WATER REUSE
IN CONTINGENCY OPERATIONS

A Strategy for Comprehensive Health Risk Management

Health Risk Analysis and Recommendations
for a Comprehensive Risk Management Approach
to Quality Assurance

Technical Guide 364a
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USAPHC
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FOREWORD

The Army Institute of Public Health (AIPH) is charged with standardizing and promulgating practices and procedures to prevent the disease, injury, and disability of Soldiers and retirees, their Families, and Army Civilians. In that capacity, the Institute conducts studies and develops technical guidance for health risk management of activities in contingency and garrison environments. This technical guide represents the culmination of one such effort and the beginning of a long-term mission to oversee the operations and assure the quality of a new water resource for contingency operations. This effort was funded by the Army Study Program and was sponsored by the Deputy Assistant Secretary of the Army for Environment, Safety, and Occupational Health.

The Army and other Services across the Department of Defense realized after experiencing years of lengthy and costly missions transporting water and wastewater around the battlefield that new water management strategies were needed. The dual burden of delivering potable water and subsequently transporting it as wastewater has limited the military's abilities to execute its combat mission. To reduce that burden, emerging technologies are being investigated to treat wastewater nearer its point of production and to reuse at least a portion of the treated wastewater for beneficial purposes that would traditionally consume additional potable water. Water reuse has the potential to significantly reduce the volumes of both potable water required and wastewater that must be moved and stored on or removed from the battlefield. It would, thus, increase the agility, flexibility, and sustainability of the Force.

The AIPH conceived the risk-management strategy documented in this technical guide to address the gap for a program of quality assurance measures for water reuse during contingency operations. This technical guide facilitates decision making on the part of materiel and combat developers who seek to leverage water reuse in the field as a solution to reducing the burden of liquid logistics on the modern expeditionary battlefield. This effort marked a return to the comprehensive study of the potential health risks resulting from water reuse in contingency operations after more than a decade of diminished attention. Prior guidance, limited specifically to the reuse of shower and laundry water in Force Provider, was published by the U.S. Army Center for Health Promotion and Preventive Medicine (now AIPH as part of the U.S. Army Public Health Command) and endorsed by the Army Surgeon General in 2001. This new technical guide is not an endpoint but represents a milestone along the continued pathway towards optimizing and ensuring safe and reliable water resources for contingency operations.

Part I of this technical guide provides background on water reuse and the AIPH risk analysis methodology. Part II documents the details of the health risk assessment. The risk assessment does not assess all the possible hazards of water reuse but rather highlights what is known and what remains unknown; it prepares the way for future risk assessments of specific water reuse scenarios as they are identified and mature. Part III introduces the risk management framework and its derivation, proposes classifications of reclaimed water quality in contingency operations, and provides risk communication priorities to assist in engaging the diverse stakeholders of water reuse in contingency operations.

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INTRODUCTION

The view on wastewater is changing. Due to resource constraints and an emphasis on sustainability, it is no longer just another waste product, but a resource that can be treated and beneficially reused. The practice is known as "water reuse," and it is emerging as part of a strategic shift in water resource management. Water reuse is important to the Military because it reduces the burden of transporting large amounts of potable water, conserves costs, improves the quality of life, and saves lives.

The transportation and security burden to deliver water and to retrograde wastewater, limits the Military's ability to execute its mission. An overwhelming percentage of convoy capacity, 70-80%, depending on reports, is dedicated to water and fuel transport (Moore 2009, Noblis 2010). Water is a resource for which there is no substitute, regardless of the areas of operation.

Water reuse, as part of an integrated water resource management strategy, allows a single volume of water to be used and reused for multiple demands, reducing the total volume that must be sourced from nature or transported from elsewhere.

Problem Statement

The future force lacks the capability to achieve logistical independence from potable water demands and wastewater handling. Combat and materiel developers have initiated the shift in water management as introduced above, but current Military doctrine lacks adequate guidelines to manage the potential health risks of water reuse in contingency operations. Technical Bulletin Medical (TB MED) 577/NAVMED P-5010-10 AFMAN 48-138_IP (Department of the Army (DA) 2010), the current manual for sanitary control and surveillance of field water supplies, provides extensive guidance for drinking water, but only limited criteria for water reuse.

Purpose

The Army Institute of Public Health (AIPH) conducted this risk analysis of water reuse in contingency operations as the foundation for water reuse guidelines that are health protective and mission sustaining. This study supports the Army Campaign Plan objective to achieve energy security and sustainability. This study also supports Net Zero initiatives as set forth by the Army and the Department of Defense (DOD), and addresses the capability gap for maintaining non-potable water systems as identified in the Army Water Security Strategy.

Authority

The office of the Deputy Assistant Secretary of the Army for Environment, Safety and Occupational Health sponsored this project's proposal to the fiscal year (FY) 2013 Headquarters Department of the Army (HQDA) Army Study Program Management Office. The proposal was selected and approved by the HQDA Study Program Coordination Committee as a funded FY2013 HQDA Army Study Program Project.

Scope

From an initially broad scope, this study was necessarily narrowed based on the findings of the initial research and state of the science scoping, as well as time and fiscal constraints. This study represents an increment of a longer-term effort to develop comprehensive guidelines for water reuse in contingency operations. It encompassed the informational foundation and strategical framework. Development of metrics and associated implementation guidance will follow in future increments, introduced at the conclusion of this report.

This study relied on existing research and experience; no toxicological or human-health effects experimentation was conducted.

Direct potable reuse, the introduction of reclaimed water directly into the potable water supply, was not within the bounds of this study, though it is referenced where appropriate.

The designation of acceptable activities for non-potable and potable water is provided in TB MED 577 (DA 2010). A similar concept was adopted and expanded in this study.

This study expanded and reinforced the foundation on which a parallel effort of the AIPH, entitled "Microbial Risk Assessment (MRA) for Unrestricted Wastewater Reuse during Army Deployments," was based. The MRA assessed the risk of gastrointestinal illness from exposure to reclaimed water based on the indicator *Escherichia coli (E.coli)*. The study reported herein took a broader viewpoint of the hazards, exposures, barriers, and potential management strategies and did not attempt to repeat the detailed quantitative process of the MRA.

Water Reuse: the use of treated wastewater for a beneficial purpose (Asano 2007). It may be recycled back into the process that generated it or repurposed for another application. The treated product is termed reclaimed water.

This study did not directly evaluate the costs, monetary or otherwise, of water reuse. This study did not include additional aspects of resource management such as water conservation.

This study concluded with the development of a risk management framework. It did not establish numerical water quality standards nor does it represent an enforceable regulation of water reuse. This study serves as the informational foundation for future guidelines to be promulgated by the Services or as a Joint technical standard.

This report begins with a brief background of the concepts of water reuse and the existing Civilian and Military standards of practice. It continues in Part II with a health risk assessment and concludes in Part III with an introduction to the risk management considerations for water reuse in contingency operations.

Methods

The study progressed from a detailed literature review and data mining of existing water quality metrics in phase 1 to a risk analysis in phase 2 and concluded with documentation and reporting in phase 3. Three virtual conferences were held with stakeholders from across the DOTMLPF[1] spectrum. These were facilitated by Defense Connect Online, a web-based conferencing and collaboration tool. Combat and materiel developers, planners, sister-Service public health commands, and other institutional research organizations were represented at each conference. In addition, the AIPH team met on a regular basis to brainstorm and draft products. Interim products were subsequently distributed to the larger stakeholder audience for comment. The final report reflects the conclusions of the author and not necessarily that of the contributing stakeholders.

Assumptions

1. Water reuse in contingency operations will first be practiced in well-developed camps where trained operators and resources are available for oversight and maintenance. Once it becomes a more mature concept to include the management framework, it may be a solution further forward.
2. Natural buffers will not be components of reuse scenarios in contingency operations. Contingency reuse scenarios will constitute direct reuse.
3. The population of concern is mostly composed of relatively healthy and fit adults. A more comprehensive definition of the military deployed population is provided in U.S. Army Public Health Command (USAPHC) Technical Guide (TG) 230 (USAPHC 2010).
4. Agriculture irrigation is not a planned-water use in contingency operations. Research which examined agricultural exposures and risk analysis were considered only to the extent that the exposure pathways and hazards were analogous to activities in a contingency environment.
5. Civilian regulatory codes for water reuse serve a valuable though incomplete tool to manage risk in contingency operations.

[1] Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel and Facilities. See Project Personnel for a partial listing of conference participants.

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Limitations

1. The current thrust of water reuse, both in materiel development and this risk analysis, is limited to non-potable water. Potable reuse risk management would likely build from the concepts herein.
2. This risk analysis considered human health risk only; additional considerations may be required for environmental risks.

Project Personnel

This study was carried out by a matrixed team of subject matter experts from within AIPH and facilitated by the assistance of external experts.

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References

A consolidated list of references is provided at Appendix A.

BACKGROUND

The Army Institute of Public Health (AIPH), then the U.S. Army Environmental Hygiene Agency (USAEHA), first examined water reuse in a 1982 information paper, entitled *"Recycle/Reuse of Wastewater"* (USAEHA 1982). Shortly thereafter, in 1986, as a component of the much larger effort to develop drinking water standards, Lawrence Livermore National Lab (LLNL), in support of the U.S. Army Biomedical Research and Development Laboratory (USABRDL), conducted a health risk assessment of infectious organisms in nonconsumptive water exposures, principally dermal exposure (LLNL 1986). Even preceding these works, was a report by USABRDL of the "Evaluation of Health Effects Data on the Reuse of Shower and Laundry Waters by Field Army Units" (USABRDL 1979). Remarkably, though much has changed in the intervening years, much remains the same. Many of the findings remain pertinent today, including those related to treatment technologies, surveillance methodologies, microbiological hazards, and exposures. The current study looked to reengage the Army public health community on these and other aspects of water reuse and establish an up-to-date informational foundation for risk management of water reuse in contingency operations. The background paragraphs which follow are provided to illustrate the perspective from which the risk analysis was carried out.

In order to analyze the potential risks of water reuse, it is first necessary to understand the concept and how the Military may apply the practice in a contingency operation. Figure 1 shows the general cycle of a volume of water from natural source through treatment, use, and reuse. Beginning with the traditional water management cycle (the colored boxes and grey arrows), natural water is collected, treated, and distributed to users. They, in turn, generate wastewater. It, too, is collected, treated, and eventually returned to a natural water body, marked "*buffer*" in Figure 1. Somewhere downstream, the cycle starts again, illustrated by the dashed arrow. In the water reuse context, this is termed de facto reuse. In the traditional cycle, most treated wastewater is discharged to a surface water body but could also include ground water. The cycle time can vary greatly and is related to the natural hydrologic cycle for the region as well as the water demand by municipalities and industry, but it may be quite protracted on the order of days to years.

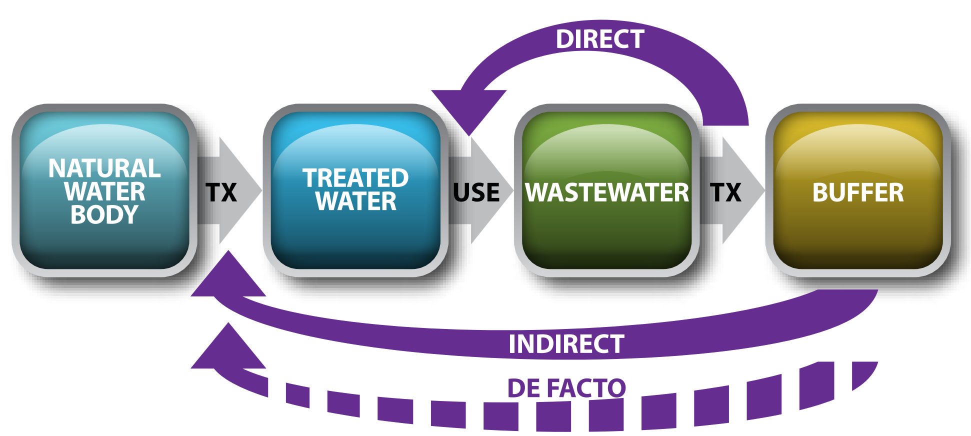

Figure 1. Water Reuse Superimposed on the Traditional Water Cycle
Adapted from USEPA 2012 Guidelines for Water Reuse
Notes: TX=treatment; buffer=natural or engineered body of water

Planned reuse, indicated by the purple arrows, increases efficiency by reducing or eliminating discharge to and the demand on natural water bodies. Reuse may be "direct," immediately reintroduced to an end-activity, or "indirect," involving a natural or engineered buffer. As indicated by the arrows, water for indirect reuse may be blended with other waters, not of wastewater origin, and may be subjected to additional treatment prior to use. The cycle time for direct reuse is significantly shorter than the traditional cycle, as short as hours. The goal of water reuse is to substitute reclaimed water for a demand previously met with potable or non-potable water from a traditional source (water of non-wastewater origin).

Civilian Context

Water reuse is commonplace in the United States and around the world. The overwhelming majority of reclaimed water is used for irrigation and industrial activities. While many instances exist, the total volume of reclaimed water remains small compared to traditional sources. Non-potable uses are slowly being matched with potable uses of reclaimed water, both purposeful and de facto. Nearly all municipal surface water sources have some degree of de facto reuse, meaning upstream wastewater effluents contribute to the flow, estimated to be on the order of 5 percent (National Research Council (NRC) 2012).

While reuse may mark a shift in resource management for the deployed Military, the Civilian sector has been focused on the escalating imbalance in supply and demand for some time, particularly in resource- constrained environments. The NRC stated, "In this new century, the United States will be challenged to provide sufficient quantities of high-quality water to its growing population" (NRC 2001). In a more recent work, the NRC gave careful attention to the way in which the U.S. does and could, going forward, manage a potential resource in municipal wastewater (NRC 2012). The NRC's in-depth review of the current state of water reuse and its many facets, the regulatory climate, and risk assessment and management techniques particular to water reuse offered a valuable resource and contains a number concepts which carry over into the Military context.

"In this new century, the United States will be challenged to provide sufficient quantities of high-quality water to its growing population" (NRC 2012).

Areas of common ground for water reuse between the Civilian and Military contexts include defined sub-classes of reclaimed water based on source, applied barriers, and intended use. Whereas in a potable-water context, a single standard exists, reclaimed water is produced based on a fit-for-purpose concept. In a related concept, one or more classes of reclaimed water are grouped into "restricted" and "unrestricted water reuse," for the purposes of both exposure limitation and quality designation.

Potentially the most import carryover principles, are the risk management constructs such as the hazard analysis and critical control point (HACCP) approach (Halliwell et al. 2013), water safety plans (World Health Organization (WHO) 2005b), and risk management plans (Natural Resource Management Ministerial Council/Environment Protection and Heritage Council/Australian Health Ministers Conference (NMRRC/EPHC/AHMC) 2006). Each of these concepts is addressed in greater detail in Part III of this report.

Civilian Regulatory Base

There are no U.S. Federal regulations governing water reuse, but guidance and best-practices are provided by way of the USEPA's 2012 Guidelines for Water Reuse. It provides an in-depth catalog of the status of reuse in the United States and templates for states to develop their own regulations or guides (USEPA 2012b). At least 25 states have formal regulations, and another 16 have guidelines for water reuse. A handful of states are leading the evolution, including California, Arizona, Florida, and

Colorado. A summary of U.S. state regulations and guidelines as compiled by the USEPA is provided in Appendix B.

Worldwide, there are a significant number of published guidelines for water reuse, including comprehensive federal statutes in Australia and international guidelines such as those published by the WHO (Natural Resource Management Ministerial Council/Environment Protection and Heritage Council/Australian Health Ministers Conference (NRMMC/EPHC/AHMC) 2006, 2008, WHO 2006a). Civilian reuse guidelines often include specific water quality criteria based on intended use, as well as treatment requirements based on the wastewater source and target quality. They may also include use-area restrictions, reliability requirements, and operations and maintenance controls (Asano et al. 2007).

A treatment technology-driven framework pervades the regulatory community. This means that standards are designed to maintain proper operation of a treatment system designed, if not proven, to mitigate the hazards. Notable exceptions from the WHO and Australia use instead a risk-based approach, including a quantitative measure of disease burden, known as disability adjusted life years or DALYs. The principle of DALYs is to sum acute and chronic morbidity and consider the relative risk of competing courses of action. The concept of DALYs and its application are further discussed in Part III of this report.

Military Application

These worldwide examples provide a foundation for military applications but do not directly address the specific conditions that Service members may face. Nearly all of the risk assessments conducted have focused on agricultural and industrial exposure scenarios. Additional extrapolation and study is necessary to quantify the health risk in military contingency reuse scenarios (Gibson, et al. 1998; Haas et al. 1996, 1999). This document begins that crosswalk. The Military will find itself very soon at the leading edge of water reuse due to the foreseen predominance of direct human contact reuse activities, such as showering, demanding near-potable water quality. Indeed, two systems currently deployed recycle laundry or shower water back into their respective processes, and future development appears to include more of the same.

The Shower Water Reuse System (SWRS) is a Product Manager Force Sustainment Systems' program for direct recycle of gray water produced by showers. With a capacity of 12,000 gallons per day and a recovery of 75%, it can provide up to 9,000 gallons of water for showers per day. The SWRS employs many of the exact technologies found in the Tactical Water Purification System, designed to produce drinking water. The combination of microfiltration, reverse osmosis, and chlorine disinfection generate a product that would likely meet the Military Field Water Standards for drinking water but in an additional risk management measure is classified non-potable.

Military Regulatory Base

Department of the Army Pamphlet 40-11, Preventive Medicine, provides limited instruction on the management of water reuse in contingency operations (HQDA 2009). Included is the prohibition of direct potable reuse of wastewater, but with specific exceptions for reuse of shower and laundry wastewaters for reuse in showers and laundry. The basis for these directives, health-risk based or otherwise, is not provided.

The USAPHC (at the time, U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM)) developed criteria for shower water reuse in the Army Force Provider, based largely on the potable water standards in effect at the time and pilot studies conducted by USABRDL (USACHPPM 2001). Table 1 summarizes the quality criteria proposed by USACHPPM to the materiel developers.

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PHYSICAL PROPERTIES	PROPOSED CRITERIA
Color (color unit)	50
Odor (total odor number)	3[a]
pH	5-9
TDS (mg/L)	2000
Turbidity (NTU)	1
Chlorine residual (mg/L)	2-5 after 30 min[b]
CHEMICAL PROPERTIES (MG/L)	
Arsenic	0.3
Cyanide	6
Lindane	0.6
MICROBIOLOGICAL	
BOD5 (mg/L)	10[a]
Coliform (cfu/100 mL)	0

Table 1. USACHPPM Proposed Water Quality Criteria for Recycled Gray Water for Force Provider

Legend:
mg/L = milligrams per liter
NTU = Nephelometric turbidity units
cfu = colony-forming unit
mL = milliliter
Notes: chemical agent and radiological contaminant criteria were equal to the Tri-Service Field (drinking) Water Standards in effect at the time for 5 liter per day consumption rate, excluded here for brevity.
[a] Design criterion only; property is not practical to measure in the field.
[b] Equivalent alternative disinfection is acceptable.
Source: USACHPPM 2001

These criteria represent a combination of technology-driven operational monitors and health and palatability thresholds. The assumption was water of this quality would be aesthetically acceptable for the designated purpose of showering, and because a small amount of water might be ingested, using the potable water standards was conservatively health protective. The proposal included a number of associated guidelines as well:

1. Use of the best practical physical chemical and/or biological treatment.
2. Discharge of at least 20% of the untreated wastewater, to include all of the laundry wash cycle.
3. Use of a filter of absolute pore size < 0.2 micrometer (µm) or equivalent technology to treat all gray water.
4. Disinfection prior to recycle/reuse by chlorination or equivalent alternative disinfection.
5. Ventilation of any enclosed shower stall to equal or exceed one stall volume per minute.
6. Quality of makeup water to meet or exceed field potable water standards.

