

AmericanLifelinesAlliance

A public-private partnership to reduce risk to utility and transportation systems from natural hazards

Development of Guidelines to Define Natural Hazards Performance Objectives for Water Systems Volume I

September 2002

www.americanlifelinesalliance.org

This report was written under contract to the American Lifelines Alliance, a public-private partnership between the Federal Emergency Management Agency (FEMA) and the American Society of Civil Engineers (ASCE). This report was reviewed by a team representing practicing engineers, managers, and academicians.



American Society of Civil Engineers



Acknowledgements

The following people (with their affiliations) contributed to this report.

Craig Taylor	Natural Hazards Management Inc., Torrance, CA
LeVal Lund	Civil Engineer, Los Angeles, CA
John Wiggins	J. H. Wiggins Company, Redondo Beach, CA
William Graf	URS Corporation, Los Angeles, CA
Timothy Volz	URS Corporation, Colorado Springs, CO
Danna Judish	URS Corporation, Colorado Springs, CO
Garry Lay	URS Corporation, Los Angeles, CA
Aziz Alfi	Seattle Department of Public Utilities, Seattle, WA
Chuck Call	Salt Lake Department of Public Utilities, Salt Lake City, UT
Bill Nabak	Green Bay Water Utility, Green Bay, WI
Dave Putnam	Metropolitan Water District of Southern California, Fontana, CA
Robert Gordon	Hillsborough County Public Works Department, Tampa, FL

Table of Contents

List of Tables	viii
List of Figures.....	ix
List of Figures.....	ix
Foreword	x
1.0 INTRODUCTION	1
1.1 Project Objective	1
1.2 Project Scope: Natural Hazards and Water Utility System Facilities Covered.....	1
1.3 Project Scope: Framework for A Decision Process.....	2
1.3.1 Background to the American Lifelines Alliance Decision Process	2
1.3.2 Sample Natural Hazards Risk Reduction Options	2
1.3.3 Types of Pertinent System Performance Metrics.....	4
1.4 Multiple Levels of Analysis	7
1.4.1 Background to Analysis Steps	7
1.4.2 Characterizing an Advanced Level of Analysis	7
1.4.3 Two types of simplifications: those for simpler systems and those for a less advanced analysis.....	8
1.4.4 Below Intermediate Analyses.....	9
1.5 Preliminary Study Scope of Work: A Sample Phase I Study.....	10
1.6 Decisions Under Both Risk and Uncertainty.....	15
1.7 Remaining Chapters of this Document.....	16
1.8 Notations and Acronyms	17
2.0 DEFINING THE WATER SYSTEM AT RISK	21
2.1 Introduction	21
2.2 Multiple Levels of Evaluation Limiting Inventory Needs	21
2.3 Costs of Decision Alternatives and Other Costs.....	23
2.4 Components and Considerations for a Comprehensive Evaluation	23
2.4.1 Overview.....	23
2.4.2 Potable Water Conveyance Facilities	24
2.4.3 Distribution Storage Reservoirs	25
2.4.4 Booster Pumping Stations and Wells.....	26
2.4.5 Building Structures ("Housing").....	26
2.4.6 Selected Non-Building Components	27
2.4.7 Water Treatment, Chlorination, and Fluoridation Facilities	28
2.4.8 Special Data Needs for Hydraulic Evaluations.....	28
2.4.9 Minimum Stakeholder Data.....	31
3.0 MODELING NATURAL HAZARDS.....	34
3.1 Introduction	34

3.2	Modeling Ground Movement Hazards.....	35
3.2.1	Gravity Landslide	35
3.2.1	Expansive Soil	44
3.2.2	Soil Collapse.....	45
3.2.3	Frost Heave	47
3.3	Flood	49
3.3.1	Riverine Flood.....	49
3.4	Wind.....	52
3.4.1	General Severe Wind	52
3.4.1	Tornado	53
3.4.1	Hurricane—Tornado.....	54
3.4.1	Hurricane-Cyclone	56
3.4.3	Hurricane-Storm Surge (Combined with River Flood and Headwater Flood).....	59
3.4.4	Combining Hurricane Effects	59
3.5	Earthquakes.....	60
3.5.1	Earthquake—General	60
3.5.2	Earthquake-Fault Rupture.....	61
3.5.3	Earthquake-Shaking	62
3.5.4	Earthquake-Landslide.....	64
3.5.6	Earthquake-Lurching and Liquefaction	66
3.5.7	Earthquake-Tsunami	67
3.5.8	Earthquake Seiche	68
3.5.9	Earthquake-Fire Following	68
4.0	COMPONENT VULNERABILITY MODELING.....	98
4.1	Introduction	98
4.2	General Methods for Developing Component Vulnerability Models	98
4.2.1	Objectives [Outputs Desired]	98
4.2.2	General Types of Methods.....	99
4.2.3	Qualitative Risk Models	100
4.2.4	Analysis of Structural and Mechanical Components.....	101
4.2.5	Analysis of Underground Components	101
4.2.6	Modeling Component Repair Costs	102
4.2.7	Modeling the Functionality of Components.....	102
4.2.8	Modeling Component Restoration Time.....	103
4.2.9	Uncertainty in Component Vulnerability Modeling	104
4.3	Steel and Concrete Water Storage Reservoirs	104
4.4	Vulnerability of Mechanical and Electrical Equipment.....	106

