AmericanLifelinesAlliance

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

Wastewater System Performance Assessment Guideline
Part 2
- Commentary -

June 2004

Final DRAFT

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Acknowledgements

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Step 4 Commentary - Define the Wastewater System to be Assessed
Supplemental Material for Step 4 of the Guideline

Step 4 of the Commentary helps define portions of the system to be included in the evaluation. Such a system definition allows the assessment to focus on only the critical portions of the system.

C-4.1 Inventory Needs

It is often not necessary to collect a complete inventory of information on the entire system. It is common that the question at hand relates to only a portion of the system. This, for instance, would be the case if the decision in question pertains to the upgrade of a wastewater treatment plant that serves only a portion of the wastewater utility system. Again, such a decision may require an inventory of only the wastewater treatment plant and the sub-system that it serves. Focus of the inventory procedure may be on details of the wastewater treatment plant.

Such a scoping study may also indicate that various natural hazards are not significant to the decision at hand. For instance, the decision at hand may pertain to the installation of a floodwall to protect a wastewater treatment plant. This decision may require only an inventory of the wastewater treatment plant and components in the sub-system that it serves and that are vulnerable to potential flood effects in the absence of a floodwall.

The decision itself may pertain either to operational or to financial system metrics and not to both, and thus the inventory needs may be reduced. Financial system risk analyses use estimates of component damage levels and costs to repair damage from natural hazards, along with revenue losses and stakeholder losses (and gains—such as for utility contractors). Financial systems risk assessment studies may range from simple tabulation of aggregate direct damage and repair cost to individual components or subsystems to more complete assessment of primary, secondary and higher-order impacts to the many wastewater system stakeholders. Information on repair and replacement costs, wastewater utility revenues, and prospective dollar losses to other stakeholders thus may be of significant interest in financial risks evaluations.

In contrast, if only operational evaluations are desired, then many of these financial inventory concerns vanish. Operational impairment studies assess the degree of impairment of the wastewater system from natural hazards. Operational impairment studies may be restricted to the estimation of service interruption areas for particular natural hazard events, or may address the complex questions relating to the time required for restoration of service.

In weighing how much effort to devote to assembling the inventory of a wastewater utility system, decision-makers should further consider multiple benefits of such an inventory. Benefits beyond those of assisting in natural and manmade hazards risk reduction decisions could include: a superior inventory of the existing system for purposes of routine repairs, maintenance, upgrades, training, personnel safety, inspection, budgeting, and monitoring and supervisory control.

C-4.2 Alternative Costs of Decision Alternatives and Other Costs

In decision-making, costs of decision alternatives (initial outlays) are always important. Low-cost risk reduction measures, such as using chains to anchor chlorine cylinders, often lie beneath the threshold of consideration for a formal risk evaluation. Higher cost alternatives (e.g., retrofit of a steel distribution reservoir), however, need to be evaluated in order to compare system performance against costs and budgetary limitations.

Principal sources of cost data are: Means Cost Data, wastewater system piping and valve vendors, and past project history where similar projects were constructed under similar conditions. Current vendor data has become much more readily available through the Internet.

The evaluation of decision alternatives may proceed through conceptual design, using qualitative assessments of cost effectiveness, and into preliminary design, so that costs (and performance) of each option can be adequately quantified. The evaluation of costs for decision alternatives may be done in-house, especially in larger wastewater agencies, and principally at earlier stages of the evaluation process. Final evaluation of the benefits and costs for large projects often requires outside assistance, in the form of studies using engineering consultants and cost estimators.

Replacement and/or repair cost information for existing facilities will be needed if it is desirable to assess aggregate system dollar losses for various scenario events and/or for a representative suite of natural hazards scenarios. This will apply only if financial criteria are used in the decision process—beyond the consideration of initial outlays.

C-4.3 Components and Considerations for a Comprehensive Evaluation

This subsection provides direction on defining the physical and functional extent of a wastewater system. First, an overview of a typical wastewater system configuration is provided and then a discussion of the considerations for selecting critical facilities and assets is presented.

C-4.3.1 Overview of Typical Wastewater System Facilities

Wastewater systems collect, transport, treat, and dispose of wastewater (sewage) from living quarters, homes, apartments, industries, commercial establishments, and in some cases, storms. Disposal is accomplished after treatment (usually) and discharge into an approved location. Their primary purpose is to protect public health and the environment.

Wastewater systems have components that can be very unsafe, particularly due to presence of hazardous gases that can result in death if inhaled, or that can explode, as well as the presence of other dangerous chemicals and pathogens.

Typical systems gather wastewater in the collection system where it is transported to the treatment plant, and after treatment, the effluent is disposed Figure C.4.1 shows a schematic diagram of a typical wastewater system.

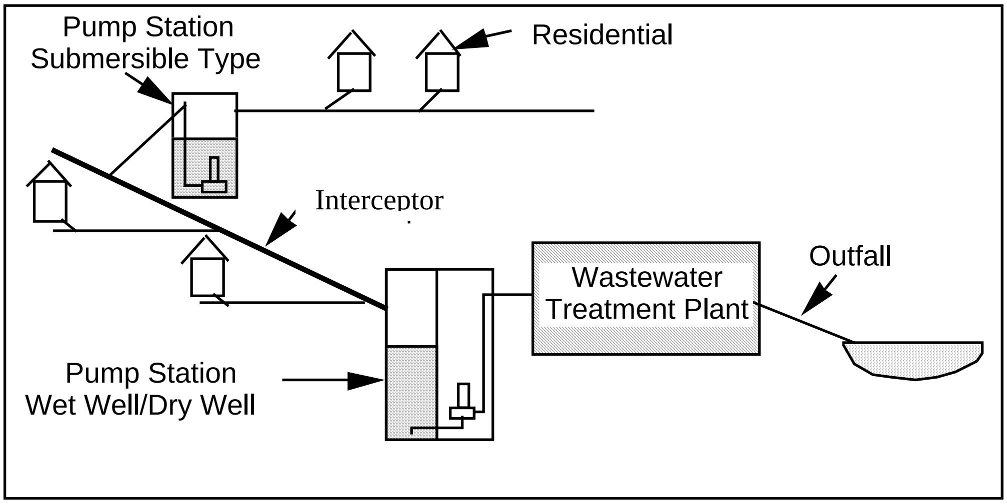

Figure C.4.1 Schematic Diagram of Typical Wastewater System

C-4.3.2 Sources of Wastewater

Sewage is discharged into the system from many sources. Domestic sewage comes from living quarters and commercial establishments. Industrial waste comes from industrial processes. Storm water run off may enter the system in the form of infiltration or inflow, or in the case of a combined sewer system, from catch basins or street storm drains. All of this wastewater enters the system through pipe connections between the system and the facility where the sewage originates, commonly known as sewer laterals. In some areas, storm runoff is collected in a storm sewer system, separate from the sanitary sewer system, and is discharged into an approved location.

C-4.3.2.1 Collection System

The collection and conveyance system is the system of pipes that collects the sewage from the sources and conveys it to a central point for treatment and/or disposal. Sewers are usually straight in both plan and elevation between manholes. The manholes are commonly spaced at about 300 feet (although substantially longer reaches can be used in specialized situations) along the sewer provide and access to the sewer for maintenance and cleaning. Large sewers (5 feet diameter or more) can have manholes more widely spaced and horizontal curves and vertical grade changes are allowed. Local sewers flow into larger sewers sometimes called interceptors or trunks.

Sewage is often pumped, when the terrain dictates, through force mains routed around or over the obstacle. Inverted siphons are also often employed to pass under streams. Other variations from the conventional system include storage in or along the system, and overflow structures that allow discharge overland or to adjacent watercourses when the collection system cannot handle the flow. Overflows in sanitary sewer systems are usually caused by grease, roots, vandalism or storms that impose flows (inflow & infiltration) in excess of the capacity of the system.

C-4.3.2.2 Treatment Plants

Wastewater treatment plants can include physical/chemical and/or biological treatment processes. The following steps in the treatment process are those most commonly found in modern treatment facilities and are described in the usual order the process train follows.

Liquid Train - Figure C.4.2 shows a schematic of a typical wastewater treatment plant liquid train.

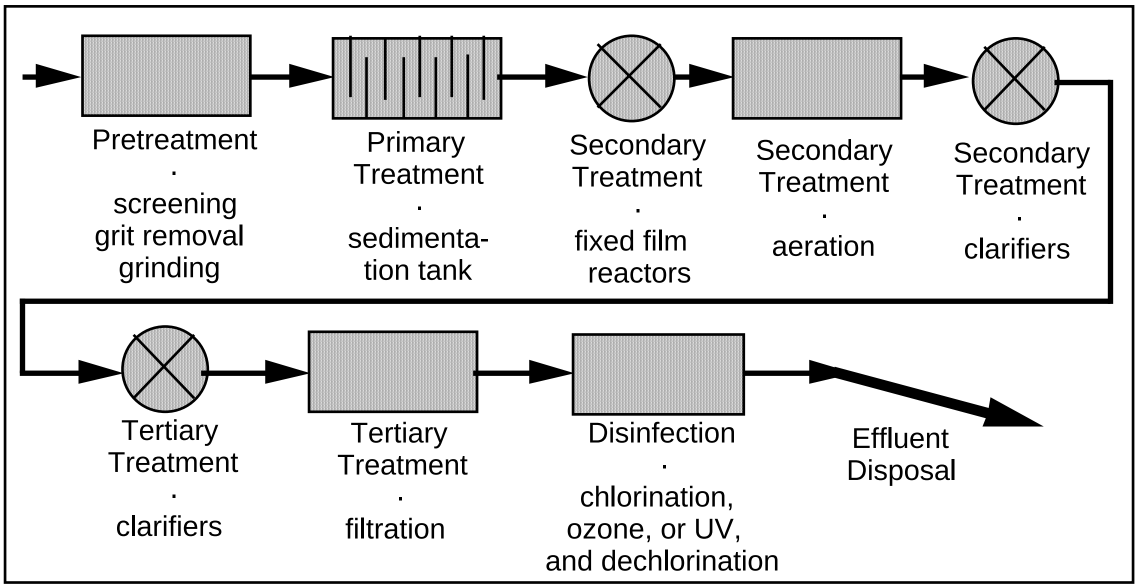

Figure C.4.2 Schematic of a Typical Wastewater Treatment Plant Liquid Train Chemicals are added to some processes.

Pretreatment - Pretreatment includes screening, grit removal, and grinding. Bar screens remove large, untreatable solid debris such as wood. Grit is removed to protect equipment later in the process from abrasion and wear and to keep the grit out of sedimentation tanks and digesters. It is accomplished by controlling the velocity of the sewage such that the grit, which has a higher specific gravity than other solids, settles out but the lighter solids do not. Solids are often processed by communitors or similar equipment to reduce the size to manageable dimensions.

Primary Treatment - Primary treatment is accomplished by sedimentation (clarification) or screening, this step separates the solids that are not in solution and makes it possible to treat them separately. The settling or clarification process for removing or separating solids involves the introduction of sewage into a basin, either circular or rectangular, with an average detention time sufficient for the solids to settle.

Secondary Treatment - Secondary treatment is usually accomplished by biological means. This process utilizes the ability of organisms to break down the sewage into simpler compounds and reduces the demand for oxygen (Biochemical Oxygen Demand, BOD). It is accomplished in two ways as follows: aerobically (with oxygen) by processes such as activated sludge, trickling filter, and aeration; and anaerobically (without oxygen) in closed digesters in which the solids previously separated are continuously mixed in the presence of bacteria which do not require oxygen and produce gasses, principally methane and hydrogen sulfide. These solids are then removed by secondary clarification.

Tertiary Treatment - Occasionally secondary effluent is treated to a higher quality using coagulation, filtration, and demineralization processes. This results in reclaimed water with a quality possibly equal to potable water for use in industry, agriculture, and landscaping.

Disinfection - This step is intended to kill any remaining harmful bacteria and is accomplished by the use of chlorine, ozone, ultraviolet light, or other processes. The effluent is typically dechlorinated using sulfur dioxide gas or other less dangerous reducing agents (e.g., sodium metabisulfite) to protect life in the receiving water.

Effluent Disposal - Liquids are normally discharged to a water course such as oceans, bays, rivers, or lakes, to a ground water basin or reclaimed water system (for tertiary effluent), or sometimes, if the treatment is incomplete, to a stabilization, evaporation, or infiltration pond.

Solids Train - Figure C.4.3 shows a schematic diagram of a typical wastewater treatment plant solids train.

Digested solids (sludge) are dried on open beds or dewatered mechanically with centrifuges or filter belt presses, and deposited in landfills or sold as fertilizer or soil conditioner. The gas produced is either burned or utilized as fuel for heat or power.

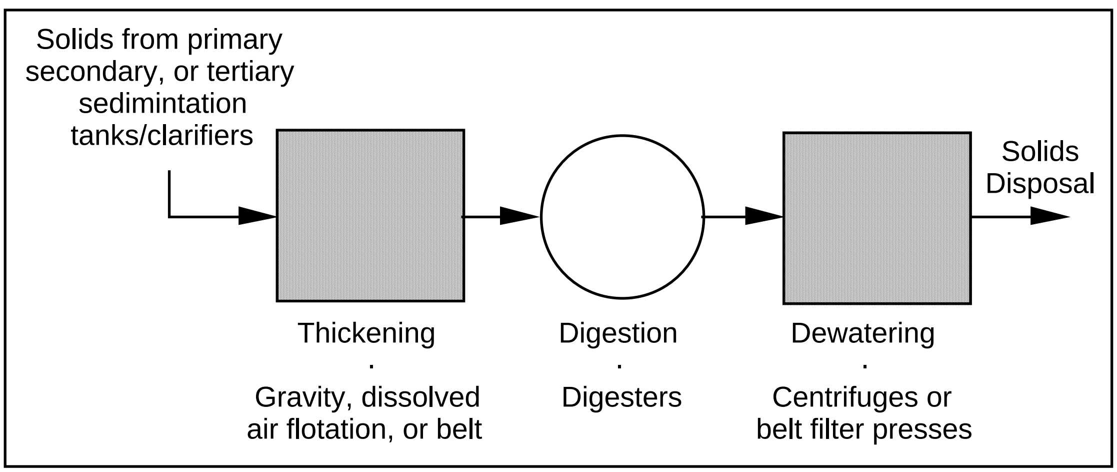

Figure C.4.3 Schematic Diagram of a Typical Wastewater Treatment Plant Solids Train

C-4.3.3 Overview of Typical Wastewater System Assets

C-4.3.3.1 Collection System Components

The wastewater system can be comprised of various conveyance facilities. These typically reflect the regional topography and geography. Wastewater collection facilities include (but are not limited to):

- Manholes and gravity pipelines
- Inverted siphons
- Lift Station/pump stations and associated inlet and discharge lines
- Backup power generation systems
- Chemical addition points
- Pressure mains or force mains
- Above-ground piping structures: pipe bridges, pipe supported by saddles or ring girders
- Valves and valve operators
- SCADA (Supervisory Control and Data Acquisition) systems

As a general rule, in very large systems and for most decisions, pipelines representing the wastewater system “backbone” typically are of a larger diameter (say 24 to 36 inches; 600 to 900 mm; and even larger for the largest systems) and may reflect the minimum size of pipelines considered in a natural hazards evaluation. For smaller systems, pipelines down to 8 inches (20 cm) in diameter may be considered.

The basic information on pipelines surveyed includes:

- Location (with reference to various nodal points)—implying lengths of pipe
- Pipe material(s)
- Year installed (implying age)
- Diameter
- Pipe joint type
- Lining and coating
- Buried or above-ground (depth?)
- Directionality of flows
- Elevations
- Special local hazards (e.g., corrosive soils, fault crossings, slope or slide areas and other ground failure potential areas)
- Previous damages, leaks, and methods of repair
- Maintenance history
- Street rehabilitation schedule
- Customer type vulnerability evaluation method(s) used

Single-site facilities include:

- Lift stations/pump stations
- Surge tanks

- Electric substations

For these facilities the following information is fundamental:

- Construction date(s)
- As-constructed drawings
- Basic design/redesign considerations used in construction
- Maximum and operating flow capacity and head (e.g., pump curves)
- Local hazards—including geotechnical assessment of site
- Type of mechanical and electrical equipment
- Type of piping connections (suction and discharge)
- Previous damage, if any, and repairs
- Power supply backup
- Hazardous materials on site

Buildings (Pump Stations and Treatment Plants) - Basic building structures that have significant occupancy tend to be covered under building codes. Nonetheless, for assessing the response of a wastewater utility system to natural hazards and manmade threats, the functionality of building structures (often, housing) may be essential. Such "housing" may be found in

- Wastewater treatment plants
- Lift stations/pump stations
- Chemical addition points
- Utility buildings, including administrative headquarters, including buildings that house record-drawing vaults, computers and financial information; an emergency and normal operating center, maintenance facilities, spare parts and material storage

For buildings that are included in the wastewater systems evaluation, the following information can be fundamental:

- As-constructed drawings
- Facility usage/function
- Location
- Base elevation (for specific flood-related hazards and for hydraulic evaluations)
- Previous damage, if any, and causes
- Previous damage repairs, if any
- Construction date(s)
- Building code(s) used in construction
- Gravity load-carrying system

- Lateral force-resisting system
- Materials used in roof and floor diaphragms, structural columns and walls
- Number of stories below ground
- Number of stories above ground
- Local hazards
- Previous damage, if any, and repairs

Basins and Concrete Tanks - Basins and concrete tanks used for treatment typically fall outside the requirements of building codes but are often designed in accordance with the American Concrete Institute (ACI) Standard 350, Code Requirements for Environmental Engineering Concrete Structures and Commentary. The following information can be fundamental in their design:

- As-constructed drawings
- Foundation (mat, pile)
- Water table (as it relates to flotation)
- Geometry
- Wall height/length and associated reinforcing design and detailing
- Water depth (all combinations)
- Baffles configuration and structural design

Treatment Plant and Pump Stations Non-Building Components - Selected non-building components can include:

- Electric equipment: control equipment, electrical raceways
- Mechanical equipment, pumps
- (SCADA) Instrumentation, chlorination control, surveillance
- Equipment for chemical storage and usage; chemical piping
- Mass and center of gravity for components with significant overturning potential

For the variety of other non-building components, the following information is useful:

- Anchorage or bracing
- Base elevation (for such hazards as floods and for hydraulic evaluations)
- Location (including story number in a building)
- Submergence-rating (if any)
- Part of which sub-system (node or link)

- Previous damage, if any, and repairs
- Evaluation method(s) used

Pumps - Pumps are used to lift wastewater when gravity flow is not possible or practical. Pump types used are horizontal and vertical configurations of non-clog, mixed-flow, and other similar proprietary variations of the open impeller design. They are driven, usually, by electric motors and often provided with gas or diesel standby drives or generators. Motor starters are across the line or reduced voltage, depending on the size, and can be manually or remotely operated. Pumps are controlled by float or probe actuated level switches, often as part of a computerized plant control system.

Gates and Regulators for Flow Control - Overflow and bypass are often controlled by shear gates, weirs, valves (plug, ball, gate, etc.) or other devices such as vortex flow controllers. This equipment is used when the capacity of the collection system is expected to be exceeded at certain times and under certain circumstances. The purpose of this type of control is to prevent overloading of sewers and treatment facilities and control discharge to storage facilities or occasionally directly to receiving waters. Such gates and valves are operated electrically, manually, hydraulically, or pneumatically. They may be stopped and started by manual switches, but usually are controlled remotely by telemetered signal or computer. The components are generally resistant to damage unless the channel in which they are installed is damaged.

Grit Removal Equipment - Grit is separated from the plant influent by a variety of equipment. Earlier plants used channels designed to provide the proper velocity through a range of flows and washed the settled grit through a cascade system or a grit washer. More recent developments for grit removal include aerated grit chambers and vortex separators and washers.

Grinders and Bar Screens - Older plants used comminutor type grinders that consist of a slotted cylinder through which the sewage flows while rotating teeth engage the slots. More recent developments include bar screens that can be manually cleaned, but are usually mechanically cleaned, where the screenings are passed through shredders or grinders and sent to a landfill.

Screens - Fine solids are often removed by screens, usually of the rotary drum type. Some screens are set on a slope and the sewage enters the upper end on the inside. The solids remain on the inside of the drum and gradually work to the downstream end where they drop into a hopper and are pressed to remove excess liquid. Other screens apply sewage to the outside of the drum and allow liquid to fall through. Micro screen or fine screens are occasionally used, but normally only for special applications.

Clarifier Mechanisms - These mechanisms consist of influent columns or ports, scrapers to move the settled solids to a hopper, skimming mechanisms to collect or concentrate the floating materials and overflow weirs or collectors for discharge of the clarified effluent. Inadequately braced center columns may be damaged in strong shaking/fluid induced loading. In rectangular tanks, scraper and skimmer flights propelled by chains are vulnerable to sloshing liquids that may knock chains off their drive sprockets.

Sludge Pumps - These pumps are specifically developed to pump liquids with high concentrations of solids. They may be positive displacement, progressive cavity or open impeller types or variations thereof. They are normally driven by electric motors and are usually manually controlled. The pumps are normally located in pits adjacent to sludge hoppers in clarifiers or digesters and are used to transfer sludge.

Mixers - Mechanical mixers are often installed in digesters and other solid process tanks to keep solids in suspension and promote uniform digestion. They are also sometimes found in liquid process basins where it is desired to prevent solids from settling or segregating. These mixers are turbine impellers with straight, curved, pitched or vaned blades mounted on a shaft that is turned by motors generally mounted above the material to be mixed. Horizontal side mount (through tank wall) mixers are also occasionally used, as are horizontal submerged in-tank mixers.

Aeration Equipment - Aeration is a common process used in sewage treatment to provide oxygen for aerobic biologic decomposition. Air is introduced through diffusers consisting of porous tubes or nozzles of various types. This requires blowers of relatively large capacity that may be centrifugal or positive displacement, usually electric motor driven and manually controlled for the most part since most aeration is a continuous process. Aeration may also be accomplished mechanically with surface aerators or submerged turbines similar to those previously described for mixers. Aeration diffusers have been dislodged and/or damaged due to sloshing sewage generated from ground shaking. In some cases, oxygen enrichment facilities (pressure swing absorption, cryogenic, etc.,) are used to enrich the oxygen concentration in the gas used in aerobic treatment.

Thickening - This step in the treatment process, intended to increase the concentration of solids before other processes uses gravity belt thickeners, centrifuges and/or dissolved air flotation. The latter requires a basin provided with skimmers, sludge scrapers and air diffusers or nozzles.

Dewatering Equipment - Sludge is dewatered, usually after digestion, by the use of belt filter presses, centrifuges, vacuum filtration or beds, gravity beds, or plate and frame presses. There are many types and variations of this equipment. It is usually manufactured as self-contained units, but may be subject to damage if not properly anchored or earthquake qualified. Belt filter presses are often supported on slender columns that may not be designed to carry lateral earthquake loading.

Digester Equipment - Anaerobic sludge digesters are closed tanks with many types of equipment associated with their operation. Many plants will include at least one tank with a floating cover that may be vulnerable to earthquake damage. Anaerobic digesters produce gas, so the associated gas control and utilization equipment will usually include gas dryers to reduce moisture in the gas, gas control and metering equipment, gas burners for waste gas and gas-driven engines to provide power and save energy. Digester covers, supported on floats immersed in sludge are vulnerable as a result of the rapid earthquake induced sloshing of the sludge that may damage cover guide wheels and tracks. The gas piping associated with this equipment may also be vulnerable to damage. Aerobic digesters use aeration equipment to further digest the sludge. The anaerobic process usually does produce hazardous gases. Sludge is dewatered using methods similar to that of anaerobically digested sludge.

Disinfection Equipment - Some plants use chorine as a disinfectant and sulfur dioxide as a dechlorinating agent. Chlorine gas is generally delivered to plants in 150-pound cylinders, ton containers or railroad tank cars. Sulfur dioxide used for dechlorination is supplied in a similar manner. The cylinders themselves may be subject to damage if not properly anchored. Since chlorine is poisonous even at low concentrations, extreme care must be taken in investigating such facilities after an earthquake. All chlorination facilities will or should be equipped with appropriate masks and safety equipment. Chlorine is dissolved in water and this solution is applied to the sewage. The piping between tanks, chlorinators and the point of application is vulnerable to damage. Many plants use sodium hypochlorite or calcium hypochlorite in place of liquid-gas chlorine for safety reasons or availability. Calcium hypochlorite is dissolved in water in mixing tanks and applied to the sewage by the same procedure as the gas water mixture. The sodium hypochlorite solution may be diluted before addition to the stream or added directly without dilution.

Ozone has become an often-used alternate to chlorine for disinfection in recent years because of the carcinogens resulting from the reaction of chlorine with some chemicals and organics in water or sewage. Ozone is usually generated on site. It can be applied to sewage as a gas requiring facilities to insure proper contact of the ozone with the sewage. The generating equipment requires power, as the ozone is generated by passing air through electrodes. The generators are generally self-contained units. Also, ozone can be delivered by rail tank car or tank truck to the treatment plant site.

Ultraviolet radiation is being used at some small treatment plants in recent years for disinfection. The process entails passing wastewater effluent over UV bulbs in thin layers. Earthquake vulnerability is likely nominal.

Controls - Sewage treatment is controlled in many ways, from completely manual operation to, almost complete computer control in very recent plants. The information on which the control is based is obtained from a myriad of measuring devices and meters including probes, floats, flow meters, flumes, chemical and solids concentration measuring devices, etc. This information is assembled or brought together in a control room where it is monitored and operating decisions are made by the operators or computers. The appropriate manual or remote switching of valves, gates and other equipment are directed from this control center. The control room would be the first place to visit in beginning the post-earthquake investigation of a treatment plant.

Power Facilities - Power facilities are sometimes used onsite to generate power from digester gases. In some cases these power facilities are critical to plant operation, as many plants do not have external power backup available.

C-4.3.4 Minimum Stakeholder Data

Under some circumstances, a quantifiable stakeholder evaluation may be desirable in order to sort out how much various stakeholders lose (and gain—for such sectors as utility contracting) from various decision alternatives pertaining to natural hazards.

The definition of stakeholders will generally be part of the scoping for the decision or decisions for which the wastewater system evaluation is to be made. Financial evaluations may focus on lost revenues to the utility—considering as well how rates may need to be raised to restore lost revenues. Insurers, lenders, and bondholders may be implicated from a financial standpoint in various decisions, as will be local, state, and federal governments expected to provide disaster assistance. Detailed evaluation of natural hazard impacts on customers will generally require business surveys to estimate prospective business interruption losses (lost revenues minus reduced expenditures).

Estimates of higher-order economic losses from natural disasters require still further data. Estimates of these higher-order economic losses generally start from estimates of “primary” losses, namely, repair costs and business interruption losses. Estimates of higher-order economic losses are not discussed in any detail in this document, and require special work by macro-economists.

Step 5 Commentary – Define Relevant Natural Hazards and Human Threats

Supplemental Material for Step 5 of the Guideline

Step 5 of the Commentary provides guidance for determining the appropriate procedures and resources to be used in identifying the type, size, location and frequency of occurrence of natural, technological and lifelines hazard events and human threats to be used in component and system performance evaluation.

C-5.1 Establish Performance Objectives

As part of performing a hazard assessment, a set of performance objectives should be established to define the level of service the utility seeks to maintain following natural hazard or human threat events. The goal of the evaluation will be to upgrade the system to meet these objectives. A hypothetical set of performance objectives is as follows:

1. For hazards having short and moderate return periods (0 to 50 years, and 50 to 250 years, respectively), a utility's objective may be to provide full service, with relatively minor impacts to the environment or public health.
2. For hazards having long return periods (greater the 250 years), a utility's objective may be to incur consequences not to exceed: localized release of untreated wastewater (overland flow), impact duration of 24 hours or less, and potential public health impacts to fewer than 100 individuals.

Once a set of performance objectives is established, the goal of the hazard assessment will be to upgrade the system to meet them. This approach balances the desire to accomplish utility's mission of protecting public health and the environment with the availability of resources to upgrade the system.

In addition to identifying performance objectives, the utility may want to establish an overall planning horizon. Such a horizon establishes the range of hazards the utility will examine. For example, a utility may set its horizon to identify hazards that will occur with a return period of 500 years or less. This planning horizon corresponds to hazards that have long return periods in the above example (greater than 250 years) and conforms with current U.S. building code criteria that buildings are to be designed so as to have some minimum margin against collapse in a 500-year earthquake.

C-5.1.1 Identifying Hazards

The goal of hazard identification is to identify hazards that present a credible threat to a utility. A credible threat may be defined as events that could occur within the utility's planning horizon. Many of the hazards may be identified in the utility's Emergency Management Plan. Additional hazards are to be identified through input from vulnerability assessment team members, researching past disaster declarations in the area, and risk assessments completed by the utility. In addition, GIS maps can be obtained to analyze several hazards in the service area.

Table C.5.1 provides an example list of hazards potentially applicable to wastewater systems and indicates how a utility might document the identification process. This list can be used as a starting point for identifying the specific hazards that represent credible potential threats to system operation. As part of the identification process, hazards excluded from the evaluation are those deemed not to be credible.

Potential hazards can be subdivided into five major hazard categories and are addressed in Table C.5.1.

Table C.5.1 Example Hazard Identification Table

Type	Hazard	How identified [Provide national source if available and link.]	Why identified
List hazard category.	List Credible Hazards.	Indicate in this column how each applicable hazard was identified, for example: findings from previous risk assessments; Geographic Information Systems (GIS) hazard maps; input from long-time employees; historical experience;	Indicate in this column the significant reasons for selecting each hazard.
Natural	Earthquake (Ground Motion, Liquefaction)		Earthquakes have the potential for causing damage to multiple facilities.
	Flooding		Flooding can potentially disable facilities and/or cause a release of untreated sewage.
	Landslides		Ground movement arising from landslides can disable facilities and/or sever pipe.
	Snow / Ice Storm		Potential to cause staff unavailability and/or impact access to facilities.
	Tree Fall (structure impact)		Potential for structural impact or damage due to up-rooting.
	Volcanic Activity / Lahar		Potential for ash-induced damage to equipment; potential for lahar flow over the service area.
	Lightning Strike		Potential for power outage, damage to SCADA system, or fire.
	Wind Storm		Potential for power outage, loss of SCADA, and tree fall.
Transport-ation	Airplane Crash		Potential damage to facilities.
	Truck/Car Structural Impact		Potential damage to facilities.
Human / Techno-logical	Building/Facility Fire/Explosion		Potential damage to facilities; potential for release of hazardous materials such as chlorine gas.
	Utility Building Piping Failure/Flood		Potential damage to facilities.
	Security Threat / Human Attack on System		Potential for disruption of service, harm to employees and/or damage to facilities.

Type	Hazard	How identified [Provide national source if available and link.]	Why identified
	Chemical Release (utility's)		Potential exists for release of hazardous chemicals.
	Hazardous Material (third-party)		Potential exists for release of hazardous chemicals.
	Mechanical / Electrical Failure		Potential for service interruption to portions of the service area.
	Operational Error		Potential for service interruption.
	Staff Unavailable		Potential for service interruption.
	Third-Party Damage (unintentional)		Potential for service interruption.
Lifeline Service Loss	Power Outage		Potential for service interruption.
	Liquid Fuel		Potential for service interruption.
	Natural Gas/Propane		Potential for heating loss / unavailability of emergency generators.
	Wire Communications		Potential for loss of SCADA and service interruption.
	Treatment Chemical Supply / Delivery		Potential for service interruption.
	Wireless Communications		Potential for disruption of communications.

C-5.1.2 Profiling Hazard Events

Table C.5.3 provides an example of how to document the location and extent of the hazards that can affect a wastewater system. Information on previous occurrences of hazard events and on the expected frequency of future hazard events is documented in the table. The frequencies of future events, expressed as high, medium or low, represent events that occur with sufficient intensity to potentially compromise service and/or cause an unauthorized release of sewage. Table C.5.2 provides an example definition of high, medium and low frequency events.

Table C.5.2 Example Definition of Hazard Frequencies

Frequency	Return Period Range (years)[1]	Median Return Period (years)	Percent Probability In 50 Years
High (H)	0 to 50	25	Approaches 100 %
Medium (M)	50 to 250	72	50 %
Low (L)	>250	475	10 %

Note 1. Events that occur with sufficient intensity to potentially compromise service or cause an unauthorized release of sewage.

Table C.5.3 Example Profiling of Hazard Events

Type	Hazard	Location and Extent	Description of Previous Occurrences	Estimated Frequency of Future Events[1]
List hazard category.	List Credible Hazards.	Enter a description of the location and extent of the hazard in this column. Refer to hazard maps utilized for the assessment, if applicable.	Enter a description of previous significant occurrences in or near the community, providing date, severity, the resulting effects and extent of damage to system facilities.	Enter the expected frequency of future events into this column.
Natural	Earthquake (Ground Motion, Liquefaction)			
	Flooding			
	Landslides			
	Prolonged Freezing			
	Snow / Ice Storm			
	Tree Fall (structure impact)			
	Volcanic Activity / Lahar			
	Lightning Strike			
	Wind Storm			
Trans-portation	Airplane Crash			
	Truck/Car Structural Impact			
Human / Techno-logical	Utility Building/Facility Fire/Explosion			
	Utility Building Piping Failure/Flood			
	Chemical Release (utility's)			
	Hazardous Material (third-party)			
	Mechanical / Electrical Failure			
	Operational Error			
	Staff Unavailable			
	Third-Party Damage (unintentional)			

Table C.5.3 Example Profiling of Hazard Events

Type	Hazard	Location and Extent	Description of Previous Occurrences	Estimated Frequency of Future Events[1]
Lifeline Service Loss	Power Outage			
	Liquid Fuel			
	Natural Gas/Propane			
	Wire Communications / SCADA			
	Sewer			
	Treatment Chemical Supply / Delivery			
	Wireless Communications			
Other	Other hazards as applicable			

Note 1. Events that occur with sufficient intensity to potentially compromise service or cause an unauthorized release of sewage.

C-5.2 Ground Movement Hazards (Landslides, Frost Heave and Settlement)

C-5.2.1 Landslides

Evaluation of the exposure of wastewater system facilities to landslide hazards involves the use of GIS data, where available, and historical experience. Overlaying the locations of system facilities with GIS map contours for landslide-prone areas provides the input for determining landslide hazard exposure. Historical experience for landslides can be used to more accurately characterize the exposure. If GIS data is unavailable, a checklist approach can be utilized in which all system facilities are listed vertically in a table, and checkmarks or notation is provided for each facility potentially impacted by landslide, based on historical experience. Such a checklist can be used to document exposure of facilities to other hazards as discussed in following subsections.

C-5.2.2 Frost Heave and Settlement

Exposure to frost heave hazards is associated with the latitude of the system and characteristics of facility sites such as the presence of ground cover and the presence of expansive soils. Mapping of soil characteristics within the system perimeter and/or freezing depths provides sufficient information regarding exposure of system facilities. Alternately, a checklist can be utilized to document historical experience.

C-5.3 Flood

Exposure to flood hazards can be evaluated using GIS data and is a function of flood depth, and potentially water velocity. For example, GIS data may provide flood contours for 100-year and/or 500-year floods. Overlaying the locations of system facilities with the GIS map contours can provide the input for determining flood hazard exposure. If GIS data is not available, a basic approach can be utilized by qualitatively characterizing the flood susceptibility of areas located within the system perimeter. A checklist can then be developed to document the anticipated exposure of system facilities (for example, facility "x" is located on the valley floor and facility "y" is located well above the valley floor).

HAZUS-MH^SM (http://www.fema.gov/hazus/) is a GIS-based planning tool that has been developed by NIBS/FEMA that can be used in assessing flood exposure (as well as earthquake and wind exposure) of the built environment. The HAZUS-MH^SM flood module can be used to help map flood plains elevations and water depths, and to estimate losses due to flooding. The user is cautioned that the actual water elevations may differ considerably across the map grid used to show water depths. The FEMA Federal Insurance and Mitigation Administration's Hazard Mapping Division maintains and updates the National Flood Insurance Program maps, another source of flood hazard data.

C-5.4 Wind (High Winds, Hurricanes and Tornados)

The primary impact of high winds is the loss of electrical power or SCADA communication components (for example, antennae, towers). Lightning sometimes accompanies storms and can result in power outage, damage to SCADA system components, and fire. The evaluation of exposure to the loss of power is addressed in Section 9.2.3.

