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Socioeconomic Benefits of Climate Information Services for Disaster Risk Reduction in Africa

Final report by the African Climate Policy Centre of the Economic Commission for Africa
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<td>African Centre for Meteorological Application for Development</td>
</tr>
<tr>
<td>ACPC</td>
<td>African Climate Policy Centre</td>
</tr>
<tr>
<td>BAU</td>
<td>business as usual</td>
</tr>
<tr>
<td>BCPR</td>
<td>Bureau of Crisis Prevention (of UNDP)</td>
</tr>
<tr>
<td>CRED</td>
<td>Centre for Research on the Epidemiology of Disasters</td>
</tr>
<tr>
<td>CIS</td>
<td>climate information services</td>
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<tr>
<td>DRR</td>
<td>disaster risk reduction</td>
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<tr>
<td>ECA</td>
<td>Economic Commission for Africa</td>
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<tr>
<td>EM-DAT</td>
<td>OFDA/CRED International Disaster Database</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
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<tr>
<td>GFCS</td>
<td>Global Framework for Climate Services</td>
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<tr>
<td>GDP</td>
<td>gross domestic product</td>
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<tr>
<td>IFRC</td>
<td>International Federation of Red Cross and Red Crescent Societies</td>
</tr>
<tr>
<td>MCA</td>
<td>multi-criteria analysis</td>
</tr>
<tr>
<td>NGO</td>
<td>non-governmental organization</td>
</tr>
<tr>
<td>OCHA</td>
<td>United Nations Office for the Coordination of Humanitarian Affairs</td>
</tr>
<tr>
<td>OFDA</td>
<td>Office of Foreign Disasters Assistance of the United States of America</td>
</tr>
<tr>
<td>RIASCO</td>
<td>Regional Inter-Agency Standing Committee, Southern Africa</td>
</tr>
<tr>
<td>SEB</td>
<td>socioeconomic benefits</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
</tr>
<tr>
<td>UNEP</td>
<td>United Nations Environment Programme</td>
</tr>
<tr>
<td>UNDRR</td>
<td>United Nations Office for Disaster Risk Reduction</td>
</tr>
<tr>
<td>WISER</td>
<td>Weather Information and Climate Services</td>
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<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
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Socioeconomic Benefits of Climate Information Services for Disaster Risk Reduction in Africa
Final report by the African Climate Policy Centre of the Economic Commission for Africa

Executive summary

The negative impacts of hydro-meteorological hazards on agriculture, food security and water resources often result in disasters. Over 90 per cent of natural disasters in Africa are a consequence of such hazards. In many regions of Africa, the threat of such climate-induced disasters is ever-present (Urama and Ozor, 2010). It is therefore incumbent upon policymakers to formulate appropriate strategies to minimize the effects of these devastating hydro-meteorological hazards on communities. In order to do so, communities and organizations needed to be provided with timely, tailored climate-related knowledge and information and products that they can use to reduce climate-related losses and to protect lives, livelihoods and property (Vaughan and Dessai, 2014). Furthermore, studies indicate that weather and climate services improve the livelihoods of smallholders in Africa (for example, Patt and others, 2005).

To demonstrate the socioeconomic benefits (SEB) of climate information services (CIS), the African Climate Policy Centre (ACPC) of the Economic Commission for Africa (ECA), under the Weather Information and Climate Services (WISER) programme, has developed an analytical framework to assess those benefits within and across various socioeconomic sectors for disaster risk reduction (DRR). The WISER framework assesses the economic and social benefits of climate information services compared to investment costs with the aim of providing decision-making support and information to inform the design of disaster risk reduction interventions. WISER climate information services are one of the key strategies aimed at ensuring the utility of timely and accurate weather and climate information that is vital for day-to-day decision-making in Africa.

The socioeconomic benefits framework presents the steps required for the effective identification and use of indicators to support a sectoral and integrated analysis of climate information services for the benefit of disaster risk reduction. It allows the development of an integrated cost-benefit analysis in which social, economic and environmental impacts are considered, in addition to policy outcomes. The cost-benefit analysis considers three main analytical components: investment, avoided costs and added benefits. The integrated cost-benefit analysis includes the economic valuation of environmental consequences.

Climate information services are an important component of the evidence base required to guide decisions regarding appropriate levels of investment to minimize potential impacts on the economy and to ensure uninterrupted delivery of critical services and infrastructure. Investing in the development of early warning systems and contingency planning, reserving contingency funds for emergency use and perhaps subsidizing vulnerable or impacted sectors is necessary to help protect socioeconomic welfare as part of critical disaster risk reduction interventions.

The Validation Workshop on Analysing and Validating the Socioeconomic Benefits of Climate Information Services for Disaster Risk Reduction in Africa was held as part of this study. It demonstrated that the model of socioeconomic benefits of climate information services for a disaster risk reduction captures social, economic and environmental dynamics within and across various economic sectors that are key for disaster risk reduction and disaster prevention. The model includes climate variations in the analysis and has the capability to estimate the cascading effects of adverse weather and climate events through all sectors. As a result, the performance of the model changes depending on the climate assumptions used and the effectiveness of the interventions implemented. The cost of climate information services is typically 1 per cent of GDP across many countries. However, a modest increase can typically lead to
benefit-cost ratios well in excess of a factor of four. It is important to note that policy effectiveness has to be assessed using a variety of indicators, across sectors and actors, and over time and space.

The findings of this study will make it possible to prepare disaster risk adaptation strategies or to expand existing national and sectoral policies and strategies. The study has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to reduce the economic vulnerability of countries to hydro-meteorological risks. Modest investments in climate information services can lead to significant savings in many socioeconomic sectors, increasing sustainable growth rates. Disaster risk reduction is a major beneficiary of appropriate investment in climate information services.
1. **Introduction:**

the socioeconomic benefits framework model

The livelihoods of Africans are highly dependent on weather and climate information. Timely and accurate weather and climate information is vital for day-to-day decision-making. Weather and climate services are therefore needed to provide people and organizations with accurate, timely, tailored climate-related knowledge and information that people can use to reduce climate-related misfortunes and to protect lives, livelihoods, and property (Vaughan and Dessai, 2014).

There is, however, an evidence gap that is an obstacle to the level of investment needed to build the resilience of smallholder agriculture and create an enabling environment for climate-smart agriculture at scale. As a result, it is difficult to assess the extent to which individual climate services or weather and climate services in general live up to the promise of benefiting society as a whole. This means that weather and climate service providers and funding agencies have very little information about the quality and relative value of weather and climate services (Vaughan and Dessai, 2014).

The aim of this study is to assess whether or not such services offer value for money in order to give providers a basis on which to decide whether or not to invest in, or continue to invest in, their provision or improvement (Anaman and others, 1995; Freebairn and Zillman, 2002).

Demonstrating the socioeconomic benefits of these services can also help potential users to understand the use and benefits of forecasts so that they know how to use weather and climate information. It also helps service providers to understand user needs and values and therefore the types of information they should generate, and to determine how best to disseminate that information (Zillman, 2007; Lazo and others, 2009). According to Perrels and others (2013), the societal value and benefits of weather and climate information services can be greatly enhanced by establishing a much closer dialogue and sense of partnership between providers and user communities at all levels.

The World Bank estimates that, with a current hydro-meteorological investment portfolio of about $500 million, globally improved weather, climate and water observation and forecasting could lead to up to $30 billion per year in increased global productivity and up to $2 billion per year in reduced asset losses (Hallegatte, 2012). This scale of improved productivity could be crucial to lifting out of poverty the millions around the world whose livelihoods are at risk of climate shocks. Recognition of these benefits and their contribution to sustainable development, poverty reduction and shared prosperity is motivating the development community to invest more holistically in modernizing hydro-meteorological services and to ensure that service providers are better connected with service users (Rogers and Tsirkunov, 2013). As part of the process of demonstrating the socioeconomic benefits of climate information services, the African Climate Policy Centre (ACPC) of the Economic Commission for Africa has developed a framework which assesses the economic and social benefits of climate information services in comparison to the cost of investment.

The framework has essentially built a business case for continuing investment in climate information services by showing the impacts of integrating climate information into the policy and resource allocation
The socioeconomic benefits framework presents the steps required for the effective identification and use of indicators to support a sectoral and integrated analysis of climate information services. Some of the steps are more relevant to climate vulnerability assessment, while others are more useful for adaptation and policy formulation and assessment. Some of the steps lead to the implementation of an integrated cost-benefit analysis in which social, economic and environmental impacts and policy outcomes are considered. The cost-benefit analysis considers three main analytical components:

- Investment
- Avoided costs
- Benefits

The integrated cost-benefit analysis includes the economic valuation of environmental consequences.

When used to inform decision-making, indicators are designed to support the initial and final stages of the development planning process: issue identification (stage 1), strategy/policy formulation and assessment (stage 2), and strategy/policy monitoring and evaluation (stage 5) (UNEP, 2014). Decision-making (stage 3) is the point when a particular policy recommendation is adopted, based on the comparison of different policy options that were developed under stage 2. Finally, the role of indicators in policy implementation (stage 4), is mainly exercised through monitoring and evaluation (stage 5), when the actual impacts of development plans are monitored both during and after implementation.

Using systems thinking and system dynamics, cross-sectoral causal descriptive models can incorporate several of the methods mentioned above, from historical observations to simulation of future scenarios. These models have traditionally been used to support planning exercises at various levels with the analysis of “what if” scenarios, for instance in the context of climate adaptation. The key features include horizontal integration (that is, a variety of sectors interconnected with one another) and a fairly aggregated level of detail for each sector. The former allows the inclusion into the model of social, economic and environmental indicators; the latter indicates that this approach is not a substitute for others, but rather complements existing, more detailed, sectoral modelling efforts with a more comprehensive framework of analysis. As a result, these models can be used to simulate alternative scenarios of action and inaction, using several weather and climate indicators as input, and provide insights into both the identification and anticipation of vulnerabilities and the identification and evaluation of interventions to improve resilience to climate variability and change (for example, based on forecasts of socioeconomic benefits).

A shared understanding is crucial for solving problems that influence several sectors or areas, which are usual in complex systems. Since the process involves broad stakeholder participation, all the parties involved need an inclusive vision in order to understand the factors that generate problems and those that could lead to solutions and establish successful private-public partnerships.

Solutions should not therefore be imposed on the system, but emerge from it. In other words, interventions should be designed to make the system start working in our favour, to solve the problem, rather than generate it. Now that the framework has been developed, the next stage is to customize it for specific sectors, starting with agriculture and disaster risk reduction. Tailoring the framework will facilitate closer
examination of the economic benefit of applying climate information services at sector level and that will enable decision makers to develop better-informed strategies for averting climate-induced disasters and to take advantage of favourable climatic conditions to help maximize the growth of their economies.

Agriculture

Here, customization involves tailoring climate information services products and applying them to agriculture in order to improve productivity. This can be done by using appropriate seed varieties, containing pests and diseases and managing agricultural operations; for example, scheduling weeding and the application of fertilizers and the hiring of temporary staff for specific tasks necessary to improve productivity. It should be noted that poor agricultural performance can lead to disasters. Since agriculture is largely rain-fed, climate information services are critical to forecasting the likely performance of agriculture.

Disaster risk reduction

The model output will provide a basis for integrating climate information services into disaster risk reduction. This involves developing and disseminating climate information and prediction products systems that can track hydro-meteorological hazards well ahead of time. This will help disaster risk managers to apply information derived from climate information services to put in place measures to avert potential weather- and climate-induced disasters. Patterns of hydro-meteorological disasters will be mapped, which will enable planners to invest resources in the areas that are currently more susceptible to flooding and droughts, so that, for instance, roads, bridges, dams and housing are designed to be as climate-proof as possible. Investing in irrigation systems will also need to be considered as poor rains can ruin rain-fed agricultural production, potentially leading to disasters.
2. Climate information services

According to the Integrated African Strategy on Meteorology (Weather and Climate Services), national meteorological and hydrological services underpin economic growth and sustainable development in Africa. It has been demonstrated that the weather and climate services they provide significantly contribute to the safety and well-being of African people and communities and support key economic areas, including agriculture, aviation, forestry, fishing, water resources, energy industries, transportation and tourism. In addition, these services are crucial to enhancing resilience and reducing vulnerability to natural hazards and the effects of climate variability and climate change.

