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Microbial Risk Assessment for Unrestricted Wastewater Reuse During Army Deployments

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Preface

The U.S. Army Public Health Command (USAPHC) is responsible for establishing and maintaining health risk assessment capabilities to provide comprehensive support to commanders and preventive medicine staff for managing occupational and environmental health hazards (Army Regulation (AR) 40-5; Department of the Army (DA) 2007a). The USAPHC is also responsible for providing support to Army Deployment Occupational and Environmental Health Risk Management Programs, including establishment of capabilities to identify and assess health threats to support planning and response operations (AR 11-35; DA 2007b). Additionally, the USAPHC is responsible for supporting the U.S. Army Medical Command's authority for issuing and maintaining interim standards for health hazards and threshold effect levels for biological contaminants for safe exposure until long-term standards are developed (AR 70-75; DA 2005b).

> Note: Each of the current versions of the above ARs refers to the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), which has been retired and renamed as the USAPHC. All responsibilities of the USACHPPM are assumed by the USAPHC.

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Microbial Risk Assessment for Unrestricted Wastewater Reuse During Army Deployments

1. SUMMARY

1.1 Purpose

This microbial risk assessment evaluates health risks associated with wastewater reuse in a deployment setting. It provides risk-based water concentrations (RBWCs) for treated wastewater unrestricted reuse scenarios. This document only provides RBWCs for *Escherichia coli*. Other documents may provide other risk estimates in the future. Readers are expected to have a general knowledge of microbiology, water treatment, and health risk assessment. This document provides information that can inform future water detection strategies and water use standards (e.g., Technical Bulletin, Medical (TB MED) 577 / NAVMED P-5010-10 / AFMAN 48-138_IP; Headquarters, Department of the Army (DA) 2010). The information is provided to assist in the development of treated wastewater guidelines.

1.2 Approach

A risk assessment was performed to assess a microbial full body contact (unrestricted), nonpotable, treated wastewater exposure scenario and to provide RBWCs. There is a desire to reuse treated wastewater for nondrinking purposes at forward operating bases (FOBs) and camps. With regard to microbial parameters, the goal is to limit exposure to water that may contain human pathogens. There is limited military guidance on wastewater reuse and the available guidance is for limited uses and is not risk based. The population evaluated in the risk assessment is military and deployed civilian and contractor personnel at deployed sites practicing treated wastewater reuse. *E. coli* is currently measured in the field as an indicator of drinking water microbial quality and indications are that it will also be used for nonpotable treated wastewater reuse decisions in the field. The risk assessment is designed to be protective of gastrointestinal illness, (diarrhea, vomiting, nausea and stomachache), caused by incidental ingestion of treated wastewater during reuse activities.

1.3 Risk-Based Water Concentrations (RBWCs)

The RBWCs represent the risk-based concentration of *E. coli* in treated wastewater for unrestricted full body contact reuse based on an exposure of 10 milliliters (mL) of incidental water ingestion per event (i.e., shower), with various exposure frequencies. The RBWCs are based on the multiple-exposure functions acceptable risk levels. The values are presented in Section 7, and range several orders of magnitude. The concentrations can be used to set a guideline, design a treatment system, and to verify the proper operation of a treatment system.

The risk-based concentrations are based on showering; however, they should be protective of other activities because showering has the most frequent exposure and the highest incidental ingestion. The concentrations are applicable for a heat casualty body cooling exposure due to the low frequency of heat casualty body cooling activities and the expectation that less water is ingested while in a cooling tub or basin versus showering. The values are also applicable for personnel decontamination activities due to the low frequency of personnel decontamination activities, the higher awareness of avoiding incidental ingestion during a decontamination exposure, and the possible addition of disinfection agents to the decontamination water.

2. REFERENCES AND TERMS

Appendix A provides the references cited and the Glossary provides a list of acronyms and terms.

3. PROBLEM FORMULATION

This section defines the problem, provides context, and defines the scope and general design of this risk assessment.

3.1 Problem Statement

There is a desire to reuse treated wastewater for nondrinking purposes at FOBs and camps because they have limited water resources. This leads to water logistics challenges and other operational risks. Well-established camps may have large lagoons of wastewater and the reuse of treated wastewater could simplify water supply logistics for nondrinking purposes. A primary concern with reuse of treated wastewater is the health risks associated with potential microbial contamination found in various kinds of wastewater. For the deployment environment, there is insufficient guidance for assessing the health risks of treated wastewater reuse. Untreated wastewater from shower, sink, bath, laundry, and sources (gray water) typically has moderate quantities of microorganisms, some of which may be pathogens, and therefore poses some degree of health risk. Wastewater that is contaminated by kitchen, toilet or latrine waste (black water) typically has greater quantities of microorganisms and poses a greater health risk. Although there have been formal health risk assessments conducted for treated wastewater reuse for civilian settings (e.g., Canada 2007; World Health Organization (WHO) 2002), the results are not directly applicable to the Army. Civilian reuse guidance in the U.S. is primarily under the authority of States with wide variability in water reuse guidance from state to state. Current reuse guidance is based on civilian water use patterns and large scale treatment plants while military use would follow different use patterns and use small scale point of use treatment systems. Health risk assessments using specific military water reuse exposure scenarios have not been conducted.

3.2 Scope

3.2.1 RBWCs

This risk assessment presents RBWCs to aid in the development of guidance for reuse of treated wastewater. This risk assessment does not set guidelines or standards. It is an analysis of available scientific information to better understand the relationship between *E. coli* concentration in water, exposure frequency to the water, and the anticipated population gastrointestinal illness rate post exposure.

3.2.2 Hazards

This risk assessment is for exposure to pathogenic microbial hazards in treated wastewater during unrestricted (full body contact) reuse. It does not provide chemical or physical property guidance for the treated wastewater.

This risk assessment uses an indicator organism to estimate risk, which is discussed in Section 4. The concentration of the bacterial indicator *E. coli* is used to estimate the risk associated with exposure to pathogenic microorganisms, such as bacteria, viruses, and protozoa. The limits of the bacterial indicator approach are discussed in Section 4 and alternatives are discussed in Section 9.

3.2.3 Population

The population for this risk assessment is deployed military and deployed civilians and contractors at sites practicing wastewater reuse. The population is examined in paragraph 3.9.1. This guidance is for the deployed environment only. Continental United States locations are required to follow local, state, and Federal guidance with regard to wastewater reuse.

3.2.4 Exposure Types

This risk assessment provides a quantitative assessment of incidental ingestion exposure during unrestricted reuse, with a qualitative discussion of other exposures. The available data limit the quantitative assessment to incidental ingestion, which is discussed in Section 4 and Section 9.

3.3 Background Information and Definitions Related to Wastewater

Water and wastewater treatment have specific vocabularies; some terms used in this risk assessment may be used with a meaning different than the reader expects. A glossary is provided at the end of this document defining terms in this risk assessment. The reader is advised to refer to the glossary as health risk assessment, water quality, and wastewater management may use similar terms with different meanings. Several key water types are defined in this section.

Human communities produce wastewater streams. For this risk assessment, wastewater is used as an overarching term that encompasses water which has been discharged from domestic or industrial sources after a variety of applications. For more specific usage, a qualifier will precede wastewater; examples are *domestic wastewater* and *industrial wastewater*. In this risk assessment, reuse will be considered primarily for domestic wastewater, with provisions for reuse of industrial wastewater diluted by other wastewater streams. Wastewater from different sources may have different physical, chemical, and biological characteristics.

In most urban communities, wastewater from the domestic, commercial, and industrial sources are combined into a municipal sewage plumbing system and sent to a treatment facility where it is treated, and subsequently discharged to surface or ground water. In some older urban communities, storm water runoff from streets and other paved areas is also routed to the treatment facility through the same wastewater collection network. Sewage systems capable of handling storm water are known as combined systems.

Generally speaking, waste from toilets, urinals, and kitchens is termed “black water”. Waste from bathtubs, showers, sinks, laundry, and dishwashers is called “gray water”. Details for these types of water are below. Black water and gray water leaving a residential home is typically combined into one waste stream, and in the wastewater industry this is referred to as “domestic wastewater.”

Use of both gray water and domestic wastewater (black + gray) will be considered in this risk assessment. Mixed wastewater which included industrial and commercial wastewater in addition to domestic wastewater could be reused; however, it may have more chemical contamination. Mixed wastewater may require more monitoring than gray water or domestic wastewater.

3.3.1 Gray Water

For this risk assessment gray water will be defined as “*Wastewater from non-human waste sources such as showers, laundry, and handwash devices” (*TB MED 593, DA 2006b; glossary). An alternate definition of gray water is “*Wastewater from bathing and washing facilities that does not contain concentrated*

human waste (i.e., waste products from toilets) or food waste (i.e., kitchen sinks and food waste grinders). Examples include bath and shower water, hand wash water, and laundry washwater. Greywater typically contains salts and minerals from detergents and soaps." (Metcalf and Eddy 2007, p. 765)

Some communities in the U.S. have plumbing systems in their buildings that keep gray water separate from black water and other types of wastewater, but this is rare. Separated gray water may be treated and reused more easily than other wastewater because it is expected to have a lower concentration of microorganisms, organic matter, and trace constituents. In some parts of the U.S., the use of gray water for irrigation is recommended during periods of water shortage.

Due to human health concerns related to the increasing prevalence of gray water reuse, gray water has been extensively characterized in the last decade (Australia 2002, 2006; Canada 2007; Friedler 2004; Massachusetts Department of Environmental Protection (MA DEP) 2002; Metcalf and Eddy 2007; Ottoson and Stenstrom 2003; Sheikh 2010; Westrell 2004; WHO 2006). Many of these characterizations have focused on the microbiological characteristics of gray water.

3.3.2 Black Water

Black water is defined by the U.S. Army, and for this risk assessment, as *"latrine wastewater containing human waste" (*TB MED 593, DA 2006b; glossary). An alternate definition is *"Wastewater consisting of only toilet water (and associated human waste products) and kitchen wastewater containing food waste. Typically high in organic matter, nutrients, and pathogens."* (Metcalf and Eddy, 2007, p. 764)

Black water is waste coming uniquely from toilets and is composed of urine, feces, toilet paper, and flush water. Due to its composition, black water contains nutrients useful for agricultural irrigation, as well as microorganisms that can potentially harm humans (pathogens) (Wendland 2009).

There are few references available in open literature characterizing black water (Wendland 2009; WHO 2002) none of which attempt to characterize black water from deployed military locations. In the U.S., this is perhaps due to the fact that black water is not typically separated from the gray water; the combination of gray and black water is common. In most U.S. communities, only one sewage pipe leaves the home or business and routes both gray and black water (domestic wastewater) from the building to a treatment facility. Due to a limited amount of data, there is some uncertainty that the black water generated at FOBs is representative of black water generated in garrison or in civilian systems. It is believed black water from deployment military locations may be different from general civilian population black water due to differences in endemic pathogens at deployed locations or an increase (or decrease) in shedding due to the varied living conditions (i.e., different diets) and environments (both physical and emotional).

3.3.3 Mixed Wastewater

Mixed wastewater is made up of commercial and industrial wastewater in addition to domestic wastewater.

Businesses and industries may produce a nondomestic liquid waste stream called industrial wastewater. Any kind of an industrial process that uses water can produce an industrial wastewater stream. Examples include chemical manufacturing, petroleum refining, automotive manufacturing, explosives manufacturing, textile mills, metal and nonmetal mineral industries, agricultural irrigation industries, paint and dye production, lumber production, power plants, and other similar types of processes (Water Environmental Federation (WEF) 1989). Typically, industrial wastewaters have much higher concentrations of toxic and industrial chemicals than domestic wastewaters. Industries that generate wastewater with high concentrations of conventional pollutants (e.g., oil and grease), toxic pollutants (e.g.

heavy metals, volatile organic compounds) or other nonconventional pollutants such as ammonia, need specialized treatment systems.

This microbial risk assessment for wastewater reuse is based on the biological material in wastewater. When industrial wastewater is used, or mixed with domestic wastewater forming mixed wastewater, toxic and industrial chemicals become a concern in the reuse of the wastewater. This document does not address potential health risks due to chemical contaminants in treated wastewater.

3.4 Microbiologic Water Quality

Microbial water quality is measured to limit exposure to water that contains human pathogens. Ideally, monitoring programs would measure pathogens directly; traditionally however, indicators are used instead. Indicators are a few select organisms measured as a surrogate for pathogens because measuring every water pathogen would be impractical.

The use of indicators to measure water quality dates back to the late 1800s when sanitary bacteriologists began testing water for sewage contamination based on (then) recently described bacterial species (*Klebsiella pneumonia* and *Bacillus coli* – later renamed to *Escherichia coli*) isolated from human feces. The concept of 'coliform bacteria' or those bacteria that resemble *E. coli* was established. The resemblance was based on similar Gram Stain results (gram-negative) and biochemical properties (e.g., lactose fermentation). At that time it was unknown that coliforms were not of just fecal origin, or that there were to be many different strains of *E. coli* to be discovered in the future (most of which are not pathogenic). Another important piece of information that was not known in the late 1800s was that humans shed approximately 1×10^{11} coliforms/day. Over time various coliform identification schemes emerged, and in the 1930s additional biochemical tests were added which allowed for the differentiation of what are termed "fecal coliforms."

The need for water sanitary engineers to be able to simply and rapidly detect fecal contamination led to the development of the Multiple-Tube Fermentation Test and membrane filtration which are evaluated using the Most Probable Number (MPN) Procedure in the early 1900s. Although these tests are not rapid (requires 48 hours for presumptive results), they are used to determine "total coliforms" in water. Total coliforms represent a group of bacteria from the *Enterobacteriaceae* family. With regard to *E. coli*, a differentiation between "thermotolerant" strains was observed, and the ability to ferment lactose at 44°C was used as a descriptor to describe "fecal coliforms."

Monitoring microbial indicators such as "total coliforms" and/or *E. coli* in wastewater treatment effluent can be used to demonstrate or evaluate the treatment efficacy. However, a positive test result for the presence of "total coliforms" (for example) only indicates that bacteria from are present. It does not indicate their species or serotype or whether they include pathogenic bacteria. Importantly, the absence of indicator bacteria cannot confirm the complete absence of pathogenic bacteria. Monitoring for indicator bacteria does not inform whether archaea, fungi, protozoa, algae, viruses or multi-cellular animal parasites are present or absent.

Despite the limitations with indicators (coliforms), they remain the current standard for water safety (as a treatment efficacy test) and therefore are a driver for the development of useable and applicable microbial risk-based concentrations and ultimately guidelines for wastewater reuse at FOBs.

The main microbiological hazard in gray water is microbial pathogens associated with fecal contamination. Examples of how potential fecal cross-contamination could occur would be if fecal material is present on the hands during hand washing or when residual fecal material is washed off during showering. In untreated wastewater microbial concentrations span several orders of magnitude depending on the sources of the wastewater. If present, the occurrence and concentration of pathogenic

microorganisms in untreated domestic wastewater depends on a number of factors. Important variables include the source and original use of the water, the general health of the population, the existence of disease carriers for particular infectious agents, excretion rates of infectious agents, duration of infection, and the ability of infectious agents to survive outside their hosts under various environmental conditions (Metcalf and Eddy 2007).

3.5 Current Detection Capabilities

Water quality surveillance in the deployed environment, "the field," consists of operational monitoring by Quartermaster Corps, or contractor operators, and quality assurance monitoring by Medical Service Corps preventive medicine (PM) officers and technicians. The water test kits fielded to the operators and PM staffs are the Water Quality Analysis Set-Purification and the Water Quality Analysis Set-Preventive Medicine (WQAS-PM), respectively. The kits contain an assortment of water quality instruments for measuring various parameters

The water quality parameters relevant to nonpotable water reuse that can be measured in the field by soldiers include turbidity, Total Dissolved Solids (TDS), total and free available chlorine, and microbiological indicators (total coliforms and *E. coli*).

Equipment for microbiological testing is currently fielded only to PM units. According to the requirements of TB MED 577, only presence/absence testing of total coliforms and *E.coli* are conducted. While a method for field-enumeration of bacteria exists, it is seldom used and may soon be phased out. The membrane filtration technique is considered too cumbersome and time consuming for successful adoption within a new monitoring scheme for water reuse.

To be able to better characterize reclaimed water, specifically to more efficiently enumerate bacteria, the procurement of additional equipment will need to be considered. One commercial off-the-shelf technology example is the IDEXX Quanti-Tray® which provides a most probable number measurement of total coliforms and *E. coli*. (®IDEXX Quanti-Tray is a registered trademark of IDEXX Laboratories, Incorporated.)

3.6 Current Gray Water Exposure Guidelines

The U.S. military has gray water reuse guidelines, but they have been assembled on an ad hoc basis to meet the immediate needs of requests from the field. Most have been recommended solely in response to a specific situation or problem without considering wider or long-term issues. The problem with the current military guidelines is that they are for limited uses and may not be risk based. Table B-20 in Appendix B lists current ad hoc guidelines. Current military guidelines include physical (pH, turbidity, hardness, total suspended solids, biological oxygen demand, TDS), chemical (free available chlorine), and microbiological indicator (total coliform and *E. coli*) water quality parameters.

3.7 Water Reuse

For FOB and base camp use, there are two categories of wastewater reuse: restricted reuse and unrestricted reuse. For this assessment, restricted reuse is defined to involve minimal incidental body contact, while unrestricted reuse involves full body contact including the head with possible incidental ingestion. Neither reuse activity includes intentionally drinking the treated wastewater.

3.8 Health Effects Associated with Historical Wastewater Exposure

Information on health effects associated with historical wastewater exposure is limited. The available data do not align easily with expected military exposure activities associated with wastewater reuse. Available data are from agricultural and recreational water exposures.

Information is available on the health effects of wastewater use in agricultural settings (see paragraph B-2.1.6 in Appendix B). Gastrointestinal illness has been associated with the use of treated wastewater in sprinkler irrigation for urban parks (Durand and Schwebach 1989). Around Mexico City, untreated wastewater was used for flood irrigation and there was a 10% increase of diarrhea and skin rashes (Downs et al. 1999).

Recreational water can contain wastewater. Some health effect information is also available for exposure to recreational water. Microbial contamination in recreational water can come from many sources, such as sewage contamination when treated effluent discharge into waterways, untreated sewage overflows, from animal field runoff, or other sources. Gastrointestinal illness has been associated with microbial contamination of recreational water. See paragraph B-2.2.4 in Appendix B for information on microbial exposures and nongastrointestinal illness. Other illnesses considered are respiratory illness, otitis (ear infections), conjunctivitis (eye infection), and dermatitis (skin infections). Evidence for associations between microbial contamination and nongastrointestinal illness is limited or not available. Gastrointestinal illness occurs at a lower threshold of fecal pollution and is more severe than respiratory illness (WHO 2005).

3.9 Conceptual Model of Health Risks Associated with Army Wastewater Reuse

The conceptual model is a written description and visual representation of predicted relationships between the sources of the microbial organisms, the potentially exposed population, and other relevant assumptions about exposure–response relationships that set the stage for the risk assessment. The following subsections describe the conceptual model, and Figure 1 provides a visual representation of potential population exposures and what exposure pathways are relevant for the risk assessment.

