Chapter 4
Vulnerability Analysis

Introduction

This chapter outlines the methodology for vulnerability analysis for different kinds of natural hazards, and the most important points for analysis.

Using a matrix allows easy visualization of the elements involved in vulnerability analysis. Four matrices are presented, addressing operative aspects, aspects of administration and response capacity, physical aspects and impact on the service, and mitigation and emergency measures. Each of these matrices has a general heading and space where the name and type of system can be entered. The information required for the matrices on operative and administrative aspects and response capacity is the same, regardless of the type of hazard evaluated. Annex 2 provides an example of matrices completed during an analysis of the water system in Limón, Costa Rica.

The analysis process requires knowledge of the system, its components, and its operation, as well as characteristics of potential hazards to the system. It is also necessary to have an understanding of organizational and legal factors affecting the operation of the system.

Identification of Organization and Prevailing Regulations

National and regional organization. Before carrying out the vulnerability analysis, it is necessary to identify the national and regional organizations, their standards of operation, and the resources that are available for water supply and disposal in emergency situations and during the recovery phase following a disaster. For example, public service companies typically maintain portable electrical plants and heavy equipment for construction, which can be used for repair of the drinking water and sewerage systems.

Legislation. General legislation covering emergency and disaster response as well as specific legislation relating to aspects of different phenomena should be identified. These might include:

i) Legislation and regulations regarding disaster response as they pertain to civil defense, emergency commissions, and national, regional, and local organizations, etc.;
ii) Legislation regarding civil responsibility in disaster management (e.g., pertaining to businesses and officials);
iii) Seismic codes and regulations applied in existing and new structures. Ascertain whether codes have been updated to conform with prevailing knowledge about seismicity in a country or region. The same applies to construction standards and regulations in areas susceptible to other hazards (e.g., hurricanes, floods, and volcanic eruptions).

Description of the Area, System, and its Operation

Description of the area: The area served by the system should be described using data such as location (including distance to other population centers, characteristics of region in which it is found); climate (temperature, precipitation); population (rate of growth, density); urban structure (residential, industrial, and commercial zoning, type of housing); public health and sanitation (health services, trash collection); socioeconomic development (economic activity, unemployment); and data on the geology, geomorphology, and topography of the zone. It is also important to include information on services such as communication systems, access routes, and general public utilities.

Physical and functional description of the system: Physical data about the system should include the most relevant information about each component, such as materials, diameters, masses, anchorings, etc., using blueprints, plans, and details. The functional description of the system will specify flow, levels, pressures, and service quality. The description will include information on operation of the system, specifying, together with respective diagrams in the case of drinking water, data such as amount supplied, capacity, continuity of service, and water quality. For sewerage systems, in addition to the diagrams, data will include coverage, drainage capacity, quality of effluents, and receiving bodies. Also to be taken into account are seasonal variations (summer and winter) that could affect modes of operation and condition of the services.

Methodology

Matrix 1A — Operation Aspects (Drinking Water Systems)

In the first column of Matrix 1A the analyzed component of drinking water systems will be noted (e.g., the intake, treatment plant, storage tanks, area supplied, etc.). In the second column, include the capacity of the component, using corresponding units such as volume (m^3), volume of flow (m^3/s), or others; in the third, the current demand; and in the fourth, the surplus or shortage, expressed in the same units used to describe capacity. In the fifth column, the presence and performance of instruments for remote warning systems associated with each of the components should be recorded (e.g., accelerographs, limnimeters, etc.). If a component necessary for the system is not present (e.g., a reservoir), “zero” capacity will be entered in the second column, and a deficit recorded in the fourth column.

In the lower left section of Matrix 1A there is a space to enter the names of entities and institutions that might provide warnings to the water authority about the development or occurrence of natural phenomena. Provide a description of how these entities function. In the lower right section, there is a list of different information channels within the water company and communication systems for providing information to the public.

Matrix IB — Operation Aspects (Sewerage Systems)

For sewerage systems, the collection area, distribution system, treatment plant, and final disposal are noted for each component in the first column of Matrix 1B. Enter coverage for zones in the second column; capacity and deficit in the third column, if they exist; and the presence of remote warning systems in the fourth column. Complete the lower part of the form, indicating information and communication channels, as in Matrix 1A.