4.4.1	Equipment Anchorage	106
4.4.2	Inundation of Equipment.....	106
4.4.3	Loss of Power and Communications	107
4.4.4	Pressure Vessels (surge tanks, chlorine cylinders, etc.).....	107
4.4.5	Pipe Bridges	107
4.5	Vulnerability Models for Underground Piping	108
4.5.1	Introduction	108
4.5.2	A Brief Summary of Empirical or Categorization Methods for Earthquake Hazards	108
4.5.3	Vulnerability of Pipelines from Frost Heave	111
4.5.4	Vulnerability of Pipelines from Other Natural Hazards	111
4.6	Vulnerability of Buildings	111
4.6.1	Introduction	111
4.6.2	Building Damage in Natural Hazards.....	112
4.6.3	Assessing Building Vulnerability for Earthquakes	112
4.6.4	Assessing Building Vulnerability – Windstorm	114
4.6.5	Assessing Building Damage in Floods.....	115
4.6.6	Assessing Building Damage in Landslides	116
4.6.7	Assessing Building Damage in Fires	116
4.6.8	Modeling Buildings within Natural Hazards Risk Assessment	116
4.7	Interdependence of Water System Facility Damage and Other Damage	117
5.0	SYSTEM VULNERABILITY MODELING	118
5.1	Introduction	118
5.2	System Losses Estimated Based on System Vulnerability Modeling	118
5.3	The Reconstruction Process	119
5.4	Simplified Graphics and Connectivity Models to Evaluate System States	122
5.4.1	Circumstances Under Which A Hydraulic Evaluation May Not Be Needed	122
5.4.2	Graphics and Connectivity Evaluations For System States	123
5.5	Hydraulic Evaluation	124
5.5.1	Introduction	124
5.5.2	Basics of Hydraulic Systems Evaluation.....	124
5.5.3	Natural Hazard Conditions.....	125
5.5.4	Adjustments for Natural Hazard Conditions	125
6.0	Summary Systems Risk Calculations	129
6.1	Overview	129
6.2	Overview of the Demonstration Water System.....	129

6.3	Estimating System Losses for Three Natural Hazards Scenarios	130
6.3.1	Overview.....	130
6.3.2	System Time-Lines for the Three Postulated Natural Hazards Events.....	131
6.3.3	Using Time-Lines to Derive Total Systems Losses from Scenarios	131
6.4	Using System Evaluations as Part of a Risk-Based Evaluation	132

List of Tables

Table 1:	Types of Publicly Available Models and Data for Creating Probabilistic Models of Natural Hazards Data	36
Table 2:	Organizations Supplying Pertinent Models, Maps, or Data for Modeling Natural Hazards Probabilistically	37
Table 3:	Sample General References for Data and Models for Developing Probabilistic Models of Natural Hazards	38
Table 4:	Natural Hazards That Can be Probabilistically Modeling Using Available Data and Published or Easily Developed Methodologies (Our Judgement).....	39
Table 5:	Sample General References for Data and Models for Developing Probabilistic Models of Landslides	40
Table 6:	Classifications and Definitions of Slope Movements (See Figure 4 for Examples)....	41
Table 7:	A Template for Modeling Gravity Landslide Intensities (Measure of Hazard Intensity inches/inch or cms/cm)	43
Table 8:	A Template for Modeling Expansive Soils (Measure of Hazard Intensity: inches/inch or cms/cm)	45
Table 9:	A Template for Modeling Soil Collapse-Hydrocompaction (Measure of Hazard Intensity: inches/inch or cms/cm)	46
Table 10:	A Template for Modeling Soil Collapse—Natural Subsidence (Measure of Intensity inches/inch or cms/cm)	47
Table 11:	Frost-Susceptible Soil Groups	48
Table 12:	A Template for Modeling Frost Heave (Measure of Hazard Intensity: inches/inch or cms/cm).....	49
Table 13:	Sample references for Modeling Floods Probabilistically.....	50
Table 14:	A Template for Modeling Riverine Flood Hazards (Measure of Intensity: feet (m) of water)	51
Table 15:	General Reference for Modeling General Severe Wind Probabilistically.....	52
Table 16:	Sample References for Modeling Tornadoes Probabilistically	53
Table 17:	The Fujita Scale for Tornadoes.....	54
Table 18:	Tornadoes Per 10,000 Sq. Mi. (or 25,889 sq. km) Per Year by State by Rank	55
Table 19:	Tornado Zones By State By > F2 Ranking/10,000 Sq Mi (or 25,889 Sqkm)/Year.....	56
Table 20:	Sample References for Modeling Hurricane-Cyclone Probabilistically.....	56
Table 20:	Sample References for Modeling Earthquakes Probabilistically.....	61
Table 21:	A Template for Modeling Fault Rupture Hazards (Measure of Intensity: inches/inch or cms/cm)	63
Table 22:	A Template for Modeling Earthquake-Shaking Hazards (Measures of Intensity: peak ground acceleration; spectral acceleration, peak ground velocity, duration of shaking, time-histories)	64
Table 23:	A Template for Modeling Earthquake-Landslide Hazards (Measures of Intensity: inches/inch or cms/cm)	66
Table 24:	Illustrative Values of K1 and K2 in Pipeline Seismic Vulnerability Models (ALA, 2001, pp. 38, 39)	110
Table 25:	Structural Performance Levels in FEMA 356	113
Table 26:	Simplified Use of Time-Lines to Derive Systems Losses in Three Scenarios	132
Table 27:	A Matrix Providing the Basis for Risk-Based Estimates	133

