AmericanLifelinesAlliance

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

Wastewater System Performance Assessment Guideline

June 2004

Part 1
Guideline

DRAFT

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

Donald Ballantyne, PE	ABS Consulting, Seattle, Washington
Steve Harris, PE	ABS Consulting, Oakland, California
Eric Jorgenson	ABS Consulting, Seattle, Washington
Bruce Kozozenski	Metropolitan St. Louis Sewer District
Paul Krauth	Utah Division of Water Quality
Larry A. Larson, CFM	Assoc. of State Floodplain Managers, Madison, Wisconsin
Hope Seligson	ABS Consulting, Irvine, California
Kim Tanner, PE	Kennedy Jenks Consultants, Phoenix, Arizona
Randy Tomsik	Portland Bureau of Environmental Services, Oregon

American Lifelines Alliance Oversight Committee

Doug Honegger	DGH Consulting, Arroyo Grande, California
Richard Sloan, PE	Pima County Wastewater Management, Tucson, Arizona
Joe Steller, RA, CRE	National Institute of Building Sciences, Washington DC

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Overview

Over the last twenty years, wastewater systems in the United States have been heavily damaged by natural disasters that occur only once in 100 to 500 years in any given community. In the 1990s, flooding in the Midwest inundated treatment plants causing extensive damage to electrical equipment, and requiring extensive cleanup[1]. In the 1994 Northridge Earthquake, the collection system was heavily damaged due to ground movement. Wind "regularly" causes power outages, and regional power outages have been caused by electrical power system deficiencies, and major ice storms. The September 11, 2001 terrorists attacks in the United States have focused the wastewater community's attention on potential attacks on wastewater facilities.

In 1998, the Federal Emergency Management Agency (FEMA) formed the American Lifelines Alliance (ALA) as a public-private partnership. In 2002, FEMA contracted with the National Institute of Building Sciences (NIBS), through its Multihazard Mitigation Council (MMC), to assist FEMA in continuing ALA guideline development efforts. Through a competitive bidding process, in 2003, ALA awarded ABS Consulting a contract to develop the Wastewater System Performance Assessment Guidelines contained herein.

O.1 Guideline Objective

The Guideline provides minimum recommended requirements for evaluating wastewater systems to allow defensible answers to questions regarding system performance in natural hazard and human threat events. The level of effort to conduct an assessment varies with the level of performance information required, the complexity of the wastewater system, and the level of definition required to characterize natural hazards and human threats. The recommendations are intended to be used by the wastewater utility to define a scope of work to be carried out by the utility itself or with the assistance of outside resources with the necessary expertise.

The Guideline is intended to provide direction to owners/operators of wastewater utilities that need to understand the risk to their systems from a variety of disaster events, and to allow them to develop a balanced approach to mitigation, focusing on hazards that pose the highest risk. It provides guidance in determining appropriate levels of effort in making sound risk management decisions to ensure reliable performance of their systems during and after all hazard events. The Guideline also allows the utility owners/operators to further refine risk and vulnerability after an initial, widely used, VSAT™ security analysis.

The Guideline helps the owners /operators to answer the following questions in their wastewater system performance assessment:

- What is the assessment objective?
- What level of assessment is required to achieve the assessment objective?
- What level of system performance is desired, and how is that level measured?
- What resources and procedures are needed to implement the Guideline and where are they located?

[1] Floods inundated wastewater treatment plants in the spring of 1993 in Des Moines, Iowa; Jefferson City, Missouri; and St. Louis Metropolitan Sewer District Missouri.

- Which natural hazard and human threat events can cause significant damage to wastewater system components?
- What damage to specific system components has the most significant impact on overall system performance?
- Are additional investments warranted to improve system performance?
- Can modification of emergency response plans improve system performance (e.g., make emergency equipment available through mutual aid agreements with other utilities in the region)?

While life safety issues are important in wastewater systems on a day-to-day basis, they are not the focus of this document. These concerns can include:

- Accidental release of hazardous chemicals such as chlorine gas.
- Entry into confined spaces (such as manholes) that do not contain air that will support life.
- Exposure to explosive gases.
- Electrical shocks.
- Drowning.
- Collapse of buildings and non-structural elements within these structures.
- Exposure to disease-causing biological agents.

Many of these concerns are addressed in current building, electrical, plumbing, and fire codes. The Occupational Safety and Hazard Administration (OSHA), and comparable state agencies, have developed regulations that are intended to address worker safety including requirements to work:

- In confined spaces.
- With electrical equipment.
- Near open water bodies (treatment process units).
- With hazardous biological material.

O.2 Risk Based Assessment

The performance assessment approach presented in this Guideline is, in general terms, developed to estimate the relative risk associated with each wastewater system component for each natural hazard or human threat. Relative risk can be calculated as:

Relative Risk = Hazard x Vulnerability x Consequence ***Equation (G-1)***

where:

Relative Risk is expressed in terms probability of exceeding a selected metric in a given time period. It is the intent that relative risk be used to rank risk of the selected system components.

Hazard (natural or human threat) is the probability of exceeding a given intensity over a given time period (e.g. 50 years), where the intensity is a metric of the severity of the particular hazard (e.g. water depth, wind speed, etc).

Vulnerability is the probability that the wastewater system components will fail of no longer be functional when subjected to the given hazard intensity.

Consequence (consequence of failure/loss of function) is defined in terms of the selected metric (such as discharge occurrence, discharge volume, or losses in dollars). Consequence is used to normalize the impact of loss of function of the particular component compared to the loss of the entire system. It is stated in terms of the metric selected for the assessment. (e.g., one sewage lift station might handle 10% of the system flow, and one might handle 25% of the system flow. This term considers their relative capacities.)

The period on which to base the probability of exceedance for the hazard is often considered 50 years. The 50 year time period represents an average estimate of the useful life of the various components of lifeline systems: mechanical equipment – 20-year life; buildings – 50-year life; buried pipelines – 100-year life.

Refer to the example in Section O.4 Step 7.

O.3 Levels of Performance Assessment

A performance assessment can be performed at different levels of detail. In this document, three levels are described: Simplified, Intermediate, and Advanced. Different levels of assessment are suggested for different project objectives. A Simplified Assessment can be deterministic[2], using scenario events without using the probability of the event in the calculations. It can also be a basic probabilistic risk assessment using approximations (e.g., high, medium, and low) for the three risk components. An Intermediate Assessment is a probabilistic risk assessment using a mean or median value for each of the three risk parameters, with minimal consideration of the variability of each term. An Advanced Assessment is a probabilistic risk assessment incorporating the variability of one or more of the risk parameters to capture their randomness and uncertainty. These three levels of analyses are discussed in detail throughout the Guideline.

Wastewater utilities implementing the Guideline will be determining whether an Intermediate or Advanced Assessment is required, based upon the findings of an initial Simplified Assessment.

The Guideline provides direction in determining the level of effort necessary to implement the assessment process. The wastewater utility will then need to decide which steps can be undertaken in-house, and which specific tasks are best carried out using outside engineering support. This will depend on technical capabilities and availability of in-house staff.

[2] Deterministic assessment – where the result can be calculated directly (no uncertainty)

O.4 8 Step Performance Assessment Process

The process for a user to apply the Guideline consists of eight steps, as illustrated in Figure 1 and described in this section. Steps 1 through 8 are described in detail in later sections of this Guideline. Some activities that will be performed in these steps can be complex.

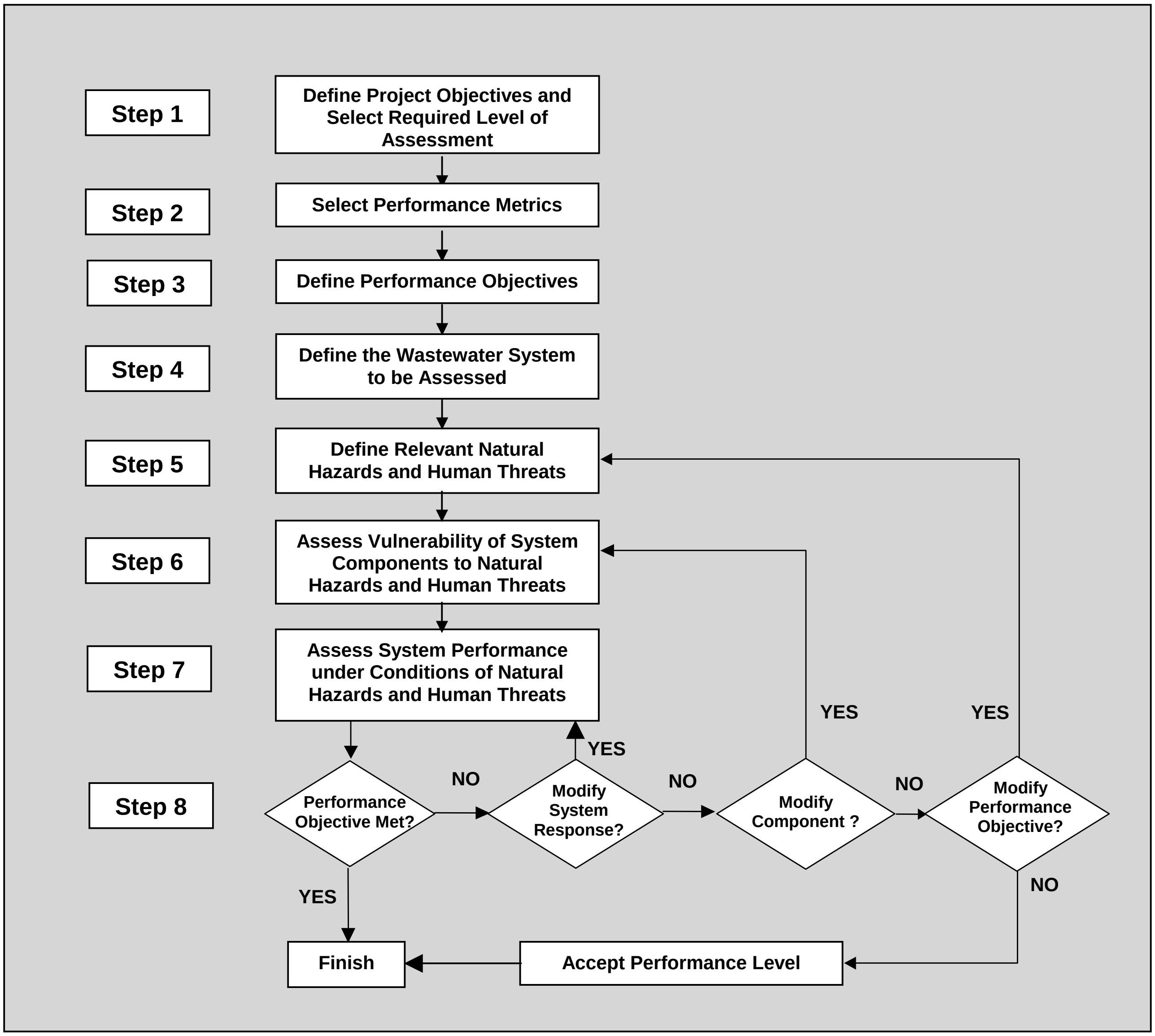

Figure 1. Overview of Performance Assessment for Natural Hazard Assessment Process.