Matrix 1A - Operation Aspects

Name of Drinking Water System:

COMPONENT	COMPONENT CAPACITY	CURRENT DEMAND	DEFICIT (-) SURPLUS (+)	REMOTE WARNING SYSTEMS

INTER-INSTITUTIONAL INFORMATION AND WARNING SYSTEMS

- ❑ Civil Defense
- ❑ Meteorological Institute
- ❑ Volcanology Institute
- ❑ Seismology Institute
- ❑ Other (list):

WATER COMPANY INFORMATION AND WARNING SYSTEMS

- ❑ UHF Radio
- ❑ VHF Radio
- ❑ Telephone
- ❑ Other (list):

INFORMATION SYSTEM FOR PUBLIC

- ❑ Radio
- ❑ Television
- ❑ Printed Brochures
- ❑ Other:

Matrix 1B - Operation Aspects

Name of Drinking Water System

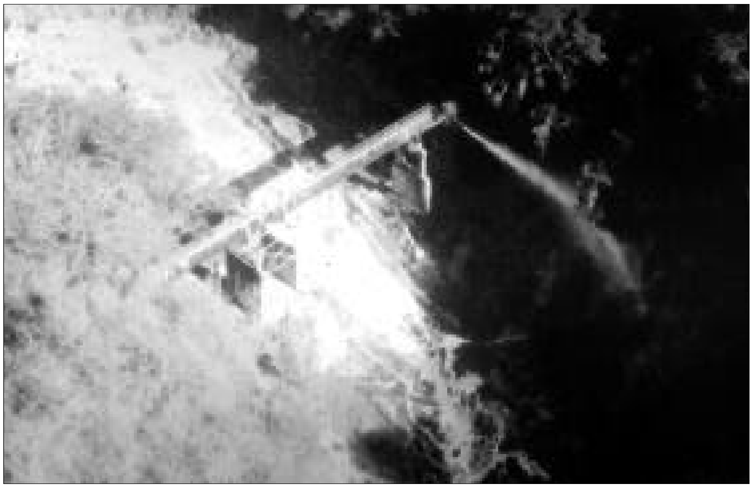
COMPONENT	COVERAGE %	CAPACITY	REMOTE WARNING SYSTEMS

INTER-INSTITUTIONAL INFORMATION AND WARNING SYSTEMS
- ❑ Civil Defense
- ❑ Meteorological Institute
- ❑ Volcanology Institute
- ❑ Seismology Institute
- ❑ Other (list):

WATER COMPANY INFORMATION AND WARNING SYSTEMS
- ❑ UHF Radio
- ❑ VHF Radio
- ❑ Telephone
- ❑ Other (list):

INFORMATION SYSTEM FOR PUBLIC
- ❑ Radio
- ❑ Television
- ❑ Printed Brochures
- ❑ Other:

Matrix 2 — Administration and Response Capacity



José Grases, 1997

If maintenance is lacking, a simple leak can be responsible for the collapse of the system.

Matrix 2 facilitates the evaluation of weaknesses and limitations related to the administration of the system. To complete this information it is important to know operation standards and available resources that could be used for the supply of drinking water and disposal of waste water in emergency situations and in the rehabilitation phase. The information needed to complete this form is the same for drinking water and sewerage systems.

Institutional Organization

In the first column of Matrix 2 the strengths and weaknesses of institutional organization should be noted. Distinctions should be made between central, regional, and local levels, and, if necessary, separate matrices should be completed for each of these levels. Indicate whether the following are in place:

- Emergency response plans; specify when periodical reviews and updating of the plans take place;
- Mitigation plans;
- Inter-institutional coordination;
- Permanent emergency committee; list the members and their responsibilities;
- Committee responsible for developing a mitigation plan.

Operation and Maintenance

In the second column of Matrix 2 strengths and weaknesses in operation and maintenance at the central, regional, and local levels are described. Indicate whether the following apply:

- Planning programs include the topic of disasters;
- Disaster and mitigation measures are included in operation programs and manuals;
- Disaster and mitigation measures are included in preventive maintenance programs;
- Availability of personnel trained in areas related to disaster prevention, mitigation, and emergency response;
- Availability of equipment, machinery, materials, and accessories for carrying out preventive programs and for service rehabilitation in case of emergency (specify the kind of equipment and machinery).