While the scope introduced above was quite narrow and specific to the Force Provider application, it formed the basis for what was later adopted as the general standards for recycled gray water in

TB MED 577 (HQDA 2010):

1. pH: 5 to 9
2. Turbidity: 1 NTU
3. Hardness: 500 mg/L

4. Total dissolved solids (TDS): 1500 mg/L
5. Coliforms: absent
6. Free-available chlorine (FAC) chlorine residual: 1 mg/L after 30 minutes.

The demand has not existed, heretofore, to expand these guidelines. With an evolution in water resource management pending, this study, and the larger effort it initiates, marks the beginning of a comprehensive strategy for proactive risk management.

Beyond reuse-specific guidance, TB MED 577 offers additional guidance which must be considered in the context of water reuse. In contingency operations, water of less than drinking water quality is permitted for use in certain activities; see excerpt below from TB MED 577 (DA 2010). This is very similar to the idea presented above of a fit-for-purpose classification of reclaimed water; with the marked difference that Table 2 assumes a non-wastewater source. Class II assumes a freshwater source that has been treated with, at a minimum, a disinfectant, and ideally filtration and disinfection. Classes III and IV are waters in their natural state without treatment. Reclaimed water designations and their acceptable uses must align and not conflict with the established water quality classifications.

WATER CLASS/QUALITY	ACCEPTABLE WATER ACTIVITIES
Class I – Potable Water	Drinking
Class II – Not Potable Disinfected Fresh Water	Well development
Class III – Not Potable Untreated Fresh	Construction
Class IV – Not Potable Brackish or Seawater	Dust control

Table 2. Water Quality Classifications and Acceptable Uses
Source: *abbreviated from TB MED 577*
(DA 2010)
Use only the complete version as published in the technical bulletin for decision making.

Risk Analysis

Much like constructing a building, in order to develop sound guidelines for water reuse in contingency operations, it was first necessary to form the foundation, and then a framework, on which to build metrics and implementation guidance giving the 'building' its functionality. In the risk analysis which follows, the risk assessment represents the foundation, while the risk management and risk communication strategies represent the framework for risk management of water reuse in contingency operations. Risk analysis can consider a full-spectrum of impacts including economics, legal, safety, and environmental health. This risk analysis was limited to the impacts on human health. This study marks a transition from research to implementation. The path to concrete guidelines will continue to be iterative, as implementation plans mature, they will demand further research, and in turn research will drive more effective strategy.

PART II – HEALTH RISK ASSESSMENT

The foundation of risk management is a detailed risk assessment. The risk assessment of water reuse in contingency operations includes the building blocks of hazard identification, barrier assessment, exposure assessment, and risk characterization. It follows closely with the model developed by the NRC for the USEPA, Figure 2. The goal of the risk assessment is to produce both a technically accurate product and one which has utility for decision makers. The risk assessment serves the added function of evaluating the relative merit of risk management options. Communication between the risk assessors and the risk managers, as well as with other stakeholders, facilitates the process. As implementation efforts progress, additional data gaps may be filled, which improve the technical analysis and better characterize the risks.

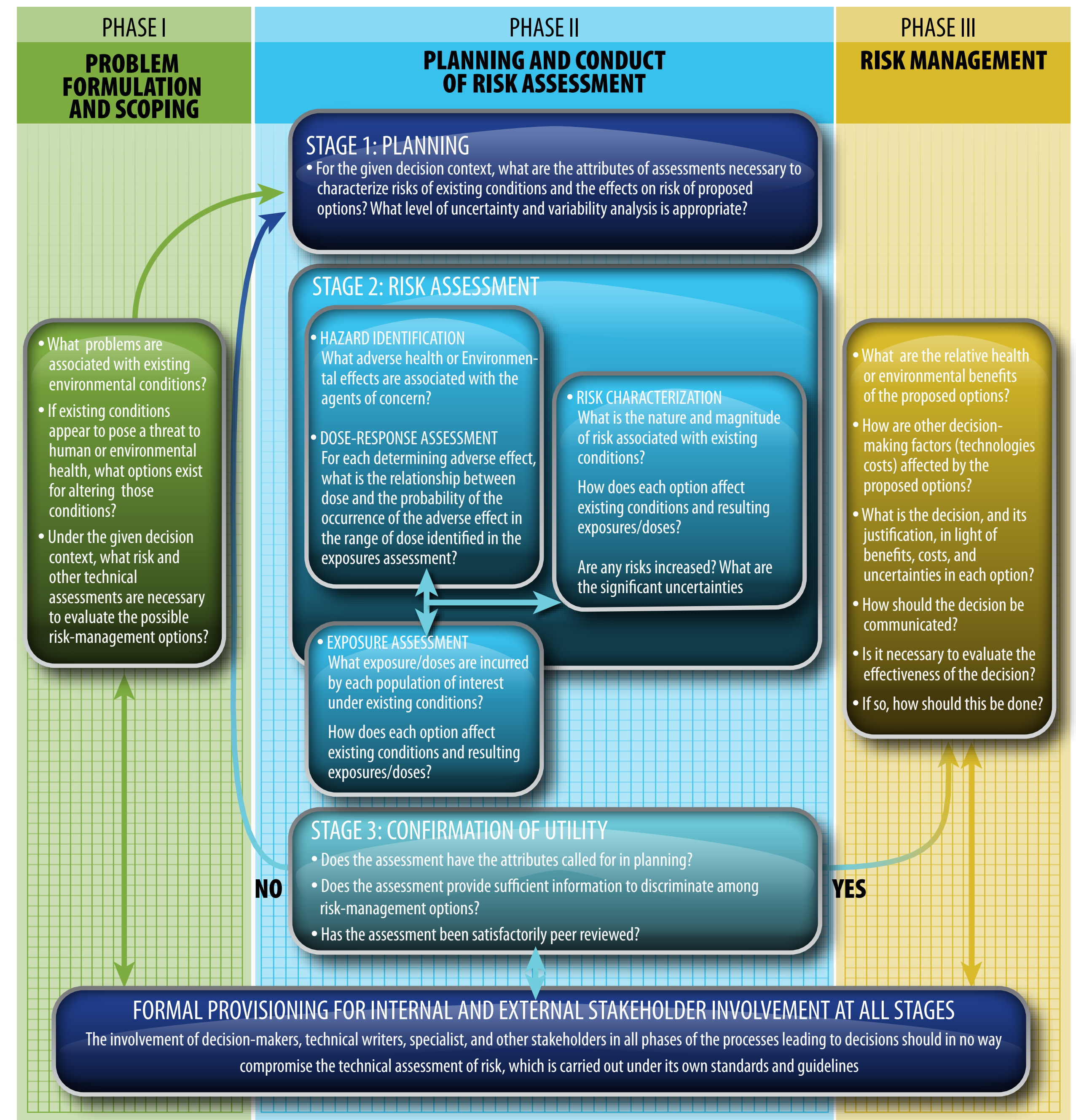

Figure 2. Risk-based Decision Making
Source: NRC 2009

In determining a threshold of safety, one must understand and, at a minimum, qualify the risks of the proposed activity. For this risk assessment,the question was, "Is reclaimed water safe for use in contingency operations? If so, for what end uses and how will quality be measured and maintained?" It is impossible to achieve a state of zero risk, particularly when considering the environment and occupation of the at-risk population in contingency operations. The health risk associated with existing water supply strategies is assumed to be relatively small. Despite gaps, both validated and anecdotal, the quality of water provided for all activities in contingency operations is high. The current water quality and associated use will, thus, stand as the threshold of safety for any alternative water supply.

Data gaps in the building blocks of this risk assessment remain due to unavailable or imprecise research. Few, if any, direct experimental studies have been performed with the hazards of interest. Epidemiological analyses of health outcomes from exposure to reclaimed water provided some information, but critical variables, such as dose and population as well as the confounder of negative results, limited their utility. The study evaluated the available information and identified gaps which remain.

HAZARD IDENTIFICATION

Gray water is wastewater from bathing or washing that does not contain concentrated food or human waste (NRC 2012, Asano et al. 2007). Examples include shower and laundry wastewater. For the purposes of water reuse in contingency operations, gray water will exclude kitchen wastes and exclude kitchen wash water.

The hazards of water reuse relate to the composition of the wastewater, a consequence of the original waste-producing activities. It is necessary, therefore, to understand the wastewater 'sources' first in order to place the hazards in context. Though water reuse would predominantly occur after a series of processes to reduce the hazards, the discussion which follows considered first the untreated wastewater, and in a subsequent section, the barriers, to include treatment, which may be applied to mitigate the identified hazards. As previously introduced, wastewater handling in contingency operations is immature, consisting primarily of containerization and retrograde or discharge; therefore, this hazard assessment used industry definitions for the purposes of source characterization. Established in industry are several classifications of wastewater, including residential, municipal, and industrial, each with different physical, chemical, and biological characteristics. Military operations introduce a number of additional, potentially unique, sources such as water-purification-unit reject. There is also the potential for wastewater significantly influenced by nuclear, chemical, biological, or radiological contaminants. This assessment assumed waters in this final group were not candidates for reuse.

Wastewater Classification

Non-industrial wastewater may be further classified by its relative composition as gray water, black water, or domestic wastewater, a combined stream of gray and black waters.

Gray Water

Gray water is wastewater from bathing or washing that does not contain concentrated food or human waste (NRC 2012, Asano et al. 2007). Examples include shower and laundry wastewater. For the purposes of water reuse in contingency operations, gray water excludes kitchen wastes and excludes kitchen wash water. About 85% of wastewater generated on contingency bases is gray water[2] (Noblis 2010).

In many contingency operations, gray water is captured separately from black water and other types of wastewater. This may prove beneficial from a hazard perspective due to lower concentrations of microbial pathogens, organic matter, and trace constituents in gray water. Gray water may contain elevated concentrations of minerals and surfactants from cleaning products (NRMMC/EPHC/AHMC 2006).

Depending on the ultimate use of the reclaimed water, treatment may range from simple disinfection to membrane filtration and advanced oxidation. Within the commercial industry, these technologies are mature and offer proven performance to reduce hazards.

Due to its abundance, relative high-quality compared to other wastewater, and the availability of mature treatment and handling techniques, gray water is the preferred candidate for water reuse. Combat developers and materiel developers have accordingly focused their time and monies to develop gray water reuse systems.

Black Water

Black water is source-separated wastewater from latrines and kitchens containing one or more of the following, urine, feces, toilet paper, food waste, and flush water (Asano et al. 2007, WHO 2006a, DA 2006).

Black water is source-separated wastewater from latrines and kitchens containing one or more of the following: urine, feces, toilet paper, food waste, and flush water (Asano et al. 2007, WHO 2006a, DA 2006).

Black water is typically high in organic matter, ammonia, and other nutrients lending to a high chemical and biochemical oxygen demand (COD/BOD). It also contains a high concentration of microbial organisms, which may include human pathogens (Wendland 2008).

Black water has not been well characterized from a human health hazard perspective. This is perhaps due to the fact that in municipal utilities, black water is not typically separated from other wastewater. In contingency operations, it may indeed be captured separately due to decentralized wastewater handling. In addition, it may have the added constituents of chemical latrines. Black water in contingency camps may be unique from black water characterized in commercial or municipal context.

Black water represents a minority fraction of the cumulative wastewater volume and contains a higher concentration of hazards. This decreases the value of black water for reuse in contingency operations. Further characterization of black water and its potential hazards is nonetheless valuable in order to adequately design, operate, and maintain barriers that allow for safe disposal or reuse. Treatment costs both in capital and operation may be higher for black water, further reducing its value.

Domestic Wastewater

Domestic wastewater is composed of gray water and black water. It contains the wastes of all non-industrial activities (WHO 2006a).

Domestic wastewater is distinguished as a unique source in this analysis because of its extensive use and characterization in municipal water reuse scenarios. Most municipal applications of reuse draw their source water from domestic wastewater. Consequently, barrier design and hazard analysis were available for domestic wastewater. Although of potentially lower quality than gray water, domestic wastewater has physical, chemical, and microbiological characteristics that make it a suitable source for water reuse.

Microbial Hazards

Properly treated and managed, reclaimed water can be a safe alternative water supply, but microbial hazards do exist in the source water which could cause illness. Microbial hazards in wastewater are pathogens of principally human fecal origin. Microbial hazards include bacterial, viral, protozoan, and helminthic pathogens. Their relative abundance, potential health effects, and fate in the reuse cycle are considered further below.

Microbial pathogens represent primarily an acute health hazard, meaning the time from exposure to illness is a period of hours to days. They are primarily transmitted

[2] It is unknown whether this figure for gray water includes kitchen wastewater, it was assumed so.

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via the fecal-oral route, either directly or indirectly (dirty hands), and infection may result from a single exposure. Microbial infections can affect the gastrointestinal tract, liver, skin, and respiratory system (NRC 2012, Durand and Schwebach 1989).

The occurrence and concentration of pathogens in wastewater depend on a number of factors, including the source and original use of the water, the general health of the population producing the waste, 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 (NRC 1998). Table 3 provides a snapshot of the relative abundance of microorganisms in wastewater and natural surface water.

MICROBIAL CLASSES (REPRESENTATIVE ORGANISM)	SURFACE WATER		DOMESTIC WASTEWATER	
	RANGE	TYPICAL	RANGE	TYPICAL
Bacteria (*Escherichia coli)*	10^0-10^5	500	10^5-10^8	10^7
Virus (*Enteric viruses)*	10^{-1}-10^3 /100 L	10/100 L	10^2-10^6	10^4
Protozoa (*Cryptosporidium parvum)*	10^{-1}-10^3 /100 L	100/100 L	10^{-1}-10^4	50

Table 3. Microorganism Concentrations found in typical Surface Water, and Domestic Wastewater

Notes: Concentrations are per 100 mL unless otherwise noted.
Adapted in part from: Asano et al. 2007, NRMMC/EPHC/AHMC 2006, USEPA 1996, NRC 1996, and Sheikh et al 1999.

As shown, there is significant variability in domestic wastewater as well as in surface water. Not shown, due to incomplete data, are separate figures for gray and black water. What is of note is that gray water has an even greater variability due to the range of contributing activities. Microorganism concentrations in gray water span the ranges shown for surface water and domestic wastewater (Ottoson and Stenstrom 2003). Gray water in contingency operations is anticipated to be moderately less contaminated due the absence of heavy fecal loads in shower or laundry water associated with very young or elderly populations.

Indicator Organisms

Because it is too costly, time-intensive, and difficult to directly measure the many individual pathogenic organisms, microbial hazards in water are traditionally measured by way of indicator organisms, such as Coliforms, *Escherichia coli,* and *Enterococcus*. The concentration of indicator organisms can be on the order of 3-log to 5-log greater than, that is, 1,000 to 100,000-times, that of a specific pathogen (Asano et al. 2007). This provides for a conservative measure of the potential pathogens (NRC 2004).

The presence and abundance of an indicator organism may be correlated with the presence of pathogens. Indicator organisms may be used to characterize the quality of a source water, or more often, are used downstream of treatment to monitor performance. As treatment is applied to reduce pathogens in wastewater, a similar fate should be realized on the indicators. Care must be taken to draw accurate correlations; however, because indicators are most often bacteria and microbial hazards also include viral and protozoan pathogens, each potentially more difficult to remove or inactivate than bacteria; again Table 3.

Dose Response

In general terms, the dose required to cause infection from exposure to a microbial hazard is low, on the order of one to tens of organisms or viral plaque-forming units for the most virulent pathogens (Feachem et al. 1983). Viral pathogens pose the greatest hazard in water reuse due to their low dose response and difficulty to remove in treatment. Protozoan pathogens, such as Giardia and Cryptosporidium are not present in sufficient amounts after treatment to constitute a substantial health risk (Ottoson and Stenstrom 2003, WHO 2006a). Illness resulting from protozoan pathogens is also characterized as self-limiting in the non-immunocompromised individual (American Public Health Association (APHA) 2004). The health risk associated with all microbial hazards can be reduced through filtration and disinfection (Rose and Gerba 1991). Further discussion on treatment is provided in the barriers section of this report.

As stated above, indicator organisms provide an indirect measure of pathogen load in water. *E. coli* and *Enterococci* are the indicators of choice for beach studies and recreational water quality guidelines. In numerous studies, a positive correlation was drawn between the concentration of E.coli and the rate of gastrointestinal illness (Rose and Grimes 2001, Tchobanoglous et al. 2003, NRMMC/EPHC/AHMC 2006, WHO 2006a, Asano et al. 2007, Water Reuse Foundation (WRF) 2007, USEPA 2009, USEPA 2012a). These findings are summarized in Table 4 and illustrated in Figure 3. The microbial hazard was characterized by the geometric mean concentration of *E. coli* over the duration of each study. Datasets were aggregated by selecting the definition of gastrointestinal illness that resulted in the highest rate of illness for a given *E. coli* concentration. In studies that reported Highly Credible Gastrointestinal Illness, the rate was converted to "NEEAR[3] Gastrointestinal Illness" by multiplying by 4.5, as discussed in EPA 2012a. Diagnosis was based on 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 (USEPA 2009, USEPA 2012a).

