Part Three

MANUAL FOR
ESTIMATING THE SOCIOECONOMIC
EFFECTS OF NATURAL DISASTERS

Part Three

INFRASTRUCTURE

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This chapter addresses the effects of natural disasters on infrastructure, in a broad sense, that is, as that corresponding to basic services drinking water and sewage, transportation and communications, and energy supply

I. DRINKING WATER AND SEWAGE

This section begins with a description of the type of damage to drinking water and sewage infrastructure which may be caused by different types of natural disasters Then, the direct effects likely to be caused by disasters are defined and the methodology for estimating the costs implied by that damage is presented The same procedure is followed for indirect effects, and the chapter concludes with the corresponding explanation of secondary effects

A. MOST PROBABLE TYPES OF DIRECT EFFECTS, BY NATURE OF DISASTER

The effects caused by a natural disaster are conditioned by the characteristics of the environment in which it occurs and even by the diverse ways a given natural phenomenon can occur, with the result that it is difficult to foresee all the damage a disaster may cause Even so, orientation which will allow for anticipating the most probable forms of damage, in each case, as an aid to finding and identifying them, is useful.

Damage does not only depend on the disaster but also on the "capacity to resist damage", a characteristic proper to each system of installations, so that a disaster of one magnitude and form may cause very diverse types of damage.

That resistance depends basically on three factors: the quality of the engineering design; the quality of the construction (including the technology: equipment and materials employed); and the quality of the operation and maintenance of the installations.

For example, if the design of a project took into account only one source of water or drainage, the system will be much more vulnerable to damage than if there were two or more, which would allow for maintaining at least a partial supply of drinking water, thus reducing sanitary problems and avoiding the need to construct emergency supply channels.

Good construction implies greater physical resistance, both with regard to the work's normal use and to the impact of a natural disaster and, therefore, means that damage will be less

Most components of drinking water and sanitary systems need adequate operation and systematic maintenance over time. When this has been provided, they display greater capacity to resist damage and are easier to repair after a disaster. Good operation requires, moreover, effective organization, with areas for repairing, replacement parts and maps of the distribution network, the existence of which may help identify, evaluate and repair the damage produced by a disaster more rapidly and at lower cost.

1. Earthquakes

a. General effects of earthquakes

According to their intensity, earthquakes may produce faults in rock, in substrata, sinking of land surfaces, slides, land slippage and mud slides[1]; saturated soils may soften (due to vibration), reducing the weight bearing capacity of soils at the level of foundations and substructures. This set of phenomena, combined with the movement of the earth, may produce destruction or other direct damage to any part of water supply, sanitary sewage or drainage systems, located within the area affected by the quake [2]

The magnitude and characteristics of the damage are usually related to:

i. The magnitude of the earthquake and its geographic extension,

ii. The anti-seismic design of the works, the quality of their construction, the technology employed, maintenance and condition at the time of the disaster;

iii. The quality of the land on which the works are located and the adjacent zone, as well. The possibility exists that the works themselves resist the quake but that adjacent land movements, for example, could cause damage due to the "domino" effects of the earthquake. This would also be the case if a dam were to burst, as a result of the quake, with the avalanche of water causing damage to sector works.

Most of these works, specially drinking water conduits, and sanitary and drainage sewers, are built under ground; and are subsequently covered so that they are not visible to the eye In the event of a quake, these structures react differently than buildings and structures at ground level

b. Ground level works

These are works, for the most part, visible, so that a visual appraisal of the damage is possible nearly from the moment of the quake itself The quake affects these works

[1] Heavy rains may also produce slides, slippages, and mud slides.

[2] A list of the types of damage the different parts of these systems can sustain is included below

through inertia (the greater the mass of the work, the greater the effect), the resistance of the structure depends on the ratio between its rigidity and its mass, while mass is not relevant for buried pipe lines, but rather the ground deformations produced by the tellurian event.

i. **Buildings, warehouses, housing and machine sheds**. Both service administration buildings, materials warehouses, technicians', guards' and operators' housing, and the diverse types of machine sheds or plants, will tend to behave in ways similar to those of similar buildings in other sectors and the damage to them should be evaluated by applying the same criteria. However, damage to machines, equipment and stored materials should be evaluated separately

ii **Tanks** In the case of water tanks, the mass of the volume of water stored may be very great and, therefore, the oscillations produced by the quake will also be very pronounced If the tanks are elevated, there exists the additional risk that seismic vibrations may break them. "This tendency of high buildings to vibrate in resonance with the vibrations of the natural earth attains maximum intensity when these have been built on thick, loose layers of deposits"[3]. Together with the effects of the quake on tank structure, the oscillation and waves of water in storage may imply additional risk, specially when dampening plates have not been installed.

According to the quality of the design, construction and maintenance of the tanks, on the one hand, and the magnitude of the quake and the reaction of the earth, on the other, damage ranging from minor to very serious may occur, including their collapse, in which case the water spilt, if it is of considerable volume, may produce significant additional damage

Semi-buried tanks. Semi-buried tanks[4], usually constructed of dry masonry, concrete, reinforced concrete or other materials, may suffer damage such as:

i cracks in walls, floor, cover or joints of these elements, as well as in entry and exit points for pipe lines. Those cracks may range from easily repairable to those which imply the complete reconstruction of the tank.

ii. partial collapse of the covering, interior pillars or part of the walls or floor, which may require repairs ranging from those which are moderately significant to total reconstruction.

iii. collapse of the tank.