The Integrated African Strategy on Meteorology enhances the cooperation between African countries and seeks to ensure that national meteorological or hydrological services have the capacity to fulfil their responsibilities, including regarding the implementation of the Global Framework for Climate Services (GFCS) spearheaded by the World Meteorological Organization (WMO) and its partners in the United Nations to improve climate services, especially for the most vulnerable. Implementation of the General Framework will enable better management of the risks of climate variability and change and adaptation to climate change through the development and incorporation of science-based climate information and prediction into planning, policy and practice at the global, regional and national levels.

As part of the Global Framework, climate information services build on continued improvements in climate forecasts and climate change scenarios to expand access to the best available climate data and information. Policymakers, planners, investors and vulnerable communities need climate information in user-friendly formats so that they can prepare for expected trends and changes. They need good-quality data from national and international databases on temperature, rainfall, wind, soil moisture and ocean conditions. They also need long-term historical averages of these parameters, and maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios. Climate information services give Africa an opportunity to find long-term solutions to the effects of the recurrent drought that undermines development efforts in the Sahara, Sahel and Kalahari deserts and in the Horn of Africa, and devastating floods such as those in West Africa and elsewhere.

Depending on the user’s needs, these data and information products may be combined with non-climate data, such as agricultural production, health trends, population distribution in high-risk areas, road and infrastructure maps for the delivery of goods, and other socioeconomic variables. The aim is to support efforts to prepare for new climate conditions and adapt to their impact on water supplies, health risks, extreme events, farm productivity, infrastructure placement, and so forth.

Expanding the production, distribution and use of relevant up-to-date climate information can best be achieved by pooling expertise and resources through international cooperation. United Nations agencies, regional institutions, national governments and researchers will work together through the Global Framework for Climate Services to disseminate data, information, services and best practices. This collaboration will build greater country capacity for managing the risks and opportunities of climate variability and change and for adapting to climate change.

Multi-timescale forecasting plays a vital role within the framework of climate information services, as shown in figure 2.1.
Enhanced integration of climate science into disaster risk reduction and climate variability and change adaptation policies and operations in Africa can be achieved by developing appropriate partnerships. Building partnerships is fundamental to establishing the ongoing and action-oriented dialogue among climate scientists, operational meteorological and climate services (information providers) at the national level and disaster risk managers and decision makers in various socioeconomic sectors (for example, energy, water resource management, agriculture, health) needed to provide relevant climate services for risk reduction measures and community-centred early warning systems that leverage national, regional and global coordination, local preparedness, response and recovery.

A World Bank study estimated that the benefits of bringing hydro-meteorological services in developing countries up to the standards of those in developed ones would increase economic productivity by $30 billion per year and reduce asset losses by up to $2 billion per year (Hallegatte, 2012).

Longer-term early warnings provide lead times of a few weeks to several months for slow-onset hazards like drought. They enable individuals and communities to make adjustments to improve agricultural planning by, for example, selecting drought-resistant crops and adjusting planting and harvesting times, and governments to adjust the delivery of health services (for example, pre-positioning pharmaceuticals and weather-informed vector-control activities).

They also enable longer-term preparedness actions, as described below. Both short-term weather forecasts and seasonal forecasts can be used to build reliable deterministic or probabilistic risk scenarios and, in turn, to strengthen disaster preparedness.

Warning of a fast-onset hazard enables preparedness capacity to be activated for early response, including by: distributing stockpiles of medicine, food, water, emergency shelter and body bags; dispatching skilled personnel for rescue, and specialists to provide medical, communication, engineering and nutrition services; and accessing contingency funding.
Seasonal forecasts are used in preparedness efforts such as training volunteers, mobilizing community disaster response teams, prepositioning stocks, and logistics planning, including securing visas for international emergency personnel and setting up camps for the displaced. Seasonal forecasts can also be used to secure emergency funding. At community level, longer-term preparedness includes the development of community preparedness plans and related infrastructure, such as shelters and raised mounds for flood evacuation, and measures such as carrying out other community disaster preparedness activities and micro-mitigation projects.

Seasonal forecasts have proved invaluable for contingency planning, which seeks to address and respond to specific events or scenarios for different hazards and settings at various scales, such as city-wide flooding or agricultural drought. Similarly, seasonal forecasts enable transboundary coordination to manage water resources in countries that share riverways in order to reduce downstream impacts.

Forecast verification

Climate information services also include forecast verification in order to inspire confidence in the application of forecast products by the user community. This is so because the main purpose of climate information services is to give the public warnings, forecasts and other hydro-meteorological information in support of safety of life and property and for day-to-day convenience in a timely and reliable manner. Consequently, climate information services programmes must include a system to evaluate whether this task is fulfilled and to regularly assess programme performance. The aim of the evaluation is twofold: first, to ensure that products such as warnings and forecasts are accurate and skilful from a technical viewpoint; and second, to ensure that they meet user requirements, and that users have a positive perception of, and are satisfied with the products (WMO/TD No. 1023, 2000).

According to WMO, the main goal of a verification process is continuous improvement of the quality (skill and accuracy) of services. This includes:

- Establishing a skill and accuracy reference against which subsequent changes in forecast procedures or the introduction of new technology can be measured.
- Identifying the specific strengths and weaknesses of a forecaster’s skills and the need for forecaster training, and identifying the strong points of models and the need for model improvement.
- Informing management about a forecast programme’s past and current skill level in order to plan future improvements; information can be used in decision-making concerning the organizational structure, modernization and restructuring of the national meteorological service.

Climate information service systems need to include verification in order to assess their utility across socioeconomic sectors. In that regard, the regional climate outlook forums pioneered in Africa have demonstrated the utility of the forecast, with steady accuracy improvements since 2000. For example, hit rates (a measure of accuracy) and false alarm rates have been compared on southern African regional climate outlook forum forecasts. It was found that the hit rate has steadily increased, while the false alarm rate has declined. This is shown in figure 2.2 (a) and (b), hit rate and false alarm rate trends for three-monthly average forecast for October to December and January to March, respectively, for the period 2000–2014. This is a further demonstration of the reliability and utility of climate information services across many socioeconomic sectors.
Figure 2.2 Trend of hit rate and false alarm rate for 2000–2014 (a) October–December, (b) January–March
3. Disaster risk reduction

Hydro-meteorological hazards, such as floods, storms, drought and extreme temperatures, strike communities around the globe each year. The top ten disasters of 2004 (UNISDR, 2004), in terms of the number of people affected, were all weather and climate-related. Since the 1980s, sub-Saharan Africa has experienced more than 1,000 disasters (www.cred.be, see 2004 statistics). Tropical cyclones mainly affect Madagascar, Mozambique and some Indian Ocean islands.

These have been a major threat to lives and sustainable development as they frequently reverse development gains. Other adverse impacts of hydro-meteorological hazards include food insecurity and epidemics, mainly cholera, meningitis and malaria. These types of disasters have occurred throughout history. In 2004, damage amounting to $130 billion resulted from such disasters (www.cred.be, see 2004 statistics). It is also estimated that in developing nations losses are typically 10–14 per cent of GDP (Abramovitz, 2001). The damage caused by just these ten events across the globe in 2004 makes it clear that the necessary steps to reduce disasters have not yet been fully taken.

The disaster profile of sub-Saharan Africa is closely linked to the vulnerability and exposure of its population, economy and community assets, and their often low capacity to cope with natural hazards. Most African countries have limited resources to invest in disaster risk reduction and minimal fiscal space to fund relief and recovery efforts after major disasters with high levels of mortality, morbidity, destroyed livelihoods, infrastructures capital and disrupted community social networks. Disasters can be a tremendous setback for economic growth and performance. The economic losses and physical damage arising from hydro-meteorological disasters are shown in figure 3.1.

Figure 3.1 Economic losses and physical damage caused by hydro-meteorological hazards

As climate change begins to manifest itself in the form of increased frequency and intensity of hazards such as floods, storms, heat waves and drought, communities need to address climate risks as a matter of urgency. The coming decades are likely to bring, among other changes, altered precipitation patterns, so...
many areas will experience more frequent floods and landslides, while others will experience prolonged drought and wildfires.

As many communities are not prepared to cope with the climate-induced disasters facing them today, building their resilience is a challenge. The aim of disaster risk reduction is to meet this challenge by addressing a comprehensive mix of factors that contribute to community vulnerabilities. Numerous tools and methodologies have been developed to put this approach into practice. The value of disaster risk reduction and the experiences gained by its practitioners have been increasingly tapped by organizations active in climate change adaptation. For example, the United Nations Development Programme (UNDP), the Organization for Economic Cooperation and Development (OECD), the World Bank and others have recently explored linkages between them.

3.1. A new approach to disaster risk reduction

The disaster management community has evolved. Until the 1990s, disaster management primarily focused on the response of governments, communities, and international organizations only after disasters had struck. This included the humanitarian aspects of relief, such as providing medical care, food and water, search and rescue, and containing secondary disasters (such as fires that occur following an earthquake). Even now, only a tiny amount of humanitarian funding is spent on disaster risk reduction. Although the international community has increasingly realized that countries experience disasters differently, the unfortunate truth is that poorer countries are hit hardest as they do not have sufficient resources to prepare for disasters. Overall education in terms of basic knowledge and awareness of disasters for the people residing in less advantaged areas still needs to be encouraged. In addition, the socioeconomic impacts of a disaster may linger far longer in poorer nations. A UNDP report states:

“In 1995, Hurricane Luis caused $330 million in direct damages to Antigua, equivalent to 66 per cent of GDP. This can be contrasted with the larger economy of Turkey that lost between US$ 9 billion and $13 billion in direct impacts from the Marmara earthquake in 1999, but whose national economy remained largely on track”.

The same report found that “while only 11 per cent of the people exposed to natural hazards live in countries classified as low human development, they account for more than 53 per cent of total recorded deaths”.

Disaster risk reduction is increasingly recognized as a major factor in achieving sustainable development, although its systematic integration into development planning and activities remains a challenge. Time and again, investments in development have been wiped away by disasters, and this damage has only increased as countries grow. According to Munich Re, the recorded economic value of disaster damage increased from $75.5 billion in the 1960s to $659.9 billion in the 1990s. These figures do not account for the losses suffered by communities in terms of lost lives and livelihoods. It is important to note that such losses are far greater in the developing world.

To reduce human and economic losses, the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters, commits countries and agencies to: integrating disaster risk reduction into sustainable development; developing and strengthening institutions, mechanisms and capacities to build resilience; and systematically incorporating disaster risk reduction
into emergency preparedness, response and recovery programmes. States have agreed to take the lead in achieving these goals by:

- Strengthening policies and institutions
- Identifying, assessing ad monitoring risk and enhancing early warning
- Using knowledge, innovation and education to build a culture of safety
- Reducing underlying risk factors, such as environmental degradation
- Strengthening preparedness for effective response

The Hyogo Framework was affirmed and expanded upon by its successor, the Sendai Framework for Disaster Risk Reduction 2015–2030, adopted at the Third United Nations World Conference on Disaster Risk Reduction in Sendai, Japan, on 18 March 2015.

The Sendai Framework is the outcome of stakeholder consultations initiated in March 2012 and intergovernmental negotiations from July 2014 to March 2015, supported by the United Nations Office for Disaster Risk Reduction (UNDRR) at the request of the General Assembly of the United Nations. The Sendai Framework also articulates the following: the need for improved understanding the three dimensions of disaster risk (exposure to hazards, vulnerability and capacity, and hazard characteristics); the strengthening of disaster risk governance, including national platforms; accountability for disaster risk management; preparedness to “build back better”; recognition of stakeholders and their roles; mobilization of risk-sensitive investment to avoid the creation of new risks; resilience of health infrastructure, cultural heritage and workplaces; strengthening international cooperation and global partnership, and risk-informed donor policies and programmes, including financial support and loans from international financial institutions. This is also consistent with the United Nations Sustainable Development Goals. The socioeconomic benefits of climate information services for disaster risk reduction model is informed by the dictates of the Sendai Framework.

