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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: <u>restricted reuse</u> and <u>unrestricted reuse</u>. 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.

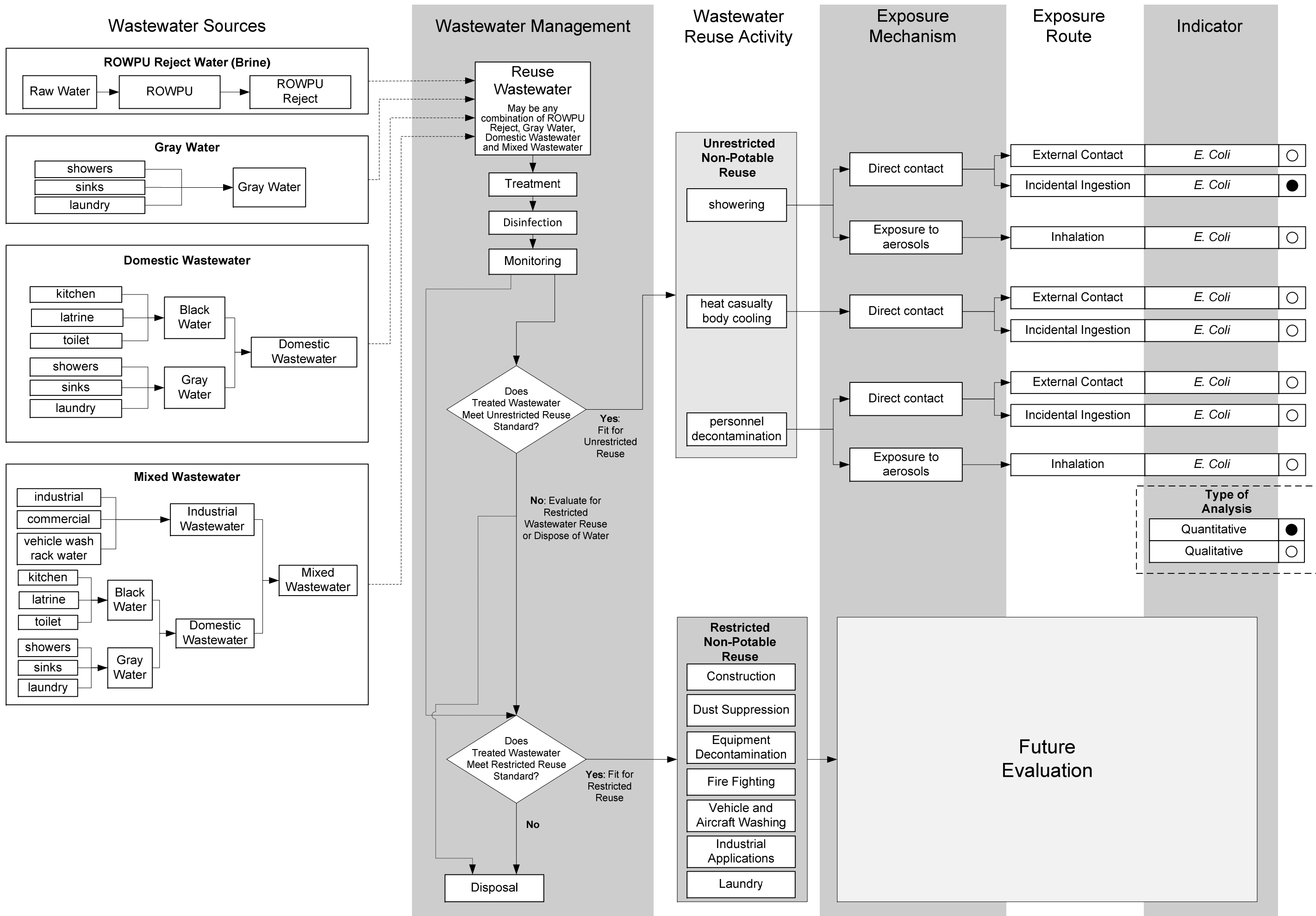

Figure 1. Conceptual Model of Health Risks Associated with Army Wastewater Reuse

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.

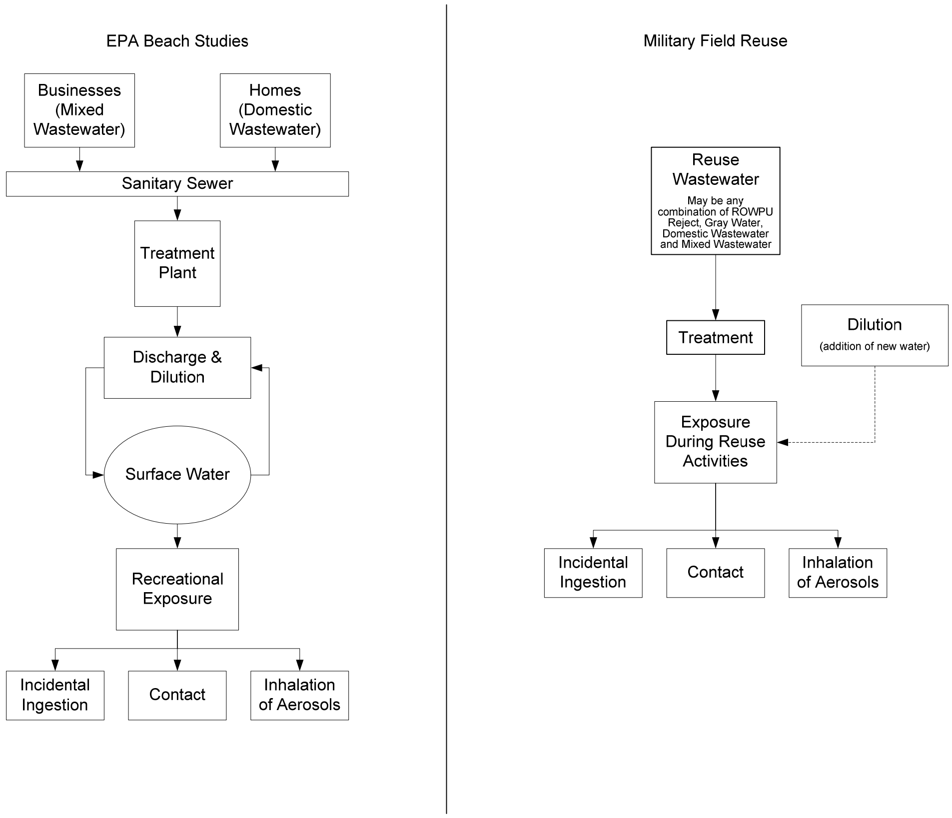

Figure 2. Comparison of Reuse Exposure to Beach Study Exposure

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 90^{th} 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 <u>Additional freshwater studies</u>

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			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]	OR[b]	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

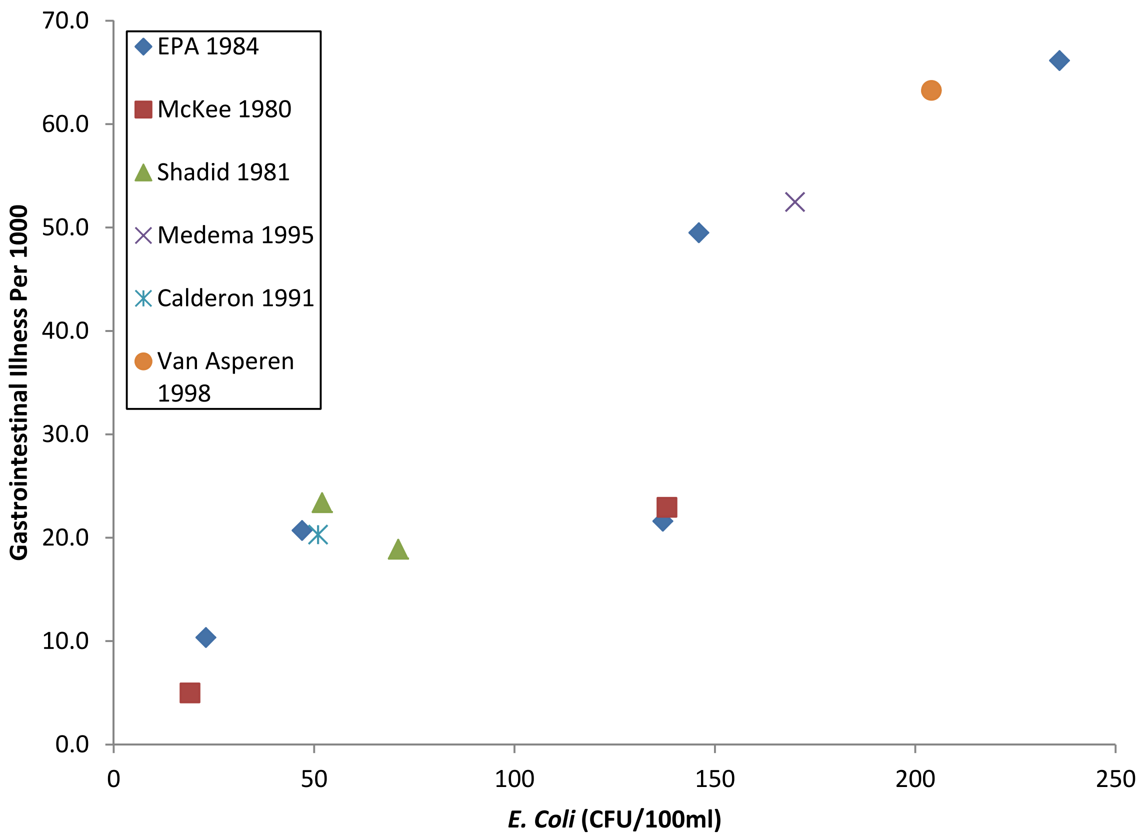

Figure 3. Epidemiological Dose-Response Data Normalized for Gastrointestinal Illness

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.

$$Estimated\ Dose\ \left[\frac{CFU}{swimming\ event}\right] = \frac{Indicator\ Density\ \left[\frac{CFU}{100ml}\right]}{100} * Ingestion\ Rate\ \left[\frac{ml}{swimming\ event}\right]$$

(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).

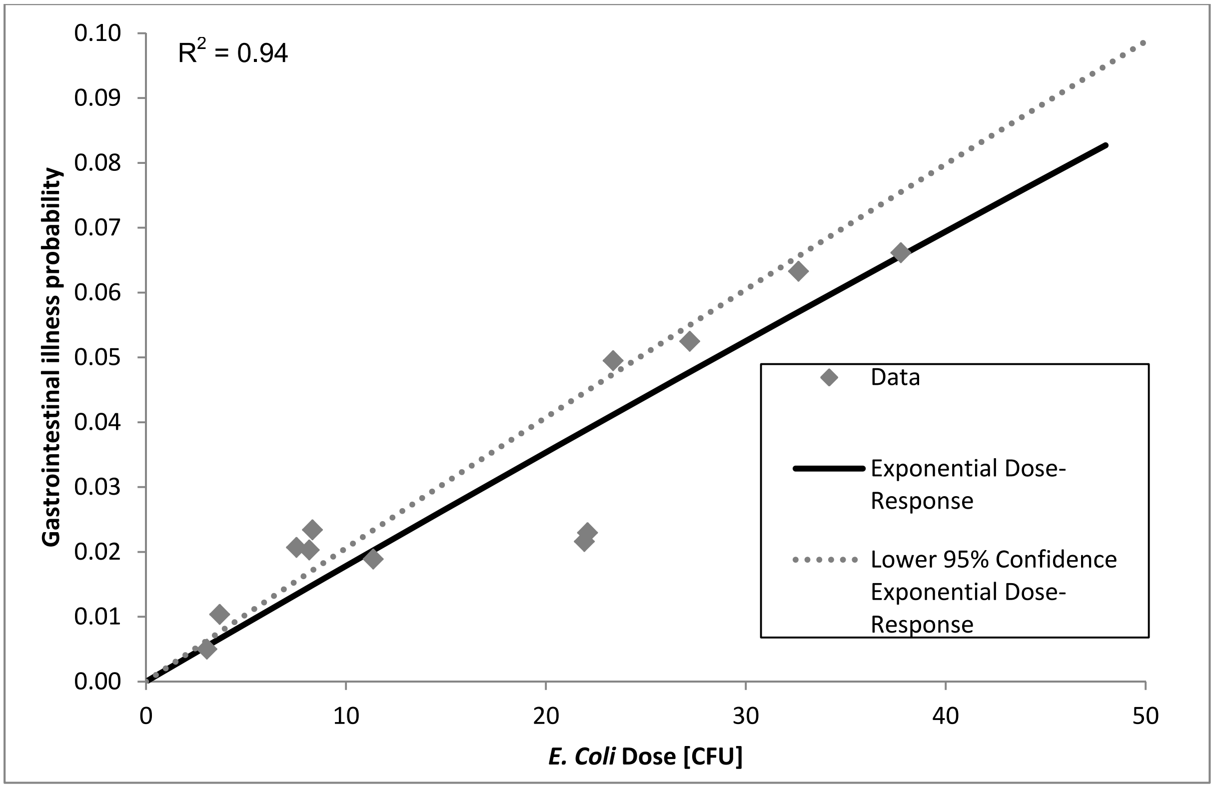

Figure 4. Exponential Dose-Response Curve

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).

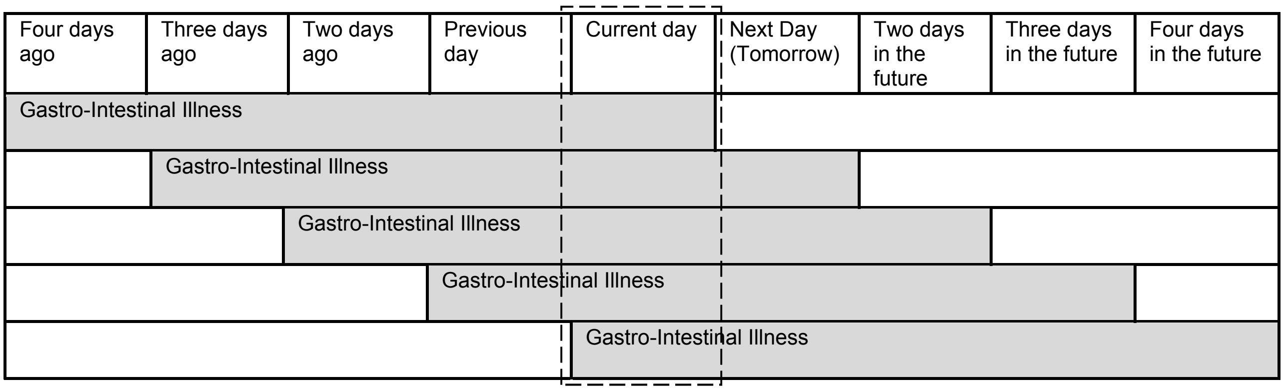

Figure 5. Rolling Illness Window

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

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

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

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

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

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

$$D_4 = p_{dose}$$ (Equation 12)

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

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

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

$$D_0 = p_{dose}(p_{dose} - 1)^4$$ (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.

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

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 5^{th} 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.

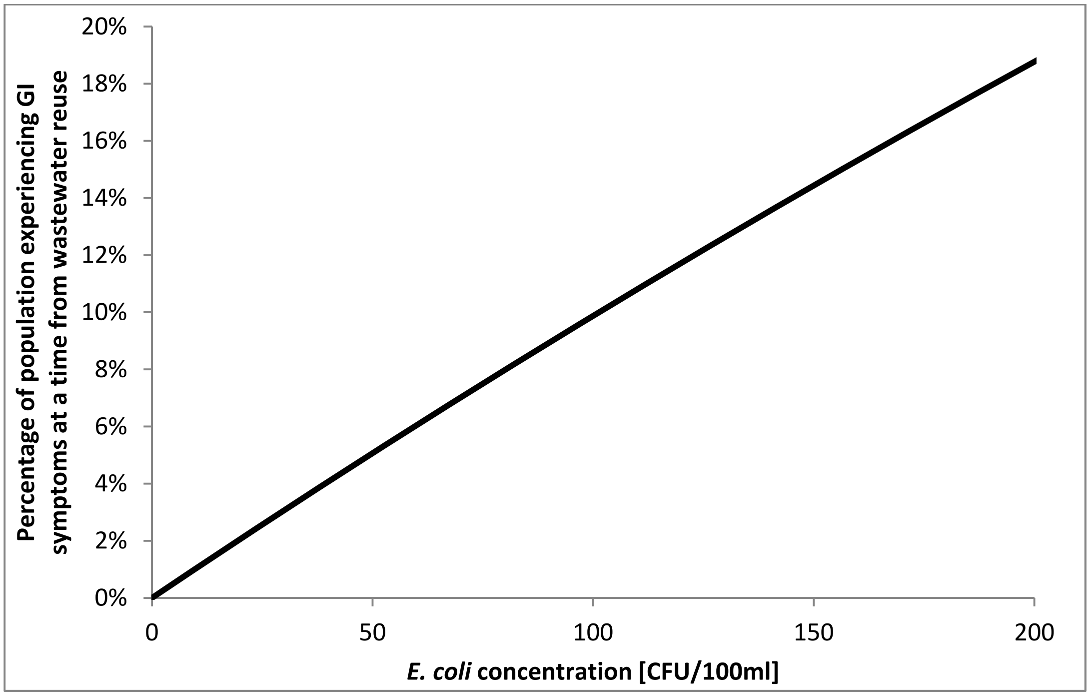

Figure 6. Percentage of Population Sick Based on *E. coli* Concentration (Wide Concentration Range) for Baseline (One Shower per Day) Exposure Scenario

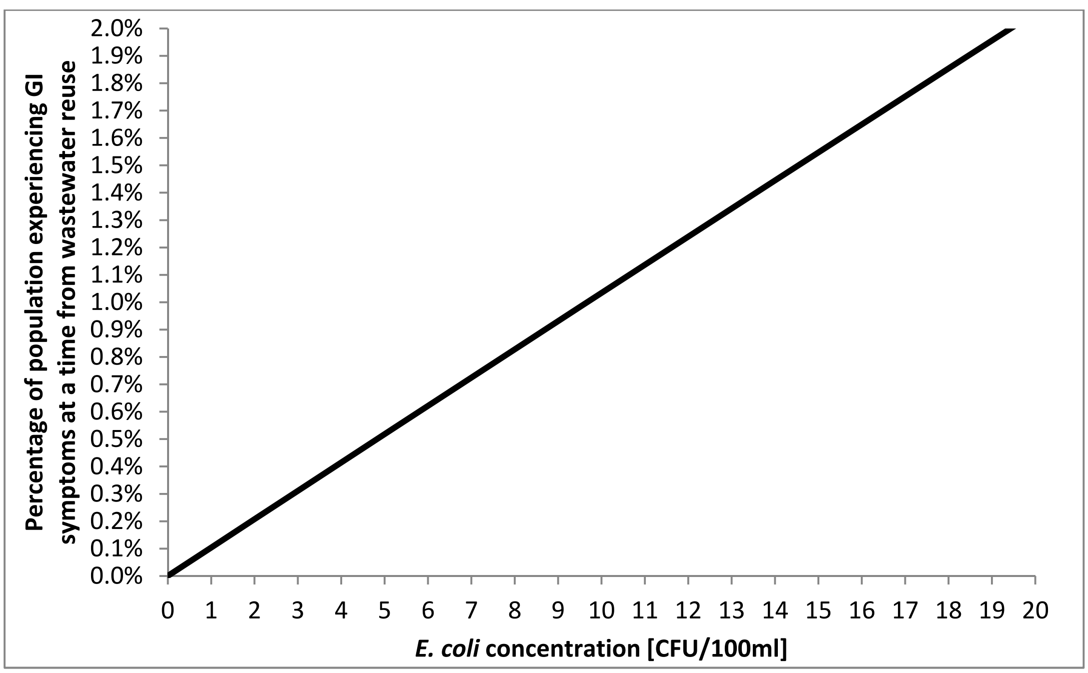

Figure 7. Percentage of Population Sick Based on *E. coli* Concentration (Low Concentration Range) for Baseline (One Shower per Day) Exposure Scenario

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 $1/5^{th}$ 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).

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

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

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

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

$$WfD_0 = portion\ of\ weekly\ showering\ population\ sick\ from\ the\ current\ day = \frac{p_{dose}}{7}$$ (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 $1/5^{th}$ 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.

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

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

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

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

$$D_0 = portion\ of\ population\ who\ will\ get\ sick\ today = \frac{WfD_4}{5} + \frac{WfD_3}{5} + \frac{WfD_2}{5} + \frac{WfD_1}{5} + \frac{WfD_0}{5}$$ (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.

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

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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APPENDIX B

BACKGROUND INFORMATION FOR DEVELOPING WASTEWATER REUSE STANDARDS

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B-1. PROBLEM STATEMENT

The deployed Soldier is sent to any country in the world to fight wars or conduct contingency operations. Forward Operating Bases (FOBs) are established as secure staging and living areas to provide support for conducting tactical operations in the surrounding regional area. Operations may last for several years. Wastewater will be produced at these FOBs. Most FOBs have limited wastewater treatment systems and storage capability. If the FOBs are used for long periods (years), such as in Iraq and Afghanistan, wastewater disposal and/or reuse will inevitably become an issue. To ensure FOB sustainability while meeting mission requirements and protecting human health and the environment, wastewater reuse options must be explored. Reusing the wastewater in beneficial ways at the FOB (for dust suppression, vehicle washing, etc.) is an alternative, but the health risks associated with specific exposure scenarios for the Soldier in the field are poorly understood.

The primary human health risk to Soldiers from wastewater or nonpotable water reuse is from microorganisms. Black water comes from toilets, urinals, and latrines, and contains mainly human waste products; it typically has significant microorganism levels and, therefore, poses a substantial health risk. Gray water is the term used for untreated wastewater from showers, sinks, bath, laundry, and kitchens. Untreated gray water typically has moderate quantities of microorganisms and also poses a health risk. When black water and gray water are combined, it is called wastewater. Toxic substances (typically chemicals from industrial facilities and operations) are not expected in waste water.

Using military-unique exposure scenarios, a microbial risk assessment (MRA) is needed to: (1) identify nonpotable water quality standards, and (2) quantify or estimate the health risks to the Soldier for military-specific exposure scenarios. The MRA results are needed to identify safe concentrations of pathogens in nonpotable water reuse applications.

B-2. BACKGROUND INFORMATION

B-2.1 Wastewater

There are several different types of wastewater, each with different physical, chemical, and biological characteristics. The most suitable type of wastewater for reuse in the field by Soldiers is gray water. Domestic wastewater, which is a mixture of gray water and black water, should also be considered for reuse.

Gray water and wastewater microbiological guidelines for a wide variety of civilian exposure scenarios have been developed. The guidelines are separated into two broad categories (restricted and unrestricted use) that refer to the degree of human contact or exposure allowed. Some of these guidelines appear to be risk based. Although these guidelines are used in many countries of the world, they do not directly address the exposure scenarios that face the Soldier in the field (see paragraph 2.1.5).

B-2.1.1 <u>Wastewater Types</u>

B-2.1.1.1 General

Human communities produce liquid wastes streams. The liquid waste, or wastewater, is essentially the water supply of the community after it has been used for a variety of applications. Wastewater can be defined as used water that has been discharged from homes, businesses, and industries. In most urban communities, wastewater from the above three 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 groundwater. In some older urban communities, storm water runoff from streets and other paved areas is also routed to the treatment facility through the same distribution network. Sewage systems capable of handling storm water are known as combined systems (http://en.wikipedia.org/wiki/Sewerage). Combined systems are usually avoided because precipitation causes widely varying flows reducing treatment facility efficiency.

In the wastewater literature, the term "wastewater" generally contains a modifier that describes the source or place of origin. For example, domestic wastewater is human waste products that come from homes and/or businesses. Industrial wastewater is industrial waste products that come from industrial manufacturing and/or processing. Commercial wastewater is commercial waste products that come from commercial activities such as vehicle washing, laundry/dry cleaning, or dining facilities.

For purposes of this appendix, the word "wastewater" is understood to mean mixed wastewater that primarily contains domestic wastewater and may contain minor amounts of commercial wastewater. The term "wastewater" has a broad definition (rather than restricting it to a combination of gray and black water) because there may be some FOBs where wastewater from vehicle or aircraft washing or other commercial activities is routed to a wastewater lagoon. The lagoon wastewater is one proposed source of water for reuse activities.

B-2.1.1.2 Domestic Wastewater

Wastewater can be described by its source or place of origin. For example, wastewater from homes is typically called domestic wastewater. Wastewater from toilets, urinals, and kitchens (called black water) and wastewater from bathtubs, showers, sinks, laundry, and dishwashers (called gray water) are the sources of domestic wastewater. Wastewater leaving residential homes is typically black water and gray water combined into one waste stream.

B-2.1.1.3 Industrial 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 Environment Federation, 1989). Industrial wastewater flow rates and characteristics depend upon the type of industrial process that produces them and the type of chemicals or additives used in the process. 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. For purposes of nonpotable water reuse for the Soldier in the field, industrial wastewaters are excluded from consideration.

B-2.1.2 <u>Gray Water</u>

B-2.1.2.1 Definition

Gray water is defined as (Metcalf and Eddy, 2007, p. 765):

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. Gray water typically contains salts and minerals from detergents and soaps.

In a similar but briefer manner, the U.S. military refers to gray water as (Department of the Army (DA), 2010a, p. 89):

"Shower and laundry wastewater,"

and the U.S. Army defines gray water as (DA, 2006b, glossary):

"Wastewater from non-human waste sources such as showers, laundry, kitchen operations, vehicle washracks, and handwash devices".

The military definition of gray water includes wastewater from kitchen operations. This definition does not differentiate between wastewater from kitchen sinks and from food waste, which can be quite different microbiologically. Some kitchen sinks are primarily used to process food waste; these sinks typically have food grinders attached to them. Other kitchen sinks are primarily used to wash and rinse dishes and hands; these sinks typically do not have food grinders attached to them. For purposes of military field water reuse, gray water as defined by Metcalf and Eddy (2007) will be used to avoid the need to make a field judgment about whether or not to include kitchen sinks.

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. Separated gray water may be treated and reused more easily than wastewater because it has a lower concentration of pathogens, 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.

B-2.1.2.2 Characterization

Over the last decade, gray water has been extensively characterized (Australia, 2002 and 2006; Health Canada, 2007; British Columbia Ministry of Agriculture, Food and Fisheries, 2001; Friedler, 2004; Massachusetts Department of Environmental Protection, 2002; Metcalf and Eddy, 2007; Ottoson and Stenstrom, 2003; Sheikh, 2010; Westrell, 2004; World Health Organization (WHO), 2006g). Many of these characterizations have focused on the microbiological characteristics of gray water. This is due to human health concerns related to the increasing prevalence of reusing it in a wide variety of applications.

