The nature of risks, a conceptual approach

CIMDEN

The Center for Research and Mitigation of Natural Disasters, -CIMDEN-, is a technical and scientific organization dedicated to the study of the problems associated with natural disasters. It focuses on the systematization of the causes that lead to such disasters to propose and implement measures that reduce the impact of such disasters in urban and rural societies of Central America.

Recognizing the need to provide a conceptual contribution for the understanding of the causes of disasters, this magazine presents the most relevant aspects regarding risk management, which is the most modern concept regarding the topic of natural disaster reduction.

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Cover: old kiosk of the El Palmar community, on the outskirts of the Santiaguito volcano in the Retalhuleu department, which was devastated by lahars in 1,984.

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Center of Investigation and Mitigation of Natural Disasters
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CHAPTER I: INTRODUCTION

Nature has played an crucial role in Central America. This region is a cradle to diverse geological phenomena since it was born from the processes that result as a consequence of tectonic-plate dynamics. Active volcanoes in different nations of the region are examples that illustrate that such processes continue to exist, and that Central America’s geological history is written on a day to day basis. The rivers that have transported volcanic sediments for thousands of years to create fertile lands on the coastal plains illustrate year by year nature’s potential to regenerate lands, modify river beds, and renew soils with nutrients from mountains and hills.

The history of Central America includes political, social, cultural, and economic processes, but these do not escape the fate of nature. The different natural events that have helped to generate the geography that we know today, have manifested themselves in multiple occasions to demonstrate us that we are vulnerable, that we do not understand our surroundings in an adequate way, and that we have not been able to adapt to reduce the impact of such events.

Throughout the last century, factors such as population growth, migration from rural to urban areas, and the lack of options for the improvement of the quality of life that characterize Central America have allowed the generation of special conditions that make communities vulnerable to natural phenomena. Human settlements in ravines, villages near river beds, and in zones closer to active volcanic cones indicate that we are defying nature, that we are reducing its domain. The more frequent natural disasters are an indication that we must recognize that we live in a dynamic world, full of natural phenomena and that we must learn to respect nature.

In a parallel way, the inadequate use of soils, excessive deforestation, and environmental pollution are social processes which are favoring the conditions for greater disasters.

Photo 1.1: A massive landslide in the region of Chalatenango, in El Salvador. It was originated in 1934 as a result of a strong storm.

However, due to the fact that we do not fully understand nature’s behavior in an adequate way, and due to the fact that many events are not frequent or predictable, we have embarked on a way of life in which we leave behind the need to understand such phenomena in an attempt to live or survive.

In another context, rising poverty conditions on the isthmus force the population to survive in more hazardous areas. The creation of urban settlements in high hazard areas,
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rejected in the past by local people due to their historic knowledge, becomes now in a process known as risk-generation that ends in a product called disaster.

In retrospect to such circumstances it is necessary to stop for a moment; analyze the situation; understand the dimension of the social evolution in which we are embarked, and correct it’s heading. The presence of disasters of the magnitude as those caused by recent earthquakes, hurricane Mitch, and by other natural phenomena must be understood in simple terms:

1. Infrastructure of almost any kind has been constructed in many areas without identifying existing natural hazards.

2. Infrastructure has been constructed without proper building codes or norms using non-adequate construction materials in regards to the surrounding environment.

3. The environment has been modified in a way in which it has become a social-natural hazard.

These three factors have generated the ideal conditions for disasters to occur, not as natural events, but as social events triggered by natural phenomena.

Photo #1.2: A two-floor house constructed in a non-adequate area collapsed because it was constructed on a low-weight resistance soil.

We must understand the relationship between demands associated with social growth and the intrinsic conditions of the geographical terrain in which we live; learn how to adapt to the reality of such events that manifest themselves frequently, and to adapt ourselves to those events that do not display a specific period of return. We must use social memory, history, and recognize that our ancestors learned how to live with nature, respecting it, providing it with the margin of security it requires so it does not harm us in it’s evolution process.

This document intends to illustrate the root-causes of disasters and a way to understand and model them through the social knitting we have created along various centuries. The understanding of natural phenomena along with the social knitting will allow us to look for social solutions and techniques for the challenges that nature imposes on us in our changing territory.

This document is conceived with the idea of providing the reader with a conceptual understanding that disasters should be conceived as products of social and natural processes which are combined to generate them. In this contexts, risks are conformed in terms of three components: hazards, vulnerabilities, and deficiencies in preparedness. Each component is analyzed in a detailed way for the reader to get a broader idea of such a component and the role which is plays in relation to natural disasters.
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Through the quantification of risk a strategic plan can be developed to reduce it within a regional or national context. The capacity to dimension the magnitude of the risk and its composition will allow authorities and institutions to conform multidisciplinary teams and resources to reduce the risks to acceptable levels. In addition, the text has been accompanied with illustrative photographs to promote a clearer understanding of the concepts that the topic of risk focuses on.

Some notes regarding exemplary measures associated with risk management have been included in the final chapters. However, the subject of risk management is still very new. In this respect, this document is a starting point in the discussion, with the goal of promoting a conceptual and applied discussion that will help concrete strategies and methods for its implementation.
CHAPTER II:
GENERAL CONCEPTS

When studying the history of Central American nations we discover an enormous number of events associated with natural phenomena that have provoked from minor to enormous material and human losses throughout centuries. Generally the damages span from a few households to entire communities or some countries simultaneously.

With the declaration of the International Decade for Natural Disaster Reduction, IDNDR on behalf of the United Nations, a more systemic process related to disaster research began to take place, which included subjects like the study of natural phenomena that cause disasters; the socioeconomic conditions that make communities more or less prone to be affected by such phenomena, and the relationships that exist between natural phenomena and such conditions.

Under the umbrella of the IDNDR, groups of researchers in natural and social sciences have combined strengths to model disasters. These groups have defined what is known as the cycle of disasters and have generated a series of models that allow entities and institutions dedicated to civil protection or civil defense to visualize and begin projects and programs destined to reduce the impact of natural phenomena.

We understand a natural disaster [1] as the combination of economical, social, technological damages, and problems that are caused by a natural event of a great intensity. In this way, the natural disaster it is directly associated with the society and a separation is made between the natural event and the problems generated by such an event within the social realm.

The definition of disasters conceived in this fashion allows one to focus on development processes which many societies of the world go through, societies which are affected by natural disasters as well as anthropogenic ones. Once a disaster is understood in this way, we speak of risk as a process that precedes a disaster, and it is said that a community is at risk when it is prone to a disaster.

The impact of an event can be manifested in many sectors of the society in parallel: infrastructure, health, life lines, commerce, education, communications, etc. The magnitude of the impact must be evaluated in a temporal level as well as in monetary, social, and economic terms. It is necessary to create a reference frame that may allow the description of a event and its impacts, which will serve sociologists, economists, health and education professionals, and the government to evaluate such impacts in a systemic way.

A simple way to represent the evolution of a society along some parameter or development indicator can be a graph that represents the behavior of the indicator as a function of time. (Raw internal product, economically active population, scholar index, etc.).
Let us consider a hypothetical example of some indicator of this kind as shown on figure 2.1. As expected, the magnitude of such an indicator rises gradually as the society evolves. Generally, a catastrophic event or phenomenon stops or reduces the level of temporal evolution of such an indicator. Assuming that the disaster takes place at Td, in such a way that at that precise time the magnitude of the indicator was Ptd, two aspects can be noted:

1. There is an interval of time which is required for the society to reach the equivalent level of development that existed before the event occurred in respect to this indicator.

2. If the development indicator has been quantified in an adequate way, it is possible to determine the difference in the magnitude of the indicator at any time after the event and its magnitude before the disaster, Ptd.

Figure 2.1: temporal evolution of a social or development parameter or indicator. The event occurs at time Td, when the magnitude of the indicator is Ptd. At t = Tr, the community reaches a state similar to the one just before the disaster in terms of this indicator.

The time interval required for the society to return to its previous level of development before the event regarding the different indicators will depend on the magnitude of such an event and the resources that the society counts on to accomplish the activities related to response, rehabilitation and, reconstruction. As expected, the temporal interval of recovery of the different indicators will vary from one to another, depending on the impact of the event in the different social and economical sectors. Next we present two hypothetical examples to illustrate this idea:

**Example A**

- **Development parameter:** child vaccination rate by month or by day.
- **Natural Phenomenon:** earthquake.

The disaster in this case is defined as the group of problems caused by the earthquake: destruction of houses, hospitals, life-lines, sudden decline of commercial activities, financial activities, etc.

The selected parameter indicates the number of children that are vaccinated by day or by month in a specific region with regards to polio and dtp. As time passes, there are more children and hence, more vaccinating campaigns become necessary (assuming that the population rises, something typical of Central America). It is clear that the number of such campaigns rises on a yearly basis, depending obviously on such factors as allocated budget, vaccine availability, number of nurses, etc.
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In reality the rate does not grow in a linear fashion as there are variations associated with the interest shown by government and health authorities in relation to child vaccination campaigns.

When an earthquake occurs, the ministry or health is forced to reorient efforts to respond to the event. In such a case, instead of vaccinating children against polio, much of the population is vaccinated against tetanus. The efforts to attend the disaster, either material, monetary, and in terms of qualified personnel, is achieved by reducing established programs which are less important at this instance.

