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Disaster mitigation in drinking water and sanitation systems

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PREFACE

This slide show targets the many countries in Latin America and the Caribbean that are vulnerable to a variety of natural hazards. It is meant to serve as a training tool and information resource on the basic elements of disaster mitigation in drinking water and sanitation systems.

Emphasis has been placed on the impact of disasters on such systems and the mitigation measures that can be adopted to reduce it. The presentation follows up on an earlier PAHO/WHO publication, *Natural Disaster Mitigation in Drinking Water and Sewerage Systems: Guidelines for Vulnerability Analysis.*

Professionals and technicians involved in the design, construction, maintenance and management of water and sanitation infrastructure are the intended audience of this package, which aims to promote and facilitate the incorporation of disaster mitigation measures in such infrastructure, reducing the damage caused by natural disasters and ensuring the continuity of key services in their aftermath.

INTRODUCTION

This training material does not exhaust all the variables involved in reducing the vulnerability of water and sanitation systems to natural hazards. However, it does cover the content outlined in **Slide 1**.

GENERAL CONSIDERATIONS ON DISASTERS AND THEIR IMPACT ON WATER AND SANITATION SYSTEMS

(Slide 2)

Numerous natural hazards loom over Latin America and the Caribbean: earthquakes, hurricanes, volcanic eruptions, floods, landslides, and drought, to name but a few (see **Slide 3**). All too frequently, such disasters ravage our countries, leaving in the wake poverty and destruction.

Consideration of recent disasters reveals an increase in vulnerability due to man-made causes. Both the frequency and impact of disasters have increased. Among other consequences, water-supply and sewerage facilities are often seriously compromised, affecting the health and welfare of the population.

The reasons for protecting water and sanitation systems from natural disasters range from protecting public health to preserving the significant investments made by water companies. (See **Slide 4**.)

The interaction between natural disasters and water and sanitation systems has shown again and again how exposed the latter are to suffering severe damage. Moreover, development initiatives rarely take into account the effect of natural disasters on such systems. The results often are:

- Economic losses for the water companies (see **Slide 5** and **Slide 6**) due to the costly direct and indirect damage caused by disasters on such systems. Direct effects involve the physical damage to the infrastructure. Indirect damage is linked to the additional expenses that the water companies need to incur in to respond to the emergency, as well as the loss of revenue due to the interruption of their services. Studies carried out after the April 1991 earthquake in Limón, Costa Rica, proved that adopting all mitigation and prevention measures needed would have cost only five million U.S. dollars, as opposed to the nine million dollars' tab of response and rehabilitation efforts—a net loss of four million dollars. (See **Slide 7**.)

- A severe degradation of the quality of the services provided, leading to increased health risks. (See **Slide 8**.)

When a disaster damages water-supply systems the impact on public health is readily apparent, for instance in the drastic increase of acute diarrheic illnesses and other water-borne diseases. (See **Slide 9**.)

Slide 10 lists some of the reasons for the particular vulnerability of water and sanitation systems to natural hazards, from the geographical extension and physical characteristics of such systems to the overwhelming importance of a reliable supply of water in emergency conditions.

The only way to ensure that such infrastructure is capable of withstanding disaster situations is to apply prevention and mitigation measures that reduce the vulnerability of the systems.

Often, vulnerability starts with the choice of an inappropriate location for the system's components. (See **Slide 11**.) When a given component cannot be sited in a safe area, its design and construction must meet preventive criteria in order to ensure continuity of services in extreme conditions. **Slide 12** shows the construction of a retention wall to protect a pumping station from the landslides that were affecting it.

If for any reason mitigation measures cannot be adopted, it is necessary to know the vulnerability of system components to the various hazards prevalent in the area, so as to plan an effective response in case of an emergency. Minimum stockpiles of chemical compounds (**Slide 13**) and spare parts, previously identified as essential, are essential in responding effectively to disaster situations.

In order not to return to the levels of vulnerability that prevailed before such an emergency—and that become all too apparent after one has struck—preventive measures must be adopted throughout the various stages of rehabilitation and reconstruction, such as changing the materials used, the site of the components, or layout of the network. (See **Slide 14**.)