- Physical and Chemical Characterization. Tables B-1 and B-2 summarize the physical and chemical constituents in typical untreated gray water obtained from several international studies. Table B-1 shows the typical composition of gray water when compared with raw sewage. Note the large variability in most gray water quality parameters.

- Microbiological Characterization. The main microbiological hazards in gray water are from fecal cross-contamination. Fecal contamination is measured traditionally by the use of common indicator organisms, such as coliforms and enterococci. Indicators have also been used to characterize the microbiological contamination in gray water (see Table B-3). In general, gray water (also black water and wastewater) microbiological characterization is by indicator organisms only. Indicator *E.coli*, coliforms, and enterococci are understood in Table B-3.

Table B-1. Typical Physical and Chemical Composition of Gray Water Compared with Raw Sewage

Parameter	Unit	Gray Water		Raw Sewage[a]
		Range	Mean	
Suspended Solids	mg/L	45-330	115	100-500
Turbidity	NTU	22->200	100	NA
BOD_5	mg/L	90-290	160	100-500
Nitrite	mg/L	<0.1-0.8	0.3	1-10
Ammonia	mg/L	<1.0-25.4	5.3	10-30
Total Kjeldahl Nitrogen	mg/l	2.1-31.5	12	20-80
Total Phosphorous	mg/L	0.6-27.3	8	5-30
Sulphate	mg/L	7.9-110	35	25-100
pH		6.6-8.7	7.5	6.5-8.5
Conductivity	mS/cm	325-1140	600	300-800
Hardness (Ca & Mg)	mg/L	15-55	45	200-700
Sodium	mg/L	29-230	70	70-300

Legend:
NA = not applicable
NTU = Nephelometric Turbidity Units
BOD = Biological Oxygen Demand
mg/L = milligrams per liter
NTU = Nephelometric Turbidity Units
mS/cm = millisiemens per centimeter
Notes:
[a] The term “raw sewage” is understood in the wastewater literature to mean untreated wastewater. It does not mean black water.
Source: Australia, 2002, page 4, Table 1.3(b).

Table B-2. Physical and Chemical Constituents in Gray Water

Parameter	Abbreviation or Symbol	Units	Mean	n	Minimum	n	Maximum	n
Suspended Solids	SS	mg/L	99.2	14	2	10	1500	11
Biochemical oxygen demand (5 day)	BOD_5	mg/L	429	10	6	7	620	7
Total organic carbon	TOC	mg/L	276.8	8	30	2	92	2
Total Kjeldahl nitrogen	TKN	mg/L	ndr	0	0.6	4	50	4
Total nitrogen	N_{tot}	mg/L	14.6	15	0.6	3	16	4
Ammonium	NH_4-N	mg/L	2.4	23	0.06	6	25.4	14
Nitrite	NO_2	mg/L	ndr	0	0	2	4.9	4
Total phosphorus	P_{tot}	mg/L	15	9	0.04	8	42	9
Phosphate	P-PO_4	mg/L	34.4	13	ndr	0	ndr	0
Sulfate	SO_4	mg/L	ndr	0	4	3	168	5
pH		mg/L	8.1	6	5	13	10	13
Electrical conductivity	EC	dS/m	0.4	1	0.08	5	1.3	5
Total dissolved salts	TDS	mg/L	ndr	0	52	3	5960	3
Sodium adsorption ratio	SAR		6.4	8	0.79	7	32.2	8
Sodium	Na	mg/L	89.9	9	7.4	8	1090	9
Calcium	CA	mg/L	20.9	8	2.3	7	824	8
Magnesium	Mg	mg/L	5.8	8	0.7	7	19	8
Chloride	Cl	mg/L	ndr	0	3.1	3	136	3
Fluoride	F	mg/L	ndr	0	0.49	2	1.6	2
Potassium	K	mg/L	20.2	7	1.1	2	17	2
Sulfur	S	mg/L	ndr	0	1.2	2	40	2
Aluminum	Al	mg/L	1.5	5	0.02	2	44	6
Iron	Fe	mg/L	0.4	1	0.79	1	28	4
Arsenic	As	µg/L	0	1	0.2	2	13	3
Boron	B	µg/L	630	3	0	0	0	0
Cadmium	Cd	µg/L	0.45	4	0	0	50	3
Cooper	Cu	µg/L	135.7	10	18	3	490	7
Cobalt	Co	µg/L	0.9	2	0	0	1.5	1
Chromium (total)	Cr	µg/L	3.7	1	0	0	5.5	1
Mercury	Hg	µg/L	ndr	0	0	0	0.02	1
Manganese	Mn	µg/L	23	2	0	0	14.3	1
Molybdenum	Mo	µg/L	1.1	1	0	0	0	0
Nickel	Ni	µg/L	11	1	0	0	28	1
Selenium	Se	µg/L	0.2	1	0	0	0	0
Strontium	Sr	µg/L	60.3	1	0	0	0	0
Zinc	Zn	µg/L	300	10	90	5	13000	7
Lead	Pb	µg/L	0	4	0	0	150	2

Legend:
N = number of samples
ndr = no data reported
mg/L = milligrams per liter
µg/L = micrograms per liter
dS/m = decisiemens per meter
mS/cm = millisiemens per centimeter
Note:
Source: Australia, 2006, page 149, Table 4.11.

Table B-3. Microbiological (Indicator Organism) Characterization of Gray Water

Water Source	Numbers of Indicator Bacteria (log numbers/100 mL)[a]				References
	Total coliforms	Thermotolerant coliforms	*E.coli*	Enterococci	
Bath, hand basin	ndr	ndr	4.4	1.0-5.4	Albrechtsen (1998)
Laundry	3.4-5.5	2.0-3.0	ndr	1.4-3.4	Christova-Boal, Eden & McFarlane (1996)
Shower, hand basin	2.7-7.4	2.2-3.5	ndr	1.9-3.4	Christova-Boal, Eden & McFarlane (1996)
Greywater	7.9	5.8	ndr	2.4	Casanova, Gerba & Karpiscak (2001)
Shower, bath	1.8-3.9	0-3.7	ndr	0-4.8	Feachem et al. (1983)
Laundry, wash	1.9-5.9	1.0-4.2	ndr	1.5-3.9	Feachem et al. (1983)
Laundry, rinse	2.3-5.2	0-5.4	ndr	0-6.1	Feachem et al. (1983)
Greywater	7.2-8.8	ndr	ndr	ndr	Gerba et al. (1995)
Hand basin, kitchen sink	ndr	5.0	ndr	4.6	Gunther (2000)
Greywater, 79% shower	7.4	4.3-6.9	ndr	ndr	Rose et al. (1991)
Kitchen sink	ndr	7.6	7.4	7.7	Naturvardsverket (1995)
Greywater	ndr	5.8	5.4	4.6	Naturvardsverket (1995)

Legend:
ndr = no data reported
mL = milliliters
Notes:
[a] Numbers in the table are log numbers, not arithmetic numbers.
Source: WHO, 2006d, page 37, Table 3.4.

Turbidity of raw gray water is highly variable. Pathogens are known to adhere to suspended solids found in highly turbid gray water. In systems that separate gray water from other wastewater, opportunistic pathogens may grow within the actual system, which would tend to increase the indicators noted above in Table 3.

B-2.1.2.3 Gray Water Management

The management of gray water involving transport, storage, treatment, and reuse is highly dependent on the use application (how it is to be used). Based upon prevalence in the literature, it appears that the major uses of gray water are related to reuse in civilian urban and agriculture settings. In housing communities that have separate gray water and black water piping, gray water is piped to a storage container, then used for landscape irrigation, and sometimes re-routed to flush toilets.

Treatment prior to use can be quite variable, and depends on the laws of the country and/or state where reuse will occur, the reuse application, the quality of the gray water, and the anticipated level of human contact. Treatment prior to use can be any combination of settling, filtration, and disinfection.

B-2.1.3 <u>Black Water</u>

B-2.1.3.1 Definition

Black water is defined as (Metcalf and Eddy, 2007, p. 764):

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.

Black water is also defined by the U.S. Army as (DA, 2006b, glossary):

"latrine wastewater containing human waste".

Black water is wastewater coming uniquely from toilets and is composed of urine, feces, toilet paper, and flush water. Food waste and the wash water used to carry the food waste are also part of black water. Due to its composition, black water contains nutrients useful for agricultural irrigation, and pathogens that can potentially harm humans (Wendland, 2008). Black water is concentrated wastewater with high concentrations of chemical oxygen demand (COD), ammonia, nutrients, and pathogens.

In general, there is very little historical characterization of black water in the literature. There are very few black water data points today mainly because there was no good reason to generate the data. For developed countries, there has been no impetus or reason (until recently) to characterize black or gray water individually because, traditionally, they have never been separated into different waste streams. The developed countries have only been interested in the characterization of wastewater (combined gray and black water) because this is what gets treated and discharged to the environment. The undeveloped countries do not have the inclination or resources to characterize black water, even though they may have separate black and gray water waste streams. In addition, there is uncertainty associated with the black water data we currently have. The uncertainty in the available data is related to the small size of the data set.

B-2.1.3.2 Characterization

Only a few references characterizing black water can be found in the open literature (Wendland, 2008; WHO, 2002). In the U.S., this is perhaps due to the fact that black water is not typically separated from other wastewater. In most U.S. communities, one sewage pipe leaves the home or business and routes all wastewater from the building (both gray water and black water mixed together) to a treatment facility. Due to a limited amount of data, there is some uncertainty that the black water characterization presented below is representative of black water generated at U.S. military installations and/or FOBs.

- <u>Physical and Chemical Characterization</u>. A physical and chemical characterization of black water is shown in Table B-4. In addition, a physical and chemical characterization of kitchen refuse and a mixture of kitchen refuse and black water can be found in Table B-5.

Table B-4. Physical and Chemical Characteristics of Black Water

Parameter	Unit	Black Water from Vacuum Toilets[a]	Synthetic Black Water Using Primary Sludge and Toilet Paper[b]	Black Water from Vacuum Toilets[c]	Synthetic Black Water Using Feces,Urine, and Water[d]	Black Water (Wendland, 2008)
Total COD	mg/L	9,500-12,300	950	19,000	ndr	8,060 ± 2,950
Dissolved COD	mg/L	1,400-2,800	120	5,000	ndr	2,440 ± 670
VFA-COD	mg/L	500-1,900	ndr	1,300	ndr	1,640 ± 470
Particulate COD	mg/L	7,000-9,600	820	14,000	ndr	6,010 ± 2,790
Total Solids	mg/L	ndr	670	ndr	10,370	6,530 ± 2,110
VS	mg/L	ndr	490	ndr	7,570	4,090 ± 1,830
TOC	mg/L	ndr	ndr	ndr	ndr	2,410 ± 720
NH_4-N	mg/L	600-1,000	4.5	1,400	692	1,111 ± 137
Total Nitrogen	mg/L		32		ndr	1,495 ± 244
Total Phosphorus	mg/L	90-140	17	280	12	175
Particulate to total COD (ratio)	-	76%	86%	74%	ndr	ndr
COD / N/P	-	95/10/1	56/2/1	68/5/1	ndr	ndr

Legend:
mg/L = milligrams per liter
COD = Chemical Oxygen Demand
VFA-COD = volatile fatty acids-chemical oxygen demand
VS = Volatile Solids
N/P = Nitrogen/Phosphorus
ndr = no data reported
Notes:
[a] Values in this column are from Kujawa-Roeleveld et al. 2006.
[b] Values in this column are from Luostarinen, 2005.
[c] Values in this column are from Zeeman et al. 2007a and b.
[d] Values in this column are from Wolff, 2000.
Source: Wendland, 2008, Table 1, page 3 and Table 8, page 30.

Table B-5. Physical and Chemical Characteristics of Black Water and Kitchen Refuse

Parameter	Unit	Kitchen Refuse (n=2)	Mixture of Black Water + Kitchen Refuse (n=25)
Total COD	mg/L	297/210	17,690 ± 4,530
Dissolved COD	mg/L	80/330	6,780 ± 1,070
Particulate COD	mg/L	216/880	10,260 ± 3,620
Total Solids	mg/L	190/500	11,808 ± 3,040
Volatile Solids	mg/L	172/370	7,920 ± 3,240
Total Organic Carbon	mg/L	80/690	5,420 ± 1,770
NH_4 - Nitrogen	mg/L	301	1,148 ± 111
Total Nitrogen	mg/L	4,901	1,503 ± 155
Total Phosphorus	mg/L	521	171
Ratio Particulate COD to total COD[a]	-	73%	59%
COD/N/P		570/9/1	75/6/1
Volatile Solids N/P		330/9/1	46/6/1

Legend:
COD = Chemical Oxygen Demand
N/P = Nitrogen/Phosphorus
mg/L = milligrams per liter
Notes:
[a] Excluding toilet paper calculated as average of the ratios of the correspondent values
Source: Wendland, 2008, Table 10, page 34.

- Microbiological Characterization. A search of the open literature resulted in a black water microbiological characterization restricted to indicator organisms only (see Table B-6). The suspected reason for this is because most developed societies (until very recently) have included black water with other types of wastewater in a single domestic wastewater stream leaving the home or business. Domestic wastewater, on the other hand, has received extensive microbiological characterization (see discussion in paragraph 2.1.4).

Table B-6. Microbiological Characterization of Black Water

Parameter	Unit	No. of samples	Black Water (BW)
E.coli	CFU/100 mL	13	9.1×10^7
Total coliforms	CFU/100 mL	13	1.3×10^8
Enterococci	CFU/100 mL	13	3.1×10^7

Legend:
CFU = colony forming units
mL = milliliters
Note:
Source: Wendland, 2008, Table 8, page 30.

In general, black water is less diluted (more concentrated) than wastewater because it contains more microorganisms from feces than wastewater. The gray water component of wastewater helps dilute the microorganism concentration because it has only a very small amount of fecal matter in it compared to black water. *E. coli* concentrations in black water are around one to two log higher than in wastewater (Wendland, 2008).

B-2.1.3.3 Black Water Management

There is limited information on black water transport, storage, treatment, disposal, and/or reuse in the open literature. This may be due to the lack of management of black water as a separate waste stream. It appears that, until very recently, many societies of the world did not document the management of black water separately from other wastewaters generated in homes and businesses.

B-2.1.4 <u>Domestic Wastewater</u>

B-2.1.4.1 Definition

Domestic wastewater is defined as (WHO, 2006b, p. 196):

"Liquid waste discharges from homes, commercial premises and similar sources to individual disposal systems or to municipal sewer pipes, and which contain mainly human excreta and used water. When produced mainly by household and commercial activities, it is called domestic or municipal wastewater or domestic sewage. In this context, domestic sewage does not contain industrial contaminants at levels that pose threats to the functioning sewage system or public health and the environment."

It is interesting to note that Army medical guidelines for field waste management (DA, 2006b) devote a chapter to wastewater, but do not explicitly define the term.

For many communities in the U.S., domestic wastewater is composed of a combination of gray water and black water.

B-2.1.4.2 Characterization

Wastewater production and disposal has a long history in the U.S., and dates back several thousand years in other parts of the world. Because of this, it has been extensively studied and characterized by many workers (Australia, 2006; Health Canada, 2007; Feachem et al. 1983; Gibson et al. 1998; Luostarinen, 2005; Metcalf and Eddy, 1979, 2003, 2007; Olivieri and Seto, 2007; Rose and Grimes, 2001; USEPA, 1980, 1999a, 2004a, 2011a, 2012a-b; Westrell, 2004; WHO, 2006a-d). The above reference list is by no means complete. Essentially, the open literature is filled with documentation on wastewater characterization from many parts of the world. Some of the most authoritative sources of information are found in the textbooks written by Metcalf and Eddy, the U.S. Environmental Protection Agency (USEPA) documents, and the WHO.

To a large degree, what is used and discarded (purposely or inadvertently) in the home and/or business is found in wastewater. A thorough characterization of modern wastewater may include any (or all) of the following constituents: water, large inorganic matter (sand, metal particles, grit), pathogenic and nonpathogenic microorganisms (such as bacteria, viruses, protozoa, worms), organic particles (human excreta, paper products, plant matter, and food particles), pharmaceuticals and over-the-counter medicines (prescription, nonprescription, and illegal drugs), caffeine, alcohols, a wide variety of liquid petroleum products, hair care and cosmetic products, hand lotions and sunscreens, animal parts (such as insects, arthropods, fish), large solids such as diapers and toys, small plastic office and household items, money (in rare instances), organic and inorganic toxins (such as pesticides, herbicides, and other poisons), paints and other emulsified liquids, oil and grease, endocrine disrupting chemicals, plus detergents and other household cleaning products.

- <u>Physical and Chemical Characterization.</u> Table B-7 shows the physical and chemical characteristics of wastewater. This list represents untreated wastewater entering a treatment plant (Metcalf and Eddy, 2007, page 106). The constituents and their associated concentrations will vary with the day of the week, the month of the year, and seasonally. The concentration data presented are for medium-strength wastewater and include a small industrial input.

Table B-7. Physical and Chemical Characteristics of Domestic Untreated Wastewater[a]

Contaminants	Unit	Concentration	
		Range	Typical
Total Solids (TS)	mg/L	390-1230	720
Total Dissolved Solids (TDS)	mg/L	270-860	500
Fixed	mg/L	160-520	300
Volatile	mg/L	110-340	200
Total Suspended Solids (TSS)	mg/L	120-400	210
Fixed	mg/L	25-85	50
Volatile	mg/L	95-315	160
Settleable solids	mg/L	5-20	10
Biochemical oxygen demand (BOD) 5 d, 20°C	mg/L	110-350	190
Total organic carbon (TOC)	mg/L	80-260	140
Chemical oxygen demand (COD)	mg/L	250-800	430
Nitrogen (total as N)	mg/L	20-70	40
Organic N	mg/L	8-25	15
Free ammonia	mg/L	12-45	25
Nitrites	mg/L	0-trace	0
Nitrates	mg/L	0-trace	0
Phosphorus (total as P)	mg/L	4-12	7
Organic P	mg/L	1-4	2
Inorganic P	mg/L	3-10	5
Chlorides[b]	mg/L	30-90	50
Sulfate[b]	mg/L	20-50	30
Oil and grease	mg/L	50-100	90
Volatile organic compounds (VOCs)	mg/L	<100->400	100-400

Legend:
mg/L = milligrams per liter
Notes:
[a] Typical wastewater composition is based on an approximate flow rate of 460 liters/capita•day (120 gallons/capita•day).
[b] Values should be increased by amount of constituent present in domestic water supply.
Source: Metcalf and Eddy, 2007, page 107, Table 3-12.

- Microbiological Characterization. A microbiological characterization of untreated wastewater is shown in Table B-8. Note that most microorganism concentrations span several orders of magnitude. 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, page 94).

Table B-8. Microorganism Concentrations Found in Untreated Wastewater and the Corresponding Median Infectious Dose

Organism	Concentration in Raw Wastewater MPN/100mL	Median Infectious Dose Number (N_{50})
Bacteria		
Bacteroides	10^7-10^{10}	ndr
Coliform, total	10^7-10^9	ndr
Coliform, fecal [a]	10^5-10^8	10^6-10^{10}
Clostridium perfringens	10^3-10^5	1-10^{10}
Enterococci	10^4-10^5	ndr
Fecal Streptococci	10^4-10^6	ndr
Pseudomonas aeruginosa	10^3-10^6	ndr
Shigella	10^0-10^3	10-20
Salmonella	10^2-10^4	ndr
Protozoa	ndr	ndr
Cryptosporidium parvum oocysts	10^1-10^5	1-10
Entamoeba histolytica cysts	10^0-10^5	10-20
Giardia lamblia cysts	10^1-10^4	<20
Helminth	ndr	ndr
Ova	10^0-10^3	ndr
Ascaris luumbricoides	ndr	1-10
Virus	ndr	ndr
Enteric virus	10^3-10^4	1-10
Coliphage	10^2-10^4	ndr

Legend:
mL = millilters
MPN = most probable number
ndr = no data reported
Notes:
[a] *Echerichia coli* (enteropathogenic)
Source: Metcalf and Eddy, 2007, page 97, Table 3-7.

B-2.1.4.3 Wastewater Management

Wastewater management is an old issue for humans, and has evolved considerably over the years. Today, communities manage their wastewater in a number of ways. Factors that influence wastewater management practices include: (1) a rural vs. urban setting, (2) available resources, (3) climate, (4) governing laws and regulations.

The purpose of wastewater treatment is to remove contaminants, disinfect the water, and improve the quality of the water so that it may ultimately be returned to the hydrologic cycle or reused in a safe manner (see Figure B-1). Physical, chemical, and biological treatment is typically used to treat wastewater. Human health and environmental concerns are the driving factors that control the quality of the water returned to the hydrologic cycle or reused.

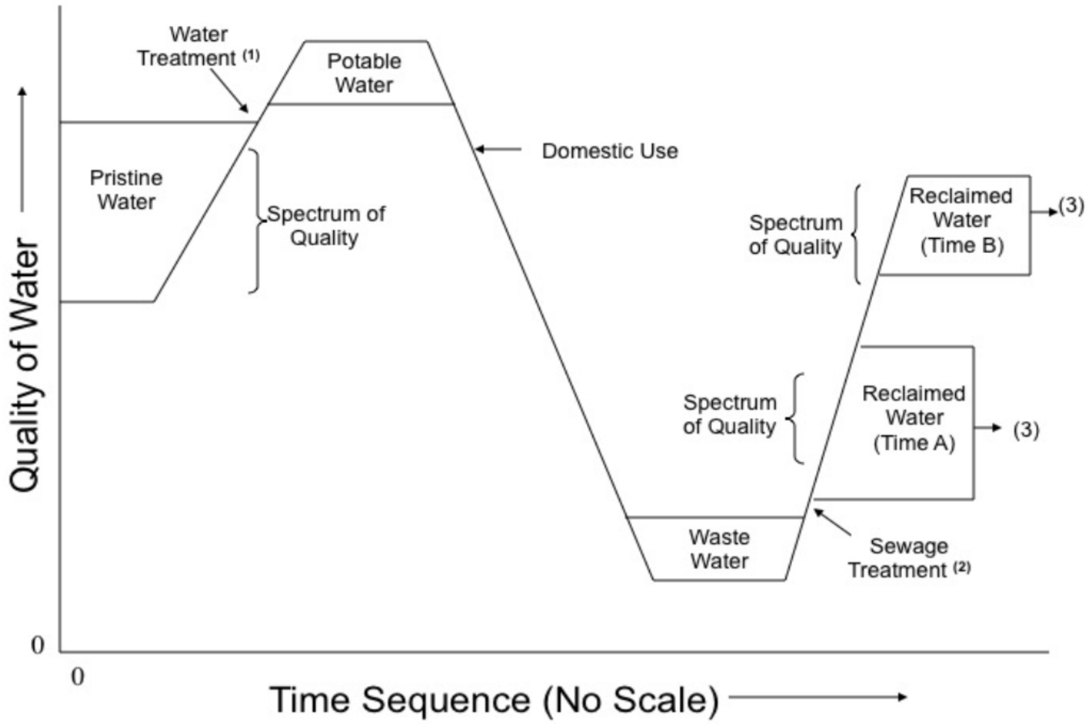

Figure B-1. Continuum of Water Quality with Use and Treatment
Source: NAS, 2012

Notes: (1) Typical processes include coagulation-flocculation, sedimentation, filtration, and disinfection. (2) Processes include secondary treatment and disinfection. (3) Effluent discharged to environmental receiving water or reused.

Sewered communities in the U.S. typically route their wastewater to a treatment plant. In some cases, lagoons are used for storage and treatment of wastewater. Treatment plants have the capability to improve the quality of the wastewater so that it may be reused for various applications. These applications include urban reuse (landscape irrigation, toilet flushing), industrial reuse (cooling water, boiler make-up water, industrial process water), agricultural reuse, environmental and recreational reuse (wetlands, impoundments, stream augmentation), groundwater recharge, and augmentation of potable water supplies (USEPA, 2004a). Rural communities in the U.S. that do not have a sewage system use on-site systems (such as a septic system and a drain field) for wastewater treatment and disposal.

B-2.1.5 Current Wastewater Microbiological Exposure Guidelines

Worldwide, there are a significant number of published exposure guidelines for both wastewater and gray water reuse (Arizona Department of State, 2001; Australia, 2006; Canadian Mortgage and Housing Corp., 2005; British Columbia Ministry of Agriculture, Food and Fisheries, 2001; Health Canada, 2010; 69 FR 67217; Hawaii Administrative Code, 2004; USEPA, 2004a and 2012a; WHO, 2004, 2006a-e; Wisconsin, 2009). These guidelines include physical parameters (turbidity, total suspended solids (TSS), pH, biological oxygen demand (BOD)), chemical parameters (nitrogen, phosphorus, chlorine residual), and microbiological indicators (*E. coli*, total and fecal coliforms, helminth eggs, fecal streptococci, salmonellae) of water quality (see Table B-26).

In general, the worldwide guidelines have been designed for civilian applications. These applications include (Metcalf and Eddy, 2007):

- agriculture (both surface and subsurface irrigation for processed foods, raw foods, and nonfood crops),
- urban residential, commercial, and business uses (landscape irrigation, toilet flushing, laundry washing, vehicle washing),
- industrial and construction uses (concrete mixing, dust suppression, soil compaction, aggregate washing, pest control, fire protection, machine coolant, water well development),
- recreational and environmental uses (marsh and lake enhancement, streamflow augmentation, fisheries, snowmaking),
- potable reuse (blending in water supply reservoirs, groundwater blending, direct potable reuse), and
- groundwater recharge (salt water intrusion control, subsidence control, groundwater replenishment).

Taken as a whole, the worldwide guidelines can be interpreted as composed of two broad categories: restricted access reuse and unrestricted access reuse. A limited definition of these terms can be found in references USEPA, 2004a, pages 153-154 and 157-158; USEPA, 2012a, pages 4-8 to 4-11; and WHO, 2006a-d, glossary. Variations on the theme can be found in Canadian Mortgage and Housing Corp., 2005, pp. 50-51. These terms refer to the degree of human contact or exposure allowed with the reused wastewater. Restricted access reuse occurs in areas where public access is controlled and public exposure is limited. Restricted reuse assumes little or no human contact with the reused water, and thus, allows for a lower water quality exposure guideline. Unrestricted access occurs in areas where public access is not controlled and public exposure may include whole body contact. Recreational activities such as swimming in lakes or impoundments undergoing enhancement with reused wastewater is an example.

Some of the above civilian applications involve applying the wastewater to the surfaces of such items as agricultural crops, landscape gardens, and grass fields. Restricted access and uses refers to restricting human contact with these applied surfaces until the primary hazard (pathogens) has desiccated or been reduced to safe levels. Unrestricted access and use allows human contact with these wet surfaces because the reuse standard is sufficiently protective of human health and allows for safe contact with the wastewater.