E. COLI **DENSITY** (geometric mean CFU/100mL)	**GASTROINTESTINAL ILLNESS RATE[a]** (per 1000 people)	**REFERENCE**
19	5.0	McKee 1980
23	10.4*	USEPA 1984
47	20.7*	USEPA 1984
51	20.3*	Calderon et al. 1991
52	23.4	Shadid 1981
71	18.9	Shadid 1981
137	21.6*	USEPA 1984
138	23.0*	McKee 1980
146	49.5*	USEPA 1984
170	52.5	Medema et al. 1995
204	63.3*	van Asperen et al. 1998
236	66.2*	USEPA 1984

Table 4. E. coli Density Arranged in Ascending Order and Calculated Gastrointestinal Illness Rate
[3]National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water Study
[a]The larger of either the reported gastrointestinal illness rate or 4.5 times the reported Highly Credible Gastrointestinal Illness (HCGI) rate in original rgerence (EPA 2012a)

*Value is the product of the 4.5 x HCGI conversion

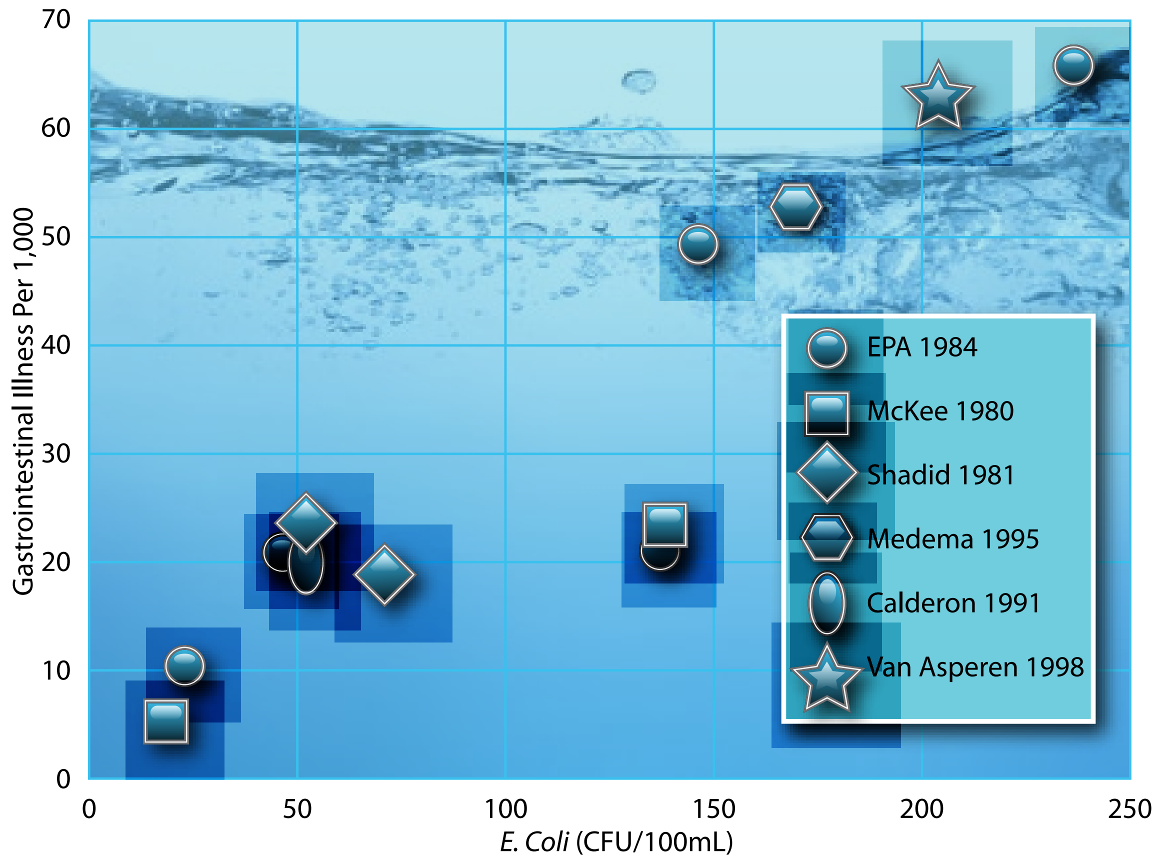

Figure 3. Epidemiological Dose-response Data Normalized For Gastrointestinal Illness

The DoD recorded over 7,500 cases of diarrheal disease between 2006-2011. In a similar time frame, the CDC reported 48 million cases per year. This equates to over 280,000 disability adjusted life years (DALYs) for the civilian population and approximately 87 DALYs for the DoD.

Gastrointestinal Health Effects

The primary health concern of microbial hazards in untreated or under-treated wastewater is gastrointestinal illness due to infection of the gut. Illness rates increase drastically when untreated wastewater contaminates drinking water supplies or is used without sufficient barriers (Downs et al. 1999, WHO 2006a).

An epidemiological survey of deployed U.S. troops was conducted to generate a baseline of the disease burden associated with gastrointestinal (GI) illness in contingency operations due to food and waterborne pathogens (see Appendix C). The survey considered all clinical visits for the period 2006-2011 in the U.S. Central Command (USCENTCOM) area of operation where the diagnosis and treatment code (International Classification of Disease-9th Revision (ICD-9)) indicated a food or waterborne causative agent. The burden of disease was quantified on the concept of DALYs; whereby, short- and long-term effects of illness, injury, or death were summed relative to a full life expectancy. The survey estimated the current impact of food and waterborne disease in contingency operations to be very low compared to other segments of the population, though significant underreporting is assumed to minimize the true disease burden.

Though there is a clear linkage between pathogen ingestion and infection, water reuse, when properly managed, is not associated with a marked increase in gastrointestinal illness. In a study of urban park irrigation, subjects reported symptoms at approximately equal frequencies whether exposed to reclaimed water or potable water irrigated parks (Durand and Schwebach 1989). Sheikh et al. (1999) reported similar findings in a long-term study of reclaimed water for food crop irrigation. Irrigation waters were found to be nearly absent of microbial pathogens and indicators. The

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pathogens detected were not in sufficient concentration to represent a health risk (Sheikh et al. 1999, Nelson et al. 2003).

Non-Gastrointestinal Health Effects

Non-GI health effects occur less frequently and require higher microbial doses than GI health effects (USEPA 2012a, WHO 2005a). It is suspected that dermal and orifice exposures to microbial hazards will result in an increased risk of non-GI illness, including respiratory, skin, ear, and eye ailments. Acute Febrile Respiratory Illness and general respiratory illness can be associated with fecal- contamination of water (WHO 2003). The pathogens of concern include fecal streptococcus, but again the probability of illness is lower and the dose required higher when compared with GI illness (Fleisher et al. 1996, WHO 2003).

Studies have also shown an increase in the rate of skin ailments due to microbial hazards in water (Ferley et al. 1989, Downs et al. 1999). The cause-effect relationship, however, between fecal contamination in water and skin symptoms remains unclear (WHO 2003). A cause-effect relationship between microbial hazards and ear infections is biologically plausible, and ear infections were reported in a study of recreational water with indices of fecal pollution (WHO 2003, Fleisher et al. 1996). Eye irritation has been linked to exposure to reused wastewater. The WHO reported compromise to the eye's immune defenses led to increased symptoms (WHO 2003).

Fate of Microbial Hazards in the Reuse Cycle

Microorganisms have varying degrees of sensitivity to treatment and other conditions through the reuse cycle. In general, bacterial pathogens are most susceptible, while protozoa and viruses show resistance through different means. Protozoa are known to be resistant to chlorine disinfection but are filtered easily. Viruses, conversely, show greater sensitivity to chlorine disinfection but may persist in filtration systems due to their small size. In contrast to drinking water systems, water reuse has the potential to foster higher rates of regrowth, both pre- and post-treatment. Nutrient load, temperature, and residual disinfectant will play a role in to what extent microbial hazards are permitted to propagate.

Chemical Hazards

While microbial hazards have been, and remain, the focus of risk assessment for water reuse and may indeed pose the greatest risk to human health, chemical contamination is a growing area of concern. The long term effects of chemical ingestion or contact are less well understood and only partially characterized. The potential list of hazards is vast, and to characterize them all individually would be a monumental task. To a degree, the foundation exists in the derivation of maximum contaminant levels, reference doses, and military exposure guidelines (MEGs) by USEPA, USAPHC, and others. Guidelines for individual chemical hazards in reclaimed water would likely follow a similar model using toxicological effects data, therapeutic dose levels for pharmaceuticals, and thresholds of toxicological concern where health information is not available or insufficient (NMHRC/APHC/EMRC 2008). Safety factors would also remain an element to account for incalculable differences in models.

Alternative approaches to chemical hazard assessment are emerging, and particularly with respect to water reuse scenarios, in order to more efficiently and holistically consider the extent of risk. This includes the consideration of chemical mixtures, and the potentially additive, synergistic, or suppressive effect on hazard severity.

Chemical hazards in water reuse can come from several sources. The water that became the wastewater could have had chemicals in it, such as pharmaceuticals, industrial runoff, agricultural runoff, wastewater treatment plant discharge, or natural geology (Focazio 2008). Additionally, the initial use of the water could have introduced chemicals. Residential use contributes chemicals from personal care products (soaps, shampoos, creams, etc.), excreted pharmaceuticals, and cleaning formulations. Finally, chemicals in wastewater could be the result of treatment (e.g., disinfection byproducts produced by the reaction of organic material and chemicals used for disinfection).

"While these findings are insufficient...[they] provide supporting evidence that if there are any health risks associated with exposure to low levels of chemical substances in reclaimed water, they are likely to be small" (NRC 2012).

Quantifying the chemical hazard in wastewater is a challenge. Within available research, there is simultaneously a vast data array and a paucity of information. Information is applied or interpreted data on which decisions can be made. Contributing to the gap between data and information are detections below quantifiable limits and insufficient health hazard characterizations (NRC 2012).

Table 5 provides an example of chemicals detected in secondary treated and disinfected wastewater. This sample set was extracted from the 24 chemicals identified in the risk exemplar conducted by the NRC Committee on the Assessment of Water Reuse as an Approach to Meeting Future Water Supply Needs (2012). Additional lists are available in the Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies (NMHRC/APHC/EMRC 2008). Because individual contaminant guidelines for water reuse do not exist, each committee used a combination of drinking water risk-based action levels in calculating relative risk or margins of safety between the observed concentration and the action level.

CHEMICAL CONSTITUENT	SECONDARY TREATED DOMESTIC WASTEWATER	SURFACE WATER
Caffeine	210 ng/L	10 ng/L
Acetaminophen	1 ng/l	<1 ng/L
Ibuprofen	38 ng/L	<1 ng/L
17-β Estradiol	0.15 ng/L	<0.1 ng/L
HAA5 (DBP)	70 μg/L	<1 μg/L
NDMA (DBP)	10 ng/L	<2 ng/L
PFOS	54 ng/l	10 ng/L

Table 5. Chemicals Detected In Secondary Treated Wastewater and Surface Water

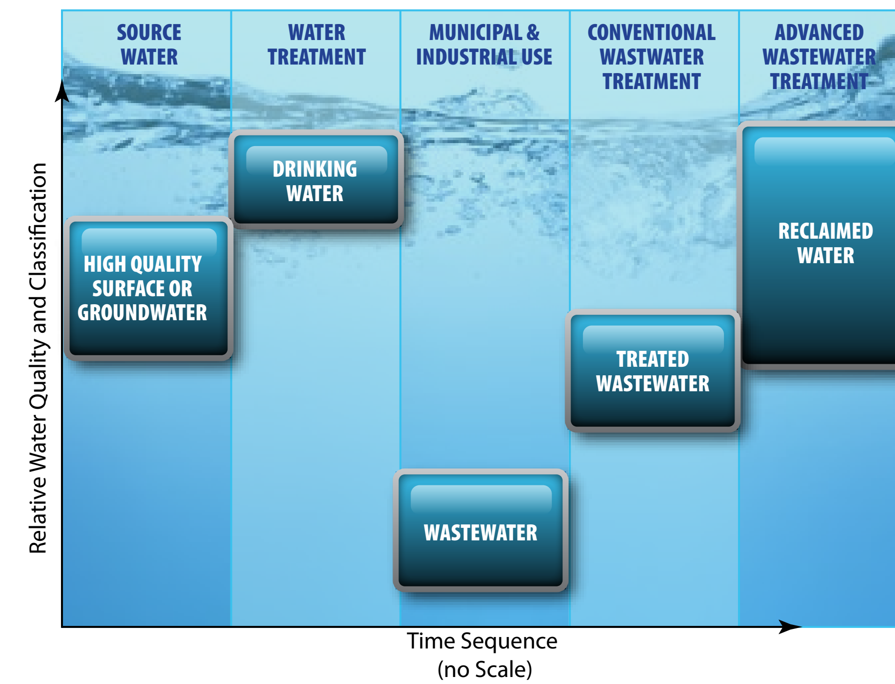
Legend:
μg/L- micrograms per liter
ng/L- nanogram per liter
DBP- disinfection byproduct
HAA5- haloacetic acids five, sum of five haloacetic acid disinfection byproducts
NDMA- N-nitrosodimethylamine
PFOS- perfluorooctane sulfonate
Notes:
Source: excerpt from NRC 2012

Health risks of chemical hazard exposure can be divided into two groups: cancer and non-cancer. However, not all chemicals have a definitive assignment in either group. Non-cancer risks range from short term irritation of tissue to endocrine disruption. Available research indicates that reclaimed water often meets drinking water regulations for the majority of chemicals (USEPA 2004). Emerging contaminants of concern, including endocrine disruptors, pharmaceuticals, disinfection byproducts, and chemical mixtures will warrant continued focus.

For wastewater reuse, two exposure pathways dominate. Chemicals that migrate through the skin present a dermal risk, and volatile chemicals that can be inhaled present a respiratory risk. It was assumed that non-potable reuse activities do not include purposeful ingestion of large volumes of water. Incidental ingestion is possible and is discussed further in the exposure characterization section of this report.

Hazards Summary

The hazards of water reuse are not unique. As the relative quality of water sources progress or digress, so, too, goes the relative concentration of hazards. Very simply, black water contains a higher concentration of hazards than gray water, and gray water a higher or similar hazard load to surface water. Figure 4 illustrates this point. Ultimately reclaimed water can be made to equal the quality of pristine natural waters



and even treated drinking water.

Figure 4. Water Quality Continuum through the Reuse Cycle
Source: Asano et al. 2007

It will be necessary to conduct detailed assessments of the wastewater source for each reuse scenario. These assessments should characterize the industrial, agricultural, and municipal contaminants in the area of operation in addition to the waste-producing activities of the Military. It will be the responsibility of risk managers, thereafter, to monitor reuse operations consummate to the identified hazards, available barriers, and exposure scenario.

BARRIER ASSESSMENT

The value of reclaimed water as an alternative supply is based on the premise that sufficient barriers can be employed to make the resultant product safe. Barriers include processes which improve water quality through treatment as well as measures taken pre- and post-treatment to control hazards or limit exposure. This section will discuss the treatment technologies most commonly used in water reuse facilities, and the additional barriers that are necessary to minimize health risk.

As demonstrated in the preceding hazard characterization, untreated wastewater presents an array of hazards which must be mitigated to reduce health risk. To that end, barriers are put into place to eliminate or reduce the hazards, and prevent or limit contact with the reclaimed water. Collectively, the approach to safe water reuse follows a multiple barrier approach. The multiple barrier approach has been the cornerstone of safe water programs for at least 50 years and consists of coordinated technical, operational, and managerial barriers that help reduce contamination at the source, enhance treatment and reliability, and ensure the water is safe for reuse. Water reuse differs from drinking water in that there is a range of acceptable water quality based on the end activity.

Which barriers are used and how each barrier is used depends on the desired endpoint. This concept is called “fit-for-purpose” (USEPA 2012b, NRC 2012). The treatment options discussed below can be used independently or in combination, and as seen in Figure 5, water can be extracted at any point in the process based on the end application and target quality.

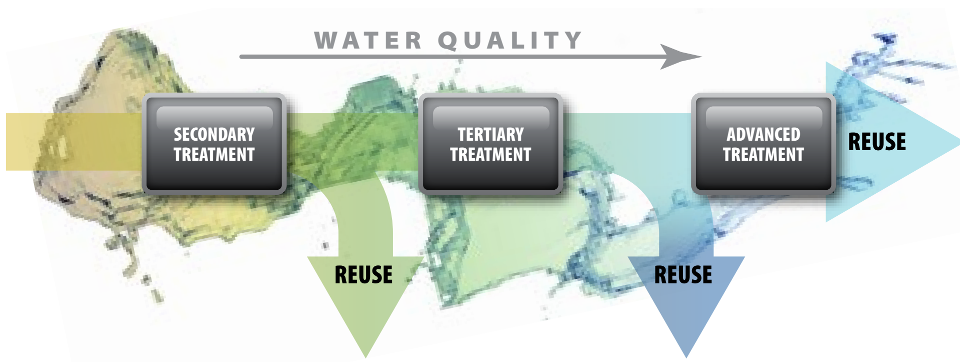


Figure 5. Water Reuse Flow Diagram Illustrates Fit-for-Purpose Quality

Treatment Barriers

Physical, chemical, and biological processes that reduce the hazards in wastewater are typically grouped into preliminary, primary, secondary, tertiary, advanced water treatment, and disinfection, see Figure 6. Each process, or sequence of processes, removes a type or types of contaminants from the water. A general discussion of each process follows.

Preliminary treatment is typically a screening process that removes large solid objects and large floating debris. A steel bar screen with uniform size openings is a typical installation of preliminary treatment. In some instances, a coarse screen may be followed by a grit chamber or finer screens to help remove additional solids. Preliminary treatment reduces interference with downstream processes and reduces maintenance and operational problems.

Primary treatment is a sedimentation process. The water velocity is slowed and settleable solids fall by gravity to the bottom of the sedimentation unit. In addition, any scum that floats to the surface may be removed by a skimmer. This type of process removes suspended solids and some organic matter from the wastewater. It can also help remove chemicals and microbes that adhere to the solids.

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Secondary treatment removes biodegradable organic matter and additional suspended solid matter. Secondary treatment includes biological and chemical processes, often relying on active bacterial colonies to perform the biodegradation of contaminants. Examples include aerated activated sludge, trickling filters, and rotating biological contactors (Asano et al. 2007). More recent designs have combined primary and secondary treatment processes by way of membrane bioreactors (MBRs). The MBRs employ submerged microfiltration or ultrafiltration (UF) membranes to treat wastewater without the need for separate primary and secondary treatment infrastructure (NRC 2012). The MBRs have the advantage of easy scalability which may be useful to the Military because of the variability in contingency camp size.

Secondary treatment processes, with the possible exception of MBRs, have inherent limitations due to the reliance on active colonies of bacteria. The startup requirements demand time and expertise that may be limited in contingency environments. The live colonies also require a minimum nutrient load which may be lacking in certain wastewater streams, such as gray water.

Tertiary treatment employs yet another level of filtration to remove suspended solids and the microbial and chemical contaminants which may be entrained or adhered to the solids. Filter techniques range from those referred to as ‘conventional’ to more advanced membrane-based techniques. Conventional methods include coagulation, flocculation, sedimentation, and depth-filtration using one or more media (typically sand or anthracite) or surface filtration using different weaves of cloth to remove particles. Cloth openings are typically between 10 and 30 microns (1 micron=1 millionth of a meter) (NRC 2012).

Membrane filtration includes microfiltration (MF) and UF, with pore sizes in the range of 0.005 to 2 microns (NRC 2012). It may also include the processes of nanofiltration (NF) and reverse osmosis (RO). The latter two will be considered advanced treatment for the purposes of this discussion relative to wastewater treatment and reuse.