The evaluation of exposure of facilities to hurricane and tornado hazards can be conducted utilizing a checklist. The exposure of specific facilities can be noted in the checklist (for example, exposure is greater for above-ground facilities and facilities located near trees).

C-5.5 Earthquakes

Evaluation of the exposure of wastewater system facilities to earthquakes involves the use of GIS data. Overlaying the locations of system facilities with GIS map contours for ground motion and/or liquefaction provides the input for determining earthquake hazard exposure. The USGS has ground motion mapping for the entire United States (http://eqhazmaps.usgs.gov/). Some states in high seismic areas have developed liquefaction mapping for urban areas. Data for ground motion and liquefaction may be available for several intensities that provide more detailed information regarding exposure. For example, an evaluation may find that of the 1000 miles of pipe existing in a particular system, 200 miles or one-fifth of the pipe may exist in areas of high liquefaction susceptibility, 300 miles may exist in areas of moderate susceptibility and 500 miles may exist in areas having little or no susceptibility. The maps developed to illustrate earthquake exposure can utilize gradations of color (green-yellow-orange-red, for example) to indicate increasing levels of exposure. For single-site facilities, such as treatment plants, evaluations of exposure in greater detail may be warranted. For example, a treatment plant may be located in a highly liquefiable area.

Characterization of the specific piping material present in hazard-prone areas is an important input to the evaluation of earthquake and ground movement hazards. When specific information regarding the piping material installed is not available, a "best guess" approach can be used in which the date of installation is estimated by correlation with the dates of construction of buildings/houses in the area. An estimate of the date of installation can often yield the most likely piping material installed at that period of time.

HAZUS-MH^{SM} (http://www.fema.gov/hazus/) is a GIS-based planning tool that has been developed by NIBS/FEMA that can be used in assessing earthquake exposure (as well as flood and wind exposure) of the built environment. Wastewater facilities are overlaid on ground motion and liquefaction susceptibility maps. Expected damage states are calculated within HAZUS-MH^{SM}.

C-5.6 Other Natural Hazards

Evaluation of exposure to other natural hazards can be accomplished by developing a checklist in which all system facilities are listed vertically in a table, and credible natural hazards are listed in the top row. Checkmarks or notation is provided for each facility potentially impacted. Potential examples of hazard exposure are the following:

- Snow / Ice storms can cause power loss and impact the ability to supply fuel to emergency diesel generators
- Volcanic tephra (fragmented, solidified lava that rises into the air) is carried by winds, and falls back to the ground. Tephra falls can result in arcing on high voltage electrical insulators (power loss), and damage to rotating equipment if the ash is allowed to get inside bearings and cylinders.
- Debris flows generated by volcanic activity produce a phenomenon referred to as a lahar, a rapidly moving mudflow. Such a mudflow can adversely impact system facilities
- Tree fall can impact structures
- Adequate staffing is essential for system operation in the long term. Staff availability could be impacted by a public health catastrophe or a labor dispute.

C-5.7 Technological Hazards

Evaluation of exposure to technological hazards (for example, third-party damage or truck/car structural impact) is best accomplished by developing checklist in which all system facilities are listed vertically in a table, and potential technological hazards are listed in the top row. Checkmarks or notation is provided for each facility potentially impacted. For example, an aboveground lift station may be sited near a highway. Other potential examples of hazard exposure are the following:

- Facilities may be located in the path of an airport
- Chlorine gas is stored at specific facilities
- Pipeline damage by a third-party is the greatest threat to pipelines. The potential for third-party damage should be noted, particularly for critical pipelines

- Mechanical/electrical failure

C-5.8 Lifelines Services Hazards

Evaluation of exposure to lifelines services hazards (for example, loss of electrical power) is also best accomplished by developing checklist in which all system facilities are listed vertically in a table, and potential lifelines services hazards are listed in the top row. Checkmarks or notation is provided for each facility potentially impacted. Potential examples of hazard exposure are the following:

- Loss of electrical power affects treatment facilities and lift stations; notation can added to the checklist to indicate which facilities have emergency backup power.
- Lift stations may rely on water-cooling and/or seal water and may shut down in the event that water is unavailable.
- Natural gas heating may be provided for lift stations; the heating is required only for severe conditions. Natural gas heating may be used for administrative offices; loss of heating may be a nuisance, but not result in significant impacts to system operation.
- Telecommunications may be required for SCADA operation; notation may added to the checklist that SCADA is needed only for system monitoring and not for system control.
- Regular chlorine gas or other chemical delivery is required for treatment operations.

Loss of electrical power can significantly impact system operation. A network assessment to evaluate the reliability of the electrical grid may be available or potentially be performed to characterize in greater detail the exposure to power loss.

C-5.9 Understanding Natural Hazards

This section provides a general qualitative description of the natural hazards described in this document. The function of this section is two-fold.

(1) An understanding of the natural hazards phenomena under consideration is critical to modeling them and hence developing risk reduction measures.

(2) Wastewater utility decision-makers and their technical staff and/or consultants can rank order the natural hazards in order of severity to a system in order to scope which natural hazards are of special interest to the wastewater utility given the specific issues to be addressed.

This chapter provides initial screening only on the basis of small-scale maps and qualitative considerations. Additional considerations to be borne in mind include the specific issues that the wastewater utility system is considering (e.g., the determination of the design parameters to be used for a water storage reservoir) and larger-scale maps that exist, for instance, in state geological surveys or elsewhere.

C-5.9.1 Ground Movement Hazards

C-5.9.1.1 General Considerations

Ground movement hazards are defined as such because external forces or environmental conditions affect the movement or failure of the earth materials. In the case of gravity landslide, the external triggering force may be gravity coupled with moisture changes. This is differentiated from earthquake-generated landslide, which involves gravity, but the landsliding action is initiated or triggered by the earthquake shaking action. Soil collapse is also initiated by gravity.

Expansive soil hazards are initiated by changes in moisture conditions (usually dessication) within certain kinds of soils. They expand differentially with the addition of water and contact or shrink differentially with desiccation.

Frost heave results in differential movement of the surficial soils that have water accumulated in the interstices between soil grains. When water freezes, the resultant ice gains about 10 percent in volume, thus causing differential movement.

C-5.9.1.2 *Gravity Landslide*

Landslides are a form of earth movement down slope under gravity loads. The speed of movement can be either slow or fast. Landslides can vary from less than one acre (4047 sq meters) to several square miles (2.59 sq km/mile) in extent and include a variety of types. Smaller landslides are predominantly rotational slumps. The larger landslides are usually earth-flows.

Debris flows are moving, fluid masses of rock, soil and debris. They are active geologic processes in the Rock Mountains, and historic debris flows have affected several communities. Debris flows usually start as shallow landslides on colluvial slopes which are steeper than about 50% as a result of intense thunderstorm precipitation or rapid infiltration of snow pack melt. The flows thin out and spread laterally on alluvial fans where hillside channels may join a main valley. The flows have the capacity of transporting very large boulders. When confined in steep, hillside channels flow depth can reach 20 feet (6.09 m.) or more. Flow depths on the fans are typically in the range of 2 to 15 feet (0.61m. to 4.57m.) with the greater depths near the fan heads. Flow velocities can vary widely depending on depth of flow, gradient and ratio of water to solids. Velocities in the range of 1 to 30 mph (1.609 km/hr to 48.3km/hr) are typical of debris flows.

Rock fall is the precipitous movement of newly detached rock blocks from a cliff or other very steep slopes. In the Rocky Mountains, rock fall is common on many highway cuts in jointed rock. Rock fall also occurs along cliffs that border many mountain valleys. In a few areas rock fall blocks have reached downslope developments and transportation corridors. Rock fall can occur anytime of the year, but it is most frequent in the spring when there is repeated freezing and thawing of water in the rock joints. After dislodging from the outcrop, rock fall blocks travel rapidly downslope generally in a relatively straight line by a series of leaps and bounces. Individual rock fall blocks can vary from less than one foot to (0.3m) tens of feet (3m) in size depending on the joint spacing at the outcrops.

Selected Sources. There are a number of federal, state, and local agencies mapping gravity landslides. Godt, 1997, provides one small-scale landslide map for the co-terminous United States. An earlier small-scale map is provided by Krohn and Slosson, 1976. Other references include Alfors et al., 1973, Briggs et al., 1975, Chassie and Goughnour, 1976, Edwards and Batson, 1980, Fleming and Taylor, 1980, Jochim et al., 1988, McCalpin, 1984, Nilsen and Turner, 1975, Pfeiffer and Bowen, 1989, Radbruch-Hall, 1979, Radbruch-Hall et al., 1976, Smith, 1958, Turner and Shuster, 1996, Varnes, 1978, Wiggins et al, 1978, and Zaruba and Vojtech, 1969.

C-5.9.1.3 *Expansive Soil*

Soils and soft rocks , which tend to swell or shrink owing to changes in moisture content are commonly known as expansive soils. In the United States, two major groups of rocks serve as parent materials of expansive soils. Both groups are more common in the Western United States than in the Eastern United States. The first group consists of ash, glass, and rocks from volcanic eruptions. The aluminum silicate minerals in these volcanic materials often decompose to form expansive clay minerals of the smectite group, the best known of which is montmorillonite. The second group consists of sedimentary rocks containing clay minerals, examples of which are the shales of the semiarid West-Central United States.

Smectite-rich materials, which serve as sources of expansive soils. Smectites are regionally abundant in geologic formations throughout the Rocky Mountains, most of the Great Plains, much of the Gulf Coastal Plain, the lower Mississippi River Valley, and the Pacific Coast. They are locally abundant in geologic formations along the Atlantic and Gulf Coastal Plains and in the Great Basin region. They are a very minor constituent of geologic formations in the rest of the United States, but they may be abundant locally in surficial deposits along both coasts and in the western and west-central parts of the Nation.

Selected sources on expansive soils include Holtz and Hart, 1978, Jones and Holtz, 1973, Krohn and Slosson, 1980, Nelson and Miller, 1992, Noe et al., 1997, Patrick and Snethen, 1976, and Tourtelot, 1974.

C-5.9.1.4 *Soil Collapse*

The lowering or collapse of the land surface either locally or over broad regional areas, has taken place in nearly every State. Although collapse is usually not spectacular or catastrophic, it causes several tens of millions of dollars in damages annually in the United States.

Natural subsidence results from processes including the dissolving of limestone and other soluble materials. Large areas of the United States are underlain by limestone and other soluble materials. As underground water percolates through such materials, soluble minerals dissolve, leaving cavities or caverns. Land overlying these caverns can collapse suddenly, forming sinkholes of 100 feet (30m) or more in depth and 300 feet (91m) or more in width. Other times, the land surface can settle slowly and irregularly. The landscape created by such subsidence is called karst terrain. This type of subsidence usually causes extensive damage to structures located over pits formed by dissolving the soluble minerals. Although the formation of sinkholes is a natural phenomenon, the process can be accelerated by human practices with regards to ground-water withdrawal, land development, and disposal of water.

The major locations of karst terrain and caverns in the United States are in parts of many of the Southeastern and Midwestern States. Sinkholes also are found in some of the Western and Northeastern States. Alabama, where soluble limestone and other rocks are present in nearly one-half of the state, has thousands of sinkholes that pose serious problems for highways and construction generally.

Man-induced subsidence has increased dramatically since 1940 as a result of the withdrawal of oil, gas, and water. Because underground fluids fill intergranular spaces and support sediment grains, removal of these fluids results in a loss of grain support, reduction of intergranular void spaces, and compaction of clays. The land surface commonly subsides wherever widespread subsurface compaction has taken place, causing damage to canals, aqueduct and pipelines, and increasing the probability of flooding in some areas. The most dramatic examples of subsidence caused by withdrawal of oil, gas, and water are along the Gulf Coast of Texas, in Arizona, and in California.

Recent research suggests that subsidence caused by withdrawal of ground water can also cause fissuring or renewal of surface movement in some areas cut by pre-existing faults. Fissuring is the formation of open cracks. Surface faulting and fissuring associated with withdrawal of ground water are believed to have either taken place or to be a potential problem in the vicinity of Las Vegas, Nevada as well as in parts of Arizona, California, Texas, and New Mexico (Holzer, 1977).

Underground mining, especially shallow coal mining, is another significant cause of subsidence. The rocks above mine workings may not have adequate support and can collapse from their own weight, either during mining or long after mining is completed. Subsidence in areas of underground mining has caused hazardous conditions in parts of Pennsylvania and other Appalachian States, Colorado, North Dakota, Wyoming, New Mexico, Washington, Iowa, and Illinois. Subsidence-related damage to surface structures is common in the area around Pittsburgh, Pennsylvania where coal has been mined extensively. Subsidence depressions and pits, forming above abandoned underground mines, are a hazard in the Sheridan, Wyoming area.

Solution mining also can cause subsidence. In solution mining, water-soluble minerals such as salt, gypsum, and potash are dissolved and pumped to the surface so that the water can be evaporated. Huge underground cavities are formed, causing surface subsidence.

Hydro-compaction, or the settling of sediments after water is added, is another significant cause of subsidence, especially in the arid to semiarid Western and Midwestern States. Areas of known compaction include San Joaquin Valley, California, Hearth Mountain-Chapman Beach and Riverton, Wyoming areas. Hysham Bench, Montana, Columbia Basin, Washington, Denver, Colorado, Washington-Hurricane area in southwest Utah and central Utah, and Missouri River Basin. Hydro-compaction takes place when dry surface or subsurface deposits are extensively wetted for the first time since their deposition as, for example, when arid land is irrigated for crop production or an irrigation canal is built on loose dry uncompacted sediments. Wetting causes a reduction in the cohesion between sediment grains, allowing the grains to move and to fill in the naturally occurring intergranular openings. The result is a lowering of the land surface from 3 to 6 feet (0.9 to 1.8m), although subsidence as much as 15 feet (4.6m) has been recorded. The effects of hydro-compaction on the land are usually uneven, causing depressions, cracks, and wavy surfaces. As a result, canals, highways, pipelines, buildings, and other structures can be seriously damaged by these hazards. Natural subsidence, man-induced subsidence and hydro-compaction can have significant impact on the change in grade for gravity-flow conveyances.

Selected references on soil collapse include Allen, 1969, Davies, 1970, Davies et al., 1976, Dunrud, 1976, Dunrud and Osterwald, 1980, Gilluly and Grant, 1949, Holzer, 1977, Jones and Larson, 1975, Lofgren, 1969, Newton, 1976, Poland and Davis, 1969, Poland and Green, 1962, Rickert et al., 1979, and U. S. Bureau of Mines, 1976.

C-5.9.1.5 Frost Heave

Frost heave is the increase in volume experienced by soils when they freeze. Water moves to the upper horizons from below; when it freezes it forms segregated ice lenses which push apart the soil around them as they grow, causing the observed volume increase. Frost heave has a number of effects upon the soil and upon structures supported by or within the soil.

During the freezing of some soils, nearly pure ice forms in segregated lenses parallel to soil isotherms (Hillel, 1980). The formation of these lenses causes frost heave, a phenomenon in which the surface of the soil is “heaved” vertically by as much as tens of inches (several tens of centimeters). The overall volume of the soil also increases greatly, and heave pressures of many atmospheres can build up (Mitchell, 1993). Frost heave often causes substantial damage to roads, foundations, lifelines, and other structures within and on top of the soil.

Three conditions are necessary for ice segregation and frost heave to occur: (1) a frost susceptible soil, (2) freezing temperature, and (3) a supply of water.

Frost heave begins when air with a sub-freezing temperature overlays a soil whose temperature is above freezing. At this point, a freezing isotherm begins moving down through the soil. The exact temperature at which the soil water begins to freeze is determined by several factors, including the amount of dissolved minerals and particle surface force effects. Regardless, ice typically begins to form before the soil reaches –0.2º C (32.4º F). Around the ice is a film of supercooled water which is gradually frozen and added to the ice mass and then, replaced by water from nearby pores in the soil. Rather than freezing water in situ through the bottlenecks of the surrounding pores, which requires a great deal of energy, the ice tends to segregate, drawing water and pushing the soil away. Experiments by Beskow (1935) revealed that pore saturation had to be greater than 90% in the soil behind the freezing front for heaving to occur. This fact suggests that a great deal of water must move from lower horizons to the upper portion of the soil.

The mechanisms of frost heave suggest that certain soils are more susceptible to heaving then others. Fine-grained clays conduct water too slowly to supply a growing ice lens, while sandy soils, due to their large pore size, are poor upward conductors of water. Thus silts, which have moderate pore size, are best at providing a steady supply of water to growing lenses of ice and are most susceptible to frost heave.

Frost heave affects soils greatly. Small lateral differences in snow cover, soil texture, vegetation, and topography can lead to differences in the amount of heave experienced by regions in the soil. Differential heaving causes layers to be displaced varying distances, leading either to the formation of wavy boundaries, or, in extreme cases, to the destruction of horizon boundaries altogether. At the surface differential heaving often forms a pattern of circular bulges with depressions between them. These small bulges are better drained than the depressions, and they thus retain their heat longer during cold spells. Frost heave then begins in the depressions first, causing lateral pressure towards the centers of the bulges. This pressure displaces more soil and pushes the bulges higher, forming hummocks; circular mounds roughly 1-2 meters (3.3-6.6 ft) in diameter and up to 5 meters (16.4 ft) high.

The final major effect of frost heave occurs during seasonal thawing. A great deal of water accumulates in the upper soil horizons when ice lenses form. During thawing, the upper portion of the soil melts first. Because the bottom layers are still frozen at this point, the melt water cannot drain. The soil becomes saturated and loses most of its strength. When soils supporting roads, fence posts, foundations, electric power and telephone poles, and other structures lose strength in this manner, the roads develop potholes while the fence posts and foundations can often become skewed. Thawing areas on slopes are also susceptible to landsliding.

Selected references include Anderson (1988), Clark (1988), Dash (1989), Hillel (1980), Mitchell (1993), and Smith (1985).

C-5.9.2 Flood Hazards

C-5.9.2.1 General Considerations

Floods have been and continue to be one of the most destructive natural hazards facing the Nation. Moreover, the probability exists that a greater flood will take place than any experienced in the past (see Figure C.5.1).

A flood is any abnormally high stream flow that overtops the natural or artificial banks of a stream. Flooding is a natural characteristic of rivers. Flood plains are normally dry-land areas on either side of a river that act as a natural reservoir and temporary channel for floodwaters when they come. If more runoff is generated than the banks of a stream channel can accommodate, the water overtops the stream banks and spreads over the flood plain causing social and economic disruption and damage to crops, lifelines and other structures. The ultimate parameter affecting damage to surface structures or crops, however, is not the quantity of water being discharged, but the elevation of the water surface above the land.

C-5.9.2.2 Riverine Flood and Scour

Taking place throughout the United States, riverine floods are caused by precipitation over large areas or by the melting of the winter's accumulation of snow or both. Riverine floods differ from flash floods or headwater flooding in their extent and duration. Whereas these floods are of relatively short duration on small streams, riverine floods take place in river systems whose tributaries may drain large geographic areas and encompass many independent river basins and states. Floods on large river systems may continue for periods ranging from a few hours to many days.

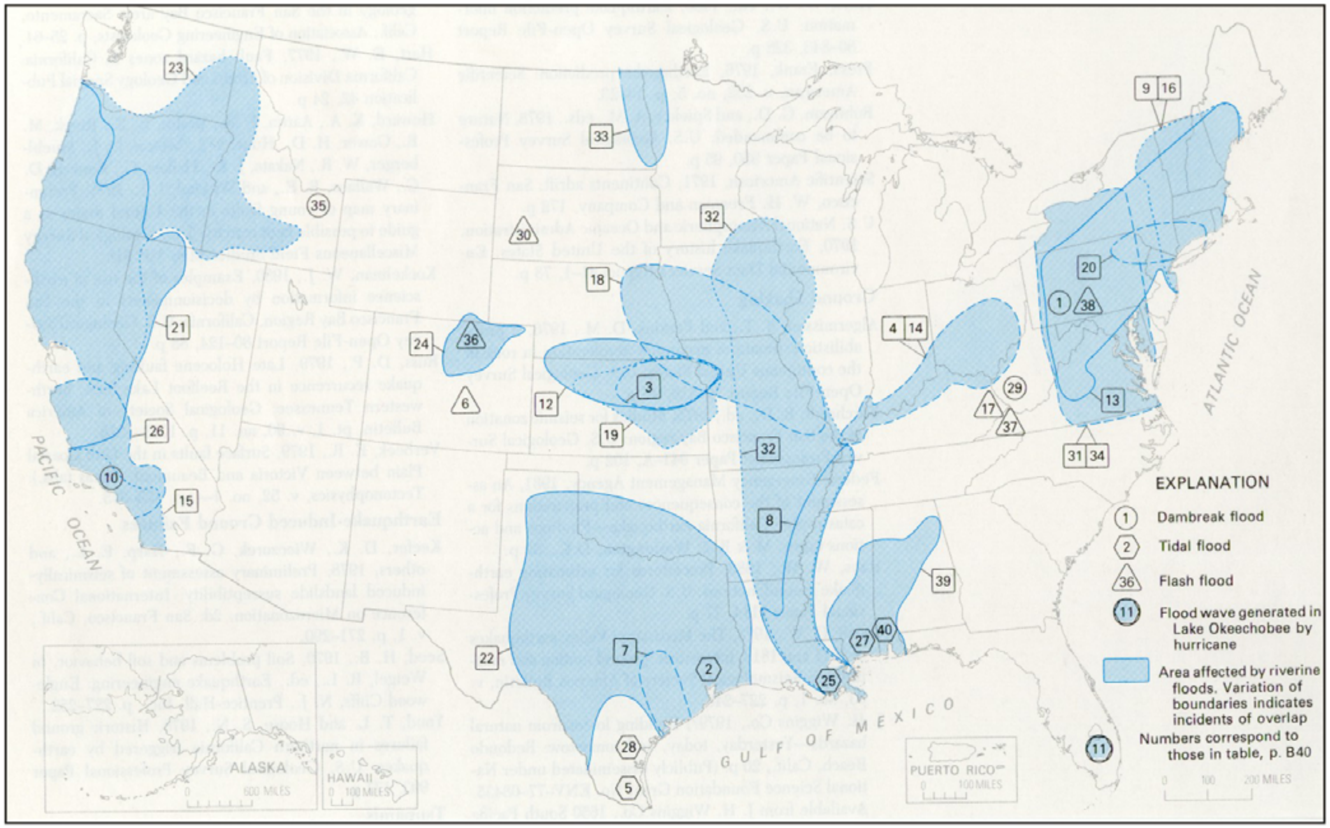

Figure C. 5.1 Map Showing Distribution of Great Floods in the Coterminous United States since 1889
(Geological Survey Professional Paper 1240-B)

Flood flows in large river systems are influenced primarily by variations in the intensity, amount, and distribution of precipitation. The condition of the ground, amount of soil moisture, seasonal variations in vegetation, depth of snow cover, and imperviousness due to urbanization directly affects flood runoff as well.

Three characteristics of river channels, (1) channel storage, (2) changing channel capacity, and (3) timing, control the movement of riverine flood waves. As a flood moves down the river system, temporary storage in the channel reduces the flood peak. As tributaries enter the main stream, the river gets larger and larger downstream. Tributaries are not of the same size nor are they spaced uniformly; therefore, their flood peaks reach the main stream at different times. The difference of timing tends to modify peaks as a flood wave moves downstream.

Selected references include Leopold and Langbein, 1960, National Oceanic and Atmospheric Administration, 1994, U. S. Congress, 1966, Flood Protection Act of 1973, U. S. Water Resources Council, 1972, 1977, 1978, Waananen et al. 1977.

C-5.9.2.3 Headwater Flood and Scour

Headwater floods include those generated in relatively flat terrains or mountainous areas with ravines or gorges. The former can form where there is no stream. For example, abnormally heavy precipitation can fall on flat terrain at such a rate that the soil cannot absorb the water or the water cannot run off as fast as it falls.

Flash floods are local floods of great volume and short duration. A flash flood generally results from a torrential rain or “cloudburst” on a relatively small drainage area. Cloudbursts, associated with severe thunderstorms, take place mostly in the summer. Flash floods can also result from the failure of a dam or from the sudden breakup of an ice jam. Each can cause the release of a large volume of flow in a short time.

Violent thunderstorms or cloudbursts can develop in a short time. They then can produce floods on relatively small and widely dispersed streams. Discharges quickly reach a maximum and diminish almost as rapidly. Flood flows frequently contain large concentrations of sediment and debris collected as they sweep channels clean.

Flash floods can take place in almost any area of the country, but they are particularly common in the mountainous areas and desert regions of the West. Flash floods are a potential source of destruction and a threat to public safety in areas where the terrain is steep, surface runoff rates are high, streams flow in narrow canyons, and severe thunderstorms prevail.

Selected references include Davies et al, 1972, Hoxit et al., 1977, McCain et al, 1979, Ray and Kjelstrom, 1978

C-5.9.3 Windstorms

C-5.9.3.1 General Considerations

Wind hazards are divided into the categories of:

- General severe wind
- Tornado and
- Hurricane

A discussion of each can be found in (Hart, 1976). They are divided into the separate categories above for the following relative differences in severity area covered and regional variation (see Table C.5.4.

Table C.5.4 Wind Hazard Categories, Severity, Area Covered, and Regionality

	Severe Wind	**Tornado**	**Hurricane**
Severity	Low	High	Medium
Area covered	Medium	Low	High
Regional Variation	No	Yes	Yes

Table C.5.5 classifies wind by the Beaufort Scale.

Table C.5.5 Classification of Wind by the Beaufort Scale

Beaufort Number	**Wind Speed (mph)**	**Descriptor**	**Effect Observed**
0	0-1	Calm	Smoke rises vertically.
1	2-3	Light air	Smoke drifts; vanes do not move.
2	4-7	Light breeze	Leaves rustle; vanes begin to move.
3	8-12	Gentle breeze	Leaves in constant motion; light flags extended.
4	13-18	Moderate breeze	Dust, leaves raised; small branches move.
5	19-24	Fresh breeze	Small trees begin to sway.
6	25-31	Strong breeze	Large branches of trees in motion; whistling heard in wires.
7	32-38	Near gale	Whole tree in motion; resistance felt in walking against wind.
8	39-46	Gale	Twigs and small branches break; progress generally impeded.
9	47-54	Strong gale	Slight structural damage occurs; slate blown from roofs.
10	55-63	Storm	Trees broken or uprooted; structural damage begins.

Beaufort Number	Wind Speed (mph)	Descriptor	Effect Observed
11	64-73	Violent storm	Some damage all over.
12	74 and above	Hurricane	Large-scale damage, calamity.

C-5.9.3.2 General Severe Wind

Severe winds are produced by (1) thunderstorms, (2) downbursts and (3) down slope winds.

Thunderstorm and Straight-Line Winds - Severe thunderstorms generate high winds and sometimes even tornadoes. Lightning accompanies thunderstorms. The non-spinning (non-tornadic) types are often referred to as thunderstorm wind or straight-line wind. Although straight-line winds are normally not as intense as tornadoes, they produce far more accumulative damage than tornadoes because they occur far more frequently and affect much larger areas. This is true even in tornado-prone areas such as Kansas or Oklahoma. Straight-line winds can have speeds approaching or sometimes exceeding 100 mph (44.7 m/s), causing roofs to be blown off; mobile homes, automobiles, and parked aircraft to be overturned; trees toppled; electric power and telephone lines downed; and so on.

Downbursts - A particular type of thunderstorm wind, called `a downburst, is generated by a falling mass of evaporatively cooled air frequently driven by hail and heavy rain in a parent thunderstorm. As the falling air mass impinges on the ground, it spreads out horizontally and generates strong surface winds of short duration. The situation is analogous to the flow generated by pouring water on the ground from a pail mounted on a moving truck, with the parent storm being the moving truck.

T. Fujita (1985) classified downbursts into two size groups: microbursts and macrobursts. A microburst has a small horizontal scale of the order of a few hundred meters, and has damaging winds lasting from 2 to 5 minutes. On the other hand, a macroburst covers an area on the order of 1-5 km (0.62-3.11 miles), and the damaging winds last 5 to 30 minutes. A downburst may be moving or stationary. The streamlines in a downburst can be straight or curved. A curved downburst may sometimes develop into a tornado.

Mountain Downslope Winds - Mountain downslope winds happen when a cold layer of air descends from the peak of a mountain or mountain chain in a manner similar to water flowing down a steep slope. Due to the acceleration caused by gravity, the wind reaching the foothill can gain speeds as high as those of hurricanes. For any air mass to be able to accelerate by gravity, the air must be a cold layer under a warm upper air generated by a cold front. This type of wind often occurs in winter when a cold front crosses a mountain (see Figure C.5.2).

As the cold air in a mountain downslope wind descends down a mountain, not only does the wind speed increase, but the air temperature also rises due to adiabatic compression of the air caused by increasing hydrostatic pressure encountered at lower elevations. For this reason, mountain downslope winds often bring warmer temperature to low areas.

Mountain downslope winds occurring in different geographical regions are called by different names. In the Rocky Mountain and Alaskan areas of the United States they are called Chinook, in southern California they are called the Santa Ana wind, in the Alps of Europe they are called Foehn, and in Yugoslavia they are called Bora. Note that Foehn and Bora are not being used as generic terms for warm and cold mountain downslope winds, respectively. Many communities on the eastern slope of the Rocky Mountains are plagued by mountain downslope winds. For example, Boulder, Colorado, each year experiences more than one downslope wind of a speed exceeding 100 mph (161 km/hr), even sometimes approaching 130 mph (209 km/hr).

C-5.9.3.3 General Considerations

General severe wind can occur and be evaluated for locations anywhere in the country using archived NOAA wind history data. Data is available by station for extreme 1%, 5%, 10% and mean wind speeds and by day, month of the year or by year. These four data points can be computed from weather station data. It can then provide a probabilistic profile of the severe wind characteristics for any site or region.

Should the fastest-mile-of-wind or peak gusts over 30, 40 or 50 mph (48, 64 or 80 km/hr) be desired by wind engineers, these data are also available for virtually every station in the nation.

Wind velocity, whether it be noted as a sustained speed or a 3 second or 5 second gust speed, is the key measure of intensity for this hazard. Available debris such as gravel or flying broken glass from damaged structures is also a loading factor associated with severe winds. Losses sustained by above-ground structures are conditioned by shape or envelope characteristics of the structure being loaded and the load resistance capacities of the structure and its elements. These are discussed in another part of the report.

It is true that wind velocity over land surfaces is affected by the land contour and roughness factor of the land caused by trees, structures or other items that tend to slow down or channel the wind. However, these factors are accounted for by the individual weather station data that might be used.

Selected References include Abbey, 1975, ANSI/ANS-2.3, 1983, Fujita, 1985.

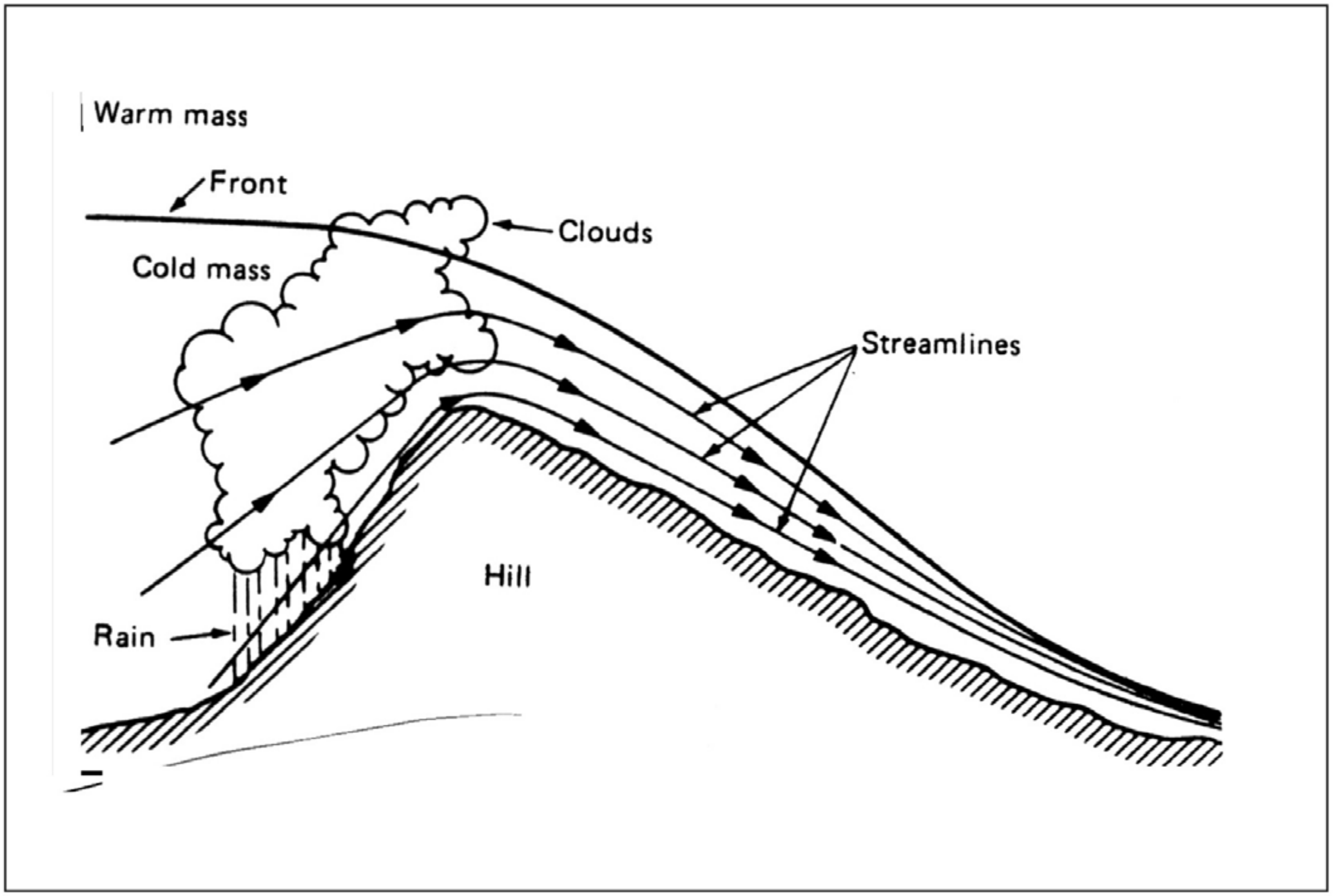

Figure C.5.2 . Mountain Downslope Wind

(Henry Liu, Wind Engineering, Prentice Hall, 1991)

C-5.9.3.4 Tornado

A tornado can be thought of as a simple vortex, a rotating, spiraling fluid, like those in a draining sink or bathtub. But behind that apparent simplicity lays a complexity of fluid dynamics, air/moisture interactions, and energy transfers. The laws of physics, probability and chaos will eventually yield answers to the many puzzling questions that tornadoes present to us even to this day.

Tornadoes occur principally in the Midwest. Although Florida also can spawn a number of tornadoes, most of them of the weak variety associated with hurricanes.

Selected references include Grazulis, 1993 and Liu, 1991.

C-5.9.3.5 Hurricane—General

Hurricanes develop from a variety of tropical weather disturbances and pass through several increasingly intense phases, classified as (a) tropical depressions (with sustained winds less than 40 mph, or 64 km/hr), (b) tropical storms (with winds between 40 and 73 mph, or 64 and 117 km/hr), and finally, (c) hurricanes (with sustained winds over 73 mph, or 117 km/hr).

The typical hurricane system has a diameter of about 300 miles (483 km), although winds of hurricane force are concentrated in a much smaller area. The air system in a hurricane in the northern hemisphere spirals counterclockwise toward the storm's low-pressure center (Figure C-5.3). The air absorbs heat and moisture from the warm ocean surface and gathers speed as it moves from higher to lower pressure. This heat and moisture constitute the hurricane's energy source, which is released again near the center where the converging air flows upward in a wall of clouds (the ring of strongest wind and rain). Inside the wall, in the hurricane eye, winds are much weaker, heavy rains cease, and the sky may even be clear.

The forward movement of the hurricane system is relatively slow, usually around 12-15 mph (19-24 km/hr) in the lower latitudes. At latitudes above North Carolina the forward movement picks up to about 30 mph (40 km/hr). In general, although it is difficult to predict, the system moves with the speed and in the direction of the steering wind current, usually with some drift to the north. A west-northwest drift will eventually carry most storms to higher latitudes where they tend to recurve from traveling left or westward to the right or eastward as they enter the mid-latitude westerlies. Movement of a hurricane over land or into regions of cooler air and water surface temperatures reduces the primary source of energy, and the intensity of the storm decreases or attenuates.