Matrix 2 - Administration and Response

NAME OF SYSTEM: ______________________________

TYPE OF SYSTEM: ❑ DRINKING WATER ❑ SEWERAGE

INSTITUTIONAL ORGANIZATION	OPERATION AND MAINTENANCE	ADMINISTRATIVE SUPPORT
A. EMERGENCY RESPONSE PLANS ❑ YES ❑ NO Date of most recent review:	A. PLANNING PROGRAMS ❑ YES ❑ NO	A. AVAILABILITY AND MANAGEMENT OF MONEY ❑ YES ❑ NO AMOUNT
B. MITIGATION PLAN ❑ YES ❑ NO	B. OPERTAION PROGRAMS AND MANUALS ❑ YES ❑ NO	
C. INTER-INSTITUTIONAL COORDINATION ❑ YES ❑ NO	C. PREVENTIVE MAINTENANCE PROGRAMS ❑ YES ❑ NO	B. LOGISTICAL SUPPORT FOR PERSONNEL (TRANSPORT AND SUPPLIES) ❑ YES ❑ NO
D. COMMITTEE FOR DEVELOPING MITIGATION PLANS ❑ YES ❑ NO	D. TRAINED PERSONNEL ❑ YES ❑ NO	
E. EMERGENCY COMMITTEE ❑ YES ❑ NO Members of Commitee: Name: Responsibility:	E. AVAILABILITY OF EQUIPMENT ❑ YES ❑ NO Type of Equipment and Machinery:	C. CONTRACT WITH PRIVATE COMPANY ❑ YES ❑ NO Name:

Administrative Support

In the third column of Matrix 2, enter information about administrative support systems. Indicate whether:

- Funds are available for emergency situations, emergency supplies; enter the amount reserved for these purposes;
- Logistic support for personnel exists (e.g., warehoused supplies and transport);
- There are simple procedures for contracting businesses and services to support mitigation measures and rehabilitation; provide details about these companies and whether they are in a registry of service providers.

The institutional capacity to carry out mitigation measures and to respond to the impact of disaster can be evaluated by analyzing the results of these three columns.

Matrix 3—Physical Aspects and Impact on the System

In the heading for Matrix 3, record the type of hazard that could impact the physical systems for drinking water or sewerage, as well as the area that would impact operations. To arrive at such an estimate, it is necessary to simulate possible events and analyze the expected consequences to the system. Disaster simulations will assist in creating risk maps, or maps of the system superimposed over areas showing the expected effects of a hazard. These estimates should also include the population, institutions, and environmental elements potentially affected.

Priorities for analysis can be noted for the entire system. Three priority levels correspond to the following levels of damage:

- Priority 1 (High): More than 50% of components and/or the intakes and distribution system are impacted;
- Priority 2 (Medium): Between 25% and 50% of components affected, without affecting the intakes and distribution system;
- Priority 3 (Low): Less than 25% of components affected, without affecting the intakes and distribution system.

Exposed Components

In the first column of Matrix 3, list the components directly exposed to the hazard. The components should preferably indicate the direction of flow of water and must be classified in the following manner: intakes (different types) and their structures, main pipelines, treatment plants, pump stations, storage tanks, and aqueduct systems.

Condition of Components

In the second column of the matrix, record the condition of the component, using descriptive terms. For example for galvanized pipes, indicate whether corrosion is present, rather than using general categories (such as "good" or "average").

Estimates of Potential Damage

In the third column of the matrix, describe the nature of the expected impact on each of the exposed elements. Table 4.1 illustrates the types of damage that could occur in some components as a

Matrix 3 - Physical Aspects and Impact on Service

NAME OF SYSTEM: ______________________________

TYPE OF SYSTEM: ❑ Drinking Water ❑ Sewerage

TYPE OF HAZARD: PRIORITY(1): ❑ 1 ❑ 2 ❑ 3

AREA OF IMPACT: ______________________________

EXPOSED COMPONENTS	CONDITION OF COMPONENT	ESTIMATED DAMAGES	REHABILITATION TIME 100 (days)	IMMEDIATE REMAINING CAPACITY		IMPACT ON SERVICE(2) (Connections)
				Units	%	

(1) Priority 1 (High): More than 50% of components and/or the intakes and distribution system affected;
Priority 2 (Medium): Between 25% and 50% of components affected, without affecting the intakes and distribution system;
Priority 3 (Low): Less than 25% of components affected, without affecting the intakes and distribution system.

