

A Review of the Global Rapid Post-Disaster Damage Estimation (GRADE) Assessments

The Frontier in Rapid Post-Disaster Damage Estimations for Developing Countries

2015 - 2024



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GFDRR
Global Facility for Disaster Reduction and Recovery



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Acronyms and Abbreviations

DaLA	Damage and Loss Assessment
FCV	Fragility, Conflict, and Violence
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GRADE	Global Rapid Post-Disaster Damage Estimation
PDNA	Post-disaster Damage and Needs Assessment
RINA	Rapid Impact and Needs Assessment
RPDNRA	Rapid Post-disaster Needs and Recovery assessment
TERRA	Türkiye Earthquakes Recovery and Reconstruction Assessment
UNOSAT	United Nations Satellite Centre
USD	United States Dollars
WASH	Water, Sanitation, and Hygiene

Glossary

Building typology	The classification of buildings based on their characteristics, such as their function, structure, style, age or other defined characteristics.
Damage	The destruction of physical assets.
Exposure	The people, property, and systems that could be affected by a disaster including the value of these assets.
Exposure at risk	A measure of the potential loss that is faced from a hazard.
Losses	The value of lost production or income.
Loss and damage	A term used to describe the negative consequences of climate change that cannot be avoided through adaptation or mitigation efforts.
Needs	The short, medium, and long-term needs for reconstruction and recovery.
Replacement cost	The cost to construct or replace an asset with equal quality and construction to its pre-disaster state.
Reconstruction cost	The cost to replicate the asset, at current construction prices, to current construction standards and quality.
Spatial resolution	The level of detail or the smallest unit that can be distinguished in an image, map, or analysis.
Tropical cyclones	Term which covers hurricanes, tropical storms, tropical cyclones, typhoons
Vernacular construction	Vernacular construction is a style of building that uses local materials and techniques to create structures that reflect the culture and environment of the region. Vernacular buildings are often simple, and can include homes, schools, and religious buildings.

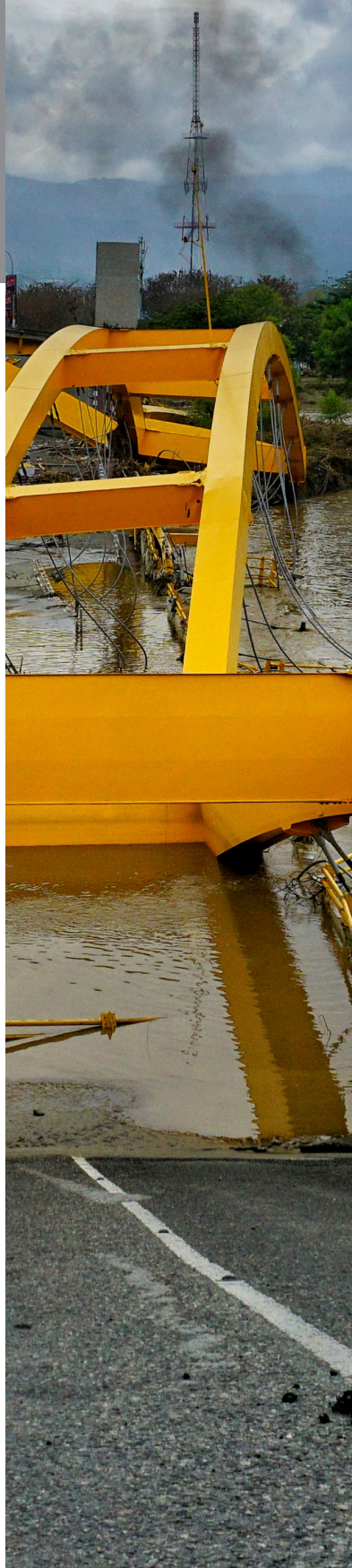


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Executive Summary

In the aftermath of disaster events, governments grapple with many challenging questions: What is the extent of the damage? What is the overall economic impact on buildings, infrastructure, or agriculture? What are the priorities for response and recovery? Reliable information can be difficult to obtain in the early days and weeks, hampering initial response and recovery efforts.

There is a need for rapid post-disaster damage assessments. Post-disaster needs assessments (PDNAs) (European Commission, World Bank, and UNDP 2013), damage and loss assessments (DaLAs) (Jovel and Mudahar 2010a; 2010b; 2010c), and other similar assessment methodologies are standard ways to assess post-disaster damages for high-consequence events in developing countries, but these assessments are often not completed until three to four months after a disaster occurs. In 2015, the World Bank first implemented the Global Rapid Post-Disaster Damage Estimation (GRADE) approach—a remote, desk-based methodology that addresses these critical questions much more quickly. Using risk-modeling expertise, structural engineering analyses, satellite and remote sensing data, drone footage, social media feeds, and disaster reporting, GRADE provides a swift estimate of direct economic damages to housing, non-residential buildings, infrastructure, and agriculture. GRADEs are not only cost effective (usually one-tenth the cost of a ground-based assessment), but also take an average of just 2.6 weeks after a disaster to complete.

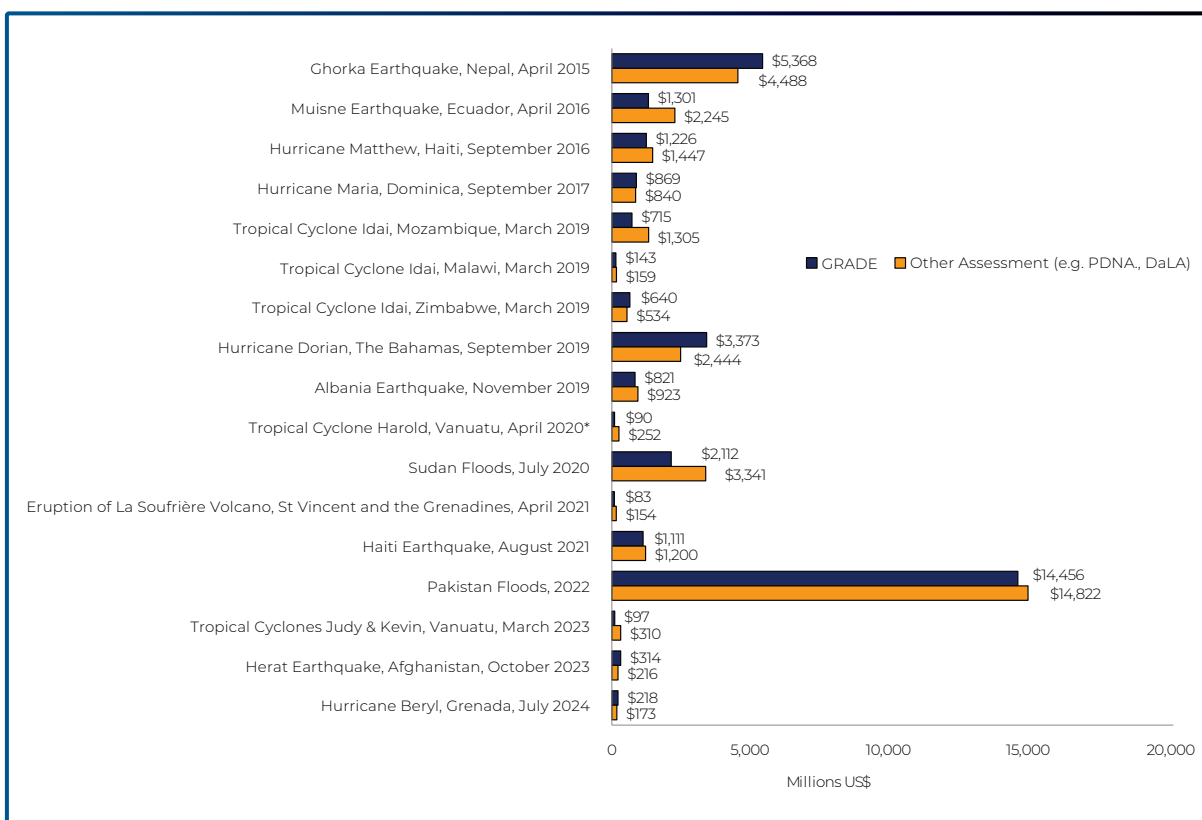
GRADE has grown continuously, going from strength to strength. Between 2015 and 2024, the GRADE methodology has been successfully deployed on 66 occasions in response to 62 disasters or events in 54 countries. (For some events, more than one GRADE was completed, for example, when the same event affected multiple countries, and some GRADEs have covered multiple events affecting one country.) As of November 2024, GRADE had responded to 11 major earthquakes, three volcanic eruptions, two human-induced disasters, 26 tropical cyclones¹, and 20 floods. GRADE has also been deployed for non-natural hazard events such as Russia’s invasion of Ukraine in 2022 and conflict in Ethiopia. Use of the GRADE methodology has become more frequent since 2020 because the COVID-19 pandemic resulted in lockdowns during which remote assessments had to be used. GRADE results have been used for post-disaster decision making not only by the World Bank, but also by governments and other development partners.

This report is a review of GRADEs conducted since 2015, and GRADE’s efficiency, comparative advantage through detailed analysis, and future. First, the GRADE approach and how it has been used and evolved since its inception are described, and the GRADE assessments conducted in the last 10 years are reviewed. It is expected that the resultant database of damage from 66 events will be critical for discussions about not only disaster risk management, but also climate resilience, including ongoing loss and damage dialogues. The in-depth case studies presented in this report—the 7.5-magnitude earthquake in Palu, Indonesia (September 2018); Tropical Cyclone Idai that affected Malawi, Mozambique, and Zimbabwe (March 2019); the situation in Ukraine at the end of March 2022; the 2022 floods in Pakistan; the Kahramanmaraş Türkiye earthquakes in February 2023; Category 5 Hurricane Beryl that hit Grenada in July 2024—demonstrate the strengths and flexibility of GRADE and its application, challenges, and lessons learned.

¹ “Tropical cyclone” is used here as a generic term including hurricanes, tropical cyclones and tropical storms regardless of where the system was observed.

The report then assesses the speed and accuracy of the GRADE approach by examining various post-disaster assessment methodologies and comparing GRADE with other detailed, on-the-ground post-disaster assessments such as PDNAs to assess the performance, accuracy, and reliability of GRADE results. For the analyzed events (17 comparable events for which a GRADE and a PDNA, DaLA, or other type of assessment were both completed), GRADEs were completed on average 12.4 weeks faster and within 88 to 90 percent accuracy of the estimated damages when compared like-for-like with other post-disaster assessment methodologies. Figure ES1 compares total estimated damages from these comparable events of GRADE and other post-disaster assessments. General overall alignment of results can be observed.

Figure ES1. Total Damages According to Global Rapid Post-Disaster Damage Estimation (GRADE) and Other Assessments for 17 Comparable Events



The differences in the results calculated using GRADE and PDNA are attributable to several factors, including key differences in the methodologies and approaches, data availability, time available for assessments, and categorization of damages and losses in different economic sectors. Although PDNAs, DaLAs, and related post-disaster assessments are well established and use detailed methodologies, a variety of factors drives inherent uncertainties in their results. Nevertheless, comparison of results can still provide insights into the performance of the GRADE methodology.

The demand for GRADE is increasing, so it is critical that it be improved and expanded to respond to government and World Bank team requests. Key focus areas include increasing the quality, availability, and usability of data; refining approaches by incorporating innovation and disruptive technologies; building new partnerships and increasing GRADE implementation capacity; and exploring additional analyses to expand GRADE's offer.

Introduction: The Need for Rapid Post-Disaster Damage Estimation



The economic impacts of disasters are vast, and the costs of disasters limit the growth and economic development of countries worldwide. Globally, between 2000 and 2024, the Emergency Events Database recorded 7,202 disaster events in developing countries that claimed approximately 1.25 million lives, affected more than 4.6 billion people (many on more than one occasion), and caused approximately U.S. dollars (USD) 1.48 trillion in economic losses—approximately one-third of total economic damages from disasters globally (in 2024 U.S. dollar values) (UNDRR 2020; CRED 2021; 2022; 2023; 2024). Trends clearly show that the cumulative global impacts of disasters in developing countries are increasing, exacerbated by many factors, including climate change, population growth, and urbanization.

The absolute costs of disasters are higher in developed countries, but in relative terms, disasters disproportionately affect poorer nations, which generally have less capacity to recover. Total direct economic damages estimated for 42 tropical cyclones as calculated using a post-disaster needs assessments (PDNA) or damage and loss assessment (DaLA) in developing countries² for events between 2000 and 2023 were USD 35.0 billion (not adjusted for inflation). However, as highlighted in section 4, their relative impacts are much bigger. The PDNA for the 2010 Haiti earthquake reported USD 4.53 billion in direct economic damages and USD 3.28 billion in losses,³ with housing accounting for 51.5 percent of the direct economic damages and 22.5 percent of the losses.

In the aftermath of disasters, governments and stakeholders must respond quickly to protect lives and manage the immediate recovery phase and medium-term reconstruction phase. To make the most effective decisions, the pressing questions that arise but that are challenging to answer include: What are the physical and economic impacts on housing, infrastructure, and other key sectors? What is the extent of the damage? Where are the damages greatest? How and where can emergency aid and resources be best distributed? What are the priorities for response, recovery, and reconstruction?

A range of development-focused stakeholders complete post-disaster damage assessments to help governments, response agencies, and other stakeholders address these questions so that they can mobilize resources quickly and effectively. Governments, the private sector, and international humanitarian agencies provide assessments that vary significantly in scope, detail, timeliness, geographic coverage, and methodology. As a result, the accuracy of assessments differs, especially in the developing world, where access to high-quality data is limited. Regardless of the challenges, demand for these types of assessments continues to increase as the scale and frequency of disasters increase, and further demand has been generated with the recent discussions on loss and damage.

The crux of the problem is the need for rapid, accurate, detailed assessments. After years of development, an innovative rapid post-disaster assessment methodology (Daniell et al. 2011a; 2011b; 2013) was used for the first time as part of the World Bank's response to the April 25, 2015, magnitude 7.8 earthquake in Nepal. The scale of damage and life loss, compounded by a lack of immediate data amidst continued aftershocks, underscored the urgent need for rapid damage assessments. The World Bank convened a team of technical

² Defined as high-income International Bank for Reconstruction and Development and International Development Agency lending countries and upper-middle-income, lower-middle income, and low-income countries as defined according to the World Bank in the year of the event. (See the World Bank Data Help Desk, World Bank Country and Lending Groups, <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>.)

³ These sums would be equivalent to USD 6.2 billion in damages and USD 4.5 billion in losses when inflated to 2024 U.S. dollars.

experts, who used internal and publicly available data and innovative risk-modeling techniques to assess the damage virtually. Within a week of the earthquake, the team produced an initial damage estimate that closely matched assessments that reported damage more than one month later⁴. Since then, the Global Rapid Post-Disaster Damage Estimation (GRADE) approach (GFDRR 2018a) has been deployed on multiple occasions to cover a wide range of disasters around the world, with results feeding into post-disaster decision making within the World Bank, national governments, and the wider development and humanitarian communities.

This report was written to provide more detail on GRADE, how it has been used and how it has evolved since its inception. It also reviews GRADE's performance by comparing it with other types of assessments. An overview of how and where GRADE has been deployed and how it has evolved since 2015 is provided in Section 2. Section 3 presents case studies and examples of GRADE in action. GRADE results are compared with those of PDNAs, DaLAs and other assessment methodologies in Section 4 to assess GRADE's performance, followed by details of the challenges and uncertainties associated with GRADE in Section 5. Section 6 examines opportunities for improvement, highlights possible innovations for GRADE, and discusses how to manage anticipated future challenges. For greater depth and detail, five appendices are also included.

Appendix A lists all 66 GRADE assessments, the dates of the events, the dates of GRADE completion, and completion times.

Appendix B is a repository dataset of total and sectoral estimated damages for each of the 66 GRADE assessments.

Appendix C is a selected list of GRADE assessments that highlights key innovations implemented and challenges encountered.

Appendix D is a list of 17 PDNAs or other types of assessments that coincided with GRADEs, including reported damages according to sector.

Appendix E provides a detailed analysis and discussion of the differences in results between GRADE and PDNA and other assessment types for cases in which differences were exceptionally large, according to sector.

⁴ During the 2015 earthquake in Nepal, just over 9,000 people were dead or missing, in addition around 104,000 people who were injured, of which around 20,700 people were seriously injured. About 499,000 houses were destroyed and 257,000 damaged. (2015 Nepal Earthquake Post-Disaster Needs Assessment, Vol. A, Key Findings).

Overview of GRADE



2.1. What GRADE is and who delivers it

Using a remote, desk-based methodology, GRADE addresses many of the critical questions that arise after a disaster by estimating physical damage to housing, non-residential buildings, infrastructure, and agriculture within an average of 2.6 weeks after an event.⁵ The methodology uses disaster risk-modeling techniques (typically used by the global (re) insurance industry); historical and damage data reported about the event; engineering, census, and socioeconomic survey data; satellite imagery; drone footage; and social media feeds to quantify damage estimates at a high level of detail.

The GRADE approach has evolved to deliver two products that respond to different situations and requests.

- ◆ The **full GRADE** is a detailed analysis that provides client countries with a rapid, accurate assessment of direct economic damage to key sectors. Geospatial damage distribution is also presented.
- ◆ The **GRADE Note** is a simplified version of the full GRADE assessment using simpler modeling techniques, coarser datasets, and faster calibration and validation processes. Although the GRADE Note maintains a high level of technical rigor, it simplifies the analytical and modeling work to reduce the time and resources required. As a more concise assessment, the GRADE Note provides information on direct economic damages to key sectors and geospatial damage distribution, where possible.

A full GRADE is conducted when a disaster has occurred that has caused substantial damage and is required for external, client-facing work. The GRADE Note is used when derivation of damage estimates is focused more on historical events and reported damages than use of sophisticated modeling techniques; GRADE results are required but for smaller-scale disaster event impacts; or GRADE results are to be shared internally in the World Bank to help develop or support specific World Bank products, projects, or actions. GRADE assessments are fast and cost effective (usually one-tenth the cost of a ground-based assessment). The estimated time frames and costs associated with a full GRADE and a GRADE Note are presented in Table 1.

⁵ 2.6 weeks is the mean time from the event occurring to completion of a GRADE for an event that is not prolonged (e.g., flood).

Table 1. Comparison of Global Rapid Post-Disaster Damage Estimation (GRADE) Products

Product	Days required	Cost (USD)	Example	Application
Full GRADE	14–21	50,000 – 75,000	2024 floods, Bangladesh	Client engagement Inform Emergency Response Projects World Bank-Funded Operation
GRADE Note	8 – 10	25,000	2024 Bujumbura Floods, Burundi	International Development Agency Crisis Response Window eligibility note Donor meeting Client engagement Inform post-disaster damage and needs assessment

The GRADE methodology continues to incorporate innovations. In exceptional circumstances, if a full GRADE or GRADE Note was not suitable or possible, it has sometimes been possible to use a GRADE Zero approach. This is a relatively new addition that remains under development and is rarely used. It can offer insights more from an advisory perspective than from an analytical one. It may also be more suitable for smaller or more localized disasters or disasters without enough data to complete a full GRADE or GRADE Note. It provides a high-level estimate of disaster impacts, with much simpler analyses of direct economic damages without any breakdowns of key sectors. A report is not developed because of time constraints, but country teams can develop one if desired. The results can be used to inform World Bank task team leaders or country management units on the immediate post-disaster actions they need to take. To conduct a GRADE on these rapid timelines, the task team must consist of 10 to 15 highly skilled disaster risk management experts with skillsets including extensive experience in hazard modeling, civil and structural engineering, risk modeling, insurance and financial impact modeling, social development, and geoscience. The task team must also work interdisciplinarily in exceptionally close collaboration.

2.2. How is a GRADE conducted?

- ◆ **Each GRADE differs in location, nature, impact, scale, severity, and complexity.** Significant planning and management are needed to ensure that each GRADE is adapted to the context and requirements. The GRADE methodology has several key elements (GFDRR, 2018a):
- ◆ **Hazard modeling**, including analysis of the location and intensity of the disaster and review of related datasets that can act as hazard modifiers, such as type of terrain, land use, soil type, and soil moisture levels
- ◆ An **exposure value assessment**, including population, housing according to structural characteristics and related cost of construction, non-residential buildings, key infrastructure, gross capital stock, agricultural production, and regional gross domestic product (GDP)

- ◆ An **assessment of the vulnerability** of various assets to the hazards, including use of early information received from relief communities for calibration validation (e.g., remotely sensed damage, drone and other video footage, building safety assessment reports)
- ◆ **Calibration against observation**, which involves analyzing interim damage estimates and reports received from government agencies, relief organizations, and the media to test the modeled results against observed or reported conditions
- ◆ **Calibration against comparable or similar historical events** to test the realistic range of results and place the current event into the relevant context of the country and region
- ◆ A **summary of impact**, with priority given to assessment of likely costs associated with damage to property, critical infrastructure, and key production sectors, as well as social impacts, including fatalities, displaced people, and references to local reports of socioeconomic impacts
- ◆ A **validation assessment** of likely damages and consequences calibrated against data from previous comparable historical events

The World Bank country management units and disaster risk management regional teams and experts are valuable resources throughout the GRADE process, helping calibrate and sense-check datasets and results. They also examine the technical content to ensure that it best serves local needs and promote the GRADE report with governments and development partners to increase its impact.

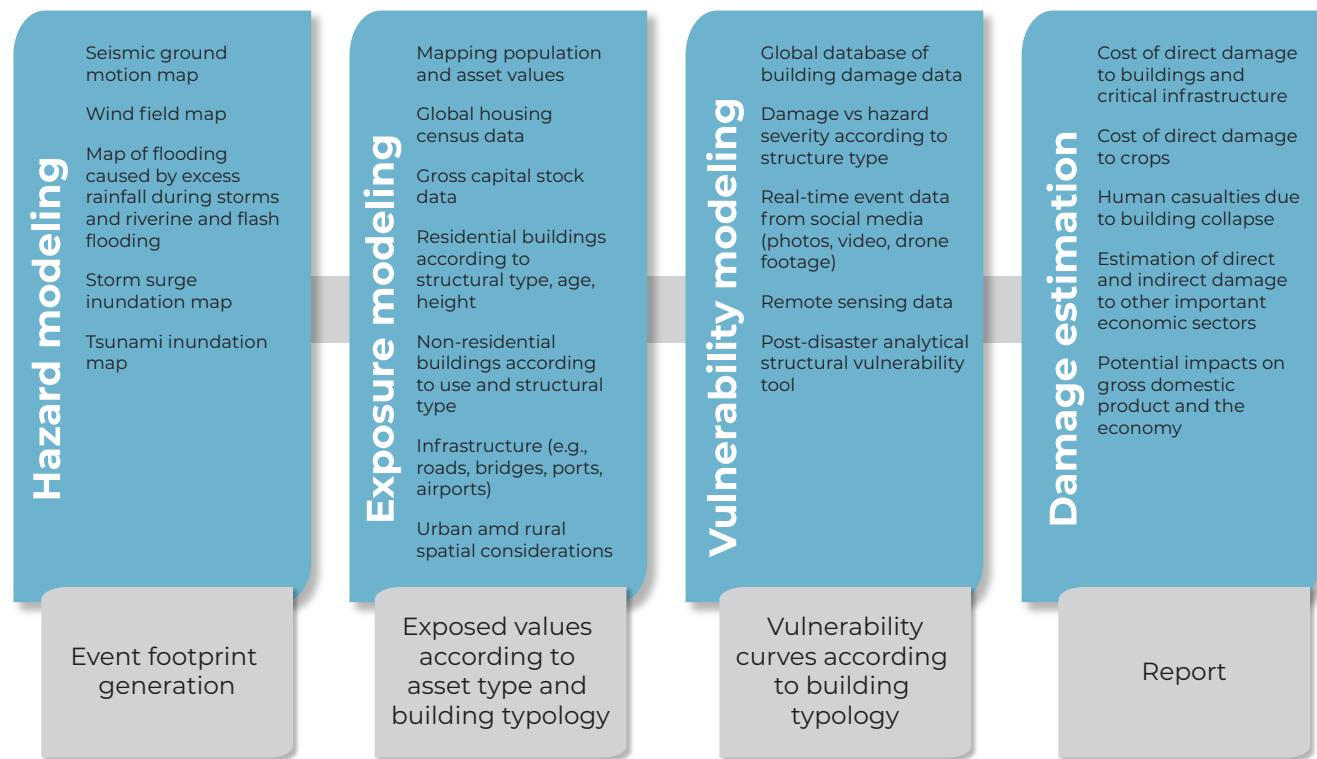
Results are presented in the form of a report that details the event, the analysis, the findings, damage estimations according to sector, geographic distribution of the damages, and recommendations for recovery.

