Chapter 1

General Issues

Disasters are mostly caused by natural phenomena, even if many of their consequences must be attributed to human actions or negligence.

In order to control or minimize natural hazards, it is essential to know the characteristics of common adverse natural phenomena and how they impact on our environment. The study and proper management of such hazards is also a prerequisite for developing operational, planning, training and simulation programs.

These actions, which will be examined at greater length in the pages that follow, comprise several stages:

1. Becoming familiar with, analyzing, and assessing the presence of natural hazards and their effect on the equipment and infrastructure of the area under study, based on the vulnerability associated with such phenomena;
2. Estimating the potential impact of natural hazards on routine as well as longer-term development activities, and on the components of water supply and sewerage systems;
3. Devising and adopting measures to reduce vulnerability and mitigate the effects of hazards;
4. Programming emergency operations.

Types of Hazards

Depending on their origin, hazards can be of two types:

a) Those related to natural events, i.e., physical phenomena arising in nature;
b) Those caused by human activity.

This classification cannot be employed rigidly, since we often find interactions between natural phenomena and human actions. For instance, a landslide may be caused by erosion as a result of deforestation, by failures in channeling runoff or wastewater, or by settlements in unstable areas.

Another way of classifying hazards is by the way they occur:

a) Sudden onset, as in the case of earthquakes;
b) Gradual onset, as in the case of drought.

The various types of hazards manifest themselves as events that can have adverse effects and can potentially lead to an emergency or even reach the level of a disaster. However, it is common for the classifications above to be applied to disasters.

Following is a summary of the main characteristics of some hazards of natural origin.

Earthquakes

Dislocations in the earth's crust, the main cause of earthquakes, deform the rocks below the earth's surface and build up energy that is suddenly released in the form of seismic waves that shake the surface.

Earthquakes are one of the most serious hazards, given their enormous destructive potential, the extension of the areas affected, and the impossibility of forecasting their occurrence.

The main effects of an earthquake, depending on its magnitude, are:
- Fault lines along rocks and below the surface;
- Sinking of the surface;
- Avalanches, landslides, and mudslides;
- Liquefaction.

Earthquakes are classified according to their magnitude and intensity. Seismic magnitude refers to the amount of energy released, which is usually measured using Richter's logarithmic scale. Intensity is measured by the degree of destruction, normally using Mercalli's modified scale, which goes from I (intensity detected only by highly sensitive devices) to XII (total destruction).

The significance and type of damage relate to the magnitude of the earthquake and the area covered, the degree to which buildings and infrastructure are seismic resistant, and the quality of soil where structures are located.

An earthquake has a specific magnitude, but its intensity varies depending on the location of the area under study with respect to the epicenter, the geological characteristics of a site, as well as materials used for structures.

Following are some of the types of damage that an earthquake can inflict on water supply and sewage systems:
- Total or partial destruction of intake, transmission, treatment, storage, and distribution systems;
- Rupture of transmission and distribution pipes and damage to joints between pipes or tanks, with consequent loss of water;
- Interruption of electric power, communications, and access routes;
- Deterioration of the water quality at the source due to landslides and other phenomena;
- Reduction in yields from groundwater sources and flow in surface water sources;
- Changes in the exit point of groundwater or in the phreatic level;
- In coastal areas, inland flood damage due to the impact of tsunamis. Introduction of salt water into coastal aquifers.

Volcanic eruptions

Volcanic eruptions result from the release of energy caused by the movement of magma near the earth's surface. The volume and magnitude of the eruption varies depending on the quantity of gases, the viscosity of the magma and the permeability of the ducts and chimneys of the volcano. The frequency of these phenomena is highly variable: some volcanoes erupt continually, while others remain dormant for thousands of years.

Two kinds of eruptions constitute volcanic hazards:

- *Explosive eruptions.* These occur when gases dissolved in molten rock (or magma) expand and escape into the air. The force of escaping gas violently shatters solid rocks.
- *Effusive eruptions.* Here it is the flow of lava, and not the explosions themselves, that constitute the major threat. Lava varies in its composition and quantity.

A volcanic eruption can generate associated events that can have more severe consequences than the eruption itself. The following are two examples:

- Seismic events due to volcanic action;
- Avalanches, landslides, and mudflows (or lahars).