(2) Number of connections affected in terms of quality, quantity, and/or continuity of service.

Table 4.1
Effects of natural disasters (PAHO, 1982)[21]

Service	Expected effects	Earthquake	Hurricane	Flood	Tsunami
Drinking water supply and disposal of waste waters	Damage to civil engineering structures	●	●	●	❍
	Rupture of water mains	●	◗	◗	❍
	Interruption of power supply	●	●	◗	◗
	Contamination (chemical or biological)	◗	●	●	●
	Disruption of transportation	●	●	●	◗
	Scarcity of personnel	●	◗	◗	❍
	Network overload (due to movements of population)	◗	●	●	❍
	Scarcity of equipment, replacement parts and supplies	●	●	●	◗

● Serious possibility ◗ Less serious possibility ❍ Minimal possibility

result of natural disasters. Detailed descriptions of natural hazards and their effects on water systems are given in Chapter 3. Consult corresponding sections for hurricanes, earthquake, floods, landslides, volcanic eruptions, and droughts to complete this section of Matrix 3.

Rehabilitation Time

In column four of Matrix 3, enter the estimated rehabilitation time (RT) for the analyzed component. The methodology for making this estimate was developed by the Pan American Center for Sanitary Engineering (CEPIS). It can be applied to structural components such as pump stations, storage tanks, treatment plants, or pipelines. The method is also valid for watersheds, aquifers, or large reservoirs, although specialized analysis is required in these cases.

The rehabilitation time depends on:

- The type and magnitude of damage, which is determined after carrying out a detailed analysis;
- The availability of personnel, materials, financing, and transportation as required, to carry out repairs;
- Accessibility of site where repairs are to be made.

Because of these factors, rehabilitation time can be estimated only in terms of ranges.

The rehabilitation time, expressed in number of days, is estimated for each affected component and for the system as a whole. To make these estimates, extensive experience is needed in repairs and reconstruction, detailed knowledge of the drinking water supply system, and awareness of available resources from the water supply company, civil defense, private companies, or other entities.

To estimate rehabilitation time for the entire system, "parallel" or "series" calculations are made using the repair times of the components. "Series" calculations are used when repairs are made sequentially; or “parallel” when components are repaired simultaneously. This method also applies by repair stages; for example the rehabilitation time (RT) can be established for a specific component at 25%, 50%, and 100% of its capacity. This is expressed as RT25, RT50, and, finally, RT, which is equivalent to RT100.

21 PAHO/WHO, *Environmental Health After Natural Disaster,* Scientific Publication, 1982.

For example, to calculate partial rehabilitation time for a large diameter pipe damaged by a landslide, factors to be considered are:

i) Time required to report the damage, close valves, and mobilize personnel, equipment, and materials to begin repairs;
ii) Time needed to reach affected areas;
iii) Time required to carry out repairs (depending on the extent of damage and the available resources);
iv) Required waiting period before initiating operation (for example, setting time of concrete for anchors);
v) Required time for putting system in operation (e.g., fill pipes).

The sum of these time segments corresponds to RT100 or rehabilitation of the pipeline to 100% of its capacity. Using this method assists in comparing rehabilitation times for different types of damage and determining the most critical components when prioritizing the execution of mitigation or retrofitting measures. The emergency plan should include procedures for obtaining alternative water sources if necessary during the rehabilitation period.

Remaining Capacity

In the fifth column of Matrix 3, enter the estimated remaining operation capacity of the component being analyzed using units (such as flow in pipes, volumes in reservoirs and tanks) and the percentage relative to the capacity prior to the impact of the disaster. The rehabilitation time (RT) and remaining capacity are good indexes of the vulnerability of particular components.

Impact on Service

The sixth column shows the impact on service for each exposed element. In calculating this impact, take into account not only total interruption of service but deterioration in terms of quality and quantity. Quantifying this impact is done by calculating the number of connections that are not functioning or the number with a significant decrease in quality (deterioration of drinking water quality, for example) or quantity (as evidenced by water rationing).