As it is shown on figure 2.1, the impact of the event or phenomenon is manifested in two combined ways:

1. The magnitude of the variation in the parameter under study.
2. The interval of time required to re-establish the parameter level to its magnitude before the event.

Only by taking these two factors in an integrated fashion can we have a clear idea of the impact of the event in such a parameter.

<table>
<thead>
<tr>
<th>Example B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Development parameter:</strong> rate of growth of paved roads</td>
</tr>
<tr>
<td><strong>Natural Phenomenon:</strong> Earthquake</td>
</tr>
</tbody>
</table>

In this case the parameter represents an average amount of kilometers of road that are paved per year or per month. Again, it is expected that governments will gradually pave dirt roads or construct new roads and highways to interconnect cities and villages.

As in the previous case, the growth of the rate is not linear in time, since some governments can increase or decrease the rate according to the proposed development plans. A particular administration may pave many roads in a determined period of time.

When there is an earthquake, it is obvious that the government will have to shift resources from the road development program to repair those roads or bridges that suffered damages or collapsed during the earthquake. This will reduce the magnitude of the parameter “rate of growth of the paved roads” while the reconstruction and rehabilitation efforts take place.

The impact of the event spans two simultaneous contexts: the decrease or reduction in the analyzed indicator and the period of time required for the government or the society to reestablish the level of development that existed before the event.
CHAPTER III:  
NATURAL DISASTERS,  
CONCEPTUAL MODELS

Natural disasters must be understood as the combination of natural events that impact on a community or a society. To visualize this idea in a clearer way, let's consider the effects of the same phenomenon in two different regions of the world:

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>PHENOMENON</th>
<th>CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahara desert</td>
<td>Drastic drought</td>
<td>A</td>
</tr>
<tr>
<td>Central America</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>North Pole</td>
<td>Snow storm</td>
<td>A</td>
</tr>
<tr>
<td>Mexico City</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Tokelan Islands (Pacific)</td>
<td>Volcanic activity</td>
<td>A</td>
</tr>
<tr>
<td>Colombia (Nevado del Ruiz)</td>
<td></td>
<td>B</td>
</tr>
</tbody>
</table>

The geographical regions that are classified as type A do not face major consequences when the phenomenon manifests itself as an event; it would be a typical conditions for these places. In areas classified as B, the impact of the phenomenon in the social environment could be immense.

When speaking about natural disasters we refer to the natural phenomena that affect many people, causing large and grave damages to the societies. Therefore many social scientists define a disaster as a product which results from the combination of an event and pre-existing adverse social conditions, whose impact is manifested as the temporal detention or reduction of the development processes.

Setting up as a reference the instant in which the natural event that causes a disaster occurs, we can speak three time intervals: the BEFORE the disaster, the DURING, and the AFTER intervals.

Figure # 3.1: temporal scheme of disasters, including the BEFORE, DURING and AFTER intervals.

For example, the occurrence of a volcanic eruption is associated with the DURING phase. The days, months and years before the eruption are classified under the BEFORE phase, and the days and months after the eruption are classified under the AFTER phase.
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During the years or decades before the eruption, it is possible that the population growth may force a segment of the population to settle on the volcano outskirts. This generates a vulnerability condition because there is then a growing population settled on the volcano outskirts.

The conditions described in the previous paragraphs show that the population settled on the outskirts of an active volcano is at risk of being impacted by an eruption. With these ideas in mind, many authors speak of natural risks, always considering the natural phenomena and the critical pre-existing social conditions. A population, a region or a country is at risk when there exists a combination of natural factors and social conditions that make such society prone to a disaster. Several authors have defined risk in the following way [2-5]:

\[
\text{Risk} = \text{Hazard} \times \text{Vulnerability}
\]

In this relationship the hazard is linked with the natural phenomenon: an earthquake, a flood, an eruption, etc. The vulnerability is linked with critical social factors that enhance the impact associated with the natural event: poorly constructed houses, deficiencies in preparedness, coping incapacities, etc.

Under this definition, it must be conceived that a city at risk is one which has the probability of being affected or that is prone to be affected by a natural event, and which does not possess adequate measures to minimize the impact of such a phenomenon. As illustrations of these concepts, two examples will be presented:

**Example A:**
- **Place:** San Salvador, El Salvador’s capital.
- **Hazard:** An eruption caused by the San Salvador volcano, El Salvador.
- **Vulnerability:** The city and its social environment constructed on the outskirts of the volcano.

**Example B:**
- **Place:** The Port of Corinto, Nicaragua.
- **Hazard:** Tsunamis, seaquakes.
- **Vulnerability:** Houses constructed near the seashore, at only 1-meter above sea level.

San Salvador, Corinto, and many cities of the world are at risk due to the combination of hazards and vulnerabilities. To reduce the risk which many cities face, either the hazard
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or the vulnerabilities or both must be reduced. Generally, it is impossible or extremely difficult to reduce the hazard. In this case we speak of prevention measures. For example, it is still impossible to prevent an earthquake or a hurricane from taking place. Therefore land-use norms or ordinances must be established to minimize the exposure of hurricanes or earthquakes. However, in some cases as in the case of floods, dams or levees can be constructed to control the flow and thus reduce the floods caused by overflows.

In contrast, the vulnerability can be reduced implementing or adopting different measures. For example, in the case of earthquakes, adobe houses with clay-tile roofs are very vulnerable. Therefore, exchanging the clay-tile roof to a metal sheeting one can be an initial measure to reduce vulnerability. Similar measures to strengthen walls could be conceived to reduce such vulnerability as well. In this case adobe walls could be substituted by walls made out of cement-blocks with concrete columns and beams.

In the case of floods, raising the floor of houses above the maximum historical level of floods is a mitigation measure. The flood can occur, but if the floor of the houses is elevated, then the impact will be minimal or non-existent.

Recently, some authors [3,6,7] have modified the definition of risk incorporating measures destined to display pre-existing conditions that may help the community face the event with lesser consequences. In this case risk has been defined in he following way:

\[
\text{Risk} = \frac{\text{Hazard} \times \text{Vulnerability}}{\text{capacities}}
\]

In this definition, capacities focus on the group of measures that are already in place to help the community cope with the event, for example those which tend to minimize human losses caused during the event. For example, the use of emergency stairs and the use of evacuation routes previously identified can contribute to reduce the loss of human lives during an fire. Early warning systems are another example of measures of this kind, whose objective is to warn the members of communities about an imminent event that will occur in a few minutes or hours. Generally, the national civil defense or civil protection agencies of a country are the ones in charge of implementing these kinds of measures to prepare the society in a better way in case of a natural disaster.

In contrast with the previous definitions, scientists from Europe manage the concept of risk in terms of three components: Hazard, Exposure and Vulnerability. In this model, risk can be visualized as the area within a triangle, as shown on the following figure:
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Figure # 3.2: risk triangle as the conceptual framework of some European scientists. Risk can be conceived in terms of the area inside the triangle. To reduce risk, the hazard, exposure and vulnerability should be reduced.

In this case, the hazard and exposure are related to the natural phenomenon. The hazard represents the natural phenomenon in itself while the exposure reflects the geographic position of an infrastructure or the people in relation to the hazard.

For example, in the case of earthquakes, the hazard could be represented as a potential earthquake of a 6.5 intensity of on the Richter scale for a particular fault, while the exposure is represented by the geographic position of a house in relation to that same fault. In this conceptual framework, the expression of risk is presented in the following way:

\[ \text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability} \]

As it can be seen, the risk is reduced via any of its three components.

Other experts have incorporated social factors inside vulnerability, such as raw internal product indexes, level of urbanization, unsatisfied needs and others. In every case, the vulnerability reflects a great number of factors that make the society prone to suffering grave damages associated with the natural event.

Recognizing that risk should also include aspects related with deficiencies in preparedness, the author has proposed the following definition for risk:

\[ \text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Deficiencies in Preparedness} \]

In this context, the hazard represents the possibility of occurrence of a natural event of a probable magnitude or intensity that includes a specific geographic area. The vulnerability represents the proneness of the social\(^1\) texture to be affected by the natural event and the deficiencies in preparedness represent the lack of measures and tasks which could reduce the loss of human lives and property in that specific interval of time at which the

\(^1\) In this case, the term includes social structures to the population, buildings, action spaces, organizations, structures, instances, and in general all the surroundings that are created around a society.
event is taking place. This separation is done to highlight the differences between the existing vulnerabilities and those deficiencies that could enhance the loss of life during the event. As examples of these deficiencies we can mention the absence of evacuation routes, early warning systems, the lack of a community organization to manage the disasters, etc.

**THE IMPACT OF NATURAL EVENTS: EMERGENCIES AND DISASTERS**

In the context of natural disasters and the institutions in charge of managing them, two concepts have been introduced with respect to the magnitude of the damages that emerge in communities as a result of the natural event and the coping capacities which communities possess to confront them.

We will define that a natural event causes an emergency when the damages it provokes are of a magnitude which can be managed by a community or a country without the need to request any external help or humanitarian assistance. In contrast, a disaster is defined as an event that has caused damages of such large proportions, that it is not possible for a community to confront it without external assistance. In other words, the severity of the damages surpasses the community’s or country’s capacity to confront them and manage them, requiring external assistance.

