabitants reside), including the country's largest city, Guayaquil, in Guayas province. The seven affected provinces accounted for 68 percent of the country's GDP in 2015, with the two worst affected provinces accounting for 8.8 percent of the GDP.

In terms of exposure to ground shaking, approximately 12.3 percent of the GDP was exposed to intensity VI (equivalent to slightly damaging ground motion) and 3.7 percent to intensity zone VII (equivalent to moderately damaging ground motion) or higher.[9]

According to reports from Ecuador's Secretariat for Risk Management, 663 Ecuadorians lost their lives, 9 were listed as missing, and 6,274 were injured,[10] while 113 were pulled out alive from the rubble of collapsed buildings and 29,067 were evacuated to temporary shelters. In addition, 28 foreign citizens lost their lives and 1 person died in neighboring Colombia. Buildings across the worst affected region suffered extensive damage, with more than 5,200 being characterized as "unsafe to enter" (red-tag), around 5,750 given a "restricted use" status until their fate would be decided by more detailed structural safety checks (yellow-tag), and 5,260 were deemed as "damaged with occupation permitted" (green-tag). Damage to the housing stock was also severe, with 18,566 dwelling units needing repairs and 23,244 units to be rebuilt (the total of 41,810 affected housing units amounted to 0.84 percent of the country's housing stock). Other impacts included interruptions to the water, power, and communication systems, as well as damage to highways, bridges, motorway overpasses, and airports.[11] Manta Port (the country's second largest port) continued to operate with limitations, while the main highways were passable, except the Chillanes-Bucay and Alóag-Santo Domingo routes.

Two weeks after the earthquake (on April 29th), GSURR D-RAS team published its loss assessment report, with the direct economic losses estimated at around US$1.3 billion, or 1.35 percent of the 2015 GDP, considering damage to civil infrastructure[12] and buildings (both residential and non-residential), including a minor demand surge and other cost increases. The residential buildings loss of approximately US$480 million was spatially distributed as shown in Figure 8 (right), while losses to the non-residential buildings amounting to US$415 million was spatially distributed as shown in Figure 8 (left), highlighting that there were significant losses from Muisne in the north to Guayaquil in the south. A further US$400 million of estimated losses was related to civil infrastructure (bridges, roads, airports, etc.), shown in Figure 9.

The GSURR D-RAS team loss estimate did not include any costs related to decisions to improve the current seismic resistance of reconstructed buildings (e.g., "build back better" initiatives) or to replace dilapidated (but not destroyed) building stock in the affected region. It also did not include social provision costs for the housing and other support of the homeless or the people who lost their employment as a direct or indirect effect of the earthquake, nor did it include losses related to the replacement of housing contents or lost business inventory and machinery. The loss calculations used the World Bank Latin American and Caribbean Country Disaster Risk Profile (CDRP) model and integrated information from the Ecuador 2010 housing census (with appropriate projections) and preliminary damage assessment reports from the affected region, cross-referenced against initial damage

[9] According to the Modified Mercalli macroseismic intensity scale (Grünthal et al., 1998).
[10] Secretaria de Gestión de Riesgos, Informe de Situación No. 71 (May 19, 2016; 20:30).
[11] The control tower of Manta Airport collapsed and the airport was closed for several days. Two more airports (Salinas and Esmeraldas) were temporarily closed.
[12] Civil infrastructure includes roads, water, energy, electricity, and bridges, among others.

Figure 8. Spatial distribution of direct damage to residential and non-residential buildings, released by GSURR D-RAS team on April 29, 2016