Table C.5.6 represents the hurricane hazard damage system.

No segment of the Gulf and Atlantic coast of the U.S. is without some vulnerability to hurricanes, but some areas have a history of more frequent hurricane occurrence than others. Parts of Texas, Louisiana, Mississippi, Alabama, Florida, and (to a lesser extent) South and North Carolina have been especially susceptible.

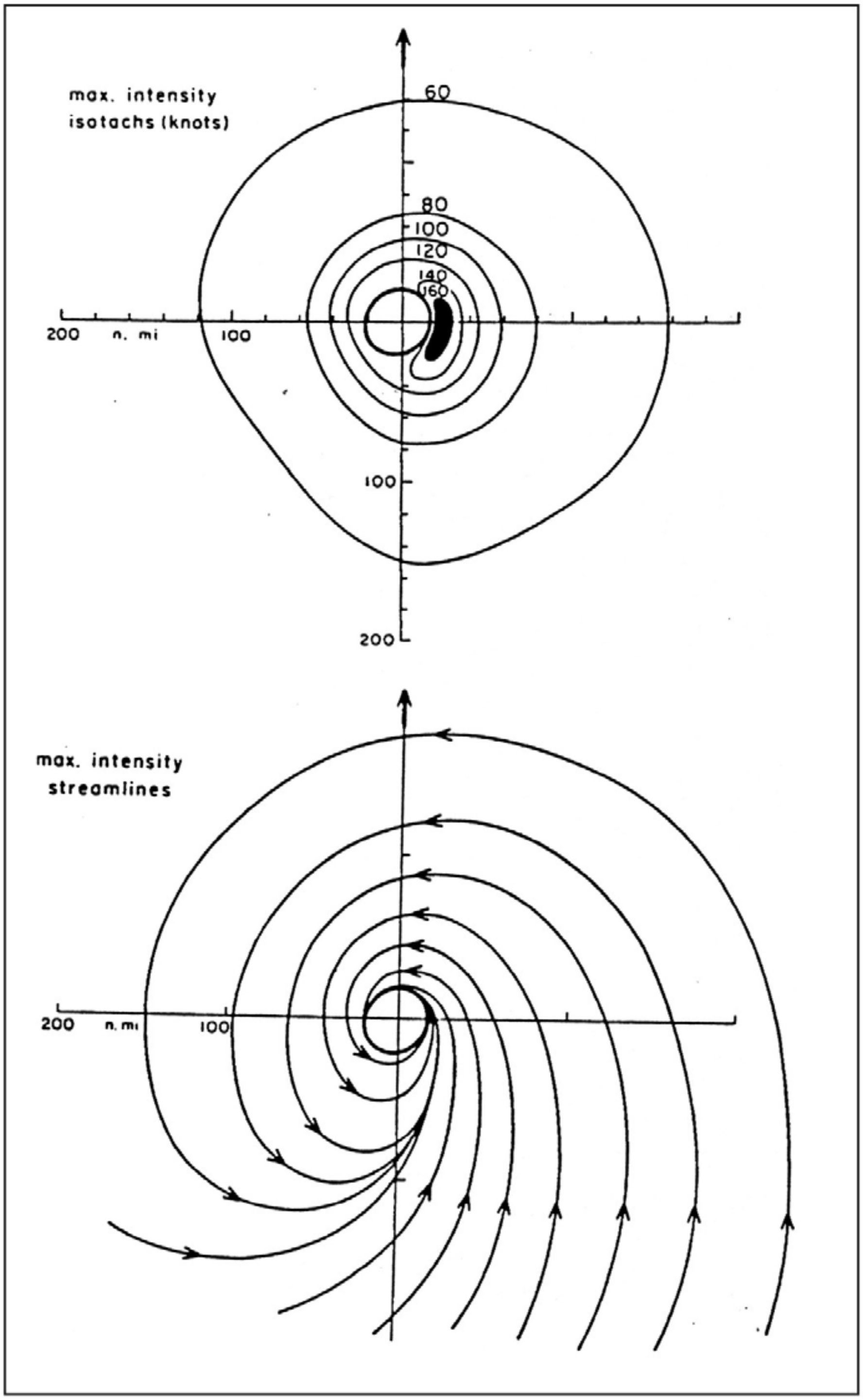

Figure C. 5.3 Model of Wind-Speed Distribution and Streamlines for an Extreme (Cat 5) Hurricane, Drawn with Respect to Direction of Motion Pointing Upward (The Hurricane and Its Impact, Louisiana State University Press, Robert H. Simpson and Herbert Riehl, 1981)

Hurricanes usually occur during the months of July, August, September, and October with the so-called season beginning in June and ending in November.

Selected references include Anthes, 1992, Baker and Miller, 1990, Burton and Kates, 1964, Coch, 1994, Diaz and Pulwartz, 1997, Emmanuel, 1987, Goldenberg and Shapiro, 1993, Gray et al., 1996, Hastenrath, 1990, Herbert et al., 1993, Herbert and Taylor, 1979a, 1979b,, Riebsame et al., Sheets, 1994, White, 1994, Wilson, 1994.

Table C. 5.6 Construct of a Hurricane Damage System

Hurricane	**Storm Center**
Hazard	Wind Rain Low central atmospheric pressure
Exacerbation	Local Tides Local coastal configuration
Results	Wind damage from hurricane and spawned tornadoes Storm Surge Riverine flooding and scour Headwater flooding and scour
Losses	Structures & contents, including lifeline structures and equipment, such as roads, bridges, and roadway culverts Lives/injuries Communications Beach erosion Fire Shipping & fishing Soil fertility from saline intrusion Land subsidence Water supply contamination Vegetation Crops Livestock

C-5.9.3.6 Hurricane-Tornado

The impact of hurricane-generated tornadoes will receive only cursory attention here for two reasons: First, the probability of this event affecting any given structure is quite small; second, the damage potential from such events is generally less than that of the sustained winds and gusts of a mature hurricane.

Hurricane tornadoes develop in the spiral rainbands, mostly in the right-front quadrant outside the areas of sustained hurricane or gale-force winds. Figure C.5.4 shows the centroid and distribution of hurricane tornadoes. Although some hurricanes produce families of tornadoes, the individual event is a small, rope-type vortex similar to a waterspout. It has a short path length and maximum wind speeds are usually less than 120 mph, (93 km/hr) (F1). Figure C.5.5 shows the distribution of tornadoes that have accompanied past hurricanes.

General damage algorithms from hurricane winds include the sporadic inclusion of tornadoes with the total winds generated being the operative parameter for damage estimation purposes.

Selected references include Golden, 1970, Gray and Novlan, 1974, Person and Sadowski, 1965.

C-5.9.3.7 Hurricane-Cyclone Wind

Cyclone wind is the element most commonly associated with hurricanes. Highest wind speeds occur in a narrow ring usually extending 10-30 miles (16-48 km) from the center of the hurricane (see Figure C.5.3). The highest measured gust wind speed was 197 mph (317 km/hr) in the Hurricane Inez, but gusts of 220 mph (354 km/hr) have been estimated from damages and barometric pressure records. In a major hurricane, gusts between 73 and 120 mph (117 and 193 km/hr) may extend 100 miles (161 km) from the center of the eye.

Minor damage begins with sustained winds of approximately 50 mph (80 km/hr). Moderate damage, such as broken windows and displaced shingles, begins with winds of around 60 mph (97 km/hr), and structural destruction begins when wind speeds reach about 100 mph, or 161 km/hr (see Table C.5.5).

Saffir and Simpson have devised a five-category scale of hurricane intensity, which is being used increasingly to describe or rate the intensity of hurricanes. It gives a general indication of both wind speed and expected storm surge height.

The likelihood of occurrence of storms having varying strength as expressed on the Saffir-Simpson scale can be treated in several ways. A smoothed strike frequency can be constructed from this data for all tropical storms.

Selected references include Batts et al., 1980, Brinkmann, 1975, Cobb, 1991, Dunn and Miller, 1960, Emanuel, 1987, Gray, 1994, Ludlam, 1963, Nalivkin, 1982, Neumann et al., 1981, Russell, 1971, Sheets, 1990, U. S. Department of Commerce, 1993.

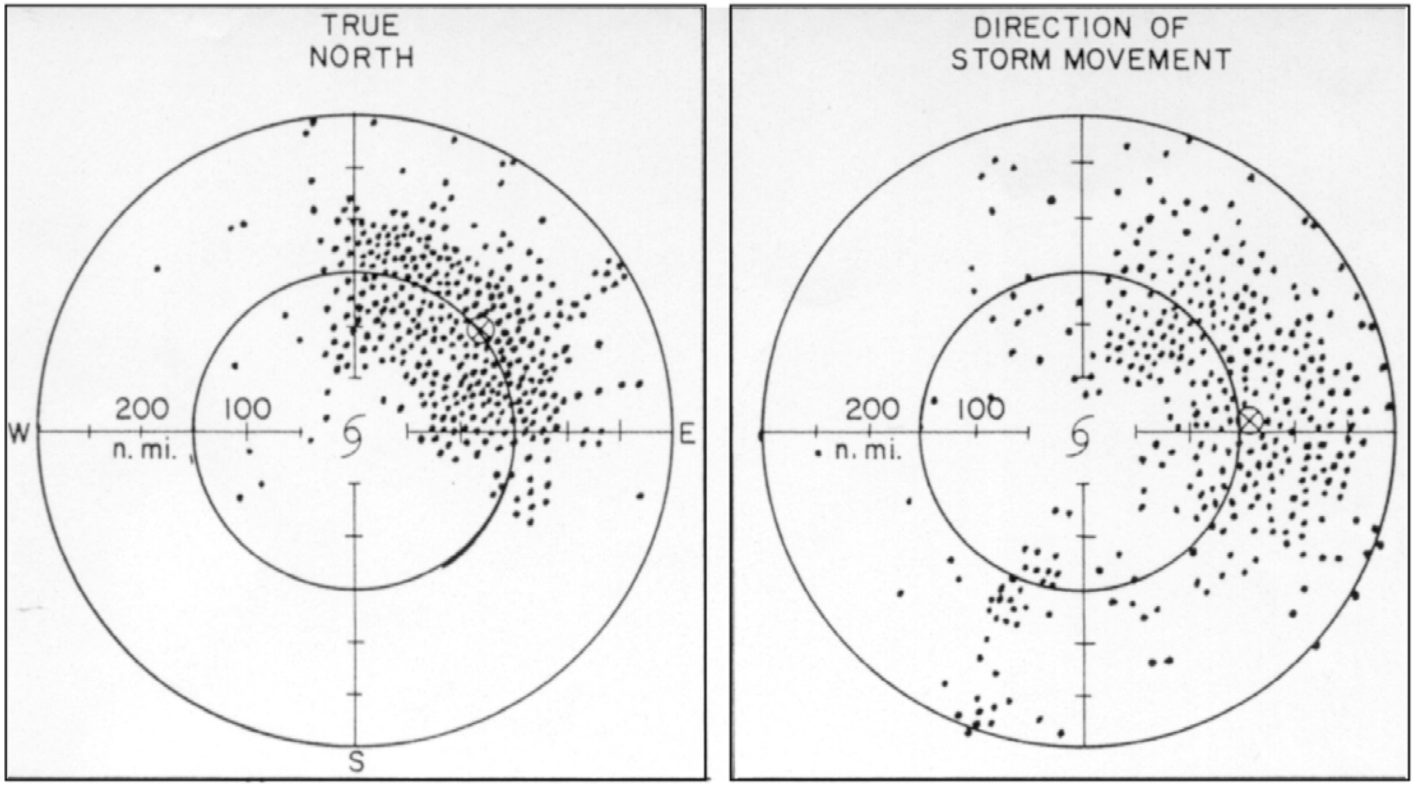

Figure C. 5.4 Typical Location of Tornadoes Accompanying a Hurricane
Only a few of the tornados touched the ground.
(Significant Tornados 1680 – 1991, Thomas P. Grazulis, 1993)

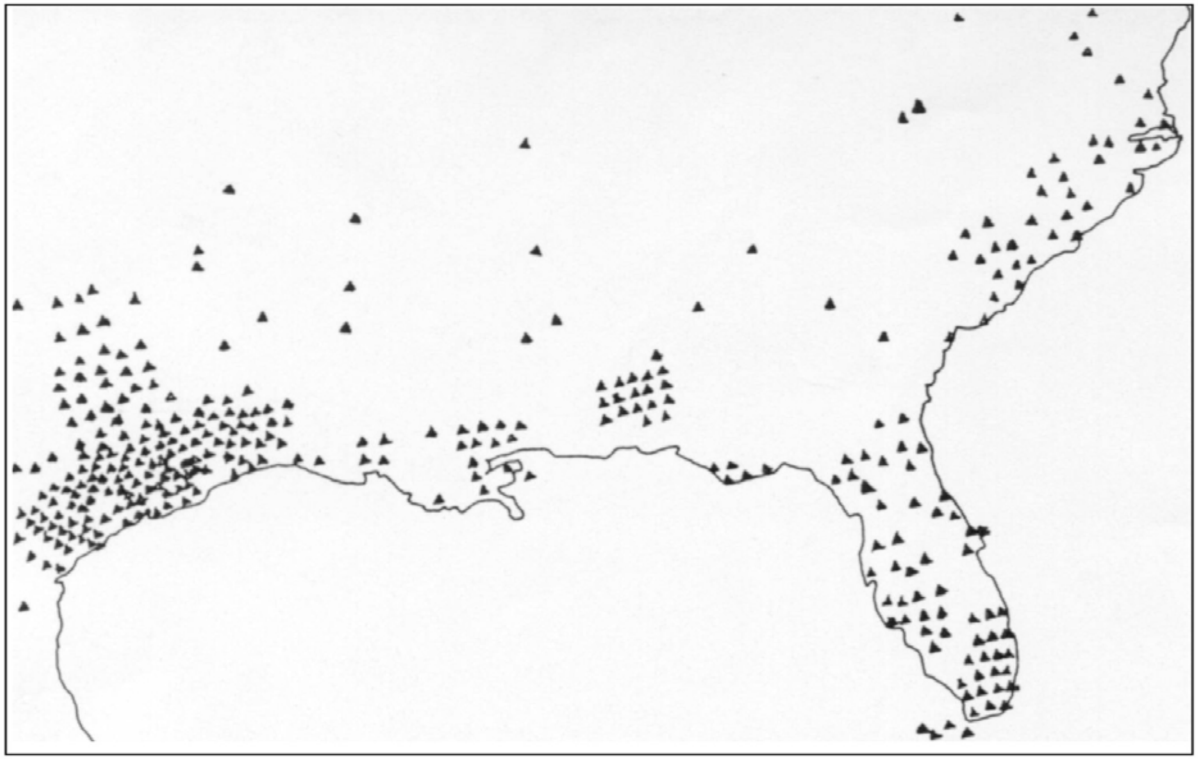

Figure C.5.5 Distribution of Hurricane Tornadoes in the Coastal United States

(Significant Tornados 1680 – 1991, Thomas P. Grazulis, 1993)

Table C.5.7 Saffir/Simpson Hurricane Scale Ranges

Hurricane Category	Central Pressure		Sustained Winds	Approximate Storm Surge Height (ft.)	General Damage Expectancy
	Mm of mercury at 0 degrees C (32 degrees F)	Sea level pressure (inches)			
Tropical Depression	≤ 1008	≤ 29.77	< 40 mph (< 64 km/hr)	≤ 2 ft (≤ 0.61m)	Virtually none
Tropical Storm	979-1007	28.91-29.74	40-73 mph (64-117km/hr)	2-3 ft (0.61-0.91m)	Some
1	980-992	28.94-29.30	74-95 mph (118-153 km/hr)	4-5 ft (1.22-1.52m)	Small
2	965-979	28.50-28.91	96-110 mph (154-177 km/hr)	6-8 ft (1.83-2.44 m)	Moderate
3	945-964	27.91-28.47	111-130 mph (178-209 km/hr)	9-12 ft (2.74-3.66m)	Extensive
4	920-944	27.17-27.88	131-155 mph (210-249 km/hr)	13-18 ft (2.96-5.49m)	Extreme
5	< 920	< 27.17	> 155 mph (>250 km/hr)	>18ft (> 5.49m)	Catastrophic

C-5.9.3.8 Hurricane-Storm Surge and Scour

About 90% of the deaths experienced in the past near the coast resulting from hurricanes are caused not by wind, but by storm surge. Storm surge is the rise of water above sea level at the time of storm onset. The height of storm surge along the open coast depends on a number of factors which include: (1) wind speed and associated barometric pressure, (2) depth of water or shoaling factor, (3) storm trajectory, and (4) speed of the storm (Figure C.5.6). Coastal configuration in the form of estuaries or bays can cause a funneling or amplification effect. Coincidence with high astronomical tide will also increase surge height. Although the maximum surge usually affects only a relatively short length of coastline, combined storm surge and wave action may have damaging effects over 100 miles (161 km) away in either direction of a major storm center.

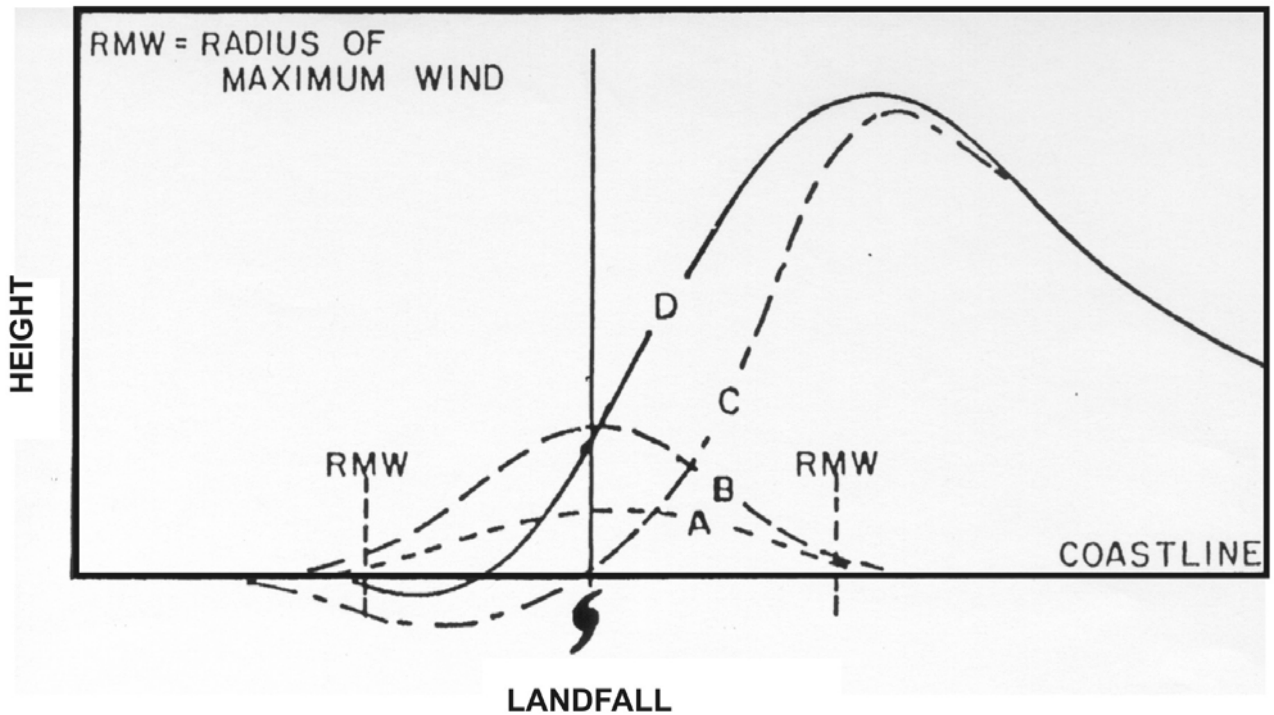

Figure C.5.6 Components of Storm Surge at a Point of Hurricane Landfall

The profiles are relative t the coastline as viewed from the sea: Line A, static negative barometric effect; Line B, dynamic negative barometric effect as a hurricane moves over shoal water; Line C, component resulting from wind loads pushing waters shoreward; Line D, combined surge profile (exclusive of contributions from wave setup)

(The Hurricane and Its Impact, Louisiana State University Press, Robert H. Simpson and Herbert Riehl, 1981)

Wind-driven waves on top of the storm surge pose a number of added problems. First of all, the wave run-up can flood areas not reached by the surge itself. Second, the battering action of waves can transmit tremendous force inland through soil pore water pressure in the saturated soils to fairly distant structures. Third, the scouring power of waves is considerable.

The duration of storm surge is usually relatively short, being dependent upon the elevation of the tide that rises and falls twice daily in most coastal places and the speed of a storm's onset. However, maximum tide elevations can be identical on consecutive days. The high velocities of hurricane winds often produce wave heights higher than the maximum level of the prevailing high tide.

The SLOSH computer model developed for FEMA computes the run-up on shore of storm surge waters. These are included and addressed by all FEMA 100 year and 500 year flood maps in the coastal areas of the U.S. Riverine and headwater flood coverage is commingled on these maps.

Storm-surge flooding is water that is pushed up onto otherwise dry land by onshore winds. Friction between the water and the moving air creates drag that, depending upon the distance of water (fetch) and the velocity of the wind, can pile water up to depths greater than 20 feet (6.1m) from the shoreline inland. The storm surge is unquestionably the most dangerous part of a hurricane as pounding waves create very hazardous flood currents. Worst-case scenarios occur when the storm surge occurs concurrently with high tide. Stream flooding is much worse inland during the storm surge because of backwater effects.

A conceptual idea of how a storm surge is that the water is pushed by the winds on the right side of the storm on to land. Winds on the left side of the storm actually push waters out of estuaries because of the seaward flow of the wind on that side.

Selected references include Department of the Army, Corps of Engineers, 1973, Jelesnianski and Taylor, 1973, Jelesnianski, 1974, Mitchell, 1893.

C-5.9.3.9 Hurricane-Headwater Flood and Scour

Heavy rainfall often accompanies hurricanes and can result in severe local inland flooding, here called headwater flooding. The amount of rainfall depends on many factors including forward speed of the storm and topography. The power of headwater flooding can be awesome in its ability to destroy not only constructed works, but also the countryside, flora and fauna.

Selected references include Conrad, 1942, Haurwitz, 1935, Ooyama, 1969, Riehl, 1979, Simpson, 1951.

C-5.9.3.10 Hurricane-Riverine Flood and Scour

Since riverine flooding accompanies all hurricanes to some degree it is also addressed here. Wind damage is usually minimal beyond about 100 miles (161 km) from a coastline locating the onset of a hurricane storm. Riverine flooding is not usually described as being experienced within this so-called first tier region. Rather, with exceptions, it is the winds, tornadoes, storm surges and headwater floods that are described as causing most of the damage in the first tier region.

Usually, riverine floods from hurricanes are described as affecting primarily areas inland from the 100 mile (161 km), hypothetical limit of wind and other subordinate hazard damages. They are still generated by locally generated heavy rains as the hurricane, cyclonic air mass passes over land. However, in the absence of heavy winds tornadoes and storm surge the headwater flood generated from heavy local rains can cause river level elevations outside of the heavy rainfall areas downstream to generate riverine flooding as well as headwater floods within those areas.

Selected references include Bailey et al. 1975, Bohman and Scott, 1980.

C-5.9.4 Earthquakes

C-5.9.4.1 General Considerations

An earthquake causes sudden trembling of the Earth as the result of abrupt release of slowly accumulating strain along a fault. The theory of plate tectonics can explain the majority of earthquakes. In this theory, re-introduced in 1967, the “solid” Earth is broken into several major plates. These 50- to 60-mile-thick (80- to 97- km) rigid plates or segments of the Earth’s crust and upper mantle move or float slowly and continuously over the interior of the Earth, meeting in some areas and separating in others. Speeds of relative motion between adjacent plates range from a fraction of an inch to about 5 inches (12.5 cm) per year. These intraplate earthquakes constitute perhaps 90% of the world’s earthquakes; another 10% of the world’s earthquakes are intraplate.

Hazards associated with earthquakes include the phenomena of surface faulting and attendant ground shaking as well as earthquake-induced landslides, liquefaction, lurching, tsunamis, seiches, and fire following.

Communities throughout the Nation face the possibility of loss from the several thousand earthquakes that happen each year. The greatest threat is from moderate earthquakes (magnitudes of 6-7) and large earthquakes (magnitudes of 7-8) because they happen more frequently than a great earthquake (magnitudes of 8 and above). For example, one moderate earthquake takes place on the average about once every 3 years in California, but a great one happens only about once every 180 years. Earthquakes happen most frequently in Alaska and least frequently in the Eastern United States (see Figures C.5.7 and C.5.8). A large set of earthquakes, such as the 1811-12 New Madrid, Missouri, earthquake series happens about once every 700 years in that area. Locations of moderate and large earthquakes in the east include the St. Lawrence River region from 1650 to 1928, in the vicinity of Boston in 1755, in the central Mississippi Valley in 1811-12, and near Charleston, South Carolina, in 1886.

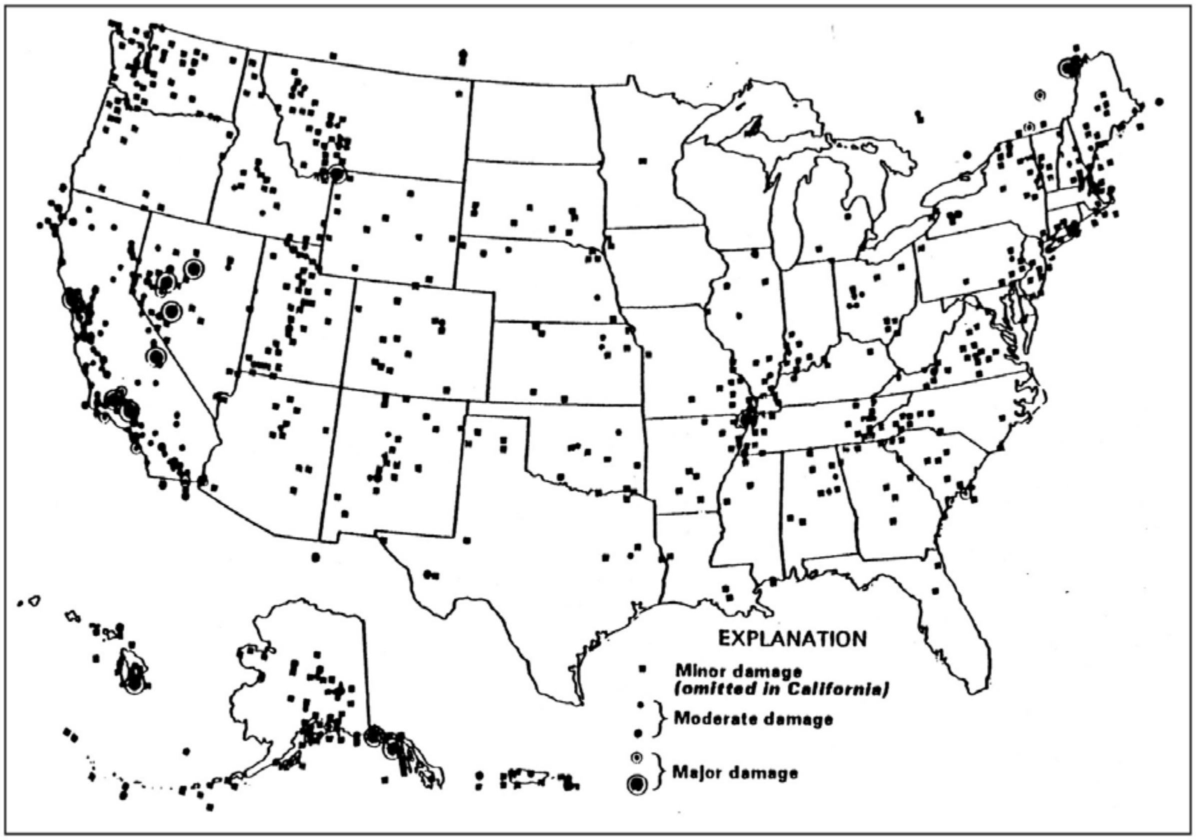

Figure C.5.7 Location of Damaging Historic Earthquakes in the United States (Geological Survey Professional Paper 1240-B)

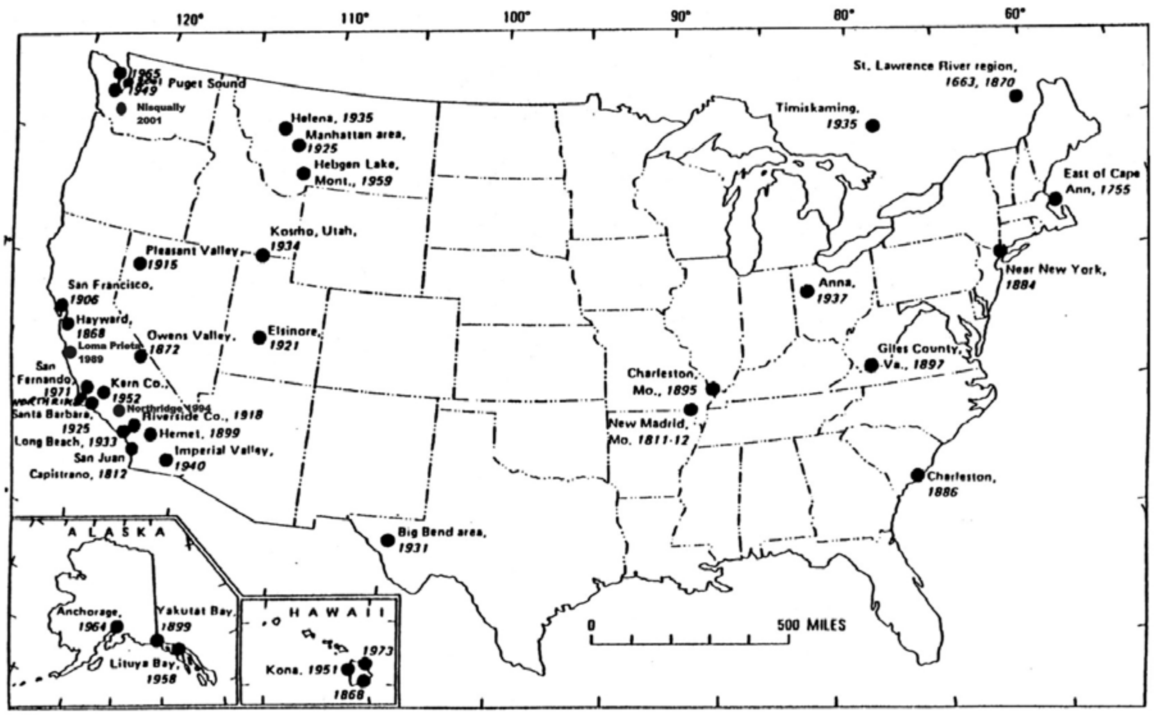

Figure C. 5.8 Location of Notable Historic Damaging Earthquakes in the United States That Have Caused Significant Damage in the Area Surrounding each Epicenter. All or part of 39 States lie in regions classed as having major and moderate seismic risk.

(Geological Survey Professional Paper 1240-B)

C-5.9.4.2 Local Earthquake—Fault Rupture

The differential movement of the two sides of a fracture at the Earth's surface is of three general types: strike-slip, normal, and reverse (see Figure C.5.9). Combinations of the strike-slip type and the other two types of faulting can be found. Although displacements of these kinds can result from landslides and other shallow, earth failure processes, surface faulting, as the term is used here, applies to differential movements caused by deep-seated tectonic or volcanic forces in the Earth, the slow movement of sedimentary deposits toward the Gulf of Mexico, and faulting associated with salt domes.

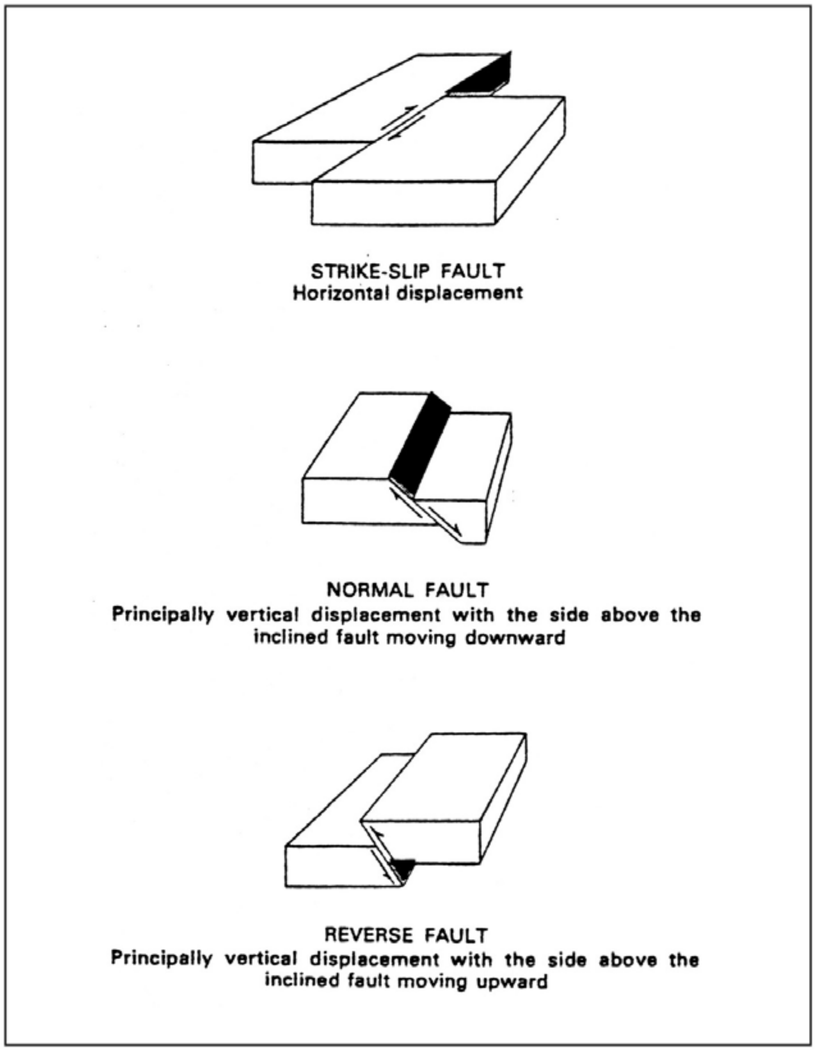

Figure C.5.9 Three General Types of Fault Movement

Surface faulting, in the case of a strike-slip fault, generally affects a long narrow zone whose total area is small compared with the total area affected by ground shaking. Nevertheless, the damage to structures located in the fault zone can be very high, especially where the land use is intensive. A variety of structures have been damaged by surface faulting, including houses, apartments, commercial buildings, nursing homes, railroads, highways, tunnels, bridges, canals, storm drains, water wells, and water, gas, and sewer lines. Damage to these types of structures has ranged from minor to very severe.

The displacements, lengths, and widths of surface fault ruptures show a wide range. Fault displacements in the United States have ranged from a fraction of an inch (2.54 cm) to more than 20 feet (6.1 m) of differential movement. As expected, the severity of potential damage increases as the size of the displacement increases. The lengths of the surface fault ruptures on land have ranged from less than 1 mile (1.61 km) to more than 200 miles (322 km). Most fault displacement is confined to a narrow zone ranging from 6 to 1,000 feet in width, but separate subsidiary fault ruptures may occur 2 to 3 miles (3.2 to 4.8 km) from the main fault. The area subject to disruption by surface faulting varies with the length and width of the rupture zone.

Avoidance, system redundancy, and engineering design including flexibility to accommodate the differential displacements are the primary actions that will reduce losses from surface faulting. Avoidance requires accurate location of the fault and an assessment of its history of activity through a detailed geologic or earthquake hypocenter examination. Structures, such as pipelines, dams, bridges, and aqueducts, sometimes cannot be built without crossing active faults. Some of these structures have been designed and constructed to accommodate some fault displacements in an earthquake.

Areas in the United States where young surface faults are known to exist are mapped by the USGS (See Chapter 3, volume 1). This map shows faults in two general categories-those that have had displacement within the last 10,000 years (Holocene period) and those that have had displacement within the last 2 million years (Quaternary period). Faults can lie dormant for many thousands of years between periods of vigorous activity, and, therefore, their behavior over a substantial part of their recent history must be considered probabilistically. Those with very long return intervals may still contribute to the overall risk to a water system—at least in defining extreme risks.