Step 1: Define the project objectives and select the required level of assessment. The project objective can be driven by government regulations, risk management concerns, public policy, prudent engineering design, or other issues or concerns. When required by regulation, the regulation itself can describe the evaluation process and the associated level of assessment. The wastewater utility, or other similar utilities in the region, may have had recent losses due to hazard events. The assessment can be driven by the desire to limit the risk to similar future events. Decision makers for the wastewater utility may have developed policies related to performance of the system. Project objective examples are:

- Quantify the risk of discharge of untreated sewage into a receiving water due to loss of function of the collection system.
- Quantify the risk of backing up sewage into residences.
- Quantify the potential direct damage (and associated economic loss) due to a major hazard event.

Step 2: Select performance metrics that serve to quantitatively describe how the wastewater system is performing relative to the project objectives. Examples are capacity measures (e.g. flow of wastewater at selected points); measures of reliability (such as frequency and magnitude of sanitary or combined sewer overflows (SSOs, CSOs), and the frequency and magnitude of discharge of inadequately treated sewage, percentage treated, etc.); measures of safety and health (similar to reliability examples as they impact water quality); and financial measures. The Environmental Protection Agency National Pollution Discharge Elimination System (EPA NPDES) permit requirements incorporate relevant performance measures such as discharge volume and water quality. However, the NPDES permit requirements may or may not be relevant to conditions following major natural hazard or human threat events that may only occur every 100 to 500 years.

Step 3: Define the performance objectives in terms of the metrics identified in Step 2. Performance objectives define "acceptable performance" of the wastewater system in probabilistic terms[3].

Step 4: Define the wastewater system to be assessed. The assessment must include all components of the system whose performance influences the metric of interest. Examples are: 1) the entire system evaluated using general, planning level information, and 2) a limited number of components selected for assessing a localized region (e.g., a salmon habitat).

Step 5: Define relevant natural hazards and human threats, and credible hazard scenarios that could affect the reliability of your wastewater system. Comprehensive lists of hazards and threats are provided in the Commentary, along with some descriptive information and suggestions on where to find additional data. Hazards are quantified in terms of the probability of occurrence in a given time period along with the associated hazard intensity for each component of the system included in the assessment. For example, an earthquake with a 10% probability of occurrence in 50 years might have a shaking intensity greater than 30% of the acceleration due to gravity (0.3 g's) or a flood elevation greater than 15 feet above flood stage. The hazard definition accounts for regional hazards (e.g., hurricane storm surge) that may not be the same throughout the system for a given scenario event. Hazard scenarios include, for example, flooding over a certain area, an earthquake of specific magnitude and location, or a specific terrorist act. For human threat events, there is inadequate data available to estimate the probability of occurrence, so design basis threats are defined assuming that an event will occur (i.e., 100 percent chance of occurrence).

[3] Probabilistic is defined as the probability of achieving the desired performance for an event that has a defined probability of exceedance in a given time period (e.g., a 90% probability of meeting permit requirements for an event with a 50% probability of occurrence in 50 years).

Step 6: Assess the vulnerability of system components to natural hazards human threats and associated intensities as determined in Step 5. Vulnerability is generally expressed in terms of direct damage and/or loss of function as a function of hazard intensity. Each component would be assigned a probability of being in a certain damage state when subjected to a given hazard intensity. For example, electrical control equipment is expected to be non-functional when the depth of water reaches 6-inches above the floor elevation of a given facility. Human threats are analyzed using the standardized approach in VSAT™ , a software package developed by the Association of Metropolitan Sewerage Agencies and/or RAM-WSM a methodology developed by Sandia National Laboratories and the AWWA Research Foundation. Given these well-defined methods and software assessment tools, human threat assessments were not typically integrated into natural hazard assessments. However, the concept of risk as a function of hazard, vulnerability and consequence is used the same as it is for natural hazard assessment.

Step 7: Assess system performance under conditions of natural hazards and human threats by considering the damage state (functionality) of each component and the resulting impact of its associated loss of function will have on the overall system. This impact on the system performance is the consequence of loss of function, as included in the risk equation. The consequence of loss of function is defined in terms of the assessment metric, and might be overflow of raw sewage or discharge of inadequately treated sewage for some percentage of the overall system. An example is shown below, and several examples that are more comprehensive are included in Commentary Appendix A. We can look at the flooding risk associated with a sewage lift station that serves 25% of the community. The relative risk of the sewage lift station for a flood scenario can be calculated as follows:

Relative Risk = Hazard x Vulnerability x Consequence ***Equation (G-1)***

Where:

Hazard – 10% probability of occurrence in 50 years for a flood resulting in a flood elevation of 100 feet above sea level at the sewage lift station.

Vulnerability – 50% probability that the lift station will not function when subjected to a flood elevation of 100 feet above sea level.

Consequence of loss of function – discharge of raw sewage from 25% of the community.

Therefore:

Relative Risk = 10% chance in 50 years X 50% probability of loss of function X 25% of the system flow

Or:

Relative Risk = 0.10 X 0.50 X 0.25 = 0.0125 or 1.25% chance in 50 years of discharging 100% of the system flow of raw sewage due to flood damage to the pump station[4].

Step 8: Assess whether the performance objectives are met by comparing the system relative risk in Step 7 with the performance objectives (acceptable risk) defined in Step 3. Calculate the

[4] The consequence (discharge of raw sewage from 25% of the community is normalized to 100% of the sewage from that portion of the community served by that pump station.

risk due to hazards in the same terms as the risk defined in the performance objectives. If the performance objectives are not met, lower the performance objectives or provide mitigation by modifying the system response or modifying system components. An overview of the mitigation process described in section O.8 but is not discussed in detail, as it is not part of the performance assessment.

O.5 Features Inherent in the Performance Assessment Process

There are several features inherent in the performance assessment process. It can be applied in a phased approach. Initially, a Simplified Assessment is conducted using ranges of quantitative (e.g., high, medium, low) information for the three risk parameters, hazard, vulnerability, and consequence of loss of function for each component. The risk equation is applied to estimate the relative risk of each component for each hazard. The results can be used to screen the hazards and components and select those with high risk for a more in-depth assessment. For example, the components that have low values for two of the three components (hazard, vulnerability, or consequence) will have a low risk, and minimal additional assessment effort is required. On the other hand, components with all high or moderate risk parameters may warrant an Intermediate or Advanced Assessment to gain a better understanding of each of the risk components. Advanced assessments will rarely be required for wastewater systems but can be used for exceptional situations.

A sensitivity analysis can be used to focus efforts on the risk parameters that have a significant influence on the results. Some of the parameters in the risk equation are sensitive to small variations in the parameters used in their development, while other parameters can vary drastically without having much influence on the result. For example, consider a forcemain loss of function caused by expansive soils, where the loss of pipeline function is not sensitive to soil movement once that movement prevents flow between broken sections of the pipe (i.e., once the soil displacement exceeds some threshold, the gravity sewer or forcemain would not be damaged any further). Another example is a siphon or forcemain exposure at a river crossing because of scouring. A small increase in flow velocity might result in a much greater scour depth, perhaps because of overtopping of a flood control structure.

O.6 Cost of Conducting Assessment

The cost to conduct a performance assessment will vary considerably based on at least four factors:

- Size of the portion of the system to be assessed.
- Level of assessment conducted (e.g., Simplified, Intermediate, or Advanced).
- Availability of hazard and vulnerability data - In some cases, hazard data will be existing and cost nothing to acquire. In some cases, there may be no hazard data at all. Vulnerability data exists for some hazards and some components must be developed for others.
- Governing regulations that may require specific procedures. (These costs may not be part of the assessment itself, but part of the overall project costs.)

Performance assessments can cost anywhere from several tens of thousands of dollars for small systems where simplified analyses are conducted, to over one million dollars for advanced assessments of large systems (costs in 2004 dollars).

O.7 Overview of Mitigation

As Figure 1 indicates, the wastewater system performance assessment is an iterative process, with iterations generally based on changes to emergency response capability, component vulnerability, or the target level of performance. Modifying emergency response implies that actions will be taken to limit the impact of system damage and might include actions such as stockpiling critical equipment to decrease repair time, providing temporary sanitary services (e.g. "Port-a–Potties"), purchasing additional pump-around equipment or improving the ability to more rapidly locate damage.

Modifying component vulnerability implies that actions will be taken to improve the response of existing components or that specifications will be defined for the design of new components to make the system more resistant to natural hazards and human threats. Examples might include strengthening lift stations or stabilizing a pipeline's alignment.

Modifying the target performance objective is typically based on a more critical assessment of the level of system performance than is actually required by stakeholders following natural hazard and human threat events. Significant changes in the selection of a target performance objective might affect the definition of relevant natural hazard or human threat events.

O.8 How to Use This Guideline

The Guideline is organized into three components, 1)Overview (this section), 2) the Guideline 8 Step Process, and the Commentary, including examples. Reading the Overview may be adequate for senior management. After reading the Overview, those that are involved in the details of the assessment process should continue on reading the 8 Guideline Steps, and the examples in Appendix A of the Commentary. Reference material is provided in the Commentary for Steps 4 through 8. The Commentary also includes Acronyms and Notations, Terms and Definitions, and References in Appendices B, C, and D, respectively. They may be useful in becoming familiar with the performance assessment process.

Once users (the people that will be scoping and/or conducting the performance assessment) are familiarized with the assessment process they can then develop a scope clearly defining the:

1. Assessment objective and level of assessment required to meet that objective
2. Assessment metrics to be used in the project
3. System performance objectives desired by the system owner and stakeholders
4. System or components of the system to be analyzed
5. Relevant natural hazards and human threats that are to be included in the evaluation.

With these assessment parameters defined, the user can assemble the project team to proceed. Depending on the scope, project team members can include professionals with expertise in areas such as system operations, geotechnical engineering, geology, and meteorology.

Step 1- Define Project Objectives and Required Level of Assessment

This step clearly defines the project objectives, and establishes the level of assessment required to meet those project objectives. Refer to Appendix A of the Commentary for assessment examples.

Recommended requirements for performing varying levels of wastewater system performance assessments are presented at the end of Sections 5 (Hazards), 6 (Component Vulnerability), and 7 (System Assessment).

1.1 Project Objectives and Associated Reasons for Conducting a Performance Assessment

The project objectives may have been brought about by a variety of concerns that pushed decision makers to conduct a performance assessment. The basis for the assessment is an important consideration in deciding the required level of assessment. Some of the more common economic and societal motivating factors are listed below.

Societal Factors

- Fines and/or jail time - resulting from illegal discharges.
- Loss of public confidence – resulting from release of raw sewage, backup of raw sewage into households, or discharging partially treated sewage into the receiving body.
- Political – resulting from peer pressure from other regional wastewater organizations, or local politicians concerned about discharge of raw or partially treated sewage in their area.
- Public health and safety – injury or death to utility staff or the public due to exposure to raw or partially treated sewage, chemical release, or building collapse.