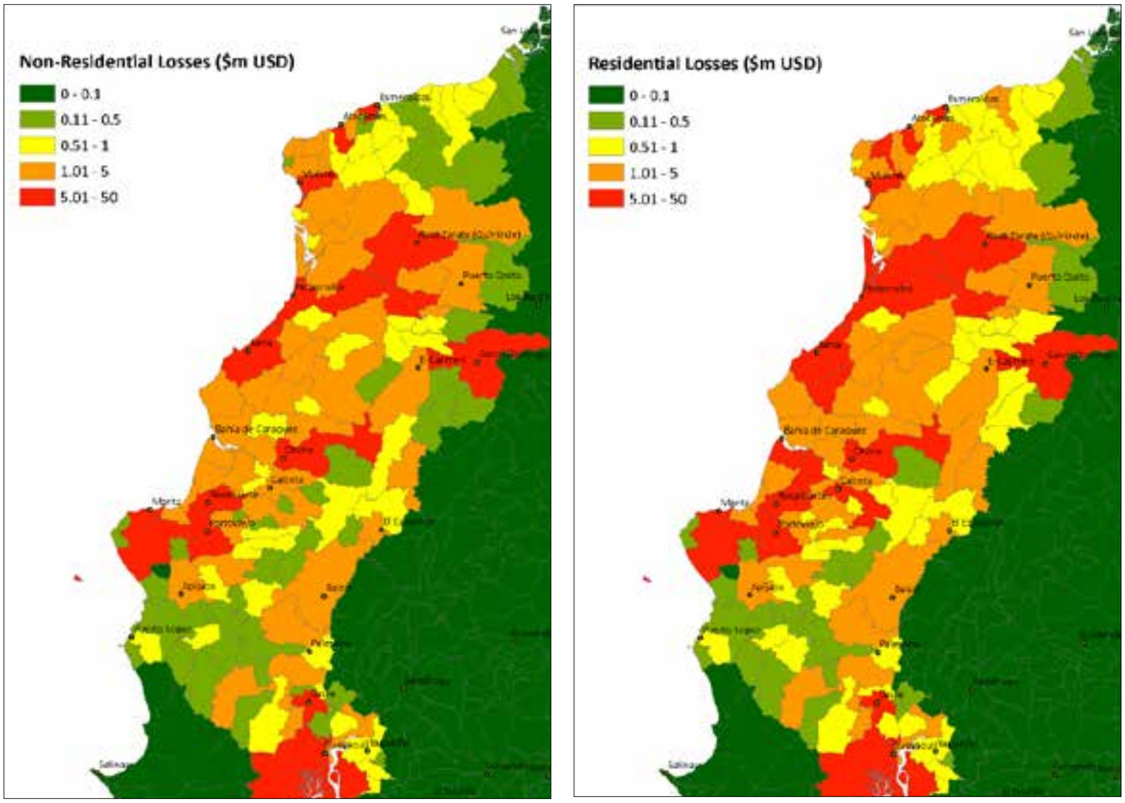


Figure 9. Spatial distribution of direct damage to infrastructure, released by GSURR D-RAS team on April 29, 2016

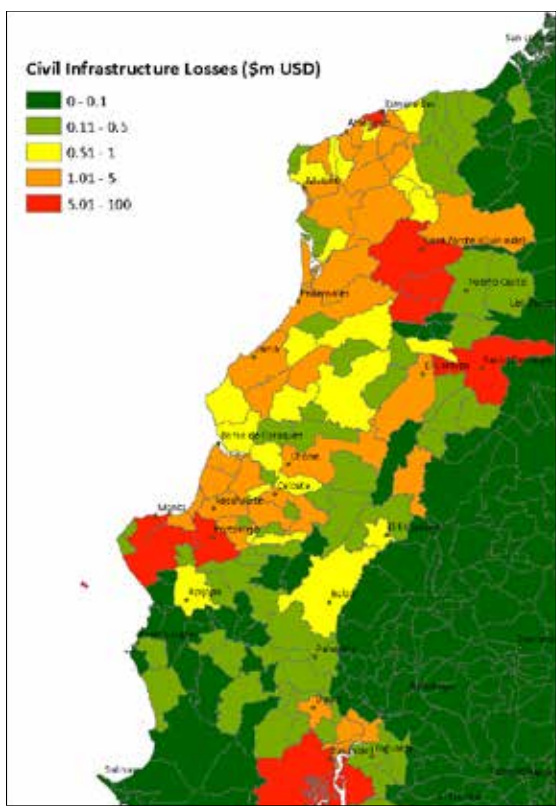
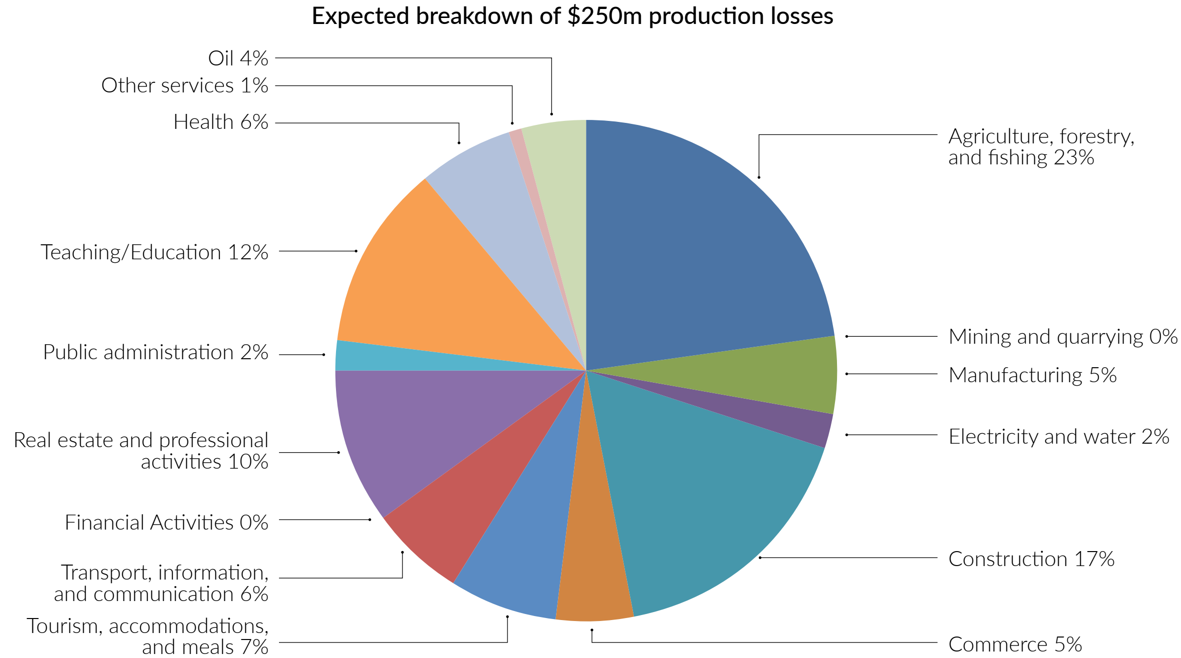


