6.0 Summary Systems Risk Calculations

6.1 Overview

Previous chapters have provided guidelines on how to develop (a) deterministic and/or probabilistic approaches to natural hazards resulting in scenarios and (b) component vulnerability evaluations that define each of these scenarios in terms of specific system states. This chapter, supplemented by Appendix G, provides further information on how these scenarios may be developed to provide pertinent information to decision-makers. From the standpoint of Figure 1, this chapter provides further clarification of the shaded box "Estimate System Performance (Loss of Service, Environmental Impacts, Higher Order Losses)."

Section 6.2 outlines a hypothetical water system used in these demonstrations of systems vulnerability procedures and issues. Appendix G further details how three events are postulated to affect water utility systems: a flood/scour event, an expansive soils event, and an earthquake. Response and recovery of the water system to these three separate events are then modeled. Actual modeling of these events and the response and recovery of a water utility to these events may of course depart significantly from model results. The focus, then, in this chapter and in Appendix G is in the estimate of systems losses. Implicit in this focus is the understanding (as in Chapter 5) that there are many issues and uncertainties in modeling response, recovery, and restoration. (The demonstration natural hazards events and how direct damages are estimated are not emphasized in this Chapter and in Appendix G.)

Section 6.3 outlines how system losses may be calculated based on these three natural hazards scenarios. An intermediate evaluation (see Chapter 1) is one in which such scenarios are developed to the point of understanding such system losses in terms of a systems model (preferably a hydraulic model as in these hypothetical examples). The systems model must moreover include sub-models for response, recovery, and system restoration.

Chapter 6.4 outlines how one might take a larger number of scenarios in order to develop a more advanced evaluation of system losses. More advanced modeling requires greater automation of procedures used, from inventory, to natural hazards events, to component vulnerability models, to hydraulic models (or connectivity models for gravity-flow systems), to system restoration models. This degree of automation is now available, but there are many issues and uncertainties that remain with respect to particular input assumptions and sub-models and hence results of such modeling efforts.

6.2 Overview of the Demonstration Water System

The water supply and distribution system as shown in Figure 35 is part of a much larger municipal water distribution system and will be used to demonstrate the vulnerability a water system has to natural hazards. A vulnerability assessment of the public water system may be based on a complete water system model or portions of a larger water system. In the example shown below, the vulnerability assessment illustrates how a subsystem of a much larger water system may be evaluated.

The hypothetical distribution system being evaluated encompasses an area of approximately 290 square miles (751 sq. km) and has various pressures service zone levels. The geographic area has high mountains/foothills on the west side and lower elevation (plains) to the east. The natural hazards in the geographic area include numerous streams that are prone to flooding and degradation of the stream channel beds (i.e. exposing water lines), expansive soil, a fault that runs parallel to the foot hills, extreme periods of low temperatures, debris flow from the mountain/foothill areas, and soil settlement.

Briefly, in Figure 35, a raw water reservoir located to the west of the water distribution system provides gravity service to two water treatment plants. Pumping Station B conveys water from Water Treatment Plant No. 1 south to Reservoir No. 3 and then by gravity from this point. Water Treatment Plant No. 2 provides potable water via gravity to the northern service areas with each pressure zone level being served by a pump station and water reservoir (i.e. Pump Station D pumps to Reservoir C/Pump Station C pumps to Reservoir 5). A second supply source is from a groundwater well located on the East Side of the distribution system near Pumping Station E.

Prior to simplifying the water system hydraulic model, one should verify that all major distribution loops are included. The subsystem evaluation requires isolating other service areas. However, it became evident that certain connections/facilities needed to operate in order to properly reflect the water system ability to provide water to this area. In general, without these connections, there could not be any backflow into the system, which would thereby increase the risk/vulnerability of this area. A steady state model of the partial water supply and distribution system is shown in Appendix G and depicts the steady state pressures based on an estimated maximum day demand without fire flow.

