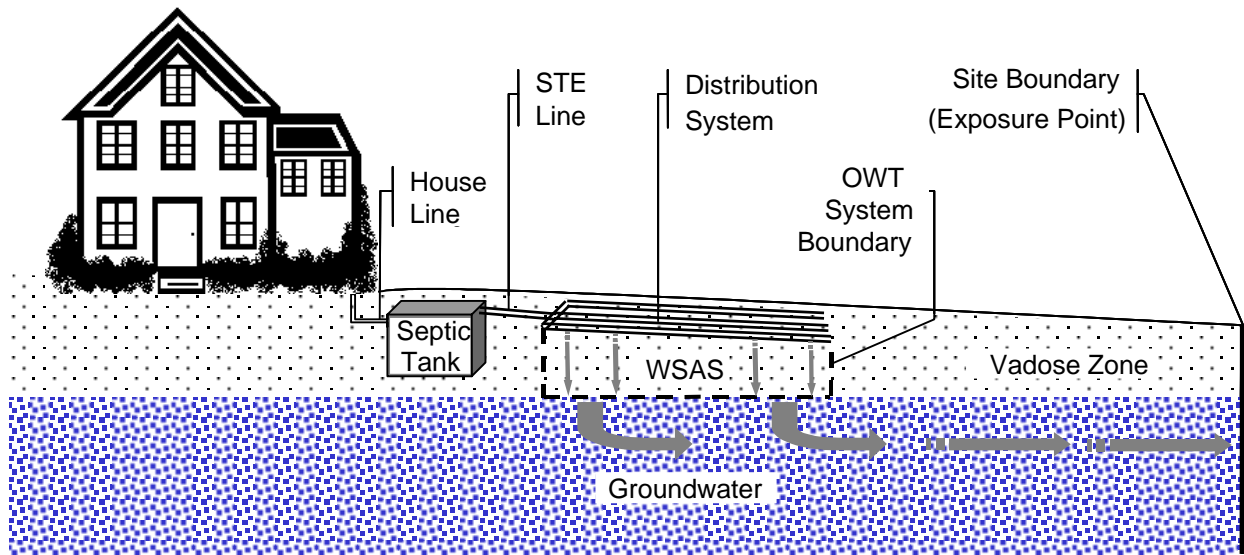




National Decentralized Water Resources Capacity Development Project

Executive Summary



Integrated Risk Assessment for Individual Onsite Wastewater Systems

Oak Ridge National Laboratory
Oak Ridge, Tennessee

December 2004

Integrated Risk Assessment for Individual Onsite Wastewater Systems

**Submitted by
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Oak Ridge, Tennessee**

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EXECUTIVE SUMMARY

The primary objective of this project was to develop an approach to risk-based decision making for individual onsite wastewater treatment (OWT) systems. This framework for individual OWT systems follows the format of *Integrated Risk Assessment/Risk Management as Applied to Decentralized Wastewater Treatment: A High-Level Framework* (Jones *et al.* 2001), which was largely based on the principles and practices of ecological risk assessment (US EPA 1998b and Suter 1993).

Risk Assessment Framework

The risk assessment framework is designed to be most useful to professionals who are trained in the principles of risk assessment. These may include biologists, engineers, or social scientists at regulatory agencies or consulting companies, the latter of which may be hired by regulatory agencies, developers, or industries that design OWT systems. The users who would make the most complete use of this framework would be multidisciplinary teams of risk assessment and OWT design experts. Users of this framework for individual OWT systems may also include technically trained stakeholders, such as county planning commissions with an interest in educating themselves about the factors contributing to biological, engineering, or social risk from individual onsite wastewater systems and methods for their assessment. Entrepreneurs might create user-friendly mathematical models that take advantage of the links among risks in the onsite wastewater system context.

Methods

The methods discussed include measurements and models for retrospective and prospective risk assessments. If the goal is to conduct assessments of proposed new individual wastewater systems (for example, permitting), then the user can focus on the discussions of modeling and ignore discussions of measurement methods for chemicals and pathogens. If the goal is to conduct a risk assessment for existing OWT systems, (for example, to determine the cause of observed illness), then measurement of nutrient or pathogen concentrations may be more important than modeling. If the user is an OWT system designer or the agent of a designer, the user must select generic environments in which the system will be used prior to conducting risk assessments. As an engineer, an OWT system designer may choose to focus on the Failure Modes and Effects Analysis of the engineering component framework, but he or she would need some knowledge of the three other types of risk in order to estimate severity of failure.

Risk Assessment Process

The general risk assessment process consists of three steps:

1. **Problem formulation**—A planning process for generating and evaluating hypotheses about the effects that might occur.
2. **Analysis**—Typically includes both the site-specific analysis or characterization of occurrence or exposure and the more general analysis or characterization of effects (exposure-response relationships). These analyses are interdependent and are typically performed concurrently.
3. **Risk characterization**—The process of combining the estimates of occurrence or exposure with the exposure-response relationships from the analysis of effects to estimate the magnitude and (if possible) probability of effects.

This framework for individual OWT systems is designed to integrate four different types of risk analyses:

- Engineering
- Public Health
- Ecological
- Socioeconomic

The risk analyses are integrated because many of these types of risks are dependent on each other. For example, the economics of water recreation is linked to the presence of water that is clean enough for drinking and swimming. Similarly, ecological risks depend on the failure rates of OWT systems. Therefore, an expert in one risk assessment component discipline would rely on information outside of that discipline to complete a risk assessment for OWT systems. The integration of risk assessment components is accomplished by embedding a component framework for each of these four types of analyses in an overall (that is, integrated) framework (Figure 1).

