1.0 INTRODUCTION

1.1 Project Objective

This document provides guidelines for developing cost and risk information for various system performance options that may be considered for water utility systems subjected to natural hazards.

This guideline is intended to provide clear, concise guidance on specifying the procedures to follow and information to consider in performing a standardized evaluation of a water system during and after potential natural hazard events. The goal of the application of this guideline is to assist water system owners and operators in defining what approaches are necessary to characterize the anticipated performance of their systems and provide a defensible basis for risk management decisions. Implementation of the approaches recommended in this guideline will allow these owners and operators to define the scope of activities necessary to determine appropriate risk management actions to reduce the impact of natural hazards on water systems to acceptable levels.

1.2 Project Scope: Natural Hazards and Water Utility System Facilities Covered

This guidelines covers the following natural hazards: earthquakes, floods, windstorm (including hurricane and tornado), and ground movements (landslide, frost heave, and settlement). By implication, liquefaction, tsunamis, and seiche are covered.

These guidelines cover water system facilities insofar as they are operationally important. Specific guidelines are designed for the following potable water facilities:

- Steel and concrete distribution reservoirs
- Transmission pipelines, tunnels, aqueducts, and canals
- Treatment plants
- Booster pumping plants
- Wells and sumps
- Pressure vessels (surge tanks, etc.)
- Inlet/outlet piping
- Distribution piping
- Service connections
- Fire hydrants
- River Diversions

These guidelines do not cover

- dams
- hydroelectric plants

Buildings and other water facilities are covered only insofar as they play key roles in water utility operations. These guidelines are not designed to replace codes designed for buildings. Conversely, because water utility components are elements within systems, it is assumed that codes designed for buildings may be sub-optimal as applied to non-building components in water utility systems.

1.3 Project Scope: Framework for A Decision Process

1.3.1 Background to the American Lifelines Alliance Decision Process

Figure 1 provides a framework for a process whereby water utility agencies can make a defensible decision with respect to decision options relative to reducing risks from natural hazards. The unshaded boxes in Figure 1 are those outside the explicit scope of this project. However, for reference purposes, it is desirable to discuss potential natural hazard risk reduction options, system performance requirements, and stakeholders in the process.

1.3.2 Sample Natural Hazards Risk Reduction Options

The following discussion outlines some of the types of decisions for which a risk and decision tool for water utilities may be used. Decisions considered through the use of such a tool may be individual initiatives, such as the redesign of a water distribution reservoir. Alternatively, water utilities undertaking a formal systems evaluation may wish to consider a comprehensive program to address the entire range of natural hazards and practical decision alternatives and schedules to reduce their system risks. Comprehensive sets of alternatives and schedules may involve many diverse activities designed to reduce natural hazards risks over time (See, for instance, AWWA-M19, 2001, Chapter 4, and for earthquake risks, see AWWA, 1994). For purposes of categorizing types of risk and decision alternatives, water utility decision-makers may consider:

1. *engineering measures*—such as through the design and construction of new facilities or the redesign and retrofit of existing facilities, geotechnical remediation, and use of temporary shoring. For instance, decision-makers may consider

    - levels of hazard-resistant design suitable for a major water utility component (e.g., water distribution reservoir)
    - elevation of equipment to avoid potential flood damage
    - submergence-rated equipment where elevation cannot be deployed
    - bracing or anchorage of equipment
    - addition of anchorage or flexible connections to water reservoirs subject to ground shaking hazards

- installation of a floodwall to protect a major water system component
- accelerated replacement of older more vulnerable pipelines
- hardening Emergency Operations Centers and other buildings critical to water systems operations

2. *Land use measures*—such as through alternative siting or reduction of exposures in building structures that may be damaged. For instance, decision-makers may consider

- alternative siting of a major water system component (e.g., away from a landslide prone region, or away from houses that could become inundated if damage occurs to the component, or outside a major flood plain)
- reduction of exposure of critical equipment and personnel in a building that is more vulnerable to damage from natural hazards

3. *System enhancement*—the use of multiple pathways and nodes (system redundancy) in order to assure that system goals are met. For instance, decision-makers may consider

- the development of a major alternative water supply source or water treatment plan
- the development of alternative sources of electric power and other energy sources
- the development of backup communications systems
- the installation of shutoff valves on gravity and pressure service lines in order
- to isolate damaged portions of the system
- the installation of a Supervisory Control and Data Acquisition (SCADA) system
- the addition of loops of parallel pipelines to enhance transmission redundancy

4. *Emergency response*—the immediate response to emergencies including disasters. For instance,

- the development of a recovery plan, with drills and regular updates, may facilitate response and recovery after natural hazards
- mutual aid agreements may assist along with cooperative activities with other key first-responder and short-term forecasting agencies.
- spare parts, materials, personnel, and equipment may be developed in key locations to assure rapid response to restore the system

5. *Disaster recovery and restoration*—the long-term restoration to normalcy after a large emergency or disaster, again through cooperative activities and strategic planning.