List of Figures

<i>Figure 2:</i>	<i>Sample Vendor Data Sheet</i>	32
<i>Figure 3:</i>	<i>Sample Building Data Form</i>	33
<i>Figure 4:</i>	<i>Examples of landslides by type of movement</i>	70
<i>Figure 5:</i>	<i>Overview map of landslide problems in the conterminous United States</i>	71
<i>Figure 6:</i>	<i>Landslide Incidence Schedule</i>	72
<i>Figure 7:</i>	<i>Landslide potential for the Los Angeles area and the Palos Verdes Peninsula in particular</i>	73
<i>Figure 8:</i>	<i>Expansive soils map, February, 1976.....</i>	74
<i>Figure 9:</i>	<i>Overview map of smectite rich materials in the conterminous United States</i>	75
<i>Figure 10:</i>	<i>Occurrence and distribution of potentially expansive materials in the United States</i>	76
<i>Figure 11:</i>	<i>Map of cavern areas</i>	77
<i>Figure 12:</i>	<i>Map of karst terrain</i>	78
<i>Figure 13:</i>	<i>Karst areas in the state of Illinois</i>	79
<i>Figure 14:</i>	<i>Determination of freezing index</i>	80
<i>Figure 15:</i>	<i>Fall freeze occurrence</i>	81
<i>Figure 16:</i>	<i>Flood hazard area for the Memphis, Tennessee area</i>	82
<i>Figure 17:</i>	<i>100 year return period, 24 hour rainfall in inches</i>	83
<i>Figure 18:</i>	<i>Frequency of occurrence versus rainfall in 24 hours for selected cities</i>	84
<i>Figure 19:</i>	<i>American Society of Civil Engineers 50 year return period wind map for severe wind and hurricane wind gusts, 1999</i>	85
<i>Figure 20:</i>	<i>Average annual tornado incidence per 10,000 square miles, 1953-1980</i>	86
<i>Figure 21:</i>	<i>Coastal counties from Texas to Maine and the 5% chance associated with the occurrence of landfalling hurricane magnitude (by category) being equaled or exceeded in any given year</i>	87
<i>Figure 22:</i>	<i>Analysis of hurricane of landfall probabilities in 100+ years</i>	88
<i>Figure 23:</i>	<i>ASCE 7-98 gust wind speed map for 50 year return period</i>	89
<i>Figure 24:</i>	<i>Probability distribution of sustain wind speeds (based on central pressure) of hurricanes, Gulf and East Coasts</i>	90
<i>Figure 25:</i>	<i>Composite estimates of expected surge height</i>	91
<i>Figure 26:</i>	<i>Storm surge and headwater flooding extent for Brazoria County, Texas</i>	92
<i>Figure 27:</i>	<i>Storm surge and headwater flooding extent for the Miami, Florida area</i>	93
<i>Figure 28:</i>	<i>USGS Probabilistic Seismic Hazard Map of the United States</i>	94
<i>Figure 29:</i>	<i>Map of young surface faulting zones in the conterminous United States</i>	95
<i>Figure 30:</i>	<i>Map of the tsunami hazard for the island of Hawaii</i>	96
<i>Figure 31:</i>	<i>Heights of the 100- and 500-yr tsunamis along the southern California Coast (Santa Barbara to San Diego)</i>	97
<i>Figure 32:</i>	<i>Types of Component Vulnerability Models</i>	99
<i>Figure 33:</i>	<i>Outline of Gravity Flow Water Network</i>	127
<i>Figure 34:</i>	<i>Two Simple Systems Illustrating Need for System Analysis</i>	128
<i>Figure 35:</i>	<i>A Hypothetical Water Distribution System</i>	135
<i>Figure 36:</i>	<i>A Time-Line Chart for Response of a Water Utility to a Hypothetical Flood/Scour Event</i>	136
<i>Figure 37:</i>	<i>A Time-Line Chart for Response of a Water Utility to an Expansive Soils Event</i>	137
<i>Figure 38:</i>	<i>A Time-Line Chart for Response of a Water Utility to a Hypothetical Earthquake ..</i>	138

Foreword

The American Lifelines Alliance (ALA) was formed in 1998 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the Federal Emergency Management Agency (FEMA). In 2001, ALA requested Natural Hazards Management, Inc to develop guidelines for assisting water utility decision-makers establish performance objectives for their water systems subjected to natural hazards.