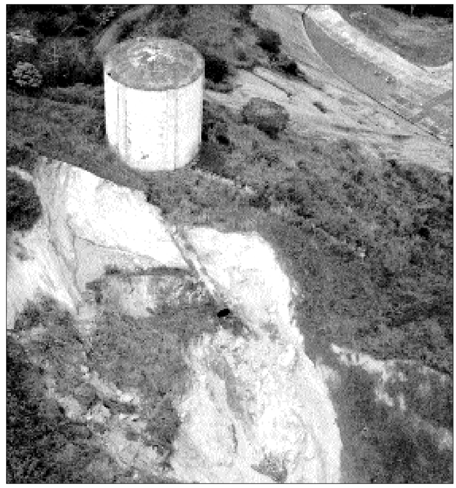
Needless to say, the eruption itself can be quite destructive, ejecting ashes, toxic gases, rocks and lava, sometimes over large distances.

The main potential effects of volcanic eruptions on water supply and sewerage systems are the following:

- Total destruction of the infrastructure in the areas directly affected by pyroclastic flows and surges. These flows tend to follow valleys and can destroy everything in their path;
- Obstruction with ash of surface water intakes, intake screens, transmission pipes, flocculators, clarifiers, and filters;
- Deterioration of the water quality at surface intakes and open reservoirs due to ash falls;
- Contamination of rivers, streams and springs in lahar deposition areas;
- Destruction of access roads to system components, communications and power lines;
- Fires;
- Collapse of or damage to structures due to ash accumulation.

Landslides

Landslides are the result of sudden or gradual changes in the composition, structure, hydrology or vegetation of sloping terrain. They are often closely linked to primary hazards such as earthquakes or water saturation caused by hurricanes or intense rainfall. In urban areas they are also associated with human actions such as providing drinking water services to communities located on slopes with unstable soil. Leaks in these systems lead to excessive moisture in the soil and can result in landslides. The situation can be critical when drinking water is supplied without providing proper sewerage at the same time.



Landslide at storage tank.

J. Grases, 1998

The magnitude of the impact of landslides depends on the volume of the mass in motion and its speed, as well as the extension of the unstable zone and the disintegration of the mass in motion.

Landslides can often be predicted, since they can be preceded by cracks and undulations in the terrain.

The most common effects of landslides are the following:

- Blockage or damage to roads along slopes;
- Changes in the normal flow of surface waters, such as rivers and streams, may result in dams or accumulations of water. Rupture of the dam can cause the violent discharge of great volumes of water or mud;
- Soils may sink or be displaced altogether, affecting houses, schools, roads and other structures.

Effects of landslides to be prevented in areas where water supply and sewerage system components are located include:

- Changes in the physical or chemical characteristics of intake water, which will affect treatment;
- Total or partial destruction of the works, particularly intake and transmission components in the path of active landslides;
- Contamination of the water at surface intakes located in mountainous areas;
- Indirect impacts due to the blocking of roads and the disruption of power and communications;
- Blockage of sewage systems due to buildup of mud and stones.

Hurricanes

Depending on wind speeds, these natural phenomena are called tropical depressions (winds up to 63 km/h accompanied by changes in atmospheric pressure), tropical storms (winds between 64 and 119 km/h accompanied by intense rainfall), or hurricanes (wind speeds of 120 km/h or higher, accompanied by heavy rainfall and significant changes in atmospheric pressure).