The GRADE methodology is inherently flexible and as such could be used to deliver results for a wide range of damaging events and situations given adequate data and resources. Over the years since GRADE's inception, some automation has been built in to reduce the resource intensity of the process, although it relies heavily on expert judgement that to date cannot be automated.

There are situations or contexts to which the GRADE methodology is not well suited. Geographically limited events (e.g., landslides) can be difficult for GRADE to model accurately, especially if good-quality data are scarce, so larger-scale events have been the focus.

Figure 1 provides an overview of the methodological steps taken during a GRADE assessment.

Figure 1. Global Rapid Post-Disaster Damage Estimation Methodology



2.3. How GRADE fits with other post-disaster assessments

The GRADE methodology complements well-established methodologies as a faster, less-resource-intensive assessment covering fewer sectors and delivering damage estimations only (not losses or needs). Some methodologies have been used for many years. For example, the PDNA is a collaborative effort between national governments, the United Nations Development Group, the World Bank, and the European Union; and the Economic Commission for Latin America and the Caribbean developed the DaLA in the 1970s. The PDNA and DaLA approaches deliver a comprehensive report that, in some cases, extends to damages, losses, and needs in key sectors and remain the standard field-based assessment methodologies for high-impact disasters in developing countries. Other methodologies exist, including the Rapid Post-Disaster Needs and Recovery Assessment (RPDNRA), which was used for flooding in Sudan in 2021 (Government of Sudan 2021) and was adapted from the PDNA methodology to better suit the development context in the country. The Rapid Impact Needs Assessment (RINA) methodology, used in Zimbabwe after Cyclone Idai in 2019 (Government of Zimbabwe 2019), was a remote assessment exercise that relied on remote sensing and data from the government and UN agencies.

Many challenges are encountered in conducting post-disaster damage assessments.

The key challenge is that field-based assessments tend to be completed months after a disaster, which makes it difficult for decision makers, who require information and results quickly. PDNAs and DaLAs often require agreement from multiple agencies and the government and must mobilize people locally, although these assessments can sometimes be conducted more rapidly when single agencies take the lead. GRADE has been developed to respond to the need to deliver good-quality results more quickly. Table 2 provides an overview and comparison of the key development-focused post-disaster assessment tools.

Table 2. *Development-Focused Post-Disaster Tools*

Tool	Provider	Description	Estimated time duration to complete	Resources and effort required	Limitations
Global Rapid Post-Disaster Damage Estimation	World Bank	A remote, desk-based approach that estimates physical damage to housing, non-residential buildings, infrastructure, and agriculture.	7-21 days (average 2.6 weeks)	Up to 15 experts for 7-21 days each	Considers damage only, not losses or needs
Post-Disaster Needs Assessment	National governments in coordination with the European Commission, United Nations Development Programme, and World Bank	An approach that produces a single consolidated report comprising assessments of damages and losses for key sectors and a recovery strategy and encompasses three assessment perspectives: valuation of physical damage and economic loss, identification of impacts on affected people and their recovery needs, and macro- and microeconomic and human development impacts	30-90+ days	Multiple surveys, ground staff, local context expertise, baseline data collection, government and other stakeholder liaison	Speed of completion; cost of assessment
Damage and Loss Assessment	National governments in coordination with United Nations Economic Commission for Latin America and the Caribbean	A methodology that captures the closest approximation of damages and losses due to a hazardous event based on assessments of the overall economy of the affected country	30-90+ days	Multiple surveys, ground staff, local context experience, baseline data collection, government and other stakeholder liaison	Speed of completion; cost of assessment

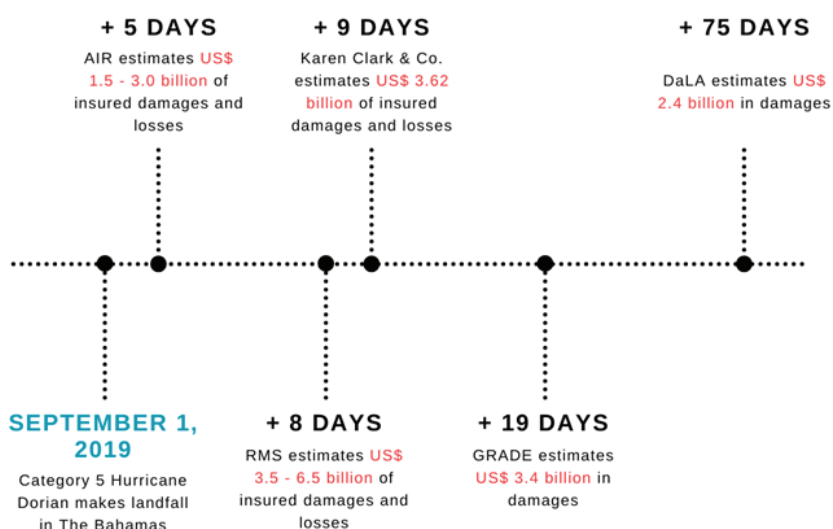
Note: For a more detailed comparison of existing post-disaster damage assessments, see the Global Rapid Post-Disaster Damage Estimation methodology report, which shows the long time and lower precision of other existing rapid assessment tools and the new technologies available that have enabled new solutions to be developed to address old problems (GFDRR, 2018a).

It is important to consider the definitions of damage and loss for different methodologies when using the results of different assessments. The GRADE methodology defines damages as the cost of direct economic damage to physical assets and uses replacement costs for like-for-like reconstruction, excluding costs associated with building back better. The PDNA methodology defines damage similarly, as the partial or total physical destruction of physical assets and infrastructure (e.g., number, surface area) in the affected areas and in terms of monetary value, expressed as replacement cost based on prices just before and after the disaster (European Commission, World Bank, and UNDP 2013). In addition, the PDNA methodology goes one step further than GRADE, calculating reconstruction costs using replacement cost estimation and adding costs for post-disaster price alterations and improvements to assets associated with risk reduction and the concept of building back better.

Although GRADE does not estimate losses, the PDNA defines losses as change in economic flows as a result of the disaster in monetary values. Unexpected expenditures for humanitarian needs in the recovery phase are also included as losses (European Commission, World Bank, and UNDP 2013). The GRADE and PDNA methodologies assign damages and losses in the agricultural sector differently. This is discussed in more detail in Section 4.3.1.

The private sector also conducts rapid damage assessments, although there are limitations on their use in the public sector. Specialized companies in the private sector such as developers of commercial catastrophe-risk models produce post-disaster analyses that can be useful, although they tend to be available only to their clients, address insured losses only (which tend to be far less in developing countries), or have no published methodology. Examples of this include Global Event Response from Moody's RMS,⁶ which provides loss ranges focusing on insured loss estimates within three to ten days but only to licensed users, and Verisk Alert, which provides loss estimates for major natural catastrophes within three to ten days, but their methodology is proprietary and therefore opaque. Damage estimates from these companies are often delivered on similar timelines as GRADE, although there is considerable uncertainty and differences in the focus of these estimates. For example, with Hurricane Dorian, which hit The Bahamas in 2019, estimates of insured damages and losses from insurance-focused modelers ranged from USD 1.5 billion to USD 6.5 billion, whereas the GRADE and DaLA estimates were USD 3.4 billion and USD 2.4 billion in total economic damages, respectively. These estimates and the amount of time taken to develop them are given in Figure 2. These estimates highlight the degree of uncertainty in the immediate aftermath of an event, although without being able to analyze the methodologies and data, the causes of these ranges are unknown. The difference in focus of the private sector and development actors is also clear, with insurance models that focus on different parts of losses (depending on what they have insured; e.g., business interruption), whereas development-focused assessments cover impacts on public and private assets regardless of insurance coverage.

Figure 2 Insured Damage and Loss Estimates from Various Organizations for The Bahamas after Hurricane Dorian in September 2019



Note: AIR is now known as Verisk.

⁶ . See Moody's at <https://www.rms.com/event-response>.

2.4. How GRADE has been used and has evolved since its inception

The challenges with private sector work are that less attention is paid to events in parts of the developing world where the proportion of insured assets against non-insured assets tends to be very low. Similarly, some hurricane models focus on wind damage, but during major hurricanes, the effects of storm surge, flooding, and rain intrusion are also substantial, and insurance coverage of these associated hazards may be insufficient. In addition, the openness of models, methodologies, and results from these sources can be limited because they are proprietary.

GRADE was successfully deployed on 66 occasions in 54 countries affected by 62 events between April 2015 and November 2024 (Figure 3). Figure 4 shows the number of GRADEs that have been conducted since 2015 and shows the evolution from being used only for earthquakes and tropical cyclones between 2015 and 2017 to include volcanic eruptions in 2018, floods in 2019, and human-induced events in 2022.

Figure 3. Summary of Global Rapid Post-Disaster Damage Estimations (GRADEs) Completed between 2015 and November 2024

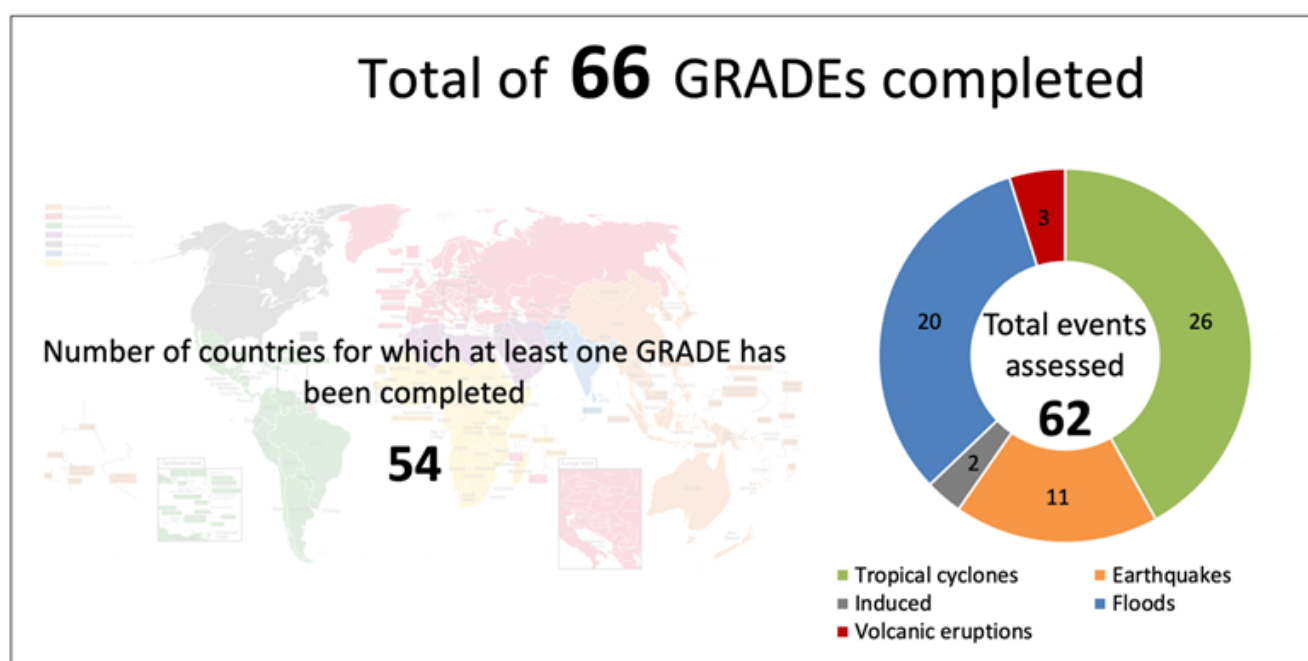


Figure 4. Global Rapid Post-Disaster Damage Estimation Assessments Completed between 2015 and November 2024 According to Event Type

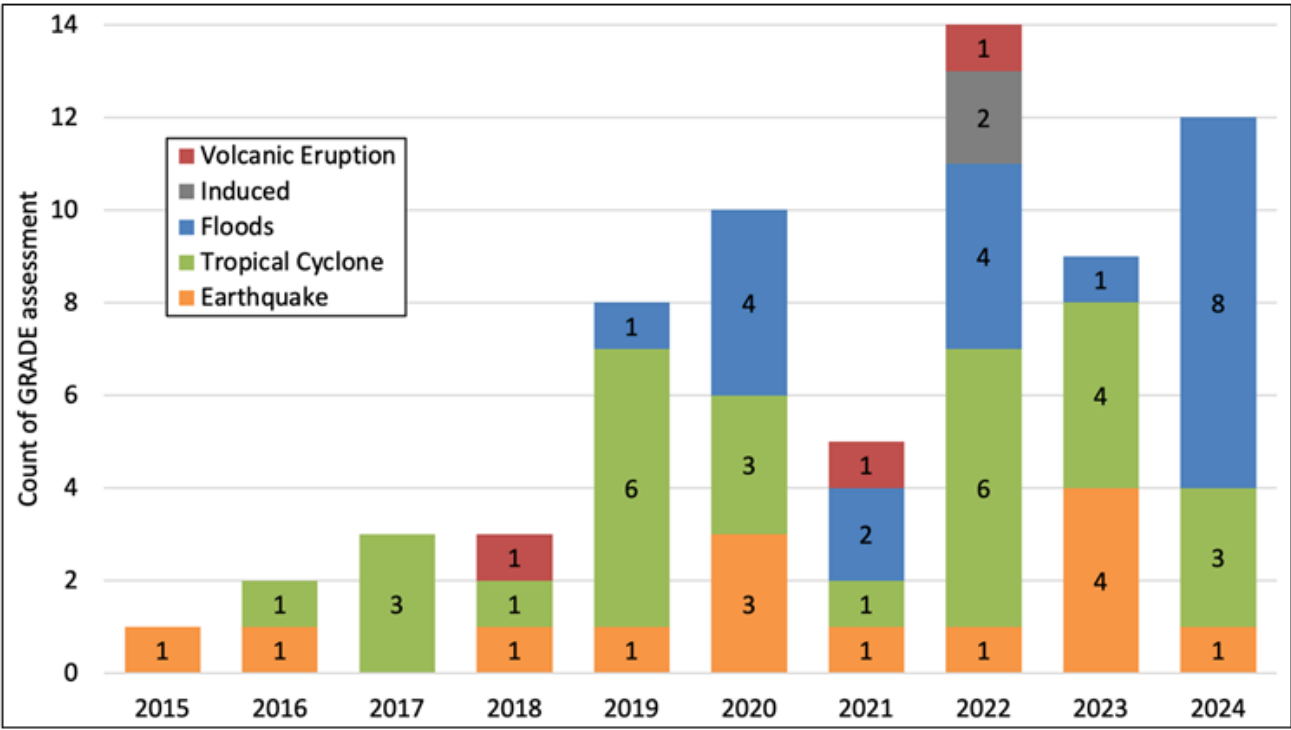


Table 3 summarizes GRADE assessments according to geographic region, showing the global reach of GRADE, with countries in Africa being assessed most frequently (23 times). There are multiple GRADEs for the same disaster if multiple countries are affected, although one GRADE was completed for Hurricane Irma in 2017 that combined the impacts on multiple countries and one GRADE for Madagascar, which experienced four storm events between January and February 2022.

Table 3. Global Rapid Post-Disaster Damage Estimation (GRADE) Assessments According to Region, Country, Year, and Type of Event, April 2015 to November 2024

Region	Earthquakes (13 total)	Tropical Cyclones (28 total)	Floods (20 total)	Volcanic eruptions (3 total)	Induced (2 total)
Latin America and Caribbean (13 total)	Muisne, Ecuador (2016) Tiburón Peninsula, Haiti (2021)	Matthew: Haiti (2016) Irma: Leeward Islands, Caribbean (2017) María: Dominica (2017) Dorian: The Bahamas (2019) Eta and Iota: Nicaragua (2020) Fiona: Dominican Republic (2022) Beryl: Grenada (2024) Beryl: Saint Vincent and the Grenadines (2024)	Rio Grande do Sul, Brazil (2024)	Fuego, Guatemala (2018) La Soufrière, Saint Vincent and the Grenadines (2021)	
East Asia and Pacific (9 total)	Sulawesi, Indonesia (2018)	Harold: Vanuatu (2020) Yasa: Fiji (2020) Judy and Kevin: Vanuatu (2023) Mocha: Myanmar (2023)	Myanmar (2019) Cambodia (2021) Thailand (2024)	Hunga Tonga-Hunga Ha'apai, Tonga (2022)	

Region	Earthquakes (13 total)	Tropical Cyclones (28 total)	Floods (20 total)	Volcanic eruptions (3 total)	Induced (2 total)
Africa (23 total)		Enawo: Madagascar (2017) Ava: Madagascar (2018) Idai: Malawi Mozambique, Zimbabwe (2019) Kenneth : Comoros, Mozambique (2019) Eloise: Mozambique (2021) Ana: Madagascar, Malawi, Mozambique, Zimbabwe (2022) Batsirai, Dumako, and Emnati: Madagascar (2022) Gombe: Mozambique (2022) Freddy: Mozambique (2023) Gamane: Madagascar (2024)	Niger (2020) Sudan (2020) South Sudan (2021) Nigeria (2022) South Sudan (2022) Democratic Republic of Congo (2023/4) Burundi (2024)		Ethiopia (2022)
South Asia (7 total)	Ghorka, Nepal (2015) Paktika, Afghanistan (2022) Herat, Afghanistan (2023)		Afghanistan (2020) Pakistan (2020) Pakistan (2022) Bangladesh (2024)		
Europe and Central Asia (9 total)	Durrës, Albania (2019) Aegean Sea, Greece (2020) Zagreb, Croatia (2020) Aegean Sea, Türkiye (2020) Kahramanmaras, Türkiye (2023)		Southeastern Europe (2023) Bosnia and Herzegovina (2024) Kazakhstan (2024)		Ukraine (2022)
Middle East and North Africa (5 total)	Kahramanmaras, NW Syria (2023) Al Haouz, Morocco (2023)	Tej, Yemen (2023)	Yemen (2022) Yemen (2024)		

The GRADE for Hurricane Irma combined impacts on Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Saint Barthélemy, Saint Martin, Sint Maarten, Turks and Caicos, U.S. Virgin Islands.

The GRADE methodology became even more pertinent with the onset of COVID-19 pandemic-related lockdowns and social distancing measures. When disasters occurred, field-based assessments became difficult, if not impossible, to conduct because of lockdowns and restrictions on travel. The GRADE assessments for the Zagreb and Aegean Sea earthquakes (March and October 2020, respectively); Tropical Cyclone Harold in Vanuatu (April 2020); floods in Afghanistan, Niger, Pakistan, and Sudan (August to October 2020); Tropical Cyclone Yasa in Fiji (December 2020), and the eruption of the Hunga Tonga-Hunga Ha’apai volcano in Tonga (January 2022) highlighted the value of being able to conduct GRADE remotely because international visitors to the disaster zones were severely restricted. Appendix A contains more details on all GRADEs, dates of the events, dates of GRADE completion, and completion times, and Appendix B contains a complete list of total and sectoral estimated damages for each of the 66 GRADE assessments. These tables highlight the efficiency and detail of the GRADE assessments.

GRADE has continuously evolved since inception — growing to include different types of disaster events, further innovations, and more data sources. The evolution has been gradual, with each event, but some of the more notable developments are described below and in Table 4 and Appendix C.

Table 4. *Global Rapid Post-Disaster Damage Estimation's (GRADE's) Key Developments, Innovations, Challenges, and Limitations*

Date	Event	Hazard types	Developments & innovations	Challenges and limitations
April 2015	Gorkha Earthquake (Nepal)	Ground shaking, landslides	Developed model to estimate number of fatalities and use of damage information alongside exposure for vulnerability modeling	Numerous landslides with uncertain impact on lives
September 2018	Central Sulawesi-Palu earthquake (Indonesia)	Fault rupture, ground shaking, tsunami, rapid mudslides	Developed an event impact demonstration using Google Earth using video, photos, and voice over	One event with four types of hazards and damage mechanisms that required multiple hazard and vulnerability models
March 2019	Tropical Cyclone Idai (Malawi, Mozambique, Zimbabwe)	Flooding, wind	Analyzed duration and depth of flooding using remote-sensed flood footprints in conjunction with digital elevation model to estimate flood depth and consecutive imagery for estimation of flood duration. Developed agricultural exposure to assess damages to agricultural sector for first time. Demonstrated use of online R-Shiny tool to visualize damages geographically for first time	Flood footprints difficult to access rapidly and often contradictory between different sources, limited information on depth and velocity of flooding, multi-country event of high consequence
September 2019	Hurricane Dorian (The Bahamas)	Storm surge, wind action	Employed Bayesian updating methodology using social media imagery to develop wind vulnerability curves	Difficult to model informal settlements next to high-end, hurricane-resistant properties; damage data unavailable
August 2020	Floods (Sudan)	Pluvial flooding	Introduced GRADE Note, developed within one week	Uncertainty of results because of long duration, high impact flood event (longer than two months) affecting entire country with different levels of severity
February 2022	Tropical cyclones Ana, Batsirai, Dumako, and Emnati (Madagascar)	Flooding, wind	Analyzed and delivered GRADEs for multiple consecutive events (four) that occurred in January and February 2022	Fathom flood footprints unavailable, satellite flood maps used which probably missed 30% of affected areas

Date	Event	Hazard types	Developments & innovations	Challenges and limitations
March 2022	Ukraine	Induced	Assessed direct economic damages from non-natural hazard for first time	Difficult to develop pre-event baseline exposure for buildings and infrastructure; challenging to gather damage data to housing and other buildings as well as to roads, bridges, railways, and other critical infrastructure in a timely manner; results limited to the initial five and a half weeks of ongoing situation.
February 2023	Earthquake (Türkiye)	Ground shaking	A combined ShakeMap developed for two major earthquakes (magnitudes 7.8 and 7.5) and several aftershocks of greater than magnitude 6	Uncertainty about human-induced damage prior to the earthquakes, including previously demolished structures. Challenges due to the lack of information on performance of the building stock, buildings costs and unit costs of construction and building content value.
July 2024	Hurricane Beryl (Grenada)	Wind	Used building-by-building virtual surveying data to calibrate damage estimations for first time	Challenges with searching for and management of substantial quantities of imagery used for virtual surveys. Challenges with biased collections of imagery as most persons take photos or videos in areas of more damage.