Economic Factors

- Expected investment in a project.
- Substantial fines levied by regulating authorities.[5]
- Direct loss - repair costs of facilities damaged in hazard events. Driven by previous loss experience or the experience of other regional wastewater utilities.
- Capital improvement plan – identify and prioritize projects to optimize a capital improvement plan.
- Project design – define capacity, reliability or other parameters to optimize a new project.
- Level of service (outage time) – define expected service outage times associated with various events with associated probabilities of occurrence.

[5] In 2001, the California EPA levied fines of $1.00/gallon for the extended release of raw sewage ($1.6 million for a discharge over 9 days) into Mission Bay in San Diego.

- Societal costs/business interruption – estimate the costs to the community due to loss of function of the system.

1.2 Selection of Levels of Assessment and Example Project Descriptions

Selection of the level of assessment is based on comparison to example projects with the Guideline user's project. Table 1 shows the level of assessment (Simplified, Intermediate, or Advanced) that is expected for each type of project. The project examples could use the Guideline as a tool to accomplish at least a portion of their scope of work. Comments are included for Intermediate and Advanced Assessments. Each of these example projects is more fully described in the text that follows. Five of these projects are described in greater detail in Appendix A of the Commentary.

Table 1. Assessment Examples and Associated Levels of Assessment

No.	Example Project Descriptions	Simplified	Intermediate	Advanced	Comments/Description
1	Multi-Hazard Screening Assessment	◆			Phase 1 of multi-phase project to rank relative risk of system components and hazards. Subsequent phases conduct Intermediate or Advanced Assessments. (Note 1)
2	Single-Hazard Screening Assessment	◆			Assessment focuses on single hazard selected based on familiarity/experience with regional hazards (e.g., flooding, earthquake). The risk associated with each system component is developed.
3	Hazard Mitigation Plan (HMP) (requirement of the Disaster Mitigation Act of 2000)	◆			FEMA requires HMPs if the utility is to receive any future federal hazard mitigation funding. Many of the Guideline components are incorporated in the HMP requirements. The HMP results in a prioritized list of mitigation projects.
4	VSAT^{TM}/RAM-W^{SM} Security Vulnerability Assessment	◆			Security vulnerability assessments may be required by EPA for wastewater systems (EPA currently requires for water systems). Project conducted to meet guidelines laid out in standardized methodology (VSAT^{TM} or RAM-W^{SM}). (Note 1)
5	Assessment of Individual Components		◆		Phase 2 of project example #1. Evaluates high-risk components on a site-specific basis that may require structural or hydraulic assessment – reviewing drawings, and performing independent calculations. (Note 1)
6	Scenario Development		◆		Deterministic assessment of the impact of a representative hazard event on the system. Includes hazard and vulnerability assessments of individual system components, and a system assessment based on expert judgment to understand the impact on the overall system function. (Note 1)

Table 1. Assessment Examples and Associated Levels of Assessment - continued

No.	Example Project Descriptions	Simplified	Intermediate	Advanced	Comments/Description
7	Design Review - Assessment of Individual Components		◆	◆	Requested for quality control to verify design. For example, a technical specialist is brought on-board to assess the flood risk of a new pump station design.
8	Risk Assessment of Existing Gravity Sewers		◆	◆	Objective is to quantify risk with a high degree of certainty. Probabilistic hazard information required. Vulnerability assessment based on both empirical and analytical assessments. (Note 1)
9	Sewer Design		◆	◆	Requires performance risk assessment of new design. Hazards are identified, and return periods/intensities evaluated and design criteria establishing the hazard intensity level is defined (e.g., design for 500-year flood).
10	Wastewater Treatment Plant Design (Considering Hazards)			◆	Assess the risk of all potential hazards that may impact the facility. Requires extensive site investigations to quantify the geotechnical environment. Design criteria set for treatment plant components. Treatment plant system assessed to assess reliability considering component reliability and redundancy.
11	System Probabilistic Performance Assessment			◆	More in-depth analysis of project No. 6. A system connectivity model is developed, the vulnerability of component evaluated for the selected hazard, and a Monte Carlo simulation applied to capture the variability of the input data and assessment methods.
12	Seismic Risk Assessment of Post-Tensioned Concrete Digester			◆	Evaluating a new structure showing signs of cracking. Seismic hazard structural loading is defined. A structural assessment is conducted including a demand/capacity ratio analysis to determine performance under seismic loading. Mitigation is recommended depending of the findings.

Note 1 – Project example included in the Commentary.

1. Multi-Hazard Screening Assessment

The objective of the assessment is to rank the hazards and system components by relative risk to determine whether an Intermediate or Advanced Assessment is required and to determine whether the system meets performance objectives (i.e., Phase 1 of a multi-phased assessment). This project uses hazard information to establish ranges of hazard return period and associated intensity. Vulnerability estimates are based upon empirical data and the experience of qualified assessors. Personnel familiar with system operation conduct the consequence assessment.

2. Single-Hazard Screening Assessment

This is similar to the Project No. 1 Multi-Hazard Screening Assessment except that it initially focuses on a single hazard. The owner/operator is familiar with the regional hazards, and moves directly to the evaluation of the risk associated with a single hazard. The hazard return periods and associated intensity used in the assessment are defined (e.g., evaluate for 100-year and 500-year return earthquakes). The risk of each system component is evaluated using published damage relationships and expert judgment.

3. Hazard Mitigation Plan (HMP) (DMA-2000)

The HMP is required by FEMA for all government entities that desire to get future mitigation grant funding. This is similar to Project No. 1 except that a specified public process is required, and mitigation measures are developed. A benefit-cost analysis is required to justify each proposed mitigation alternative.

4. VSAT^{TM}/RAM-W^{SM} Security Vulnerability Assessment

VSAT^{TM} , RAM-W^{SM} or comparable evaluation methodologies/tools were required for all water systems serving greater than 3,300 people. A similar requirement may be ultimately invoked for wastewater systems. The methodologies are similar to a comprehensive system single-hazard screening assessment focusing on ranking security threats with specific requirements defined in each of the two methods (VSAT^{TM}, RAM-W^{SM}). For such events, the hazard probability is defined to be 100%. The vulnerability is assessed by inspection by personnel familiar with security systems. Personnel familiar with the system operation perform the consequence assessment.

5. Assessment of Individual Components

This is the second phase in a single- or multi-hazard screening assessment (e.g. Project Nos. 1 and 2). This assessment stems from the findings of those projects. This project requires site/component specific structural and/or flood assessments of a system component. The project scope includes a site visit, review of design drawings, and performing independent analysis using empirical methods.

6. Scenario Development

This is the second phase of a performance assessment focusing on one or more hazards. The hazard data can be obtained in regional mapping format. The vulnerability of each component is quantified by applying damage relations (fragility curves). The consequence assessment evaluates the system impact when it is subjected to this specific hazard event. The system is evaluated based on expert judgment of system operations personnel.

7. Design Review - Assessment of Individual Components

A design review requested for quality control, or to focus more closely on the vulnerability to a specific hazard. A flood specialist is brought on board to review the siting and design of a sewage lift station. An Intermediate Assessment relies on existing engineering assessments and design drawings. An Advanced Assessment requires topographic site investigations and independent hydrologic assessments (e.g. develop/run Army Corps of Engineers Hydraulic Engineering Center (HEC) methods).

8. Risk Assessment of Existing Gravity Sewers

The risk assessment of an existing gravity sewer requires gathering and/or developing information to characterize the sewer design, and the geotechnical environment in which it is installed. In this example, the effort is driven by interest of the local population. Hazard information is required to define the probability of occurrence/return period, and the associated hazard intensity. The sewer damage mechanisms are identified by examining historical failures of similar sewers subjected to similar hazard conditions. For damage mechanisms that are deemed feasible (based on expert judgment), the evaluation requires a demand/capacity structural assessment.

9. Sewer Design

A sewer design project is brought about by a need for additional capacity or by development of a new area. Design of a new sewer may, depending on the diameter and depth, be a conventional design, taking design information from industry and local standards. For larger diameter pipe, a geotechnical investigation may be required, and a structural assessment required to select the pipe class. Depending on the local soil conditions, it is often beneficial to perform geotechnical site investigations to give construction bidders a better idea of what they may encounter.

10. Wastewater Treatment Plant Design (Considering Hazards)

Design of a wastewater treatment plant is required to increase the system's capacity. A wastewater treatment plant is a very complex system requiring planning and design of its multiple facets. For a project of this type, analyses would be undertaken to assess the risk associated with hazards under consideration. Extensive site investigations would be performed. The facility would be design to a wide range of applicable codes and standards. Typically, such a facility has extensive redundancy incorporated into the design. It would be unlikely that a probabilistic risk assessment would be carried out on the treatment plant system components unless loss of function would result in catastrophic losses.

11. System Probabilistic Performance Assessment

This is similar to Project No. 6, Scenario Development, except that the probabilities of hazard occurrence and component functionality are incorporated, and a Monte Carlo simulation is employed to account for the variability of the information input into the assessment.

12. Seismic Risk Assessment of Post-Tensioned Digester

This project is the evaluation of a new sludge digester that is showing signs of structural cracking. A structural assessment is required to evaluate the demand/capacity ratio under normal operation, and when placed on seismic loads for several levels of earthquakes. Potential corrosion of the reinforcing is evaluated. The assessment will result in an estimate of probability of failure under normal operation, and when subjected to selected levels of earthquake loading currently, and after 10 and 25 years. Engineering reports and design drawings are required. A site investigation would be required, including draining the structure to allow internal inspection.

Step 2 - Select Performance Metrics

The wastewater utility has the responsibility for selecting the metrics to quantitatively describe wastewater system performance relative to the project objectives. Potential metrics recommended are: 1) public health/backup of raw sewage, 2) discharge of raw/inadequately treated sewage, 3) direct damage/financial impact, and 4) security system performance. Other metrics may be defined and used at the discretion of the utility.

2.1 Public Health/Backup of Raw Sewage

The originating purpose of providing sanitary sewers was to protect public health by transporting raw sewage away from the population. The metric can be posed in terms of the success of achieving this objective:

- Define probability of achieving performance objective (e.g. – 90% probability of achieving).
- Define the probabilities of occurrence (e.g. 50% in 50 years and 10% in 50 years).
- Provide different criteria as a function of method of contact (backup into buildings, overflow onto city streets).

2.2 Discharge of Raw/Inadequate Treated Sewage

Wastewater systems are intended to protect public health and the environment. Metrics commonly used quantify the impact on public health and the environment (e.g. flow associated with biochemical oxygen demand, dissolved oxygen of the receiving water). For day-to-day, month-to-month, and year-to-year operation, EPA NPDES regulations contain the controlling metrics: does the discharge meet the various water quality requirements. However, it is the intent that this document address disasters that only occur one time, or less than one time during the life of any system component. For some events that occur every 100 to 500 years, it is assumed that discharge of raw /inadequately treated sewage will occur. The intent of the metric is to quantify that discharge and the probability of its occurrence.