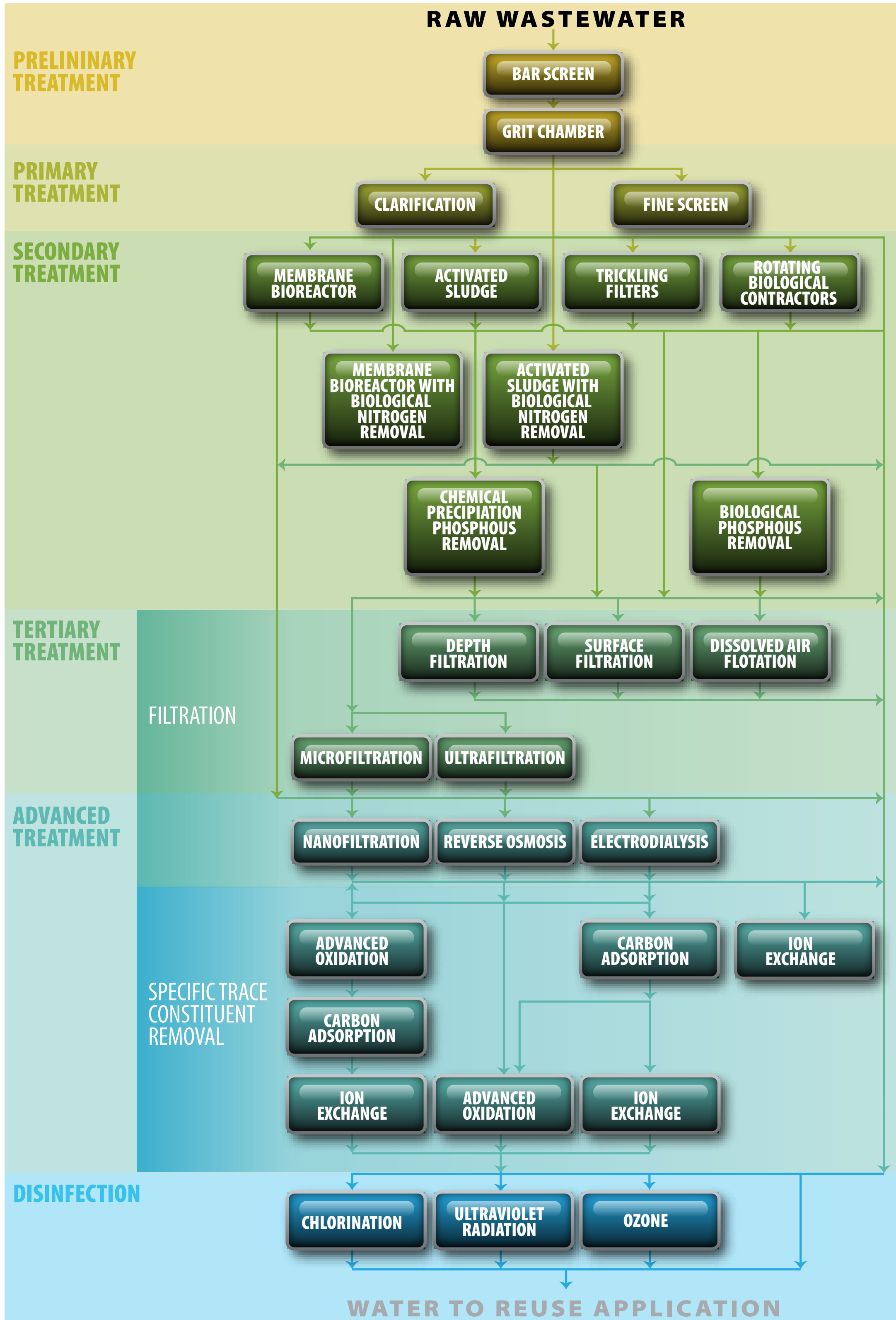

Figure 6. Treatment Process Barriers Employed in Water Reuse

Figure 7 is a graphical representation of various membranes (the light blue rectangles) with progressively smaller pore sizes from MF to RO. Water is moving from left to right in the figure. The figure shows the types of constituents blocked to the left of each membrane. As water moves from left to the right, it is of progressively higher quality.

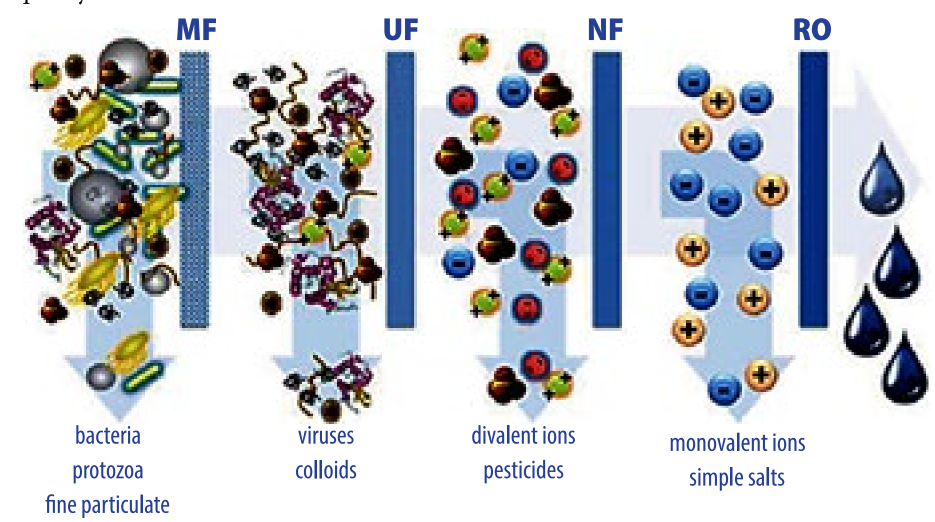

Figure 7. Membrane Process Removal of Constituents
Source: NRC 2012

The MF and UF membranes are not absolute barriers to microbial contaminants, but can generally be expected to perform on the upper end of the scale with ranges from 90 to 99.9999% (1-6 logs) reduction of bacteria and protozoa. Only UF membranes have a sufficiently small pore size to reliably reduce greater than 2 logs of viruses. Membrane breakthrough and installation errors may still permit the passage of microbial hazards, making disinfection an important final step to protect public health and ensure safe water for reuse purposes (NRC 2012; NMHRC/APHC/EMRC 2008). The performance of membranes and other treatment modalities to reduce microbial contaminants is summarized in Table 6.

CONTAMINANT	ADVANCED	TERTIARY		SECONDARY	
	Reverse osmosis	Depth filtration	Microfiltration	Trickling filter	Activated sludge
Fecal coliforms	4-7	0-1	1-4	0.8-2	0-2
Cryptosporidium	4-7	0-3	1-4	-----*	1
Giardia	>7	0-3	2-6	-----*	2
Enteric viruses	4-7	0-1	0-2	0-0.8	0.6-2
Helminth ova	>7	0-4	2-6	1	<0.1

Table 6. Performance of Treatment Barriers to Reduce Microbial Contaminants
Note: units are log10 reduction of indicated organism or group
Source: Asano et al. 2007
**dashed entries indicate data not reported*

Disadvantages of membrane filtration include its relative complexity, higher capital cost as compared to conventional filters, and potential for irreversible fouling reducing production or necessitating replacement (Asano et al. 2007).

Advanced wastewater treatment processes provide reduction of nutrients, trace organics, and total dissolved solids. In addition, they provide a redundant barrier to pathogens that may have survived previous stages of treatment. Advanced processes include NF and RO and targeted technologies (such as activated carbon adsorption, electrodialysis, gas stripping, and chemical oxidation) addressed below with disinfectants (see Figure 8). These combined treatment trains have the potential to reduce regulated and unregulated chemicals of health concern to non-detectable levels, producing water of near-potable quality (Tchobanoglous et al. 2011).

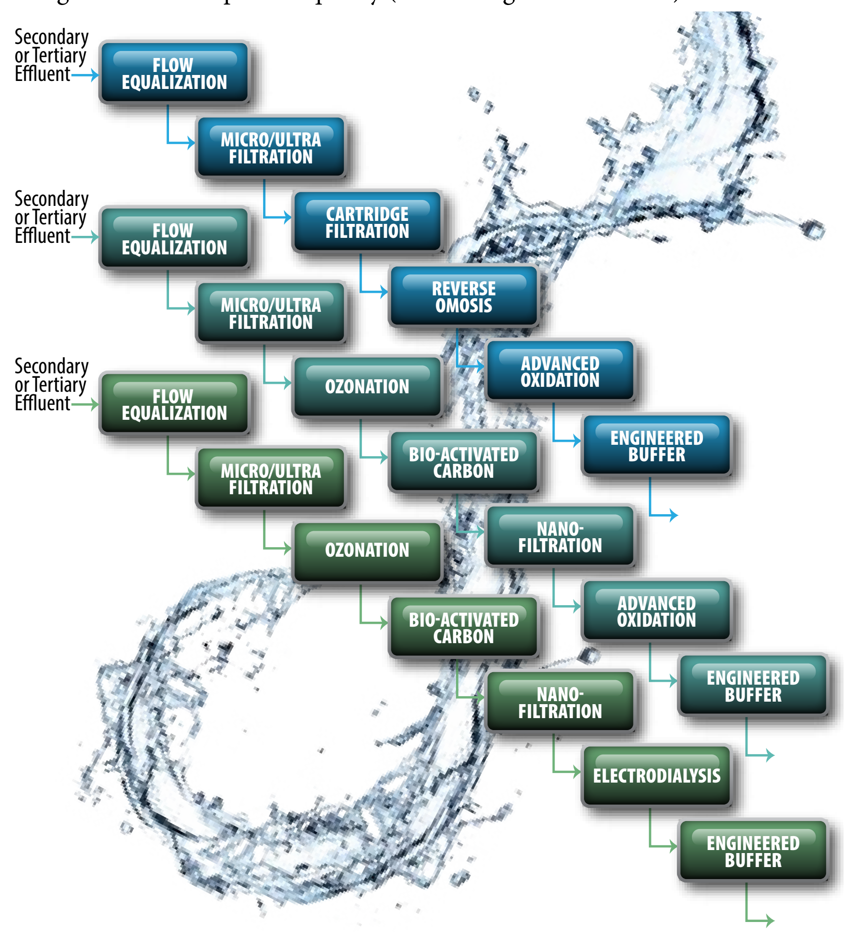

Figure 8. Examples of Advanced Wastewater Treatment Trains
Source: Tchobanoglous et al. 2011

Disinfection

Disinfection may be employed after secondary, tertiary, or advanced treatment processes and is often considered an integral part of those levels of treatment. Disinfection processes are designed to kill or inactivate microorganisms, particularly pathogens. Chlorine, ultraviolet (UV) light, and ozone are the most common forms of disinfection. Disinfection involves exposing the water to an oxidant for a specific period of time to kill or inactivate microbes that were not removed by the preceding treatment processes. A secondary purpose for disinfection is to provide a measurable disinfectant residual in storage and distribution systems as a sentinel to post-treatment contamination and to mitigate biofilm growth.

The preferred Military water disinfectant is chlorine (DA 2010). The most common chemical issued to the military for bulk water disinfection is calcium hypochlorite that is approximately 68–70 percent available chlorine. The effectiveness of disinfection is a function of the residual concentration (C) and contact time (t). Residual

concentration refers to the free oxidant remaining after reacting with organic and inorganic matter, oxidant demand, in the water. The oxidant demand has the potential to be much greater in reclaimed water as compared to drinking water. It is also not uncommon to see much higher Ct requirements for reclaimed water (USEPA 2012b).

Alternative disinfectants include ozone and UV. Ozone is produced by subjecting oxygen gas to an electrical charge. The gas dissolves in water and produces hydroxyl radicals (OH-) that react with organic matter, killing or inactivating microbes. UV radiation is also used to disinfect water. UV light inactivates pathogens by disrupting replication, disabling their ability to infect a host. The dose of UV is a product of the lamp intensity and contact time. UV efficacy, like chlorine, is dependent on the intensity reaching the pathogen after blockage or absorbance by other matter in the water. UV out-performs chlorine in inactivating protozoan cysts, while viruses are less susceptible. UV does not provide a secondary disinfectant residual and measuring the initial dose in the contingency environment may be difficult. Additional disinfectants include chlorine dioxide and chloramines.

A final consideration in disinfectant application is the potential for producing disinfection byproducts (DBPs). The extent to which DBPs may be formed and consequently impact water quality must be evaluated in the course of system design and validation. Chlorine, chlorine dioxide, and ozone are all known to produce DBPs, while UV does not (Asano et al. 2007). The potential health hazard of DBPs is discussed in the hazards portion of this study.

Engineered and Natural Buffers

Engineered buffers (tanks and other manmade containers) and natural buffers (aquifers, lakes, reservoirs, impoundments, rivers) are employed in water reuse to provide an additional step in the process that helps to erase the past identity of the water as wastewater and gives the water a new identity as purified, safe, 'reclaimed water.' Buffers also serve as a barrier.

Engineered and natural buffers may provide: (1) additional retention time, (2) reduction in contaminant levels, and (3) blending or dilution. It cannot be demonstrated, however, that such barriers provide any public health protection that is not also available by other engineered processes (NRC 2012). It is not anticipated that water reuse in contingency operations will have the availability of natural buffers. Engineered buffers may be employed as barriers or as a practical matter to temper fluctuation in flow.

Administrative Controls

The focus thus far has been exclusively on treatment barriers. While a large and critical element of the risk-mitigation strategy, treatment is not the only barrier in water reuse management. Administrative controls include physical and policy barriers as well as quality-monitoring of the same.

Source control involves controlling specific contributions (e.g., a wash rack) from entering the wastewater or eliminating a particular wastewater stream (e.g., black water,) all together. Some radionuclides, industrial chemicals, pesticides, pharmaceuticals, and consumer products pass through conventional wastewater treatment systems with little or no removal (NRC 2012). The presence of these substances in reclaimed water is a potential public health hazard, limiting the reuse potential of the water, or requiring added expense and time for advanced treatment. Similarly, it is possible to improve the relative quality of a mixed source by adding greater proportions of higher quality water; for example, using gray water preferentially to other wastewaters.

Barriers are only as effective as their performance, relative to design expectations.

Operational controls and monitoring are the quality control checks used to maintain operations at their design level. Formal quality control programs, such as the Hazard Analysis Critical Control Point (HACCP) concept, identify and monitor critical operations (Tchobanoglous et al. 2011). It is likely that a performance evaluation technique such as HACCP will be a critical element of managing water reuse in contingency operations.

An additional control within the operations phase of water reuse is adequate operator training. Treatment systems and quality management systems are only as good as the human operator/maintainer. Operator certification and continuing education to maintain proficiency are pivotal to maintaining quality and safety in water reuse operations.

Exposure Restrictions

The final barrier is one unique to water reuse. If the quality of the product water makes it impractical or unsafe for use where humans would be exposed, restrictions are established which eliminate or significantly limit such access. This may be through cordoning, signage, timing of application, closed systems which have no potential for contact, or any combination of these and other restrictions. Rather than remove the hazard, this type of barrier removes the exposure, producing the same end effect—reduced risk. In municipal water reuse, this barrier is relied on perhaps as much as if not more so than any other. It is anticipated that water reuse in contingency operations will practice exposure restrictions to a degree but due to the current demand for high-quality reclaimed water, may at least begin with different management approaches. The exceptions will likely lie in the limited industrial functions present on contingency bases, such as construction and dust control.

At the individual level, separation from reclaimed water can be achieved by employing personal protective equipment (PPE). In addition to the other examples given above, PPE offers a measure of exposure control to the operator of an activity using reclaimed water, such as vehicle washing.

EXPOSURE ASSESSMENT

In human health risk assessments, exposure is the contact between a person, the receptor, and a physical, chemical, or biological agent (NRC 2009). The amount of an exposure, or the dose, is a function of the concentration of a contaminant in the media—here reclaimed water—and the amount of reclaimed water encountered (i.e., ingested, inhaled, or in contact), as well as the frequency, the duration, and the interval between encounters.

Water reuse in contingency operations presents a continuum of possible exposures due to a broad range of water reuse activities (see Figure 9). Depending on the activity, exposure may include only incidental contact or may involve full-body immersion and incidental ingestion. Potable reuse was excluded from this exposure assessment, though is included in the figure for reference. The quality of reclaimed water is dictated by the activity and its exposure.

Figure 9. Exposure Continuum for Water Reuse Activities

In water reuse terms, "*restricted*" and "*unrestricted*" characterize groups of reuse activities and their requisite water quality. They indicate the expected or permissive degree of exposure. To minimize the risk for activities where the exposure potential is high (unrestricted), the water quality must be accordingly high. Conversely, where exposure can be restricted or eliminated, lower quality water may be appropriate. This echoes the fit-for-purpose paradigm introduced earlier.

Exposures for some activities, such as showering, are well defined and quantifiable. Other activities, like dust suppression, have more variability, both in the degree of exposure and who is exposed and when. Thus, not only is there a continuum of exposure among activities, but within a single activity as well. This is explored further below. For simplicity, activities are illustrated as discrete events in Figure 9 vice multiple or continuous exposures.

Conceptual Model

The conceptual model is a written and visual tool to organize and communicate information about the predicted relationships between hazards and receptors. It presents the relevant assumptions about exposure–response relationships and sets the stage for the risk characterization. It is also useful to identify what questions need to be answered and prioritize data collection.

The conceptual model for water reuse in contingency operations (Figure 10) began with the identification of exposure pathways. An exposure pathway is the connection between the hazard source, reclaimed water, and the receptor, deployed Service member. Exposure pathways can be "complete" or "incomplete" depending on the activity. Each exposure pathway can include one or more routes to the receptor: ingestion, inhalation, or dermal. Ocular (eyes) and aural (ears) exposures were included in the dermal route. Where multiple routes were identified for a single activity, the predominant route of exposure was retained through the model. For example, the ingestion route was selected in deference to the dermal route for the showering scenario. Figure 10 is not all inclusive but provides a broad overview of possible exposure pathways for water reuse in contingency operations.