Figure 10. Breakdown by sector of the modeled by GSURR D-RAS production losses



estimates from satellite (EU-Copernicus and UNOSAT) and ground-based observations and the judgments of the experts in the team.

Additionally, the GSURR D-RAS team calculations indicated up to US$250 million of production losses, which would include losses in economic sectors, such as agriculture, fishing, commerce, and tourism. The breakdown of the production losses by sector is shown in Figure 10.

These estimates did not take into account potential indirect losses due to business interruption, loss of employment, or value added, and did not include estimates on the impact on Ecuador's potential output (due to the earthquake's impact on the country's stock of human assets and private and public capital).

A.2.1 Ecuador TTL Feedback

Ecuador DRM Team (Diana Marcela Rubiano Vargas, Van Anh Vu Hong, Nicholas James Callender) reported the following:

> "The post-disaster rapid damage assessment work done through the GSURR D-RAS team was of high utility to the Ecuador DRM team following the magnitude 7.8 earthquake that struck Ecuador in April 2016. Through this instrument and product, the DRM team had quick information on hand to determine the needs the client may have, was able to prepare for the appropriate financial and technical response, and had a sound methodological and technical basis for providing access to disaster-contingent funds under Component 2 of the US$150 million Emergency Recovery Loan.
>
> This early assessment of exposure and associated losses was critical in the speed of response and greatly aided in mobilizing [World] Bank resources to attend to the response and recovery. The modeled outcomes allowed for the triggering of the IMF emergency facility based on rapid information generated on the key GDP contributing sectors and the assessment of infrastructural damage. It was highly useful to have modeled loss numbers that served this purpose without starting a damage assessment process on the ground, which would have required to wait for the Government to identify and coordinate all stakeholders and to follow PDNA processes'

timeline usually orchestrated by [United Nations] agencies.

In the days following the event, there was significant uncertainty in the overall impact of the disaster and loss estimations; a Presidential statement was made two days after the event citing US$3 billion in damages and losses. In the context of this uncertainty, it was invaluable to have an objective model to provide estimations of direct losses to buildings and critical infrastructure and direct/indirect economic impacts on GDP and the economy. The Government-led PDNA process resulted in a reconstruction cost amounting to US$3.3 billion; this data was collected throughout the month of May, with the official documentation being available much later. Beyond the utility of having an earlier assessment of impact, the results of the PDNA varied from the rapid damage assessment work; it was useful to have these data points to compare to the PDNA results and see where results differed or where discrepancies across data may be. However, it is worth highlighting that, while the main objective of the PDNA led by the [Government of Ecuador] was to have an estimate for total recovery costs (including immediate response costs), the post-disaster rapid damage assessment was done by the GSURR D-RAS team primarily to inform the IMF and the [World] Bank as soon as possible so that they could respond effectively to the needs and possible requirements from the [Government] (i.e., through the IMF emergency facility)."

A.3 October 2016 Hurricane Matthew in Haiti

Haiti is exposed to a severe hurricane hazard and has experienced at least 40 such events since 1851, with at least 5 having winds over 200 km/hr (equivalent to Category 4 hurricanes): Flora in 1963, Cleo in 1964, Inez in 1966, David in 1979, and Allen in 1980. Since Hurricane Allen, there had been no other events with wind speeds exceeding the 200 km/hr level until Hurricane Matthew, although flood and mudslide losses associated with hurricanes and tropical storms have been quite severe (e.g., Georges in 1998, Jeanne in 2004, the 2007 season with two storms, the 2008 season with four damaging storms, and Sandy and Isaac in 2012).

Hurricane Matthew made landfall in Haiti's western peninsula as a Category 4 hurricane on October 4, 2016, with 232 km/hr sustained winds and peak gusts reaching up to 278 km/hr. In terms of rainfall, more than 600 mm was recorded in a number of communes in the three days from October 3rd to October 5th.