The first application of GRADE was for the magnitude 7.8 Gorkha Earthquake in Nepal in April 2015, where it was used to model fatalities and estimate damages using damage reporting and existing vulnerability exposure data. Widespread landslides were not included in the GRADE assessment, which created uncertainty regarding total impacts on lives and damage estimations and complicated the process.

Three years later, the magnitude 7.5 Central Sulawesi-Palu Earthquake in Indonesia in September 2018 involved a combination of impacts from fault rupture, ground shaking, tsunami, and mudflows. For the first time, the GRADE assessment used multiple hazard and vulnerability models to obtain accurate estimates of the impacts. Another notable innovation of the GRADE assessment for this event was in the development and use of enhanced communication tools with the creation of an impact demonstration tool using Google Earth that integrated videos, photos, and voiceovers to communicate the complex impacts of the event and the GRADE results internally at the World Bank.

In March 2019, Cyclone Idai hit Malawi, Mozambique, and Zimbabwe, and the GRADE assessment analyzed flood duration and depth using remote-sensed flood footprints and digital elevation models for the first time. In addition, given the widescale agricultural impacts, it was the first time that agricultural damages were assessed. Damages were visualized geographically using an online tool called R-Shiny. Challenges arose from delayed, inconsistent flood footprint data; limited information on flood velocity and depth; and the multi-country scope of the disaster.

Statistical approaches such as Bayesian updating techniques were first used for improving vulnerability functions for the GRADE for Category 5 Hurricane Dorian in The Bahamas in 2019. Improvements to vulnerability functions could be made after reviewing damage to different building typologies using imagery from social media (de Bruijn, J. A. et al., 2020). There were challenges with this approach in areas of informal settlements close to well-constructed buildings.

GRADE was used for a series of four tropical cyclones in Madagascar in 2022, which was the first time an assessment was conducted for multiple, consecutive, interacting events. The same principles were used for consecutive earthquakes in Türkiye in February 2023 but with the development of combined ShakeMaps with the compound hazard from the magnitude 7.8 and 7.5 earthquakes.

Virtual damage surveying was used for the first time as part of a GRADE after Hurricane Beryl in Grenada in 2024 to improve exposure and vulnerability assessments of wind damage. It is an excellent damage assessment technique, although it does not have many applicable contexts for which GRADE could use it. A smaller affected area and the availability of large quantities of high-quality imagery are required for this technique to be possible, and these were not encountered during GRADEs before Hurricane Beryl in Grenada in July 2024.

The first GRADE developed for a non-natural disaster was for Ukraine in 2022, followed by a GRADE assessment for the Tigray conflict in Ethiopia later the same year.

These innovations support GRADE, and various development partners have used results to raise and allocate financing to aid disaster response, recovery, and reconstruction. Within the World Bank, GRADE assessments have helped countries in Africa leverage USD 1.74 billion from the International Development Agency Crisis Response Window (Table 5), which has enabled financing to be released quickly to support recovery, response, and reconstruction after disasters.

Table 5. Allocations from the International Development Agency Crisis Response Window after Global Rapid Post-Disaster Damage Estimation (GRADE) Assessments

Event	GRADE Damage Estimate	Allocation from Crisis Response Window
	USD million	
Tropical Cyclone Idai, Mozambique (2019)	715	350
Tropical Cyclone Idai, Malawi (2019)	143	120
Tropical Cyclone Idai, Zimbabwe (2019)	640	75
Tropical Cyclone Kenneth, Comoros (2019)	99	45
Tropical Cyclone Kenneth, Mozambique (2019)	95	40
Floods, Niger (2020)	194	100
Floods, South Sudan (2021)	671	100
Floods, South Sudan (2022)	515	100
Tropical cyclones Ana and Gombe, Mozambique (2022)	596	300
Tropical cyclone Ana, Malawi (2022)	256	60
Tropical cyclones Ana, Batsirai, Dumako, and Emnati, Madagascar (2022)	657	250
Floods, Democratic Republic of Congo (2023)	1,313	200
Total		1,740

Clean up after the 2024 floods in Chiang Rai, Thailand. Photo credit: Anurak Sirithep / Shutterstock.com



GRADE in Action

3

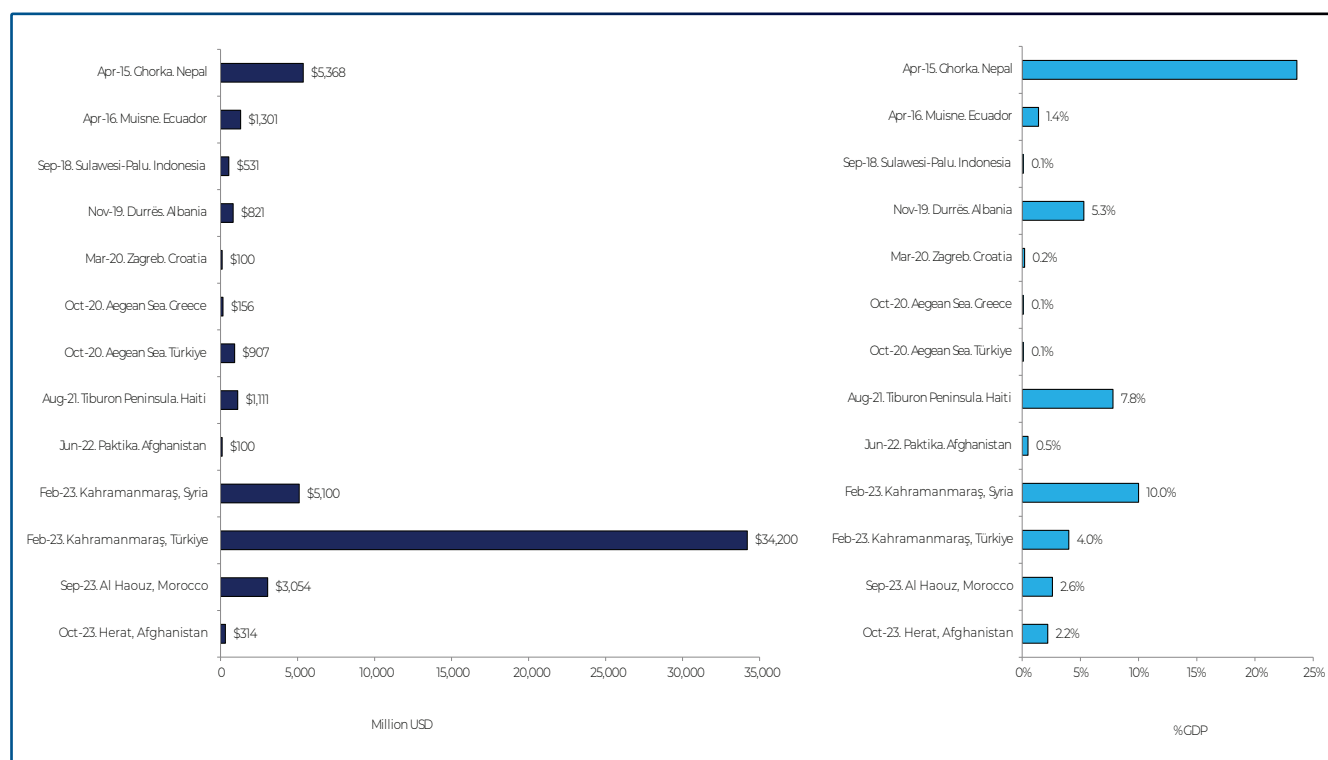
The GRADE approach has been used since 2015 to conduct disaster damage assessments worldwide, showcasing its versatility in application and ability to assess damages across a diverse range of crises. This section highlights the most compelling findings and explores select case studies to illustrate the depth and significance of the work accomplished.

3.1. Headline results from completed GRADEs

3.1.1. Earthquakes

Figure 5 shows direct economic damages from 11 major earthquakes that occurred between April 2015 and November 2024, affecting 13 countries, estimated by GRADE in USD million and percentage of a country's GDP. Thirteen earthquake-related GRADEs have been conducted because the 2023 earthquake in southern Türkiye also affected Syria, and the 2020 earthquake in the Aegean Sea affected Greece and Türkiye.

Figure 5. Total Direct Economic Damages to Physical Assets from Earthquakes Estimated Using Global Rapid Post-Disaster Damage Estimation (GRADE) between April 2015 and November 2024: (A) USD Million and (B) Percentage of a Country's Gross Domestic Product (GDP).

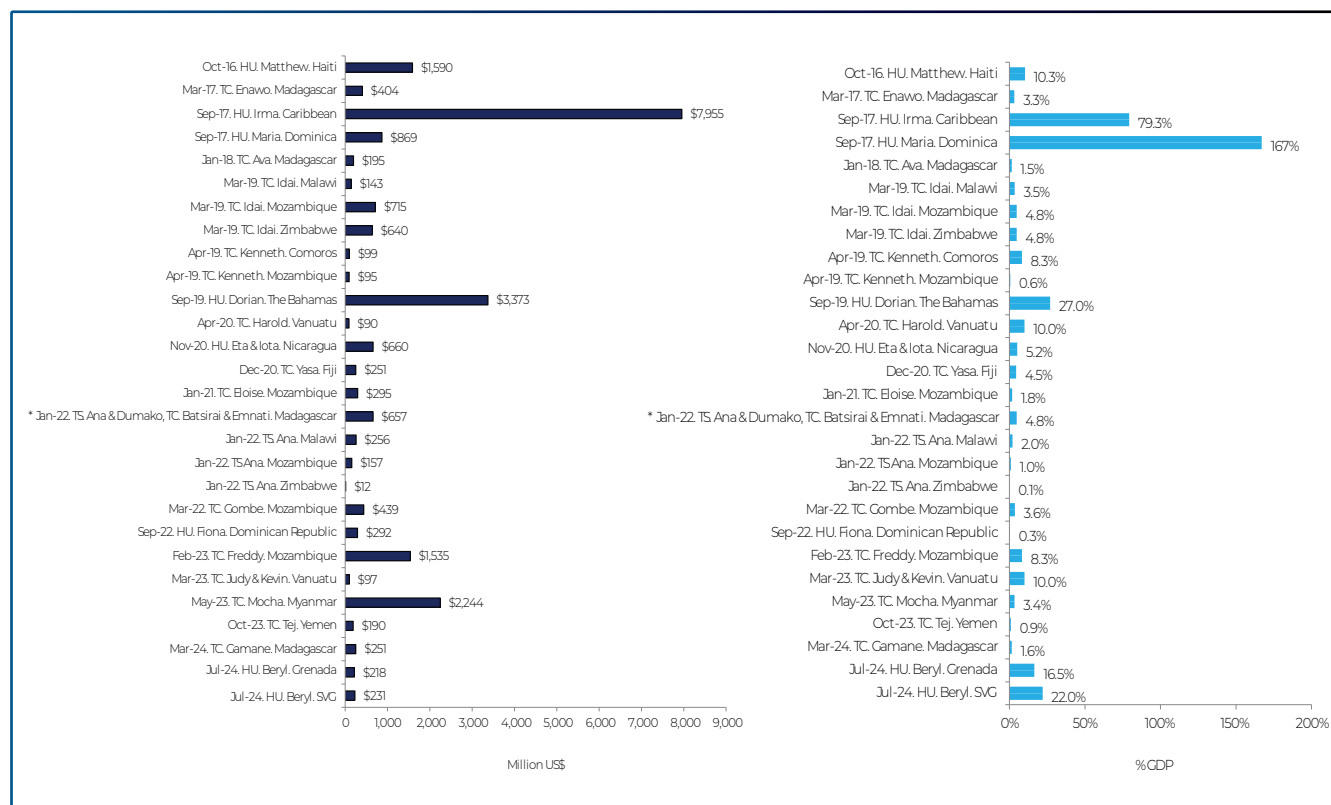


Note: Percentage of GDP based on GDP of year before event's occurrence. For more details on the events and GRADE assessments, see Appendices A and B

3.1.2. Tropical cyclones

Figure 6 shows direct economic damages to physical assets estimated using 28 GRADE assessments for tropical cyclones. For more details on the events and the GRADE assessments and estimated damages, see Appendices A, B, and C. Damages from Hurricane Irma in September 2019 encompass damage estimates for 13 countries, islands, and territories⁷ in the Caribbean.

Figure 6. *Direct Economic Damages to Physical Assets due to Tropical Cyclones Estimated Using Global Rapid Post-Disaster Damage Estimation (GRADE) between October 2016 and November 2024 in (A) USD millions and (B) Percentage Gross Domestic Product (GDP)*



Note: Percentage of GDP based on GDP of year before event's occurrence. For more details on events and GRADE assessments, see Appendices A and B.

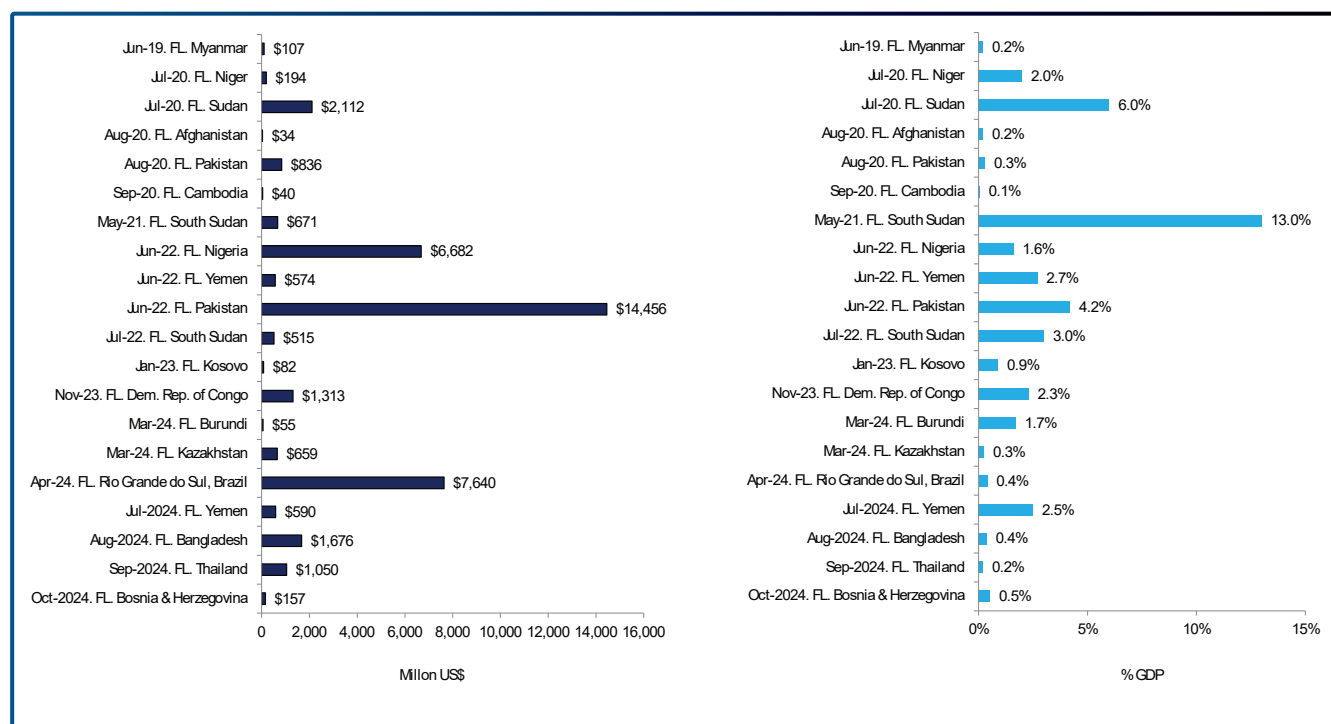
**Combined damages from tropical cyclones Ana, Batsirai, Dumako, and Emnati in January/February 2022 in Madagascar.*

⁷ Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Saint Barthélemy, Saint Martin, Sint Maarten, Turks and Caicos, U.S. Virgin Islands.

3.1.3. Floods and other hazards

Figure 7 shows GRADE assessments for 20 major floods events in 17 countries. The floods were mostly long lasting (two to four months). The floods in Pakistan that started in July 2022 and culminated in September 2022 resulted in USD 14.5 billion in direct economic damages to physical assets, accounting for slightly more than 4 percent of the country's GDP.

Figure 7. Direct Economic Damages to Physical Assets from 20 Major Flood Events in 17 Countries Estimated Using Global Rapid Post-Disaster Damage Estimation (GRADE) between 2019 and 2024 in (A) USD millions and (B) Percentage of Gross Domestic Product (GDP)



Note: Percentage GDP based on GDP of year before event's occurrence. For more details on the events and GRADE assessments, see Appendices A and B.

The volcanic eruptions of Fuego (Guatemala) in June 2018, La Soufrière (Saint Vincent and the Grenadines) in April 2021, and Hunga Tonga-Hunga Ha'apai (Tonga) in January 2022 resulted in GRADE estimates of direct economic damages to physical assets of more than USD 40 million, USD 83 million, and USD 91 million, respectively. Direct economic damages from the Hunga Tonga-Hunga Ha'apai eruption accounted for almost 20 percent of Tonga's 2021 GDP.

The estimated direct economic damages to physical assets in Ukraine as of March 31, 2022 (five weeks after the invasion) were almost USD 60 billion (almost 30 percent of Ukraine's 2021 GDP), and the estimated damage from the conflict in Tigray, Ethiopia, were USD 3 billion up to June 2022 (slightly less than 3 percent of Ethiopia's 2021 GDP).

3.2. Selected detailed examples of GRADE in action

3.2.1. Magnitude 7.5 earthquake in Palu, Central Sulawesi, Indonesia, September 28, 2018

This event was selected because it was a complex event with ground shaking, tsunami, and mudflow impacts. It occurred on the Palu-Koro active fault in September 2018 and had a cascade of effects on Palu City and nearby Donggala and Sigi regencies. It is likely that an earthquake-induced submarine landslide in the narrow Bay of Palu was the trigger for tsunami waves up to 11 meters high that devastated coastal areas around the bay and Palu City, where a festival was taking place on the shoreline. Extensive liquefaction triggered mudflows in the areas of Balaroa, Petobo, and Jono Oge that added to the destruction and loss of life. Damage caused by ground shaking was also significant, resulting in the collapse of several major structures in Palu City (e.g., two hotels, a hospital, a shopping mall, a university building, a major bridge). This earthquake led to more than 4,300 dead or missing and more than 12,600 injured; 4,400 seriously. Satellite remote sensing analysis released on October 18, 2018 for the entire affected region, identified 14,650 damaged buildings, of which 6,022 were deemed to have been destroyed. More than 80 percent of these buildings were in the areas that the tsunami and mudflows affected. (There was no overlap between these areas.).

Eleven days after the earthquake, on October 9, 2018, the GRADE report informed the World Bank's decision to release funds of up to USD 1 billion to supplement relief and reconstruction efforts in the disaster-affected areas⁸. The rapid release of the GRADE report was received with wide acclaim, as conveyed by then-World Bank Chief Executive Officer Kristalina Georgieva when she visited Indonesia in October 2018. The National Disaster Management Authority completed the more-detailed ground-based building damage assessment four months later, on February 5, 2019, with housing damage reports classifying 68,450 housing units as damaged or destroyed.

Success begets success. With the success of GRADE during this event, in August 2019, the GRADE methodology was selected as part of a regional workshop that assessed various post-disaster assessment methodologies. This Advanced Course on Early Recovery Preparation, which the Association of Southeast Asian Nations Emergency Response and Assessment Team organized, generated further interest in the GRADE methodology. The task team was invited to deliver further training on the GRADE methodology and capacity building of local stakeholders in the ASEAN region. These training sessions helped strengthen the use of new technologies and coordination among stakeholders in the region.

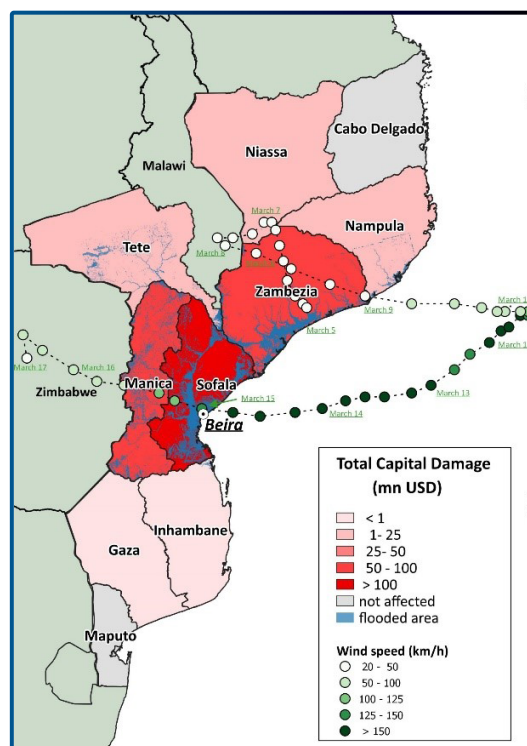
3.2.2. Cyclone Idai (Malawi, Mozambique, Zimbabwe), March 2019

After Cyclone Idai caused extensive damage across Malawi, Mozambique, and Zimbabwe in March 2019, for the first time, a GRADE report informed the World Bank's decision to activate the International Development Association Crisis Response Window and provide more than USD 0.5 billion for the three countries. In early March 2019, a severe weather system formed off the shore of central Mozambique and Malawi was inundated with severe rainfall for longer than a week, causing substantial flooding and damage in seven of Malawi's 32 districts and moderate to minor damage in 10 other districts. The

⁸ World Bank Group. 2018. "World Bank Announces \$1bn Assistance for Indonesia Natural Disaster Recovery and Preparedness." <https://www.worldbank.org/en/news/press-release/2018/10/14/world-bank-announces-assistance-for-indonesia-natural-disaster-recovery-and-preparedness>.

system then looped back to the Mozambique channel and intensified into Tropical Cyclone Idai. On March 14, 2019, Idai made landfall in Mozambique, where it moved west across the low-lying plains of central Mozambique before crossing into Zimbabwe a day later with the strength of a tropical storm. This devastating event seriously affected five of Mozambique's eleven provinces (Sofala, Zambezia, Manica, Nampula, Tete) and caused minor damage in Gaza, Inhambane, and Niassa provinces (Map 1).