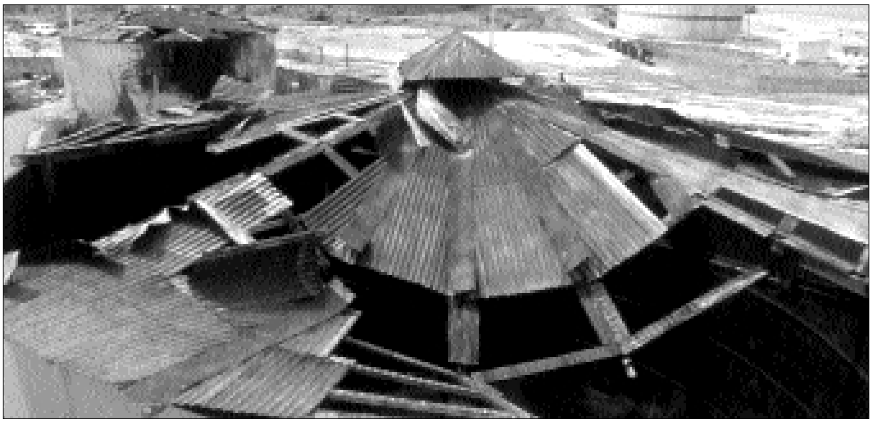
Hurricanes arise from the interaction of hot, humid air coming from the ocean and cold air. These currents gyrate and travel at speeds between 10 and 50 km/h, with an erratic trajectory. Some models are now available to predict the possible course of hurricanes, which can be adjusted as the event unfolds.

Hurricanes may have the following effects:

- Damage to power lines, including the collapse of posts and high-tension towers as a result of the high winds;
- Damage to infrastructure located near waterways;
- Damage to homes due to the strong winds, particularly in coastal areas;
- An increase in precipitation that may give rise to severe urban flooding.

The impact of hurricanes on water supply and sewerage systems can include the following effects:

- Partial or total damage to facilities, command posts and buildings, including broken windows, damaged roofs, and flooding;
- Rupture of mains and pipes in exposed areas, such as over rivers and streams;
- Rupture or disjointing of pipes in mountainous areas due to landslides and water torrents;
- Rupture and damage to tanks and reservoirs;
- Damage to electrical transmission and distribution systems.

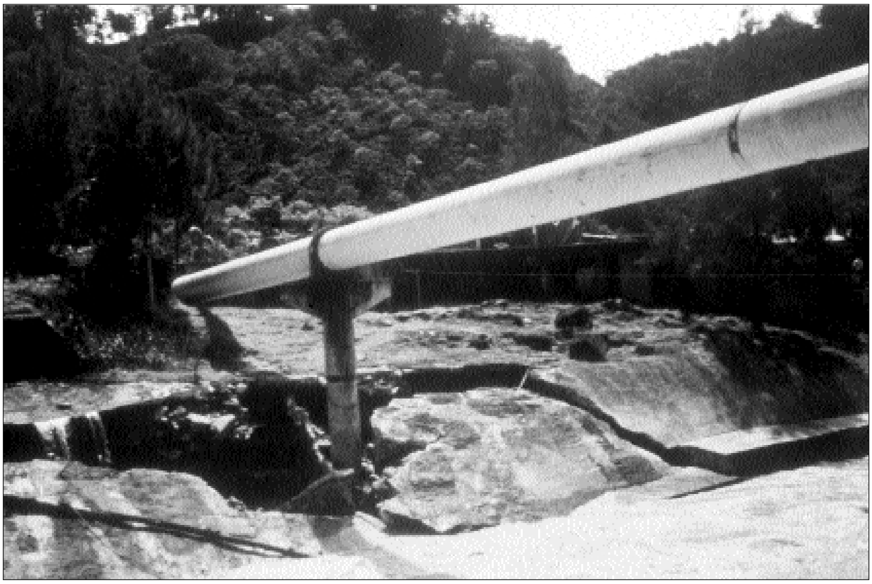


Damage to the roof of a water tank sustained during a hurricane.

PAHO/WHO

Floods

Floods are the result of excessive rainfall, unusually high sea levels, or the rupture of dams and dikes. Increasingly, floods result from human activity causing environmental degradation, deforestation, and inappropriate land use. On the other hand, some floods are the result of the geomorphology and climatology of water catchment areas.



Flood damage to the bridge supporting the main water pipe of the Orosi system in Costa Rica in October 1999. Some 500 tons of concrete were displaced.

A. Rodríguez

The magnitude of the effects of floods is related to the level reached by the water, its speed, and the geographical area covered. Other significant factors are the design quality of the installations and the type of soil on which they are built.

The usual impacts of floods are the following:

- Damage or destruction of housing built close to waterways;
- The flooding of urban areas—even entire cities—built in low-lying areas, affecting the economy and the provision of services;
- Accumulation of water in low-lying areas, creating breeding opportunities for disease-carrying insects.