The most affected provinces were Grand'Anse, Nippes, and Sud, which are home to nearly 1.6 million Haitians (14.5 percent of the country's 2015 estimated population of 10.9 million). Around 1.7 percent of Haiti's capital stock and 3.5 percent of the population were exposed to wind speeds of over 200 km/hr. An additional 5 percent of capital and 9 percent of the population were exposed to wind speeds from 100 km/hr to 200 km/hr. More than 64 percent of Haiti's capital stock was exposed to rainfall of more than 400 mm, especially in the southern parts of the country. The residential and non-residential components of Haiti's capital stock were estimated at US$33.2 billion.

According to Haiti's Civil Protection Office (Pwoteksyon Sivil), 546 people were killed, 128 were listed as missing, and 439 were injured. More than 25,500 houses were reported to have been destroyed and more than 2,500 flooded, while more than 175,000 people were evacuated to shelters. Other impacts included interruptions to the water, power, and communication systems, as well as damage to roads, bridges, and agricultural production.

Having reviewed hurricane and flood PDNAs worldwide for the last 20+ years, the experts with the GSURR D-RAS team identified a need to split wind- from rain-/flood-based losses during severe hurricanes, as the sectoral losses are very different from each of these components. The GSURR D-RAS team conducted a detailed assessment of Haiti's buildings, education and health facilities, electricity, and roads to give an indication of the infrastructure and social sector damage that had incurred.

The housing typologies in the affected departments were mostly single-family, concrete block, unreinforced masonry walls with light wooden roof structures covered by metal sheets, with some thatch and straw roofing toward the western tip of the Tiburon peninsula. There were also light wood frame houses enclosed in metal sheeting or other wooden, fibrous materials. The affected region was predominantly rural and more vulnerable to the extreme wind pressures experienced during Matthew. However, in Les Cayes town center, through remote sensing and damage analysis, the GSURR D-RAS team estimated lower loss ratios due to the prevalence of reinforced concrete structures with flat concrete slabs.

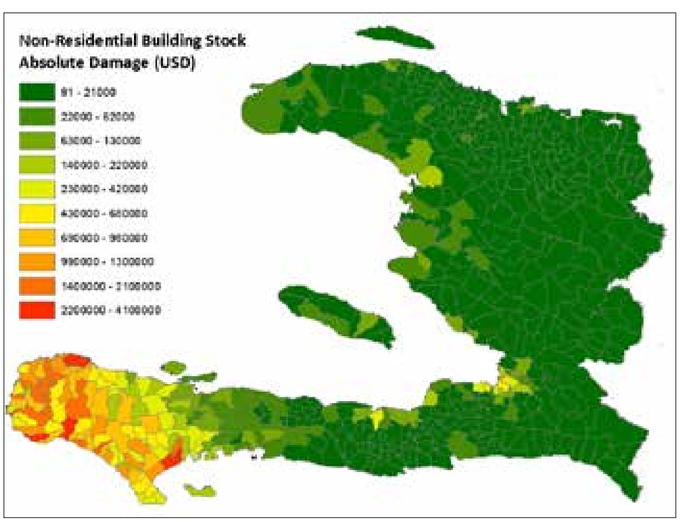
The non-residential losses were modeled using capital stock estimates checked against a ground-up stock of education, health, and other public and private non-residential buildings, including structures for sheltering livestock. The 2010–11 school building census was also accessed and taken into account. A check of the materials of construction of schools showed a high ratio of less vulnerable concrete and block/cement construction. Health facilities similarly were obtained from the listing of the Haitian Ministry of Health. The replacement values were checked against local rebuilding costs of schools after the 2010 earthquake.

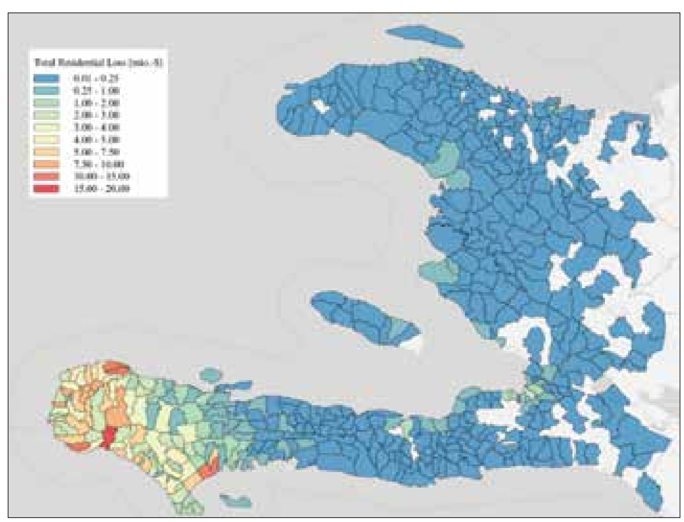
GRADE estimated the present value of Haiti's residential stock at around US$21 billion, with **direct economic losses at US$402 million, or 4.5 percent of the 2015 GDP**. For the non-residential buildings, the replacement value was estimated at around US$12 billion, with **direct economic losses at US$92 million, or 1 percent of the 2015 GDP**. Allowing for uncertainties in the wind speeds and vulnerability functions, a loss range from US$359 million to US$841 million was estimated for the combined building stock. The spatial distribution of the damages is shown in Figure 11 (right) for the residential and Figure 11 (left) for the non-residential buildings. It should be noted that these amounts did not include losses to building contents and other associated costs, such as business interruption, resupply of lost stock, and cost of debris removal.