6. *Risk transfer*—the use of insurance or other liability transfers (e.g., contractual liability transfers with manufacturers, suppliers, consultants) in order to limit the water utility's post-disaster liabilities and assure that adequate recovery funds exist, and

7. *Financial Reserving*—such as retaining funds for emergency response and recovery contingencies.

1.3.3 Types of Pertinent System Performance Metrics.

For evaluating such risk and decision alternatives, water utility managers may use a variety of metrics. In general, health, safety, and welfare are the overarching goals to be evaluated. The primary system metrics for evaluating these decisions will pertain to "welfare" (broadly speaking, economic) metrics of

- percent served (in total or by sector) within a specific number of days with raw water with adequate fire flow pressures, and/or
- percent served (in total or by sector) within a specific number of days with fully treated water

The discussion below explains why by and large the appropriate metrics used in water systems subjected to natural hazards are welfare criteria, with health and safety standards and procedures being largely taken for granted.

Health Standards and Procedures as Givens.

In this document, health standards and procedures serve as givens for potable water systems in the United States. In some other countries, post-disaster health issues have been paramount concerns. In the United States, through a public review process, the Environmental Protection Agency (EPA) develops Safe Drinking Water (SDW) regulations from legislation that has been passed by Congress and signed by the President. States may choose to implement directly EPA regulations or develop their own regulations at least as stringent.

In post-disaster planning, most water utilities have an emergency response plan that contains

1. A "Boil Water Notice" to inform the public to boil water before its use when there is a potential for water pollution resulting from damaged water facilities. State and local officials must approve lifting this notice.

2. An increase in normal field and laboratory water quality testing, especially in areas of water system damage or potential pollution sources.

3. An increase in treatment, especially with approved water treatment chemicals at the water treatment plant.

4. An increase in the disinfection dosage of chlorine or other oxidation chemicals in the field at the areas of significant damage, in the water treatment plant, or as a general precautionary measure. (L. Lund, written communication, 11/05/01).

As a result, existing health standards and procedures are built into the water utility response and restoration procedures leading to the lifting of the "Boil Water" notice. Likewise, numerous means are generally available for the emergency distribution of water for drinking and sanitation soon after a water utility disaster in the United States.

As a consequence, these stringent health standards and procedures are generally pre-supposed in the evaluation of natural disaster effects on water systems in the United States. Being pre-supposed, these stringent health standards and procedures generally do not constitute the type of system performance metrics used in the evaluation of a water system threatened by natural hazards. Instead, health standards and procedures constitute constraints on how rapidly the "Boil Water" notice can be lifted, and thus extend the return to full normalcy for the water system that has been damaged by natural hazards. (See American Water Works Association (AWWA)-M19 for an extremely strong emphasis on post-disaster health-related activities.)

Safety Standards and Procedures as Givens.

Similar remarks apply to safety standards and procedures. Natural hazard events can lead to a large number of life-safety hazards: electrocution, drowning, falling, being crushed, being cut, being burned, inhaling chlorine, and so on. Safety procedures within water utilities and for other emergency first responders must cover the bulk of these life-safety hazards, except for selected considerations pertaining to fires and inundation zones. (See AWWA-M19 for an extremely strong emphasis on safety practices after water utility emergencies; see American Water Works Association Research Foundation (AWWARF) (1998) for very strong safety and health practices related to water treatment plants)

Security Standards and Procedures as Givens

As a result of the September 11, 2001 hijackings and deaths, and injuries associated with the World Trade Center, Pentagon, and aircraft damages, security measures have been greatly heightened for water systems. At the time of this document, the House of Representatives had passed HR 3448, the Tauzin-Dingell "Public Health Security and Bioterrorism Act" which includes a requirement for all water utilities serving over 3300 people to complete security vulnerability assessments. Like health and safety standards and procedures, security standards and procedures are regarded for this document as given. However, data and models developed in assessing security vulnerabilities may be useful in developing natural hazards evaluations for water systems.

Sample Welfare System Performance Metrics

Hence, the main thrust of system performance metrics used in conjunction with this document will be welfare metrics—with health and safety standards and procedures presupposed as being stringent. Very typically, these will be of the following forms:

Metric (target): Z% of C served in W days with raw water with adequate fire flow pressures

Metric (target): X% of C served in Y days with fully treated water

In these generalized forms, "C" can stand for the entire system, or for selected stakeholders within the system. Examples of stakeholders include "C=" residential customers, emergency operations centers, hospitals, manufacturers, industrial zones, hotels and motels, nursing homes, and so on. These metrics could be measured alternatively in terms of number of service connections, populations served, or volume of water served (i.e., cubic feet or gallons).

In the above forms, one can use existing financial and economic data to convert such metrics into dollar terms. These would include water utility revenues lost, business interruption losses, and other higher order effects of such financial and productivity losses.

One can also add probabilities to the above metrics. For instance, instead of a target of X% of C served in Y days with fully treated water, one may use a more complex target such as "With a probability of P, X% of C served in Y days with fully treated water." From a practical standpoint, deciding in advance of a water system evaluation how reliable the water system should be is likely to be short-sighted, especially if costs are high to achieve the pre-specified level of reliability. The acceptability of the pre-specified metric may well change as one considers existing technologies to reduce risks and who pays for their incorporation into the system.