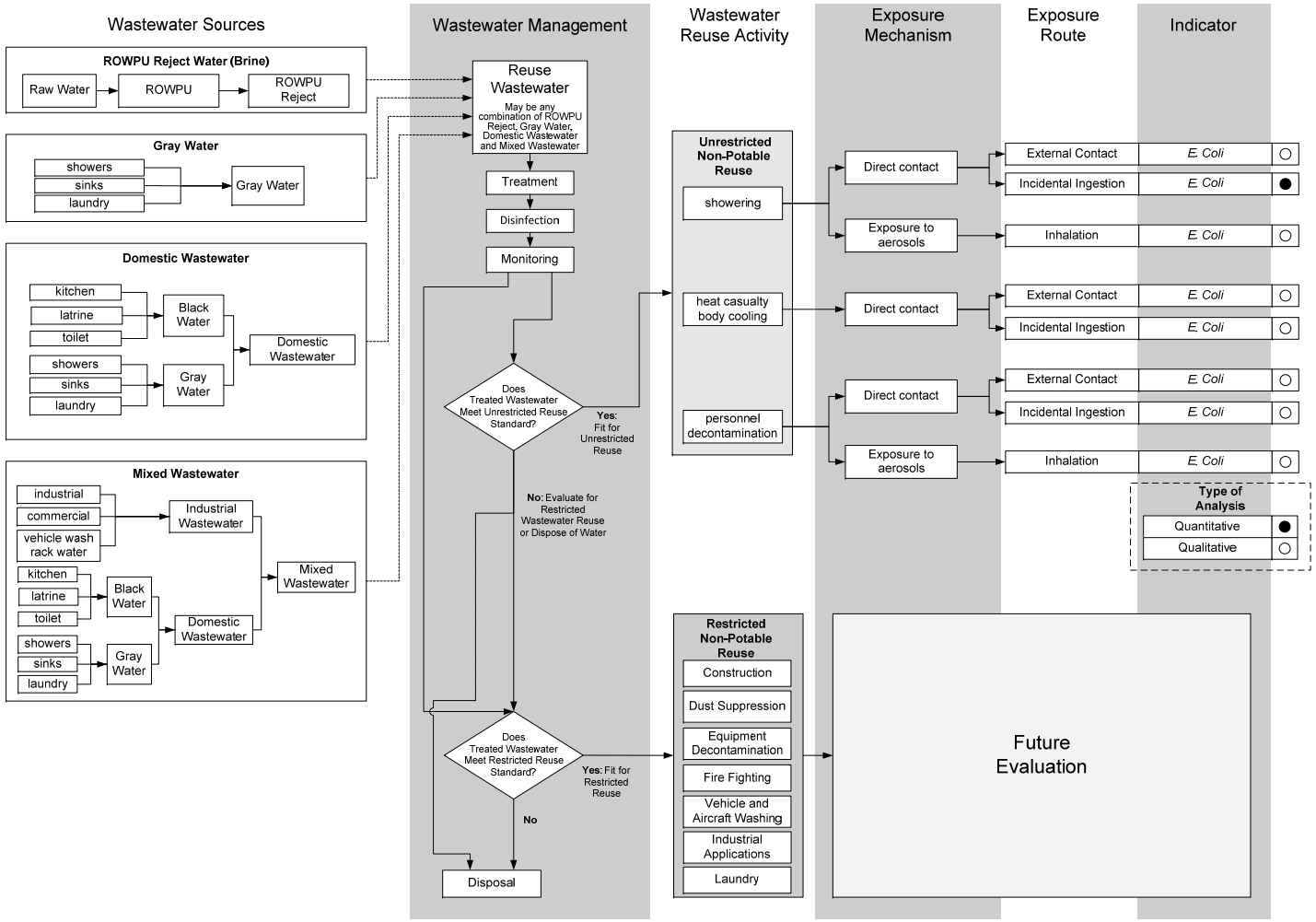

Figure 1. Conceptual Model of Health Risks Associated with Army Wastewater Reuse

3.9.1 Population of Concern

The population being evaluated in the risk assessment is comprised of military and deployed civilians and contractors at deployed sites practicing treated wastewater reuse. This guidance is for the deployed environment only. Continental United States locations are required to follow local, state, and Federal guidance with regard to wastewater reuse.

The deployed military population includes Active Duty, Reserve, and National Guard personnel and is mostly composed of relatively healthy and fit adults, 18 to 55 years of age (Defense Manpower Data Center (DMDC) 2004). While this description addresses the majority of personnel (e.g., estimated 90 percent or greater), demographic and other data show that there are personnel that fall outside this description. For example, particularly with increased reliance on National Guard and Reservists, an increased number of older personnel are now deployed. In addition, it is known that a small percentage of females become pregnant right before or during deployment. The assumption that deployed military individuals will have no predisposing physical or mental factors that could exacerbate exposure to environmental stressors (e.g., pathogenic microorganisms or chemicals) is not supported by population assessments. While there are basic health and fitness requirements that must be met and maintained by military personnel, an assessment of the factors that can lead to susceptibilities suggests that many of the same primary susceptibility factors exist for the deployed military population. Predisposing factors such as age (> 40 years), illness (e.g., asthma), physical and emotional stressors, life-style choices (e.g., smoking or alcohol use), physiological state (e.g., fatigue, hypothermia, underlying cardiovascular disease, injury or trauma resulting in open wounds), or unique genetic traits may alter susceptibility. In general, risk analysts are typically not likely to know: (1) who those individuals are, (2) what portion of the population is susceptible, and/or (3) the extent of the susceptibilities within the population. This population description is also used for chemical military exposure guideline development (U.S. Army Public Health Command (Provisional) (USAPHC (Prov)) 2010).

Deployed civilians and contractors are assumed to be as fit and able to be deployed as military. Similar unknowns for sensitivities and pre-existing conditions are expected in the deployed civilian and contractor sub population as in the deployed military (OSD 2014).

The population of concern may or may not have been previously exposed to the possible pathogens in wastewater via other routes or pathways. Regardless, the exposed population is assumed to not have immunity to the potential pathogens in wastewater.

3.9.2 Exposure Scenarios and Activities

Exposure to reused treated wastewater will occur through different activities. For the conceptual model, three high contact, unrestricted-use activities were examined and expanded to specific exposure scenarios for evaluation in the risk assessment: showering, heat casualty body cooling, and personnel decontamination. The conceptual model diagram (Figure 1) illustrates how reuse scenarios and activities are related. An exposure scenario has a wastewater reuse activity, an exposure mechanism, and an exposure route. The three high-contact activities were analyzed in the initial effort because the higher exposures are assumed to be “worst case”; the evaluations could be applied (in the interim) to lower contact reuse activities. In this risk assessment it is assumed that for all reuse scenarios wastewater will only be used after treatment, and it is assumed the treatment is effective.

3.9.3 Exposure Route

Due to limited dose-response data (see Section 6) the only exposure route that can be assessed is incidental ingestion. While the dermal route is diagramed in the conceptual site model (Figure 1) data

limitations preclude assessment. Therefore, it is assumed personnel participating in wastewater reuse activities do not have open wounds.

3.10 Risk Assessment Plan

The following sections outline the risk assessment process applied to derive the RBWCs.

3.10.1 Microbial Indicator Selection

The conceptual model includes a microbial indicator in order to evaluate specific exposure pathways. *E. coli* was selected for this assessment for each exposure scenario. In the future, different indicators may be selected for each exposure route (contact, incidental ingestion, and inhalation). Current detection capabilities have influenced the selection of the microbial indicator because detection is limited to *E. coli*. Equipment is fielded to detect *E. coli* in water; however, the fielded equipment cannot determine strains or serotypes. When technology is fielded that can detect other pathogens or determine strains, sub-species or serotypes, it should be integrated into the monitoring scheme for reuse of treated wastewater.

3.10.2 Exposure Assessment

Details for the exposure activities being analyzed within the risk assessment (showering, heat casualty body cooling, and personnel decontamination) were collected to quantify exposure. The exposure assessment is activity-specific; whereby, there are different exposure estimates for each activity.

3.10.3 Dose-Response Assessment

The dose-response assessment links an exposure to a potential health effect. For this risk assessment, the dose-response assessment provides a correlation between the indicator organism in water and the observed health effects in the exposed population. This relationship drives the establishment of any proposed exposure guideline.

3.10.4 Derivation of RBWCs

The RBWCs are derived using a synthesis of the exposure and the dose-response assessments. The exposure assessment provides information to determine the amount of water a person is exposed to during a reuse scenario. The dose-response assessment is used to determine the amount of indicator organisms a person can be exposed to corresponding to a level of acceptable risk. The dose and the exposure are used to determine the water concentration for a given acceptable risk.

3.10.5 Potential Future Efforts

During potential future risk assessment efforts low contact activities can be considered. The low contact activities identified thus far are dust suppression, vehicle and aircraft washing, equipment decontamination, construction, and firefighting. The assessment of these exposure scenarios is beyond the scope of this particular risk assessment.

4. MICROBIAL INDICATORS AND ASSOCIATED ILLNESSES

The best way to characterize risk associated with treated wastewater reuse would be the ability to identify and quantify any (all) remaining pathogens in the water after treatment. In order for this to be possible, two things are required. First, timely identification strategies and quantification methods of the pathogen(s) would be required. Second, the dose-response relationship would need to be known for each pathogen.

Raw wastewater has been characterized, and there are many references which provide pathogen or contaminant lists for various waters (e.g., sewage, drinking water; Table 1). Unfortunately, it is very difficult to know which, if any, pathogens would be present after treatment; therefore, to create a detection scheme to meet the first need is realistically impossible. Next, even if the pathogen could be identified due to the very limited nature of dose-response data for pathogens, it is very unlikely that the dose-response relationship is established.

Table 1. Key References for Microbiological Contamination of Wastewater

Reference	List Description	Purpose of Reference
Rose and Grimes 2001	Waste associated pathogenic viruses, bacteria, fungi, cyanobacteria, eukaryotic algae, protozoa, and helminths	Present new tools for evaluation of microbial water quality and risk assessment
Metcalf and Eddy 2003	Biological characterization of wastewater	Textbook
Australia 2006	Treated sewage	Australian national standards for water recycling
World Health Organization 2006	Microbial analysis of wastewater	World guidelines primarily for underdeveloped countries for safe use of human waste products in agriculture
Metcalf and Eddy 2007	Chemical and microbiological characterization	Textbook
Water Reuse Foundation 2007	Pathogen concentrations in raw wastewater and secondary effluent	Research report summarizing application of microbial risk assessment for water reuse risks. Applications focus on agricultural and urban landscape irrigation.
EPA 2009	Known and potential zoonotic waterborne pathogens	Conceptualize potential risk to humans from warm-blooded animal feces in recreational waters
Water Reuse Foundation 2010	Categories of microbes in reclaimed water	Characterization of wastewater and treatment technology, storage, and distribution systems
EPA 2012	Wastewater constituents	National guidance for States on wastewater reuse for urban, agricultural, environmental, recreational, industrial, and groundwater recharge purposes

Due to the limited ability to identify and correlate a health effect (dose-response data) for individual pathogens, the only way to characterize risk associated with wastewater reuse is to apply the indicator approach. Over the last 100 years the indicator approach has been utilized to maintain water quality and to protect public health. In the context of water quality, the EPA has defined an indicator as *"a parameter that can be measured and used as a surrogate for another parameter or condition which either cannot be directly measured or is difficult to directly measure"* (EPA 2006). The parameter may refer to a microbe

(e.g., a particular organism, *E. coli*, or group of microbes, total coliforms), a chemical characteristic (e.g., pH) or a physical property (e.g., turbidity). The basic premise of the indicator approach is to evaluate a sample of water based on the observed value (numerical, or presence/absence) of an indicator and from those results form a general statement with regard to the quality or condition of the water. The concept of indicator in the water and wastewater industry has been extended to cover nonmicrobial parameters. They have been used to demonstrate the efficacy of a treatment process or to ensure a process is operating properly (i.e., process indicator). In this context, it is preferable to use the term in conjunction with the treatment that is being considered (e.g., filtration indicator, disinfection indicator). A good example of a process indicator is turbidity as an indicator of filtration efficacy. Turbidity can be used to show how particulate material suspended in the water is removed by passing the water through a series of progressively finer filters. Indicators used to infer process efficacy are technology-based metrics.

For example, turbidity is a measure of light penetration or light scatter in water and related to the amount of suspended matter in the water. A rise in turbidity downstream of a treatment system may indicate a malfunction in the treatment process, potentially allowing harmful substances to pass through. Such an increase in turbidity might also indicate degradation of a treatment system component indicating the treatment process may require maintenance.

For treated water, and this risk assessment, it is important to note that the indicator approach based on a microbial indicator is also testing treatment process efficacy and should not be misinterpreted as a way to directly measure health risk. Treatment efficacy does impact and correlate to health risk; generally speaking, for a source water with constant quality, as treatment efficacy increases, health risk decreases. Therefore, it is possible to evaluate treatment efficacy using the indicator approach and then speculate on health risk.

A wide variety of microbes have been proposed or used as microbial indicators in an attempt to evaluate water quality (Table 2).

Direct monitoring and testing for pathogens is not normally done for wastewater or gray water reuse purposes. It is also not normally done for potable water. Below are several reasons why direct pathogen testing is not conducted.

- Waterborne pathogens are biologically diverse, including bacteria, viruses, protozoa, and helminths. While methods for detection of some pathogens and microorganisms have been developed, some of the methods are extremely labor intensive, time consuming, require long incubation periods, require special reagents, or are very expensive (EPA 2006). In addition, some pathogen analytical methods have low recovery rates, particularly for parasitic cysts and oocysts (New Zealand 2005).

- Some pathogens and viruses have never been successfully propagated in the laboratory.

- Even where the methods are available, few laboratories have the expertise and the facilities to isolate and identify pathogens capable of causing waterborne disease.

- Monitoring directly for a single pathogen will only provide information for that specific pathogen and may not provide information about other potential pathogens, unless the degree of co-occurrence can be determined.

- The resources and technology needed to monitor for all potential pathogens is not typically available for most Army water reuse activities.

- In most field situations, direct pathogen monitoring is not practical and requires a sophisticated analytical laboratory.

Table 2. Indicators and Their Public Health Risk Significance for Water Quality

Indicator Name	Purpose	Justification	Interpretation
Total Coliforms	Determine overall water quality	Coliforms (a broad class of bacteria with specific bacteriologic characteristics) are present in large numbers in the environment. Total coliforms have been used as an indicator of water quality since the early 1900s. They are mainly of fecal origin (are present in the guts of humans and other warm blooded animals), but survive and grow in the environment. They can be detected even after extensive dilution.	The presence of coliforms indicates there are bacteria in the water. Because there are bacteria in the water there is a potential for some of those bacteria to be pathogens. Total Coliforms are associated with warm blooded animal sources.
Heterotrophic Bacteria	Determine general water quality	Broad class of organisms that use organic (carbon-containing) substances for nutrients. The group includes virtually all pathogenic bacteria. A measurement of these organisms provides an indication of general water quality within the distribution system. Increases in this organism indicate treatment breakthrough, contamination introduced post-treatment, and microbial growth in the distribution system.	Presence indicates bacteria in water.
Pseudomonas and *Aeromonas*	Determine general water quality	Ubiquitous in the environment. These organisms are indicators of distribution system integrity. Their presence suggests inadequate chlorine residual or the potential for biofilms.	Presence suggests inadequate chlorine residual.
Enterococci and Fecal *Streptococci*	Determine if fecal contamination is present	Commonly found in feces of humans and is more resistant to chlorination than *E. coli*. These organisms are found in the intestinal tract of humans and other animals, are consistently associated with human and animal fecal waste, and generally do not grow in the environment except for the tropics. The World Health Organization regards them as specific indices of fecal pollution.	Presence indicates fecal contamination.

[continued next page]

Table 2. Indicators and Their Public Health Risk Significance for Water Quality (continued)

Indicator Name	Purpose	Justification	Interpretation
Fecal Coliforms	Determine if fecal contamination is present	Biochemical characteristics further define a particular group of coliforms, fecal coliforms that are shed from warm-blooded animals (includes humans) in feces. They are reliable indicators of disease causing bacteria, and slightly less effective in determining the presence of viral and protozoan pathogens compared to bacteria.	Presence of fecal coliforms provides strong evidence that fecal contamination has occurred. There is a potential that pathogens may be present.
Escherichia coli (*E. coli*)	Determine if fecal contamination is present	A specific fecal coliform. *E. coli* are shed in high numbers in feces. They have been found in wastewater treatment effluent and have been used as indicators of fecal contamination for over 50 years. Their presence in water is strong evidence of human or animal fecal contamination. Their concentration in drinking water correlates with the presence of gastrointestinal illness.	Confirmation of fecal contamination. There is a potential that pathogens may be present.
Somatic Coliphage	Virus surrogate to determine if viruses present	Coliphages are viruses that infect *E. coli.* These viruses behave more like human enteric viruses than do bacterial indicators. They have been used as indicators because of their constant presence in feces and sewage. They are the best indicator for viral pathogens in water.	Unknown.
Clostridium perfringens	Surrogate to determine virus and protozoal load.	Exclusive fecal origin that has been correlated to enteric viruses, *Giardia*, and *Cryptosporidium*. This organism inhabits the intestinal track of humans and other animals, and is a definitive fecal indicator; standard methods are available for its rapid and reliable recovery and identification.	Unknown due to long survival times. Persistence for long periods can lead to false positives.

Therefore, to monitor wastewater or gray water quality in a field setting for reuse purposes, reliance is usually placed on quick and simple tests to confirm treatment efficacy.

E. coli is currently measured in the field as an indicator of microbial water quality. For potable water use, the presence of *E. coli* means the water is unsafe to drink with a presence/absence test (TB MED 577, DA 2010). For nondrinking wastewater reuse, equipment to quantify the number of *E. coli* in a water sample could be fielded in the future such as the IDEXX Quanti-Tray Data on human exposure to recreational water influenced by treated wastewater is available which correlates gastrointestinal

symptoms to *E. coli* concentration in water (EPA 1984; EPA 1986). The available *E. coli,* as an indicator of microbial load, dose-response data limit this risk assessment to incidental ingestion. Gastrointestinal illness is anticipated at *E. coli* concentrations lower than those required for inhaled or dermal effects (WHO 2005). Several states with wastewater reuse standards, such as Colorado and Oregon, have based their standards on the *E. coli* portion of EPA's 1986 Ambient Water Quality Criteria for Bacteria.

The arguments for using *E. coli* as a microbial indicator for wastewater reuse are quite compelling (New Zealand 2005):

- it is a strict indicator of fecal contamination, whereas fecal and total coliforms are not;
- it is a species, whereas fecal and total coliforms are groups of species;
- it is almost always present when pathogens are present;
- it is routinely associated with health risk effects in water ingestion studies;
- it is now amenable to rapid and accurate field enumeration (e.g., the Colilert and IDEXX Quanti-Tray; and
- some strains are pathogenic (e.g., O157:H7).

Even though *E.coli* seems to be the best choice for a microbial indicator, there are several reasons why it should be used in conjunction with physical/chemical indicators. First, the absence of *E. coli* does not guarantee the absence of pathogens. Although the presence of *E. coli* is a definite indication of fecal contamination, absence only suggests pathogens are also absent. Second, other physical and chemical indicators can provide supplemental information on pathogen presence. For example, pathogens can hide in the suspended solids that cause turbidity. Thus, turbidity can provide some indirect indication of potential pathogen presence. In addition, when chlorine, an oxidant, is introduced into treated wastewater, some of the chlorine is consumed in order to kill the pathogens. The oxidant demand, concentration lost after dosing, is related to the organic load, a portion of which may include pathogenic organisms. Chlorine residual can thus provide some indirect indication of pathogen die off. Third, monitoring and treatment equipment are rarely 100% effective and properly operating all of the time. Some pathogens may survive the treatment and monitoring process (when equipment is not functioning at 100%) and pose a potential health risk for anyone using the water. Multiple barriers (both in the treatment process and in the monitoring process) are the best defense against pathogen bypass. Guidelines based on physical or chemical indicators are outside the scope of this microbial risk assessment.