To illustrate these concepts better, two examples are presented. Let’s consider a small flood that affects 5 houses in an large city. As it is to expected, any large city probably has the resources to respond to this emergency via opening a temporary shelter and providing the affected people with social assistance to repair any damages. In this case, the local resources are sufficient to resolve the problems caused by the flood, and there is no need to request external assistance.

In contrast, an earthquake like the one in Guatemala in the year 1976, which caused over 23,000 fatalities and the collapse of entire villages is considered a disaster. Authorities at every level did not have the required resources to cope with all the problems that emerged. Therefore, an international call was made to request humanitarian assistance in order to manage the disaster.

With these definitions in mind it becomes necessary to focus more precisely on the concepts of risk, hazard, vulnerability, and deficiencies in preparedness to understand how they combine to conform the existing risk and how they differentiate from one another. This will be the focus of the following chapters.

**THE CONCEPT OF RISK AND ITS COMPLEXITIES**

When working on the subject of disaster reduction it is obvious that the ultimate goal is to reduce risks. However, while the definitions of risk are conceptually simple, their application or use is not, since there is a lack of an adequate system to evaluate and integrate hazards, vulnerabilities and deficiencies in preparedness into a single term. To illustrate this issue more clearly, let’s consider the case of a community that is at risk due to floods and earthquakes simultaneously.
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In the case of floods, hazards are generated by hurricanes or thunderstorms. The vulnerability centers on neighborhoods that are more susceptible to floods. Preparedness measures include monitoring atmospheric conditions, the implementation and operation of early warning systems, and the setup of shelters inside public or private buildings that will not get flooded.

In contrast, in the case of earthquakes it is probable that all the community is exposed to the hazard. Preparedness measures are concentrated on the elaboration of emergency plans, drill exercises on buildings or schools, and shelters are set up on plains, and outside public buildings.

How can risk be reduced if there are two kinds of hazards, vulnerabilities and deficiencies in preparedness which are so different from one another? The answer is obvious, both risks must be reduced. However, which one do we start with? Here, the definition is very vague and it does not allow us to prioritize risks.

In another context, vulnerability also lacks of a definition that will allow it to be more useful. To illustrate this point better, let's consider a capital city, like Guatemala. Although it is not directly vulnerable to floods, it is vulnerable to becoming in-communicated as a result of strong rain showers that could block access routes from the Atlantic or from the pacific oceans and respective shipping ports. During hurricane Mitch, fuel became scarce in the city because the roads towards the refineries in both coasts were temporarily closed because of the multiple landslides and bridge collapses.

The questions that must be asked and resolved in this case are: how vulnerable is the city? How should we compare this vulnerability with other types of vulnerabilities associated with floods?

As it can be seen, the application of the concepts of risk, hazard, vulnerability, and deficiencies in preparedness is limited currently, because there are no tools to evaluate them and no tools to test in what degree various measures reduce them. The objective of any systematization will be to provide the entities in charge of disaster reduction with a method that will allow them to evaluate and compare risks of different types and prioritize the measures that should be implemented. In particular, the systematization of vulnerability will allow authorities to model this concept in an integral way, dimension the type and magnitude of the different vulnerabilities and define strategies to reduce them.

Due to the fact that risks are hazard-dependent, it is obvious that a classification of risks must be based on these. The next chapter is devoted to this issue of hazards.
When we analyze the rainfall patterns over Central America, it can be concluded that the region experiences only two seasons: a dry and a rainy one. Generally, the dry season begins in November and ends in April. The rainy season begins in May and ends in October. We know that every year these two seasons occur. We can say that we know a lot about the pattern and period of return of this hazard called rainfall.

However, when we speak of hurricanes, we do not know this hazard very well. We know that the average number of hurricanes which can occur in the Caribbean per year, from June to October, ranges from 12 to 14. However, we do not know with certainty how many will hit Nicaragua or Cuba in a year, a decade, or a century!

A conclusion from the above paragraphs is that some hazards have a known period of return spanning years, decades, or centuries. On the contrary, other hazards do not have established period of returns. Rainfall in the rain season has an annual period of return. However, it is yet impossible to assign a period of return to volcanic eruptions of catastrophic magnitude.

The concept of period of return associated with natural phenomena is of great use because entities of civil protection can use it to prepare in a better way to face the risks which they create. Floods are an example of a phenomenon that occurs annually. The presence of a period of return allows authorities and civil protection personnel to initiate activities to reduce the impact of the flood, in particular the loss of human lives.

Map IV-1: a segment of the erratic trajectory of hurricane Mitch in 1,998. As a hurricane, it was not born in Africa; it was born in the Caribbean. Later on it moved from the coast of Honduras, to the coast of El Salvador, then to Guatemala and Mexico. It later went across Tehuantepec towards the Gulf of Mexico. Source: National Hurricane Center, Miami, Fla.

Hurricanes in the Caribbean have an annual period of return. The trajectories that hurricanes follow are ruled by the earth’s rotation, wind systems, high and low pressure systems present in their trajectories, and other factors such as cold fronts. However, at this time we do not possess meteorological models that may allow us to predict with certainty their entire trajectory before their entrance to the Caribbean from the Atlantic. Hurricane Mitch’s devious and rare trajectory is an example of the complexity of these systems that make them chaotic and unpredictable in Central America, even if they occur every year. Map IV-1 shows a drawing of a segment of this hurricane’s trajectory.
In the case of earthquakes, the situation is equally complex. Guatemala has been devastated by strong earthquakes in 1773, 1917-18 and 1976. We can say that there is an enormous earthquake in Guatemala almost every half a century, with a magnitude over 7.0 on the Richter scale. In a similar way, El Salvador experimented two devastating earthquakes in a period of 15 years, in 1986 and very recently in the year 2001. However, seismologists are incapable of assuring that there will be a strong earthquake in the year 2020. In the case of earthquakes, active faults have been mapped and we possess databases on them. But, as it occurs with hurricanes, the systems are so complex that we cannot forecast if there will be a large earthquake during this decade or not which could be like the one in 1976 in Guatemala. The case of El Salvador is illustrative in this matter, since no one expected an earthquake in the year 2001, with so little time after the 1986 earthquake.

Map IV-2: tectonic plates present in Central America. The North American plate is located to the north of Guatemala city. The Cocos plate lies within the Pacific ocean, borders all Central America and a segment of Mexico. The Caribbean plate includes a small segment of Mexico, the southern part of Guatemala and the rest of Central America, as well as several Caribbean islands. The yellow lines mark the intersections between such plates. The star marks the epicenter of the recent earthquake that occurred in El Salvador on January 13th, 2001. Source: USGS webpage

Because of this uncertainty, we have turned to statistics to try to model these complex dynamic systems. Statistical models that relate the period of return of events with their different magnitudes are currently developed and used. Using the magnitudes and period of return of different historic events, statistical functions based on exponential distributions are used to calculate period of returns of similar events of a higher magnitude.

Earthquakes and hurricanes allow us to make the following reflections: as nature’s phenomena, these events are of such a large magnitude, that it is impossible to control them, and therefore, prevent their manifestation. That is why we try to find the precursor signals that indicate us if they will take place, in other words, to forecast such events!
In this context we define that a forecast for an event must contemplate the geographical location with a certain margin of error that is defined through the model and the time location within a certain time interval, which must also be defined through the model. An example of a forecast may be:

<table>
<thead>
<tr>
<th>Phenomenon:</th>
<th>earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probable epicenter:</td>
<td>Motagua fault, with a probable epicenter located in a 50 km radius around the city Los Amates.</td>
</tr>
<tr>
<td>Probable intensity:</td>
<td>7.5 more or less 0.5 from the Richter scale.</td>
</tr>
<tr>
<td>Temporal period:</td>
<td>between October 2020 and January 2021.</td>
</tr>
</tbody>
</table>

For the case of hurricanes we must define their trajectory in a similar way, with a certain margin of error in geographical location, arrival time for particular sites. Once the spatial and temporal locations have been defined along with their margins of error, the next step is to develop iso-intensity maps. For the case of earthquakes, such iso-intensity maps could be presented in the following way:

Map IV-3: Hypothetical map of iso-intensities for an earthquake in the Motagua fault, with an epicenter in Los Amates. The epicenter is indicated with a red dot. The area inside the internal green circle includes areas which intensities over VII are expected, and the area inside the external blue circle represents regions in which intensities above V are expected.

With this and other information regarding ground accelerations, as well as studies of site response, we can proceed to elaborate building codes and rural and urban zoning norms that are useful to regulate the territorial development of urban and rural communities taking into consideration the geographical nature of these hazards.

For the case of floods caused by the overflow of rivers, a similar procedure can be followed. With information regarding the magnitude of the rain in the basin, the regions that will be flooded in the flood plains can be estimated.
This information will be useful for the generation of zoning maps that will be used to
orient the villagers about the potential ground use for houses and crops, and to represent
possible flood zones.