Noticeably absent from these system decision metrics are references to illness and life-safety. This is for reasons given above—that the extremely important considerations of warding off disease, injury, and deaths are accounted for in existing standards and procedures. In addition, absent as well are qualitative system performance factors. Full-scale decision-making will involve not merely "welfare" considerations of the financial or economic kind but considerations pertaining to administration, social impacts, psychological impacts, political and legal concerns, and a host of other considerations that are not explicitly covered in this document.

In addition, this document is designed to accommodate decision metrics that are (a) scenario-based (called deterministic) or (b) risk-based (called probabilistic). The varieties of these decision metrics are extremely large. However, scenario-based methods rely on the evaluation of a water system subjected to a small number of natural hazard scenarios. These, for instance, could include the repetition of past floods, hurricanes, severe rains, earthquakes, and so on. Or, these natural hazard events could be modeled to accommodate the latest scientific and engineering knowledge of the natural hazards phenomena. A risk-based method for evaluating water systems, as described in the remainder of this document, will again be based on individual scenarios, but enough of these will be modeled through random processes to provide statistical results. Familiar versions of cost-benefit and related financial methods typically require a risk-based approach. (See Alesch et al., 2002).

1.3.4 Basic Stakeholders in the Decision

A key factor in decision-making is consideration of who pays and who benefits from the decision. Basic stakeholders in the decision to reduce water utility system risks from natural hazards may involve:

- the water utility itself
- pertinent wholesalers or distributors associated with the water utility

- municipal governments to the extent that they subsidize or are subsidized by the water utility
- other water utilities associated with the primary water utility through mutual aid agreements
- local fire departments concerned to assure that fire flows are adequate
- various categories of customers (e.g., differentiated by service zones and/or by such customer types as industrial, institutional, commercial, and residential) and/or specific lists of customers (e.g., health-care facilities, emergency operating and public safety facilities, special manufacturers)
- insurers, bond-holders, bond rating agencies, and lending institutions
- federal and state agencies that may provide federal or state disaster assistance
- other federal, state, and local agencies that have additional expenses during disruptions to the water system
- other infrastructure systems (e.g., energy, wastewater, communications) that may be affected by disruption to the water system, and
- federal, state and local agencies that regulate health effects (water quality) and/or that are involved with proactive antiterrorism programs (system performance).

In addition to various basic stakeholders, entire communities may be involved in various ways in disruption to a water system. For instance, the tourist industry may be harmed, out-migration may be increased, general contractors may have additional work, a surplus of general contracting labor may arise from the additional contracting labor needs in the affected region, and so on. Higher-order ripple effects of damages to potable water systems will generally be outside the scope of these guidelines, but there are expected to be many.

1.4 Multiple Levels of Analysis

1.4.1 Background to Analysis Steps

As elaborated in subsequent chapters, the basic iterative steps in a water systems risk evaluation for natural hazards consist of inventorying pertinent water system components, defining natural hazard scenario events and their natural consequences, evaluating the response of water system components to these natural hazard scenario events, and evaluating the system response to damages to the water utility components (see shaded steps in Figure 1).

To the extent possible, the guidelines produced in this document will be uniform among the great variety of water utilities. To some degree, this is made possible by current advanced technologies that permit hydraulic evaluations even for small water systems.

1.4.2 Characterizing an Advanced Level of Analysis

The most advanced level of analysis would consist of the following features:

- The analysis covers major natural hazards affecting the water utility system and its major facilities
- The analysis does not itself introduce various clear biases such as conservatism
- The analysis treats the system through hydraulic models
- The analysis considers various stakeholders, such as through the evaluation of results at various service zones or for various classes of customers
- The analysis treats natural hazards probabilistically, through the random selection of initiating events some of which (e.g., earthquakes, hurricanes) may affect the entire system more or less all at once
- As needed, special facilities are given special scientific and engineering evaluations, and
- A significant selection of seismic decision alternatives is postulated, along with their costs

1.4.3 Two types of simplifications: those for simpler systems and those for a less advanced analysis

However, this document also recognizes the great differences in technical capacity and availability among water utilities. Some water utilities are very large, covering hundreds of thousands of customers. In contrast, most water utilities cover a much smaller number of customers, with tens of thousands being more normal, and even fewer customers in many cases. A paramount concern for most water utilities is to maintain low rates, which limit the development of technical capacity and availability. In addition, not all decisions require that a full-scale evaluation be undertaken of the entire system and all natural hazards.