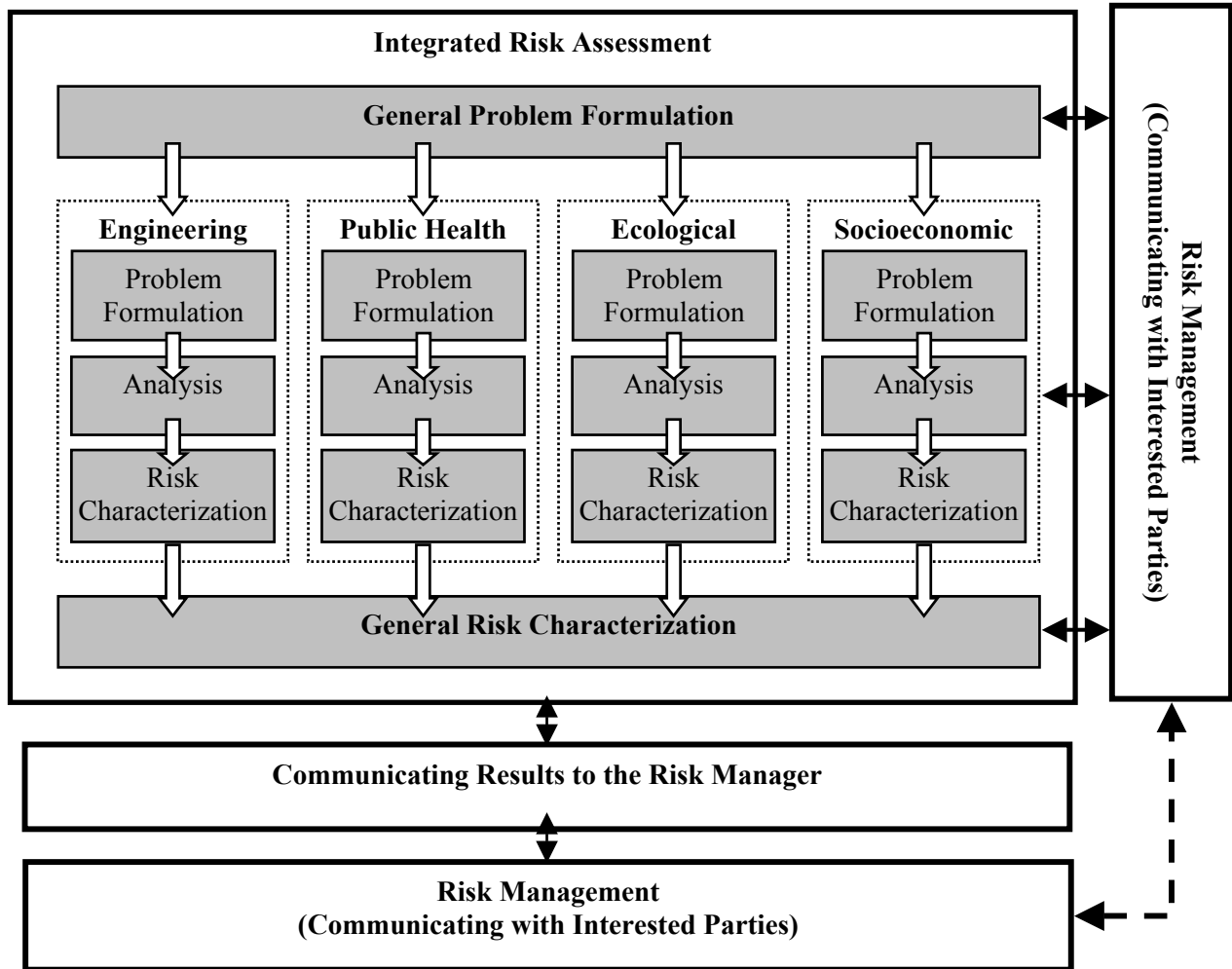


Figure 1
Integrated Risk Assessment Framework for Onsite Wastewater Treatment Systems

Integrated risk assessments can be used to address some of the issues that are typically left to the risk management process. For example, the socioeconomic component of this framework systematically addresses issues that are often addressed *ad hoc* in the risk management process. Examples include:

- Inequities in the distribution of costs/risks among members of the community
- Intrusiveness of regulatory requirements and management practices (for example, property inspections by non-owners)
- Aesthetic impacts (for example, noise, smell, and visual appearance)

Similarly, the engineering component framework permits the explicit and transparent consideration of mitigative measures to reduce the risks of system dysfunction.

This framework was not developed to support macro-scale (for example, watershed-scale) risk assessments for multiple OWT systems. An addendum to this framework is needed for use in addressing the cumulative and emergent effects of multiple OWT systems and offsite treatment systems. Also, the framework was not developed to address benefits of different treatment systems; only the socioeconomic component framework addresses benefits directly. The framework does not support fully probabilistic analyses; only the human health risk assessment component framework (and to a lesser extent, the ecological risk assessment framework) expresses risk in terms of probabilities. Similarly, the framework was not developed to support comparative assessments of alternative wastewater systems. However, it could be used in that context if conservative estimates of exposure and effects, which could bias the analysis toward particular alternatives, are not used. Methods for balancing different types of risks, such as low human health and ecological risk for one alternative system, and high socioeconomic risk for another system, must be developed and applied in the risk management process.

General Problem Formulation

The general problem formulation is a planning step that defines the scope and objectives of the integrated risk assessment for an individual OWT system. This planning step must involve all components of the risk assessment. Three primary purposes for which assessments for individual OWT systems may be conducted are

1. Planning for a new installation on a previously undeveloped site
2. Evaluation of the potential or observed effects of an existing OWT system
3. Evaluation of potential retrofits for a currently failing OWT system

The purposes and goals of the assessment should be aligned with those of decision makers (risk managers). A typical risk management goal is to balance: the risks of endangering public health and reducing local property values due to complete failure of an OWT system (for example, surface breakthrough) against the risk of increased installation and operating costs to the home owner and the risk of eliminating the opportunity for the community to develop the site in question.