One of the peculiarities of water and sanitation systems is that each component might be exposed to different hazards. Hence, measures must be taken to respond to each of the vulnerabilities identified throughout the network. (See **Slide 15**[1].)

[1] this slide has animation and takes a minute in being displayed.

RISK MANAGEMENT (**Slide 16**)

Vulnerability is linked to the intensity and hazardousness of any given event as well as to the characteristics of the component in question. While hazards cannot be eliminated, vulnerability can be reduced to minimize the resultant damage and improve response in the immediate aftermath of a natural disaster. Reducing the potential impact of such an event calls for *disaster risk management.* Risk is directly proportional to the existing hazard and the vulnerability of the component in question (**Slide 17**). Risk reduction therefore requires reducing either the hazard or the degree of vulnerability.

When natural hazards are liable to affect water and sanitation systems, whether extant or under construction, risk management aims to reduce the effects of a potential disaster by taking prevention or mitigation measures. Specific measures are chosen after a vulnerability assessment has been conducted of the various components and the hazards to which they are exposed.

Slide 18 shows the mitigation measures applied to a water main. A seismic vulnerability assessment revealed the need to widen the main's foundations in order to make it safer and reduce the risk of failure due to earthquakes.

Mitigation requires an investment, and its cost must be estimated. However, water companies should bear in mind that vulnerability reduction minimizes losses and the need for additional investments after a disaster. Generally, the impact of such catastrophic emergencies sets back a water company's development plans by several years, since operation and expansion budgets must be reallocated to rebuild what has been damaged or destroyed.

This does not mean that costly investments are always necessary for effective mitigation, at least in comparison with the price tag of rehabilitation and reconstruction. (**Slide 19**.)

The costs associated with vulnerability reduction—as well as the risk management strategies to be followed—differ considerably depending on whether they apply to existing systems or those yet to be built (**Slide 20**). In the case of existing systems, the difficulties in reaching and modifying, or replacing, some components (for instance, underground mains) make the work more expensive. Systems still in the planning stage provide a unique opportunity to incorporate prevention measures into the original design, reducing costs without interfering with everyday operations.

This process of defining and implementing mitigation measures is greatly enriched when it is the result of interdisciplinary, interinstitutional efforts in which professionals and technicians contribute their knowledge and experience, making the entire group feel more motivated and committed to the success of the enterprise (**Slide 21**).

VULNERABILITY ASSESSMENT (**Slide 22**)

Risk maps

The impact of natural hazards on water and sanitation systems depends on the degree of exposure to the hazard, the technical characteristics of the component, and the structure of the system itself. It is therefore essential first of all to identify which hazards threaten the system, particularly since its geographical extension often means that different components are exposed to different hazards. (**Slide 23, Slide 24**.)

When hazards have been mapped and correlated with the location of the various components of the system, a risk map is obtained. It shows which components are exposed to which hazards, and is a first step towards vulnerability assessment.

Geographical information systems are highly effective for producing risk maps, since they analyze the available information graphically, allowing for the zoning of hazards and identifying the components most exposed to them.

Vulnerability Assessment

Vulnerability is the likelihood that an element or set of elements will be damaged or destroyed by the occurrence of a disaster. When a pipeline is laid out on a riverside, or following the course of a highway, the system is more exposed to damage if the volume of water in the river increases (**Slide 25, Slide 26**) or the road is hit by, say, an earthquake. To prevent this from happening, vulnerability must be assessed *before* such sites are chosen.

For instance, some professionals suggest that if the structure of a bridge is going to be taken advantage of to lay a pipeline, this should be done on the side of the bridge that is downriver, so that the bridge's beams can protect the pipes in the event of a flash flood.

Once the hazards prevalent in the area have been identified, as well as their potential effects, vulnerability analysis makes it possible to identify the physical weaknesses of the system components. Only by determining these weaknesses can corrective measures be taken (**Slide 27**).

Defining the criteria for reducing the risk to water and sanitation systems from natural disasters is the shared responsibility of water companies and the sector's regulatory bodies or supervisory institutions. When components are not properly sited, the infrastructure can collapse even in the absence of major disasters.