Given these wide ranges in technical capacity and availability, and the wide range of possible decisions for which this document is a guide, this document includes guidelines for the use of simplified procedures. These simplifications will be divided into those that render an analysis less advanced and those that recognize special features of the system so that an advanced analysis

Simplifications that can be used that can still lead to an advanced analysis include:

- The water system in question is of limited spatial extent (e.g., say, four square miles with an aspect ratio (length to width) that is not too high) and so permits the use of a simplified method for such natural hazards as hurricane and earthquake
- One or more of the natural hazards has an insignificant potential effect on the water system (e.g., hurricanes in Montana)
- The system is primarily a gravity-flow system so that a full-fledged hydraulic evaluation may not be needed
- The entire system is linear so that simplified systems methods can be used. Or, the portion of the system of special interest is very linear or non-redundant so that simplified systems methods can be used

- The system contains major components that are impervious to the natural hazards under evaluation (e.g., buried pipelines relative to severe winds).

The following simplifications could lead to an intermediate analysis (depending on circumstances—a scoping study could defend some of these simplifications):

- The guidelines are to be used to assist in developing a scoping study, that is, a study of what natural hazards and components should be evaluated (see section 1.5 for a sample scoping study—which by itself would result in an intermediate analysis)
- The guidelines are to be used to undertake a decision that involves only a sub-system of the entire water system (e.g., a sub-system consisting of a booster pumping station and a distribution reservoir)
- The guidelines are to be used for a decision that involves only selected natural hazards (e.g., severe winds only)
- The guidelines are to be used only to assess system performance from an operational standpoint, such as through the use of pre-selected (as opposed to randomly selected) natural hazards scenarios, and
- The guidelines are to be used to evaluate a specific stakeholder interest (e.g., distribution systems served by a wholesaler, residential customers, a specific large manufacturer, emergency and critical health facilities) and so do not require that the full system be evaluated.

Note that in some of these cases the evaluation could be very advanced in at least some respects.

1.4.4 Below Intermediate Analyses

Very often it is desirable simply to obtain some very initial evaluation of the water system performance subjected to natural hazards. Some of the following features of an analysis lend it to being less than an intermediate analysis:

- Conservatism is used in various analysis steps (as may be useful in near real-time post-disaster evaluations used for immediate post-disaster response and strategizing); no sensitivity evaluations are performed to evaluate the impacts of this conservatism on the water system risk results
- A geographically large system is evaluated with respect to initiating events defined for site-specific rather than system purposes (e.g., zip code measures of natural hazard intensity)
- Very coarse assumptions are used to produce very precise results, with little or no explanation regarding the coarseness of the assumptions and their impacts on results
- The evaluation is performed for primarily promotional purposes, that is, to promote actions based on showing how extreme a natural hazard risk can be rather than to put the natural hazard risk and costs of reducing it into perspective.

1.5 Preliminary Study Scope of Work: A Sample Phase I Study

A phase 1 study provides an overview of the seismic risks facing the utility. Depending on findings, further phases may include more detailed studies at selected sites, or for systems or components identified as significant contributors to seismic risks, retrofit design or other active risk-reduction steps. A phase 1 project scope typically includes facilities data gathering, natural hazards review, site visits, preliminary vulnerability modeling, and limited risk analysis. The scope and sequence of each task may be varied in proportion to hazard levels or water agency needs. The discussion below provides one outline of such a scoping study. Some water utility agencies, such as Metropolitan Water Department, have their own scoping study approaches (Dave Putnam, written comm., 6/02) modified for their own systems and evaluation needs (e.g., antiterrorism concerns may be combined with natural hazards concerns).

Task 1. Data Gathering

In this task, the basic documents needed for the study are assembled:

- Facility design drawings, specifications and reports,
- Soils and geological reports for buildings, reservoirs and pump stations,
- Water service transmission and distribution piping maps, GIS, and water system analysis models,
- Equipment lists,
- Pressure zone maps,
- Critical customer lists,
- Water consumption records,
- Emergency response or contingency plans,
- Hazmat Risk Management Prevention Plans or similar studies,
- Zoning maps

Task 2. Asset Inventory Development

An inventory list (an electronic list, often in Microsoft Excel or other database format) for the agency buildings and equipment is essential. Such a list provides a valuable vehicle for prioritizing site visits, design document review and other data gathering activities. The inventory of above-ground assets is particularly helpful to prioritize site visits, so that high-value and important items are examined and appropriately modeled. Where this list is lacking, it should be developed.

Ideally, the database should list replacement values for the buildings, other structures and equipment at all of the facilities. This can serve as a starting point, to construct the inventory database for the project, adding information about site conditions and the seismic vulnerability of the elements. The database can be expanded to include information on the agency's water reservoirs, transmission piping and distribution piping systems.

Task 3. Develop Operational Importance Ratings

Once the full inventory is assembled, water agency operations managers can assign operational criticality ratings to the major components. Piping and Instrumentation Diagrams (P&ID's) can be analyzed and prioritized assigned. For the first phase of review, a judgment-based system can be used, considering system criticality, component criticality. For preliminary studies, lacking a detailed numerical water system model with which to rate the operational importance of each major component, a judgmental rating system may be implemented. The system described below illustrates how this may be done. A series of factors is elaborated, to assess the importance of each component with respect to a set of performance objectives. Each rating has a set of consistent definitions. Judgmental rating factors are used to combine the individual ratings into an overall operational criticality rating.