The national atlas website locates these faults more precisely in pictorial form while the USGS, National Seismic Hazard Mapping Project-Fault Parameters precisely locates the active faults and their widths. State Geologists have even more detailed information on fault location and age for each of their states, should the USGS data be deemed to be incomplete. The State of California, for instance, has for three decades undertaken extensive mapping of active fault traces.

Selected references include Blair and Spangle, 1979, Bonilla, 1979, Cluff and Bolt, 1969, Hart, 1977, Howard et al., 1978, Kockelman, 1980, Russ, 1979, Verbeek, 1979.

C-5.9.4.3 Earthquake—Shaking

Ground shaking is caused by body and surface traveling seismic waves. As a generalization, the severity of ground shaking increases as the magnitude or earthquake size increases and decreases as distance from the causative fault increases. Surface and buried structures are more easily damaged from horizontal motions than from vertical motions.

Body waves mainly cause high-frequency vibrations (less than two seconds per cycle), surface waves only low frequency vibrations. Body and surface waves cause the ground, and consequently a structure to vibrate in a complex manner. The objective of most earthquake-resistant design for surface structures is to construct a structure so that it can withstand the ground shaking.

In land-use zoning and earthquake-resistant design, knowledge of the amplitude, frequency composition, and the time duration of ground shaking is desirable. These quantities can be determined from empirical data and correlating them with the magnitude and the distribution of Modified Mercalli Intensity of the earthquake, distance of the structure from the causative fault, and the physical properties of the soil and rock underlying the structure. The subjective Modified Mercalli Intensity Scale indicates the intensity of ground shaking on man, structures and the surface of the Earth. It can be correlated with physical shaking properties.

The size of the geographic area affected by ground shaking depends on the magnitude of the earthquake and the rate at which the amplitudes of seismic waves decrease as distance from the causative fault increases. Comparison of the areas affected by the same Modified Mercalli intensity of ground shaking in the 1906 San Francisco, California, the 1974 Northridge, California, the 1811-12 New Madrid, Missouri, and the 1886 Charleston, South Carolina, earthquakes shows that a given intensity of ground shaking extends over a much larger area in the Eastern United States than it does in the west for comparable magnitude events. Ground shaking affects a larger area east of about the 104-degree longitude line because amplitudes of seismic waves decrease more slowly than those west of the 104-degree longitude line, as distance from the causative fault increases.

Considerable efforts have been undertaken by government, academicians, and consultants to evaluate earthquake hazards from strong ground motions. Particular reference is made to efforts by the USGS to develop probabilistic strong ground motion maps. These maps define strong ground shaking at various return intervals (e.g., 50 year life with a 10%, 5% and 2% chance of occurrence) for the entire United States (see Chapter 3, volume 1). These efforts may be called probabilistic seismic (site) hazard evaluations (PSHA's). As noted throughout this document, evaluating water systems risks requires the use of individual scenarios, since they are not located at a single site. As a consequence, with rare exceptions, the results of PSHA's are not useful in the actual evaluation of water system risks—unless wastewater utility systems are small in spatial extent. However, the models developed by geoscientists and engineers in constructing probabilistic seismic hazard maps can be desegregated and then recombined to produce bases for earthquake hazard evaluations.

Of special interest in the USGS source is a catalog of previous historic earthquakes. These can provide a first basis for constructing specific scenarios. More detailed investigations of existing fault systems can provide, as needed greater detail on specific earthquake scenarios—treated first as repetitions of past history. Likewise, various other entities (such as Tri-Net) have developed deterministic scenarios that may be useful in intermediate operations assessments for wastewater utility systems.

<u>Selected references</u> include Abrahamson and Silva, 1997, Algermissen and Perkins, 1976, Bolt, 1993, Borcherdt, 1975, Federal Emergency Management Agency, 1981, Frankel et al., 1996, Hays, 1980, Hwang and Huo, 1997, Nuttli, 1973, Somerville, 1997, J. H. Wiggins, 1979.

C-5.9.4.4 Earthquake—Landslide

Because certain types of ground failures are frequently associated with earthquakes as well as other causes such as gravity, moisture changes, etc. they will be discussed in this section for continuity.

Several types of landslides take place in conjunction with earthquakes. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. Shallow debris slides forming on steep slopes and soil and rock slumps and block slides forming on moderate to steep slopes also take place, but they are less frequent. Reactivation of dormant slumps or block slides by earthquakes is rare and is most likely preceded by heavy or continuous rains.

Large earthquake-induced rock avalanches, soil avalanches, and underwater landslides can and do occur. They can be very destructive. Rock avalanches originate on over-steepened slopes in weak rocks. The size of the area affected by earthquake-induced slope failures depends on the magnitude of the earthquake, its focal depth, the topography and geologic conditions near the causative fault, and the amplitude, frequency composition, prior rains or other sources of wetting and duration of ground shaking. In past earthquakes, landslides have been abundant in some areas having intensities of ground shaking as low as VI on the Modified Mercalli Intensity Scale or about 6% of gravity as the associated peak acceleration. In this case the earth material was already in a state of incipient failure.

<u>Selected references</u> include Brown and Kockelman, 1983, Keefer et al., 1978, Nilsen et al., 1979, Seed, 1970, Youd and Hoose, 1978.

C-5.9.4.5 Earthquake—Lurching/Lateral Spreads

Lurching includes lateral spread, flow failures and loss of bearing strength during an earthquake. It is sometimes hard to distinguish landslide from lurching or liquefaction since land failure is the common result of each. Lateral spreads involve the movement of large blocks of soil as a result of liquefaction in a subsurface layer. Movement takes place in response to the ground shaking generated by an earthquake. Lateral spreads generally develop on gentle slopes, most commonly on those between 0.3 and 3 degrees. Horizontal movements of lateral spreads commonly are as much as 10 to 15 feet (3.0 to 4.6 m), but, where slopes are particularly favorable and the duration of ground shaking is long, lateral movement may be as much as 100 to 150 feet (30 to 46 m). Lateral spreads usually break up internally, forming numerous fissures and scarps in the surficial earth materials.

Lateral spreads are particularly destructive to pipelines.

Flow failures, consisting of liquefied soil or blocks of intact material riding on a layer of liquefied soil, are the most catastrophic type of ground failure caused by lurching. These failures commonly move several tens of feet and, if geometric conditions permit, several tens of miles.

Flows travel at velocities as great as many tens of miles per hour. Flow failures usually form in loose saturated sands or silts on slopes greater than 3 degrees.

Flow failures can originate either underwater or on land. Many of the largest and most damaging flow failures have taken place underwater in coastal areas.

When the soil supporting a structure loses strength due largely to the presence of water from frequent precipitation or seaside infiltration, large deformations can occur within the soil, allowing the structure to settle and tip.

Actions for reducing damage due to loss of bearing strength include: (1) site selection to avoid the hazard, (2) stabilization of liquefiable layers to prevent loss of strength, and (3) use of deep foundations (such as piles) to transfer loads to layers underlying potentially liquefiable ones.

C-5.9.4.6 Earthquake—Liquefaction

Liquefaction is a physical process that takes place during some earthquakes that may lead to ground failure. As the name suggests, water must saturate the interstices (be below the water table) of the grains making up the soil. As a consequence of liquefaction, clay-free soil deposits (primarily fine sands and silts) temporarily lose strength and behave as viscous fluids rather than as solids. Liquefaction takes place when seismic shear waves pass through a saturated granular soil layer, distort its granular structure, and cause some of the void spaces to collapse. Disruptions to the soil generated by these collapses cause the transfer of the ground shaking load from grain-to-grain contacts in the soil layer to the interstitial pore water. This transfer of load increases pressure in the pore water, either causing drainage to occur or, if drainage is restricted, a sudden buildup of pore-water pressure. When the pore-water pressure rises to about the pressure caused by the weight of the column of soil, the granular soil layer behaves like the fluid water rather than like the solid grains for a short period. In this condition, soil deformations can occur easily.

Liquefaction can be associated with landslide and lurching as the earlier discussion of these hazards suggests. However, in this section it is referred primarily to areas with no slope. It is restricted to certain geologic and hydrologic environments, mainly areas where sands and silts were deposited in the last 10,000 years and where the ground water table is within 30 feet (9.1m) of the surface. Generally, the younger and looser the sediment and the higher the water table, the more susceptible a level soil is to liquefaction.

Actions for reducing losses from liquefaction include: (1) zoning to limit construction in susceptible areas, (2) stabilization to prevent liquefaction and ground failure, and (3) construction of displacement-resistant foundations. Engineering techniques for stabilizing sites against liquefaction include compaction, grouting, or drainage of susceptible soils. These techniques are generally expensive and, therefore, are not economically feasible unless critically important water supply and other lifeline facilities are being built. Construction of displacement-resistant foundations is presently beyond the state-of-the-art for ground-failure displacements greater than about one foot (0.3 m).

Selected references include California Division of Mines and Geology, 1992, Leighton and Associates, 1993, Youd, 1992, Youd and Hoose, 1978.

C-5.9.4.7 Earthquake—Tsunami

Tsunamis are water waves that are caused by the sudden vertical movement of a large area of the sea floor during an undersea earthquake. (Note that an earthquake that occurs on land can trigger submarine slips, which in turn can create tsunamis.) The earthquake may be tectonic or volcanic in origin. Tsunamis are often called tidal waves, but this term is a misnomer. Unlike regular ocean tides, tsunamis are not caused by the tidal action of the Moon and Sun.

The height of a tsunami in the deep ocean is typically about one foot (30 cm), but the distance between wave crests can be very long, more than 60 miles (96.5 km). The speed at which the tsunami travels decreases as water depth decreases. In the mid-Pacific, where the water depths reach about 3 miles (4.8 km), tsunami speeds can be more than 400 miles per hour (644 km/hr). As tsunamis reach shallow water around islands or a shallow continental shelf, the height of the waves increases may times, sometimes reaching as much as 80 feet (24m). (During the eruption of Krakatoa in Indonesia waves of about 200 feet (or 61m) were observed.) The great distance between wave crests prevents tsunamis from dissipating energy like a breaking surf; instead, tsunamis cause water levels to recede and rise rapidly along coast lines.

Tsunamis and earthquake ground shaking differ in their destructive characteristics. Ground shaking causes destruction mainly in the vicinity of the causative fault, but tsunamis cause destruction both locally and at very distant locations from the area of tsunami generation since they can travel thousands of miles with very little amplitude attenuation.

A current theory under development is that during an earthquake some of the largest localized tsunamis are caused by underwater landslides instead of by the motion of the seafloor. From an emergency standpoint, the implication is “If you see the sea receding, get out and stay out!” This viewpoint saved many lives in the village Biai Martele in Vanuatu, affected by a tsunamis in December, 1999 (See Douglas Smith, 2000; Tappin et al., 2002; Grilli and Watts, 2001)

Destruction to structures and other facilities is a consequence of the time between successive wave crests, the wave heights at the shoreline and inland locations, and the wave and current velocities. The effects of tsunamis include structural failure, scouring, erosion, flooding, and movement of stone and debris.

Selected references include Houston, 1980, Houston et al., 1977, Wiegel, 1970.

C-5.9.4.8 Earthquake—Seiche

A seiche is a natural standing wave in the water of a lake or bay. It can be caused by seismic disturbances, among other causes, and continues after the seismic shaking has stopped. Every enclosed body of water has a number of natural resonances. If you sit in a bathtub part full of water and rock back and forth you will find that at the right period (about a second) you can easily get the waves to grow until they overflow the bath. The resonant oscillation of the water is a seiche. Seiches are often generated in swimming pools by small oscillations from earthquakes – the oscillations happen to be at the right frequency for the swimming pools to "catch" them.

Seiching is the formation of standing waves in a water body, due to wave formation and subsequent reflections from the ends. These waves may be incited by earthquake motions (similar to the motions caused by shaking a glass of water), impulsive winds over the surface, or due to tsunami wave motions entering a basin. The various modes of seiching correspond to the natural frequency of the water body.

A rectangular basin (of infinite width) with given length and depth is modeled as seiching in accordance with mode that is specified. The period of seiching (T) is determined by finding the correct length wave that will fit in the basin for the given water depth (based on linear water wave theory). For shallow water theory, the seiching period is given by twice the basin length (l) divided by the modal number (n) and the speed of a shallow water wave, which depends on the water depth h:

$$T = 2l/(n^*(gh)^{0.5} \qquad \textbf{\textit{Equation (C-5-1)}}$$

There are an infinite number of seiching modes possible, from the lowest (mode 1) to infinity. The period of oscillation decreases with mode number. Realistically, the lower modes probably occur in nature, as frictional damping reduces the amplitudes of the higher modes (higher frequency).

San Francisco Bay is used as an example. If the length is 2 miles (3.21km) and the depth 50 feet (15.2m), then the period of the first mode is 264 seconds. The 30th mode is about 9 seconds. Nearby earthquakes are not expected to stimulate these modes. Any higher modes within the frequency range would experience damping. Only large distant earthquakes with clearly defined surface waves may excite San Francisco Bay. These might originate on the eastside of the Sierra Madre range. However, the only known earthquake that occurred at distance, the 1964 Great Alaskan earthquake, did not cause visible seiche.

<u>Selected reference</u>: Chapters 4 and 5 of Dean and Dalrymple.

C-5.10 Human Threats

This section discusses the identification of critical facilities and assets that will form an inventory of structures and equipment that will be examined as part of the security vulnerability assessment. Next, the considerations for evaluating the effectiveness of physical protection systems (such as fences and access control systems) and the vulnerabilities of cyber systems and operational systems (such as the procedures in place to respond to security breaches) are presented.

Human threats comprise actions by an individual or individuals to inflict adverse impacts on system facilities and/or assets. Human threats are addressed separately from natural, technological and lifelines hazards in this document since such threats possess the following unique characteristics:

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 most natural hazards can be. The evaluation needs to examine what threat is reasonable to protect against and select what the probability of attack is to be.
2. The nature of the damage caused can be significantly different from the potential damage anticipated from natural and other hazards: an attacker may attempt to introduce explosive material into the system that may subsequently detonate, for example.
3. The systems in place to reduce the vulnerabilities to human threats and enhance security are to some degree different than those for natural and other hazards. Such systems comprise physical protection, operating systems and cyber security.

In response to the Public Health Security and Bioterrorism Preparedness and Response Act of 2002, the RAM-W 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. The RAM-W methodology forms the basis for the discussion in this chapter and the subsequent chapter. An additional methodology, VSAT, has also been developed for performing security vulnerability assessments of water and wastewater systems. Utilization of this methodology will be discussed in Chapter 11.

RAM-W utilizes the following risk equation:

$$R = P_A * (1 - P_E) * C \qquad \textit{Equation (C-5-2)}$$

where:

R = Relative Risk (no units)

P_A = Likelihood (probability) of occurrence of the hazard/threat

P_E = System Effectiveness (subtracted from 1 equals vulnerability)

C = Consequences to the system of failure of a particular facility or component

The elements and approach of the RAM-W℠ methodology are illustrated in Figure C.5.10. The remainder of this chapter will discuss the Threat Assessment element of the methodology.

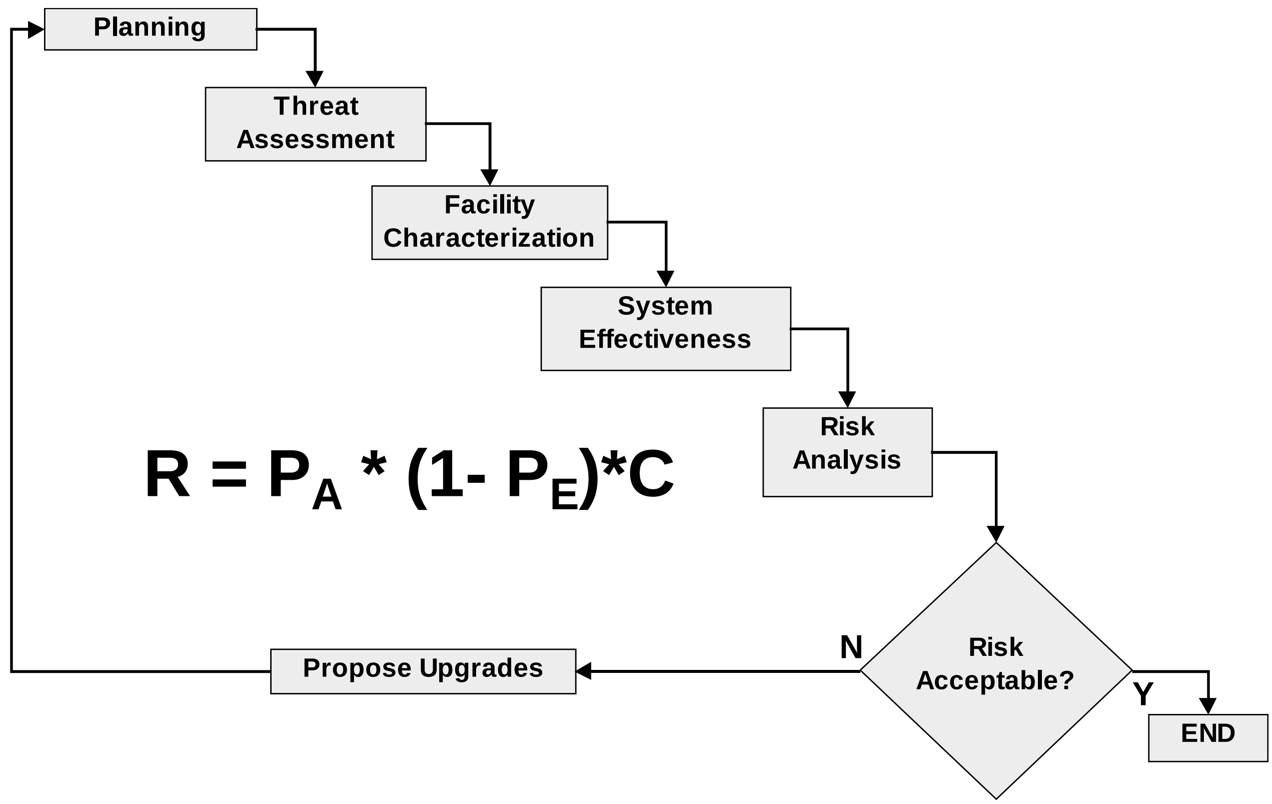

Figure C.5.10 RAM-W^{SM} Methodology

C-5.10.1 Categories of Adversaries - Inside, Outside, and Cyber

As part of analyzing human threats, it is helpful to distinguish between three broad and generally accepted classifications of threat:

- **Outsider**: an individual/group with no direct or indirect affiliation to the utility,
- **Insider**: an employee, contract person, or other individual who has some degree of access to the utility, and
- **Cyber**: an individual/group that poses a threat to system operation and/or utility functions via computer interfaces.

Each of these threat categories can possess some differences in characteristics with respect to motivation, access to facilities, knowledge of the system, tactics and others, and thus warrant separate examination. Table C.5.8 illustrates characterizes different levels of threat within each category.

C-5.10.2 Factors Influencing the Probability of Attack

Currently, there are no readily available means to accurately characterize the probability or likelihood of a state-sponsored terrorist attack. To the extent that national authorities gain such knowledge, it is highly classified. Continuing down the threat spectrum, through domestic terrorism, to disgruntled employees, to immature individuals, the likelihood for attack in general increases. The factors that influence the probability of attack can be effectively examined by utilizing an assessment tool termed CARVER. CARVER is an acronym that stands for:

- Criticality
- Accessibility
- Recuperability
- Vulnerability
- Effect on Populace
- Recognizability

The relative value of an attack determined through the CARVER methodology reflects the "target ability" of the system being examined. A higher number indicates a more "desirable" target; a lower number indicates a less desirable the target from the assailant's perspective. A potential target is rated on scale of *1-5*, with lower numbers being less desirable.

FEMA 426 has recently published a document entitled *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings* (http://www.fema.gov/fima/rmsp426.shtm) that provides generalized information on assessing the potential for an attack.

C-5.10.2.1 Cyber Attacks

Worldwide, the one significant cyber-terror attack that was successful resulted in the pumping of raw wastewater into an Australian water supply. The attacker contaminated the waterways of the Sunshine Coast in Queensland in March and April 2000. The attacker was a former employee who did the damage for personal reasons. He learned how to use the controls as an insider, while an employee. He utilized remote radio transmissions to take control of the sewage pumping station at Pacific Paradise, north of Maroochydore. Over a period of two months, while trying to get a consultant's job with Maroochy Shire Council to clear up the pollution he was causing, he made 46 attacks, releasing hundreds of thousands of gallons of raw sewage into public waterways.

The *Washington Post* reported on June 27, 2002 that a suspicious pattern of surveillance against Silicon Valley computers had been discovered. The attackers were coming from the Middle East and South Asia, exploring the digital systems used to manage San Francisco Bay Area utilities and government offices. According to the *Post*,

Table C.5.8 Characterization of Potential Human Threats
[In the Prob (Probability) Column, VH=very high, H=high, M=medium, L=low, L-VL=low to very low, and VL=very low],

Prob	Adversary	Motivation	Example Acts	Example Utility Experience	No. Persons	Equipment / Vehicles	Knowledge	Weapons	Tactics
	Outsider								
VH	Immature	Opportunity [showing off / boredom]	Graffiti	Graffiti, gang activity-graffiti, teenagers jumping fence; trash in parking areas	1 to 3	car, paint, tools of opportunity	none	none	none
H	Vandal / Homeless	Opportunity	Property damage; attack employee or property	Vandals causing damage (tagging/paint cans in vehicles]	1 to 2	car, hand tools	none	none	Minimal pre-planning; opportunistic. Generally non-forced entry, defile and run
M	Criminal	Profit, revenge, spousal, irrate rate payer	Attack employee or property.	Drug activity. Employee vehicle vandalism. Theft of commercial explosives. Terminated sex offender.	1 to 4	cars, tools, entry tools	from surveillance or collusion	small arms	assault, coercion/hostage, sabotage, mujlitple vehicles
M	Disgruntled	Revenge, spousal, union issue, irrate rate payer, "savior"	Attack employee or property	Terminated sex offender.	1	cars, tools	surveillance, unwitting employee	small arms	assault, coercion/ hostage, sabotage
L	Sociopath	Pathological	Damage major equipment, poison water supply	Psyochotic episode-rate payer calls for service	1	car	limited	small arms	none
L - VL	Terrorist, **DOMESTIC**	Political, social cause [environmental, militia]	Major services disruption, destroy sources/system	Aryan Nation cells. Theft of 300 lbs commercial explosives.	1 to 15	car, radios, surveillance equip, tactical gear	system study, military service/ rudimentary trng, CARVER, local	small arms, heavier weapons, home-made explosives	sabotage, collusion
VL	Terrorist, **INTERNATIONAL**	Religious, ethnic	Major service disruption, destroy sources/system, poison supply	Terrorist suspect held at detention center in area. Local theft of 300 lbs commercial explosives.	1 to 3 person cell. Possibly multiple cells in area but probably working independently.	Simple tools / on-site heavy equipment / car, radios, surveillance equip. Prefer innocuous tools that are easily procured and disguised.	Limited technical knowledge or tactical training. Study system+H18, rudimentary trng, CARVER-like.	small arms, explosives	Sabotage of relatively accessible sites of potential economic, psychological, cultural significance or other symbolism. Some willing to sacrifice life… but not majority. Intent: economic, psychological, [or both] destabilization. Look for easiest target to achieve objectives. Not sophisticated or particularly innovative but skilled at making use of basic "tools" and available material. Event anniversaries. No regard for life; seek highest possible body count. PATIENT.

Table C.5-8 Characterization of Potential Human Threats (continued)

Prob	Adversary	Motivation	Example Acts	Example Utility Experience	No. Persons	Equipment / Vehicles	Knowledge	Weapons	Tactics
	Insider	***[witting / unwitting / active / passive]***							
M	Admin	Disgruntled, termination, spousal, collusion, union, "savior"	Threats, property damage, disrupt record keeping, attack personnel	Embezzlement of funds	1	car, tools, computer	admin system, policies, procedures	none	sabotage, capitalize on access
M	ADP/IT	Disgruntled, termination, spousal, collusion, union, "savior"	Threats, property damage, disrupt service, attack personnel		1	car, tools, SCADA, security system interface	IT systems, policies, procedures	none	sabotage, capitalize on access
M	Plan Ops / Watch stander	Disgruntled, termination, spousal, collusion, union, "savior"	Threats, property damage, disrupt service, attack personnel		1	SCADA, sampling, car, tools	system, policies, procedures	none	sabotage, capitalize on access
M	Maintenance	Disgruntled, termination, spousal, collusion, union, "savior"	Threats, property damage, disrupt service, attack personnel		1	heavy equipment, car, tools	system, policies, procedures	none	sabotage, capitalize on access
M	Contractor [service: vendor/trash/delivery/ security firm]	Disgruntled, termination, spousal, collusion, "savior"	Threats, property damage, disrupt service, attack personnel	On-site contractor physical confrontation	1	security system, car, tools	system	guard: small arms	sabotage, capitalize on access
VL	Terrorist ["sleeper"]	Political, religious, social cause	Destroy sources/system, poison supply		1	car, tools	system, policies, procedures	small arms, explosives	sabotage, capitalize on access, fatalities

Prob	Adversary	Motivation	Example Acts	Example Utility Experience	No. Persons	Equipment / Vehicles	Knowledge	Weapons	Tactics
	Cyber								
H	Amateur	Opportunity / challenge	Disrupt email, denial of service, website deface.		1	computer/internet, hacking software	none	n/a [virus]	internet penetration, hacker virus, email attachments
M	Expert Hacker / Group	Challenge / disgruntled	Cyber instrusion into SCADA, billing, administrative services to disrupt/destroy data, denial of service, disrupt SCADA/operations, or disrupt billing.		1 to 4	computer/internet, hacking software	none	n/a [virus]	internet penetration accessing SCADA/billing/other
L	Cyber Insider / vendor	Disgruntled, termination, spousal, collusion, "savior"	Disrupt SCADA, billing, or alarm systems		1	computer/internet access, internal computer, hacking software, virus	SCADA and internal admin	n/a [virus]	internet/ internal penetration targeting SCADA/billing/other
VL	Terrorist [domestic, state, non-state int'l]	Political, religious, social cause	Cyber instrusion into SCADA, billing, administrative services. System damage, loss of life via SCADA		1 to …	sophisticated computer/internet, internal computer, hacking software, virus	none	n/a [virus]	internet penetration targeting SCADA/other

> "A forensic summary of the investigation, prepared in the Defense Department, said the bureau found "multiple casings of sites" nationwide. Routed through telecommunications switches in Saudi Arabia, Indonesia and Pakistan, the visitors studied emergency telephone systems, electrical generation and transmission, water storage and distribution, nuclear power plants and gas facilities. Some of the probes suggested planning for a conventional attack, U.S. Officials said. But others homed in on a class of digital devices that allow remote control of services such as fire dispatch and of equipment such as pipelines. More information about those devices -- and how to program them -- turned up on al Qaeda computers seized in 2003, according to law enforcement and national security officials. Unsettling signs of al Qaeda's aims and skills in cyberspace have led some government experts to conclude that terrorists are at the threshold of using the Internet as a direct instrument of bloodshed."

The cyber probers appear to be extremely interested in distributed control systems, or DCS, and Supervisory Control and Data Acquisition, or SCADA, systems. Because the digital controls were not designed with public access in mind, they typically lack even rudimentary security.

Based on the information provided by the CIA, the publicity about the Australian case, and the potential for significant consequences, serious efforts should be made to prevent cyber attacks against wastewater systems.

C-5.10.3 Uncertainty of Probability of Attack

The likelihood of occurrence of a terrorist attack on utility facilities is very difficult to quantify. Unlike natural disasters which can be analyzed and probabilities of occurrence developed based on historical data and engineering principals, terrorism by its very nature and definition defies a reasonable level of predictability. While the relevance of the probability of attack – P_A – in analyzing risk is generally accepted, quantifying P_A is the subject of much debate. Relative to the analytical process outlined in Figure C.5.11 it is generally contended that:

- The probability of a terrorist attack cannot be measured.
- The measure of effectiveness for deterrence of a terrorist attack cannot be gauged.

When focusing internally on the utility system and facilities, the likelihood of an attack on one part of the system versus another is extremely difficult to differentiate. For this reason, the probability of attack is assigned a value of 1.0. Regardless of the value assigned, other variables in the analytical process are sufficient to complete the assessment; these remain the principal variables that utility can influence: the reduction of vulnerability.

This is not to imply that deterrence does not have its place. Proactive deterrent measures can have significant impact on overall security. As an example, surveillance of a potential target is standard procedure for terrorists; if their surveillance reveals a well guarded, relatively hardened facility with alert personnel, they are far more likely to select a comparable target that is more vulnerable. The difficulty arises in measuring the effectiveness of deterrence. While much theoretical discussion surrounds this issue, in the interests of providing reasonable and prudent recommendations, assigning a probability of attack of 1.0 is recommended.

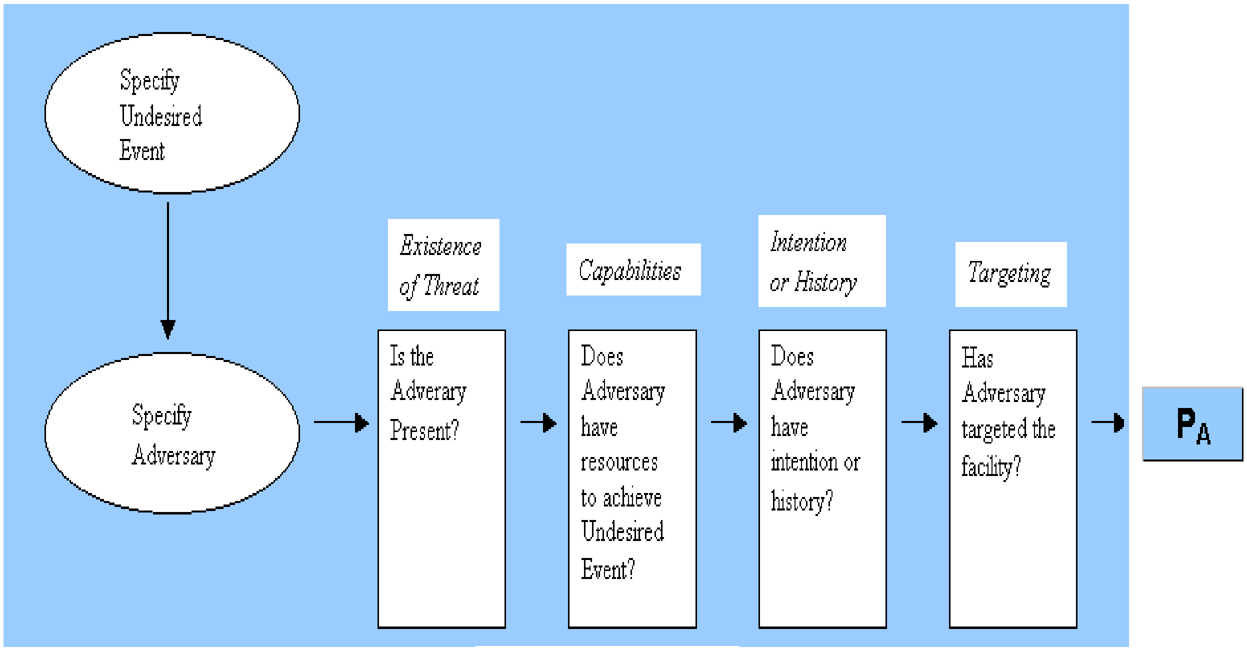

Figure C.5.11 Quantifying P_A

A highly pragmatic approach to estimating the probability of an attack on a wastewater system may suggest that the actual likelihood is relatively low. If one assumes there are 400 large wastewater treatment utilities in the US and that one significant attack will be conducted at a large utility every five years hence (an attack in which the system overall is significantly disabled), the average return period for an attack on any given large facility is 2,000 years. A similar estimation can be calculated for moderately sized utilities. If one assumes there are 8,000 medium and small utilities in the US, the return period, based on the same assumptions above, is 40,000 years. Return periods of these magnitudes represent extremely rare events, and help to put the actual expected likelihood of an attack into perspective. Again, for purposes of the assessment, a probability of attack of 1.0 is recommended.

C-5.10.4 Design Basis Threat

The design basis threat (DBT) is the “design criteria” for the security assessment, against which utility’s current level of security will be compared. Potential threats to the system span a spectrum of acts, ranging for example from teenagers perpetrating acts of graffiti, through a cadre of dedicated state-sponsored terrorists with ample resources, to large military actions. Based on information furnished by local and regional law enforcement agencies (LEA), the security consultant, utility’s own history of security threats and violations, a utility’s preference to provide protection against a major security threat must be balanced against the understanding that the resources required to provide this protection may not be available. By consideration of these factors, utility selects a DBT within the spectrum of possible DBTs (as illustrated in Table C.9.1), as a starting point for the assessment of current security vulnerability, and the determination of possible improvements. Like any design process, the RAM-W methodology encourages a re-examination of the DBT, based on the outcome achieved from the initial starting point.

The DBT is a key element of the RAM-W^{SM} methodology. It influences every parameter of RAM-W risk equation, directly impacting the assessment and final results. Defining the DBT has a five-fold purpose:

- The DBT reduces the terrorist spectrum to a manageable size and characterizing the threat to which utility may be conceivably exposed ("what is the threat?").
- The DBT reduces the broad field of potential adversarial actions that could conceivably be perpetrated against utility to quantifiable threats against which utility can reasonably defend itself **("**what is the threat against which utility can reasonably design its system, both physical and operational, to defend against?"); keeps this metric in the forefront throughout the analytical process.
- The DBT provides the basis for developing tailored physical, operating, and cyber procedures and countermeasures to reduce utility vulnerability.
- The DBT ensures senior management concurrence upon and support of the design basis ("buy in").

In addition to understanding the DBT's purpose, it is important to recognize how the DBT is developed. The flow diagram depicted in Figure C.5.12 provides the process and key constraints that influence it:

1. Threats exist from which utility will not be able to protect itself, and
2. Resource limitations (time, dollars, personnel, political sensitivities).

In developing the DBT, there are three generally accepted classifications:

- **Outsider**: an individual/group with no direct or indirect utility affiliation
- **Insider**: an employee, contract person, or other individual who has some degree of access to utility
- **Cyber**: a hacker

Within each DBT classification, a number of sub-category threats are developed and each is scrutinized on the basis of *access*, *motive*, and *opportunity*. The process is iterative, incorporates multiple forms of information collection, and entails detailed characterization of threat capabilities. Site surveys and meetings with LEA bolster initial analyses of the DBT developed on the basis of the threat assessment. The DBT development process explores a broad adversarial spectrum and focuses on potential exploitation of both systemic and site-specific vulnerabilities. The spectrum is systematically reduced and culminates with the selection of a single generic profile for each classification (*outsider*, *insider*, and *cyber*). Indicative of its import, the DBT is briefed to and receives utility senior management endorsement before the RAM-W assessment continues.

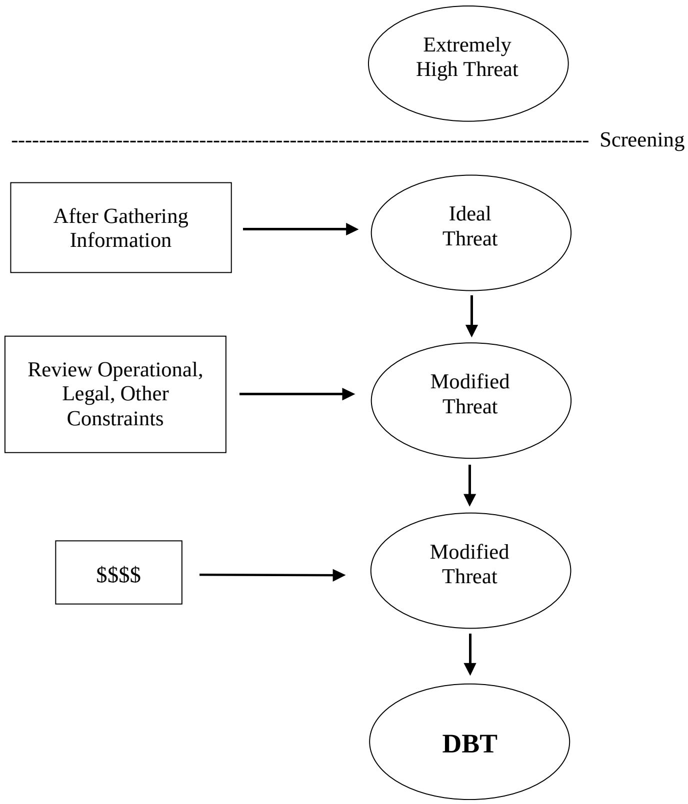

Figure C.5.12 Design Basis Threat Selection

The Sandia RAM-W methodology assumes that the likelihood of attack should be seen as certain, which therefore influences the choice of the DBT – in effect, the choice of the DBT is based on an assumed eventual attack. However, if utility is alerted at some time that a threat exceeding their DBT may exist, the threat can be subsequently mitigated by emergency planning and pre-planned ad-hoc operational measures. Utility's emergency operations plan should include this potentiality.