Based upon a preliminary review of the worldwide literature, some of the guidelines appear to be risk based. For others, it is unclear whether the standards are risk based. For example, the WHO guidelines on using wastewater in agriculture appear to be supported with a quantitative microbial risk analysis (WHO, 2006b, p. 47). However, the analysis used exposures related to growing and eating crops. Soldiers, on the other hand, do not normally engage in farming practices. Australia (2006) uses a risk-based approach, but the exposure assessment is for civilian applications. These exposures have even been quantified in terms of volume of reused water ingested and frequency of ingestion per person per year (see Table B-9).

Similarly, Canada has adopted a risk-based approach to their reclaimed water guidelines, but the exposure assessment only applies to toilet and urinal flushing (Health Canada, 2007). For the U.S., there is no evidence that the USEPA national guidelines for water reuse (EPA, 2004a and 2012a) are risk-based. The USEPA guidelines are technology-based standards that rely on the 30/30/1 rule for secondary treated effluent from a wastewater treatment plant (30 mg/L BOD, 30 mg/L TSS, 1 mg/L chlorine residual).

Table B-9. Intended Uses and Associated Exposures for Reused Water in Australia

Activity	Route of Exposure	Volume (mL)	Frequency /person /year	Comments
Garden irrigation	Ingestion of sprays	0.1	90	Garden watering estimated to typically occur every second day during dry moths (half year). Exposure to aerosols occurs during watering.
Garden irrigation	Routine ingestion; Accidental ingestion	1 100	90 1	Routine exposure results from indirect ingestion via contact with plants, lawns, etc. Infrequent event.
Municipal irrigation	Ingestion	1	50	Frequencies moderate as most people use municipal areas sparingly (estimate ½-3 weeks). People are unlikely to be directly exposed to large amounts of spray and therefore exposure is from indirect ingestion via contact with lawns, etc. Likely to be higher when used to irrigate facilities such as sports grounds and golf courses (estimate 1/week)
Food crop consumption (home grown)	Ingestion	5 (lettuce) 1 (other raw produce)	7 50	100 grams (g) of lettuce leaves hold 10.8 mL water and cucumbers 0.4 mL at worst case (immediately post watering).[a] A serving of lettuce (40 g) might hold 5 mL of recycled water and other produce might hold up to 1 mL per serving. Calculated frequencies are based on data.[b]
Food crop consumption (commercial)	Ingestion	5 (lettuce) 1 (other raw produce)	70 140	100 g of lettuce leaves hold 10.8 mL water and cucumbers 0.4 mL at worst case (immediately post watering).[a] A serving of lettuce (40 g) might hold 5 mL of recycled water and other produce might hold up to 1 mL per serving. Calculated frequencies are based on ABS data.[c]
Toilet flushing	Ingestion of sprays	0.01	1100	Frequency based on three uses of home toilet per day. Aerosol volumes are less than those produced by garden irrigation
Washing machine use	Ingestion of sprays	0.01	100	Assumes one member of household exposed. Calculated frequency based on ABS data.[d] Aerosol volumes are less than those produced by garden irrigation (machines usually closed during operation).
Fire fighting	Ingestion of water, sprays	20	50	Median ingestion for firefighters estimated at 20 mL per fire with a maximum number of fires fought within area served by recycled water of 50 per year.

Legend:
ABS = Australian Bureau of Statistics
Notes:
[a] Shuval et al. (1997)
[b] ABS data show that 12% of households grow lettuce and 35% grow some type of produce (ABS, 1995); they also show that Australians eat leafy vegetables 140 times per year and eat other vegetables at similar rate (ABS, 1994). Hence, it can be estimated the "other produce," such as tomatoes, carrots, etc. in combination, are eaten 280 times per year. Watering with recycled water is used to augment rainfall. Assuming that watering occurs for six months of the year, frequency of consumption of lettuce irrigated with recycled water = 140x0.5x125, and frequency of consumption of other raw produce=280x0.5x35%.
[c] Using the same ABS data as in Note b, frequency of consumption of lettuce irrigated with recycled

water = 140x0.5 for lettuce and frequency of consumption of other raw produce = 280x0.5.
[d] ABS data show an average of 2.6 people per household (ABS, 2001). The amount of washing is estimated at five loads per week; therefore, the frequency =5x52÷2.6.
[e] Firefighting is an occupational exposure; the exposures were assessed by the Queensland Department of Emergency Services.
[f] WHO (2004)
Source: Australia, 2006, page 92, Table 3.3.

For military applications, the worldwide standards provide a general framework but do not directly address the many exposure scenarios that Soldiers reusing water in the field may face. Almost all of the worldwide MRAs conducted to date have focused primarily on civilian exposure scenarios found in agriculture and some industries (Gibson, Haas, and Rose, 1998; Haas et al. 1996 and 1999; Hamilton et al. 2006; Hoornstra and Hartog, 2003; Loret et al. 2009; Olivieri and Seto, 2007; Ottoson and Stenstrom, 2003; Regli et al. 1991; Rose et al. 1991; Rose and Gerba, 1991a and b; Ryu et al. 2005 and 2007; Sobsey et al. 1993; USEPA, 1992; Westrell, 2004). The agricultural exposure scenarios mainly involve exposures to farmers and their families (when using wastewater or gray water for crop production), and exposures to people consuming agricultural products grown with wastewater or gray water irrigation. In addition, other civilian exposure scenarios involve residential, commercial, and industrial practices associated with fixed facilities and infrastructure. The Soldier in the field does not normally engage in farming or fixed infrastructure water reuse activities. Thus, these exposure scenarios are not directly applicable to deployed Soldiers. Furthermore, there has been no known nonpotable water reuse MRA conducted to date for or by the U.S. Army.

B-2.1.6 Health Effects Associated with Microbial Exposures in Wastewater

B-2.1.6.1 General

Health effects (mainly epidemiological) investigations concerned with wastewater exposures have primarily focused on two main exposure scenarios: drinking water and agricultural exposures. Documentation on illnesses related to wastewater-contaminated drinking water is extensive. Agriculturally related exposure scenarios include the use of raw or minimally treated wastewater for food crop irrigation, farm workers who routinely contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using nondisinfected wastewater. These agriculturally related investigations have all provided evidence of infectious disease transmission from such practices (Lund, 1980; Feachem et al. 1983; Shuval et al. 1986; USEPA, 2004a, p.100; USEPA, 2012a). This is mainly the case in developing countries where irrigation of market crops with poorly treated wastewater is a major source of disease.

Health effects studies related to military-specific wastewater reuse exposures (showering, heat casualty body cooling, personnel and equipment decontamination, etc.) have not been found in the open literature.

B-2.1.6.2 Health Effects Associated with Agricultural Use of Wastewater

A substantial part of the literature on the health effects of wastewater in agricultural use focus on variations in the degree of exposure such as contact with wet grass and accidental or incidental ingestion.

Durand and Schwebach (1989) investigated the gastrointestinal effects of employing treated wastewater as a sprinkler applied irrigation source for urban parks. Contact with wet grass and elevated densities of common indicator bacteria were associated with an increased rate of gastrointestinal illness. Results of the Durand and Schwebach (1989) study suggest that treated wastewater can be used for public park irrigation without undue hazard to health provided indicator bacteria levels are kept below the following: fecal coliform ≤ 500 colony forming units (CFU)/100 mL, fecal streptococci ≤ 500 CFU/100 mL, total coliforms ≤ 3000 CFU/100 mL.

Rose and Gerba (1991b) studied the use of reclaimed water for a variety of uses in Arizona and Florida, including public access irrigation, fire protection, toilet flushing, construction, and dust control. State mandated treatment for these reuse options includes secondary treatment, filtration with coagulant aids, and a high level of disinfection. The exposure studied was accidental ingestion of 100 mL of reclaimed water. Human health risk was modeled using a probability of infection model. Rose and Gerba (1991) found that the risk of infection from 100 mL accidental ingestion ranged from 2×10^{-3} to 2×10^{-4} for levels of viruses and protozoa found in chlorinated secondary effluent, and the risk was reduced to 2×10^{-4} to 2×10^{-6} with filtration and disinfection.

Downs et al. (1999) studied the effects of untreated raw wastewater irrigation around Mexico City. Untreated wastewater is used for flood irrigation of cropland in a naturally semiarid region, recharging the local aquifer system that provides drinking water for the community. Although the study does not mention hydrogeologic details, the untreated wastewater infiltrated vertically through the soil profile a certain distance, intercepted the water table, mixed with the drinking water aquifer, and was carried with other aquifer water in a downgradient direction until it was pulled to the surface and into someone's house by a drinking water well. The study examined the effects of drinking and bathing with the wastewater-contaminated aquifer water. Study results indicated that 10% (out of 210 families) reported frequent diarrhea and 9% reported persistent skin rashes.

The World Health Organization (WHO, 2006a and b) developed exposure guidelines for the use of wastewater in agriculture (see Table B-10).

Table B-10. The World Health Organization Guidelines for Wastewater Use in Agriculture (Summary of QMRA results for rotavirus[a] infection risks for different exposures)

Exposure scenario	Water quality[b] (*E. coli*/100 mL wastewater of 100 g soil)	Median infection risk per person per year	Notes
Unrestricted Irrigation (crop consumers)			
Lettuce	10^3-10^4	10^{-3}	100 g eaten raw per person every 2 days 10-15 mL wastewater remaining on crop
Onion	10^3-10^4	5×10^{-2}	100 g eaten raw per person per week for 5 months 1-5 mL wastewater remaining on crop
Restricted Irrigation (farmers or other heavily exposed population)			
Highly mechanized	10^5	10^{-3}	100 days exposure per year 1-10 mg soil consumed per exposure
Labor intensive	10^3-10^4	10^{-3}	150-300 days exposure per year 10-100 mg soil consumed per exposure

Legend:
mL = milliliters
g = grams
mg = milligrams
Notes:
[a]Risks estimated for *Campylobacter* and *Cryptosporidium* are lower.
[b]Nondisinfected effluents
Source: WHO, 2006a, p.24; 2006b, p. xvi.

These guidelines summarize the quantitative MRA evidence for transmission of rotavirus infection due to unrestricted and restricted irrigation. In Table B-10, unrestricted irrigation refers to eating uncooked food chain crops (such as lettuce) that are irrigated with nondisinfected wastewater. Restricted irrigation refers to direct contact with the nondisinfected wastewater, and/or involuntary ingestion of soil particles (≤ 100 mg per person per day) by those working in wastewater-irrigated fields (WHO, 2006a and b). Highly mechanized restricted irrigation refers to farming practices in developed countries where heavy machinery is used and gloves are worn. Labor-intensive restricted irrigation refers to farming without heavy machinery and gloves or other protective clothing is not worn.

The WHO guidelines are supported by three types of evidence: microbial analysis, epidemiological studies, and quantitative MRAs. For microbial analysis, indicators of fecal contamination have been used as proxies for pathogens with similar properties that may be present in wastewater (WHO, 2006a and b). Usually, their presence in wastewater is proportionately related to the amount of fecal contamination present. For wastewater, indicators can show how much treatment has taken place and thus give a rough estimate of the risk associated with its use. For the WHO, *E. coli* is the indicator of choice because these bacteria are the most commonly monitored of the indicators that are related to fecal contamination. After a review of many microbial analysis studies, the WHO concluded that irrigating salad crops with wastewater containing 10^3 *E. coli* per 100 mL provides a reasonable level of safety for human health protection.

The epidemiological evidence for unrestricted use (salad crops irrigated with wastewater and eaten raw) suggests that direct contact with untreated wastewater through flood or furrow irrigation can lead to helminth infection (mainly Ascaris). However, Ascaris infections can be reduced by treating the wastewater prior to use. The Ascaris infection rate is dependent on treatment level; the recommended Ascaris concentration is below 1 egg per liter (WHO, 2006b). Epidemiological evidence for diarrheal disease related to direct contact with wastewater suggests that wastewater quality should be below 10^4 thermotolerant coliforms per 100 mL to adequately protect human health (WHO, 2006b). The better quality studies of sprinkler irrigation of treated wastewater indicate that there may be an increased risk of infection when the quality of the wastewater is 10^6 thermotolerant coliforms per 100 mL, but no increased risk of infection when the water quality is 10^4 to 10^5 thermotolerant coliforms per 100 mL (WHO, 2006b).

The results of quantitative MRAs for the unrestricted irrigation exposure scenarios for lettuce and onion, and the highly mechanized and labor intensive restricted irrigation exposure scenarios are shown in Tables B-11 to B-14 below.

Table B-11. Estimated Infection Risk When Consuming Raw Lettuce that Has Been Irrigated with Wastewater
(Unrestricted Irrigation: Median Infection Risks from the Consumption of Wastewater Irrigated Llettuce Estimated by 10 000-trial Monte Carol Simulations[a])

Wastewater quality (*E. coli* per 100 mL)	Median infection risk (per person per year)		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7-10^8	0.99	0.28	0.50
10^6-10^7	0.65	6.3×10^{-2}	6.3×10^{-2}
10^5-10^6	9.7×10^{-2}	2.4×10^{-3}	6.3×10^{-3}
10^4-10^5	9.6×10^{-3}	2.6×10^{-4}	6.8×10^{-4}
10^3-10^4	1.0×10^{-3}	2.6×10^{-5}	3.1×10^{-5}
100-1000	8.6×10^{-5}	3.1×10^{-6}	6.4×10^{-6}
10-100	8.0×10^{-6}	3.1×10^{-7}	6.7×10^{-7}
1-10	1.0×10^{-6}	3.0×10^{-6}	7.0×10^{-8}

Legend:
mL = milliliters
Notes:
[a] 100 g lettuce eaten per person per two days; 10-15 mL wastewater remaining on 100 g lettuce after irrigation; 0.1-1 rotavirus and Campylobacter and 0.01-0.1 Cryptosporidium oocyst per 105 *E. coli*; 10-2-10-3 rotavirus and Campylobacter die-off and 0-0.1 Cryptosporidium oocyst die off between harvest and consumption; ID50 = 6.17 ± 25% and α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for Campylobacter; r=0.0042 ± 25% for Cryptosporidium.
Source: WHO, 2006b, p. 52.

Table B-12. Estimated Infection Risk When Consuming Raw Onions that Have Been Irrigated with Wastewater
(Unrestricted Irrigation: Median Infection Risks from the Consumption of Wastewater Irrigated Onions Estimated by 10 000-trial Monte Carol Simulations[a])

Wastewater quality (*E. coli* per 100 mL)	Median infection risk (per person per year)		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7-10^8	1.0	0.99	3.6×10^{-2}
10^6-10^7	0.99	0.81	3.9×10^{-3}
10^5-10^6	0.99	0.17	3.2×10^{-4}
10^4-10^5	0.43	1.6×10^{-2}	3.7×10^{-5}
10^3-10^5	0.39	1.7×10^{-2}	2.8×10^{-4}
3×10^4	0.29	1.1×10^{-2}	2.3×10^{-4}
10^3-10^4	4.5×10^{-2}	2.6×10^{-3}	3.7×10^{-6}
100-1000	5.6×10^{-3}	1.0×10^{-4}	3.8×10^{-7}
10-100	4.4×10^{-4}	1.1×10^{-5}	3.0×10^{-8}
1-10	5.7×10^{-5}	1.8×10^{-6}	$<10^{-8}$

Legend:
mL = milliliters
Notes:
[a]100 grams (g) of onion consumed per person once per week for 5 months; 1-5 mL wastewater remaining on 100g onions after irrigation; 1-10 rotavirus and Campylobacter and 0.1-1 Cryptosporidium oocyst per 105 *E. coli*;0.1-1 rotavirus and Campylobacter die-off and 0.01-0.1 Cryptosporidium oocyst die off between harvest and consumption; ID50 = 6.17 ± 25% and α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for Campylobacter; r=0.0042 ± 25% for Cryptosporidium.
Source: WHO, 2006b, p. 53.

Table B-13. Estimated Infection Risk When Using Wastewater Irrigation in Highly Mechanized Agriculture
(Restricted Irrigation: Highly Mechanized Agriculture – Median Infection Risks from Ingestion of Wastewater-Contaminated Soil Estimated by 10 000-Trial Monte Carol Simulations[a])

Soil quality (*E. coli* per 100 grams)	Median infection risk (per person per year)		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7-10^8	0.5	2.1×10^{-2}	4.7×10^{-4}
10^6-10^7	6.8×10^{-2}	1.9×10^{-3}	4.7×10^{-5}
10^5-10^6	6.7×10^{-3}	1.9×10^{-4}	4.6×10^{-6}
10^4-10^5	6.5×10^{-4}	2.3×10^{-5}	4.6×10^{-7}
10^3-10^5	6.8×10^{-5}	2.4×10^{-6}	5.0×10^{-8}
100-1000	6.3×10^{-6}	2.2×10^{-7}	$\leq 1 \times 10^{-8}$
10-100	6.9×10^{-7}	2.2×10^{-8}	-

Notes:
[a]1-10 mg soil ingested per person per day for 100 days per year; 0.1-1 rotavirus and Campylobacter and 0.01-0.1 Cryptosporidium oocyst per 105 *E. coli*; ID50 = 6.17 ± 25% and α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for Campylobacter; r=0.0042 ± 25% for Cryptosporidium.
Source: WHO, 2006b, p. 51.

Table B-14. Estimated Infection Risk When Using Wastewater Irrigation in Labor-Intensive Agriculture
(Restricted Irrigation: Labor Intensive Agriculture With Exposures For 300 Days Per Year - Agriculture – Median Infection Risks from Ingestion of Wastewater-Contaminated Soil Estimated by 10 000-Trial Monte Carol Simulations[a])

Soil quality (*E. coli* per 100 g)	Median infection risk (per person per year)		
	Rotavirus	*Campylobacter*	*Cryptosporidium*
10^7-10^8	0.99	0.5	1.4×10^{-2}
10^6-10^7	0.88	6.7×10^{-2}	1.4×10^{-3}
10^5-10^6	0.19	7.3×10^{-3}	1.4×10^{-4}
10^4-10^5	2.0×10^{-2}	7.0×10^{-4}	1.3×10^{-5}
10^3-10^5	1.8×10^{-3}	6.1×10^{-5}	1.4×10^{-6}
100-1000	1.9×10^{-4}	5.6×10^{-6}	1.4×10^{-7}
10-100	2.0×10^{-5}	5.6×10^{-7}	1.4×10^{-8}

Notes:
[a]1-10 mg soil ingested per person per day for 300 days per year; 0.1-1 rotavirus and Campylobacter and 0.01-0.1 Cryptosporidium oocyst per 105 *E. coli*; ID50 = 6.17 ± 25% and α = 0.253 ± 25% for rotavirus; ID50 = 896 ± 25% and α = 0.145 ± 25% for Campylobacter; r=0.0042 ± 25% for Cryptosporidium.
Source: WHO, 2006b, p. 51.

The estimated risks are roughly consistent with the disease incidences determined by epidemiological field studies (WHO, 2006b).

B-2.1.6.3 Health Effects Associated with Use of Gray Water

Health effects associated with gray water have not been studied as much as wastewater. Only a few studies were found. Gray water exposure was studied by Ottoson and Stenstrom (2003). A screening level quantitative MRA was undertaken for rotavirus, Salmonella enterica, Serovar typhimurium, Camplyobacter jejuni, Giardia lamblia, and Cryptosporidium parvum in Swedish gray water. These were the identified reference pathogens for the study. Exposure scenarios studied included accidental ingestion of 1 mL, direct exposure after irrigation (assuming 1 mL intake/day and

26 days/year), and drinking groundwater recharged from a gray water storage pond. Results indicated that, in all exposure scenarios, rotavirus posed the highest risk. Giardia and cryptosporidium have low infectious doses but were not present in sufficient amounts to constitute a substantial health risk. Median risk of infection ranged from $10^{-0.2}$ to 10^{-11} for salmonella.

The WHO has guidelines for gray water use in agriculture (see Table B-15). Restricted and unrestricted agricultural use guidelines are shown in Table B-15.

Table B-15. WHO Guidelines for Gray Water Use in Agriculture (Guideline Values for Verification Monitoring in Large-Scale Treatment Systems of Greywater, Excreta and Faecal Sludge for Use in Agriculture)

	Helminth eggs (number per gram total solids or per litter)	*E. coli* (number per 100 mL)
Treated faeces and faecal sludge	<1/g total solids	<100 g/total solids
Greywater for use in:		
• Restricted irrigation	<1/liter	$<10^5$[a] Relaxed to $<10^6$ when exposure is limited or re-growth is likely
• Unrestricted irrigation of crops eaten raw	<1/liter	$<10^3$ Relaxed to $<10^4$ For high-growing leaf crops or drip irrigation

Legend:
g = grams
mL = milliliters
Notes:
[a]These values are acceptable due to the re-growth potential of *E. coli* and other faecal coliforms in greywater.
Source: WHO, 2006d, p. xvi.

Similar to the WHO wastewater guidelines, the gray water guidelines are supported by the quantitative MRA evidence of Ottoson and Stenstrom (2003).

Based upon a literature search, there is a dearth of information on the health effects from exposure to gray water. This is particularly true for military related exposure scenarios (heat casualty body cooling, personnel decontamination, etc.). This represents a data gap for military nonpotable water reuse.

B-2.2 Recreational Water

B-2.2.1 General

The USEPA faced a human health risk issue over the last several decades regarding recreational water. People in the U.S. were getting sick from contacting recreational surface waters. The history of disease outbreaks and illness associated with swimming in poor quality surface water is quite extensive and well documented (American Public Health Association (APHA), 1924; European Parliament/Council of the European Union (EP/CPU), 2006; 69 FR 41719; 69 FR 67217; Ferley et al. 1989; Pruss, 1998; USEPA, 1983, 1984, 1986, 1999c, 2000, 2002, 2003, 2004a and b, 2007a-c, 2008a and b; Wade et al. 2003 and 2010; WHO, 1999 and 2003b). Essentially, the USEPA had to determine what quality of recreational water is safe to contact. To solve this issue, the USEPA developed regulations and guidelines for swimming and conducting other recreational activities in surface water. The states either adopted or modified these regulations and guidelines for their particular situation. Other international organizations also faced this situation and developed guidelines independently. The World Health Organization (WHO, 2003b) and the European Union (EP/CPU, 2006) developed guidelines for safe use of recreational water.

B-2.2.2 Exposure Definitions

Regulatory entities and world health authorities have addressed exposures to recreational water by assessing two different exposure scenarios: primary contact recreation and secondary contact recreation. Each scenario is defined below.

B-2.2.2.1 Primary Contact Recreation

Primary contact recreation is defined as water-related recreational activities where there is a high degree of bodily contact with the water (e.g., where there is a high likelihood of full body contact and incidental ingestion of water). Full body contact refers to complete immersion in the water, including the head. Examples include swimming, rafting, certain kinds of kayaking, tubing, skin diving, surfing, skiing, and water play by children (69 FR 67217; USEPA, 2002, 2007c, and 2009f). Swimming is defined as having all upper body orifices exposed to the water (USEPA, 1984). The main route of exposure to illness-causing organisms during recreation in water is through accidental or incidental ingestion of contaminated water while engaging in these activities (USEPA, 1984; 69 FR 67217). Secondary routes of exposure include dermal contact and exposures to the eyes, ears, and nose.

B-2.2.2.2 Secondary Contact Recreation

Secondary contact recreation is defined as water-related activities where there is a low likelihood of skin contact and incidental ingestion. Examples include wading, fishing, and boating (USEPA, 2009e).

B-2.2.3 Current Recreational Water Microbiological Exposure Guidelines

B-2.2.3.1 Worldwide Guidelines

Recreational water exposure guidelines have been published for many countries throughout the world (EP/CPU, 2006; 69 FR 41719, 69 FR 67217; Pruss, 1998; USEPA, 1983, 1984, 1986, 1999c, 2000, 2002, 2003, 2004a and b, 2007a and c, 2008b; Wade et al. 2010; WHO, 1999, 2000, and 2003b). Table B-16 shows worldwide guidelines for select countries. Overall, the purpose of the guidelines is to protect human health during recreational water exposure. The guidelines are quantified in terms of indicator microorganisms, rather than individual pathogens. The indicator organisms specify a level of microbial water quality considered “safe” for human contact such as swimming.

Table B-16. Worldwide Recreational Water Quality Guidelines

Country	Primary Contact Recreation		
	Total Coliform	Fecal Coliform	Other
Brazil	80%<5000[m]	80%<1000[m]	ndr
Colombia	1000	200	ndr
Cuba	1000[a]	200[a] 90%<400	ndr
EEC[b], Europe	80%<500[c] 95%<10000[d]	80%<100[e] 95%<2000[d]	Fecal streptococci 100[c] Salmonella 0/liter[d] Enterococci 90%<100
Ecuador	1000	200	
France	<2000	<500	Fecal streptococci <100
Israel	80%<1000[g]	ndr	ndr
Japan	1000	ndr	ndr
Mexico	80%<1000[f] 100%<10000[k]	ndr	ndr
Peru	80%<5000[f]	80%	ndr
Poland	ndr		*E.coli*<1000
Puerto Rico	ndr	200[h] 80%<400	ndr
United States, California	80%<1000[ij] 100%<10000[k]	200[aj] 90%<400[l]	ndr
United States, EPA	ndr	ndr	Enterococci 35[a] (marine), 33[a] (fresh); *E.coli* 126[a] (fresh)
Former USSR	ndr	ndr	*E.coli* <100
UNEP/WHO	ndr	50%<100[n] 90%<1000[n]	ndr
Uruguay	ndr	<500[n] <1000[o]	ndr
Venezuela	90%<1000 100%<5000	90%<200 100%<400	ndr
Yugoslavia	2000		ndr

Legend: ndr = no data reported.

Notes:

[a] Logarithmic average for a period of 30 days of at least 5 samples
[b] Minimum sampling frequency-fortnightly
[c] Guide
[d] Mandatory
[e] Monthly average
[f] At least five samples per month
[g] Minimum 10 samples per month
[h] At least five samples taken sequentially from the waters in a given instance
[i] Period of 30 days
[j] Within a zone bounded by the shoreline and a distance of 1000 feet from the shoreline or the 30-foot depth contour, whichever is further from the shoreline
[k] Not a sample taken during the verification of 48 hours should exceed 10,000/100mL period
[l] Period of 60 days
[m] "Satisfactory" waters, samples obtained in each of the preceding 5 weeks
[n] Geometric mean of at least five samples
[o] Not to be exceeded in at least five samples

Source: Adapted from WHO, 1999, p. 5; and WHO, 2000, pp. 14-15.

B-2.2.3.2 The 1986 USEPA Fresh Recreational Water Quality Criteria and Subsequent Developments

In 1986, the USEPA published recreational water quality criteria for bacteria (see Table B-17) (USEPA, 1986). The criteria represent bacterial exposure guidelines for recreational activities in water. In particular, the criteria apply to primary contact recreational activities where full body contact with the water is assumed.