The main effects of floods on water supply and sewerage systems are the following:

- Total or partial destruction of river water intakes;
- Damage to pumping stations close to flooding waterways;
- Blockage of components due to excessive sedimentation;
- Loss of intake due to changes in the course of rivers and streams;
- Rupture of exposed pipes across and along rivers and streams;
- Contamination in water catchment areas;
- Power cuts, road blockages, and disruption of communications;
- Intrusion of salt water into continental aquifers, contaminating or reducing the availability of groundwater.

Drought

Droughts are prolonged dry periods during natural climatic cycles, caused by a complex set of hydrometeorological elements that affect the soil and the atmosphere. They do not necessarily start when it stops raining, since enough water might have been stored in dams or in the ground to maintain the hydric balance for some time.

Among the effects of drought are the following:

- Reduction of surface water due to lack of rainfall, putting agriculture and animal husbandry at risk;
- Changes in the fauna where waterways are affected;
- Changes in the standard of living due to the negative impact of drought on the economy.

The potential impact of drought on water supply and sewerage systems includes the following effects:

- Loss or reduction of surface- and groundwater sources and deterioration of water quality;
- A decline in water levels at intake points and in storage facilities;
- The need to distribute water with water trucks, affecting quality and increasing costs;
- Damage to the system due to lack of use;
- Accumulation of solid matter in sewage systems.

Table 3 summarizes the impact of these adverse events on water supply and wastewater systems, as well as the severity of the impact.

Table 3. Magnitude of effects caused by hazards

Effects on water supply and sewerage systems	Earthquake	Volcanic eruption	Landslide	Hurricane	Flood	Drought
Structural damage to system infrastructure	●	○	●	●	●	○
Rupture of mains and pipes	●	○	●	◐	●	○
Obstructions in intake points, intake screens, treatment plants and transmission pipes	○	●	◐	◐	●	○
Pathogenic contamination and chemical pollution of water supply	◐	●	○	●	●	○
Water shortages	◐	◐	○	○	○	●
Disruption of power, communications and road system	●	○	◐	●	◐	◐
Shortage of personnel	●	◐	◐	◐	◐	○
Lack of equipment, spare parts and materials	●	○	◐	●	●	○

Symbols used: ● **Severe effect** ◐ **Moderate effect** ○ **Minimal effect**

Hazard Assessment

As will be seen further on, one of the key steps in vulnerability analysis is identifying and assessing the hazards prevalent in the area where the water agency's or company's systems are located, which calls for a review of the company's historical records and a description of the damage suffered by each system over time.

If the assessment reveals a high level of risk—such as the possibility of a major earthquake—it is best to hire specialists to carry out a seismic risk assessment of the system's structures. In any case, disaster planning available through professional evaluation will always be of use.

Assessments must be carried out for each of the hazards to which the site is exposed, and should consider the likely frequency, intensity, the area of impact and the potential damage. The highest priority should be assigned to those hazards most likely to affect the agency or company, its physical structures and its services.

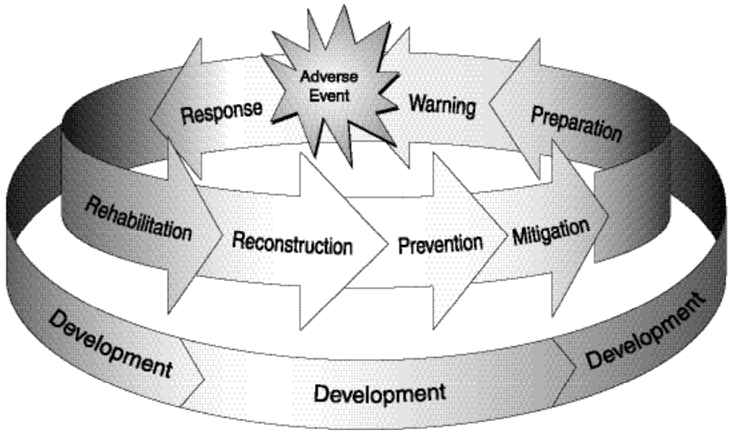
A given hazard may not affect the company's systems but rather the environment, including the population (which will logically include many of the firm's employees) as well as other companies or institutions that provide key services, such as electrical utilities or telecommunications networks. There may likewise be certain hazards that can affect some of the components of the system without affecting the company's customers.