Operational Criticality Rating

The Operational Criticality Rating (OCR) combines a Facility Criticality Rating (FCR), and a Component Criticality Ratio (CCR).

$$OCR = A \times FCR + B \times CCR$$

A and B are judgmental weights, assigned by the analyst and water agency operations experts. The weighting factors are normalized, that is:

$$A + B = 1.0$$

Each of the individual criticality ratings (FCR and CCR) range from 1 (insignificant) to 5 (highly critical). The judgmental weighting factors (A and B) establish the relative importance of facility versus any particular component. As an example of values that may be used for Operational Criticality Rating (OCR), with A = 0.67 and B = 0.33, we obtain:

$$OCR = 0.67 \times FCR + 0.33 \times CCR$$

This would stress the operational importance of components at a critical facility (i.e., one with a high Facility Criticality Rating, or FCR), compared to the components at a noncritical facility.

Facility Criticality Rating

The Facility Criticality Rating (FCR) is composed of two ratings, the System Operation Rating (SOR) and the Capacity / Size Rating (CSR):

$$FCR = (C \times SOR) + (D \times CSR)$$

C and D are judgmental weights, and

$$C + D = 1.0$$

The FCR remains the same for each component at any given facility. For example, a settling tank and any given pump at a particular plant would both have the same FCR since they are components of the same facility. The intent of the FCR is to establish the importance of each facility to the backbone system. As another example, reservoir Alpha may be rated higher than reservoir Beta, which has the same capacity, if the SOR at reservoir Alpha is higher and they are two separate facilities. Individual criticality ratings may be developed as along the following lines:

- *SOR – System Operations Rating*

  The SOR ranges from 5 (highly significant with respect to system operation) to 1 (insignificant with respect to system operation).

- *CSR – Capacity/Size Rating*

  The CSR for a reservoir may be rated in accordance with the capacity range criteria below (rating numbers are provided as an example only):

  5 – 2,500,000 gallons or greater
  4 – 1,800,000 to 2,500,000 gallons
  3 – 1,300,000 to 1,800,000 gallons
  2 – 750,000 to 1,300,000 gallons
  1 – Less than 750,000 gallons

- *The CSR for a pump station may be rated in accordance with the following ranges for the capacity of the station (rating numbers are provided as an example only)*

  5 – Greater than 10,000 gpm
  4 – 5,000 to 10,000 gpm
  3 – 2,500 to 5,000 gpm
  2 – 1,000 to 2,500 gpm
  1 – Less than 1,000 gpm

Similarly, for other components, CSR is qualitatively based on relative water throughput.

Component Criticality Rating

The Component Criticality Rating (CCR) combines four ratings:

LSR = Life Safety Rating (based on fraction of time occupied)

FFR = Fire Flow Rating (significance to fire fighting)

DWR = Drinking Water Rating (significance to drinking water supply)

DPR = Damage Potential Rating (potential for causing damage to adjacent facilities)

$$CCR = (E \times LSR) + (F \times FFR) + (G \times DWR) + (H \times DPR)$$

E, F, G, and H are judgmental weights, constrained such that

$$E + F + G + H = 1.0$$

As an example, with judgmental weights E = F = G = 0.3 and H = 0.1, we would give equal weight to operator life-safety, fire flow and drinking water, with lesser importance to damage to adjacent facilities. Individual criticality ratings may be developed as follows:

- *LSR – Life Safety Rating*

  The LSR criteria may be assessed as follows:

  5 – Continuously occupied
  4 – Hazardous materials release potential
  3 – Occupied 50% of time
  2 – Occupied 25% of time
  1 – Occupied 10% of time

- *FFR – Fire Flow Rating*

  The FFR ranges from 5 (highly significant with respect to providing water for fire suppression) to 1 (insignificant with respect to providing water for fire suppression).

- *DWR – Drinking Water Rating*

  The DWR ranges from 5 (highly significant with respect to providing drinking water following an event) to 1 (insignificant with respect to providing drinking water following an event).

- *DPR – Damage Potential Rating*

  The DPR ranges from 5 (highly significant issues with respect to damage potential to adjacent facilities or properties, e.g., numerous residences in the path of a potentially catastrophic reservoir failure) to 1 (minimal damage potential to adjacent facilities or properties).

Task 4. Site Visits

The project team conducts preliminary walk-through surveys of the important facilities (headquarters, EOC, maintenance yard, etc.), and visits typical pump stations, reservoirs, and potable water pressure reducing facilities. The project team is escorted by knowledgeable agency representatives, who provide information regarding the operational importance of the facilities, as well as information regarding facility design and agency master plans for the facilities.

Task 5. Review Natural Hazards

Geologic hazards, weather-related hazards and other natural hazards are characterized throughout the water system. Hazards without significant frequency or severity are eliminated from consideration, and the significant hazards are evaluated using simplified methods. For a phase I effort, published geologic mapping may be used, together with limited field reconnaissance. A geographic information system (GIS) representation of the agency's transmission piping may be adapted for use on this project. The geology may then be digitized, and the agency's facilities overlaid to provide preliminary analysis of site conditions, and to illustrate these conditions to the agency. The GIS model also allows piping damage rates to be tallied subject to various geologic conditions, such as landslides, ground movements from freeze/thaw, or seismic hazards. Seismic hazards such as liquefaction and landslide may be examined, using published earthquake hazard zone maps to show how much of the system may be affected, and to assist in scoping further geologic investigations to assess the spatial variation of the hazard severity.