The vulnerabilities detected in the system may be identified either quantitatively or qualitatively so as to become aware of the situations of greater risk and assign priorities for meeting measures. In the case of each vulnerable component, an estimate must be made regarding the level of damage it may sustain in the event of a disaster, from no damage at all to the total destruction of the component. This analysis must be carried out for each specific event and each component of the system that is being assessed. (**Slide 28**.)

When carrying out the vulnerability assessment, it is necessary to identify the local and national agency in charge of disaster reduction, their procedures and methods, and the resources available tot hem. It is also important to characterize the area where the system component is located—distance from other towns, urban structure, public health situation, degree of socioeconomic development, services available, ways of access, etc.—and obtain a physical description of the system, including the most relevant information concerning each component and its operation, without leaving out seasonal data.

Slide 29 summarizes the links between the various risk management activities in water and sanitation systems. It underscores that, in producing disaster and emergency response plans, it is vital to be aware of the prevailing hazards and the potential impact they might have on the system components and the level of service. Vulnerability analysis requires that the following aspects be taken into account:

- ***Administrative aspects and response capacity*** **(Slide 30)**

  Next, operation and management standards and available resources must be identified, both in normal situations and in emergencies and disasters. The company's response capacity is partly a function of its prevention, mitigation and preparedness measures, the way it has organized the operation and maintenance of its systems, and the administrative support it can rely on for such tasks.

  In an emergency, it will be necessary to make decisions and carry out speedy actions that do not follow regular procedures, such as the issuing of public tenders for major equipment purchases or outsourced works. It is therefore important to develop special, streamlined administrative procedures that can be put into effect regardless of whether the emergency is decreed by the company itself or the local or national government.

- ***Physical aspects and impact on the service*** **(Slide 31)**

  Once the natural hazards threatening each system component have been identified, technical studies (vulnerability assessments) are carried out to estimate the damage each of them may undergo. Only then may the company estimate the level of service it could provide in the event of any given emergency. This can be determined in terms of the system's remaining supply capacity and the expected changes to the quality of the service. It will also depend on the time required to restore services, whether partially or totally.

- ***Mitigation and emergency measures*** **(Slide 32)**

  Having characterized the prevailing hazards and the likely damage to the system, it is now possible to design and implement mitigation, preparedness and response measures. Since systems that are invulnerable to damage in any form are financially and technically impossible, it is necessary to assign priorities to the mitigation measures to be implemented.

  The results of the vulnerability assessment can have different uses, depending on the company's resources and the criteria applied by management. **Slide 33** shows various uses to which the findings can be put. What is essential is that these assessments not remain mere academic exercises to be filed away and ignored by the company's decision makers.

TYPES OF HAZARDS AND THEIR CONSEQUENCES OF WATER AND SANITATION SYSTEMS (Slide 34)

The most frequent natural hazards in Latin America and the Caribbean are earthquakes, hurricanes, floods, landslides, volcanic eruptions and drought. **(Slide 35[2].)** *This slide is interactive; you can choose the types of hazard you intend to focus on.*

In this section, each of these phenomena will be described, including the factors that turn them into natural disasters, how they affect water and sanitation systems, and some specific mitigation and prevention measures.

[2] this slide is interactive, thus you will be able to select the type of disaster of its interest to display.

Earthquakes

Earthquakes may have various causes. However, their destructive power will depend in part on the characteristics mentioned in **Slide 36**:

- Maximum probable magnitude, which relates to the quantity of energy released by seismic motion.
- Intensity, measured by the Mercalli scale, which takes into account the effects felt by people, the damage to buildings, and the changes to the terrain.
- Likelihood of occurrence.
- Background—seismic events in the past as well as currently active faults. (The seismic history of the area is a key source of data.)
- Quality and types of soil and potential for liquefaction.
- Conditions of groundwater, level and variations over time.

It is important to be aware of potentially unstable areas: soil that is liquefiable or oversaturated, that might be displaced by a seismic event, and so on. The greatest danger is associated with fracture areas, seismic faults, and the former epicenters of destructive earthquakes.

Seismic events may lead to underground instabilities, the terrain caving in, landslides, rock slides or mudflows. They can also render oversaturated soil too soft, leading to its collapse and damaging system components in the affected area.