6.3 Estimating System Losses for Three Natural Hazards Scenarios

6.3.1 Overview

This section deals with some of the ways in which the system evaluation results for specific scenarios may be used to develop estimates of systems losses of interest to decision-makers. In terms of “levels of analysis” indicated in Chapter 1, this section relates to an intermediate level of analysis. A few selected scenarios will not provide a full estimate of system risk (see section 6.4). Nonetheless, scenario evaluations are required for estimates of system risk and by themselves these scenario evaluations can provide important information for decision-makers.

Appendix G summarizes the hydraulic evaluations for these three scenarios. In Appendix G, first damage is postulated (in principle, this could be developed through the use of guidelines in Chapter 2 through 5 although only coarse hypothetical scenarios are developed here). Next, various stages of response, recovery, and restoration are modeled. At each stage, hydraulic evaluations are performed in order to determine which portions of the system are adversely affected by the state of the system. These hydraulic evaluations could be used further to determine which customers (e.g., by service zone, customer type) are expected to be without adequate water. The procedures used could also be employed to develop improved response, recovery, and restoration strategies.

While it has been stated on several occasions in this document that response, recovery, and restoration modeling contains many uncertainties (see Chapter 5), hydraulic evaluation models are more standardized. Furthermore, some hydraulic models (e.g., KYPIPE and GISELLE) have been adapted to modeling the response of water systems subjected to natural hazards events. Still, there is much work that could be done to automate and validate hydraulic modeling efforts and assumptions made to adapt them to natural hazards events (see Appendix G for some of these assumptions). This process of automation and validation would be extremely important for a risk-based modeling that requires the quantitative modeling of many natural hazards scenarios.

6.3.2 System Time-Lines for the Three Postulated Natural Hazards Events

Figures 35, 36, and 37 provide summary time-lines from the three natural hazards scenarios detailed in Appendix G.

For the flood-scour event time-line shown in Figure 36, losses (here treated as percent of customers served) manifest themselves fully two hours after the postulated event and continue until the damaged pipeline is repaired 48 hours later, after which the system is steadily restored to full usage.

For the expansive soils event time-line shown in Figure 37, there are many more variations in system reliability as detection is slow (one pipe leak is not detected for 152 hours) and the solution of some major problems leads to the recognition of others. (See Appendix G for details.)

For the earthquake time-line shown in Figure 38, the event immediately causes nearly total lack of system reliability. The isolation of breaks permits fire flows to be restored to most of the system. Again, though, as a pumping station is brought back on line, further leaks are detected, leading again to a drop in system reliability.

This general tendency of the water system to vary in system reliability after a postulated event rather than to improve continuously in reliability has been shown in other studies (see, for instance, Miller, 2001).

6.3.3 Using Time-Lines to Derive Total Systems Losses from Scenarios

Table 26 provides an illustration of how system losses may be calculated based on the three illustrative scenarios (with special reference to figures 35, 36, and 37) System losses estimated in Table 26 are developed merely to indicate how one might rapidly evaluate overall system losses. The average system loss of $1 per customer-day is used in this table for merely illustrative purposes. In a metered system, these losses might be assumed to accrue to the water utility organization itself. In a system in which rates are adjusted to maintain the system, losses might ultimately be accrued to the general customers through rate increases. Table 26 does not, however, break out customers by various stakeholder groups, although the analyses shown in the Appendix G permit such a breakdown, starting with various service zones.

Table 26: Simplified Use of Time-Lines to Derive Systems Losses in Three Scenarios

Natural Hazard Event	Hours	Approximate Reliability (mean values)	Customers Not Served (Based on 100,000 customers)	System Dollar Loss (Assumed $1 per customer-day)
Flood	48.0	75.0%	25,000	$ 50,000
	4.0	87.5%	12,500	$ 2,083
Total:				$ 52,083
Expansive Soils	24.0	92.5%	7,500	$ 7,500
	6.0	75.0%	25,000	$ 6,250
	66.0	65.0%	35,000	$ 96,250
	48.0	77.5%	22,500	$ 45,000
	8.0	90.0%	10,000	$ 3,333
	4.5	77.5%	22,500	$ 4,219
	35.5	65.0%	35,000	$ 51,771
	4.0	80.0%	20,000	$ 3,333
	12.0	97.5%	2,500	$ 1,250
Total:				$ 218,906
Earthquake	24.0	40.0%	60,000	$ 60,000
	132.0	75.0%	25,000	$ 137,500
	12.0	62.5%	37,500	$ 18,750
	60.0	72.5%	27,500	$ 68,750
Total:				$ 285,000