5. EXPOSURE ASSESSMENT

This exposure assessment evaluates the potential wastewater reuse exposures for the three scenarios identified in the conceptual model: showering, heat casualty body cooling, and personnel decontamination. Within these scenarios, exposures can occur through either direct liquid contact or direct aerosol contact. With both liquid and aerosol contact, pathogens in the water may then come into contact with the body. Direct liquid contact can include intentional or incidental water ingestion, liquid contact with the skin, liquid contact with the eyes, and liquid entering the ears. Direct aerosol contact can occur when aerosolized water droplets that contain pathogens are inhaled, or contacted on the skin, eyes, or other mucous membranes.

5.1 Exposure Assessment Design

The exposure assessment design involves identifying exposure factors that must be considered in order to characterize exposure and any assumptions that must be made.

5.1.1 Exposure Factors

There are several dimensions of exposure (i.e., "exposure factors") where quantitative values are desired in order to characterize full exposure potential. However, due to information and data limitations, and the initial scope of effort for this assessment, only a limited subset of exposure factor values are actually required to complete a sufficient exposure assessment for each of the three scenarios. Table 3 summarizes the exposure factors of relevance to a full exposure assessment and identifies those that are required to have quantitative values in order to move the assessment forward. The required elements are discussed in subsections below. New information for any of the exposure factors may instigate another iteration of the risk assessment. For example, if there is a desire to assess the inhalation route, additional exposure factors such as the rate of material transfer from lungs to the gastrointestinal tract (breathing in aerosolized water into the lungs, coughing up mucus from the lungs and then swallowing the mucus to the stomach) would be required.

Table 3. Required and Desired Exposure Factors for Incidental Ingestion

Exposure Factors	Required (●) and Desired (☐) Quantitative Values		
	Showering	Heat Casualty Body Cooling	Personnel Decontamination
Liquid Ingestion (Intentional)	☐	☐	☐
Liquid Ingestion (Incidental)	●	●	●
Exposure Duration	●	●	●
Exposure Frequency	●	●	●
Exposure Timing	☐	☐	☐
Water Volume	☐	☐	☐

5.1.2 Exposure Assessment Assumptions

There are several assumptions that must be made in order to proceed with an exposure assessment with the goal of quantifying exposure.

1. There is sufficient data available to quantify exposure for these activities and where data are lacking, there is sufficient information available to estimate or use surrogate values.

2. Water will not be intentionally swallowed during showering, heat-casualty body cooling, and decontamination.

3. Activities such as tooth-brushing will not occur during showering.

4. The head will get wet for showering, heat-casualty body cooling, and decontamination.

5. Baths are not showers.

5.2 Exposure Factors for the Showering Scenario

For nonpotable water reuse in the field, one of the exposure scenarios considered is showering. For most western cultures, people have an intuitive understanding of showering and what it involves. However, for such a common activity for so many, a formal comprehensive definition of showering was not found. Definitions of showering that were found include:

1. "washing yourself by standing upright under water sprayed from a nozzle" (The Free Dictionary; http://www.thefreedictionary.com/);

2. "A shower is a place in which a person bathes under a spray of water" (Wikipedia; http://en.wikipedia.org/wiki/Main_Page);

3. "A bath in which the water is sprayed on the bather in fine streams from a showerhead, usually secured overhead" *(*American Heritage Dictionary; http://ahdictionary.com/*).*

When showers are available, deployed soldiers in the field wash their face, neck, head, and hair when showering, completely exposing their entire heads to the water spray. However, a formal definition of showering that included head exposure was not found.

Therefore, for purposes of this risk assessment, showering is defined as:

Washing yourself by standing upright under water sprayed from an overhead nozzle, where the entire surface of the body (including the face, neck, and head) and body orifices are exposed to the water for a given period of time. Water exposures while showering definitely include dermal contact on the entire skin surface, and potentially include incidental ingestion, inhalation, ear entry, and wound entry. Baths are not considered showering.

5.2.1 Exposure Frequency

The frequency of a shower is an important part of the exposure characterization. The Surgeon General minimum is one shower per week for a person (United States Army Combined Arms Support Command (CASCOM) 2008). The army goal is to provide two showers per week (CASCOM 2008). For water logistical purposes, U.S. Army Field Manual 10-52 (FM 10-52; Water Supply in Theaters of Operation) assumes at the Company, Battalion, and Brigade levels a person in an arid zone will take one shower per week (DA 1990). U.S. Army Center for Health Promotion and Preventive Medicine Technical Guide 307 (USACHPPM TG 307; Sanitation and Hygiene Standards for Establishing, Operating, and Inspecting Army Field Detention Facilities) assumes an individual taking one shower a week (USACHPPM 2006). The Force Provider System is designed to provide one shower per person each day (U.S. Army Natick Soldier RD&E Center (NSRDEC) 2009).

5.2.2 Exposure Time

Showers can vary in length. In the 2008 CASCOM water planning guide a shower is defined as lasting 7 minutes (CASCOM 2008). AR 700-135 (Soldier Support in the Field) specifies providing a minimum of 7 minutes for showering per person (DA 2009). A 10-minute shower is used for equipment development; three Army shower systems are designed to provide 10-minute showers: the Battlefield 12-head shower, the Containerized Shower, and the Force Provider System (NSRDEC 2009). For the nonmilitary population, the mean time spent showering was 17 minutes per day (EPA 2011).

5.2.3 Total volume

The amount of water used during a shower is related to the total exposure. CASCOM (2008) defines a shower as using 11.9 gallons of water. The Containerized Shower System provides a 2.5 gallon per minute flow rate of water at each shower head (DA 2005a). By multiplying the 10-minute shower time assumed in the Containerized Shower specifications by the 2.5 gallon per minute flow rate, a shower would be expected to use 25 gallons of water. A typical shower head in a residential home has a flow rate of 2.4 gallons per minute (Zhou 2007). A 17-minute shower with a flow rate of 2.4 gallons per minute would use 41 gallons of water.

5.2.4 Incidental Ingestion

During showering, the primary exposure route leading to GI illness will be incidental ingestion. Pacific Northwest National Lab (PNNL) assumes 10 mL of water are ingested per residential shower in their Multimedia Environmental Pollutant Assessment System (MEPAS) simulation application (PNNL 1995). In a risk assessment for contaminated water at a camp in Afghanistan, the risk assessors assumed 30 mL of water were ingested per military shower (reference not publicly available).

5.2.5 Exposure Factors Summary

Table 4 summarizes the exposure factors selected for showering. The values selected for the assessment are based on the available sources of data with values selected to be representative of field conditions and reflect high exposure potential. The selected values only estimate field conditions; better values may be determined but would require field measurements. Alternative frequencies of showers are also considered (paragraph 5.2.6 and Table 5).

5.2.6 Alternative Shower Scenarios

The number of showers taken in a time period could vary from a well-established camp to a new FOB. The frequency of showers shown in Table 4, seven showers per week, is the baseline shower frequency for the risk assessment. Because it is difficult to predict shower activity in the field, and it may vary between different FOBs and camps, three alternatives are also considered. Alternatives are expressed over a 2-week period to avoid a fractional shower in a week for the every other day alternative. Alternative A is showering twice a day leading to 28 showers in 2 weeks. Alternative B is showering every other day, leading to seven showers in a 2-week period. Alternative C is showering once a week for two showers in 2 weeks. The four shower frequencies are summarized in Table 5. For the alternatives, the other exposure factors are unchanged.

Table 4. Summary of Shower Exposure Data

Parameter	Units	Lower Value	Value for Assessment (Values selected to be representative of deployed environment)	Upper Value
Exposure Frequency (Frequency of shower)	Showers/ week	1[a]	7[b]	7[c]
Exposure Time (Length of shower)	Minutes	7[a]	10[b]	17[c]
Total Volume (Water used per shower)	Gallons	11.9[a]	25[d]	41[e]
Incidental Ingestion (Water ingested per shower)	mL	10[f]	10[f]	30[g]
Exposure Duration	Years		1	

Notes:
[a] CASCOM 2008
[b] NSRDEC 2009
[c] Average value from the EPA Exposures factors hand book (EPA 2011)
[d] Calculated using a 2.5 gpm flow rate for the Containerized Shower System (DA 2005a) for 10 minutes (NSRDEC 2009)
[e] Calculated using a 2.4 gallon per minute flow rate (Zhou et al. 2007) during a 17-minute shower (EPA 2011)
[f] PNNL 1995
[g] 30 mL of water ingested per shower has been used in prior shower risk assessments

Table 5. Shower Frequency Alternatives

Alternative	Description	Shower Frequency (Showers/2 weeks)[a]
Baseline	Daily	14
A	Twice a day	28
B	Every other day	7
C	Once a week	2

Notes:
[a] Shower frequency is reported per 2 weeks to avoid a fractional shower in a week for the every other day alternative.

5.3 Exposure Factors for the Heat Casualty Body Cooling Scenario

Body cooling can take several forms, all of which involve contact with water. Army heat casualty management is described in TB MED 507 (Department of the Army and Air Force, Heat Stress Control and Heat Casualty Management). Initial cooling involves removing clothing and soaking the heat casualty's skin with water. Cool water and ice water immersion are the most effective methods to lower the heat casualty's body temperature. Once rapid cooling has been used to lower the rectal temperature below 101°F, a tepid shower can be used to maintain the temperature below 100°F (DA 2003).

5.3.1 Exposure Frequency

Heat casualty body cooling is not expected to be a frequent occurrence, so the exposure frequency will be treated as once per year.

5.3.2 Exposure Time

In an ice water tub for 15 to 30 minutes, an overheated person can be cooled from 110°F to 102°F. The use of an ice water filled tub for body cooling can reduce body temperature by an average of 17°F an hour (Roberts, 1998).

5.3.3 Incidental Ingestion

No data were available for water ingested by adults while in a tub. The closest surrogate data available was water ingested while wading in a swimming pool. In EPA's exposures factors hand book, the average water ingested during wading in a swimming pool was 3.5 milliliters per hour (mL/hr), while the median was 2.0 mL/hr (EPA 2011).

5.3.4 Incidental Inhalation

Compared to showering, aerosolized water is not expected to be a concern for water bath based heat casualty body cooling. Once the tub is filled there will not be flowing water to generate aerosols. A shower can be used for body cooling, and if a shower is used there would be inhalation of aerosolized water, but inhalation is not a parameter for water bath based heat casualty body cooling in this risk assessment.

Table 6 summarizes the exposure factors to be used for the heat casualty body cooling activity. The lower value would be an individual who quickly responds to cooling, so exposure time is limited to 15 minutes. The upper value represents a case of heat stroke requiring an hour of cooling in a water bath. The upper value is used for the assessment to be protective of serious heat casualty incidents.

Table 6. Summary of Heat Casualty Cooling Exposure Data

Parameter	Units	Lower Value	Value for Assessment (Values selected to be representative of deployed environment)	Upper Value
Exposure Frequency (Frequency of Heat Casualty Body Cooling)	Cooling/Year		1	1
Exposure Time (Length in cooling tub)	Minutes	15[a]	60[b]	60[b]
Incidental Ingestion (Water ingested while in the cooling tub)	mL	0.88[c]	3.5[d]	3.5[d]

Notes:
[a] The lower range of time to cool a body to 102°F (Roberts 1998).
[b] The time required to achieve 10°C of cooling or 17°F (Roberts 1998).
[c] The mean water ingested while wading in a pool, scaled to 15 minutes (EPA 2011).
[d] The mean value of water ingested while wading for an hour (EPA 2011).

5.4 Exposure Factors for the Personnel Decontamination Scenario

This analysis focuses on chemical, biological, radiological and nuclear (CBRN) decontamination, as it represents the typical types of activities associated with any kind of decontamination activity in the field. FM 3-11.5 (CBRN Decontamination Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Decontamination) explains decontamination for the three types of contamination (DA 2006a).

For chemical decontamination, a Skin Decontamination Kit (SDK) is the preferred method. If an SDK is not available, contamination may be blotted from the skin with a cloth and flushed with water. Washing with soap and water, preferably warm water, is the best method for toxic-agent removal if SDKs are not available (DA 2006a).

For biological decontamination, washing is performed using soap and water. Hypochlorite solution or other disinfectants are reserved for the spill of a solid or liquid agent from munitions directly onto the skin. Grossly contaminated skin surfaces should be washed with a 0.5 percent chlorine solution, if available, with a contact time of 10 to 15 minutes (DA 2006a).

For radiological decontamination, dust particles are brushed, washed or wiped off (DA 2006a).

Limited information is available on water exposure during decontamination operations. According to FM 3-11.5, showers offer the best facility to complete personal decontamination. Additionally, other forms of water application are compared to showering such as rigging fire hoses to create a makeshift shower (DA 2006a). FM 3-11.21 (CBRN Decontamination Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Consequence Management Operations) recommends using soap and a warm water shower for chemical, biological, and radiological consequence management decontamination (DA 2008).

For the risk assessment, personnel decontamination will be evaluated as a showering exposure. Showers are one type of decontamination. The exposure frequency will be once per year because personnel decontamination is expected to be an infrequent event. The other exposure factors will be the same as for showering.

5.5 Exposure Summary for Assessment

The exposure factors required for the exposure scenarios are summarized in Table 7. The frequency of showering is greater than the frequency of heat casualty body cooling or personnel decontamination. The frequency of showering and the volume of water ingested while showering means that showering will be the activity driving the exposure risk, so showering will be used to calculate the risk-based concentrations.

Table 7. Selected Exposure Factor Values for the Risk Assessment

Activity	Water Ingested per Activity Event	Frequency of Activity
Showering	10 mL[a]	Daily[b,c]
Heat Casualty Body Cooling	3.5 mL[d]	One time per year[e]
Personnel Decontamination	10 mL[f]	One time per year[g]

Notes:
[a] PNNL 1995
[b] The Force Provider System is designed to provide one shower per person daily (NSRDEC 2009).
[c] Daily showers are the baseline assessment. Alternative showering frequencies are also analyzed.
[d] The mean value of water ingested while wading for an hour (EPA 2011).
[e] Heat casualty body cooling is expected to be an infrequent event.
[f] Showering value is used as a surrogate.
[g] Personnel decontamination is expected to be an infrequent event.

6. DOSE-RESPONSE ASSESSMENT

Data directly relating exposure to treated (or untreated) wastewater and health effects was not available. Instead, surrogate data from swimming was collected and related to showering. Data from multiple sources were compiled and a dose-response equation was developed with the combined data set.

6.1 Availability of Relevant Dose-Response Data

Exposure response data for waterborne *E. coli* and illness is needed to conduct the risk assessment. There is however no direct exposure data for humans to treated wastewater. Instead, data from a different exposure activity (swimming) are used.

Freshwater beach studies relating the concentration of *E. coli*, a fecal indicator, to gastrointestinal illness are available. In the studies, freshwater beaches with water influenced by sewage treatment plant effluent were monitored. For risk assessment purposes, the exposure related to the unrestricted use of treated wastewater can be likened to swimming. In assessing microbial risk while swimming, the EPA assumed full body immersion, including the head. The definition of an unrestricted wastewater reuse activity involves full body contact with water, including the head (see paragraph 3.7). Figure 2 compares exposure in a beach study to exposure in wastewater reuse.

6.2 Comparison of Swimming and Showering

The data being used to develop the dose-response relationship for a shower exposure scenario are epidemiological data from recreational water exposures of the public during swimming at beaches and fresh water lakes and streams. In this context, the epidemiological data (from a swimming activity) are being used as alternative data to estimate a dose-response relationship for a showering activity. The alternative data are data from a sampled population (swimmers) that is similar to, but not a subset of, the target population (Soldiers showering). It is thus important to determine if water-related exposures of the surrogate population (swimmers) are representative of the target population water-related exposures (i.e., people showering).

In terms of exposure to water, recreational water users are generally divided into two categories: swimmers and waders (McKee 1980). For purposes of this risk assessment, the following definitions will apply.

1. Swimmer: an individual who goes in the water and swims (moves or propels unsupported through water using natural means of propulsion such as legs and arms), getting the entire lower body, upper body, head, and face wet.

2. Wader: an individual who goes in the water, does not swim, and only gets the lower body below the waist wet.

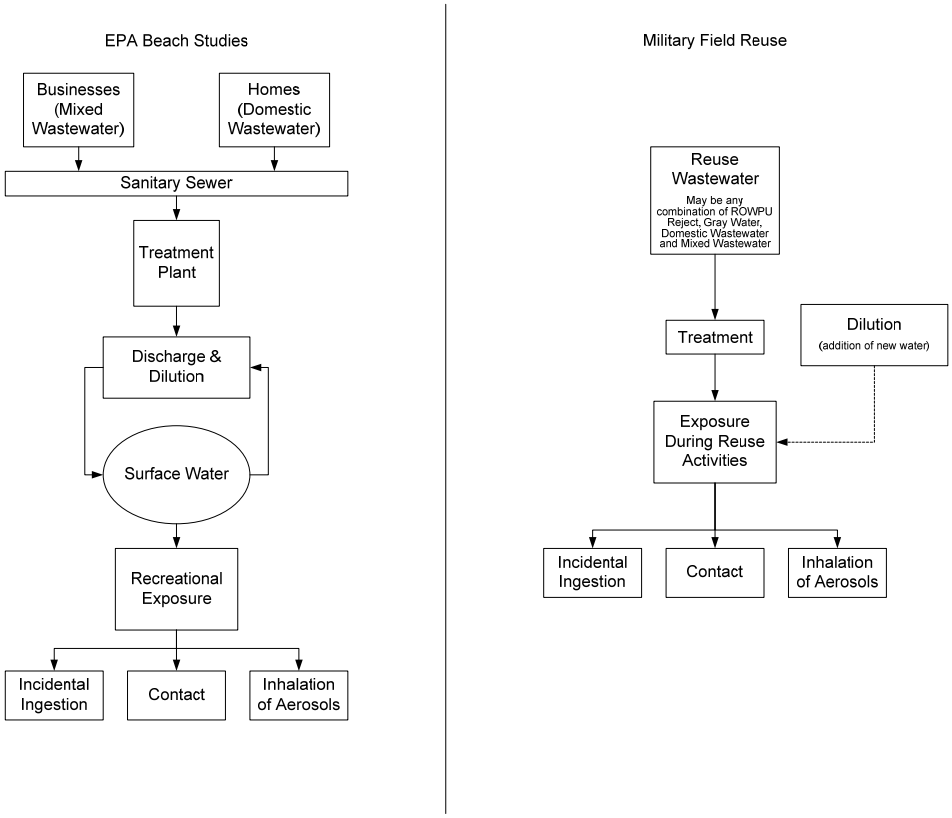

Figure 2. Comparison of Reuse Exposure to Beach Study Exposure

Swimming and showering are similar but not identical activities. Because they are not identical, it may be argued that the dose-response relationship from swimming exposures is different from and do not apply to showering activities. Alternatively, swimming and showering may share enough similarities to make the dose-response relationship developed from one activity applicable to the other activity.

Showering is generally described as continual wetting of the skin surface with a water spray while rubbing the skin with a cleansing agent. The spray is continuous but typically only contacts one side of the body at a time, but the noncontact side does not have time to dry before it is re-wetted. Swimming is generally described as submersion of skin surfaces in water. Submersion means all sides of the body that are submerged are in continuous contact with the water. The submerged part of the body has 100% continuous contact with the water. In order to determine the similarities and differences between swimming and showering, a qualitative comparison of the two is presented in Table 8.

