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This is the first and summary volume of the nine-volume study entitled Evaluation of Military Field-Water Quality. This study is a comprehensive assessment of the chemical, radiological, and biological constituents of field-water supplies that could pose health risks to military personnel around the world; it also provides a detailed evaluation of the field-water-treatment capability of the U.S. Armed Forces.

This study identified as being of concern three physical properties, i.e., turbidity, color, and total dissolved solids; seven chemical constituents, i.e., chloride, magnesium, sulfate, arsenic, cyanide, lindane, and metabolites of algae and associated aquatic bacteria; and over twenty types of water-related pathogenic microorganisms. It also addresses five threat agents, i.e., hydrogen cyanide, radioactivity, organophosphorus nerve agents, the trichothecene mycotoxin T-2, and lewisite. An overview of the criteria and recommendations for standards for these constituents for 5 and 15 L/d consumption rates
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for short-term and long-term exposure periods are presented in this volume, as are health-effects summaries for assessing the potential soldier performance degradation when recommended standards are exceeded. In addition, the existing military field-water-treatment capability is reviewed, and an abbreviated discussion is presented of the general physical, chemical, and biological qualities of field waters in geographic regions worldwide, representing potential theaters of operation for U.S. military forces. Finally, research recommendations are outlined.

This is the Executive Summary volume of a nine-volume study entitled Evaluation of Military Field-Water Quality. Titles of the other eight volumes are as follows: Vol. 2, Constituents of Military Concern from Natural and Anthropogenic Sources; Vol. 3, Opportunity Poisons; Vol. 4, Health Criteria and Recommendations for Standards; Vol. 5, Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks, and Recommendations for Establishing Related Standards; Vol. 6, Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks, and Recommendations for Establishing Related Standards; Vol. 7, Performance Evaluation of the 600-GPH Reverse Osmosis Water Purification Unit (ROWPU): Reverse Osmosis (RO) Components; Vol. 8, Performance of Mobile Water Purification Unit (MWPU) and Pretreatment Components of the 600-GPH Reverse Osmosis Water Purification Unit (ROWPU) and Consideration of Reverse Osmosis (RO) Bypass, Potable-Water Disinfection, and Water-Quality Analysis Techniques; and Vol. 9, Data for Assessing Health Risks in Potential Theaters of Operation for U.S. Military Forces.

AD
UCRL-21008 Vol. 1

Evaluation of Military Field-Water Quality

Volume 1. Executive Summary

J. I. Daniels and G. M. Gallegos (Editors)

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The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

FOREWORD

This is the Executive Summary volume of a nine-volume study entitled Evaluation of Military Field-Water Quality. Titles of the other eight volumes are as follows: Vol. 2, Constituents of Military Concern from Natural and Anthropogenic Sources; Vol. 3, Opportunity Poisons; Vol. 4, Health Criteria and Recommendations for Standards; Vol. 5, Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks, and Recommendations for Establishing Related Standards; Vol.6, Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks, and Recommendations for Establishing Related Standards; Vol. 7, Performance Evaluation of the 600-GPH Reverse Osmosis Water Purification Unit (ROWPU): Reverse Osmosis (RO) Components; Vol. 8, Performance of Mobile Water Purification Unit (MWPU) and Pretreatment Components of the 600-GPH Reverse Osmosis Water Purification Unit (ROWPU) and Consideration of Reverse Osmosis (RO) Bypass, Potable-Water Disinfection, and Water-Quality Analysis Techniques; and Vol. 9, Data for Assessing Health Risks in Potential Theaters of Operation for U.S. Military Forces.