Map 1. Results for Mozambique Showing Flood Extents and Wind Track Flows, Including 10-Minute Sustained Wind Speeds of Tropical Cyclone Idai in March 2019



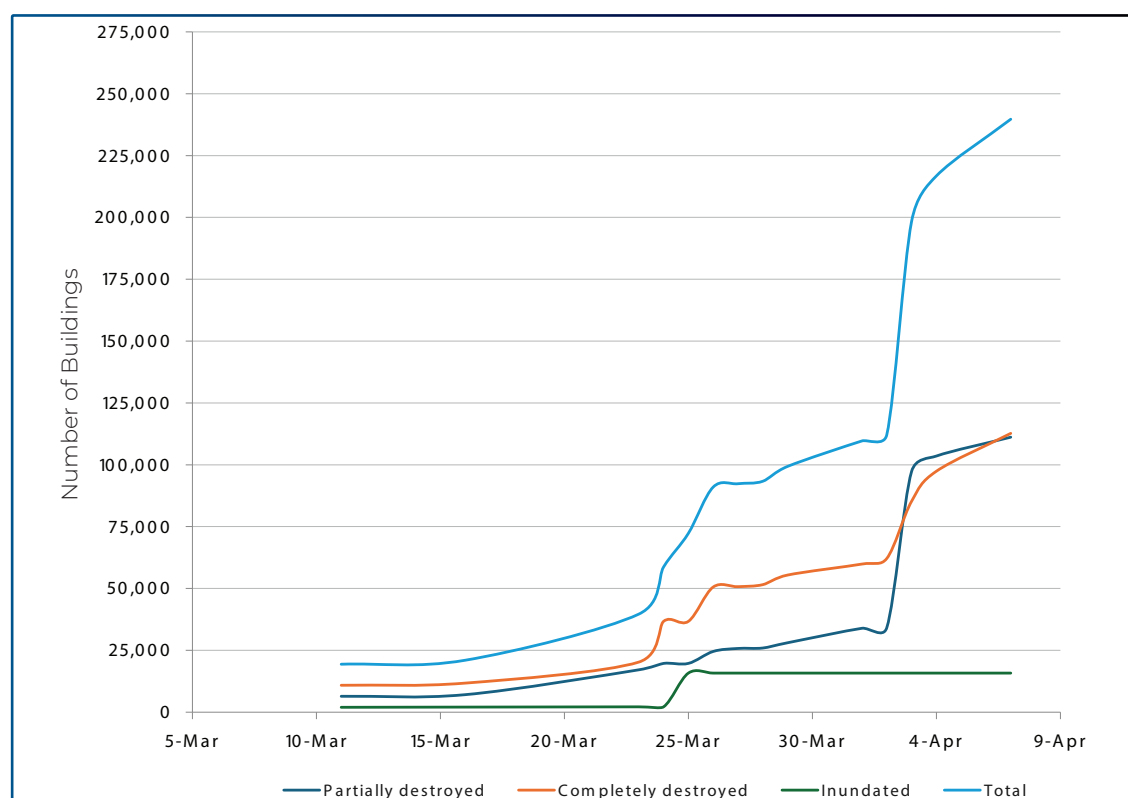
Within 18 days, the GRADE had addressed many of the critical questions that the governments and World Bank management faced. In the days during and after Tropical Cyclone Idai, news reports revealed widespread devastation. World Bank management sought to quickly obtain credible estimates of the impact that could guide the scope, scale, and type of support to offer, so a GRADE report was requested. Previous GRADE assessments, such as for cyclones Enawo (2017) and Ava (2018) in Madagascar, had shown the challenges of modeling complex patterns of damage from wind, rain intrusion, storm surge, and flooding occurring simultaneously. In addition, tropical cyclones and flood events often have multiple phases, during which compound damage may occur.

Table 6 highlights the results according to sector and country. The team had to contend with the unique technical complexities of this assessment, which included multiple countries and two phases of flooding. The length of the event and the timeliness of data and reporting were key challenges. The team was developing an assessment in the midst of a prolonged event with increasing damage during two main phases of flooding (March 5–13, 2019, and March 14, 2019, onward, when the system strengthened to an intense tropical cyclone). Reported damage spiked four days after the GRADE report was completed (Figure 8). GRADE raised the question of how to address prolonged events during which damages and losses continue to accumulate along with internal and external pressure to deliver accurate results to respond as quickly and accurately as possible.

Table 6. Estimates of Capital Damage According to Sector Examined in Tropical Cyclone Idai Global Rapid Post-Disaster Damage Estimation Assessment

Country	Residential buildings	Non-residential buildings	Infrastructure	Agriculture	Total
USD million					
Mozambique	178	149	188	200	715
Malawi	28	24	48	43	143
Zimbabwe	66	67	311	196	640
Total	272	240	547	439	1,498

Figure 8. Time Series of Damage Statistics Reported in Mozambique after Cyclone Idai in March 2019



Source: National Institute of Disaster Management-Mozambique.

Lack of data was a major challenge, given the varied and extensive data requirements for assessing a disaster of this scale. Exposure models existed for Malawi and Mozambique, but the team had to develop its own model for Zimbabwe. Availability of damage and impact data differed significantly between the three countries, and data were often contradictory, so the team relied heavily on its collective expertise and experience from past events when evaluating data and reporting. The wide scale of impacts across a range of contexts was a challenge, too. The impacts extended across international borders, covering many different

terrains, including urban and rural areas, with different levels of different hazards (wind, floods, landslides, mudslides) affecting different areas and a range of construction costs and building methods and materials.

Each GRADE analysis is demanding, but the Cyclone Idai analysis was particularly so.

The task team worked extended hours (with over 2,000 person hours in total) across multiple time zones to produce results within 18 calendar days. This dynamic, fast-paced nature of damage assessments is the norm rather than the exception in post-disaster situations and has now been the case for all GRADE assessments completed.

3.2.3. Ukraine, February 2022

The GRADE methodology, which was originally conceived to assess the impact of natural hazards rapidly, was adapted for the invasion to quantify damages between February 24, 2022, and March 31, 2022. During this period, damages were reported in 23 of the country's 27 first-level administrative divisions (one autonomous republic, 24 regions [oblasts], two cities with special status [Kyiv, Sevastopol]), predominantly in northern and eastern Ukraine but also in other regions. Damage was reported to all types of buildings, including private homes; apartment buildings; schools and other educational facilities; hospitals and other health care facilities; and administrative, industrial, and cultural buildings (e.g., theaters, museums). Damage to roads, railways, power plants, refineries, oil depots, ports, airports, and other infrastructure was also significant.

It was estimated that damages to buildings and infrastructure (as of March 31, 2022) were at least USD 59.2 billion, more than 120 percent of Ukraine's projected budget for 2022. Damages will have increased significantly since March 31, 2022. Estimated damages to the residential, non-residential, and infrastructure sectors were at least USD 18.8 billion, USD 12.9 billion, and USD 27.6 billion, respectively. The most greatly affected sector was infrastructure, accounting for 47 percent of damages, followed by the residential sector, with 32 percent. The assessment was not conducted at an individual facility level but at a geographic area level. The task team adopted an aggregated approach, with some detailed assessments examining damage at various spatial resolutions (from regional to single asset), making evaluations as to the degree of damage and the replacement value based on interactions with the Kyiv School of Economics Institute and reviews of public resources and social media.

There was considerable uncertainty about the detailed impacts because this is a complex, evolving event. Economic losses were not estimated. Trying to estimate damage during an ongoing invasion was challenging. Data collection was exceptionally difficult—far beyond the challenges of conducting impact assessments of natural hazard events during peacetime. Nevertheless, although GRADE was not originally designed to assess damages from induced events, the flexibility of the GRADE methodology proved timely and providential in this case.

3.2.4. Pakistan monsoon floods, mid-June to mid-September 2022

The size, duration, and impact of the 2022 Pakistan floods made this event particularly noteworthy. The 2022 monsoon rains and associated impacts of the floods started on June 14, 2022, and continued until late September. Rainfall was 2.9 times as great as the most recent 30-year nationwide average, causing floods, flash floods, and landslides across the country. On August 25, 2022, the government declared a national emergency, with southern

and central Pakistan the most affected. By the end of the crisis, damage was reported in 74 percent of districts, compared with 49 percent of districts in the devastating 2010 floods. According to the National Disaster Management Authority, more than 1,600 people were killed and more than 12,800 injured.

In response to the worsening situation, the GRADE assessment was started on August 27, 2022, and completed by September 15, 2022. GRADE's estimates of direct economic damages to physical assets were based on multiple data sources, risk modeling methodologies, and subject matter expertise. Not only were the reported impacts that the national and provincial disaster management authorities released used to derive the estimates, but also agricultural impact information from the Food and Agriculture Organization of the United Nations and other World Bank model estimates were used. The housing stock exposure in the affected region was developed within the re-analysis of the 2010 floods for the 2018 Global Facility for Disaster Reduction and Recovery (GFDRR) Aftershocks report (GFDRR 2018b) and projected to mid-2022. Damage ratios from the 2010 and 2011 Pakistan flood PDNAs were re-assessed for the GRADE analysis.

Good river flow data and other hazard data were available for this event via the Federal Flood Commission and past PDNAs and were used in the GRADE assessment, although flood footprints differ depending on the timing of data collection. The combination of these data sources led the team to conduct a methodology adjusted to the circumstances that was explained in detail in an annex of the GRADE report.

GRADE estimated that total economic damages for the disaster were USD 11.4 billion to USD 17.5 billion. At the time, this was the largest natural hazard related disaster that GRADE had assessed, at nearly double the economic damages of Hurricane Irma in 2017. The GRADE rapid damage assessment supported World Bank response plans, including macroeconomic assessments and dialogue with the country and the donor community, and informed the consequent PDNA process.

The GRADE assessment results complemented the PDNA results. On October 22, 2022, the preliminary PDNA was released, followed by a supplemental PDNA report on December 22, 2022. The PDNA estimated total costs of damage to be USD 14.9 billion, which was well aligned with the GRADE assessment, although there were differences according to sector that are discussed in later sections. Long-duration floods are inherently complex to assess. Flood waters fluctuate with additional rainfall in river basins, compounding damages over time. The long duration of the floods (more than three months) meant that it was difficult to assess the flood-affected areas comprehensively, which contributed to the uncertainties associated with the GRADE damage estimates.

3.2.5. Magnitude 7.8 and 7.5 Kahramanmaraş earthquakes in southern Türkiye, February 2023

The double earthquakes in the Kahramanmaraş region in southern Türkiye were among the most severe in recent times. On February 6, 2023, two earthquakes occurred at 04:17 and 13:24 local time on the East Anatolian fault, a 700-km-long, northeast–southwest fault system that forms the boundary between the Anatolian and Arabian plates. Strong to violent ground motion affected approximately 10 million people in Türkiye (11.8 percent of the population). The combination of shallow focal depth, strong shaking, high population density, and vulnerable buildings led to this event becoming the most lethal and costly earthquake in Türkiye since at least 1900. There had not been an earthquake of such

magnitude in much of the affected region in at least 250 years, and the region between Kahramanmaraş and Gaziantep had not experienced a major earthquake since 1513. Building damage was extensive, with thousands collapsing, trapping their occupants under the rubble. Many buildings that survived the first earthquake collapsed in the second. The official death toll in Türkiye reported on April 22, 2023, was 50,783, with 107,204 injured and 216,347 evacuated from the region to other provinces. In addition, an estimated 8,500 people were killed and 14,800 injured in northwestern parts of neighboring Syria.

The initial request to conduct a full GRADE assessment was received within hours of the earthquake, with the formal decision to proceed following one to two days later.

The report, released on February 20, 2023 two weeks after the event, informed the World Bank's decision to release more USD 1 billion in funds to support recovery and reconstruction in the disaster-affected areas (World Bank 2023).

GRADE's first task was to generate robust ShakeMaps for the two earthquakes based on advanced ground motion modeling using appropriate ground motion propagation functions, also taking into account soil conditions across the affected region. Several iterations and calibration were necessary using information from recorded ground motion from the observation stations in the affected region. The GRADE ShakeMaps were then combined with the baseline exposure model for residential and non-residential buildings in the region and with selection of appropriate vulnerability curves and unit costs of construction for the types of existing building stock from official sources to derive a modeled damage estimate. Existing earthquake risk models such as the 2018 Global Earthquake Model and the 2015 Global Assessment Report were also consulted. An intense effort was simultaneously made to assemble damage data via official channels (the government of Türkiye provided good building damage data early on) and internet searches. Because damage statistics were not completed by the end of the GRADE assessment period, a combination of modeling and provisional damage data was used to derive the value of direct economic damages.

The GRADE assessment estimated direct economic damages in terms of replacement cost to be USD 34.2 billion in total (median estimate), of which USD 18.0 billion (~53 percent of the total) was for residential buildings and contents damage, USD 9.7 billion (~28 percent of the total) for non-residential buildings and contents damage, and USD 6.4 billion (~19 percent of the total) for infrastructure damage. The main challenges to estimating these damages were timely completion of the seismic hazard, exposure, and vulnerability models to enable direct economic damages to be estimated. Uncertainties related to this effort are numerous across the entire spectrum of the modeling process, including lack of soil type data, characterization of the building stock according to type of construction, period of construction and number of floors, estimation of respective built floor areas, and related unitary costs of construction (per square meter).

On March 17, 2023, the official Türkiye Earthquakes Recovery and Reconstruction Assessment (TERRA) report (with the support of the United Nations Development Programme, the World Bank, and the European Union) was also released. This report estimated that reconstruction and recovery costs could reach USD 84.8 billion, of which USD 57.6 billion was for residential buildings, USD 3.1 billion for loss of domestic goods (contents), USD 16 billion for non-residential buildings and contents such as machinery and equipment, and USD 5.5 billion for infrastructure, with agriculture, demolition, debris removal and management, and damage to motor vehicles making up the rest. The TERRA report's total cost estimates were approximately 3.4 times and 1.7 times as great as the GRADE estimates for residential and non-residential buildings, respectively, and for

infrastructure, the GRADE assessment estimated USD 6.4 billion in damages, compared with the TERRA report's USD 5.5 billion. It is assumed that the large differences in the building sectors were because the more than 230,000 destroyed buildings would be rebuilt with build back better principles (designed based on current earthquake code requirements). See section 4.3.4 for more details.

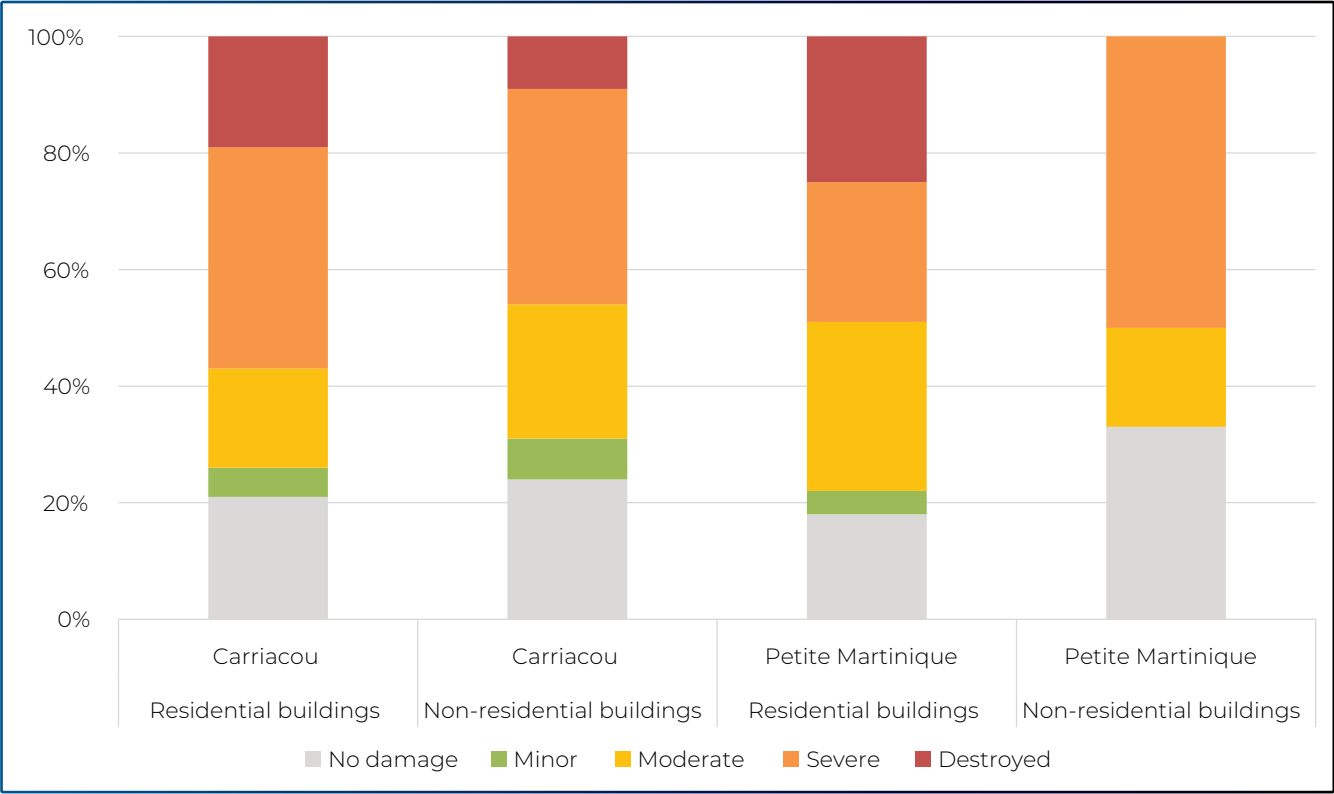
3.2.6. Hurricane Beryl, Grenada, July 2024

Testing innovative techniques was a highlight of this assessment. Virtual damage surveying consists of finding and reviewing video footage and photographs to assess damage to a representative sample of buildings and types of structures. The results of the survey have the potential to improve the assessment results markedly by refining the vulnerability and exposure elements of the analysis. Hurricane Beryl made landfall on the island of Carriacou in Grenada as a high-end Category 4 hurricane on July 1, 2024. Wind speeds ranged from maximum sustained winds of 150 mph (240 km/h), equivalent to a Category 4 hurricane, in Carriacou and Petite Martinique, to Category 1 hurricane force winds in the southwest of the main island of Grenada.

This event was a prime candidate for employing this innovative technique, because most of the damage in Grenada occurred on the smaller Grenadian islands of Carriacou and Petit Martinique, and ample imagery was available, which meant that a representative sample of damage could be surveyed. Extensive, good-quality imagery, from damaged and non-damaged areas, is vital to the success of virtual surveying and was available for Carriacou and Petite Martinique, with drive-by videos, unmanned aerial vehicle (or drone) imagery, and social media feeds with imagery of large parts of the islands. The virtual survey collected information on building use (e.g., residential, commercial, industrial, public) and structural characteristics and assessed damage to roof coverings, roof frames, and walls, resulting in an overall damage grading. It also assessed the value of structures on a scale of 1 (more-rudimentary buildings or low-income housing) to 5 (luxury high-end villas or large, high-quality non-residential buildings) to assist in estimating costs of damage.

The surveys were completed by assessing all buildings that could be observed in enough detail individually. Survey data for each building were collected in a database, and each building was geo-located on Google Earth and tagged. Careful attention was paid to collecting data on non-damaged buildings because it is important to capture an overall representative sample. A total of 439 buildings were surveyed virtually in Carriacou and Petit Martinique (Figure 9).

Figure 9. Results of Virtual Damage Surveying in Carriacou and Petite Martinique after Hurricane Beryl in July 2024



To calibrate and validate these results, they were compared with results from Grenada Central Statistics Office damage surveys. Differences were found in how the level of damage was assigned to each building because of different damage level definitions, limitations of virtual surveys, or surveyor biases, although when damage levels were compared, the results from the datasets were well aligned, increasing confidence in the GRADE results.

Having observed the types of damage through the survey process, there was more confidence in the damage estimates. The GRADE results were shared with stakeholders and development partners, including the PDNA team. The PDNA was released on November 8, 2024, and a comparison of its damage estimates is included in this report. This type of virtual survey, although successful in this case, would be viable for only a few events for which GRADEs are completed because it requires a smaller geographic scale, in combination with good-quality and availability of post-disaster imagery.

Performance Of GRADE: Comparing Results With Those Of Other Post-Disaster Assessments



In the last 10 years, there have been 17 cases in which a GRADE and a PDNA, DaLA, or other assessment have been conducted for the same event and are suitable for comparison. The events for which multiple assessment types have been conducted provide the opportunity to compare the assessment methodologies (Table 2), although for more prolonged events, the timing differs depending on the situation. The decision whether to conduct a GRADE or another assessment may not be taken immediately after the event starts. For example, floods, volcanic activity, or induced events can take time to intensify and peak and the impacts accumulate so decisions may be taken during a disaster of this kind. For this reason, two prolonged flood events are not included in the comparison of times of completion as it can be difficult to define the start date and this may not be representative of the start of the GRADE assessment process.

No methodology is perfect, but it can be helpful to compare speed and results between different post-disaster damage assessment methods to understand their characteristics and performance. A rapid GRADE assessment is not meant to replace a detailed PDNA; each assessment has its own purpose and importance. The speed and low cost of GRADE allows for more events to be addressed, whereas a PDNA will usually be conducted for the most destructive events and will address damages, losses, and needs for recovery and reconstruction. In addition, although PDNAs, DaLAs, and other post-disaster assessments are the most thorough and effective field-based assessment methodologies, their results are not entirely accurate. Many factors cause uncertainties in post-disaster assessments, such as complexity of events; extent of damage; experience and biases of evaluators and surveyors; availability of complete, good-quality data; and sampling required for field-based assessments, that some methodologies cannot avoid.

4.1. Comparison of completion times

Speed of completion of assessments is of critical importance to governments, World Bank teams, and other decision makers. Using virtual methodologies; having an experienced team on standby; and sharing results directly with governments, the World Bank, and other stakeholders enables GRADE assessments to be conducted quickly. Other assessments, such as PDNAs, require formal requests from governments, assembly of expert teams, field deployment, and production and publication of a report (European Commission et al. 2018) which prolongs the process significantly.

Average time for completion of a GRADE (excluding prolonged events) is 2.6 weeks. It is also useful to compare the timelines of GRADE and other assessments for the same events to understand how GRADE performs in terms of speed. For timeliness comparisons, a subset of 15 events were selected (Table 7). To be selected, the event had to have results from a GRADE and a PDNA, DaLA, or other assessment. Long-duration events, such as floods, were excluded, because it is difficult to measure the timing of the start of an event, and therefore the time to completion, so if it were included, it would skew the results.

For the 15 events assessed, GRADE delivered results on average 12.4 weeks faster than other assessments. The average completion time for a PDNA or other assessment was 14.7 weeks, compared with 2.3 weeks for GRADE. The minimum time to complete them was 6.4 weeks for the 2016 earthquake in Muisne, Ecuador, which was not a full PDNA, and the maximum was 21.0 weeks for Tropical Cyclone Harold in Vanuatu in April 2020, which was completed in the midst of the global COVID-19 pandemic. For the same 15 events, GRADE results were available between 0.6 and 4.1 weeks and on average 2.3 weeks after the occurrence of the event. The minimum time for GRADE completion (0.6 weeks) was for Hurricane Maria in Dominica in September 2017, and the maximum was 4.1 weeks, for Hurricane Beryl in Grenada in July 2024.

Table 7. Time to Complete Global Rapid Post-Disaster Damage Estimation (GRADE) Assessments, Post-Disaster Needs Assessments (PDNAs), Damage and Loss Assessments (DaLAs) and Other Assessments

Event	GRADE		Other assessment	
	GRADE product	Weeks from event to assessment completion	Type of assessment	Weeks from event to assessment completion
Ghorka Earthquake, Nepal, April 2015	GRADE Note	1.0	PDNA	8.0
Muisne Earthquake, Ecuador, April 2016	GRADE Note	1.9	PDNA	6.4
Hurricane Matthew, Haiti, September 2016	Full GRADE	2.3	PDNA	17.9
Hurricane Maria, Dominica, September 2017	GRADE Note	0.6	PDNA	8.3
Tropical Cyclone Idai, Mozambique, March 2019	Full GRADE	1.9	PDNA	9.9
Tropical Cyclone Idai, Malawi, March 2019	Full GRADE	2.1	PDNA	15.7
Tropical Cyclone Idai, Zimbabwe, March 2019	Full GRADE	2.7	RINA	11.1
Hurricane Dorian, The Bahamas, September 2019	Full GRADE	2.7	DaLA	10.7
Earthquake, Albania, November 2019	Full GRADE	2.9	PDNA	9.3
Tropical Cyclone Harold, Vanuatu April 2020	GRADE Note	2.3	PDNA	21.0
La Soufrière Volcano, Saint Vincent and the Grenadines, April 2021	Full GRADE	1.7	PDNA	34.0
Earthquake, Haiti, August 2021	Full GRADE	1.9	PDNA	14.4
Tropical cyclones Judy and Kevin, Vanuatu, March 2023	Full GRADE	3	PDNA	16.1
Earthquake, Herat, Afghanistan, October 2023	Full GRADE	3.4	PDNA	19.6
Hurricane Beryl, Grenada, July 2024	Full GRADE	4.1 ^a	PDNA	18.6
Average time from start of event to completion	-	2.3	-	14.7

a. The GRADE assessment was completed, and results were presented to the government of Grenada on July 30, 2024. The GRADE report was published after receiving government feedback on September 9, 2024.