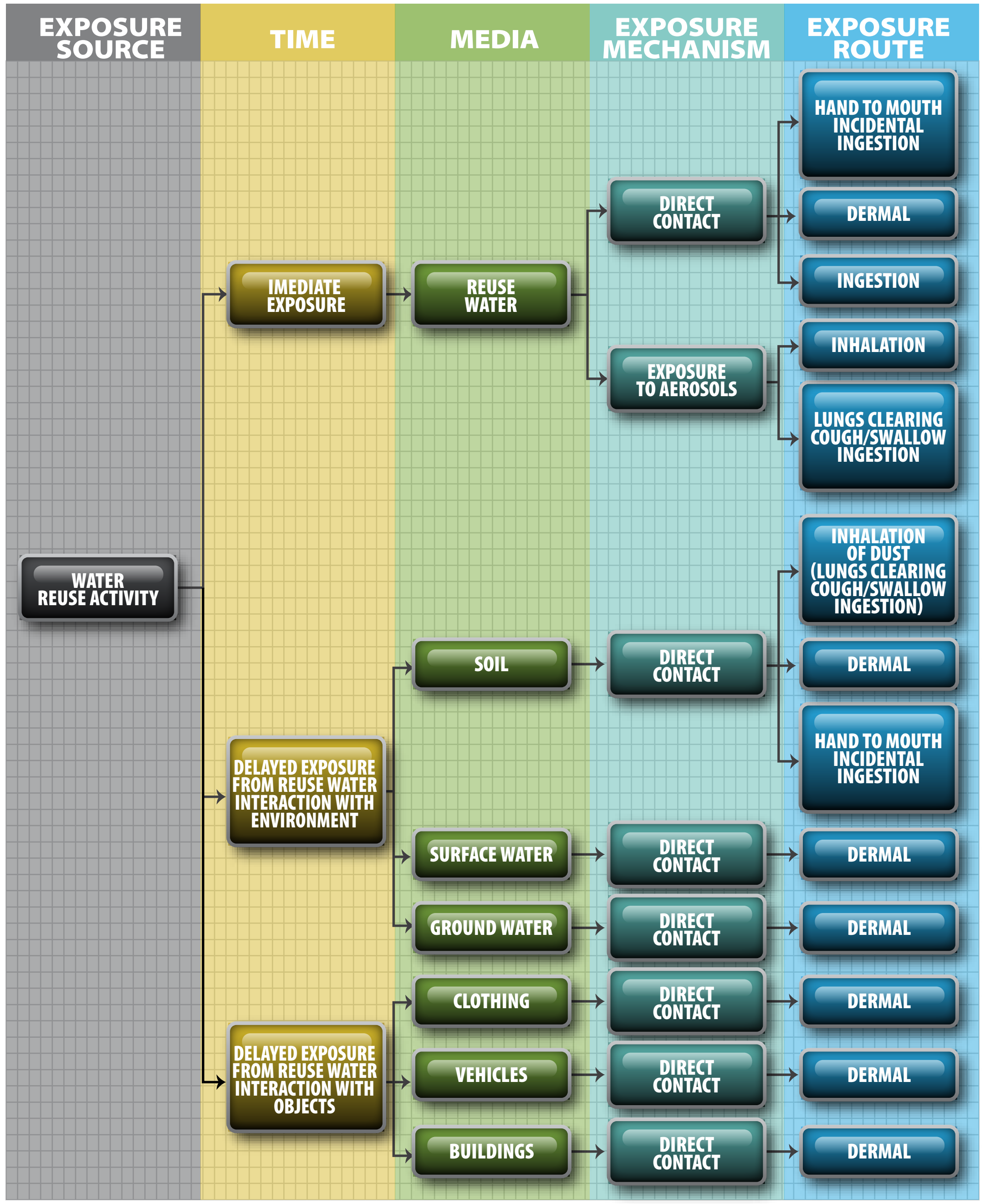

Figure 10. Conceptual Model of Water Reuse Exposures

Representative Activities

Table 7 presents several water reuse activities and the associated routes which make up the exposure pathway for each. Due to the large number of possible water reuse activities, four were selected to carry through the exposure assessment. The four activities—showering, laundry, vehicle washing, and dust suppression—span the exposure continuum and illustrate the process used to estimate exposure. The four activities are more fully described below:

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Activity		Incidental Ingestion	Inhala-tion	Dermal		
				Skin Surface	Ocular (Eyes)	Aural (Ears)
Showering		Y	Y	Y	Y	Y
Kitchen Use		Y	Y	Y	N	N
Hygiene		Y	Y	Y	Y	Y
Personal Decontamination		Y	Y	Y	Y	Y
Laundry	operators	Y	Y	Y	Y	Y
	user	N	N	Y	N	N
High Contact Cleaning (pressure washing of buildings, sidewalks, etc.)		N	Y	Y	Y	Y
Vehicle Washing		Y	Y	Y	Y	Y
Outdoor activities (irrigation)		N	N	Y	N	N
Dust Suppression	operator	Y	Y	Y	Y	Y
	pedestrian	N	Y	Y	N	N
Indoor Cleaning (mopping, table washing)		N	N	Y	N	N
Toilet Flushing		N	N	N	N	N
Industrial / Construction		N	Y	Y	N	N
Fire Fighting		Y	Y	Y	Y	Y

Table 7. Water Reuse Scenarios and their Exposure Pathways

Notes: A "Y" indicates that the exposure is complete and an "N" indicates that the exposure is incomplete.

Showering is washing oneself 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 include dermal contact on the entire skin surface and potentially include incidental ingestion, inhalation, ear entry, and wound entry. All personnel are exposed. Baths are not considered showering.

Laundry is the machine-aided washing of clothing, linens, and other wears. It includes an exposure pathway for operators directly to the water and saturated clothing. It also includes a second exposure pathway for the entire population who wears or uses laundered items ("user"). The two pathways are distinct because drying and subsequent time before use interrupts many of the potential exposure routes.

Vehicle Washing is spraying with pressurized water. It is a periodic event. Only the operator is exposed. The assessment considered a worst-case scenario where operators wore no PPE.

Dust Suppression is the application of water to reduce the suspension of soil. This operator is potentially exposed during application. There is a second exposure pathway for all other personnel who encounter the area during application or who subsequently encounter soil wetted by the water. They are denoted as pedestrians in Table 7. Again, operators were void of PPE for this assessment.

Exposure Factors

Exposure factors further define the relationship between receptor and hazard source. Table 8 annotates the exposure factors for each of the representative activities and whether they are required, desired, or not necessary to move the assessment forward. The values for each factor are scenario-specific. The first phase of risk management, as introduced in a subsequent section of this report, involves assessing the exposure factors based on the concept of operations.

Required (■) Desired (◆) Not Required (●)

EXPOSURE ROUTE	EXPOSURE FACTORS	SHOWERING	LAUNDRY		VEHICLE WASHING	DUST SUPPRESSION	
			OPERATOR	USER		OPERATOR	PEDESTRIAN
All	Frequency	■	■	■	■	■	■
	Duration	■	■	■	■	■	■
	Total Water Volume	◆	◆	◆	◆	◆	◆
Incidental Ingestion	Ingested volume	■	■	●	■	■	◆
Inhalation	Breathing rate	■	■	●	■	■	■
	Aerosolization of water	■	■	●	■	■	◆
	Ventilation rate	◆	■	●	◆	■	◆
Dermal	Surface Area	■	■	■	■	■	■

Table 8. Exposure Factors for Representative Water Reuse Activities

Time a Critical Variable

In the estimation of exposure, time is a critical variable. Many of the exposure factors are measures of time or are time-related. Some of these factors are difficult to quantify. Consider showering and dust suppression. A shower has a defined event duration that occurs at a relatively predictable frequency. There is also a definitive end to the exposure; no shower, no exposure. On the other hand, dust suppression is highly variable both in duration and frequency. Dust suppression also involves a prolonged, secondary exposure to water remaining on the ground or soil saturated with water.

Frequency dictates hazard concentration. The most appropriate concentration may be the peak measurement, or it may be the average. Generally speaking, peak concentrations offer a conservative assessment of discrete exposures, and average concentrations are appropriate for assessing continuous or prolonged exposures.

Duration dictates cumulative dosing. Cumulative dosing is the increase in effective concentration due to the inability of the receptor to clear the hazard. Cumulative dosing determines the response intensity, ranging from remaining healthy to death. Cumulative dosing is buffered by the clearance rate of the receptor. Clearance mechanisms reduce the number of organisms or concentration of chemicals. The rate of clearance is not a constant and at present is undefined.

Seasonal variations impact the time variable. For example, dust suppression occurs more frequently in the dry season. Showers occur more frequently in warmer months. As before, peak or average values for each factor could be assessed.

Also taken into consideration was the length of contingency operations. In contrast to most water-related exposure models based on a lifetime exposure, the period of deployment is more finite, on the order of months to years. This could be further modified based on changing conditions; short- versus long-term exposures. Conservatively, the representative activities were assumed to occur throughout a deployment cycle of 1 year.

Exposure Summary

Exposure assessment is essential to characterizing and managing risk. The degree of exposure dictates the appropriate quality of reclaimed water, the requisite controls, and the residual health risk for each reuse scenario.

Exposure assessment is an iterative process. As better information becomes available, risk-based guidance may change. Risk assessors must balance the desire for evermore precise and quantitative assessments with the utility of the results to the risk managers. Some exposures will allow for quantitative modeling, while others will best be handled in terms of relative risk.

HEALTH RISK CHARACTERIZATION

Waterborne hazards present a risk to human health. The intent of this risk assessment was to evaluate to what degree water reuse might add to the existing burden of disease associated with water use in contingency operations. Furthermore, this risk assessment models how future risk assessors might conduct similar evaluations of specific water reuse scenarios. The existing burden of disease has been studied by many including an epidemiological baseline generated in the course of this study. The epidemiological survey conducted in the course of this study suggested a very low rate of clinical waterborne illness among deployed Military forces in the USCENTCOM area of operations between 2006 and 2011. (See Appendix C for the complete survey.) Anecdotally, gastrointestinal distress, specifically of symptomatic diarrhea among deployed Service members is much higher, comparable perhaps to the worldwide rate of 1 case-per-person-per-year. The rate among the U.S. Civilian populace is markedly lower, approximately 0.7 cases-per-person-per-year (WHO 2003).

Data, as summarized by the NRC, suggests the potential health risks associated with water reuse to be "small" (2012). The processes are mature enough and the controls robust enough to provide an equally safe alternative to conventional supplies.

These data points serve as a record of the burden of disease prior to widespread adoption of water reuse in contingency environments. It is the responsibility of risk managers going forward to ensure that the impact of water reuse does not further burden the health status of deployed forces.

The risk characterization section which follows highlights the key findings of the risk assessment and future research needs.

Key findings

As was previously noted, it is not possible, nor practical, to eliminate the risks from waterborne hazards in contingency operations. Army policy is to reduce occupational and environmental health risks as low as practicable within the context of operational mission parameters (DA 2007).

Water reuse has the potential to offer deployed forces an alternative water resource. The risk associated with water reuse is different from existing supplies. It is the estimation of this study that those risks can be managed, and water reuse can offer a low-risk resource to meet non-potable demands.

This study evaluated risk in a relative fashion vice a quantitative risk estimate to inform risk managers and other stakeholders of the potential health consequences of water reuse in contingency operations. This was determined to be a more feasible and efficient approach in the near term. The AIPH will continue to collect, apply, and review the utility of quantitative measures to facilitate decision making.

Hazards

Hazards exist in wastewater, and on the whole, at higher concentrations as compared to natural surface or ground water sources. They are, however, not unique hazards. Wastewater, as a source, may be more secure than surface water which is vulnerable to purposeful and accidental contamination. The source may or may not be more consistent or controllable from a quality perspective. Treatment of wastewater has the potential to generate byproducts which exceed the levels currently experienced with traditional sources.

Health hazards of both microbial and chemical origin could persist after treatment of wastewater. An extensive repository of chemical hazard dose-response and toxicological data exists for the ingestion pathway. The effect of multiple low-level exposures and the potential interaction of multiple simultaneous hazards are less understood. The potential fate of chemicals in treatment, transport, and secondary reactions are also challenging to characterize. In general, less dose-response information is available for microbial hazards.

Barriers

Barriers exist for the full spectrum of potential hazards. Despite the caveats above, it is estimated that should the full spectrum of potential treatment modalities be employed, chemical and microbial hazards would be reduced below levels likely to cause a health hazard. Traditional secondary wastewater processes are likely to require supplementation to reach higher echelons of reclaimed water quality, but the technologies to do so are mature.

In considering treatment barriers and their impact on health-risk associated with water reuse, the most likely and most dangerous risk outcomes are as follows:

The most likely risk of water reuse treatment barriers is subpar performance of a single barrier resulting in hazard-reduction below design. This would lead to microbial contaminants present in concentrations sufficient to cause acute health impact to some consumers. It could also result in chemical contaminants in concentrations which would cause chronic health impact if they continue to be experienced over the long-term.

The most dangerous risk of water reuse treatment barriers is catastrophic failure of a single barrier or subpar performance of multiple barriers resulting in abhorrent water quality. The failure would result in microbial and chemical hazards present in concentrations sufficient to cause acute health impacts.

Exposure

The exposure variable of the risk assessment is the largest remaining gap. Water reuse exposure is multi-factorial and highly varied depending on the reuse activity and implementation concept. Exposure factor values are dependent on mission-specific concepts of operation and materiel design. As with the overall risk characterization, it may be most efficient to compare the relative risk of different activities where the exposure remains constant (e.g., showering in reclaimed water versus disinfected fresh water).

This study was limited to non-potable water activities and the resultant exposure pathways.

Future Research Needs

1. Characterization of wastewater quality in contingency operations.
2. Definition of exposure factor values for each reuse activity and concept of operations.
3. Enhanced research of the health effects associated with dermal and inhalation exposure to waterborne contaminants of wastewater origin.
4. Risk/benefit analysis of chlorine versus alternative disinfectants in water reuse.
5. Enhanced epidemiologic data of existing and post-water reuse implementation disease burden.
6. Effect of closed loop direct reuse on hazard concentration and mutation. Need for makeup water
7. Efficacy of non-treatment barriers in contingency operations.

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PART III – RISK MANAGEMENT

The US National Research Council (NRC) considered reclaimed water as an alternative water supply and concluded that planned reuse was viable– but only when there was a careful, thorough, project-specific assessment that included contaminant monitoring, health and safety testing, and system reliability evaluation (NRC 1998). Furthermore, reuse projects should include multiple, independent barriers that address a broad spectrum of microbial and organic chemical contaminants.

Risk cannot be eliminated, but it can be mitigated, and it can be managed. Managing to an acceptable threshold of safety does not mean zero risk but that the sum of the risks is not mission-degrading .

Thus far, the study findings have illustrated the potential risks associated with water reuse. Building on these findings from the risk assessment, the study team constructed a risk management framework. Each reuse scenario or concept of operations (CONOP) is to be managed according to a risk management plan. The plan, while specific to the CONOP, is shaped by the common framework proposed below. A sample template for such a plan is included with this report as Appendix D. The scope of this study did not permit for consideration of all eventualities nor an executable risk management plan for all reuse scenarios. Such work will be forthcoming as the risk management framework is adjudicated by the many stakeholders.

In addition to the risk management framework, this part of the report includes the considerations of health risk communication. Historically in the United States, water reuse initiatives have faced substantial stakeholder resistance due to strong negative feelings and misperceptions associated with the idea of reusing wastewater. Engaging stakeholders proactively to gauge and address their concerns and educate them about the benefits of water reuse is critical to eliminating undue concerns and achieving stakeholder acceptance.

RISK MANAGEMENT FRAMEWORK

High-quality reclaimed water can be achieved through the application of multiple barriers. Achieving highly-consistent water quality is the role of comprehensive risk management. The framework which follows is intended to assure water quality and protect health. It represents the reduction of multiple industry practices that offer the most effective approaches to water reuse risk management. The intent is to identify and manage risks in a proactive way.

The framework involves four phases: define the influent wastewater (source) and planned reuse activity; technology design and validation through protocol driven testing; operational controls; and verification monitoring. This phased risk management approach is illustrated in Figure 11.

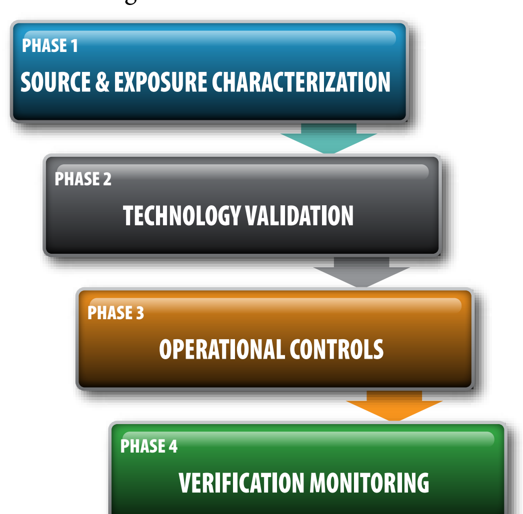

Figure 11. Risk Management Framework

Derivation of the Framework

The risk management framework proposed herein draws from a number of established models with demonstrated success. The language and construct borrow heavily from the Australian National Guidelines for Water Recycling and the WHO Water Safety Plans (NRMMC/EPHC/AHMC 2006, WHO 2005b). The Australian risk management framework is illustrated in Figure 12.

Figure 12. Elements of the Australian National Risk Management Framework for Recycled (Reclaimed) Water Quality and Use
Source: NRMMC/EPHC/AHMC 2006

An emphasis of the Australian model is proactive risk management, vice reactionary. Another well-known quality-assurance model, HACCP, echoes this principle.

Hazard Analysis Critical Control Point

Cross-walking HACCP and water supply management reveals many common elements and a few outstanding gaps. A detailed comparison of HACCP and an established water reuse guideline from the state of California is provided in Appendix E (Halliwell et al. 2013). The basic HACCP approach includes the following 7 stages:

1. Hazard identification
2. Critical control identification and design
3. Critical limits set
4. Monitoring system design and installation
5. Corrective actions planned and practiced
6. Verification validation
7. Documentation

Critical controls or processes are those essential for reducing or removing hazards. Furthermore, the critical controls must possess finite limits of operation that can be monitored for acceptable performance.

WHO Water Safety Plan

The remaining building block of the proposed risk management framework comes from the WHO Water Safety Plan. The Water Safety Plan and the larger model of risk management it supports is built on an iterative cycle which considers public health concerns, environmental exposure, risk assessment, establishment of health-based targets, and public health status. The Water Safety Plan becomes one of the 'ways' to manage risk, and the supporting 'means' include system validation, operational monitoring, and documentation and communication (WHO 2005b).

- Identify potential hazards
- Estimate risk associated with hazards
- Mitigate risk with preventive controls
- Monitor to assure efficacy of controls

Built into each of these reference models is the resiliency offered by a multiple barrier approach.

Multiple Barrier Approach

The multiple barrier approach is a tried and true approach, not new to U.S. Military field-water supply management. Barriers continue to include source selection and control, robust and redundant treatment, disinfection, operational monitoring, and verification monitoring. Added components include the validation of barriers, both treatment and administrative, and detailed operational plans specific to each reuse scenario. Operational monitoring plans include the explicit designation of critical control points, essential process elements which either prevent or reduce hazards.

Phases of the Risk Management Framework

The risk management framework for contingency water reuse operations involves four phases as detailed below. They progress from preparation and planning to testing and implementation.

The process begins with the formation of an integrated team of stakeholders and ends with execution of a risk management plan. Before entering phase 1, risk managers assemble this team respective to the specific reuse scenario. The team may develop and change through the phases but likely begins with, but is not limited to, a combat developer, a materiel developer, a user representative, a risk assessor, an operator/maintainer representative, and a strategic planner. This team must begin by framing the CONOP and considering the risks and benefits of the potential courses of action.

PHASE 1: SOURCE AND EXPOSURE CHARACTERIZATION

The team initiates phase 1 by characterizing the proposed wastewater source and planned end-use activity(ies). This phase serves to identify hazards, characterize exposures, and evaluate barrier alternatives. Building on the foundation provided by this study, this team assesses the specific risk potential of the reuse scenario at hand. During this phase, the team also considers accidental or purposeful misuse of the product and how it might drive the design and application of barriers. A deliberate consideration of this phase is source control; whereby, industrial wastes and certain hazard-producing activities are best controlled at the source rather than through treatment. The outcome of phase 1 is a proposal for how barriers will be applied to control risk. The proposal includes treatment and administrative barriers, and specifically identifies the critical control points and limits.

PHASE 2: TECHNOLOGY VALIDATION

Phase 2 is a test of the phase 1 proposal. Validation must objectively demonstrate with empirical evidence the design and performance specifications (such as reductions of microbial hazards). In addition to physical testing of new technology platforms, the team may assess hazard-reduction credits. Phase 2 also expressly considers

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failure of the treatment barrier as a potential hazard source. Redundant systems combined with operational response plans ensure that such hazards do not persist into the product. This phase generates the operational monitoring plan or modifies it based on test outcomes.

PHASE 3: OPERATIONAL CONTROLS

Phase 3 marks the transition from planning and testing to implementation. The refined proposal of phase 1 takes shape as a management plan, outlining among other things the controls which verify proper operation of each critical process. Monitoring all system effluent for discrete microbiological and chemical hazards in real-time would provide ideal quality control. Because this is neither possible with present technology nor practical were technology available, operational controls rely on the use of indicators and surrogates. Indicators include process monitors (such as pressure) and hazard indicators (such as total coliforms). Surrogates (such as turbidity) provide additional near-real-time feedback of performance.

The emphasis is on proactive monitoring—how to stop the water before it is released into distribution if critical limits are not met.

Operational controls also include physical elements (such as cross-connection control, back-flow prevention, and access control).