The types of damage wrought by earthquakes on water and sanitation systems include the following (**Slide 37**):

- Total or partial destruction of the collection, treatment, storage and distribution structure. **Slide 38** shows the damage to a treatment plant, which in addition to losing all its panels suffered severe damage to the structure itself.
- Rupture of the pipes and damage to the joints, leading to a drop in the water supply and alteration of its quality (**Slide 39**).
- Variations in the volume of surface or groundwater. Changes in the location where water comes out of springs.

Specific damage, as shown in **Slide 40**, can render the entire system unusable if components vital to its operation are affected.

Hurricanes

Hurricanes, which occur in tropical cyclone basins, originate in the North Atlantic and can affect the Pacific Ocean, the Caribbean, and the Gulf of Mexico. They are characterized by sustained wind speeds, cyclonic waves, alterations in sea level, heavy precipitation, and various effects inland (**Slide 41**). Information on historic events is useful to determine the specific nature of this hazard in any given location.

The strong winds associated with hurricanes are more likely to damage surface works; risk increases in direct proportion to the height of the works and the surface exposed to the wind, and depends mainly on whether the works were designed and built to resist such winds.

Hurricanes can cause different types of damage to water and sanitation systems (**Slide 42**):

- Partial or total damage to facilities or other structures due to the force of the wind or rains (**Slide 43**). Some of the damage to structures may be difficult to anticipate, as in the example shown on **Slide 44**.
- The rupture or misalignment of pipes in exposed mountain areas due to flash floods and landslides.
- Damage to superficial components such as catchment facilities (**Slide 45**) or electrical equipment damaged by flooding (**Slide 46**).
- Contamination of the water in tanks and pipelines.
- Rupture and failure of components due to subsidence of the terrain as a result of flooding in oversaturated areas.

Floods

Floods are natural phenomena that may be caused by excessive rainfall, hurricanes, abnormal rises in sea level, the thawing of ice and snow, or a combination of the above.

It is important to be aware of the factors that modify runoff behavior in a watershed. Some are climatic: variations in rainfall patterns, intersection areas, evaporation and transpiration. Others are physiographic: characteristics of the basin such as geological conditions, topography, the course of riverbeds, absorption capacity, type of soil, and land use (**Slide 47**).

Historical statistics (precipitation levels, river levels, etc.) are a key input for the design of water systems. Special attention must be paid to recurrence periods and variations in the water level over the years and decades.

Flood-prone areas such as floodplains are the ones most at risk. When siting system components, the nature of the terrain, including adjacent areas, must be taken into account.

Flood damage can take many forms: the wrenching force of flash floods, the impact of floating debris, landslides in oversaturated areas, rockslides, and so on. The amount of damage depends on the levels reached by the water, the violence and speed of its flow, and the geographical area covered.

The following are some of the forms in which floods may damage water and sanitation systems (**Slide 48**):

- Total or partial destruction of collection structures on rivers or brooks.
- Silting up of components.
- Depletion of catchments due to the diversion of river courses.
- Rupture of exposed pipes in the path of rivers or brooks.
- Rupture of pipes in coastal areas and adjacent to river banks due to storm surges.
- Contamination of catchment water.
- Damage to pumping equipment and electrical equipment in general.

Broadly speaking, both too much water and too little can be a problem for water supply and sewerage systems. In the case of floods, water and sanitation system components are most vulnerable when located where water collects or in the path of flash floods. (**Slide 49**.)

Some water-supply system components themselves may increase the vulnerability of the systems and that of the population, for instance when a dam or reservoir breaks (**Slide 50**), ruptures occur in high-pressure pipes, or drinking water is supplied to settlements located in unstable terrain without the necessary drainage, so that runoff saturates the soil causing landslides and other mishaps.

During floods, sanitation systems, particularly combined sewers, may become obstructed and fail (**Slide 51**). Sewerage obstructions and leaks put water-supply systems at risk from fecal and other contamination (**Slide 52**), particularly when water-distribution and sewage networks follow roughly the same layout and are thus in close proximity.

It should be expected that different areas, or of different extension, will become prone to flooding at different times, depending on precipitation and recurrence patterns (**Slide 53**). When waterworks are designed, it is vital that historical variations in precipitation levels or river overflows be taken into account.