Table 8. Exposure Comparisons Between Showering and Swimming

Liquid Contact Exposure Route	Description of exposure route	Showering	Freshwater Swimming
External (dermal) Contact	Lower body exposure	The entire lower body will get wet from direct spray or from water running down the upper body to the lower body. The lower body is not submerged, but is continually wetted from direct spray or drip from the upper body.	Wading can involve getting only the lower legs wet; in some cases the entire legs below the waist will get wet. Wading typically involves total submersion of the lower body
	Upper body exposure	The entire upper body both front and back receive direct spray from the showerhead.	Full body contact swimming involves immersion of the entire upper body in the water with complete exposure.
	Head exposure	The entire face, neck, and head receive direct spray from showerhead. Eyes are generally closed but some exposure is expected (e.g., splashing, dripping from eyebrows). Minimal water enters the ear canal.	Full body contact swimming involves immersion of the head, face, and neck in the water with complete exposure. Eyes may be opened allowing for greater exposure. Water may enter and remain in the ear canal.
	Wounds/ Cuts	Open wounds/cuts can be kept out of water or contact minimized	Wounds/cuts are typically immersed.
	Exposure time	7-17 minutes (see Table 4)	Swimming (with complete lower body, upper body, and head contact) typically lasts for 15 minutes to >1 hour. Exposure time is highly variable and swimmer-dependent.
	Exposure frequency	Two showers per day to one shower per week (see Table 5)	Variable (swimmer-dependent)
	Water temperature	Water is usually heated to 95-100°F (TB MED 577)	Water is ambient and in the range of 65-85°F
	Total volume	11.9 to 41 gallons/shower (see Table 4)	Not applicable
	Mechanical action of water	Moderate to large; provides some cleaning action (Lane and Blank 1945; Byrne et al. 1990; LLNL 1991). Type of showerhead and water pressure will influence cleaning action.	Simple immersion provides minimal to negligible mechanical action. Rivers and streams have variable flow frequencies which influences mechanical action.
	Clothing worn	None	Bathing suit (amount of body covered can vary). Clothing worn while swimming (i.e., bathing suit) becomes saturated and is in intimate contact with skin.
Incidental Ingestion	Incidental Ingestion volume (adults)	10 mL/shower (PNNL 2006) 10 mL/day (WA DOH 2003)	Mean: 16 mL/event (45 minutes); 21 mL/hour; Max: 53 mL/event (45 minutes); 71 mL/hour (EPA 2011)
	Exposure Time	7-17 minutes (see Table 4)	Swimming can typically last for 15 minutes to >1 hour. The exposure time a swimmer incidentally ingests water during swimming has not been quantified. Ingestion may occur throughout the swimming event or it may be episodic.
	Exposure frequency	Two showers per day to one shower per week (see Table 5)	Variable (swimmer-dependent)
	Water temperature	95-100°F (TB MED 577)	Usually in the range of 65-85°F
Misc.	Use of cleansing agent	Used during most of shower; used over entire skin surface.	Not used

6.3 Alternative Exposure Pathways: Dermal and Inhalation

Results from the National Epidemiological and Environmental Assessment of Recreational (NEEAR) study concluded that the Recreational Water Quality Criteria based on fecal indicator bacteria (i.e., *E. coli*) for gastrointestinal illness prevents most types of recreational waterborne diseases (e.g., skin rashes or respiratory disease). Dermal and respiratory diseases generally occur at a lower rate than gastrointestinal illness (EPA 2012; WHO 2005). Ocular and aural diseases may also occur. The remaining dose-response data for the alternative exposure pathways was not used (EPA 2012) because the NEEAR studies did not collect new data for *E. coli* (EPA 2009).

In terms of external (dermal) contact, both showering and swimming involve full body contact with water, to include the lower body, upper body, head, face, hair, and neck. Both activities involve continual skin surface wetting as long as the activity occurs. Therefore, external (dermal) contact exposures for swimming and showering are nearly identical.

Water ingestion and orifice entry is similar for both showering and swimming due to full body contact and intimate exposure with water over the entire skin surface. The swimming-related ingestion amount (16 mL) appears to be higher than the showering-related ingestion amount (10 mL) perhaps due to the longer swimming time compared to the showering time. However, both ingestion amounts are within an order of magnitude.

Incidental ingestion rates for both showering and swimming are similar. Incidental ingestion rates for showering are 10 mL per shower (PNNL 2006; Washington Department of Health (WA DOH) 2003); mean rates for swimming are 16 mL/event and 21 mL/hour (EPA 2011).

The exposure time, frequency, and water temperature differ for the two activities. Showering is usually a very short exposure time activity (i.e., several minutes). Swimming is usually a longer exposure time activity (i.e., can be 1 hour or more). Swimming is generally less frequent than showering and typically does not occur with heated water.

Showering and swimming differ in their ability to cleanse the skin through physical means alone. The physical action of pressurized water from a showerhead has been shown to provide more efficient cleaning than simple immersion in water (Lane and Blank 1945). Experimental data appear to validate this observation (Byrne et al. 1990; Lawrence Livermore National Laboratory (LLNL) 1991; Ojajarvi 1981). This suggests that showering may provide less exposure to microbes than swimming, because showering contains a physical process for microorganism removal that is not present while swimming. However, this effect has not been widely studied and no known risk assessments have addressed the possible reduction in risk from the physical action of water during showering. Thus, there is some uncertainty regarding reduced risks from the mechanical action of water during showering.

The presence of soap or another cleansing agent and the interaction of the cleansing agent with the water and the skin during showering may have an effect on the exposure to pathogens. Additionally, some soap contains antimicrobial ingredients. In general, most soaps utilize chemicals that break down fats and oils that bind to dirt and other particles, allowing them all to be rinsed away in a flow of water. Surface bacteria and viruses tend to be washed away with the dirt and oils. This process removes microorganisms from the skin, but does not necessarily kill or inactivate them. Thus, microbial shedding via a soap/water emulsion is part of the showering process; skin microbial removal efficiencies as high as 98% can be achieved (LLNL 1991; Ojajarvi 1981). This is not the case for swimming because cleansing agents are not used while swimming. Showering with soap may thus present less exposure to microbes than swimming. However, due to the paucity of data, there is some uncertainty regarding reduced risks from soap use during showering.

A bathing suit is normally worn while swimming and no clothing is normally worn while showering. While swimming, the bathing suit becomes saturated and is in intimate contact with skin. This would indicate that a swimming suit has a negligible effect on exposure to water. Therefore, for risk assessment purposes, a bathing suit worn while swimming may have an effect for dermal exposures (increased contact time); however, swim suits or clothing are not expected to impact incidental ingestion.

As discussed above, both swimming and showering share a significant amount of exposure similarities. The primary hazards for both the swimming and the showering scenarios are microbes in the water and the potential for infection and illness due to exposure to the pathogens. These hazards are directly related to intimate contact with water (skin contact, ingestion, and eye and ear contact). The potential hazards encountered from these exposures (dermal, ocular/aural, ingestion) to both recreational water while swimming and shower water while showering are nearly identical. These exposure scenarios are so similar that the exposures to swimming in recreational water can be likened to exposures to showering in shower water. Dermal and ocular/aural exposures are not evaluated in this assessment because health effects for these exposure pathways are not correlated with *E. coli.* An additional indicator organism would be required to determine risk associated with dermal and ocular/aural exposure.

Data from swimming exposures in recreational water will be used to develop the dose-response relationship for showering.

6.4 Gastrointestinal Illness and Available Data from Recreational Water Studies

The available dose-response data evaluates the correlation between exposure to recreational water and gastrointestinal illness.

6.4.1 Definitions of Gastrointestinal Illness from Available Dose-Response Studies

Gastrointestinal illness has been defined various ways in the dose-response references presented in Table 9. Due to the need to estimate risk from incidental consumption of water with minimal information regarding the possible contamination sources as well as other factors (such as time in residence, amount consumed), it was decided to capture as much data as possible, including the most broad definitions of gastrointestinal illness.

The broadest definitions are “gastrointestinal illness” and “NEEAR Gastrointestinal Illness” (NGI) because they do not require fever and therefore have a greater chance of including viral and other illness caused by microbes. Also, NGI allows for a longer incubation period; illnesses up to 12 days after exposure are acceptable. The most conservative (most limiting) definition is “Highly Credible Gastrointestinal Illness” (HCGI) because it requires a fever. Fever is a symptom that is generally limited to a bacterial infection. The challenge for researchers was to be able to differentiate between gastrointestinal illness caused by a microbial organism that was present in the water versus other causes (either from other sources or other causes such as nervousness etc.).

The criteria for inclusion of data in the dose-response evaluation within this risk assessment were that gastrointestinal illness was defined and that a geometric mean for the *E. coli* density was provided. Because the differences between the definitions of gastrointestinal illness (Table 9) appear to be arbitrary, it was decided that all definitions are comparable and the highest illness rate would be selected in the analysis (see paragraph 6.4.5). This decision results in a “worst case” analysis because the higher rate of illness is associated with a given *E. coli* density.

Table 9. Summary of "Gastrointestinal Illness" Definitions

Case Definition Term	Description		Source of definition	Relevant freshwater references that applied the case definition (Notes)
	Illness	Severity		
Netherlands – 1	Diarrhea (two or more loose motions per 24 hours) accompanied by two other symptoms (fever, vomiting, nausea, stomach ache or gripes (sharp pain in the bowel). All complaints present for at least two parts of the day (night, morning, afternoon, evening).	Not reported	Hoogenboom-Verdegall et al. 1990	Medema et al. 1995 van Asperen et al. 1998
Netherlands – 2	Diarrhea; or nausea; or vomiting' or stomach ache; or gripes. All complaints present for at least two parts of the day (night, morning, afternoon, evening) or on two parts of the day within successive 24 hours	Not reported	van Asperen et al. 1998	van Asperen et al. 1998
United Kingdom – 1	Vomiting; or diarrhea (three or more loose stools in 24 hours); or nausea accompanied by a fever. All complaints present for at least one part of the day (night, morning, afternoon, evening).	Not reported	Kay et al. 1994	van Asperen et al. 1998
United States – 1 "Gastrointestinal Symptoms" (GI)	Vomiting, Diarrhea, Stomachache, Nausea	No prejudgment of "important" illnesses	Cabelli et al. 1982	Cabelli et al. 1982 (no specification of "and" or "or" nor timeframe relative to sampling van Asperen et al. 1998
United States – 2 "Highly Credible Gastrointestinal Illness" (HCGI)	Any of the following (within 8 – 10 days after swimming): Vomiting, instances of diarrhea accompanied by fever or that were disabling, or cases of nausea or stomachache that were accompanied by fever.	Estimated by whether respondents remained home, remained in bed or sought medical advice	Cabelli et al. 1982	Cabelli et al. 1982 EPA 1984
United States – 3 "NEEAR Gastrointestinal Illness" (NGI)	Any of the following (within 10 to 12 days after swimming): Diarrhea (three or more loose stools in a 24-hour period); vomiting; nausea and stomachache; or nausea or stomachache and impact on daily activity.	Not reported	EPA 2009 EPA 2012	EPA 2009 EPA 2012

6.4.2 Freshwater Epidemiological Studies Utilized by EPA to set Recreational Water Quality Criteria

For decades total *E. coli* has been used as an indicator of water quality. Because *E. coli* is commonly found in human and animal feces, the presence of *E. coli* may indicate fecal contamination. The *E. coli* itself may not necessarily be pathogenic (able to cause illness), instead the presence of *E. coli* is used as an indicator of the possible presence of other microorganisms, some of which may be pathogens. The EPA is responsible for publishing water quality criteria per the Clean Water Act of 1977. The term "water quality criteria" has different meanings within the Clean Water Act. In the context of the recreational water quality criteria, the term represents a nonregulatory scientific assessment of health effects.

The bacterial indicator concentration indirectly measures the total microbial load in the water. It is important to note that the cause of the reported illnesses was not determined. The presence of the *E. coli* in the water simply allows the inference that it is possible that other microorganisms are also present in the water. In addition, the bacterial indicator concentration is not the same as how many pathogens a swimmer ingested (was exposed to via the ingestion route) or the dose. To determine the dose the water concentration as well as the amount of water ingested while swimming is needed.

When possible, original sources were used for recreational water sources. Dose-response data used to set Recreational Water Quality Criteria in 2012 were published in EPA 1984, (EPA 2012). In an attempt to retrieve the original raw data used in the EPA report, the data citations were consulted and requests for the original literature were made. The raw data is referenced in two doctoral dissertations at the University of Oklahoma (McKee 1980 and Shadid 1981) and one peer-reviewed manuscript labeled "in preparation." The two dissertations were obtained and are reviewed below. They provided extensive detail of the day to day indicator concentrations, the age distribution of the study participants, and the interview process. However, the available information does not allow for linking specific study participants to the water concentration on the day they were at the beach. The peer-reviewed manuscript could not be found, and it was later learned that the manuscript was never published. The lead author, Dr. Alfred P. Dufour, was contacted and he stated that the paper was not completed and the original data has since been lost. Furthermore, he said the only information available on the Lake Erie studies is the information contained in the EPA (1984) document (Personal communication between Mr. Stephen Comaty and Dr. Alfred Dufour, 19 October 2012). Due to the missing original data, the data is presented as it was in the 1984 EPA report.

- Development of Health Effects Criteria for Freshwater Bathing Beaches by Use of Microbial Indicators (McKee 1980)

Three beaches were the sites of the research to support the development of recreational water quality criteria. Two "barely acceptable" beaches (Salt Creek North and Keystone Ramp) and a "relatively unpolluted" beach (Washington Irving South) were sampled, and symptoms were recorded among swimmers and nonswimmers (controls). Family groups were contacted while at the beaches on the weekends and follow-up telephone calls 8 – 10 days later recorded any health-related symptoms.

Pre-test sampling (performed summer of 1978) revealed consistently high levels of *E. coli* and enterococci at the "barely acceptable" beaches. Participants were divided into two categories:

1. Nonswimmers – those who either did not go in the water (nonbathers) or went in the water but did not get their head or face wet (waders)
2. Swimmers – those who swam and got their head or face wet.

Those who did not spend more than 10 minutes in the water were considered nonswimmers, regardless if they got their head or face wet.

Water samples were collected periodically during the maximum swimming activity each interviewing day (weekend days). Three samples were taken each day at chest depth approximately 4 inches below the surface of the water. Samples were iced and returned to the Tulsa City-County Health Department Laboratory where they were assayed within 6 hours of collection. The M-Tec procedure of Dufour et al. (1981) was used to enumerate thermotolerant *E. coli.*

Gastrointestinal symptoms were listed simply as "vomiting," "diarrhea," "stomach ache," and "nausea." Respiratory (e.g., sore throat, and cough) and other nonspecific symptoms (e.g., headache, backache, and skin rash) were noted. Illness severity was grouped by "home because of symptoms," "stayed in bed" or "consulted medical help." Table 10 presents the results for McKee (1980).

Table 10. Selected Dose-Response Data for Keystone Lake, Oklahoma (McKee 1980)

Year	Total Number of Interviews (Swimmers/Nonswimmers)	Beach	*E. coli* Density/100 mL		HCGI Rate (per 1000 individuals)
			Mean	Range	
1979	3,059 / 970	Keystone – West	138	30 - 300	5.1
1979	2,440 / 970	Keystone – East	19	1 – 44	0.5

- Microbial Indices of Recreational Water Quality (Shadid 1981)

This study continued McKee's 1980 work. The same three beaches were the sites of the research to support the development of microbial recreational water quality criteria. In this study, the same method and procedures as McKee, 1980 were used.

Shadid used the McKee 1979 data as well as the 1980 data in the analysis (Table 11).

Table 11. Selected Dose-Response Data for Keystone Lake, Oklahoma (Shadid 1981).

Year	Total Number of Interviews (Swimmers/Nonswimmers)	Beach	*E. coli* Density/100 mL		HCGI Rate (per 1000 individuals)
			Mean	Range	
1980	5,121 / 1,211	Keystone – West	52	14 – 200	5.2
1980	3,562 / 1,211	Keystone – East	71	12 – 215	3.0

- Health Effects Criteria for Fresh Recreational Waters (EPA 1984)

In 1972, the EPA initiated a series of studies at marine and fresh water beaches to determine if swimming in sewage-contaminated water posed a health risk for bathers, and if so, to what type of illness (EPA 1986). In 1986, the EPA used these studies to publish their Ambient Water Quality Criteria for Bacteria – 1986 (EPA 1986). The data from the beach studies appear to be the best available data to relate the presence of an indicator in water to illness.

The EPA published the fresh water results in a report titled "Health Effects Criteria for Fresh Recreational Waters" (EPA 1984). The fresh water studies mimicked sister-studies that had been performed at marine beaches (EPA 1981). Data was collected at two fresh water beaches in Oklahoma (Keystone Lake – 2 years of data; McKee 1980 and Shadid 1981) and Pennsylvania (Lake Erie – 3 years of data; EPA 1984). Two sites at each location were selected: one representing a beach near a point of discharge from a sewage treatment facility and one further away (control). *E. coli* and enterococci (*Streptococcus faecalis* and *Streptococcus faecium*) were the two indicators monitored during all phases of the study. Fecal coliforms were also monitored during portions of the study. Trained interviewers collected information from participants at the beach, and then telephone interviews were conducted 8 to 10 days after the swimming event to inquire about the onset of any symptoms. Participants could only have swam on the day of the data collection; if the person had swam in the previous 5 days or swam in the following week, they were not included in the study.

The Lake Erie data (Table 10) provided points that where swimmer-non swimmer illness rates were significant at a p = 0.05 level. The data was used to set the Recreational Water Quality Criteria (EPA 1986 and EPA 2012). The continued use of the Lake Erie data by the EPA in 2012 sets a precedent to use it in the current dose-response analysis. However, the lack of original source data causes the strength of the dose-response data to be low.

Table 12. Selected Dose-Response Data for Lake Erie, Pennsylvania (EPA 1984)

Year	Total Number of Interviews (Swimmers/Nonswimmers)	Beach	*E. coli* Density/100 mL		HCGI Rate (per 1000 individuals)
			Mean	Range	
1979	3,020 / 1,310	A	23	7 – 268	2.3
	2,056 / 1,039	B	47	14 – 413	4.6
1980	2,907 / 1,436	A	137	66 – 536	4.8
	2,427 / 1,558	B	236	110 – 950	14.7
1982	4,374 / 1,650	B	146	23 – 524	11

- EPA National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) Studies

The Clean Water Act was amended by the Beaches Environmental Assessment and Coastal Health (BEACH) Act in 2000. This required EPA to publish new or revised criteria for pathogens and pathogen indicators. In 2003, 2004, 2005, 2007, and 2009 EPA conducted epidemiological investigations at U.S. beaches. As a group these investigations are called the NEEAR study (EPA 2012). The NEEAR study was a prospective cohort epidemiological study that enrolled 54,250 participants and encompassed nine locations including fresh water, marine, tropical, and temperate beaches (EPA 2009; Wade et al. 2008 2010).

One of the outcomes of the NEEAR studies was the criticism of the HCGI. HCGI is considered too specific (by requiring fever) and suspects that illness has been under counted (EPA 2012). It is

anticipated that the elimination of the fever requirement allows for the inclusion of viral gastroenteritis (viral gastroenteritis usually does not include fever); therefore, allowing for a more accurate reflection of total gastrointestinal illnesses. The relaxing of the illness definition is more inclusive because it is believed that viruses are the etiologic agent responsible for most gastrointestinal illnesses from recreational waters impacted by human fecal contamination (Soller et al. 2010). The EPA applies an estimated translation factor of 4.5 to convert between HCGI and the NEEAR-GI illness definition (NGI). Using the factor of 4.5, the HCGI is converted to NGI.