The nine volumes of this study contain a comprehensive assessment of the chemical, radiological, and biological constituents of field-water supplies that could pose health risks to military personnel as well as a detailed evaluation of the field-water-treatment capability of the U.S. Armed Forces. The scientific expertise for performing the analyses in this study came from the University of California Lawrence Livermore National Laboratory (LLNL) in Livermore, CA; the University of California campuses located in Berkeley (UCB) and Davis (UCD), CA; the University of Illinois campus in Champaign-Urbana, IL; and the consulting firms of IWG Corporation in San Diego, CA, and V.J. Ciccone & Associates (VJCA), Inc., in Woodbridge, VA. Additionally, a Department of Defense (DoD) Multiservice Steering Group (MSG), consisting of both military and civilian representatives from the Armed Forces of the United States (Army, Navy, Air Force, and Marines), as well as representatives from the U.S. Department of Defense, and the U.S. Environmental Protection Agency provided guidance and critical reviews to the researchers. The reports addressing chemical, radiological, and biological constituents of field-water supplies were also reviewed by scientists at Oak Ridge National Laboratory in Oak Ridge, TN, at the request of the U.S. Army. Furthermore, personnel at several research laboratories, military installations, and agencies of the U.S. Army and the other Armed Forces provided technical assistance and information to the research on topics related to field water and the U.S. military community.

ACKNOWLEDGMENTS

The principal investigators at the Lawrence Livermore National Laboratory (LLNL), Drs. Jeffrey Daniels, David Layton, and Lynn Anspaugh, extend their gratitude and appreciation to all of the participants in this study for their cooperation, assistance, contributions and patience; especially Dr. Stephen A. Schaub, the project officer for this monumental research effort, and to his military and civilian colleagues and staff at the U.S. Army Biomedical Research and Development Laboratory (USABRDL). A special thank you is extended to the editors, secretaries, and administrative personnel of the Environmental Sciences Division and the Technical Information Department at LLNL.

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Volume 1. Executive Summary

ABSTRACT

This is the first and summary volume of the nine-volume study entitled *Evaluation of Military Field-Water Quality*. This study is a comprehensive assessment of the chemical, radiological, and biological constituents of field-water supplies that could pose health risks to military personnel around the world; it also provides a detailed evaluation of the field-water-treatment capability of the U.S. Armed Forces.

This study identifies as being of concern three physical properties, i.e., turbidity, color, and total dissolved solids; seven chemical constituents, i.e., chloride, magnesium, sulfate, arsenic, cyanide, lindane, and metabolites of algae and associated aquatic bacteria; and over twenty types of water-related pathogenic microorganisms. It also addresses five threat agents, i.e., hydrogen cyanide, radioactivity, organophosphorous nerve agents, the trichothecene mycotoxin T-2, and lewisite. An overview of the criteria and recommendations for standards for these constituents for 5 and 15 L/d consumption rates for short-term (≤7 d) and long-term (≤1 y) exposure periods are presented in this volume, as are health-effects summaries for assessing the potential soldier performance degradation when recommended standards are exceeded. In addition, the existing military field-water-treatment capability is reviewed, and an abbreviated discussion is presented of the general physical, chemical, and biological qualities of field waters in geographic regions worldwide, representing potential theaters of operation for U.S. military forces. Finally, research recommendations are outlined.

Chapter 1. Overview

J.I. Daniels,[*] G.M. Gallegos,[†] S.A. Schaub[‡]

This Executive Summary is the first volume of the nine-volume study entitled *Evaluation of Military Field-Water Quality*. The study comprises a comprehensive assessment of the chemical, radiological, and biological constituents of field-water supplies around the world that could pose health risks to military personnel. It also provides a detailed evaluation of the field-water-treatment capability of the U.S. Armed Forces and theater-specific water-quality concerns.

The impetus for this comprehensive field-water-quality database assessment effort was the realization in the early 1980's that a fresh look at military field-water quality was necessary in light of drinking-water problems associated with new potential theaters of operation, new concepts and doctrine, anticipated increased water-consumption factors, and development of new water-treatment equipment. At a meeting of the Army medical community in 1980, reprensentatives from the Academy of Health Sciences, Preventive Medicine Consultants to the Surgeon General, and the Environmental Hygiene Agency, established the requirement for this preventive medicine update. The need was further validated in 1981 upon formation of the Water Resources Management Action Group (a multiservice action officer function to promote improved water support for military contingencies, especially in southwest Asia), which was sponsored by the Army Deputy Chief of Staff for Logistics. This group saw that improved preventive-medicine criteria were needed for protection of soldier health, combat readiness, and performance, and also for the development of field-water-treatment equipment that would be used to prevent hazardous levels of chemicals, microorganisms, and threat agents from reaching the soldier through his water supplies.