4.2. Comparison of total and sectoral direct damage estimates

Table 8 compares reported damages estimated using GRADE, PDNA, DaLA, and other types of assessments according to total damage and sector. Other assessments often consider damages to more sectors and subsectors than GRADE (e.g., environment, disaster response, governance), so the damage estimations compared herein are damages related to the four sectors that GRADE considers: residential, non-residential, infrastructure, and agriculture. Therefore, total damages estimated using other assessments may be greater than reported and compared herein. The combined total of the additional sectors estimated using other assessments is shown in the rightmost column of Table D.1 as “Other sectors.” When comparing the damage estimations derived using GRADE with those of other assessments, two additional events are included in the analysis. Although omitted from the comparison of timelines to completion (Table 7), prolonged events such as floods can be included in the comparison without any concern about bias. Therefore, the July 2020 floods in Sudan and the June 2022 floods in Pakistan are included in the comparison of damage estimations.

Table 8. Comparison between Damage Estimations for Global Rapid Post-Disaster Damage Estimation (GRADE) Assessments, Post-Disaster Damage and Needs Assessments (PDNAs), Damage and Loss Assessments (DaLAs), Rapid Impact and Needs Assessments (RINAs,) and Rapid Post-Disaster Needs and Recovery Assessment (RPDNRAs) for 17 Events

Event	GRADE type	Other assessment type	Total	Residential	Non-Residential	Infrastructure	Agriculture
			GRADE results as percentage of other assessments' results				
Earthquake, Ghorka, Nepal, April 2016	GRADE Note	PDNA	120	86	155	250	-
Earthquake, Muisne, Ecuador, April 2016	GRADE Note	PDNA	58	82	47	52	-
Hurricane Matthew, Haiti, September 2016	Full GRADE	PDNA	85	69	95	111	96
Hurricane Maria, Dominica, September 2017	Full GRADE	PDNA	103	109	135	79	-
Tropical Cyclone Idai, Mozambique, March 2019	GRADE Note	PDNA	55	43	62	32	309
Tropical Cyclone Idai, Malawi, March 2019	GRADE Note	PDNA	90	34	114	100	614
Tropical Cyclone Idai, Zimbabwe, March 2019	Full GRADE	RINA	120	39	319	164	126
Hurricane Dorian, The Bahamas, September 2019	Full GRADE	DaLA	138	131	130	206	-

Event	GRADE type	Other assessment type	Total	Residential	Non-Residential	Infrastructure	Agriculture
			GRADE results as percentage of other assessments' results				
Earthquake, Albania, November 2019	Full GRADE	PDNA	89	84	104	130	-
Tropical Cyclone Harold, Vanuatu, April 2020 ^a	GRADE Note	PDNA	36	34		40	
Floods, Sudan, July 2020	GRADE Note	Rapid PDNRA	63	18	316	86	3536
La Soufrière Volcano, Saint Vincent and the Grenadines, April 2021	Full GRADE	PDNA	54	11	57	336	82
Earthquake, Haiti, August 2021	Full GRADE	PDNA	93	97	55	170	-
Floods, Pakistan, 2022	Full GRADE	PDNA	98	56	143	70	183
Tropical cyclones Judy and Kevin, Vanuatu, March 2023	GRADE Note	PDNA	31	11	60	49	57
Earthquake, Herat, Afghanistan, October 2023*	Full GRADE	PDNA	146	126	201	118	
Hurricane Beryl, Grenada, July 2024	Full GRADE	PDNA	126	43	418	1032	220
Average ^b			88%	65%	151	191	581
Median ^c			90%	63%	122	111	183
Total			95%	66%	115	88	201

Notes: The values show the GRADE results as a percentage of the other assessments' results for the four sectors (as defined according to GRADE) included in the table (residential, non-residential, infrastructure, agriculture) and the combined totals of these sectors only. The July 2020 floods in Sudan and the June 2022 floods in Pakistan are included because there were sufficient data, whereas it was not possible to compare times in these cases summarized in Table 7 because of the uncertainty inherent in determining the start and end of prolonged flooding events.

b. Residential and non-residential damages and agricultural and infrastructure damages from Tropical Cyclone Harold in Vanuatu in April 2020 are combined because data suitable for discriminating between sectors were limited. For the same reason, the infrastructure and agricultural damages from the 2023 earthquake in Afghanistan are combined.

c. Average and median percentage comparisons of sectoral damages exclude 2020 Tropical Cyclone Harold in Vanuatu and the 2023 earthquake in Afghanistan.

The comparison shows that total direct economic damages to physical assets modeled using GRADE are, on average, 88 to 90 percent of PDNAs or other assessment results (Figure 10). Put another way, the GRADE results are within 12 percent using the mean or within 10 percent using the median of the damage results obtained using PDNAs or other types of assessment for the same events. Table 8 compares total damages estimated using GRADE and other assessments for the 17 events. The results show good alignment across all disaster types, regions, and sizes of events. Damages were less than USD 1 billion according to all assessments for all but two of the 17 events. Close alignment of results (less than 15 percent variation in total damages) was observed in six of the compared cases, of which the closest were Hurricane Maria in Dominica in September 2019 and the floods in Pakistan in 2022, which both had variation in results of only 2 percent. More details on total damages and according to sector can be found in Appendix B (for GRADE) and Appendix D (for PDNA and other types of assessments). Further discussion of the differences between GRADE and other assessments can be found in Section 5, although when the additional sectors that other assessments consider but GRADE does not (environment, disaster response, governance) are included, total direct economic damages modeled using GRADE on average reduces slightly to 84 to 89 percent of the PDNA or other assessment results (mean and median values, respectively).

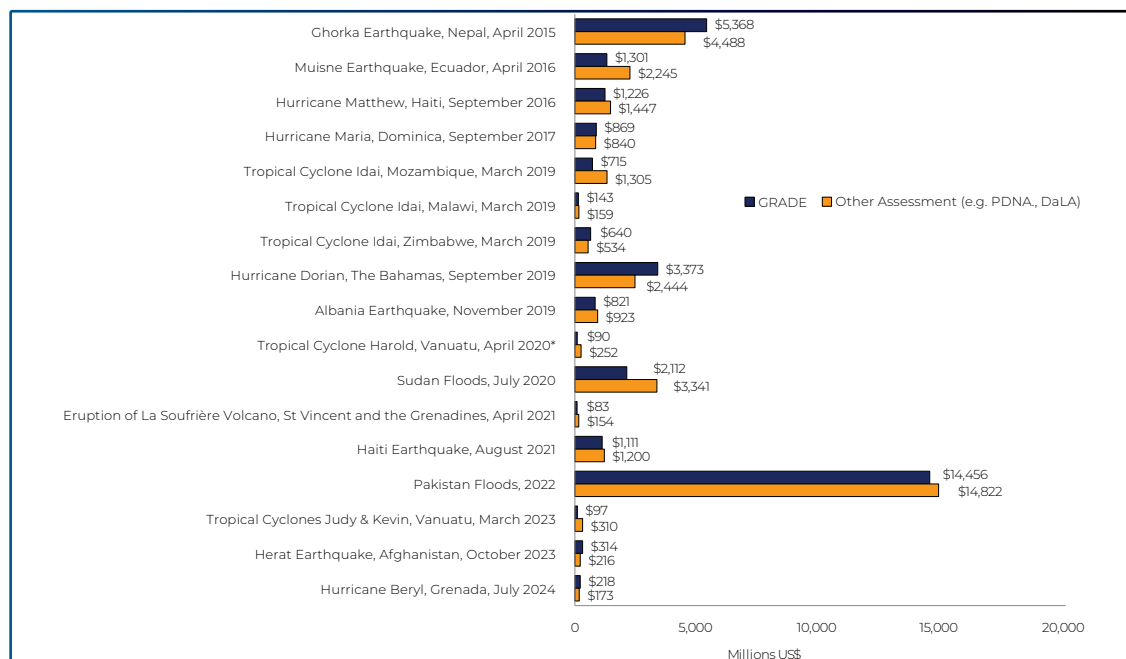
For the residential buildings sector, GRADE on average estimated lower damages than other assessments. The comparisons show an average 65 percent GRADE to PDNA percentage ratio, ranging between 11 and 131 percent. Two GRADE assessments indicated damages that were 97 and 108 percent of the respective PDNA estimates (the Haiti earthquake in August 2021, and Hurricane Maria in Dominica in September 2019, respectively). Section 4.3 and Appendix E.1 discuss these differences.

For the non-residential buildings sector, on average, GRADE assessments are higher than other assessments. The comparisons show an average 151 percent GRADE-to-PDNA percentage ratio (range 47 to 418 percent). In two cases, results were very similar: the earthquake in Albania in November 2019 and Hurricane Matthew in Haiti in September 2016 (GRADE results were 104 and 95 percent of the other assessment, respectively). Section 4.3 and Appendix E.2 discuss these differences.

For the infrastructure sector, GRADE assessments are generally higher than other assessments. The comparisons show an average 191 percent GRADE-to-PDNA percentage ratio (range 32 to 1,032 percent), with the best comparisons for Tropical Cyclone Idai in Malawi in March 2019 (100 percent) and Hurricane Matthew in Haiti in September 2016 (111 percent). Section 4.3 and Appendix E.3 discuss these differences.

For the agricultural sector, nine comparisons were possible, and GRADE assessments are generally higher than other assessments. The comparisons show an average 581 percent GRADE-to-PDNA percentage ratio (range 57 to 3,586 percent), with good comparisons for Hurricane Matthew in Haiti in 2016 (96 percent) and the La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021 (82 percent). Section 4.3 and Appendix E.4 discuss these differences.

Figure 10. Comparison of Total Damages for Global Rapid Post-Disaster Damage Estimation (GRADE) and Other Assessments for 17 Events



4.3. Reasons for differences in results between GRADE and other assessments

There are numerous reasons for the differences between GRADE results and those arrived at using other methodologies and assessment processes. This section explores the key reasons for some of the larger differences in results. Appendices E.1 to E.4 provide a deeper exploration of the differences in results according to sector.

4.3.1. Methodological differences

The differences in results between GRADE, PDNA, and other assessment frameworks are partly due to variations in methodologies and key assumptions. GRADE assessments develop updated exposure models, analyze hazards and vulnerabilities, and use risk models with initial damage data, satellite imagery, social media feeds, and early reporting from official sources to build a picture of the situation remotely. GRADE also carefully considers relevant historical events that can help extrapolate patterns of damage and scales of impacts to current events. GRADE also focuses on calibration of all of these data sources, and the task team uses them to refine and improve estimations as a key part of the GRADE methodology. In contrast, PDNAs and other assessment methodologies can draw on more complete damage data reporting given their later implementation and direct involvement with authorities on the ground.

After the 2021 La Soufrière volcanic eruption, differences were observed in residential estimates between GRADE and PDNA (USD 11 million versus USD 97.6 million) because of differences in how the methodologies assigned damage ratios. The PDNA assumed that all houses in the “green” zone (where ashfall thickness was less than 3 cm) would incur damage costs of 5 percent of the replacement value, which accounted for approximately 60 percent of the PDNA’s total residential damages. In addition, the PDNA used a damage ratio of 25

percent for the “yellow” zone, which was considerably higher than the ratio that GRADE used. The GRADE task team developed damage ratios based on available datasets, imagery, and reports and calibrated these ratios with historical events. These differences in assumptions between the methodologies led to substantial differences in results.

4.3.2. Timing and availability of data

Timing plays a crucial role in the differences between GRADE and the other assessments.

As time passes after a disaster, post-disaster data increase in quantity and completeness and improve in quality. Because GRADE assessments are conducted soon after disasters, they rely on more limited, earlier data, whereas PDNAs and DaLAs benefit from working with more comprehensive damage datasets. This gap in data availability often leads to significant differences in reported damages. This can be clearly seen in the results for Tropical Cyclone Idai in 2019. In Mozambique, GRADE’s analysis occurred before the full scope of damage had been reported. By contrast, the PDNA assessment, conducted later, had access to more-comprehensive reports. The number of reported houses damaged increased from 95,000 when the GRADE was completed to nearly 240,000 10 days later. Affected agricultural land area increased from 475,000 hectares used for GRADE to 715,000 hectares used for the PDNA.

Sometimes, although rarely, even the PDNA is completed in advance of full impact reports, which was the case with the energy infrastructure sector in Mozambique for Tropical Cyclone Idai in 2019, causing additional discrepancies between results. For the same event in Malawi, at the time the GRADE assessment was conducted, the Department of Disaster Management Affairs was reporting approximately 22,000 damaged or destroyed houses, whereas the final tally was approximately 288,000.

In Saint Vincent and the Grenadines, after the La Soufrière volcano eruption in 2021, the areas worst affected by the eruption were completely evacuated and closed. At the time GRADE was conducted, little data had emerged on the situation in the evacuated zone. Remote sensing products available from Copernicus Emergency Management System showed that approximately 60 non-residential buildings were “possibly” damaged, but they were released just after the GRADE report was completed. It became evident that there was more damage to agricultural areas and other non-residential buildings when these areas re-opened, and the DaLA was able to make use of that later, more complete data.

4.3.3. Assignments of damages to different sectors and different definitions of sectors

One of the major differences in results lies in how damages are assigned across sectors.

For example, damage to crops and loss of livestock are recorded as losses by PDNAs, but GRADE records them in damages. This reallocation can create significant variations in sector-specific damage totals. Several cases in which damage assessments are widely different for agriculture between GRADE and PDNAs or DaLAs stem from this. These cases are discussed in more detail in Appendix E.4.

Similarly, how PDNAs and DaLAs assign damage to non-residential buildings is different from how GRADE does so (Table 9), therefore care must be taken when comparing results. GRADE considers any building that is non-residential in the non-residential sector. This includes hospital buildings, agricultural buildings, airport terminals, electrical substation buildings, industrial warehouses, hotels, school buildings—essentially any building that is not residential—but PDNAs and DaLAs distribute these assets throughout the social, productive, infrastructure, and cross-sector estimations.

Table 9. *Classification of Damages According to Global Rapid Post-Disaster Damage Estimation (GRADE) and Post-Disaster Damage and Needs Assessment (PDNA)*

GRADE		PDNA	
Sector	Damage	Sector	Damage
Residential	Damage to residential buildings and contents, depending on type of construction and 'as was' unit costs of replacement at the time of the disaster; includes single- and multiple-residence buildings	Social	◆ Housing (private or public) ◆ Other housing, land and settlements ◆ Education ◆ Health ◆ Nutrition ◆ Food security ◆ Culture, sports, heritage ◆ Justice and community services
Non-residential	Damage to all types of non-residential buildings and contents, depending on type of construction and 'as was' unit costs of replacement at the time of the disaster; includes commercial, industrial, public buildings (e.g., schools, hospitals, health care centers, government offices, houses of worship), hotels and other tourism assets, buildings in ports and airports, mixed-use buildings, agricultural buildings	Productive	◆ Commerce ◆ Micro business ◆ Cooperatives ◆ Finance ◆ Industry including manufacturing ◆ Tourism accommodation ◆ Tourism parks ◆ Agriculture, including fisheries, forestry, livestock, and arable farming (excluding effects on seasonal or annual crops, perishing livestock, that are considered as losses but including effects on fruit plants and trees) ◆ Agroindustry ◆ Irrigation
Infrastructure	Damage to all types of infrastructure, depending on type of construction and 'as was' unit costs of replacement at the time of the disaster, including roads, bridges, railways, ports, jetties, coastal structures, airports, power networks, telecommunications networks, water and wastewater networks, large-scale irrigation infrastructure	Infrastructure	◆ Energy production facilities ◆ Telecommunications ◆ Transportation ◆ Water, sanitation, and hygiene ◆ Municipal services ◆ Water resources ◆ Community infrastructure ◆ Airports ◆ Ports ◆ Other public buildings

GRADE		PDNA	
Sector	Damage	Sector	Damage
Agriculture	Damage to agricultural assets, including in situ crops, crops in storage, livestock, small-scale irrigation networks, fisheries assets, farm machinery and equipment	Cross Sectors	Damage to: ◆ The environment Costs associated with: ◆ Disaster risk reduction or management ◆ Governance ◆ Jobs ◆ Emergency response ◆ Gender ◆ Livelihood ◆ Social protection ◆ Civil protection

In Zimbabwe, GRADE estimated damages to non-residential buildings from Tropical Cyclone Idai in 2019 to be USD 67 million, but the PDNA considered only health care and education sector damages, so damages totaled USD 21 million. A similar issue occurred in Saint Vincent and the Grenadines during the La Soufrière eruption, for which GRADE categorized damage to agricultural infrastructure, such as fisheries complexes and livestock centers, under “non-residential buildings,” whereas PDNA placed them in the agricultural sector. This difference in sectoral assignments led to inconsistent reporting of total damages.

There are similar challenges related to infrastructure sector comparative analysis. In Vanuatu, for tropical cyclones Judy and Kevin in 2023, there were inconsistencies in classification of damage to auxiliary housing infrastructure (to account, e.g., for water tanks, retaining walls, drainage) as damage to infrastructure or included as part of residential damages. Estimated infrastructure damages in the GRADE from the 2021 La Soufrière volcanic eruption in Saint Vincent and the Grenadines were more than three times as high as the PDNA estimates. The fact that infrastructure damage modeled using GRADE included damage to numerous agricultural infrastructure facilities explains this difference (see also Appendix E). Therefore, in this case, it is more appropriate to compare combined damage to infrastructure and agriculture of the two assessments (PDNA, USD 49.7 million; GRADE, USD 68.0 million; i.e., the GRADE estimate is ~37 percent higher than the PDNA estimate). The PDNA for Vanuatu after tropical cyclones Judy and Kevin covered only energy infrastructure under Department of Energy-managed initiatives in Shefa and Tafea, solar farms at the Parliament house, the Ministry of Climate Change headquarters in Port Vila, the Natai fish market, and the Tanna concession area, whereas GRADE considered damage to all energy infrastructure. These differences in definitions and assignments affect overall sectoral results.

4.3.4. Differences in cost of damage and costs to replace or repair

Costs assigned to different damage vary by assessment methodology. GRADE uses costs for replacement to an asset’s pre-disaster state, with no costs for improvements or resilience included. Other assessments may include improvements, replacement to meet the current building code, or greening an asset.

In the 2020 Sudan floods, the RPDNRA used a much higher average value per destroyed house than GRADE. This was the primary cause of the estimated residential damage being much higher for the RPDNRA (USD 2.92 billion) than for GRADE (USD 526 million).

Similarly, in Zimbabwe, after Tropical Cyclone Idai, the RINA estimated damages per house to be approximately USD 12,000, much higher than GRADE, but the RINA damage ratios used were not reported. Not all of the damaged houses were destroyed, which suggests a significantly higher baseline replacement value. The GRADE exposure model estimated a mean house replacement value in the affected districts of USD 3,200, considering that 72 percent of the houses in the predominantly rural affected districts were made with “traditional materials” or “mixed traditional/modern materials” that have low unit costs of construction.

This difference is evident in infrastructure assessments as well. For Tropical Cyclone Idai in Mozambique, the PDNA estimated road damage costs using an average of USD 178,200 per kilometer, which was significantly higher than the African Development Bank’s published rates for the types of roads found in Mozambique (see Appendix E for more details). GRADE used a lower figure based on restoring roads to their pre-disaster conditions, leading to the PDNA reporting a significantly higher estimate for infrastructure damage than GRADE. Furthermore, in Vanuatu’s cyclones, the PDNA included additional costs for auxiliary infrastructure such as retaining walls and water systems that GRADE did not include. These inclusions resulted in PDNA estimates being nearly double those of GRADE.

In addition, based on global experience, reconstruction costs are much higher than “as was” replacement costs, because they include costs associated with building back better (e.g., application of earthquake- or wind-resistant design guidelines based on the latest local or international codes), recovery needs beyond the built environment, demand surge in prices of construction materials, and so forth. Reconstruction costs are also expected to be proportionately higher for non-residential than residential buildings because of the possibility of upgrades and “build back better” practices (because a large share of capital stock and production technologies for non-residential buildings may be outdated). In addition, development of new sites that are deemed safer in the face of the predominant hazards often inflate reconstruction costs.

An example of this is the 2023 earthquake in Türkiye, for which the costs assigned for repair and reconstruction were high. The TERRA report estimated total residential building reconstruction costs of USD 60.66 billion, including USD 54.7 billion for reconstruction and repair of unusable homes (including destroyed and severely and moderately damaged homes), USD 0.7 billion for repair of homes with light damage, and USD 3.1 billion for replacement of lost furniture in unusable homes. Given that there were approximately 817,500 unusable housing units, average cost per unusable unit would be USD 67,000, or approximately USD 1,000 per m² for an average home of 67 m². For lightly damaged housing units, although no entitlement arises, the average amount of assistance for repairs was USD 530 per unit, which may not be sufficient to cover all the costs for the 1.28 million lightly damaged housing units in the affected region. At the same time, the unit cost of construction for reinforced concrete residential buildings in Türkiye in 2022 was USD 300 to USD 500 per m², so TERRA’s reconstruction costs were approximately double on a per m² basis (see also discussion in section 3.2.3 and Appendix E).

Challenges, Lessons Learned, Opportunities and the Future of GRADE



5.1. Key Issues and Challenges

Modelling risk and disasters is a complex multi-disciplinary science. For the 66 GRADEs completed as of November 2024, the GRADE task team had to assess; develop solutions for; and manage hazard types, regions, and contexts for numerous challenges. The key challenges are summarized below.

5.1.1. Nature of events

The nature of events presents challenges that the task team has had to address and overcome to deliver GRADE assessments. There are challenges with modeling long event timelines (e.g., damaging flooding that extends for months). It is challenging to incorporate duration as a function of damage, including how damage may compound and accumulate over time, and to decide when to draw the line for a damage analysis. For the La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021, the task team conducted GRADE using a future-focused scenario-based assessment that was developed to aid decision makers faced with high levels of uncertainty.

The complexity of interdependent and interacting hazards can be challenging. For example, during the January 2022 eruption of the Hunga Tonga-Hunga Ha'apai volcano, a tsunami and volcanic tephra fallout affected many of the islands in the Tonga archipelago. To model damages while data from the ground were being gradually released, tsunami hazard and vulnerability modeling had to be developed; vulnerability of roofs and crops to increasing thickness of tephra had to be assessed; and costs to remove tephra from roads, sidewalks, and roofs had to be estimated.

The sheer scale of events can make it difficult to complete assessments within the rapid timelines, especially if there are substantially different contexts to consider within the affected area (e.g., urban and rural, low-lying and mountainous, multi-country, arid and humid climates). The greater the variation, the more analysis and checking that is required to ensure accuracy.