Elevated tanks. Mid-sized or large elevated tanks[5] are usually made of steel or reinforced concrete.

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[3] "Prevención y mitigación de desastres. Vo. 8. Aspectos de Saneamiento", UNDRO, 1982.

[4] Regulation or storage tanks for cities and towns are included here

Tanks supported by steel structures, with broad diagonal trusses, hold up well in earthquakes; their most vulnerable point is where the tubes (which form part of the support structure) enter the ground. However, diverse types of design, construction and maintenance of steel tanks, combined with diverse magnitudes of quakes and different responses from the foundation ground, may produce.

i. light damage, such as diagonal truss breakage, which can be repaired or replaced rapidly,

ii. damage to support structures and/or to the tank itself (where the water is stored), which may vary from minor to very serious, and which will most probably occur at the joint with the support structure or where water pipes enter or exit;

iii. Collapse of the tank:

The examination of the damage must be performed by a specialist in steel structures in order to determine, if the damage is severe, whether the structure can be repaired and it is worth doing, or if total reconstruction is preferable

According to the UNDRO document, mentioned above, the survival rate of elevated reinforced concrete tanks is lower than that for steel tanks and the precautions to be taken in their construction are less clearly defined A structure of reinforced concrete will tend to hide the effects of damage much more than a steel structure, so that every trace of damage which goes beyond a superficial loss of stucco should be examined and diagnosed by a specialist, so that what seem simple cracks do not become, in a new quake, the source of a more serious problem

A quake may produce:

i. superficial loss of stucco, easy to repair, although perhaps requiring scaffolding;

ii. damage to entrance and exit pipes or to attached elements, such as stairways or the like, which, if the structure of the tank itself is not compromised, may be repaired by work of low or mid-range difficulty;

iii. cracks in the support structure and/or in the tank, which may appear, for example, in the overlap zones of an excessive number of iron plates; where pipe enters concrete walls: at the joint of the tank with the support structure or at the base of the structure itself;

iv tilting of the structure due to foundation failure, usually very serious in nature,

v collapse of the tank.

[5] Regulation or storage tanks for cities and towns are included here.

Small elevated tanks These are small elevated tanks, used for isolated houses, small groups of houses, schools, small industries, etc . constructed of a great variety of materials which include support structures of wood or metal profiles, reinforced concrete, etc.

The tank will be of corrugated or smooth iron plates, asbestos cement, fibre glass or reinforced concrete, etc.

Corrugated iron tanks collapse frequently in earthquakes, although experience shows that this occurs more due to poor maintenance than to instability.

Small elevated tanks may suffer damage in the support structure and/or in the tank, ranging from slight and easily reparable, to the collapse of the structure and/or the need to replace the tank It is probable that part of the material of wooden structures can be recovered, as is also the case for metal structures (except parts which may have rusted)

iii. **Dams and reservoirs**. Only dams and reservoirs for the supply of drinking water are treated here, excluding those designed for other uses which fall beyond the scope of this chapter.

Important seismic movement may cause large waves in the reservoirs, as a result of horizontal movement, with the risk of overflows. This danger may be greater when land slides and slippage, caused by the earthquake itself, fall inside the reservoir, producing what amounts to an interior tidal wave.

The bursting of a dam may have very serious consequences. However, in this section, only the damage suffered by the dam itself and replacement costs are considered, excluding reference to the damage which the avalanche of water may produce to the works of other sectors.

Rock filled dams These are more flexible than concrete dams and are more resistant than earth dams but the concrete or clay coverings usually used to waterproof them may be cracked by the earthquake and leaks may ensue. Damage to be considered may involve: i) minor cracks or leaks; ii) medium or severe cracks or leaks, iii) debris slides within the dam; iv) collapse of the dam.

Earth dams. These may suffer damage, during the quake, due to faults in the foundations, interior cracks, land sliding off dikes or overflows due to interior waves, or slides in the contention wall Possible damage to be considered may involve i) slight damage which, if it involves leaks, must be repaired rapidly to avoid larger leaks produced by erosion, ii) mid-range or severe damage; iii) debris slides within the dam, which may require dredging; iv) collapse of the dam.

Concrete dams These can crack or suffer damage in their foundations As in all dams, there is also the danger that waves will overflow. Damage to be considered may involve i) cracks or slight leaks which must be repaired rapidly, ii) those which are mid-range or severe and may require emptying the dam (which may imply losing the water stored in it); iii) debris slides within the dam forming barriers, iv) collapse of the dam.

iv. Some considerations for the evaluation of damage

- Damage to works connected to dams, such as canals, pipe lines, pump plants, etc (when they exist), should be evaluated separately, using the corresponding indicators or unit prices for those works.
- The same criterion should be applied for access roads, fences, electrical lines, guard houses, etc., which may form part of the general works installation whose central feature is the dam or reservoir.[6]
- For the evaluation of damage to the dam itself, two alternatives are available:
- estimate it as a percentage = p% of the total value of the construction of the dam itself;
- estimate globally each of the main sections of repair works

c. Underground or buried works

In this section, works located underground are considered, such as:

- all types of pipe lines and drinking water conduits, sanitary and drainage sewers, including the respective distribution networks, chambers, valves and domestic installations;
- collectors of subterranean waters, such as wells, drains, galleries, etc.

