Error! Bookmark not defined.**CHAPTER 2**

Error! Bookmark not defined.**VULNERABILITY ANALYSIS**

Error! Bookmark not defined.**1. INTRODUCTION**

The basis of preparation of the mitigation and emergency plan is the knowledge of **operational vulnerability** (deficiencies in the provision of services, such as quantity, continuity and quality of the water supplied and quantity of wastewater disposal), of **physical vulnerability** (the physical weaknesses of the systems components), and of **administrative vulnerability** (organizational and administrative weaknesses of the utility to respond to the impacts).

The area threats are identified through the analysis of natural phenomena probabilities and the estimate of human activity and the system's operational risks. The human activity risks have also been called technological risks.

The process of identification and quantification of these weaknesses is called vulnerability analysis and is the process through which the capacity of the system and its components is determined in order to resist the threat impact. The system and organization strengths are also identified, for instance, personnel with experience in operation, maintenance, design, and construction to face emergencies and disasters.

The vulnerability analysis fulfills three basic objectives:

a. To define the measures included in the mitigation plan, such as reinforcement works, specific plans for basin improvement and detailed studies of foundation and structures to reduce the component's vulnerability.

b. To define measures and procedures to prepare the emergency plan, which will facilitate the utility mobilization in order to provide the service when facing emergencies and disasters if the impact occurred before implementing the mitigation measures.

c. To evaluate the effectiveness of the mitigation plan, the emergency plan and the implementation and training activities such as simulations, seminars and workshops.

The process starts from the knowledge of the system and its components, its operation and the characterization of the occurrence that will impact it. The overlapping of the occurrence on a map of risks over a map of the system will determine the most vulnerable components and as a final result, will identify the mitigation measures that should be applied and the emergency measures that should be implemented if the mitigation ones would have not been considered.

Every work should be followed by a vulnerability study, in such a way that, before its construction, all possible disasters and emergencies inherent to the area are foreseen. Many of the problems that are presented when the threats impact a system are due to problems that were not foreseen when conceiving and designing the works, such as the location in land vulnerable to floods and geological faults, deficient building structures, rigid pipe installations, etc.

This chapter presents the general methodology or steps necessary for preparing the drinking water and sewerage system vulnerability analysis. The methodology is simple in order to facilitate its application in the most common situations that could be presented in the different geographical areas of the Region.

Error! Bookmark not defined.2. CONCEPT OF VULNERABILITY

In its broader sense, vulnerability is the susceptibility or internal risk factor of a component or system as a whole, to be totally or partially damaged by a threat impact. The magnitude of the quantified or measured damage is called vulnerability.

There are two conditions that contribute to the component's vulnerability:

a. The existence of the threat

b. The weakness of the component.

These two conditions should be analyzed separately and in a combined form, since the first one depends only on the area where the component is and the second one depends on the component itself: location, state and conservation.

The existence of the threat is a condition of the area where the element settles, for instance: area affected by floods, seismic area, etc. The weakness of the element depends on two conditions.

a. The location of the component with regard to the area or threat impact, for instance, areas susceptible to floods, areas close to geological faults

b. The state, conservation, and maintenance of the component. For example, a pumping station in bad conditions due to old equipment and lack of maintenance located in a very safe site, will be vulnerable due to its own state. If the season is, in addition, susceptible to floods under certain conditions, it will be vulnerable due to its own condition and location.

The knowledge of the vulnerability magnitude will determine the mitigation and emergency measures to be implemented in order to face the impact.

The vulnerability of an element can increase or decrease depending on the conditions of their environment and constitution. Thus, the vulnerability of a drinking water pipeline that runs parallel to a river can increase if the river changes its course and approaches dangerously to the pipeline, and it can decrease if protection walls are built.

The vulnerability analysis as a diagnosis is applied not only to the impact of serious natural phenomena such as earthquakes and hurricanes, but also to the risk of accidents that affect the services, such as contaminations, epidemic outbreaks, and pipeline ruptures.

Error! Bookmark not defined.3. APPLICATION OF THE VULNERABILITY ANALYSIS

The vulnerability analysis is applied to each component of the system as a result of the individual analysis of its components. It is applied as a diagnosis tool for the preparation of the mitigation and emergency plans in the planning phase for the preparedness of serious natural disasters and those situations that restrain the continuous and permanent delivery of the services.

In general, it is applied first to the operational situations and to the organizational and administrative aspects; and subsequently to the natural phenomena impact, which facilitates its application when gaining experience in situations that range from lower to higher complexity.

Error! Bookmark not defined.4. LEVELS OF ANALYSIS

The vulnerability analysis is carried out in three levels, namely:

a. First level: detailed analysis
b. Second level: specialized analysis
c. Third level: evaluation analysis.