Historically accepted risk ranges for illness due to waterborne pathogens in recreational waters were used to derive the water quality criteria. At the time, the accepted risk level for exposure to fresh recreational water was 8×10^{-3} (0.8% or 8 acute gastrointestinal illnesses in 1000 persons exposed) (Regli et al. 1988; USEPA, 1986; 2004b; 2006, p. 45; 2009b, p. 25; and 2011b, p. 154). It is unknown whether these recreational water risk levels would be considered acceptable today (USEPA, 2009d).

Table B-17. USEPA 1986 Ambient Water Quality Criteria for Bacteria in Fresh Recreational Water

ENTEROCOCCI					
Risk Level (% of swimmers)	Geometric Mean Density	Single Sample Maximum Allowable Density (per 100 milliliter)			
		75th percentile	82nd percentile	90th percentile	95th percentile
0.8	33	62	79	107	151
0.9	42	79	100	137	193
1.0	54	101	108	175	247
E. Coli					
0.8	126	236	299	409	576
0.9	161	301	382	523	736
1.0	206	385	489	668	940

Note:
Source: USEPA, 1986 and 2009e.

The USEPA bacteria water quality criteria are for indicator organisms, specifically enterococci and *E. coli.* The criteria are defined as a concentration of the indicator above which the health risk from waterborne disease is unacceptably high (USEPA, 2003).

Indicator organisms are not generally pathogenic themselves (although pathogenic strains of *E. coli* are known to exist). Generally, pathogens are disease-causing microorganisms that include viruses, protozoa, bacteria, and helminths. Monitoring for most of these disease-causing pathogens is difficult and expensive. The USEPA recognized this and recommended indicators for monitoring recreational waters to protect human health from exposure to pathogens. Indicators have similar characteristics to pathogens (life span, similar responses to environmental conditions, come from the same species), but are not normally pathogenic.

In 2002, the USEPA published implementation guidance for ambient water quality criteria for bacteria (USEPA, 2002). The USEPA continued to support enterococci and *E.coli* as the best indicator organisms for protecting the public from water-borne illnesses in recreational water. The USEPA also continued to promote a shift away from fecal coliforms as an indicator.

Use of the geometric mean and a single sample maximum was discussed in the 2002 guidance (USEPA, 2002). The geometric mean is the value most closely linked to illness rates (see Figure B-2) (USEPA, 2009e). It is best used when a large number of samples are available.

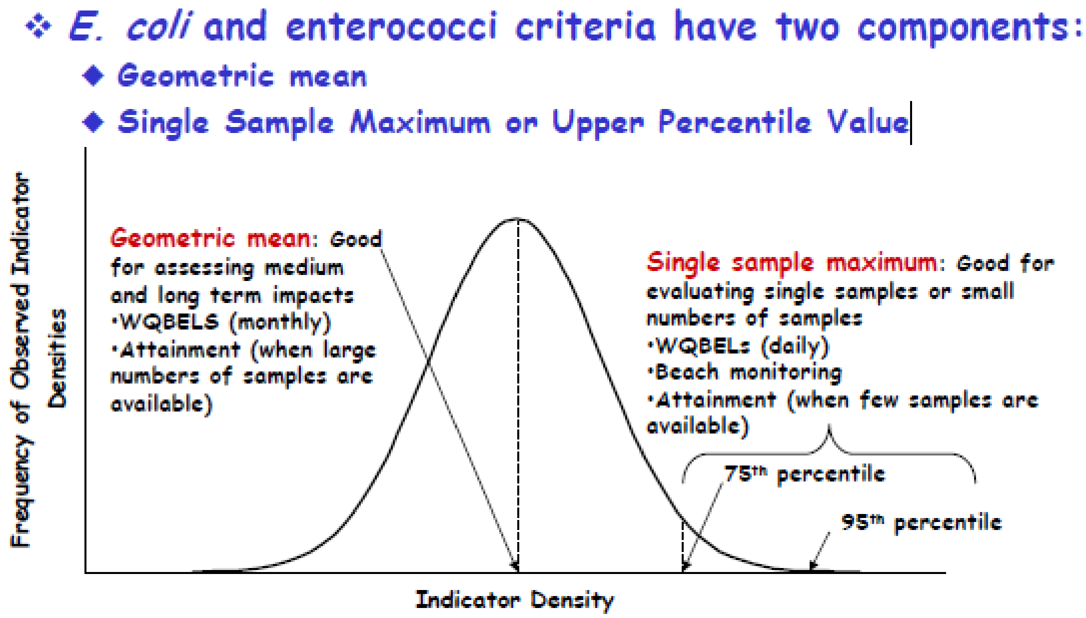

Figure B-2. The Geometric Mean and the Single Sample Maximum Concepts as They Apply to the Ambient Water Quality Criteria for Bacteria
Source: USEPA, 2009e

The single sample maximum represents the >75th percentile (USEPA, 2009e) (see Figure B-2). It is not intended to be used as a "not to be exceeded" value. Rather, the value is based on a percentile of the distribution around a chosen mean, which only a certain number of samples should exceed (USEPA, 2009e). It was intended to be used when evaluating a single sample, or a small number of samples.

The official recommended criteria are shown at the 0.8 risk level in Table B-17 (69 FR 67217; USEPA, 2009e). The differential risk concept (discussed in USEPA, 2002) allows flexibility to adopt risk levels up to 1.0 in fresh water, depending upon use. For example, the 75th percentile applies to a designated use beach with heavy use; the 82nd percentile applies to a moderate use beach; the 90th percentile applies to a light use beach; and the 95th percentile applies to an infrequent use beach. Presumably, the less a beach is used, the lower the recreational water exposure for the users.

In 2007, the USEPA compiled recommendations from scientific experts on critical research needs for the development of new or revised recreational water quality criteria (USEPA, 2007a). A science plan has been developed (USEPA, 2007c). Based on the results of the science plan, the USEPA should publish new recreational water quality criteria for microorganisms in 2012 (USEPA, 2009e).

B-2.2.3.3 The Revised (2012) USEPA Fresh Recreational Water Quality Criteria

In late 2011, the USEPA published a revision of the recreational fresh water criteria in a draft report (USEPA, 2011b). The geometric mean for *E. coli* remained essentially the same as the 1986 criteria (126 CFU/100 mL, see Table B-17). In addition, the USEPA introduced the concept of statistical threshold value (STV) and defined it as the upper 75th percentile of the water quality distribution. The STV for *E. coli* in fresh water was set at 235 CFU/100 mL, and essentially replaces the 75th percentile single sample maximum. Note that the STV is only 1 CFU smaller than the 75th percentile for the single sample maximum (236) shown in Table B-17. Therefore, there is almost no difference in the old and draft revised numerical criteria.

One important difference between the old (1986) and draft revised (2012) criteria is the concept of indicator/method. In the draft revised criteria, the USEPA links these two ideas and adds them to the criteria. Indicator organisms can be detected by different methods. Information on both the indicator organism and the method of detection is important because the detection method may result in different units of the organism. For example, the membrane filter method (a culture method) results in the number of CFU that arise from bacteria captured on the filter per volume of water. The substrate method (another culture method) produces a most probable number (MPN) per volume. Results for quantitative polymerase chain reaction (qPCR) analysis are reported in calibrator cell equivalent (CCE) units that are calculated based on the target deoxyribonucleic acid (DNA) sequence from test samples relative to those in calibrator samples that contain a known quantity of target organisms. Therefore, the draft revised criteria are stated as (USEPA, 2011b):

"*Culturable E. coli at a geometric mean of 126 CFU per 100 mL and a statistical threshold value of 235 CFU per 100 mL measured using EPA method 1603".*

Of special note in the draft revised criteria, the USEPA defined fecal indicator bacteria (i.e., *E. coli*) as pathogen indicators (i.e., substances that indicate the potential for human infectious diseases), even though they are not generally thought of as pathogen indicators.

The final version of the revised recreational water quality criteria was published in November 2012 (USEPA, 2012c) (see Table B-18).

Table B-18. USEPA 2012 Recreational Water Quality Criteria

Criteria elements	**Estimated illness rate (NGI): 36 per 1000 primary contact recreators**			**Estimated illness rate (NGI): 32 per 1000 primary contact recreators**	
	Magnitude			**Magnitude**	
Indicator	**GM (CFU/100 mL)[a]**	**STV (CFU/100 mL)[a]**		**GM (CFU/100 mL)[a]**	**STV (CFU/100 mL)[a]**
Enterococci-marine and fresh	35	130	OR	30	110
OR					
E. coli –fresh	126	410		100	320
Duration and Frequency: The water body GM should not be greater than the selected GM magnitude in any 30-day interval. There should not be greater than a 10% excursion frequency of the selected STV magnitude in the same 30-day interval.					

Legend:
CFU = colony forming units
GM = geometric mean
mL = milliliters
NEEAR = National Epidemiological and Environmental Assessment of Recreational Water
NGI = NEEAR gastrointestinal illness
STV = statistical threshold value
Note:
[a] USEPA recommends using EPA method 1600 to measure culturable enterococci or another equivalent method that measures culturable enterococci, and using EPA method 1603 to measure culturable *E. coli* or another equivalent method that measures culturable *E. coli*.

The 2012 criteria contain two sets of criteria. One set of criteria is for an illness rate of 36 National Epidemiological and Environmental Assessment of Recreational Water gastrointestinal illness (NGI) per 1000 recreators (the left side of Table B-18). These criteria correlate to water quality levels associated with the 1986 criteria. Although it is unknown whether these recreational water risk levels would be considered acceptable today, this illness rate has a history with the public. Another set of criteria is for an illness rate of 32 NGI per 1000 recreators (the right side of Table B-18). The USEPA published these criteria to encourage an incremental improvement in water quality in the future.

The National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) studies were epidemiological investigations conducted by the USEPA at U.S. beaches during 2003-2009 (USEPA, 2010c; Wade et al. 2008 and 2010). The purpose of the studies were to obtain and evaluate a new set of health and water quality data at a number of beaches for the new, rapid, state-of-the-art methods and to use the results to support the development of new or revised criteria for the protection of primary contact recreation. These studies used an updated definition of gastrointestinal (GI) illness, defining GI illness as (USEPA, 2010c):

"any of the following [within 10-12 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."

This illness definition is referred to as NGI and is the definition of illness associated with the 2012 recreational water quality criteria. Note that fever is not required for NGI, a departure from previous definitions of GI illness.

The geometric mean (GM) value corresponds to the 50th percentile and the Statistical Threshold Value (STV) corresponds to the 90th percentile of the same water quality distribution. [Note that in the draft 2012 criteria, the STV was the upper 75th percentile.] The USEPA recommends using both the GM and the STV because used together they would indicate whether the water quality is protective of primary contact recreation (i.e., full body contact). Using the GM alone would not reflect spikes in water quality and water quality variations over time. The GM is calculated in the same way recommended in the 1986 criteria. The STV is calculated in a manner similar to the single sample maximum in the 1986 criteria.

The USEPA states that (USEPA, 2012c):

"both criteria sets are protective of the designated use of primary contact recreation… Primary contact recreation typically includes activities where immersion and incidental ingestion are likely and there is a high degree of bodily contact with the water, such as swimming, bathing, surfing, skiing, tubing, skin diving, water play by children, or similar water-contact activities."

This indicates that the criteria are designed for unrestricted use of the water (i.e., full body contact) where the entire skin surface (to include the head, neck, and face) is wetted and incidental ingestion potentially would occur.

The USEPA derived the 2012 criteria for pathogen indicators, noting that the technical basis for using indicators is that pathogens often co-occur with indicators of fecal contamination. The USEPA also stated that at this time the state of the science is insufficient to publish criteria for pathogens. The concept of indicator/method and the definition of fecal indicator bacteria from the draft 2012 criteria were kept in the final 2012 criteria.

B-2.2.4 Health Effects Associated with Microbial Exposures in Recreational Water

B-2.2.4.1 Microbial Exposures and Gastrointestinal Illnesses

The story begins in 1924. In response to widespread demands for bathing place sanitation standards, the APHA recommended a total coliform criterion (200 CFU/100 mL) for public pools (APHA, 1924). This criterion was recommended because (APHA, 1924):

"the committee has presented certain evidences as to the causation of various transmissible diseases by the waters of poorly constructed and equipped or improperly operated swimming pools".

This was the first microbiological water quality standard to protect people from pathogens in recreational water.

From 1948-1950, the U.S. Public Health Service conducted health studies at beaches on Lake Michigan, the Ohio River, and Long Island Sound (USEPA, 2009e). As a result of these studies, this criterion was further revised and expanded in 1968 to read (National Technical Advisory Committee (NTAC), 1968):

"Based on a minimum of five samples taken over a 30-day period, the fecal coliform bacterial level in primary contact recreation waters should not exceed a log mean of 200 CFU per 100 mL, nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 CFU per 100 mL …. In waters designated for secondary contact recreation use, the fecal coliform content should not exceed a log mean of 1000 CFU per 100 mL, nor equal or exceed 2000 CFU per 100 mL in more than 10% of the samples".

The criterion was revised from total coliform to fecal coliform as the appropriate indicator. A recommended criterion for primary contact recreation was 200 CFU per 100 mL (log mean of ≥5 samples) and 400 CFU per 100 mL (≤10 % of samples). For secondary contact recreation, the recommended criterion was 1000 CFU/100 mL (log mean of ≥5 samples) and 2000 CFU/100mL (≤10 % of samples) (NTAC, 1968). These criteria were based on an epidemiologically detectable human health effect at the levels of 2300-2400 fecal coliforms per 100 mL identified in the Lake Michigan, Ohio River, and Long Island Sound studies (NTAC, 1968). The criteria were immediately challenged by the National Academy of Science citing a paucity of supporting data.

From 1972 to 1980, the USEPA conducted a series of epidemiological studies at freshwater and marine beaches. The purpose of the studies was to determine if a relationship existed between different bacteria indicators and swimming-related illnesses (namely acute gastrointestinal illness). In 1984, the USEPA reported their findings for fresh waters (USEPA, 1984). Conclusions of the report indicated that swimming associated gastrointestinal illnesses were directly linked to water quality impairments caused by sewage and that the illnesses were prevalent when concentrations of enterococci and *E. coli* bacteria were high (see Figures B-3 and B-4). A relationship with fecal coliform was not found. The study also concluded that the rate of illness in swimmers can be estimated when using either *E. coli* or enterococci as an indicator.

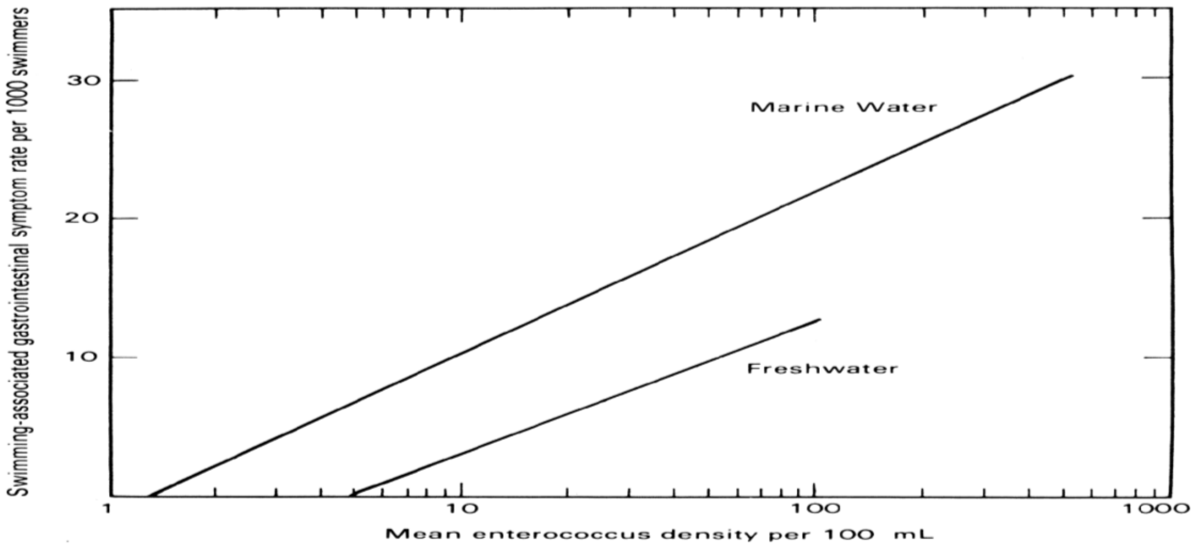

Figure 9. Marine and freshwater criteria for swimming-associated gastrointestinal illness and water quality using enterococci to measure the water quality. (Marine data obtained from Table 7, Reference 6.)

Figure B-3. Mean Enterococcus Density/Swimming Associated Illness Relationship for Fresh Recreational Waters
Source: USEPA, 1984

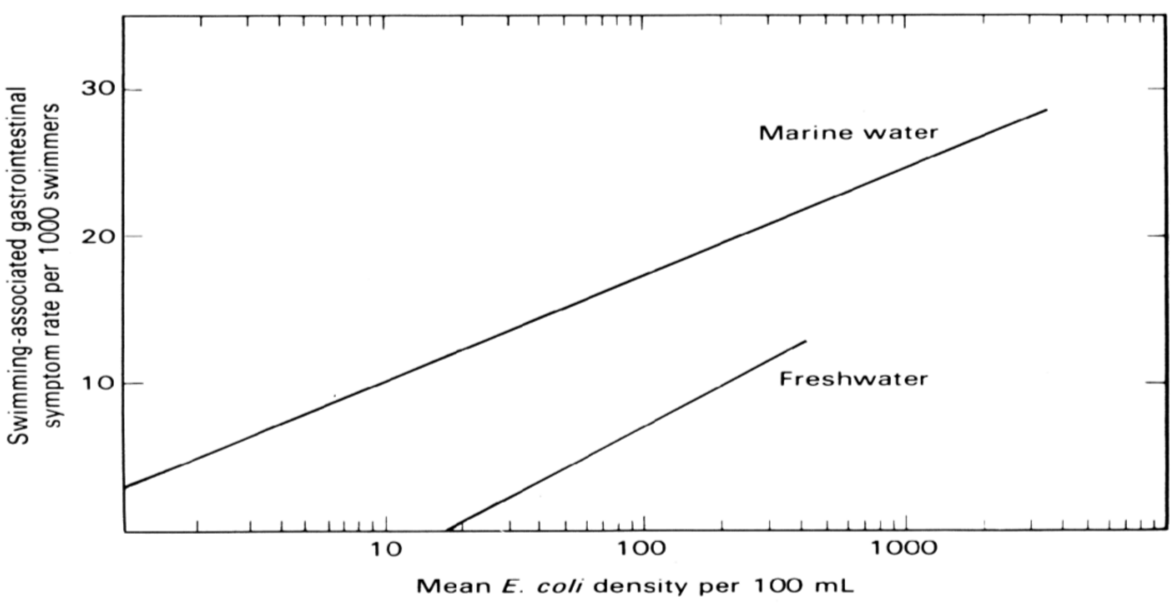

Figure 10. Marine and freshwater criteria for swimming-associated gastrointestinal illness and water quality using *E. coli* to measure the water quality. (Marine data obtained from Table 9, Reference 6.)

Figure B-4. Mean *E. Coli* Density/Swimming Associated Illness Relationship for Fresh Recreational Waters
Source: USEPA, 1984

The USEPA concluded that the newly recommended indicator organisms, enterococci and *E. coli*, were superior to the fecal coliform group (USEPA, 1984, 1986, and 2009e). The USEPA reasoned that there was a positive relationship between bacterial density and the number of observed illnesses for enterococci and *E. coli* indicators, while no such relationship was observed for fecal coliform. The USEPA did not address how to implement the criteria for secondary contact recreational activities and exposures.

The results of a worldwide literature review on the subject were consistent with the conclusion of USEPA (1984). Pruss (1998) states:

"*The indicator microorganisms that correlate best with health outcomes were enterococci/fecal streptococci for both marine and fresh water, and E. coli for fresh water".*

A causal relationship between illness and indicator organism (enterococci, fecal streptococci, *E. coli)* concentration was identified. Pruss (1998) states:

"The review of 22 selected studies suggests that there is a causal relationship between the gastrointestinal symptoms and recreational water quality, measured by indicator bacteria concentration, because they report a strong and consistent association with temporality and dose-response relationships, as well as biological plausibility and analogy to clinical cases in drinking water pollution".

Pruss (1998) also identified a low indicator organism threshold for illness:

"In both marine and fresh water, increased risk of gastrointestinal symptoms was reported for water quality values ranging from only a few indicator counts/100 mL to about 30 indicator counts/100 mL…This suggests a low threshold value for increased risk compared to water qualities frequently encountered in coastal recreational waters and suggests the existence of dose-response relationships between the bacterial count and symptoms".

In 2003, results of another independent study were consistent with USEPA. Wade et al. (2003) reviewed 976 potentially relevant studies in an attempt to quantify the association between microbial indicators, recreational water quality, and gastrointestinal illness. It was found that, in fresh water, *E. coli* was a more consistent predictor of gastrointestinal illness than enterococci or other bacterial indicators. Conclusions of the study indicated that enterococci and *E. coli* are adequate indicators of gastrointestinal illness, but fecal coliforms are not.

In 2006, swimming-related gastrointestinal illness rates were found to be significantly associated with fecal contamination, as measured by quantitative polymerase chain reaction (qPCR) (Wade et al. 2006). Results showed that Enterococcus, measured by qPCR, can predict gastrointestinal illness after swimming in fecally contaminated fresh recreational water. This was the first study to show that water quality measured by rapid methods (≤ 2 hours) can predict swimming-associated health effects.

In 2009, the USEPA National Health and Environmental Effects Research Laboratory (NHEERL), in collaboration with the National Exposure Research Laboratory (NERL), reported on epidemiology work that studied beach-goers health, and measured water quality with new and faster ways of testing for microbial indicators of health effects (USEPA, 2009f). This work is part of the NEEAR Study (see the website: http://www.epa.gov/nheerl/neear/.). The primary goal of the study was to describe associations between water quality indicators and health effects at beaches impacted by urban runoff and sewage treatment. These studies have demonstrated that fecal indicator bacteria, measured by qPCR, were associated with gastrointestinal illness at beach swimming sites with nearby treated sewage discharges. Results indicated that the overall incidence of symptoms appears to be consistent with what has been previously observed, at least for gastrointestinal illness (the symptom most frequently associated with recreational water exposure) (Pruss, 1998; Wade et al. 2003).

In 2010, an epidemiological study was conducted at three sewage-impacted marine beaches in the U.S. (Wade et al. 2010). The study investigated the relationship between the fecal indicator bacteria

Enterococcus (using qPCR methods) and illness among swimmers. Gastrointestinal illness, upper respiratory illness, rash, eye irritations, and earache were all defined and considered health endpoints to be evaluated. Exposure to recreational water was called swimming and it was defined as “body immersion to the waist or higher” (Wade et al. 2010). Recreational water samples were collected and qPCR analytical methods were used to obtain microbiological sample results. Study results indicate that the occurrence of gastrointestinal illness among swimmers was associated with an increase in exposure to qPCR-determined estimates of Enterococcus; the relationship between indicators and other non-gastrointestinal illnesses were not statistically significant. This study provides the first evidence of a relationship between gastrointestinal illness and Enterococci determined by qPCR methods in marine recreational water.

Throughout the entire history of recreational water quality criteria development, the recommended microbial water indicator levels have been a response to sewage contaminated water (i.e., water contaminated from human sources). Only recently has USEPA begun assessing microbial contamination in recreational waters from other sources such as domestic animals. In 2007, this issue was discussed at an expert’s workshop (USEPA, 2007a). The experts could not conclusively say that nonhuman sources were less risky to humans, and suggested more research in this area. In 2010, the results of a quantitative MRA evaluating agricultural animal sources of contamination on water quality were published (USEPA, 2010b). This report indicated that the risk of illness from recreational water impacted by animal microbial contamination (cattle, pigs, and chickens) is equivalent to or less than the risk identified in the 1986 criteria.

B-2.2.4.2 Microbial Exposures and Non-Gastrointestinal Illnesses

For the literature reviewed, it is important to note that studies relating fresh recreational water exposures to specific illnesses other than gastrointestinal (e.g., skin rashes, pink eye, etc.) appear to be rare. A search of U.S. medical databases for recreational water exposure related illnesses was not conducted. Rather, a limited search was conducted that focused on recreational water quality criteria and the underlying scientific basis for the criteria. The primary exposure route considered in these studies was incidental or accidental ingestion of recreational water.

It is suspected that dermal and orifice exposures to microbes in recreational water during swimming will result in non-gastrointestinal illnesses. A cause-effect relationship between fecal-derived recreational water pollution and Acute Febrile Respiratory Illness (AFRI) and general respiratory illness is biologically plausible (WHO, 2003b). A significant dose-response relationship (between AFRI and fecal streptococci) has been reported (Fleisher et al. 1996). When compared with gastroenteritis, probabilities of contracting AFRI are generally lower, and the threshold at which illness is observed is higher (WHO, 2003b).

A cause-effect relationship between fecal-derived pollution and ear infections is biologically plausible (WHO, 2003b). Associations between ear infections and microbiological indices of fecal pollution and bather load have been reported (Fleisher et al. 1996). When compared with gastroenteritis, the statistical probabilities are generally lower and are associated with higher fecal indicator concentrations than those for gastrointestinal symptoms or AFRI.

Increased rates of eye symptoms have been reported among swimmers, and evidence suggests that swimming, regardless of water quality, compromises the eye’s immune defenses, leading to increased symptom reporting in marine waters (WHO, 2003b). Despite biological plausibility, no credible evidence for increased rates of eye ailments associated with water pollution is available (Pruss, 1998).

Some studies have reported increased rates of skin symptoms among swimmers, and associations between skin symptoms and microbial water quality have also been reported (Ferley et al. 1989). Controlled studies, however, have not found such association and the relationship between fecal contamination in recreational water and skin symptoms remains unclear (WHO, 2003b).

A more expanded literature search may find a broader range of recreational water related illnesses.

B-2.3 Water Reuse and Human Health Effects-Basic Relationships

B-2.3.1 Turbidity and Health Effects

Turbidity is a measure of the relative clarity of water. Turbidity in water is caused by suspended and colloidal matter, such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. However, turbidity is not a direct measure of particles suspended in the water. It is, rather, a measure of the scattering effect that such particles have on light. In samples containing suspended solids, the manner in which water interferes with light transmittance is related to the size, shape and composition of the particles in the water and to the wavelength (color) of the light that falls on the particles (incident light).

The microbiological quality of wastewater can be significantly affected by turbidity. Microbial growth in water is most extensive on the surfaces of particles. This growth occurs because nutrients adsorb to surfaces which allows bacteria to grow more efficiently than in free suspension.