This information is essential to the vulnerability analysis and should be given special emphasis. It should be elaborated by professionals with extensive experience in operation, maintenance, design, and repair of drinking water systems, as well as the determination of external forces in different situations. This information, together with the rehabilitation time, will be used in the emergency plan to indicate the need to provide alternative water sources, the time when service should be implemented, and the priority connections and installations in a water supply and sewerage system.

Matrix 4A — Mitigation and Emergency Measures (Administration and Operation)

Reduced operative and administrative vulnerability can be achieved with measures such as improvements in communication systems, provision of adequate numbers and types of transport vehicles, provision of auxiliary generators, frequent line inspections, detection of slow landslides, repair of leaks in areas of unstable soils, and planning for emergency response. Such preventive measures will optimize the operation of the system and minimize the risk of failure under normal conditions of service

Matrix 4A - Mitigation and Emergency Measures (Administrative and Operational Aspects)

Name of system: ❑ Drinking Water ❑ Sewerage

AREA	MITIGATION		EMERGENCY	
		COST		COST
A) INSTITUTIONAL ORGANIZATION				
B) OPERATION AND MAINTENANCE				
C) ADMINISTRATIVE SUPPORT				
D) OPERATIONAL ASPECTS				
SUBTOTAL				
TOTAL				

as well as reducing losses in case disaster occurs.

Mitigation and emergency measures for each potentially vulnerable component are entered in Matrix 4A. In each case, estimated costs for mitigation measures and costs for emergency measures should be calculated as they correspond to organization, administration, operation, and maintenance.

Matrix 4B — Mitigation and Emergency Measures (Physical Aspects)

Matrix 4B integrates mitigation and emergency measures for physical components. They are listed in the same order as in Matrix 3. This matrix should be completed by the same team of professionals that carried out the physical vulnerability analysis.

Matrix 4B is divided into two sections. In the first, mitigation measures for physical components are listed, such as retrofitting, substitution, repair, placement of redundant equipment, improved access, etc. Priority of action should be specified for each component depending on whether it requires: (a) greater rehabilitation time; (b) greater frequency of repair; and/or (c) is a critical component. Costs associated with implementing these measures should likewise be noted. In the second section of the Matrix—the emergency plan—the necessary emergency measures and procedures are noted assuming that mitigation measures have not been carried out.

Mitigation measures to reduce vulnerability of certain components of drinking water and sewerage systems include:

- Replace equipment or accessories if in poor condition, and monitor components periodically if they are in average condition (for example, electrical pumps, auxiliary generators, and valves);
- Repair elements, equipment, and accessories that are defective;
- Replace elements, equipment, and accessories that are inadequate or nonfunctioning;
- Obtain missing components, equipment, and accessories (for example, auxiliary generators in areas where there are prolonged or frequent electrical outages).

Mitigation measures to be considered to reduce vulnerability to the impact of specific hazards are outlined below:

Active Landslides

- Relocate components if possible or use drainage ditches in the unstable zone;
- Construct small retaining walls around the structures, or provide small anchors on the pipes;
- Change rigid components and place flexible piping in sinusoidal reaches;
- Bury pipes in solid rock in areas with steep slopes and little topsoil cover;

Osorio, 1997

Water system authorities should take emergency measures to ensure that the population has a safe and reliable source of drinking water in case of disaster.

MatriX 4B - Mitigation and Emergency Measures (Physical Aspects)

Name of System:

❑ Drinking Water ❑ Sewerage

COMPONENT	MITIGATION		EMERGENCY PLAN	
		COST		COST
TOTAL				

- Plant and maintain the vegetation coverage of the site or watershed. Remove vegetation from top and toe of very steep embankments.

Floods

- Construct underground river passes for pipelines and adequate settling basins;
- Install automatic shut-off for horizontal pumps;
- Plant and maintain vegetation cover of the watershed; use landfill to raise ground level.

Volcanic Activity

- Relocate components if possible or provide permanent covers to protect storage and treatment tanks and settling basins;
- Construct protective walls and underground river passages for pipes.

Earthquakes

- Provide structural retrofitting of the components;
- Protect sites against landslides, rockslides, and floods;
- Retrofit or change cracked elements or those of poor quality material; replace rigid connections and accessories.