Error! Bookmark not defined.4.1 First level or detailed analysis

This first level is used to determine the mitigation and emergency measures that should be implemented in order to reduce the vulnerability of the system considering its operational, physical and administrative components. In this level, higher complexity studies that should be carried out and that correspond to the second level are also identified.

The analysis is carried out by stages, from the simple recognition to locate the situations that compromise the components, up to detailed engineering, structural and hydrologic studies.

The analysis complexity will depend on the system. In the simplest rural and urban systems a detailed tour will be enough to determine the vulnerable situations and the required mitigation and emergency measures to be implemented for the typical threats of the area. In the largest and metropolitan urban systems, high complexity studies will be required depending on the system.

Error! Bookmark not defined.4.2 Second level or specialized analysis

This second level involves specialized vulnerability studies that the drinking water and sanitation utilities usually are not able to perform, such as structural analysis studies of dams, treatment plants, storage tanks, large diameter pipes, slopes and soils stability, hydrologic studies of avenues, silt control and basin management, etc.

These studies are headed toward determining the structure vulnerability and the mitigation measures, such as programs for an integrated basin management to improve and maintain the water quantity and quality and reduce silt hauling; water catchment improvement and substitution works (i.e, surface catchments through infiltration galleries); structural reinforcement works.

flexible treatment of large diameter-pipes; works headed toward improving equipment redundancy and operational flexibility, etc.

The need for these studies is identified at the first level of analysis, where the available information is compiled and the reference terms are prepared for contracting specialized consultants.

Error! Bookmark not defined.4 3 Third level or evaluation analysis

The vulnerability analysis at the third level presupposes the effect of a mitigation and emergency plan and is carried out after a threat impact and after simulations, vulnerability analysis workshops and seminars.

The previous activities must be continuous and permanent, in such a way that the emergency plan remains in effect throughout the year and not as a simple document to be used in case of emergency.

Error! Bookmark not defined.5. MEASUREMENT OF THE VULNERABILITY

It is necessary to "measure" the vulnerability in such a way to be able to compare the components and give priority to the critical or vulnerable components when implementing the mitigation measures. Several methods have been proposed and some require a complex probabilistic estimate.

It is intended in these Guidelines to establish an easy methodology that allows to quickly and effectively determine the critical components for the preparation of the mitigation and emergency plan. The two methodologies proposed are the following:

Error! Bookmark not defined.5.1 Methodology of the American Water Works Association

The AWWA establishes the reliability (CE) of a component in terms of water production capacity (Qp) after the impact with respect to the required water quantity (Qn). Thus, the reliability is expressed as:

$$CE = Qp / Qn$$

Vulnerability is the opposite of reliability and is expressed as:

$$V = 1 - CE = 1 - Qp / Qn$$

Thus, for example, if 30% of a catchment is spoiled after a flood, the reliability and vulnerability values will be 0.7 and 0.3, respectively. Both values can be expressed as 70% and 30%, respectively for the previous example.

Although this methodology gives a vulnerability value, the value reports that the catchment has an operation index of 70% and that it will be necessary to rehabilitate it in order to capture the remaining 30%. Nevertheless this value by itself does not give an idea of the damage magnitude, nor of the time that the rehabilitation will take, which is an important value to determine if it will be necessary to provide the lacking one, or the minimum water requirement of the population in need of the service during a considerably long period.

Error! Bookmark not defined.5 2 **Methodology of the rehabilitation times**

This methodology was developed in CEPIS by the author of these Guidelines upon seeking a vulnerability measure that reports not only the component's remainder capacity but the magnitude of the damage and the rehabilitation expectations in terms of time. This methodology is applied to structural components such as pumping stations, storage tanks, treatment plants, or line conveyance or distribution pipelines. The method requires specialized analyses in the case of aquifers or large dams.

The rehabilitation time depends on:

a. The magnitude of the damage
b. The availability of human, material, financial and transportation resources to repair the damage
c. The access to the site where the rehabilitation should take place

The rehabilitation time (RT), in days, is established for each affected component of the system. Therefore, it will be necessary to calculate the RT for each component and for the system as a whole.

This methodology is applied also by rehabilitation stages. For example, an RT can be established for a given component at 25%, 50% and finally at 100% of its capacity. This is expressed as RT_{25}, RT_{50} and finally RT, that amounts RT_{100}.

To establish rehabilitation times, broad experience in rehabilitation, reconstruction and repair is required. Detailed knowledge of the drinking water supply system, the available resources and the capacity of the utility to face these situations with its own resources, and civil defense and private enterprises resources are also necessary.