In addition, around US$148 million of the combined residential and non-residential building stock was estimated to have been damaged as a result of flooding, using a hybrid method of flash flooding via direct rainfall and fluvial flooding scenarios based on various frequencies of occurrence for losses due to flooding.

Given the limitations of the early response (e.g., lack of a flood footprint), the flood loss estimation was considered to have wider uncertainty than the wind loss estimate. However, the outputs helped develop the rapid PDNA, which, in turn, was used by the IMF to determine whether it should trigger its post-crisis mechanism for the country.

Figure 11. **Spatial distribution of direct damage due to wind to residential and non-residential buildings, released by GSURR D-RAS team on October 19, 2016**





A.3.1 Haiti TTL Feedback

Sergio Dell'Anna, DRM specialist Haiti, reported the following:

"There were several lessons learned from the disaster response to [Hurricane] Matthew in Haiti. There was a ***greater*** need for a unified approach than a submission of one product, as different stakeholders had different requirements with different timelines. There were three different products that were produced. These included 1) a damage assessment using the GRADE methodology and expertise that contributed to the rapid Damage and Loss Assessment led by Ministry of Economy and Finance, Haiti, with the support of the [World Bank], [the Inter-American Development Bank], and a few [United Nations] agencies and 2) detailed PDNA assessment led by the Ministry of Planning with the support of [the European Union], [the Inter-American Development Bank], [United Nations] agencies, and [the World Bank].

Some key lessons learned:

1. The GSURR D-RAS team rapid assessment results were used by the World Bank Country Management Unit (CMU) and other stakeholders. This was directly in response to the requirement for a rapid sector analysis for World Bank internal purposes. It also highlighted the usefulness and need for a rapid damage assessment.
2. It also raised key issues, such as the importance of communicating uncertainty with the limits of data available, communicating how the model works and how it complements macroeconomic analysis.
3. Within the ministries too there were concerns about ownership of data. Key concerns included if the ministry has the data, how rapid assessment was conducted without using of this data, since the quality and detail of data available in Haiti in various line ministries is much higher and detailed than other data available outside the government institutions. The GSURR D-RAS team relied heavily on freely available datasets and used official statistics to calibrate the model and results. This also allows the possibility to rerun the GSURR D-RAS model with more and better information.
4. Some sectors of the Rapid Assessment and the PDNA exercise were sample based, such as the housing sector, [which] were initially considered. [The approach to other] sectors, such as the education and health sectors, included a more precise traffic light color level of damage analysis using high level of data available in country and by having the Rapid Assessment 'feeding' the D-RAS model.
5. It was also important to differentiate damage and loss components as specified by the PDNA process, particularly since loss components are very important for macroeconomic analysis."

A.4 2017 Cyclone Enawo in Madagascar

Tropical Cyclone (TC) Enawo made landfall in northeast Madagascar on March 7, 2017, as a Category 4 cyclone, and then moved southward as a tropical depression before exiting the country on March 10. The northeast regions suffered from wind damage and widespread flooding. TC Enawo was the strongest cyclone to strike Madagascar since 2004, with maximum wind speeds of 230 km/hr at landfall, and up to 220 mm of rain in 24 hours were recorded in Sambava. The wind field was set up on the basis of Best Track data and calibrated with station data. Data on the commune level were collected and digitized as part of the process in order to calculate the affected population.

A capital stock loss model was set up by the GSURR D-RAS team using vulnerability functions calibrated from previous studies of cyclones in Madagascar, the Madagascar building typologies themselves, and the interaction with wind speed. This was combined with the value of assets, which was derived from a bottom-up (construction cost per m^2 built) and top-down (investment) approach to estimate the overall capital stock of the residential and non-residential assets. The capital stock losses were estimated independently and provided the first estimate of losses. These fitted well with the used results of AIR.