The level of treatment required to protect the environment is primarily a function of the receiving water. Small streams are much more fragile than the ocean. Effluent dominated riparian areas[6] (found in arid environments) also exhibit different characteristics that must be considered accordingly. As a result, different contaminant levels are appropriate for different types of receiving waters, for example, streams, rivers, lakes and the ocean. Depending on the utility, it may be appropriate to further differentiate between these categories based on the size of the water body and site-specific environmental issues.

The sewage discharge metric can be defined for both the collection and treatment systems:

Collection/Transport System Metrics (have actual metrics underlined)

- Define probability of achieving performance objective (e.g. – 90% probability of achieving).

[6] Habitat generated by the presence of discharged effluent that would otherwise not exist in a desert environment

- For different hazards, define the probabilities of occurrence (e.g. 50% in 50 years and 10% in 50 years).
- Provide different criteria as a function of the receiving water (e.g. stream, river, lake, ocean).
- Define maximum flows (although this may be controlled by the flow in the particular sewer).[7]
- Define violation maximum duration (e.g. – 7 days, 30 days).

Wastewater Treatment Plant Metrics

- Define probability of achieving performance objective (e.g. – 90% probability of achieving).
- For different hazards, define the probabilities of occurrence (e.g. 50% in 50 years and 10% in 50 years).
- Define maximum flows (this will be controlled by the collection system unless significant volumes of onsite storage are provided).
- Define discharge of different water quality levels that may also be a function of the receiving water (could be disinfection, primary treatment, secondary treatment, etc.) for maximum duration (e.g. – 7 days, 30 days).

2.3 Direct Damage/Financial Impact

Direct damage/financial impact is the second metric. Historically, property losses are an order of magnitude smaller than societal economic losses (as driven by loss of function impacting public health and environmental impact) and usually do not control. However, in some situations, direct damage to wastewater system components should be taken into account. Cleanup and repair costs associated with flood inundation of a treatment plant, is one example. Another example where direct damage is significant is earthquake damage to the collection system. In many cases, the collection system will continue to function following an earthquake, but repairs/replacement may be required over the long-term to allow for adequate system maintenance.

There is potential for secondary damage due to loss of wastewater service to commercial or industrial facilities (e.g., factories shut down) to be greater than direct losses due to damage to the system. If the collection system is damaged, the more likely scenario is that the wastewater is produced as usual, and discharged untreated. In some types of hazard events such as earthquakes, the water system is also likely to be damaged and non-functional, so minimal sewage is produced, and pump-arounds are sometimes implemented to maintain service. In a pump-around, sewage is pumped out of one manhole and into the next to move the sewage past a collapsed or blocked sewer. Secondary/indirect financial impact is not a recommended metric.

[7] Any discharge of untreated or partially treated sewage is unauthorized, and is a violation of the NPDES permit. However, in extreme hazard events that may occur once every 50, 100, or even every 500 years, there may be some expectation that some sewage may overflow, and consideration should be given to quantifying acceptable volumes.

The metric takes the form: probability (say 90%) of limiting direct losses due to natural (or manmade) hazards to X dollars over a given time period (say 50 years – same time frame as the hazard quantification).

2.4 Security System Performance

Security system performance is another potential metric. Failure of the security system is another hazard, and can be treated in the same way as natural hazards in regards to metrics. The performance objective is stated in terms of probability of limiting raw sewage discharge when subjected to a design basis threat. The direct damage metric could also be applicable to failure of the security system.

Current assessment methods such as VSAT™ and RAM-W℠ evaluate the relative security of system components and the overall system. These methods do not quantify the hazard probability of occurrence, as there is inadequate empirical data to support development. However, they do define the hazard intensity in terms of a "design basis threat" (refer to Step 9 discussion). However, a metric can be defined by making an assumption about the hazard probability of occurrence. This would take the same form as the sewage discharge metric.

- Define probability of achieving performance objective (e.g. – 75% probability of achieving).
- Define the probability of occurrence (e.g. 40% in 50 years or 100-year return period).
- Define event maximum resulting from failure of the security system in the same terms as general system failure – flow. (This will be controlled by the collection system unless significant volumes of onsite storage are provided.)
- Define discharge of different water quality levels that may also be a function of the receiving water (could be disinfection, primary treatment, secondary treatment, etc.) for maximum duration (e.g. – 7 days, 30 days).

Step 3 - Define Performance Objectives

As stated in Step 2, the amount of untreated or inadequately treated sewage discharged is the primary metric for assessing public health and environmental impact. This section considers how to set performance objectives for this metric.

Stakeholders

The assessment of whether or not a wastewater system has adequate resiliency to natural hazard events can differ considerably among stakeholders. Identification of the appropriate stakeholders and their associated need for wastewater service is a basic requirement for defining performance objectives. Basic stakeholders in the decision to potentially reduce wastewater utility system risks associated with natural hazards and human threats include:

- The wastewater utility management and governing body.
- Pertinent wholesalers associated with the wastewater utility.
- Municipal governments to the extent that they subsidize or are subsidized by the wastewater utility, or that may be co-located.
- Various categories of customers (generators of wastewater, customers that purchase treated effluent for irrigation, etc.).
- Insurers, bondholders, bond rating agencies, and lending institutions.
- Federal and state agencies that provide federal or state disaster assistance.
- Federal, state and local agencies that regulate health effects and issue permits to operate the system (wastewater quality) and/or that are involved with proactive antiterrorism programs (system performance).

Stakeholders can be accessed either individually or in groups through community outreach programs. One of the issues in conducting these programs is the difficulty in communicating the issue of risk over a period that extends beyond the person's professional life or even lifetime. For example, consider the insignificance of the risk that a non-utility person may assign to discharging raw sewage into a river once every 100 or 500 years.

Facilitating interaction with stakeholders typically requires that a set of performance objectives be initially defined by the wastewater utility for the purposes of implementing an assessment and estimating the costs associated with meeting each objective. Having this information provides a framework for discussing alternatives with the stakeholders and soliciting their comments. The goal is to arrive at a mutually agreed upon performance objective with its associated cost and implementation schedule.

3.1 Performance Objectives - Suggested Starting Point

Table 2 provides a potential starting point for system performance objectives for a generic wastewater system in which the collection system controls the overall system performance. Table 2 incorporates all of the metrics identified in Step 2: probability of achieving performance objective; defining different hazard probabilities of occurrence; providing different criteria as a function of the receiving water; defining maximum flows; and defining discharge maximum duration. Note that these performance objectives are those resulting from hazards and not those encountered in nominal day-to-day operations (e.g., overflow/backups from roots, grease and vandalism, accidental damage to lines by construction activities, etc.).

Table 2. Performance Objectives

Performance Objective Category	**100-Year Return Event (40% in 50 years)**	**500-Year Return Event (10% in 50 years)**
Public Health		
Backup of any raw sewage into buildings	Not acceptable (less than 1% probability of occurrence)	Not acceptable (less than 5% probability of occurrence)
Overflow of raw sewage into streets	Acceptable in localized areas; less than 24 hrs	Acceptable (treatment plant is inundated) less than 72 hrs
Environmental		
Discharge of raw sewage to stormwater system, ditch or stream	Acceptable in localized areas; less than 72 hrs	Acceptable less than 7 days
Discharge of raw sewage to lake or river	Acceptable in accordance with CSO/NPDES	Acceptable less than 30 days
Discharge of raw sewage to salt water	Acceptable in accordance with CSO/NPDES	Acceptable less than 90 days
Discharge of disinfected primary effluent	Acceptable less than 30 days	Acceptable less than 180 days
Discharge of disinfected secondary effluent (meet NPDES permit requirements)	Acceptable	Acceptable

Step 4 - Define the Wastewater System to be Assessed

The wastewater system to be assessed is defined as the facilities (components and pipelines) relevant to the performance objective. The type of information required to describe those facilities is dependent upon the level of assessment, particularly the methods used to assess component vulnerability. Refer to Commentary Step 4 for supplemental information, and descriptive material describing wastewater system components.

Do not collect data for the sake of collecting data, but gather it with a specific need in mind. Data collection and evaluation covering the entire system is minimized in the Simplified Assessment. The Simplified Assessment identifies the high-risk components, allowing subsequent evaluations to focus in depth on selected components.

In many cases, only a portion of the system needs to be considered. An example would be an assessment intended to answer questions related to the design performance level for a specific lift station. Such a decision would only require an assessment of the sub-system that consists of the lift station and the associated electrical and mechanical equipment, and forcemain discharging from the lift station. Specific information on the characteristics of other system components would not be required.

From the outset, the evaluation would focus on individual components for a variety of issues such as: operational, reliability, capacity, deterioration, and or replacement. Each of these types of assessments would require more than a simplified effort and more information to conduct the assessment.

The performance assessment can focus on potential damage from selected hazards. Understanding the damage mechanisms associated with those hazards can limit the extent of the system requiring evaluation, and therefore required information. For example, vulnerability to flooding is highly dependent on elevation, and has limited dependency on the type of structure. Conversely, earthquake vulnerability is highly dependent on the type of structure and soil type, but is not dependent on elevation. For a flood, structures in the floodplain are vulnerable, whereas in an earthquake, all structures are potentially vulnerable.

Different evaluation objectives can result in a different perspective on the system inventory. The performance assessment can focus on system operations or on infrastructure vulnerability/ damage exposure (probable maximum losses). An operational risk assessment focuses on the reliability of each component and system redundancy whereas infrastructure vulnerability would focus on individual components.

The definition of the wastewater system at risk can be categorized by the level of assessment, the associated information required, and the extent of the system to be evaluated.

Step 5 - Define Relevant Natural Hazards and Human Threats

This section provides direction in defining relevant natural hazards and human threats, and credible hazard scenarios affecting the reliability of your wastewater system. Lists of hazards and threats are provided in the Commentary, Section C-5, along with some descriptive material, and suggestions regarding resources for additional information. Natural hazards are defined by the probability of occurrence in a given time period, and the associated hazard intensity. The hazard intensity is a measure of the damaging peril such as earthquake ground shaking, flood inundation location and depth, or wind speed. As the probability of the hazard event decreases, the associated intensity increases. For example, a flood with a 10% chance of occurrence in 50 years (500-year average return period) will inundate a larger area than a flood that has a 40% chance of occurrence in 50 years (100-year average return period). Human threats comprise actions by an individual or individuals to inflict adverse impacts on system facilities and/or assets. For human threat events, there is inadequate data available to estimate the probability of occurrence, so design basis threats are defined assuming that an event will occur.

For single site facilities, hazard probabilities and associated intensities can be used directly, such as is done with building codes. However, for distributed lifeline systems, scenario events (with a determined probability) must be used, to reflect the variation in hazard intensity across the system in any given event. For example, a hurricane only reaches its maximum wind velocity over a portion of the wastewater system's service area. Further, applying probabilistic ground motions across the entire service area (that is, localized ground motions of a given probability level, as distinguished from an earthquake event at a given probability level with associated ground motion estimates) would result in an overestimation of the impact of a single event.

Deterministic scenarios represent a single event with an associated estimate of a return period and hazard intensity (e.g., earthquake level of shaking, flooding – water depth). Multiple scenarios can be developed to cover a range of return periods and intensities. A combination of multiple scenarios can be used to develop a probabilistic relationship describing the likelihood of an event occurring over a given time period, along with the associated expected intensity.