Results for the NEEAR studies also indicate that criteria limiting exposure based on fecal indicator bacteria (i.e., *E. coli*) for gastrointestinal illness will prevent most types of recreational waterborne diseases (e.g., skin rashes or respiratory disease), because these illnesses generally occur at a lower rate than gastrointestinal illness (EPA 2012). However, culturable *E. coli* was not included in the NEEAR studies because the focus was on evaluation of a single indicator that could be used in both fresh and marine waters; therefore, no new data is available from the NEEAR studies for use in this risk assessment.

- Recreational Water Quality Criteria (EPA 2012)

In 2012, EPA updated the 1986 Recreational Water Quality Criteria to include both a geometric mean and a statistical threshold value. In addition, the new criteria are presented with a magnitude, duration, and frequency of excursion for both the geometric mean and the statistical threshold value (Table 13). The EPA provides two illness rates in Table 13 and recommends that states make a risk management decision regarding which illness rate is most appropriate for their waters. The data from the NEEAR study was used to update the marine criteria (not shown); however, no new data was used to update the freshwater criteria because it is based on culturable *E. coli*, which was not part of the NEEAR study.

The statistical threshold value corresponds to the 90th percentile of the same water distribution used to derive the geometric mean and therefore provides the same level of public health protection. The statistical threshold value is derived from the observed pooled variance of the epidemiological data and represents the wide range of weather and hydrological conditions over the full course of the studies. It takes into consideration the expected variability in water quality measurements and allows for “spikes” in water quality. The EPA believes that the use of the statistical threshold value and the geometric mean together better ensure water quality levels that are protective of designated use.

6.4.3 Additional freshwater studies

Data from the following was also incorporated into the assessment.

- Health Effects of Swimmers and Nonpoint Sources of Contaminated Water (Calderon et al. 1991)

The purpose of Calderon et al. (1991) was to determine risk associated with swimming in water contaminated with animal fecal waste. A 3-acre pond in central Connecticut was the study site. One side of the pond is used for recreational use with a small sandy beach. There were no human sources to contaminate the stream water which feeds the pond. The watershed was populated by animals such as squirrels, rabbits, small rodents, and deer. Additionally, bathers may have brought pathogens in on their bodies. Water samples were taken daily from two sampling sites within the swimming area at knee depth. Samples were analyzed for *E. coli*, *P. aeruginosa,* staphylococci, enterococci, and fecal coliforms (Table 14).

Table 13. Recommended 2012 Recreational Water Quality Criteria (Table 4 in EPA 2012)

Criteria Element	Estimated NGI Rate = 36 per 1,000 primary contact swimmers		OR[b]	Estimated NGI Rate = 32 per 1,000 primary contact swimmers	
Magnitude Indicator Density (CFU/100 mL) of culturable *E. coli*	Geometric Mean	Statistical Threshold Value[a]		Geometric Mean	Statistical Threshold Value
	126	410		100	320
Duration	The water body geometric mean should not be greater than the selected geometric mean magnitude in any 30-day interval.				
Frequency	There should not be greater than a 10 percent excursion frequency of the selected statistical threshold value magnitude in the same 30-day interval.				

Notes:
[a] Statistical threshold value: the 90th percentile of the water quality distribution
[b] EPA provides two illness rates and recommends that states make a risk management decision regarding which illness rate is most appropriate for their waters.

Table 14. Selected Dose-Response Data for an Unnamed 3-Acre Pond in Connecticut (Calderon et al. 1991)

Total Number of Participants (Swimmers/Nonswimmers)	*E. coli* Density/100 mL		Gastrointestinal Illness Symptoms Rate per 1000 individuals
	Mean	Range	
104 families (1,310 / 8,356 person-days)	51	7 – 363	20.3

Study participants were members of a small community who had restricted access. They were solicited by an information letter with their annual recreation park membership invoice. Families enrolled were provided a questionnaire with demographic information and a daily diary for health status and swimming activity.

Swimming was considered full immersion, head and body beneath the surface of the water.

Gastrointestinal illness symptoms included vomiting, nausea, diarrhea, a stomachache and fever above 37.8°C (100°F). Other symptoms such as headache, backache, earache, itchy or watery eyes, skin rash, sneezing, and wheezing were also listed on the questionnaire. Severity of illness was assessed by whether or not an individual had to stay home, remain in bed, or sought medical help. Gastrointestinal illness was recorded as a positive response to vomiting, diarrhea, stomachache, or nausea, as long as the illness occurred 1 – 3 days after a swimming episode.

Water samples were collected daily from two sites within the swimming area. Samples were obtained in knee depth water following procedures outlined in *Standard Methods for the Examination of Water and Wastewater* (American Public Health Associated (APHA) 1980). Samples were held on ice and analyzed within 5 hours using the mTEC method (Dufour et al. 1981).

- The Relationship Between Health Effects in Triathletes and Microbiological Quality of Freshwater (Medema et al. 1995)

Medema et al. (1995) investigated the relationship between microbiological water quality parameters and health complaints among triathletes who completed the swim portion of their race in a fresh water river (Lek River, The Netherlands). Triathletes (n=311) and biathletes (n=99) (run-bike-run; control) returned questionnaires regarding personal characteristics, amount of training, competition experience, exposure to water (e.g., swallowed water; wore goggles) and occurrence of health effects. Water samples were collected from three sampling sites; an upstream location, start, and finish at 4 time points and a different depths. Samples were analyzed for thermotolerant coliforms (*E. coli,* fecal streptococci, *Aeromonas, Pseudomonas aeruginosa, Campylobacter, Salmonella, Staphylococcus aureus,* and *Pleisomonas shigelloides)*, as well as enteroviruses and retroviruses (Table 15). Bacteriological analyses were performed using Dutch standard methods.

Two case definitions were used for gastroenteritis:

1. Highly credible gastroenteritis described by Cabelli et al. (1982)
2. Diarrhea (two or more loose motions per 24 hours) accompanied by two other symptoms (fever, vomiting, nausea, abdominal pain/cramps) occurring for at least 24 hours

Table 15. Selected Dose-Response Data for the River Lek, The Netherlands (Medema et al. 1995)

Total Number of Participants (Swimmers/Nonswimmers)	*E. coli* Density/100 mL		Gastroenteritis Symptoms Rate per 1000 individuals
	Mean	Range	
314 / 81	170	Not reported	9.6

- Risk of Gastroenteritis Among Triathletes in Relation to Faecal Pollution of Fresh Waters (van Asperen et al. 1998)

The purpose of this prospective cohort study among triathletes was to evaluate the risk of gastroenteritis after racing in water (seven events) that met current bathing water standards. Duathletes (run-bike-run) were used as controls.

The strength of this study is that the study population was exposed to the same water over a period of 15 – 40 minutes, depending on how long it took to complete the 1.5 km swim. If an athlete was on the contest list a week prior to the race then they were invited to participate in the study. A postal questionnaire was provided to collect demographic information and training history, plus any exposure to any surface waters in the week before and after the race. Wetsuit and goggle use was recorded as well as whether or not water was ingested (72% reported swallowing water). Athletes were asked if they developed gastroenteritis in the 2 days before the race and 6 days after. Those with illness 2 days before the race were not included in the study.

Gastroenteritis symptoms were nausea, vomiting, stomachache, diarrhea, and fever. Disability was estimated by if daily activities were discontinued, remained in bed, sought medical advice or used any drug. Athletes that competed in more than one event were included repeatedly as each event was considered independent. The study compared the outcome when different definitions of gastroenteritis were applied (Table 9).

On race day sample collection bottles were filled along the swimming course from a boat that accompanied the swimmers. Samples were from 0 to 30 cm below the surface, stored on ice and

transported to the laboratory within 4 hours. Analysis occurred in duplicate within 28 hours using Lauryl Sulphate Agar (4 hours at 25°C and 18 hours at 44°C) with *E. coli* confirmation on Brilliant Green Lactose Broth (48 hours at 37°C; Table 16) (Havelaar and During 1988).

The highest attack rate was for the NL-2 case definition and lowest for the NL-1 case definition van Asperen et al. (1998) also suggest threshold levels beyond which increased attack rates were observed. For *E. coli* the proposed threshold level is a geometric mean of 355/100 mL. It is believed that exposure to water below this concentration would result in attack rates comparable to those among nonswimmers (based on NL-2 definition).

Table 16. Selected Dose-Response Data for Seven Triathlon Locations in the Netherlands (van Asperen et al. 1998)

Total Number of Participants (Swimmers/Nonswimmers)	*E. coli* Density/100 mL		U.S. Case Definition* of Gastrointestinal Illness Symptoms Rate per 1000 individuals
	Mean	Range	
824 / 771	204	11 – 2,600	14.1

Note:
* U.S. Case Definition = HCGI

6.4.4 Excluded Studies

The concentrations in the excluded studies spanned several orders of magnitude. A geometric mean is better representative of data spanning multiple orders of magnitude than an average or arithmetic mean. The excluded studies did not provide a geometric mean so they were not used in dose response development.

- A Randomized Controlled Trial Assessing Infectious Disease Risks from Bathing in Fresh Recreational Waters in Relation to the Concentration of Escherichia coli, Intestinal Enterococci, Clostridium perfringens, and Somatic Coliphages (Wiedenmann 2006)

Epidemiologic studies were performed at freshwater beaches in Germany to evaluate recreational water quality standards. A cohort study was performed with a pre-exposure interview, participants split into bathers and nonbathers, and interviews performed after exposure. Water samples were collected every 20 minutes then analyzed in a mobile laboratory. The results were examined based on exposure quartile and quintiles for indicators in the bathing water. A no-observed-adverse-effect level (NOAEL) was found based on the quartile and quintile groupings. The study found an NOAEL at an average of 100 *E. coli* per 100 mL. The study compared their NOAEL to the EPA 1986 guidance of 126 *E. coli* per 100 mL.

Wiedenmann et al. (2006) was not selected as a study for inclusion in the dose-response data pool because it did not report geometric mean *E. coli* concentrations.

- Association of Gastrointestinal Illness and Recreational Water Exposure at an Inland U.S. Beach (Marion et al. 2010)

Recreational water contact-associated illness was studied at East Fork Lake, Ohio in 2010 (Marion et al. 2010). Study participants were recruited from the beach on the same day that the water was sampled. Participants were then telephone-interviewed 8 – 9 days later to determine possible water-related illness.

The study recruited participants over 26 weekend days in the summer. The survey used was modified from the EPA NEEAR study. The survey was used to gather information on the exposure status, illness status and symptoms, and demographic. Swimmers were defined as those who "wade, swim or play in the water." There was no clarification of head submersion requirements in the swimmer category. Health outcomes were focused on gastrointestinal illness using the definition of HCGI as the case definition.

Three models were considered. The first model estimated gastrointestinal illness risk for swimmers. This model adjusted for age (categorized as "young child, older child, teenager, young adult, adult, and older adult"), gender, and reservoir inflow. The second model incorporates illness risk including those who consumed food at the beach, not just swimmers or nonswimmers. The third model included swimmers and assessed illness risk among swimmers in waters with varying densities of *E. coli*.

Water samples were collected daily about 1 foot below the surface in water that was approximately 3 feet deep. Laboratory analysis was performed within 6 hours of collection using EPA Method 1603.

Unfortunately, Marion et al. (2010) expresses results as Arithmetic means, which mean this data cannot be used in conjunction with the other dose-response data reviewed in this report.

6.4.5 Summary of Selected Dose-Response Data from Recreational Water Studies

Epidemiological exposure data was collected from six swimming studies. The studies used nonswimming control groups to estimate the background gastrointestinal illness rates. The control gastrointestinal illness rates were subtracted from the gastrointestinal illness associated with the swimming groups to estimate the gastrointestinal illness caused by contact with the recreational water. The *E. coli* exposures of the swimmers are characterized by the geometric mean concentration of *E. coli* in the recreational water over the study duration. The relevant information from the six studies is summarized in Table 17.

6.5 Analysis of Selected Dose-Response Data

6.5.1 Development of Initial Analytical Data Set

Based on the discussion in paragraph 6.4.1 regarding the definition of gastrointestinal illness, it was decided to use the most-encompassing definitions (NGI and GI) to analyze the dose-response data from the epidemiological data. Therefore, the analytical dataset was generated by selecting the highest illness rate for each given *E. coli* density from the studies presented in Table 17. Table 18 and Figure 3 presents the selected dose-response dataset.

Table 17. Summary of Epidemiological Exposure-Dose-Response Data Utilized to Derive Risk-Based Water Concentrations

Reference	*E. coli* Density[a]		Illness Rate (cases per 1000 exposed)		
	Method	CFU/100mL	HCGI	GI	NGI [b]
McKee et al. 1980	m-Tec (Dufour et al. 1981)	138	5.1	9.0	***23.0***
		19	0.5	***5.0***	2.3
Shadid et al. 1981	m-Tec (Dufour et al. 1981)	52	5.2	17.7	***23.4***
		71	3.0	***18.9***	13.5
EPA 1984	m-Tec (Dufour et al. 1981)	23	2.3	9.9	***10.4***
		47	4.6	11.7	***20.7***
		137	4.8	9.6	***21.6***
		236	14.7	30.0	***66.2***
		146	11.0	11.6	***49.5***
Calderon et al. 1991	m-Tec (Dufour et al. 1981)	51	N/A	***20.3***	N/A
Medema et al. 1995	Dutch standard methods	170	9.6	52.5	***43.4***
van Asperen et al. 1998	Lauryl Sulfate Agar with confirmation (Havelaar and During 1988)	204	14.1	N/A	***63.3***

Legend:
N/A = not studied in the report
HCGI = Highly Credible Gastrointestinal Illness
GI = Gastrointestinal Symptoms
NGI = National Epidemiological and Environmental Assessment of Recreational (NEEAR) Gastrointestinal Illness
M-Tec: procedure used to enumerate thermotolerant *E. coli*
Notes:
Bold Italic values indicate selected illness rate for analysis
[a] geometric mean over study duration
[b] 4.5 times HCGI rate (EPA 2012)

Table 18. *E. coli* Density Arranged in Ascending Order with Selected Illness Rate and Calculated Gastrointestinal Illness Rate

E. coli Density (CFU/100 mL) [geometric mean over study duration]	Selected Gastrointestinal Illness rate (cases per 1000 people)	Reference
19	5.0	McKee 1980
23	10.4	EPA 1984
47	20.7	EPA 1984
51	20.3	Calderon et al. 1991
52	23.4	Shadid 1981
71	18.9	Shadid 1981
137	21.6	EPA 1984
138	23.0	McKee 1980
146	49.5	EPA 1984
170	52.5	Medema et al. 1995
204	63.3	van Asperen et al. 1998
236	66.2	EPA 1984

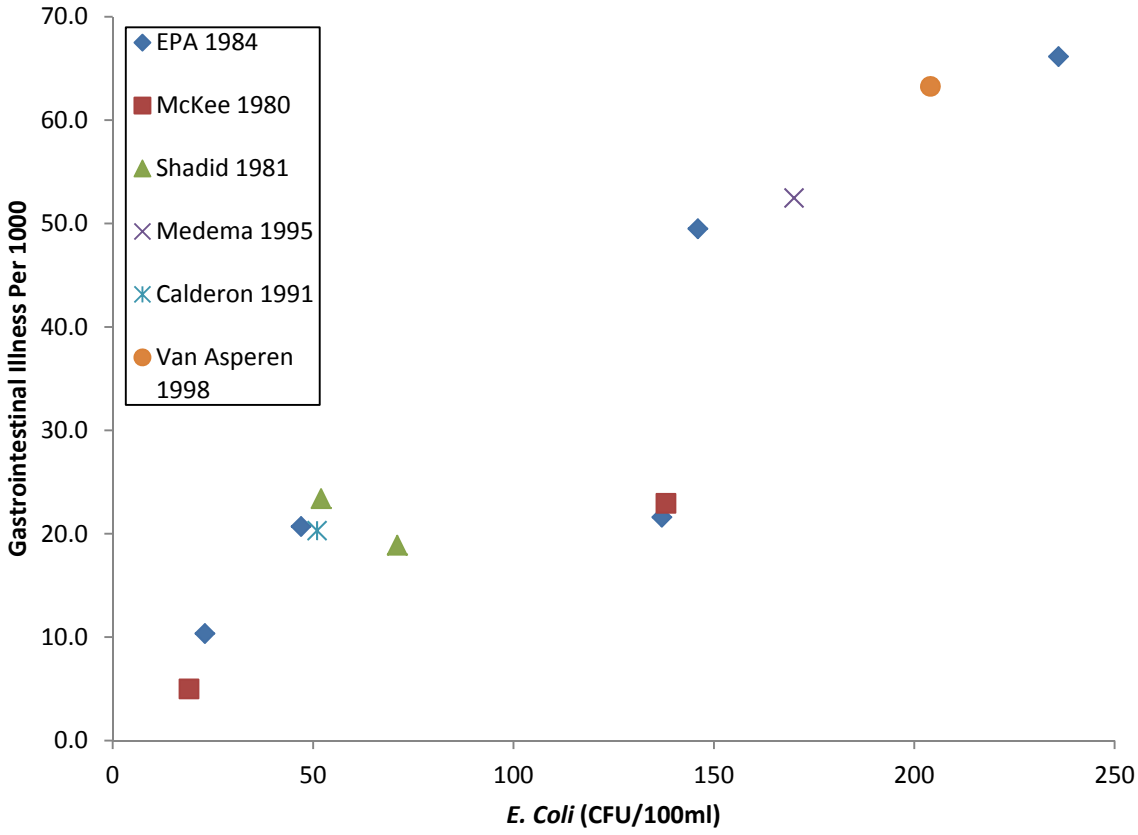

Figure 3. Epidemiological Dose-Response Data Normalized for Gastrointestinal Illness

6.5.2 Estimating Ingested Dose from *E. coli* Density

The studies reported the density of *E. coli* in the recreational water. To determine a dose-response relationship, the intake of water while swimming is estimated. In the 2011 EPA Exposures Factors Handbook (EPA 2011), paragraph 3.2.3 describes water ingestion while swimming. The swimming studies assessed children and adults; and as expected, children are expected to ingest more water while swimming than adults. The mean water ingested while swimming by an adult is 16 mL per swimming event, while the mean water ingested while swimming by a child is 37 mL per swimming event (EPA 2011).

To estimate the ingested dose of *E. coli* from the recreational water, the lower value (i.e., adult value of 16 mL) of ingested water was selected. This is considered conservative because the incidence of gastrointestinal illness is associated with a lower dose (Equation 1). If the child value had been selected then the same gastrointestinal illness would be associated with a higher dose, and therefore less protective.

$$Estimated\ Dose\ \left[\frac{CFU}{swimming\ event}\right] = \frac{Indicator\ Density\ \left[\frac{CFU}{100ml}\right]}{100} * Ingestion\ Rate\ \left[\frac{ml}{swimming\ event}\right] \quad \text{(Equation 1)}$$

Table 19 shows the estimated *E. coli* dose and the calculated rate of gastrointestinal illness.