The following is an example DBT. Utility management should ultimately approve the DBT:

- **OUTSIDER**: Three - four individuals of a small, largely unsupported and independent activist--or loosely federated terrorist--cell; minimal training in wastewater system design or operations; access to vehicles and limited small arms; capable of stealing/operating heavy construction equipment assembling rudimentary improvised explosives; effective basic surveillance; minimal formal training in small unit operations. Very limited financial resources. No insider collusion. Goal: Disrupt operations.
- **INSIDER**: One disgruntled employee or contractor with basic knowledge of and access to the wastewater system, system operation, and system controls. Intent: non-injury disruption of services or personal vengeance against an employee.
- **CYBER:** A hacker with ability to compromise SCADA system if access gained and no collusion. Intent: Disrupt utility services facilities through SCADA manipulation to damage system, cause public loss of confidence, and/or cause third-party consequential damages.

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

Supplemental Material for Step 6 of the Guideline

Step 6 of the Commentary covers general considerations in estimating the damage of wastewater system components to specific natural hazards and human threats. Of special importance in a wastewater system evaluation is how damage is estimated in terms of the component functionality and also its restoration time. Costs of damage are of secondary importance with reference to a wastewater systems evaluation.

The general form of a component vulnerability model may be represented in terms of damage (e.g., functionality, critical downtime, and/or repair cost) as a function of natural hazard intensity. The form of the model may be deterministic or it may be probabilistic. Probabilistic models are often called fragility models. One may use very simple forms of such a vulnerability model, a triangular probability density function resulting in an “S”-shaped cumulative distribution function. More complex forms are available, and given the robustness of computer methods, non-parametric methods are also useful. However, the greater challenge is how to define credible models for assessing the vulnerability of components—especially in view of the many natural hazards discussed in this document and the comparative dearth of systematic data on which to base these models.

C-6.1 General Methods for Developing Component Vulnerability Models

C-6.1.1 Objectives [Outputs Desired]

The objective of methods to develop component vulnerability modes is for each level of site-specific hazard intensity to estimate, for each component (a) direct economic loss and (b) downtime. Direct economic loss (repair cost) is important ultimately for establishing aggregate repair costs given specific natural hazard events. Estimating component downtime is important in ultimately estimating time-lines of system recovery, and time-element losses.

Plots (a) through (d) in Figure C.6.1 exemplify the types of outputs from component vulnerability models. Plots (a) and (b) are deterministic component vulnerability models and (c) and (d) are fragility models (for which many variants exist).

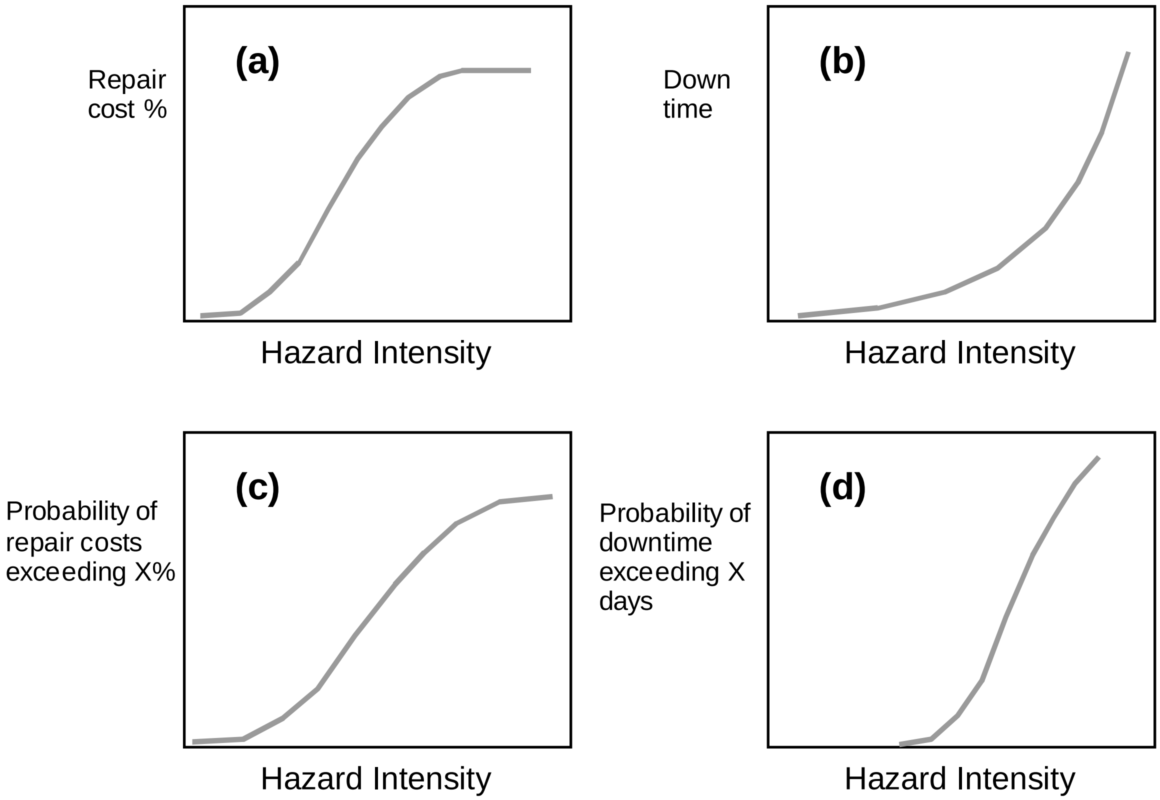

Figure C. 6.1 Types of Component Vulnerability Models

C-6.1.2 General Types of Methods

Under ideal conditions, component vulnerability models for wastewater systems would be drawn from a large database, spanning all types of components, under the full range of levels for each hazard. With enough samples, the data would define the statistical distributions of damage, functionality and repair time for each level, for each hazard. For new components, or for hazards not covered by the database, assessment or testing (experiment) would extend the models as needed, with the results reviewed and applied by experts. Visual inspections would be conducted to assess conditions and confirm the system and component data contained on as-built documents.

Unfortunately, loss experience databases for wastewater system component vulnerability exist for only a few major structures or components (buildings, underground piping, electrical cabinets, pumps, etc.), for mostly low levels of certain hazards (e.g., ground shaking, wind, corrosion, etc.). Often, the hazard level at which damage or failure occurred must be estimated from hazard models, since few components are instrumented. Damage reconnaissance reports help to indicate the components having the greatest vulnerability to particular hazards. Test data (IEEE) from the nuclear industry helps to extend the existing databases.

Where damage statistics or experimental data lack, visual inspection and rating methods provide a risk profile, narrowing the focus to a manageable number of major components. Assessment and expert judgment may then be used to construct the needed vulnerability models.

In summary, methods for developing vulnerability models include (a) empirical, (b) visual inspection and rating, (c) analytical, (d) experimental, and (e) expert judgment. Further, the integration of these five types of methods has been disappointing for natural hazards generally. For these reasons and also for economic reasons, we therefore currently recommend for most wastewater agencies the application of visual inspection and rating methods supplemented by empirical and judgmental methods for assessing the vulnerability of pipelines. In some cases, analytical models may be combined with limited statistics to refine initial vulnerability functions based upon judgment. In rare cases, dependent on the decision context, the stage of the investigation, and the size of the utility, more specialized methods may be applied (see, for instance, Der Kiureghian, 2002, and Werner and Taylor, 2002, for illustrative methods that could be applied in more specialized cases).

C-6.1.3 Qualitative Risk Models

Qualitative models can be used with visual inspection and rating techniques in preliminary risk assessment phases, as a means of screening the risks, deciding which natural hazards are material to agency risks, and which components or subsystems may need further evaluation and/or mitigation.

Once the severity and spatial distribution of natural hazards within the wastewater system is evaluated, the agency can decide which of the hazards present substantial risk, and to which components. These components can then be judgmentally rated by experienced engineers for:

- Vulnerability (low, moderate, high, very high) to damage in each defined, relevant hazard
- Operational importance
- Life-safety implications of failure

These judgmental, relative rankings of risk can be used to identify components with high or very high rankings in a number of categories, so that further investigation can be done. The visual surveys can also identify specific weaknesses (e.g., poor or missing anchorage, configuration, support), which can be corrected without further assessment. System modeling can reflect vulnerability either before such judgment-based lower-cost mitigations or after these mitigations are undertaken.

C-6.1.4 Assessment of Structural and Mechanical Components

Analytical methods for defining the vulnerability for structural and mechanical/electrical components range from the simple to the very complex. Due to the cost and effort involved, analytical methods are generally employed only for the components found to be most critical or susceptible under each defined hazard, as identified by initial screening surveys. Often, the mechanical or structural failure of the component will imply failure of the component to function, but this is not always the case, as where structural redundancy requires multiple component failure prior to loss of function.

Simple manual calculations may be sufficient in many cases to estimate the forces, accelerations or displacements that will cause mechanical or structural failure in a particular critical component. An example would be the seismic evaluation of anchorage bolt adequacy for a pump or electrical transformer, where anchorage is the key ‘weak link’ controlling failure (in this case overturning) of the equipment. The loads are obtained by multiplying the weight of the equipment by the acceleration (in ‘g’ units) at the location of the equipment (on grade or within a building). A similar calculation would be made for an electrical cabinet exposed to hurricane wind forces, where the wind velocity at the cabinet is used, together with the shape of the cabinet, to estimate the applied pressures. In either case, bolt shear and tension forces are computed for the forces and overturning moments and compared to the bolts’ capacity. Mean tested bolt capacities would be used to estimate the state of the anchorage relative to anchor failure, rather than design values. Upper and lower bound bolt capacities from such tests would provide a means to bound the failure uncertainty.

Well-developed finite element software exists for buildings and aboveground piping. Used by skilled engineers, finite element software packages typically permit assessment for gravity loads in conjunction with temperature changes, temperature differences, pressure loadings, inertia loadings specified as static accelerations, base-motion spectra or acceleration time histories. Some packages will allow assessment for independently specified support displacements. Familiarity with the program and skill in modeling are generally required. The output from the models are typically given as stresses, displacements, accelerations, and many of these packages compare these output parameters with those permitted under relevant design codes. A knowledgeable engineer must interpret the assessment results for their implications in terms of damage, cost to repair and functionality. To be used effectively, structural or mechanical models must be used in conjunction with engineering judgment (expert opinion).

C-6.1.5 Assessment of Underground Components

Underground wastewater system elements include piping, basins, tunnels, vaults, building basements and foundations. Finite element and finite difference assessment methods can be used to assess the effects of interaction of these components with the surrounding soils. Nonlinear, large-displacement finite difference programs may be used to assess the forces and displacements imposed upon underground components with the occurrence of hazards such as liquefaction or slope instability. In these analyses, the wastewater system component (e.g., basin, tunnel, etc.) is represented by finite elements within the soil continuum, and the soil pressures and displacements computed. These tractions may then be imposed as loadings in finite element models of the individual wastewater system components, to evaluate damage and potential loss of function.

C-6.1.6 Modeling Component Repair Costs

As a secondary consideration in this document, component vulnerability models for component repair cost can be used directly to estimate system-wide direct damage. These repair cost estimates are valuable in the immediate aftermath of disasters in order to provide FEMA with estimated “capped” losses (a conservative estimate of losses). These simple damage models can also help in estimating the size and siting of repair inventories.

There are many published sources for wastewater system component direct damage models. These include: ALA, 2001; ATC-13, Applied Technology Council (http://www.atcouncil.org/), 1985; ATC-25, Applied Technology Council, 1991; HAZUS [FEMA/National Institute of Buildings and Standards Sciences]; Cassaro et al., 1993; and Taylor, ed., 1991. The damage models are based on heuristic, analytical, and empirical methods – or a combination of these methods.

C-6.1.7 Modeling the Functionality of Components

The functionality of a wastewater system component may have some degree of correlation — rarely perfect — with its repair costs. For instance, repair costs for a damaged outlet connection at a sewage lift station may be small by comparison to other repair costs but may lead to significant functionality problems. In contrast, other damages to the lift station may be costly to repair, but may not impair it’s function.

> Many repair cost models assume a perfect degree of correlation between repair costs and functionality. Such models may be used for an initial evaluation of component functionality although improvements are desirable with respect to the definition of various component failure modes and their implications for component functionality.

C-6.1.8 Modeling Component Restoration Time

As important as functionality modeling, restoration modeling 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.

Repair costs and downtimes vary regionally and over time, reflecting differences in construction practice, labor rates, etc. Wastewater agency managers and their technical staffs are often the best sources for realistic current data, based on:

- Construction of new components and systems,
- Repair or replacement of existing systems under normal conditions, and in some cases
- Repair and replacement of existing systems under previous upset (post event) conditions.

This experience must be adapted to represent the post-event conditions for each hazard under consideration.

More complex modeling techniques are needed where component or subsystem configurations are non-standard, where hazards (and consequently risks) are high, and where post-event function is critical. Advanced models may also be needed where simplified methods cannot represent the complex behaviors leading to damage or failure.

Generally, preliminary, lower bound estimates of component repair times will require a number of simplifying assumptions:

- Repair inventories are available and undamaged
- Trained and capable repair crews are available
- Repair crews, equipment and materials can reach the damaged site
- Repair times are greater than or equal to repair times for similar components under normal conditions

One practical way to estimate downtime is to apply the same methods as used in construction project estimation. The restoration process is divided into a number of phases, and each phase subdivided into tasks. Work crews are sized and the duration of individual repairs estimated based on assumed worker productivity. The availability of replacement components including equipment is checked against inventories of spares, and time allotted for ordering from vendors, with requisite lead-times, where needed. Design lead-time, inspections and tests are allotted. Reasonable repair production downtime is included.

Using the above approach, a generic timeline can be developed for each component or subsystem type, to repair a given system for the damage that occurs in a given hazard. The process can then be automated and incorporated into recovery algorithms. Repair parts inventories including equipment can be tracked, and the algorithms written to account for finite inventories and work crews, bringing some of the event-specific correlations into natural hazard recovery simulations.

Increases in post-disaster repair times and costs typically occur as a result of systems features. For instance, continuing hazard, limited access, labor, material and the like can lead to increased costs on an aggregated basis.

C-6.1.9 Uncertainty in Component Vulnerability Modeling

The uncertainty in component vulnerability modeling is a major issue. For instance, visual inspection and rating methods suffer from a lack of integration of empirical, visual inspection and rating, analytic, and experimental methods. However, in modeling the vulnerability of components, it is essential to distinguish between the uncertainty of the natural hazard intensity and the uncertainty of the response of the component to that hazard. These uncertainties should be tracked separately through the risk assessment. Otherwise, the overall uncertainty in the process may be exaggerated.

C-6.2 Vulnerability of Mechanical and Electrical Equipment

C-6.2.1 Equipment Anchorage

Mechanical and electrical equipment are generally vulnerable to earthquake ground shaking hazards, and ground failure hazards (depending upon foundation conditions). For exposed equipment, wind hazards may be significant, especially for tall equipment, lightweight equipment and equipment presenting a large surface area to wind exposures. A key element of the vulnerability of equipment to earthquake or wind damage is the anchorage of the equipment.

Experienced civil or structural engineers should assess anchorage adequacy. Factors to consider include equipment size, weight and configuration, as well as anchorage size, type, embedment and installation. Where anchorage appears to be inadequate, the adequacy of anchorage may be assessed using applicable building code requirements[1]. Additional data on anchor capacity may be obtained from vendor catalogs and ICBO reports [International Conference of Building Officials, Whittier, California].

C-6.2.2 Inundation of Equipment

For electrical and mechanical components subject to inundation hazards -- failure may be assumed when water levels are estimated to be above base of unit, with a relatively narrow uncertainty. In these models, it is most important to include the uncertainty in the hazard demand (i.e., the water height estimate at each equipment mounting location).

Equipment under consideration may be found in wastewater treatment plants, pump stations, diversion structures, etc., and includes:

- Mechanical equipment – pumps, filters, valves and valve operators
- Electrical equipment - switchgear, motor control centers, breaker panels, cabinets, transformers (on grade, in buildings, and pole supported)
- Transmission towers
- Electrical raceways and conduit
- Pressure vessels (surge tanks, etc.)
- Sewage lift stations
- Above-ground piping, pipe bridges, pipe supports, and pipeways
- Equipment for chemical storage and usage; chemical piping
- SCADA instrumentation and control equipment
- Instrumentation, chlorination control, surveillance

[1] Refer to the building code adopted by the local community such as the International Building Code or the Uniform Building Code.

- Communications equipment (telephone, cellular, radio, etc.)
- Vaults and Tunnels

C-6.2.3 Loss of Power and Communications

Hurricanes, windstorms, flooding and earthquakes often result in power failures, as well as loss of telephone and data links. Damage to electrical power equipment and telecommunication equipment, and the resultant system impacts and loss of service may be modeled as a part of wastewater system natural hazards modeling, or “postulated” as a part of the natural hazards scenario. Typically, direct damage is modest, but the impacts on operations and restoration of system function are significant, especially where adequate backup systems are not in place.

C-6.2.4 Pressure Vessels (surge tanks, chlorine cylinders, etc.)

Vessels are generally steel shells, and may be cylindrical or (rarely) spherical. Cylindrical vessels with horizontal axes are often supported on saddles or legs. Vessels with vertical axes are supported at grade or on legs. Chemical gas cylinders may rest in cradles. Structural failures in earthquake include anchorage connectors, supporting legs, or sliding in saddles. Rupture at connections or objects penetrating the shell may generate “missile” hazard, if the tank can escape its structural attachment. Escaping contents can pose a health risk or an explosion risk.

In wind-related events, lateral forces can (more rarely) cause failures similar to those described for earthquake forces. Additionally, wind-generated missiles can penetrate pressure vessels, generating an additional missile hazard, as well as health risk or an explosion risk. Within an enclosed building, sudden vessel rupture or ignition of escaping flammable contents may present serious blast hazard to the building, its contents, other equipment and occupants. Escaping corrosive chemicals or oxidizers may attack vulnerable items nearby.

C-6.2.5 Pipe Bridges

Pipes may cross rivers, flood control channels, ravines or other obstructions on a highway or railroad bridge, or special pipe bridges may be used. Generally, failure of the bridge or excessive bridge movements can cause failure of the pipeline. Failures often occur at abutments, where differential movements may be large.

C-6.3 Vulnerability Models for Underground Piping

For most decisions, empirical or categorization methods for underground piping are enough to provide a sound basis for a subsequent systems evaluation of the wastewater system. In a few cases, especially those involving the construction of new pipelines, more detailed analytic methods may be desirable. This section, however, emphasizes only the majority of cases in which empirical or categorization methods are adequate.

C-6.3.1 Brief Summary of Empirical or Categorization Methods for Earthquake Hazards

The most comprehensive summary of earthquake damage data for water pipelines is found in ALA, 2001 (refer to References). This discussion will cover only some of the main details of that discussion. Wastewater gravity pipeline performance is generally better than pressurized potable water pipelines. Gravity pipelines are weaker because they are not designed to resist pressure. However, gravity pipeline “failures” that result in failure of the overall system are unusual. Gravity pipeline leaks have little immediate impact on the function of the pipe. Pipeline breaks may cause loss of function but only after the pipeline is physically separated or offset to the extent that sewage cannot pass. For example, in the 1994 Northridge Earthquake, the Los Angeles department of Water and Power suffered just over 1,000 water pipeline failures (leaks and breaks). By comparison, in the same are, the Los Angeles Department of Public Works had only ten locations where sewers collapsed to the extent that sewage would not pass and pump arounds were required. Ultimately, a significant length of sewer piping had to be replaced. Otherwise, there is minimal published data on sewer performance in earthquakes.

Long-term damage may be comparable. Sewers in liquefiable soils often float so they are no longer at grade. This causes solids deposition and maintenance problems. Pipeline leaks allow increased infiltration putting more of a hydraulic load on the wastewater treatment plant particularly during wet weather periods.

ALA (2001) (see Appendix D - References) summarizes data for two types of earthquake hazards: strong ground motions expressed as peak ground velocity (PGV) and permanent ground deformation (PGD). The basic rates are expressed as repairs per 1000 lineal feet of piping repair rate (RR). Distinctions are generally made among diverse types of pipeline material (e.g., cast iron, asbestos cement, welded steel, polyvinyl chloride, and ductile iron) and diverse types of joint (lead or cement-caulked, rubber gasket, arc-welded, riveted, screwed). Further distinctions cover corrosive versus non-corrosive soils, and large versus small diameter pipelines. Discussion of repairs made for breaks and repairs made for leaks are beyond the scope of this document, although many of the repairs needed will likely be for leaks. (See Cassaro et al., 1992 for one detailed discussion of how to analyze repair, to separate them into breaks and leaks). Furthermore, leaks unnoticed at the time of the earthquake may become exposed at significant periods after a damaging earthquake.

For estimating pipeline damage rates, the following two equations are provided in ALA (2001):

$$Ln\ (RR) = Ln\ (K_1 * 0.00187 * PGV) + 1.15 * \varepsilon \qquad \textbf{Equation (C-6-1)}$$

$$Ln\ (RR) = Ln\ (K_2 * 1.06 * PGD^{0.319}) + 0.74 * \varepsilon \qquad \textbf{Equation (C-6-2)}$$

in which:

* means multiplied by
Ln is the natural logarithm,
RR = repairs per 1000 lineal feet of pipeline,

K_1, K_2 are coefficients dependent on such factors as pipeline material, joint type, corrosivity of soils (see C.9.1 for illustrative values),
PGV = peak ground velocity (measured in inches/second),
PGD = peak ground deformation (measured in inches),
ε is a normally distributed uncertainty factor with a mean (and median) of zero, a standard deviation of 1

The above equations have an upper limit for PGV of about 50 inches/sec and upper limit of about 100 inches of PGD.

The uncertainties in the above equations are very large. If a robust simulation method is used, then these uncertainties can be modeled through the use of many simulations. Methods for simulating a normal distribution with a mean and median of zero and a standard deviation of unity are found in many works. (See, for instance, Law and Kelton, 1991)

It should be mentioned that equation (5) has a form that is more suitable for the evaluation of repair rates. Owing to practical and physical limitations, one should not expect over a certain number of repairs for 1000 lineal feet of pipe. For instance, on practical grounds, one may divide 1000 lineal feet of pipe into 18- or 20-feet sections and arrive at a practical limit of approximately 50-56 breaks. Even in the worst case, when 1000 lineal feet of pipeline have been severely damaged, replacement of the pipeline would lead to some such upper bound. Worst cases on record have been approximately 12 breaks per 1000 lineal feet of pipeline. The linear form of the equation can in principle (and has for some alternative models) lead to estimates of numbers of breaks far in excess of 50-56 at higher estimates of strong ground shaking. This will not be the case for the first equation above only as a result of the low coefficients used (although for three standard deviations, some estimates may be, say, 4 repairs per 1000 lineal feet of pipeline).

For many applications, it may be desirable to simplify the above equations through the omission of the uncertainty terms and rely on median estimates of damage. In particular, one may let

$$RR = K_1 * 0.00187 * PGV \qquad \textit{Equation (C-6-3)}$$

$$RR = K_2 * 1.06 * PGD^{0.319} \qquad \textit{Equation (C-6-4)}$$

The values of K1 and K2 will only be illustrated in this document, with the anticipation that the more detailed discussion in ALA, 2001 will be used as needed. Table C.6.1 summarizes some of these values and shows how the baseline cases tend to be small cast iron pipelines, with varying coefficients for those pipelines depending on their estimated degree of seismic vulnerability.

Table C.6.1 Illustrative Values of K1 / K2 in Pipeline Seismic Vulnerability Models (ALA, 2001, pp. 38, 39)

Pipe Material	Joint Type	Illustrative K_1	Illustrative K_2
Cast Iron (or Asbestos Cement)	Cement	1.0	1.0

Pipe Material	Joint Type	Illustrative K_1	Illustrative K_2
Ductile Iron	Rubber gasket	0.5	0.5
Large Diameter Welded Steel	Lap—Arc welded	0.15	0.15
Polyvinyl Chloride (PVC)	Rubber gasket	0.5	0.8

ALA further contains methods for estimating the probability of some pipe break, and further distinguishes between the above methods for various ground deformations and fault rupture deformations.

Generally speaking, a Poisson process may be used to estimate whether or not a specific pipeline has suffered one or more breaks. In general, the probability, P, of n repairs can be established according to the following equation (ALA, 2001):

$$P(x=n) = (RR*L)^n \, e^{-RR*L}/n! \qquad \textbf{Equation (C-6-5)}$$

in which

n is the number of repairs,

RR is the repair rate per 1000 lineal feet as determined by previous equations, and

L is the length of pipe (divided by 1000 lineal feet)

This equation will thus permit one to estimate whether or not 0, 1, 2, or more repairs are expected for a specific length of pipeline. In a full simulation, one can use a uniform random generator to estimate for each simulation how many repairs are needed on the pipe segment being evaluated. For instance, if (RR*L) = 0.6, then P(x=0) = 0.549, P(x=1) = 0.329, and so on. If the uniform random generator yields a value of below 0.549, then zero repairs may be simulated. If the uniform random generator is above 0.549 but below 0.878, then one repair may be simulated, and so on.

For fault crossing hazards, ALA, 2001 provides heuristic models:

For segmented pipelines, no failure occurs if PGD is less than 1 inch, the probability of failure is 0.5 for PGD from 1 to 12 inches, 0.8 for PGD from 13 to 24 inches, and 0.95 for PGD over 24 inches.

For continuous welded-steel pipelines, the probability of failure is less than 0.95 and determined otherwise by the equation 0.70*PGD/60.

These and other models in ALA, 2001 are currently under review in an ASTM (American Society of Testing and Materials) standards committee.

C-6.3.2 Vulnerability of Pipelines from Frost Heave

Estimating frost heave depends principally on grain size (grain sizes with 3% or more by weight less than 0.02mm or 0.0004inches), temperatures or freezing values, and groundwater within 5 feet (1.5 m) at any time of the year.

Since generalized models of pipeline repairs owing to frost heave are unavailable, it is suggested that local wastewater utilities affected by frost heave hazards develop their own empirical data on breaks and leaks. Following Cassaro et al. (1992), the local wastewater utility can develop longitudinal estimates of pipe repairs first as a function of temperature. These estimates can be further broken down by soil type, water table depth, installation period (if pertinent), joint construction, and pipe material.

C-6.3.3 Vulnerability of Pipelines from Other Natural Hazards

Other natural hazard events that may lead to pipeline damage include gravity landslide, expansive soils, soil collapse, riverine flood and scour, headwater flood and scour, hurricane—storm surge and scour, hurricane—headwater flood and scour, and hurricane—riverine flood and scour.

The authors do not know of systematically collected data on pipeline damage from these natural hazards events, although local flood control districts and FEMA may have data, for instance, on pipeline damage based on watercourse hazards. In the absence of data, estimates of PGD from an evaluation of natural hazards may yield reasonable but very coarse estimates of damage as based on models developed for earthquake permanent ground deformations. The state-of-the-art in assessing pipeline damages from these natural hazards (e.g., gravity landslide, expansive soils, and so on) is here assumed to be very wanting. Since very little exists in the form of generic pipeline vulnerability relationships for many hazards (e.g., ground movement), these vulnerability relationships can be treated by analytical methods for site-specific assessments. This is appropriate for critical components and hazards that are typically very localized, such as landslides and zones of soil expansion or settlement.

C-6.4 Vulnerability of Buildings

Buildings are considered in this document insofar as they are essential to wastewater system operations. Wastewater agency buildings may include:

- The wastewater district office, the headquarters building, and Emergency Operations Centers
- Shelter structures for pump stations and wastewater treatment plants
- The maintenance yard and garage structures
- Warehouse (parts, stock, and equipment)

Buildings house and protect critical control equipment and personnel from weather-related phenomena and hazards.

C-6.4.1 Building Damage in Natural Hazards

Buildings may be damaged by most of the other natural hazards under consideration:

- Earthquakes produce inertial forces by ground shaking, and damaging differential ground deformations associated with soil liquefaction, surface fault rupture, and landslide.
- Winds (hurricane, tornado or other) cause differential pressures, and transport debris (including wind-generated missiles). Wind pressures may damage roof, window, door damage, leading to loss of integrity of the building envelope, with wind and water-related damage to internal nonstructural walls, ceilings and floors, equipment and other contents. The sudden change in pressure from violating the building envelope can also lead to general structural failure.
- Floods, tsunami or seiche (damage from immersion, and force of flowing water, as appropriate) or storm surge can inundate structures, causing damage to damage to wood framing, drywall, ceilings, contents, stored data, and damage to electrical, mechanical and other equipment.
- Slope failures can damage building foundations, or lead to total collapse of the structure.
- Expansive soils and freeze/thaw cycles can damage building foundations and other exposed elements.
- Susceptibility of buildings to wildfire hazards depend upon clear space between surrounding trees or brush and the building perimeter, as well as the flammability of exterior building materials.

C-6.4.2 Assessing Building Vulnerability for Earthquakes

In earthquake, damage can occur to contents or contained equipment, to architectural elements (nonstructural damage), or to the lateral force resisting system. Damage to building elements such as contents, storage racks, suspended ceilings or piping (e.g., a water quality laboratory) may result from in-structure accelerations, which tend to be amplified over the building height. Damage to building structural elements may occur due to excessive displacement demands related to interstory drift, or from overstress, or from connection weaknesses. The strength and toughness (ductility) of the structural and nonstructural elements depend upon the materials used (steel, masonry, wood, concrete) and design detailing. Overall building vulnerability may be increased by nonductile (brittle) elements or connections, interruptions to the load path, poor configurations (plan or vertical irregularity), low redundancy, or low strength.

The assessment of building vulnerability for earthquake hazards has benefited from the efforts of many individuals and institutions, culminating in documents produced under FEMA's National Earthquake Hazard Reduction Program (NEHRP):

FEMA 154 - Rapid Visual Screening of Buildings for Potential Seismic Hazards [1988]

FEMA 310 - Guidelines for Seismic Evaluation of Existing Buildings

FEMA 273 (now FEMA 356) - Guidelines for Seismic Rehabilitation of Buildings

In preliminary studies, the rapid screening techniques are particularly useful. In subsequent phases of study, the more detailed techniques of FEMA 310 may be useful. Where weaknesses are found and mitigation is required to meet wastewater system life-safety or performance objectives, FEMA 356 may be employed.

One weakness of these methods in the current context is that they were not developed specifically for wastewater agency buildings. Neither do they provide models that are easily adapted for use in wastewater system modeling. They provide methods to evaluate the critical weaknesses of a building and predict its general damage states (meeting or not meeting particular performance objectives) for a given level of earthquake hazards. A building may be evaluated at several hazard levels to develop a model that directly relates ground motion and related earthquake hazards directly to a damage state. The earthquake performance levels in FEMA 356 are described as follows:

Table C.6.2 Structural Performance Levels in FEMA 356

(S-1) Immediate Occupancy Structural Performance Level	The post-earthquake damage state that remains safe to occupy, essentially retains the pre-earthquake design strength and stiffness of the structure, and is in compliance with the acceptance criteria ...
(S-2) Damage Control Structural Performance Range	The continuous range of damage states between the Life Safety Structural Performance Level (S-3) and the Immediate Occupancy Structural Performance Level (S-1).
(S-3) Life Safety Structural Performance Level	The post-earthquake damage state that includes damage to structural components but retains a margin against onset of partial or total collapse in compliance with the acceptance criteria specified in this standard for this Structural Performance Level.
(S-4) Limited Safety Structural Performance Range	The continuous range of damage states between the Life Safety Structural Performance Level (S-3) and the Collapse Prevention Structural Performance Level (S-5).
(S-5) Collapse Prevention Structural Performance Level	The post-earthquake damage state that includes damage to structural components such that the structure continues to support gravity loads but retains no margin against collapse in compliance with the acceptance criteria …

[Adapted from Section 1.5.1, FEMA 356]

FEMA 356 provides thorough description of the damage states for the elements of each defined type of building structure to achieve the selected earthquake performance level.

Buildings designed and constructed without special criteria, energy dissipation or seismic isolation systems will generally not meet the objectives of the Immediate Occupancy

Performance Level (S-1) under the earthquake hazard levels specified in FEMA 356. This does not necessarily imply failure to function under the presumed earthquake hazard level. Judgment is needed to adapt the Rehabilitation Guidelines into useful relationships for building damage, functionality or restoration time.

Simple damage functions for buildings are provided by other sources, such as ATC-13, models by Karl Steinbrugge, models by J.H. Wiggins, and models developed as a part of FEMA's HAZUS software [Kircher et al]. These predict repair costs and/or damage states for classes of building construction.

For instance, damage relationships are often derived from ATC-13 [Applied Technology Council, 1985], a widely used and intended for coastal California construction, designed for the equivalent Uniform Building Code Seismic Zone 4. ATC-13 provides damage functions to estimate repair costs as a fraction of building replacement value, for 40 building types. Outside of California, these relationships may need to be adjusted to account for local design and construction practice. This is usually done through engineering judgment. One hypothesis that can serve as a basis for adjustment of building damage functions is that buildings designed for Zone 3, when exposed to Zone 3 ground motions (i.e., having a peak ground acceleration of 0.3g), will experience damage levels similar to Seismic Zone 4 construction subjected to Zone 4 ground motions (i.e., having a peak ground acceleration of 0.4g).

C-6.4.3 Assessing Building Vulnerability – Windstorm

Unlike earthquake damage where the building frame itself can sustain a high degree of damage, damage to buildings associated with wind forces (hurricanes and other extreme winds) is usually caused by failures of the building envelope, including the roof cover, windows and doors. Exceptions to this occur for small buildings, where the entire building may be displaced from its foundation, and for the most extreme winds (e.g., tornadoes) where complete structural failure may occur.

Many wastewater agency buildings are of light-metal construction. These may be open shelters or enclosed buildings, and damage may include loss of exterior wall or roof sheathing, sliding or lifting of the entire structure. Damage to the shelter may lead to high levels of damage to the associated equipment.

Where walls are constructed of concrete, brick masonry or concrete block, the most vulnerable portions of the building are generally the windows and doors, as well as the wood or metal roof deck. During a severe wind event, doors or windows may fail inwards, precipitating an increase in pressure inside that section of the building, which loads the underside of the roof deck, significantly increasing the net upward load on the building. Since the roof deck is usually designed assuming an enclosed space (i.e. no change in internal pressures), the increase in internal pressure can easily exceed design loads and cause roof system failure. Another source of wind-related failure comes from wind-borne debris, from gravel to large, heavy objects, which can break windows, or even penetrate the building shell.

For important buildings, vulnerability models may use a load and resistance modeling approach, where simulated winds are passed by the building, with the wind speed and wind direction varied, and maximum force demands tracked. A direction-dependent vulnerability model may be used in conjunction with a directional wind-loading model used to estimate the loads at any point on the building at any point in time. Given the wind load demands acting on the exterior of the building, the loads are compared to the modeled resistance of the relevant building components. The component is assumed to fail when the load exceeds the resistance. This assessment can be performed in a deterministic manner, or with probability distributions for the component failures. Once an envelope component fails, the change in internal pressures is computed, and other internal components are examined for the increased load.

More approximate building damage models may be developed through judgment, based on visual survey and review of the design documents. Design documents often state the design assumptions used, such as basic wind speed. Visual survey can indicate whether significant modifications have been made since original construction, and whether preexisting damage or deterioration has undermined capacity of the existing building. The visual survey should also focus on exterior elements that may fail and violate the building envelope. Relevant codes for hurricane winds include ASCE-7 and the Southern Building Code (SBC). Local and national wind design regulations have changed significantly over time, especially after milestone storms (e.g., Hurricane Andrew, etc.).

C-6.4.4 Assessing Building Damage in Floods

Building damage in floods is largely a function of the level to which flood waters rise. A simple model may assume that, if the flood occurs, the entire building may be lost, together with the contents on each floor subject to inundation. Hence, the focus is on the probability of occurrence of the flood event, and on the maximum flood height, rather than on models to quantify the degree of building damage.