3.2. Focus on communities and vulnerability

One of the underlying principles of disaster risk reduction is to consider disasters as a result of the vulnerability of a community. Vulnerability has been defined as “a set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility of a community to the impact of disasters”. Taken from this standpoint and incorporating the resources within the community, risk can be defined as:

\[
\text{RISK} = \frac{\text{HAZARD} \times \text{VULNERABILITY}}{\text{CAPACITY}}
\]

By analysing vulnerabilities and capacities, a fuller picture emerges of how to reduce disaster risks. The disaster risk reduction approach considers a comprehensive range of vulnerability factors and aims to devise strategies that safeguard life and development before, during, and after a disaster.

3.3. Disaster risk reduction tools

One common characteristic of disaster risk reduction tools is the emphasis on taking a holistic view of disaster risk reduction; in particular, the importance of linkage with diverse stakeholders because it
cannot be overemphasized that disasters are multisectoral in their impacts. Even for those tools with a narrower target group (such as climate forecasters or water utilities), the process requires that wide-ranging sources of knowledge be drawn on for successful risk reduction in the community. This attempt to analyse risk from diverse perspectives means that the tools are also suitable for climate change adaptation since the impacts will affect various sectors and communities.

Figure 3.2 Conceptual representation of the socioeconomic benefits of climate information services for disaster risk reduction

When all disaster risk reduction tools using optimum climate information services are fully developed with appropriate investments, communities will benefit enormously. Figure 3.2 shows how the system will reach implementation.

It is critical for decision makers at all levels to be committed to disaster risk reduction so that appropriate resources and planning guidance are provided. Just as important is the participation and understanding of individuals at the local level where disasters are felt. This category includes a country’s overall policies, the legislative process and the institutional framework for implementing measures. The tools that have been developed for policy and institutions are aimed at mainstreaming disaster risk reduction into development planning from the national to the community level in order to bring about a “culture of safety and resilience”.
4. Socioeconomic benefits framework

To adequately capture the socioeconomic benefits that can be derived from climate information services, the assessment has to be conducted from a systems perspective. The socioeconomic benefits resulting from such services are multisectoral: they can be demonstrated for disaster risk reduction, agriculture, water, health, energy and other sectors that are interlinked. In fact, disaster risk reduction has to consider impacts on and of these sectors since they are inextricably linked. They also extend to climate change adaptation. It is important to note that the benefits often depend on a multitude of factors. A systems dynamics approach is a useful tool for demonstrating the interlinkages between benefits that depend on the application of the climate system. This can be shown in a diagram depicting a conceptual representation of systems dynamics (figure 4.1).

Figure 4.1 Conceptual representation of the system dynamics model
Overview

System dynamics is a computer-aided approach to policy analysis and design. It is applied to dynamic problems arising in complex social, managerial, economic or ecological systems — literally any dynamic system characterized by interdependence, mutual interaction, information feedback and circular causality.

The field developed initially from the work of Jay W. Forrester. His seminal book, *Industrial Dynamics*, is still a significant statement of philosophy and methodology in the field (Forrester, 1961). Within 10 years of its publication, the scope of applications grew from corporate and industrial problems to include the management of research and development, urban stagnation and decay, commodity cycles and the dynamics of growth in a finite world. It is now applied in economics, public policy, environmental studies, defence, theory-building in social science and other areas, as well as its home field, management. System dynamics emerges out of servomechanisms engineering, not general systems theory or cybernetics (Richardson, 1981).

System dynamics is a methodology used to create models that are descriptive and focus on the identification of causal relationships influencing the creation and evolution of the issues investigated (Sterman, 2000). System dynamics models are in fact most commonly used as “what if” tools that provide information on what would happen if a policy is implemented at a specific point in time and within a specific context (Probst and Bassi, 2014).

System dynamics seeks to understand what the main drivers of the behaviour of the system are. This implies identifying properties of real systems, such as feedback loops, nonlinearity and delays through the selection and representation of causal relationships existing within the system analysed (Sterman, 2000). Potential limitations of simulation models include the correct definition of a system’s boundaries and a realistic identification of the causal relationships characterizing the functioning of the systems analysed (for example, concerning the use of causality rather than correlation).
5. **Rationale for using a system dynamics approach to assess the socioeconomic benefits of climate information services for disaster risk reduction**

An integrated and systemic cost-benefit analysis methodology is proposed for the assessment, consisting of three main analytical components: investment, avoided costs and added benefits. The conceptual framework used for the analysis is represented in Figure 5.1. The assessment of the socioeconomic benefits of climate information services is based on the amount of avoided costs and added benefits that investments in climate information services generate over time, meaning that cumulative benefits and costs are compared to determine the benefit-cost ratio of climate information service implementation. To better illustrate the applicability of this approach, climate change adaptation techniques are employed. For example, sustainability certification (to reduce the negative impacts of human activity and improve adaptation and resilience) is presented throughout the report for selected sectors.

*Figure 5.1 Conceptual framework used for the analysis*
(a). Investments: from a private sector perspective, “investments” refers to the monetary costs of implementing a decision, such as complying with sustainability standards, including, for example, annual certification fees, auditing and other management costs, such as: purchase of machinery and the transformation of production processes and techniques, potential additional labour and training costs. From a public-sector point of view, it refers to the allocation and/or reallocation of financial resources with the aim of reaching a stated policy target (such as to create enabling conditions for the development of sustainable businesses in a given country).

(b). Avoided costs: the estimation of potential costs that could be avoided as a result of the successful implementation of an investment/policy. In the case of sustainability principles and processes, these refer to the use of green production practices (as a result of sustainability certification) and may include direct savings derived from a more efficient use of natural resources, and indirect avoided costs, such as health expenditure, avoided losses from environmental degradation, and avoided payments for the replacement of key ecosystem services (UNEP, 2012a).

(c). Added benefits: the monetary evaluation of economic, social and environmental benefits deriving from investment/policy implementation, focusing on short-, medium- and long-term impacts across sectors and actors. These are all additional benefits that would not accrue in a business-as-usual scenario.

5.1. Investment

A set of possible indicators of investment can be broadly subdivided into capital and operational and management costs, training costs, and government costs. These indicators are selected for the examples of sustainability certification, for agriculture, fisheries and aquaculture, disaster risk reduction and forestry. This set of indicators is neither exhaustive nor applicable in its entirety to all policies and sectoral analyses. It rather reflects a generic portfolio of indicators that can be flexibly customized (that is, expanded or narrowed down) to the requirements and objectives of specific sectoral assessments.

5.2. Avoided costs

A key aspect that is often neglected when measuring the effectiveness of investment in sustainability is the cost-saving deriving from such interventions. More specifically, improving the sustainability of a sector has the potential to:

(1). Reduce costs currently sustained by public and private actors as a result of the current ineffective natural resources management and use;

(2). Avoid potential future costs deriving from the depletion of natural capital and ecosystem degradation.

Consequently, an integrated analysis of the impacts of climate variability and climate change adaptation interventions should include estimation of potential (policy-induced) avoided costs, using historical and current data on environmental, social and economic performance.
5.3. Added benefits

Once the total investment and avoided costs (both public and private) have been estimated, the additional benefits potentially deriving from policy implementation should be properly assessed. In particular, economic, social and environmental benefits should be identified, and adequately measured by means of relevant indicators.
6. Assessment of socioeconomic benefits in models

There are methods that allow the quantification and valuation of the socioeconomic benefits of weather and climate services. These in turn allow the analysis of the economic costs and benefits of those services. Previous studies have shown that weather and climate services deliver very high economic benefits and, when compared to the costs of investing, produce a high benefit-cost ratio (that is, a high economic ranking).

The approach used to quantify looks at the action and outcomes of the use of enhanced weather and climate services and compares them to a baseline without this additional information: the difference is the quantified benefit. This is often known as the value of the information.

The key steps in modelling and assessing socioeconomic benefits are:

- Identifying current and future vulnerability to climate variability and climate change. This includes an assessment of the exposure of built capital and infrastructure, of the vulnerability of people and villages to extreme weather events, and of the potential sensitivity of economic activities (such as agricultural production) to changing weather patterns.

- Identifying indicators that can be used to measure performance and vulnerabilities across social, economic and environmental dimensions. Since not all the impacts of climate change are economic, it is important to identify social and environmental indicators that could potentially be subject to economic valuation.

- Identifying the potential benefits of the weather and climate service and how these benefits will arise from the steps in the weather chain (from weather or climate information to end users). This should include all benefits, that is, financial benefits and non-market benefits such as health. It is also important to note the actors (for example, the public and private service providers and users) across the chain.

- Reviewing and deciding on the potential methods for assessing these benefits and vulnerabilities, taking account of resources and how adequately these methods represent the local context. This may need to involve steps to quantify and potentially value market and non-market sectors. It could include integrated or sectoral modelling, survey and econometric data analysis or lighter touch qualitative methods.

- Deriving a baseline of the current situation without the new information provision and, to the extent possible, quantify the potential social, economic and environmental impacts of climate change. This includes an assessment of the impacts across sectors and actors (such as households, private and public sector), and over time (that is, short term versus long term).

- Identifying, simulating and analysing alternative scenarios of action (that is, with different degrees of availability of climate information and uptake from local economic actors) to estimate deviations from the baseline. This allows the impacts on vulnerabilities to be assessed:
the potential cost reductions and the potential emergence of new opportunities across social, economic and environmental indicators.

- Assessing the change from the baseline with the new weather and climate services in place. This should include the potential benefits, but ensure that the efficiency losses along the weather chain are considered.

- Assessing the costs of the project, including investment in meteorological stations, system operation and information provision (thus capturing equipment and resource (labour) costs).

- Comparing benefits against costs, estimating to the extent possible the economic value of avoided social and environmental impacts, together with avoided economic costs and benefits. The comparison of costs and benefits should also highlight the improved resilience by sector and economic actor to better inform decision-making.

- Identifying omissions, considering bias and undertaking sensitivity analysis. When assessing costs and benefits, it is crucial to acknowledge any missing information or social and environmental impact that could not be monetized to ensure that, if a partial analysis is carried out, it is acknowledged that the results may be an underestimation of the socioeconomic benefits brought about by investments in weather information. The use of multi-criteria analysis (MCA) may be considered.

- Exploring how benefits could be enhanced through interventions along the weather chain, through the implementation of complementary interventions across sectors and actors and over time. It is crucial to identify whether or not there is complementarity/synergy between investments in the weather value chain and sectoral development targets, as this would increase the effectiveness of budgetary allocation.

### WISER guidance on socioeconomic benefits

Upstream weather and climate services are usually seen as non-technical in nature and people find it difficult to assess their benefits in quantitative terms. This part of the guidance aims to address this problem by outlining how to identify and quantify the benefits of weather and climate services.

There are several reasons why it is beneficial to consider socioeconomic benefits:

- Doing so can help to identify the impact of the project and what it is trying to achieve in terms of delivering benefits to users.

- It can help gain an understanding of how to maximize user-benefits, looking at how benefits are delivered, from initial services down through the user chain.

- It can provide information to policymakers on the benefits of weather and climate services and thus help to justify current and future investment in those services.

### How socioeconomic benefits can be quantified

There are methods that allow the quantification and valuation (monetization) of the benefits of weather and climate services. These in turn allow the analysis of the economic costs and benefits of those services.

Using such methods, previous studies have shown that weather and climate services deliver very high economic benefits and, compared to the costs of investment, produce a high benefit-cost ratio (that is, a high economic ranking).
The approach used to quantify socioeconomic benefits looks at the action and outcomes of the use of enhanced weather and climate services and compares this to a baseline without this additional information: the difference is the quantified benefit. This is often known as the value of the information.

Importantly, there are several categories of benefits, including direct and indirect benefits, and market and non-market impacts. As these are wider than financial benefits alone and capture the full economic benefits, they are referred to as socioeconomic benefits.

Types of socioeconomic benefits

A wide range of different benefits may arise from weather and climate services. These include areas where there is an obvious financial benefit, but also other areas that provide benefits and are more difficult to value in monetary terms. While the direct losses can usually be quantified and then valued using market prices, the intangibles involve non-market effects, which use economic methods to derive economic values.
7. Customization of socioeconomic benefits to disaster risk reduction

Studies during the first phase of WISER allowed the quantification and valuation of climate information services benefits to the economy. Such studies have shown that these services deliver very high economic benefits and, when compared to the costs of investing, they produce a high benefit-cost ratio. It has been established that most global disasters are caused by hydro-meteorological hazards.