These works are significantly different from those above ground, given that they are mainly not in view, so that most of the damage will not be directly visible. This will make the true determination of damage much slower and laborious. In the Mexico City earthquake[7], for example, even though the most severe damage to drinking water conduits had been repaired within 15 days of the disaster, it took months to complete the needed minor repairs, while the reparation of storm and sanitary sewers was even more complex and slower.

The quake acts with inertia against constructions built above ground, in contrast, underground structures (such as pipe lines, for example) move with the ground,

[6] The same criterion is suggested for collectors and different plants.

[7] See CEPAL, Daños causados por el movimiento telúrico en México y sus repercusiones sobre la economía del país, October, 1985.

producing deformations which may cause damage. In industrialized countries, tubings have traditionally been made of rigid material, selected to resist water erosion (inside) or the chemical contents of the ground (outside), but not quakes, given the low risk of that phenomenon in those countries. However, long-term technological dependence has led to the use of those inadequate materials in this region with its high risk of seismic activity Consequently, earthquakes damage rigid tubes and/or their rigid joints. This implies that less damage can be expected in relatively flexible tubing (PCV or welded steel, for example) and more damage in the more rigid tubes, such as compressed mortar, concrete, cast iron and asbestos cement, specially if they have rigid joints.

i. **Impact of soil type on damage**. In land fill embankments or in soft soils, the quake may produce cracks which can break the pipe lines in them. Breaks have also been observed in zones of transition in the quality of the soil, as well as where density changes in natural fills.

Softening of the soil is one of the most harmful effects of earthquakes because it lowers the soil's capacity to sustain foundations. Large part of the damage sustained by pipe lines, in flood plains or ground made up of water-saturated sand, is due to softening caused by seismic vibrations. It happened in Japan, once, that, due to seismic vibration, a zone of saturated sand became practically liquid and the tubes and chambers in it "floated", causing severe damage to those installations.

Moreover, it is worth keeping in mind that large diameter tubes, near the surface, suffer greater damage than those of less diameter, given their smaller capacity to resist "Rayleigh waves", which, having been produced by the quake, move across the surface of the land in a way similar to, although less obvious than, waves at sea.

Another zone of danger for water conduits or sewers is proximity to buildings overthrown by the quake. The breakage of pipe lines which enter or exit buildings may extend that damage to the public network to which they are connected.

ii. **Usefulness of plots and maps of seismic risk, by soil quality** Given the difficulties involved in locating damage to installed pipe lines, the examination of seismic risk maps of the localities affected by the earthquake (if they exist) is recommended, because damage is more likely to have occurred in the zones more vulnerable to quakes, for example:

- Areas with deep layers of "soft" soils, sand and sedimentary gravel, marshes and land fills (subsoils which do not absorb seismic vibrations as does hard rock);
- Areas with layers of loose sand, saturated with water and others, with layers of loose soils, in which the ground may soften;
- Faults in rock strata: pipe lines which cross those faults may suffer damage

III Suggestions for finding pipe line damage.

Drinking water pipe lines. Damage to drinking water pipe lines usually produces visible leaks near the breaks in tubes or joints, although in order to determine their magnitude and extent and repair them (which is usually urgent), it will be necessary to excavate and expose the broken pipes. However, it may happen that high soil permeability around the break, or low water pressure, will hide breaks which may be discovered later, once service is restored, considering, for example:

i New visible leaks, made evident by increased water pressure, once the breaks discovered first have been repaired;

ii Presence of areas of the city or town which continue without water or receive it at pressures lower than normal, which may be due to damage to feeder lines for those zones, which it will be necessary to discover and repair,

iii. Detection of leaks. This may be very time consuming, specially if equipment and experience are lacking locally. Moreover, it may be difficult to discern which leaks were caused by the quake and which were in existence before;

iv. Through the use of flow monitors in the feeder lines or network, if they are available and can be installed at adequate points, to discover other leaks;

Sanitary sewer pipes. Breaks in these pipes may lead to visible leaks of sewage on the surface which may indicate a zone of damage Here, as well, it will be necessary to expose the pipes to determine the true magnitude of the damage and effect repairs. However, given that these systems usually operate by gravity flow, and not under pressure, there may be fewer leaks visible than in drinking water lines, in which pressure may make leaks more immediately evident. As well, inspection chambers may make the ocular inspection of the flow in successive chambers possible, which will make it easier both to detect leaky stretches (by comparing the flow in successive chambers), and to detect obstructions in the pipes (by comparing sewage levels in neighboring chambers). If they are not antecedent to the quake, those obstructions may be the result of breaks due to the earthquake