PHASE 4: VERIFICATION MONITORING

The final phase of the risk-management framework is verification monitoring, the quality assurance task. The role of verification monitoring is to answer on a recurring basis: is the plan working, are the barriers adequate, and are the operational controls effective to control risk? An additional function is to monitor trends and perform retrospective analyses.

Verification monitors include numeric metrics and formal inspection/audit programs (such as those promulgated in drinking water regulations and guidelines). Through approximately 1998, it was the consensus opinion in the water industry that drinking water regulations were not sufficient to protect public health if the water source were heavily contaminated (i.e., wastewater (NRC 1998)). The 2012 NRC committee on water reuse formed a different opinion noting that municipalities have for many years managed de facto potable reuse without consequence (NRC 2012). Though an incomplete strategy to risk management, the drinking water standards offer an unmatched volume of health-effects data. It is practical to consider that for some contingency reuse scenarios, the most applicable values for specific parameters are those originally promulgated for drinking water.

Most reuse scenarios represent a lower degree of exposure compared to drinking. Drinking water standards and guidelines can be adjusted to account for this. Assuming like exposure pathways, the values are adjusted relative to the volume of water. The USAPHC followed such a model in evaluating water samples from Operations Iraqi Freedom and Enduring Freedom. The exposures included showering, where the estimated ingestion volume was much less than even the lowest drinking water volume of 5-liters per day (L/day). The MEGs were, therefore, adjusted by a factor of 2.5 to reflect a very conservative rate of 2-L/day (USAPHC 2010). This also matched USEPA consumption rate.

An additional consideration for applying regulations and guides developed for drinking water is the fate of hazards in a reclaimed water system. Due to such factors as nutrient loads in some classes of reclaimed water, there are second- and third-order effects not associated with drinking water systems. These conditions have long-term impact on water quality and could impact human health. For these reasons, when and if drinking water standards are applied as numerical verification monitors of individual parameters, it must be done as part of a comprehensive risk management plan.

Additional Elements

In addition to the four overarching phases of the framework, there are additional elements important to effective risk management. One such element is involvement of stakeholders outside of the risk management team. Early and regular communication is integral to the success of a plan. This should include communication of the plan, the responsible parties, and feedback mechanisms. These ideas will be expanded further in the section which follows. Users not only provide the key to success, but also provide a continual monitoring asset.

In order to maintain quality and effective plans, they need to be formalized and codified. Responsibilities should be clearly defined for the whole of the reuse scenario, from installation to operation, maintenance, and monitoring. Water reuse will involve the existing water triad of Engineers, Logisticians, and Public Health and may expand to an even broader circle. The goal should be continuous process improvement.

Tolerable Risk

Any risk management framework must be grounded in a tolerable risk level and be distinct from and simultaneously coordinated with water-quality standards and guidelines for parallel functions (i.e., drinking water).

A common threshold of tolerable risk used in drinking water as well of other environmental impact assessments is 10^{-6} or 1 in a million for a specific disease endpoint (such as increased cancer risk) or population impact such as DALYs. Relating this to water reuse, the WHO correlates a 10^{-6} increase in DALYs per person per year with an increase in the frequency of diarrheal illness between 1 in 1000 and 1 in 10,000 (WHO 2006a). As a point of reference, the basal level of gastrointestinal illness, specifically diarrheal, is estimated to be between 1 case in 10 people and 1 case per person per year, worldwide (WHO 2006a).

In the end, there will be some degree of residual risk. How the individual risks and cumulative risks are managed depends on a number of variables. To address them in a consistent fashion, a tolerable risk threshold must be established.

Reclaimed Water Quality Classifications

The culmination of work, which began with this study, will be the promulgation of water reuse guidelines for contingency operations. A key component of the guidelines is water quality classification. Reclaimed water is often classified based on the source, applied barriers, and intended use. The proposed criteria shown in Table 9 begin the process of codifying reclaimed water classifications for contingency operations. Each class of reclaimed water is characterized by an objective treatment process and further defined by criteria for each phase of the management framework introduced above. Additional criteria will be applied on a scenario-by-scenario basis. This table represents a compilation of existing industry definitions and guideline for water reuse. Further assessment and deliberation among the Defense stakeholders will be necessary to prove that these metrics in combination with scenario-specific risk management plans are sufficient to control quality and protect health. An excerpt of the model codes considered in developing this table is included as Appendix D; a more complete listing is available in the USEPA 2012 Guidelines for Water Reuse.

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		UNRESTRICTED NON-POTABLE	RESTRICTED NON-POTABLE	
		CLASS A+ (NEAR-POTABLE)	CLASS A (TERTIARY)	CLASS B (SECONDARY)
Example activity		Showering	Laundry	Dust suppression
Treatment process (highest employed)		membrane filtration (micro-, ultra-, nano-filtration, and/or RO)→ advanced oxidation (disinfection via ozone/ peroxide/UV)	Sedimentation, flocculation, filtration	conventional primary and secondary treatment[1]→ disinfection (chlorination)→ engineered buffer
Disinfection (equivalent chlorine CT)[2]		120 mg·min/L	60 mg·min/L	30 mg·min/L
Validation monitoring	Viral reduction†	>6 log	5 log	3 log
	BOD / TSS	5 / 5 mg/L	10 / 10 mg/L	30 / 30 mg/L
Operational monitoring		Turbidity < 0.1 NTU FAC 2 mg/L	Turbidity <2 NTU FAC 1 mg/L	Turbidity < 10 NTU FAC 1 mg/L
Verification monitoring E.coli /100mL (mean / max)[3,4]		<1 / 3	<3 / 14	<100 / 200
Source water control		radionuclides, industrial chemicals, pesticides, pharmaceuticals, and consumer products [5]		

Table 9. Proposed Classification of Reclaimed Water in Contingency Operations

Legend:
RO-reverse osmosis
Log-logarithmic reduction, example: 2-log equals 100-fold reduction
NTU-Nephelometric Turbidity Unit
Notes:
The treatment technologies from right to left are additive. In other words, Class B treatment would include the processes of Class C plus conventional tertiary treatment (e.g., flocculation, sedimentation, and filtration).
† Scenario-dependent based on source and intended use. The figures provided herein are to be used as a guide only. A scenario-specific plan must characterize the source quality, exposure, and the corresponding threshold of performance.

1. *Source water-dependent, secondary biological processes may be impractical and an alternative filtration processes substituted for select sources (i.e., gray water).*
2. *Disinfection requirements may be alternatively met through a combination of filtration credits and disinfection. CT calculation assumes the use of chlorine, pH 5.5-6.5, >5°C.*
3. *30-day mean, single sample max.*
4. *E.coli concentrations not independently derived; based in part on the findings of the Microbial Risk Assessment (USAPHC 2013), the USEPA recreational water quality standards (2012a), and monitoring requirements of U.S. states (USEPA 2012b).*
5. *These wastewater constituents have been found to pass through conventional wastewater treatment systems with little or no removal. Where source control is not possible or practical, alternative controls will be necessary, treatment or use restrictions.*

HEALTH RISK COMMUNICATION

Health risk communication is a science-based approach for communicating effectively in high-stakes, emotionally charged, and controversial situations. It focuses on proactively establishing a dialogue with stakeholders in order to identify and acknowledge their concerns and perceptions. Health risk communications address the often technically complex issues in terms that the stakeholder can understand. Stakeholders, as addressed in detail below, include Service Members, commanders, Families, and planners. They do not all perceive risks in the same way, and different stakeholders may perceive the same risk differently. These differing perceptions of risk cloud how information is received and processed, and if left unaddressed, can escalate unnecessary fears and anxiety. Effective risk communication begins with understanding the perceptions of the stakeholders, and then implementing a combination of one- and two-way communications.

Risk communication efforts can only be effective when a plethora of factors are considered, including the stakeholders' emotions, beliefs, and values. Ideally, stakeholder risk perception would be based on scientific principles, economic realities, and logic, not emotions and assumptions. In reality, however, personal- and group-value systems and cultures play a large role in one's view of risk. Risk communicators must also understand that individuals experiencing change may not clearly absorb or evaluate information in a logical way. Finally, risk communicators must not assume the matters important to one stakeholder are common to all.

Background

Historically in the United States, community stakeholders have resisted water reuse due to the negative connotation associated with wastewater and the idea of using it for anything beyond disposal. In some, cases negative opinions have been reinforced by the use of campaign slogans such as "toilet to tap." In cases where communications were prioritized, stakeholder acceptance was drastically increased, and projects more rapidly met their goals.

Water reuse in contingency operations presents a similar challenge to educate a diverse group of stakeholders, each with a potentially unique perception of the risks. A sound health risk communication strategy, which provides familiarization, a sense of control and personal benefit, and avoids the "I'm being ordered to accept this" mentality are essential to the success of water reuse in contingency operations.

The final point of voluntary acceptance merits additional mention because when participation in an activity is mandatory, individuals perceive that activity as more risky. In contingency operations, the selection of water resources is rarely the choice of the user.

Health Risk Communication Strategy

This study examined health risk communications for water reuse in contingency operations and devised a strategy for implementation. The approach included identifying stakeholders, establishing a common vocabulary, forming key message points, and prioritizing communication products. Goals of the health risk communication strategy include—

1. Stakeholder acceptance of water reuse as safe and beneficial.
2. Stakeholder concerns identified, understood, validated, and addressed.
3. A transparent dialogue among stakeholders, which provides opportunity for feedback and input.
4. Accurate communication of the health implications of water reuse that drives informed decisions.
5. Consistent messaging to all stakeholders.

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Stakeholders

Water reuse in contingency operations has a diverse group of stakeholders, much like other supply commodities but with the unique challenge that water reuse will likely be new to many. Unlike food or drinking water, there may or may not be assumed benefits to water reuse, and perceived risks may vary greatly based on personal beliefs, education, and experience. Communication strategies need to be prioritized based on the complex array of needs, wants, and concerns. Stakeholders include—

- Users
- Family members
- Logisticians
- Policy makers
- Planners
- Materiel developers
- Commanders
- Medical professionals

Beginning with potentially the most diverse stakeholder group, the user-group is made up of Service Members and deployed Civilians (defense and contract employed) as the customers of all life-support commodities in a contingency environment. They have a personal stake in the quality and safety of the water they may be showering in, laundering their clothes in, or using in their various missions. In addition to concerns of health and safety, users are likely to want to understand, if not realize, the personal benefits of water reuse. They need to understand that water reuse is not some experimental activity but a safe, purposeful, and practical strategy to increase reliability and sustainability of the water supply.

The next stakeholder group is arguably even more diverse than the deployed user. Whereas in a municipal setting, Family members would all themselves be users; here we have a removed population, yet with a personal stake. What this stakeholder group will demand in terms of information may be difficult to discern. The format and timeliness of health risk communication products will be vital. There are many communication channels for use in reaching this stakeholder group. The USAPHC has partnered with the USEPA in its effort to determine effective outreach, education, and social-marketing strategies. Results of the associated surveys and focus groups will help to identify the concerns of this stakeholder group.

Logisticians, like commanders, are liable to see the greatest potential in water reuse as a supplement to or replacement for traditional water supplies. Along with planners, logisticians may realize a mobility and agility advantage. They may have concerns about the change in transport, set up, operation, and maintenance requirements. Many will also be users and have occupational exposures to varying degrees and, therefore, have personal stakes as described above. There may be nuanced differences in the reaction of Military logisticians and contracted resources. Slow uptake by logisticians of existing water reuse systems, such as the Force Provider Shower Water Reuse System, prove it is not enough to deliver a materiel solution. The strategy must include a training and communication plan. Logisticians are essential to the successful evolution of support strategy.

Defense policy makers have in recent years demonstrated a significant lean to sustainability and resource autonomy. While the posturing, such as NetZero, has focused largely on fixed installations, it is a reasonable assumption that similar strategies will be applied in contingency operations. It will not be difficult to drive acceptance of water reuse to policy makers, but the assurance of safety will be pivotal. Posturing to advance "green" is one thing, but only in so much as it can be done without sacrifice to the Service Member and the military fighting strength.

Commanders typically have a different set of concerns related to overall mission success. Mission capability, efficiency, resource availability, and budgets are top priorities. Commanders also have a personal and cooperative stake in the health risk associated with water reuse. There is certainly concern for the health and safety of Service Members in their charge as individuals, but on a macro level they require personnel to be at high-readiness levels in order to achieve mission success. Commanders are the first and last line of communication with Service Members and, as such, are an important conduit for risk communicators to exploit. The commander's sphere of influence is potentially great. They must be able to communicate effectively and consistently about the safety, risks, and benefits of water reuse as well as allocate the resources necessary to make sure good health risk communication is conducted throughout their Commands. If the communications strategy fails to resonate with commanders, failure is likely.

Commanders turn to their medical staff officers for medical expertise and recommendations. This includes clinical medicine as well as preventive medicine personnel who must be equally prepared to field questions from concerned users. It is incumbent on the success of a health risk communication strategy to reach this stakeholder with the requisite level of technical detail. Medical personnel will in turn become risk communicators themselves, and their ability to deliver consistent information will be essential to eliminating undue concerns.

Robust, consistent, and timely communications build trust, temper expectations, and influence behavior. Without early and regular communication, water reuse initiatives are destined for failure.

Common Vocabulary

The health risk communications strategy for water reuse in contingency operations includes standardized definitions and terms. Definitions need to be complete, transparent, and understandable to all stakeholders. The Glossary contains an initial glossary of terms. This list can be reduced and refined based on the communication format or stakeholder.

Key Message Points

- *The Department of Defense is committed to protecting the health and safety of the Soldier, Civilian and contractor workforce in contingency operations, to include ensuring that all water which is provided is absolutely safe for its intended purpose.*
- *Water reuse refers to the practice of capturing used water, treating it, then using it again for a beneficial application. Water reuse is commonplace throughout the United States and is a proven strategy for water resource management.*
- *Water reuse ensures a more consistent water supply for activities (such as showering and laundry) which directly contribute to the health and quality of life of deployed Warfighters.*
- *Water reuse increases agility and flexibility, allowing leaders to consider siting options for contingency operations even if they have water supply limitations.*
- *Water reuse reduces the number of convoys needed to transport water.*
- *Water reuse reduces the need for wastewater lagoons which have a negative aesthetic impact and potentially attract vectors.*
- *The USAPHC is developing guidelines for water reuse in contingency operations to ensure water is safe for its intended purpose. Reuse systems undergo rigorous testing and will be monitored regularly to ensure they are operating properly.*

Key message points will be added and updated as the practices of water reuse in contingency operations expand and mature and as specific reuse scenarios demand.

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Communication Products

The next element is a catalog of tiered messages, each following a specific communications medium and format. The goal is to address the specific concerns about each activity with various stakeholders. These messages must reach stakeholders prior to the implementation of water reuse, and ideally when the stakeholder is in a conducive environment, not in the midst of a contingency operation. Potential products include fact sheets, frequently asked questions, press releases, command talking points, and posters for display at points of use. Appendix F contains a sample of frequently asked questions which might be part of the communication package for leaders. As the formats change to answer specific needs, the underlying message must remain constant.

Future Efforts

The risk communication effort continues. Following the completion of this study, AIPH will work with various stakeholder groups to publish products. The health risk communications strategy is adaptable, and will evolve as contingency reuse practices evolve. Lessons-learned from implementation of this strategy as well as that of efforts throughout the United States will facilitate improvement.

Effective health risk communications is essential to ensuring water reuse in contingency operations is a force multiplier, and not a detractor. The health hazards can be managed to maintain low risk. It is incumbent upon the practitioners and champions to effectively communicate the same.

PART IV – CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The study team concluded that it is sufficiently health-protective to integrate water reuse into a comprehensive resource management strategy for contingency operations, provided it is matched with a proactive risk management framework as proposed herein. While much remains unknown about the dose response relationships and the exposures are incompletely defined, the barriers are mature enough to manage risk to a low level across a spectrum of reuse activities.

The hazards of water reuse are not unique. The prevalence of de facto reuse and ubiquitous influence of municipal, agricultural, and industrial wastes on current drinking water sources indicate the supply and regulatory industries are accounting for their presence.

Treatment technologies are sufficiently mature and robust to create any quality of water, up to and including drinking-quality water from wastewater. Confidence in their reliability and quality assurance, and perhaps most significantly public perception, limit the immediate adoption of direct potable reuse. A risk-based regulatory framework is needed to both maintain quality and increase confidence in reuse as a safe alternative.

A new quality assurance framework is needed for water reuse. The existing guidance is insufficient to execute water reuse in the field safely and sustainably. A framework which identifies and manages risks proactively will be most effective. The AIPH team continues to work with risk managers from the materiel and combat development community to flesh out the strategy for how to manage risks and to develop water quality standards and guidelines.

Proactive and effective risk communications is pivotal to the implementation of water reuse strategies. The AIPH Health Risk Communication Program is able to provide a unique perspective to help characterize public perceptions and beliefs related to this issue, and develop proven communication solutions acceptable to Project Managers and stakeholders.

There is not an established consensus of acceptable risk or disease burden for contingency operations. "As low as reasonably possible," does not permit for quantitative risk assessments. The Civilian threshold of one in a million may be overly conservative for the duration and competing risk/rewards of contingency operations.

Many health agencies around the world have spent many years and millions of dollars to conduct similar studies. The AIPH in cooperation with combat and materiel developers will continue to progress prudently and incrementally to ensure the continued quality of water supplies for deployed Forces.

RECOMMENDATIONS

- Develop cooperative Joint guidelines for water reuse in contingency operations which follow a comprehensive, proactive risk management framework.
- Require written risk management plans, specific to the reuse scenario, developed in advance, which follow the four-phased framework proposed by this study or a similarly holistic multiple barrier approach.
- For any scenarios where extensive human contact or incidental ingestion is probable, require documentation of the critical controls, their limits, an operational monitoring plan, and a plan for risk management verification.

- Incorporate into the combat development cycle a requirement for risk management plans in all future capability and requirements documents. Retroactively phase in risk management plans for existing water reuse scenarios.
- Develop a communications strategy. Involve stakeholders early and often in the process.
- Designate a threshold of acceptable risk/disease burden.
- Pursue water reuse in combination with comprehensive strategies for water and energy efficiency
- Adopt common language consistent with national and industry bodies.

APPENDIX A

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APPENDIX B

Example Reuse Standards

	Unrestricted Urban Reuse (Class A or Type I)						
	USEPA 2012[a]	SWRS[b]	Arizona Class A	California Disinfected Tertiary	Florida	Massachusetts Class A	Texas Type I
Treatment Design	Secondary, filtration, disinfection	<0.2 µm pore size, 20% blowdown,	Secondary, filtration, disinfection	"tertiary":oxidized, coagulated, filtered, disinfected	Secondary, filtration, high-level disinfection	NS	NS
pH	6-9	5-9	NS	NS	6.0-8.5	6.5-8.5	NS
FAC / CT mg/L	1 / 90[c]	1	NS	5 / 450[e]	1 / 25-120[f]	NS[g]	NS
BOD mg/L	10	10[d]	NS	NS	20	10	5
TSS mg/L	NS[e]	NS	NS	NS	5	5	NS
Turbidity (NTU) mean / NTE	2 / 5	1 / NS	2 / 5	2 / 10	2-2.5 / NS	2 / NS	3 / NS
Total Coliforms /100mL mean / NTE	NS / NS	0 / NS	NS / NS	2.2 / 23	NS / NS	NS / NS	NS / NS
Fecal Coliforms /100mL mean / NTE	0 / 14	0[†] / NS	0 / 23	NS / NS	0 / 25	0 / 14	20 / 75
Other				5 log virus reduction	*Giardia* and *Crypto* monitoring		

Table B-1. Examples of Unrestricted Urban Reuse Standards

Source: Consolidated from USEPA 2012 Guidelines for Water Reuse. Select figures only are presented here. This representation should not be used as an authoritative source for regulating activities. Consult the respective jurisdiction codes for compliance purposes.