A foremost consideration was the need to update the preventive-medicine handbook on water, the TB MED 229 (this document has now been superseded by TB MED 577). For this handbook, it was determined that improvements were needed in the

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definition of the water constituents for which standards were required and the establishment of those standards for drinking-water consumption for temperate, hot-arid, and arctic regions. Additionally, it was deemed necessary for the updated TB MED to have information on the potential health risks from consumption of waters that did not meet the standards and also information on theater-specific water-quality constituents that could impact on the health of soldiers if consumption was considered necessary for accomplishment of a mission (even though no general water-quality standards had been established). The current study used an exhaustive search of the open literature to develop standards and risk-assessment indices for those water-quality parameters of worldwide occurrence that if consumed can have debilitating toxicologic effects. The recommended standards and risk-assessment indices developed from this project will be submitted to the medical departments of the Army, Air Force, and Navy for consideration as joint service documents. Also, if approved by the joint services medical departments, these standards will be submitted to the Quadrapartite and NATO standardization communities for further consideration as updates to QSTAG–245 and NATO–2136 potable water standards.

The scientific expertise for performing the assessment came from the University of California Lawrence Livermore National Laboratory in Livermore, CA; the University of California campuses located in Berkeley and Davis, CA; the University of Illinois campus in Champaign-Urbana, IL; and the consulting firms of IWG Corporation in San Diego, CA, and V.J. Ciccone & Associates, Inc., in Woodbridge, VA. In addition, a Department of Defense Multiservice Steering Group, consisting of both military and civilian representatives from the Armed forces of the United States, as well as representatives from the U.S. Department of Defense, and the U.S. Environmental Protection Agency provided guidance and critical reviews to the researchers. The reports addressing chemical, radiological, and biological constituents of field-water supplies as well as chemical-warfare agents were also reviewed by scientists at Oak Ridge National Laboratory in Oak Ridge, TN, at the request of the U.S. Army. Furthermore, personnel at several Army research laboratories, military installations, and commands within the U.S. Army and the other Armed Forces provided technical assistance and information to the researchers on topics related to field-water detection, treatment, and distribution in support of military field operations.

The objective of the assessment was to conduct research so that exposure of field personnel to high risks of disease, illness, or injury (performance degradation or casualty) related to field water could be better anticipated and managed. For example, the current Army field-water-quality standards were developed in the 1960's, and these standards cannot be presumed to reflect (1) health-effects data reported since that time, (2) improved methods for analyzing health risks, or (3) current military doctrine and strategies. Moreover, previous standards emphasized prevention of casualties. However, performance degradation is now regarded an important consideration in the ability of field personnel to carry out their missions; it is as important as the prevention of casualties and needs to be addressed.

To meet the objective, it was first necessary to identify the chemical, biological, and radiological constituents and threat agents in waters around the world that could be present in combat water supplies ultimately intended for consumption by military personnel. After these constituents and agents were identified, the risks associated with exposure were evaluated and recommendations for standards that would preclude soldier performance degradation were developed. The recommended standards were based on 5 and 15 L/d consumption rates for short-term (≤7 d) and long-term (≤1 y) exposure. The field personnel were assumed to be healthy, male and female, 18 to 55 years old, and with no predisposing physical or mental factors that would exacerbate health effects. To be conservative, the standard weight of all military personnel was considered to be 70 kg. The recommended standards were derived for oral exposure to a single constituent. The field-water-quality standards recommended for adoption by the Armed Forces of the United States were developed in the face of limited and sometimes discordant data. Consequently, research necessary to reduce important sources of uncertainty or to strengthen the scientific basis of the recommended standards is described. The reverse osmosis water purification unit (ROWPU) recently introduced for field use was evaluated for its effectiveness, as were other existing water-treatment equipment and disinfection processes.