5.1.2. Data availability and quality

Lack of access to reliable, up-to-date data is a perennial challenge in many developing and vulnerable countries. Developing exposure models quickly can be challenging for countries with outdated or incomplete housing census data or other relevant data sources. Gathering damage data relies on good sources of reporting, which are not always available, especially for large disasters. There were inconsistent reports on damage severity in The Bahamas after Hurricane Dorian, making the cross-checking process particularly difficult. Good-quality data on construction and replacement costs are challenging to obtain, which can greatly affect the results. Moreover, for contexts in which there have been previous damaging events, it can be challenging to obtain adequate data to distinguish between prior damage and damage caused by the current event.

Innovations, including social media, can be helpful in gathering supplementary data, although there are discrepancies in reported damage in assessments using artificial intelligence (de Bruijn et al. 2020), and artificial intelligence does not provide a complete picture. Some disasters have many aerial images to draw upon, but some do not, depending on their location, priorities for satellites, and which companies or organizations make their data available for free or at low cost.

All components of a risk model have data scarcity and quality challenges, including transparency. Integrating variation in building types into models is particularly difficult, including modeling the range from high-value properties to informal settlements, sometimes side by side, and modeling based on limited structural characteristic data. There are also challenges with transparency of data sources, methodologies used, assumptions made across these models, data sets, and quality and completeness of disaster reporting, without which it can be difficult to judge the reliability and quality of data.

5.1.3. Sources of uncertainty

Modeling the impact of disasters is complex. The GRADE methodology uses risk modeling and reported data on the post-disaster situation, both of which add uncertainty to the results.

Uncertainty stems from incomplete or inaccurate damage data reporting, which is typical in the time frame of a GRADE. This is a significant challenge for all types of events but especially for large, widespread disasters that strain crisis response and damage assessment capabilities. Damage assessment protocols are often lacking or are weak in developing countries. Although modeling can provide answers, a full, well-designed damage assessment effort can substantially reduce uncertainty.

Each type of hazard is associated with a varying degree of uncertainty in models. For example, seismic ground motion can be different in locations with different soil conditions; hurricane winds can be different depending on topography, altitude, and distance from the coast; extent and depth of flooding (or tsunami run up) can be greater in certain locations because of the dynamics of flows interacting with urban or rural landscapes.

Modeling longer-duration flood events comes with a unique set of challenges. As the event evolves, flood extent and duration can change rapidly and have substantial effects on damage. Although satellite imagery of flood events can be helpful, cloud cover and limited satellite passes (common in the developing world) can hamper it, and it may not cover the entire affected region.

Recent advances in exposure modeling enable rapid estimation of the amount of built environment in any given location on the planet, albeit with uncertainties. Furthermore, although building footprints are relatively easily identified, data on the number of floors and building use are limited, adding substantial uncertainty to the model. GRADE has developed methods, approaches, and validation processes to reduce uncertainty stemming from these limitations, but uncertainty cannot be eliminated completely.

Vulnerability to different hazards depends on structural attributes of buildings, which are difficult to ascertain accurately for large numbers of buildings or assets affected by large disasters. In these cases, judgements are made and approximations used, but substantial uncertainty can be added to the vulnerability modeling. Estimating the replacement value of different types of buildings is also a source of substantial uncertainty, as is estimating a damage ratio given a damage state (e.g., the amount of damage and therefore the cost of repair for partially damaged buildings).

There are multiple sources of uncertainty in the GRADE results, but by using meticulous validation and calibration of results, expert judgement, and multiple levels of the process, uncertainty can be reduced.

5.1.4. Fragility, conflict, and violence and social and gender impacts

Data pertaining to fragility, conflict, and violence (FCV) and gender and social challenges are even scarcer than data on buildings and infrastructure. In the context of FCV, impacts on different groups vary, and responses must vary as well to ensure an effective, equitable response. A particularly challenging GRADE assessment focused on FCV and social vulnerability was conducted in response to Cyclone Mocha, which hit Myanmar in June 2023. Given lack of information and responding to demand from the international community, a highly successful GRADE assessment was conducted in collaboration with the United Nations Development Programme and other UN agencies (GFDRR 2023).

There is growing evidence of the gender impacts of disasters and increasing advocacy for gender issues being highlighted in post-disaster reports. To date, reporting on gender issues has been challenging for several reasons. First, data are scarce for the baseline situation and in disaster reporting from the affected areas after a disaster. Second, there is the challenge of presenting the gender impacts in a convincing way to ensure that action is taken in addition to the typical economic and infrastructure recovery and response.

5.1.5. Communication, publication, and use

Communication of GRADE findings can be a sensitive matter that may require that certain data and results be withheld initially, perhaps because of a country's requests or use of sensitive data (e.g., government information). One of the most challenging things to communicate is uncertainty regarding results, and this becomes even more challenging for complex events with compounding impacts over long durations. GRADE assessments strive to identify clearly which datasets, approaches, and methodologies have been used to arrive at the results, in order to be open and transparent.

5.2. Lessons learned

After 66 GRADE assessments, the team has learned numerous invaluable lessons. The key lessons are highlighted below.

Clear definitions and descriptions of what is included in post-disaster assessments is critical. Different methodologies such as GRADE and PDNA have different strengths and weaknesses, but all are valid. For example, when a PDNA is published, it can be challenging to compare results with GRADE results if definitions are omitted, because including different assets in different damage categories can lead to different results. What is meant by non-residential? Does it include contents? Which contents are excluded? Does it include agriculture, industrial buildings, commercial spaces, and public sector buildings? GRADE has evolved such that the definitions and descriptions are clear.

A clearer narrative on loss versus damage is required to ensure that GRADE results are understood. GRADE estimates damage after an event, which is communicated clearly in every GRADE report, to avoid confusion. Task teams have tried to extend the analysis to estimate losses, but the timelines are too restrictive and resources too stretched to provide a rapid, reliable, accurate estimate of losses.

Clear communication on the findings, scope, and role of GRADE is important. Use of GRADE has been multifaceted, for example, to provide first-order, credible damage estimates to World Bank management to support internal decision making; to equip governments

with rapid, sectoral damage impact information to inform response, recovery, and donor financing needs; and to facilitate understanding of the scope and nature of disaster events and their effects. Communication of GRADE findings must therefore be clear, comprehensible, and direct to ensure that they are interpreted and acted upon effectively. Although the main output of GRADE is a technical report, the critical information needed to guide recovery planning and decision making is presented plainly, and the methodology used is transparent. When possible, visual aids, simulations, and charts are used to represent and clarify multi-hazard situations. Publication of GRADE reports is important for the growing body of knowledge of disasters and for the wider disaster response and risk management community. Eight of the 61 GRADE reports (GRADE Notes and full GRADEs) have been openly published,⁹ and more have had their headline results released. Results are sometimes not published because of their sensitivity, but more often it is because time and resources within governments in disaster response phases to approve or agree to publication of the reports are limited. When results have been published or results released, there have been high levels of publicity and media attention. Given the importance of these results being available publicly, a process will be developed to implement agreements for publication before and during the GRADE assessment period.

Typical assumptions made in damage estimation, which are reached through experience and evidence, are tested in FCV contexts and often found to be inadequate. GRADE assessments in FCV contexts introduce complexity and additional challenges, including additional vulnerable groups or a need to focus on them (e.g., internally displaced persons) and on external factors compounding the event or affecting viable response activities and plans. The assessments will improve as experience grows and the evidence base, datasets, and understanding increase.

GRADE must continue to evolve and improve to continue to respond to demand, streamline the process, and increase accuracy. This will be possible as the process continues to be implemented and reviews such as this continue to be conducted. Repeated assessments in disaster-prone countries make the process easier. Development of datasets, tools, and automation and their continuous improvement and expansion will continue to improve performance.

5.3. Opportunities

Opportunities for GRADE are outlined below given the challenges experienced, lessons learned, and other experiences and observations.

To achieve a richer data environment to improve GRADE requires continued efforts to update and maintain datasets and increase sources of post-disaster datasets, including by building partnerships with the private sector and other organizations working in this space (e.g., help acquiring post-disaster aerial imagery, drone fly overs, ground-based observation data). Gathering good-quality data is particularly critical in FCV contexts. The potential for automation, artificial intelligence, and machine learning must be explored further to see if they could increase automation (and hence reduce human resource needs and increase speed).

⁹ GRADE reports have been published on the Hunga Tonga-Hunga Ha'api volcanic eruption in Tonga (2022); Ukraine (2022); the earthquakes in Türkiye and Syria (2023); Tropical Cyclone Mocha in Myanmar (2023); the earthquakes in Herat, Afghanistan (2023); and Hurricane Beryl in Grenada and Saint Vincent and the Grenadines (2024).

More research and work are needed on global construction and replacement costs to increase the accuracy of GRADE and other post-disaster assessments.

In addition to improving and expanding datasets and toolkits to help development practitioners mainstream gender considerations into disaster planning and response, awareness must be raised of the interaction between gender issues and disasters.

A continuous learning process is required to advance GRADE, ideally through structured reviews, regular performance assessments, and periodic feedback from stakeholders, including idea generation.

Continued improvement of the communication templates will enable the task team to respond to stakeholders more quickly and communicate results more effectively and efficiently.

5.4. The future of GRADE: responding to demand and enhancing the methodology

GRADE has continued to innovate and adapt, which is key to rapid assessments. The GRADE methodology has evolved significantly since 2015 to meet the need for rapid, accurate post-disaster damage assessments, but as the frequency and severity of disasters increase, the demand for GRADE assessments will continue to outstrip capacity. To remain responsive, effective, and relevant, GRADE must address this rising demand while improving its methodology to maintain accuracy and quality.

5.4.1. Responding to growing demand for GRADE assessments

Increasing global demand for GRADE assessments stems from the intensifying impact of disasters and increasing awareness of the availability and success of these types of assessments. Meeting this demand will require a multifaceted approach, including expanding resources, streamlining processes, and fostering strategic partnerships. To increase GRADE's capacity, it will be essential to expand the pool of experts capable of conducting assessments. This could involve engaging regional and national disaster risk management agencies, universities, and private sector entities with the necessary expertise. Collaboration with regional and sector-specific institutions may also help address a broader range of disasters, including those with localized impacts. Pre-arranged consultancy agreements and capacity-building initiatives can expand the network of collaborators. Such partnerships would also enable GRADE to provide rapid first-order approximations for disasters of varying scales. Alternative models for increasing capacity should be explored, with a focus on ensuring proficiency in all areas of the approach.

Continuous improvement and automation of GRADE processes can help meet demand more efficiently. Enhancements to, and expansion of, key datasets (e.g., exposure, vulnerability, historical disaster data) are critical. Partnerships with organizations such as the World Bank Digital Development Partnership can support this effort by using new tools and datasets. Leveraging machine learning and artificial intelligence can help automate repetitive tasks, and blockchain technology may decentralize assessment capabilities, enabling regional stakeholders to conduct assessments independently.

GRADE's development continues to support innovation such as with the Sistema de Reopilación y Evaluación de Daños (known as SIREN), a damage data collection and assessment tool that facilitates post-disaster damage data collection through a mobile and web platform and secures and consolidates the data. It enables swift, accurate data collection for damage estimation, enhancing coordination for efficient resource allocation, better decision making, and long-term recovery planning.

5.4.2. Improving GRADE's methodology for greater accuracy and efficiency

Future collaboration with institutions specializing in civil engineering, remote sensing, and data analytics will enhance GRADE's capabilities. Past successes with University College London that provided valuable insights into types of buildings and vulnerability functions can be expanded to deepen GRADE's expertise in various disaster types and regions. For example, collaboration with organizations and private sector companies that provide remote sensing data will provide high-resolution, near-real-time imaging to support and improve GRADE assessments.

A structured benchmarking process could evaluate the suitability of existing disaster impact assessment tools to be integrated into or partially adopted for use in GRADE assessments. This would involve assessing global disaster risk data and modeling tools to determine their optimal use cases, limitations, and reliability. In disaster-prone regions, benchmarking sectors such as infrastructure, agriculture, and natural assets would also be useful. GRADE's development will focus on deepening insights into these sectors through historical data analysis, vulnerability assessments, and exposure modeling.

5.4.3. Expanding GRADE

Since its inception, GRADE has evolved to encompass a broad spectrum of natural and human-induced hazards, yet there is potential for further enhancement. Assessments covering additional hazards such as droughts, heatwaves, and disease outbreaks could be explored, and the breadth and variety of outputs could be expanded to better serve needs in post-disaster contexts, although it is crucial to balance these advances with GRADE's key value addition—rapid delivery of reliable results. Any expansion in scope must carefully consider the potential trade-offs between value production and speed.

Currently, GRADE is focused on estimating economic damages of physical assets, a critical tool for governments navigating post-disaster recovery. Although highly valuable, loss assessments—quantifying broader economic impacts—are complex to complete in a short period of time. These assessments rely less on the methodologies and datasets that GRADE uses and more on data collected from the field, as seen in PDNAs, DaLAs, and the like.

GRADE's damage estimates account for reconstruction costs based on like-for-like replacement of assets, but the goal of post-disaster reconstruction is often to rebuild with resilience, enhancing assets to better withstand future hazards. This principle, referred to as “build back better,” highlights the opportunity to increase resilience in the aftermath of a disaster. Such improvements, albeit invaluable, incur higher upfront costs than simple replacement. Providing decision makers with detailed estimates of these enhanced reconstruction costs could be useful for planning and resource allocation but would require clear definitions of the scope of resilience enhancements. Presenting like-for-like and resilience-oriented cost scenarios would enable more-informed decision making.

GRADE's scope could extend to new sectors. Although it currently evaluates damages to the residential, non-residential, infrastructure, and agricultural sectors, there is potential to assess other critical areas such as environmental damages, debris clearance costs, and the social impacts of disasters.

As GRADE considers these opportunities for growth and advancement, its primary mission must remain at the forefront. It must remain focused on providing rapid, remote, reliable damage estimates, which sets it apart from field-based post-disaster assessment methodologies. Nevertheless, broadening GRADE's scope and exploring improvements to its outputs will strengthen its role as a vital resource for post-disaster decision makers globally.

Damage caused by 2017 Hurricane Maria in Dominica. Photo Credit: World Bank



Conclusion



This report outlines the development and growth of the GRADE methodology and its application to disaster response and recovery efforts over the last decade. The high and growing demand for GRADE assessments since its launch underlines the urgent global need and demand for it. Through its innovative, desk-based approach, GRADE has repeatedly been able to address the pressing need for accurate, rapid, cost-effective disaster assessments.

The report's key insights are as follows:

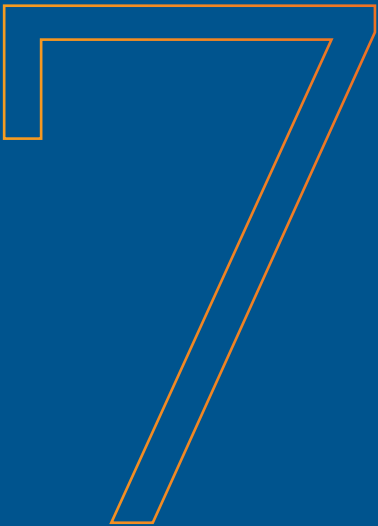
- ◆ **Impact on decision making** GRADE's rapid assessments have had tangible impacts on disaster response and recovery financing. For instance, the quick release of GRADE results after the Türkiye earthquakes in 2023 and Cyclone Idai in 2019 enabled the World Bank and other stakeholders to mobilize more than USD 1 billion in recovery funds in record time. The methodology has also played a critical role in activating mechanisms such as the International Development Association Crisis Response Window, ensuring timely financial support for affected countries. GRADE will continue to play an important role in support of activation of World Bank products and sector-based assessments and inform thematic and cross-cutting areas such as gender and FCV country contexts and discussions related to loss and damage.
- ◆ **Timeliness and accuracy** The GRADE methodology has revolutionized post-disaster damage assessment. With an average time to completion of just 2.6 weeks for rapid assessments, GRADE has outpaced traditional ground-based approaches. When directly compared with these assessment methodologies for select events, GRADE delivers on average 12.4 weeks faster than PDNAs, DaLAs, and other assessments. In addition, GRADE's damage estimates are within 10 to 12 percent of estimates from these more detailed assessments, demonstrating its credibility and reliability in providing early insights to decision makers.
- ◆ **Global reach and versatility** Between 2015 and 2024, GRADE was deployed 66 times in 54 countries for 62 events. These included major natural hazards such as earthquakes, floods, tropical cyclones, and volcanic eruptions and non-natural hazard-related damages in Ukraine and the Tigray conflict in Ethiopia. This wide application highlights the versatility of the methodology in addressing a diverse range of challenges, from immediate economic damage assessments to informing broader recovery strategies.
- ◆ **Innovative use of technology** GRADE's ability to innovate and use advanced tools such as satellite data, drone footage, and social media feeds alongside traditional damage reporting has set it apart from traditional methods. For example, use of virtual damage surveys during Hurricane Beryl in Grenada in 2024 demonstrated the potential of emerging technologies to enhance exposure and vulnerability assessments. These innovations not only increased the speed and accuracy of GRADE assessments, but also highlighted the methodology's adaptability in resource-constrained or inaccessible environments.
- ◆ **Challenges and areas for improvement** Despite its successes, GRADE faces several challenges, including data availability, differences in damage categorizations, and

the need for clearer communication about results and assumptions. Differences in sectoral damage estimations—such as assessment methodologies categorizing agricultural losses differently—highlight the need for progress on harmonization and alignment. In addition, the complexity of prolonged disasters, such as the 2022 Pakistan floods, emphasizes the importance of developing methodologies that can account for compounding impacts over time.

- ◆ **Growing demand for GRADE** The increasing frequency and intensity of disasters, coupled with increasing awareness of GRADE's capabilities, has led to a surge in demand for its assessments. This demand underscores the need to expand GRADE's capacity, improve methodologies, and foster partnerships with regional and national stakeholders to expand operations effectively.

The evolution and application of GRADE over the past decade have demonstrated its critical role in transforming post-disaster damage assessments. By delivering reliable, timely, cost-effective insights, GRADE has not only increased support for governments and humanitarian organizations responding to disasters, but has also done so more quickly, enabling faster, more-effective decision making. As disasters become more frequent and severe, continued refinement and expansion of GRADE will be vital to meeting growing demand for rapid, high-quality assessments. By embracing innovation, fostering partnerships, and addressing challenges, GRADE is positioned to remain a key part of the global disaster response system, enabling faster, more-informed decisions that ultimately save lives and promote development.

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Appendix A. GRADE Assessment Reports and Time for Completion

Event date	GRADE completion date	Weeks to complete ^a	Event	Type
2015.04.25	2015.05.02	1.0	Earthquake, Ghorka, Nepal	GRADE Note
2016.04.16	2016.04.29	1.9	Earthquake, Muisne, Ecuador	GRADE Note
2016.10.04	2016.10.20	2.3	Hurricane Matthew, Haiti	Full GRADE
2017.03.07	2017.03.21	2.0	Tropical Cyclone Enawo, Madagascar	Full GRADE
2017.09.06	2017.09.08	0.3	Hurricane Irma, Caribbean ^b	GRADE Zero
2017.09.18	2017.09.22	0.6	Hurricane Maria, Dominica	GRADE Note
2018.01.05	2018.02.07	4.7	Tropical Cyclone Ava, Madagascar	GRADE Note
2018.06.03	2018.06.11	1.1	Volcanic eruption, Fuego, Guatemala	Full GRADE and Google Earth demonstration
2018.09.28	2018.10.09	1.6	Earthquake, Sulawesi-Palu, Indonesia	Full GRADE and Google Earth demonstration
2019.03.14	2019.03.27	1.9	Tropical Cyclone Idai, Mozambique	Full GRADE
2019.03.14	2019.03.29	2.1	Tropical Cyclone Idai, Malawi	Full GRADE
2019.03.14	2019.04.02	2.7	Tropical Cyclone Idai, Zimbabwe	Full GRADE
2019.04.24	2019.05.02	1.1	Tropical Cyclone Kenneth, Comoros	GRADE Note
2019.04.25	2019.05.02	1.0	Tropical Cyclone Kenneth, Mozambique	GRADE Note
2019.06.25–08.23	2019.08.30	9.4/1.0	Flood, Myanmar	Full GRADE
2019.09.01	2019.09.20	2.7	Hurricane Dorian, The Bahamas	Full GRADE
2019.11.26	2019.12.16	2.9	Earthquake, Durrës, Albania	Full GRADE
2020.03.22	2020.03.27	0.7	Earthquake, Zagreb, Croatia	GRADE Note
2020.04.06	2020.04.22	2.3	Tropical Cyclone Harold, Vanuatu	GRADE Note
2020.08.25	2020.09.11	2.4	Flood, Afghanistan	GRADE Note
2020.07–09.10	2020.09.24	12.3/2.0	Flood, Niger	GRADE Note
2020.07.15–09.25	2020.10.30	15.3/5.0	Flood, Sudan	GRADE Note
2020.08.31	2020.09.14	2.0	Flood, Pakistan	GRADE Note
2020.09.01–11.20	2021.02.03	—	Flood, Cambodia	GRADE Zero
2020.10.30	2020.11.19	2.9	Earthquake, Aegean Sea, Türkiye	Full GRADE
2020.10.30	2020.11.20	3.0	Earthquake, Aegean Sea, Greece	Full GRADE
2020.11.03 and 11.15	—	—	Hurricanes Eta and Iota, Nicaragua	GRADE Zero

Event date	GRADE completion date	Weeks to complete ^a	Event	Type
2020.11–2022.06	2022.08.03	—	Induced, Ethiopia	GRADE Note
2020.12.16	2020.12.23	1.0	Tropical Cyclone Yasa, Fiji	GRADE Note
2021.01.23	2021.02.15	3.3	Tropical Cyclone Eloise, Mozambique	GRADE Note
2021.04.09	2021.04.21	1.7	Volcanic eruption, La Soufrière, Saint Vincent and the Grenadines	Full GRADE
2021.05.15–10.29	2021.11.05	24.9/1.0	Flood, South Sudan	GRADE Note
2021.08.14	2021.08.27	1.9	Earthquake, Tiburon Peninsula, Haiti	Full GRADE
2022.01.15	2022.02.07	3.3	Volcanic eruption, Hunga Tonga-Hunga Ha'apai, Tonga	Full GRADE and Google Earth demonstration
2022.01.22–02.23	2022.03.12	7.0/2.4	Tropical cyclones Ana, Batsirai, Dumako, and Emnati, Madagascar	Full GRADE
2022.01.24	2022.02.18	3.6	Tropical Cyclone, Ana, Malawi	Full GRADE
2022.01.25	2022.02.18	3.4	Tropical Cyclone, Ana, Mozambique	GRADE Note
2022.01.25	2022.02.15	3.0	Tropical Cyclone, Ana, Zimbabwe	GRADE Note
2022.02.24	2022.04.07	2.7	Induced, Ukraine ^C	Full GRADE
2022.03.11	2022.03.31	2.9	Tropical Cyclone Gombe, Mozambique	GRADE Note
2022.06.01–11.25	2022.11.30	26.0/5.6	Flood, Nigeria	GRADE Note
2022.06.08–08.31	2022.11.16	—	Flood, Yemen	GRADE Zero
2022.06.14–10.15	2022.09.13	13.0/2.4	Flood, Pakistan	Full GRADE
2022.06.22	2022.07.01	1.3	Earthquake, Paktika, Afghanistan	Full GRADE
2022.07.01–11.16	2022.11.16	20.7/4.0	Flood, South Sudan	GRADE Note
2022.09.19	2022.09.27	1.1	Hurricane Fiona, Dominican Republic	GRADE Note
2023.01.17	2023.02.07	3.0	Flood, Southeastern Europe	GRADE Note
2023.02.06	2023.02.20	2.0	Earthquake, Türkiye-Syria, Türkiye	Full GRADE
2023.02.06	2023.02.20	2.0	Earthquake, Türkiye-Syria, Syria	Full GRADE
2023.02.24 and 03.11	2023.03.27	4.4	Tropical Cyclone Freddy, Mozambique	Full GRADE
2023.03.01 and 03.03	2023.03.22	3.0	Tropical cyclones Judy and Kevin, Vanuatu	GRADE Note
2023.05.14	2023.06.29	6.6	Tropical Cyclone Mocha, Myanmar	Full GRADE
2023.09.08	2023.09.26	2.6	Earthquake, Morocco	Full GRADE
2023.10.07–10.15	2023.10.31	3.4	Earthquake, Afghanistan	Full GRADE

Event date	GRADE completion date	Weeks to complete ^a	Event	Type
2023.10.24	2023.11.15	3.1	Tropical Cyclone Tej, Yemen	Full GRADE
2023.11.15–2024.01.31	2024.02.16	13.3/2.3	Flood, Democratic Republic of Congo	Full GRADE
2024.03.12	2024.05.08	8.1/2.0	Flood, Bujumbura Floods, Burundi	GRADE Note
2024.03.27	2024.04.24	5.0	Tropical Cyclone Gamane, Madagascar	GRADE Note
2024.03.27–05.15	2024.06.14	11.3/8.4	Flood, Kazakhstan	Full GRADE
2024.04.27–05.24	2024.06.26	13.0/6.0	Flood, Rio Grande do Sul, Brazil	Full GRADE
2024.07.01	2024.08.01	4.1	Hurricane Beryl, Grenada	Full GRADE
2024.07.01	2024.07.26	3.6	Hurricane Beryl, St, Vincent and the Grenadines	Full GRADE
2024.07–08	2024.09.25	12.3/2.4	Flood, Yemen	Full GRADE
2024.08.14–09.16	2024.10.25	10.3/8.0	Flood, Bangladesh	Full GRADE
2024.09.01	2024.10.04	4.7	Flood, Thailand	GRADE Zero
2024.10.03	2024.10.22	2.7	Flood, Bosnia	GRADE Note

- a. Number of weeks to complete is from the event's starting date; when two values are quoted, the first is from the event's start, and the second is from initiation of the GRADE assessment. These latter cases correspond to long-lasting flood events.
- b. Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Saint Barthélemy, Saint Martin, Sint Maarten, Turks and Caicos, U.S. Virgin Islands.
- c. Time required for the full GRADE in the case of Ukraine is from the start of the GRADE assessment.