Excessive turbidity may represent a health concern for people who are exposed to reused nonpotable water. Microbes attach to the particulate material and inert substances contributing to turbidity; the particles provide shelter for microbes by reducing their exposure to attack by chlorine and other disinfectants (Marshall, 1976; Olson et al., 1981; Herson et al., 1984). Although turbidity is not a direct indicator of health risk, numerous studies have shown a strong relationship between the removal of turbidity and the removal of pathogens (USEPA, 1999b). For example, LeChavallier and Norton (1992) investigated source water (raw water from the Ohio River) that had turbidities ranging from 1-120 Nephelometric Turbidity Units (NTU). After filtration, pathogen levels dropped by 2.5 log (319 times). This suggests that, although very low turbidity values do not completely ensure pathogens are absent, it is a good surrogate measure for human health protection.

Other than recreational water studies, no known studies have addressed the human health risk issue of using moderate turbidity nonpotable water (from 10-50 NTU) for a variety of purposes where a certain degree of human skin contact, ingestion, and inhalation is involved. The Soldier faces this issue in the field faces when conducting tasks such as dust control, vehicle washing, concrete mixing, and soil compaction, where potable water is either not available or is scarce. The Soldier needs to determine, with the analytical equipment available to him in the field, if the water is safe to use.

B-2.3.2 Turbidity and Microorganism Relationship

Microorganism counts have been shown to be positively correlated to turbidity (see Figure B-4). This relationship has been documented for ambient surface water (LeChevallier and Norton, 1992; Christensen et al., 2001), storm water (WHO, 1999), wastewater (USEPA, 2004a), drinking water (Health Canada, 2003), and in drinking water distributions systems (Reilly and Kippin, 1983). It has been documented for turbidities ranging from 1-120 NTU (LeChevallier and Norton, 1992), and for microorganisms such as bacteria, protozoa, viruses, and helminths (LeChevallier and Norton, 1992; Reilly and Kippin, 1983). This relationship (Figure B-5) indicates that reuse of some source waters by Soldiers in the field may present a health risk if skin contact, inhalation, or ingestion of the water occurs. Disinfection is therefore a prudent part of nonpotable water reuse.

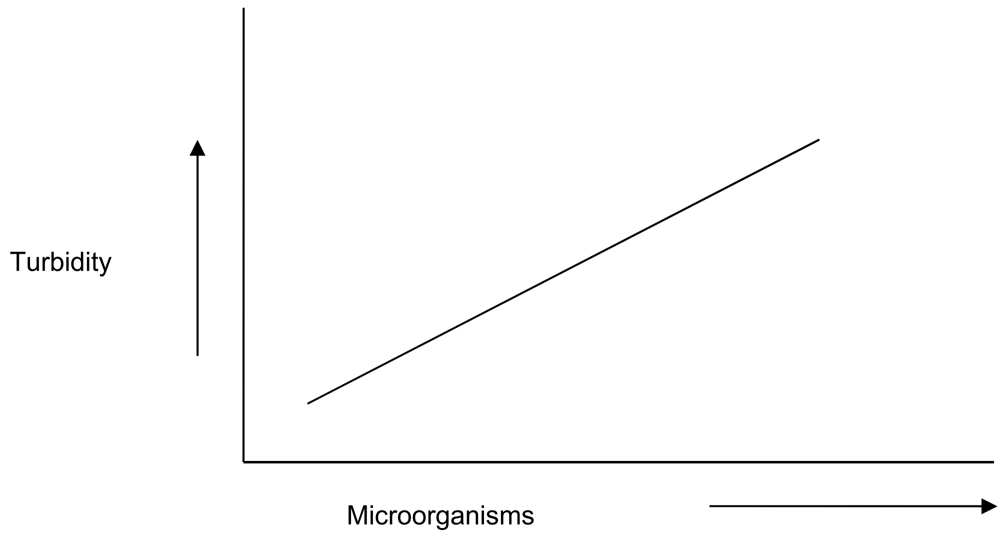

Figure B-5. Relationship Between Turbidity and Microorganisms

LeChevallier and Norton (1992) examined the relationship among turbidity, bacteria, Giardia, and Cryptosporidium. They found that: (1) turbidity is a good surrogate for water quality, and (2) total coliform, fecal coliform, Giardia, and Cryptosporidium concentrations are positively correlated with turbidity in raw (unfiltered) water.

B-2.3.3 Turbidity and Chlorine Residual Relationship

As the turbidity of a given source water increases, chlorine disinfection (for a given dose and contact time) should become increasingly difficult and eventually become ineffective (i.e., the chlorine residual values should drop to zero) at some level of turbidity (see Figure B-6). This is due to the fact that chlorine is consumed by particles and microorganisms in the water (chlorine demand). At some point, the solids in the water (at a high enough turbidity) will overwhelm the chlorine and consume all of it, thus eliminating the chlorine residual. With no chlorine residual to counteract them, pathogenic microorganisms could be present and viable. When human skin contact, ingestion, or inhalation occurs or is likely, nonpotable water will be safe for Soldiers to use only if a chlorine residual can be maintained. It would therefore be beneficial to know if a turbidity threshold in nonpotable water exists for maintaining a chlorine residual. The turbidity range below the threshold may represent water quality suitable for reuse by Soldiers.

Suspended matter that causes turbidity in water (e.g., organic, inorganic, higher microorganisms) can protect bacteria and viruses from the effects of disinfection. LeChevallier et al. (1981), studying the efficiency of chlorination in killing coliforms in unfiltered surface water supplies, found a negative correlation with turbidity. A derived model predicted that an increase in turbidity from 1-10 NTU would result in an eight-fold decrease in the disinfection efficiency at a fixed chlorine dose. A study by the USEPA, which examined the efficiency of disinfection at turbidities of 1-5 NTU on poliovirus and sewage effluent coliforms, found that viruses and coliforms that adsorbed to organic matter were more resistant to disinfection than those that adsorbed to inorganic material such as clay and aluminum phosphate (USEPA, 1978). For organic particulates, a reduction of turbidity from 5-1 NTU reduced the concentrations of disinfectant-resistant organisms approximately five-fold.

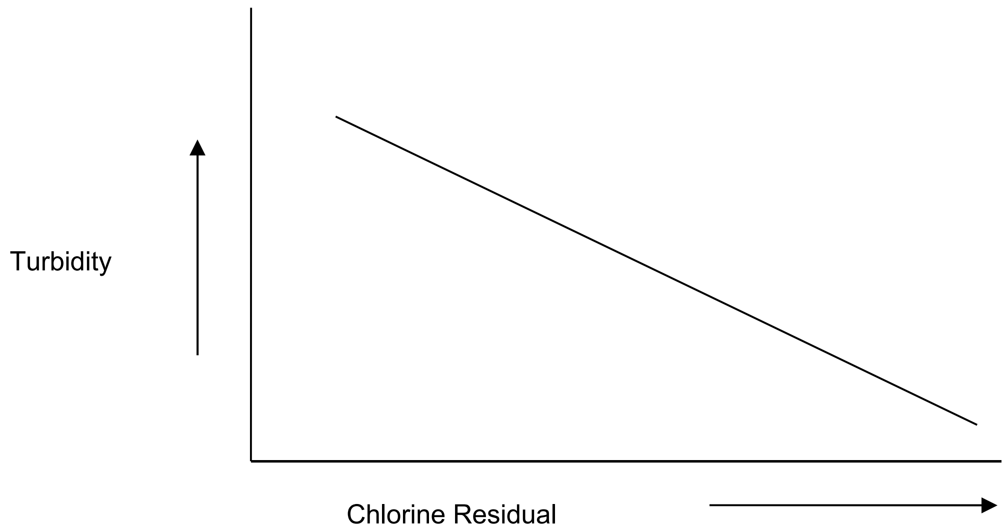

Figure B-6. Relationship Between Turbidity and Chlorine Residual

Chlorine (as hypochlorous acid) reacts readily with organic matter containing unsaturated bonds, phenolic groups and nitrogen groups, giving rise to taste- and odor-producing compounds (Sawyer and McCarty, 1967) and trihalomethanes (Rook, 1977). Hence, waters with high turbidity from organic sources, such as wastewater, may give rise to a substantial chlorine demand. This could result in reductions in the free chlorine residual and reduce the effectiveness of chlorine as a disinfectant.

B-2.3.4 Turbidity and TSS Relationship

There is no direct correlation between turbidity and TSS. However, both can provide a general measure of the source water quality. State regulators sometimes require turbidity measurements for monitoring of source water in certain reuse applications. An approximate relationship between TSS and turbidity for treated wastewater is described below (USEPA, 2004a, p. 402).

Secondary effluent: TSS (mg/L) = (2 to 2.4) x turbidity units
Tertiary effluent: TSS (mg/L) = (1.3 to 1.6) x turbidity units

B-2.3.5 Microbial Indicator Organisms and Health Effects

B-2.3.5.1 General

The use of indicator organisms that signal the presence of pathogens in water has been used successfully for a long time. The fecal indicator bacteria most commonly used today are enterococci, *E. coli*, and fecal coliforms. However, there are still uncertainties about how microbial water quality is measured and monitored, and how a number of environmental and physical factors may influence the usefulness of fecal bacteria as indicators. No single indicator or approach is likely to represent all of the facets and issues associated with nonpotable water reuse. Table B-19 provides an overview of possible indicators and describes their strengths and weaknesses.

At the moment, the Soldier in the field does not have the capability to measure pathogens directly. This situation is not likely to change in the near future. The Soldier will most likely have to rely on one or more of the indicators in Table B-19 to measure and monitor water quality and make a determination when nonpotable water is safe to reuse.

Table B-19. Indicator Organisms Used to Identify the Presence of Pathogens

Indicator/use	Function	
	Pros	**Cons**
Fecal Streptococci/ Enterococci	Marine and potentially freshwater human health indicator. More persistent in water and sediments than coliforms. FS may be cheaper than enterococci to assay.	May not be valid for tropical waters due to potential growth in soils.
Thermo-tolerant coliforms	Indicator of recent fecal contamination.	Possibly not suitable for tropical waters due to growth in soils and waters. Confounded by nonsewage sources (e.g., Klebsiella spp in pulp and paper wastewaters)
E.Coli	Potentially a freshwater human health indicator. Indicator of recent fecal contamination. Potential for typing *E. coli* to aid in sourcing fecal contamination. Rapid identification possible if define as β-glucuronidase producing bacteria.	Possibly not suitable for tropical waters due to growth in soils and waters.
Sulphite-reducing clostridia/ *Clostridium perfringens*	Always in sewage-impacted waters. Possibly correlated with enteric viruses and parasitic protozoa. Inexpensive assay with H_2S production.	May also come from dog feces. May be too conservative an indicator. Enumeration requires anaerobic culture.
Somatic coliphages	Standard method well established. Similar physical behavior to human enteric viruses.	Not specific to sewage. May not be as persistent as human enteric viruses. May grow in the environment.
F-specific RNA phages	Standard ISO method available. More persistent than some coliphages. Host does not grow in environmental waters below 30^0C.	Not specific to sewage. Host may lose plasmid. Not as persistent in marine waters.
Bacteroides fragilis phages	Appears to be specific to sewage. ISO method recently published. More resistant than other phages in the environment and similar to hardy human enteric viruses.	Requires anaerobic culture. Numbers in sewage are lower than other phages, and most humans do not excrete this phage (hence no value for small populations).
Fecal sterols	Coprostanol largely specific to sewage. Coprostanol degradation in water similar to die-off of thermotolerant coliforms. Ratio of 5β/5α stanols >0.5 is indicative of fecal contamination (i.e., coprostanol/5α-cholestanol >0.5 indicates human fecal contamination). C_{29} 5β (24-ethylcoprostanol)/5α stanol ratio / 0.5 indicates herbivore feces. Ratio of coprostanol: 24-ethylcoprostanol can be used to indicate the proportion of human fecal contamination, which can be further supported by ratios with fecal indicator bacteria (Leeming et al., 1996)	Requires gas chromatographic analysis and is expensive (about $100/sample). Requires up to 10 liters of sample to be filtered through a glass fiber filter (Whatman) to concentrate particulate stanols.
Turbidity	Simple, direct and inexpensive assay available in the field.	May not be related to sewage; correlation must be shown for each site type.
Cryptospor-idium (Animal sourced pathogens)	Required for potential zoonoses, such as Cryptosporidium *spp*., where fecal indicator bacteria may have died out, or not present.	Expensive and specialized assay (e.g., USEPA Method 1622). Human/animal speciation of serotypes not currently defined.

Note: Source: WHO, 1999, page 9.

Perhaps the best overall discussion of indicators for assessing microbial water quality and human health is found in a WHO document (WHO, 2001). Development of indicators (including the coliforms, streptococci, enterococci, sulphite-reducing clostridia and other anaerobes, bacteriophages, and fecal sterol biomarkers) from the 19th century to the present are explained. Newer methods for indicator organism development (chromogenic substances, monoclonal and polyclonal antibodies, gene-sequencing, immunomagnetic separation, fluorescent markers) are also covered.

B-2.3.5.2 Worldwide Use and Research Results

The WHO uses enterococci as the fecal indicator of choice for protecting human health from exposure to recreational water (USEPA, 2007a; WHO, 2003b). The U.S. and the European Union use a combination of enterococci and *E. coli* for evaluating pathogen presence in recreational waters (69 FR 67217; USEPA, 2007a).

Based on an extensive literature review, Tyagi et al. (2006) identified the four most significant indicators of microbial water contamination: (1) *E. coli*, (2) enterococci, (3) coliphages, and (4) Clostridium perfringens. Tyagi et al. (2006) state:

"The study of these four indicators will reveal the total spectrum of waterborne pathogens. E. coli and enterococci indicate the presence of bacterial pathogens; coliphages indicate the presence of enteric viruses; and Clostridium perfringens, an obligate anaerobe, indicates the presence of parasitic protozoan and enteric viruses".

These researchers conclude that monitoring a suite of indicators (*E. coli*, enterococci, coliphages, and Clostridium perfringens) in wastewaters and reclaimed waters is more likely to be predictive of the presence of certain pathogens, and thus protective of public health. No other single indicator or combination of indicators is a better predictor of pathogen presence.

This is consistent with the results of Harwood et al. (2005). The validity of using a suite of indicator organisms (total and fecal coliforms, enterococci, Clostridium perfringens, and F-specific coliphages) to predict the presence or absence of pathogens (infectious enteric viruses, Cryptosporidium, and Giardia) was tested at six wastewater reclamation facilities. No strong correlation was found for any single indicator-pathogen combination. When data for all indicators were tested using discriminant analysis, the presence/absence patterns for Giardia, Cryptosporidium, and infectious enteric viruses were predicted in over 71% of wastewaters. Harwood et al. (2005) states:

"Public health is not adequately protected by measuring single indicator organisms… monitoring for a suite of indicator organisms in wastewater is more likely to be predictive of the presence of certain pathogens".

Other researchers, studying recreational water, do not entirely agree. Considering indicators and methods for measuring fecal contamination in recreational water, USEPA (2007a) states:

"using suites of pathogens as the basis for new or revised criteria was not favored among workshop participants as a first line-of-defense".

These researchers based their judgment on the very high spatial and temporal variability of concentrations and types of pathogens in natural ambient waters (rivers, lakes, beaches, reservoirs, etc.). This assumption may not be valid for wastewaters being considered for nonpotable reuse by the Soldier in the field. The types and concentrations ranges of pathogens in wastewaters are fairly well known (see paragraph B-2.1).

B-2.4 The U.S. Army Situation

B-2.4.1 Wastewater at FOBs

B-2.4.1.1 General

Direct knowledge of specific wastewater disposal or reuse activities at overseas FOBs can only be obtained by individuals visiting the bases. Indirect knowledge about wastewater activities at FOBs comes from published open literature reports and returning Soldiers. Even indirect knowledge is sketchy because little has been formally written and returning Soldiers have not had specific wastewater or water reuse missions at FOBs. These limitations cloud attempts to provide detailed information about nonpotable water reuse at FOBs.

Just like communities in the U.S., FOBs generate wastewater (black water and gray water). Measures at individual FOBs for generating and managing wastewater will differ according to the FOB population, general standards, contractor services, and location (Noblis, 2010). As a general rule, the smaller and more austere the FOB, the more primitive the methods employed for managing wastewater (Noblis, 2010). The smaller and more austere FOBs tend to separate gray water and black water. The more sophisticated FOBs will combine gray water and black water and pipe it to a wastewater treatment facility. Military sources for information and topics related to field wastewater are shown in Table B-20. Note that some of these military sources discuss water reuse, but none have risk-based water reuse standards or guidelines that apply overall to the U.S. Army.

Table B-20. Military Source Documents for Various Topics Related to Field Wastewater

Source, Date	Title of Document	Topic Covered	Chapter, Pages
TB MED 593, (DA, 2006b)	Guidelines for Field Waste Management	Human waste disposal methods	Chapter 6
		Wastewater, black water, and gray water definitions, nonpotable water reuse standards, wastewater disposal methods	Chapter 7
TB MED 577, (DA, 2010a)	Sanitary Control and Surveillance of Field Water Supplies	Water recycle and reuse, including gray water reuse standards for Force Provider base camps.	Chapter 9
FM 4-25.12, (DA, 2002)	Unit Field Sanitation Team	Field methods for human solid and liquid waste disposal	Chapter 2, section IV, and Appendix A
FM 8-10-15, (DA, 1997)	Employment of the Field and General Hospitals	Field wastewater sources, collection, and disposal, including human waste	Appendix C
TM 3-34.70, (DA 2012)	Plumbing, Pipe Fitting, and Sewerage	Field wastewater and human waste collection and disposal	Section 1
FM 4-20.07, (DA, 2008)	Quartermaster Force Provider Company	Gray and black water collection and disposal for Force Provider base camps	Section 2
FM 3-34.5/ MCRP 4-11B, (DA, 2010b)	Environmental Considerations	Composite risk management concept	Section 2
		Predeployment and deployment training and guidance in handling, storage, transporting, and disposing gray water	Section 3
		Base camp operations, including field sanitation and dust suppression	Appendix G
TM 5-814-8, (DA, 1987)	Evaluation Criteria Guide for Water Pollution Prevention, Control, and Abatement Programs	Domestic and industrial wastewaters processed at a wastewater treatment plant	Entire document
		Wastewater characteristics	Chapter 3
		Wastewater disposal alternatives	Chapter 5
		Primary and secondary treatment	Chapter 6
TM 5-814-3, (DA, 1988)	Domestic Wastewater Treatment	Operation of a wastewater treatment plant	Entire document
		Wastewater characteristics	Chapter 4
		Wastewater treatment plant processes	Chapter 5
		Military treatment systems	Chapter 7
		Characteristics of treatment plants	Chapters 9-15
		Sludge handling	Chapter 16
		Wastewater disinfection	Chapter 17
FM 4-25.12, (DA, 2002)	Unit Field Sanitation Team	Field waste management, including human waste and wastewater	Chapter 7
MIL-HDBK-1165, (Department of Navy, 1997)	Military Handbook, Water Conservation	Water conservations techniques related to toilets, urinals, showerheads, faucets, washing machines, dishwashers, garbage disposals, washracks, and irrigation	Section 5
		Defines black water and gray water	p. 76
		Brief discussion of water reuse	p. 76

B-2.4.1.2 Black Water

Table 21 lists black water and wastewater treatment methods at FOBs and their relative sophistication.

Table B-21. Wastewater Treatment Methods Used at FOBs in Iraq and Afghanistan

Method	Technology Level
Burn out latrines	Primitive treatment
Chemical latrines	
Sewerage lagoons	
Septic system and leach fields	
Wastewater treatment facility	Advanced treatment

Note:
Source: Noblis, 2010.

When base camps are first established, human waste is disposed of by expedient methods such as burn-out latrines (see Figure B-7). The waste is “treated” by adding fuel to the wastes and setting it on fire. This method of handling human waste is unsafe, creates air pollution, and consumes valuable fuel.

Figure B-7. Waste Burn-Out Activity with Latrine in Background
Improvements to Burn-Out Latrine Technology are Shown in Figure B-8
Source: USACE, 2008

Figure B-8. Automated Burn-Out Latrine
Concept Design 2000 Portable Incinerating Toilet with Single Commode Stall
Source: USACE, 2008

As the base camp matures, burn-out latrines are usually replaced with chemical toilets, or latrines with flush toilets that drain to storage tanks or septic tanks (U.S. Army Corps of Engineers (USACE), 2008). Because these facilities require a contractor to pump the waste, the contractor's vacuum truck must enter the camp frequently. This is a security risk and a burden on camp security personnel.

Structures with flush toilets draining to septic systems require leach fields. Leach fields are usually sited quickly with little thought given to soil suitability (USACE, 2008). Septic systems also have to be pumped. Septic systems are designed for specific flows. However, since base camp populations are not stable, flow surges often overload the systems.

When base camps are occupied for long-term use, wastewater collection and treatment systems are constructed. These may range from temporary aboveground piping that empties into a lagoon (see Figures B-9 and B-10) to permanent buried piping that feeds into a package wastewater treatment plant (Figure B-11).

Typically, burn out latrines, chemical latrines, and septic systems will contain black water only. Sewerage lagoons and wastewater treatment facilities will contain wastewater (a combination of gray water and black water).

Figure B-9. Dumping of Wastewater in a Lagoon in Iraq
Source: USACE, 2008

Figure B-10. A Facultative Lagoon
Source: USACE, 2008

Figure B-11. Wastewater Treatment System for an FOB
Source: USACE, 2008

B-2.4.1.3 Gray Water

At some FOBs, gray water and black water are collected and stored separately (see Figure B-12). Wastewater from showers, sinks, baths, and laundry is piped to individual blivets or large onion skin bags. This segregation allows for separate collection, treatment, and possible reuse of gray water.

Figure B-12. Water Storage Bladders (Onion Skin Bags)

Laundry units at the more mature FOBs are generally less sustainable. Segregation of gray water for separate treatment followed by recycle and reuse is not yet standard procedure at all base camps (Noblis, 2010).

B-2.4.1.4 Force Provider Base Camps

Some FOBs are set up using Force Provider Base Camps (a high quality deployable base camp to support expeditionary missions). The term “base camp in a can” is an apt description of Force Provider. Packaged and folded up, it will fit in the cargo section of a C130 military transport plane. After assembly, it is a complete base camp, and includes 71 separate deployable systems including eight latrine systems, eight shower systems, four kitchen systems, a containerized batch laundry system, and two wastewater evacuation trailers (DA, 2008) (see Figure B-13).

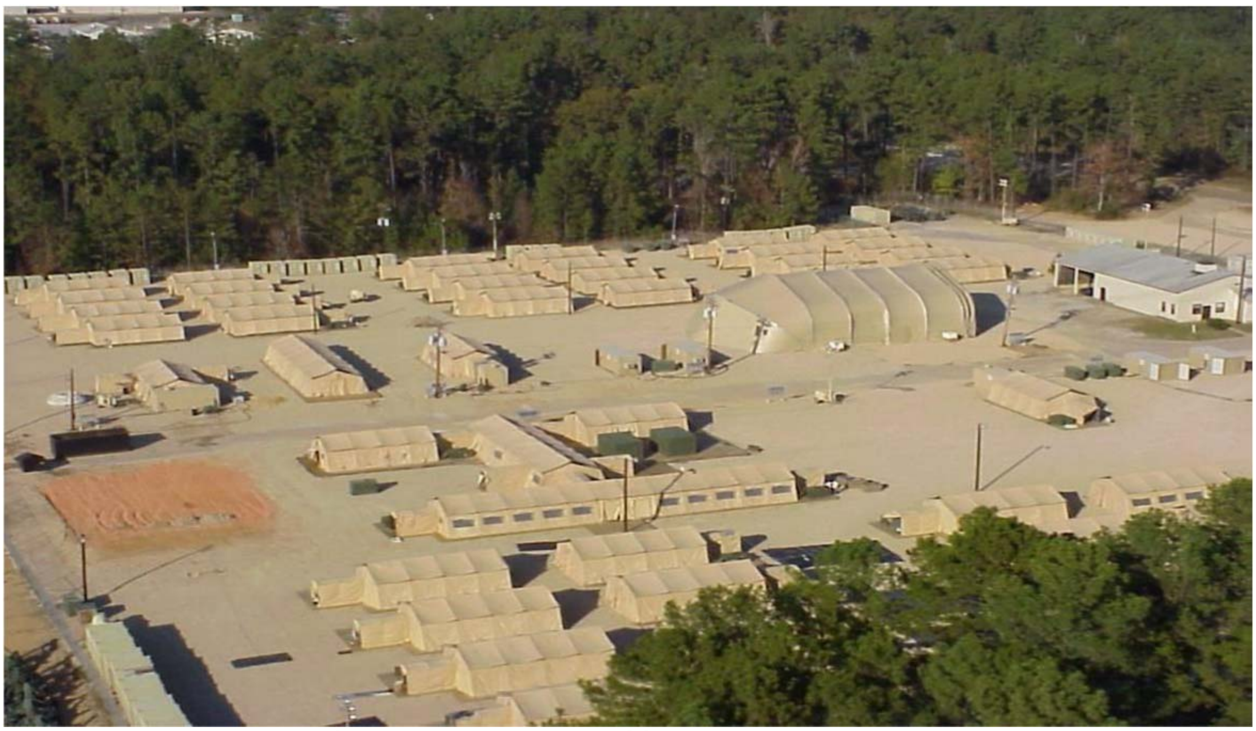

Figure B-13. Force Provider Base Camp System
Source: TARDEC, 2009

Force Provider and Quartermaster Corps laundry units have equipment that is designed to reuse wastewater. Deployable laundry equipment can store rinse water for reuse as wash water. A new deployable shower water recycle system developed at the Natick Soldier Center incorporates the Tactical Water Purification System (TWPS) technology. The system will handle 12,000 gallons/day from the Force Provider shower subsystem. Seventy-five percent of the shower water is recycled.

The U.S. Army Public Health Command (USAPHC) has been involved in a number of initiatives to evaluate the health implications and develop guidance and standards for reuse of various gray waters for showering. One study involved the Force Provider shower water recycling system (U.S. Army Aberdeen Test Center (USAATC), 2008). Working with the USAATC and Developmental Test Command, the USAPHC confirmed the operational performance of the Force Provider Shower Water Reuse System and its ability to produce product water of acceptable quality (USAPHC, 2010a).

B-2.4.1.5 Wastewater Amounts

The amount of wastewater generated at FOBs also varies with the size of the FOB. Estimates range from 1.5 to 44 gallons of wastewater per person per day (Noblis, 2010). On average, 15% of all wastewater is black water, with gray water making up the remaining 85% (Noblis, 2010; Research, Development and Engineering Command, 2010).