To understand the hazard better, let’s consider the case of a population constructed
near the edge of a river. As the rains take place, the level of the river rises gradually in
relation to the accumulated precipitation in the upper part of the basin. When the river
level rises, the houses and streets that are located in the lower level begin to flood. This
first group of houses and streets are in a high hazard level. If the flood rises, the second
group of houses and streets will be flooded as the waters of the river overflow. As it goes
on, more and more houses will be flooded as the river level rises during its overflow. In
figure 4.1, the red-colored area represents the area of higher hazard, due to the fact that
it’s easy for the river to reach this level during an overflow. The light gray area represents an
area of minor hazard, due to that it is at a higher elevation in comparison with the river
level, therefore it is less probable for it to get flooded. In this way a hazard map can be
created that represents the hazard related to flooding. To generate the hazard map,
topographic surveys of the level of the streets and other interest points are performed and
introduced into hydrologic flow models which can predict the extension of floods for a
particular amount of flow.

Figure #4.1: A hypothetical town on the banks of a river can be flooded during overflows. The red-
colored region represents the area that is initially flooded. The yellow-colored area is the next one to
be flooded. Finally, the gray area at the left represents an area that is rarely flooded. This is the
basis for a hazard map.

Photograph # 4.1 shows how the a segment of a community which has been built in a high-hazard zone. The
building on the right is the local church, with is used as a shelter during floods, due to the fact that when it was
constructed, its floor level was elevated artificially. With this procedure, the vulnerability of the church was reduced,
even though it remains in the same high-hazard area.

Photograph # 4.1: Texcuaco, a small village in the Escuintla province in Guatemala, experiences floods on a yearly basis.
Once the hazard has been characterized in an adequate way through studies of its behavior (intensities, period of returns, geographical span, etc), the next step is to elaborate the corresponding hazard maps, in which the hazard is represented in the form of iso-magnitude polygons (low hazard, medium hazard, and high-hazard for example). This allows authorities and civil protection agencies to determine probable impacts of disasters. In a similar way, it allows municipal authorities to develop and implement schemes for land-use and territorial ordering or zoning according to hazards within their jurisdiction.

Although the elaboration of hazard maps is a complex task, the use of digital cartography has facilitated the task of representing hazards and their intensities on top of already existing cartography. In the next chapter the issue of vulnerabilities is addressed.
During the catastrophic earthquakes in Guatemala in 1976 and El Salvador in 2001, hundreds of thousands of adobe houses with clay-tile roofs were destroyed. The construction of adobe houses has been a traditional technique for several centuries that uses materials available locally, it requires very little technique, and can be done anywhere.

In general, adobe is an excellent construction material if it is only exposed to compression stresses. However, because of its nature, adobe does not resist vibrations nor any type of shear stresses, due to its poor adherence.

In addition to the traditional use of adobe, villages of Central America have been characterized for their use of clay-tile roofs. These red colored roofs, made of individual clay tiles stacked one of top of the other, have embellished villages all over the territory. However their weight is a great disadvantage. Considering that a tile weighs around 4 to 7 pounds when dry and even up to 10 pounds when it is saturated with humidity during the rain season, a clay-tile roof is a potential source of fatalities if the wooden structure that has to support it is rotten or weak and fails during an earthquake.

During the 1976 Guatemala earthquake at 3:03 am, more than 23,000 inhabitants lost their lives in an instant when adobe walls and clay-tile roofs collapsed killing the sleeping population. In contrast to the case of Guatemala, the recent earthquake in El Salvador in the year 2001 caused few fatalities, because it occurred at 11:13 am on a saturday morning, when the majority of the population was outside, on usual weekend activities. However, it has been determined that nearly 170,000 houses were practically destroyed during this earthquake in El Salvador.

Learning from the Guatemalan experience regarding adobe walls and clay-tile roofs, the Guatemalan population located in the area of the Motagua fault reconstructed houses and buildings using modern construction techniques using cement-blocks reinforced with concrete beams and columns. However, in other regions of the country, where the 1976 earthquake had a small impact, hundreds of thousands of adobe houses still remain, awaiting the same fate as those houses destroyed by previous earthquakes.

Systematizing these paragraphs we can conclude that houses constructed from adobe and clay-tile roofs are at risk of being destroyed during an earthquake, that is why we say...
that these houses are **vulnerable**. But when we analyze what is vulnerable besides the structure of the house itself, we see that the functionality of the house is vulnerable as well. When an adobe house falls, the family is left without a house: without a place to sleep, rest, eat, cook, eat, and socialize.

Let’s consider now a hypothetical example of a store located in a zone exposed to flooding, in which food products are sold. If the store is flooded completely, the owner can not sell the products. So, besides structural vulnerability associated with the building, there exists a functional vulnerability and in this case an economical or financial one as well.

These two examples indicate that there are many types of vulnerability, such as:

- **Structural Vulnerability**
- **Functional Vulnerability**
- **Economic or economic-income Vulnerability**
- **Social Vulnerability**
- **Cultural Vulnerability**
- **Psychological Vulnerability**

**STRUCTURAL VULNERABILITY:**

Structural vulnerability reflects how prone the structure of a building is to be damaged by a natural phenomenon such as an earthquake, a flood, or a hurricane. We can include under this vulnerability all the elements of the building which compose it: walls, ceilings, doors, windows, and floors.

As it can be expected, structural vulnerability is directly related with the type of hazard in consideration. To illustrate this point, let’s consider a house constructed with modern norms of engineering: cement-block walls reinforced with concrete columns and beams. Let’s also consider that the roof is made out of metal sheets over a wooden structure constructed adequately. A house of this kind is less vulnerable to earthquakes due to its structure. However, if the house is constructed near the skirts of an active volcano, a strong eruption may occur and piroclastic material and ash can accumulate on the roof top, later causing the roof to collapse. In a similar way, a house of this kind, constructed near the edge of a river is not vulnerable to earthquakes, but may be vulnerable to landslides.

**Photo #5.2: Two houses vulnerable to floods.** The house on the right has its front door facing the river. When the river flow increases, water goes in through the door and floods the entire house. In contrast, the house on the left has no door at this level, and is also a two-story house, making it less vulnerable to floods as its inhabitants can move upstairs should the first floor become flooded.
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**FUNCTIONAL VULNERABILITY:**

Let us now consider the case of a banking institution which is housed in a properly-built concrete building. As expected, this type of institution employs electronic and computer equipment. If during an earthquake the electrical and communication installations collapse, standard banking operations cannot be completed. Even if the building does not show structural damage, the institution will not be able to offer the routine services to the client if it does not have electric energy to run the standard equipment. In a similar way, operations such as telephone calls via a central telephone plant, photocopies, electronic bank transfers, and other services cannot be provided until the electrical energy and telecommunications network is rehabilitated or reconstructed within the building.

This example illustrates the functional vulnerability to which some businesses and commercial institutions are subjected to. Just like in the case of structural vulnerability, the functional vulnerability is associated with the type of hazard in question.

A flood or a fire is capable of destroying important papers and magnetic media, though the structure of the building may not suffer damage if it is made of concrete. Therefore specific measures must be taken to reduce the functional vulnerability associated with the handling of information.

Currently, a part of systems engineering is focusing these types of functional vulnerabilities and it is known as reliability engineering. Although it does not study particularly the case of natural disasters, it analyzes the vulnerability of routine operations of the enterprise to reduce the risk of the collapse of its services.

**ECONOMIC OR ECONOMIC INCOME VULNERABILITY**

In a similar fashion to the functional vulnerability, economic or economic-income vulnerability represents how prone a household or an institution is regarding economic losses as a consequence of natural disasters.

An illustrative example is the income of farmers who base their income on agricultural crops which are prone to being damaged or destroyed by floods or droughts. People who dedicate themselves exclusively to agriculture in floodplains are vulnerable because their economical income is affected by a flood or a drought that can destroy partial or entire crops.

Another example is related to cattle farming in flood-prone areas or in regions on the foothills of active volcanoes. During the recent hurricane Mitch, cattle farmers experienced enormous losses in Guatemala and Honduras. On the one hand, the wooden fences and barbed wire fences were impossible barriers for cattle to cross, causing their death during the flood. In addition, when pastures were flooded for several weeks, they could no longer be used for feeding, so the remaining cattle starved to death. These two causes provoked economic losses to the owners.
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As a final example, agriculture near the foothills of an active volcano is mentioned. Eruptions can cause enormous losses to agriculture in these regions as a result of the ash deposits which can cover entire crops as well as pastures used for cattle.

SOCIAL VULNERABILITY

This vulnerability is the most complex one to define due to the multiple social factors that integrate it. Some illustrative examples are provided in the paragraphs below.

Let’s consider two neighboring houses, in such way that they are exposed to the same hazard. However, in one of the two houses three very elderly people and two babies less than one year of age live. In contrast, in the other one there are 4 teenagers and adults but not elderly people.

As it is to be expected, during a natural event the babies and elderly people need handling assistance and more time to evacuate their house because of their poor mobility. However, normal adults and teenagers do not need handling assistance and can evacuate their house very quickly due to their high mobility. This implies that the house with the babies and elderly people presents a higher social vulnerability than the one with teenagers.

Some authors specify educational vulnerability as the inherent conditions of the educational process which make it prone to be affected by disasters, such as the destruction of schools, or the use of school buildings as temporary shelters, interrupting the educational process.