Appendix B. GRADE Sectoral and Total Damages

Disclaimer: In addition to the disclaimer for this report, the Disaster Resilience Analytics and Solutions team at the World Bank estimated the values presented in Appendix B using the GRADE methodology. They have been developed for internal use by the World Bank primarily to provide advice to client governments.

Event	Residential	Non-Residential	Infrastructure	Agriculture	Environmental	Flood	Other	Total	Percentage of gross domestic product
	U.S. dollars, million								
2015, earthquake, Ghorka, Nepal	3,036	1,434	1,313	—	—	—	—	5,368	23.6
2016, earthquake, Muisne, Ecuador	486	415	400	—	—	—	—	1,301	1.4
2016, Hurricane Matthew, Haiti	496	271	255	204	216	149	—	1,590	10.3
2017, Tropical Cyclone Enawo, Madagascar	154	40	3	207	—	—	—	404	3.3
2017, Hurricane Irma, Caribbeana	—	—	—	—	—	—	—	7,955	79.3
2017, Hurricane Maria, Dominica	384	244	241	—	—	—	—	869	166.5
2018, Tropical Cyclone Ava, Madagascar	76	22	47	50	—	—	—	195	1.5
2018, volcanic eruption, Fuego, Guatemalab	5	>30	—	>>5	—	—	—	>>40	0.1
2018, earthquake, Sulawesi-Palu, Indonesia	181	185	165	—	—	—	—	531	0.1
2019, Tropical Cyclone Idai, Mozambique	178	149	188	200	—	—	—	715	4.8
2019, Tropical Cyclone Idai, Malawi	28	24	48	43	—	—	—	143	3.5
2019, Tropical Cyclone Idai, Zimbabwe	66	67	311	196	—	—	—	640	4.8
2019, Tropical Cyclone Kenneth, Comoros	14	9	13	63	—	—	—	99	8.3

Event	Residential	Non-Residential	Infrastructure	Agriculture	Environmental	Flood	Other	Total	Percentage of gross domestic product
	U.S. dollars, million								
2019, Tropical Cyclone Kenneth, Mozambique	—	—	—	—	—	—	—	95	0.6
2019, flood, Myanmar	44	30		33	—	—	—	107	107
2019, Hurricane Dorian, The Bahamas	1,952	929	492	—	—	—	—	3,373	27.0
2019, earthquake, Durrës, Albania	617	175	29	—	—	—	—	821	5.3
2020, earthquake, Zagreb, Croatia	—	—	—	—	—	—	—	>>100	>>0.2
2020, Tropical Cyclone Harold, Vanuatu	65		25		—	—	—	90	10
2020, flood, Afghanistan	15	18			—	—	—	33	0.2
2020, flood, Niger	43	—	—	—	—	—	151d	194	2.0
2020, flood, Sudan	526	158	289	1,139	—	—	—	2,112	6.0
2020, flood, Pakistan	227	—	147	449	—	—	13e	836	0.3
2020, flood, Cambodia	—	—	—	40	—	—	—	40	0.1
2020, earthquake, Aegean Sea, Türkiye	640	192	76	—	—	—	—	907	0.1
2020, earthquake, Aegean Sea, Greece	120	27	10	—	—	—	—	156	0.1
2020, Hurricanes Eta and Iota, Nicaragua	—	—	—	—	—	—	—	660	5.2
2020, induced, Ethiopia	2,200	1,225	—	—	—	—	—	8,000	9.5
2020, Tropical Cyclone Yasa, Fiji	80	30	23	52	—	65	—	251	4.5
2021, Tropical Cyclone Eloise, Mozambique	69	132	94	—	—	—	295	1.8	

Event	Residential	Non-Residential	Infrastructure	Agriculture	Environmental	Flood	Other	Total	Percentage of gross domestic product
	U.S. dollars, million								
2021, volcanic eruption, La Soufrière, Saint Vincent and the Grenadines	11	4	37	31	—	—	—	82	9.5
2021, flood, South Sudan	312		125	234	—	—	—	671	13.2
2021, earthquake, Tiburon Peninsula, Haiti	730	162	219	—	—	—	—	1,111	7.8
2022, volcanic eruption, Hunga Tonga-Hunga Ha'apai, Tonga	15	29	21	21	—	—	5f	91	18.5
2022, Tropical cyclones Ana, Batsirai, Dumako, Emnati, Madagascar	133	80	170	275	—	—	—	657	4.8
2022, Tropical Cyclone Ana, Malawic	105	26	96.5	28	—	—	—	256	2.0
2022, Tropical Cyclone Ana, Mozambique c	23	14	97	23	—	—	—	157	1.0
2022, Tropical Cyclone Ana, Zimbabwe	—	—	—	—	—	—	—	12	0.1
2022, induced, Ukraine (partial)	18,753	12,928	27,565	—	—	—	—	59,246	29.6
2022, Tropical Cyclone Gombe, Mozambique	151	92	160	36	—	—	—	439	3.6
2022, flood, Nigeria	2,237	1,376	1,232	1,837	—	—	—	6,682	1.6
2022, flood, Yemen	210		—	172	192	—	—	574	2.7
2022, flood, Pakistan c	3,143	1,249	3,240	6,829	—	—	—	14,460	4.2
2022, earthquake, Paktika, Afghanistan	54	30	16	—	—	—	—	100	0.5
2022, flood, South Sudan	242		102	171	—	—	—	515	3.0

Event	Residential	Non-Residential	Infrastructure	Agriculture	Environmental	Flood	Other	Total	Percentage of gross domestic product
	U.S. dollars, million								
2022, Hurricane Fiona, Dominican Republic	101		73	119	—	—	—	292	0.3
2023, flood, Southeastern Europe	18	11	38	15	—	—	—	82	0.9
2023, earthquake, Türkiye	18,036	9,691	6,424	—	—	—	—	34,151	4.0
2023, earthquake, Syria	2,466	1,705	912	—	—	—	—	5,083	10
2023, Tropical Cyclone Freddy, Mozambique	484	276	577	197	—	—	—	1,535	9.7
2023, Tropical cyclones Judy and Kevin, Vanuatu	18	16	35	28	—	—	—	97	10.0
2023, Tropical Cyclone Mocha, Myanmar	1,107	410	490	237	—	—	—	2,244	3.4
2023, earthquake, Morocco	1,607	804	643	—	—	—	—	3,054	2.6
2023, earthquake, Afghanistan	125	125	64		—	—	—	314	2.2
2023, Tropical Cyclone Tej, Yemen	70	20	65	35	—	—	—	190	0.9
2023, flood, Democratic Republic of Congo	403	281	423	206	—	—	—	1,313	2.3
2024, flood, Bujumbura Floods, Burundi	22	10	10	12	—	—	—	55	1.7
2024, Tropical Cyclone Gamane, Madagascar	44	25	34	148	—	—	—	251	1.6
2024, flood, Kazakhstan	212	141	271	35	—	—	—	659	0.3
2024, flood, Rio Grande do Sul, Brazil	2,300	1,460	2,060	1,820	—	—	—	7,640	0.4
2024, Hurricane Beryl, Grenada	59	53	63	43	—	—	—	218	16.5

Event	Residential	Non-Residential	Infrastructure	Agriculture	Environmental	Flood	Other	Total	Percentage of gross domestic product
	U.S. dollars, million								
2024, Hurricane Beryl, St. Vincent and the Grenadines	79	80	72		—	—	—	231	22.0
2024, flood, Yemen	195	94	157	144	—	—	—	590	2.5
2024, flood, Bangladesh	403	165	640	468	—	—	—	1,676	0.4
2024, flood, Thailand	425		350	275	—	—	—	1,050	0.2
2024, flood, Bosnia & Herzegovnia	43	25	70	20	—	—	—	157	0.5

- Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Saint Barthélemy, Saint Martin, Sint Maarten, Turks and Caicos, U.S. Virgin Islands.
- For the 2018 eruption of the Fuego volcano in Guatemala, there were no ash fallout data at the time of the assessment, so it was suggested that damages to agriculture were far greater than USD 5 million.
- Average of upper and lower estimate.
- Infrastructure; crops; irrigation; flood management; water, sanitation, and hygiene; energy; transportation; communication; casualties; clean-up; vehicles; and social protection. Total damages would be USD 1,044 million if indirect damages were considered.
- Casualties, clean-up, motors, and social protection. Total damages would be USD 255.5 million if indirect damages were considered.
- Ash removal and associated clean-up costs for Tongatapu.

Appendix C. Developments, Innovations, Challenges, and Limitations during the Evolution of GRADE

Table C.1. Expanded Global Rapid Post-Disaster Damage Estimation (GRADE's) Key Developments, Innovations, Challenges, and Limitations

Event date	Event	Hazard types	Developments and innovations	Challenges and limitations
2015.04.25	Earthquake, Ghorka, Nepal	Ground shaking, landslides	Developed model to estimate number of fatalities and use of damage information alongside exposure for vulnerability modeling	Numerous landslides with uncertain impact on lives
2016.04.16	Earthquake, Muisne, Ecuador	Ground shaking	Used detailed damage data according to structural type available from on the ground engineering assessments which improved vulnerability. Ground motion using GRADE ShakeMap.	Modeling exposure and vulnerability to account for mixture of low-cost and engineered buildings
2016.10.04	Hurricane Matthew, Haiti	Storm surge, wind	Damage analysis using data from social media	Lack of good damage data in time frame of GRADE
2017.03.07	Tropical Cyclone Enawo, Madagascar	Wind, flooding	First assessment of agricultural exposure and damage	Limited impact data during time frame of GRADE
2017.09.18	Hurricane Maria, Dominica	Wind, landslides	Damage surveys conducted virtually using helicopter flyover footage	Challenges discerning wind-induced damage from impacts due to storm surge and thousands of landslides
2018.06.03	Volcanic eruption, Fuego, Guatemala	Pyroclastic flow, lahars	Developed event impact demonstration on Google Earth	Impacts highly localized and required high-resolution footprints
2018.09.28	Earthquake, Sulawesi-Palu, Indonesia	Fault rupture, ground shaking, tsunami, rapid mudslides	Developed an event impact demonstration using Google Earth using video, photos, and voice over	One event, four types of hazards and damage mechanisms (fault rupture, ground shaking, tsunami, rapid mudslides) that required multiple hazard and vulnerability models
2018.06.03	VE. Fuego. Guatemala (GTM)	Pyroclastic flow and Lahars	Developed KMZ event impact demonstration	Impacts highly localized required high-resolution footprints
2018.09.28	EQ. Sulawesi-Palu. Indonesia	Fault rupture, ground shaking, tsunami, and rapid mudslides	Developed KMZ event impact demonstration employing video, photos, and voice over; GRADE report presented to World Bank President	One event-four types of hazards/ damage mechanisms (fault rupture, ground shaking, tsunami, and rapid mudslides) that required multiple hazard and vulnerability models
2019.03.14	Tropical Cyclone Idai, Mozambique	Flooding, wind	Analyzed duration and depth of flooding using remote-sensed flood footprints in conjunction with digital elevation model to estimate flood depth and consecutive imagery for estimation of flood duration. Developed agricultural exposure to assess damages to agricultural sector for first time. Demonstrated use of online R-Shiny tool to visualize damages geographically for first time.	Flood footprints difficult to access rapidly and often contradictory between different sources, limited information on depth and velocity of flooding, multi-country event of high consequence
2019.03.14	Tropical Cyclone Idai, Zimbabwe			
2019.03.14	Tropical Cyclone Idai, Malawi			
2019.09.01	Hurricane Dorian, The Bahamas	Storm surge, wind	Employed Bayesian updating methodology using social media imagery to develop wind vulnerability curves	Difficult to model informal settlements next to high-end, hurricane-resistant properties; damage data unavailable
2020.04.06	TC.Tropical Cyclone Harold., Vanuatu	Storm surge, wind	Developed frequently asked questions (FAQs) document to improve communication of findings locally	

Event date	Event	Hazard types	Developments and innovations	Challenges and limitations
2020.07.01 --09.20	Flood, Sudan	Flooding	Introduced GRADE Note, developed within one week	Uncertainty of results because of long duration, high impact flood event (longer than two months) affecting entire country with different levels of severity
2020.10.30	Earthquake, Aegean Sea, Türkiye	Ground shaking, tsunami	Developed a tsunami run-up model and mapping of collapses of major reinforced concrete building (and casualties related to these)	
2020.10.30	Earthquake, Aegean Sea, Greece	Ground shaking, tsunami	Developed a tsunami run-up model and mapping of collapses of major reinforced concrete building (and casualties related to these)	
2022.01.22–02.23	Tropical cyclones Ana, Batsirai, Dumako, Emnati, Madagascar	Flooding, wind	Analyzed and delivered GRADEs for multiple consecutive events (four) that occurred in January and February 2022	Fathom flood footprints unavailable, satellite flood maps used which probably missed 30% of affected areas
2022.02.24	Induced, Ukraine	Induced	Assessed direct economic damages from non-natural hazard for first time	Difficult to develop pre-event baseline exposure for buildings and infrastructure; challenging to gather damage data for housing and other buildings as well as for roads, bridges, railways, and other critical infrastructure in a timely manner; results limited to the initial five and a half weeks of ongoing situation.
2020.11–2022.06	Induced, Ethiopia	Induced		Incomplete data and uncertainties across the regions affected by the 2-year long conflict
2022.06.14–10.15	Flood, Pakistan	Flooding		Long-lasting and widespread flooding event with tremendous consequences
2023.02.06	Earthquake, Türkiye	Ground shaking	A combined ShakeMap developed for two major earthquakes (magnitudes 7.8 and 7.5) and several aftershocks of greater than magnitude 6	Uncertainty about human-induced damage prior to the earthquakes, including previously demolished structures. Challenges due to the lack of information on performance of the building stock, building costs and unit costs of construction and building content value.
2023.02.06	Earthquake, Syria	Ground shaking	A combined ShakeMap developed for two major earthquakes (magnitudes 7.8 and 7.5) and several aftershocks of greater than magnitude 6	Uncertainty about human-induced damage prior to the earthquakes, including previously demolished structures. Challenges due to the lack of information on performance of the building stock, building costs and unit costs of construction and building content value.
2023.03.01–03	Tropical cyclones Judy and Kevin, Vanuatu	Wind, flooding, storm surge, landslides	Road accessibility analysis for better estimation of damage to infrastructure; updated building and infrastructure exposure model developed	Cumulative damage from two Category 4 tropical cyclones over a four-day period; highly heterogeneous geographic distribution of damage
2023.05.14	Tropical Cyclone Mocha, Myanmar	Wind, storm surge, flooding, landslides	Agricultural damages estimated based on disaggregation, quantification, and values of crops from 2021 Statistical Yearbook and previous agricultural censuses combined with current yield estimates from state and district agricultural departments	Affected areas in fragile situation with limited access to information; uncertainties accounting for devastation in internally displaced person camps; uncertainties due to incomplete damage data
2023.10.07–15	Earthquake, Afghanistan	Ground shaking	Development of custom ShakeMap to illustrate reported impacts of the four earthquakes; consecutive satellite imagery analysis used for better damage calibration across remote areas	Cumulative damage from earthquake sequence of four events of the same magnitude (6.3)

Event date	Event	Hazard types	Developments and innovations	Challenges and limitations
2023.10.23–24	Tropical Cyclone Tej, Yemen	Wind, flooding	Analysis included detailed comparison with three previous tropical cyclones (2008, 2015, 2018) including analysis of PDNA for 2008 Tropical Storm 3B.	Affected areas in fragile situation with limited access to information
2023.11.15–2024.01.31	Flood, Democratic Republic of Congo	Flooding, landslides		Infrequent, patchy satellite imagery of varying resolutions and no flood hazard maps to guide analysis; damage data not available.
2024.03.12–04.30	Flood, Burundi	Flooding		Slow-onset flood event with compounding impacts from rainfall and flooding from other events in recent months; challenging to differentiate between sources or timelines of damage; comparison with historical events (except 2014) difficult given lack of damage reporting and data
2024.03.27–05.15	Flood, Kazakhstan	Flooding	Used rapid flood simulation technique (FastFlood), with results calibrated based on water discharge measurements and flood extents derived through satellite imagery	Flood simulation challenges in some areas because of flood protection infrastructure, water management infrastructure, and water transportation infrastructure and lack of data on these elements
2024.07.01	Hurricane Beryl, Grenada	Wind	Used building-by-building virtual surveying data to calibrate damage estimations for first time	Challenges with searching for and management of substantial quantities of imagery used for virtual surveys. Challenges with biased collections of imagery as most persons take photos or videos in areas of more damage.
2024.08.1–09.16	Flood, Bangladesh	Flooding	Ran flood simulation using FastFlood tool to overcome challenges with limited remote sensing data; calibrated model using satellite data from June 2024 floods for which comprehensive flood extent maps were available	Inability to map full extent of August floods using open satellite programs such as Sentinel-1/2 or the Japan Aerospace Exploration Agency's Advanced Land Observing Satellite because of cloud cover and lack of satellite images during critical flood periods

Note: PDNA, post-disaster damage and needs assessment.

- a. Anguilla, Antigua and Barbuda, The Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Puerto Rico, Saint Barthélemy, Saint Martin, Sint Maarten, Turks and Caicos, U.S. Virgin Islands (the assessments were summarized in one report).

Appendix D. Damages Estimated Using Post-Disaster Needs Assessments and Damage, Loss, and Needs Assessments

Table D.1. Damages Estimated Using Post-Disaster Needs Assessments (PDNAs) and Damage, Loss, and Needs Assessments (DaLAs) for Global Rapid Post-Disaster Damage Estimation categories

Event	Assessment type	Residential	Non-residential	Infrastructure	Agriculture	Total	Other sectors
		U.S. dollars, million					
2015.04, earthquake, Nepal	PDNA	3,036	927	525	—	4,488	687
2016.04, earthquake, Ecuador	DaLA	590	883	772	—	2,245	265
2016.09, Hurricane Matthew, Haiti	PDNA	722	285	229	211	1,447	487
2017.09, Hurricane, Maria, Dominica	PDNA	354	181	306	—	840	90
2019.03, Tropical Cyclone Idai, Mozambique	PDNA	411	239	590	65	1,305	105
2019.03, Tropical Cyclone Idai, Malawi	PDNA	83	21	48	7	159	—
2019.03, Tropical Cyclone Idai, Zimbabwe	Rapid Impact and Needs Assessment	168	21	190	155	534	50
2019.09, Hurricane Dorian, The Bahamas	DaLA	1,487	717	239	—	2,444	21
2019.11, earthquake, Albania	PDNA	733	167	23	—	923	11
2020.04, Tropical Cyclone Harold, Vanuatu	PDNA	91	99	51	11	252	—
2020.10, flood, Sudan	Rapid Post Disaster Needs and Recovery Assessment	2,921	50	338	32	3,341	—
2021.04, volcanic eruption, La Soufrière, Saint Vincent and the Grenadines	PDNA	98	7	11	38	154	—
2021.08, earthquake, Haiti	PDNA	754	292	129	25	1,200	43

Event	Assessment type	Residential	Non-residential	Infrastructure	Agriculture	Total	Other sectors
		U.S. dollars, million					
2022.09, flood, Pakistan	PDNA	5,586	873	4,638	3,725	14,822	83
2023.10 earthquakes, Afghanistan	PDNA	164	27	71	48	310	4
2023.03, earthquake, Afghanistan	PDNA	99	62	40	15	216	1
2024, Hurricane Beryl, Grenada	PDNA	135	13	6	20	173	—

Note: Only damage to sectors considered in comparison are shown



Appendix E. Detailed Analysis of Results between Global Rapid Post-Disaster Damage Estimation and Other Assessment Types

Methodological differences between Global Rapid Post-Disaster Damage Estimation (GRADE) assessments, post-disaster damage and needs assessments (PDNAs), and other types of assessments (e.g., damage and loss assessments [DaLAs]) explain some of the differences between results from GRADE and other assessments. The following subsections discuss the reasons for the large differences between GRADE and PDNA observed in some of the comparison cases and sectors (Section 4):

- ◆ March 2019, Tropical Cyclone Idai, Mozambique—Sectors: residential, infrastructure, agriculture
- ◆ March 2019, Tropical Cyclone Idai, Malawi—Sectors: residential, agriculture
- ◆ March 2019, Tropical Cyclone Idai, Zimbabwe—Sectors: residential, non-residential
- ◆ September 2019, Hurricane Dorian, The Bahamas—Sector: infrastructure
- ◆ July 2017, floods, Sudan—Sectors: residential, non-residential, agriculture
- ◆ April 2021, volcanic eruption La Soufriere, St. Vincent and the Grenadines—Sectors: residential, non-residential, infrastructure, agriculture
- ◆ August 2021, earthquake, Haiti—Sector: non-residential
- ◆ March 2023, tropical cyclones Judy and Kevin, Vanuatu—Sectors: residential, infrastructure

In addition, when sectoral damages are smaller (e.g., less than USD 100 million), small differences in damage estimates are large in percentage terms. This is the case for comparison of damages from Tropical Cyclone Idai to agriculture in Mozambique and to non-residential buildings in Zimbabwe in 2019; to non-residential buildings from the floods in Sudan in 2020; and to all sectors from Tropical Cyclone Idai in Malawi in 2019, Hurricane Beryl in Grenada in 2024, and the La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021.