On the other hand, in areas without drinking water (due to the effects of the disaster), there will be no return flow of sewage, so that the final inspection of sewers requires the prior reestablishing of drinking water service

Storm sewer pipes. If the disaster occurred during the rainy season, the inspection of this system will be similar to that indicated in the previous section. In contrast, if it occurred during the dry season, damage inspection may involve visual inspection, throughout drainage channels and accessible large collectors, if they exist, and the revision of smaller diametre sections from neighboring inspection chambers

These measures, however, do not ensure that evidence of other damage, not detected previously, will not appear in the next rainy season

iv **Quantification of damaged pipe lines**. It is, at any rate, clear that the quantification of damage to pipe lines, both for drinking water and for sewage and storm sewers, requires the participation of the administration of the respective services (combining parallel location and repair of damage, because there is no sense in excavating to discover damage, without simultaneously performing the necessary repairs) For this to occur, more time than that available for an initial evaluation of damage will probably be needed.

Perhaps a system based on a preliminary selection, consisting of a sample of damaged stretches in the network, may be helpful in the generation of a very rough estimate of the pipe lines to be replaced or substituted

v. **Danger of contamination of the water in the drinking water networks**. If the pipe lines of drinking water networks and those of the sanitary sewers break simultaneously, some of the sewage may mix with or enter the drinking water network. This occurs because those two networks have usually been constructed next to and near each other. Thus, breaks may occur near each other which make the entry of sewage into the drinking water network possible (specially if the volume of sewage spilled is considerable) In some cases, subterranean waters near the surface cover both systems. If the quake produces breaks and leaks in the sewer system, the phreatic layer will be contaminated. In turn, that layer may contaminate the water network through breaks or filtration into the drinking water through non-hermetically sealed joints, if there is negative pressure (less than atmospheric) in that network, due to breaks in its lower sections or the effects of water rationing.

d. Possible impact of the quake on aquifer collection

i. **Risk or reductions in the amount of water collected**. In zones where water is extracted from wells or deep galleries, it may occur that the earthquake will divert subterranean waters to recently opened faults, producing a reduction (and even the end) of the flow which was being collected in those installations.

ii **Risk of aquifer contamination**. There is also a risk that subterranean water will be contaminated if recently opened cracks or faults mix surface water or that from latrines with the aquifer This is a serious risk because it may render one or several collectors useless. The possibilities of recovery depend largely on chance and vary from case to case

iii **Damage to deep wells, mid-range wells and those of large diametre, etc**. Given the variety of wells in existence, damage may range from·

- sinking of the ground adjacent to the well, with slight or severe damage;
- collapse and total loss of the well (due, for example, to a fault which passes through the well itself and leads to its collapse, or to cave-ins which cover it);
- slight or severe damage to pump mechanisms (pump equipment is to be evaluated separately).

iv. **Damage to drip galleries or drains**[8]. The quake may cause diverse types of damage, such as:

- cracks in walls, tubes or voussoirs which form the gallery or drain, which may vary from small cracks, relatively easy to repair (if the gallery is accessible) to larger cracks which will require interior reinforcement or the replacement of the covering;
- cave-in of part of the gallery or drain, or of some inspection wells;
- total collapse of the gallery or drain,
- damage to pump equipment (if it exists), which is to evaluated separately.

e. Contamination of the sources of drinking water

In the preceding section, reference was made to the risks of aquifer contamination, caused by the quake, although contamination of surface sources of drinking water, either from animal carcasses, oil spills, or industrial or toxic products in the water, is much more frequent. This may be one of the most serious effects of the earthquake, given the large scale sanitation risks it implies. In that case, it will be necessary to seek alternative sources, with extreme urgency, and construct (or utilize, if existent) new water collection and distribution works, if the case so requires

2. Flooding

a. General effects of flooding

Flooding occurs for several reasons, for example, heavy rains, melting, river or dam overflows, storms, tidal waves, etc These may be very violent and cause great damage. Their magnitude will be related to:

i. | the level achieved by flood waters, the violence and rapidity with which they occur and the geographical area they cover,

[8] Drip gallery: this is a type of collector similar to a drain, but built at greater depth and like a tunnel, with small openings in its walls so that subterranean water may enter

ii the quality of the design and construction of the relevant works, insofar as precautions for a certain level of flooding were considered and implemented, or not;

iii. the quality of the land on which the works are located, in terms of their capacity to resist, or not, the erosion which the floods may cause, together with the quality of the land adjacent to the works, in terms of the danger of cave-ins or land slides which torrential or persistent rain may provoke

b. Contamination of drinking water by flooding

Among the damage which natural disasters may produce, the most serious and grave risk, given its consequences, is large-scale contamination of drinking water. In that situation, many diseases usually associated with the lack of hygiene may assume the form of diseases of hydric origin and affect a large part of the population Those diseases may include typhoid and cholera, where they are endemic, and bacillus and amoebic dysentery, infectious hepatitis and gastroenteritis The grave risk of the appearance of these diseases means that methods of water treatment with chemical sterilizing agents (such as chlorine, for example) or the boiling of water for human consumption is of the greatest importance.