Better weather and climate services lead to improved information, such as better forecasts, early warning systems and seasonal forecasting. These services in turn provide benefits to users and lead to positive outcomes resulting from the actions and decisions subsequently taken. Some examples include the following:

- Early warning systems can significantly reduce the damage and losses – and reduce loss of life and injuries – caused by extreme events and disasters.
- Seasonal outlooks can help improve agricultural production (higher yields) and reduce losses from extreme events.

Taking the above into account, there was a need to extend and customize socioeconomic benefits to disaster risk reduction. The approach used to quantify such benefits looks at the action and outcomes derived from the use of enhanced weather and climate services and compares them to a baseline without this additional information: the difference is the quantified benefit in disaster risk reduction. Focusing on the socioeconomic benefits of climate information services, with particular reference to disaster risk reduction, helps to maximize the impact of weather and climate services by enabling appropriate interventions along the user chain.

A number of steps were needed to apply the socioeconomic benefit framework developed during the first phase of WISER to disaster risk reduction. This led to a systemic analysis being conducted of sectoral and cross-sectoral vulnerabilities and opportunities.

These steps were as follows:

Customize the socioeconomic benefit framework, methods and tools to evaluate their application to disaster risk reduction.

- Establish and test the framework to drive uptake and investments in disaster risk reduction at various levels.
- Carry out analytical studies to show the need for investment in climate information services and provide strategic guidance for investment in disaster risk reduction.
- Demonstrate the applicability of the socioeconomic benefit framework to disaster risk reduction, disseminate the framework and ensure wide use of it.
- Analyse and develop indicators and trackers for climate information service uptake in the development of disaster risk reduction policies.
• Contribute to strengthening the human and institutional capacities of African countries to plan and optimize investments in disaster risk reduction.

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• Analyse and develop indicators and trackers for climate information service uptake in the development of disaster risk reduction policies.

• Contribute to strengthening the human and institutional capacities of African countries to plan and optimize investments in disaster risk reduction.
8. Data

In recent years, countries have established loss-monitoring systems, usually with external support. There are significant concerns regarding the reliability and sustainability of these systems, however. In many instances, data coverage is sporadic, so that loss estimates are missing, data quality is questionable, and operators lack the financial resources to maintain loss databases (UNDP/BCPR 2013). On the other hand, equally important data on vulnerability and resilience are largely missing, making it difficult to track loss reduction progress in conjunction with resilience.

Better data on losses, both historic and current, are also essential for the attribution of extreme weather impacts to climate change (Basher 1999). The ability to recognize that weather patterns and their impacts have changed is crucial if the need is to be established for climate adaptation rather than conventional disaster risk management. Consequently, losses (or avoided losses) should be considered a performance measure of risk management, as should resilience.

In order to carry out the research necessary to solve socioeconomic and other problems, relevant good-quality data from national and international databases on parameters are needed on temperature, rainfall, wind, soil moisture and ocean conditions, among others. Long-term historical averages of these parameters and maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios would assist in the formulation of the strategies necessary to minimize the potential impacts on communities of hydro-meteorological hazards. Depending on the user’s needs, these data and information products may be combined with non-climate data, including agricultural production, health trends, population distribution in high-risk areas, road and infrastructure maps for the delivery of goods and other socioeconomic variables, GDP and water resources, land use, vulnerability of communities to hydro-meteorological hazards, and economic damage due to disasters.

A climate information service is an important component of the evidence base required to guide decisions regarding appropriate levels of investment to minimize potential impacts on the economy, ensuring uninterrupted delivery of critical services and infrastructure. Investing in the development of early warning systems and contingency planning, reserving contingency funds for emergency use, and potentially subsidizing vulnerable or impacted sectors (such as agriculture) is necessary to help protect socioeconomic welfare.

Since the 1970s, mortality resulting from disasters has decreased in some regions as a consequence of the development of multi-hazard early warning systems. Effective early warning systems include risk knowledge, monitoring and warning services, dissemination and communication and response capacity. Lessons learned from a number of good national practices in multi-hazard early warning systems indicate that these systems enable decisions to be taken that protect lives and livelihoods in short- and longer-term timeframes by extending the lead time for contingency planning and preparation. Short-term warnings can enable evacuations and transportation to predetermined shelters, the protection of some assets (for instance, by calling boats to shore, boarding up buildings and pre-positioning emergency capacities).

The main data source used by UNDRR for disaster profiles is obtained by using DesInventar as a disaster information management system on the following web page: www.desinventar.net/data_sources.html. World Bank climatology data are available at: http://sdwebx.worldbank.org/climateportal/index.
The challenges involved in data acquisition include:

1. Disaggregation of data.
2. Identifying all possible data sources for a national effort.
3. Making the information accessible.
4. Reconciling data from multiple sources.
5. Conflicting figures for the effects of the same event.

Hydro-meteorological data were obtained from World Bank sources.

8.1. Defining and measuring the data

In the first phase of the socioeconomic benefits project the areas of socioeconomic impacts included in the model were: population; health; education; roads; macroeconomy; water; agriculture; and energy sectors. However, as some raw data were not available, the use of proxy data had to be considered to represent some economic damage in certain sectors as these were deemed to be appropriate. At the same time, some explicit impacts did not need to be included for the following reasons:

- **Population**
  - Effect of floods on migration
    - This parameter can be removed due to the difficulty of isolating the effect of floods or drought on migration.

- **Education**
  - No direct impacts. Excel spreadsheet quantifies damage to education: however, there was no information on how it occurred.

- **Health**
  - At this stage: additional costs in health care per capita due to adverse weather
    - Intended to capture additional health care costs per capita in the event of adverse weather (flood or drought).

- **Roads**
  - Effect of flooding on functioning roads
    - Captures the loss of roads due to floods.
    - Is used to calculate the additional cost of re-establishing the road network.

- **Macroeconomy**
Socioeconomic Benefits of Climate Information Services for Disaster Risk Reduction in Africa

Final report by the African Climate Policy Centre of the Economic Commission for Africa

- Capital erosion due to floods
  - Intended to capture the loss of physical capital in the event of floods, and hence affects productivity and total value added.
- Effect of drought on total factor productivity
  - Intended to capture the impact that droughts (and the resulting lack of food) has on total factor productivity and hence total value added.

• Water sector
  - Effect of temperature (/drought) on evapotranspiration
    - Intended to capture the impact of higher temperatures on the evapotranspiration rate of rain. Evapotranspiration also depends on the saturation of the air with humidity, and wind speed, neither of which is included in the model.
  - Effect of temperature on natural vegetation cover
    - Intended to capture the change in percolation rate related to the loss of surface vegetation. Less vegetation leads to the loss of roots in the ground, which makes the ground less permeable and therefore causes more water to run off into surface water streams.

• Agriculture
  - Effect of drought on average lifetime of agricultural land
    - Intended to capture the loss of agricultural land in the event of drought. An adjustment process in this part of the structure leads to a continuous renewal of agricultural land, trying to reach pre-disaster levels.
  - Effect of adverse weather on agricultural yields
    - Intended to capture the loss of agricultural production through floods or drought. This might need to be refined (possibly in phase III), as lack of water does not affect agricultural productivity in the same way as floods. Moreover, when floodwaters have gone down, the land is left more fertile, while drought causes desertification and the land therefore takes longer to recover.

• Energy
  - Effect of precipitations and temperature on the load factor of conventional power generation capacity
    - Intended to capture the effect of water availability on the capacity of power generation to remain operational (for example, water for cooling purposes).
    - Also: intended to capture the impact of temperature/water temperature on the operation of thermal power plants.
  - Both affect the operation of power plants in a negative way and either lead to more fuel consumption and hence higher emissions or result in a temporary shutdown of plants due to “overheating”.
  - Water flow impact on hydropower load factor
- Intended to capture the impact of “water availability” on hydropower electricity generation.

* Effect of temperature and drought on the occurrence of forest fires/fires related to the power distribution network

- Intended to capture the interaction between temperature, drought and power distribution infrastructure, and their combined impact on the occurrence of fires.

Data on some of the parameters of impacts have not been considered for the work on the disaster risk reduction and climate information services phase mainly because such data are not available. Proxy data have been used instead. Moreover, hydro-meteorological data such as precipitation, flooding, droughts, storms and tropical cyclones have been acquired and processed for the purposes of their introduction into the model.

8.2. Methods of obtaining data

Data were obtained from the public domain from credible sources, including UNDRR, the International Federation of Red Cross and Red Crescent Societies (IFRC), the World Bank, WMO, FAO and UNDP.

As an alternative to using observed data on fatalities and economic losses to set baselines and determine progress, metrics on expected disaster fatalities and expected economic losses should be developed and disaster risk reduction policies tracked through procedures such as identifying the percentage of the population living or working in buildings of moderate and high susceptibility to collapse in high-hazard earthquake zones (see section 4.2). The long-term aim could be for every country to use full catastrophe models to monitor progress. However, these will take time to develop. Both methods require the collection of high-resolution exposure information, including on building locations and values.

In future, detailed data on disaster losses and the attributes of buildings damaged will be important for testing and improving the methodology for measuring assumed relationships between fatality rates and different building styles or evacuation procedures. The occurrence of particular disasters will also test mitigation strategies. Improvements will therefore be needed in disaster loss data collection, including the generation of data sets to assess impacts on the poorest (sections 5.2 and 5.4). Consistent global definitions and methodology are important for the collection of risk and loss data.
9. **Model description**

The modelling was carried out on Vensim software, using system dynamics principles.

**9.1. Vensim model**

Vensim, designed by Ventana Corp., is a visual modelling tool that allows the conceptualization, documentation, simulation, analysis and optimization of models of complex dynamic systems. It provides a flexible approach to creating models by allowing ideas to be included, diagrams built and, when appropriate, a formal simulation model to be devised. Modelling starts with causal loop diagrams, equations, or stock and flow diagrams. Models can also be imported from other applications, thus providing the user with the powerful Vensim analysis and optimization tools.

For advanced modelling, Vensim PLE Plus, Vensim DSS and Vensim Pro are needed because they allow the use of arrays in the equation editor. Vensim Model Reader is only for running models; it does not have the capabilities to design models. The Model Reader can however read arrays.

**9.2. Causal relationships**

Causal relationships are relationships that show how variables in a Vensim model affect each other. They are interpreted by causal loop diagrams. An arrow going from A to B indicates that A causes B. Causal loop diagrams can be very helpful in conceptualizing and communicating structures. By connecting words with arrows, relationships among system variables are entered and recorded as causal connections. Causal relationships can aid analysis of a model throughout the building process, displaying the causes and uses of a variable and the loops involving the variable. As an example, figure 9.1 shows several examples of relationships in causal loops. One example is climate information service adjustment, which is affected by:

1. Desired climate information service coverage
2. Time to establish climate information service
3. Climate information service investment policy switch, and
4. Start time of climate information service investment.

In turn, climate information service adjustment affects the rate of change in climate information service coverage.
9.3. Structural assumptions

The main structural assumptions used to build the model are given below. (Numerical assumptions are addressed under parametrization). The assumptions used in the model are based on the available literature and models, as well as on data.

(1). Climate events and their magnitude are calculated on the basis of average monthly precipitation and predefined threshold values. The threshold values for floods and droughts were provided as follows:

(2). Drought: 25 per cent below monthly average

(3). Flood: 25 per cent above monthly average

(4). Climate information service coverage in the context of the socioeconomic benefits of the climate information services model refers to both infrastructure (observational networks, radar, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). Assuming a value of 0.6 indicates that 60 per cent of infrastructure and skills are available.

(5). The effectiveness of interventions, and therefore damage avoided, is based on climate information service coverage. Information on the relationship between that coverage and disaster risk reduction intervention effectiveness was provided by specialists in the areas. It is defined as the following, non-linear relationship: it is assumed that extreme weather events affect production (for example, agricultural production) in the short term.

(6). It is assumed that agricultural land affected by drought events can be re-established within one
year, provided that land for conversion is available.

(7). It is assumed that drought events only affect the share of population that is living in drought-prone areas. The impact of drought events therefore depends on the number of people living in these areas and the magnitude of the drought.

(8). The impact of floods, as opposed to the impact of drought events, is based on total population as floods can potentially happen anywhere in the event of extreme rainfall over extended periods of time.

(9). Extraordinary health care expenditure is assumed to be incurred only for the total number of people affected by events.
10. Critical evaluation and documentation of causal relationships

Modelling requires critical examination of causal relationships, which entails careful assessment of assumptions made, limitations, data requirements and any data gaps.