In addition, an agriculture sector model was developed to fill a gap in the analysis of the event to assess agricultural losses by using the collection of detailed information of 15 crop types, crop timings, and historical losses from previous Madagascar cyclones, with the help of publications from the government, FAO, and Météo France. Thus, vulnerability functions were built for each crop type depending on the stage of its development and potential damageability. This development of agricultural sector losses was needed, as in previous Madagascar cyclone events the agricultural sector losses had represented the highest proportion of the losses. The losses were estimated at approximately US$207 million, dominated by the impact on the vanilla plantations in Sava and Diana regions, amounting to losses estimated at US$164 million (Figure 12).

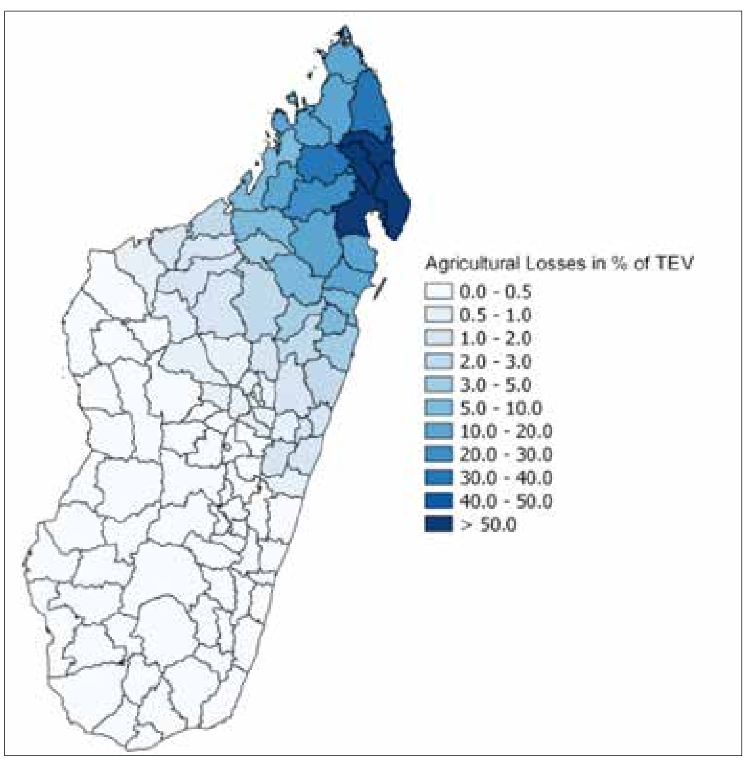
This post-event loss calculation effort provided a useful initial estimate of the damages that can complement possible additional DALAs with ground validation. It presented an interesting problem in lack of information on ground, as with station data. The added issue of agricultural production and the importance of agricultural to the subsistence economy in the worst affected region created the need for a quick estimate of the scale of the disaster. The modeled loss approach offered an early estimate of the economic impact of the cyclone, which the government could use to start the recovery planning process.

A.4.1 Madagascar TTL Feedback

Michel Matera, TTL, reported the following:

> "I am strongly in favor of this approach as it gave us in record time a very good estimate of the economic losses, it immediately opened the door of the Ministry of Finance for discussion and provided a key input to the CMU for its discussion with [World] Bank management at the highest level. As the [World] Bank is trying to act more quickly in response to disasters, especially in regards to securing [Crisis Response Window] resources, for example, this approach can help build a strong rational for the [World] Bank's response. Of course, it does not replace a detailed assessment that is needed to design a response plan, but it allows the [World] Bank team to focus on the response planning without losing the big picture number."

Figure 12. Spatial distribution of damage and losses as percent of total exposed value to the agriculture sector after Cyclone Enawo in March 2017



Appendix B. Summary of Post-Disaster Damage Assessment Approaches

	Tool						
				Private Sector (Insurance)			
	GRADE	PDNA	DALA	RMS Event Response	AIR Alert Worldwide	PERILS AG	Reinsurers
Brief description	See report	The PDNA produces a single, consolidated report comprising an assessment and a recovery strategy. A PDNA encompasses three assessment perspectives: the valuation of physical damages and economic losses; the identification of impacts on affected people and their recovery needs; and macroeconomic, microeconomic, and human development impacts (World Bank, United Nations Development Programme/ UNDG, European Commission).	The Economic Commission for Latin America and the Caribbean DALA method captures the closest approximation of damage and losses due to hazardous events based on assessments of the overall economy of the affected country.	Following a major catastrophe, modelled and non-modelled industry loss ranges are provided to Licensed Users. Emphasis is on insured loss estimates.	An online service providing up-to-date information and loss estimates for major natural catastrophes occurring worldwide.	PERILS produces event insured loss information relating to qualifying Australian Catastrophe Models, Canadian Catastrophe Models, Europe Windstorm, Italy Earthquake and Italy Flood, UK Flood, Turkey Earthquake, and Turkey Flood events.	Reinsurers release loss estimates after events based on the total insured losses seen, media reports, and then a scaled-up loss figure.
Timeline	5–14 days	2–3 months on average	The assessment usually takes place at least 21 days after the impact of the hazardous event.	3–10 days	3–10 days	3-10 days for first assessment; final assessment one year after the event	3 days to 3 months
Cost (expert needs, etc.)	Up to 5 experts for 5 to 10 days each	Many surveys required; ground staff; onsite experience, baseline data collections, government interaction.	Many surveys required; ground staff; onsite experience, baseline data collections, government interaction.	Unknown, internal models, reconnaissance teams	Unknown, internal models	Unknown	Internal using insurance data; one expert with wider discussion
Data needs (open available data, expert judgment, satellite imagery, etc.)	Openly available data, government data, expert judgment, satellite imagery	Baseline data, census data, survey data, field visits, satellite imagery, official statistics.	Baseline data, census data, survey data, field visits, satellite imagery, official statistics.	Insurance exposure and loss data, as well as proprietary risk models	Insurance exposure and loss data, as well as proprietary risk models	Own industry exposure databases and insurance data (proprietary)	Own data as to insurance penetration