Contamination of drinking water and of the ground can occur in different ways

i Contamination of surface sources of drinking water. from animal carcasses accumulating near intakes, due to excessive opaqueness of the water, or due to the presence of different types of toxic or contaminant substances.

ii Contamination of aquifer sources when flood levels overflow well heads and flow directly into wells and other collectors.

iii. When the levels in the rivers and bodies of water into which sanitary and storm sewers drain rise, sewage may flow back through the sewers, flooding the interiors of houses and the lower floors of buildings and the streets In houses, this occurs via the sanitary artifacts themselves and household drains; in the streets, through inspection chambers and rain water drains. (If retention valves have been considered in the design and construction of the sewers, this type of back flow could be avoided, although that is rare in the countries of the region).

iv. If fuels become wet during the flooding, it will be more difficult to boil contaminated water, to sterilize it

In order to evaluate the costs arising from contamination, it will be necessary to consider:

- the cost of emergency or alternative collection works, and operating costs;

- the cost of emergency drinking water supply for the population, for example, tank trucks and the like,
- cleaning and disinfecting of contaminated drinking water sources,
- cleaning of houses and streets contaminated by sewage and/or the flood itself

c. Flood damage

i Damage to pipe lines and connected installations Damage to pipe lines and connected installations, such as diverse types of chambers and valves, are considered in this section Flooding may produce damage like the following:

- Erode land and, thus, expose, move or even carry pipe away;
- Raise the level of aquifer waters and, consequently, float pipe and chambers, moving them out of their normal positions. That damage will only exceptionally be slight; most often it is from mid-range to severe,
- Sweep away and cause total loss of pipe lines.

ii. Damage to semi-buried tanks. Tanks are usually located on high ground, so that this type of damage is rare

Flooding may cause damage by:

- Erosion of foundations, opening cracks and/or causing the partial collapse of tanks, more so if they are made of dry masonry than of reinforced concrete,
- A tank, if a large percentage of it is below ground level, may float when flooding occurs in conjunction with a high phreatic level (which is very probable in certain soils, due to prolonged rains). The risk is greater if the tank is not full of water. This may cause serious partial damage or even destroy the tank

iii Damage to pump equipment and electrical installations.

- If flooding is sufficiently high, electric motors, motorized pumps, starters or diverse types of electric control panels may be damaged by humidity.
- It is also possible that low and high tension lines will fall, due to erosion at the base of the installation, causing damage to that base, –to the high and low tension lines; –to electric control panels; and –to sub-stations.

iv Damage to intakes, dams and constructions at ground level. If the dynamic force of the flood is sufficient and devices to protect against it are lacking, erosion may occur around any sector installation in the affected area, which may be located in the path of the most violent segment of the flood and which, moreover, is below flood level.

These conditions may have special impact on constructions such as: intakes and complementary works for example, canals and water conduits, machine housings, treatment plants, etc , which should be evaluated separately

v. Dams and reservoirs The high risk for dams and reservoirs located in the course of a river on the rise due to flooding is evident. Dams designed and constructed to hold drinking water are vulnerable to floods, specially if they have low overflow capacity Moreover, if the sluices and gates are insufficient, there is danger, not only of serious damage, but also of the destruction or collapse of the dam itself, with the subsequent danger of a new disaster and enormous additional losses caused by the avalanche of stored water

3. Volcanic eruption

a. General effects of volcanic eruptions

Volcanic eruptions can cause "serial" disasters, the effects of which may be greater than those of the eruption itself, and may include:

i seismic effects produced by the volcano in eruption,

ii. flooding and/or avalanches of snow, earth or mud, produced by the heating of the ground and local vibrations.

iii as well, the eruption itself may involve the eruption of ash, dust or gasses, the eruption of rock or stone and of lava. The main damage the eruption itself may cause are

b. Drinking water contamination by volcanic eruptions

i. Contamination of surface sources of drinking water by deposits of ash, the effects of gasses or toxic substances or the death of animals near intake works or near open aqueducts.

ii The contamination of underground waters is relatively improbable, unless the ash fall is so plentiful and/or contains extremely toxic materials, or if these enter wells (when they do not have protective covers) and the stored water becomes contaminated.

iii. Contamination may occur in filter or treatment plants, due to the fall of volcanic ash on the coagulation or decanting tanks, or on the filters, contaminating the water or making the filters inoperative due to clogging with water-borne ash;

iv Contamination of open tanks or deposits

c. Evaluation of damage by contamination

These types of contamination do not –usually- cause damage to the works, as such Costs will rather involve the cleaning and washing of the filters (which can be appraised in terms of the labour involved). However, it may be necessary to replace inoperative intakes or plants temporarily. In order to evaluate the cost of the damage, it is recommended to consider, if necessary, the following·

- the cost of building emergency collector works and their operating costs;
- the cost of supplying emergency drinking water to the population (if these costs are different from those accounted for in the preceding point); and
- the cleaning and disinfecting of drinking water sources and collectors, plants, tanks and deposits, etc.

i. Damage to pipe lines, semi-buried tanks and connected installations. Lava flows, if sufficiently abundant and of sufficient erosive capacity, may cause damage even to underground installations, such as:

   - drinking water pipe lines or drains. They may expose, move, carry away and/or crush pipe lines, chambers and valves;
   - semi-buried tanks· partial or total destruction.

ii. Damage to ground level works and buildings Eruptions of lava, stone or large rocks, which may be thrown great distances, may produce damage in every type of installation of these systems. Depending on the violence of the eruption, the distance of the installations from the centre and other chance factors, the damage produced may range from slight to the total destruction of any of them

4. Wind storms

a. Wind storm damage

Wind storms, as such, cause damage mainly to ground level works. The risk of damage increases in direct relation to the their height and the area exposed to the wind. Damage depends on the capacity to resist wind with which they were constructed.

i The buildings, houses, machine sheds of drinking water and sewage systems will behave in ways similar to those of other sectors and the damage they sustain should be evaluated according to the criteria indicated for the Housing Sector.

ii. Elevated tanks If the wind is sufficiently strong, it may knock over one or more tanks and, secondarily, cause damage as a result of the abrupt emptying of the water stored in the tank (which may be several thousand m^3), together with the damage produced to connecting pipe lines and nearby structures by the collapse itself

On the other hand, if the structure itself is sufficiently resistant to the wind or the wind is insufficiently strong to knock over the tank, damage may still be caused to installations adjacent to the tank, such as, for example, access stairways, protective railings, or to the connecting pipe lines Among the types of damage most likely to occur are those which affect·

- public drinking water storage tanks of towns and cities –which probably have the largest storage capacity–;
- the tanks of industries, markets, schools, etc., of intermediate size,
- the generally small tanks for domestic use, when they are at the level of the house

5. Droughts

a. General effects of droughts

Droughts, unlike other natural disasters, do not occur suddenly, but rather arise from the accumulated lack or insufficiency of rain or snow during months or even years. Their main impact is related to the reduction or elimination of the sources of drinking water. Surface water courses, such as rivers and streams, will usually suffer the effects of the drought long before the aquifers, due mainly to two factors:

i Surface waters generally flow much more rapidly than those of aquifers. This means that rain water or that coming from the melting of snow will reach the sea, via rivers, much more rapidly[9] than water underground. For this reason, river flows are much more rapidly impacted by droughts (or heavy rains), unless there are lakes or artificial reservoirs which regulate the annual level of rains and make the flow of the corresponding river steady.

ii. Aquifers have two characteristics which are very effective in lessening and delaying the impact of drought (specially when hydro-geological conditions are favourable) a large storage capacity in the pores of permeable ground (similar to water in the pores of a sponge) and the low velocity with whiih the water drains through them to finally reach the sea That velocity, of a few meters a day,[10] implies that its flow is the result of the accumulation of the rains of many consecutive years and, that aquifer fluctuations, therefore, depend much less on annual levels of rain

[9] With a velocity of only 0.1 m/hour, for example, water in a river will go 8.64 Km/day and will take 12 days to go 100 Kms

[10] At a steady velocity, of around 1 m/day, it will take 274 years to go 100 Kms

b. Damage produced by drought

i. Damage in surface sources of drinking water. Depending on the characteristics of the surface source(s) of drinking water and the development of the drought:

Less than normal supply flows of drinking water may occasion, depending on the drought's gravity:

- a moderate restriction of consumption,
- rationing, from mid-range to severe,
- increased pumping heights in certain collectors;
- the total loss of some sources.

ii. Contamination of drinking water sources due to factors such as

- reduced self-purifying capacity of rivers and streams, due to reduced flow;
- increased concentration of pesticides, insecticides or industrial waste, due to the same phenomenon;
- contamination caused by fish killed by reduced supplies of free oxygen, for example;
- contamination caused by animal carcasses near drinking water intakes,
- the preceding factors may require increasing or varying the chemical additives in the water to reduce sanitary risks or opaqueness;
- the need to construct (or put in operation) alternative sources of drinking water [11]

iii. Damage to aquifer sources. Depending on the duration of the drought and local hydra-geological characteristics, there may be new demands for aquifer waters.

- for emergency supplies of drinking water; and
- for alternative supplies for industry and agriculture,
- which may imply: a relative reduction of phreatic levels, leading to reduced well production and higher pumping heights to achieve the necessary flow

[11] In many cases, this may involve the collection of aquifer water from deep wells.

This may involve higher operating costs for wells than previously, including a probable reduction in pump performance and even –in certain cases– the risk of having to pay fines to the electric company for low watt power

iv. Alternate sources of drinking water. The need to provide alternate sources of drinking water (given the reduced capacity of surface waters) may make it necessary to:

- construct emergency wells and rapidly equip them to supplement the drinking water supply;
- use existing wells, originally destined to other uses (industrial, sports or farming, for example), using them for the necessary supply of public drinking water;
- mixed solutions, combining i. and ii.