The general problem formulation includes the following steps:

1. Description of the spatial and temporal bounds of the assessment
2. Definition of the OWT system to be evaluated
3. Identification and description of the source and the potential stressors and receptors
4. Selection of assessment endpoints (values that are to be protected) with assurance that they can be addressed within the appropriate component assessments
5. Development of a conceptual model for the system to be evaluated
6. Selection of appropriate measures of effects and exposure

These are also steps in the problem formulations for the component frameworks.

The spatial and temporal bounds of the assessment determine what types of stressors and receptors are appropriate. The High-Level Framework (Jones *et al.* 2001) considered two spatial scales—the micro-scale and the macro-scale. The micro-scale referred to an individual residential lot with an onsite drinking water well and an onsite wastewater treatment system. The macro-scale referred to a watershed that contains many individual decentralized systems, as well as other point and nonpoint sources of pollution. The current framework addresses the micro-scale assessment of OWT systems, including areas of potential offsite impact. Macro-scale issues are mentioned in this framework, especially in the context of ecological and socioeconomic risks, many of which tend to be observed at larger scales than the micro-scale.

For OWT systems, the temporal scale of assessment may be based on the time elapsed since the system or component was installed. A risk assessment is denoted as “retrospective” if the goal is to evaluate the potential causes of the current conditions. Prospective assessments are used to estimate potential future risks. A set of default reference points of time elapsed since installation has been selected to illustrate the framework.

Outdated treatment/disposal systems are included in the framework, in addition to three example systems selected to represent categories of modern onsite wastewater treatment systems (Table 1):

- Traditional
- Contemporary
- Emerging systems

The definition of the four OWT categories and the general types of components that are used to represent those systems is based largely on expected effluent quality for each treatment train.

Table 1
Example Treatment System Categories and Components Included in the Framework

System Categories	Major System Components			
	Receiving Tank/ Pre-Treatment	Tank-Based Advanced Treatment	Soil Infiltration/ Vadose Zone Percolation	Discharge Point
Outdated	Cesspool ^a	None	Incidental	Surface soil or water
Traditional	Septic tank ^b	None	Wastewater soil absorption system (WSAS), gravity-fed	Subsurface to Vadose and saturated zones
Contemporary	Septic tank ^{b, c}	Aerobic Treatment Unit (ATU)	WSAS, reduced sizing	Subsurface to Vadose and saturated zones
Emerging	Septic tank ^b	Porous Media Biofilter (PMB) and Disinfection	Drip irrigation	Shallow subsurface

Source: Adapted from Siegrist *et al.* 2000; Table 1, p. 6

^a Straight-pipe systems may have cesspools or non-functioning septic tanks, but they are assumed in this example to be failing standard treatment requirements.

^b Septic tanks are assumed to be designed water-tight. Leaks are addressed in the engineering framework as a potential failure mode.

^c Some ATUs have a built-in trash trap and do not recommend the use of a septic tank in advance of the ATU.

Potential stressors include any physical, chemical, or biological entity that can induce an adverse response in a receptor. The primary stressors for this framework are:

- Pathogens (for example, bacteria, protozoa, and viruses)
- Total and specific forms of nutrients (nitrogen and phosphorus)
- Unaesthetic features
- Noxious odors
- Oxygen demand

Both stress induced by ordinary function (nominal performance) and that induced by dysfunction (non-performance) are considered. Potential receptors include human and non-human organisms and systems (for example, ecosystems, communities, and social and economic systems).

Assessment endpoints are an explicit expression of the value that is to be protected through the use of one or more component frameworks. Endpoints typically consist of

1. An entity
2. A property of the entity that can be measured or estimated
3. A level of effect on the property that constitutes an unacceptable risk

An appropriate level of effect cannot be specified in this assessment framework, because users of the framework must define these with input from stakeholders and regulators. Assessment endpoints are based on their susceptibilities to the stressors of concern and relevance to public policy and management goals. A set of default assessment endpoints is discussed in this framework. Conceptual models are used to describe and to depict visually the expected relationships among the stressors, exposure pathways, and receptors (assessment endpoint entities) in the problem formulation. Only those relationships considered in the risk assessment are typically included in the model.

A generic conceptual model for the transport of wastewater and its constituents (for example, organic material, nutrients, and pathogens) has been developed, as well as specific conceptual models for each component framework. The source is assumed to be the year-round residence of a single family of four with an average daily loading rate of approximately 280 gallons. However, the framework is flexible enough to accommodate other assumptions (for example, seasonal occupation, multi-family homes, or restaurants) with some modification. The conceptual model includes assumptions about:

- Backup of the treatment system
- Surface breakthrough from structural failure
- Contamination of the land surface
- Transport into drinking water wells and groundwater
- Exposure of offsite people
- Exposure of aquatic biota

Engineering Component Framework

This component framework uses the risk analysis methodology called Failure Modes and Effects Analysis (FMEA) to address the issues specific to the design and performance of the OWT system of interest. As with all component frameworks, the assessment format includes problem formulation, analysis, and risk characterization. The problem formulation consists of planning the FMEA.

FMEA is an inductive analysis in which a detailed systematic component-by-component assessment is made of all possible failure modes and their resulting effects on a system. A failure mode is the manner in which the system or component has failed. For example, failure modes for mixing liquids would include no mixing, too vigorous mixing, insufficient mixing, or mixing of the wrong thing. Possible single modes of failure or malfunctions of each component in a system are identified and analyzed to determine the effects on surrounding components and the system. The causes of a failure mode are the

- Physical or chemical processes
- Design defects
- Quality defects
- Part misapplication
- Other methods that are the reasons for failure

FMEA is designed for evaluating system failures (dysfunction), but the methodology can also be used to evaluate OWT system performance under normal operating conditions, in which case a fraction of the assessment endpoint (and an associated event duration) is specified as a level of treatment that warrants attention.