Once the RT is established for the components, it is necessary to estimate the RT for the system, that will be the sum in "series" or "parallel" of the component rehabilitation times. It is made in series when the rehabilitation is done one after the other or when a component is rehabilitated followed then by the second one because of resources. It is parallel when the rehabilitation is carried out simultaneously or independently.

In order to estimate the RT it is necessary to carry out a detailed analysis of each component once the damage degree is determined. Personnel, equipment and materials needed for the procedure rehabilitation and improvement can be identified through this analysis.

As an example, the partial times are indicated in order to establish the RT of a broken large diameter pipeline:

- Number of damages expected
- Time taken to report the damage
- Time taken to close the valves
- Mobilization time to initiate the repair (personnel, equipment, materials, etc.)
- Time taken to access or to arrive to the damaged place
- Time taken to execute the repair (depends on the damage and the existing resources magnitude)
- Waiting period after the repair, before reinitiating the operation (to wait for the anchorage to forge, for example)
- Operation time (pipes filling).

The total sum of these partial times will correspond to 100% of the piping capacity RT.

In an exercise about a drinking water management and distribution system, for instance, the estimated RT will have two purposes: to compare the RT of the different damages in order to determine the critical components or those with higher RT and thus, prioritize the execution of mitigation or reinforcement measures; and to determine other ways of supplying drinking water during rehabilitation, such as water distribution in tank trucks, qualification of other sources, etc. that should be included as a procedure in the emergency plan.

It is important to take into account that the determination of definite RT may lead to an iterative process. For some initial resources an RT will be obtained for a given component. It may however not be acceptable, therefore resources would have to be reassigned When continuing the analysis for the rest of the system, it may perhaps be necessary to reassign the available resources to the reparation of other component with higher priority.

Error! Bookmark not defined.6. STEPS OF THE ANALYSIS

In order to carry out this analysis it is necessary to be aware of the national organization and regulation concerning emergency and disaster preparedness; to identify and characterize the possible area threats; and to know in detail the drinking water supply system, its components, and operation.

The overlapping of threats over the system's components will determine their resistance capacity and their weakness or vulnerability and thus, the mitigation and emergency measures will be determined.

The analysis of the different probable threats in the area will generate a general table of threats, components and RT, which will allow to determine that the critical or most vulnerable components of the system are those with greater RT.

The vulnerability analysis must be carried out by professionals with broad experience in the operation, design, and repair of the system's components. A good dose of imagination is also required to foresee possible damages and measures that could be avoided.

The drinking water or sewerage systems vulnerability analysis demands the following steps.

Error! Bookmark not defined.6.1 First step: Identification of the current organization and legislation

a. National and regional organization

Prior to the vulnerability analysis, it is necessary to identify the national and regional organization, its operation standards and the available resources that could be used for water supply and wastewater disposal in case of emergency and to collaborate during the rehabilitation.

It is common that these organizations have portable plants and heavy construction equipment to repair both the drinking water and sewerage system, aspects that should be assessed in the analysis preparation The information obtained in this first step is the basis for completing the third vulnerability matrix.

b. Current legal regulation

The following legislation must be identified at this stage:

i) Legislation and regulation regarding the preparedness of the different emergency and disaster phases, civil defense, emergency commissions, national, regional and local organizations, etc.

ii) Applicable civil responsibility and liabilities legislation in the management of emergencies and disasters at the utility and staff member level.

iii) Codes for the design and analysis, such as seismic codes.

Error! Bookmark not defined.6.2 Second step: Description of the area and system and its operation

a. Description of the area

It is suitable to characterize the system area through the following data: location (distance to other populated centers, region where it is located, etc.); weather (temperature, precipitation, moisture, etc.); population (growth rate, density, etc.); urban structure (neighborhoods and villages, industrial, commercial and household areas, type of dwellings, construction quality, etc.): public health and sanitation (health services, refuse collection, health statistics); socioeconomic development (socioeconomic activities, unemployment, etc.), geological, geomorphological and topographical data.

It is important to know the area services: communications (television, radio, mail, telegraph, telephone, fax, etc.); access and communication routes (roads, trains, airports, fluvial and marine ports, as well as trip frequency in the different routes); electric power (who operates it, coverage, reliability, safety, etc.).

It is necessary to evaluate the physical and administrative vulnerability (response capacity) of the communication and electric power supply routes (for systems with pumping) in coordination with the corresponding ministry and utility. This information is very useful when proposing mitigation and emergency measures, since it may significantly modify the estimated RT, and thus the types and costs of such measures.

b. Physical description of the system

The physical plans of the system will be compiled at this stage and the system will be described with each component's most relevant data: elevations, materials, diameters, volumes, etc. The description will be accompanied by a precise outline that will facilitate the system comprehension.

c. Functional description of the system

Parallel to the physical description, the description of the system operation will be done with each component's most relevant data: flows, levels, pressures and service quality. In the case of drinking water it is necessary to know the quantity provided, supplies and total, service continuity and water quality. In the case of the sewerage system it is necessary to know the coverage, disposal capacity and the effluent and reception bodies quality.