The Disaster Cycle

The disaster cycle includes different stages, which can be summarized as three phases or periods:

- **Before the disaster,** which may be a period of calm or a declared state of alert depending on the event being analyzed;
- **During the disaster,** a stage that may be very brief or very long depending on the characteristics of the phenomenon;
- **After the disaster,** in which the focus is on recovering from the impact of the disaster, and which may be a short-, medium- or long-term endeavor.

Since it is difficult to identify precisely the beginning and end of each of these phases, it is preferable to speak of the different stages in the disaster cycle, which are summarized in the following figure.



Planning for emergency operations—also known as preparedness—involves designing a series of activities that, properly executed, should make it possible to prepare in advance for a disaster and respond promptly once it occurs. It is important to identify the activities to be carried out at each stage of the disaster cycle, particularly those involving the stage prior to the event, and the response stage, which must include the uninterrupted operation and maintenance of water supply and sewerage systems.

In planning for emergencies and disasters, the stage before an adverse event is the most important. It is then that one can anticipate the performance of the company and the physical components of water supply and sewerage systems.

Three sets of activities prior to the occurrence of a disaster or emergency are required:

- Prevention
- Mitigation
- Preparedness

After the disaster has occurred it is time for response activities, which may involve search and rescue, relief, and aid to the victims. Water supply and sewerage companies and agencies must respond quickly and effectively by implementing the emergency plan, and by trying to maintain the largest possible volume of water in the storage tanks until the actual condition of the systems can be verified.

The following set of activities is required after the onset of a disaster:

- Response
- Rehabilitation
- Reconstruction

The rehabilitation of water supply and sewerage systems is of crucial importance, since the speed with which these services can be restored will have a significant impact on the health of the population.

With reconstruction, the essential thing is for the company to incorporate prevention and mitigation measures when designing the new construction or retrofitting plans, so as to prevent the same weaknesses the systems had before the disaster.

Vulnerability Analysis and Measures for Prevention and Mitigation

Vulnerability analysis involves assessing the risks of physical, operational, or administrative damage to the various components of water supply and sewerage systems in the face of potential hazards. The results of the assessment should indicate those hazards threatening the entire system, as well as those that would affect only certain components.

After completing the assessment, one should have all the information required to carry out specific activities to reduce possible damage to the system through the prevention and mitigation program. If a given component cannot be modified to reduce its vulnerability, this contingency should be noted in the emergency plan. Since it takes time to carry out prevention and mitigation measures, the emergency plan must reflect current conditions, including those structures that are being retrofitted to reduce their vulnerability. Annex 1 presents two matrices identifying impacts of various hazards on water supply and sewerage components and measures that can be taken to mitigate these effects.