Landslides

This phenomenon may be caused by earthquakes, intense rains, volcanic eruptions, even human activities such as those that lead to deforestation. Regardless of the cause, it occurs in isolated fashion in specific places, hence the need to identify those points in the system that might be affected.

In order to forecast landslides, it is essential to know the geology of the region, particularly steep slopes, ravines, drainage and filtration catchment areas, the topography and stability of the soil, areas with concentrated fissures and places where liquefaction has taken place due to earthquakes or precipitation. (**Slide 54**).

Vulnerability of water and sanitation systems to landslides is high, particularly in areas where collection facilities are located in mountainous areas and pipes must descend down mountain slopes to reach the areas serviced. In such areas, landslides may cause the following types of damage (**Slide 55**):

- Total or partial destruction of vital system components, particularly collection and conduction facilities, located on or near the path of landslides in unstable terrain with steep slopes.
- Water contamination in surface catchment areas in mountainous regions.

In many cases, inappropriate siting, or leaks in water-supply system components, can cause landslides that damage a given component or even render an entire system inoperative. (**Slide 56**[3].) *This slide is animated and takes one minute to view.*

Landslides are generally the result of cumulative changes over weeks, months, even years. Water companies often have enough time to take precautionary measures to prevent damage to the system (**Slide 57**). However, landslides caused by unpredictable natural phenomena such as earthquakes or heavy rainstorms (**Slide 58**) do not allow for preventive actions—unless these were taken at the time the system was designed.

[3] this slide has animation and takes a minute in being displayed

Several measures are available to reduce vulnerability to landslides. They vary depending on the particular needs of each case (**Slide 59**):

- Reforestation campaigns.
- The construction or reinforcement of retaining walls and drainage components.
- Slope stabilization.
- When pipes have to be laid on slopes, use of materials appropriate to the contours of the terrain.

Volcanic eruptions

Volcanic eruptions differ in their effects depending on the type of emissions that occur, the viscosity of the magma, the quantity of gases released, the flow of lava (which varies in volume, extension, thickness, and speed of movement), the type of ashes ejected, and the areas subjected to lava flows and ash fall. (**Slide 60**.)

Although the frequency of eruptions is notoriously erratic, historic and even prehistoric records provide clues to the recurrence of this phenomenon. Most active volcanoes in Latin America and the Caribbean are monitored in some fashion, allowing for the adoption of preventive measures before the most critical stages of the eruptive phase.

Generally, volcanic eruptions unleash a chain of disasters—landslides, mudslides, avalanches and rock flows due to the extreme heat and vibrations, as well as emissions of ash, dust or gases.

Impact areas may be covered by lava or affected by acid rain and ashes. The waterways, treatment plants and pump-houses located in such areas are most at risk.

Volcanic eruptions can affect water and sanitation systems (**Slide 61**) in several ways:

- The total destruction of system components in areas of direct impact. (**Slide 62**.)
- The obstruction by ashes of catchment facilities, silt basins, water mains, flocculators, and filters. (**Slide 63**.)
- Degradation of water quality due to ashes; pollution of rivers, brooks and water bodies in the areas where ashes fall.

To reduce such risks, the following measures should be taken:

- Protecting reservoirs and other water storage facilities by covering them either permanently or temporarily. (**Slide 64**.)
- Building alternative (redundant) water-supply and sewerage systems.

Drought

Drought is a reduction in the water or humidity available that brings about a decrease in the normal flow rate of surface and ground water sources. The precise definition of drought varies depending on whether it is viewed as meteorological, hydrological, or agricultural (**Slide 65**).

Areas most vulnerable to drought are those with a predominantly dry climate where soil does not retain much humidity. Drought may bring about a reduction or even extinction of the water supply from habitual sources. Surface water sources such as rivers and lakes generally suffer the effects of drought much earlier than groundwater sources. Drought may affect the drinking water supply (**Slide 66**) in the following ways:

- Loss or decrease in the flow of surface or ground water.
- Degradation in service quality or increases in operation costs.
- Rationing or suspension of the service.
- Inability to rely on the current system.