B. METHODOLOGY FOR ESTIMATING DIRECT DAMAGE

1. Inventory of damage

In order to estimate the cost of direct damage, it is recommended that an inventory be made. This involves several phases, many of which can be implemented simultaneously They are the following

a. Identification and reliability of the sources of information

i. Specific identification of the sources of information used, among which the following should be considered:

- governmental or municipal organisms directly responsible for drinking water and sewer services, and other bodies related to the sector,
- professional and sector organisms and/or associations related to the issue (such as the local chapter of AIDIS, for example);
- sector engineering and constancy firms;
- national and international experts who may be in the country and may have information or experience in the area,
- and other sources to be identified in each case.

ii. Verify and indicate the reliability of the data received in each case. Undertake field trips and verifications as necessary and possible.

iii It is worth noting the degree of reliability and relative precision of reports on the amount of damage done to works, for the diverse estimates of damage. It is also useful to indicate what has been verified personally and what corresponds to third party information, or to rough, unconfirmed estimates, or which reports it proved impossible to verify.

b. Lists of direct damage

i. **Separate lists by site of damage**. It is suggested that damage be grouped according to the following considerations:

   i damage suffered by each city or town, and distinguish urban from the rural damage;

   ii. damage by system, so that the damage suffered by each system are listed together, that is:

   - a certain drinking water system,
   - a certain sanitary sewer system,
   - other sanitation systems;
   - a certain storm sewer

   iii. Within each city and each system, group damage by plant or sub-system, for example, for the drinking water system of a city:

   - collectors. collector A, collector B, etc.;
   - treatment plants: plant A, plant B, etc.;
   - main conduits to tanks;
   - tanks: tank A, tank B, etc,,
   - distribution network and
   - others, specified in each case

   This will facilitate obtaining the cost of total damage to the drinking water system of each city, by adding the sub-totals thus generated.

   iv. Together with each damage list, the evaluator should also indicate: –the name of the corresponding city or town; –origin(s) of the information; –reliability of the information; and –the system and sub-systems to which the damage corresponds

c. Characteristics of damaged sub-systems

In order to ascertain the extent to which collecting data will be worthwhile, the availability of information in the official sources should be considered. If the city is large, the drinking water and sewer systems may be very large and complex and the information about them may be incomplete, even in normal times. Moreover, due to the disaster, many sector personnel will be working on emergency tasks, so that the evaluator will not find their time readily available.

In that case, it may be preferable to seek only the information strictly necessary about damaged sub-systems and not about those which continue to function normally, unless that information is useful for estimating damage or weighing indirect effects Therefore, only the main characteristics of damaged sub-systems should be indicated

d. Direct damage, as such

This type of damage is to be recorded by sub-systems as indicated above. Damage lists should be drawn up, grouping damage by materials, equipment or works of the same kind. It is recommended that a procedure such as the following be adopted:

i. For each type of damaged material or installation, a brief description of its main characteristics, of the type of damage and the approximate amount of installation or material affected, in adequate units of measurement, should be made.

ii For each type of damaged installation and/or material, indicate.

- the type of installation and/or material;
- the unit price for its construction or total replacement (PU);
- the unit price for repairs, as a percentage (R%) of the preceding unit price.

Thus, the following data should be obtained for each damaged installation·

Ud = unit cost by damage = (PU) x (R%)

Ur = unit cost by replacement = (PU) x 100% = (PU)

iii The estimate of the percentage (R%) to which certain installations, materials or equipment have been damaged, may be obtained as a weighted appraisal, considering –whether it will be possible to repair or partially reconstruct the installation, material or equipment or if, given the extent of the damage, total reconstruction or replacement is necessary; –if it is possible to repair the damage, the cost of that damage is to be estimated as a percentage (R%) of the total cost of that installation (part of an installation, material or equipment); –if it is necessary to reconstruct or totally replace the installation, it is understood that R = 100%.

iv. The estimate of the percentages R% may be made on the basis of the appraisals of the Service personnel responsible for each system and/or other sources, although the final appraisal must be that of the mission expert

e. Demolition, wrecking and removal of debris

Along with what has been indicated in the preceding section, demolition, wrecking and debris removal must also be considered To that end, it is suggested that:

i for each type of damaged installation or material (identified as recommended above), it be considered whether reconstruction or repairs will require prior demolition, wrecking and removal of debris. If such is the case, the approximate amount of the installation or material to be demolished and removed is to be indicated, in adequate units of measurement, which, insofar as possible, should be the same as that used to quantify the damage;

ii the main works or activities considered within the "demolition (or wrecking) and removal of debris" be indicated, for each item, but as one global unit price, which includes these factors, within each item.

iii However, it will be necessary to bear in mind the degree of difficulty and costs implied by different installations and materials Thus, for example, it will be necessary to distinguish the "demolition" of a tank of reinforced concrete from the simple "wrecking" of asbestos cement pipe lines, whose joints will be easier to disassemble, allowing as well for the partial recovery of material

iv. If it is not possible to make precise price estimates in this area, a criterion such as that recommended above can be used. estimating the cost of the "demolition. wrecking and removal of debris", as D% of the unit price. However, there is no reason for D% to be equal for the different items, due to the diverse degrees of difficulty involved in the demolition or wrecking indicated above.

v. If, as a result of demolition and wrecking, it is possible to recover some of the material, either for use by the company or for sale, its eventual value is to be estimated as a percentage (V%) of the unit price of that material when new. These sums may be subtracted from the cost of the "demolition, wrecking and removal of debris".