10.1. Structural assumptions

The main structural assumptions used to build the model are given below. (Numerical assumptions are addressed under parametrization.) The assumptions used in the model are based on the available literature and models, as well as on data.

- Climate events and their magnitude are calculated on the basis of average monthly precipitation and predefined threshold values. The threshold values for floods and droughts were provided as follows:
  - Drought: 25 per cent below monthly average
  - Flood: 25 per cent above monthly average
- Climate information service coverage in the context of the socioeconomic benefits of the climate information services model refers to both infrastructure (observational networks, radar, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). Assuming a value of 0.6 indicates that 60 per cent of infrastructure and skills are available.
- The effectiveness of interventions, and therefore damage avoided, is based on climate information service coverage. Information on the relationship between that coverage and disaster risk reduction intervention effectiveness was provided by specialists in the areas. It is defined as the following, non-linear relationship: it is assumed that extreme weather events affect production (such as agricultural production) in the short term.
- It is assumed that agricultural land affected by drought events can be re-established within one year, provided that land for conversion is available.
- It is assumed that drought events only affect the share of population that is living in drought-prone areas. The impact of drought events therefore depends on the number of people living in these areas and the magnitude of the drought.
- The impact of floods, as opposed to the impact of drought events, is based on total population as floods can potentially happen anywhere in the event of extreme rainfall over extended periods of time.
- Extraordinary health-care expenditure is assumed to be incurred only for the total number of people affected by events.
- It is assumed that capital (such as infrastructure) is damaged by extreme events and that only roads are rebuilt. Other damage to capital is carried over through to the end of the simulation.
Reinvesting the costs avoided by disaster risk reduction interventions would lead to higher economic growth but, as damage is avoided, there is no perceived need to reinvest (or invest) money.

10.2. Limitations

Limitations arise as a result of the data used. The data used for the parameterization of the model were calculated based on a data set providing climate-related impacts across multiple African countries (UNISDR, 2017). The data set was incomplete for many events, so the average of the information that was available had to be used. The model therefore uses average parameters to calculate the climate impacts of floods and droughts on various sectors. Furthermore, the model uses monthly averages for precipitation and expert confidence ranges to determine the frequency of adverse climate events.

For a proper assessment of climate impacts and the socioeconomic benefits of climate information services, country-specific data on macroeconomic variables (for example, GDP by sector, employment, health care) are needed to customize the model.

10.3. Data requirements and sources

Climate and socioeconomic data are needed for the system dynamics modelling of the socioeconomic benefits of climate information services for disaster risk reduction, including economic damage, people affected, and constraints on agricultural production. These types of data were obtained from the public domain using the websites of credible, relevant organizations, such as United Nations agencies, official government compilations, relief organizations, and the media. The multiple sources enabled some measure of authentication of independent data sources.

10.4. Data gaps

Identified data gaps range across all sectors and are mainly related to the lack of post-disaster assessments of the actual damage that occurred during adverse weather events.

Assessment of economic damage

The data set mainly provided impacts on physical factors, such as population (for example, affected, missing, dead) and the amount of agricultural land and cattle affected or lost as a result of an event. Information on the economic value of events was either not available or provided on an aggregate level. Aggregate information of impacts allows the estimation of impacts compared to GDP but does not provide information on the economic sectors in which the damage was caused. Post-disaster assessment of damage by sector (and actor), such as conducted after cyclone Eline in Mozambique in 2000 is therefore needed.
11. Analysis

The analysis was done using the relevant equations and parameters for generating the outputs.

11.1. Relevant equations and parameters determined

The main structural assumptions used to build the model are given below. (Numerical assumptions are addressed under parametrization). The assumptions used in the model are based on the available literature and models, as well as on data.

Climate information service coverage in the context of the socioeconomic benefits of the climate information services model refers to both infrastructure (observational networks, radar, weather satellites, computers, telecommunication facilities) and skills (forecasting modelling, data processing, tailor-making and communication of products). Assuming a value of 0.6 indicates that 60 per cent of infrastructure and skills are available.

The effectiveness of interventions, and therefore damage avoided, is based on climate information service coverage. On the basis of available information on the relationship between such coverage and disaster risk reduction intervention effectiveness, the following, non-linear relationship exists:

**Figure 11.1 Relationship between climate information service coverage and disaster risk reduction intervention effectiveness**

11.2. Model parameterization

Relevant parameters were determined, and equations set out for the development of the models.

Share of agricultural land affected by floods

Based on the available data (UNISDR, 2017), the share of agricultural land affected by floods ranged from 0 per cent to 20 per cent. The analysis of the data indicated that, even in months with a relatively high above average precipitation (such as 50 per cent), the share of agricultural land affected could be relatively low. A non-linear function was therefore established to determine the share of agricultural land affected by floods. The amount of agricultural land affected by flood events is thus determined based on the total amount of agricultural land and the non-linear function of the flood indicator (figure 11.2).
The share of agricultural land affected by floods is thus dependent on the flood indicator, which indicates the magnitude of the event. Subsequently, the total amount of agricultural land affected by floods is calculated by the following equation:

\[
\text{Agricultural land affected by floods} = \text{total agricultural land} \times \text{share of agricultural land affected by flood}
\]

**Share of agricultural land affected by drought**

Based on the available data (UNISDR, 2017), the share of agricultural land affected by drought was determined to range from 0 per cent to 30 per cent. The analysis of the data indicated that, even in months with a relatively low below average precipitation (such as 15–20 per cent), the share of agricultural land affected could be relatively low. It should be noted that a drought indicator per se does not necessarily provide all the information needed to determine the strength and impact of a drought, as discussed in the limitations section. Therefore, the function assumes a linear increase of up to 15 per cent of land affected for precipitation 25 per cent below average, and after that a steep increase to 60 per cent to simulate extreme drought events (35 per cent below average monthly rainfall or less).

Based on this information, a non-linear function was established to determine the share of agricultural land affected by drought (figure 11.3). The amount of agricultural land affected by drought events is thus determined based on the total amount of agricultural land and the non-linear function of the drought indicator.
Figure 11.3 Share of agricultural land affected by drought

![Graph showing share of agricultural land affected by drought](image)

The share of agricultural land affected by drought is therefore dependent on the water scarcity indicator, which indicates the magnitude of the event. Subsequently, the total amount of agricultural land affected by drought is calculated by the following equation:

\[
\text{Agricultural land affected by drought} = \text{total agricultural land} \times \text{share of agricultural land affected by drought}
\]

Share of livestock affected by floods

The share of livestock affected by floods is assumed to range between 0 per cent and 0.05 per cent per flood event, depending on the magnitude of the event. As discussed in the section on limitations, the impact of floods is not bound to a specific region, which implies that the share of livestock affected by floods could be significantly higher, depending on the country context.

Based on the available information (UNISDR, 2017), a linear relationship for the share of livestock affected by floods was established. The relationship between the flood indicator and the share of livestock lost is illustrated in figure 11.4.

Figure 11.4 Share of livestock affected by floods

![Graph showing share of livestock affected by floods](image)

The share of livestock affected by floods is thus dependent on the flood indicator, which indicates the magnitude of the event. Subsequently, the total head of livestock affected by floods is calculated by the following equation:
Loss of livestock due to floods = livestock * flood impact on livestock table (flood indicator)

Share of livestock affected by drought

The share of livestock affected by drought is assumed to range between 0 per cent and 7 per cent per drought event, depending on its magnitude. As discussed in the section on limitations, the impact of drought is not bound to a specific region, which implies that the share of livestock affected by drought could be significantly higher, depending on the country context.

Based on the available information (UNISDR, 2017), a non-linear relationship for the share of livestock affected by drought was established. The function assumes a linear increase in loss of livestock from 0 to 1 per cent as average monthly precipitation falls from 100 per cent to 75 per cent. As soon as monthly average precipitation drops below 75 per cent, the share of livestock affected increases strongly, assuming a lack of sufficient water to maintain all animals. The relationship between the water scarcity indicator and the share of livestock lost is illustrated in figure 11.4.

**Figure 11.5 Share of livestock affected by drought**

The share of livestock affected by drought is thus dependent on the water scarcity indicator, which indicates the magnitude of the event. Subsequently, the total head of livestock affected by drought is calculated by the following equation:

Loss of livestock due to drought = livestock * drought impact on livestock table (water scarcity indicator)

Share of population affected by adverse weather

The share of population affected by flood and drought is dependent on the flood indicator and the water scarcity indicator and table functions determined based on the analysed data set (UNISDR, 2017). The share of population affected by drought is estimated on the basis of the share of population living in drought-prone areas and the share of population affected by drought. The latter variable comprises a linear relationship which has been estimated based on the available data and is shown in figure 11.6.
This linear function is based on the assumption that drought impacts gradually affect the population living in drought-prone areas and that all people living in drought-prone areas are affected starting from precipitation levels of 30 per cent below average. The population affected by drought is calculated as follows:

$$ \text{Population affected by drought} = \text{population living in drought-prone areas} \times \text{share of population affected by drought} $$

Furthermore, while the value 1 represents 100 per cent, this share applies to the population living in drought-prone areas only, so the number of people would be equivalent to the share of total population living in these areas. The number of people living in drought-prone areas is calculated by the following equation:

$$ \text{Population living in drought-prone areas} = \text{population} \times \text{share of population living in drought-prone areas} $$

### 11.3. Simulation of the model

**Time**

The projections of the model depend on the accuracy of climate forecasts, which means that the degree of uncertainty in the projections increases over time. In addition, the socioeconomic benefits of climate information services model does not capture daily precipitation but uses monthly average precipitation to determine the number and magnitude of climate impacts. This implies that events causing floods (such as three days of heavy rainfall) are not and cannot be considered in the analysis. Similarly, the model does not look at the number of months during which average precipitation is below the monthly average, which could be used as an additional indicator for droughts, together with the month during which the drought occurs.

The magnitude of impacts varies between countries and depends on a variety of factors, such as the structure of the economy, the share of people living in disaster-prone areas and the strength of climate variability and change impacts. At this stage, the model represents average climate impacts derived from events across multiple African countries. The magnitude of impacts in this model is calculated on
the basis of the initial parameterization of the model (Mauritius) and the average parameters derived from the data set as described in section 11.1. This implies that the simulation results obtained from the model provide information about the socioeconomic benefits of climate information services on a general level and that the assessment of actual benefits requires the customization of the model to a country context. Climate-related impacts and damage are often related to landscape attributes and depend on geographical factors, such as slope, land cover, soil type and regional climate conditions. Consequently, only certain areas of a country may be affected by climate events, although the impacts of those events (such as food scarcity) may be felt nation-wide. At this stage, the model is set up to calculate climate impacts at country level, but it could be calibrated to the subnational level if data were available. The proper assessment of climate impacts in a specific country context would account for the share of agricultural land located in drought-prone areas, the share of population living in drought-prone areas, national food imports and other important variables that provide information about the magnitude of impacts.

In addition, the current formulation of the model does not allow for droughts and floods to happen simultaneously. Both event types occur if average monthly precipitation exceeds or undercuts predefined threshold values (<75 per cent and >125 per cent of normal average). A flood and a drought can therefore occur in two successive months, but not at the same time.

### 11.4. Model validation

Model validation, that is, a comparison of the simulation with data on events and impacts, has been done up to 2018. Figure 11.7 represents the number of extreme adverse weather events that occurred between 1980 and 2015. Between 2000 and 2015, the model indicates a flood event almost every other year, and three to four severe drought events (including some minor drought events) in both scenarios, which is consistent with the frequency and impacts indicated in the data set (UNISDR, 2017). According to the data, Ethiopia, Mozambique and the Niger experienced between three and five drought events between 1980 and 2015, with a significant number of people affected. Furthermore, the data set indicates that, since 2000, almost all countries have experienced annual flood events.

**Figure 11.7 Flood indicator and water scarcity indicator, 1980–2015**

**Figure 11.8 Impact of floods and drought on land (magnitude)**

Figure 11.8 provides an overview of the shares of agricultural land affected by floods and drought. The simulations indicate that major events affecting large amounts of land happen on average every three to
five years. Based on the available data set, the frequency of events is comparable to the data provided for Ethiopia and Mozambique. The model also generates an average amount of land devastated by floods of 1.4 per cent per year in the climate scenario, which is in the range of the calculated averages from the data set. According to the data, the average amounts of land devastated in the event of a flood event range from around 1 to 1.5 per cent for Senegal and Ethiopia, to around 4 to 6 per cent for the Niger and Mozambique. This indicates that flood impacts are captured moderately in the model.