With partial inundation, the basic frame of a steel, masonry or concrete building may survive inundation. A wood-frame building may be a total loss. The nonstructural elements, including electrical power and electronic systems, communication systems, etc., may need to be replaced.

C-6.4.5 Assessing Building Damage in Landslides

A simple model may assume that, if the landslide occurs, the entire building is lost, together with its contents. Hence, the focus is on the probability of occurrence of the landslide event, rather than on models to quantify the degree of building damage.

C-6.4.6 Assessing Building Damage in Fires

A simple model may assume that, if a wildfire occurs affecting the building site, the entire building is lost, together with its contents. Firebreaks and fire-resistant building exteriors may reduce the likelihood of loss, and a probability distribution can be constructed, relating fire intensity and duration to the probability of total building loss. Active fire suppression (i.e., by the fire department) may reduce or eliminate losses, but the availability of these resources may be limited in a large or widespread fire.

For fires occurring within the structure due to storm-induced electrical short-circuits or earthquake-induced ignitions, automatic fire sprinkler systems may limit structural and nonstructural losses to the area where the fire initiates. In the case of earthquake-initiated fires, the post-earthquake operability of the fire sprinkler system, or the availability of water at adequate pressure and flow rates, may also come into question.

C-6.4.7 Modeling Buildings within Natural Hazards Risk Assessment

The estimation of repair costs for the building itself requires the use of a damage function. These relate damage to hazard intensity (wind speed, ground acceleration, water depth, etc.), generally as a fraction of building replacement value. Hence, an accurate prediction of repair costs requires good replacement value data for large, important buildings. More approximate replacement values may be derived from Means Cost Data or other sources, and such approximate methods may be appropriate for smaller buildings.

Collateral damage to contents and equipment - There is a correlation of building distortion (drift) and the degree of damage that occurs to contents and equipment, especially equipment that is rigidly connected to more than one structural member. In the most extreme case, structural collapse may destroy all contents and equipment within. In a more limited case, damage to a building wall may precipitate damage to the supported equipment.

There are correlations of acceleration and damage to contents and equipment, as in earthquake shaking. Building structures amplify ground motions, so the seismic environment at the actual mounting point must be considered. Contents may be highly damaged by loss of building envelope integrity in winds.

The inventories needed for wastewater system repair following a natural hazard event may themselves be damaged in the event. As an example, in the M6 Whittier-Narrows earthquake in 1987, sewer system components were damaged due to poor storage practice in sanitation district yard in Whittier.

*Damage resulting in loss of occupancy (*for occupied structures, such as an office, Emergency Operations Center, etc.) - At a certain damage level or damage state, post-earthquake damage inspections may determine that the building is unsafe to occupy (i.e., it may be red-tagged or yellow-tagged). The duration of vacancy to effect repairs is a complex function of the degree of damage, the type of construction, the resources of the wastewater agency, and the availability of engineering and construction (repair) resources. The period of vacancy is subject to a limit -- either the time required to relocate the critical functions, or the time for complete reconstruction. Non-occupied buildings are an exception.

Wastewater System Functional Impacts - In modeling wastewater system impacts from building damage, the role and function of the building must be defined within the wastewater system. What functions are carried out in the building? Are key wastewater agency personnel housed within it, and would injury or loss of life impair agency response and recovery? Is the building an Emergency Operations Center, does it house SCADA systems, or does it serve as a communications hub? What are the system-wide consequences of the loss of these functions at this location? How would wastewater agency personnel resume functions elsewhere?

C-6.5 Vulnerability to Human Threats

The security vulnerability assessment will examine the facilities identified to be critical and the critical assets that make up those facilities. This subsection addresses the steps to be taken to accomplish these tasks.

C-6.5.1 Establishing a Critical Facility Inventory

As part of discussions among the members of the vulnerability assessment team, an inventory should be developed to identify all facilities that contribute to the normal functioning of wastewater system. Such facilities will typically consist of the following:

- Wastewater reclamation plant(s)
- Lift stations (list specific stations)
- Collection system(s)
- Maintenance facilities
- Administration offices
- Identifying critical assets

The identification of critical facilities typically does not provide enough information to proceed with the security vulnerability assessment. In reality, there are often key assets within each facility that, as a single point of failure, can significantly impair the system mission. Thus, a more detailed assessment of the key facilities is required, both to confirm the criticality of the facilities, and to identify if there are only a few assets, rather than the entire facility, which actually need to be protected.

The RAM-W methodology utilizes fault tree assessment for the identification of critical assets. The fault tree is a graphical and computational tool that allows the most critical assets to be identified through the use of logical “AND” and “OR” gates. Redundant assets are placed under “AND” gates to show that more than one item must be disabled for a significant impact to occur (for example, damage of the SCADA system AND failure to manually control the wastewater system). Non-redundant facilities and assets are placed under “OR” gates to show that failure of any of the items would significantly impact system operation (for example, damaging a critical lift station).

An example fault tree is provided as an attachment to this section of the commentary. The top event for the fault tree is provided on the first page of the tree and signifies the primary undesirable outcome from an attack, “Wastewater System Operation Compromised or Disabled”. The events or combinations of events that would cause the top-most events to occur are arranged in the fault tree logic by the use of AND and OR gates (an AND gate is denoted by a straight line at its base; an OR gate is denoted by a chevron at its base; transfers between pages of the tree are denoted by triangles).

Wastewater system flows tend to be linear, and thus, the findings of the fault tree assessment will often indicate that most facilities and the assets within them that are required to function for normal system operation are critical.

An example inventory of critical assets for typical wastewater system facilities is provided below:

Wastewater Reclamation Plant

- Influent pump station (pumps / electrical / structure)
- Bar screen
- Chlorination / de-chlorination
- Aerated grit chamber
- Primary sedimentation tanks
- Sludge pump
- Trickling filters / pumps
- Aeration tanks
- Secondary clarifiers
- Chlorine contact tank
- Effluent pump station (pumps / electrical)
- Outfall
- Primary digester
- Transfer and sludge circulation pumps
- Sludge lagoons
- Gravity thickeners
- Power
- Electrical equipment
- Channels/piping
- Building structure (e.g., influent PS)
- Utilities corridor
- Distributed control system
- Chlorine storage (potential weapon of mass destruction)
- Misuse or disable SCADA

Combined Sewer Overflow

- Channels/piping
- Influent pump station (pumps / electrical / structure)
- Bar screen
- Hypochlorite / chlorine
- Aerated grit chamber
- Primary sedimentation tanks
- Sludge pump
- Electrical equipment
- Distributed control system

- Building structure
- Storage lagoons
- Outfall
- Misuse or disable SCADA

Lift Stations

- Power supply/transformer
- Electrical equipment
- Misuse or disable SCADA
- Pumps/piping/valves
- Building structure

Collection System

- Break in sewage collection
- Break in sewage interceptor
- Contamination of biological process
- Blast in sewer
- Misuse or disable SCADA

Maintenance Facilities

- Building structure
- Equipment
- Personnel
- Communications/telephone/radio
- Misuse or disable SCADA

Administration Building

- Personnel
- Communications/telephone/radio
- Engineering
- SCADA / control system

C-6.5.2 Effectiveness of Physical Protection (Security) Systems - Deter, Detect, Delay, Respond

A brief discussion of the relationship between the four elements of security—deter / detect / delay / and respond—will assist in understanding the assessment of the security effectiveness. A security system that lacks sufficient balance between these four elements is not sound. Two examples clearly demonstrate this: a state-of-the-art detection system with moderate-to-good delay features but only marginal response capabilities, or an excellent response service complemented by a viable delay system but poor detection. In the first case, the terrorist action may be detected but there is no mechanism for effective interdiction; in the latter, the response force is capable of responding quickly, but there is insufficient detection. In either case, security is compromised despite strong unilateral elements within the system.

Figure C.6.2 depicts the relationships and interdependencies well. In virtually every example except a suicide mission, if $T_C > T_I$ the terrorist activity can be interdicted. If $T_C < T_I$—whether due to inadequate detection, delay, or response—the terrorist will succeed.

It is typically unrealistic to presume that sufficient private security personnel can be maintained 24/7 to respond adequately to intrusion alarms across the system, or that public law enforcement agencies (LEAs) will be able to respond in sufficient time to disrupt a perpetrator. A far more responsible and realistic approach is to design a system that determines if sabotage is imminent or might have occurred and takes measures to minimize risk to the public and environment. This can only be accomplished through integration of physical protection systems (PPSs) and operating systems (OSs). PPSs are the physical elements of a security system and OSs are the operational elements. Assessing the vulnerability of each of these, as well as the vulnerability of cyber systems (which have PPS and OS elements) will be addressed in the following subsections.

C-6.5.2.1 Assessment of Physical Protection System Effectiveness - Access Control

Too frequently, access control is viewed as only controlling physical access to operational facilities. In fact, access control applies to every form of access to include physical plants; transmission and distribution systems; supporting services; SCADA and IT systems; administration; intellectual property; and any other aspect of the utility wherein unfettered access could lead to a compromise of security.

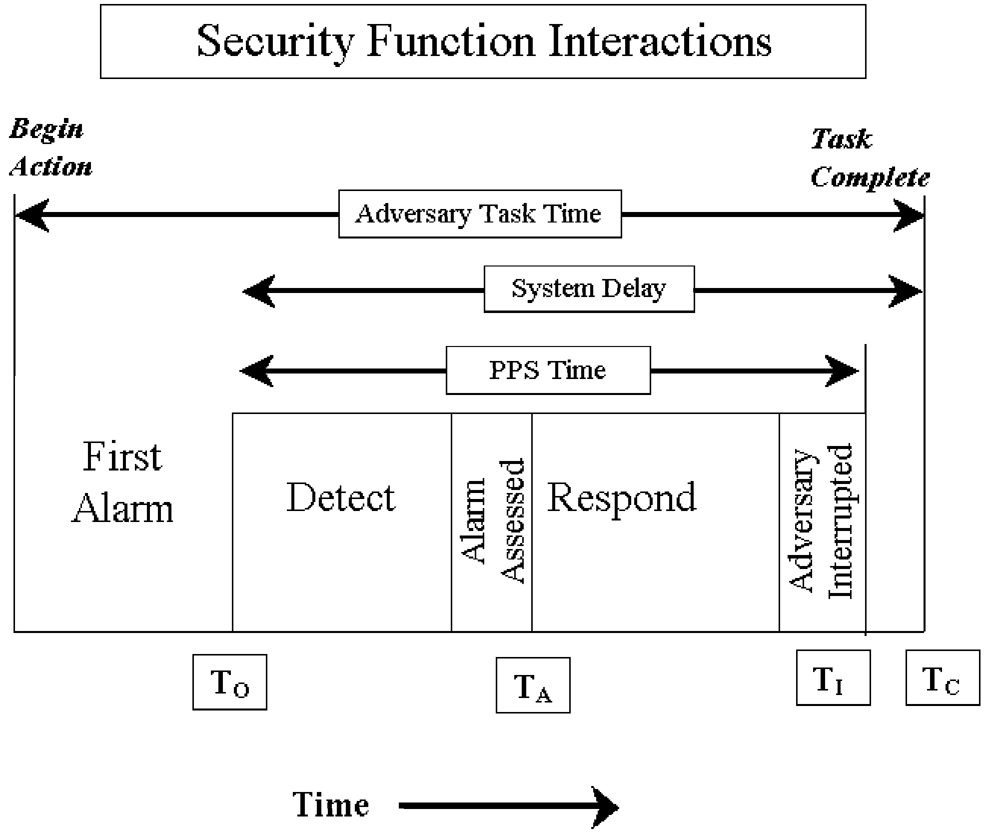

Figure C.6.2 Deter, Detect, Delay and Respond

Standard unmanned personnel access control systems include cipher locks, electronic recognition, biometrics, or combination of these mechanisms; all can provide a tracking, cataloging, and multi-level control capability. All have some *deterrent* value, limited *detection* capability, and varying *delay* value. Each affords a degree of effectiveness and the cost of installing and maintaining can vary significantly from system to system. For example, cipher locks are relatively easily compromised by poor code security (individual or systemic shortcomings); electronic recognition comes in various forms and provides greater overall access control than cipher locks; biometrics provide even greater control and are the most difficult to defeat. Because biometrics cannot be lost, stolen, or shared, they provide a higher level of security than badges and/or access cards.

One important element to designing an effective access control architecture is maintaining defense-in-depth without making it overly intrusive on operations and maximizing cost-benefit. A system-wide standard controlling access to general facilities can be augmented by an additional, more strenuous control system around critical elements.[2]

2 For example: access to the administrative office could be controlled by electronic card reader while access to the SCADA network, IT servers, and motor pool would require additional, more restrictive access control in the form of a “higher” card authorization or a secondary system (biometric).

Manned access control typically encompasses gate guards or closed-circuit television (CCTV)[3] and remotely controlled access (receptionist, guard, system operator). The access system must provide for granting access to non-card-carrying personnel. This is most easily accomplished by integrating CCTV camera and remote control features to allow a designated the utility employee (generally, the receptionist) to positively identify the visitor and his vehicle and then remotely trigger access through the designated visitor gate/door. This integrated system is referred to as the ***entry-access CCTV***. It is important to note that systems that include a human interface can be either more or less effective than non-human systems; their effectiveness being largely dependent on the professionalism of the responsible individual(s). Additionally, the resources required to sustain an effective manned system are not insignificant.

Access control systems can vary significantly in size, complexity, and application. Their employment can be as narrow as preventing unauthorized access to the most restricted areas or as expansive as a company-wide, graduated system that regulates and monitors the comings and goings of all employees and visitors. Over-reliance on a particular hardware (e.g., CCTV, padlocks, fencing) can seriously skew the *deter/detect/delay/respond* balance and weaken overall security system effectiveness. Response to attempted intrusions can run the gamut: local warnings or alarms, system lock down, revocation of access, or any number of other reactive measures. Caution must be exercised to prevent such systems from being administratively burdensome and operationally intrusive. Care should also be taken to configure the system to meet the user's current and longer-term needs. Access control system design and implementation must weigh life cycle security, operations, maintenance, safety, cost, and personnel vetting considerations.

A graduated access control system provides the highest level of security and includes a number of advantages:

- Definitive access authorized and controlled by system manager.
- Designed on the basis of need and clearance to control personnel, vehicular, and systems access controlled via levels or zones
- Integrates well into administrative and/or IT systems.
- Can provide "real time" as well as archival alerts and documentation.
- Can be expanded to meet corporate growth.
- Expeditious cancellation of access in event of employee termination, loss of badge/other, or other form of potential compromise.
- Relative ease of implementation and management.
- Badges provide a visible as well as electronic form of access verification.
- Avoids single point of failure within access control system.

If level/zone control is to be implemented, authorization/access standards and protocols should be jointly developed by a team of the utility management, operations, and administration

[3] This CCTV system is separate from intrusion detection CCTV systems. It allows the individual monitoring to visually confirm visitors before granting them admittance to a facility.

representatives to determine (1) which areas should be afforded higher access control and (2) who—by position—should have access to what. Zone access should be determined on the basis of two criteria: an individual's (1) *authorization* to have access to an area/system and (2) his *need* to actually gain access to the area. As an example, senior management may be authorized to have access to all areas and systems, but unless a senior individual needs access to an area/system (specifically those listed below), it may be more appropriate to limit that manager's access to "escort required" or "pre-approval by controlling authority" status. Access cards should be electronically and visually coded so that both card readers and other employees can determine "at a glance" an individual's authorization to be in a restricted area and regulate access. A careful balance must be achieved between insufficient access control to sensitive areas and overly limiting access and disrupting operations.

At a number of sites, multiple entities (e.g., landscapers/maintenance) have access. These represent a complication to effective access control. In order to maintain a balance between effective security and unduly impeding operations of both the utility and the organizations requiring access, an accommodation must be reached. The use of padlocks and lockboxes affords little effective access control, particularly given the typical ubiquity of keys and lack of a key control system. While emergency access is a consideration in some cases, the vast majority of access is administrative. Extending a badge access control to these other entities may be impractical and a potential administrative nightmare. Furthermore, some sites are not readily adaptable to electronic access control systems. To maintain effective access control under these conditions short of revoking site access, a utility has a number of options, several of which are listed below.

- Require either check-in/out of a utility-controlled key or digital access control.
- Require admittance and lock-up through coordination with a roving utility unit.
- Establish and remotely control electronic locks on gates to the sites.
- Allow limited distribution of access keys and employ incentives/penalties if entities do not follow prescribed entry/lock-up procedures (the principal ones being advance notification of entry and notification of lock-up).
- Institute a more effective and tightly controlled lockbox program.

It is impractical to place access controls on every entrance portal and gate at every facility. A combination of regulated access points, remote alarms, and local sensor and alarms can reasonably ensure security integrity. Technology should be supplemented by procedures prescribed in the utility EAPs (define)(Emergency Action Plans?) governing response to intrusion alarms, coordination with law enforcement, and periodic testing.

Guards - Manned access control typically encompasses (1) gate guards or (2) CCTV and access remotely controlled by a receptionist, guard, or other employee. In addition to sentry positions, guards can be employed as roving patrols (either vehicular or on foot) and as a response force. Regardless of the type or design of a system or the guard's specific role, a human-technology interface occurs. Conventional thinking maintains that the earlier the interface occurs during an intrusion, the greater the likelihood of a successful intervention. However, it can also be argued that with technology, the human-technology interface can effectively and more safely occur later in the sequence of events. Irrespective of timing, human nature plays a critical role.

Historically, the human element has proven to be both the strongest and weakest link in the chain. While system effectiveness is largely dependent on the professionalism of the individuals involved, human complacency is the primary element undermining guard efficacy. Any number of procedures and systems exist to reduce complacency and enhance guard force readiness and responsiveness. Guards can be of very limited value even for rudimentary deterrence. Unless they are present in sufficient numbers to demonstrate viable coverage and effectively interdict an intrusion at the critical facilities, even an unsophisticated intruder can easily avoid them. Undeniably, a guard presence contributes to security but the cost-benefit must be weighed.[4] As an alternative to employing or outsourcing guard services (most often to reduce corporate expense), companies often attempt to impose guard responsibilities on internal employees. This is neither a sound security nor business strategy as it tends to distract the employees from their primary job and does very little in terms of enhancing security. Owing to the potential resource demands associated with increased security, outsourcing of guard or roving patrol services to include intrusion alarm monitoring) is often prudent. That said, the need for an on-site guard presence at system facilities can be effectively eliminated with a properly designed security architecture and proactive, security-minded employees.

Controlling access of the general public and service companies with business at system facilities requires a careful balance. Administrative measures such as requiring ratepayers to call ahead to schedule appointments or limiting customers exclusively to telephonic and mail-in services should be considered. From a purely access control standpoint, having a system that requires some form of personal identification prior to entering a compound or building is the most effective. The reception-monitored entrance, locking of other outer doors, and “buzz-in” from reception to employee working areas currently employed in the Administrative Office are a definite step in the right direction. However, a determined individual could quickly compromise these measures simply by hurdling the reception counter. With some reconfiguration of the entrance area, integration of CCTV, hardening of the foyer, and revised buzz-in/emergency response protocols, security of the district complex and its personnel could be significantly strengthened during and after working hours. In addition to access control, such measures constitute very effective *deterrence*.

Tailgating and Vestibules - Tailgating through access control points and propping open of controlled portals is a persistent problem. Tailgating—by both vehicles and pedestrians—must be minimized. One of the most effective ways to minimize tailgating is to create a vestibule-like configuration or series of barriers that preclude (or control) a second vehicle/person from entering a limited access area until the first vehicle/person has cleared it. This is particularly applicable to Administrative Offices.

Constructing vestibules or effective vehicles barriers can be expensive, can significantly encroach on working areas, and will generally require some form of monitoring to ensure violations do not occur. To be effective, certain basic steps must be taken; for example:

- Visitors should be required to state their name and business and provide identification before being “buzzed in.”.

[4] As a rule of thumb, the number of personnel required to maintain 24/7 presence of one guard ranges from 5 to 7 (due to training, rotations, sickness, time off, and turnover). Depending on whether a guard force is maintained in-house or outsourced and a number of other parameters, this can equate to between $150K - $250K per annum.

- All entrances to the building/parking areas (to include roof accesses and delivery gates) must be equally secure.

The vestibule concept can be flexible to allow ratepayers into the building but control their access to a designated customer service area situated within a hardened zone.[5] The objective of the vestibule (in conjunction with access control measures discussed below) is to prevent a malevolent actor from gaining access to personnel while still allowing efficient conduct of business and retaining an atmosphere of customer-friendliness.

Safe Rooms - A safe room is an area situated and configured to provide emergency protection in the event of a hostage-like situation. Typically, it is a fairly centralized, easily accessed, and easily secured room capable of accommodating a reasonable number of personnel for a short duration. Ideally, it can offer a viable emergency escape route and/or be protected from the threat of fire, bombs, or other malevolent acts. In cases such as an administrative office, a full-fledged safe room may not be required. Rather, a safe haven that provides simple protection from the DBT for staff cloistered within the room for a short period until the police arrive should suffice. Reinforcement of a room to create that safe haven can be elaborate or simple. Unless a major potential threat exists, the simpler and less expensive option is recommended.[6] In addition to security considerations, the design and provisioning of the safe room should support basic personnel safety requirements.

Parking Restrictions - Restricting parking to specific areas–typically not adjacent to important buildings—and funneling pedestrian traffic to specific entrances are simple and effective first steps. Controlling access to employee parking via access control measures and physical barriers, establishing separate visitor parking, and funneling pedestrian traffic to designated entrances are all effective measures. Fencing, barriers, landscaping (e.g., trees, earthen berms), and large planters are all viable barrier options and provide varying degrees of aesthetics.

In more remote areas, denial of access as a means of security should be weighed against public access issues and engaging the public as part of the system's security architecture. One potential alternative is permitting public access for recreation if feasible and inviting the public to report suspicious activities. This enhances *deterrence/detection/response* through increase public presence, awareness, and involvement.[7]

Intrusion Detection - Redundancy is a fundamental tool in maximizing PPS and OS effectiveness. Whether discussing intrusion detection, communications, monitoring/response, or systems, at a minimum redundancy reduces susceptibility to single-point-of-failure and increases emergency action options. Applications of PPS and OS redundancy include:

- Alarm notification of multiple personnel
- Concurrent visual, audible, and electronic alarms
- Progressive sensors/alarms

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[5] Zone configurations can range from elevated counters(similar to what currently exists) to roll-down barricades to bulletproof enclosures and intercoms (similar to drive-up banking).

[6] In keeping with the "reasonable and prudent" standard, a safe room must offer protection but should not be so cumbersome, expensive, or operationally impractical as to significantly impair daily operations.

[7] This is particularly relevant to areas in close proximity to housing developments.

- Redundant operations and communications systems

Progressive Intrusion Alarms - One concept of viable intrusion detection is one of progressive detection. Multiple sensors are integrated to detect both an intrusion and a sequence of action portending malevolent acts. Through a simple but carefully crafted design, this approach reduces false alarms, provides a higher standard for response, and is far more effective for distributed systems. Complementing access control measures, progressive intrusion detection represents arguably the most effective defense against the utility security incursions. While detection systems are limited in their ability to dissuade or prevent terrorists or other serious "bad actors" from perpetrating a crime, they play a critical *indications and warning* role. Progressive intrusion detection will, in conjunction with other countermeasures, provide reasonable forewarning and a measure of intent sufficient to allow operators to respond proactively to protect both systems and consumers.

A variety of external and internal intrusion sensor technologies exist, to include seismic, motion, thermal, closed circuit television, beam interruption, pressure, acoustic, and various combinations. Each has unique capabilities and limitations. Operational constraints and overall efficiency varies, as do procurement, installation, and maintenance costs. A system that integrates complementary technologies in a cost effective manner generally provides the best overall long-term security.

To provide both defense-in-depth and progressive alarms, a minimum of two alarms should generally be installed at sites where critical systems are potentially exposed. These alarms must be configured to clearly demonstrate *progressive intrusion toward sensitive system elements*—thus confirming malevolent intent—when activated. They should alarm sequentially to a centralized alarm system—preferably a commercial security service <u>and</u> a designated Duty Officer.[8] Electronic sensors that alarm remotely should be accompanied by on-site day/night visual alarms to alert passing security/law enforcement/roving units to the intrusion. Alarm power sources and antennas must be protected from compromise. If possible, all antennas, power sources, and wiring should be located well within the first intrusion perimeter, hardened, and preferably at a point well beyond reach or compromise.

To achieve effective "progressive alarms" for the more remote sites, the first alarm must be triggered as the intruder approaches the target (for example, a lift station). For most lift stations, the access hatches and ventilation shafts presents the most likely avenue of approach. For above-ground tanks, the access ladder presents the most likely avenue of approach. The second alarm must be activated if the containment is breached. As vaults will most likely be breached via either their access portals or ventilation, the second sensor must be triggered if these are compromised (for example, a motion detector could be placed within the vault). For above-ground tanks, the second sensor must be activated if the hatch is opened. Regardless of the detector configuration, sensors must be sufficiently protected to ensure that corrosion of sensors, power sources, or signal relays from ambient conditions (e.g., UV, exposure, high humidity) does not occur. Intrusion detection should be designed so that attempts to tamper with sensing/transmitting components will also generate an alarm.

[8] The utility utilizes the services of an alarm monitoring service. See later discussions of *outsourcing* and *duty officer*. Alarms that alert simultaneously to a duty officer (via beeper, cell phone, or other immediate means of notification) and the monitoring service are typically the most effective.

A basic system of perimeter intrusion sensors—typically infra-read (IR) beams—can provide first echelon, 360° intrusion detection around critical buildings. Depending on their installation, sensitivity, and the environment, such sensors can be subject to an unacceptable false alarm rates and unfavorable operating conditions (e.g., rain, fog).[9] Additionally, unless configured in comprehensively overlapped patterns, the beams can be easily bypassed. Other types of intrusion alarms deployed around a perimeter are subject to similar limitations.

While perimeter intrusion sensors can be used to protect wastewater facilities, on a practical and cost-benefit level, they are of limited value. The proximity of wastewater facilities to private residences and public areas severely limits the value of perimeter intrusion detection. By reducing perimeter detection, the time available between detection and a response is obviously reduced. However, as a practical matter (1) the time required for authorities to effectively respond to most sites would exceed even a prolonged detection window and (2) the generation of false perimeter alarms would very quickly nullify their potential value. Perimeter intrusion alarms may have application at the most critical facilities, but far more effective is a system that provides <u>with a very high degree of certainty</u> a warning of malevolent intent. And if a suitable level of detection can be achieved via alternative intrusion alarms, *perimeter* intrusion alarms may be unnecessarily redundant.

A level of detection deemed most effective for wastewater facilities encompasses three types of alarms. These are typically employed in pairs and/or various combinations in order to confirm *progressive intrusion toward sensitive system elements*. These are:

- Contact alarms: activated when a door, hatch, window, cover, or other form of portal access is opened and an electric circuit is broken.
- Motion detection alarms: activated when motion outside ambient norms is detected in or across an area.
- Video alarms: parameters established via software and CCTV monitors trigger an alarm if specific criteria are met (i.e., personnel or vehicular movement, percentage picture change, designated security areas compromised).

Temporary sensors—employed during periods of heightened security and/or to identify repeat intruders—can be effective (particularly against vandals and trespassers).

Outsourcing **-** Many utilities outsource alarm monitoring to a commercial service; this is the recommended manner for monitoring and reporting sensor alarms. However, improvement of both the *detection* and *response* procedures to alarm notifications (operational (OS) and security (PPS)) warrants improvement.

Related to outsourcing is the issue of critical personnel. The temporary loss of an operations or maintenance person will not typically disrupt system operations. It is not uncommon for the IT organization to be "one deep" and the loss of the key individual could prove catastrophic under certain circumstances. Cross-training and or outsourcing are two ways of reducing the vulnerability created by single-person point of failure.

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[9] See also *Surveillance* below.

Surveillance **-** Experienced intruders and trained terrorists will frequently conduct surveillance of potential targets prior to executing an attack. Particularly in the case of more remote sites, they will often test security by activating detection systems and gauging the response from afar. This is particularly effective to determine LEA response times, neighborhood reaction, lighting sequences, and actions taken by security at the scene. In this regard, effective detection, meaningful delay, and/or timely response can serve as a significant deterrent. Conversely, a weak security system is quickly evaluated as such and may confirm the intruder's target selection.

Physical Protection **-** Fences—particularly in remote areas—are analogous to padlocks in that they largely keep honest people honest. While they have a practical application, their value is often misunderstood. A fence can be a deterrent and delay an attack. However, its utility is significantly diminished in situations where it can easily be by-passed (as occurs in more remote sites). Erecting a high, razor tape-topped, buried cable cyclone fence around a remote facility may deter the casual passerby but does very little to deter a determined intruder. Cost-benefit assessment often reveals that resources expended to purchase and install such a fence would be better spent on installing a rudimentary detection system and a very simple fence.

Visitor parking at the administrative offices should be separated from employee parking and kept more distant from the building (see earlier discussion under *Access Control*). Several vehicle control options exist:

- Install a separate visitor gate and parking lot.
- Install an employee access control system and keep the gate closed at all times except when vehicles are passing through.
- If employee/visitor parking is not segregated, institute reception-controlled parking access for visitors.

Package Screening **-** Physical protection and access control must extend beyond personnel/vehicles to include packages, mail, and other forms of delivery. The utility can receive numerous visitors and/or deliveries a day. If package handling/security procedures are not currently in place, the entire compound effectively is placed at risk. Standard package handling procedures reduce the likelihood of dangers emanating from deliveries and are an integral part of both access control and physical protection.

Hazardous Chemicals **-** Particular consideration should be given to the protection of hazardous chemical storage. Progressive intrusion alarms can be utilized. If a hoist is installed, electrical deactivation of the hoist would reduce the likelihood that chlorine cylinders could be stolen.

Extremis Situations **-** Another dimension of access control is *in extremis* situations where personnel are subject to hostage-taking or similar crises. For this eventuality, consideration should be given to *panic buttons* and a *safe room*. Panic buttons are simply hidden switches judiciously located in key areas and accessible by individuals likely to be the target of or observe a situation that could escalate into a serious confrontation. Alarms are typically configured to alert law enforcement and corporate security personnel without alarming the antagonist(s). EAPs should provide clear guidance with regard to panic buttons, bug this information should be limited to those with "the need to know" to minimize the chances of the system being compromised by an insider.

Provision of an *under-duress* signal allowing the sender to transmit an alarm that, unbeknownst to the aggressor, communicates the fact that the sender is under duress is a further security measure. This could prove critical in a situation where an operator or roving unit is taken hostage and coerced into neutralizing alarms or other plant operations. A simple code signifying that the action is being taken *under-duress* alerts the security company of a situation and allows them to notify authorities immediately.

A *safe room* is a designated room or area where employees can quickly gather to preempt or avoid a hostage situation. At a minimum, *safe rooms* are typically configured with:

- Relatively central location to maximize immediate access by all concerned.
- Access routes, which anticipate personnel in possible states of fear or panic, with disabilities, and under conditions of emergency lighting.
- Primary and secondary communications to law enforcement
- Key telephone numbers for LEA and senior management
- As appropriate, emergency water, food, ventilation, fire extinguishing, and bathroom (pot-a-potty)
- CCTV to monitor activity in building outside the safe room.
- Emergency exit (if practical)

The existence of and procedures associated with *panic buttons* and *safe rooms* are, by their very nature, sensitive. Senior management discretion should be exercised in discussing and coordinating this emergency provision to minimize concern and knowledge of the room's purpose. As with all security protocols, the procedures are at least as important as the notification process, and EAPs should provide clear guidance regarding *panic buttons* and *safe rooms*. Furthermore, emergency procedures should be rudimentary in recognition of typical human reaction during an *in-extremis* situation.

Equipping vehicles with satellite and ground-based tracking systems should be considered as a means of improving both personnel safety/security and fleet management. These systems allow tacking/monitoring of the car, emergency assistance, limited remote operations, and notification of authorities under *in-extremis* situations.

Vault Access - Critical system valves and interties can be situated in relatively exposed in-ground vaults accessed through heavy—but minimally protected—horizontal doors. Mounting locking bars with simple padlocking systems over the doors can cost-effectively reinforce these.

Contamination of Treatment Process - Manholes and service connections provide potential access for contamination of the treatment process.

Duty Officer - Formally designating a 24/7 the utility Duty Officer and daily security protocol is a highly effective means of sustaining security. This involves designating a rotating Duty Officer who, for the period of his "watch" (typically 24 hours), has the responsibility of overseeing both operational and security procedures and systems. No different than traditional typical duty officer responsibilities, this is a collateral duty personnel to be qualified, trained, and proactive. It is not mandatory (and seldom necessary) for the Duty Officer to be on the premises 24 hours a day, but the Duty Officer should figure predominantly in all aspects of security.

Properly instituted, a Duty Officer program fosters a climate of security, institutes daily review and exercise of basic security procedures, and ensures continuity of effort and personal involvement.

C-6.5.2.2 Assessment of Physical Protection System Effectiveness - Alarms, Sensors, and Security Systems

Much of the discussion regarding alarms, sensors, and security systems was covered previously under access control and intrusion detection. There are several simple techniques that can significantly strengthen overall effectiveness; among these: integrating sensors and personnel alarms. As addressed earlier, combinations of different types of sensors can prove to be one of the most effective means of securing an area. Sensors vary in their ability to detect different types of intrusions, pose different challenges to intruders seeking to neutralize or bypass them, and have different susceptibilities to climatic and other conditions; some are already partially utilized by the utility. Their applications can vary from local or remote enunciation to controlling system operations. Among the personnel alarms are *panic buttons* and *under-duress* signals discussed earlier; both are intended to forewarn of a situation that may endanger the utility operations or personnel. Incorporation of these into the alarm architecture and response planning requires considerable forethought to ensure viability and effectiveness and should be treated as sensitive information.

Portable Sensors/Alarms **-** During periods of heightened security, portable intrusion alarms can be deployed to high priority facilities to augment existing systems. This requires having units on-hand, reserving sufficient bandwidth to incorporate sensor signals in to the communications backbone, and maintaining in-house expertise (for set-up and maintenance). The trade-off between augmenting security through increased technology or increased guards/patrols is typically based on resources, priorities, and simple practicalities. Such measures should be considered during periods of heightened alert.

Lighting **-** Lighting can be a significant deterrent to nighttime intrusions. Intrusion-activated lighting is an even greater deterrent and can serve as a means of detection. Intrusion-activated lighting integrated into intrusion alarms systems and augmented by CCTV monitoring is perhaps the most effective means of maximizing nighttime deterrence, detection, and—to a limited extent—delay.

C-6.5.3 Vulnerability of SCADA Systems

C-6.5.3.1 Cyber Access Control and Intrusion Detection

In today's Internet environment, computers, networks and applications evolve at a very fast pace. Competing demands—heightened cyber security, simplicity and ease of operation, and non-intrusiveness on daily operations, to name a few—impact cyber security as much as physical security. It is imperative that utilities design and maintain a cyber security architecture that protects the security of information, integrity of the system, and privacy of communications. While the cyber environment may be more dynamic because the threat evolves more rapidly, underlying security principles remain the same as those of physical security. Implementing graduated access control and an effective intrusion detection system for the SCADA is neither difficult nor revolutionary. Safeguarding the SCADA system implies safeguarding the physical systems and computer access. In addition to PPS and software security, hardware access control must be employed. Here, again, a variety of options arise from biometric devices to sophisticated passwords to other controls. Continual attention to access control is warranted and user awareness must be continually reinforced. As with the PPS, SCADA SOPs and EAPs addressing cyber security must be established and maintained.

C-6.5.3.2 Two-Man Rule

In addition to technological measures, there are other basic measures that can contribute significantly to both access control and intrusion detection/prevention. Principal among these is the *two-man rule* to defend against insider threats. The *two-man rule* simply requires that two individuals act jointly to affect change or authorize an action; unilateral action is not sufficient and may well cause an alarm to be sounded if attempted. Widely used in sensitive government programs, this technique is based on a proven concept that it is much more difficult to compromise two insiders than just one. Additionally, there is always a possibility that a key individual can be coerced to take some action that threatens the system. Useful in physical, operations, or cyber settings, this rule is often applied to situations where supervisory oversight is appropriate but there is no need for constant supervisor participation or to prevent *under-duress* unilateral compromise. A potential application of the *two-man rule*: allowing no major system alterations or settings to be made to the SCADA without senior management "on line" approval. While this would not guarantee system security, it could provide safeguards to minimize access and/or consequences and provide notification of unauthorized attempts.