Problem Formulation

The problem formulation for a FMEA entails the organization of as much information as possible about the system concept, design, and operational requirements. The FMEA may be performed with limited design information by answering the following questions:

- How can each part conceivably fail?
- What mechanisms might produce these modes of failure?
- What could the effects be if these failures did occur?
- Is the failure in the safe or unsafe direction?
- How is the failure detected?
- What inherent provisions are provided in the design to compensate for the failure?

The task of identifying subsystem failure modes can take either of two approaches:

1. Functional approach—Listing each subsystem, its functions, and the failure modes leading to the loss of each function
2. Hardware approach—Listing each part and its probable failure modes

The hardware approach is used most often when detailed part design information is available. With either approach, the potential failure modes are identified through answers to the following questions:

- In what way can this subsystem fail to perform its intended function?
- What can go wrong although the subsystem is manufactured/assembled to specifications?
- If the subsystem function was tested, how would its failure mode be recognized?
- How will the environment contribute to or cause a failure?
- In the application of the subsystem, how will it interact with other subsystems?

General types of failure modes for the functional approach include:

- Failure to operate at the prescribed time
- Failure to stop operating at the prescribed time
- Intermittent operation
- Wearing out of components
- Degraded output

General types of failure modes for the hardware approach for the traditional wastewater disposal system include:

- Plugged system
- Too little flow
- Too much flow
- No settling
- No anaerobic activity
- Leak or rupture
- Flooding

Causes of a failure mode can be divided into two categories: (1) design deficiency, or (2) process variation that can be described in terms of something that can be corrected or can be controlled.

Analysis

In the analysis stage of the assessment, the probability and magnitude of the failures are estimated. Occurrence (OCC) is the likelihood that a specific cause of failure will occur. Each cause of failure listed in the FMEA requires an estimate of its possible failure rates and/or its mean time between failure probabilities.

OCC can be based upon historical data, including the service history, warranty data, and maintenance experience with similar or surrogate parts. OCC probabilities can be based on the frequency of the initiating event (for example, seismic events or floods), the independent failure rate of components (for example, valves or piping), or historical experience/engineering judgment (for example, saturation of leach fields).

The second part of the analysis is the estimation of the severity of a failure. Severity (SEV) of the impact for each failure mode is assessed and classified according to rankings outlined in a severity table. Health and safety of the homeowners and offsite personnel are often the primary criteria in determining the SEV ratings for OWT systems, although effects on environmental entities and property are also considered.

Both the magnitude of effluent characteristics (that is, biological oxygen demand, total suspended solids, total nitrogen, phosphorus, and fecal coliforms), and duration of the failure event or routine performance level are considered. Duration is defined as the time elapsed between the start and end of the event, that is, between the point in time at which the OWT system component is no longer achieving the specified level of treatment and the point in time at which it is once again achieving the specified level of treatment.

The severity scales used in the FMEA for individual OWT systems vary by assessment endpoint. The severity scale is designed to yield a score of:

- Between 7–10 for events that warrant action
- Exactly 6 for events that may warrant attention
- Between 1–5 for events that are considered negligible

Example severity scales developed specifically for OWT issues are presented for each of the engineering assessment endpoints. The same severity scale can be used to estimate both the unmitigated and mitigated risks of a particular failure mode. Mitigation measures are assumed to reduce severity to a marginal level. Selection of appropriate severity scales is best accomplished with stakeholder input.

Risk Characterization

Two risk characterization procedures are recommended in the engineering component framework. The first risk characterization effort defines the “unmitigated” risks. If unacceptable risks are estimated in this step, then additional detection and process controls are considered and the risks are re-evaluated and categorized as “mitigated” risks. In the latter procedure, the user evaluates the ability of the proposed mitigative measures (that is, control processes or detection and correction attributes or mechanisms) to avoid a failure event or to detect a failure event and to correct the problem.

Public Health Component Framework

The public health risk assessment component is used to evaluate potential health risks from exposure to wastewater effluent or environmental media that have come in contact with wastewater effluent. The goal of this framework is to provide quantitative risk estimates for constituents of concern that originate in wastewater effluent of OWT systems.

Problem Formulation

The public health risk component focuses on primary constituents of concern (stressors) to humans in wastewater effluent: nitrogen-containing compounds (nitrate and nitrite) and microbial pathogens. The human health property evaluated as the result of exposure to chemicals originating in wastewater is systemic toxicity (noncarcinogenic effects). Chemicals of most concern with respect to adverse impact to public health in wastewater effluent are nitrogen-containing compounds—nitrate and nitrite. Cyanosis among infants who drink well water is a commonly encountered clinical manifestation of nitrate toxicity.

The two human health properties commonly evaluated as a result of exposure to microorganisms originating in wastewater are infection and illness. Because the risk of illness can vary greatly with the type and strain of microorganism, as well as host age and other host factors, the microbial assessment endpoint evaluated in this public health framework is risk of infection. Microbial pathogens of concern include viruses, bacteria, and protozoa. In this framework the indicator of bacterial pathogens is fecal coliforms, and the indicator of viruses is rotavirus.

Analysis

Assessment entities include potentially exposed populations and can be evaluated based on several subcategories such as age (for example, children, adults, geriatrics). In addition, sensitive subpopulations may be evaluated based on gender, ethnicity, baseline health status (immunocompromised, hereditary diseases, and other factors), or any other site-specific health characteristic of the potentially exposed population that warrants consideration. The level of effect guideline for chemicals in this public health risk assessment is defined as exceedence of the reference doses (RfDs) for systemic toxicity. The attribute evaluated for microbial exposures is risk of infection. Likewise, the microbial risk of infection guideline is defined as greater than 1×10^{-4} .