	Tool						
				Private Sector (Insurance)			
	GRADE	PDNA	DALA	RMS Event Response	AIR Alert Worldwide	PERILS AG	Reinsurers
Resolution and extent of modeling	Desk-based study, rapid analysis, housing, infrastructure and other important sectors	Sectoral breakdown, often also by province.	Sectoral breakdown, often also by province.	Single number with range	Single number with range	Single number, but with some breakdown, depending on the event	Disaster dependent, but generally a total economic loss and insured loss estimate (single number)
Outputs (what are the outputs)	Outputs include damage information to building stock (disaggregated); fatalities and economic loss information; exposure information; baseline data.	Damage as the replacement value of totally or partially destroyed physical assets; losses in the flows of the economy that arise from the temporary absence of the damaged assets; microeconomic and human development impacts; the resultant impact on post-disaster macroeconomic performance, with special reference to economic growth/GDP, the balance of payments, and fiscal situation of the government.	Damage as the replacement value of totally or partially destroyed physical assets; losses in the flows of the economy that arise from the temporary absence of the damaged assets; the resultant impact on post-disaster macroeconomic performance, with special reference to economic growth/GDP, the balance of payments, and fiscal situation of the government.	Economic loss, sometimes insured loss	Economic loss, sometimes insured loss	Economic losses (insured) for different occupancy data	Economic losses (insured and scaled-up uninsured portion)
Complementarity in terms of outputs	Own study	The results of the PDNA are used to inform governments and the stakeholders of the overall impact.	The amount of damage identified is used as the basis for estimating reconstruction needs, while the amount and type of losses identified provide the means to estimate the overall socioeconomic impact of the disaster and the needs for economic recovery.	If a more detailed version is released, a check of the model results.	If a more detailed version is released; a check of the model results.	This provides a baseline check for the total value of the event using insurance data and penetration.	If data come fast enough, this provides an additional "scale" of disaster.
Limitations	Desk-based study, rapid analysis, etc.	Speed of analysis and collection; detail required (also a positive)	Speed of analysis and collection; detail required (also a positive)	Proprietary, no methodology shown	Proprietary, no methodology shown	Proprietary, only where there is a big insurance event for key markets.	Proprietary, no clear methodology shown

	Tool						
	Academia (Universities and Research)				Nongovernment Organization - Rapid Loss Estimation Software Groups		
	CEDIM Forensic Disaster Analyses	Research Institutions and Universities	ARIA	Government Sectors	GDACS	QLARM, PAGER, EXTREMUM, CATDAT EQLIPSE	Aid Organizations/ ReliefWeb
Brief description	CEDIM Forensic Disaster Analyses encompass a group of around 30 researchers at Karlsruhe Institute of Technology and around the world. In the aftermath of disasters, a decision is made as to rapid or lengthened analysis implementation, cross-cutting various sectors to estimate the losses. The rapid analysis utilizes CATDAT EQLIPSE, a rapid disaster loss estimation tool.	Reconnaissance reports	ARIA is a JPL- and NASA-funded project being developed by JPL and Caltech. It is building an automated system for providing rapid and reliable GPS and satellite data to support the local, national and international hazard monitoring and response communities. Using space-based imagery of disasters, ARIA data products can provide rapid assessments of the geographic region impacted by a disaster, as well as detailed imaging of the locations where damage occurred.	Government Institutions provide loss estimates and data after events in their own countries	GDACS was created as a cooperation framework between the United Nations and the European Commission in 2004 to address significant gaps in information collection and analysis in the early phase of major sudden-onset disasters.	Rapid loss estimation software differ depending on the purpose for which they were established. PAGER, EXTREMUM, and QLARM look primarily at the issue of fatalities in earthquakes, as well as providing useful hazard assessments; CATDAT EQLIPSE produces fatality and economic loss estimates for a variety of perils. All software packages use empirical and analytical data to derive the losses of the event.	Aid organizations create situation reports in the aftermath of events, aggregating information from local sources; external sources, such as local networks; and attempts to create maps. These are displayed in a variety of portals, such as ReliefWeb, HDX, or PreventionWeb.
Timeline	1 day to 4 weeks after disaster	0 days to years after disaster	1 day to 2 weeks	Immediate to weeks depending on scale of disaster	Immediate to days	Immediate to days after (with adjustments of source parameters, etc.)	Immediate to as long as the event response is required
Cost (expert needs, etc.)	Personnel but no dedicated budget	Personnel, unknown	Personnel, unknown	Personnel, unknown	Unknown, much automated	Unknown	Unknown
Data needs (open available data, expert judgment, satellite imagery, etc.)	Own data, available data, free datasets, CATDAT	Own data, available data, free datasets	Own data, available data, baseline free	Own data, methods, survey data, internal data, models	Datasets from different institutions	Own data, datasets, exposure, station data	External data, own surveys, local contacts, social media