Table 19. Estimated *E. coli* Dose

***E. coli* Density (CFU/100mL) [geometric mean over study duration]**	**Estimated *E. coli* Dose (CFU)**	**Selected Gastrointestinal Illness rate**	
		Cases Per 1000 People	**Gastrointestinal Illness probability**
19	3	5.0	0.0050
23	4	10.4	0.0104
47	8	20.7	0.0207
51	8	20.3	0.0203
52	8	23.4	0.0234
71	11	18.9	0.0189
137	22	21.6	0.0216
138	22	23.0	0.0230
146	23	49.5	0.0495
170	27	52.5	0.0525
204	33	63.3	0.0633
236	38	66.2	0.0662

6.5.3 Modeling of the Dose-Response Relationship

The exponential dose-response function model is commonly applied to microbial dose-response data (Haas et al.1999). When plotted, the data appear linear. In the low dose region the exponential dose-response function behaves linearly. Due to the shape of the data and the simple nature of the exponential dose-response model, the exponential dose-response model was selected for the data. In going from a set of discrete points where each is a rate of gastrointestinal illness at a given dose to a dose response equation a change is made from a measured rate of gastrointestinal illness to a probability of gastrointestinal illness at a dose where a study does not have data. The form of an exponential dose-response function is shown in the following equation:

$$P_{response} = 1 - e^{-k\,D} \qquad \text{(Equation 2)}$$

Where:
D = dose (organisms)
k = model parameter (unitless)
$P_{response}$ = the probability of gastrointestinal illness.

Using Microsoft® Excel®, an exponential dose-response function was fit to the dose-response data (Table 19). The exponential dose-response function can be linearized allowing Excel's regression tools to determine k. The linearized form of the exponential dose-response function is shown in the Equation 3. A linear equation has the form y = ax + b. In the linearized form of the exponential dose-response function y is ln(1- $Illness\ Rate$), a is - k, x is D and b is 0. To find k, the discrete gastrointestinal illness rate points were used. (Microsoft® Excel®, are registered trademarks of the Microsoft Corporation.)

$$\ln(1 - Illness\ Rate) = -k\,D \qquad \text{(Equation 3)}$$

The data in Table 17 were analyzed using the regression tool data analysis tool pack, with the constant set to 0. The resulting value for a (or – k) is -0.0018 (Equation 4). The dose-response function was found to be:

$$P_{response} = 1 - e^{-0.0018 * Dose} \qquad \text{(Equation 4)}$$

The least squares correlation coefficient (R^2) for the exponential dose-response curve fit to the swimming data from the six reports data is 0.94. The regression tool reported the 95% confidence values for k. The lower 95% confidence value for k was -0.0021 (Equation 5).

$$P_{response}\ Lower\ 95\% = 1 - e^{-0.0021 * Dose} \qquad \text{(Equation 5)}$$

The dose-response curve, the lower 95% confidence dose response curve, and the data points are shown in Figure 4.

The fitted dose-response equation is most applicable for the range of the underlying epidemiological data. For this assessment, use of the dose-response curve will be limited to *E. coli* indicator doses between 0 and 40 colony forming units (CFU).

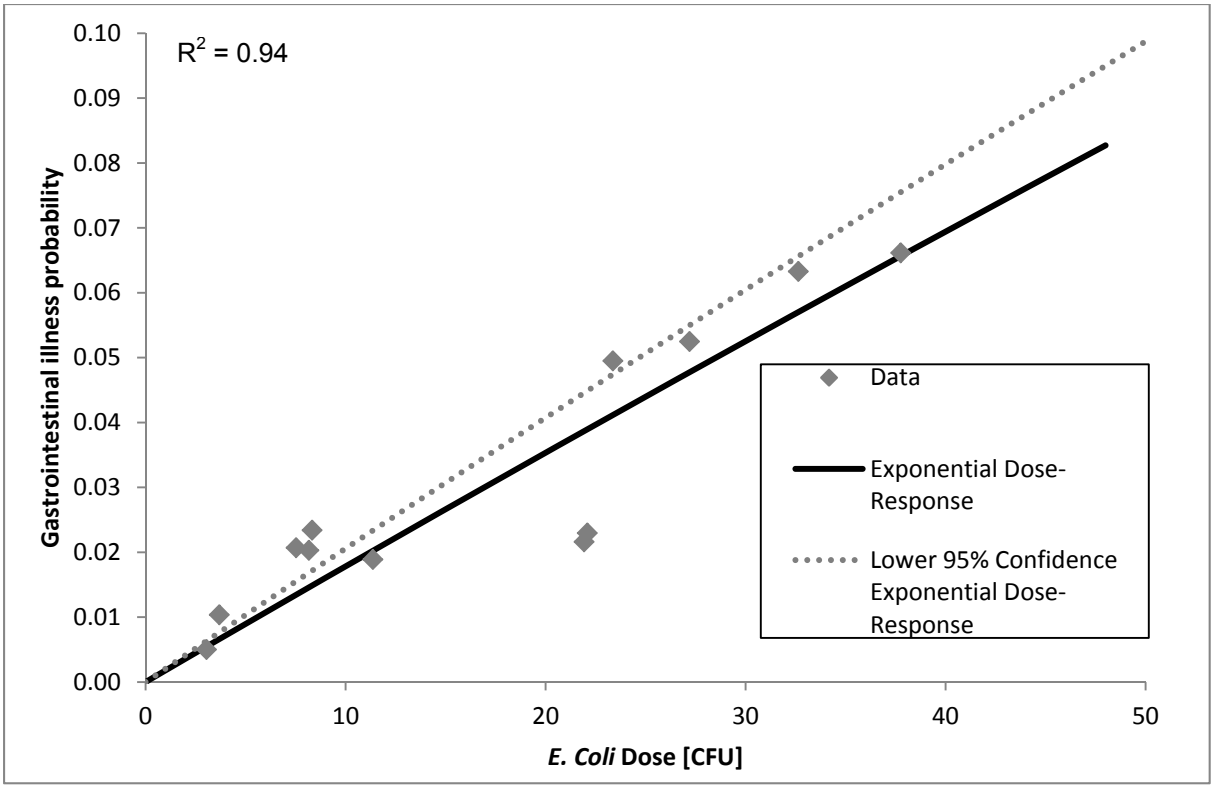

Figure 4. Exponential Dose-Response Curve

7. RISK CHARACTERIZATION

The purpose of this risk characterization is to present health RBWCs to aid the development of a microbial guideline for wastewater reuse during Army deployments. The results of the exposure assessment phase of this risk assessment (incidental water ingestion during showering) served as input into the dose-response assessment phase, where a quantitative dose-response relationship was defined (gastrointestinal illness rate per unit exposure to the indicator organism). From here, and described below, an acceptable risk level is defined, risk models are used to determine potential tolerable water concentrations of *E. coli*, assumptions are identified, and key uncertainties associated with the risk-based concentrations are described.

7.1 Overarching Assumptions Associated with the Risk Model

The following assumptions are embedded in the risk models that have been used to determine potential tolerable water concentrations of microbial contaminants for unrestricted wastewater reuse.

1. Wastewater will only be used after treatment and disinfection – Testing for compliance will occur after treatment and disinfection. No specific treatment was assumed for the risk assessment. However for the beach study dose response data to be valid, the selected treatment process must be as effective as the sewage treatment plants influencing the water quality at the study beaches.

2. Exposures are considered quasi-independent – It is anticipated that Soldiers will take more than one shower in the treated wastewater and that the showers would occur daily with approximately 24 hours between each shower. The innate immune system works immediately and effectively and is expected to accommodate small exposures (expected to be a low concentration in a small amount of water). However, due to stress of deployment the innate immune system may not be at peak performance and some organisms may evade the innate immune system. The acquired immune system has approximately a 3 – 7 day lag-time for response; therefore, bacterial invaders may remain (and multiply) in the host for several days. Therefore, it is assumed that the exposures (e.g., showers) are quasi-independent. A short-term increase in bacterial load in the host is expected, but that load is anticipated to decrease over time due to the immediate nature of the innate immune system. Further decrease will then be a function of the acquired immune system. The acquired immune system should become more efficient over time given exposure to the same pathogens. Therefore, the bacterial load in the host may rise and then decrease, but may not reach zero between each exposure. The exposure is termed quasi-independent because the exposures are not independent since there is less than 24 hours between each exposure (not enough time for complete clearance), but they are also not necessarily additive because the exposures are not happening within minutes of each other.

3. Exposed population is "healthy" – The deployed military population includes Active Duty, Reserve, and National Guard personnel and is mostly composed of relatively healthy and fit adults, 18 to 55 years of age, with an average weight of approximately 70 kilograms (kg) (i.e., approximately 154 pounds). While this description addresses the majority of personnel (e.g. estimated 90 percent or greater), demographic and other data show that there are personnel that fall outside this description. For example, particularly with increased reliance on National Guard and Reservists, an increased number of older personnel are now deployed. In addition, it is known that a small percentage of females become pregnant right before or during deployment. The assumption that deployed military individuals will have no predisposing physical or mental factors that could exacerbate exposure to environmental stressors (e.g., pathogenic microorganisms or chemicals) does not appear to be entirely supported through scientific evidence. While there are basic health and fitness requirements that must be met and maintained by military personnel, an assessment of the factors that can lead to susceptibilities suggests that many of the same primary susceptibility factors exist for the deployed military population. Predisposing factors such as age (> 40 years), illness (e.g., asthma), physical and emotional stressors, life-style choices (e.g., smoking or alcohol use), physiological state (e.g., fatigue, hypothermia, underlying cardiovascular disease), or unique genetic traits may alter susceptibility. In general, risk analysts are typically not likely to know: (1) who those individuals are, (2) what portion of the population is susceptible, and/or (3) the extent of the susceptibilities within the population. Deployed civilians and contractors are assumed to be healthy enough to be deployed with military.

4. The exposed and dose-response data study populations have similar immunity to waterborne pathogens. – While it is known that acquired immunity can be obtained after continual exposure to water containing waterborne pathogens, it is assumed that the exposed population (deployed Soldiers) has similar immunity as those who were swimming in the recreational water from which the dose-response relationship was derived. Acquired immunity due to continual or multiple exposures to endemic pathogens is not expected to be present in the study population. Because it is not possible to know the immunity status of each population with regard to waterborne pathogens, it is assumed they have the same level of immunity which would be no immunity.

5. Secondary transmission is not considered – While secondary transmission is possible for some waterborne pathogens, secondary transmission is beyond the scope of the current risk assessment.

6. Epidemic conditions are not present in the population – Fecal shedding of pathogens is not out of the ordinary. The occurrence of an epidemic in the population may result in increased fecal shedding and the bacterial load in the water may be higher than an indicator would predict (EPA 1986).

7. Fecal contamination is the primary source of pathogens – The major health risks involved in wastewater reuse is from human fecal contamination (i.e., pathogen shedding) in the wastewater. Fecal shedding is the primary concern, but pathogens could potentially come from skin (showering), foodborne (kitchen water), and other sources.

7.2 Acceptable Risk

A level of acceptable risk is needed to characterize risk and to derive a risk-based concentration. The indicator chosen for the wastewater reuse assessment, *E. coli*, has a correlation between *E. coli* concentration in water and gastrointestinal illness (review Section 6). In the context of this risk assessment, risk is the probability of gastrointestinal symptoms in the population, such as diarrhea, given exposure to treated wastewater.

7.2.1 Acceptable Risk for Civilians

The WHO specifies their risk for wastewater reuse in disability adjusted life years (DALY). A DALY is an expression of disease burden. It is expressed as the number of years lost due to ill-health, disability, or early death. One DALY can be considered one lost year of "health." The WHO determined that a waterborne disease burden of 10^{-6} DALYs per person per year is a tolerable risk (WHO 2008). In their water reuse report, the U.S. National Research Council of the National Academy of Sciences (NAS 2012) converted the WHO's tolerable risk for reuse from DALY to a risk of 1 diarrheal illness per 1,000 people per year.

The EPA has set an acceptable microbial risk precedent for drinking water at a risk of 1 illness in 10,000 people exposed per year (EPA 2004).

EPA guidance levels for recreational water exposures were based an acceptable risk of 36 in 1,000 people experiencing gastrointestinal illness per a day of swimming (EPA 2012).

The meaning of the WHO and EPA drinking water values differ from the meaning of the EPA recreational water values. The WHO and EPA drinking water values specify an illness risk per time. The EPA recreational water exposure guideline specifies an illness rate per exposure. Therefore, the drinking water and recreational guidelines are not directly comparable.

Table 20 summarizes the previously established civilian acceptable risk levels:

Table 20. Examples of Acceptable Civilian Risk of Gastrointestinal Illness from Contaminated Water Exposure

Guidance	Type of Risk	Risk	Rate	Reference
EPA Drinking Water	Risk Per Time	1 in 10,000 per year	0.0001 per year	EPA 2004
EPA Recreational Water	Risk per event	36 in 1,000	0.036	EPA 2012
WHO Water Reuse	Risk Per Time	1 in 1,000 per year	0.001 per year	NAS 2012

7.2.2 Acceptable Risk for Deployed Army Personnel

During deployment, it is Army policy that occupational and environmental health risks are reduced as low as practicable, within the context of operational mission parameters (AR 11-35, DA 2007b). In this context, 'as low as practicable' is generally interpreted to mean that U.S. civilian standards are met. There is no U.S. civilian standard for wastewater reuse for the exposure scenarios that are the focus of this assessment. Three acceptable risk levels are presented:

- Interpretation of the 1 in 100 Risk-Based Water Concentration: This acceptable risk level corresponds to 1 person in 100 who incidentally ingested 10 mL of treated wastewater experiencing gastrointestinal illness at a given time from showering (or other unrestricted activities) in treated wastewater. If the concentration of *E. coli* in the shower water was equal to a concentration set at this acceptable risk level, then if 1,000 people showered in that treated wastewater once a day for a month, then it would be expected on average 10 people would be experiencing gastrointestinal illness due to the water on any given day.

- Interpretation of the 1 in 1,000 Risk-Based Water Concentration: This acceptable risk level corresponds to a 1 person in 1,000 who incidentally ingested 10 mL of treated wastewater experiencing gastrointestinal illness at a given time from showering (or other unrestricted activities) in treated wastewater. If the concentration of *E. coli* in the shower water was equal to a concentration set at this acceptable risk level, then if 1,000 people showered in that treated wastewater once a day for more than a month, then it would be expected on average 1 person would be experiencing gastrointestinal illness due to the water on any given day.

- Interpretation of the 1 in 10,000 Risk-Based Water Concentration: This acceptable risk level corresponds to a 1 person in 10,000 who incidentally ingested 10 mL of treated wastewater experiencing gastrointestinal illness at a given time from showering (or other unrestricted activities) in treated wastewater. If the concentration of *E. coli* in the shower water was equal to a concentration set at this acceptable risk level, then if 10,000 people showered in that treated wastewater for an extended length of time, then it would be expected on average only 1 person would be experiencing gastrointestinal illness due to the water on any given day.

7.3 Multiple Exposure Events and Characterizing Risk

The established dose-response relationship reflects a single exposure event; beach goers who had swam recently were excluded from the studies. Because showering is expected to occur more than once during residence at a forward operating base, an adjustment is required to reflect multiple exposures. A one-time exposure to a pathogen carries a risk of a health impact, and multiple exposures (e.g., exposures on successive days) may increase the risk. Very little is known about the description of risk from multiple exposures to the same agent. As a default, multiple exposures have been modeled as independent events (Haas, 1996). It is biologically possible that exposures are additive over a period of a short time if the immune system is not intact (immunocompromised) or overwhelmed. Likewise, immune system processes may work effectively and result in completely independent exposures. Dose-response experiments using multiple dose protocols would be necessary to further improve this assessment (NAS 2012).

For multiple exposures to potential pathogens in wastewater, the separation time between the different shower times for each shower to be considered independent is unknown, and may vary with a given microorganism and individual. If the clearing time is greater than the time between showers, the exposures would not be considered independent.

7.4 Population Illness Model

For this risk assessment, risk is measured as the portion of the population sick at a given time. The dose-response curve from the dose-response assessment relates the probability that a member of the population will develop gastrointestinal illness after exposure to a waterborne pathogen, expressed as a dose of *E. coli.* To estimate the portion of people ill at a given time, the duration of gastrointestinal illness is needed.

7.4.1 Duration of Gastrointestinal Illness

To model multiple exposures, the duration of gastrointestinal illness must be defined. Gastrointestinal illness symptoms can last hours to days, reflecting a single event (e.g., one bout of diarrhea in the middle of the night) to multiple events (e.g., diarrhea bouts over several days). Because the etiologic agent is not known, the value assigned to the duration of the gastrointestinal illness is not agent or illness specific but is instead a generic value. A value of 4 days was selected because it is assumed that after 4 days of gastrointestinal illness a person would seek medical attention. Likewise, 4 days is supported by the knowledge that by this time most self-limiting infections (which most gastrointestinal illnesses are) will begin to subside because either the microbial population has declined (due to natural die off, limited nutrients, immune system interaction), the availability of new cells to infect has drastically diminished, and/or damage to the surrounding tissue does not allow for new attachment.

7.4.2 Portion of the Population Experiencing Illness

To assess the risk from multiple exposures to waterborne pathogens during a showering exposure, the portion of the population experiencing or recovering from gastrointestinal illness on a given day must be determined. With the illness duration defined (4 days) a model is developed to determine the portion of the population sick or recovering from gastrointestinal illness. With illness duration set at 4 days, people ill over 5 days are summed to find the number of people ill on any given day. The model is designed as a rolling window, with people contracting, developing and recovering from gastrointestinal illness over 4 days.

Figure 5 illustrates the concept that at a defined time (current day), people will be in the “ill category” from 4 days ago, from 3 days ago, from 2 days ago, from the previous day, and getting sick that day. Each showering exposure to treated wastewater has a probability of causing illness. The incubation period and the time to health outcome are based on the broadest definition (NGI) of gastrointestinal illness. Cases that present prior to 3 days are likely to have been caused by other (previous) exposures or other reasons (e.g., nervous stomach or other induced causes). The requirement for the 3-day time post exposure is to allow for the causative microbial agent to replicate and initiate disease. This may not be the most desirable way to assess a cause and effect relationship, but it is what was used in the questionnaires or follow-up interviews and it does make biological sense. The NGI definition allows for a 10 to 12 day follow-up interview window to potentially capture the reporting of more cases and that is when most cases are expected to occur. The model does not distinguish which exposure caused the illness; it only keeps track of the portion of population members experiencing illness at a given time.

The rolling window means the people ill 4 days ago will have completely recovered from their illness tomorrow, but there will be new people developing illness tomorrow. So as illness from 4 days ago “falls off,” a new group of people who will be ill for the next 4 days will be added to the ill portion of the population.

The portion of people who will develop gastrointestinal illness each day can be estimated based on the indicator *E. coli* dose ingested (Equation 6). However, a member of the population cannot be sick twice

at once, so the people ill from previous days must be subtracted from the pool of people who can get sick on successive days (Equations 7 – 11).