Task 6. Vulnerability Modeling

Based on the distribution of natural hazards, and the distribution of critical components, brief reviews of selected design documents can be conducted. Visual surveys can also be used to evaluate the vulnerability of the agency's buildings, large structures and major equipment items. Simple financial loss models estimate facility damage as a fraction of each asset's replacement cost, using the inventory discussed under Task 1.

Task 7. Risk Analysis

The risk analysis may utilize individual scenarios (events), or sets of scenarios. Thus, the analysis may be event-driven, using conventional event tree methods. This is a top-down method, where levels of damage and probabilities of failure for each component of the system are assessed, and failures are simulated. System-wide consequences may then be evaluated formally (using a water system model) or informally (using judgment).

Alternatively, for this preliminary phase, the risk analysis can be component-driven.

1.6 Decisions Under Both Risk and Uncertainty

The goal of an evaluation of a water system subjected to natural hazards events is to gather and synthesize information that assists decision-making. That portion of a decision based on the synthesized information from such an evaluation may be called a portion of the decision under risk. In a decision under risk, there is still an element of chance, but this is fully quantified through the risk evaluation process. For instance, in a deck of cards, the chance of picking a heart is one-in-four—as long as there are no jokers in the deck. Taking a chance of picking a heart can be a decision under risk—as long as one knows what the chances are of picking the heart. Through the synthesis of information in a water system evaluation, one can remove uncertainty and ignorance. The systems approach in Figure 1 implies that one puts together piecemeal information from the system at risk, natural hazards that may impact it, the vulnerabilities of its components to these natural hazards, and the response of the system to natural hazard damages to these components. This systems approach implies that decisions based only on piecemeal information have greater uncertainty and ignorance than those based on a more synoptic approach.

In contrast, decisions under uncertainty—in their extreme form—do not have relevant information. For instance, one may be forbidden to know how many cards are in the "deck" or "pile" and one may not know what proportion of the cards in the deck or pile are hearts. In this case, one's wager on picking a heart would be a decision under uncertainty—or abject ignorance.

The ideal goal of the evaluation of a water system subjected to natural hazards is thus to produce a decision under risk, and not a decision under uncertainty. In a decision under risk, to repeat, all key factors bearing on the decision would be fully and adequately quantified. A systems approach to water systems moves in this direction. Ignorance of the system at risk, natural hazards that may affect it, the vulnerability of its components, and the potential response of the system are removed. Nonetheless, the state-of-the-art in this type of evaluation does not permit one to remove all uncertainties and unknowns. This is chiefly a result of the uneven quality of data and models used in such an evaluation. There are very few instances (e.g., very short-term forecasts of floods) in which ignorance is almost virtually removed.

Considering natural hazards events alone, and not the uncertainties in estimating water facility and system response to them, one may be guided by earlier words on nuclear power studies:

> The ANS-2.12 [American Nuclear Society] Working Group wishes to clearly state that it is difficult to precisely establish the probability of occurrence of natural and external man-made hazards. The phenomena are complex and the probability of each is a function of parameters such as geographical location, time of year and nature of the hazards (ANS, 1978, foreword)

In this document, such cautionary remarks are scattered throughout. The goal of an evaluation of a water system subjected to natural hazards is to develop systematic information for a decision both under risk and uncertainty. Uncertainty and ignorance are reduced, but almost never to a point of certainty. Virtually all models used in this evaluation procedure suffer from aspects of ignorance and uncertainty. An evaluation of a water system subjected to natural hazard events thus produces bounded patterns, not estimates that can be trusted at several decimal places.

1.7 Remaining Chapters of this Document

Four steps are involved in developing baseline information: defining system performance requirements, identifying natural hazard risk reduction options, defining the system to be evaluated, and identifying natural hazard events to be considered. The first two lie outside the scope of this document except insofar as this document must provide a framework for a variety of system performance requirements and natural hazard risk reduction options, respectively.

The remaining steps in Figure 1, except for the actual decision-making itself, will be discussed in detail in the subsequent chapters of this report.

In Chapter 2, Definition of System and Hazards to be Evaluated, guidelines will be developed for determining the appropriate procedures to be used in defining the extent of the water system to be evaluated. These guidelines will be provided to describe adequately the inventory of components and component functionality through available documents, drawing reviews, field observations, historical operational experience, and interaction with water utility personnel. Forms, checklists, and other materials will be provided to facilitate this inventory assessment procedure. Section 2.2 emphasizes potential simplifying procedures--the various circumstances under which only a portion of the water system needs to be inventoried for purposes of addressing a specific decision pertaining to natural hazards.