E.1 Differences in damage estimates for residential buildings

Modeling damage to residential buildings is complex, particularly in the developing world, where building code adherence is low, and self-built, informal, or unregulated housing is prevalent. There are many residential buildings, and there are huge differences and unknowns in design and construction practices, regulation of designs and materials, and maintenance standards. Seemingly minor details such as including hurricane straps on residential buildings can greatly affect the amount of damage incurred, but the GRADE analysis will rarely have access to data on how many houses include these elements and whether they have been installed correctly and maintained properly. There are many unknowns and variables for the experts to assess and judge.

Estimated damages to housing from the **2021 La Soufrière volcanic eruption** were far greater according to the PDNA (USD 97.6 million) than GRADE (USD 11 million). Unlike GRADE, the PDNA assumed that all houses in the “green” zone (where ashfall thickness was less than 3 cm) would incur damages of 5 percent of the replacement value, which accounted for approximately 60 percent of the PDNA’s total residential damages because 80 percent of the houses on the island of Saint Vincent were in the “green” zone. In addition, the PDNA used a damage ratio of 25 percent for the “yellow” zone, which was considerably higher than the ratio that GRADE used. During the GRADE assessment (first two weeks after the eruption), only anecdotal, fragmented damage information emerged from the “red” zone, because it was closed, and the population had been evacuated, but information from on-the-ground video and drone footage emerged from the worst-affected settlements of Chateaubelair, Georgetown, New Sandy Bay, and Owia, and the GRADE team analyzed these areas in detail to calibrate their damage estimation. On May 11, 2021, the Minister of Finance, in a speech in Parliament, listed 18 of the 30 most significant impacts in order of expenditure, amounting to USD 37 million, of which approximately 12 percent (USD 4.3 million) was related to the housing sector for building materials to homes damaged by the eruption and mudslides and for reconstruction of homes. On August 6, 2021, it was announced that the housing repair program would commence in the northern areas of Saint Vincent Island (mostly in the “red” zone) and that the latest assessment identified 553 homes with some level of damage, with the housing minister noting that the preliminary assessment was that homes in the “red” and “orange” zones sustained more than USD 7.4 million in damages¹⁰ as opposed to USD 22 million estimated by the PDNA.

Likewise, estimated damages to housing in the **2020 Sudan floods** were far greater in the PDNA even though the PDNA and GRADE both accounted for almost the same number of destroyed and partially damaged houses. The key reason for this difference was that the PDNA used a mean value for a destroyed house of USD 28,800 (which is very high for current living standards in the flood-affected areas of Sudan), bringing the total estimated damages to USD 2.92 billion, as opposed to USD 526 million in the GRADE assessment that used “as-was” replacement values for the destroyed building stock.

GRADE assessed damages to housing from **Tropical Cyclone Idai in Mozambique and Malawi in 2019** to be 43 and 34 percent, respectively, of those estimated using PDNA. These differences stem from the time taken to collate and release official damage reporting. In this case, official damage reporting arrived two weeks after GRADE was completed. This can be clearly seen in Figure 8 for Mozambique, where the number of houses damaged or destroyed that the National Institute of Disaster Management reported increased from approximately 95,000 to nearly 240,000 ten days after GRADE was completed. For Malawi, when the GRADE assessment was conducted, the Department of Disaster Management Affairs was reporting approximately 22,000 damaged or destroyed houses; the final tally was approximately 288,000. GRADE captured some of these differences through analysis of exposure and satellite imagery.

According to the GRADE assessment, the impacts on housing **from Tropical Cyclone Idai in Zimbabwe in 2019** totaled USD 66 million, which accounted for only 39 percent of the USD 168 million estimated according to the Rapid Post Disaster Needs and Recovery Assessment (RINA), which was based on remote sensing and government damage data several weeks after the GRADE assessment was completed. For the eight districts covered (all in Manicaland Province), the RINA accounted for 17,715 damaged or destroyed houses

¹⁰ Times Staff. 2021. “House Repair Programme To Commence Soon In Northern St Vincent.” St. Vincent Times. <https://www.stvincenttimes.com/house-repair-programme-to-commence-soon-in-northern-st-vincent/>.

(including many destroyed by landslides), as opposed to 10,730 in GRADE, with differences occurring in all affected districts. GRADE damages were based on the capital stock, flood footprints, and wind field modeling in 16 affected districts combined for validation with published damage reports up to March 30, 2019, from Civil Protection Zimbabwe and international development agencies. RINA estimated damages per house of USD 12,000, but the damage ratios used were not reported. Because not all of the damaged houses were destroyed, their reported values suggest a significantly higher baseline replacement value. The GRADE exposure model estimated a mean house replacement value in the affected districts of USD 3,200, considering that 72 percent of the houses in the predominantly rural districts affected made with “traditional materials” or “mixed traditional/modern materials” with low unit costs of construction. The differences in damage valuations would have caused significant differences.

For Category 4 tropical cyclones Judy and Kevin in Vanuatu on March 1, 2023, and March 3, 2023, the differences between damages to housing from the GRADE Note (USD 17.8 million; released on March 22, 2023) and the PDNA (USD 163.6 million; released on June 22, 2023) were significant. The GRADE Note estimated median damages to more than 4,000 housing units due to wind, storm surge, and flooding, excluding housing contents, based on damage reports during the first three weeks and reported that destructive winds and precipitation extensively damaged traditional and wooden houses built from low-cost construction materials such as semi-permanent or traditional construction, with Malampa, Penama, Shefa, and Tafea being the worst-affected provinces. The GRADE Note estimated a replacement value of homes in these four provinces of USD 1.42 billion, resulting in an overall damage ratio of 1.25 percent, ranging from 0.4 percent in Penama to 4.8 percent in Tafea.

The PDNA damage estimate to housing included housing contents, tanks, and drainage and other infrastructure at housing sites covering 12,769 partially damaged and 6,384 destroyed houses in Malampa, Shefa, and Tafea provinces. The number of housing units destroyed and partially damaged was based on a remote sensing assessment by the United Nations Satellite Centre (UNOSAT). (No ground surveys were conducted.) The damage and loss assessment included only UNOSAT’s priority areas 1 and 2. The numbers of damaged or destroyed houses that UNOSAT proposed were split based on Vanuatu’s 2020 Population and Housing Census categories for wall materials and flooring into permanent (houses with concrete, cement, or brick walls), traditional (houses with earth or sand floors), and semi-permanent houses (houses with all other construction material combinations). The PDNA methodology assumed that a semi-permanent house was 1.66 times as likely to be damaged and a traditional house twice as likely to be damaged as a permanent house under the same conditions. These assumptions led to the following damage ratios in the three provinces: nearly 29 percent of the destroyed or partially damaged houses would have been permanent, nearly 56 percent would have been semi-permanent, and 15.6 percent would have been traditional (with these percentages different in each province). The PDNA proposed a mean replacement cost of USD 12,525 for the destroyed houses and a mean repair cost of USD 5,010 for the partially damaged houses (a damage factor of 40 percent), regardless of housing category. These values were based on replacement costs per square meter used in PDNAs from tropical cyclones Pam (2015) and Harold (2020) projected to 2023.

Damage to household goods was estimated to be equivalent to 15 percent of housing replacement or repair costs, and a factor equivalent to 10 percent of damage was added for water tanks and drainage and other infrastructure at housing sites. There may be double

counting of damages to auxiliary housing infrastructure (e.g., to account for water tanks, retaining walls, drainage) because the housing section assumes USD 12.8 million in damages for this based on an arbitrary percentage, and the water, sanitation and hygiene (WASH) section estimates also include USD 5.6 million in damages to private household water systems. There may also have been double counting for electricity supply to housing.

There may be errors in the presentation of total impacts, because damage to private household sanitation and hygiene infrastructure was estimated to be USD 17.7 million in the text of the PDNA report, but this value is not included in the Summary of Damage and Loss Table in the Executive Summary, where the losses are given as only USD 0.78 million.

Differing assumptions on damage level in different places and the costs of that damage may explain most of the differences between GRADE and the PDNA. There are differences between the number of structures damaged in different places, the damage ratios used, the quantity of different types of construction, reconstruction and repair costs according to types of construction, and how housing contents and auxiliary infrastructure are accounted for.

E.2 Differences in damage estimates for non-residential buildings

For Tropical Cyclone Idai in Zimbabwe in March 2019, the GRADE estimate for non-residential buildings was USD 67 million, including all non-residential sectors (e.g., health care, education, commerce, industry, agriculture, warehouses). The RINA reported USD 15 million in damages to the health care sector and USD 6 million to the education sector. The difference is the coverage of the health sector by the RINA.

Non-residential damages from the La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021 estimated using GRADE were USD 4 million, or 61 percent of the PDNA assessment (USD 6.8 million), with the latter reporting direct damages to the health care, education, and tourism sectors only. Key reasons for the underestimation of the damages by GRADE include differences in categorization of assets (in the PDNA, damages to several agricultural buildings were included in the agricultural sector damages) and the facts that the areas that the eruption most affected were completely closed during the time of the GRADE and that more damage to agricultural and other non-residential buildings were revealed when these areas re-opened. Remote sensing products available from COPERNICUS showed that approximately 60 non-residential buildings were “possibly” damaged, but they were released just after the GRADE report was completed. The GRADE assessment accounted for accumulated damages from volcanic tephra fallout between April 9, 2021, and April 13, 2021.

For non-residential damages from the August 2021 earthquake in Haiti, GRADE damages (USD 162 million) were a little more than half of those from the PDNA (USD 292 million). Although unit costs of construction for the various types of non-residential buildings are not given in the PDNA, it is likely that the difference was because GRADE used lower unit costs of construction. Average residential unit cost of construction was USD 190/m² for GRADE and USD 310/m² for PDNA.

The GRADE Note estimated non-residential direct economic damages to physical assets from the floods in Sudan from July to September 2020, released on October 30, 2020, of USD 158 million (30 percent of damages to residential buildings), whereas the Rapid Post-Disaster Needs and Recovery Assessment (RPDNRA), released in March 2021, reported

damages of USD 51 million (less than 2 percent of damages to residential buildings). In this GRADE Note, impacts on the non-residential building sector were examined according to previous PDNAs in the region, adjusted to reported flood damage data and damage ratios relative to the housing sector. For the health care sector, the RPDNRA estimated damages for 44 health care facilities, whereas reports used for the GRADE Note indicated that 2,671 health care facilities had been damaged¹¹. For the education sector, GRADE Note damages were estimated based on reports that the floods had damaged 559 schools, whereas the RPDNRA estimate was based on the final statistics, which included 123 destroyed and 1,235 partially damaged schools. The differences between GRADE and RPDNRA assessments result mainly from the fact that the former used damage information for many more health care facilities than the latter.

E.3 Differences in damage estimates for infrastructure

GRADE's assessment of damages to infrastructure (USD 188 million) from **Tropical Cyclone Idai in Mozambique in 2019** was approximately one-third of the PDNA estimate (USD 590 million). Both assessments included transportation (roads, bridges, railways), energy (power plants, transmission and distribution lines, substations, transformers), and WASH.

The PDNA estimated damages to roads of USD 350 million (59 percent of PDNA infrastructure damages). Although not specifically mentioned in the report, average road rehabilitation cost was approximately USD 178,200 per kilometer for 1,962 km of damaged paved and unpaved national, municipal, and district roads (no splits according to category). (Almost 80 percent of the existing road network in the affected provinces was unpaved, but there was no information about the proportion of the damaged roads.) Estimates included damage to 90 culverts and 50 bridges. Unit costs for road maintenance, rehabilitation, and new construction vary significantly, but the African Development Bank (2014) has proposed that median unit cost values in Africa range from USD 13,200 per lane-km for regaveling unpaved roads, to USD 167,000 per lane-km for paved road rehabilitation, to USD 235,000 per lane-km for new construction of paved roads, depending on the size of the project (all values projected to 2019 USD). It is therefore assumed that the unit cost per km used in the PDNA is rehabilitation or reconstruction of damaged roads to a higher specification (build –back better), including potentially upgrading unpaved roads to paved. It is also stated in the PDNA that, in addition to national roads, municipal and district roads, which were already in poor condition because of lack of maintenance, incurred massive damage. GRADE considers only rehabilitation of damaged roads to the same specification as before the disaster. This difference in methodology can account for at least USD 250 million of the difference between the two assessments.

The remaining 41 percent (USD 241 million) of the PDNA estimated damages to infrastructure was in energy,¹² telecommunications,¹³ WASH,¹⁴ urban and rural drainage systems, and non-road transportation infrastructure. The energy sector accounts for approximately 55 percent of this subtotal (USD 133.5 million), but the estimate may be conservative because assessments of damage to the energy infrastructure had not been completed at the time of the PDNA (May 2019), whereas GRADE included these sectors in the infrastructure assessment.

¹¹ OCHA-Sudan: Floods Flash Update No 4, Last updated: August 27, 2020

¹² Including hydropower plants, transmission lines, primary and secondary substations, distribution lines, transformers, and standalone solar photovoltaic systems.

¹³ Including cell towers, long-haul microwave infrastructure, and optic fiber.

¹⁴ Including 705 wells and boreholes and 5 main and 12 secondary and rural water supply systems.

GRADE's assessment of damages to infrastructure from **Hurricane Dorian in The Bahamas in 2019**, was double the damages that the DaLA reported. The uncertainty in this case is related to the fact that GRADE assessed hazard impacts based on wind-field models of the hurricane along with post-event satellite images for inundation maps and used higher unit costs of construction. The DaLA estimated damages to infrastructure of USD 239.1 million, of which approximately USD 131 million (55 percent) was for damages to the energy system (power generation, transmission and distribution systems), approximately USD 51 million (21 percent) to transportation (roads, ports, airports), approximately USD 42 million (18 percent) to telecommunications (above-ground and ground-level assets and equipment; electronic systems; wiring; conductors; buried fiber optic cables and copper wires; wireless infrastructure such as antennas, base transceiver stations, and satellite dishes), and approximately USD 15 million (6 percent) to WASH (water pumping systems, storage tanks, distribution system, Water and Sewerage Corporation assets). Few details were provided on how these estimates were obtained. Two-thirds of the estimated total infrastructure damage occurred in Abaco, and 53 percent of the damage to transportation occurred on Grand Bahama, with 93 percent of that total sustained at the Grand Bahama International Airport. From this, it can be deduced that damages to roads and ports on Grand Bahama were USD 1.9 million according to the DaLA, although Grand Bahama experienced extensive damage to its road network (e.g., the main road crossing the island, Grand Bahama Highway, was extensively damaged in certain sections, mainly from storm surge) and docks and harbors (Freeport, Lucaya, West End). The overall GRADE assessment for infrastructure damages in Grand Bahama was USD 179 million, whereas the DaLA estimated USD 79.6 million (~45 percent of the GRADE assessment); in the Abacos, GRADE estimated USD 313 million, in comparison with USD 159.5 million from DaLA (51 percent of GRADE).

The DaLA did not account for substantial damage to oil facilities (e.g., at South Riding Point Terminal at High Rock and Buckeye Terminal in Freeport, both on Grand Bahama), except for USD 102 million estimated as “additional costs” related to cleaning up the oil spill in the South Riding Point Terminal that was assigned to the environment sector.

Estimated infrastructure damages according to GRADE (USD 37 million) from the **La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021** was more than three times as high as the PDNA estimate (USD 11.3 million). The fact that infrastructure damages that GRADE modeled included damage to numerous agricultural infrastructure facilities (e.g., Agricultural Biotechnology Center, arrowroot and cassava factories, fisheries complex, Caribbean Agricultural Research and Development Institute Field Station, Ministry of Agriculture Livestock Centre, Langley Park Palletization Centre, Perseverance Agricultural Station) explains this difference. Therefore, it is appropriate to compare the combined damages to infrastructure and agriculture of the two assessments (USD 49.7 million PDNA, USD 68 million GRADE [~37 percent higher than PDNA]).

The GRADE Note (released on March 22, 2023) estimate of damages to infrastructure (USD 35 million) from **Category 4 tropical cyclones Judy and Kevin in Vanuatu on March 1, 2023, and March 3, 2023**, was 49 percent of that of the PDNA (released on June 22, 2023) (USD 71.3 million). The GRADE Note estimated median damages to physical infrastructure, irrigation, flood management, WASH, energy, transportation, telecommunications, schools, health care, power, vehicles, and social protection from wind, storm surge, and flooding in Malampa, Penama, Shefa, and Tafea provinces. The GRADE Note estimated the replacement value of infrastructure in these four provinces to be USD 1.41 billion, resulting in a damage ratio of 2.5 percent, ranging from 0.9 percent in Penama to 6.8 percent in Tafea. The PDNA estimate of damages to the energy sector included only damage related to public assets

and services because there were no estimates from the electricity concessionaires, meaning that the actual impact on the energy sector was grossly underestimated and accounted for only the urbanized developed areas on Efate and Tanna. The assessment covered only energy initiatives in Shefa and Tafea that the Department of Energy managed and solar farms at the Parliament house and Ministry of Climate Change headquarters in Port Vila, the Natai fish market, and the Tanna concession area. Origin Energy submitted evidence of damage to the sea wall and jetty within their facility but did not include any related estimates. As a result, damage to the energy sector was assessed at just USD 0.06 million. For the telecommunications sector, damage was assessed at USD 6.25 million.

Communication distribution networks, including public and private physical assets within the distribution networks, such as towers for cellular systems and microwave networks, sustained the greatest damage. (Transmission towers in Shefa and Tafea were destroyed, and towers and equipment in all affected provinces were damaged.) The most-affected areas in this sector were Shefa and Tafea provinces, although substantial damage was also sustained in Malampa, Penama, and Sanma.

In the WASH sector, damage was assessed at USD 10.2 million. Effects included damage to rural and peri-urban water supply networks, including destruction of rainwater catchment systems, with roofing, guttering, and pipework the most affected. Flooding, scouring, and landslips damaged piped rural water supply systems. The greatest damage was to the large number of rainwater capture and storage systems, which are mainly on private houses. No damage was reported to Port Vila's urban water infrastructure. Above-ground sanitation structures made from bush materials were greatly damaged, but no detailed damage assessment reports were available at the time of the PDNA assessment, so damage was estimated from existing data for private and public (community) ownership of water and household sanitation infrastructure. The PDNA assessed 2,507 water supply installations, with 19,542 households potentially affected. Damage assessment was limited to household toilets (excluding other WASH infrastructure), and it was deemed that the cost of toilet reconstruction should be sufficient for handwashing facilities to be included. It was assumed that the strong winds and flooding destroyed nearly all of the pit toilets and 80 percent of the ventilated pit latrines. Approximately 22,530 rural and 11,118 urban household sanitation infrastructure facilities were damaged.

Nearly 77 percent of the infrastructure damage assessed in the PDNA was incurred in the transportation sector (USD 54.8 million), particularly the aviation, maritime, and road transportation systems. The transportation sector in parts of Malampa and Penama provinces and all of Shefa and Tafea provinces was damaged. The downpour that accompanied the twin cyclones flooded several areas, washed away sidewalks, and damaged coastal protection in Shefa and Tafea provinces and a bridge at Imanaka Creek, Tanna Island, Tafea Province. The terminal building at Bauerfield International Airport was damaged, and aviation navigational markers and beacons were damaged at Klem's Hills. The Port Vila Main Wharf was damaged (150-ton bollards damaged, and foundation undermined, 12 of 26 fenders damaged beyond repair, main pipe supplying potable water to vessels ruptured). Concrete drainage structures, bridges, and sidewalks were damaged. Based on this full account of damage, much of the damage was to the road infrastructure, for which no specific information is given. Instead, damages and calculations of costs for the land transportation sub-sector are detailed in the sector's annex, which is not included in the PDNA report, although, as mentioned in the PDNA, nearly 88 percent of the road network in Vanuatu has a gravel or soil surface and thus is of low value. In addition, estimated damage to the transportation sector was much higher than in previous PDNAs (Tropical Cyclone

Pam in 2015, Tropical Cyclone Harold in 2020)—more than double in both cases. In addition, estimated recovery needs in the roads sub-sector are nearly four times the damages, so this comparison cannot be conclusive without access to the infrastructure sector annexes.

E.4 Differences in damage estimates for agriculture

For the agricultural sector, the GRADE methodology uses damage analysis for different crops and livestock. Damages are estimated based on previous yields, crop cycles, and crop percentage in the affected area. The PDNA methodology usually attributes damage to crops and livestock lost to loss estimations and only impacts on agricultural infrastructure (e.g., irrigation) to damage estimation.

Damages to crops from **Tropical Cyclone Idai in Malawi in 2019** have been accounted for as losses in the PDNA. When these are added to damage, the GRADE/PDNA comparison is 239 percent (USD 43 million in GRADE, USD 18 million in the PDNA), instead of 656 percent. This is one case in which small differences in estimated damages result in large percentage differences.

Because of uncertainties at the time of GRADE completion (two weeks after the event), a range of USD 141 million to USD 258 million in damages to agriculture from **Tropical Cyclone Idai in Mozambique in 2019** was estimated based on National Institute of Disaster Management reports that nearly 475,000 hectares of cropland had been flooded. The PDNA (released 10 weeks after the event) reported that approximately 715,000 hectares of cultivated land had been flooded, with most farmers reporting losses of all or a large proportion of their seed stores, as well as the standing crops they were about to harvest. For the GRADE/PDNA comparison, the middle value was considered for GRADE (USD 200 million) and USD 64 million in the PDNA. The PDNA attributed less than 4 percent of the effects on agricultural crops to damage (USD 17 million) because damages to crops were considered to be production losses, which were assessed at nearly USD 470 million. When the differences in flooded cropland between the two assessments are considered, and the PDNA's crop production losses are considered as damages, the GRADE/PDNA comparison is 59 percent (or 76 percent when compared with GRADE's upper estimate), instead of 310 percent. Differences in assumed yields and crop values may account for the remaining difference.

Likewise, for **floods in Sudan in 2020**, the GRADE Note proposed a range of USD 610 million to USD 1,415 million in agricultural damages, with a best estimate of USD 1,139 million. The RPDNRA reported damages to agriculture of USD 32 million, which corresponds to livestock that died, whereas USD 579 million in losses was reported, which correspond to crops. In terms of flooded cropland, the impact data that the Food and Agriculture Organization of the United Nations reported was used in both assessments. When PDNA's crop production losses are accounted for as damages, the GRADE Note/PDNA comparison is 197 percent. Differences in assumed yields and crop values account for this wide difference.

For the **La Soufrière volcanic eruption in Saint Vincent and the Grenadines in 2021**, the comparison of damages to agriculture (81 percent) is again not a like-for-like comparison because damages to important agricultural infrastructure buildings (Agricultural Biotechnology Center, arrowroot and cassava factories, fisheries complex, Caribbean Agricultural Research and Development Institute Field Station, Ministry of Agriculture Livestock Centre, Langley Park Palletization Centre, Perseverance Agricultural Station) were included in agricultural damages in the PDNA, whereas they were included in non-residential buildings or infrastructure in GRADE.



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