Certain prevention and mitigation measures can be taken (**Slide 67**):

- Assessing the conditions of existing wells.
- Assessing the quality and volume of underground water, and having the equipment needed to facilitate operations in the event of a decrease in volume while preventing pollution of water sources.
- Establishing alternative sources and interconnecting them with existing systems; considering the possibility of emergency drilling.
- Rationing water consumption.

DISASTER PREVENTION AND MITIGATION

(**Slide 68**)

Vulnerability reduction can be achieved through the use of prevention and mitigation measures that help correct deficiencies before disaster strikes and minimize the risk of failure in normal conditions. Mitigation and prevention is the product of interdisciplinary efforts by professionals with experience in the design, operation, maintenance, and repair of the system components. It is therefore not an isolated task, but an integral part of all planning and development decisions regarding water and sanitation systems.

Mitigation and prevention is practiced (see **Slide 69**):

- In new works, by applying prevention criteria in the design, choice of site, selection of materials, grid design and incorporation of redundancy components.
- In existing works, by engaging in conservation and maintenance activities, repairs, replacement of old components, relocation of incorrectly sited components, and new projects aimed at increasing redundancy.

Priority must be given to those actions that take into account:

- The Magnitude of the Decrease in Supply (MDS) with respect to total supply volume.
- The Time Needed to Repair the component that is out of order (TNR).

$$MDP = \frac{Q_{\ remanente}}{Q_{\ producción}} * 100$$

The units of measure to quantify risk are Lost Production Days (LPD), equivalent to the decrease in the total capacity of the system while repairs are carried out. This indicator is independent of the frequency of the hazard; in relation to reserve capacity, it makes it possible to characterize existing risks and define mitigation measures. As a top priority, those components should be considered in which total LPD is greater than reserve capacity.

$$DPP = MDP * TRF$$

The purpose of this prevention and mitigation strategy is to counter the weaknesses in the system based on the frequency and intensity of the phenomena that may occur.

In most cases, the problems that cause damage to water and sanitation systems are not exclusively related to the disaster itself, but rather reflect insufficient consideration of natural phenomena as a variable in the planning, design, construction, operation and maintenance of such systems. (**Slide 70**.)

Most hazards can be mitigated by decentralizing water and sanitation systems; for instance, by establishing alternative water sources so as not to disrupt the service. One way of achieving this is to incorporate redundancy into the systems. Should damage occur to a component or system, another connection is available that can be brought on line promptly so that services can be restored without delay. Special emphasis must be placed on the desirability of having control valves in strategic locations. (**Slide 71**.)

Interconnected systems and redundant components increase the reliability of the system as a whole and provide greater flexibility even when engaging in routine tasks such as maintenance.

Operation and maintenance activities are an ideal opportunity to work on reducing systems vulnerability (**Slide 72**). However, some situations call for the execution of special works and projects aimed exclusively at vulnerability reduction (**Slide 73**).

If the vulnerability assessment uncovers a highly vulnerable component and the decision is made not to intervene for cost reasons, the company should at least have the necessary material to replace the component as quickly as possible in the event of failure. Water companies' purchasing departments should prioritize those materials and equipment that will be required in major emergencies and would be hard to procure in the local market. Moreover, spare-part and accessory storage facilities should be decentralized, located strategically, and properly protected so they can continue to operate in an emergency. (**Slide 74**).

When it is difficult to inspect system components, it takes longer to identify which have been damaged, increasing the time of time required for rehabilitation (**Slide 75**). In the design and construction of sanitation works, attention must be paid to how difficult it might be to reach certain areas and components (**Slide 76**).

In an emergency, efforts to restore the service as quickly as possible often lead to rehabilitation works that are carried out without regard for disaster mitigation, often preserving or even increasing the degree of vulnerability prevalent before the emergency. Rehabilitation measures that are applied without regard to prevention solve the problem in the short term, but in the long run can be much costlier (**Slide 77**).

Thanks to advances in disaster mitigation and technology, it is increasingly more feasible to assess the expected behavior of the physical components of sanitation systems. However, it would be unrealistic to expect even the most thorough prevention measures to keep all system components intact in the event of a major disaster. The goal of disaster mitigation is to reduce such damage as much as possible. However, the company should not refrain from planning alternative methods of distributing water to the population should a disaster strike. (**Slide 78**.)