The description will be accompanied by precise outlines which will facilitate the system's comprehension. Summer and winter period variations presenting different operation and service condition modalities should be considered. This information will serve to complete the operational vulnerability matrix.

Error! Bookmark not defined.6.3 Third step: Estimate of the operational vulnerability (first vulnerability matrix)

In the case of drinking water systems, the analyzed component, catchment, treatment plant, tank, supply area, or pressure area should be recorded in the first column of the matrix. In the second column, the component capacity, current requirement and surplus or deficit. In the third column, the service continuity of pressure areas or network sectors and in the fourth column, the water quality with its deficiencies (if any). If there is no required component (reservoir, for instance), zero will be recorded in the second column (capacity), and in the third column the volume will be registered as deficit.

For sewerage systems, the analyzed component will be recorded in the first column of the matrix: collection and conduction area, treatment plant, and final disposal. In the second column, coverage; in the third column, the capacity and deficit (if any); and in the fourth column the final effluent quality indicating the final disposal source.

Error! Bookmark not defined.6.4 Fourth step: Estimate of the physical vulnerability and impact on the service (second vulnerability matrix)

a Identification of threats

In the first column of this matrix the area threats that could affect the physical drinking water or sewerage systems will be recorded. The analysis should be done for each system separately. In this column a brief description of the threat and its effects will be done. The threats should be classified as follows:

i) Originated by natural phenomena such as earthquakes, hurricanes, floods, volcanic eruptions, etc.

ii) Originated by human activity such as chemical spills, contamination, etc.

iii) Originated by the system operation such as ruptures of large diameter pipelines

b Characteristics of the threat

In the second column, the values inherent to the threat will be indicated, for a hurricane, for instance: forecast of the impact area, time of duration of the impact, expected wind speed, expected precipitation, and probable water levels in the channels. For earthquakes: sources of the threat, values of recurrence, maximum magnitudes, maximum probable duration, and expected accelerations and displacements.

This information will be expressed in an area map or plan. These characteristics should be as close as possible to the impact forecast and obtained from the occurrence probability analysis.

Thus, it is necessary to appeal to specialized analyses of the threat history in the region. This information should be expressed in seismic or hydrologic risk maps in such a way that the overlapping at the same scale of the risk maps with the drinking water system plans will indicate the components of higher risk.

c. Relative priority

In the third column, the threat priority will be recorded if the area was subject to several threats. When initiating the analysis, the priority of each threat is not always known with accuracy. Therefore, tentative priorities that will be corrected once concluded the analysis will be indicated at the beginning.

d. Information and alert systems

The fourth column of the matrix will be subdivided into three subcolumns. In the first subcolumn, the information and alert systems towards the utility will be indicated for each threat and at the same level, for instance, the communication system between civil defense and the utility. In the second column, the information systems within the utility and towards its regions. In the third subcolumn, the information systems after the occurrence, included the mass media and the information to the clients. In the later vulnerability analysis, the effectiveness of these systems and the necessary improvement measures will be evaluated so that the systems operate effectively.

e. Impact areas

In the fifth column the direct impact areas will be indicated, for example: catchment areas due to strong rains; areas of smooth and loose soils where pipelines are located in the case of earthquakes, etc.

At the same time, the impact areas will be indicated on risk maps based on maps of the area under study, for instance, geological information maps where the seismic information will be recorded; general information maps where the information on flood levels will be registered for the different occurrence periods, etc.

f. Exposed components

In the sixth column the structures of the components exposed directly to the threat impact will be registered. The components should be indicated preferably in the sense of the water flow and classified in the following way: catchments (different types) and their structures, pipelines, treatment plants, pumping stations, storage tanks, conveyance networks or main lines and distribution networks.

g. Characteristics of the impact: damages, vulnerability (RT) and remaining capacity

This seventh column will be divided into three subcolumns. In the first one, the characteristics of the impact on each exposed element will be described. In the second one, the estimate of the rehabilitation time before the impact. In the third one, the component's operation remaining capacity in flow and percentage units. The rehabilitation time and remaining capacity correspond to the vulnerability values of the exposed component.

This information is the key of the vulnerability analysis and should receive special emphasis. It should be prepared by professionals with broad experience in operation, maintenance, design, and rehabilitation of drinking water systems, that may accurately predict the situations generating the impact in order to determine the vulnerability parameters.

h. Impact on the drinking water or sewerage system

In this eighth column and for each exposed element, the impact on the service, the population that remains partially or totally without service, the quantity of people and areas of service, and the priority services of the area such as hospitals, shelters, etc. should be registered. This information, together with the rehabilitation time, will be used to indicate in the emergency plan the needs to provide water by other means, the time taken to implement this service, and the priority connections and facilities to face the drainage.