Supplementing Chapter 2 is Appendix B. For the illustration of inventory procedures, Appendix B contains an idealized water utility system that contains virtually all components of potential interest, and which one can imagine being subjected to all pertinent natural hazard events.

In Chapter 3, Modeling Natural Hazards, guidelines are developed for determining the appropriate procedures for evaluating natural hazards events and their consequences at specific sites within a water utility system. Appendix C supplements this Chapter with a discussion of the phenomenology of natural hazards.

Modeling for all natural hazards will be based on scenarios, defined in terms of initiating locations and severities. Purely deterministic methods will use only individual scenarios. Probabilistic methods will consider randomness and uncertainties in a more comprehensive selection of scenarios.

Simplified methods are provided in special cases such as for a geographically small water system, for the evaluation of a non-redundant system component, or the evaluation of a geographically small sub-region of the system.

In Chapter 4, Evaluation of Component Performance, guidelines are developed for determining the appropriate procedures to be used in establishing (a) the damage state of the component (b) how this damaged component will be repaired or replaced, (c) repair or replacement costs and times, and (d) the degree of functionality of the component during repair. Alternative procedures for component performance evaluation are identified and evaluated. Examples are also provided.

Levels of component performance evaluation are provided depending on the criticality of the components to the water system decision being made. In addition, guidelines are provided for excluding specific components relative to selected natural hazards. For instance, below-ground facilities may generally be ignored if severe winds are being analyzed. Appendix D provides additional information to assist in the development of component vulnerability models.

In Chapter 5, Evaluation of System Performance, guidelines are developed for determining appropriate procedures to be used in evaluating the performance of the system relative to performance metrics established by decision-makers. These guidelines address (a) how the system state may vary with time after the occurrence of the hazard event, (b) how damage to various links in the system affect the system's ability to provide water service to customers, (c) possible economic impacts of loss of service to customers, and (d) incremental costs of providing the means to achieve various performance objectives.

Various potential simplifications of systems evaluations are also discussed depending on the nature of the decision being made and the type of the water system (e.g., gravity flow versus systems requiring booster pumping).

Appendix E provides additional information helpful in developing systems evaluations.

In Chapter 6, Example System Evaluations, example system evaluations and the display of results are provided. These examples will vary with the selection of system performance metrics by decision-makers. These example system evaluations will be applied to an idealized system, and will further show how simplified procedures can be used in special cases.

Additional Material--Appendices, References, and Nomenclature--are contained at the end of this report. Likewise, references are provided for the material in the main body of this report as well as for the Appendices. The technical commentary, consisting of Appendices, is provided under a separate cover. Appendix A provides a full commentary on this Chapter, and includes a detailed account of the decision procedure considered by American Lifelines Alliance. Other Appendixes have been referenced already.

1.8 Notations and Acronyms

The following list provides notations and acronyms used throughout this document:

AAL	Average Annualized Loss
AC	Asbestos Cement
ALA	American Lifelines Alliance
ANS	American Nuclear Society
ANSI	American National Standards Institute
ASC	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	(now international, originally: American Society of Testing and Materials)
ATC	Applied Technology Council
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
BW	Bergey Windpower
C	Centigrade
CAD	Computer-Aided Drafting Systems

CCR	Component Criticality Rating
CI	Cast Iron
cm	Centimeters
cm/s	Centimeters per second
COLE	Modified shrink-swell categories of the NRCS
CSR	Capacity/Size Rating
cfs	cubic feet per second
DEM	Digital Elevation Maps
DI	Ductile iron
DPR	Damage Potential Rating
DWR	Drinking Water Rating
EBMUD	East Bay Municipal Utility District
EOC	Emergency Operating Center
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute, Inc.
EPS	Extended Period Simulation
F	Fahrenheit
F0 to F5	Fujita Scale Categories for Tornadoes
FCR	Facility Criticality Rating
FEMA	Federal Emergency Management Agency
FFR	Fire Flow Rating
FHWA	U. S. Federal Highway Administration
ft	Feet
fps	Feet per second
g	gravity
GIS	Geographical Information System
gpm	gallons per minute
HAZUS	earthquake hazard computer program
HR	U. S. House of Representatives Rule
ICBO	International Conference of Building Officials
in	inches
JHW	J. H. Wiggins Company
LADWP	Los Angeles Department of Water and Power
LC	Lockshell Corporation
ln	natural logarithm
LSR	Life Safety Rating
kg	kilogram
kg/sq.cm	kilograms per square centimeter
kg/sq.m	kilograms per square meter
km	kilometer
km/hr	kilometers per hour
M	earthquake magnitude
m	meters
MD	maximum day flow demand
mb	millibar
m/s	meters per second
MH	maximum hour flow demand
mi	miles