	Tool						
	Academia (Universities and Research)				Nongovernment Organization - Rapid Loss Estimation Software Groups		
	CEDIM Forensic Disaster Analyses	Research Institutions and Universities	ARIA	Government Sectors	GDACS	QLARM, PAGER, EXTREMUM, CATDAT EQLIPSE	Aid Organizations/ ReliefWeb
Resolution and extent of modeling	Desk-based study except for some field studies; rapid and detailed analysis	Desk and field surveys; ad hoc methods used.	Various resolutions; see https://aria.jpl.nasa.gov/products	Resolution differs but generally impact area related	Resolution differs depending on the peril.	Resolution differs depending on software package, but generally a summation of various units.	Resolution differs, but generally whatever scale is found.
Outputs (what are the outputs)	Deaths, injuries, socioeconomic effects, homelessness, recovery needs, economic effects, hazard details, model parameters	Differs depending on group	Hazard modeling and satellite-based damage assessment	Differs depending on the country (desk-based study except for some field studies, rapid sectoral analysis). Damage statistics by severity of damage (destroyed, partially damaged etc.), Loss estimates by affected sector	GDACS Disaster Alerts: automated estimates and risk analysis –provided by the European Commission JRC and the Global Flood Observatory. The Virtual OSOCC is an online platform for real-time information exchange and cooperation among all actors in the first phase of the disaster. Information updates from the affected country and international responders are moderated by a dedicated team. It is managed by the United Nations Office for the Coordination of Humanitarian Affairs. Maps and satellite imagery from various providers, including UNOSAT and MapAction, are shared on the Virtual OSOCC. The GDACS Satellite Mapping and Coordination System provides a communication and coordination platform.	Number of fatalities, sometimes homeless, and broad economic loss estimate	Number of fatalities, homelessness, shelter needs, recovery estimates, affected houses, critical infrastructure, humanitarian data
Complementarity in terms of outputs	Complementary in terms of personnel and methodology	Complementary in terms of personnel and methodology	Complementary in terms of satellite data analysis and providing additional information	Datasets including impact hazard maps from local seismological, meteorological measurements, station data, weather information, hazard components; exposure data including buildings	Complementary, but GDACS provides more rapid data, including JRC results, etc.	Outputs provide a quick check of the scale of the disaster, as well as datasets such as Shakemaps (from USGS), etc.	Useful ad hoc data for analysis. Ground-based data often from non-technical support.
Limitations	Desk-based study, which is time critical	Ad hoc, timelines differ, difficult to assess the quality	Satellite/remote-sensing based	Ad hoc depending on the country and the institution	Mostly population exposure and hazard data, and no loss information; modeled, rapid datasets	Generally only for earthquakes; three methods of which only the empirical method is released; more suited to fatality estimation rather than economic loss information	Ad hoc and the data are only sporadically available.

GFDRR

Global Facility for Disaster Reduction and Recovery

The Global Facility for Disaster Reduction and Recovery (GFDRR) is a global partnership that helps developing countries better understand and reduce their vulnerabilities to natural hazards and adapt to climate change. Working with over 400 local, national, regional, and international partners, GFDRR provides grant financing, technical assistance, training, and knowledge sharing activities to mainstream disaster and climate risk management in policies and strategies. Managed by the World Bank, GFDRR is supported by 33 countries and 11 international organizations.

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World Bank GSURR D-RAS KSB is a team of technical experts who carry out advisory and analytical services, including developing custom-built tools and solutions related to disaster risk management (DRM).

For more information on implementing recovery programs, please visit the GFDRR Recovery Hub:

https://www.gfdrr.org/recovery-hub