**Figure 11.8 Impact of floods and droughts on agricultural land, 1980–2015**

Regarding the impacts of drought on agricultural land, the data analysis provided a range from 0.5 per cent for moderate events to more than 40 to 60 per cent of farmland damaged by a severe event. For 2010 and 2011, the model generates a 12.8 per cent and 10.4 per cent share of farmland damaged on average, which means that drought impacts are also captured moderately and could be much more severe in the case of extreme events.

**Impact of floods and drought on GDP**

Compared to the baseline scenario, the generated behaviour in the climate scenario shows the impacts of adverse events. Over a period of 35 years (1980–2015), total real GDP is 3.68 per cent lower as a consequence of capital erosion due to adverse weather. The difference in total GDP is equivalent to 5.4 billion Mauritian rupees (MUR), or roughly $168 million, by 2015.

**Figure 11.9 Real GDP in business-as-usual and climate scenario, 1980–2015**
Population affected

The total affected population is in the range of 50,000 to 150,000 people, which is equivalent to 5–15 per cent of total population, depending on the magnitude of climate events. These numbers are in line with the numbers in the available data sets, although only general validation is possible at this stage. The total share of population affected by droughts depends on the share of people living in drought-prone areas, which is assumed to be 13 per cent for the current simulations. This indicates that the number of people affected may be significantly higher, especially in countries with a high percentage of subsistence farmers in rural areas.

Figure 11.10 Total affected population in the business-as-usual and climate scenario, 1980–2015
12. Quantitative model results

12.1. Agriculture: impact on land and productivity

Climate impacts on agriculture distinguish between the share of agricultural land affected by floods and agricultural land affected by droughts. The causal relationships used to determine the impact of climate hazards on the amount of affected agricultural land are displayed in figure 12.1.

The amount of affected agricultural land depends on the magnitude of climate events. According to FAO, droughts can reduce total agricultural productivity by 70 per cent (FAO, 2015). The socioeconomic benefits of climate information services model uses two different variables for yield. The first is the regular production yield, which is affected by total factor productivity and the elasticity of agricultural yield to total factor productivity. In addition to the normal agricultural yield, the model considers a reduced yield for production on affected agricultural land, which is equivalent to 30 per cent of the baseline yield and hence captures the 70 per cent indicated by FAO. Figure 12.2 illustrates the causal relationships used to calculate total agricultural production into the model.
12.2. Livestock: losses due to climate change

The causal relationships used to introduce the impact of floods and droughts on livestock into the model are illustrated in Figure 12.3. The change in livestock is an inflow to the stock of livestock and calculated based on an exogenous annual growth rate. Floods and droughts pose different threats to livestock and the model assumes two separate impacts to ensure that both types of events affect livestock differently. The impacts of adverse weather are therefore captured through the outflows loss of livestock due to floods and loss of livestock due to droughts.

Figure 12.3 Climate impacts on livestock

Whereas the livestock losses due to floods and droughts are physical flows of animals that are affected by adverse weather, these flows inform the assessment of the economic impact of such events. The number of animals lost per event is used to determine the economic value (loss) per event, which is then used for the assessment of avoided costs and added benefits of climate information services interventions.

Number of people affected by climate events

An additional variable introduced into the model is the number of people affected by adverse weather events. The proper assessment of population-related additional costs requires an estimate of the number of people affected by flood and drought events, respectively. The estimate of the number of people affected is based on:

1. The share of people living in flood- and drought-prone areas, respectively
2. The magnitude of the climate event, in other words, the share of people within these areas that are affected by a certain event. At this stage, regionalization (share of people in areas prone to adverse weather) is only assumed for drought events, as flood events can potentially occur anywhere in the event of extreme rainfall.

Figure 12.4 illustrates the factors determining the number of people affected by climate events.
At this stage, the number of affected people is used to determine the additional health care expenditure. In later iterations of the model, this number can potentially be used to determine disaster relief payments, such as payments for food and water delivery to affected areas or resettlement costs.

Climate information service investment and impact

The impact of climate information services coverage on intervention effectiveness was introduced into the model. More data are needed to parameterize this effect adequately, but the structure for including this impact is in place and operational. Figure 12.5 represents the structure used to capture the impact of climate information services coverage on intervention effectiveness. This structure allows for the adjustment of that coverage based on a desired coverage value. It is also able to calculate the necessary investment for the increase in coverage over time.
Disaster risk reduction indicators

A sketch providing an overview of the main disaster risk reduction indicators has been introduced into the model. It displays graphs of key variables in the model for each of the simulated scenarios to enable users to see the generated behaviour and hence the impact of investment in climate information services. The sketch will be refined based on input from the intended end users concerning desired variables to be displayed and their mode of representation (such as graph, bar chart, table) to ensure the application of the outputs for various audiences.

**Figure 12.6 Climate impacts on population**

The data set mainly provided impacts on physical factors, such as population (for example, affected, missing, dead) and the amount of agricultural land and cattle affected or lost as a result of an event. Information on the economic value of particular events was either not available or provided on an aggregate level. Aggregate information of impacts allows the estimation of impacts compared to GDP but does not provide information on the economic sectors in which the damage was caused. Consequently, post-disaster assessment of damage by sector (and actor), such as conducted after cyclone Eline in Mozambique in 2000 are needed.

**Assessment of impacts by sector**

In addition to the number of people affected by adverse climate events, information on physical impacts on infrastructure and capital are needed. Floods have detrimental impacts on roads, real estate, power distribution and mobility, and information on the loss of physical variables is very scarce or not available at all. The assessment of changes in different capital stocks is crucial if the full range of impacts are to be assessed, since replacement or rebuilding requires additional capital investment and stimulates economic activity.

**Positive spillover effects from adverse climate events**

Next to information on the physical (and economic) impacts of adverse weather events, information on potential positive impacts would benefit the analysis. While floods destroy land and capital, they can potentially contribute to increasing agricultural land fertility and hence productivity in subsequent years. The assessment of the potentially positive impacts of adverse weather events would add an additional perspective to the disaster risk reduction assessment of adverse weather.
Socioeconomic benefits of climate information services across sectors

Increased share of agriculture in GDP

The current set-up of the model assumes that agriculture has a 5–7 per cent share in the total GDP of Mauritius. The sensitivity scenario increases the value of damage to agriculture to 50 per cent in a country where agricultural production is assumed to make up a large share of GDP. A tenfold increase in the value added per ton of agricultural produce is assumed. The change in value added per ton affects the calculation of lost agricultural production, which implies that no GDP impacts are assumed. To capture the implications on real GDP, the model would need to be recalibrated, which is beyond the scope of this sensitivity analysis.

Figure 12.7 shows the cumulative economic value of lost agricultural production and the total cumulative impacts of climate events. The increase in value added per ton of agricultural produce increases the cumulative economic value of lost agricultural production from MUR 1.45 billion to MUR 14.5 billion in 2050. The increase in value added from agricultural production increases the total cumulative impacts of adverse climate events by 5 per cent.1

Value of infrastructure damage – road network

The value of damage to roads in countries with high infrastructure needs needs to be increased. The cost per kilometre of roads is currently assumed to be roughly $300,000, which is quite low compared to international averages for paved roads. For the sensitivity scenario, the costs per kilometre of road will be increased by a factor of four, to approximately $1.2 million per kilometre.

The results for cumulative additional costs for road construction and total cumulative impacts from adverse weather are shown in . The increase in costs per kilometre of road increases the cumulative additional costs for rebuilding roads from MUR 13.2 billion to MUR 52.8 billion in 2050.

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1 Losses from agriculture are captured through the loss in capital. This sensitivity scenario thus addresses losses related to reductions in value added from agricultural output.
Cumulative additional cost for re-establishing the road network

The increase in additional costs for maintaining the road network increases the total cumulative impacts of adverse climate events by 15 per cent.

Figure 12.8 Sensitivity scenario – roads
Quantitative results (model results)

The climate information services socioeconomic benefits model determines the socioeconomic benefits of climate information services between 2020 and 2050. The following four scenarios serve for the quantitative assessment of those benefits:

1. The no climate scenario
   …assumes no climate impacts and no investments, and hence represents the current state of macroeconomic planning models.

2. The reference (or baseline) scenario
   …assumes 0 per cent coverage throughout the simulation, which implies no anticipation of climate events and hence 100 per cent of damage.

3. The business-as-usual (BAU) scenario
   …assumes 30 per cent coverage throughout the simulation, which translates as an intervention effectiveness of 12 per cent. This means that only 88 per cent of the damage occurs.

4. The climate information services investment scenario assumes an increase in climate information service coverage from 30 per cent to 95 per cent between 2020 and 2030, and a further increase from 95 per cent to 100 per cent between 2030 and 2040. This translates as an intervention effectiveness of 68 per cent and 74.5 per cent by 2030 and 2040, respectively, which implies that 74.5 per cent of damage can be avoided by 2040.

The no climate scenario does not consider climate impacts and serves for the assessment of climate impacts on various sectors, since, if climate change is not considered, the projected results will be higher (such as GDP). The reference scenario, or business-as-usual scenario, provides the full impact of climate events and provides a baseline for the assessment of the socioeconomic benefits of climate information services. As there are already climate information services in the business-as-usual scenario, there will be savings in that case. Given that the application of climate information services is beneficial for disaster risk reduction and the abatement of climate change-related damage to various sectors, the climate information service investment scenario with full coverage is simulated to assess the full range of potential socioeconomic benefits that could be obtained through such services.

Table 12.1 provides an overview of the assessment of the socioeconomic benefits of climate information services in the current model. It summarizes the total impacts, avoided impacts, investments and the total socioeconomic benefits generated by the respective investment over its lifetime (30 years assumed). The no climate information services scenario serves as a baseline that shows total damage if no climate information services are provided. More detailed results on impacts by sector are provided at the end of this section.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total impacts (millions of US dollars)</th>
<th>Total SEBs (millions of US dollars)</th>
<th>Total investment (millions of US dollars)</th>
<th>Cost-benefit ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference (0 per cent climate information service coverage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 Climate impacts in the no climate information service scenario will always be the strongest (12 per cent higher than in the climate scenario), while the behaviour will be comparable to the climate scenario. Illustrations in this section therefore only contain graphs on the climate scenario and the climate information service investment scenario.
Socioeconomic Benefits of Climate Information Services for Disaster Risk Reduction in Africa

<table>
<thead>
<tr>
<th>Full climate impacts</th>
<th>9 160.55</th>
<th>-</th>
<th>-</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-as-usual (30 per cent climate information service coverage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impacts climate</td>
<td>8 159.32</td>
<td>1 001.23</td>
<td>208.31</td>
<td>4.81</td>
</tr>
<tr>
<td>Climate information service investment (100 per cent coverage by 2035)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIS investment</td>
<td>3027.19</td>
<td>6133.36</td>
<td>845.14</td>
<td>7.26</td>
</tr>
</tbody>
</table>

The following sections provide an overview on the three simulated scenarios.

1.1 Parameterization of precipitation

The parameter for annual rainfall uses seasonality and a baseline medium- to longer-term trend. In figure 12.9, the left-hand graph illustrates precipitation in 1980 to highlight assumptions on seasonality, while the graph on the right shows precipitation in the baseline scenario over the full range of the simulation (1980–2050).

**Figure 12.9 Seasonal precipitation and precipitation**

Capturing seasonality in precipitation is necessary to understand the dynamics, first, of the sectors that are dependent on rain, and, second, the probability of adverse weather events (such as floods and droughts). As an example, the agricultural sector is heavily dependent on rainfall for growing crops, which implies that changes in the amount of seasonal rainfall or a shift in the rainy season can have detrimental consequences for production, especially if farmers are unprepared for them.