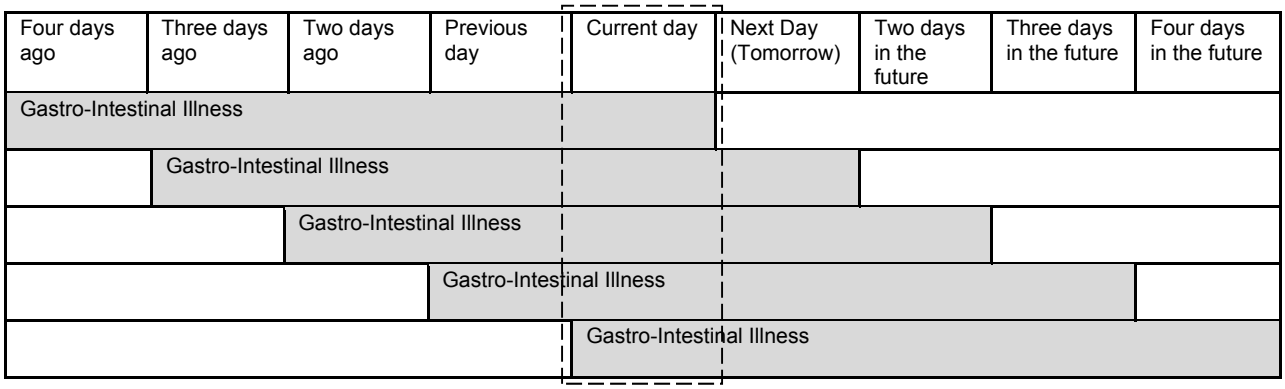

Figure 5. Rolling Illness Window

$$p_{dose} = probability\ of\ illness\ from\ daily\ dose\ of\ E.coli = P_{response}\ Lower\ 95\% = 1 - e^{-0.0021 * Dose} \quad \text{(Equation 6)}$$

$$D_4 = portion\ of\ population\ sick\ from\ 4\ days\ ago = p_{dose} \quad \text{(Equation 7)}$$

$$D_3 = portion\ of\ population\ sick\ from\ 3\ days\ ago = p_{dose}(1 - D_4) \quad \text{(Equation 8)}$$

$$D_2 = portion\ of\ population\ sick\ from\ 2\ days\ ago = p_{dose}(1 - D_4 - D_3) \quad \text{(Equation 9)}$$

$$D_1 = portion\ of\ population\ sick\ from\ 1\ day\ ago = p_{dose}(1 - D_4 - D_3 - D_2) \quad \text{(Equation 10)}$$

$$D_0 = portion\ of\ population\ who\ will\ get\ sick\ today = p_{dose}(1 - D_4 - D_3 - D_2 - D_1) \quad \text{(Equation 11)}$$

By successively substituting D_0, D_1, D_2, D_3, and D_4 in the equations above, the portion of the population sick can be related to p_{dose}, as shown in Equations 12 – 16.

$$D_4 = p_{dose} \quad \text{(Equation 12)}$$

$$D_3 = -p_{dose}(p_{dose} - 1) \quad \text{(Equation 13)}$$

$$D_2 = p_{dose}(p_{dose} - 1)^2 \quad \text{(Equation 14)}$$

$$D_1 = -p_{dose}(p_{dose} - 1)^3 \quad \text{(Equation 15)}$$

$$D_0 = p_{dose}(p_{dose} - 1)^4 \quad \text{(Equation 16)}$$

Equations 12 – 16 can be summed to find the total portion of the population experiencing or recovering from wastewater reuse related gastrointestinal illness at a time ($p_{ill\ total}$; Equation 17).

$$p_{ill\ total} = D_4 + D_3 + D_2 + D_1 + D_0 \quad \text{(Equation 17)}$$

By substituting D_0, D_1, D_2, D_3, and D_4 into the equation above, and simplifying, the total number of people can be expressed as a polynomial in terms of the probability of illness from a dose of *E. coli*, as shown in Equation 18.

$$p_{ill\ total} = ({p_{dose}}^5 - 5\,{p_{dose}}^4 + 10\,{p_{dose}}^3 - 10\,{p_{dose}}^2 + 5\,p_{dose}) \quad \text{(Equation 18)}$$

If the dose response equation is placed into the above equation for p_{dose}, the result is the total number of people sick as a function of dose. The raising of the exponential dose response function to the 5th power results in a very complicated equation. The function was numerically analyzed using Microsoft Excel.

Next the dose is converted to a concentration because a concentration is what is measurable in the field. A volume of water of 10 mL ingested per shower was used to convert dose into a concentration, as shown in Equation 19.

$$concentration = \frac{dose}{volume} \quad \text{(Equation 19)}$$

The results of the dose-concentration conversion, the estimated number of total people sick, and the dose-response equation is captured in Figure 6 and Figure 7. The figures illustrate how the *E. coli* concentration in treated wastewater shower water relates to the percentage of the population sick at a given time with gastrointestinal illness.

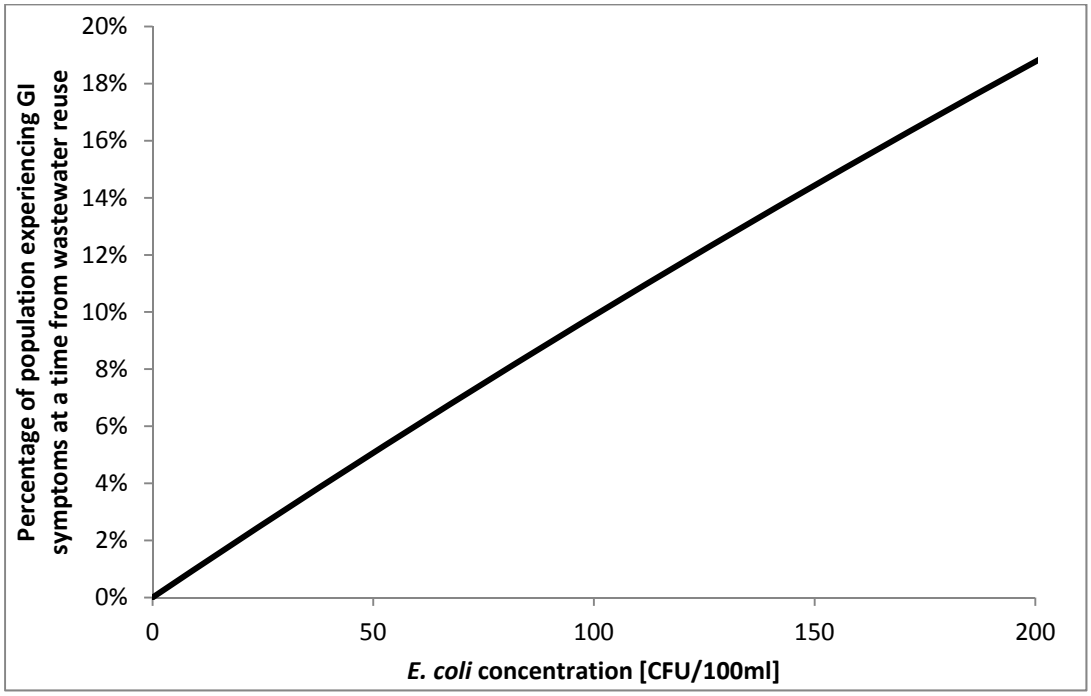

Figure 6. Percentage of Population Sick Based on *E. coli* Concentration (Wide Concentration Range) for Baseline (One Shower per Day) Exposure Scenario

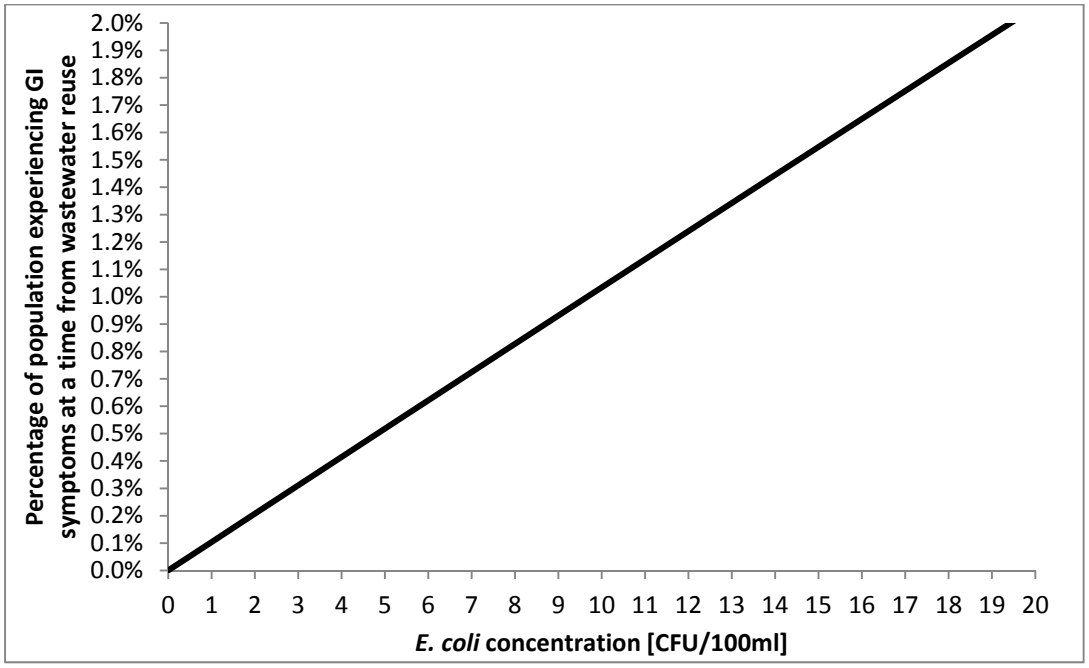

Figure 7. Percentage of Population Sick Based on *E. coli* Concentration (Low Concentration Range) for Baseline (One Shower per Day) Exposure Scenario

For the baseline exposure of one shower per day, *E. coli* concentrations corresponding to 0.01% (1 in 10,000), 0.1% (1 in 1,000), and 1% (1 in 100) gastrointestinal illness rates in the showering population were found to be 10 CFU/10 liters, 95 CFU/10 liters and 957 CFU/10 liters respectively, as shown in Figure 7. The concentrations are rounded to one significant figure for discussion in section 7.6.

7.5 Analysis for Alternative Shower Frequencies

As discussed in paragraph 5.2.6, alternative shower frequencies are evaluated to determine risk-based concentrations. Table 5 lists the alternative frequencies. Changing the shower frequencies impacts the application of the model for each of the three alternatives.

7.5.1 Alternative A: Twice daily showers

Showers taken in the same day may not be independent biologically. Therefore, to estimate total exposure as a worst case, it is assumed the microbial dose for the two showers is additive. If the same amount of water is ingested during both showers, the allowable concentration of microbial content in the shower water would be half of the baseline case. That adjustment leads to: *E. coli* concentrations corresponding to 0.01% (1 in 10,000), 0.1% (1 in 1,000), and 1% (1 in 100) gastrointestinal illness rates in the showering population were found to be 5 CFU/10 liters, 48 CFU/10 liters and 479 CFU/10 liters respectively. Concentrations are expressed per the minimum order-of-magnitude-volume that result in a whole number of CFU. The concentrations are rounded to one significant figure for discussion in section 7.6.

7.5.2 Alternative B: Showering Every Other Day

For the every other day shower alternative, an assumption was made that half the showering population showered one day, and the other half showered the next day. The population was broken up into the group that showered on the even days and the group that showered on odd days. For examining the rolling illness window shown in Figure 5, an even day was defined as 4 days ago, 2 days ago, or the current day; while an odd day was defined as 3 days ago or 1 day ago. The people who shower on even days are assigned to the even group (E). The people who shower on odd days are assigned to the odd group (O). The combination of the even and odd groups equals the total members of the population (A).

The time illness starts after showering needs to be tracked for Alternative B. A person who showered on an even day could start experiencing symptoms the day of the exposure (an even day) or the following day (an odd day) and so on for up to 12 days the limit of the illness in the studies used to generate the dose-response curve (see NGI in Table 9). For the model it was decided to limit the time to onset of illness to 5 days to minimize mathematical complexity and to focus on first cases of illness. It was assumed that the likelihood of illness after exposure is equal for any given day in the first 5 days after exposure. This assumption is considered conservative because it concentrates all illness towards the beginning of the time period. The 5-day limitation forces the model to predict all possible illnesses in a shorter time period. Therefore, for a given water concentration more illness is predicted during the 5-day rolling window than a 12-day distribution.

The above illness onset consideration requires the tracking of two things. First, the likelihood someone would experience gastrointestinal illness symptoms from exposure on a given day, and second, when they would experience those symptoms. In Equations 20 – 29 the "f" in the notation represents the day a person is sick *from* (e.g., "EfD_4" represents the portion of the even population that gets sick from their exposure 4 days ago). Note the EfD_x, OfD_x, and AfD_x are functions of the dose and therefore estimate the probability of illness. The second set of equations (Equations 30 – 34) capture the day they present with observable illness (e.g., "D_4" is the portion of the total population that first observed signs and

symptoms of illness 4 days ago). The D_x (the number of people sick only for the specific day noted) is a function of probability (i.e., EfD_x, OfD_x, and AfD_x) and the distribution of the time to illness.

The following equations track the days members of the even group had an exposure that will lead to illness. People who will get sick are subtracted from the pool of people who can get sick in the following days to prevent over counting.

$$EfD_4 = portion\ of\ even\ population\ sick\ from\ 4\ days\ ago = p_{dose} \quad \text{(Equation 20)}$$

$$EfD_2 = portion\ of\ even\ population\ sick\ from\ 2\ days\ ago = p_{dose}(1 - EfD_4) \quad \text{(Equation 21)}$$

$$EfD_0 = portion\ of\ even\ population\ that\ will\ get\ sick\ today = p_{dose}(1 - EfD_4 - EfD_2) \quad \text{(Equation 22)}$$

The following equations track the days members from the odd group had an exposure that will lead to illness. People who will get sick are subtracted from the pool of people who can get sick in the following days to prevent over counting.

$$OfD_3 = portion\ of\ odd\ population\ sick\ from\ 3\ days\ ago = p_{dose} \quad \text{(Equation 23)}$$

$$OfD_1 = portion\ of\ odd\ population\ sick\ from\ 1\ days\ ago = p_{dose}(1 - OfD_3) \quad \text{(Equation 24)}$$

The population is divided equally among the even and odd groups. Because only half the population is exposed on a given day (either the even group or the odd group is showering) to evaluate the effect of the shower on the total population the even and odd group results must be considered within the impact on the total population (even + odd). For example, if 50% of the even group is ill from Day 4 this means that only one-quarter of the total population is ill. This is captured by Equations 25 – 29.

$$AfD_4 = portion\ of\ population\ sick\ from\ 4\ days\ ago = \frac{EfD_4}{2} \quad \text{(Equation 25)}$$

$$AfD_3 = portion\ of\ population\ sick\ from\ 3\ days\ ago = \frac{OfD_3}{2} \quad \text{(Equation 26)}$$

$$AfD_2 = portion\ of\ population\ sick\ from\ 2\ days\ ago = \frac{EfD_2}{2} \quad \text{(Equation 27)}$$

$$AfD_1 = portion\ of\ population\ sick\ from\ 1\ days\ ago = \frac{OfD_1}{2} \quad \text{(Equation 28)}$$

$$AfD_0 = portion\ of\ population\ sick\ from\ the\ current\ day = \frac{EfD_0}{2} \quad \text{(Equation 29)}$$

After calculating the probability of becoming sick from an exposure (above equations) the next step is to determine which day a given person, who has been exposed to a dose that can make them sick, actually becomes sick. It is assumed that a given person has an equal chance of becoming sick (developing illness) on any of the 5 days post-exposure. This means that for the portion of the population that had an exposure which will lead to illness (AfDx) the distribution of the illness is equally spread among the 5 days. That is of the population that will get sick, only 1/5th gets sick each day (Equations 30 – 34). This assumption was applied for mathematical simplicity and because the actual distribution of illness is unknown. Once a person is sick, the model assumes that person will be sick for 5 days.

$$D_4 = portion\ of\ population\ sick\ from\ 4\ days\ ago = \frac{AfD_4}{5} \quad \text{(Equation 30)}$$

$$D_3 = portion\ of\ population\ sick\ from\ 3\ days\ ago = \frac{AfD_4}{5} + \frac{AfD_3}{5} \quad \text{(Equation 31)}$$

$$D_2 = portion\ of\ population\ sick\ from\ 2\ days\ ago = \frac{AfD_4}{5} + \frac{AfD_3}{5} + \frac{AfD_2}{5} \quad \text{(Equation 32)}$$

$$D_1 = portion\ of\ population\ sick\ from\ 1\ day\ ago = \frac{AfD_4}{5} + \frac{AfD_3}{5} + \frac{AfD_2}{5} + \frac{AfD_1}{5} \quad \text{(Equation 33)}$$

$$D_0 = portion\ of\ population\ who\ will\ get\ sick\ today = \frac{AfD_4}{5} + \frac{AfD_3}{5} + \frac{AfD_2}{5} + \frac{AfD_1}{5} + \frac{AfD_0}{5} \quad \text{(Equation 34)}$$

By summing the results of Equations 30 to 34, the total portion of the population can be found for a given dose, as shown in Equation 35.

$$p_{ill\ total} = D_4 + D_3 + D_2 + D_1 + D_0 \quad \text{(Equation 35)}$$

Alternative B was analyzed numerically in a spreadsheet. For Alternative B the *E. coli* concentrations corresponding to 0.01% (1 in 10,000), 0.1% (1 in 1,000), and 1% (1 in 100) gastrointestinal illness rates in the showering population were found to be 32 CFU/10 liters, 318 CFU/10 liters and 3,195 CFU/10 liters, respectively. The concentrations are rounded to one significant figure for discussion in section 7.6.

7.5.3 Alternative C: Showering Once a Week

For the one shower a week alternative, an assumption was made that one seventh of the population showered each day. In examining the 5-day rolling illness window shown in Figure 5, some members of the population will not shower during the window because their day to shower is outside the 5-day window. As the rolling window rolls over a total of 7 days (1 week), it will capture everyone in the population. The population who showers once a week is known as the "weekly showers'" (W).

The time illness starts after showering needs to be tracked for Alternative C. A person who showered 1 day of the week could start experiencing symptoms the day of the exposure, or the following day, or 2 days later, and so on for up to 12 days the limit of the illness in the studies used to generate the dose-response curve (see NGI in Table 9). For the model it was decided to limit the time to onset of illness to 5 days to minimize mathematical complexity and to focus on first cases of illness. It was assumed that the likelihood of illness after exposure is equal for any given day in the first 5 days after exposure. This assumption is considered conservative because it concentrates all illness towards the beginning of the time period. The 5-day limitation forces the model to predict all possible illnesses in a shorter time period. Therefore, for a given water concentration more illness is predicted during the 5-day rolling window than a 12-day distribution.

The above illness onset consideration requires the tracking of two things. First, the likelihood someone would experience gastrointestinal illness symptoms from exposure on a given day, and second, when they would experience those symptoms. In Equations 36 – 40 the "f" in the notation represents the day a person is sick *from* (e.g., "WfD_4" represents the portion of the population who showered once, 4 days ago, and gets sick from that exposure). Note the WfD_x is a function of the dose and therefore estimates the probability of illness. The second set of equations (Equations 41 – 45) capture the day those exposed

present with observable illness (e.g., "D_4" is the portion of the total population that first observed signs and symptoms of illness 4 days ago). The D_x (the number of people sick only for the specific day noted) is a function of probability (i.e., WfD_x) and the distribution of the time to illness.