It is important to address such social vulnerabilities and identify which sectors of the population are more vulnerable to specific types of hazards. For example, malnourished children who have not developed an adequate immune defense system will be more vulnerable to diseases such as diarrhea or pneumonia. However, well-fed children will be able to defend themselves better from these bacteria that can be present when floods occur.

CULTURAL VULNERABILITY

Another example of social vulnerability is manifested in the case of social issues such as religion and cultural heritage. Religious fatalism can be used in a negative aspect by priests, blaming all disasters on sins and assuming that such disasters are acts of God to punish people for their sins. In such cases, it is very difficult to convince true-believers that one can indeed implement measures to minimize the risks and hence the disasters. Therefore a social vulnerability must be determined for this context.

In other cases cultural vulnerability can be associated with lack of experience, negligence regarding hazards and existing vulnerabilities.

PSYCHOLOGICAL VULNERABILITY
Historically, some people that have survived an earthquake or a tragedy of enormous proportions manifest fear when similar natural phenomena occur, even if they are of a smaller magnitude. This means that a previous disaster of large proportions can generate a psychological vulnerability in some people.

Generally, this vulnerability is mostly detected in the case of earthquakes. People who are affected by a strong earthquake become scared or frightened when a tremor occurs. This condition does not allow them to react in an efficient or logical way during similar events. Considering the complexity of such a vulnerability, further research by experts is needed in this field.

Although some authors define additional vulnerabilities of other types, these remain out of the interest of this text. However, the reader is referred to the bibliographic references cited at the end of the text.

As it has been commented in previous chapters, there are social factors that make us more prone to disasters due to the fact that such factors tend to increase vulnerabilities and deficiencies in preparedness. A more detailed description of such factors is presented in the following paragraphs.

**FACTORS THAT CAN GENERATE OR INCREASE THE LEVEL OF VULNERABILITIES AND RISKS**

As we mentioned before, the thematic vulnerabilities are directly associated to a hazard. In addition, it must be realized that there are certain social factors that can generate or increase the vulnerabilities and risks; among these the lack of land-use and geographical zoning norms, the lack of building codes, migration from rural to urban areas, population growth, poverty, lack of knowledge related to risk and disaster, and traditional or religious beliefs. Poor people have so few resources, that they barely survive day by day. The daily necessities of this sector of the population absorb practically the totality of their incomes, and so this sector is forced to:

1. **live in high hazard areas.**
2. **construct houses with construction materials and techniques that lead to structural and functional vulnerabilities.**

Two additional factors which enhance vulnerabilities are the population growth and migration to urban areas. Such factors are very common in Central American nations as a consequence of people migrating to urban areas to seek better living conditions, or to seek the safety of cities in countries going through civil conflicts of great proportions.

Another factor which is enhancing vulnerabilities is the lack of experience regarding risks and disasters. As an example we mention the Guatemalan population under 30 years of age that begins the construction of houses with adobe as a construction material, where the last earthquake took place almost 30 years ago. If there is no “social memory” to make these young people aware of the risk they will face with respect to an earthquake by using this material, poverty and other social conditions may lead them to do so.
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These factors determine the creation or enhancement of vulnerabilities, and therefore risks. However, they cannot be associated to any hazard in particular, since they include all kind of hazards. Because of this fact they are considered as generators of vulnerabilities.

VULNERABILITY INTEGRATION

The total vulnerability of a sector must be determined considering the thematic vulnerabilities. Mathematically we could express the total vulnerability of a family household as the sum of the different vulnerabilities:

\[ V_{\text{total}} = V_{\text{struct.}} + V_{\text{Func.}} + V_{\text{Econ.}} + V_{\text{Social}} + V_{\text{Psyco}} + \ldots \]

However, the addition of such vulnerabilities is rather difficult, as these are related to very different concepts. The mathematical way to do so would be to find suitable coefficients for each vulnerability, but even the assignment of the numerical values to such coefficients is rather difficult, as such coefficients should represent the relative weight on one vulnerability with respect to the remaining ones.

VULNERABILITY OF A COMMUNITY

As we mentioned before, the total vulnerability for a community is represented through the composition of the vulnerabilities of the familiar surrounding and the specific vulnerabilities of the community. The total community vulnerability would be expressed in the following way:

\[ V_{\text{total}} = V_{\text{of all houses}} + V_{\text{struct}} + V_{\text{funct}} + V_{\text{social}} + \ldots \]

The structural vulnerability of vital lines (accesses, potable water and its distribution pattern, public enlightenment, electrical cables, telephone lines, sewer drainage, etc.) are combined with the functional vulnerability of commerce, markets, health centers, schools and other public buildings on which the community counts on, and with the social vulnerability related to the community (culture, sports, religion, etc.). To widen the discussion two illustrative examples will be presented in which hazards and vulnerabilities are analyzed.

PACAYA VOLCANO EXAMPLE:

Pacaya volcano began its most recent eruptive cycle in 1961. Many populations can be found on its outskirts, specially on the north and west flanks. Pacaya’s eruptions can be classified as strombolian, manifesting themselves as isolated events, in which the volcano presents all its facets: tremors, gas emissions, explosive eruptions, ash and piroclastic flows and lava rivers.

Photo #5.3: Pacaya volcano south of Guatemala City. There are several rural populations on its outskirts.
Currently, one of the hazards associated with eruptions is the emission of pyroclastic flows and ash, due to the fact that these can be transported by winds several kilometers from the cone. Two main factors to consider in Pacaya volcano are:

- **Winds usually blowing in a southwestern direction, which shifts the hazard towards this preferred direction.**
- **The natural migration of the active cone towards the southwestern direction, due to geological processes that rule the volcanic behavior.**

The housing vulnerability is composed of those factors such as house infrastructure and functionality, family-income; and within the community context it is important to consider accesses to different energy and potable water sources.

Map V-1: hazard map of piroclastic flows of the Pacaya volcano. Source: INSIVUMEH digitalized by CONRED.

The structural vulnerability of the houses must be associated to the incapacity of the roofs to support the weight of piroclastic material deposited by the volcano during the eruption, and the existence of glass in the windows that may break when the material falls to the ground in case of strong winds.

A survey carried out in the year 2000 in the different communities that surround the volcano indicates that almost all the houses are constructed with cement blocks, reinforced with concrete columns, and metallic sheeting rooftops; which resist adequately the impacts of piroclastic material. However, the majority of the metal roofs are built with little inclination, which hinders the sliding of ash or piroclastic material when it falls. This represents a great problem if the quantity of material accumulated on the roof surpasses its weight capacity. Therefore, we are able to conclude that the typical houses are structurally vulnerable. To reduce the vulnerability, the roofs have to be constructed with a larger angle of inclination to avoid the accumulation of ash on top of them.

Photo #5.4: A house constructed using cement blocks in El Patrocinio, showing piroclastic material on its roof from a recent eruption. It can be seen that the house resists the impact of such material pretty well. Note the material in the surroundings.
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With respect to the functional vulnerability, the populations situated to the north of the volcano obtain their water from the Calderas lagoon, while the populations in the southeast do it using natural wells and springs.

In the majority of the cases, the water is transported through a network of metallic or PVC pipes buried underground, which is why water flow is not vulnerable to this hazard related to the deposition of ashes and pyroclastic material. This implies that the houses have little functional vulnerability with respect to water sources.

In respect to economical vulnerability, some people in the region dedicate themselves to coffee-related agriculture and basic grains such as beans and corn. It has been observed that the plantations are vulnerable to the falling of pyroclastic material and the emission of noxious gases. One important aspect to notice in regards to agriculture is the time of year when eruptions take place. Young coffee plantations or those that are ready to be harvested (crop season) are very vulnerable. Such factors tend to increase the economic income vulnerability. However, one important fact which has been detected that may reduce this vulnerability is the fact that many people from these small communities work daily on the industrial corridor industries located in the pacific highway, in regions far away of the volcano. The income generated from these sources is less vulnerable than any income generated through agriculture near the active cone.

With respect to the community vulnerability, it is interesting to note that El Patrocinio and El Rodeo, which are the communities located in the highest hazard region, only possess one access route, which rises their community vulnerability. In contrast, the communities located in the north side of the volcano have two access routes; this duplication reduces the vulnerability by a half. When the hazard is integrated with the vulnerabilities, it is easy to determine that the populations located in the southwestern area of the volcano, like El Patrocinio and El Rodeo, are those at higher risk because these zones present a higher hazard and a higher community vulnerability because they can only be reached through one single unpaved road.

EXAMPLE: FLOODS IN COASTAL PLAINS

Several communities located on the coastal plains suffer yearly floods as a result of storms and tropical depressions that are common in the rainy season, during the months from June to October.

Some of the larger rivers of the region overflow causing enormous losses in agriculture and multiple problems in many communities in these coastal plains.

Photo #5.6: a vulnerable house flooded in the coastal plains. Situations such as these are common in many basins.

Although the hazard related to floods is known, our ancestors found a way to reduce the vulnerability by constructing wooden houses over pillars of the same material, in such a way that if a flood occurred, it was not necessary to evacuate the house, since it was not
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flooded. However, the introduction of the construction technique using adobe walls or cement blocks modified the structure of the houses in a radical way, eliminating pillars and thus lowering the level of the floor to the ground, increasing their functional vulnerability.