Hazards can be categorized as independent or dependent. Independent hazards are initiated without influence from other hazards. Earthquake fault rupture and hurricane wind are examples. Dependent hazards are dependent on the initiating hazard. For example, earthquake shaking, an independent hazard, can cause liquefaction, lateral spreading, and landslides to occur (dependent hazards). The dependent hazard intensities must be calculated from the independent hazard intensity. For example, the probability of liquefaction in an earthquake is determined from the independent ground motion and the liquefaction susceptibility relationship. Further, lateral spreading displacement (due to the liquefaction) is a function of ground motion, the earthquake magnitude (which takes into account duration), ground slope, and grain size distribution, etc.

Hazard scenarios include both the independent and dependent hazards. For example, an "intense rain storm" scenario might include multiple hazards: flooding, scour/erosion, landslides, and power outage.

Hazard events can be independent of one another, or they can be correlated. For example, an earthquake event and a flood event are independent. That is, an earthquake event does not increase the probability of occurrence a flood event. The probabilities of occurrence of independent events must be multiplied when considering the likelihood of the two scenarios occurring concurrently. Usually the resulting probabilities are very small and can be dropped from further consideration. For example, the probability of having a 500-year flood (e.g., 10% probability in 50 years or 0.2% probability in one year), and a 500-year earthquake (same probabilities of occurrence) in the same year would be 0.2% times 0.2% or 0.0004%, and much less to have them occur within several weeks of one another). An event with low a probability would have a return period that is typically well outside the planning horizon for anything other than events that can produce mass casualties. 100-year to 500-year planning horizons are typical for wastewater systems.

Some hazard events can be correlated. For example, flooding and power outage often occurs at the same time and must be considered in the hazard occurrence probability. For example, consider the probability of having a 500-year flood (10% probability in 50 years or 0.2% probability in one year) and regional power outage (say 50% in 50 years or 1% in one year). The probability of having both in the same year if they are independent (caused by unrelated events) would be 0.2% times 1% or 0.002%, and much less to have them occur together, impacting the system at the same time. However, if they are correlated, a regional power outage might be expected to occur say 50% of the time when a 500-year flood occurred or 0.5 times 0.2%, or 0.1% probability per year.

Flooding events in adjacent watersheds are likely to be highly correlated. Landslides can be correlated with both earthquakes and with intense rain. In a Simplified Hazard Assessment, where the risk to system components is being independently determined, the effect of correlation of the various hazards on individual components must be considered.

Publicly available sources of information on various natural hazards are provided in the Commentary. In general, the quality of hazard data (Quality Ranking) and the associated ability to define a hazard in the manner necessary to perform a risk assessment falls into one of three categories as shown in Table 3 where:

A. Information is readily available to allow a complete or near complete definition of the natural hazard severity and probability of occurrence for a Simplified Assessment.

B. Information is readily available on the intensity of the hazard but the probability of occurrence of the hazard scenario is based largely on judgment.

C. Investigations are necessary to provide information supporting judgments on natural hazard severity and probability of occurrence.

Table 3. Assessment of the Quality of Readily Available Data on Various Natural Hazards

Natural Hazard	Quality Ranking	Independent Event (I) or Dependent on Initiating Event (D)
Earthquake – Fault Rupture	Varies	I
Earthquake – Shaking	A	I
Earthquake – Landslide	Varies	D
Earthquake – Liquefaction	Varies	D
Earthquake – Lateral Spread	C	D
Earthquake – Tsunami	B	D
Earthquake – Fire Following	C	D
Hurricane, Tornado, Cyclone	A	I
Hurricane – Storm Surge	A	D
Flood	A	I and D
Riverine Flood	A	I and D
General Severe Wind	B	I
Frost Heave	B	D
Expansive Soil	Varies	I

The information about the quality of available data shown in Table 4 can be used to assist in developing the project scope. It provides information on the quality of existing data that will assist the Guideline user in determining what additional work is required to acquire the required data. General requirements for hazard information for Simplified, Intermediate, and Advanced Assessments are described in the subsequent section. The information in Table 4 will help the user understand whether the hazard data required for a selected level of assessment is available or whether it will have to be developed as part of the scope.

5.1 Design Basis Threat for Human threats

Like natural hazards, it would be desirable to quantify the human threat likelihood. There is little recurrence data to enable the evaluation team to use historical data. Further, the threat is constantly changing. That is, the threat (of terrorism) was different 10 years ago compared to what it is today, and compared to what it will be 10 years from now, with changes in world politics. The real value of quantifying the design basis threat would be to compare the human threat risk against the risk of natural hazards.

One approach is to assume that the human threat event will happen (probability equals 100%). This results in a relative risk assessment, and provides no guidance on the relative risk between natural hazards and the human threat.

Another approach is to bound the threat likelihood. That is, to make assumptions based on available information and rational judgment. For example, how many terrorist attacks resulting in system loss of function would the evaluator expect within the next 50 years anywhere within the United States. Consider the number of wastewater utilities of comparable or larger size that constitutes a reasonable target, as well as the other infrastructure systems that may be targets, such as water supply and power.

The human threat "intensity" must be defined to allow evaluation of the vulnerability of the various system components. There is a range of threat intensities, ranging from vandals to state-sponsored terrorists. It is not feasible to plan to protect against a state-sponsored terrorist. The utility must develop a design basis human threat considering:

- The number of people likely to participate in the attack
- Their training
- Available equipment
- Available weapons
- Knowledge of the wastewater system

Once this design basis threat has been established, the vulnerability to the system components can be evaluated.

5.2 Hazard Assessment Levels

This section provides direction on the type of hazard information that is appropriate for each of the three levels of assessment. This direction is intended to serve as a starting point. Real world considerations, such as the availability of data and the specific project objective, can result in changes to the hazard information that is actually used. The data requirements as specified for each level of assessment are cumulative, starting with the Simplified Assessment. The general hazard assessment methodology for Simplified, Intermediate, and Advanced Assessments for specific hazards is summarized in Table 4.

Simplified Hazard Assessment

- Use the Simplified Hazard Assessment to screen for hazards that present the highest risk to the utility[8], and prioritize them further using Intermediate or Advanced Assessments. A VSAT™-type hazard assessment falls into this category.[9]
    - Review the literature and local hazard information.
    - Review available hazard mapping.
    - Research historical impacts of the hazards on your system.
    - If hazard maps are not available, develop them using other relevant information such as geologic and topographic maps.
    - Deterministic assessment methods may be used in lieu of probabilistic methods.

[8] Use the Simplified Assessment including hazard, vulnerability, and consequence as a screening tool.
[9] VSAT™ does not attempt to quantify the human threat hazard, assuming it can occur.

Table 4. Hazard Assessment Methods and Simplified, Intermediate, and Advanced Assessment Levels

Earthquake Hazard (All Dependent on Strong Ground Shaking)
Surface Fault Rupture
Simplified
• Review active fault hazard mapping for area, if available
Advanced
• Conduct site specific fault investigation
Strong Ground Shaking
Simplified
• Review literature on regional seismicity (www.usgs.gov)
• Review seismic hazard mapping for area (http://eqhazmaps.usgs.gov)
• Review seismic site amplification mapping for area (if available)
• Review surface geology maps (to determine site amplification if maps not available)
• Estimate ground motion levels using published amplification factors and existing maps
Intermediate
• Develop ground motion amplification factors
• Estimate ground motion levels using empirical models
Advanced
• Estimate ground motion levels using analytical models or tools
Liquefaction
Simplified
• Review liquefaction susceptibility maps (if available)
• Review relevant geotechnical data (if susceptibility maps not available)
• Identify potentially liquefiable soil deposits by judgment (if susceptibility maps not available)
Intermediate
• Locate system facilities within potential liquefaction areas
• Perform field reconnaissance (by qualified geotechnical engineers)
• Identify potentially liquefiable soil deposits by engineering analysis of soils data
• Estimate liquefaction potential using liquefaction susceptibility maps and ground motion maps
• Estimate lateral spread displacements using empirical methods
Advanced
• Conduct soil borings, SPTs, and/or CPTs
• Perform detailed analysis using analytical tools

Table 4. Hazard Assessment Methods and Simplified, Intermediate, and Advanced Assessment Levels - continued

Landslide
Simplified
• Review earthquake landslide hazard maps (if available)
• Review topographic maps
• Locate system facilities within potential landslide areas
• Evaluate landslide potential using expert judgment (if maps not available)
Intermediate
• Review stereo aerial photographs (if available)
• Perform field reconnaissance (by qualified geologists)
• Evaluate landslide potential using statistical or empirical analysis
Advanced
• Evaluate landslide potential using analytical models
Tsunami
Simplified
• Review regional tsunamis hazard
• Review tsunami hazard maps (if available)
• Review topographic maps of coastal areas subject to tsunamis (if no tsunami hazard maps available)
• Estimate potential tsunami flooding using expert judgment (if tsunamis hazard maps not available)
• Locate facilities within tsunamis inundation area
Advanced
• Review bathymetric maps of near-shore areas
• Estimate potential tsunami flooding using judgment and evaluation of potential tsunami sources
• Perform site-specific inundation modeling
Ground Deformation Hazard – Landslide (Non-Earthquake Related)
Simplified
• Review landslide hazard maps
• Review historic local landslide information
• Review surface geology maps
• Review topographic maps
• Locate system facilities within potential landslide areas
• Evaluate landslide potential using expert judgment (if hazard maps not available)
Intermediate
• Review stereo aerial photographs (if available)
• Perform field reconnaissance (by qualified geologists)
• Evaluate landslide potential using statistical or empirical analysis
Advanced
• Evaluate landslide potential using analytical models

Table 4. Hazard Assessment Methods and Simplified, Intermediate, and Advanced Assessment Levels - continued

Ground Deformation Hazard –Settlement (Natural/Manmade Deposits)
Simplified
• Review surface geology maps
• Review topographic maps
• Review historic local settlement information
• Review ground water maps and available geotechnical reports
• Evaluate settlement potential using expert judgment
Intermediate
• Perform field reconnaissance (by qualified geotechnical engineers)
• Evaluate settlement potential using empirical methods
Advanced
• Evaluate settlement potential using advanced analytical methods
Ground Deformation Hazard – Frost Heave
Simplified
• Review historic local frost heave information
• Review surface geology maps
• Evaluate frost-heave potential using expert judgment
Intermediate
• Perform field reconnaissance (by qualified geotechnical engineers)
• Review existing soil borings, test pits, and ditch logs, as available
• Evaluate frost-heave potential using empirical methods
Advanced
• Conduct soil borings
• Evaluate frost-heave potential using advanced analytical models
Wind and Icing Hazard
Simplified
• Review system feeds with power utility
• Review power reliability with power utility
• Review historical power reliability
Advanced
• Conduct power system reliability assessment
Flooding Hazard
Simplified
• Review Q3 digital flood maps and national Flood Insurance Rate Maps (www.fema.gov/fhm)
• Gather local flood data from local/regional jurisdiction
• Locate system facilities within potential flood zones
Intermediate
• Identify potential flooding hazard from local dams or floodways
• Evaluate flooding potential using expert judgment
Advanced
• Collect topographic, stream, rainfall data
• Perform analytical flood hazard analysis (HEC RAS, HAZUS-MH)

- Hazard maps may be available from federal, state, or local government sources. Probabilistic maps are desirable, including the probability of occurrence in a given time period, and the associated intensity. The maps should also describe the basis of the information and provide definitions of the hazard intensities shown. It is also desirable to have these maps in Geographic Information System (GIS) format to allow the hazard information to be related to the system components.