Table 26, as based on Figures 35, 36, and 37, yields the (hypothetical and/or demonstration) conclusion that the flood event has system losses slightly above $52,000, the expansive soils event(s) has system losses above $218,000, and the earthquake event has system losses of about $285,000.

Other information that could be derived from Figures 35, 36, and 37 could include probability distributions for system reliability (with the criterion of percent of customers served) for the time-periods in which the system has been disrupted. These probability distributions could suggest how one natural hazard event compares with another in terms of reliability. Although perfect reliability would be ideal, decision-makers might also want to set lower more realistic reliability targets for their water utility system.

6.4 Using System Evaluations as Part of a Risk-Based Evaluation

A risk-based evaluation is required whenever one is undertaking a financial evaluation (e.g., cost-benefit, mean-variance). (See Alesch et al., 2002) To achieve this more advanced level of evaluation, considerable automation of the shaded steps in Figure 1 is required.

For a risk-based evaluation, a key step in this automation process is the random selection of natural hazards events. Fortunately, there are many parties over the past fifteen years who have developed, largely for proprietary (e.g, insurance and other financial services) purposes, representative suites of major natural hazards events. As indicated in Chapter 3, publicly available data and models for several major natural hazards can be adapted to develop such random samples of natural hazards events (see Taylor et al., 2001, on hurricanes and earthquakes).

For purposes of a risk-based evaluation, long-distance effects, site hazard effects, component vulnerability models, and system performance models in Figure 1 can be deterministic—although random uncertainties could be included as known. In addition, Chapters 2 through 5 stress throughout the uneven development of models for evaluating water systems subjected to natural hazards.

Based on a random selection of natural hazards events and the automation of other shaded steps in Figure 1, one can develop a matrix such as that represented by Table 27. This matrix can be developed for a specific natural hazard (e.g., flooding) or for all natural hazards taken together. In Table 27, each row represents the results of a natural hazard scenario. Each scenario has an estimated frequency of occurrence and an estimate of system losses. The system losses found in Table 26 could provide examples had the natural hazards scenarios been randomly chosen, or assigned a frequency of occurrence. Table 27 also contains an estimate of losses to some stakeholder Q. An examination of how scenario losses are generated in Appendix G provides clues as to how losses to specific stakeholders (e.g., service zones) can be derived.

Table 27: A Matrix Providing the Basis for Risk-Based Estimates

Randomly Selected Natural Hazard Event	Annualized Frequency of Occurrence	System Loss	Stakeholder Q Loss
E_1	F_1	L_1	Q_1
E_2	F_2	L_2	Q_2
...	...	...	...
E_n	F_n	L_n	Q_n

Such a table provides an adequate means to estimate mean annualized system losses as well as mean Stakeholder Q losses for some stakeholder. As well, one can use Table 26 to derive estimates of standard deviation and coefficient of skewness, two other statistics that can prove to be useful in risk-based evaluations of water systems.

For various decision alternatives, one must first provide estimates of marginal costs (costs relative to the status quo). One must further modify one or more of the sub-models (for natural hazards, component vulnerabilities, or system performance) to show the change from the status quo. Producing a Table 27 for the proposed decision alternative can again yield such statistics as mean system losses, their standard deviation, and their coefficient of skewness. Thus, one can develop such overall statistics as reduced mean losses, reduced standard deviation, and the like in order to compare alternatives on a financial basis.

Similar procedures can be developed to assess system reliability. For instance, time-lines can be used to indicate whether or not in specific scenarios a pre-specified system reliability is achieved. For instance, Figures 35, 36, and 37 can be used to determine whether or not the water utility is 95% reliable within 10 days after the natural hazard event. Given a random selection of natural hazards scenarios, one develop a suitable matrix to assess the overall system reliability.