C-6.5.3.3 Outsourcing

Earlier discussion touched briefly on outsourcing physical security. This applies equally to cyber security. Too frequently, IT personnel are simply expected to assume and become conversant in all aspects of cyber security. Given the dynamic nature of cyber threats and the continual advancements in both technology and counter-technology, outsourcing provides a viable and often essential alternative to in-house cyber security efforts. A further advantage of outsourcing is that, properly leveraged, it can prevent a single employee from gaining complete access to, knowledge of, and the ability to compromise key elements of cyber security architecture.

Outsourcing of both physical and cyber security offers several advantages; among these:

- Allows utility personnel to focus on their primary job, the one for which they are trained.
- Prevents untrained personnel from acting in capacities requiring security training.
- Increases likelihood that security systems, training, and processes will be kept abreast of market developments.
- Facilitates standardization across the company.
- Reduces impact on growing organization whose growth in personnel is purportedly not keeping pace.

C-6.5.4 Vulnerability of Operating Systems

Assessment of operating system vulnerabilities involves assessment of the following:

- Personnel vetting
- Communications
- Training, education and exercises
- Emergency action plans
- Cooperative, interagency and mutual support
- Management

C-6.5.4.1 Personnel Vetting

Closely aligned with access control is personnel vetting—the process of confirming an employee's or potential employee's qualifications, aptitude, and suitability for a position. Vetting is not limited to new hires; it applies equally to clearing an individual for promotion and increased responsibility/access. Effective pre-screening procedures offer a powerful deterrent in and of themselves as potential malevolent actors faced with a proactive and thorough background job application process will likely seek employment elsewhere. Pre-hiring protocols should include closer scrutiny of past employment and military/government service, written permission to conduct detailed financial background checks for personnel handing finances; more in-depth background checks if an individual is hired and subsequently considered for a position of greater responsibility; and polygraphs for critical positions. Screening procedures often need to be coordinated with unions.[10] Company policies should also look beyond direct employees to include vendors, sub-contractors, security services, and building lessees—all of whom have greater access than the general public and represent a potential cover for someone seeking unauthorized access to the premises.

Personnel vetting should not be considered a "one time" event. If personnel are promoted, demoted, or undergo a significant shift in responsibilities, a review process may be appropriate. Additionally, employees can become disgruntled; this is often evinced long before a serious situation arises. Personnel vetting of demoted or similarly impacted employees and general awareness training for all employees can reduce the potential of disgruntlement going undetected.

C-6.5.4.2 Communications

Communications is typically an area of security vulnerability. Whether due to a lack of equipment, insufficient system redundancy, susceptibility to compromise, incompatibility with other emergency systems/services, weak emergency procedures, or a combination of these, communications has the potential to immobilize response in emergencies. Be it voice, SCADA, security, or RF data relay from PLC to the master SCADA terminal—all forms of communication are susceptible to both intentional and unintentional compromise. ***Redundancy*** and ***simplicity*** of emergency communications procedures are two key means of reducing communications vulnerability.

[10] In the case of unionized employees, management should stress the role and importance of security protocols in ensuring a safe working environment for all employees.

An often-overlooked area related to communications is protection of information that can be acquired from corporate websites and through written requests. Caution must be exercised to avoid divulging sensitive information that could be exploited by terrorists. Review and revamp of websites to preclude the release of sensitive information is an easy first step. A second—and equally simple—step is to establish a standard procedure in response to any request for information. In response to a request, the requestor should be required to provide specific background information, references, and demonstrate a clear need for the information. Not only will this allow the utility to properly screen the request, it serves as a strong deterrent to requestors with malevolent intent.

Another important consideration regards outside communications with SCADA systems. Potential vulnerabilities of any communication links should be closely examined and considerations should be made to improve security. For example, while having accessibility to SCADA via the Internet provides significant flexibility to operations staff, such connections are potentially vulnerable to cyber attack even with carefully planned access controls. An alternate approach, for example, is to use secure radio communications links between designated computers and the SCADA system. Such links can be designed to continuously vary the frequency of communication for added security. Procedures, of course, should also be implemented in this case to protect physically and electronically protect computers fitted with such links. It is imperative that any SCADA system that has control capacity be completely isolated from the internet.

In some cases, utility information is already in the public domain owing to (1) EPA and other agency regulations which previously permitted/required release on information due to "the public's right to know" and (2) access created by the Freedom of Information Act.[11] Two prime examples are annual hazardous material reports and risk management plans. Once mandated to be accessible to the public, access to these and other sensitive reports was curtailed after 9-11. Unfortunately, in addition to those document already released by the government, many remain available on websites such as one maintained by Green Peace. These examples demonstrate the need for vigilance and prudence in preparing/releasing sensitive information… even when required to do so by regulating bodies. Though current EPA guidelines are designed to prevent the release of sensitive information, it is recommended that utilities carefully scrutinize and minimize the information it releases to that material it would not be uncomfortable releasing to the public.

Shredding of sensitive documents—either in-house or out-sourced—is an effective means of safeguarding information and reducing proliferation of printed material.

C-6.5.4.3 Training, Education, and Exercises

An active training program in compliance with wastewater industry and hazardous material requirements is valuable. This encourages employee self-improvement through education and such foresightedness should extend to security training and exercises. Opportunities for training and exercise participation in security, interoperability, and emergency management exist at

[11] As an example, *Greenpeace* posted a number of Risk Management Plans on the Internet well in advance of 9-11; some of these may still be accessible today.

individual, corporate, and interagency levels and should be fully explored to keep personnel abreast and engaged.

Historically, when money becomes tight, the first two areas where management focuses its budget cuts are training and security. This inclination can only be successfully countered through effective training, management awareness, and emphasis on maintaining a reasonable and prudent security standard. Awareness of management's fiduciary responsibilities and potential liabilities is also important.

C-6.5.4.4 Emergency Action Plans

Emergency action planning encompasses a broad spectrum—from planning for routine system outages and natural disasters to conceptualizing how to deal with complex crises. As discussed previously, emergency action planning is a continuous process. Plans should be designed to avoid as well as mitigate emergencies. Emergency operations guidelines assist operators in taking proper action at remote sites during an emergency. These are indispensable at the "operator" level but the actions outlined must dovetail with the emergency actions planned at higher levels. In developing these guidelines and other EAPs, appropriate coordination with city and county emergency management agencies and other wastewater utilities should not be overlooked.

From a terrorism prevention/deterrence/mitigation perspective, there are a number of emergency action factors to be considered:

- Pre-determined system isolation or flow diversion in the event of system contamination
- Heightened system-wide contaminant testing
- Heightened levels of security to parallel Homeland Security Advisory System warnings
- Indications & Warnings training and information exchange
- Interagency training and exercises

As discussed below, both the opportunity and willingness on the part of local law enforcement agencies (LEAs) and emergency management organizations to work to facilitate the development/refinement of viable EAPs is valuable. EAPs delineate specific procedures regarding how to respond to and mitigate crises and should include—at a minimum—specific guidance regarding:

- Interoperability of primary and alternate
    - Response plans and procedures (specifically terrorism and hazmat)
    - Communications
    - Command and control (to include emergency operation center roles)
    - Logistical coordination
- Coordination and periodic exercises with local LEA to respond to intrusion alarms
- Assets, mutual support, and crisis team participation opportunities available to the utility via interface with emergency management organizations and plans

- Crisis priorities as identified by both of the utility and the emergency management organizations (EAPs should recognize and capitalize on priority synergy wherever possible as well as recognize and accommodate conflicting priorities).

C-6.5.4.5 Cooperative, Interagency, and Mutual Support

Given the opportunity for access to 800 MHz systems, utilities can be well positioned to establish a direct emergency communications interface with LEA. Equally important, this provides an opportunity for regional utilities to organize their emergency communications to form collective “talk groups” both during times of emergency and pursue mutual support initiatives.

Mutual Support **-** Generally speaking, wastewater purveyors stand to benefit from closer association with emergency management organizations. The converse is also true… LEAs can benefit significantly from interface with proactive utilities. The value of the latter is often underestimated and should be emphasized in every discussion with LEAs. Mutual benefits include intelligence sharing, specific roles/support during disasters, avoidance of “reinvention” or counter-productive crisis procedures, resource/cost sharing, more integrated emergency response, and “a seat at the table” in emergency planning discussions. This should be further extended to cooperation with local law enforcement and peer wastewater organizations in the region. By interfacing more with these groups, the utility can broaden interaction to include mutual support (e.g., shared resources, joint training, and shared lessons learned).

There are a number of specific outreach and interaction activities in which the utility should become involved. Continued and broadened community outreach is perhaps the most important because an informed and proactive public represents the best first line of defense in any civic protection effort; the citizens are quite literally the eyes and ears that can become an extension of the utility and security architecture. It is also the populace whose confidence the utility must retain during times of crisis. Opportunities to meet, discuss, train, and exercise together with other organizations are of critical importance and must be aggressively sought. As in the case of LEAs, the utility should not wait for organizations to approach them.

C-6.5.4.6 Management

Buy-in and proactive leadership at all levels of management are key to implementing and sustaining effective security across the utility. More than mere lip service, management must be directly involved in—and proactive in improving—corporate awareness, security reviews, and training/exercises. Consistent allocation of resources (funding, personnel, and time) to the foregoing is the clearest measure of management’s commitment to security. Management and labor invariably find themselves at odds over aspects of security. Key to resolving issues is demonstrating that all benefit from improved security. Often, increased security is seen as being intrusive on individuals’ rights or privacy; in reality, the *greater good* principle applies. Measures taken to reasonably reduce the vulnerability of one typically enhance the security of all. Improving workplace security benefits employees, management, and shareholders alike… and must be an ALL HANDS priority.

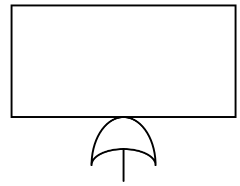
Supportive Climate **-** In addition to undertaking specific PPS and OS security initiatives, creation and maintenance of a climate supportive of security is essential to maintaining a vibrant security program. Incentives—beneficial suggestions, recognition of individuals exercising good security practices, security competitions—and other creative measures should be employed to foster awareness of and support for the utility's security program. Such efforts can and should complement programs for reporting operational/maintenance deficiencies.

Cost benefit **-** Implied throughout this assessment, evaluation of physical security options on the basis of cost-effectiveness is the bottom line. Effectiveness must be carefully considered in light of a component's role and value in an integrated security environment. As demonstrated earlier in discussions of both CCTV and fences, a poorly conceived or designed system can result in expenditures that do little or nothing to enhance overall security.   If a contemplated component does not realistically contribute to the *deterrence/detection/delay/response* of a facility, it should not be included … or a lesser system that fulfills the basic need should be substituted.

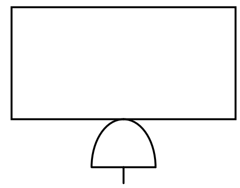
Public Affairs **-** Public relations often overlooked in emergency action planning. Proper preparation of public relations entails anticipating and scripting responses to potential questions, identifying and training a qualified spokesperson, and establishing an SOP to respond quickly and effectively to media inquiries. Particularly from the standpoint of customer confidence, public relations are an important line of defense.

Fault Tree Symbols

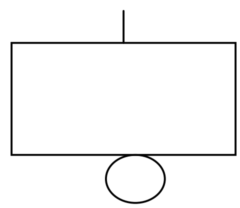
Or Gate – Event will occur if any input event occurs



And Gate – Event will occur only if all inputs occur



Basic Event – A single undesired event



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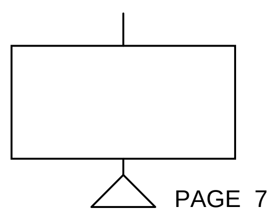
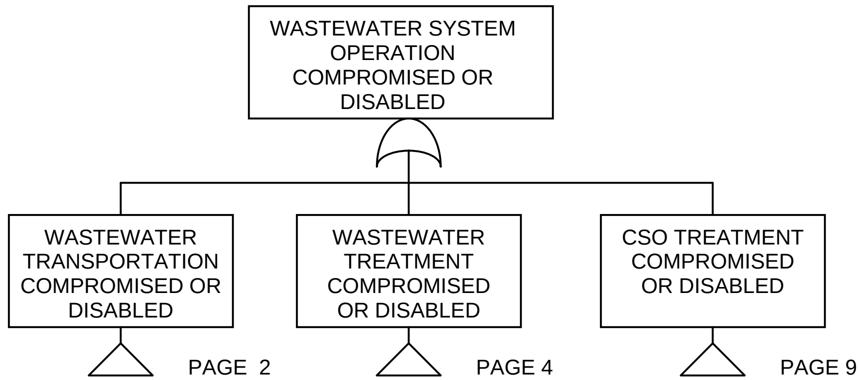


Fault Tree Page 1



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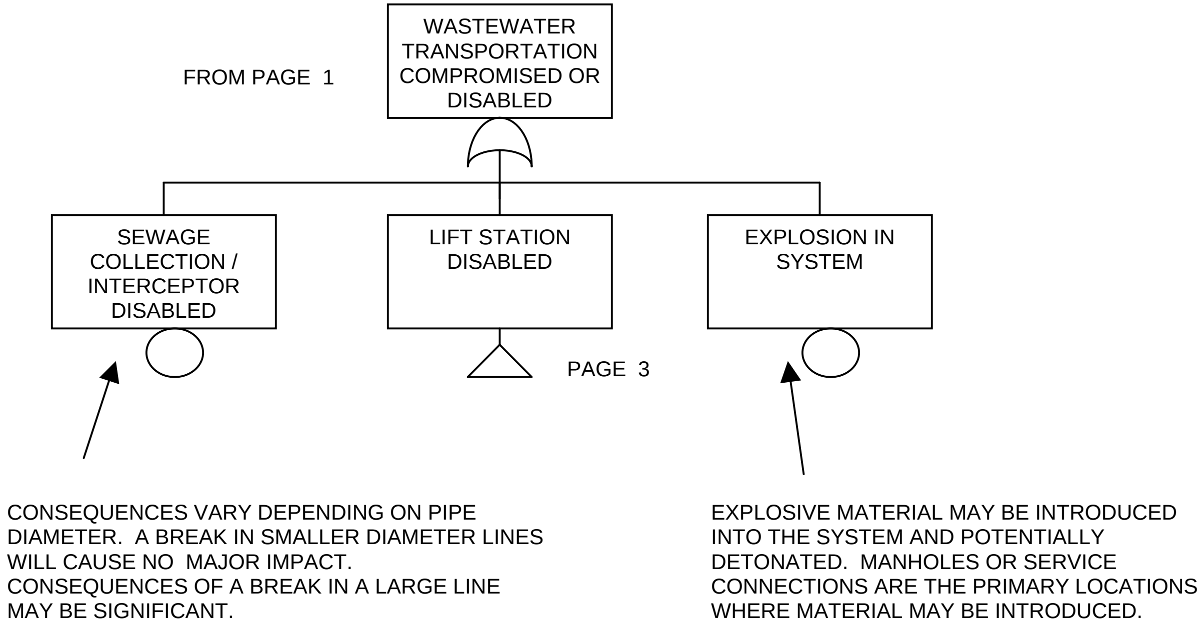

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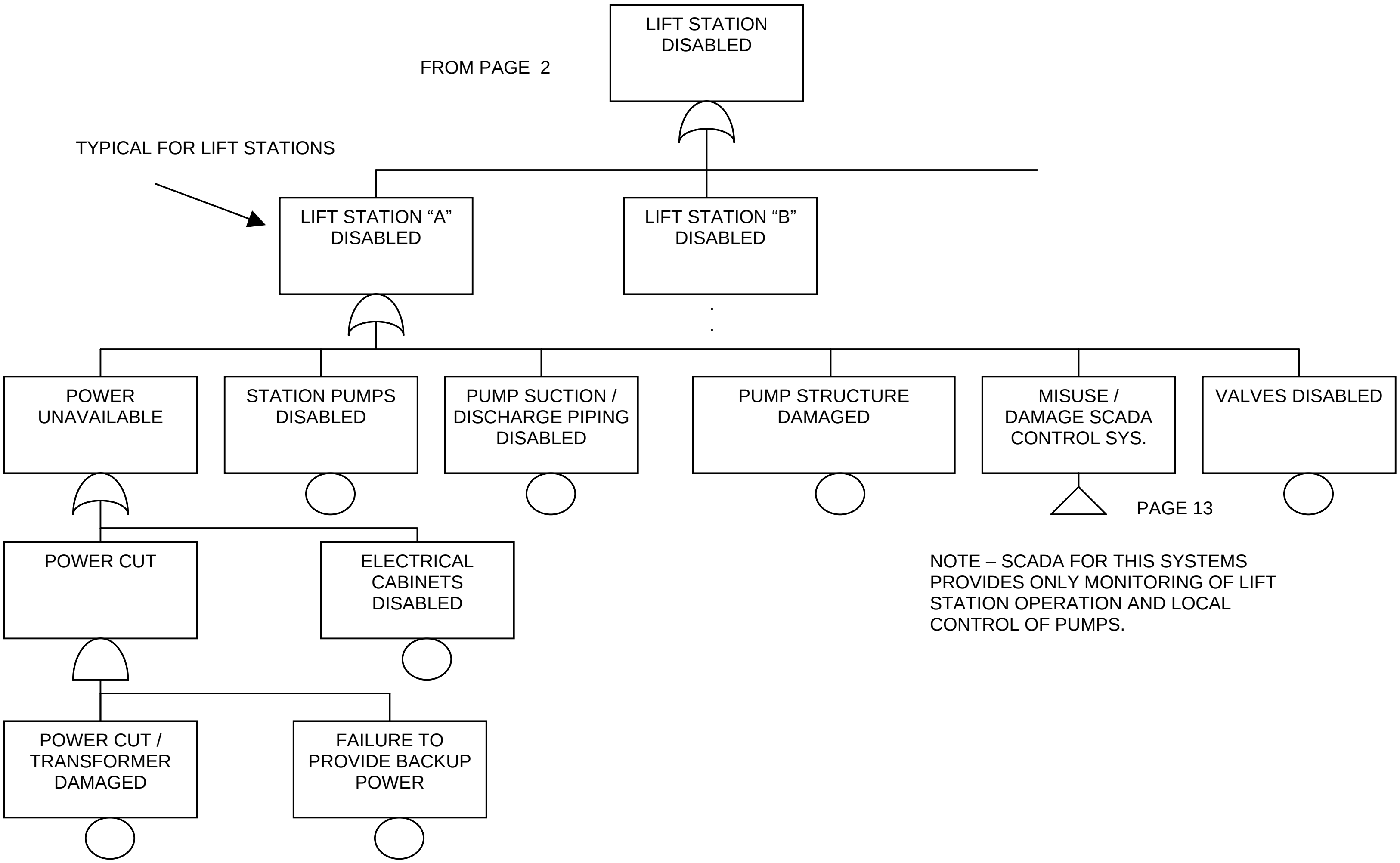
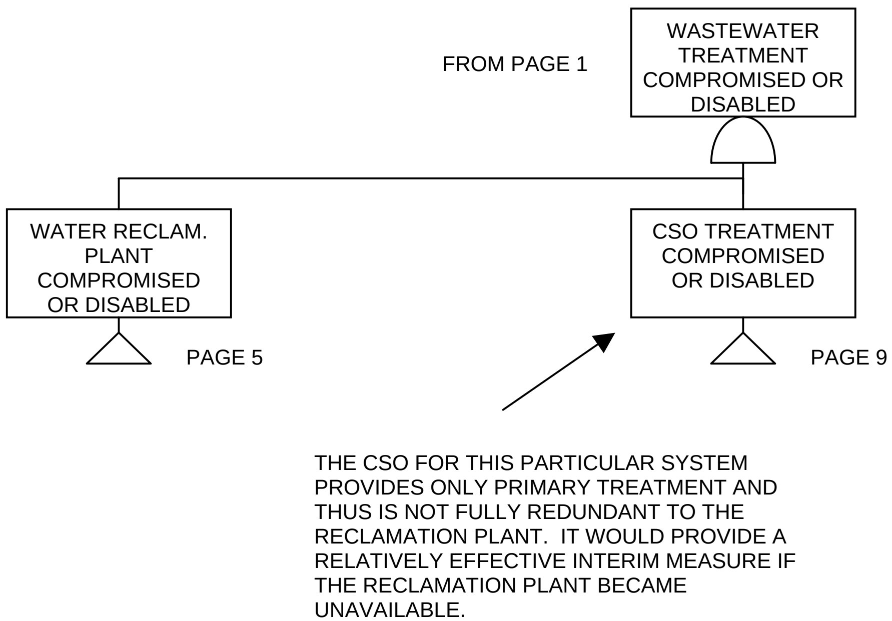


NOTE – SCADA FOR THIS SYSTEMS PROVIDES ONLY MONITORING OF LIFT STATION OPERATION AND LOCAL CONTROL OF PUMPS.

Fault Tree Page 4



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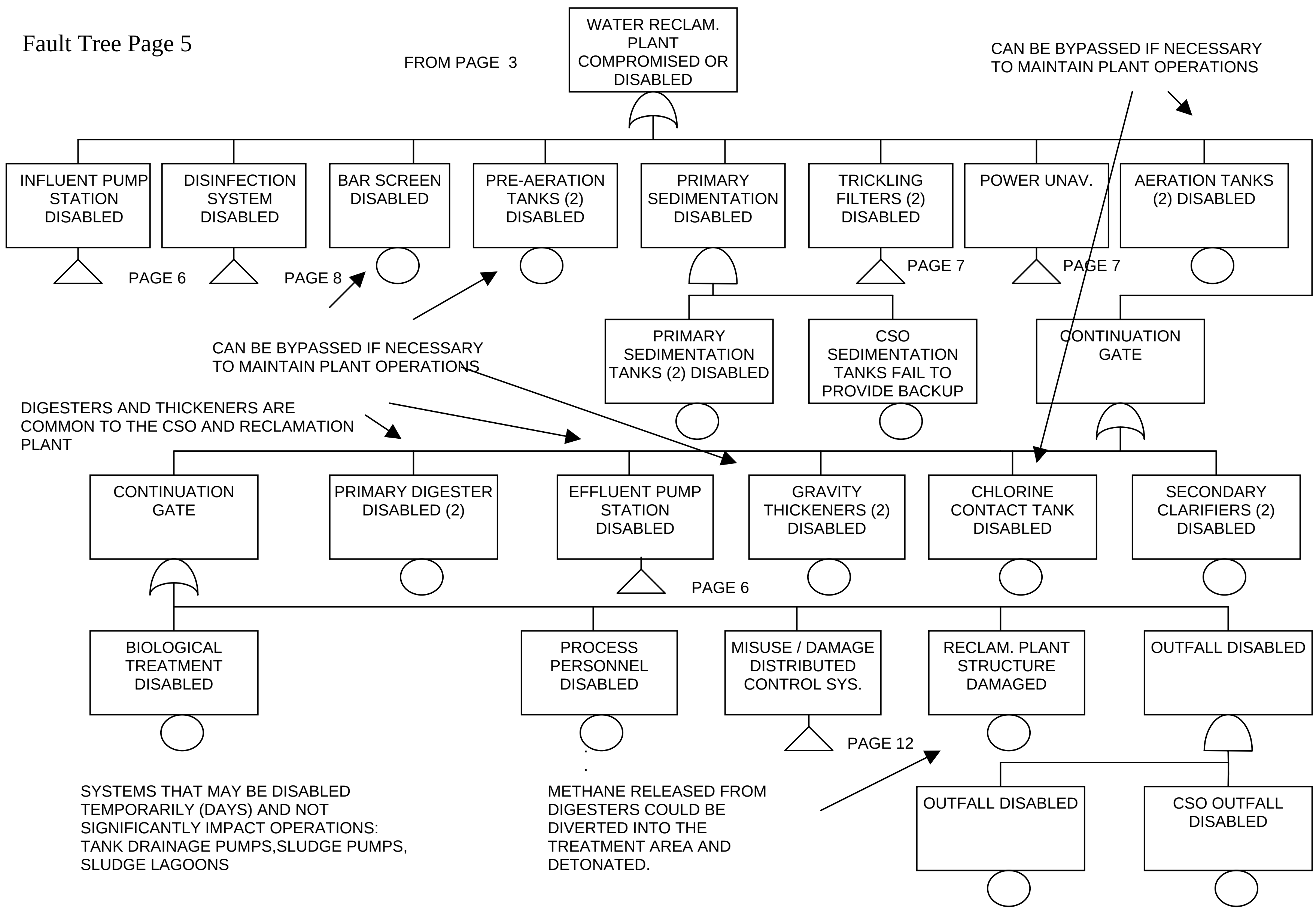

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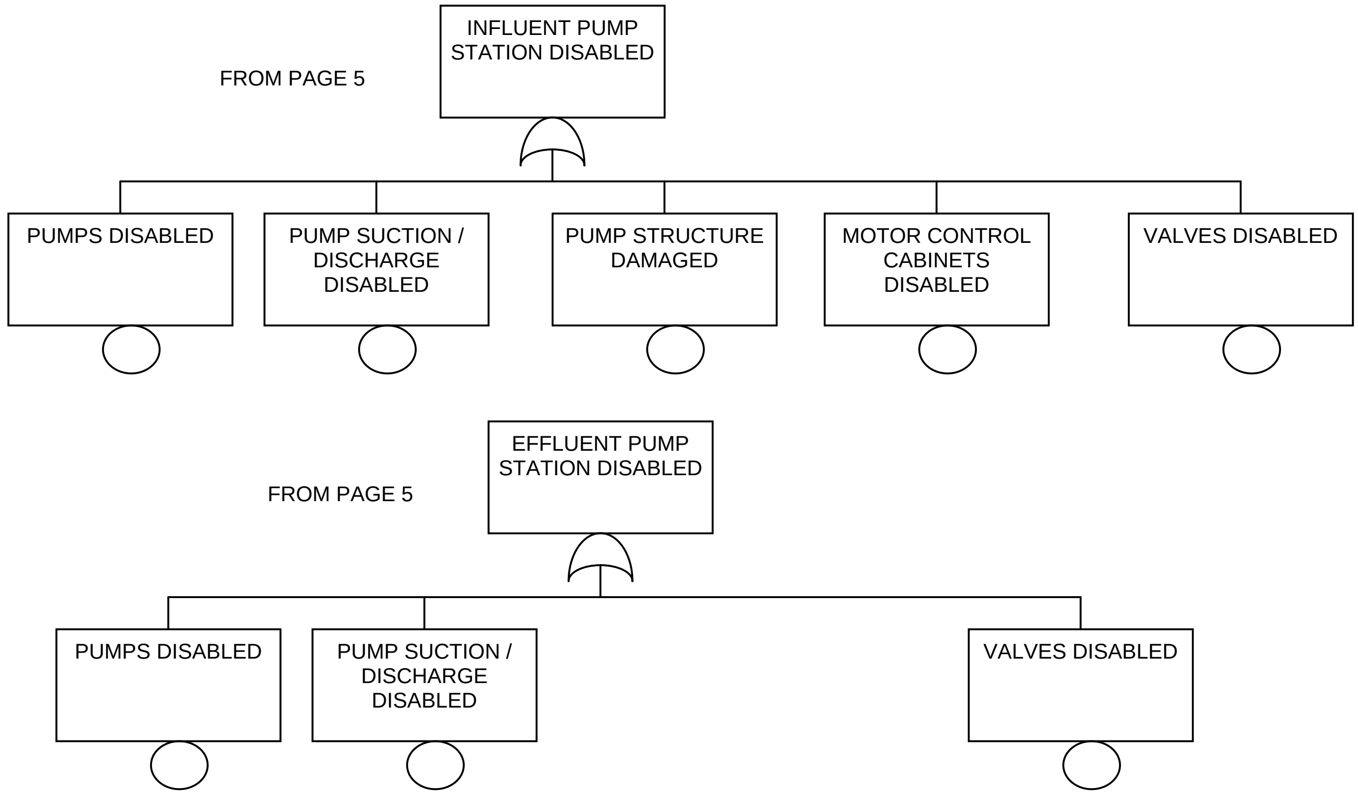

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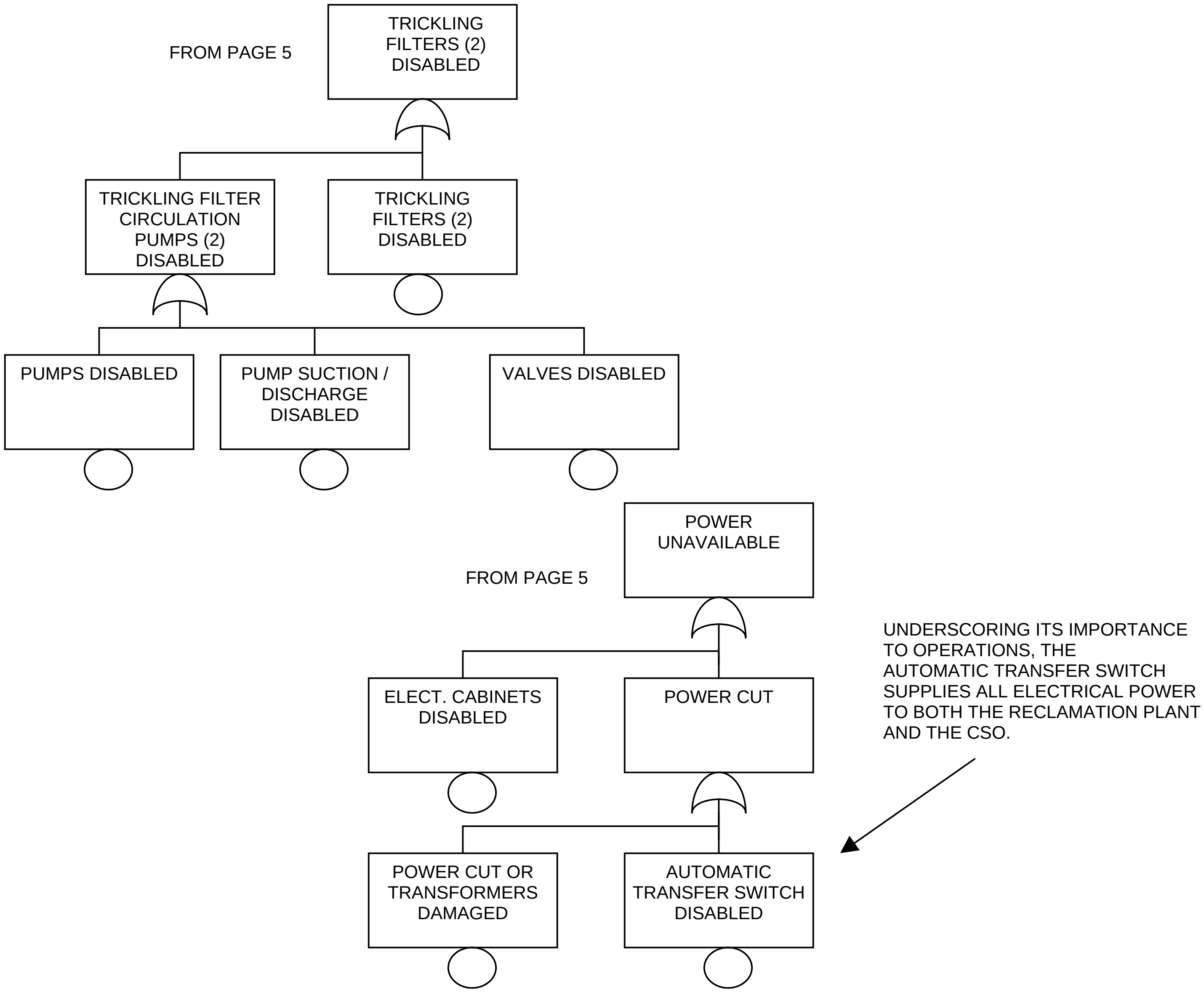

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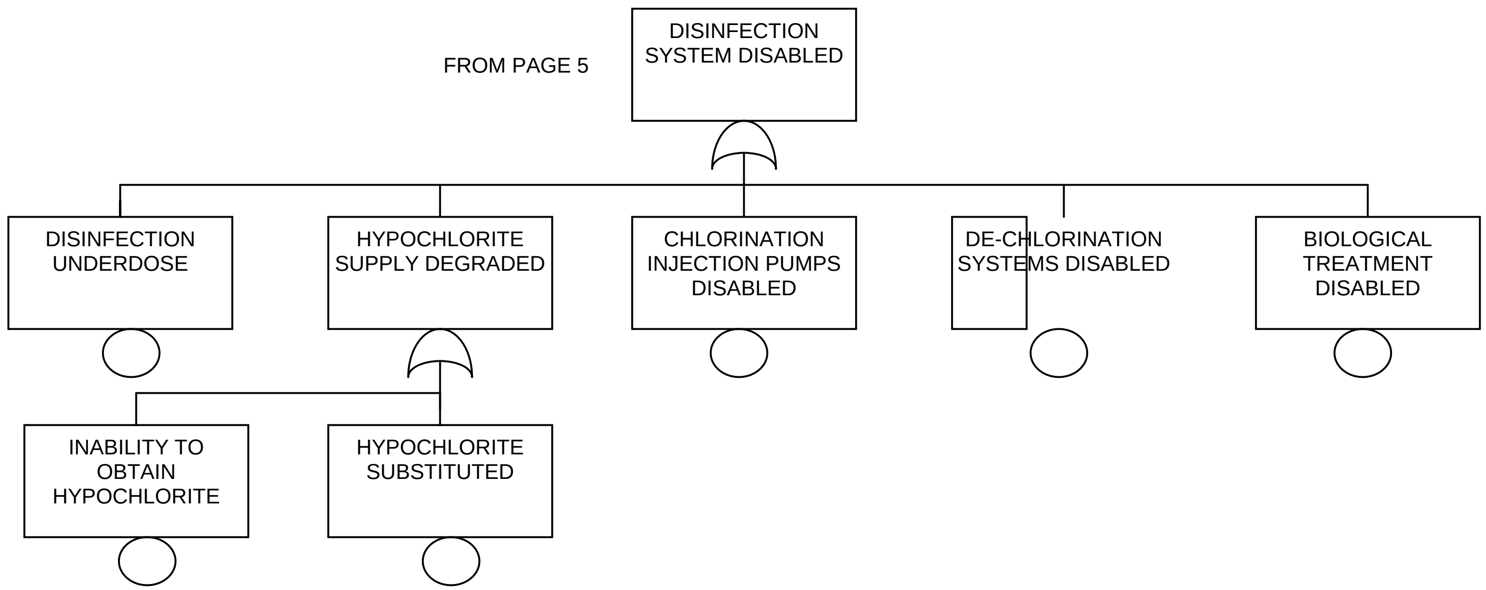