B-2.4.1.6 Ongoing Water Reuse Initiatives

Two research and development efforts in the area of wastewater reuse at FOBs are currently ongoing. The Strategic Environmental Research and Development Program (SERDP) issued a statement of need to develop onsite sustainable wastewater treatment at FOBs (SERDP, 2011). The U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC) issued a contract proposal to develop expeditionary gray water reuse technologies (Small Business Innovative Research, 2011).

B-2.4.1.7 Nonpotable Water Reuse at FOBs

Others who have studied wastewater issues at FOBs in Iraq and Afghanistan have concluded that nonpotable water reuse would enhance the Soldiers' ability to accomplish their mission. They have stated (Noblis, 2010):

"a deployable and easy-to-use water reclamation station, which transforms wastewater into reusable water within the base, would improve the base environment, security, Soldier's health, stewardship of foreign lands, and concurrently reduce costs and fresh water demand from off-base sources".

At this time, there are no military-specific nonpotable water quality standards that quantify or estimate the health risks from exposure to pathogenic microorganisms. In addition, current analytical water quality monitoring equipment may be inadequate. To protect the Soldier from potential and actual health risks from exposure to pathogens, the Soldier needs: (1) nonpotable water quality standards for military specific exposure scenarios, (2) appropriate analytical monitoring equipment, and (3) specific guidance on nonpotable water reuse.

B-2.4.2 <u>Reverse Osmosis Water Purification Units (ROWPUs)</u>

B-2.4.2.1 General

The Soldier in the field uses military ROWPUs to produce potable water at FOBs. ROWPUs produce waste products during their operation. The brine/reject water from ROWPUs should be investigated for its nonpotable water reuse potential.

One of the most thorough discussions of ROWPUs is found in TB MED 577 (DA, 2010a). A summary of this discussion is presented in the following paragraphs. See Figure B-14 for a ROWPU flow diagram.

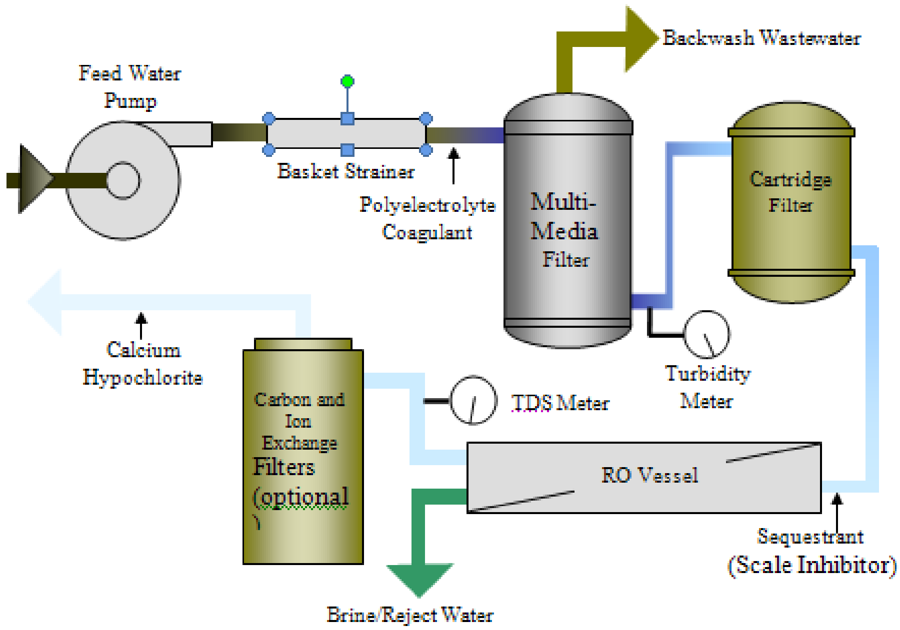

Figure B-14. 600 Gallon Per Hour and 3000 Gallon Per Hour ROWPU Flow Diagram
Source: DA, 2010b

ROWPUs are generally used during deployments to treat field water because they can reliably and consistently produce potable water from fresh, brackish, and seawater sources. Military ROWPUs are multi-process systems that will remove all waterborne pathogens such as parasites, bacteria, and viruses. ROWPUs come in different sizes (125, 600, 1500, 3000 gallon per hour, and 150,000 gallon per day). No other individual pieces or combinations of field water treatment equipment will remove as wide a range of inorganic and organic contaminants as completely as ROWPUs (DA, 2010a).

The heart of the ROWPU is the reverse osmosis membrane (ROM) or vessel (see Figure B-15). The ROM consists of several flat membrane sheets spiral wound around a tubular core. Each sheet is separated by a spacer. Feed water that travels through (permeates) the ROM travels into the tubular core and is discharged as permeate, which becomes product (potable) water. Product water is used for drinking. Feed water that travels between the ROM and the spacer does not permeate the ROM; it is discharged as concentrate (brine, reject water). Concentrate or reject water is a good candidate for reuse applications.

ROMs have not been specifically tested for removal of bacteria, viruses, and parasites such as Giardia and Cryptosporidium cysts. Based on size exclusion, an undamaged and properly operated ROM will remove a significant percentage (up to 100%) of all microbiological organisms. However, due to loading rate limitations on membrane units, disinfection must still be provided to ensure the complete absence of viable pathogenic organisms in treated water. Thus, the ROWPU is an effective barrier to waterborne pathogens (DA, 2010a).

Disinfection is usually the last process and final treatment barrier to microbiological contaminants. Disinfection involves exposing the water to an oxidant for a specific period of time to kill or inactivate pathogenic microorganisms that were not removed by the preceding processes (see the calcium hypochlorite step in the lower left side of Figure B-14). A secondary purpose for disinfecting military drinking water is to provide a measurable disinfectant residual in storage and distribution systems as a sentinel to post-treatment contamination and to prevent/minimize biofilm growth.

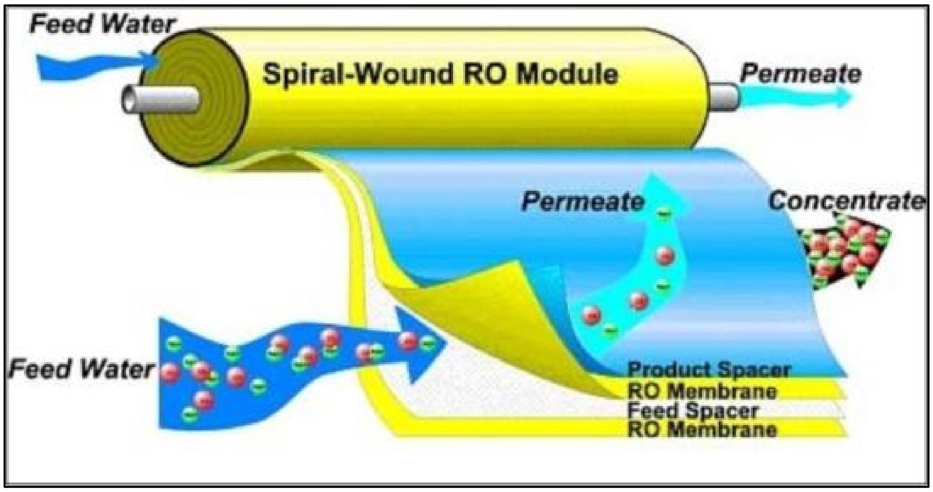

Figure B-15. The Reverse Osmosis Membrane

The preferred military water disinfectant is chlorine (DA, 2010a). The most common chemical issued to the military for bulk water disinfection is calcium hypochlorite that is approximately 68 – 70% free available chlorine. It is added to water and allowed to remain in contact with the microorganisms in the water for a specified period of time (usually 30 minutes).

B-2.4.2.2 ROWPU Wastes

ROWPU operations produce two separate waste streams: the brine/reject water and the filter backwash wastewater. The cartridge filter shown in Figure B-14 is replaced as needed, not backwashed. The brine/reject water is shown by the green arrow pointing downward in Figure B-14, and the "concentrate" arrow in Figure B-15. The filter backwash wastewater is shown by the yellow arrow pointing to the right in Figure B-14. When the ROWPU is operating, the amount of brine/reject water may be as much or more than the product water, while the backwash waste will vary with the RO unit, but in general will be a small fraction of the product water amount.

The backwash wastewater from ROWPUs is typically contaminated with chemicals and is similar in character to industrial wastewater. Therefore, for purposes of nonpotable water reuse, any ROWPU backwash wastewater will not be used and will not be considered further.

The ROWPU reject water is one of the source waters that will be considered for nonpotable water reuse. The contaminants present in the reject water include most of the contaminants that are in the source water, but they are at different concentrations (DA, 2010a). The concentrations of various contaminants in the reject water vary depending on the particular pretreatment filtration employed. The suspended solids concentration is less than that of the raw water because they are removed by the pretreatment filtration systems. However, the dissolved solids, alkalinity, metals, and chloride concentrations in the brine are as much as two times their respective concentrations in the source depending on the RO membrane flux and contaminant rejection rates since they are not generally removed by pre-RO filtration and are rejected by the ROMs. Reject water microorganism concentrations are equal to or greater than the raw water concentrations for the 600 and 3000 gallon per hour ROWPUs, but much less for the smaller units. The phosphate concentration is greater in the brine than in the raw water when sodium hexametaphosphate (600 gallon per hour ROWPU) is added during the treatment process.

B-2.4.2.3 ROWPU Reject Water Characterization

Only one reference characterizing RO reject water was found. In 2008, the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) studied several fully operational RO tactical water treatment systems in field environments at U.S. military camps in Iraq (USACHPPM, 2009d). The systems studied included the 3000 gallon per hour ROWPUs. Samples of the RO reject water were analyzed. The results are shown in Tables B-22 and B-23. The study concluded that (USCHPPM, 2009d):

"RO reject water was on par with or better than raw waters in microbiological and physical character; dissolved chemical constituents, though not identified in the course of this study, would be concentrated. Chlorinating the RO reject water to provide an adequate disinfection residual would likely yield microbiologically safe water…the use of disinfected RO reject water for non-drinking activities including showering, poses a negligible health hazard."

Table B-22. Physical and Chemical Constituents in ROWPU Reject Water

Parameter	Abbreviation or Symbol	Units	Mean	Range	n
PHYSICAL CONSTITUENTS					
color	color	units	10	5-15	9
conductivity	EC	dS/m	2182	670-5260	11
dissolved solids, total	TDS	mg/L	1417	322-3760	11
MBAS	MBAS	mg/L	0.0418	0.026-0.076	4
pH	pH	pH	7.6	6.5-8	12
Turbidity[a]	Turb	NTU	22	0-159	33
CHEMICAL CONSTITUENTS - CONVENTIONAL					
Alkalinity, total	T-ALK	mg/L	252	85-620	11
Ammonia-N	NH4	mg/L	0.071	0.069-0.074	2
chloride	Cl	mg/L	276	16-830	8
Chlorine, total[a]	Chlor	mg/L	0.68	0-10	33
Fluoride	F	mg/L	0.21	0.132-0.27	6
Hardness	C-hard	mg/L	552	100-1060	10
Nitrite/Nitrate	N	mg/L N	1.44	0.089-5	10
organic carbon, total	TOC	mg/L	2.7	1-5.3	10
Phosphate	P	mg/L	0.302	0.0567-0.801	10
Sulphate	SO4	mg/L	579	75-1700	8
CHEMICAL CONSTITUENTS - METALS					
Aluminum	Al	mg/L	1.39	0.846-1.9	4
Antimony	Sb	mg/L	------	0.0059	1
Arsenic	As	mg/L	0.002	0.00163-0.0024	4
Barium	Ba	mg/L	0.069	0.031-0.14	9
Boron	B	mg/L	0.52	0.096-0.96	8
Cadmium	Cd	mg/L	-----	0.0006	1
Calcium	Ca	mg/L	92	21-214	10
Chromium	Cr	mg/L	-----	0.00713	1
Copper	Cu	mg/L	0.026	0.0196-0.032	3
Iron	Fe	mg/L	0.82	0.047-2.2	9
Lead	Pb	mg/L	0.004	0.002-0.0088	4
Magnesium	Ma	mg/L	64.4	11-140	10
Manganese	Mn	mg/L	0.110	0.012-0.38	7
Selenium	Se	mg/L	-----	0.0035	1
Sodium	Na	mg/L	172	15-566	10
Thallium	Tl	mg/L	-----	0.002	1
Zinc	Zn	mg/L	0.41	0.046-0.77	2

Legend:
n = number of samples
dS/m = decisiemens per meter
mg/L = milligrams per liter
NTU = Nephelometric Turbidity Units
Notes:
[a] parameter measured in the field.
Source: USACHPPM, 2009d.

Table B-23. Microbiological Characterization of ROWPU Reject Water

Parameter	Units	Mean	Range	n
E.coli	CFU/100 mL	42	0-411	33
Total coliforms	CFU/100 mL	276	0-2500	33

Legend:
n = number of samples
CFU = colony forming units
mg/mL = milligrams per milliliter
Note:
Source: USACHPPM, 2009d

B-2.4.3 Current U.S. Military Guidelines

B-2.4.3.1 General

The U.S. Military has some wastewater and gray water reuse guidelines (see Table B-24). Most of them apply to Army and Air Force facilities. Although the Navy has a water reuse policy (Chief of Naval Operations Instruction (OPNAVINST) 5090.1C, Navy Environmental and Natural Resources Program Manual, section 9-5.5) (Department of the Navy, 2007), it does not have specific microbiological water reuse standards or guidelines (Electronic Mail message, 26 May 2011).

For comparison purposes, the USEPA and WHO guidelines are provided on the right side of Table B-24. In the USEPA and WHO columns, “R” indicates restricted access reuse and “U” indicates unrestricted access reuse. The purpose of the military guidelines is to protect human health when Soldiers are exposed to wastewater or gray water during water reuse activities. The military guidelines include physical (pH, turbidity, hardness, TSS, BOD, total dissolved solids), chemical (free available chlorine), and microbiological indicator (*E. coli*, total coliform) water quality parameters. These guidelines are for limited uses (DA 2010b; DA, 2006b; U.S. Air Force (USAF), 2004; USACHPPM, 2008), and/or apply to limited areas (DA, 2004a and b). Essentially, most of them 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 longer-term issues, or other areas.

Table B-24. Wastewater Reuse Guidelines

Source / Parameter	TB MED 577 [1]	TB MED 593 [2]	Air Force [3]	Camp Speicher, Iraq [4]	USACHPPM Information Paper [5]	LSA Anaconda, Iraq [6]	USEPA[7]		WHO[8]	
							Restricted	Unrestricted	Restricted	Unrestricted
pH	5-9	N/A	6-9	N/A	N/A	6-9	6-9	6-9	N/A	N/A
Turbidity	1	N/A	≤2	N/A	N/A	N/A	N/A	≤2	N/A	N/A
Hard-ness	500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TDS	1500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Coli-forms	0	N/A	0 (14 max)	≤10	≤200 (800 max)	0	≤200 (800 max)	0 (14 max)	≤1000	≤10
E. Coli	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
FAC	1	detectable	≥1	≥1	1	5	1	1		
TSS	N/A	30	≤5	N/A	30	≤30	≤30	N/A	≤140	≤10
BOD	N/A	30	≤10	N/A	30	≤30	≤30	≤10	≤240	≤10
Limita-tions	1. Apply to Force Provider only; not applicable to other deployment settings. 2. Apply to gray water only; not applicable for wastewater. 3. Apply to shower and personal use scenario only; not applicable to other use scenarios. 4. Represent best professional judgment; not risk based.	1. Apply to Army only; not applicable to deployment settings for other services. 2. Apply to gray water only; not applicable for wastewater. 3. Represent technology-based standard; not risk based.	1. Apply to Air Force only; not applicable to Army deployment settings. 2. Apply to gray water only; not applicable for wastewater. 3. Apply to dust suppression only; not applicable to other use scenarios. 4. No evidence guidance is risk based.	1. Apply to Camp Speicher only; not applicable to deployment settings for other areas. 2. Apply to gray water only; not applicable for wastewater. 3. Apply to dust suppression only; not applicable to other use scenarios. 4. Represent best professional judgment; not risk based.	1. Apply to Army only; not applicable to deployment settings for other services. 2. Apply to gray water only; not applicable for wastewater. 3. Apply to dust suppression only; not applicable to other use scenarios. 4. Represent technology-based guidelines; not risk based.	1. Apply to LSA Anaconda only; not applicable to deployment settings for other areas. 2. Apply to gray water only; not applicable for wastewater. 3. Apply to dust suppression only; not applicable to other use scenarios. 4. Represent technology-based guidelines; not risk based.	1. Apply to agriculture, urban landscape, industrial, construction, environmental reuse, and groundwater recharge; not directly applicable to military reuse scenarios. 2. Apply to wastewater. 3. Represent technology-based guidelines; not risk based.		1. Adapted for Middle Eastern Countries. 2. Apply to gray water only; not applicable for wastewater. 3. Guidance is risk based but applies to agriculture irrigation, residential use only; not applicable to other use scenarios.	

Legend: R = Restricted access use U = Unrestricted access use BOD = Biological Oxygen Demand
Notes: 1 – DA, 2010a 2 - DA, 2006b 3 - USAF, 2004 4 - DA, 2004a 5 – USACHPPM, 2008 6 - DA, 2004b 7 – USEPA, 2004a 8 – WHO, 2006g

B-2.4.3.2 Limitations of the Current Military Guidelines

There are at least five reasons why the current U.S. military guidelines are inadequate for nonpotable water reuse in the field. Each reason is discussed below.

- The Guidelines are Not Risk Based. Although the military guidelines were published to protect Soldier health from exposure to pathogens, there is no evidence a quantitative MRA was conducted as part of their development (see USEPA, 2012b for guidelines on conducting an MRA). As shown in Table B-24, they are technology-based or represent best professional judgment. This is a serious limitation. These standards may be too stringent or not stringent enough for the wide variety of reuse applications. Thus, there is uncertainty about the human health risks of reusing nonpotable water that meet these guidelines. The development of military guidelines for nonpotable water reuse involves the interrelated issues of standards and risk. In particular, microbial standards must correspond to a specified level of risk. Water-based acceptable risks may be based on a background level of illnesses associated with pathogens found in the water (USACHPPM, 2009b), or margin of safety approaches where the emphasis is on differences above background exposure (USEPA, 2009c), or even levels of risk that have been specified for other water-related activities such as military field drinking water (Lawrence Livermore National Laboratory, 1986, p.77). At this time, acceptable risk regarding military guidelines for nonpotable water reuse has not been articulated or quantified.

- The Guidelines Do Not Apply To All Types of Wastewater. The current guidelines do not apply to all types of wastewater generated by U.S. military personnel at FOBs. They were developed for gray water only. They do not apply to other wastewaters. At some FOBs, wastewater (combined gray water and black water) is generated and stored in lagoons or other storage facilities. The current guidelines would not apply to reuse of this wastewater.

- The Guidelines Do Not Apply To All Reuse Applications or Settings. The current guidelines do not apply to all water reuse applications and subsequent exposure scenarios that the Soldier in the field may encounter. Four of the guidelines apply to dust suppression only (USAF, 2004; DA, 2004a and b; USACHPPM, 2008). One guideline applies to showering and personal use only (DA, 2010a). One guideline applies to Force Provider base camps only (DA, 2010a). Thus, currently the Soldier in the field has water reuse guidelines for only two uses: showering and dust suppression. Nonpotable water reuse guidance for other purposes is not addressed in the current guidelines.

- The Guidelines are Not Consistent or Standardized. The current guidelines are not consistent or standardized throughout the Department of Defense (DOD); they are service and/or location specific. There is Air Force guidance for dust suppression (USAF, 2004) and Army guidance for dust suppression (DA, 2004a and b; USACHPPM, 2008). Two of the Army guidance documents apply to specific locations (DA, 2004a and b). As noted in Table B-24, the guidance documents are not consistent with each other. Inconsistencies may confuse the Soldier in the field when trying to conduct nonpotable water reuse.

- There is No Policy to Implement the Guidelines. At this time, there is no Army-wide or DOD-wide policy on nonpotable water reuse. This is true for garrison installations in the U.S. and for the Soldier in the field deployed overseas in FOBs. Ongoing efforts to develop such a policy (USACE, 2010 and 2011) are limited to continental United States installations.

B-2.4.4 <u>Water Quality Measurement Equipment Currently Available to the Soldier in the Field</u>

The Soldier in the field has several water quality analysis kits for determining the quality of a given type of water. The kits are primarily used for determining the quality of drinking water, but they can also be used for determining the quality of other types of water as well, including wastewater, gray water, and recreational water. The kits are called the Water Quality Analysis Set-Purification (WQAS-P) (Figure B-16), the Water Quality Analysis Set-Preventive Medicine (WQAS-PM), the Direct Reading Environmental Laboratory (DREL or DR), the ITS Quick Kit, and the SensION 156 kit. The kits contain an assortment of water quality instruments for measuring various parameters (see Table B-25). In addition, several individual water quality meters are available (digital titrator, turbidimeter).

Figure B-16. Water Quality Analysis Set-Purification (WQAS-P)
Source: TARDEC, 2009

Table B-25. Capabilities of Water Quality Measurement Equipment for the Soldier in the Field

Equipment name	Equipment	Parameter	Contaminant Class	Method	Range(mg/L)
WQAS-PM	Digital Titrator	Acidity	Physical, other misc.	NaOH, Digital Titrator	10-4000
WQAS-PM	Digital Titrator	Alkalinity	Physical, other misc.	H2SO4, Hach Mthd 8203	10-4000
WQAS-PM	DR2400	Bromine	Inorganics	DPD	0.05 - 4.50
WQAS-PM	Digital Titrator	Chloride	Inorganics	AgNO3, Hach Mthd 8207	10 - 10000
WQAS-PM	WQAS-PM	Chlorine Dioxide	Inorganics		0.04 - 5.00
WQAS-PM	DR2400	Chlorine, Free	Inorganics	DPD Hach Mthd 8021 (LaMotte)	0.02 - 2.00
WQAS-PM	DR2400	Chlorine, Total	Inorganics	DPD Hach Mthd 8167 (LaMotte)	0.02 - 2.00
WQAS-PM	WQAS-PM	Chromium, Hexavalent	Metals		0.01 - 0.70
WQAS-PM	WQAS-PM	Color, True, Apparent	Physical, other misc.	Platinum-Cobalt	5 - 500 Pt Co Units
WQAS-PM	WQAS-PM	Copper	Metals		0.04 - 5.00
WQAS-PM	WQAS-PM	Dissolved Oxygen	Inorganics		1-10
WQAS-PM	WQAS-PM	Fluoride	Inorganics	Reagent Solution	0.02 - 2.00
WQAS-PM	WQAS-PM	Hardness, Total	Physical, other misc.	EDTA/ManVer Hach Mthd 8213	10 - 4000
WQAS-PM	WQAS-PM	Iodine	Inorganics		0.07 - 7.00
WQAS-PM	DR2400	Iron, Total	Metals	FerroVer, Hach Mthd 8008	0.02 - 3.00
WQAS-PM	WQAS-PM	Lead	Metals		5 - 150 µg/L
WQAS-PM	WQAS-PM	Manganese, HR	Metals		0.2 - 20.0
WQAS-PM	WQAS-PM	Manganese, LR	Metals		0.007 - 0.700
WQAS-PM	WQAS-PM	Nitrogen, Ammonia	Inorganics		0.01 - 0.50
WQAS-PM	DR2400	Nitrate	Inorganics	Cadmium Reduction, Hach Mthd 8039	0.3 - 30.0
WQAS-PM	DR2400	Nitrite	Inorganics	Diazotization, Hach Mthd 8507	0.002 - 0.300
WQAS-PM	WQAS-PM	Ozone	Inorganics		0.01 - 0.25
WQAS-PM	WQAS-PM	Ozone	Inorganics		0.01 - 0.75
WQAS-PM	WQAS-PM	Ozone	Inorganics		0.01 - 1.50
WQAS-PM	WQAS-PM	Phosphorus, Reactive	Inorganics		0.02 - 2.50
WQAS-PM	DR2400	Phosphorus, Total	Inorganics	Acid Persulfate Digestion, Hach Mthd 8190	0.02-2.50
WQAS-PM	DR2400	Silica	Inorganics	Silicomolybdate, Hach Mthd 8185	1.0 - 100.0
WQAS-PM	WQAS-PM	Silica	Inorganics		0.1 - 1.60
WQAS-PM	DR2400	Sulfate	Inorganics	SulfaVer4, Hach Mthd 8051	2-70

Table B-25. Capabilities of Water Quality Measurement Equipment for the Soldier in the Field (continued)

Equipment Name	Equipment	Parameter	Contaminant Class	Method	Range(mg/L)
WQAS-PM	WQAS-PM	Sulfide	Inorganics		5 - 800 µg/L
WQAS-PM	WQAS-PM	Suspended Solids	Physical, other misc.		0 - 750
WQAS-PM	WQAS-PM	Zinc	Metals		0.01 - 3.00
WQAS-PM	WQAS-PM	Total Coliform	Bacteriological	Colilert	presence/absence
WQAS-PM	WQAS-PM	*E. coli*	Bacteriological	Colilert	presence/absence
WQAS-PM	2100P Turbidi-meter	Turbidity (Hach)	Physical, other misc.	Meter	0.1-400
WQAS-PM	SensION 156	pH	Physical, other misc.	Meter	-2.0-19.9
WQAS-PM	SensION 156	TDS	Physical, other misc.	Meter	0-50000
WQAS-PM	SensION 156	Temperature	Physical, other misc.	Meter	-5.0-105C
WQAS-PM	ITS Quick Kit	Arsenic	Inorganics	Quick Kit	0-0.5
WQAS-PM	DR2400	Cyanide	Inorganics	Pyridine-Pyrazalone, Hach Mthd 8027	0-1.0
WQAS-PM	Digital Titrator	Magnesium	Metals	EDTA, Hach Mthd 8213/8204	10-4000
WQAS-P	WQAS-P	Chlorine, Free	Inorganics		0-10
WQAS-P	WQAS-P	Chlorine, Total	Inorganics		0-10
WQAS-P	WQAS-P	Conductivity	Physical, other misc.		0-9999uS
WQAS-P	WQAS-P	Conductivity	Physical, other misc.		10-200mS
WQAS-P	WQAS-P	Oxidation Reduction Potential	Physical, other misc.		999mV
WQAS-P	WQAS-P	pH	Physical, other misc.	Electro meter	0-14
WQAS-P	WQAS-P	Resistivity	Physical, other misc.		10KU-30MU
WQAS-P	WQAS-P	Temperature	Physical, other misc.		0-71C
WQAS-P	WQAS-P	Total Dissolved Solids	Physical, other misc.		0-9999
WQAS-P	WQAS-P	Total Dissolved Solids	Physical, other misc.		10-200ppt
WQAS-P	WQAS-P	Turbidity	Physical, other misc.		0-1000FTU

The WQAS-P kit (and capabilities) is usually associated with the quartermaster corps and those Soldiers responsible for drinking water production. Preventive medicine personnel typically have access to the WQAS-PM kits and their capabilities. Note that preventive medicine personnel (and the WQAS-PM kits) are not present at all FOBs.