Error! Bookmark not defined.6.5 Fifth step: Estimate of the utility's administrative vulnerability and response capacity (third vulnerability matrix)

a. Institutional organization

In the first column of this matrix the result of the vulnerability analysis corresponding to the institutional organization will be indicated. The central, regional and local level should be distinguished.

The most relevant aspects to consider are existence of the emergency and disasters preparedness program and the mitigation and emergency plans; constitution and operation of the emergency committee and the plan formulation commissions; grade of dissemination and knowledge by the staff members involved; coordination aspects with civil defense or corresponding agency, power utility, communications; and evaluation of the information and alert system.

It is also important to consider the management experience in situations and the existence of unwritten routines, but already tested in previous emergencies.

b Operation and maintenance

In the second column of this matrix the result of the vulnerability analysis corresponding to operation and maintenance aspects for the central, regional and local levels will be registered. This is a key aspect in the emergency and disaster preparedness and the utilities with adequate preventive and corrective operation and maintenance programs are in better condition to provide an effective response to emergencies and disasters.

The most relevant aspects to consider are: existence of suitable programs for the corrective and preventive operation and maintenance planning; coordination with other service institutions such as power utilities and telephones; trained personnel; existence of spare parts for reparations: equipment and machinery availability of their own or of the private utility.

c. Administrative support

In the third column of this matrix the result of the vulnerability analysis of the administrative support systems will be recorded. Although they are part of the emergency plan, it is necessary to evaluate them separately.

The most relevant aspects to consider are: money availability and management in emergency and disaster situations; logistic support from personnel, warehouses, and transportation: contracting availability of private utilities to support mitigation and rehabilitation measures.

d. Response capacity

In the fourth column of this matrix the institutional response ability to implement mitigation measures and to face the threat impact, will be indicated. This column is the result of the evaluations of the three previous columns.

Error! Bookmark not defined.6.6 Sixth step: Mitigation and emergency measures (fourth vulnerability matrix)

In this matrix, the mitigation and emergency measures will be proposed for each analyzed vulnerability aspect: operational, physical and administrative. A column divided into four subcolumns will be filled out for each case. The first two for the mitigation measures and its estimated costs and the third and fourth for the emergency measures and its estimated cost.

a. Operational vulnerability

The first part of this matrix will correspond to the mitigation and emergency measures for the operational aspects identified as vulnerable in the first vulnerability matrix.

b. Physical vulnerability

The second part of this matrix will correspond to the mitigation and emergency measures of the physical components and will be indicated in the same order in which they were analyzed in the second vulnerability matrix.

This part will be divided into two sections; first, the mitigation plan, where the mitigation measures for the physical components corresponding to reinforcement, substitution, rehabilitation, installation of redundant equipment, improvement of accesses, etc. will be registered Along with each component. preparedness corresponding to those with a longer rehabilitation period, frequency, or critical components will be indicated. Secondly, the emergency plan, where the emergency measures and procedures to be applied if the impact occurred before implementing the mitigation measures will be recorded.

It is advisable that this matrix is filled out by the same professional staff who was responsible of the physical vulnerability analysis. It is essential to know the system operation at this stage, since it will facilitate the mitigation plan formulation and the design and construction complementary studies; and the proposal of alternative drinking water supply procedures in order to prepare the emergency plan.

c. Administrative vulnerability

In the third part of this matrix the mitigation and emergency measures that should be implemented in order to correct or strengthen the administrative aspects identified in the third matrix will be registered.

The vulnerability matrixes outlines are specified in annex 1, with columns, subcolumns, and respective headings.

Error! Bookmark not defined.**CHAPTER 3**

Error! Bookmark not defined.**GUIDELINE FOR THE VULNERABILITY ANALYSIS APPLIED TO EARTHQUAKES**

Error! Bookmark not defined.1. INTRODUCTION

This chapter describes a guideline of the vulnerability analysis methodology explained in the previous chapter that applies to earthquakes. The key aspects in which the analysis should be focused and the references with the information required for the analysis are indicated.

The evaluation of the regional and local seismic risk of the area or region to be analyzed is essential for estimating the vulnerability and the possible damages of the components at risk. This evaluation should be based on the region's seismic history, which is found in seismologic observation institutes or similar entities.

It is common that the seismic vulnerability analysis is carried out by a joint team of private consultants or specialized institutions such as the mentioned institutes, universities and others, and professionals of the utility. The first ones will contribute with specific knowledge and technologies of seismic risk analysis, and soils and structures analysis, and the second ones with knowledge of the structures, its operation and the relative importance as part of the system in order to give priority to the mitigation measures and establish the emergency plan procedures.