NTE- not to exceed, companion concentration are mean values, over 30 days in most cases

NS-not specified by this authority, or this criteria is generated on a case by case basis

[†] Specified as E.coli

[a] Consolidated guideline suggested by the USEPA

[b] Shower water recycle system, standards for gray water recycle (USACHPPM 2001), not a promulgated state or Federal code, provided for comparison only

[c] T ≥ 90 minutes

[d] by way of invoking USEPA guidelines

[e] Technology-dependent, systems employing membrane filtration should not exceed 0.2 mg/L

[f] CT based on fecal coliform count prior to disinfection

[g] Disinfection recommendations made based on reuse activity, 0.5 mg/L in conveyance

	Restricted Urban Reuse (Class B or Type II)							
	USEPA 2012	Arizona	California	Mass	Texas	Virginia	Australia	NSF/ANSI 350 Class R
TX	Secondary, disinfection	Secondary, disinfection	Oxidized, disinfected	NS	NS	Secondary, disinfection	Secondary, disinfection	NS
FAC / CT	1 / 30	NS	NS	NS	NS	1 / 30	NS	≥0.5 - ≤2.5
BOD	30	NS	NS	30	20	30	20	10 (as CBOD)
TSS	30	NS	NS	10	NS	30	30	10
Turbidity (NTU) mean / NTE	NS	NS	NS	10	NS	NS	2	5
Total Coliforms /100mL mean / NTE	NS	NS	23 / 240	NS	NS	NS	NS	NS
Fecal Coliforms /100mL mean / NTE	200 / 800	200 / 800	NS	14 / 100	200 / 800	NS	NS	NS
E. Coli /100mL mean / NTE	NS	NS	NS	NS	NS	126/ 235	100 / NS	14 / 240
Other								Odor, oily film, color

Table B-2. Examples of Restricted Urban Reuse Standards

Source: Consolidated from USEPA 2012 Guidelines for Water Reuse. Select figures only are presented here. This representation should not be used as an authoritative source for regulating activities. Consult the respective jurisdiction codes for compliance purposes.

NTE- not to exceed, companion concentration are mean values, over 30 days in most cases

NS-not specified by this authority, or this criteria is generated on a case by case basis

	Restricted Irrigation (Class C)					
	USEPA 2012	Mass	Arizona	Florida	Washington	WHO 2006
TX	Secondary, disinfection	NS	secondary	Secondary, basic disinfection	Oxidized, disinfected	NS
FAC / CT	1 / 30	NS	NS	0.5 / 7.5 25-120[a]	1 / 30	NS
BOD	30	30	NS	NS	30	240
TSS	30	30	NS	NS	30	140
Total Coliforms /100mL mean / NTE	NS	NS	NS	NS	23 / 240	1000
Fecal Coliforms /100mL mean / NTE	200	200	1000 / 4000	NS	NS	NS

Table B-3. Examples of Restricted Irrigation Reuse Standards

Source: Consolidated from USEPA 2012 Guidelines for Water Reuse. Select figures only are presented here. This representation should not be used as an authoritative source for regulating activities. Consult the respective jurisdiction codes for compliance purposes.

[a] CT based on fecal coliform count prior to disinfection

NS-not specified by this authority, or this criteria is generated on a case by case basis

APPENDIX C

Epidemiological Survey
Waterborne and Foodborne Illness in USCENTCOM

BACKGROUND

Food and waterborne pathogens can cause significant health threats, illnesses, and vulnerabilities that affect forward-deployed and domestic military personnel. These pathogens include a broad range of bacteria, viruses, fungi, and protozoa. In this study, food and waterborne pathogens were combined due to cross-contamination in food preparation and common ICD-9 (diagnosis & treatment) coding in clinical assessment. Nevertheless, a burden of disease (BoD) baseline allows for future trend analyses and comparisons to be made relative to the current impact of food and waterborne illness, prior to widespread water reuse initiatives.

SURVEILLANCE

Surveillance in the public health domain is the continuous, collaborative aggregation, analysis, understanding, frequency, and distribution of health-related data in efforts to reduce community morbidity and mortality; it is the quintessential tool for supporting the labors of public health's functions (CDC 2009). More specifically, it provides the baseline information that aids public health interventions, provides means to evaluate the BoD within communities, and facilitates planning efforts. Most importantly, public health surveillance provides a vigilant and sentinel barrier that could identify lurking biological threats.

METHODS AND DATA SOURCES

For estimation of the food and waterborne associated BoD, DALY was selected as the unit of measurement. A DALY is a standard epidemiologic measure used to assess the burden of disease—it accounts for the impact of illness, injury, and death in relation to life expectancy. The DALYs are the measurement tool of choice for Federal and international public health agencies for the assessment of the burden of disease, variance, association, and trend extrapolation (Steenland and Armstrong 2006).

The DALYs were calculated using morbidity and mortality data gathered from Department of Defense (DOD) databases, disease-weight-scaling (see Tab A), standard life expectancy (U.S. Census Data), disease incidence (see Tab C), and days of illness associated with disease (see Table D-1). Reference data sources included the World Health Organization (WHO), Centers for Disease Control and Prevention (CDC), Army Disease Reporting System internet (DRSi), TRANSCOM Regulating and Command & Control Evacuation System (TRAC2ES), and Military Health System (MHS) Management Analysis & Reporting Tool (M2) data.

To monitor trends and perform future analyses with comparison to the data presented here, the methods described herein must be replicated to ensure accurate comparison.

BURDEN OF DISEASE

Globally, unsafe water, sanitation, and inadequate hygiene contribute to over 4.6 billion cases of diarrheal illness per year, 1.7 million deaths per year, and 124 million quality life years lost (WHO 2013a and 2002). In the United States, over 48 million cases were reported and, of those, 128 thousand were hospitalized. Additionally, there are approximately 3,000 associated deaths per year and 286,800 quality life years lost (CDC 2011).

The DOD recorded 7,546 continental United States (CONUS) cases of diarrheal disease with a calculated 87 quality life years lost. The U.S. Central Command (USCENTCOM) alone recorded 68 cases with a calculated 78 quality life years lost between 2006-2011, see Table D-1. Note: USCENTCOM recorded cases are likely a significant underrepresentation of the actual BoD, as further discussed under the limitations section.

	DALYs	Data Source:
Global Civilian	124 billion	WHO
US Civilian	286,800 million	CDC
DoD CONUS	**87**	DRSi, M2
DoD CENTCOM	**78**	DRSi, TRAC2ES

Table C-1. DALY (quality life years lost) Associated with Food and Waterborne Disease 2006–2011

The BoD calculated in this study is intended to establish a pre-water reuse baseline and to serve as a template for preventive medicine to use to calculate theater specific BoDs following the implementation of water reuse. Equations 1–3 provide the necessary variables and formulas for calculating DALYs.

$$\text{Years of Life Lost (YLL)} = N \times L \qquad \text{(Equation 1)}$$
$$\text{Years Lost due to Disability (YLD)} = I \times DW \times R \qquad \text{(Equation 2)}$$
$$DALY = YLL + YLD \qquad \text{(Equation 3)}$$

Where:
N = number of deaths, if zero use one (1)
L = standard life expectancy at age of death in years (global 70 yrs, US 78 yrs)
I = number of incident cases
DW = disability weight (0.11, diarrheal disease)
R = average duration of the case until remission or death, 4 days [0.01 years]

LIMITATIONS

The DALYs presented herein are likely an underestimation of the actual BoD due to reliance on passive data collection systems, operational pressures limiting reporting in theater, non-reported field treatment, and other data system constraints. In the future, if significant changes in comparison to the baseline DALY are presumed or calculated, the Army Institute of Public Health *(usarmy.apg.medcom-phc.mbx.disease-epidemiologyprogram13@mail.mil)* should be contacted to ensure methodological consistency and statistical significance prior to dissemination of results.

Data used for calculations of DOD DALY were extracted from the following systems: DRSi, TRAC2ES, and M2.

For purposes of DALY calculation, both food and waterborne pathogens and associated International Classification of Diseases-9th Edition (ICD-9) codes were used (see Appendix C).

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Tab A to Appendix C.

Global Burden of Disease: Disability weights for diseases and conditions (except cancers and injuries)

Sequela	Average Disability	Range (b)	Source
Tuberculosis - Cases	0.271	0.264 - 0.294	GBD 1990 (c), varies with age
Syphilis			
Congenital syphilis	0.315		GBD 1990
Primary	0.015	0.014 - 0.015	GBD 1990 (c), varies with age
Secondary	0.048	0.044 - 0.048	GBD 1990 (c), varies with age
Tertiary -- Neurologic	0.283		GBD 1990
Chlamydia			
Cervicitis	0.049		GBD 1990
Neonatal pneumonia	0.280		GBD 1990
Ophthalmia neonatorum	0.180		GBD 1990
Pelvic inflammatory disease	0.329	0.194 - 0.382	GBD 1990 (c): untreated 0.420, treated 0.169
Ectopic pregnancy	0.549		GBD 1990
Tubo-ovarian abscess	0.548		GBD 1990
Chronic pelvic pain	0.122		GBD 1990
Infertility	0.180		GBD 1990
Symptomatic urethritis	0.067		GBD 1990
Epididymitis	0.167		GBD 1990
Gonorrhea			
Cervicitis	0.049		GBD 1990
Corneal scar -- Blindness	0.600		GBD 1990
Ophthalmia neonatorum	0.180		GBD 1990
Pelvic inflammatory disease	0.169		GBD 1990
Ectopic pregnancy	0.549		GBD 1990
Tubo-ovarian abscess	0.548		GBD 1990
Chronic pelvic pain	0.122		GBD 1990
Infertility	0.180		GBD 1990
Symptomatic urethritis	0.067		GBD 1990
Epididymitis	0.167		GBD 1990
Corneal scar -- Low vision	0.233	0.233 - 0.245	GBD 1990 (c), varies with age
Stricture	0.151		GBD 1990
HIV/AIDS			
HIV cases	0.135	0.123 - 0.136	GBD 1990 (c), varies with age
AIDS cases not on ART	0.505		GBD 1990
AIDS cases on ART	0.167	0.145 - 0.469	GBD 2004
Diarrheal diseases - Episodes	0.105	0.086 - 0.119	GBD 1990 (c), varies with age
Pertussis			
Episodes	0.137	0.017 - 0.160	GBD 1990
Encephalopathy	0.452	0.402 - 0.461	GBD 1990 (c), varies with age and treatment
Poliomyelitis - Cases - lameness	0.369		GBD 1990
Diphtheria			
Episodes	0.231		GBD 1990
Neurological complications	0.078		GBD 1990
Myocarditis	0.323		GBD 1990
Measles - Episodes	0.152		GBD 1990
Tetanus - Episodes	0.638	0.604 - 0.640	GBD 1990 (c), varies with age
Meningitis			
Streptococcus pneumoniae – Episodes	0.615	0.613 - 0.616	GBD 1990 (c), varies with age
Haemophilus influenzae – Episodes	0.616	0.613 - 0.616	GBD 1990 (c), varies with age
Neisseria meningitidis – Episodes	0.615	0.613 - 0.616	GBD 1990 (c), varies with age

Meningococcaemia episodes without

Tab B to Appendix C.

Calculating DALY

Global DALY:

YLL = 1,700,000 x 70 = 119,000,000
YLD = 4,600,000,000 x .11 x.01 = 5,060,000
YLL + YLD = 124,060,000 **= 124 million quality life years lost due to food & waterborne disease**

U.S. DALY:

YLL = 3,000 x 78 = 234,000
Y LD = 48,000,000 x .11 x .01 = 52,800
YLL + YLD = 286,800 = **287 thousand quality life years lost due to food & waterborne disease**

USCENTCOM DOD DALY (DRSi data):

YLL = 1 x 78 = 78
YLD = 88 x .11 x.01 = 0.10
YLL + YLD = **78.1 quality life years lost due to food & waterborne disease**

USCENTCOM DOD DALY (TRAC2ES [TRANSCOM Regulating and Command & Control Evacuation System] data)

YLL = 1 x 78 = 78
YLD = 47 x .11 x.01 = 0.05
YLL + YLD = **78.1 quality life years lost due to food & waterborne disease**

CONUS DOD DALY (DRSi data):

YLL = 1 x 78 = 78
YLD = 1010 x .11 x.01 = 1.11
YLL + YLD = **79.1 quality life years lost due to food & waterborne disease**

CONUS DOD DALY (M2 data)

YLL = 1 x 78 = 78
YLD = 14081 x .11 x.01 = 15.5
YLL + YLD = **94 quality life years lost due to food & waterborne disease**

Tab C to Appendix C.

Code	Description	Code	Description
001.00	Cholera	008.02	Intestinal infection due to enterotoxigenic E. coli
002.00	Typhoid and Paratyphoid	008.03	Intestinal infection due to enteroinvasive E. coli
003.00	Other salmonella infections	008.04	Intestinal infection due to enterohemorrhagic E. coli
004.00	Shigellosis	008.05	Open ICD-9 Code (currently not used)
005.00	Other food poisoning (bacterial)	008.07	Open ICD-9 Code (currently not used)
005.10	Botulism food poisoning	008.09	Intestinal infection due to other intestinal E. coli infections
005.20	Food poisoning due to Clostridium perfringens	008.41-2	Intestinal infection due to staphylococcus
005.30	Food poisoning due to other Clostridia	008.43	Intestinal infection due to campylobacter
005.40	Food poisoning due to Vibrio parahaemolyticus	008.44	Intestinal infection due to yersinia enterocolitica
005.80	Other bacterial food poisoning	008.46-9	Intestinal infection due to other anaerobes
005.90	Food poisoning, unspecified	008.5	Bacterial enteritis, unspecified
006.00	Amebiasis	008.6	Enteritis due to specified virus
007.00	Other protozoal intestinal diseases	008.61	Enteritis due to rotavirus
007.10	Giardiasis	008.62	Enteritis due to adenovirus
007.20	Coccidiosis	008.63	Enteritis due to norwalk virus
007.30	Intestinal trichomoniasis	008.64	Enteritis due to other small round viruses
007.40	Cryptosporidiosis	008.65	Enteritis due to calicivirus
007.50	Cyclosporiasis	008.66	Enteritis due to astrovirus
007.60	Open ICD-9 Code (currently not used)	008.67	Enteritis due to enterovirus nec
007.70	Open ICD-9 Code (currently not used)	008.69	Enteritis due to other viral enteritis
007.80	Other specified protozoal intestinal diseases	008.8	Intestinal infection due to other organism, not elsewhere classified
007.90	Unspecified protozoal intestinal disease	009	Ill-defined intestinal infections
008.00	Intestinal infection due to E. coli, unspecified	558.9	Other and unspecified noninfectious gastroenteritis and colitis
008.01	Intestinal infection due to enteropathogenic E. coli		

Food and Waterborne Associated Illness ICD-9 Codes

* **Code search**: *http://www.icd10data.com/Search.aspx?search*

APPENDIX D

Risk Management Template Example

It is the intent of this template is to facilitate the development of specific and detailed Risk Management Plans. The template is consequently generalized, providing an outline of the information that should be included in an actual Plan

Goals

MIL Water Reuse Risk Management Template No. 00001

Category: Restricted, Class B

Scenario: Gray water for restricted outdoor use

Recommended treatment: filtration and disinfection

This paragraph should speak to the analysis of alternatives and why water reuse was chosen as the best solution.

1. Elimination of liquid waste for beneficial and cost-effective practice.
2. Force protection due to reduction elimination of contract services to remove liquid waste, deliver water.
3. Reduction of health hazard and nuisance.
4. Reduction in potable water use.

Assumptions

1. The reuse activity includes intermittent occupational exposure directly to the water and a bystander exposure to the water and residues left from the activity.
2. Complete exposure pathways exist for dermal and inhalation. The ingestion pathway is potentially complete.
3. There is benefit to the reuse practice, e.g. suppressing dust, which outweighs the potential risk of waterborne illness.

Potential Residual Hazards—Post-Treatment

1. Chlorine-resistant organisms; those which form protective structures
2. Viral pathogens
3. Environmentally resistant organism, those which can survive on the soil

Uncontrolled Risks

The treated water being misused for activities other than the intended purpose; failure to adhere to the defined controls. This includes accidental use by Military members or the local population.
Hazards associated with mishandling of untreated waste to include potential accumulation of biogases.
The environmental effect of this reuse scenario was minimally considered in developing this plan.

Source Characterization

This section should specifically define the intended wastewater source for the scenario along with as much characterization as possible.
Potential Sources:

- Shower wastewater
- Water treatment system reject
- Laundry wastewater
- Cooling water waste
- Vehicle wash water

Characteristics of gray water:

- May contain human contaminants-bodily fluids and particles (skin, hair)
- Microbial contaminants are primarily of human fecal origin
- Lint, hair, and similar relative to the source
- Contains detergents of uncontrolled makeup
- May contain personal care products, pharmaceuticals, and/or derivatives of the same
- Contains an undefined fraction of some contaminants from the original natural water source
- Likely contains a disinfectant and potentially disinfection byproducts
- If the previous water was itself reclaimed water, the above conditions may be altered

Possible Source controls:

- Segregation of ill patrons from centralized shower units
- Recommended or required soap products for use in centralized shower units
- Location of latrines convenient to showers to reduce urination in showers

Treatment Design and Validation

Minimum treatment—disinfection to provide CT of 30 mg·min/L free chlorine at >5°C and pH of 5.5-6.5; or equivalent.

Preferred treatment—as defined for Class B, to include: filtration, disinfection, and engineered buffer, discussed further below
Intent of treatment—reduce by 3-log potential microbial pathogens

- ✓ Minimum quality standards: BOD and TSS ≤ 30mg/L, Turbidity ≤ 10 NTU
- ✓ Reduce potentially offensive odors in effluent
- ✓ Reduce the potential environmental effect as required by local statute or best stewardship practice
- ✓ Buffer holds volume of water equal to 150% average batch volume, CT verified before release for use.

Validation

The tests provided are for example purposes. Validation should be designed to test the performance of controls and their set limits.