The conceptual site model should describe:

- Location of the OWT system
- Location of residences and wells
- Topography
- Groundwater
- Surface waters

-
- Soils
 - Potentially exposed populations

Exposure pathways and points occur onsite (within the residential lot) and offsite. The generic conceptual model provided the basis for the development of the conceptual model for the public health frameworks for pathogens and nitrates.

The spatial extent of the risk assessment is defined by the boundaries of the site on which the OWT system is located and the migration pathways to potentially exposed persons (for example, offsite publics or tourists exposed at the site boundary). Likewise, the assessor should specify the temporal scale of analysis based on the lifetime of the OWT system or components of interest, the travel time of wastewater constituents of concern to a potential exposure point, or local or state regulations.

Current exposure concentrations for some constituents of concern can be directly measured, such as the concentration of nitrate in soil, surface water, or groundwater. Likewise, current concentrations of some microbial pathogens can be measured in soil, surface water, or groundwater. Fate and transport models are often utilized to estimate exposure concentrations of

- Viruses at all times (which are difficult to measure)
- Chemicals at past or future points in time
- Bacteria and protozoa at past and future points in time

For adverse impact to human health to occur, a potentially exposed population is required at the exposure point. Potential receptors include residents and visitors onsite and residents and tourists at the site boundary. Routes of exposure for potential receptors include ingestion, dermal contact, and inhalation. For each exposure route, an exposure model is constructed and applied to estimate a daily intake for the wastewater constituent of concern. Daily intakes can be estimated for acute and/or chronic exposures of individuals with differences in body weight, ingestion rates, and exposure frequencies. The estimated doses are compared to health toxicity values or guideline values to determine if adverse health impacts are predicted and the level of the effect.

Risk Characterization

The risk characterization step of the risk assessment process evaluates the exposure and effects data developed in the analysis step while producing estimates of risk as well as explanations of results and uncertainties associated with the risk estimates. If the calculated chemical intake exceeds the chemical-specific reference dose (RfD), adverse health effects maybe expected (that is, the hazard quotient is greater than 1.0). The quantification of microbial risk from exposure to wastewater effluent or to environmental media that have contacted wastewater effluent is more challenging because of the

- Numerous routes of exposure,
- Differing numbers of organisms in various media,
- Differing amounts of media consumed per individual

-
- Potential propagation of infectious agents
 - Potential latency period

Dose/response data are available for several pathogenic microbial species associated with wastewater, including several bacteria, one or two protozoans, and select viruses. To assess risks of infection from microbial exposures, the measured fecal coliforms in environmental samples are assumed to be *E. coli*. While most *E. coli* are not pathogenic, the presence of *E. coli* suggests the potential presence of pathogenic strains.

To estimate the risk of microbial infection from ingestion and/or contact with soil, groundwater or surface water, a beta-Poisson dose-response model is used. The beta-Poisson model is also used to estimate risk of rotavirus infection. Measured rotavirus concentrations are used to determine doses of microorganisms from the exposure models. Exposure to microbes that results in a risk of infection greater than 1×10^{-4} exceeds the example guideline for this public health risk framework and indicates that risk management preventative measures may be warranted.

Conservative assumptions are intended to provide a margin of safety due to the uncertainty in the estimates of risk to the public. Because precise information is not known about all exposure parameters such as the amount of groundwater ingested, exposure durations, or the amount of time recreationers spend in the water while swimming, best estimates and conservative assumptions are made during the risk assessment process.

If time and resources permit, a quantitative uncertainty analysis of the parameters and models used to estimate risk may provide a better understanding of technical issues associated with the risk estimates. Quantitative methods for uncertainty analysis are more accessible for the public health component framework than for the broader socioeconomic or ecological frameworks.

Ecological Component Framework

The ecological component framework is used to evaluate the potential adverse impacts on non-human biota and ecosystems. The three-stage risk assessment format used throughout the integrated framework (that is, problem formulation, analysis, and risk characterization) is also used in this component framework.

Problem Formulation

As stated in the general problem formulation, this framework is designed to address micro-scale OWT systems, that is, an individual residential lot with an OWT system. Although some ecological impacts are evident only at the macro-scale (for example, population-level impacts on wide-ranging, mobile species), others can potentially manifest at smaller geographic scales (for example, impacts on individual plants and sensitive receptors). This situation is particularly true for sites where the dilution of OWT effluent at the exposure point is low.

The micro-scale is pertinent to residential treatment systems located adjacent to small ponds, streams, or lagoons and some parts of shallow estuaries (for example, coves where tidal water exchange is very limited). With respect to amphibians, the micro-scale is also relevant for sites with small or temporary ditches onsite or at the site boundary. The spatial bounds for the ecological assessment may extend somewhat beyond the site boundary, but it is still a micro-level assessment because only one OWT system is being evaluated.

Although the exposure models and exposure-response models presented here could also be used for macro-level assessments, the localized scale of analysis is the primary justification for the selection of stressors and assessment endpoints emphasized in this component framework. Most potential effects at the local scale are direct effects (for example, increased plant biomass), rather than secondary effects (for example, effects from losses of forage or habitat or from increases in predation).

Analysis

The temporal bounds of analysis may be based on several factors, including:

- The lifetime of a treatment system
- The lifespan or sensitive life-stage of a particular receptor
- Periods of high release (for example, storm events)
- Regulatory requirements
- A decision by a risk manager (decision maker)

The nutrients nitrogen and phosphorus are the principal ecological stressors associated with residential OWT systems. However, the user must identify the stressors that are the focus of each particular risk assessment. Nutrient inputs to a surface water body have the greatest impact if background concentrations limit production or growth rates (for example, primary production) of one or more assessment endpoint entities. In general, nitrogen is a limiting nutrient in estuarine waters in temperate environments and phosphorus is a limiting nutrient in most fresh waters in temperate environments.