In any case, the earthquakes effects are of such a magnitude and impact on the service that all the utilities located in seismic risk areas are obliged to study in depth the vulnerability of their structures, to implement a mitigation plan, and to be prepared to face the emergencies and disasters that could occur with an emergency plan which is permanently updated and disseminated.

Error! Bookmark not defined.2. FIRST STEP: IDENTIFICATION OF THE ORGANIZATION AND LEGISLATION IN FORCE

Error! Bookmark not defined.2.1 National and regional organization

The national and regional organization and the standards and procedures of operation should be identified. organization, hierarchies, information and communication systems, governmental and regional support to drinking water supply utilities and available resources that could be used for drinking water supply in case of emergencies and disasters.

It is common that these organizations have personnel, equipment and material resources to provide drinking water, including portable plants and heavy duty equipment for repairs, which would reduce the rehabilitation period.

Error! Bookmark not defined.2.2 Legal regulation in force

The general legislation for the country's emergency and disaster preparedness and the specific one regarding seismologic aspects should be identified at this stage, as follows:

i) Legislation and regulation regarding activities at different stages of emergencies and disasters: civil defense, emergency teams, national, regional and local organization, etc.

ii) Civil responsibility and liabilities legislation in the management of emergencies and disasters at utility and staff members level.

iii) Codes and seismic regulations applied in the new constructions and old structures analyses. It should be found out if they are updated and if they respond to current knowledge of the country's or region's seismicity. If they are obsolete, actions should be taken to find out which parameters should be used for the analysis.

Error! Bookmark not defined.3. SECOND STEP: DESCRIPTION OF THE AREA, OF THE SYSTEM AND ITS OPERATION

This step will follow the general methodology of chapter 2.

Error! Bookmark not defined.4. THIRD STEP: ESTIMATE OF THE OPERATIONAL VULNERABILITY (FIRST VULNERABILITY MATRIX)

This step will follow the general methodology of chapter 2.

Error! Bookmark not defined.5. FOURTH STEP: ESTIMATE OF THE PHYSICAL VULNERABILITY AND IMPACT ON THE SERVICE (SECOND VULNERABILITY MATRIX)

Error! Bookmark not defined.5.1 Identification of threats

In the first column the expected seismic type and the associated phenomena (liquefaction, slides, tsunamis, etc.) will be indicated.

In the second column of the matrix, the threat will be described briefly, as a summary of the information provided in the fifth column. The probability of occurrence and the expected magnitude and intensity will be indicated specifically.

Error! Bookmark not defined.5.2 **Characteristics of the seismic threat**

a. Brief general description

i) General information

The phenomena that lead to earthquakes can be caused by tectonic movements, volcanic activity, large failures and explosions. The most frequent are the tectonic movements consisting of sudden liberation of stored energy in shock or contact areas between the earth surface plates.

The subduction processes in the entire Pacific Coast of the Americas have to be considered. The oceanic plates of the Pacific are introducing themselves under the continental plates, generating friction and energy buildup areas known as subduction areas that extend from the northern to the southern part of the continent. Along these areas, large mountainous and volcanic chains are located. Most of the earthquakes in these areas are associated with the release of stored energy through this process.

The regional and local fault systems must also be considered, such as the fault of the Motagua in Guatemala that caused the 1976 earthquake and the local fault system of the Central Valley of Costa Rica that caused the 1983 and 1984 earthquakes.

The identification of these subduction systems and of local faults is essential to determine the vulnerability of the structures located on or near them.

ii) Seismic magnitude

The seismic magnitude is the energy released by an earthquake in its epicenter. It is estimated from the registration obtained at any distance from the place of origin through formulas developed for this purpose and is expressed in ergs. The most common is the scale of Richter, indicated below

Magnitude	Energy released in ergs
3.0 - 3.9	$9.5 \times 10^{15} - 4.0 \times 10^{17}$
4.0 - 4.9	$6.0 \times 10^{17} - 8.8 \times 10^{18}$
5.0 - 5.9	$9.5 \times 10^{18} - 4.0 \times 10^{20}$
6.0 - 6.9	$6.0 \times 10^{20} - 8.8 \times 10^{21}$
7.0 - 7.9	$9.5 \times 10^{22} - 4.0 \times 10^{23}$
8.0 - 8.9	$6.0 \times 10^{23} - 8.8 \times 10^{24}$

iii) Seismic intensity

The intensity of an earthquake is measured according to its degree of destruction. An earthquake can have a given magnitude and different degrees of intensity depending on the site of measurement. In order to measure the seismic intensity, the following modified scale of Mercalli is used:

Intensity	Description
I	Detected by very sensitive instruments
II	Perceived only by people at rest
III	Perceived inside of buildings through vibrations similar to those of a truck
IV	Movements of dishes, windows, lamps
V	Breakage of dishes, windows and others
VI	Fall of finishes, chimneys, minor structural damages
VII	Considerable damages in poorly constructed buildings
VIII	Fall of walls, monuments, chimneys
IX	Movements of foundations in masonry buildings, large cracks in the floor, piping rupture
X	Destruction of most masonry, large cracks in the floor, railway rails bending, and slides
XI	Only very few constructions remain, bridge rupture
XII	Total damage, presence of waves in the surface, distortion of level lines, objects thrown to the air.

iv) Magnitude intensity relation

O' Rourke [2, 20] establishes the following relation between magnitude and intensity:

Magnitude (M)	Maximum intensity
2	I to II
3	III
4	V
5	VI to VII
6	VII to VIII
7	IX to X
8	XI

b. Evaluation of the seismic threat

The characteristics of the threat are determined through an evaluation of the seismic threat, which allows to define the analysis and design parameters necessary for public works. These parameters are the acceleration and the speed that can be expected in sites where drinking water system structures for different periods of return and where the prevailing periods of ground movement are located, when considering earthquakes based on different seismic sources of the area under study.

Different methodologies have been proposed to determine these parameters. One of the most known is Cornell [2c,4], whose theoretical fundamental considers that the earthquake occurrence process is a Poisson process, which implies a space-time independence between the analyzed tremors and that there is no memory in the system with regard to past or future occurrences. This theory establishes the probability that soil movement surpasses level x in a given site according to the average number of occurrences by unit of time in which an occurrence surpasses value x. The model of tremor recurrence, according to the theory, is similar to that of Gutemberg and Richter.

In order to estimate the seismic threat it is necessary to analyze the active faults and to characterize the region seismicity in accordance with historical registrations and data on subduction, tremors between plates and those originated on local fault systems. With the source and occurrence parameters, the seismicity model can be prepared and the maximum magnitudes, the attenuation relations, the maximum probable duration of the tremors, the maximum soil accelerations, the maximum expected speeds, and the distortions for a probability of expected surplus may be foreseen.

O' Rourke [2c] suggests a simplified method to estimate the maximum soil accelerations and durations during the strong phase of the movement. The seismic codes of the countries also provide this information for the analysis and design of the civil structures.

For the concrete and steel structures and pipelines analysis, structural engineering [7d] provides the elements to define the required reinforcements to minimize the threat impact effects.

The interpretation of seismic information and the establishment of these parameters, as well as the structures analysis, should be carried out by professionals with broad experience in the area.

Error! Bookmark not defined.5.3 Relative priority

In the third column of the matrix, the relative priority of the threat with regard to all the possible threats in the region will be indicated. The priority assigned at this time will be tentative and it will be modified, if necessary, when completing the vulnerability analysis for all threats.

Error! Bookmark not defined.5.4 Information and alert system

In the first subcolumn of this fourth column of the matrix the information and communication systems of the country's specialized national institutes with the drinking water utility will be registered, both for alert and seismic occurrences in different regions of the country.

It is common not to report an earthquake to the drinking water utilities. They know this because the earthquake was felt and also through the radio, television and press. Agreements and communication systems should exist to establish that when an earthquake occurs in a region, the utility's operation centers must be reported by telephone and fax about the epicenters and magnitudes. This will facilitate the mobilization, the damage analysis and a quick, timely and effective attention.

In the second subcolumn the utility's internal information and communication systems will be indicated, including the ones established toward their regions. The evaluation of these systems is essential to confirm that the information is timely and truthful. In the third subcolumn the information systems that will be activated after the main occurrence will be registered.

The earthquakes usually appear suddenly and violently, which does not give time for alarm period, and the forecast for earthquakes of great intensity. Although there are theories developed with rigorous scientific methods, there has been little success [21].

Some signs of an earthquake occurrence are associated with the presence of radon gas in the wells, anomalous behavior of animals, low intensity earthquakes occurrence as a prelude of greater earthquakes, appraisal of variations in the magnetic field, and periods of regional and local earthquakes originated on greater earthquakes that activate the regional and local fault systems.

In the Pacific Coast, the interaction of plates in continuous movement and the existence of several regional, geological and local faults, together with areas of stillness or that have not shown ruptures in the previous immediate periods, are enough elements to maintain the utilities under alert

Error! Bookmark not defined.5.5 Impact area

In the fifth column of the matrix the direct impact area will be described, information that will be obtained from the seismicity analysis of the area or region where the drinking water system is settled. The seismicity study will give priority to the higher risk areas and will consider the soil condition, the regional and local fault systems, and the active system condition.