- For probabilistic hazards assessments, the hazard is stated as a combination of the probability of occurrence and the associated intensity. Determine the hazard intensity for each component in the Simplified Assessment. The first approach used to allow comparison between the severities of different hazards, maps with common probabilities of occurrence should be used. That is, the 500-year return period earthquake hazard should be compared with the 500-year flood hazard.

- For dependent hazards, a combination of the independent and dependent hazard information must be used to determine the net hazard. For example, to determine the probability that earthquake-induced liquefaction will occur, both the earthquake shaking intensity and the liquefaction susceptibility must be considered. This information is often mapped regionally.

- In the second approach, the analyst can select a hazard return period with an associated intensity that will result in a “high” probability of loss of function for the most vulnerable system component. The same hazard map showing intensities for one probabilistic recurrence interval (e.g. the 500-year flood elevation) would be used to determine the hazard intensity for each system component. The probability of loss of function for the other components can range from low to high depending on their specific risk attributes. Another way of stating is, select the hazard level that is likely to cause loss of function of the most vulnerable component and look at what other hazards with a similar recurrence interval might do to stress the system.

- The hazard probability of occurrence (or return period) can be stated quantitatively, albeit using an approximation, for each system component. For example, the hazard probability can be defined as low, medium, or high representing hazards with return periods of > 250 years, 50 to 250 years, and < 50 years. When hazard information is not available, it is much easier to assign hazard probabilities/return periods using these ranges. These return periods can be converted to numerical values for manipulation by using the median of each range. It is preferable to report them as qualitative values.

- A third approach that can be used in the Simplified Assessment is the use of scenario hazard events that make up a significant contribution to the probabilistic hazard. This would be a deterministic assessment, and not a probabilistic assessment. For example, select a flood scenario that has a return period of approximately 500 years that will impact many of the system components. This approach is different than using approximated hazard return periods and associated intensities as discussed above, but can provide useful results.

Intermediate Hazard Assessment

- Field reconnaissance to each system component is expected to verify the information on the hazard map.
- Use empirical methods to quantify the hazard and hazard intensity . The assessments will include a hazard analysis based on site-specific information rather than regional information.
- Use quantitative probability of occurrence and intensity values. Recognize that there is variability in the data due to randomness and uncertainty, but it is not intended that an assessment considering the variability be conducted at this level.

Advanced Hazard Assessment

- The Advanced Hazard Assessment makes use of analytical methods to quantify the hazard and associated intensity. Refer to Table 4 for hazard-specific assessment methods.
- Site investigations are expected as part of an Advanced Hazard Assessment. Examples include geotechnical investigations including borings and laboratory soil testing and topographic surveys to gather information for hydraulic flood analyses.
- For the Advanced Assessment, a true probabilistic assessment is desired for the relevant hazards. This approach captures the uncertainty associated with both the hazard probability of occurrence and the associated hazard intensities. Many scenarios are selected to define a relationship between hazard intensity and probability of occurrence.
- It is important to note that an assessment of this level would probably never be warranted for a wastewater utility.

Step 6 - Assess Vulnerability of System Components to Natural Hazards and Human Threats

Vulnerability is generally expressed in terms of: 1) direct damage/repair costs, 2) loss of function, or 3) restoration time as a function of each specific hazard's intensity. Direct damage economic losses (repair cost) are important for establishing total repair costs for specific natural hazard events. Determination of the loss of component function allows an estimation of service impairment related to the component. Estimating component repair time is important for estimating system recovery duration and secondary losses related to the duration of service interruption. This section is intended to provide an overview to assist in preparing a scope of work for a vulnerability assessment.

Human threats as addressed in this document are those addressed by VSAT™ and by RAM-W^{SM}. Both VSAT™ and RAM-W^{SM} analyses are considered Simplified Assessments. VSAT™ is the security vulnerability assessment tool[10] promoted by the Association of Metropolitan Sewer Agencies (AMSA). It is also applicable to water systems. VSAT™ is a software program that works as a tool to help the user conduct the security vulnerability assessment. It is based on RAM-W^{SM,} the security risk assessment methodology developed by Sandia National Laboratory in association with the American Water Works Association Research Foundation (AWWARF), and the EPA. RAM-W^{SM} was developed for the security assessment of potable water systems, and was the methodology required for evaluation of water systems serving more than 100,000 people. RAM-W^{SM} is a methodology, and is not implemented in software.

Human threats are typically addressed separately from natural and technological hazards for the following reasons:

1. The causes that motivate a person to attack a portion of the system are not easily quantified in the way that a recurrence interval for a particular flood can be. The evaluation needs to examine what threat is reasonable to protect against, and determine the probability of attack.
2. The nature of the damage caused can be significantly different from the potential damage anticipated from natural and other hazards: for example, an attacker may attempt to introduce explosive material into the system that subsequently detonates.

The systems in place to reduce the vulnerabilities to human threats and enhance security are to some degree different from those for natural and other hazards. Such systems comprise physical protection, operating systems and cyber security.

The form of the vulnerability assessment can be deterministic or probabilistic. In most cases, Simplified Vulnerability Assessments are sufficient, as methods that are more complex often suffer from a lack of empirical data to support the damage relationship and its variability. Available methods for developing damage relationships include (a) empirical, (b) visual inspection and rating, (c) analytical, (d) experimental, and (e) expert judgment. These five types of methods differ significantly, although sometimes overlap. Several methods might be used for

[10] The term security vulnerability assessment is used by the US Environmental Protection Agency. A more correct term to describe their application would be a security risk assessment as it incorporates parameters for the hazard, vulnerability, and consequence of loss of function.

a Simplified Assessment (empirical, inspection and rating or expert judgment). For Advanced Assessments, analytical methods are applicable such as finite element analyses. Experimental methods are not practical or necessary, except in extreme situations where the other four methods are not applicable, and the potential risk is very high.

6.1 Representing Component Vulnerability

Damage relationships are required to estimate repair costs, component functionality, and restoration times. Simplified Vulnerability Assessments can assume close correlation between all three. For Intermediate and Advanced Assessments, improvements are desirable with respect to the definition of various component failure modes and their implications for the three component vulnerability parameters.

Repair costs and restoration times vary regionally and over time, reflecting differences in construction practice and labor rates, although there are many other parameters used in the assessment with significantly greater uncertainty. Wastewater agency managers and staff are often the best sources for realistic cost data, based on:

- Repair or replacement of existing systems under normal conditions.
- Repair and replacement of existing systems under post event conditions.

Experience data must be adapted to represent the post-event conditions for each hazard under consideration, at some time in the future when, for example, construction equipment is difficult to obtain because it is in high demand, and access to repair sites is hampered by damaged roads and bridges (e.g. – after an earthquake).

Repair cost damage relationships are often presented in terms of percent of replacement cost as a function of hazard intensity. For example, hypothetically, for an earthquake ground acceleration of 20 percent of gravity (g), the damage as a function of replacement cost would be 10 percent. For an acceleration of 40 percent g, the damage as a percent of replacement cost would be 80 percent. When percent of replacement cost is used, the installed replacement costs for every component in the system must be developed. The utility risk manager often maintains that information for insurance purposes.

Damage relationships can relate to the functionality of components of the wastewater system. The functionality may have some degree of correlation, rarely perfect, with repair costs. For instance, the repair costs for a toppled electrical cabinet (due to earthquake shaking) can be small by comparison to other repair costs, but lead to significant functionality problems. In contrast, damage to the wastewater collection system piping can be costly even though it may remain functional. Assessment of restoration time for individual components yields critical information on when the wastewater system will be fully restored, and what countermeasures are needed to offset potentially long downtimes for critical wastewater system components.

An Advanced Assessment method for defining damage states is structural-based damage descriptors for the component's structural elements. This can be used for assessments of pipelines, tanks, and building structures. These descriptors can consist of limit-state forces, deformations, etc., associated with various modes of damage to structural elements or components. For example, the earthquake performance of a post-tensioned concrete digester may be suspect. The input loading is calculated to determine the demand. The structural capacity is determined based on the allowable strain, which is determined by evaluating. If demand values of these parameters exceed any of the limit-state values for any element, the damage mode associated with that damage state is assumed to occur for that element. After repeating this for all elements in the component, an overall damage state for the component is developed in terms of these damage descriptors. Then, repair procedures established from these improved damage state descriptions can be used to provide more rational estimates of functionality, component repair costs, and restoration time.

6.2 Damage Databases for Wastewater System Components

There is limited experience data specific to wastewater system component vulnerability. However, relevant experience databases have been assembled for the nuclear industry, the building structure industry, and for some components of the water industry. Refer to ATC-13 and HAZUS 99 for earthquake damage relationships and HAZUS-MH for earthquake, flood inundation, and wind damage relationships.

However, use caution when applying "water" experience databases to wastewater systems due to inherent differences between the two types of systems. Wastewater facilities are, in general, located in low-lying areas to take advantage of transporting sewage downhill via gravity. As a result, wastewater treatment and pumping facilities typically have more exposure to flooding (because they are more likely to be located in floodplains), and earthquake (because they are more likely to be located in alluvial soils vulnerable to liquefaction).

Gravity sewers differ from water pipelines as follows:

- They are generally buried deeper.
- The pipe body/materials and joints are typically weaker as they are not designed for pressure.
- They are more buoyant because they are only partially filled with sewage. This makes them more vulnerable to flotation in areas with high groundwater tables. Similarly, manholes are vulnerable to displacement under surcharged conditions.
- Sewer pipelines can generally withstand more damage and remain functional, relative to pressurized water pipelines. Damaged sewers often continue to operate, transporting sewage until the sewer pipe is offset (shear) and/or separated to the point that sewage flow is blocked. By comparison, pressurized pipelines (such as water pipelines) will discharge far greater amounts of water than gravity pipelines given the same physical leak size. Other "failures" occur that will result in increased infiltration, but these failures may not cause immediate loss of function.

Further, wastewater lift stations differ from water booster stations. They are designed with a deep wet well (typically over 15 feet deep and in extreme cases approaching 100 feet deep) where sewage collects by gravity. Water booster stations are usually located on grade or in shallow vaults. Therefore, lift stations can be vulnerable to liquefaction or excessive buoyant forces in areas with high groundwater tables.

6.3 Forcemain and Gravity Sewer Vulnerability Assessment

Pipeline damage relationships are usually developed in the form of failures per unit length. Failures are further divided into two types: leaks and breaks. For gravity sewers, leaks are defined as locations where sewage can leak out or ground water can infiltrate. Breaks are defined as locations where there is loss of hydraulic continuity and the flow cannot pass, and pump-rounds are required. Similarly, for forcemains (which are pressurized), leaks refer to locations where sewage can leak out, and breaks refer to pipe damage so severe that there is a loss in hydraulic continuity and the pipe cannot transmit sewage.