The exchange of construction techniques, eliminating the construction of wooden houses on stilts for block structures is due to two factors: the difficulty of finding quality wood because of the transformation of forests into crops such as cotton, sugar cane, corn, and pasture for cattle; and the cultural adoption of such modern techniques.

Photo # 5.6: houses vulnerable to floods due to the low levels of their floors according to the overflow of water.

Considering the structural vulnerability of houses, wood is more vulnerable than cement blocks in respect to long-term floods because of water’s chemical attack on wood, which does not occur on cement blocks. The substitution of wood for block minimizes the preventive treatment that must be done over wood on a yearly basis, using chemicals like sealers and varnishes. This substitution reduces the structural vulnerability of houses. However, the functional vulnerability of the cement-block houses increases when the floor of a block house is left at the ground level or a few centimeters above it. As a result, river overflows generate problems to all these houses, since the cost of rising the floor of a cement-block house is more expensive.

Photos # 5.7 and 5.8: cattle farming and agriculture are sources of income. However, both types of activities are vulnerable to floods provoked by torrential rains and hurricanes.

With respect to the economic-income vulnerability, some flood areas are typical sources of income associated with cattle-farming and agriculture. In this case the degree of vulnerability associated with the execution of such activities in these areas must be determined. In regards to the cattle-farming, hurricane Mitch demonstrated that the
vulnerability increases when barbed wire is used in fences, because as cattle try to escape the flooding, they become entangled and drown.

The vulnerability of many crops cannot be easily reduced, because this implies searching for species genetically able to resist the flooding, as in the case of rice. Therefore the hazard must be reduced or managed to avoid disasters.

The hazards and vulnerabilities can be integrated to determine the risk that communities are exposed to. As concluding remarks in this chapter we present some key points:

- The hazard increases moving closer to the river. Therefore high resolution topographical surveys must be carried out to determine the distinct levels of hazard for each basin.
- The functional vulnerability of the houses increases when the floor levels are very low.
- The social vulnerability increases when the number of buildings increase, as in the case of schools and public health centers susceptible to flooding.
- The social vulnerability also increases or when there exists only one access to the community and it's at risk of flooding during the rainy season.

When integrating theses and other vulnerability factors, we can conclude that the hazard is higher near the river shores and decreases when the distance between the river and the geographical zone in question increases. Therefore, cattle farmers and agriculturists who are far away from the river border face smaller risk than those near the shores of the rivers.
CHAPTER VI: DEFICIENCIES IN THE PREPAREDNESS, THE OTHER SOCIAL COUNTERPART

In Central America it is common to find urban settlements, marginal zones that are born spontaneously in areas which are invaded in a massive way. In many cases these are settled in high hazard areas, where natural phenomena can provoke fatalities and losses due to the fact that the population which has settled there is vulnerable and is not prepared to face a disaster.

As typical examples we can mention the settlements located in ravines and high-slope areas, near river shores, or a few meters away from train tracks. Due to the fact that the majority of these settlements are established in an illegal way, and do not contemplate any type of regulation regarding their "urbanization", in many cases the access to such settlements is difficult, specially in the rain season.

Photo # 6.1: urban settlements situated in the ravines within Guatemala city. In many cases these settlements are consolidated via the invasion of private or public land.

In a similar way, such settlements do not incorporate any preparedness measures in case of disasters. This is due to the fact that in many cases such measures are neglected from the list of priorities, as daily subsistence, and the fight against common violence and vandalism, the legalization of the lot in use, and the satisfaction of basic needs for a minimal economic subsistence are leading this list of priorities.

However, when a landslide occurs the situation becomes very complex. In some cases difficulties arise during rescue operations as teams cannot access the area to begin their search and rescue operations, and it is equally difficult to secure transportation of victims to emergency centers to be attended due to poor access conditions. In a similar way, fires become very complex to combat due to the absence of hydrants, or due to the long paths which must be used to reach the area where the fire is occurring.

The examples mentioned in the previous paragraph illustrate that sometimes there are critical situations which impede a fast and efficient response when a natural phenomenon occurs. We name these conditions as deficiencies in the preparedness, since they manifest the existence of conditions that can enhance the dimension of a disaster. In many cases, the existence of such deficiencies in preparedness can represent the difference between life and death.
Another illustrative example is the case of floods. When a sudden flood occurs in an area, the inability to swim, not being able to rely on a lifesaver, and not being able to give mouth to mouth resuscitation to someone who is unconscious reflects the existence of critical conditions that, as in the previous case, can mean the difference between life and death. As it is to be expected, in communities prone to disasters, the deficiencies in preparedness include different critical conditions.

In the case of violent volcanic eruptions, where massive evacuations must be carried out as soon as possible, not being able to rely on an evacuation plan which includes the inventory of local vehicles such as trucks for the evacuation of people can make a notable difference.

In this case it may be difficult to provide potable water and food to the families that have been left behind without a possibility of coming out in time from the zone impacted by the event.

In a similar way, the lack of signals regarding evacuation routes in case of natural events of large magnitude can cause complex problems for tourists or visitors that are not familiar with the geographical area and its highways.

Just the same, a community that does not possess local fire brigades and equipment to combat forest fires will have no other option but to wait for external fire brigades to combat such fires, which may signify the loss of belongings, cattle, meadows, and crops, due to the additional time that external brigades take to reach the location where these forest fires are taking place.

All these examples illustrate the existence of deficiencies in preparedness that may in a certain way, raise the dimension of the disasters. Expressed in an opposite way, when communities count with adequate preparedness measures, it is possible to minimize losses to the minimum. The implementation of preparedness measures can save human lives and some belongings, but we must recognize that such preparedness measures do not reduce vulnerabilities nor existing hazards.

Considering the examples mentioned before, it becomes necessary to incorporate such deficiencies in preparedness as components of risks and to reduce them whenever possible. Currently there are institutions dedicated specifically to prepare communities for these cases regarding natural disasters. These institutions, which include national emergency committees or councils, rescue teams, fire department, the Red Cross, special search and rescue teams in case of special events like earthquakes and landslides, have the responsibility regarding the design and implementation of such preparedness measures with the goal of reducing the losses caused by natural events.
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Generally, the first deficiency that emerges within a community is the lack of knowledge regarding the possibility of events capable of provoking a disaster. Not recognizing that one is located in an area of catastrophic events such as landslides is a typical example, but it is never forgotten once it happened before. Another deficiency is related with the population’s lack of interest to maintain itself informed about the conditions regarding natural events that have the potential to generate disasters.

Other factors are more related with the response once the natural event that causes the disaster has occurred. We can include the incapacity to react in an efficient manner during the event (search and rescue operations in special situations, first aid and resuscitation techniques), the lack of basic equipment (fire extinguishers, tools to accomplish specific operations, lifejacket in case of floods), and the incapacity to coordinate the inter-institutional efforts during response operations (coordination of rescue teams, ambulances, search and rescue groups, medical assistance, etc.).

Although the three components of risk have been introduced in a general way, a discussion regarding how the three components are integrated becomes necessary. This is the focus of upcoming chapters.
We have already stated that risk can be defined as the integration of hazards, vulnerabilities, and deficiencies in preparedness. To make a description of the risk that societies face, it is necessary to relate the hazard maps with the thematic vulnerability expressions and the existing deficiencies in preparedness. One way to represent risks can be using geographical information systems or GIS.

Map VII-1 represents a preliminary risk map of the Pacaya Volcano area. The houses within all the communities are practically the same as similar techniques and construction materials are employed, which implies that the total structural vulnerability of each community is the sum of the individual vulnerabilities of the houses within such a community. However, El Patrocinio, El Caracol, and El Rodeo are characterized with a higher community vulnerability because they have only one access road. In contrast, San Francisco, El Cedro, and Calderas have two access roads, which makes these communities less vulnerable. Finally, all the communities have similar deficiencies in their preparedness measures.

Integrating all the risk factors in these communities, it can be concluded that San Vicente Pacaya is at low risk in comparison with the rest. In contrast, El Patrocinio, El Rodeo and El Caracol are considered as high risk communities since they conjugate high hazards and larger community vulnerabilities.

Map VII-1: Risk map for the communities located on the rims of Pacaya Volcano. San Vicente, represented with a large, green-colored polygon is at low risk. Communities in yellow-colored polygons are at medium risk, while communities in red polygons are at high risk.
The nature of risks, a conceptual approach

Following a simple scheme, communities classified as low risk can be represented using green figures, those classified as medium risk in yellow ones, and higher risk communities in red polygons. Due to the fact than in many cases it is necessary to represent the dimension of the communities, the use of polygons of different sizes has been incorporated in this map. El Patrocinio and El Cedro contain about 150 houses each, San Francisco and Calderas have around 70 houses, while El Rodeo and El Caracol have less than 20 houses each one. To represent the dimension of risk in a better fashion considering the number of houses in the communities, the use of polygons of different sizes is recommended.