Two types of surface water ecosystems are distinguished based on differences in prevailing nutrient dynamics:

1. Freshwater systems (for example, ponds)
2. Estuarine systems (for example, coastal lagoons).

In the characterization of exposure, differences between lotic (flowing) and lentic (still) waters also are noted.

A generic conceptual model for the potential effects of an OWT system on a freshwater receiving environment is generated. Phosphorus exposure is the major determinant of phytoplankton production in most North American lakes. This nutrient may also be limiting in streams, but high water flows and flood events may overwhelm the effects of nutrients.

Various forms of nitrogen can be directly toxic to aquatic biota, especially reduced forms such as ammonia, though the primary exposures of aquatic organisms and amphibians to nitrogen from an OWT system following release and oxidation in soil are exposures to nitrate. Organic matter and reduced nitrogen forms, such as organic and ammonium, that are associated with wastewater and directly released to surface water bodies are additional stressors that can cause oxygen limitation.

A generic conceptual model for wastewater treatment unit effects in a shallow estuary or lagoon is generated and discussed. Nitrogen is the primary stressor, which can be directly toxic or can interact with biota to produce secondary stressors (limited light penetration, oxygen limitation, reduction in habitat, or reduction in forage vegetation or prey). Organic matter and reduced nitrogen forms, such as organic and ammonium, that are associated with wastewater and directly released to surface water bodies are additional stressors that can cause oxygen limitation. Algal production, macrophyte production, fish community abundance and production, benthic community abundance and production, and amphibian community abundance and production are examples of options for risk assessment endpoint properties for OWT systems.

The characterization of exposure is the phase of an ecological risk assessment in which the spatial and temporal distributions of the intensity of the contact of endpoint entities with stressors (for example, nutrients) are estimated. Exposure must be characterized in terms that are useful for estimating effects. That is, if the average annual input of phosphorus is known, it may need to be converted to the average annual concentration of phosphorus in the water body if the exposure-response relationship is based on this latter unit.

The exposure of ecological receptors to nutrients is characterized by measurement or modeling. Measurements of most forms of nutrients and dissolved oxygen are easy, and if sufficient measurements are taken to characterize spatial and temporal variability, measurement is clearly more accurate than modeling for a risk assessment of current nutrient releases. However, measurement cannot distinguish the incremental exposure associated with wastewater treatment releases from other sources of nutrients. Prospective risk assessments require modeling of concentrations of nutrients in surface water at the exposure point. Retrospective risk assessments require modeling if historical measurements are not available. Most exposure-response models for ecological receptors in surface water require concentrations of nutrients as measures of exposure. Ecotoxicologists tend to measure or to model nutrient concentrations rather than loading rates, although loading rates may be the starting point.

OWT system effluent that migrates to surface water through the soil probably will not retain enough organic carbon to create substantial carbonaceous biochemical oxygen demand (CBOD) in receiving waters, based on data from sand filters and the behavior of dissolved organic carbon in sand aquifers. However, untreated wastewater that reaches the soil surface and either flows to the receiving water or is transported in surface run-off could produce locally high CBOD and, therefore, localized areas of hypoxia.

Exposure-response relationships may be available or derived from field observations, laboratory or mesocosm tests with site-specific media, or relationships from published studies. These latter relationships may focus on exposure measures, ecological receptors, and locations that are somewhat different from those of concern in a particular assessment, but they may be the only relationships available for retrospective or prospective assessments for which field observations or surface water samples are not available.

Exposure-response models may be empirical models derived from measurements at one or more sites (for example, biological surveys), mechanistic models derived from first principles, or thresholds determined from the literature or from site-specific tests. In this risk assessment framework, only one mechanistic model was identified to characterize ecological effects. When field observations are used, it may not be possible to attribute causation, if multiple stressors are present or if multiple sources of one stressor are present.

Risk Characterization

In the risk characterization, the information in the characterization of exposure and the characterization of effects is combined to estimate risks. If sufficient data are available, the risk characterization should consist of a comparison of distributions of exposure concentrations and those of probable effects for each assessment endpoint. The evidence is often presented in a weight-of-evidence table, with qualitative or quantitative uncertainty. For each line of evidence, several factors are considered, including:

- Data quality
- Relationship of measures of effect to the assessment endpoint
- Relevance of measures of exposure at the site to those that feed into the exposure-response relationship

For example, the weight of evidence could utilize effects models based on total nitrogen loading, models based on nitrate concentration, and biological survey results. Lines of evidence may be weighted differentially, if the assessor has more confidence in one than in another. If the goal of the ecological risk assessment is to estimate the magnitude of effect, the estimates of magnitude that result from using different methods to characterize exposure or effects may be weighted, and the result may be a weighted average estimate of the magnitude of effects. In any ecological risk assessment, sources of variability and uncertainty in results must be described, and wherever possible, quantified.

Socioeconomic Component Framework

This framework is developed for use in evaluating potential socioeconomic impacts and risks from

- Exposure to wastewater effluent or environmental media that have come in contact with wastewater effluent
- Efforts to manage those effluents with an OWT system

The socioeconomic component addresses many issues that are typically part of the risk management process, such as monetary costs of the design and installation or replacement of the OWT system, maintenance costs, and opportunity costs.

Only the impact and risk assessment at the micro-scale (that is, a single residential OWT system) is addressed in this document. However, macro-level issues are relevant in a micro-level assessment to the extent that they create or influence stressors and other aspects of risk assessment that must be addressed in an assessment of an individual OWT system. For example, the presence, capabilities, services, and costs of a maintenance contractor or a responsible management entity are macro-level factors that affect the likelihood of system failures and determine the fees that are paid out by the individual system for maintenance or oversight.