**Climate information services coverage**

Figure 12.10 illustrates the development of climate information service coverage and disaster risk reduction intervention effectiveness in the business-as-usual and climate information service investment scenarios. The business-as-usual scenario assumes a continuation of historical trends, which implies a constant share of climate information service coverage throughout the simulation and hence a disaster risk reduction intervention effectiveness of 12 per cent. The climate information service investment scenario assumes an increase in information service coverage from 30 per cent to 100 per cent between 2020 and 2040, which simultaneously increases the effectiveness of disaster risk reduction interventions from 12 per cent to 75 per cent during the same period.
Climate information service coverage is used to determine the effectiveness of disaster risk reduction interventions that result from the generation of socioeconomic benefits by those services throughout the simulation. The successful planning and implementation of disaster risk reduction interventions contribute to abating climate-related damage and generating added benefits, as illustrated in the subsequent paragraphs.

**Extreme events: frequency**

The frequency and magnitude of events is assumed to remain constant. As illustrated in Figure 12.11, minor flood and drought events happen every other year, with an underlying frequency of two to three major events, both flood and drought, per decade. This represents a continuation of the average historical trend that was obtained from the data and described in section 11.3.

**Impact of floods and drought on land (magnitude)**

The impact of floods and drought in the business-as-usual scenario follows the historical trends described earlier, based on the assumption that climate information service coverage remains constant. Figure 12.12 illustrates the development of the share of agricultural land affected by floods and droughts respectively in the business-as-usual and climate information service investment scenarios. As a result of an increase in disaster risk reduction intervention effectiveness through investments in climate information service coverage, both shares start to decrease from 2020 onward.
The annual and cumulative amounts of agricultural land for the business-as-usual and climate information service investment scenarios are shown in figure 12.13. Investments in climate information services increase service coverage and therefore disaster risk reduction intervention effectiveness. As a result, the negative annual impacts of adverse weather events on agricultural land decrease with investments in climate information services, as illustrated in Figure 12.10. The model increase of climate information service coverage contributes to a significant reduction in the amount of agricultural land affected and to a 583,800-hectare reduction in the cumulative amount of agricultural land affected by adverse climate events between 2020 and 2050.

Total agricultural production and cumulative agricultural production for the no climate, business-as-usual and climate information service investment scenarios are illustrated in figure 12.14. In the climate information service investment scenario, total agricultural production becomes more resilient to climate events as a result of increasing disaster risk reduction intervention effectiveness. The increase in resilience is indicated through the reduction in the observed dips in the total agricultural production rate. The cumulative loss of agricultural production between 2020 and 2050 is 2.7 million and 1.4 million tons for the business-as-usual and climate information service investment scenarios, respectively. The respective losses are equivalent to 2.5 per cent and 1.3 per cent of cumulative agricultural production in the no climate scenario.
Impact of floods and drought on GDP

Both the climate and the climate information service scenarios show a lower economic performance than the no climate scenario. Compared to the baseline, total real GDP in 2050 is 3.5 per cent and 2.25 per cent lower for the business-as-usual and climate information service investment scenarios, respectively. By 2050, the cumulative difference between the no climate and business-as-usual scenarios totals MUR 348.2 billion, while the difference between the no climate and climate information service investment scenarios is MUR 252.5 billion. The development of total real GDP and cumulative GDP are shown in figure 12.15.

The difference in annual real GDP translates into a cumulative total reduction of $10.82 billion and $7.85 billion for the business-as-usual and climate information service investment scenarios, respectively, or an average annual reduction of $360.7 million and $261.6 million between 2020 and 2050. During that period, the reductions in GDP represent an average of 7.46 per cent of GDP in the business-as-usual scenario and 5.41 per cent of GDP in the climate information service investment scenario, which indicates that investments in climate information services can potentially contribute up to 2 per cent to GDP growth.

Population affected

Figure 12.16 compares the annual and cumulative number of people affected by adverse climate events in the no climate, business-as-usual and climate information service investment scenario between 1980 and 2050. Investments in climate information services after 2020 lead to an increased disaster risk.
reduction intervention effectiveness, which reduces the share of people affected by 69 per cent by 2030 and up to 75 per cent from 2045 forward. Cumulatively, investments in increasing climate information services coverage in the information services investment scenario reduce the number of people affected between 2030 and 2050 by almost 2.74 million.

**Figure 12.16** Total affected population and cumulative population affected in all scenarios, 1980–2050

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**Economic assessment of climate-related impacts**

This section provides an overview of the cumulative climate-related impacts in the reference, business-as-usual and climate information service investment scenarios. The reference scenario is used here to assess the contribution of current climate information service practices in the business-as-usual scenario.

Figure 12.17 illustrates the cumulative economic value of lost agricultural production and losses of livestock between 2020 and 2050 for all three scenarios. The results indicate that added benefits generated by current climate information service practices in the business-as-usual scenario total approximately MUR 159.5 million, or $4.95 million. Additional investments in information service coverage, as assumed in the climate information service investment scenario, generate added benefits of MUR 884 million, or $27.5 million, in addition to the savings achieved in the business-as-usual scenario.3

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3 These results are based on the economic structure of Mauritius, where agriculture accounts for between 5 and 7 per cent of total GDP. For economies in which it accounts for 40 to 50 per cent of GDP, this value can increase significantly (by up to a factor of 10, depending on value added per unit of output).
Climate information service coverage determines the success of disaster risk reduction interventions and ultimately the number of people in need of additional medical assistance as a consequence of suffering hardship from adverse climate events. The more people affected, the more extraordinary spending on health care is required to avert the crisis. Figure 12.18 illustrates the additional health care expenditure resulting from the impact of adverse climate events on human health. The current climate information services practices in the business-as-usual scenario contribute to a reduction of MUR 365 million, or $11.35 million, in cumulative health care expenditure between 2020 and 2050, compared to the reference scenario. The results indicate that an increase in climate information service coverage could generate savings of MUR 1.67 billion ($51.76 million), in addition to the savings achieved in the business-as-usual scenario. Comparing cumulative extra health care to cumulative population affected yields $90 per person over 30 years in additional health care expenditure, which is equivalent to $3 per person per year on a levelized basis.

In addition to added benefits from agricultural production and avoided costs in the health care sector, an increase in climate information services as assumed in the climate information service investment scenario generates significant benefits from avoiding damage to roads and capital. Climate information service practices in the business-as-usual scenario cumulatively avoid MUR 31.7 billion in damage to roads and capital between 2020 and 2050, equivalent to roughly $985 million. The results of the climate information services investment scenario indicate that, compared to business-as-usual, an additional MUR 162.8 billion ($5.05 billion) in damage to roads and capital can be avoided during the same period.
The development of cumulative losses from capital and cumulative additional costs for road construction for all three scenarios are shown in figure 12.19.

**Figure 12.19 Cumulative climate impacts on roads and capital, 2020–2050**

Economic analysis

This section first provides an overview of total climate-related impacts by sector for the reference, business-as-usual and climate information services investment scenario, and then presents the benefits of climate information service coverage and disaster risk reduction intervention effectiveness.

Table 12.2 presents the cumulative economic impacts of adverse weather events by sector between 2020 and 2050 for each of the scenarios. The values indicated for the reference scenario assume that there is no climate information service coverage, which is not representative of current practices, but useful for benchmarking the performance of current practices to their potential. In the reference scenario, cumulative economic impacts total $9.16 billion, while cumulative impacts in the business-as-usual and climate information services investment scenario total $8.16 billion and $3.03 billion, respectively. In all scenarios, the largest portion of damage stems from loss of capital, such as sown area, equipment, buildings, and other productive assets.
Table 12.2 Climate-related impacts between 2020 and 2050, by sector and scenario

<table>
<thead>
<tr>
<th>Sector</th>
<th>Costs of adverse weather by scenario and sector</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference BAU</td>
<td>BAU</td>
<td>Per cent of reference</td>
<td>CIS investment</td>
<td>Per cent of reference</td>
</tr>
<tr>
<td></td>
<td>($ million)</td>
<td>($ million)</td>
<td></td>
<td>($ million)</td>
<td></td>
</tr>
<tr>
<td>Roads</td>
<td>465.6</td>
<td>410.3</td>
<td>-11.88</td>
<td>166.1</td>
<td>-64.33</td>
</tr>
<tr>
<td>Health care</td>
<td>94.8</td>
<td>83.4</td>
<td>-11.98</td>
<td>31.7</td>
<td>-66.58</td>
</tr>
<tr>
<td>Total agriculture</td>
<td>54.8</td>
<td>49.8</td>
<td>-9.05</td>
<td>22.3</td>
<td>-59.21</td>
</tr>
<tr>
<td>Livestock</td>
<td>5.3</td>
<td>4.7</td>
<td>-11.45</td>
<td>2.2</td>
<td>-58.91</td>
</tr>
<tr>
<td>Agricultural production</td>
<td>49.5</td>
<td>45.2</td>
<td>-8.79</td>
<td>20.2</td>
<td>-59.25</td>
</tr>
<tr>
<td>Capital</td>
<td>8 545.3</td>
<td>7 615.8</td>
<td>-10.88</td>
<td>2 807.1</td>
<td>-67.15</td>
</tr>
<tr>
<td>Total</td>
<td>9 160.5</td>
<td>8 159.3</td>
<td>-10.93</td>
<td>3 027.2</td>
<td>-66.95</td>
</tr>
</tbody>
</table>

Table 12.3 provides an overview of the socioeconomic benefits generated by climate information services in the business-as-usual and climate information service investment scenarios. The column “BAU to reference” summarizes the net benefits generated through climate information services in the business-as-usual scenario, when compared to the reference. The next column, “Added benefits of CIS investment”, provides information on the socioeconomic benefits achieved in addition to those generated in the business-as-usual scenario. “Total SEBs” represents the sum of socioeconomic benefits generated by climate information services in both the business-as-usual and the climate information services investment scenarios.

The difference in impacts between the reference and the business-as-usual scenarios can be regarded as the socioeconomic benefits of climate information services in the latter scenario. In the business-as-usual scenario, climate information services contribute to reducing climate-related impacts by roughly $1 billion between 2020 and 2050. Assuming an annual investment of 0.1 per cent of GDP, investment costs total $211.3 million for the same period. This implies that the socioeconomic benefits of the climate information services model generates a benefit-cost ratio of 4.74 for the business-as-usual scenario, indicating that investments yield more than four times their value in avoided damage and added benefits.

Table 12.3 Added benefits by scenario and sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>BAU to reference</th>
<th>Added benefits of CIS investment</th>
<th>Total SEBs</th>
<th>Total investment (in BAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>55.3</td>
<td>244.2</td>
<td>299.5</td>
<td></td>
</tr>
<tr>
<td>Health care</td>
<td>11.4</td>
<td>51.8</td>
<td>63.1</td>
<td></td>
</tr>
<tr>
<td>Total agriculture</td>
<td>5.0</td>
<td>27.5</td>
<td>32.4</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td>0.6</td>
<td>2.5</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Agricultural production</td>
<td>4.4</td>
<td>25.0</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>929.6</td>
<td>4 808.7</td>
<td>5 738.3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1 001.2</td>
<td>5 132.1</td>
<td>6 133.4</td>
<td>211.3</td>
</tr>
</tbody>
</table>

The results indicate that an increase in climate information service coverage as proposed in the climate information service investment scenario could potentially add a total of $5.13 billion to the $1 billion in benefits generated in the business-as-usual scenario by 2050. Assuming that business-as-usual investment would quadruple, assuming a fraction of 0.4 per cent of GDP, then the benefits generated in
addition to the business-as-usual scenario yield a benefit-cost ratio of 6.07, which is almost three times higher than the benefit-cost ratio of climate information services in the business-as-usual scenario.

The socioeconomic benefits of climate information services have been shown to have great potential for weather- and climate-sensitive sectors. The benefit-cost ratios are consistent with those in the literature. It has been demonstrated that when there is a fully functioning climate information service, its utilization typically achieves a twofold to fourfold return on investment. The socioeconomic benefit findings serve as a means to prepare disaster risk adaptation strategies or to expand existing national and sectoral policies and strategies. The study has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to decrease the economic vulnerability of countries to hydro-meteorological risks.