mm	millimeters
MMI	Modified Mercalli Intensity
Mph	miles per hour
NCDC	National Climatic Data Center
NCSU	North Carolina State University
NFPA	National Fire Protection Association
NOAA	National Oceanic and Atmospheric Administration
NRCS	National Resources Conservation Service of the U. S. Department of Agriculture
NWS	National Weather Service
OCR	Operational Criticality Rating
PGA	peak ground acceleration (% of gravity)
PGD	peak ground displacement (inches or centimeters)
PGV	peak ground velocity (inches/second or centimeters/second)
PI	plasticity index
psi	pounds per square inch
PVC	polyvinyl chloride
RMW	radius of maximum wind
RR	repair rate (as in repairs per 1000 lineal feet of piping or repairs per km of piping)
RS	response spectrum
SCADA	Supervisory Control and Data Acquisition
SDW	Safe Drinking Water Act (of 1974)
SG	Various State Geologists
SLOSH	storm surge computer program
SOR	System Operation Rating
TCLEE	Technical Council on Lifeline Earthquake Engineering of ASCE
TPG	Thomas P. Grazulis
TSF	tons per square foot standard deviation (sum of deviations from the mean squared then divided by the number of samples minus one); a measure of dispersion from the mean or arithmetic average
UBC	Uniform Building Code
USACE	United States ArmyCorps of Engineers
USDOI	United States Department of the Interior
USGS	United States Geological Survey
WTP	Water Treatment Plan
yr	Year

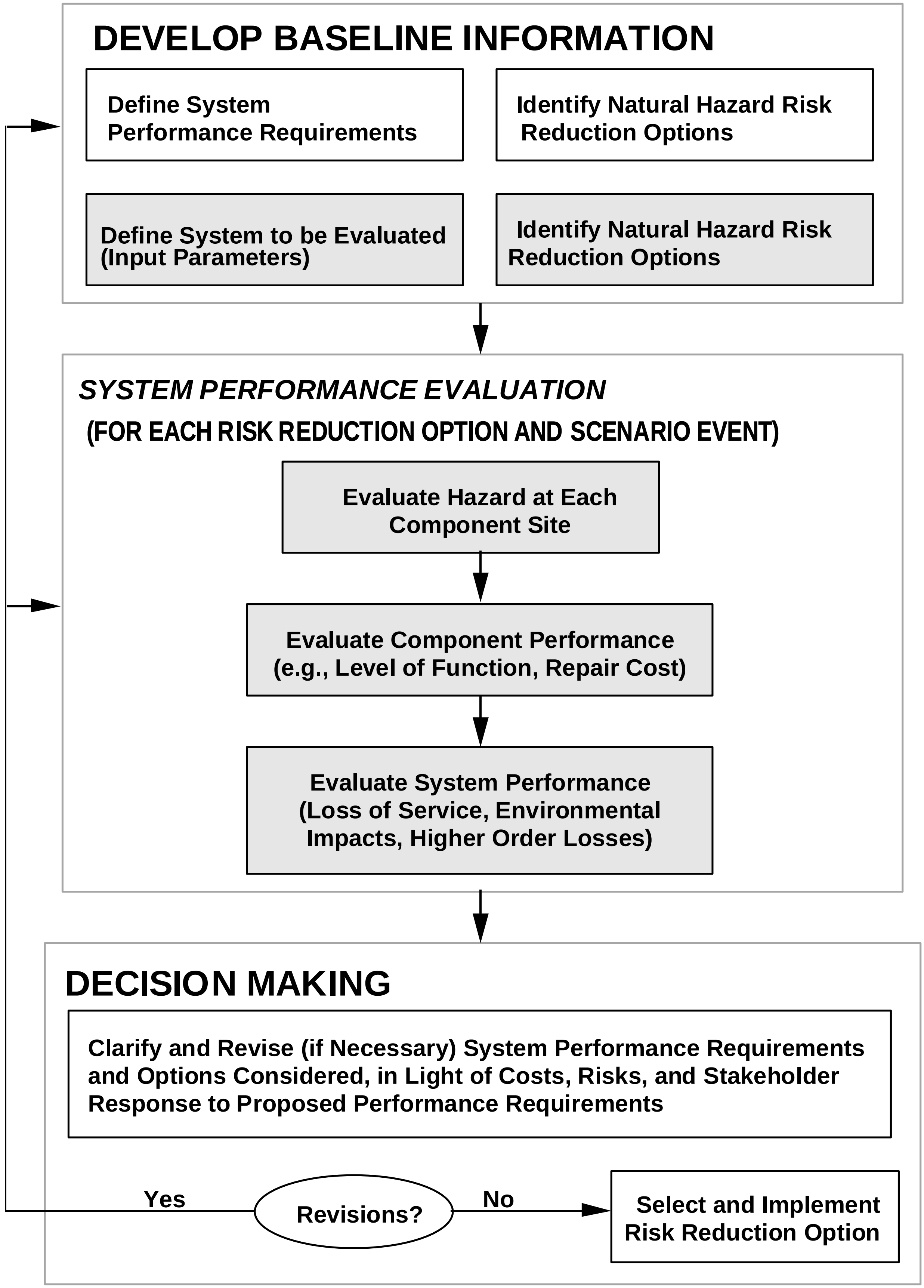

Figure 1: A Decision-Making Framework for Establishing Acceptable Performance Requirements for Water Utility Systems Subjected to Natural Hazards (Shaded Boxes are the Focus of These Guidelines)