It is advisable to report the tectonic-earthquake information: isoseismic lines, faults, etc., on a geological map of the region, in such a way that it is presented in a single map. The overlapping of the drinking water system plans at the same scale of the geological-earthquake map will indicate the structures or components of higher risk systems, which should lead to an essential analysis.

Error! Bookmark not defined.5.6 Components or elements exposed

In the first subcolumn of the sixth column of the matrix, the structures or components of the system ordered in the waterflow sense will be registered: catchments (different types such as derivation dams, galleries, springs, wells, etc.) and their structures, pipelines, treatment plants, pumping stations, storage tanks, main conveyance networks or main lines and distribution networks. The ones presenting a higher risk because of their location in higher seismicity areas will be indicated.

In the second subcolumn of this sixth column the condition of each structure or component will be indicated, as a summary of the information obtained in the second step.

Error! Bookmark not defined.5.7 Characteristics of the impact (seventh column)

a. General effects

In general, the seismic impacts and earthquakes represent one of the most serious threats for the drinking water system due to the enormous energy released, its unexpected occurrence. its irregular periodicity, and particularly. its consequences, such as:

i) Soil movements that damage the structures close to the epicenters, as in the earthquakes in Managua in 1976, City of Guatemala in 1976 and Limon, Costa Rica in 1991.

ii) Liquefaction phenomena activated by earthquakes, which become one of the most destructive geological threats. This phenomenon consists of the liquefaction of sandy soils that lose stability and behave as gelatinous masses when seismic movements occur

iii) Fault activation in the impact area of the earthquake, which subsequently generates local earthquakes due to the soil masses accommodation.

iv) Collapses in rough topography areas and low stability soils that completely alter the water quality during long periods.

v) Tsunamis or seismic waves generated by the earthquakes that are produced in the subsoil of the oceans and that cause floods and destruction in the coastal areas, such as the wave that impacted the Pacific coast of Nicaragua in 1994.

b. Effects on the components of the drinking water system

Almost all components of a drinking water system can undergo the direct consequences of an earthquake. In basins with pronounced slopes and smooth soils, slides that modify water quality and generate avalanches that destroy surface catchments are produced; the aquifers can change significantly and can even be completely lost; the well struts are damaged by shear fracture: the concrete structures experience in higher or lower degree crackings and structural failures that put them out of use: the valve boxes and tanks fail in the rigid concrete joints with the pipelines. the rigid pipelines are damaged by sharp fractures, and those of flexible joints are uncoupled, among some cases.

In addition. indirect effects in the systems should be considered, such as faults in the energy supply, communications, and blockings in the road system.

Experiences of damages due to historical occurrences [2c] are very useful for the evaluation of damages as a result of the vulnerability analysis.

c. Results of the vulnerability analysis

As a result of the seismic analysis of structures and pipelines, probable damages such as faults in concrete and steel structures; pipelines and other services such as energy, communications, and roads, will be determined

A thorough checking of all the system structures will determine many risky situations in case of earthquakes: anchorages and defective supports, pipelines embedded in concrete walls, rigid pipelines which require flexibility, etc. This check and identification of risk situations should constitute the first stage of the analysis.

In the case of nontraditional pipelines, the manufacturer could be asked to inform about the experiences on seismic behaviors, the type of expected damage and suggestions for repair.

The results of the analysis will be registered in the three subcolumns of the seventh column of the matrix: in the first ones the damages estimated in the component (type and number) will be described; in the second one, the RT estimated for the total rehabilitation of each component, and at the end of the column, the RT for the whole system or water supply subsystem; in the third one, the remaining capacity of the component indicated in units of flow, liters per second, for instance, and as a percentage of the total capacity of the component.

If advisable, the TR50 and TR25 can also be indicated in the second subcolumn, and in the third subcolumn, the remaining capacities corresponding to these periods of repair.

Error! Bookmark not defined.5.8 Impact on the drinking water or sewerage service

In the eighth column of the matrix the impact on the service of each damaged component will be recorded, quantified in number of persons or the system's connections affected, as well as the essential connections of each area or subarea of supply.

Error! Bookmark not defined.6. FIFTH STEP: ESTIMATE OF THE ADMINISTRATIVE VULNERABILITY OF THE UTILITY AND RESPONSE CAPACITY (THIRD VULNERABILITY MATRIX)

This matrix should be filled out in accordance with the general methodology of chapter 2.

Error! Bookmark not defined.7. SIXTH STEP: MITIGATION AND EMERGENCY MEASURES (FOURTH MATRIX OF VULNERABILITY)

This matrix will be filled out in accordance with the general methodology of chapter 2.