In this case the map has been elaborated considering that the communities are located in different hazard areas. However, the complexity of the risk is manifested when hazards and vulnerabilities of different magnitudes must be simultaneously combined in a single region. In this case, criteria to define how to combine these factors must be defined. For example, the case of low vulnerable communities located in high hazard areas can occur, and in contrast very vulnerable communities in low hazard areas can also occur. How do we measure dimensions of risk for these cases? A way could be to define a priori these types of combinations as examples of medium risk, in contrast with low risks where hazards and vulnerabilities are low, and in contrast to the case of severe or high risks, where hazards and vulnerabilities are both high.

Another issue to consider is the size of the population. If the size of a population is duplicated in relation with the number of houses, but it maintains it's vulnerability and it's hazard, how does one manifest the difference in the risks between both communities? It would seem obvious that by rising the vulnerability (because there are more houses), the risk should also rise, because more damage can occur. Based on this logic, it has been chosen to use the size of polygons to represent the community risk, allowing one to maintain three risk categories: low, high and medium. As it is to expect, this is not the only way in which risks can be represented, but it is a practical one.

In this and previous chapters we have presented conceptual ideas regarding hazards and vulnerabilities, and discussed issues regarding risks associated with various sectors. The reduction of risks via their components hazards, vulnerabilities, and deficiencies in preparedness is the subject that is presented in the next chapter.
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CHAPTER VIII: RISK MANAGEMENT

The conceptual framework associated with the issue of disasters defines risk as the combination of natural hazards, social vulnerabilities, and deficiencies in preparedness. In this way it is possible to separate the natural contributions associated with natural phenomena such as earthquakes and hurricanes, from the social contributions related with construction techniques, land use, and other social factors.

In this context prevention is defined as the set of measures adopted to reduce or minimize the exposure to natural hazards. Dams and borders constructed to control water flow in rivers are a clear example of prevention. Zoning norms and norms regarding land-use are other examples of prevention. In contrast, mitigation is defined as the set of measures adopted to reduce vulnerability. The retrofitting of roads or houses, just like the creation of additional potable water and energy sources are examples of mitigation activities.

Although prevention and mitigation measures are useful to reduce risk, there are natural phenomena for which there are no simple preventive measures. In these cases it is necessary to prepare the population in order to minimize the damage caused by such phenomena and avoid human losses. In this case we speak of measures designed in the context of the preparedness. Recalling the definition of risk:

\[ \text{Risk} = \text{Hazard} \times \text{Vulnerability} \times \text{Deficiencies in Preparedness} \]

One concludes that to reduce the risk it is necessary then to reduce the hazard, the vulnerability, and/or minimize the existing deficiencies in preparedness. The following graph presents these concepts.

Figure #8.1: The hazard and vulnerability are reduced through prevention and mitigation respectively. In this context, the risk is represented as the area inside the triangle.

It has been noted that the risks could grow if the population cannot respond in an adequate way during disasters. In this
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definition preparedness activities focus on the practical measures that are taken just before and during a natural phenomenon, with the goal of reducing the impact of the phenomenon while it occurs. Examples of such measures include the development and implementation of emergency plans, evacuation routes, training, simulations, implementation of early warning systems, and other similar measures.

In the context of BEFORE, DURING and AFTER time intervals, it is important to notice how prevention and mitigation are implemented to minimize the hazards and vulnerabilities that already exist. In contrast, preparedness measures are implemented to be able to respond efficiently DURING the phenomenon.

To reduce the impacts caused by floods in Central America, early warning systems are being introduced. In this context, we understand that an early warning system is an organized structure which includes monitoring the hazard, forecasting events, the emission of warnings, and onset of the response. Monitoring is executed continuously so that the emergency and local authorities can follow up the phenomena in question and their evolution. Warning activities must be coordinated by civil protection committees, should involve local mass media such as FM and AM radio stations, and have the purpose of warning the population regarding possible catastrophic events. Finally, should it become necessary, local authorities and emergency committees will implement the response procedures described in the emergency plans.

While the subject of risk management is being undertaken by many institutions within Central America, strategies for the insertion of the three types of measures it includes must focus on the assignment of specific responsibilities. As it is to expected, preventive measures should be the responsibility of municipal authorities and central
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governments. Mitigation-related measures to reduce vulnerabilities should be the responsibility of the civil society and the institutions in charge of the social structure. In contrast, preparedness should be a responsibility of institutions devotes to these tasks, such as the emergency committees, relief corps, the Red Cross, and similar institutions.

Such strategies must be planned with one basic idea in mind: the implementation of risk management is something that is done to benefit the entire population following basic principles of promoting a framework which minimizes disasters related to all hazards.

PLANNING SUSTAINABLE DEVELOPMENT

When we think about the concept of sustainable development it is inevitable to elude the strategy of structured planning. When referring to natural disasters, a structured plan spanning various levels encourages this kind of development. On the one hand, the municipal sector must establish territorial ordering schemes taking into account existing hazards to avoid the construction of houses or infrastructure in high hazard areas. On the other hand, the same municipal sector must implement building codes that incorporate the most modern knowledge regarding construction techniques in relation to events such as earthquakes to inhibit the construction of vulnerable infrastructure [8].

Through these two measures a more sustainable social development will be almost guaranteed by minimizing the exposure to the hazards through constructions in low hazard areas and minimizing the vulnerability through the use of materials and techniques that guaranty the solidity of structures in relation to existing hazards.

For example, when referring to communities crossed by rivers, City Halls must determine a minimal buffer zone in relation to floods and prohibit the construction of structures in that area. City Halls should also require that floors of houses and infrastructure be constructed at a minimum height above the historical levels of past floods to guarantee the functionality of the houses in case of a flood. The use of construction materials that will not be affected by floods should also be promoted to minimize structural damage. Finally, norms and programs should also be implemented to reduce the vulnerability of existing infrastructure through the adaptation of such structures to the new building codes.

While sustainable development can be reached with the implementation and enforcement of such measures, their implementation and enforcement implies an enormous effort for any municipal administration, because such an administration must create the capacity within its technical personnel for the design and implementation of these measures, as well as personnel to evaluate and guaranty that the constructions are done satisfying the requirements of building codes and the land-use ordinances.

In the following section we will present three examples regarding risk management where preventive, mitigation, and preparedness measures are illustrated separately.
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MANAGING THE HAZARD: FLOODS

When dealing with floods, we recognize that the hazard is the overflow of rivers from their banks towards areas used by communities for purposes such as agriculture, housing, or cattle farming. In contrast to earthquakes and hurricanes, this hazard can be managed through small and large engineering measures.

To minimize the possibility of flooding, the construction of levees, control dams, and dredging has been widely used. The end result achieved with these measures is to avoid the river from overflowing its banks and therefore causing major damage [9]. The construction of levees with gabions has been providing good results to avoid flooding in villages and regions of Central America. In many cases, the key has been the construction of such levees allowing for a large buffer zone between the river bank and the levee, so that the level of the river does not rise as much, the speed of the flow is maintained as low as possible and the thus the hydraulic erosion which it causes is minimal on the levees when ever the river flow is large because of storms or tropical depressions. The issue of hydraulic erosion of levees has been a costly lesson, which has not been learnt by many institutions in Central America. The construction of levees piling up sand from the banks has been shown to be very vulnerable to rivers flowing at elevated heights and therefore at high speeds.

Due to the fact that the construction of levees can span many kilometers and thus can be very expensive, these measures are usually funded through government funds. The justification for the government to construct these structures must be based on the need to reduce the level of risk of a significant number of the population within one or several communities, or to minimize the exposure to the hazard in pastures and land used for agriculture.

Photos 8.3 and 8.4: examples of borders to avoid flooding. On the left there is a border with rocks. On the right there is a border with gabions. In both cases the erosive power of water flow is reduced. See that in each case a security margin has been left for the river to accommodate large flows.

Although it has not been common in the Central American region, the use of dams for river flow control is another type of measure that reduces the hazard related to flooding.
Multiple dams of this kind have been built in Europe and North America to reduce the risk of flooding through the control of the quantity of flow in the river basin. Dams offer the capacity to store water resulting from rainfall on the basin in a temporal way, to be released in a controlled way later on. This control allows authorities that operate these dams to manage the flows of water, avoiding floods which may reach down river and provoke disasters. Just like levees, the construction of dams is a project of large dimensions, which requires the intervention of the government because of their high cost.

As a drastic alternative when floods are very frequent, communities can be moved from a high risk area to a low risk one, located further away from the river basin. However, such measure must be planned and executed in a way in which the new community is created considering all the aspects of urbanism and prevention available, so as not to reproduce high risk areas in relation to another type of hazard. For example, it is not wise to translate a community from a high risk area of flooding to a high risk area of eruptions or landslides. It is necessary to guaranty that the new chosen zone proposed to establish the community is at low hazard for any type of hazard.

**MANAGING THE VULNERABILITY RELATED TO FLOODS**

As it has been mentioned before, the occurrence of a disaster is proof that vulnerabilities associated with hazards have been created before the event. To reduce each type of existing vulnerability, these must be analyzed in a specific way. For example, to reduce the functional vulnerability of houses in the case of floods, the floor level must be raised above a certain minimum level that can be established through simple studies of previous flooding and topographic surveys.

To reduce the functional vulnerability of latrines, these must be properly sealed and elevated to ensure that even if during the flood, these will still remain usable. In this way subsequent damage and health problems caused by the backflow of their storage wells is avoided.