The water quality parameters important to Soldiers engaged in nonpotable water reuse in the field are highlighted in yellow in Table B-25. These parameters are: microbiological indicators (total coliforms, *E. coli*), a physical parameter (turbidity), and a chemical parameter (total and free available chlorine).

Nonpotable water reuse in the field may require the procurement of additional equipment (commercial off-the-shelf technology) for monitoring water quality. One possibility is the IDEXX Quanti-tray which provides quantitative measurements of total coliforms and *E. coli*.

B-2.5 Summary

B-2.5.1 Recommended Sources for Nonpotable Water Reuse

There are three sources of wastewater produced at FOBs that should be investigated for reuse applications: gray water, wastewater, and ROWPU brine/reject water. These three types of water have physical, chemical, and microbiological characteristics that appear to be suitable as source water for reuse applications.

B-2.5.2 Wastewater at FOBs

A significant fact is that about 85% of wastewater generated at FOBs is gray water and 15% is black water. This makes gray water an excellent candidate for reuse attempts. Technologies for gray water treatment and reuse have been studied but have not been fully implemented at FOBs, particularly gray water reuse after minimal treatment. Minimally treated gray water may potentially be used for dust control, vehicle washing, other industrial applications, or to satisfy the liquid requirements for solid waste processing. However, safely using the gray water needs to be established and documented.

Given what we know about wastewater at FOBs, there are at least four reasons to develop safe water reuse options for the Soldier in the field. First, safe reuse options can reduce the overall water demand of the FOB thereby saving lives (U.S. Army Environmental Policy Institute, 2009). Second, safe reuse options can also reduce the footprint of the FOB thereby supporting the Army's Zero Footprint Camp (ZFC) initiative. The ZFC is a new initiative being developed by the U.S. Army Soldier and Biological Chemical Command and the TARDEC. In addition to potable water, which requires only 20% of the total volume in Soldier sustainment, a category known as "consumable" water that includes water for laundry but not considered potable is becoming part of the system calculation (U.S. Army Research Office, 2007). Third, safe reuse options can reduce FOB operations and maintenance costs by reusing what would otherwise be a waste product requiring disposal. Lastly, safe reuse options can minimize the environmental impacts from base camp operations.

B-2.5.3 Exposure Guidelines and Health Effects

Both wastewater and recreational water exposure guidelines have been developed for many countries. The current worldwide wastewater reuse guidelines and exposure scenarios are mainly applicable to: (1) agricultural practices, and (2) civilian residential, commercial, and industrial practices associated with fixed infrastructure facilities. Formal health risk assessments conducted for wastewater reuse are not directly applicable to the Army because the exposure scenarios in military applications are different from agricultural and infrastructure applications. This represents a health risk uncertainty for the Soldier in the field attempting wastewater reuse and a data gap for the Army.
The U.S. recreational water exposure guidelines have evolved over the past 80-90 years primarily in response to concerns about gastrointestinal illnesses from swimming in public recreational waters. The

U.S. and many other countries have microbial water quality guidelines for primary and secondary contact recreation. These guidelines specify microbial indicator organism concentrations for the safe use of recreational water. At this time, the USEPA recommends enterococci and *E. coli* as the best indicators for assessing the microbial quality of recreational waters. Specific concentrations of these indicators have been related to a risk level for exposure to recreational water. The USEPA guidelines are supported by extensive and thorough worldwide scientific investigations and health effects studies over the past 50 years. As a result, there is a high degree of confidence in the guidelines and the supporting science.

The U.S. Military has a limited set of water reuse exposure guidelines. These guidelines are inadequate because:

- they are not risk based,
- they do not apply to all types of wastewater,
- they do not apply to all reuse applications or settings,
- they are not consistent or standardized, and
- there is no policy to implement the guidelines.

B-2.5.4 Applying Basic Science to the Army Situation in the Field

Over the last several decades, some basic water science and technology relationships have been demonstrated and subsequently described in the literature. We know that turbidity and TSS are positively related and chlorine residual is negatively related to microorganism concentrations in water. We also know that most microorganisms are not directly measured in water; indicator organisms are used to infer the presence or absence of entire classes of pathogens. Indicator organism suites found to be most closely associated with pathogens include *E. coli*, enterococci, coliphages, and Clostridium perfringens.

These basic science relationships and knowledge have health implications for anyone reusing nonpotable water. The science needs to be applied to help develop safe water reuse options for the Soldier in the field. At this time, the Soldier in the field has basic analytical equipment and capabilities to assess water quality. For purposes of nonpotable water reuse, the most important water quality parameters the Soldier in the field can measure are: free and total available chlorine, total coliforms, *E. coli*, and turbidity. The water quality assessment and field capabilities of the Soldier in the field are not expected to change in the near future.

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B-4. WASTEWATER MICROBIOLOGICAL EXPOSURE GUIDELINES

TABLE B-26. CURRENT WASTEWATER MICROBIOLOGICAL EXPOSURE GUIDELINES

Reuse Category	Source Water Type	Regulatory Entity	←---- Application ----→							←---- Standard * ----→									←---- Other/Comments **----→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
WW- RESTRICTED ACCESS USES																			
Restricted	WW	WHO (2006)	Yes	Yes									≤1000 *E. coli*/100 mL; ≤ 1 helminth eggs/L (arithmetic mean)	non-disinfected effluents					Use: Restricted Irrigation (farmers or heavily exposed populations where intensive labor is required (i.e., 150-300 days exposure per year). Median infection risk = 10^{-3} /person/year, (derived from QMRA) (Vol. 2, p. 50-52, 60 and Table 3.17). Health-based target = 10^{-6} DALY/person/year, achieved by 2-3 log unit pathogen (Rotavirus) reduction, obtained by wastewater treatment. Source: WHO, 2006, Safe Use of Wastewater, Excreta, and Greywater, Volume 1 (Policy and Regulatory Aspects, ch. 2) and Volume 2. (Wastewater Use in Agriculture, exsum). Tolerable risk level = 10^{-6} DALY (Vol. 2, p. 15, 59). Tolerable infection risk = 10^{-3} to 10^{-4} (vol.2, p. 47 (USA), 60-61, Table 4.2 (industrial countries).
Restricted	WW	USEPA guidelines for water reuse (2004)		Yes					Yes-construction	≤ 30 mg/L	≤ 30 mg/L		≤ 200 fecal coliform/100 ml	≥ 1 mg/L Cl residual (minimum)				6 - 9	Restricted uses include: (1) restricted access area irrigation, (2) commercially processed food crops and nonfood crop ag. reuse, (3) construction and industrial environmental use, (4) landscape impoundments where public contact is not allowed, (5) environmental reuse, including wetlands, marshes, stream augmentation. Source: USEPA, 2004, Guidelines for Water Reuse, Office of Wastewater Management, Office of Research and Development, Washington, D.C., EPA/625/C-04/108.
Restricted	WW	Arizona Admin. Code (2001) Class B		Yes				Yes					< 200 FC CFU/100 mL median (in four of the last seven daily samples); max < 800.	disinfection required; no chlorine residual specified.		< 10 mg/L			Surface irrigation of orchards and vineyards, golf course and restricted access landscape irrigation, landscape impoundment and dust control.Treatment: secondary treatment and disinfection. Source: Arizona Administrative Code (2001), Title 18, chapter 11, article 3, Reclaimed Water Quality Standards.

Reuse Category	Source Water Type	Regulatory Entity	←---- Application ----→							←---- Standard * ----→									←---- Other/Comments **----→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine I Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted	WW	Arizona Admin. Code (2001) Class C		Yes									< 1000 FC CFU/100 mL median (in four of the last seven daily samples); max < 4000.	disinfection required; no chlorine residual specified.					Irrigation of pasture, nondairy livestock, sod, fiber seed, forage crops, silviculture. Treatment: Secondary treatment with or without disinfection. Source: Arizona Administrative Code (2001), Title 18, chapter 11, article 3, Reclaimed Water Quality Standards.
Restricted	WW	Florida: Ch. 62-610 reuse of reclaimed water, land application		Yes. Land application	Yes			Yes	Yes-fire protection, construction	≤ 20 mg/L CBOD	≤ 5 mg/L	≤ 5 NTU	75% below detect; max ≤25 MPN/100 mL FC.	≥ 1 mg/L 15 minute Cl residual					Fire protection, construction dust control and aesthetic purposes.
Restricted	WW	*Hawaii State Department of Health Wastewater Branch. (2002) R-2 water - oxidized and disinfected*	Yes	Yes					Yes.	30 mg/L (mean)	30 mg/L (mean)		≤ 23/100 mL of the last 7 days; no more than one sample in 30 day period >200/100 mL.						Aboveground irrigation with buffer for non-edible vegetation in areas with limited public exposure, and ornamental plants for commercial use. Underground with buffer only for parks, elementary schoolyards, athletic fields and landscape around some residential property; underground only for aboveground food crops. Human contact minimized. Source: Hawaii Administrative Code (2004), Title 11, chapter 62; and Hawaii, 2002, Guidelines for the Treatment and Use of Recycled Water.
Restricted	WW	*Hawaii State Department of Health Wastewater Branch. (2002) R-3 water - oxidized*	Yes	Yes. Drip only.						30 mg/L (mean)	30 mg/L (mean)		No state requirements.	not disinfected					Underground only. No human contact allowed. Treatment: secondary. Source: Hawaii Administrative Code (2004), Title 11, chapter 62; and Hawaii State Department of Health Wastewater Branch, 2002, Guidelines for the Treatment and Use of Recycled Water.
Restricted	WW	Massachusetts: interim guidelines on reclaimed water (revised)			Yes					< 30 mg/L	<10 mg/L	< 5 NTU	< 100 CFU/100 mL FC, median; from last 7 days.	Detected		< 10 mg/L	Monitor 2 times per month	6 - 9 (90%)	
Restricted	WW	*Oregon (2008) Class D recycled water (oxidized and disinfected wastewater)*		Yes									≤ 30 day long mean of 126 *E. coli*/100 mL and 406 *E. coli*/100 mL in any single sample.						Irrigation of firewood, ornamental nursery stock, Christmas trees, sod or pasture for animals. Bacterial standard is very similar to the USEPA criteria for bathing in recreational waters (Federal Register, 16 Nov 2004).

Reuse Category	Source Water Type	Regulatory Entity	←------------------------------------ Application --→							←-- Standard * ---→									←---------------------------------- Other/Comments **---------------------------------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted	WW	*Oregon (2008) Class C recycled water (oxidized and disinfected wastewater)*		Yes					Yes-construction				≤ 23 TC/100 mL based on last 7 days; and 240 TC/100 mL in any two consecutive samples.						Irrigation of firewood, ornamental nursery stock, Christmas trees, sod or pasture for animals; processed food crops; orchards or vineyards if applied directly to soil; landscape irrigation of golf courses, cemeteries, or industrial or business campuses. Some industrial, commercial or construction uses. Water supply for landscape impoundments.
Restricted	WW	*Oregon (2008) Class B recycled water (oxidized and disinfected wastewater)*		Yes	Yes								≤ 2 TC/100 mL based on last 7 days; and < 23 TC/ 100 mL in any single sample.						Same uses as Class C, plus: nonresidential toilet or urinal flushing, floor drain trap priming; Water supply source for restricted recreational impoundments.
Restricted	WW	*Texas-Chap 210- use of reclaimed water- subchap C: Quality criteria, specific uses for reclaimed water: Type II*		Yes						≤ 20 mg/L		≤ 5 NTU	≤ 200 CFU/100 FC median, in 4 of last 7 samples; max ≤ 800.						Where public is not present during irrigation activities or would not come into contact with reclaimed water.
Restricted	Reuse water; WW or GW not specified	Wisconsin Plumbing Treatment Standards - *Using reuse as source.*	Yes							≤ 30 mg/L	≤ 35 mg/L		< 200 fecal coliform CFU/100 mL						Also have limit of ≤ 15 mg/L oil and grease.Intended use is subsurface infiltration and irrigation; implies restricted use (minimal to negligible human contact). Source: Wisconsin, 2009, Department of Commerce, Chapter Comm 82 (Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing), Subchapter VII, Comm 82.70 (Plumbing Treatment Standards).

Reuse Category	Source Water Type	Regulatory Entity	←---- Application ----→							←---- Standard * ----→									←---- Other/Comments **----→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted	WW	*Wisconsin Plumbing Treatment Standards*		Yes, except for food crops	Yes	Yes	Yes	Yes	Yes	≤ 10 mg/L	≤ 5 mg/L		no detectable fecal coliform CFU/100 mL	≥ 1 mg/L and ≤ 10 mg/L free chlorine residual					Intended use is surface irrigation, vehicle washing, toilet flushing, clothes washing, dust control, soil compaction, aggregate washing, making concrete; implies restricted use with incidental human contact. Source: Wisconsin, 2009, Department of Commerce, Chapter 82 (Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing), Subchapter VII, Comm 82.70 (Plumbing Treatment Standards).
Restricted	WW	NOWRA (Draft 7) (National Onsite Wastewater Recycling Association)			Yes					< 30 mg/L	< 30 mg/L	< 5 NTU	< 200 CFU/100 mL median value for E coli; maximum < 800 CFU/100 mL for E coli.	> 1 mg/L after 30 minutes				6 to 9	
Restricted	WW	South Australia reclaimed water guidelines - treated effluent:		Yes						< 20 mg/L	< 30 mg/L	"Present"?	< 100 CFU/100 mL, Median FC						These uses include secondary contact recreation and ornamental ponds with public access. Includes restricted crop irrigation, pasture irrigation.
Restricted	WW	*Australia, National Guidelines (2006) Class B?*								<20 mg/L	<30 mg/L		<100 *E. Coli* per 100 mL (median)	chlorine residual required but not quantified					Uses: Restricted Access, plus minimum buffer distance or wait until dry for irrigation, crops with no ground contact, pathogen reduction between harvest and sale. Treatment: secondary and disinfection. Source: Australia, 2006, National Guidelines for Water Recycling, Phase 1, Managing Health and Environmental Risk, Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, Australian Health Minister's Conference, November.

Reuse Category	Source Water Type	Regulatory Entity	←------ Application ------→							←------ Standard * ------→									←------ Other/Comments **------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted	WW	*Australia, National Guidelines (2006) Class C?*								<20 mg/L	<30 mg/L		<1000 *E. Coli* per 100 mL (median)						Uses: Enhanced Restricted Access, plus minimum buffer distance or wait until dry for irrigation, crops with no ground contact and heavily processed, crops cooked, pathogen reduction between harvest and sale. Treatment: secondary or primary with lagoon detention. Source: Australia, 2006, National Guidelines for Water Recycling, Phase 1, Managing Health and Environmental Risk, Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, Australian Health Minister's Conference, November.
Restricted	WW	*Australia, National Guidelines (2006) Class D?*											<10,000 *E. Coli* per 100 mL (median)						Uses: Limited Use, nonfood crop irrigation (trees, turf, woodlots, flowers) only; no public access and drip irrigation only, extended buffer. Treatment: secondary or primary with lagoon detention. Source: Australia, 2006, National Guidelines for Water Recycling, Phase 1, Managing Health and Environmental Risk, Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, Australian Health Minister's Conference, November.
Restricted	WW	Canada: *Alberta*		Yes						< 100 mg/L	< 100 mg/L		< 200 Fecal Coliform MPN/100 mL (geometric mean)						Minimum treatment requirement is primary treatment followed by seven month storage; Nonfood and golf course irrigation. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol
Restricted	WW	Canada: *Saskatchewan* -		Yes									< 1,000 Fecal Coliform MPN/100 mL						Uses: Ag irrigation - nonfood crops. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol.
Restricted	WW	Canada: Saskatchewan -		Yes									≤ 200 fecal coliforms MPN/100 mL (median); ≤ 400 (two consec. samples)						Uses: Golf course irrigation. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol.
Restricted	WW	*Canada: Manitoba*		Yes									≤ 200 MPN/100 mL (median, either FC or *E. coli*)						Uses: Parks, golf courses and gardens irrigation. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol.

Reuse Category	Source Water Type	Regulatory Entity	←Application→							←Standard *→									←Other/Comments **→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine I Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted (incidental contact from flush aerosols only)	WW	Canada Mortgage and Housing Corp. (CMHC) Consensus Standard: *Low risk applications*	Yes		Yes					≤ 30 mg/L	≤ 30 mg/L	≤ 5 mg/L	≤ 200 Fecal coliform or E.coli CFU/100 mL;	0.1 to 1.0 mg/L					Uses: toilet flushing and subsurface irrigation only. These are considered "low risk applications" because only indirect contact (incidental aerosol spray) with the reclaimed water is allowed. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol, for use in Residential Applications in Canada. Reuse water applications, including raw (potable) water source, food crop (garden) irrigation, showers and bathing, were deemed unacceptable for individual onsite or small cluster-treatment system technologies.
Restricted	WW	*British Columbia Waste Management Act municipal sewage regulation: Restricted public access*		Yes	Yes		Yes .		Yes-fire protection, street cleaning	≤ 45 mg/L	≤ 45 mg/L		≤ 200 CFU/100 mL median FC					6 - 9 (90%)	Public access to irrigated land and contact with reclaimed water not allowed. Treatment: secondary treatment and disinfection. This is broken into: Urban uses (parks, playgrounds, cemeteries, golf courses, road right-of way, school grounds, residential lawns, green belts, vehicle and driveway washing, landscaping, toilet flushing, outside fire protection, street cleaning); Agricultural uses (aquaculture, food crops eaten raw, orchards and vineyards, pasture, frost protection, seed crops); and Recreational (stream augmentation, impoundments for boating and fishing, snow making - not for skiing and snowboarding, landscape waterfalls). Source: Canada (British Columbia) Municipal Sewage Regulation; and Canada (British Columbia), 2001, Guide to Irrigation System Design with Reclaimed Water.
Restricted (incidental contact from flush aerosols only)	WW	Canadian Guidelines for Domestic Reclaimed Water			Yes					≤ 10 mg/L median; ≤ 20 mg/L maximum	≤ 10 mg/L median; ≤ 20 mg/L maximum (measur-ed prior to dis-infection)	≤2 NTU median; ≤5 NTU max (alt to TSS)	ND *E. coli* and Thermotolerant coliform (CFU/100 mL): maximum is ≤ 200 CFU/100mL.	≥ 0.5 mg/L total chlorine residual, measured at point where treated eff leaves reservoir or storage					Use: Toilet flushing only. Exposure from aerosols assumed to be 11 mL/person/year from flushing 3 times/day. Source: Canada, 2010, Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing (draft is 2007)
Restricted (only incidental contact allowed).	WW	Canada, Saskatchewan		Yes									≤ 2.2 MPN/100 mL (median, either Fecal coliform or *E. coli*); < 23 max.						Uses: Ag irrigation - food crops (nonroot crop and not eaten raw). Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol.
Restricted (only incidental contact allowed).	WW	*Canada, Prince Edward Island*		Yes						<10 mg/L	< 10 mg/L		< 2.2 Fecal Coliform MPN/100 mL			< 5 mg/L	< 5 mg/L		Uses: Golf course irrigation. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol.
Restricted or unrestricted not specified.	WW or GW not specified.	*China: Flushing and fire water*			Yes?				Yes. Firefighting.	< 15 mg/L		≤ 10 NTU	≤ 100 CFU/100 mL coliform bacteria	≥ 0.2 mg/L Cl residual					No odor. Uses: flushing and firefighting (flushing may apply to toilets or fire hydrants). Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
Restricted or unrestricted not specified.	WW or GW not specified.	*China: Irrigation*		Yes								≤ 20 NTU	≤ 100 CFU/100 mL coliform bacteria	≥ 0.2 mg/L Cl residual					No odor. Uses: irrigation. Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34
Restricted or unrestricted not specified.	WW or GW not specified.	*China: Car washing*				Yes			≤ 15 mg/L		≤ 5 NTU	≤ 3 CFU/100 mL coliform bacteria	≥ 0.2 mg/L Cl residual						No odor. Uses: irrigation. Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34

Reuse Category	Source Water Type	Regulatory Entity	←---------- Application ----------→							←---------- Standard * ----------→									←---------- Other/Comments **----------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspende d Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	Other/Comments
UnRestricted		Germany (2005)			Yes	Yes				≤ 5 mg/L (7-day BOD)			< 100/mL total coliform; < 10/mL fecal coliform; <1/mL Pseudomonas aeruginosa						Also requires > 50% oxygen saturation (related to the "shelf life" of the water.
Restricted		Germany (2005)		Yes									≤ 100 colonies/100 mL fecal streptococci; ≤ 200 colonies/100 mL *E. coli*; ND						Crops on open land and greenhouses for raw consumption, school sport fields, public parks.
Restricted		Germany (2005)		Yes									≤ 400 colonies/100 mL fecal streptococci; ≤ 2000 colonies/100 mL *E. coli*; ND salmonellae/1000 mL						Crops in greenhouses not intended for consumption; crops on open land for raw consumption up to fruiting state or vegetables up to 2 weeks prior to harvest; fruits and vegetables for conservation; greenland or forage plants up to 2 weeks before cut or grazing; all other open crops on open land without restriction; other sport fields.
Restricted or unrestricted not specified.	WW or GW not specifi	Japan: *Toilet flush water*			Yes								≤ 10 CFU/100 mL *E. coli*	Retained				5.8 - 8.6	No unpleasant appearance and odor. Uses: toilet flushing. Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
Restricted or unrestricted not specified.	WW or GW not specifi	Korea: *Toilet flush water*			Yes					≤ 10 mg/L		≤ 5 NTU	≤ 10 CFU/100 mL coliform bacteria	Detected				5.8 - 8.6	No unpleasant appearance and odor. Uses: toilet flushing. Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
Restricted or unrestricted not specified.	WW or GW not specifi	*Korea: Gardening*		Yes						≤ 10 mg/L		≤ 10 NTU	None					5.8 - 8.6	No unpleasant appearance and odor. Uses: irrigation (gardening). Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
Unrestricted (irrigation only)	W W	*Bahrain*		Yes									≤ 200 Fecal Coliforms per 100 mL (geometric mean) during irrigation; ≤ 1 intestinal nemotode per liter (geometric mean)						Uses: Allow Direct Contact by Public; agricultural irrigation such as public lawns, hotel lawns, sports fields, public parks, crops eaten uncooked. Treatment:: not specified. Exposed group: workers, crop consumers, public. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.. WHO standards prior to 2003, (superceded by 2006 standards).
Restricted (irrigation only)	W W	*Bahrain*		Yes									≤1000 Fecal Coliforms per 100 mL (geometric mean); ≤ 1 intestinal nemotode per liter (geometric mean)						Uses: Allow Indirect (Incidental) Contact by Public; agricultural irrigation such as sports fields, public parks, crops eaten uncooked.Treatment: unspecified. Exposed group: workers, crop consumers, public.Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E. WHO standards prior to 2003, (superceded by 2006 standards).
Unrestricted (irrigation only- direct contact allowed)	W W	*Middle East Experts Review (2004)*		Yes									≤200 Thermotolerant Coliforms per 100 mL (geometric mean); < 1 intestinal nemotode per liter (geometric mean)						Uses: Unrestrictred Irrigation, Allow Direct Contact by Public; irrigation of public lawns, hotel lawns, sports fields, public parks, crops eaten uncooked. Treatment: ponds with 21 day retention time, secondary treatment and storage, sand filtration. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, WHO-EM/CEH/142/E.

Reuse Category	Source Water Type	Regulatory Entity	←------------ Application ------------→							←------------ Standard * ------------→									←------------ Other/Comments **------------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted (irrigation only-only indirect [incidental] contact allowed)	W W	*Middle East Experts Review (2004)*		Yes. Furrow or flood irrigation.									≤1000 Thermotolerant Coliforms per 100 mL (geometric mean); < 1 intestinal nemotode per liter (geometric mean)						Uses: Unrestrictred Irrigation, Allow Indirect (Incidental) Contact by Public; irrigation of sports fields, public parks, crops eaten uncooked. Treatment: ponds with 21 day retention time, secondary treatment and storage, sand filtration. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted (irrigation only-no contact allowed)	W W	*Middle East Experts Review (2004)*		Yes. Sprinkler irrigation.									≤10,000 Thermotolerant Coliforms per 100 mL (geometric mean); < 1 intestinal nemotode per liter (geometric mean)						Uses: Restrictred Irrigation, irrigation of cereal crops, industrial crops, fodder crops, pasture, trees. Workers should use PPE. Treatment: ponds with 21-day retention time, secondary treatment and storage, sand filtration. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted	W W	*Jordan (2002)*	no specified human exposure scenario stated-assumed incidental contact allowed.							60 mg/L	60 mg/L		<1000 *E. coli* MPN / 100mL; ≤1 helminth eggs/L.						Uses: Discharge to surface water. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Unrestricted	W W	*Jordan (2002)*	assumed down-gradient use is drinking water							15 mg/L	50 mg/L	2 NTU	<2.2 *E. coli* MPN / 100mL; ≤1 helminth eggs/L.						Uses: Groundwater recharge. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health
Unrestricted (irrigation only-direct contact allowed)	W W	*Jordan (2002)*		Yes						30 mg/L	50 mg/L	10 NTU	<100 *E. coli* MPN / 100mL; ≤1 helminth eggs/L.						Uses: Irrigation, parking areas, playgrounds, side of roads inside cities, cooked vegetables. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted (irrigation only-only indirect [incidental] contact allowed)	W W	*Jordan (2002)*		Yes						200 mg/L	150 mg/L	no NTU standard	<1000 *E. coli* MPN / 100mL; ≤1 helminth eggs/L.						Uses: Irrigation, trees, green areas, side of roads outside cities. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted (irrigation only-no contact allowed)	W W	*Jordan (2002)*		Yes						300 mg/L	150 mg/L	no NTU standard	≤1 helminth eggs/L; no *E. coli* standard.						Uses: Irrigation, field crops, industrial crops, forestry. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E. No public contact.