Problem Formulation

Many of the impacts and risks that wastewater treatment systems pose to the socioeconomic environment grow out of concerns related to the engineering, public health, and ecological dimensions of the system being studied. People value their money, their health, and their ecosystems, meaning that impacts or risks to any of these phenomena result directly or indirectly to impacts or risks to the socioeconomic environment. The impacts or risks of a wastewater treatment system are understood to occur in the context of an existing socioeconomic environment. Thus, the assessor needs to understand and be able to characterize that environment in order to be able to assess the impacts or risks associated with the given wastewater treatment system, compared with the pre-existing condition of that environment.

For the assessment of impacts and risks of wastewater treatment systems at the micro-scale, the existing socioeconomic environment would include but not be limited to the following characteristics:

- Economic status of each receptor and the receptor's neighbors (receptors are people, groups, or social or political constructs that are potentially exposed to one or more stressors)
- Presence or absence of vulnerable populations among each receptor and the receptor's neighbors (that is, vulnerable in terms of susceptibility to health or economic stresses)
- Development status of the receptor's property (for example, as a permanent, temporary, or seasonal residential property) and neighboring properties, including the current value of the properties and the aesthetic qualities of existing land uses

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- Existing wastewater treatment capacity/capability of the receptor's and neighbors' environment
 - Existing wastewater treatment capacity/capability of the source OWT system, including hydraulic capacity and capability of accepting household chemicals, high CBOD loads, and other components
 - Presence, capabilities, services, and costs of a maintenance contractor or a responsible management entity (will affect the likelihood of system failures and will determine what, if any, fees are paid out by the individual system for maintenance and/or oversight)
 - Capabilities and willingness of receptors (including those of absentee property owners) to maintain existing or new wastewater treatment system
 - Sensitivity of receptors to intervention(s) taken by outside agents (for example, to inspect or maintain an onsite wastewater treatment system or otherwise take action on the property)
 - Temporal and climatic variability of the receptor's environment (for example, seasonal, diurnal, or meteorological variations)
 - Potential for catastrophic natural events (such as, flood, earthquake, landslide, or hurricane)

Stressors are any physical, chemical, or biological entity that can induce an adverse response in a receptor, either directly or indirectly. In many cases the effect can be positive or beneficial as well as adverse; therefore benefits are included in this framework. Benefits can include increases in property value, increases in development potential, and improved health status (and reductions in health care costs associated with that improved health status). In the context of the socioeconomic impact and risk assessment for wastewater treatment systems, stressors are more likely to indirectly affect the socioeconomic environment via the physical environment.

Socioeconomic stressors can be both tangible (such as real monetary costs or changes in property value) and intangible (such as "psychic costs" of allowing others on one's property for periodic system inspection). For many of the stressors (and attributes), the interrelationships among concepts and variables are complicated. For instance, one can argue that property value is simply a metric for a bundle of characteristics, some of which are physical and tangible (such as size of lot, size of house, number of bedrooms, *and* the kind of wastewater treatment system) but others that are more perceptual (such as perception of sanitation, healthiness of a home, aesthetics of landscaping, and sense of well being).

The assessor needs to identify those aspects of the wastewater treatment system that could adversely or beneficially affect the socioeconomic environment. Moreover, the assessor must identify those aspects of the system that could affect the environment if the system operates or works successfully and if the system fails (whether due to a design flaw, improper maintenance, or capacity overload due to climatic or behavioral changes).

Time and monetary costs are the principal socioeconomic stressors associated with the micro-scale of the OWT system. The time and monetary costs borne by the different receptors and the distribution of those costs by the receptors are the principal measurements that will need to be characterized in the assessment. Additional, intangible stressors can often be addressed by measuring related time and monetary costs as surrogates.

Receptors can be selected as assessment endpoint entities. At the micro-scale of this assessment framework, the receptors include:

- Individuals (property owners, occupants—permanent, temporary, or seasonally transient)
- Vulnerable subgroups or populations
- Adjacent populations (including any vulnerable populations)

The resources of those individuals or groups of individuals, and the relevant characteristics of those receptors (such as socioeconomic status, happiness, wealth, and health) are the important attributes for which endpoints are needed in the assessment.

Levels of effect may be specified for assessment endpoints that constitute adverse effects (but not usually for beneficial effects). The user of this framework should be aware that changes in values for the endpoints are susceptible to variable interpretation by different interested parties or stakeholders and, as pointed out previously, that both the “real” and “perceived” changes in value for some if not all of those endpoints may be of interest to the decision maker.

In contrast to the engineering, public health, and ecological dimensions of the assessment framework, where acceptability endpoints are better understood and more generally agreed to, assessment endpoints for the socioeconomic dimension of the problem are sometimes more difficult to identify and often more difficult to quantify (in general because they are less amenable to common understanding or agreement). This dilemma is particularly problematic when addressing the “intangible” values that are important to the assessment (such as the psychic costs or stigma of alternative wastewater treatment systems).

Analysis

In contrast with the other components of this framework, the characterization of exposure in the socioeconomic impact and risk assessment is not based on discipline-specific modeling or estimation but rather derives from either the presence (or absence) of the OWT system of interest (and results in the effects on the endpoints) or from the findings of the exposure assessment of the other risk assessment domains. In the latter instance, the socioeconomic risk assessor would characterize socioeconomic exposure in terms of the spatial and temporal distributions of the intensity of the engineering, human health, and ecological exposures and effects.

The characterization of effects is the determination of the nature of adverse and beneficial effects of the stressors on the receptors and the receptor’s (entity’s) properties and attributes. These effects may be available or derived from field observations and research, secondary data sources (for example, census data), or from published studies.