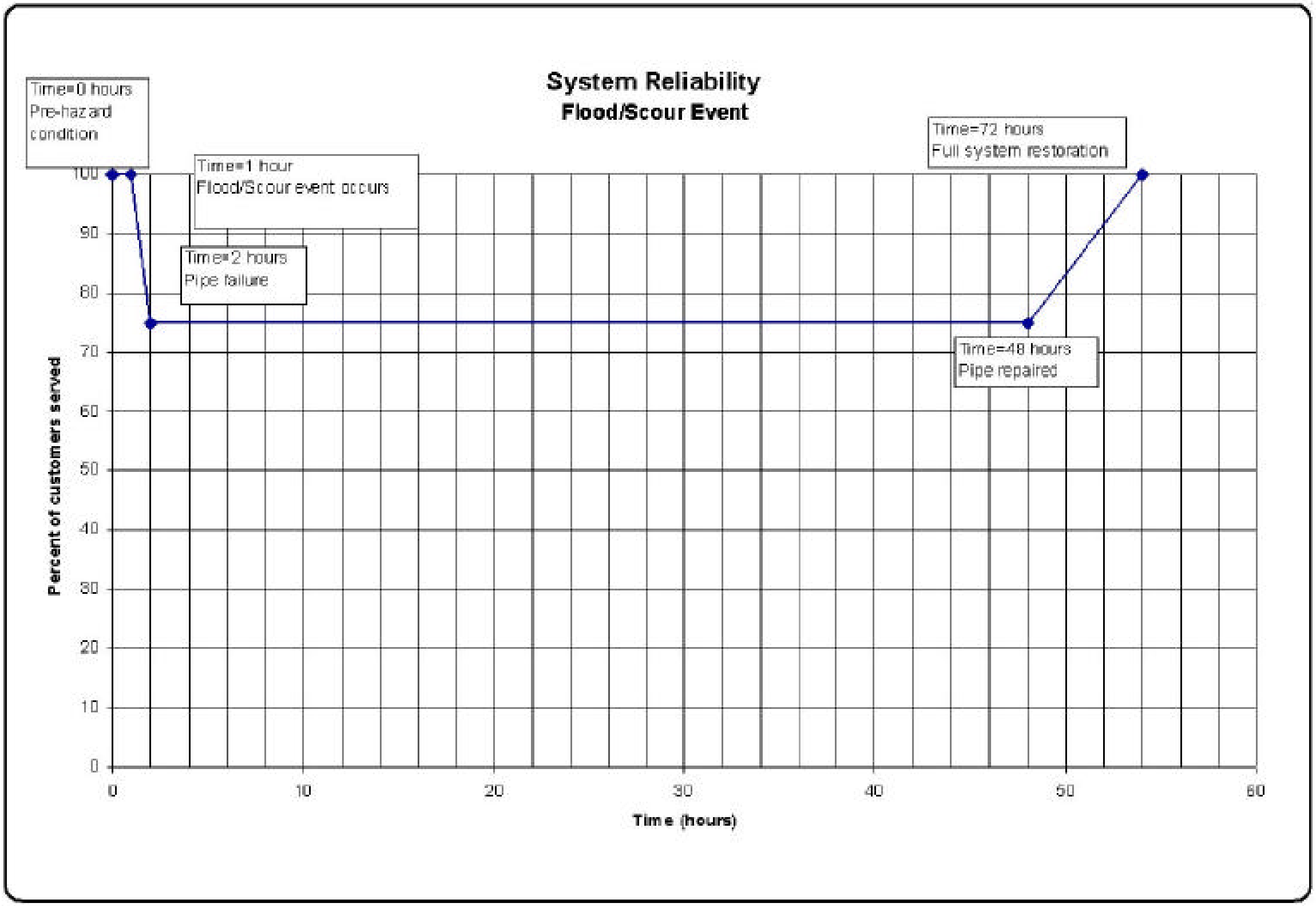

Figure 36: A Time-Line Chart for Response of a Water Utility to a Hypothetical Flood/Scour Event