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4 The calculation assumes $5.132 billion in added benefits through investments in climate information service coverage, assuming that investment doubles ($211.3 \times 2 = 422.6$), which yields: $5,132 \text{ million} / 845.12 \text{ million} = 12.14$. 
13. Main outcomes of the workshop on analysing and validating the socioeconomic benefits of weather and climate information services for disaster risk reduction in Africa

As part of the study, a Workshop on Analysing and Validating the Socioeconomic Benefits of Weather and Climate Information Services for Disaster Risk Reduction in Africa was held in Addis Ababa, on 20 and 21 March 2018. The workshop was attended by disaster risk reduction and climate scientists and producers from sub-Saharan Africa. After providing the workshop with the rationale of the socioeconomic benefit models based on a system dynamics approach, the socioeconomic benefits of climate information systems for disaster risk reduction model was demonstrated. The workshop endorsed the study on the socioeconomic benefits of climate information systems for disaster risk reduction and other applications. In particular, it noted the following as among the main outcomes of the workshop:

(1). The "Proof of the Concept" was fully endorsed by the participants as a significant tool to assist all stakeholders.

(2). There was a need to engage subregional national authorities in charge of relevant data depositories in order to access updated data, including data and mapping on vulnerability and exposure demographics.

(3). Training was needed for specific sector professionals at the subregional and national levels.

(4). Projects should seek partnerships with research institutions and universities and regional climate centres in order to refine the socioeconomic benefits of climate information services models.

(5). Pilot studies needed to be carried out at subregional levels across sub-Saharan Africa.

(6). The study results should assist in the investment in climate information services for socioeconomic benefits.
14. Conclusion and recommendations

The findings of the study provide a means of preparing better disaster risk reduction strategies or to expand existing national and sectoral policies and strategies when proper investments are made. It has laid the groundwork for discussions and analysis of the effectiveness and viability of various measures to decrease the economic vulnerability of countries to hydro-meteorological risks. Seasonal climate predictions with long lead times enable decision-makers and communities in general to protect property and infrastructure. For example, reservoir operators can reduce water gradually to accommodate incoming floodwaters. Early warning can also provide information on the occurrence of a public health hazard and enable a more efficient response to seasonal drought and food insecurity. Effective systems, therefore, require a combination of government leadership and multiagency coordination to ensure effective responses based on pre-agreed operating procedures and community participation (Rogers and Tsirkunov, 2013).

The study has demonstrated the immeasurable benefits for preparedness efforts of the socioeconomic benefits of climate information systems. Seasonal forecasts can also be used to secure emergency funding. It has been conservatively estimated that upgrading all hydro-meteorological information production and early-warning capacity in developing countries would save an average of 23,000 lives annually and provide between $3 billion and $30 billion per year in additional economic benefits for disaster reduction (Hallegatte, 2012). National meteorological and hydrological services are a small but important public sector, with budgets that average about 0.01–0.05 per cent of national GDP (Hallegatte, 2012). Consistent with the findings of the current study, assessments elsewhere show high economic returns from better meteorological and hydrological services, with cost-benefit ratios of 1:4–1:6 (Tsirkunov and others 2007). Appropriate investment in climate information services is therefore needed in order to have the capacity necessary to reduce disasters triggered by hydro-meteorological hazards. It is important to note that countries in Africa also have challenges in the development of data sets of fatalities and economic losses due to disaster. Appropriate policies clearly need to be drawn up.
The following recommendations, among other things, are deemed necessary for the purposes of achieving the goal of maximizing the socioeconomic benefits of climate information services for disaster risk reduction:

(1). Set baselines and metrics and determine progress on expected disaster fatalities and expected economic losses with appropriate disaster risk reduction policies that can be tracked through procedures such as identifying the percentage of the population living or working in buildings of moderate and high susceptibility to collapse in high-hazard zones. This includes mapping vulnerability, exposure and risks at the subregional and national levels.

(2). Establish or strengthen partnerships with academia and civil society for further development of tailor-made products.

(3). Carry out pilot studies of the socioeconomic benefits of climate information services for disaster risk reduction at the subregional and national levels.

(4). Develop a clear and measurable definition of each indicator to be collected. The definition of each indicator (for example, the number of people in an area covered by an effective action plan) needs to be both precise and simple so that all countries are able to follow and adhere to the same global norms.

(5). Develop a transparent methodology for calculation or compilation of the indicator. Rigorous methods that describe the calculation of expected economic and human losses should be tested and set out in guidelines to help national and regional bodies compile this information. The guidelines must be workable in all the different resource and capability scenarios.

(6). Ensure the validity and independent quality of data. Every effort should be made to ensure the accuracy of the data collected and the sustainability of the collection procedures. A transparent data validation method is also needed. Key at-risk cities should be prioritized for data collection and validation.

(7). Identify incentives that may constitute tipping-points for behavioural change towards prospective disaster risk management and risk-sensitive choices at a significant scale, thereby increasing the political, social and economic saliency of disaster risk management.

(8). Following validation of the model, conduct a series of hands-on training sessions on economic assessments of weather and climate forecast and their application to decision-making in different sectors by the user community, regional climate centres and national meteorological or hydrological services. This should lead to the formulation of appropriate policies to establish a community of practitioners on the economic utility of weather and climate forecasts in Africa.


16. Annex

16.1. Theory of system dynamics

Modelling and simulation

Mathematically, the basic structure of a formal system dynamics computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations,

$$\frac{dx(t)}{dt} = f(x, p)$$

where $x$ is a vector of levels (stocks or state variables), $p$ is a set of parameters, and $f$ is a nonlinear vector-valued function.

Simulation of such systems is easily accomplished by partitioning simulated time into discrete intervals of length $dt$ and stepping the system through time one $dt$ at a time. Each state variable is computed from its previous value and its net rate of change $x'(t): x(t) = x(t-dt) + dt \cdot x'(t-dt)$. In the earliest simulation language in the field (DYNAMO) this equation was written with time scripts $K$ (the current moment), $J$ (the previous moment), and $JK$ (the interval between time $J$ and $K$): $x, K = x, J + DT \cdot XRATE.JK$ (see, for example, Richardson and Pugh, 1981). The computation interval $dt$ is selected small enough to have no discernible effect on the patterns of dynamic behaviour exhibited by the model. In more recent simulation environments, more sophisticated integration schemes are available (although the equation written by the user may look like this simple Euler integration scheme), and time scripts may not be in evidence. Important current simulation environments include Vensim (Ventana Systems, http://www.vensim.com), STELLA and iThink (isee Systems, http://www.iseesystems.com), PowerSim (http://www.powersim.com), and AnyLogic North America, LLC. (AnyLogic, http://www.anylogic.com/).

Forrester’s original work stressed a continuous approach, but increasingly modern applications of system dynamics contain a mix of discrete difference equations and continuous differential or integral equations. Some practitioners associated with the field of system dynamics work on the mathematics of such structures, including the theory and mechanics of computer simulation, analysis and simplification of dynamic systems, policy optimization, dynamical systems theory, and complex nonlinear dynamics and deterministic chaos.

The main applied work in the field, however, focuses on understanding the dynamics of complex systems for the purpose of policy analysis and design. The conceptual tools and concepts of the field — including feedback thinking, stocks and flows, the concept of feedback loop dominance, and an endogenous point of view — are as important to the field as its simulation methods.

Feedback thinking

Conceptually, the feedback concept is at the heart of the system dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualizing the structure of a complex system and for communicating model-based insights. Intuitively, a feedback loop exists when information resulting from some action travels through a system and eventually returns in some form to its point of
15. References


origin, potentially influencing future action. If the tendency in the loop is to reinforce the initial action, the loop is called a positive or reinforcing feedback loop; if the tendency is to oppose the initial action, the loop is called a negative or balancing feedback loop.

The sign of the loop is called its polarity.Balancing loops can be variously characterized as goal-seeking, equilibrating, or stabilizing processes. They can sometimes generate oscillations, as when a pendulum seeking its equilibrium goal gathers momentum and overshoots it. Reinforcing loops are sources of growth or accelerating collapse; they are disequilibrating and destabilizing. Combined, reinforcing and balancing circular causal feedback processes can generate all manner of dynamic patterns.

**Loop dominance and nonlinearity**

The loop concept underlying feedback and circular causality by itself is not enough, however. The explanatory power and insightfulness of feedback understandings also rest on the notions of active structure and loop dominance. Complex systems change over time. A crucial requirement for a powerful view of a dynamic system is the ability of a mental or formal model to change the strengths of influences as conditions change, that is to say, the ability to shift active or dominant structure.

In a system of equations, this ability to shift loop dominance comes about endogenously from nonlinearities in the system. For example, the S-shaped dynamic behaviour of the classic logistic growth model \( \frac{dP}{dt} = aP - bP^2 \) can be seen as the consequence of a shift in loop dominance from a positive, self-reinforcing feedback loop \((aP)\) producing exponential-like growth to a negative balancing feedback loop \((-bP^2)\) that brings the system to its eventual goal. Only nonlinear models can endogenously alter their active or dominant structure and shift loop dominance. From a feedback perspective, the ability of nonlinearities to generate shifts in loop dominance and capture the shifting nature of reality is the fundamental reason for advocating nonlinear models of social system behaviour.

**The endogenous point of view**

The concept of endogenous change is fundamental to the system dynamics approach. It dictates aspects of model formulation: exogenous disturbances are seen at most as triggers of system behaviour (like displacing a pendulum); the causes are contained within the structure of the system itself (like the interaction of a pendulum’s position and momentum that produces oscillations). Corrective responses are also not modelled as functions of time, but are dependent on conditions within the system. Time by itself is not seen as a cause.

But more importantly, theory building, and policy analysis are significantly affected by this endogenous perspective. Taking an endogenous view exposes the natural compensating tendencies in social systems that conspire to defeat many policy initiatives. Feedback and circular causality are delayed, devious, and deceptive. For understanding, system dynamics practitioners strive for an endogenous point of view. The effort is to uncover the sources of system behaviour that exist within the structure of the system itself.

**System structure**

These ideas are captured in Forrester’s (1969) organizing framework for system structure:

- Closed boundary
Feedback loops

- Levels
- Rates
  - Goal
  - Observed condition
  - Discrepancy
  - Desired action

The closed boundary signals the endogenous point of view. The word closed here does not refer to open and closed systems in the general system sense, but rather refers to the effort to view a system as causally closed. The modeller’s goal is to assemble a formal structure that can, by itself, without exogenous explanations, reproduce the essential characteristics of a dynamic problem.

The causally closed system boundary at the head of this organizing framework identifies the endogenous point of view as the feedback view pressed to an extreme. Feedback thinking can be seen as a consequence of the effort to capture dynamics within a closed causal boundary. Without causal loops, all variables must trace the sources of their variation ultimately outside a system. Assuming instead that the causes of all significant behaviour in the system are contained within some closed causal boundary forces causal influences to feedback upon themselves, forming causal loops. Feedback loops enable the endogenous point of view and give it structure.

Levels and rates

Stocks (levels) and the flows (rates) that affect them are essential components of system structure. A map of causal influences and feedback loops is not enough to determine the dynamic behaviour of a system. A constant inflow yields a linearly rising stock; a linearly rising inflow yields a stock rising along a parabolic path, and so on. Stocks (accumulations, state variables) are the memory of a dynamic system and are the sources of its disequilibrium and dynamic behaviour.

Forrester (1961) placed the operating policies of a system among its rates (flows), many of which assume the classic structure of a balancing feedback loop striving to take action to reduce the discrepancy between the observed condition of the system and a goal. The simplest such rate structure results in an equation of the form NETFLOW = (GOAL – STOCK)/(ADJTIM), where ADJTIM is the time over which the level adjusts to reach the goal.

Behaviour is a consequence of system structure

The importance of levels and rates appears most clearly when one takes a continuous view of structure and dynamics. Although a discrete view, focusing on separate events and decisions, is entirely compatible with an endogenous feedback perspective, the system dynamics approach emphasizes a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them. Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behaviour. It is that underlying tide of policy structure and continuous behaviour that is the system dynamicist’s focus.
There is thus a distancing inherent in the system dynamics approach — not so close as to be confused by discrete decisions and myriad operational details, but not so far away as to miss the critical elements of policy structure and behaviour. Events are deliberately blurred into dynamic behaviour. Decisions are deliberately blurred into perceived policy structures. Insights into the connections between system structure and dynamic behaviour, which are the goal of the system dynamics approach, come from this particular distance of perspective.

The system dynamics approach involves:

1. Defining problems dynamically, in terms of graphs over time.
2. Striving for an endogenous, behavioural view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
3. Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.
4. Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
5. Formulating a behavioural model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
6. Deriving understandings and applicable policy insights from the resulting model.
7. Implementing changes resulting from model-based understandings and insights.