2. Unit prices and global costs

a. Unit prices to be considered in the evaluation of damage.

These may be based on

i. Those provided by studies or lists of unit prices normally used by the organisms responsible for the corresponding services and systems. It is worth indicating the date of the lists. If necessary, they must be up-dated by simple coefficients, to correct the effects of inflation and other factors,

ii Estimated unit prices, provided by direct surveys or appropriate local sources;

iii "Comparative unit prices", gathered for the region and which may serve to verify those mentioned in the two preceding points and may be used in their place, if deemed appropriate,

iv. Other unit price lists obtained from construction manuals, catalogues or national magazines, for example.

b. Labour and the domestic and imported component of materials prices

Whatever the sources or unit price estimates used, when drawing up the lists, it is worth considering:

i the labour content;

ii. the percentage of domestic materials and;

iii. imported materials, as % with respect to the unit price

This last calculation will make it possible to distinguish the value of imports and their impact on the balance of payments, within the figures for total direct damage

c. Types of works, unit or global prices

Drinking water, sanitation and storm sewer systems embrace a wide variety of types of works, material and equipment The cost of some of these elements is easy to estimate, on the basis of unit price lists. Such is the case, for example, for pipe lines and water conduits, the unit price for which can be expressed in terms of lineal meters, either for the pipe itself, or its installation.

In contrast, there are other types of works –such as water treatment plants– for example, consisting of various components which may come from different sources and involve diverse technologies and prices. In that case, costs should be estimated on the basis of the total price per plant This may be done on the basis of the following data

i Local information about construction costs for the plant and its current value,

ii. The use of price manuals or studies from other countries, preferably those most similar to the case under study,

iii. Use of the Manual developed by the Pan-American Sanitation Office,[12]

iv. If the plant is only partially damaged, these indications should only be applied to the relevant elements.

3. Approximate cost functions

a. Simplified cost functions

The functions used to describe cost variations occasioned by changes in design parametres (for example, flow capacity) are usually

$$C = ax^{b}$$

In which C = cost

x = design parametre, as Q (flow capacity in lt./sec.), for example.

a,b, are factors and exponents which describe the variation of the function in each case.

(This equation can be written in nearly straight lines on double logarithmic paper).

b. OPS-BID Manual of cost functions[13]

On the other hand, in the Pan-American Sanitary Bureau Manual mentioned above, a more complex function is used (which functions with the use of a computer) and which yields closer approximations

Those functions take the form:

[12] See Water and Wastewater Cost Analysis Handbook for Latin America and the Caribbean, Pan-American Santitation Office and the International Development Bank, September, 1986

[13] See again OPS-BID, Op.Cit

$$C = a + b\,x^{c}\ \ y^{d}$$

in which C = cost

x,y, are independent variables (for example, design parametres)

a,b,c, and d, factors and exponents which describe the variation of the function in each case

c. Evaluation of damage to buildings

Damage to administration buildings, and to personnel and guard housing, diverse types of machine housings, etc should by evaluated according to the criteria indicated in the chapter on "Housing".

d. Evaluation of damage to electric installation access roads

Damage to access and other kinds of road should be evaluated according to criteria indicated in the chapter on "Transportation and Communications" and those which refer to electric installations, as indicated in the relevant chapter

4. Examples of the evaluation of direct damage

a. Example of an inventory of direct damage

Chart 1 presents an example of an inventory of direct damage suffered by a hypothetical city. In order to effect the evaluation and gather the necessary information, the following is recommended:

i On the pages of the inventory made for the evaluation, include only the information necessary to identify the work, the equipment and/or material damaged, in such a way as to be able to indicate the corresponding unit price (U.P.).

ii. However, it may occur that additional information is required about the main characteristics of sub-systems to delimit the relative importance of the damage and evaluate indirect damage It is recommended that such information be included separately, but annexed to the inventories.

iii. Moreover, the summary inventory itself may need additional notes, which provide, for example, more detailed information about damage to a certain work, material or equipment, or which explain the method utilized to estimate the value (R%) of each item, when necessary.

b. Example of an evaluation of direct damage

It is recommended that Chart 1, "Example of summary inventory of direct damage", be examined. That chart is the basis for the elaboration of Chart 2, which contains two additional columns: "Unit Prices" (U.P.) and "Subtotals" = (U.P.) x (R%) x (amount damaged). In order to determine unit prices, what has been indicated in earlier sections of this chapter should be taken into account.

c. Unit prices and their break down

What follows is the break down of some unit prices[14], by component (the % of which is supposed and approximate), which should be determined in each real case.

M.O = % of U.P., in labour

M.N = % of U P., in domestic material

C.I = % of U.P., in imported component

G G = % of U P . in general and expenses and profits

i. <u>Concrete well with a 2 Mts. interior diametre</u>

U.P = US$ 500/lm

M.O = 30 % (U P)

M.N = 35 % (U.P.)

C.I = 15 % (U P)

G G = 20 % (U.P)

[14] All of these unit prices and their components are not from a real case; they are only suppositions for the sake of giving an example.