Reuse Category	Source Water Type	Regulatory Entity	←--- Application ---→							←--- Standard * ---→									←--- Other/Comments ** ---→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted?	W W	*Kuwait (2001)*	Irrigation only-no specified human exposure scenario stated.							20 mg/L	15 mg/L		<400 total coliforms MPN; <20 fecal coliforms MPN/100mL						Uses: Irrigation Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Unrestricted (irrigation only-direct contact allowed)	W W	*Oman (1993)*		Yes						15 mg/L	15 mg/L		<200 fecal coliforms MPN/100 mL; <1 viable nemotode ova/L						Uses: Irrigation, public parks, hotel lawns, rec. areas, public access areas, lakes with public contact, vegetables and fruit eaten raw, plus controlled aquifer recharge. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E. Allow public contact.
Restricted (irrigation only-no contact allowed)	W W	*Oman (1993)*		Yes						20 mg/L	30 mg/L		<1000 fecal coliforms MPN/100 mL; <1 viable nemotode ova/L						Uses: Irrigation, vegetables cooked or processed, fodder and seed crops, pasture, no public access areas. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Unrestricted (irrigation only-direct contact allowed)	W W	*Saudi Arabia (2002)*		Yes						10 mg/L	10 mg/L		<2.2 TTCC MPN/100 mL; <1 nemotodes/L. TTCC= thermotolerant total coliform count?						Uses: Unrestricted Irrigation. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted (irrigation only-only indirect [incidental] contact allowed)	W W	*Saudi Arabia (2002)*		Yes						40 mg/L	40 mg/L		<1000 TTCC MPN/100 mL; <1 nemotodes/L. TTCC= thermotolerant total coliform count?						Uses: Restricted Irrigation. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
Restricted	W W	*Tunisia (1989)*		Yes. No human exposure scenario stated.						30 mg/L	30 mg/L		≤1 nemotodes/L (mean).						Uses: Agriculture. Treatment: unspecified. Source: WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
WW - UNRESTRICTED ACCESS USES																			
Unrestricted	WW	WHO (2006)	Yes	Yes									≤1000 *E. coli*/100 mL; ≤ 1 helminth eggs/L (arithmetic mean)	non-disinfected effluents					Use: Unrestricted Irrigation (crop consumers-100 g eaten raw/person/every 2 days; 10-15 mL wastewater remaining on crop). Median infection risk = 10^{-3} /person/year (derived from QMRA) (Vol. 2 p. 50-52, 60 and Table 3.17). Health based target = 10^{-6} DALY/person/year, achieved by 6-7 log unit pathogen (Rotavirus) reduction, obtained by wastewater treatment and other health protection measures (pathogen die-off, washing produce, drip irrigation, PPE, etc.). Source: WHO, 2006, Safe Use of Wastewater, Excreta, and Greywater, Volume 1 (Policy and Regulatory Aspects, ch.2), and Volume 2 (Wastewater Use in Agriculture, exsum). Tolerable risk level = 10^{-6} DALY (Vol. 2, p. 15, 59). Tolerable infection risk = 10^{-3} to 10^{-4} (vol.2, p. 47 (USA), 0-61, Table 4.2 (industrial countries).

Reuse Category	Source Water Type	Regulatory Entity	←---- Application ----→							←---- Standard * ----→									←---- Other/Comments **----→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Unrestricted	WW	Arizona Admin. Code (2001) - Title 18, Ch. 11, Article 3- Class A Reclaimed Water Quality Standards		Yes	Yes		Yes	Yes	Yes-fire protection, coolant			< 2 NTU, max of < 5 NTU	< 1 FC CFU/100 mL median (no detectable FC or enteric viruses in four of last seven daily samples); max <23.	disinfection required; no chlorine residual specified.		< 10 mg/L			Irrigation of food crops, recreational impoundments, residential, school ground, open access landscape irrigation, toilet/urinal flushing, fire protection systems, spray irrigation of orchards or vineyards, commercial closed-loop air conditioning, vehicle and equipment washing, snow making. Treatment: secondary treatment, filtration, disinfection. Source: rizona Administrative Code (2001), Title 18, ch. 11, article 3, reclaimed water quality standards.
Unrestricted		California *Title 22* California Code of Regulations "disinfected tertiary"		Yes	Yes	Yes	Yes		Yes-process water that may contact workers			≤ average of 2 NTU & ≤ 5 NTU 95% in 24- hours; 10 NTU max	≤ 2.2 MPN/100 mL (median TC for last 7 days; shall not exceed 23/100 mL more than once for last 30 day period; not exceed 240/100 mL)	continuous monitoring at the plant; provide CT (total residual x modal contact time measured at the same point) > 450 mg-min/L at all times with modal contact time > 90 min					Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop. Parks and playgrounds, school yards, residential landscaping, unrestricted access golf course, and unrestricted access impoundments (recreational ponds/lakes). There are additional requirements for body contact impoundments. Flushing toilets and urinals, priming drain traps, industrial process water that may come into contact with workers, structural firefighting, decorative fountains, commercial laundries, artificial snow making for commercial outdoor use and commercial car washes. There is a whole class of other uses in which there is minimal public contact expected where disinfected secondary is allowed (also a distinction is made between secondary 2.2 TC and 23 TC)
Unrestricted	WW	Georgia - Design guidelines for water reclamation and urban water reuse (draft)		Yes			Yes			≤ 5 mg/L	≤ 5 mg/L	< 2 NTU (95%)	≤ 23 CFU/100 mL FC median; monthly geo mean.	Detect - 15 min Cl residual				6 to 9	Irrigation of golf course, playground parks.
Unrestricted	WW	*Hawaii State Department of Health Wastewater Branch (2002) R- 1 water - oxidized, filtered, disinfected*	Yes	Yes	Yes	Yes. Commercial and public laundries.			Yes	30 mg/L (mean)	30 mg/L (mean)		(a) disinfection combined with filtration to inactivate or remove 99.999% of plaque-forming units of MS2 or polio virus; and (b) ≤ 2.2/100 mL FC median of last 7 days; ≤ 23/100 mL in no more than one sample in 30 day period; no sample >200/100 mL.	no chlorine residual specified.					No restrictions on human contact. Covers a wide range of uses including irrigation of food crops where recycled water contacts the edible portion of the crop, including all root crops; parks, elementary schoolyards, athletic fields and landscape around some residential property; non-edible vegetation in areas with limited public exposure; ornamental plants for commercial use; aboveground food crops not contacted by irrigation. Includes commercial and public laundries, decorative fountains, and washing yards, lot and driveways. "*Oxidized wastewater*" means wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen. Source: Hawaii Administrative Code (2004), Title 11, chapter 62; and Hawaii State Department of Health Wastewater Branch (2002), Guidelines for the Treatment and Use of Recycled Water.
Unrestricted	WW	Massachusetts: interim guidelines on reclaimed water (revised)		Yes						≤ 10 mg/L	≤ 5 mg/L	≤ 2 NTU	< 1 CFU/100 mL FC, median; running count over last 7 days; not to exceed 14/100 mL.	≥ 1 mg/L 30 minute Cl residual		≤ 10 mg/L		6 - 9 (90%)	Irrigation uses include golf course, landscape projects.
Unrestricted	WW	New Jersey: reclaimed water for beneficial reuse (draft)		Yes			Yes				≤ 5 mg/L	≤ 2 NTU	< 2.2 CFU/100 mL FC, median over 7 days; max ≤14 in any sample	≥ 10 mg/L 15 minute Cl residual		≤ 10 mg/L			UV dose 100 mJ/cm^2. Irrigation uses include golf course, playground or park; hydroseeding.

Reuse Category	Source Water Type	Regulatory Entity	←---------- Application ----------→							←---------- Standard * ----------→									←---------- Other/Comments ** ----------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Unrestricted	WW	*Oregon (2008) Class A recycled water (oxidized, filtered and disinfected wastewater)*		Yes	Yes		Yes					Before disinfec-tion, ≤ 2 NTU within 24 hr period; 5 NTU >5% of time within 24 hr period; <10 NTU at any time.	After disinfection, median of ≤ 2 TC/100 mL based on last 7 days; and < 23 TC/ 100 mL in any single sample.						Same uses as Class B, plus: irrigation for any agricultural or horticultural use; landscape irrigation of parks, playgrounds, school yards, residential landscapes or other landscapes accessible to the public. Commercial car washing or fountains when the water is not intended for human consumption. Water supply source for nonrestricted recreational impoundments. Artificial groundwater recharge by surface infiltration or subsurface injection.
Unrestricted	WW	Texas - Chap 210 - use of reclaimed water - subchap C: Quality criteria and specific uses for reclaimed water: *Type I*		Yes	Yes					≤ 5 mg/L		≤ 3 NTU	≤ 20 CFU/100 mL FC median, ≤ 75 max.						Residential and landscaping, parks, golf courses, school yards and athletic fields.
Unrestricted	WW	Washington State water reclamation and reuse stds		Yes - see comments	Yes					≤ 30 mg/L	≤ 30 mg/L	≤ 2 NTU, ≤ 5 NTU max, continuous monitoring	≤ 20 CFU/100 mL FC median						Irrigation - food crops and nonfood crops, landscape irrigation both restricted and open access areas; Impoundments; Restricted and unrestricted recreational; Fish hatchery basins, fountains, flushing of sewers, street cleaning, washing, dust control; Firefighting and protection.
Unrestricted	WW	USEPA guidelines for water reuse (2004)	Yes	Yes	Yes		Yes			≤ 10 mg/L		≤ 2 NTU	< 1 FC CFU/100 mL median (for last 7 days; should not exceed 14/100 mL for any single sample)	≥ 1 mg/L 30 minute Cl residual				6 to 9	Unrestricted urban reuse (parks, playgrounds, school yards, residences, toilet flushing air conditioning, fire protection, construction, ornamental fountains and aesthetic impoundments. All types of landscape irrigation (golf courses) vehicle washing, toilet flushing, fire protection commercial air conditioning); Ag reuse on food crops (surface or spray irrigation of any food crop, including crops eaten raw); Unrestricted recreational reuse (impoundment of water in which no limitations are imposed on body-contact water recreation activities). Source: USEPA, 2004, Guidelines for Water Reuse, Office of Wastewater Management, Office of Research and Development, Washington, D.C., EPA/625/C-04/108.
Unrestricted	WW	*Canada-British Columbia Waste Management Act municipal sewage regulation: Unrestricted public access*		Yes	Yes		Yes		Yes. Fire protection.	< 10 mg/L		≤ 2 NTU	≤ 2.2 fecal coliform CFU/100 mL (median)					6 – 9 90%)	Public access and contact with reclaimed water is allowed. Treatment: secondary treatment, chemical addition, filtration, disinfection. This is broken into: Urban uses (parks, playgrounds, cemeteries, golf courses, road right-of way, school grounds, residential lawns, green belts, vehicle and driveway washing, landscaping, toilet flushing, outside fire protection, street cleaning); Agricultural uses (aquaculture, food crops eaten raw, orchards and vineyards, pasture, frost protection, seed crops); and Recreational (stream augmentation, impoundments for boating and fishing, snow making - not for skiing and snowboarding, landscape waterfalls). Source: Canada, British Columbia, Municipal Sewage Regulation; and Canada, British Columbia, 2001, Guide to Irrigation System Design with Reclaimed Water

Reuse Category	Source Water Type	Regulatory Entity	←------ Application ------→							←------ Standard * ------→									←------ Other/Comments **------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted (direct contact with water from irrigation and laundry allowed)	WW	Canada Mortgage and Housing Corp. (CMHC) Consensus Standard: High *risk applications*		Yes		Yes				≤ 10 mg/L	≤ 10 mg/L	≤ 2 mg/L	< 1 fecal coliform CFU/100 (median), < 1 total coliform CFU/100 mL (median) and <23 fecal coliform (max); < 1 *E. coli* CFU/100 mL.	0.1 to 1.0 mg/L					Uses: landscape surface irrigation and laundry only.These are considered "high risk applications" because direct contact with reclaimed water is allowed. Source: Canada, 2005, Canadian Mortgage and Housing Corporation Research Report, Water Reuse Standards and Reuse Protocol, for use in Residential Applications in Canada. Reuse water applications, including raw (potable) water source, food crop (garden) irrigation, showers and bathing, were deemed unacceptable for individual onsite or small cluster-treatment system technologies.
Unrestricted	WW	South Australia reclaimed water guidelines - treated effluent:		Yes	Yes		Yes			< 20 mg/L	-	< 2 NTU	< 10 CFU/100 mL Median FC						These uses include primary contact recreation and residential nonpotable uses. Includes garden watering and path/wall washing.
Unrestricted	WW	*Australia, National Guidelines (2006) Class A?*										turbidity criteria determined on a case-by-case basis	< 1 *E. Coli* per 100 mL (median)	disinfection required; chlorine residual to be determined on a case-by-case basis					Uses: Unrestricted Access and Application, toilet flushing, washing machines, garden use, outdoor or indoor dual reticulation (piping), sports grounds, golf courses, dust suppression, commercial food crops consumed raw or unprocessed. Treatment: advanced, filtration, disinfection. Source: Australia, 2006, National Guidelines for Water Recycling, Phase 1, Managing Health and Environmental Risk, Natural Resource Management Ministerial Council, Environmental Protection and Heritage Council, Australian Health Minister's Conference, November.
Restricted or unrestricted not specified.	WW or GW not specified	Japan: *Landscape irrigation*		Yes									Not detected *E. coli*	≥ 0.4 mg/L Cl residual				5.8 - 8.6	No unpleasant appearance and odor. Uses: landscape irrigation. Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
Restricted or unrestricted not specified.	WW or GW not specified	*Korea: Sprinkling*		Yes						≤ 10 mg/L		≤ 5 NTU	None	≥ 0.2 mg/L Cl residual				5.8 - 8.6	No unpleasant appearance and odor. Uses: irrigation (sprinkling and gardening). Treatment: not specified. Source: Canada, 2005, Canadian Mortgage and Housing Corporation (CMHC) Research Report, Water Reuse Standards and Reuse Protocol, Table 25, p. 34.
GW- RESTRICTED ACCESS USES																			
Restricted	GW	WHO (2006) - *Recommended permit limits*		Yes						≤ 240 mg/L	≤ 140 mg/L		≤ 1000 CFU/100 mL fecal coliform bacteria						Irrigation of ornamentals, fruit trees, and fodder crops.Direct contact and storage not allowed. Adapted to local conditions of Eastern Mediterranean Region. Source: WHO, 2006, Overview of Greywater Management Health Considerations, Center for Environmental Health Activities, Amman, Jordan, WHO-EM/CEH/125/E, page 43. Note that the 1000 MPN fecal coliform/100 mL standard is also the1989 WHO standard for wastewater use in agriculture.
Restricted	GW	WHO (2006) - *Recommended permit limits*		Yes						≤ 20 mg/L	≤ 20 mg/L		≤ 200 CFU/100 mL fecal coliform bacteria						Irrigation of vegetables likely to be eaten uncooked.Secondary treatment required. No contact with vegetable crop allowed. Adapted to local conditions of Eastern Mediterranean Region. Source: WHO, 2006, Overview of Greywater Management Health Considerations, Center for Environmental Health Activities, Amman, Jordan, WHO-EM/CEH/125/E, page

Reuse Category	Source Water Type	Regulatory Entity	←--- Application ---→							←--- Standard * ---→									←--- Other/Comments **---→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine I Residual	Total Kjeldahl N	Total N	Total P	pH	
Restricted	GW	Australia- NSW Health Department - Domestic Greywater Treatment Systems Accreditation Guidelines (Feb 2005):	Yes							90% samples: <20; maximum threshold <30.	90% samples: <30; maximum threshold <45.				TBD	TBD	TBD		
Restricted	GW	Australia_NSW Health Department - Domestic Greywater Treatment Systems Accreditation Guidelines (Feb 2005):		Yes						90% samples: <20; maximum threshold <30.	90% samples: <30; maximum threshold <45.		Thermotolerant coliform (CFU/100 mL): 90% samples <30; maximum threshold <100.	Free Cl residual: 90% samples - >0.2 - <2.0; maximum threshold - <2.0.	TBD	TBD	TBD		
Restricted	GW	Australia- NSW Health Department - Domestic Greywater Treatment Systems			Yes	Yes				90% samples: <10; maximum threshold <20.	90% samples: <10; maximum threshold <20.		Thermotolerant coliform (CFU/100 mL): 90% samples <10; maximum threshold <30.	Free Cl residual: 90% samples - >0.5 - <2.0; maximum threshold -	TBD	TBD	TBD		
Restricted	GW	Australia-New South Wales - Health: greywater reuse in sewered single domestic premises	Yes	Yes	Yes	Yes				≤ 20 mg/L	≤ 30 mg/L		≤ 10 CFU/100 mL, median FC						
	GW	*Middle East Experts Review (2004)*		Yes						≤ 240 mg/L	≤140 mg/L		≤1000 Thermotolerant Coliforms per 100 mL (geometric mean)						Uses: irrigation of ornamental fruit trees, fodder crops. Treatment: unspecified. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
	GW	*Middle East Experts Review (2004)*		Yes						≤ 20 mg/L	≤20 mg/L		≤200 Thermotolerant Coliforms per 100 mL (geometric mean)						Uses: irrigation of vegetables eaten raw. Treatment: unspecified. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-EM/CEH/142/E.
	GW	*Middle East Experts Review (2004)*			Yes					≤ 10 mg/L	≤10 mg/L		≤10 Thermotolerant Coliforms per 100 mL (geometric mean)						Uses: toilet flushing. Treatment: unspecified. Source: WHO, 2004, WHO/AFESD Regional Consultation to Review National Priorities and Action Plans for Wastewater Reuse and Management, WHO-EM/CEH/106E; and WHO, 2006, A Compendium of Standards for Wastewater Reuse in the Eastern Mediterranean Region, Regional Office for the Eastern Mediterranean, Regional Center for Environmental Health Activities, WHO-

Reuse Category	Source Water Type	Regulatory Entity	←---------- Application ----------→							←---------- Standard * ----------→									←---------- Other/Comments **----------→
			Subsurface Irrigation	Surface Irrigation	Toilet Flushing	Laundry	Vehicle Washing	Dust Control	Industrial Uses ***	Biological Oxygen Demand	Total Suspended Solids	Turbidity	Bacterial	Chlorine l Residual	Total Kjeldahl N	Total N	Total P	pH	
GW- UNRESTRICTED ACCESS USES																			
Unrestricted	GW	WHO (2006) - *Recommended permit limits*			Yes		Yes			≤ 10 mg/L	≤ 10 mg/L		≤ 10 CFU/100 mL fecal coliform bacteria						Uses: toilet flushing, car washing.Secondary treatment and disinfection. Source: WHO, 2006, Overview of Greywater Management Health Considerations, Center for Environmental Health Activities, Amman, Jordan, WHO-EM/CEH/125/E, page 43.

*The standards in this table have mainly been developed for civilian purposes (primarily irrigation [food and nonfood crops], but also including residential, commercial, and industrial uses).

** The source for some of the information in this table is NSF International (POC is Tom Bruursema). When a specific reference appears in the "other/comments" column, the information has been added to the table by the U.S. Army Public Health Command.

*** Industrial Uses include: concrete mixing, soil compaction, aggregate washing, pest control, fire protection, machine coolant, well development

TBD-to be determined GW=greywater WW=wastewater=reclaimed

DALY = Disability Adjusted Life Year

restricted or unrestricted? - irrigate vegetated fields where PT is performed ?

APPENDIX C

Methodology for Calculating Yearly Risk for Multiple Exposures to Treated Wastewater

C1. INCORPORATION OF MULTIPLE EXPOSURE EVENTS FOR CHARACTERIZING RISK OVER TIME

C1.1 Binomial Exposure Model

With regard to GI illness, each exposure to treated wastewater has two possible outcomes: GI illness is experienced or GI illness is not experienced. The binomial response (yes or no) for GI illness after exposure allows the binomial model to be used to model multiple exposure events. The binomial exposure model has been used to model multiple exposures to *Cryptosporidium* in water (Pintar 2012) and a similar analysis can be applied to indicator *E. coli* as used in this microbial risk assessment.

A binomial process has two, and only two, possible outcomes; a good example is a coin flip. In the case of flipping a fair coin, the probability of heads is the same as the probability of tails. For any flip of the coin, either outcome could result. The binomial model can be used to answer questions such as "how likely are 4 heads in a row" or "what is the most coin flips in a row that could be expected to come up all tails at least 60% of the time".

In applying the binomial model to the multiple exposures, each exposure is similar to flipping a coin, but a coin *without* an equal chance of heads or tails (e.g., a weighted coin). The probability of experiencing illness is different than the probability of not experiencing illness because there is only one specific dose where the probability of illness is the same as the probability of no illness (50/50 chance to experience illness or no illness). For this risk assessment, because the doses are expected to be low, it is assumed exposure will be below the dose where the probabilities are equal; hence the weighted coin weighted for no illness. Every exposure will result in some dose of microbial content (unless there is zero microbial content in the treated wastewater) and that dose will have a corresponding probability of causing no illness or illness; the dose-response function calculates the chance of illness for a dose (see Section 6.5.3 for the established dose-response relationship).

Equation C1 is the binomial model (Pintar 2012).

$$P_{multiple} = 1 - (1 - P_{single})^n \qquad \text{(Equation C1)}$$

$P_{multiple}$, is the probability that at least one exposure event will result in illness at some point during n exposures.

The probability of a single exposure event causing illness is P_{single}; this is the probability of illness from the established dose-response relationship for a given exposure dose (see Section 6.5.3); therefore (1-P_{single}) is the probability of a single exposure event not causing illness. The number of exposures is n. The quantity $(1 - P_{single})^n$ is the probability none of n exposures result in illness and $1 - (1 - P_{single})^n$ (or $P_{multiple}$) is the probability at least one of n exposures resulted in illness. The RBWC's are concentrations, so it is necessary to convert from concentration to dose to use the binomial model. Equation C2 converts a concentration to a dose based on 10ml of incidental water ingested per shower. Once a dose per shower is found, P_{single} is calculated using the lower 95% confidence dose-response function from section 6.5.3, equation 5.

$$dose = concentration * volume \qquad \text{(Equation C2)}$$

For examining the chance of illness during the year, n will be the total number of showers taken in a year. For the twice daily showering scenario, n=73. For the one shower per day scenario, n=365. For the every other day shower scenario, n=183. For the one shower per week scenario, n=52.

An underlying assumption of the binomial process is that each exposure is an independent event. To use the binomial model, the exposures are assumed to be quasi-independent (see section 7.1, item 2.).

C1.2 Applying the Binomial Exposure Model to the RBWC's

Table C1 below shows the steps to go from the concentrations in Table 21 to the corresponding yearly risk; the probability of an average member of the population experiencing GI illness at least once in a year from a shower with treated wastewater. The RBWC's are converted to average doses using equation C2. Equation 5 is used to find the probability of illness from a single exposure, P_{single}. Each shower frequency has a corresponding n, the number of showers in a year. $P_{multiple}$ is expressed as a percentage that members of the population will experience GI illness at least once during a year, and as a proportion for comparison to the daily GI illness rate.

Table C1. Summary of Calculations to find Yearly Population GI Illness Risk

From Table 21				Calculated					
Daily Population GI Illness Rate	Shower Frequency	*Escherichia coli* Water Concentration (RBWC)		Average Dose[a] of Indicator *E. coli*[b] per shower	GI Illness Probability (95%) per shower (P_{single}[c])	Showers per Year (n)	Yearly GI Illness Risk ($P_{multiple}$)[d]		
		CFU / 100 ml	CFU / 10 liters	CFU	Probability		Percentage	Proportion	Confidence
1 in 100	Two showers per day	5	500	0.5	1.0E-03	730	54%	54 in 100	Low[e]
	One shower per day	10	1000	1	2.1E-03	365	54%	54 in 100	
	One shower every two days	30	3000	3	6.3E-03	183	68%	68 in 100	
	One shower per week	100	10,000	10	2.1E-02	52	66%	66 in 100	
1 in 1,000	Two showers per day	N/A[f]	50	0.05	1.0E-04	730	7.4%	74 in 1,000	Low[e]
	One shower per day	1	100	0.1	2.1E-04	365	7.4%	74 in 1,000	
	One shower every two days	3	300	0.3	6.3E-04	183	10.9%	109 in 1,000	
	One shower per week	10	1000	1	2.1E-03	52	10.3%	103 in 1,000	
1 in 10,000	Two showers per day	N/A[f]	5	0.005	1.0E-05	730	0.76%	76 in 10,000	Low[e]
	One shower per day	N/A[f]	10	0.01	2.1E-05	365	0.76%	76 in 10,000	
	One shower every two days	N/A[f]	30	0.03	6.3E-05	183	1.1%	115 in 10,000	
	One shower per week	1	100	0.1	2.1E-04	52	1.09%	109 in 10,000	

Legend:

[a]Dose is calculated using a value of 10ml of incidental water ingested while showering.

[b]*E. coli* is an indicator of microbial content in the treated wastewater. The exact pathogens responsible for GI illness in the treated wastewater may be unknown. Only viable complete pathogens cause illness. A dose of a fractional CFU of *E. coli* does not mean a portion of an *E. coli* is expected to cause illness rather it reflects the presence of some quantity of viable complete pathogen cells/viruses/protozoa.

[c]P_{single} is calculated based on the a given RBWC and reflects the dose-response relationship. P_{single} is the probability a single shower will lead to an average member of the population experiencing GI illness.

[d]$P_{multiple}$ is the probability at least one, of all showers taken in a year, will cause an average member of the population to experience GI illness at least once in that year.

[e]The confidence in the yearly risk is low, but the calculated yearly risk is anticipated to overestimate the probability of GI illness, so the calculated risk should be a upper bound for the yearly risk of GI illness.

[f]Not applicable, concentrations whose volumes lead to fractional CFU. A larger sampling volume results in a whole number CFU per volume concentration.

As an example based on one row in the table: If a population of 1,000 people showered once a day for a year in treated wastewater with an *E. coli* concentration of 100 CFU/10 liters (1 CFU/100 mL), it would be expected on any day 1 person in the 1,000 person population would be experiencing GI illness and that during the year 74 people of the same 1,000 person population exposed may experience GI illness.

C1.3 Confidence and Uncertainties

Uncertainties are recognized in the application of the binomial model to wastewater reuse. The binomial model assumes independent exposures, which is may not be accurate. For the twice daily showering alternative, it is unlikely exposures are independent. For the one shower per week alternative, it is likely exposures are independent. The binomial model as implemented in this section assumes all exposures have the same probability of resulting in GI illness. In the field, the wastewater will vary so the resulting treated wastewater may vary in microbial quality. Because of the uncertainties, the confidence assigned to the model results is low.

Despite the uncertainties in the application of the binomial model, it is anticipated to be a worst case model making the resulting estimations conservative. When the exponential dose-response function is used with the binomial model, the result is equivalent to summing all exposures over the year and finding the risk from the total yearly dose. With the small doses the RWBC's correlate to, the body should be able to clear exposed pathogens fast enough that a year total dose should not reflect the actual exposure case; the binomial model should overestimate risk if the assumptions in section 7.1 are valid. The binomial models predictions should overestimate the expected illness so while the confidence is low, the values provided by the binomial model should be an upper bound for the yearly risk from GI illness.

C1.4 Interpretation of Yearly Risk

Context regarding GI illness is provided to assist stakeholders with the application of the yearly risk information. 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.

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
<u>Terms</u>

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.

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