Risk Characterization

In the impact and risk characterization portion of the assessment, the information in the characterization of effects is used to estimate impacts and risks. The engineering subcomponent should provide information regarding the design, installation and maintenance and repair costs of the OWT system of interest. The assessor can stipulate, by assumption, the cost of money or assume variable costs of money (for opportunity cost). Likewise, the engineering subcomponent should supply information regarding the time cost of the OWT system (in terms of hours per month to maintain the system) and whether that time is a cost to the property owner or to a firm contracted for OWT system maintenance. Also, for socioeconomic risk assessment of operational failure, the engineering subcomponent would provide estimates of rates of failure, which then translate to frequency and severity of socioeconomic stressors such as cost to repair a system, aesthetic (for example, olfactory) “insult” from failure, loss of property value if repair is not possible, and other stressors.

In many socioeconomic impact and risk assessments, only one line of evidence may be available for the impact and risk characterization of a socioeconomic endpoint property and stressor. However, if multiple measures are available, all of these may be used to obtain distinct estimates of impacts and risks to the assessment endpoints. The evidence may be presented in a weight-of-evidence table, with consideration of qualitative or quantitative uncertainty. For each line of evidence, several factors are considered, including data quality and the relationship of measures of effect to the assessment endpoint.

General Risk Characterization

The primary objective of the general risk characterization is to summarize and to integrate the results of each component assessment into a cohesive evaluation of the risks to all of the selected assessment endpoints. Meeting this objective entails:

- Summarizing the risks and uncertainties characterized in each component assessment
- Characterizing the integrated risks and uncertainties for assessment endpoints that are potentially affected by one or more other assessment endpoints
- Summarizing the integrated risks and uncertainties characterized in this section

This approach highlights the fact that risks can be divided into two general categories for the purposes of this framework: independent risks and conditional risks. The estimation of independent risks is carried out without reference to the estimation of all other risks to a particular assessment endpoint. For example, the risk of treatment failure (dysfunction) due to seasonal flooding of the WSAS can be estimated in the engineering risk assessment even if the other three component assessments are not performed. Conditional risks are those for which the estimation of risk is conditional on the estimates for one or more other risks. The risk of infection by a virus is, in part, conditional on the risk of having a treatment failure due to seasonal flooding of the WSAS, which then results in exposure of the residents to viruses.

Independent Risks

Independent risk results need to be presented in adequate detail for decision making, including at a minimum, a rating for both the estimated risks and the uncertainties associated with those estimates. Some component assessments include a rating system in their design, whereas others may just report the results without explicitly classifying the risks as being more or less than the assessment endpoint level. The former method is preferred over the latter. For example, the engineering framework in this assessment uses a Roman numeral ranking system ranging from I to IV and the ecological framework uses a weight-of-evidence process to assign a plus/minus rating for each assessment endpoint. These ratings can be used without modification for the general risk characterization. However, a rating should be assigned in the general risk characterization section if the component assessment does not do so directly. For example, the risk of infection from the public health component framework is reported as an estimated rate of infection for example, 1:10,000) rather than as a rating.

A simple acceptable/unacceptable rating system is a useful and intuitive tool for this purpose. The decision rules for that system are:

- **U**—Indicates an unacceptable exceedance of the selected level of effect for the assessment endpoint
- **A**—Indicates an acceptable rating
- **I**—Indicates that insufficient evidence was available to conclude whether the selected level of effect for the assessment endpoint was exceeded (that is, the acceptability of the risk is indeterminate)

To support the risk management process, the general risk characterization needs to summarize the previously detailed uncertainties in a simple and consistent manner.

A simple and effective rating method also entails classifying the level of confidence associated with a risk rating as low, moderate, or high. These clearly defined rankings must be applied consistently across all assessment endpoints. Combining the risk and confidence ratings in one table for each assessment endpoint is a useful practice for risk communication purposes.

Conditional Risks

Conditional risks are best evaluated in the general risk characterization. Therefore, the user must provide additional details in this section regarding the characterization of risks, which are dependent on the estimates for one or more other risks.

Two potential methods for integrating the risks from multiple component assessments were discussed in Jones *et al.* (2001): mathematically propagating risks estimated in each component and logically weighing the evidence of risks presented in each component.


Mathematical propagation is only possible when quantitative estimates of risk are calculated for all of the assessment endpoints included in the conditional risk calculation. However, only the public health framework is designed to result in probability estimates (for example, a 1:10,000 risk of infection) as a component of the current integrated framework. Therefore mathematical propagation of risks cannot be used in this framework.

The characterization of conditional risks in this integrated framework is based on a variation of the weight-of-evidence process. In this general risk characterization section, the component assessment for each assessment endpoint is treated as a line of evidence for the conditional risks associated with two or more assessment endpoints. The user must logically evaluate the likely interactions between each assessment endpoint to see how these interactions support or refute the hypothesis that an OWT system poses a risk to a particular assessment endpoint. This evaluation is accomplished by weighing the evidence for conditional risks. Evidence that supports or refutes the hypothesis that interactions among two assessment endpoints lead to increased risks to one of those assessment endpoints should be discussed in detail.

A rating should be assigned in the general risk characterization section for each of the conditional risks being evaluated. This rating system should be compatible with the rating systems used to summarize the independent risks. A variation of the acceptable/unacceptable rating system discussed above is used to rate the conditional risks.

Uncertainties associated with estimating conditional risks should be described. Sufficient detail should be provided to help decision makers understand the origin, magnitude, and tractability of these uncertainties. Tractability refers to the level of effort that would be required to substantially reduce these uncertainties (that is, increase confidence). The ratings of low, moderate, and high confidence are recommended for the characterization of conditional risks. The risk and confidence ratings for conditional risks can be presented in a summary table similar to that used for independent risks.

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