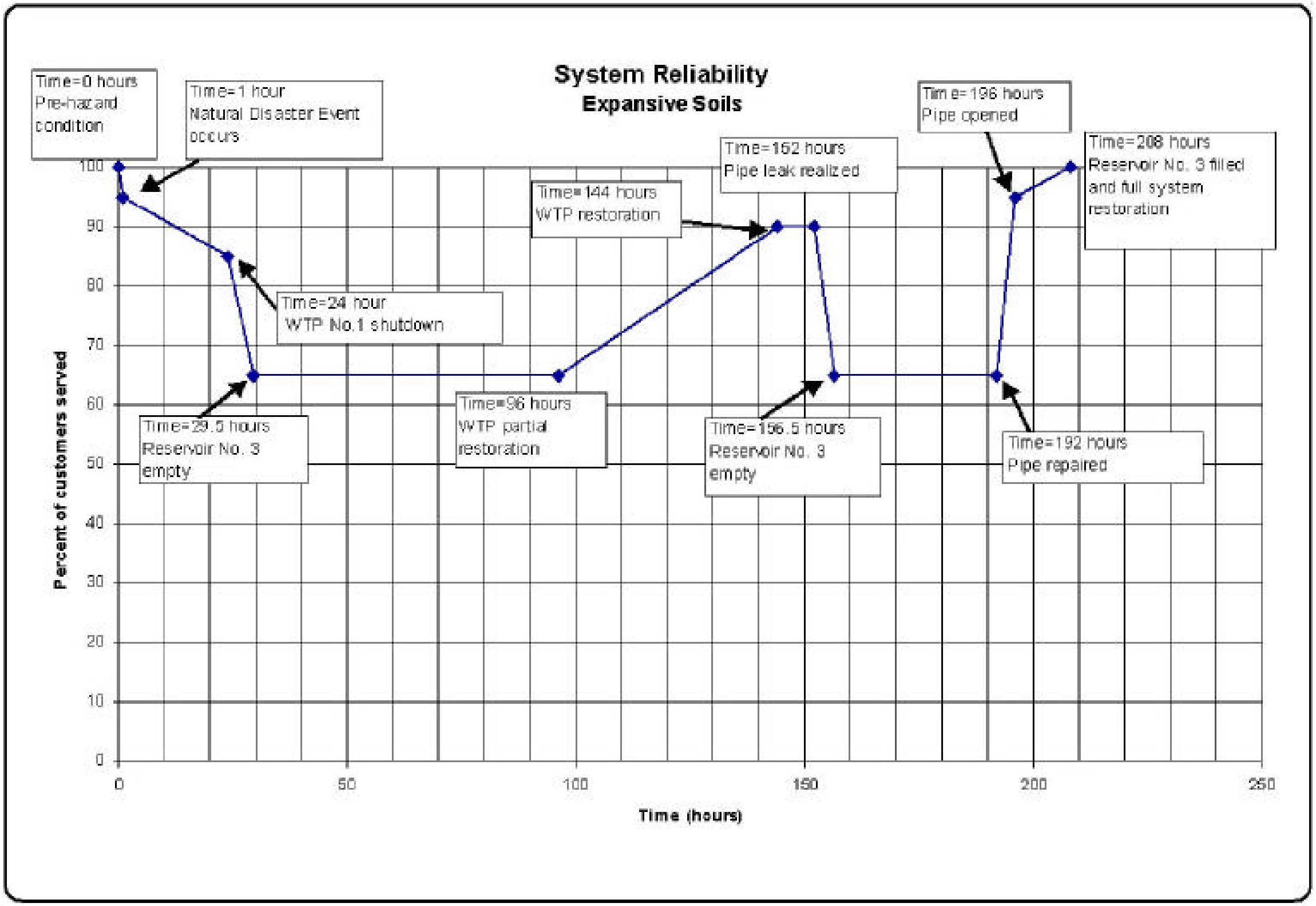

Figure 37: A Time-Line Chart for Response of a Water Utility to an Expansive Soils Event