No pre-commissioning validation required, below requirements to be satisfied during first 6 months of operation or pre-commissioning

1. Oxidant demand testing on representative or actual wastewater (e.g,. persistent free available chlorine residual after 12-hr holding period)
2. Effluent meets minimum quality standards of Class B water at 150% of design loading rate for a sustained period of no less than 8-hrs on actual or representative wastewater.
3. Operational controls detect variance in quality

Operational Controls

₸ Treatment operation controls
^ Administrative controls

- ₸ Daily disinfection monitoring
- ₸ Minimum holding period equal to 150% contact time average
- ₸ Avoid cross connections
- ^ Application rate and time—avoid high traffic periods, allow drying before reoccupation, adjust per weather conditions
- ^ Establish minimum standoff distances for spray drift, static and wind-driven
- ^ Establish minimum separation with vulnerable infrastructure (drinking water, medical activities)
- ^ Avoid second order effects associated with standing water—vector harborage, increased risk of bystander contact
- ^ Determine and implement PPM for applicators (e.g. gloves, eye-protection)
- ^ Personal and equipment decon following application
- ^ Clearly mark storage containers, transport vehicles, and associated lines and dispensing equipment
- ^ Equipment used for reclaimed water will not be subsequently reused for potable purposes

Verification Monitoring

- ✓ Verify operational controls
- ✓ Verify disinfectant residual at point of use

Definitions

CT-concentration time; the product of the free chlorine concentration and contact time, expressed in mg·min/L
BOD-biochemical oxygen demand, measured as BOD-5
TSS-total suspended solids

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APPENDIX E

General Comparison Of Hazard Analysis Critical Control Point Approach And California Title 22 Requirements

HACCP Step and Key Criteria	CALIFORNIA CODE OF REGULATIONS - TITLE 22 - KEY ELEMENTS OF WATER RECYCLING CRITERIA														
	Plant Design					Plant Operation / Maintenance			Plant Performance Monitoring					RW Use Areas	
	Process design reliability	Standby power	Unit process alarms	Process design flexibility	Engineering report	WW Operator training	Operating records / reporting	Preventive maintenance	Filter influent Turbidity	Continuous turbidity monitoring	Filter effluent turbidity	Effluent total coliform	Disinfection process monitoring	RW Use area requirements	Cross-connection control
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1. Assemble a HACCP Team															
Commitment from senior management						◒	◒	◒							
Quality assurance						◒									◒
Roles and responsibilities						●								●	●
Internal communication						●									
2. Describe the Product															
Source control and raw wastewater quality			●				●								
Recycled water production specification			●				●		●	●	●		●	●	
3. Identify Intended Use															
Regulatory awareness					●	●								●	●
External communication														●	●
Standards									●		●	●	●		
4. Identify Intended Use															
Process flow diagram	●				●										
Traceability					●		●							●	●
5. Identify Intended Use															
Process validation					●		●				●	●	●		
6. Conduct Hazard Analysis															
Hazard analysis															
7. Identify Critical Control Points															
Critical control points			◒		◒										
8. Establish Critical Limits															
Critical limits			◒		◒										
Preventive measures								●							
9. Identify Monitoring Procedures															
Monitoring and control			●				●			◒	◒		◒		
Verification - process (end point)														◒	◒
External supplies															
10. Establish Corrective Action Procedures															
Emergency preparedness	●	●	●					●							
Corrective action			●				◒			◒	◒		◒		
Non-complying product	●			◒											
Maintenance								●							
Training						●								●	●
Calibration							●	●							
11. Validate/Verify HACCP Plan															
Verification - internal audit							◒								
Management review						◒									
Product performance						●	◒								
Feedback loops							◒								◒
Continuous improvement						●									
Contractors															
12. Establish Documentation and Recordkeeping															
Document control					◒		●								

Legend: Are Title 22 requirements equivalent to HACCP approach? ● Yes ◒ Partial (blank) No

APPENDIX F

USAPHC Water Reuse In Contingency Operations
Information For Leaders

The following is a sample of frequently asked questions about water reuse. They were developed specifically for Army leaders and are intended as part of a larger communications campaign described in Part III of the report.

QUESTION: *What is water reuse?*

ANSWER: Water reuse is an emerging strategy for water resource management, both in the Civilian sector and for Military deployments. Water reuse refers to the practice of capturing used water, treating it, then using it again for a beneficial application. The commodity is termed "reclaimed water". It may be recycled back into the process that generated it or repurposed for another application. In either case, a volume of water may be used and reused for multiple demands, reducing the total volume that must be sourced from nature or transported from elsewhere.

Water reuse is commonplace around the United States and throughout the world. While most reclaimed water is used for irrigation and industrial activities, nearly all municipal surface water supplies include an estimated 5% of water which was previously used, treated, and discharged by a municipality further upstream. This non-purposeful reuse is referred to as de facto water reuse.

Field water reuse is accomplished by capturing highly treated reclaimed water and introducing it back into the water supply distribution system. The quality achieved during water treatment depends on the water's intended use. Two systems currently deployed recycle laundry and shower water. As much as 75% of shower water can be reused for showering. The risk management framework for field water reuse includes water quality characterization, treatment validation, detailed operational monitoring, and continuous verification.

QUESTION: *Is water reuse safe?*

ANSWER: Yes. The USAPHC is in the process of developing joint guidelines for water reuse in contingency environments to ensure that reclaimed water is absolutely safe to use for its intended purpose. Field water reuse systems undergo rigorous testing during the DOD procurement process and employ the multiple barrier approach (long used by the Military for field water supply management) to achieve high-quality reclaimed water. In addition to barriers (such as water source selection and control, robust and redundant treatment, disinfection, and monitoring), detailed operational plans will also be available for each specific reuse scenario.

QUESTION: *What are the risks of reusing water?*

ANSWER: To ensure that Service members have access to safe water, the USAPHC is characterizing the risks associated with water reuse as employed in contingency environments. The focus will be on neutralizing microbial hazards to reduce gastrointestinal illness in the field. Risk management plans for water reuse are also being developed. Provided the risk management plans are followed, the risk to health will be low. The health risk associated with existing water supply strategies is relatively small, while the quality of water provided for all activities is high. The USAPHC will use this as the threshold of

responsibility for any alternative water supply, to include reclaimed water.

QUESTION: *What are the benefits of reusing water?*

ANSWER: Field water reuse systems increase agility, allowing planners and leaders to consider desirable sites as options for contingency operations which might otherwise be unsuitable due to water supply limitations. Limitations can be a lack of water or poor quality of available water. Operating in these regions often necessitates the use of convoys for water transport. Service members and resources are vulnerable to attack while en route to and from the water procurement location.

When wastewater is not reclaimed for reuse, it must be disposed of in an appropriate manner. Typically, wastewater in contingency environments is either hauled away at significant cost, or it is discharged to the ground, with or without treatment, creating favorable living and breeding conditions for pests. Insects and other pests are not only a nuisance but often carry vector-borne diseases which can decrease readiness. Water reuse makes the Army and DOD more sustainable and more independent. The comprehensive risk management strategy proposed by USAPHC makes field water reuse a safe and highly beneficial option for Military leaders.

QUESTION: *What's my role as a leader?*

ANSWER: As a leader, you'll need to dedicate the necessary resources to train your people on water reuse management strategy. A second role will be to communicate with your unit about the advantages of water reuse, such as logistical independence, the reduced need for convoys and lower exposure to vector-borne diseases. Communication is essential to uptake. Uptake is essential to success. Success is essential to savings.

QUESTION: *Where can I go to learn more?*

ANSWER: To learn more about Water Reuse, please visit the following:
http://athirstyplanet.com/be_informed/what_is_water_reuse/history
http://www.watereuse.org/information-resources/about-water-reuse/faqs-0

GLOSSARY

Section I

ACRONYMS

AHMC
Australian Health Ministers Conference
AIPH
Army Institute of Public Health
APHA
American Public Health Association
BOD/BoD
Biochemical Oxygen Demand (BOD5-measurement carried out over 5 days of incubation)/burden of disease
CERL
Construction Engineering Research Laboratory (of the U.S. Army Corps of Engineers)
cfu
colony-forming unit
COD
Chemical and biochemical oxygen demand
CONOP
Concept of Operations
DALYs
Disability Adjusted Life Years
DA
Department of the Army
DBP
Disinfection by Products
DOD/DoD
Department of Defense
EDS
Epidemiology and Disease Surveillance
EPHC
Environment Protection and Heritage Council
ERDC
U.S. Engineer Research Development Center (of the U.S. Army Corps of Engineers)
FAC
free-available chlorine
FY
fiscal year
GI
gastrointestinal
HACCP
Hazard Analysis Critical Control Point
ICD-9
International Classification of Diseases-9th Revision
L
liter
MBR
Membrane Bioreactors
MEG
Military-exposure guideline
MF
Microfiltration
µm
micrometer
µg/L
microgram per liter
mL
milliliter
mg/L
milligrams per Liter
MRA
Microbial Risk Assessment
NF
nanofiltration
NMRRC
National Resource Management Ministerial Council
ng/L
nanogram per liter
NRC
National Research Council
NTU
Nephelometric Turbidity Units
ORD
Office of Research and Development
PPE
personal protective equipment
RO
reverse osmosis
SWRS
Shower Water Reuse System
TB MED
Technical Bulletin, Medical
TARDEC
Tank Automotive Research Development and Engineering Center
TDS
total dissolved solids
TSS
total suspended solids
UF
ultrafiltration

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µm
micrometer
USABRDL
U.S. Army Biomedical Research and Development Laboratory
USCENTCOM
U.S. Central Command
USACHPPM
U.S. Army Center for Health Promotion and Preventive Medicine
USAEHA
U.S. Army Environmental Hygiene Agency

USAPHC
U.S. Army Public Health Command
USEPA
U.S. Environmental Protection Agency
UV
Ultraviolet

WHO
World Health Organization
WRRF
WateReuse Research Foundation

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Section II

TERMS

The definitions provided herein are for informational purposes. They were generated from existing industry and academic sources as well as subject matter knowledge of the study team. Some definitions were modified to the contingency mission scenario. Prior to final adoption as consensus terminology, it is likely further deliberation will be required.

30/30/1 Rule
30 milligrams per liter (mg/L) biochemical oxygen demand (BOD), 30 mg/L total suspended solids (TSS), 1 mg/L chlorine residual. This language refers to the discharge quality standards for treated wastewater under USEPA NPDES. Otherwise known as secondary effluent.

Administrative Controls
Non-treatment barriers to ensure quality or avoid hazard exposure. Include physical barriers such as cordons, policy measures such as standards of practice, and monitoring of the same.

Black Water
Black water is source-separated wastewater from latrines and kitchens containing one or more of the following, urine, feces, toilet paper, food waste, and flush water (Asano et al. 2007, WHO 2006a, DA 2006).

Biochemical Oxygen Demand (BOD)
The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period (Sawyer, McCarty, and Parkin 2003). Commonly used as an indicator of organic content in water and a measure of treatment efficacy. The analytical test involves measuring initial and post-incubation (5 days at 20°Celsius) dissolved oxygen concentration.

Chemical Latrine
Portable, self-contained toilet or urinal used to store human waste which uses a concentrated disinfectant, deodorant chemical solution.

Chemical Oxygen Demand (COD)
Chemical oxygen demand (COD) is a measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals. Used as an indirect measure of organic matter in water.

CT
Concentration ($C_{mg/L}$)·Time ($T_{minutes}$). The product of these two variables represents the disinfectant effectiveness. CT tables are provided by USEPA and others for various microbial hazards and water conditions. Though concentration should be measured after the demand has been realized, CT may not fully account for the interference of other water constituents.

Contact Time
The prescribed period of oxidation for a disinfectant to render a desired level of microbial inactivation. Based on disinfectant concentration and present hazards, time may be adjusted to meet the necessary concentration·time quotient.

Contingency Operations
Activities carried out in austere environments or under austere conditions; synonymous with deployed operations.

Contingency Base
A non-enduring location outside of the United States that supports and sustains operations during named and unnamed contingencies or other operations as directed by appropriate authority and is categorized by mission life-cycle requirements as initial,

temporary, or semi-permanent (DOD 2013).

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

De facto reuse
A subset of indirect reuse. A source water body that contains a significant fraction of wastewater effluent, typically from upstream wastewater discharges, although the water supply has not been permitted as a water reuse project. Wastewater contribution is assumed to be on the order of 5% by volume, but may vary greatly depending on demand on the watershed and seasonal fluctuations (NRC 2012).

Demand, disinfectant
The portion of disinfectant consumed by organic and other matter in the water. Efficacy of a disinfectant to provide microbial hazard inactivation must account for the demand in dosing.

Direct Potable Reuse
- see Potable Reuse, Direct

National Pollutant Discharge Elimination System (NPDES)
Originally published by the USEPA in 1972 and later amended in 1985, the NPDES program defines limits for secondary treated wastewater effluent that is discharged to the environment, including: 5-day BOD (30 mg/L), TSS (30 mg/L), and pH (6-9) (33 U.S.C. 1342).

Domestic Wastewater
Composed of gray water and black water. It contains the wastes of all non-industrial activities
(WHO 2006a).

Engineered buffer
Tanks and other manmade containers employed in water reuse to provide an additional barrier and/or process equalizer.

Exposure Pathway
The movement of a hazard, over time, from the source to the occurrence of an exposure. Exposure pathways may be complex; exposures may occur via aerosolization, water, food, soil, fecal-oral, and/or inanimate objects (USEPA 2007).

Exposure Route
The point or mechanism by which a hazard comes into contact with the receptor. The three common routes are: oral, inhalation, and dermal (USEPA 2007).

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.

Fit-for-Purpose
Classification or handling of reclaimed water quality based on the source, applied barriers, and intended use. Water is of appropriate quality and hazards sufficiently mitigated based on the intended exposure, 'purpose.'

Free-Available Chlorine (FAC)
The chlorine equilibrium products present in the forms of hypochlorous acid and hypochlorite ions (DA 1010). Chlorine residual available for disinfection after the oxidant demand has been satisfied.

Gray Water
Gray water is wastewater from bathing or washing that does not contain concentrated food or human waste (NRC 2012, Asano et al. 2007). Examples include shower and laundry wastewater. For the purposes of water reuse in contingency operations, gray water will exclude kitchen wastes and exclude kitchen wash water.

Guideline
Recommended or suggested standards, criteria, rules, or procedures that are voluntary, advisory, and non-enforceable. When guidelines are promulgated by contract or local statute they become accountable, similar to regulations (see "regulations") (Asano et al. 2007).

Hazard Analysis Critical Control Point (HACCP)
A systematic approach to proactive quality assurance by identifying the critical process or processes and applying controls therein to prevent passage or development of hazards.

Hazard
A physical, chemical, or biological substance that has the potential to cause harm to human health.

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 (USEPA 2007).

Health Risk
The result when a hazard has a negative impact on the physical wellbeing of a human receptor. See also, 'risk.'

Indicator organism
An organism which may be easily monitored and for which the lifecycle and survival in an environment correlate with the presence or absence of other organisms (pathogens) of public health concern (Asano et al. 2007).

Indirect Reuse
Water reuse scenarios for which a natural or engineered buffer is employed prior to the end-use activity.

Indirect Potable Reuse
See Potable reuse, indirect

Liquid logistics
The processes, materiel, and manning responsible for storing, moving, and coordinating water and fuel supply.

Log reduction
Log removal= $-\log_{10}$ ((concentration (out))/(concentration (in)))

Membrane Filtration
A group of treatment processes which employ semi-permeable materials spun, woven, or cast into filters for the purpose of separating contaminants from water. Includes micro-, ultra-, and nanofiltration as well as reverse osmosis. The latter two processes apply high pressure to reverse the natural osmotic flow of solute across the membrane.

Mixed Wastewater
The combination of domestic wastewater and at least one additional uniquely sourced wastewater such as industrial wastewater.

Natural buffer
Natural water bodies, above or below ground, employed in water reuse to provide an additional barrier and/or process equalizer.

Non-potable Water Reuse
Water reuse activities that do not include potable use. Likely implies a separate, designated distribution system from the potable water systems.

Operational Controls
Analytical measures of system processes which indicate performance and deviation from acceptable ranges. Such measures include pressure, turbidity, chlorine residual, and other general water quality parameters.

Palatable
Water, which is aesthetically acceptable in taste, odor, color, and temperature.

Potable
For U.S. contingency operations: Water that has been tested and approved by preventive medicine personnel to meet the short- and long-term potability standards and is, therefore, considered safe to drink for the period that the standards apply to (DA 2010).

Potable reuse, direct
The introduction of highly treated reclaimed water directly into the potable water supply distribution system (adopted from Asano et al. 2007).

Potable reuse, indirect
The introduction of highly treated reclaimed water into the source body for a potable water treatment system (i.e., the groundwater aquifer or surface water body).

Quantitative Microbial Risk Assessment
The application of the principles of risk assessment to the estimate of consequences from a planned, predicted, or actual exposure to infectious microorganisms (Haas et al. 1999).

Receptor
A being which could come to harm. For the purposes of human health risk assessment, the receptor is the human user of the water.

Reclaimed Water
Treated municipal wastewater that is used for beneficial purposes (Asano et al. 2007).

Recycled Water
Reclaimed water used again in the process that created it.

Regulation
Criteria, standards, rules, or requirements that have been legally adopted and are enforceable by government agencies (Asano et al. 2007).

Restricted Reuse
The use of reclaimed water for activities that involve minimal body contact either by avoidance or through the use of personal protective equipment (e.g., dust suppression). Access to the activity may be limited for the general population by cordon, time, or both.

Reuse, water
The use of treated wastewater for a beneficial purpose (Asano et al. 2007). It may be recycled back into the process that generated it or repurposed for another application.

Reverse Osmosis (RO)
A water treatment process by which dissolved materials and sub-micron particles (≥0.001 micron) are removed from water by employing a semi-permeable membrane and high pressure to reverse the natural osmotic flow across the membrane. Near pure water is produced on the permeate side of the membrane and reject, or in the case of desalination, brine, is produced on the other.

Risk
A combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of exposure.

Shower Wastewater
Wastewater that flows into a drain when showering. It typically contains residue that has been washed off the individual showering, along with soap products.

Sludge
The solid residue remaining from the municipal wastewater treatment process. It resembles a soil-like material, has about 10%–30% solids, and can contain microorganisms and chemicals in higher concentrations than wastewater. It is typically rich in the major plant nutrients nitrogen, phosphorus, and potassium, and is sometimes used as a fertilizer substitute.

Stakeholders
Individuals and groups with a vested interest in the success or failure of an endeavor. A vested interest may be motivated by economic, political, professional, social, personal, or other concerns.

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Source Characterization
Physical, chemical, and microbiological characterization of the raw water that is used to aid in water treatment design.

Sustainability
The principle of optimizing the benefits of a present system without diminishing the capacity for similar benefits in the future (Asano et al. 2007).

Toilet to Tap
A colloquial term used to brand wastewater reuse with a negative mental image of a direct plumbing connection between a toilet and a potable outlet.

Total Coliforms
A term referring to the whole of the Coliform bacteria class that can be found in the environment, soil, and water. Total coliforms are used as an indicator of water quality.

Total Dissolved Solids
Matter in solution. In water quality terms, total dissolved solids represent primarily water-soluble inorganic salts, measured by way of drying or more-commonly as electrical conductivity.

Treatment Design and Validation
The engineering research, calculations, experimentation, and verification of a system to treat water of the specified (or worse) source conditions to the specified (or better) product quality.

Treated wastewater, domestic
Wastewater from a combination of toilets, sinks, showers, and the kitchen that has undergone some form of natural or engineered treatment to improve its quality.

Treated grey water
Wastewater from sinks and showers that has undergone some form of natural or engineered treatment to improve its quality.

Turbidity
A measure of the light transmitting properties of water. It indicates the quality of water with respect to colloidal and residual suspended matter. The measurement of turbidity is based on comparison of the intensity of light scattered by a sample to the light scattered by a reference suspension under the same conditions. Results are reported in Nephelometric Turbidity Units (NTU) (Tchobanoglous et al 2003).

Unrestricted Reuse
The use of reclaimed water for activities that involve full body contact including the head with possible incidental ingestion (e.g., showering).

Water Reuse
See Reuse, water

USAPHC

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