The most effective way to apply the hazard information to pipeline systems is with GIS. The GIS system can assist the analyst to estimate the total number of failures per branch of pipe. This can then be converted into a probability of maintaining flow for the particular pipe segment.

6.4 Interdependence of Wastewater Facility Damage and Other Damage

Other structures, such as highway or railway bridges, often support pipelines. Movements of a bridge structure with respect to its abutments may damage the pipeline. Collapse of the bridge will destroy the pipeline segment. If the bridge collapses, repair of the pipeline will require extensive and expensive temporary pipe bridge or other means, pending repair or replacement of the bridge. Meaningful assessment of the bridge's vulnerability, and its potential relative movements (structure versus abutments) requires a high level of effort and significant expertise. Often, local, state or federal highway departments are able to provide assistance, providing information about the design criteria used for the bridge, typical design margins with respect to defined hazards, past performance of similar structures in the vicinity, or even specific analyses performed for the hazard of interest. Other examples of interdependence include the collapse of an enclosure building that destroys a chlorination system, or an Emergency Operations Center that is destroyed by flooding, taking with it the enclosed SCADA equipment.

6.5 Secondary Damage

Wastewater system component loss of function sometimes result in damage to other facilities outside the wastewater system resulting in additional losses. Gravity sewers are traditionally buried in the same right-of-way as other utilities and are usually buried deeper. Failure of sewers can result in development of large sinkholes that result in damage to the utilities above.

Failure of sewers can cause the system to backup resulting in flooding upstream. In a backup, sewage will start to overflow at the lowest upstream point in the system resulting in possible damage to adjacent structures, etc., or overflow into storm drain systems.

Failure to provide adequate treatment of wastewater before it is discharged will "contaminate" the receiving water. In many instances, communities downstream draw their potable water from these same rivers. Increased levels of contamination make it difficult to treat adequately.

6.6 Uncertainty in Component Vulnerability Assessment

The uncertainty in component vulnerability assessment can be a major issue. For instance, if visual inspection and rating methods are used, there is a high degree of uncertainty. There is no data available to establish the relative uncertainty between the various methods used to develop damage relationships. However, Advanced Assessments are expected to distinguish between the uncertainty of the natural hazard intensity and the uncertainty of the response of the component to that hazard. Track uncertainties separately through the risk assessment to avoid exaggerating the overall uncertainty in the process.

6.7 VSAT Methodology

The VSAT™ methodology was designed to assist with the identification of security risks posed to critical assets of wastewater systems and to perform benefit-cost analyses of potential mitigation. To compute risk, a system's critical assets are paired with perceived security threats, and the likelihood and consequences for each pair are assessed. Threat-asset pairs with relatively higher probabilities of occurrence and/or more severe consequences correspond with greater security risks. Cost benefit analyses performed within VSAT™ focuses available resources for security upgrades on the most significant risks. Commentary C-6 provides supplemental information on developing data to be input into the VSAT™ program.

6.8 RAM-WSM Methodology

In response to the Public Health Security and Bioterrorism Preparedness and Response Act of 2002, the RAM-W^{SM} methodology was developed by Sandia National Laboratories to assess human threats for water utilities. This methodology has been broadly utilized and generally accepted and is easily adapted to the assessment of wastewater utilities. Similar methodologies have been developed for dams and electrical power transmission, RAM-D^{SM} and RAM-T^{SM}, respectively.

The RAM-W^{SM} methodology begins with the identification and ranking of critical system facilities using a process termed "pairwise comparison". An inventory of critical assets associated with each critical facility is then developed using general system knowledge, or for a more rigorous evaluation, fault tree assessment (see Commentary, Section C-6). Critical assets are the components required for maintaining the functioning of system facilities (the pumps, valves, pipes, electrical equipment, and power supply at a transfer station for example).

The RAM-W^{SM} methodology continues with the application of the risk equation (G-1) to obtain a risk value (R) for each critical asset. The terms of the risk equation are developed as follows:

$$R = P_A * (1-P_E) * C \qquad \textit{Equation (G-2)}$$

Where:

- R = Relative Risk. The hazard probability is defined as 1.0 (100 percent), so the calculation only uses the vulnerability (1-P_E) and the consequence parameters, without consideration of the hazard, and therefore the result is the "relative" risk.
- P_A – the likelihood of attack – is generally assumed to be 1.0. Estimating the actual probability of attack to a system would be very difficult. The use of 1.0 carries the assumption that an attack will occur. A design basis threat characterizes the nature of the potential attack, allowing the utility to design its security protection systems to "reasonably and prudently" mitigate such an attack as defined in the regulation. "Reasonably" and "prudently" are qualitative measures of reliability.

- P_E is a measure of the assessed effectiveness of a system's current security protection. Generally, a value of 0.1 to 0.3 would be assigned if security systems in place were judged to have little effectiveness. Higher values are assigned (0.9 typically representing the maximum) for higher levels of effectiveness. P_E is determined using a qualitative assessment.

- C is a measure of the consequences of an attack on a critical asset. Consequences are determined based on the impact to the system's operating objectives. Several objectives may be considered with a low, medium or high consequence assigned for each objective. An overall consequence value derived by this process for each critical asset is utilized in the risk equation.

The RAM-W^{SM} methodology then assesses the relative benefit/cost of proposed security system upgrades. A risk-prioritized plan for risk reduction is developed based on the results that provide recommended upgrades for both physical protection systems (such as intrusion alarms and upgraded locks) as well as operating systems (development of procedures to respond to a suspected attack).

6.9 Defining Vulnerability for Various Levels of Assessment

Summarizing the section's discussion, vulnerability or damage relationships applicable to the three levels of assessment can be defined as shown below and summarized for various categories of wastewater system components in Table 5.

Simplified Vulnerability Assessment

- Use damage relationships from existing sources (such as HAZUS or ATC-13) or develop new ones using visual inspection and rating, and/or empirical data. Personnel familiar with damage mechanisms for the specified hazard for the particular component should develop the damage relationships.
- Use either scenario-based deterministic evaluations or probabilistic assessments where risk parameters are quantitative but represent ranges (i.e., high, moderate, low) are required.
- Functionality, repair costs, and restoration are closely correlated.
- Estimates of component repair times on best estimates for material, crew, and equipment availability. Utility operations personnel are typically a good source for this information.

Table 5. Vulnerability Assessment Levels of Wastewater System Components

Assess Sewer Vulnerability to Ground Movement Hazards
Simplified
• Gather sewer material/joint type information in GIS format
• Relate sewer pipe data to hazard data using GIS
• Assess vulnerability to ground movement hazards by application of published damage relationships (such as ALA, 2000). If damage relationships are not available for specific hazards, develop using historical data.
Intermediate
• Conduct structural assessment of pipeline for a limited number of representative cases for similar pipe materials/joint types, and expected soil movement. (For segmented pipe – joint separation; for continuous pipe - pipe stress)
• Or evaluate site specific cases using engineering judgment considering the hazard environment and design details
Advanced
• Conduct structural assessment for site-specific cases
• Incorporate uncertainty in assessment
Assess Building Vulnerability
Simplified
• Gather information by interviewing company operations managers and building maintenance personnel
• Identify critical functions within buildings, and the damage state that would impair or impede these functions
• Assess direct damage, building performance, and/or restoration time using judgment (estimates or informed estimates) and/or experience (statistical) data from past events or using empirical damage models (e.g., HAZUS), with minimal field data collection
Intermediate
• Perform general site survey(s) to assess local conditions and to collect information on the general vulnerability of buildings
• Perform general site survey(s) to assess collateral hazards from off-site sources, and nearby structures and equipment
• Review structural drawings, design calculations, foundation investigation reports, and past structural assessment reports to assess building capacity
• Perform independent structural calculations to assess building capacity
Advanced
• Develop computer-based structural analysis model(s) to assess building response

Table 5. Vulnerability Assessment Levels of Wastewater System Components - continued

Assess Equipment Vulnerability
Simplified
• Inspect equipment with qualified engineer using judgment – look for structural (anchorage), and installation details (inundation)
Intermediate
• Review equipment manufacturer shop drawings addressing design to address hazard or perform structural calculations on key pieces of equipment
Assess Basins, Concrete Tanks and Below Grade Structure Vulnerability
Simplified
• Assess tank structural integrity using engineering judgment considering performance in past events and general familiarity with design issues.
Intermediate
• Assess structural integrity using ACI-350 Standard or equivalent design standards.
• Assess effects of liquid sloshing on floating digester roofs

Intermediate Vulnerability Assessment

- Assessment methods are applicable to the highest risk system components as determined using the Simplified Assessment. There is no hard number of “High” risk components, but there is typically a logical break in the risk ranking.
- Use quantitative damage relationships based on using empirical data[11].
- Probabilistic assessments to address uncertainty are not required for this level of assessment, but acknowledge variability of the data.
- Develop functionality, repair costs, and restoration relationships independently (i.e. not assuming correlation between functionality, repair costs, and restoration time).

Advanced Vulnerability Assessment

- Advanced vulnerability assessment methods are applicable to components where further clarification of the vulnerability (in accordance with the selected metric in the performance objectives) is required.
- Use of damage relationships developed using analytical methods are expected.
- Probabilistic assessment to address variability in vulnerability as measured by repair cost, functionality, or repair time is expected.

[11] There is limited empirical data for disaster performance that has been gathered for wastewater systems. It may be appropriate to gather empirical data, such as from wastewater treatment plant flooding that has occurred in the mid-west over the past 15 years, or to use data from industries with similar system components such as water supply. Caution should be used and reviewed for applicability when using data from other industries.

Step 7 – Assess System Performance under Conditions of Natural Hazards and Human Threats

This section discusses assessment of the system performance for each hazard or threat scenario by considering the damage state (functional, not functional, partially functional) of each component and the resulting impact of its loss of function on the overall system. The impact on the system performance is often referred to as the Consequence of the Loss of Function, the third parameter in the risk equation. A system response method that determines the degree to which service is provided is expected for Advanced Assessments. This section is intended to provide an overview to assist in preparing a scope of work for a system performance assessment.

7.1 Correlation Factor

A Correlation Factor is added to the risk equation in the Simplified Assessment to take into account the number of system components a single hazard event will impact:

Relative Risk = Hazard x Vulnerability x Consequence x Correlation Factor

where:

Hazard – probability of occurrence in 50 years with a given intensity

Vulnerability – probability of loss of function given the intensity

Consequence – (Consequence of Loss of Function) is a term used to normalize the impact of loss of function of the particular component compared to the loss of the entire system. It is stated in terms of the metric selected for the assessment. (e.g. one sewage lift station might handle 20% of the system flow, and one might handle 50% of the system flow. This term considers their relative capacities.)