Vulnerability Analysis

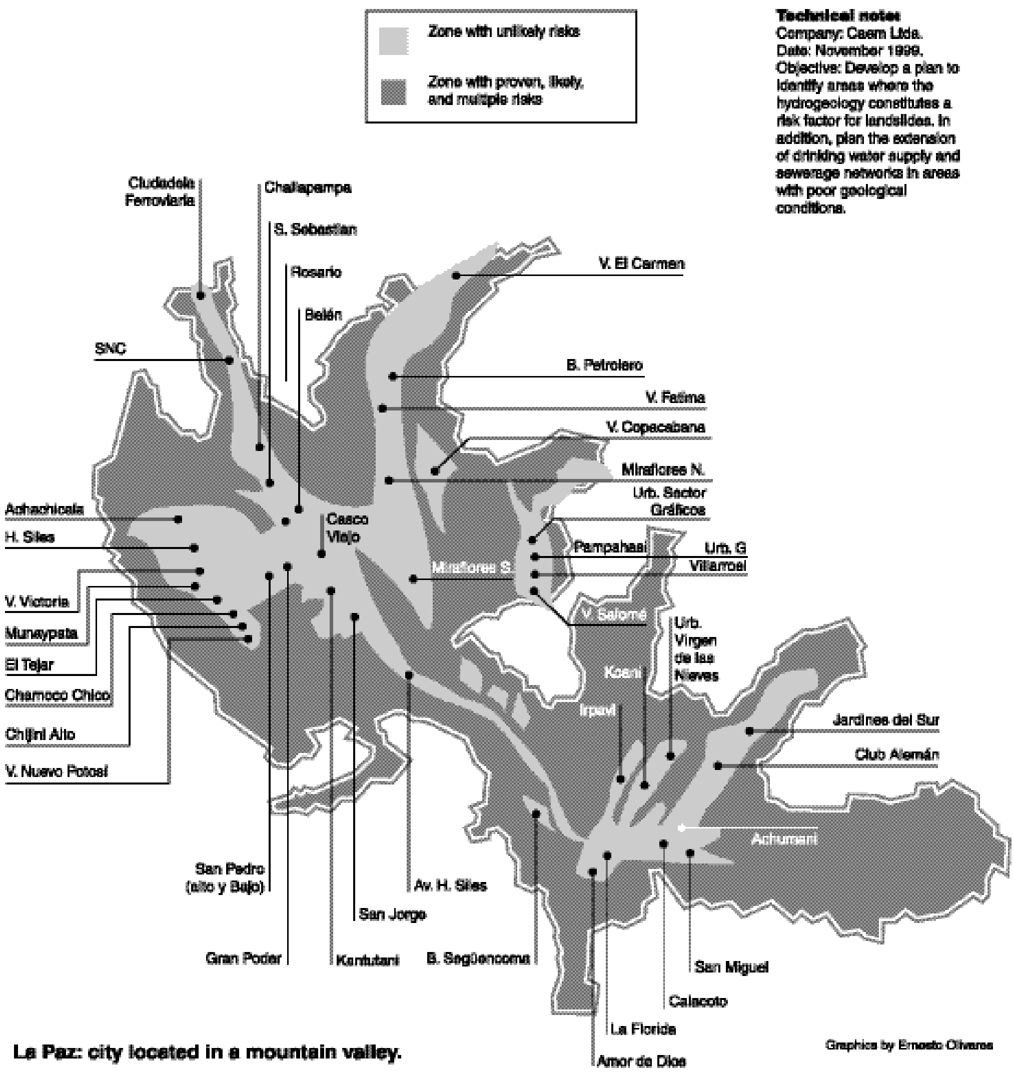
As already noted, vulnerability assessment is the starting point for effectively reducing the impact of disasters through prevention and mitigation programs as well as the design of emergency plans. This section presents some guidelines in this regard.[6]

The methodology for carrying out vulnerability analysis is based on the use of up-to-date and reliable information. One of the first steps is the collection of data about the components of the system, including information about the operational methods as well as the building plans of the structures to be protected. Attention must be paid to all the potential hazards in the vicinity of the system.

This first step makes it possible to present all the relevant information in

[6] For more information please see the book *Natural Disaster Mitigation in Drinking Water and Sewerage Systems: Guidelines for Vulnerability Analysis* (Washington D.C.: PAHO, 1998).

Risk Map of La Paz, Bolivia



Technical notes:
Company: Caem Ltda.
Date: November 1999.
Objective: Develop a plan to identify areas where the hydrogeology constitutes a risk factor for landslides. In addition, plan the extension of drinking water supply and sewerage networks in areas with poor geological conditions.

La Paz: city located in a mountain valley.

Graphics by Ernesto Olivares

1952 The engineer Ernest Drobovolny made the first geological studies of the La Paz valley. This study revealed two major landslides that occurred during the colonial period, affecting the Tembladerani and Santa Barbara neighborhoods.

1952 A slide occurred in Capitán Ravelo Street and there were frequent breaks in the Cotahuma and Pokeni streams. During this period, urban expansion began to take over the slopes of the mountains, and settlements were established in hazardous areas.

1990 - 2000 Various events were recorded in Callapa, Tejar, Alto Tacoma, Cotahuma, IV Centenario, Kupini, Alto Seguencoma, Alto Tacagua, Valle de las Flores, and Ventilla I. Other smaller slides occurred, but they are significant because they affected housing, roads, and the service infrastructure.

Hazard map prepared by Aguas del Illimani, La Paz, Bolivia, 2000.