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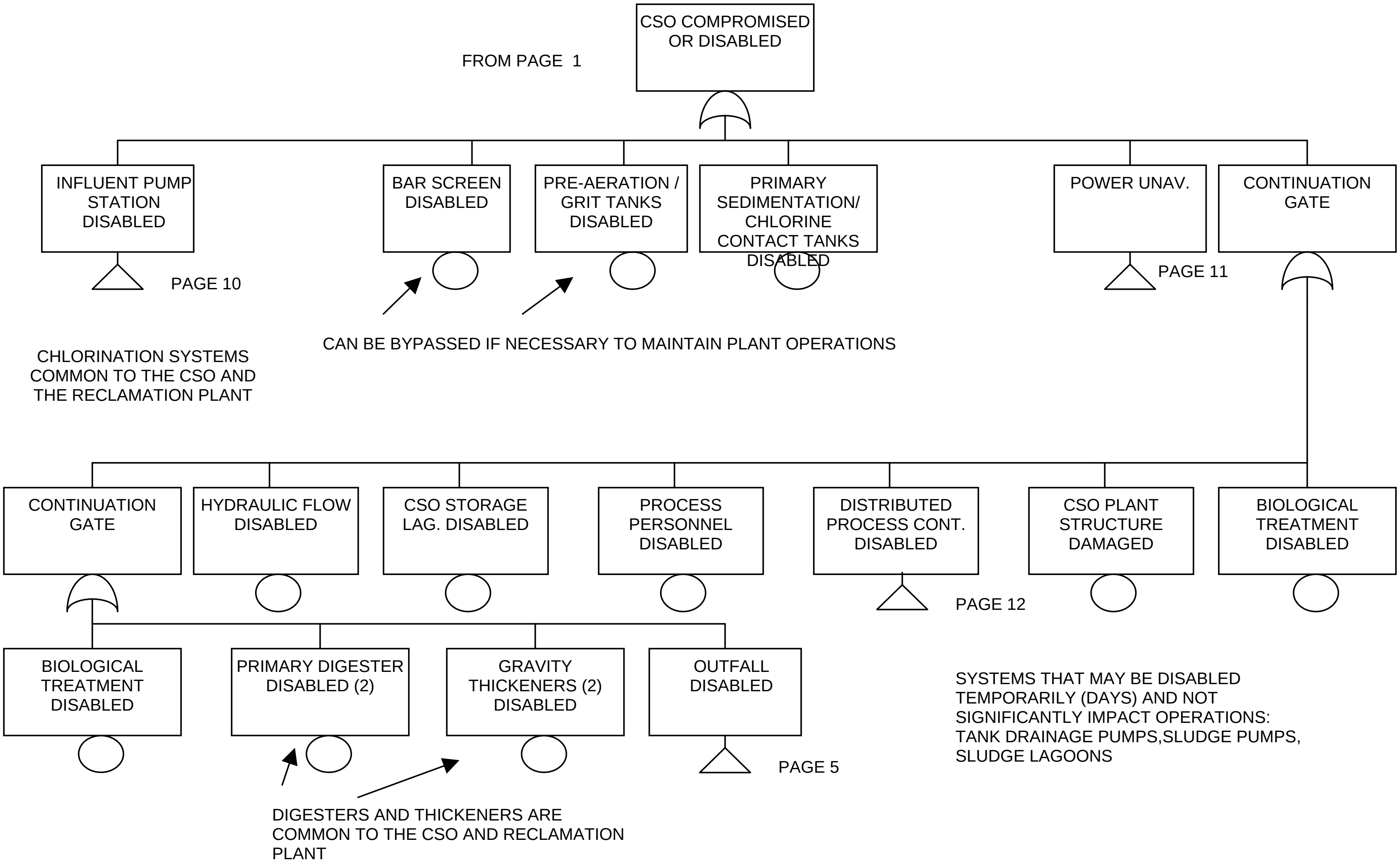

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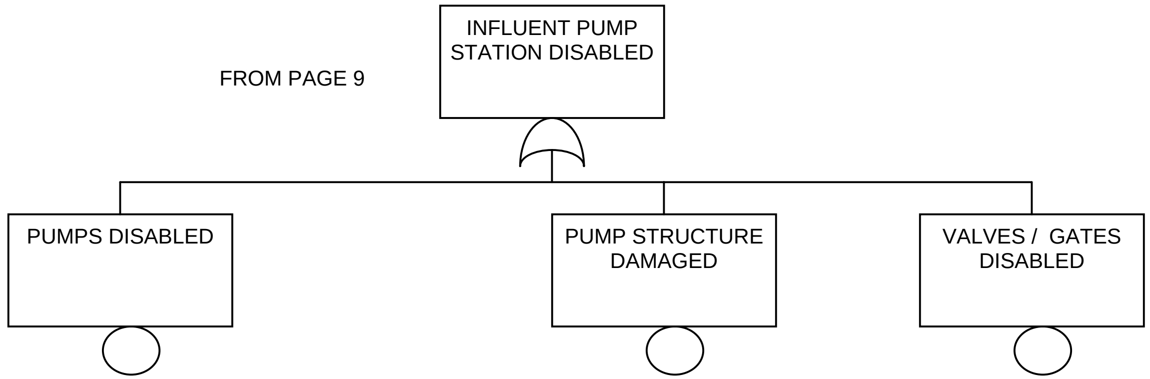

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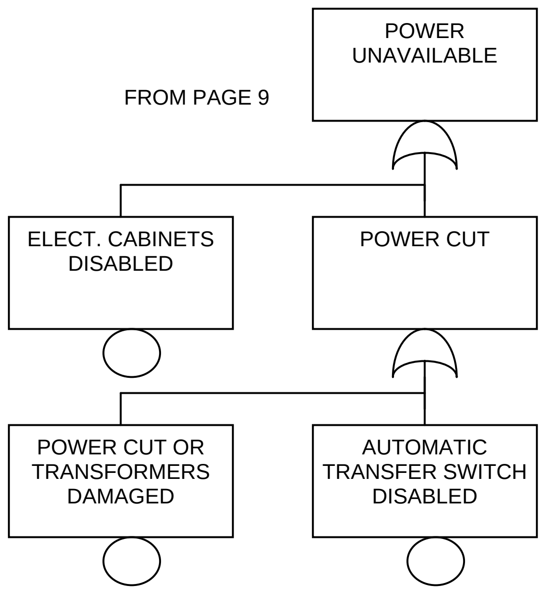

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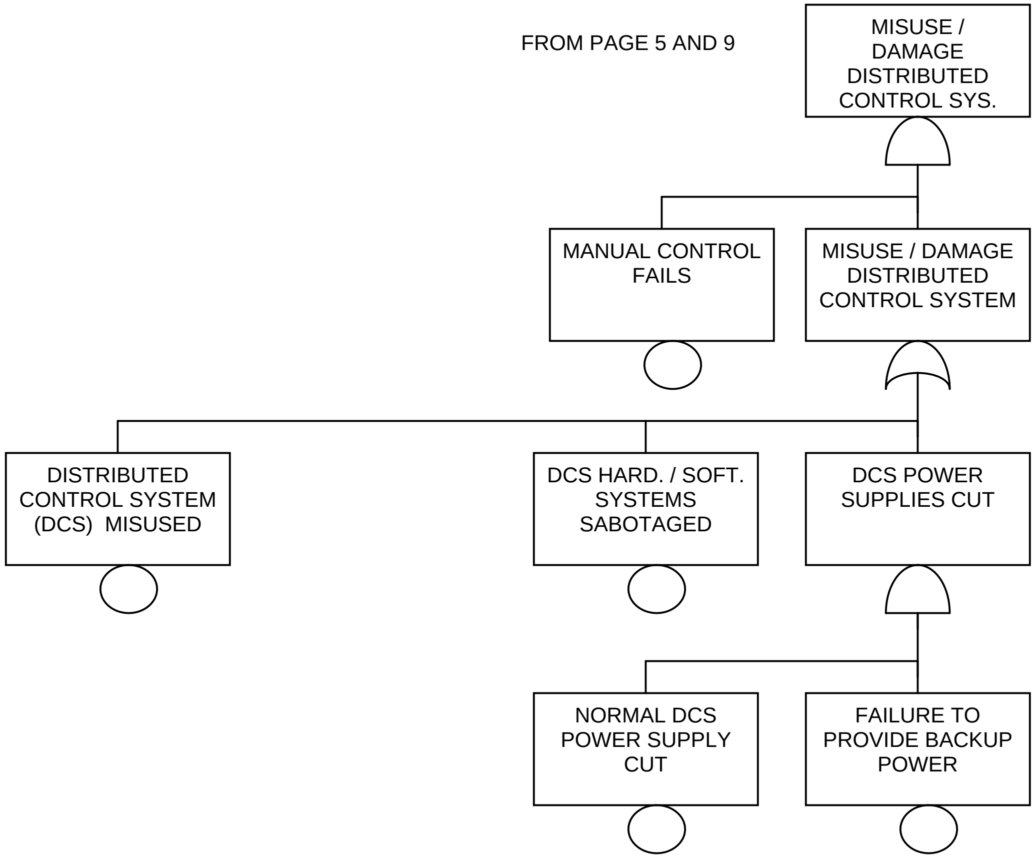

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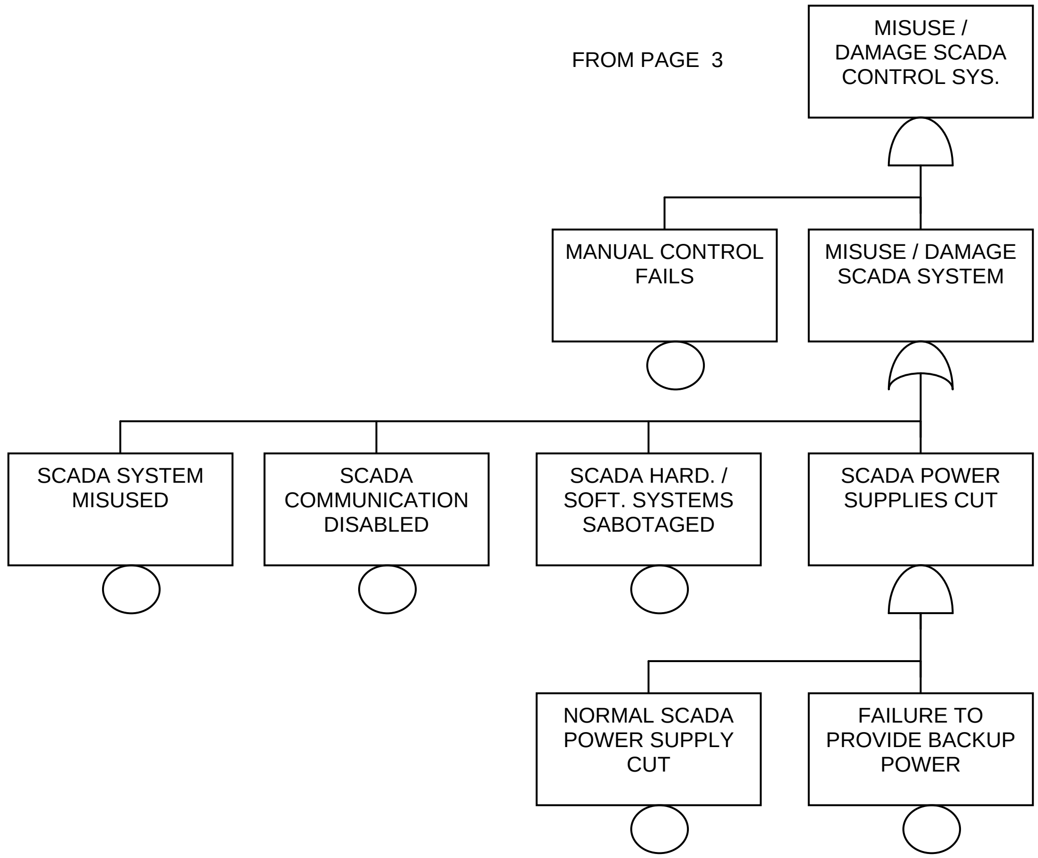

Step 7 Commentary Assess System Performance under Conditions of Natural Hazards and Human Threats

Supplemental Material for Section 7 of the Guideline

Essential to the evaluation of system performance is a system vulnerability model. In such a system vulnerability model, the basic issues to be addressed are whether or not the final nodes (service zones, service connections) can collect and transport sewage to the wastewater treatment plant.

This commentary will begin with a brief discussion of the types of system losses or adverse consequences on interest in a system risk evaluation. The remainder of this commentary will focus first on modeling the post-disaster reconstruction process, and a simplified graphical system assessment.

There is minimal discussion regarding hydraulic modeling of the wastewater collection system. Most systems are trunk and branch type systems, and if a component fails, it stops the flow of everything upstream of the component. In general, system functionality can be evaluated using simple spreadsheets. In most cases, hydraulic evaluations are not required as collection systems are typically linear gravity flow systems. For evaluation, a graphical portrayal of the system is adequate. The flow can be traced from its source down stream to the treatment plant. If any components are not functional, the system will backup and ultimately overflow. Series or linear systems are those that have no redundancy, i.e., there is only one pathway from the service connection to the treatment plant. Parallel (redundant) systems are those that have at least multiple pathways and possibly multiple destinations (treatment plants). These are uncommon in wastewater systems.

Reconstruction times required to restore service can be estimated by summing the time it takes to repair individual components. Component repair times can be estimated based on available equipment and labor, and the crew time required to repair.

C-7.1 System Losses Estimated Based on System Vulnerability Modeling

System losses after natural disasters can be interpreted in many ways. For instance, one can evaluate the volume of sewage that is illegally discharged, the numbers and durations of service areas lacking with no sanitary sewer service. One can further identify those service areas that are more susceptible to service outages after natural disasters. In addition, there are extra costs required to respond to and recover from the natural disaster.

One can further translate these discharges and losses of service into various economic terms. One such translation is in terms of prospective revenue losses to the utility itself. These will be a function of rates and lack of sewage collection as these apply to different customers within the system as well as extra costs to respond to the system damages. Some of these revenue losses will be over and above the repair and labor costs that the utility system itself incurs after governmental disaster assistance moneys, if any, are received.

Another such translation is to develop estimates of losses to the customers themselves. There may be fines and cleanup costs associated with the illegal sewage discharge. Commercial, industrial, or institutional customers may have well-defined sewage collection needs and may know fairly well

System states at time-periods after the natural disaster can be more challenging to model than system states immediately after the disaster. This is because modeling the restoration processes for water systems could involve consideration of such factors as:

- Times to repair diverse components with various damages (e.g., times to repair a pipeline break)
- Prioritization of repairs and restoration activities (e.g., easy repairs first, main trunk lines next, restoration rapid for emergency operation facilities, hospitals, and other critical facilities)
- Effectiveness of mutual-aid agreements
- Availability of qualified repair crews
- Use of utility contractors
- Effectiveness of initial damage surveys
- Functioning of communications systems
- Access to damaged facilities (e.g., vehicle access, roadway access, safety of entering a locale)
- Technology used to assess damage and make repairs (e.g., how do newer technologies accelerate the repair process and/or create more resistant facilities after the process is over)
- Spare parts
- Adequacy of equipment available
- The use of SCADA and other control and/or monitoring systems
- Coordination with water, building and safety, electric power, natural gas, fire services, and other agencies
- Response to public including media concerns
- Governmental policies on outside resources provided, mitigation, reimbursement for disaster response and recovery activities, safety, security, and health.
- The reasonableness and fortuitousness of actions taken in the midst of a disaster (e.g., mistakes made while responding in a crisis or the sub-optimality of actual wastewater system restoration processes; challenging decisions such as to whether a distribution storage tank should be allowed to be drained in order to maintain adequate fire flows)

There are various ways to approach modeling the restoration process so that a helpful assessment of wastewater system losses can be made. These involve:

1. An assessment of how long it would take to repair various system components (including an assessment of the labor required for such repairs);

2. An assessment of the prospective availability of labor, equipment, financing, and spare parts needed to make repairs, including labor, equipment, and spare parts through mutual-aid agreements and state and federal assistance;

3. A preliminary assessment of the priorities within the system should a large-scale disaster take place (e.g., should prospective labor, equipment, financing, and spare parts not permit all damaged components to be repaired at the same time, or should repairs be required to proceed in an orderly fashion in spite of an abundance of labor, equipment, and spare parts and what temporary repairs should be made);

4. Assumptions on (and/or evaluations of) how the utility will fare with respect to other infrastructure systems (e.g., firefighting, communications, water, electric power, natural gas, petroleum, transportation).

The minimum amount of time to restore a system thus includes time for a damage survey, time to locate and mobilize repair crews, equipment, and supplies, and the time for repairs to be made.

With limited resources, priorities need to be set on which portions of the disrupted utility system should be repaired and restored. The following steps could be modeled in a wastewater system restoration process that suffers from limited resources-resources that will not permit all repairs to be made simultaneously:

1. Before the disaster, an emergency wastewater plan is developed as part of the utility's emergency response and recovery plan. This emergency wastewater plan includes the designation of responsibilities, communications capabilities, mutual-aid agreements, planned cooperative efforts with other agencies (e.g., the Corps of Engineers, FEMA, state disaster management agencies, state health agencies), and potential operational strategies for restoring the system.

2. Once the disaster occurs, a field damage survey must be undertaken. This field survey will include not only the identification of malfunctioning wastewater components, but also special facilities and/or service zones that are specially suffering. Customer communications and SCADA system data are among further supplements to field damage survey results.

3. Based on this field survey, a strategic approach to restoring the system needs to be undertaken. This strategic approach will require adequate coordination, communication, transportation, and safe and healthful execution. Priorities in service restoration need to be set. For instance, most medical facilities need continuous service. Likewise, emergency operations facilities including fire and police departments will be prioritized highly for service continuity and restoration.

4. Collection piping should be strategically repaired in order to service higher priority service zones and locations. This will involve identification of how flows are transported to from these service zones and/or high-priority facilities.

5. Repairs of all damaged and necessary components should be completed after these immediate strategic steps.

6. The entire system is restored once all service zones achieve pre-disaster transmission capabilities.

Modeling all of these steps could yield a very complex model. Optimizing prospective emergency response activities could be one of the uses of an evaluation of system risks to wastewater utilities threatened by natural disasters. Actual response to a natural disaster is virtually always expected to be somewhat sub-optimal. Sources of sub-optimal post-disaster restoration are numerous: personnel may be unavailable; there may be airborne hazards (e.g., chlorine leaks) or waterborne hazards; roadways may be impassable; communications may be disrupted; unexpected or undetected damages may have occurred; and utility vehicles may be damaged or otherwise not working.

However, in spite of such limitations of any restoration model, if the assumptions of such a model are well-understood, then it can be useful in developing system states at various times after a postulated natural disaster so that system losses can be estimated.

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

Supplemental Material for Section 8 of the Guideline

C-8.1 Risk and Uncertainty in the Decision Process

The goal of the Guideline is to facilitate development of the necessary information to assist in risk management decision-making for a wastewater system subjected to natural hazards and human threats. That portion of a decision based on the synthesized information from such an evaluation may be called a portion of the decision under risk. In a decision under risk, there is still an element of chance, but this is quantified through the risk evaluation process. For instance, in a deck of cards, the chance of picking a heart is one-in-four, as long as there are no jokers in the deck. Taking a chance of picking a heart can be a decision under risk, as long as one knows what the chances are of picking the heart.

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

The ideal goal of the evaluation of a wastewater system subjected to natural hazards and human threats is to produce a decision under risk, and not a decision under uncertainty. In a decision under risk, to repeat, all key factors bearing on the decision would be fully and adequately quantified. The systems approach in this guideline is based on a process where one combines information on the system at risk, the natural hazards and human threats that may impact it, the vulnerabilities of its components to these natural hazards and human threats, and the response of the system to damage to these components. Through the synthesis of information in a wastewater system evaluation, one seeks to remove uncertainty and ignorance. Nonetheless, the state-of-the-art in this type of evaluation does not permit one to remove all uncertainties and unknowns. This is chiefly a result of the uneven quality of data and models used in such an evaluation. There are very few instances (e.g., very short-term forecasts of floods) in which ignorance is almost virtually removed.

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

Appendix A - Examples

This Commentary Appendix includes five examples: two of a Simplified Assessment, two of an Intermediate Assessment, and one of an Advanced Assessment. The examples expand on those shown in Table 1 of the Guideline. The numbers listed before each example relate to the numbering system in Step 1 text and on Table 1 of the Guideline. The first paragraph for each example comes from the Section 2 description.

Simplified Assessment Level Examples

Comprehensive System Multi-Hazard Risk Assessment – Screening (Project No 1 in Guideline Step 1)

The objective of the assessment is to rank the hazards and system components by relative risk to determine whether an Intermediate of Advanced Assessment is required, 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.

Project Objective

The project objective for Phase 1 of the project is to rank the hazards and system components by relative risk. It is the intent that the hazards and wastewater system components with the highest relative risk will be assessed in Phase 2 in Intermediate and Advanced Assessments. The ultimate project goal is to develop an understanding of the risk from multi-hazards (may include all three assessment levels), and to develop a plan to manage the risk if it is greater than desired (risk management methodology not included in the Guideline).

Metric

The Phase 1 metric is the relative risk of discharging 100 percent of the system flow as untreated or inadequately sewage over a 50 year period. The Phase 2 metric will be probability of discharging untreated of inadequately treated sewage over a 50-year period.

Performance Objective

The utility performance objective is shown in Table 2 of the Guideline, which is reproduced in this Appendix as Table A-2.

Wastewater System at Risk

The Phase 1 assessment is evaluating the entire system. The Phase 2 assessment will only evaluate the highest ranked hazards and system components.

Natural Hazards

This is a multi-hazard assessment. Refer to Table C.5.1 in this Commentary for a list of potentially relevant hazards. These may be added to or reduced depending on the local environment. For each hazard, calculate the relative risk in accordance with Equation ES-1 (Guideline Executive Summary), Figure A-1 in this Commentary, and as described below.

Select the hazard probability of occurrence in 50 years at the level where it first causes one of the system components to fail. For example, this could be a 72-year flood (50% in 50 years). The intensity associated with the 72-year flood is then used to assess the vulnerability of all components for this hazard.

Table A-1. Performance Objectives

	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

Component Vulnerability

For the selected hazard and associated intensity, select the vulnerability for each component. The vulnerability of the component selected above will be High (70% probability of failure for given intensity). For other components, the vulnerability may be High, Medium, or Low.

System Performance

The system performance is not evaluated at this Phase 1 level. However, “consequence” provides a proxy for system performance (40% in the example).

The results of the spreadsheet calculation can be further analyzed by assessing the average and maximum relative risks for both hazards and components as shown in Table A-2.

Flooding would be selected as having the highest risk in Phase 1, and would be recommended for further assessment in Phase 2. Interceptor #1 and the Wastewater Treatment Plant have the highest component relative risk and would be recommended for further assessment in Phase 2.Also refer to the Step 7, Section 7.1 in the Guideline for discussion about correlation factors.

HAZARD			
Rank	Probability in 50 years	Return (years)	Probability Range
H	100%	25	0 - 50 years
M	50%	72	50 - 250 years
L	10%	475	> 250 years
VULNERABILITY			
	Probability of Loss of Function	Likelihood of Loss of Function (General Descriptor)	Probability Range
H	70%	Likely	>50%
M	25%	Possibly	10 - 50%
L	7%	Unlikely	< 10%
CONSEQUENCES			
	System Impact (% of system)	Impact (General Descriptor)	Percent Range
H	40%	High	> 40% of system
M	10%	Moderate	> 1% of system
L	1%	Low	Aggressive response

Risk = Hazard% x Vulnerability % x Consequences %

Earthquake Risk = 10% x 70% x 40% =
Relative Risk –Interceptor 2.8% (3%)

Flood Risk = 50% x 70% x 40% =
Relative Risk – Interceptor 14%

SYSTEM / COMPONENT	**Consequence of Failure (% people without wastewater)**	Flooding		Earthquake	
Hazard Probability (% in 50 years)		**50%**		**10%**	
		Vuln	**Risk**	**Vuln**	**Risk**
Pump Station #1	40%	7%	1%	25%	1%
Pump Station #2	10%	70%	4%	7%	0%
Pump Station #3	1%	25%	0%	70%	0%
Siphon #1	10%	25%	1%	25%	0%
Interceptor #1	40%	70%	14%	70%	3%
West Basin Collection System	40%	7%	1%	7%	0%
Wastewater Treatment Plant #1	40%	70%	14%	25%	1%

Figure A-1 Performance Risk Example Calculation Table (Table developed for the Guideline Commentary based on similar tables in previous projects conducted by ABSG Consulting, Inc.)

Table A-2. Summary of Relative Risks for Flooding and Earthquake for Seven Components

Component	Relative Risk			
	Flooding	**Earthquake**	**Average (Component)**	**Maximum (Component)**
Pump Station #1	1%	1%	1%	1%
Pump Station #2	4%	0%	2%	4%
Pump Station #3	0%	0%	0%	0%
Siphon #1	1%	0%	1%	1%
Interceptor #1	14%	3%	9%	14%
West Basin Collection System	1%	0%	1%	1%
Wastewater Treatment Plant #1	14%	1%	8%	14%
Average (Hazard)	5%	1%		
Maximum (Hazard)	14%	3%		

VSAT™/RAM-W℠ System Evaluation (Project No 4 in Guideline Step 1)

VSAT™ (http://www.vsatusers.net/), RAM-W℠ 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™ , RAM-W℠) . The hazard probability is defined to be 100 percent. The vulnerability is assessed by inspection by personnel familiar with security systems. Personnel familiar with the system operation perform the consequence assessment.

A VSAT™ assessment follows the same general approach as the previous example with the following comments:

Project Objective

Identify security vulnerabilities with highest relative risk.

Metric

Measure of public health impact (such as chlorine release and the associated implications). Measure in terms of number of illnesses per 50 years (same as hazard time frame).

Performance Objective

Reduce the security risk[1].

Wastewater System at Risk

The entire system is being evaluated.

Human Threat

The human threat Design Basis Threat is shown on Table C-10.1.

Component Vulnerability

Each system component and the elements that make up the component (e.g., power supply, pumps, building, SCADA, etc) are evaluated individually by a security professional conducting site visits. Vulnerability is rated using a qualitative scale from Low to High.

System Performance

The system performance is evaluated only from the perspective of the consequence of failure. That is, a higher consequence of failure value is given to components that will have a greater impact on the overall system.

[1] Neither VSAT™ or RAM-W℠ methodologies quantify the risk. They define the intensity in terms of a design basis threat, but assume that the "attack" will occur. The relative security risk of each component is calculated. Recommendations resulting from the analyses are to "improve" system security, but to not provide a basis for the level of improvement.

An overview of the assessment follows:

The Hazard is set to 100% (assumes that it will happen)

The Vulnerability and the Consequence are studied in pairs. For example:

1) Condition: Pump Station #3 is attacked by damaging the power supply.
Vulnerability: The Pump Station transformer is unprotected, and is highly vulnerable.
Consequence: Damage to the power supply can result in 1% of the population losing service. That can be addressed using a vactor, pumper truck or portable generator.

2) Condition: Wastewater Treatment Plant chlorine supply is attacked.
Vulnerability: The Wastewater Treatment Plant is moderately vulnerable to attack.
Consequences: The consequences of releasing a large chlorine plume could be severe. The Wastewater Treatment Plant chlorine supply risk is the highest, and would be brought forward for further consideration.

Intermediate Assessment Level Examples

Comprehensive Single-Hazard Assessment - Detailed Assessment of Individual Components (Project No. 5 in Guideline Step 1)

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.

Project Objective

This is a Phase 2 seismic assessment of a wastewater treatment plant. The objective is to identify deficiencies that will keep the plant and overall system form meeting the Performance Objectives [refer to Guideline Table 2, or Commentary Table A-1(earlier in this Appendix)].

Metric

Measure of public health and environmental impact (such as probability of backup or sewage into buildings or discharge of raw sewage to the receiving water in a 50-year period (same time frame as hazard).

Performance Objective

Refer to Guideline Table 2, or Commentary Table A-1 (earlier in this Appendix) in the Guideline that includes two probabilities of occurrence, one for a “moderate” 100-year return event, and one for a “large” 500-year return event.

Wastewater System at Risk

This Phase 2 assessment is focusing on the Wastewater Treatment Plant. The plant was ranked as the highest risk component in a Phase 1 assessment of the overall system.

Natural Hazards

Flooding was identified as being the highest risk hazard in the previous Phase 1 assessment.

Component Vulnerability

The wastewater water treatment plant can be subdivided into multiple components on a process basis and/or on a functional basis (e.g. power supply, plant piping). In this Phase 2 assessment, the design drawings are reviewed to compare the flood design basis of the plant and components with the flood hazard being assessed, and a walkdown of the site in conducted to identify modifications or other features that are judged to be obvious seismic deficiencies. For the treatment plant components identified as being vulnerable to failure for the two levels of flooding (100-year and 500-year return), engineering estimates are provided of the likelihood that the identified components would remain functional for two levels of flooding.

System Performance

The wastewater treatment plant is an integral part of the overall system. However, it is a system in itself. The impact of reduced functionality of vulnerable components, in terms of the volume of raw sewage discharge (flow plus duration) is determined by consulting with operations personnel. The probability of discharge of raw sewage is compared to the project objectives for two levels of flooding. If the project objectives are not met, potential modifications are developed with priority given to those modifications that result in the largest reduction in raw sewage discharge for the least amount of investment with modifications (e.g., component modification, system modification, emergency response measures) addressing the 100-year hazard given priority of those addressing the 500-year hazard.

Scenario Model Development (Project No. 6 in Guideline Step 1)

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.

Project Objective

This is Phase 2 of the evaluation discussed in Project 1, above. The project objective is to evaluate the reliability of the wastewater "system" using expert judgment, taking into account the vulnerability of the individual system components, and their connectivity.

Metric

Measure of public health and environmental impact (such as discharge of raw sewage to the receiving water).

Performance Objective

Refer to Guideline Table 2, or Commentary Table A-1 (earlier in this Appendix) in the Guideline that includes two probabilities of occurrence, one for a "moderate" 100-year return event, and one for a "large" 500-year return event. Note that this result cannot be used directly to determine whether the performance objectives are met, as it is scenario based (i.e., not probabilistic)

Wastewater System at Risk

This is an assessment of the overall system.

Natural Hazards

Flooding (as determined in the Phase 1 assessment)

Component Vulnerability

The component vulnerability is determined by evaluating each one, facility by facility. Detailed engineering reports and design drawings are reviewed. The vulnerability of the plant site to flooding is determined based on flood mapping and existing studies. Additional effort may be required to update the most recent flood study.

System Performance

The evaluation approach is to develop a scenario system model to determine how the system will perform in the selected flood event. The damage state of each component (see previous paragraph) is input into the model. The spreadsheet model incorporates the damage state of each component and the connectivity of the various system components.

The result in an estimate of the probability failure of the system for a given flood scenario.

Advanced Assessment Level Example

Risk Assessment of an Existing Gravity Sewer (Project No. 8 in Guideline Step 1)

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.

Project Objective

The project was initiated at the insistence of a council person (i.e., politically motivated) that was concerned about the consequences of failure of a sewer submerged in a lake. The project objective is to determine the probability of failure of selected sewers resulting in discharge of raw sewage to a receiving water for several levels of probabilistic earthquake ground motions.

Metric

Probability of raw sewage discharge into the lake over a 50-year period (same time frame as hazard)

Performance Objective

Refer to Guideline Table 2, or Commentary Table A-1 (earlier in this Appendix) in the Guideline that includes two probabilities of occurrence, one for a “moderate” 100-year return event, and one for a “large” 500-year return event.

Wastewater System at Risk

This evaluation focuses on selected segments of the sewage collection system believed to be vulnerable to earthquakes.

Natural Hazards

Earthquake

Component Vulnerability

Detailed design information is gathered including engineering reports and design drawings. Available geotechnical information is gathered, but because of the age of the sewer, there is limited geotechnical data addressing earthquake geotechnical failures.

The potential damage mechanisms are identified. Each one is evaluated using a demand/capacity ratio assessment, and assumed soils loading. It is determined that the soils loading is a very important factor controlling the result, so soils boring data is requested an obtained.

The assessment is completed showing the probability of failure in 50 years for the selected segments of pipe, all for two levels of earthquake. Mitigation alternatives and costs are prepared. The reduced probability of failure for each mitigation alternative is weighed against the mitigation cost. The owner will select a preferred alternative.

System Performance

A system assessment is not part of this evaluation.

Appendix B - Acronyms and Notations

ACI – American Concrete Institute

ALA – American Lifeline Alliance

AMSA – Association of Metropolitan Sewerage Agencies

ASCE – American Society of Civil Engineers

ASTM – American Society of Testing Materials

ATC – Applied Technology Council

AWWARF - American Water Works Research Foundation

C = Consequences to the system of failure of a particular facility or component

CARVER – Criticality, Accessibility, Recuperability, Vulnerability, Effect on the Populace, and Recognizability

CCTV – Closed Circuit Television

CIP – Capital Improvement Plan

COE – Corp of Engineers

CSO – Combined Sewage Overflow

DBT – Design Basis Threat

DMA-2000 – Disaster Mitigation Act of 2000

EAP – Emergency Action Plan

EPA – Environmental Protection Agency

FEMA – Federal Emergency Management Agency

FM&E – Failure Mode & Effect

GIS – Geographic Information System

H = hazard as defined by an intensity and an annual probability of exceedance [Include in definitions.]

HAZOPS – Hazard and Operability Studies

HAZUS-99 – HAZards US - 1999 Version; earthquake loss estimation software

HAZUS-MH – HAZards US – Multi-Hazard; multi-hazard loss estimation software

HMP – Hazard Mitigation Plan

HEC – (Army Corp of Engineers) Hydraulic Engineering Center

IBC – International Building Code

IBCO – International Conference of Building Officials

IEEE – Institute of Electrical and Electronics Engineers

K – Correlation Factor

K_1 and K_2- Coefficients dependent on pipe material, joint type

LEA – Law Enforcement Agencies

LEL – Lower Explosive Limit

MHz - Megahertz

MMI – Modified Mercalli Index

NEHRP – National Earthquake Hazards Reduction Program

NIBS – National Institute of Building Sciences

NPDES – National Pollution Discharge Elimination Systems

OS – Operating Systems

OSHA – Occupational Safety & Health Administration

P_A = Likelihood (probability) of occurrence of the hazard/threat

P_E = System Effectiveness (subtracted from 1 equals vulnerability)

PGD – Permanent ground deformation

PGV – Peak ground velocity

PLC – Programmable Logic Controller

PPS – Physical Protection Systems

PSHA – Probabilistic Seismic Hazard Assessment

R - Risk

RAM-W^{SM} Risk Assessment Methodology for Water Utilities

RF – Radio Frequency

RMP – Risk Management Plan

RR – Repair Rate

SBC – Southern Building Code

SCADA – Supervisory Control and Data Acquisition

SOP – Standard Operating Procedure

SSO – Sanitary Sewage Overflow

T – period (of earthquake shaking or seiche)

T_A – Elapsed Time when the Security Alarm is assessed

T_C- Elapsed Time when the Security Event is Complete

T_I- Elapsed Time when the Security Event is Interrupted

T_O – Elapsed Time when the Security Event is detected

UBC – Uniform Building Code

USGS – United States Geologic Survey

UV – Ultraviolet

V = vulnerability as expressed by probability of a functional state given a particular hazard, H

VSAT^{TM} – Vulnerability Self Assessment Tool

Appendix C - Terms and Definitions

Anaerobic – Without oxygen.

CARVER – stands for Criticality, Accessibility, Recuperability, Vulnerability, Effect on the Populace, and Recognizability. A method to assess the factors that influence the probability of attack.

Chlorinate – Add chlorine (for disinfection).

Consequence – The outcome of an event.

Credible Hazard – Hazard that has a hazard frequency within the planning horizon of the evaluation; e.g. 1,000 years. It would be unrealistic to consider hazards such as meteor impact that have very long hazard frequencies.

Debris Flow – Moving fluid masses of rock, soil and debris.

Dechlorinate – Remove chlorine.

Design Basis Threat – The security hazard on which the system will be analyzed.

Deterministic – Describes a system whose time evolution can be predicted exactly. 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).

Hazard – Source of danger.

Hazard Frequency – The average time between hazard events of equal of larger magnitude.

Hazard Mitigation Plan – An assessment and resulting document that identifies hazards that may impact a portfolio of facilities (such as a wastewater system), assesses the vulnerability of each of the facilities to each hazard, determines the consequences of damage to each of the facilities, ranks the risk associated with each hazard-facility combination, and identifies improvements that can reduce the risk, and prioritizes recommended improvements for facilities within the portfolio that are the most effective.

Human Threat – Hazard of intentional acts by humans that can range from vandalism to state sponsored terrorism.

Intensity – Measure of the level of hazard at a specific location, such as wind velocity or level of earthquake shaking as a percent of gravity.

Lahar – Debris flow generated by volcanic activity.

Magnitude – Measure of the size of an earthquake as a function of released energy.

Metric – Measurement parameter such as: length or flow rate.

Monte Carlo Assessment – A means of statistical evaluation of mathematical functions using random samples. It can be used in establishing the damage state of a component. For example, a random number generator produces a number (a probability) between zero and 100 percent. If the component has a 70 percent probability of failure, and the random number generator produces 50 percent (less than 70 percent), the damage state for the component is “non-functional”. If the random number generator produces 90 percent, (e.g. greater than 70 percent), the component remains “functional”.

Pairwise Comparison – Process of ranking critical facilities by rating the importance of every facility against every other facility.

Performance Objective – Desired system function reliability as a function of hazard return period.

Probabilistic – 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 percent probability of meeting permit requirements for an event with a 50 percent probability of occurrence in 50 years.

Return Period – See Hazard Frequency

Risk – Danger; peril; exposure to loss, injury, or destruction.

Seiche – A naturally standing wave in the water of a lake or bay.

System Vulnerability – Susceptible to loss of system function as a result of failure of one or more system components.

Technological Hazard – Hazards that result from the built environment, but are not intentional acts such as “third-party damage”, accidental damage to buried utilities.

Tephra – Fragmented, solidified lava that rises into the air.

Vulnerability – The state of being vulnerable, susceptible to wounds or injuries; capable of being assailed.

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