Correlation Factor – dimensionless term to take into account the number of components affected in one hazard event. The Correlation Factor reflects the number of system components the hazard would likely impact in a single event, and the percentage of them that it would likely damage in that event. It is used to address the breadth of the hazard exposure (e.g., how many system components would be impacted in any single hazard event.) The correlation factor is only required in the Simplified Assessment as it does not otherwise consider how many components might be out of service simultaneously.

Example:

A small wastewater system includes four components[12]: 1) wastewater treatment plant (100% of system flow), 2) pump station (20% of system flow), 3) sewer (20% of system flow), and 4) pump station (50% of system flow). Loss of function of any of these components would result in discharge of untreated sewage.

Assume two scenarios, 1) 500-year flood, and 2) lightning strike (100-year return). Assume the 500-year flood (10% in 50 years) inundates the components 1, 2, and 3.

[12] Only four components are selected to demonstrate the method. Such a system would have many sections of sewer, as well as other components.

Component 4 is outside the 500-year flood plain. The vulnerability (loss of function) of components 1, 2, and 3 with the associated depth of water at their particular location is: 10%, 90%, and 50%, respectively. The Correlation Factor for this event is 1.5, calculated as follows: Number of components the hazard exposed – 3 in 500-year flood plain times the percentage of them it would likely impact– say 50%[13].

The lightning strike scenario is that it hits component 4, starting an electrical fire, and burns all the electrical equipment. This is a 100-year event (40% in 50 years). The pump station vulnerability if it is hit (probability of loss of function) is 25%. The Correlation Factor for this event is 0.1: Number of components exposed– 1[14]times the percentage of them that would be impacted – say 10%.

The relative risk can be calculated for each hazard event as shown in Tables 6 and 7.

Table 6. Wastewater System Relative Risk for 10 Percent in 50-Year Flood Event

Component	Hazard Probability (% in 50 years)	Vulnerability (Probability of loss of function)	Consequence of Loss of Function (% of total system flow)	Correlation Factor (number of components exposed x% likely impacted)	Relative Risk
Treatment Plant	10%	10%	100%	1.5	0.015
Pump Station	10%	90%	20%	1.5	0.027
Sewer	10%	50%	20%	1.5	0.015
Pump Station	0% (outside flood plain)	NA	50%	NA	NA
Average Relative Risk (for components exposed)					0.019
Maximum Relative Risk					0.027

[13] Hazard events vary. Even though 3 components are in the 500-year flood plain, we are assuming that only 50% would be impacted. This could be a result of the variability of the hazard information, the position of the components within the flood plain, or other factors.
[14] Assume for this illustrative example that this pump station (component #4), because of its exposure half way up a hill, is the only one of the four components in the lightning strike zone, and that being in the lightning strike zone has a 10% probability of being hit, and is moderately vulnerable if it does get hit (50% probability of loss of function).

Table 7. Wastewater System Relative Risk for 40 Percent in 50-Year Lightning Strike Event

Component	Hazard Probability (% in 50 years)	Vulnerability (Probability of loss of function)	Consequence of Loss of Function (% of total system flow)	Correlation Factor (number of components exposed x% likely impacted)	Relative Risk
Treatment Plant	40%	NA	100%	NA	NA
Pump Station	40%	NA	20%	NA	NA
Sewer	40%	NA	20%	NA	NA
Pump Station	40%	25%	50%	0.05	0.05
Average Relative Risk (for components exposed)					0.05
Maximum Relative Risk					0.05

In the flood event, the Correlation Factor takes into account that three components were exposed to the flood, and 50 percent of those were actually inundated. In the lightning strike event, the Correlation Factor takes into account that one component was exposed (in the strike zone), and that only 10 percent of the exposed components would actually be hit by lightning.

7.2 Wastewater System Modeling

Wastewater collection systems typically operate by gravity, with the wastewater flowing through pipelines in open channel flow. They are typically branched systems where the branches combine into larger branches. Hydraulic analyses are conducted to determine the capacity of the system, but are not used to evaluate the redundancy of the system, as would be the case for pressurized water networks.

Most collection systems do not have parallel pipelines in the collection system providing redundancy, except in the following situations:

- Second pipeline constructed to increase capacity.
- Multiple pressure pipelines installed and controlled to maintain a minimum velocity (3 fps) to avoid solids deposition.

System hydraulic evaluations are probably not useful if:

1. The system is a simple gravity flow branched system.
2. The pertinent portion of the system is so linear that hydraulic issues (e.g., which customers would not be served given various system failures) are known in advance.

7.3 Levels of Wastewater System Analysis

The three levels of assessment employ increasingly complex evaluation techniques. The same assessment "method" can be repeated for each hazard scenario by replacing the hazard intensities. The same "method" can be used for different hazards by replacing the hazard intensities and the vulnerability/damage relationships. Table 8 summarizes Simplified, Intermediate and Advance System Performance Assessment methods.

Table 8. System Performance Assessment Methods Summary

Simplified
• Review system maps and schematics
• Review hazard probability for each component for each hazard from Step 5
• Review component performance from Step 6
• Determine Consequence of Loss of Function for each component
• Estimate relative risk of each system component for each hazard. Rank by relative risk by component and by hazard.[15]
Intermediate
• Review system maps and schematics
• Review system performance in past natural hazards/events
• Review component performance from Step 6
• Estimate system performance using expert judgment (work with system operations personnel)
Advanced
• Develop system connectivity model of critical operations
• Determine component functionality from Step 6 for each component for each hazard
• Run systems analysis for selected hazards

Simplified Performance Assessment

- This is a screening assessment for either the collection system or the treatment plant(s). Calculate the risk of loss of function of each component, for each relevant hazard, using the risk equation.
- The "system" is considered by the consequence term, but no system method is prepared.
- A "feel" for the variability of the result can be estimated by using the extremes of the ranges for each of the parameters in the risk equation. Consider this with caution, as the results would have a very small probability of actually occurring.
- Incorporate the correlation factor to the risk equation.
- The results can then be reviewed and the highest risk components and hazards selected for an Intermediate or Advanced Assessment.
- There is no repair cost or outage time evaluation.

[15] System performance risk taken into account by incorporating Correlation Factor.

Intermediate Performance Assessment

- The hazard intensity and vulnerability parameters are quantitative.
- Review and combine the results for each sewer branch and flow train in the treatment plant, resulting in an estimate of the probability of loss of function of each.
- The outage time can be calculated by combining the total number of pipeline failures or man-hours for the treatment plant and lift station restoration. The results can be divided by the available manpower to estimate the system restoration time.
- The repair cost can be calculated by applying a repair cost-damage relationship to each component, and summing the results. Repair cost-damage relationships are typically developed in terms of percent of replacement cost, so replacement costs of each component must be developed.
- A probabilistic but is not intended to consider the variability of the data and uncertainty of the results.

Advanced Assessment

- Develop a spreadsheet method incorporating the connectivity of the system. For each system component (including pipeline segments), the hazard scenario specific probability of loss of function is calculated by multiplying the hazard probability of occurrence by the probability of loss of function. The method then combines the probabilities of loss of function for each component along the pipeline branch or treatment plant train, and calculates the sub-system or system probability of loss of function. Design the method to show where loss of function occurs and where sewage overflows take place. Analyze each branch and flow train through the plant, and combine the results. Depending on the complexity of the system, particularly the treatment plant, the method can take the form of a fault tree.
- Calculate the outage time by developing restoration rates for pipelines and other system components. The repair rates are applied to the various components until all are repaired. This is performed in incremental steps and the method can be run at each step, showing the status of the system in progressive time increments.
- The same method can be used to calculate repair costs, except the connectivity module is not required. Apply damage relationships for repair costs rather than loss of functionality. When the costs of repair for the individual components are summed, it results in the repair cost for the specific scenario.
- Make a probabilistic estimate taking into account the variability of the risk parameters and quantification of the uncertainty of the results. Both the hazard intensities and the vulnerability relationships cover a range with a distribution of probabilities.
- The result of the functionality assessment will be the probability of collecting (or treating) the sewage flow through the selected portions of the system. This result will be updated in time steps until the system is totally restored.

Step 8 – Assess Whether the Performance Objectives are Met, Actions to Improve Reliability, and Periodic Review

System performance assessments are important tools to assist in wastewater system risk management. The following discussion outlines actions that wastewater utilities may take to improve system performance and reliability.

8.1 Actions to Improve Reliability

Actions that are typically considered to improve system reliability are categorized below:

1. Prevention: limiting access to the sewer GIS layer to people with a demonstrated need-to-know, securing manhole covers upstream of critical areas, LEL detectors upstream of headworks that can automatically divert flows to an alternative holding area, etc.
2. Engineering: 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 wastewater utility component (e.g., wastewater treatment plant).
   - Elevation of equipment to avoid potential flood damage.
   - Submergence-rated equipment where elevation cannot be deployed.
   - Bracing or anchorage of equipment.
   - Installation of a floodwall to protect a major wastewater system component.
   - Accelerated replacement of older more vulnerable pipelines.
   - Hardening Emergency Operations Centers and other buildings critical to wastewater systems operations.
3. Land Use: alternative siting or reduction of exposure in building structures that may be damaged. For instance, decision-makers may consider:
   - Alternative siting of a major wastewater 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.[16]
   - Reduction of exposure of critical equipment and personnel in a building that is more vulnerable to damage from natural hazards and human threats
4. 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:
   - Development of alternative sources of electric power and other energy sources

[16] Wastewater treatment plants are typically located in low-lying areas to take advantage of the sewage gravity flow. This is in direct conflict to locating treatment plants outside floodplains.

- Development of backup communications systems.
- Installation of overflows to the stormwater system or open ditches on gravity sewers in order to keep raw sewage from backing up into buildings and causing a public health problem.
- Installation of a Supervisory Control and Data Acquisition (SCADA) system.

5. Emergency Response: the immediate response to emergencies including disasters. For instance:
    - Development of a response and recovery plan, with drills and regular updates, to facilitate response and recovery after natural hazards and human threats.
    - Mutual aid agreements and cooperative activities with other key first-responder and short-term forecasting agencies.
    - Spare parts, materials, personnel, and equipment may be stockpiled in key locations to assure rapid response to restore the system.
6. Disaster Recovery and Restoration: the long-term restoration to normalcy after a large emergency or disaster, again through cooperative activities and strategic planning.
7. Risk Transfer: the use of insurance or other liability transfers (e.g., contractual liability transfers with manufacturers, suppliers, consultants) in order to limit the wastewater utility's post-disaster liabilities and assure that adequate recovery funds exist.
8. Financial Reserving: such as retaining funds for emergency response and recovery contingencies.

8.2 Periodic Review

It is important to recognize that any assessment of wastewater system performance only represents a snapshot of the wastewater system at a particular point in time. An essential element of maintaining confidence in the ability of the wastewater system to perform as desired is to periodically reassess the system performance. Factors warranting a reassessment would include significant changes to the wastewater system, the availability of new or substantially revised hazard information, or a significant change in the needs of wastewater system stakeholders.

It is not possible to provide specific guidance on the period for updating an assessment of wastewater systems because the factors justifying a reassessment may vary considerable among wastewater systems. However, in the absence of significant system changes, a reassessment every ten to twenty years is generally appropriate.