For Alternative C no one who showered 4, 3, 2, or 1 day(s) ago would shower again before the end of the rolling illness shown in Figure 5. Therefore, the chance of a showering member of the population experiencing gastrointestinal illness is the probability of gastrointestinal illness at the exposed dose. The portion of the population who would be expected to develop gastrointestinal illness from showering on a given day would be the probability at a dose divided by the number of days in a week, 7. That leads to five equations for the 5 days being examined in the rolling illness window (Equations 36 – 40).

$$WfD_4 = portion\ of\ weekly\ showering\ population\ sick\ from\ 4\ days\ ago = \frac{p_{dose}}{7} \quad \text{(Equation 36)}$$

$$WfD_3 = portion\ of\ weekly\ showering\ population\ sick\ from\ 3\ days\ ago = \frac{p_{dose}}{7} \quad \text{(Equation 37)}$$

$$WfD_2 = portion\ of\ weekly\ showering\ population\ sick\ from\ 2\ days\ ago = \frac{p_{dose}}{7} \quad \text{(Equation 38)}$$

$$WfD_1 = portion\ of\ weekly\ showering\ population\ sick\ from\ 1\ days\ ago = \frac{p_{dose}}{7} \quad \text{(Equation 39)}$$

$$WfD_0 = portion\ of\ weekly\ showering\ population\ sick\ from\ the\ current\ day = \frac{p_{dose}}{7} \quad \text{(Equation 40)}$$

After calculating the probability of becoming sick from an exposure (above equations), the next step is to determine which day a given person who has been exposed to a dose that can make them sick actually becomes sick. It is assumed that a given person has an equal chance of becoming sick (developing illness) on any of the 5 days post-exposure. This means that for the portion of the population that had an exposure that which will lead to illness (WfDx) the distribution of the illness is equally spread among the 5 days. That is of the population that will get sick, only 1/5th gets sick each day (Equations 41 – 45). This assumption was applied for mathematical simplicity and because the actual distribution of illness is unknown. Once a person is sick, the model assumes that person will be sick for 5 days.

$$D_4 = portion\ of\ population\ sick\ from\ 4\ days\ ago = \frac{WfD_4}{5} \quad \text{(Equation 41)}$$

$$D_3 = portion\ of\ population\ sick\ from\ 3\ days\ ago = \frac{WfD_4}{5} + \frac{WfD_3}{5} \quad \text{(Equation 42)}$$

$$D_2 = portion\ of\ population\ sick\ from\ 2\ days\ ago = \frac{WfD_4}{5} + \frac{WfD_3}{5} + \frac{WfD_2}{5} \quad \text{(Equation 43)}$$

$$D_1 = portion\ of\ population\ sick\ from\ 1\ day\ ago = \frac{WfD_4}{5} + \frac{WfD_3}{5} + \frac{WfD_2}{5} + \frac{WfD_1}{5} \quad \text{(Equation 44)}$$

$$D_0 = portion\ of\ population\ who\ will\ get\ sick\ today = \frac{WfD_4}{5} + \frac{WfD_3}{5} + \frac{WfD_2}{5} + \frac{WfD_1}{5} + \frac{WfD_0}{5} \quad \text{(Equation 45)}$$

By summing the results of Equations 41 – 45, the total portion of the population can be found for a given dose, as shown in Equation 46.

$$p_{ill\ total} = D_4 + D_3 + D_2 + D_1 + D_0 \quad \text{(Equation 46)}$$

Alternative C was analyzed numerically in a spreadsheet. For the showering once a week alternative, the *E. coli* concentrations corresponding to 0.01% (1 in 10,000), 0.1% (1 in 1,000), and 1% (1 in 100) gastrointestinal illness rates in the showering population were found to be 111 CFU/10 liters, 1,112 CFU/10 liters and 11,242 CFU/10 liters respectively. The concentrations are rounded to one significant figure for discussion in section 7.6.

7.6 Proposed Risked-Based Water Concentrations for Unrestricted Wastewater Reuse

The RBWCs represent the allowable concentration of *E. coli* in treated wastewater for unrestricted full body contact reuse based on an exposure of 10 mL of incidental water ingestion per event (i.e., shower), with various exposure frequencies. The RBWCs are based on the multiple-exposure functions (paragraphs 7.4.2-7.5.3) for the acceptable risk levels discussed in paragraph 7.2. The concentrations can be used to set a guideline, design a treatment system, and to verify the proper operation of the treatment system. Table 21 presents the RBWCs. Table 21 is designed to allow policymakers to weigh the tradeoffs between illness rate in the population, exposure frequency, and allowable concentration of indicator E. coli to develop a limit or standard for unrestricted wastewater reuse. Paragraphs 7.6.1 and 7.6.2 provide application guidance based on *E. coli* detection capability.

Table 21. Field Wastewater Unrestricted Risk-Based Concentrations

Daily Gastrointestinal Illness Rate[b] (Portion of showering population experiencing GI symptoms due to exposure to shower water)	Units[c]	*Escherichia coli* Water Concentration[a]				Confidence
		Two showers per day	One shower per day	One shower every 2 days (shower every other day)	One shower per week	
		Alternative A	Baseline	Alternative B	Alternative C	
1 in 100	**CFU / 100 mL**	**5**	**10**	**30**	**100**	Moderate
	CFU / 1 liter	50	100	300	1,000	
	CFU / 10 liters	500	1,000	3,000	10,000	
1 in 1,000	**CFU / 100 mL**	N/A[d]	**1**	**3**	**10**	
	CFU / 1 liter	5	10	30	100	
	CFU / 10 liters	50	100	300	1,000	
1 in 10,000	**CFU / 100 mL**	N/A[d]	N/A[d]	N/A[d]	**1**	
	CFU / 1 liter	N/A[d]	1	3	10	
	CFU / 10 liters	5	10	30	100	

Notes:
[a]Concentrations are rounded to one significant figure. See paragraphs 7.4.2, 7.5.1, 7.5.2, and 7.5.3 for the unrounded concentrations.
[b]Daly GI illness rate in the population. See appendix C for yearly risk analysis.
[c]Convention in water monitoring is to report microbial content in CFU per 100 mL of water. CFU per 1 liter and 10 liters are reported to show concentrations that are less than 1 CFU/100 mL.
[d] Not applicable, concentrations whose volumes lead to fractional CFU. A larger sampling volume results in a whole number CFU per volume concentration.

The RBWCs are based on showering; however, they should be applicable for other activities because showering has the most frequent exposure and the highest incidental ingestion. The concentrations are considered pertinent to a heat casualty body cooling exposure due to the low frequency of heat casualty body cooling activities and the expectation that less water is ingested while in a cooling tub or basin versus showering. The proposed RBWCs are valid for personnel decontamination activities due to the low frequency of personnel decontamination activities, the higher awareness of avoiding incidental ingestion during a decontamination exposure, and the possible addition of disinfection agents to the decontamination water.

7.6.1 Application of RBWCs with Current Detection Capability

Based on current presence/absence detection capabilities, if *E. coli* is detected in the treated wastewater it is not recommended to be used for unrestricted reuse activities.

The treatment process should incorporate multiple barriers to prevent an equipment break down or source water change from resulting in people being exposed to microbial contamination above the selected RBWC. Examples of multiple barriers include, but is not limited to, redundant treatment equipment, go/no go testing prior to use, offline-batch treatment providing time to monitor process results, and periodic inspections of the reuse process from source to exposure.

7.6.2 Application with Quantitative Detection Capability

With quantitative detection capability, risked-based decisions can be made on the reuse of treated wastewater. To set a risk-based standard or guideline using the information in Table 21, a showering rate and an illness rate need to be selected by policy makers. If, for example, daily showering and an illness rate of 1 in 100 are selected, the resulting *E. coli* concentration is 10 CFU per 100 mL of treated wastewater. All together that means if 100 people were to shower once a day in treated wastewater with 10 CFU of *E. coli* per 100 mL, it is expected 1 of them would be experiencing or recovering from gastrointestinal illness symptoms at a given time from exposure to the treated wastewater. Showering is the unrestricted activity with the highest predicted exposure, so a value selected for showering should be protective of all unrestricted wastewater reuse exposures.

7.7 Yearly Risk

The RBWC's in Table 21 are calculated based on a daily population gastrointestinal illness rate. The concentrations presented for each daily illness rate have a corresponding yearly gastrointestinal illness risk (annual risk). A full analysis of the annual risk is provided in Appendix C. For the daily illness rate of 1 in 100, the estimated probability of experiencing gastrointestinal illness due to showering with treated reuse-water for a year is 50 – 70% (yearly risk), depending on the water concentration of indicator *E. coli* and exposure frequency (shower frequency). That range of estimated yearly risk is similar to the estimated background/baseline burden of acute gastrointestinal illness, 71.6%, found in the general population with unknown/unestablished etiology (Thomas et al. 2006). For the daily illness rate of 1 in 1,000, the yearly risk of experiencing GI illness is 7 – 10 % depending on the water concentration of indicator *E. coli* and exposure frequency. This range of estimated yearly risk is less than the estimated background burden of gastrointestinal illness. For the daily illness rate of 1 in 10,000, the estimated yearly risk of experiencing GI illness is 1%, which is well below the estimated background burden of gastrointestinal illness in the general population.

7.8 Confidence and Uncertainty

The overall confidence for the values presented in Table 21 is moderate. The confidence assignment found in Table 21 is a reflection of uncertainty associated with various components of the risk

assessment. Greater uncertainty is reflected by a lower confidence rating. Confidence is a subjective measure but should be based on well-reasoned judgment (USACHPPM 2001). Factors that are considered to evaluate uncertainty and determine a confidence assignment include: data quality and comparability, comparability of assumptions to expected field activities and other unknown, uncertain or missing information (USACHPPM 2001). While it may be desirable to pin-point which element has the largest impact on the confidence assignment, or which element is considered 'most important,' this kind of clear delineation is not possible because the overall confidence assignment (that which is found in Table 21) is a reflection of the totality of the information used in the risk assessment.

In the risk assessment several elements were combined to derive the values and the impact the elements had on the confidence for the presented values.

- Indicator Organism: While the indicator organism approach can be criticized for several reasons (review Section 4), *E. coli* is a valid indicator for gastrointestinal illnesses. Other illnesses such as dermal, respiratory, ocular or aural diseases generally occur at doses less than those required for gastrointestinal illnesses (WHO 2005); therefore, there is an anticipated level of conservation (health-protectiveness) inherent in the use of *E. coli* as an indicator for illness in general. Therefore, the confidence for the indicator organism approach is moderate.

- Exposure Factors: The confidence for the selected exposure factors is moderate. Factors were chosen to be representative of the deployed population and anticipated field activities. A spectrum of values was considered and values were carefully selected as to not introduce over-conservative measures (always selecting the lowest value; review Table 4). Values that represented the average of a parameter were often used to infuse conditions that better reflect anticipated reality. In addition, the evaluation of multiple exposures (review paragraph 7.3) increases confidence because the assessment takes a step towards bridging an important gap that would otherwise remain unfilled. The confidence in this element has a strong influence in the overall confidence because the amount of water ingested is a key piece in the progression of events that must occur in order for disease to develop.

- Surrogate Dose-Response Data: Due to the inability to use wastewater-based data there are many unknowns with regard to the characterization of the water (e.g., which pathogens are expected and at what concentration). The confidence in this element is low because it is unknown if the data used accurately reflects treated wastewater. This element does not play a large role in the overall confidence assignment because it is not anticipated that the pathogens would be very different.

- Dose-Response Data: The confidence in the dose-response data is moderate because the data comes from multiple countries and multiple decades; when plotted, the data has a good correlation coefficient for the exponential dose-response model. The dose-response relationship is a corner-stone of the presented values and therefore this element has a strong influence for the overall confidence.

- Activity Conversion: The confidence in the conversion between swimming data and an incidental ingestion exposure for the dose-response data is moderate. The data are for swimming exposure, not showering exposure, so a conversion was necessary. It is anticipated that swimming is a riskier activity for incidental ingestion.

Table 22 illustrates how the elements of the risk assessment influence the overall confidence in the presented values. The confidence of assignment of moderate is a reflection of several protective elements (indicator organism approach and dose-response data). An assignment of 'high' was not made for several reasons including the unknown impacts associated with the various exposure factors and the

limitations of the dose-response data for multiple exposures. An assignment of 'low' was not made because, although there are several places for improvement, the amount of available data for exposure factors and the dose-response relationship was relatively high.

Table 22. Uncertainty Table

Type of uncertainty	Discussion of uncertainty	Effect on Risk-Based Water Concentrations
Indicator organism	Indicator *E. coli* is a measure of bacterial load in the water. The actual presence or absence of pathogenic organisms is only inferred by the use of the indicator. *E. coli* is a good indicator for gastrointestinal illness but provides no information on dermal, respiratory, ocular, or aural diseases.	Protective: Gastrointestinal illness occurs at doses below the doses required for dermal, respiratory, ocular or aural diseases (WHO 2005).
Exposure factors	Factors were chosen to be representative of the deployed population.	Varies: Alternative shower frequency evaluation provides a range of values.
Surrogate dose-response data	Direct wastewater dose-response data was not available. Dose-response data for recreational water exposures was used.	Unknown: It is expected that the dose-response relationship for *E. coli* is similar in both types of water, but empirical evidence is not available.
Dose-response data	Data were from multiple countries and multiple decades. When plotted, the data has a good correlation coefficient for the exponential dose response model. The model may not be the best, but in the dose range studied, the model behaves linearly and the data can be described linearly.	Protective: Compared to a linear extrapolation, the exponential dose response function predicts more illness at a given dose.
Conversion between exposures for the dose-response data	The data are for swimming exposure, not showering exposure, so a conversion was made from swimming to dose. A single factor was used to estimate the ingested dose based on an adult swimming. It is unknown how the swimming conditions the factor was based on compare to the swimming conditions in the epidemiological studies.	Unknown: The most conservative water ingested while swimming value was selected. Impact of other exposure factors is unknown.

7.9 Other Considerations

7.9.1 Physical Properties of Water

As previously established, this risk assessment did not seek to determine guidance for physical properties; however, they are significant for water quality monitoring and treatment operational control. Physical properties of water are those parameters that reflect the appearance and general state of the water (e.g., color, temperature, pH, turbidity). Furthermore, the microbial content in a given water may impact or be impacted by the physical properties of the water. The physical properties used in wastewater monitoring most likely related to microbial content include total suspended solids and biochemical oxygen demand. These serve as indirect measures of water quality and as operational monitors throughout the treatment process.

7.9.2 Biological Military Exposure Guidelines

The RBWCs are not based on the formal Biological Military Exposure Guideline (BMEG) analysis. A BMEG is a specialized dose-response analysis linking a single pathogen to its associated health outcomes. In this risk assessment, *E. coli* is used as an indicator of microbial populations in water. The presence of *E. coli* in a water sample is interpreted that other bacteria and other microorganisms (viruses and protozoa) may be in the water sample. Based on the current fielded detection strategies, there is no way to determine species or level of microbial contamination in water. For this iteration of the RBWC's the BMEG process is not used.

During the early phase of the current effort a preliminary BMEG was derived for Shiga-toxin producing *E. coli* (STEC; USAPHC 2012). It was possible to derive a BMEG for *E. coli* O157:H7 because it is the most studied STEC and there is dose-response and health effect data available that meet the data qualification standards. A direct relationship between STEC and indicator *E. coli* has not been established; therefore, the BMEG for the STEC cannot be used to support the RBWCs.

8. RECOMMENDATIONS FOR RESTRICTED WASTEWATER REUSE

Restricted wastewater reuse may be evaluated in a future effort. In the interim, any proposed unrestricted RBWCs may also be applied for restricted wastewater reuse. The unrestricted RBWCs assume full body contact including possible submersion of the head. Restricted wastewater reuse will involve only limited body contact so the unrestricted RBWCs are expected to be applicable for restricted exposures.

9. POTENTIAL FUTURE EFFORTS

Additional risk assessment efforts related to wastewater reuse could improve upon the current assessment. Example future efforts are identified below.

- Restricted wastewater reuse may be evaluated in a future effort, whereby low contact-restricted reuse activities would be evaluated. The low contact activities are dust suppression, vehicle and aircraft washing, equipment decontamination, construction, and firefighting.

- Use of additional microbial organisms (more than just *E. coli*) may improve the risk assessment. For example, an organism linked to dermal effects such as *Pseudomonas aeruginosa* could be used to develop dermal risk-based guidance. Likewise, microbiological guidance for treated wastewater reuse based on *Cryptosporidium* would enable monitoring risk from health effects caused by a disinfection resistant organism.

- The ability to better assess health risk from treated wastewater is rooted in the ability to detect virulence factors or toxins from *any* microbial pathogen (bacterial, viral, or protozoan). Future efforts need to explore how this could be accomplished.

- The application of exposure guidelines for field guidelines is limited by current detection technology. Current field-based detection capabilities only determine the presence/absence of total coliforms and *E. coli* (TB MED 577), and serotyping is not performed. Until identification and quantification capabilities are deployed to the field developing a useful guideline is restricted to *E. coli* and total coliforms. With regard to advancement of detection technology, it may be wise to consider developing technology that does not focus only on *E. coli* but instead develop technology that selective identification and quantification capabilities. For example, develop a capability to identify and quantify viable organisms that can produce Shiga toxins (verotoxins) (Brian et al. 1992; Casadevall and Pirofski 1999; Heijnen and Medema 2006; Chin et al. 2011).

- Risk communication strategies will be needed prior to the implementation of wastewater reuse. Strategies need to be developed for users of the treated water (e.g. deployed Soldiers) as well as those involved with the decision to use treated wastewater (e.g., decision makers, public affairs officers).

APPENDIX A

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GLOSSARY

Section I
Acronyms/Abbreviations

AR
Army Regulation

BMEG
Biological Military Exposure Guideline

CBRN
Chemical, Biological, Radiological, Nuclear

CFU
Colony Forming Unit

DA
Department of the Army

DALY
Disability adjusted life years

EPA
Environmental Protection Agency

FOBs
Forward Operating Base

GI
Gastrointestinal Illness, GI symptoms included vomiting, diarrhea, stomachache, or nausea

HCGI
Highly Credible Gastrointestinal Illness (HCGI)

kg
Kilogram, a unit of mass

L
Liter, a measure of volume

MEPAS
Multimedia Environmental Pollutant Assessment System; an exposure model developed by Pacific Northwest National Labs

mL
Milliliter, a measure of volume. There are 1,000 mL in 1 liter. An mL is the same volume as a cubic centimeter.

MPN
Most Probable Number, a measure of the amount of microorganisms in a sample, based on serial dilutions

NEEAR
National Epidemiological and Environmental Assessment of Recreational Water Study

NGI
NEEAR definition of Gastrointestinal Illness

NOAEL
No-observed-adverse-effect level

PHIP
Public Health Information Paper

PNNL
Pacific Northwest National Labs

RBWCs
Risk-Based Water Concentrations

SDK
Skin Decontamination Kit

STEC
Shiga-toxin producing *E. coli*

TG
Technical Guide

USACHPPM
U.S. Army Center for Health Promotion and Preventive Medicine, former name of USAPHC

USAPHC
U.S. Army Public Health Command

WQAS-P
Water Quality Analysis Set-Purification

WQAS-PM
Water Quality Analysis Set-Preventive Medicine

Section II
Terms

Black Water
Latrine wastewater containing human waste

Data Utility
The usefulness of data (or data set) to answer a particular question [Source: Thran and Tannenbaum 2008]

Domestic Wastewater
Mixed gray water and black water

Escherichia coli
A species of bacteria. It is a coliform bacteria. Some serotoypes (a specific kind of *E. coli*) of *E.coli* are pathogenic (able to cause disease).

Fecal Coliforms
Fecal coliforms are a subset of coliforms that are associated with the fecal material from warm-blooded animals. The representative species of fecal coliforms is *Escherichia coli*.

Gray Water
Wastewater from nonhuman waste sources such as showers, laundry, and handwash devices

Health Endpoint
An observable or measurable biological event used as an index to determine when a deviation in the normal function of the host has occurred [Source: EPA 2007]

Highly Credible Gastrointestinal Illness (HCGI)
Defined as any one of the following: (1) vomiting, (2) diarrhea with a fever or disabling condition (remained home, remained in bed or sought medical advice due to symptoms) and (3) stomachache or nausea accompanied by a fever

Mixed Wastewater
Wastewater is made up of commercial and industrial wastewater in addition to domestic wastewater (gray and black water).

NEEAR Gastrointestinal Illness (NGI)
Any of the following [within 10 to 12 days after swimming]: (a) diarrhea (three or more loose stools in a 24-hour period), (b) vomiting, (c) nausea and stomachache, or (d) nausea or stomachache and impact on daily activity

Total Coliforms
A term used to describe the amount of coliform bacteria in a water sample. Coliform bacteria are a large class of bacteria that can be found in the environment, soil, and water. Total coliforms are used as an indicator of water quality.