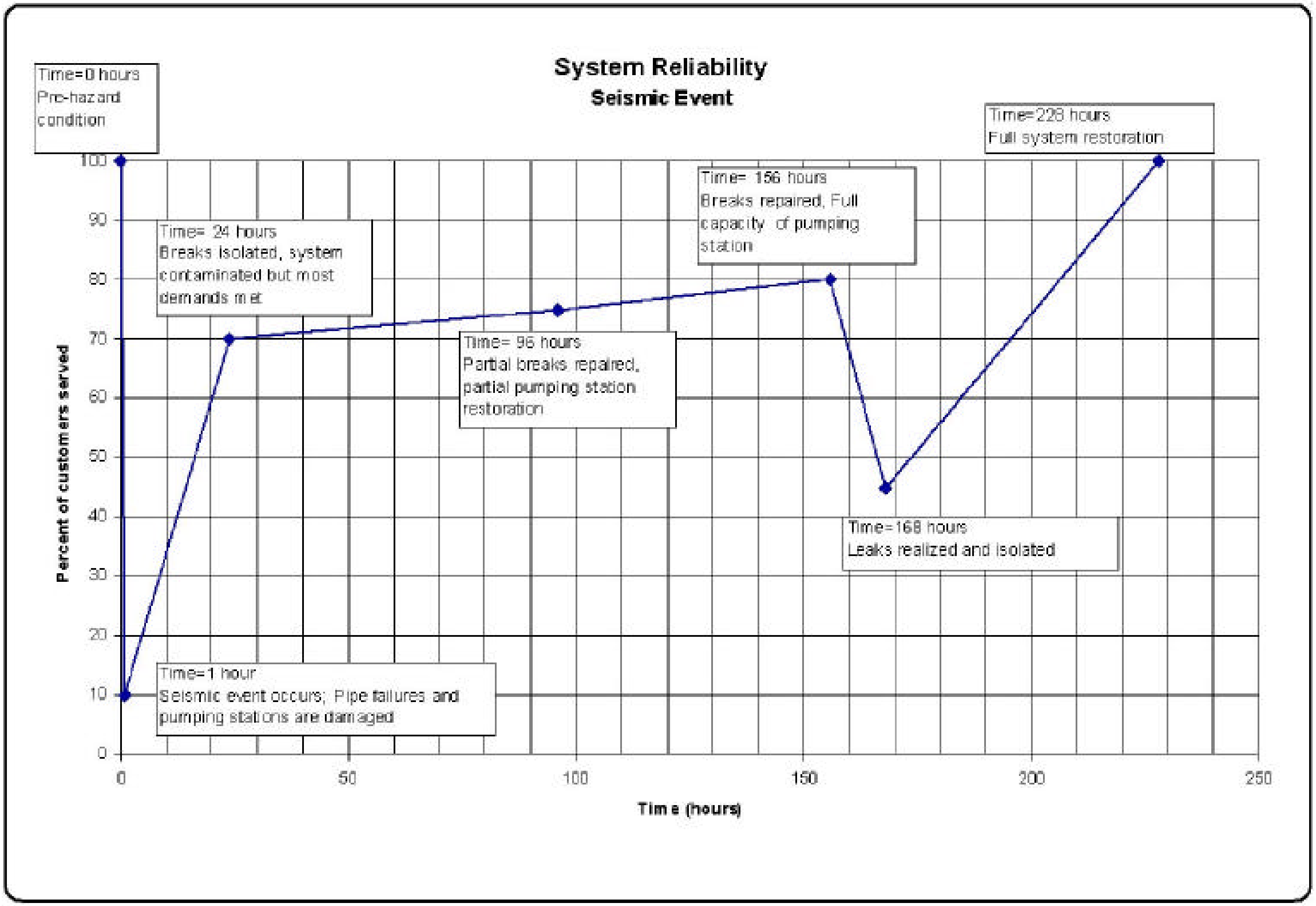

Figure 38: A Time-Line Chart for Response of a Water Utility to a Hypothetical Earthquake