To reduce the vulnerability related to cattle farming in case of floods, fences must be re-designed and the owners of the lands must reach an agreement in which cattle is allowed to migrate to territory located in a lower hazard area in case of flooding. In a parallel way, management of pastures in non-floodable areas must be contemplated to guaranty food for cattle when local pastures are flooded for some time.

With respect to agriculture, it is hard to reduce the vulnerability of the crops and this could only be done through genetic modifications in plants that will allow them to survive in the case of floods. However, an alternative could be to replace vulnerable crops for less vulnerable ones.

These examples of mitigation must allow us to understand that prevention and mitigation are responsibility of every sector of the population.
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REDUCING THE DEFICIENCIES IN THE PREPAREDNESS IN CASE OF FLOODS

As it has been stated, the deficiencies associated with preparedness reflect that a community or population is not ready to respond to the immediate consequences that arise with the event that provokes the emergency or disaster. In extreme situations, this situation can lead to chaos, panic, and rise the magnitude of the disaster as a result of activities that worsen it rather than managing it in any way. Among typical preparedness measures, the following can be mentioned:

**Community Organization:** an efficient and opportune response in case of disasters begins with the organization of the community via the establishment of specific committees which are in charge of executing diverse activities in case that a disaster occurs. Generally the term emergency committee is employed, and such a committee has the capacity and necessary resources to confront the problems that a community can face at a given moment.

![Photo #8.5: members of the local emergency committee address the population in a simulation.](image)

The creation of an emergency committee is the first step in community organization. This committee is composed of representatives from municipal authorities, relevant institutions such as firemen, the police, Red Cross, health centers, rescuers, and civil society representatives. Generally, this committee is created and formalized by the national entity of civil protection of the country.

Once the committee has been established, the creation of sub-committees of various types follows, such as: search and rescue, shelter management, social assistance, medical assistance, vigilance, and others. These sub-committees are supported by volunteer brigades, who are trained to accomplish certain functions or specific tasks.

**Emergency plan:** the next step is the establishment of a committee that elaborates the emergency plan, which describes the measures that will be implemented in case of a disaster, the available resources to execute such measures and the designation of responsibilities in regards to their execution. Generally, the plan begins with the making of a hazard or a risk map, in which members of the committee define the different hazards which the community is exposed to, the existing vulnerabilities and existing preparedness deficiencies. Once the risk to which the population is exposed to is determined, an inventory of the available resources to face the emergency or disaster is made, in which resources of every kind are included: materials, tools, vehicles, communications, logistic and it's source. Later on a listing of different actions is established, in which resources and responsibilities are designated in a certain way so that the response is executed efficiently.

**Divulgation:** due to the fact that the plan involves the movement of vulnerable groups, it is necessary to divulgate the plan and it's different phases to the community, so that the
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population knows how to react when an event occurs. In a sense, the population must know where the designated shelters are and what they may take with them.

Simulations: simulations are community exercises that are executed to fulfill two objectives: to determine existing critical issues in the emergency plan, which need to be improved through the analysis of results obtained from these exercises, and to train the different sub-committees and brigades with regards to their respective functions, as well as to be able to evaluate their performance during the exercise.

Training: the key to the success in the implementation of preparedness measures lies on the training of members of the emergency committee, volunteer brigades, and sub-committees. Generally the training is provided by members of several units of the national civil protection agency. The training includes every aspect of preparedness, such as the elaboration of an emergency plans, planning and execution of simulations, and other practical aspects.

Other measures to be implemented to reduce deficiencies in preparedness include the design and establishment of evacuation routes. The use of road signs has the goal of orienting members of communities where to go in case of emergencies and disasters.

Photo #8.6: a sign to orient the population on where to go in case of a disaster.

Generally four different kinds of signs are implemented:

- Arrows that indicate evacuation routes,
- Meeting points
- Shelter locations,
- First aid centers

Photo #8.7: a red cross is a typical signal to orientate the population towards a first aid post.

Other measures include the establishment of sirens to warn the population in case of critical situations, as well as the implementation of early warning systems in case of a potentially catastrophic event.

As it has been indicated earlier, early warning systems have the goal of warning the population in case of a natural event of proportions capable of provoking substantial damages. Any EWS must satisfy the operative criteria of providing a warning with sufficient anticipation so that the population can take the minimal precautions necessary in relation to the incoming event. In case of floods these systems are integrated around
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three components: monitoring of hydro-meteorological conditions, forecasting, and warning. The functional integration of such systems is shown in the next figure.

The monitoring of hydro-meteorological conditions can be executed in two ways. In the most sophisticated way automatic measuring equipment is connected to a satellite or radio communication system. Local hydro-meteorological conditions on the basin are then measured in real time and transmitted to a center with the purpose of being analyzed continuously. Forecasts are then issued when conditions are set for a large event. This type of systems is used in Central America by national institutions of meteorology and hydrology. However, the use of sophisticated equipment requires highly qualified personnel, as it's acquisition and operation is much more expensive.

In contrast with this sophisticated monitoring form, a simpler way has been designed, in which community members directly participate in all activities using very simple equipment. In this case, the operators of these stations report via HF or VHF radio networks the information they obtain to a local forecasting center, where data is analyzed using simple routines.

Among the major advantages obtained using community-based systems, the following can be mentioned:

- Such systems help national civil protection agencies to involve actively rural populations at risk.

- These systems incorporate a communication network via HF or VHF radio that allows the members of communities to exchange relevant social information, besides hydro-meteorological information.

- Such systems have a very low operational cost, since the monitoring equipment is very simple and the systems are operated by a group of volunteers in a permanent way. In recent emergencies caused by hurricanes such as Mitch, it has been demonstrated that the volunteers are capable of accepting the challenge of operating such systems in a continuous way during weeks, practically in a continuous basis.

The next figure shows a sketch of an early warning community system operated in the District of Chepo Panama [10]. The monitoring stations situated in the upper basin report data regarding river levels and accumulated rain to a central station (1) located in Chepo, where data is analyzed to generate flood forecasts. In case of floods, the communities of Lomas del Rio and Las Margaritas are warned. Every community is connected via the radio network which operates on a frequency provided by the Panama’s national civil protection agency, SINAPROC.
In regards to sustainability of such systems, the best experiences gathered in Central America point to those systems which are maintained by national civil protection institutions.

Figure #8.4: Sketch of the community-operated early warning system for floods in the Mamoni river, Chepo District, Panama.
CHAPTER IX: CONCLUSIONS

Natural disasters are the reflection of development processes articulated in an inadequate way, considering the geophysical surrounding in which communities are established. In a way, such disasters are the result of risk generation processes.

Risks are dynamic processes that are generated throughout many years or decades. The process of risk-generation can be based on trends, traditions, lack of knowledge about risks, non-adequate construction techniques, defective construction materials, economical limitations, etc. Disasters are no more than the products of these risks generating processes.

To reduce natural disasters it is necessary to focus and reduce risks; these processes that generate favorable conditions that make us so vulnerable. The reduction of risk encompasses many phases and sectors. It begins via an awareness at every level, including the evaluation of hazards that surround us, determining inherent vulnerabilities that we create, and performing studies about the mechanisms and strategies that we must impose to initiate the reduction of existing vulnerabilities and to avoid the construction of new vulnerabilities.

The tasks associated with risk reduction are the responsibility of every sector, due to the fact that the risks have been created because of negligence, by not wanting to face realities of events that we neglect but that can appear at any moment.

In many Central American countries, the task has begun with a better understanding of the hazards. To this date, much has been learned regarding diverse phenomena which manifest themselves in the region. The relation between these phenomena and local geological processes is now being studied to understand the hazards in a better fashion. Among these studies, hydro-geological hazards such as river floods and landslides are being undertaken.

The knowledge regarding these processes give us a clear idea of the territorial concessions that we must give to nature via measures referred to as land-use ordinances or norms. In a similar way, this understanding will help us establish measures that will help diminish the exposure to hazards.

At the same time, much emphasis has been placed on vulnerability reduction, initially in a conceptual way through awareness processes. In the future we will have to act at every level to introduce regulations and laws that allow municipal governments to implement building codes to avoid the construction of infrastructure in an inadequate way. We need to find ways to make the population understand that the mandatory implementation of rules and building codes, as well as the use of proper construction materials is a strategy which has the purpose of guarantying a sustainable development and minimize the impact of the phenomena.

In addition, financial sources, and strategies must be designed and established to help the population and the different institutions reduce existing vulnerabilities and risks. In these cases what is needed is the implementation of measures that provide the adaptation
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of structures to newer building codes that guaranty a minimal impact with respect to natural phenomena. In a similar way, the search for mechanisms to translate houses and infrastructure from high hazard areas to low hazard areas must be initiated. The establishment of buffer zones along river banks will allow municipal authorities to control urban growth, avoiding material damage to houses and other kinds of infrastructure during floods.

Without a doubt, all these processes will require technical and financial assistance and compromise with nature, compromise of the dimension of a infrastructure versus it’s cost, compromises between budgets and prevention.

As long as we learn to recognize existing natural phenomena in our surroundings, and understand how to construct our future considering the requirements that this surrounding sets upon us, in this measure we will be making our future development in a more sustainable one.
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REFERENCES