CONTENTS OF VOLUMES

In Vols. 2 through 9, (1) the waterborne constituents of concern to military personnel are identified, (2) field-drinking-water criteria and standards for these constituents are recommended, (3) the performance-degrading health risks associated with concentrations of these constituents in field water that exceed recommended standards are assessed, (4) current water-treatment practices of the U.S. military are evaluated, and (5) data for assessing health risks related to field water in potential theaters of operation for U.S. military forces are provided. Specifically,

- The organic-chemical contaminants (excluding pesticides) that are constituents of military concern from natural and anthropogenic sources are identified in Vol. 2, Part 1; the pesticides that are constituents of military concern are identified in Vol. 2, Part 2; and the inorganic chemicals and physical properties that are constituents of military concern from natural and anthropogenic sources are identified in Vol. 2, Part 3.
- Opportunity poisons, which are substances that may be available in military inventories as well as the civilian market place and that may be overtly or covertly used to contaminate field water to deny use of the source or to poison it, are discussed in Vol. 3.
- Health criteria, recommendations for standards, and health risks for the chemicals and physical properties of military concern associated with natural and anthropogenic contaminants of water are presented in Vol. 4, Part 1; and interim standards for selected threat agents and the health risks from exceeding these standards are provided in Vol. 4, Part 2.
- An assessment of health risks and recommendations for establishing standards for infectious organisms of military concern associated with consumption of field water appears in Vol. 5.
- An assessment of health risks and recommendations for establishing standards for infectious organisms of military concern associated with nonconsumptive exposure to field water is contained in Vol. 6.
- The performance of the reverse osmosis (RO) components of the 600-GPH reverse osmosis water purification unit (ROWPU) is evaluated in Vol. 7.
- The performance of the Mobile Water Purification Unit (MWPU) or Erdlator and the pretreatment components of the 600-GPH ROWPU and RO by-pass option are addressed in Vol. 8, as are potable-water disinfection practices and the water-quality-analysis techniques presently used by U.S. military forces.
- Data for assessing health risks associated with constituents of military concern from natural and anthropogenic sources that are present at levels above recommended field-water-quality standards are described in Vol. 9. Also evaluated is the general physical, chemical, and biological quality of field waters in geographic regions worldwide that represent potential theaters of operation for U.S. military forces.

An abridged discussion of the contents of each of these volumes appears in Chapters 2 through 6 of this volume.

SYNOPSIS OF RESULTS

The results obtained from this comprehensive research effort are briefly presented below. The recommended field-water-quality standards are listed in Table 1-1. Health-effects summaries for each of the chemical constituents of field water for which standards are recommended are presented graphically in Figs. 1-1 to 1-13. The risk of death or performance degradation as a result of exposure to radiation is illustrated in Fig. 1-14. These figures should help military personnel identify the health risks associated with consumption of water exceeding the recommended standards.

A mechanism for assessing health risks associated with concentrations of eleven specific waterborne pathogenic microorganisms is presented in Table 1-2, along with an example of how to interpret the table. Although eleven water-washed and water-based microorganisms and the agents that cause cercarial dermatitis (e.g., Trichobilharzia, Gigantobilharzia, and Austrobilharzia) were also identified as being of concern, the data were too limited to evaluate the probability of illness from exposure to them. These eleven microorganisms are *Staphylococcus* spp., *Leptospira* spp., *Balantidium coli, Ascaris lumbricoides, Schistosoma* spp., *Dracunculus medinensis, Acanthamoeba* spp., *Naegleria* spp., Non-*cholerae Vibria* spp., *Pseudomonas* spp., and *Aeromonas* spp.

The reverse osmosis water purification unit (ROWPU) was evaluated and found to be capable of producing, from seawater and single-salt solutions, potable water that meets the recommended standards. The evaluation of the general physical, chemical, and biological quality of field waters in geographic regions worldwide indicated that critical regions for high levels of inorganic chemicals are those with (1) high degrees of evaporation compared to precipitation, (2) areas near oceans, and (3) locations where water comes in direct contact with geological formations of soluble salts. Most organic chemicals, as well as high levels of arsenic and cyanide, would most likely be associated with regions of high industrialization and agriculture. Pesticides, such as lindane, would generally be limited to agricultural areas, and pathogenic microorganisms would be found at highest concentrations in developing countries, particularly in equatorial Africa and Asia, where sanitation practices are limited.

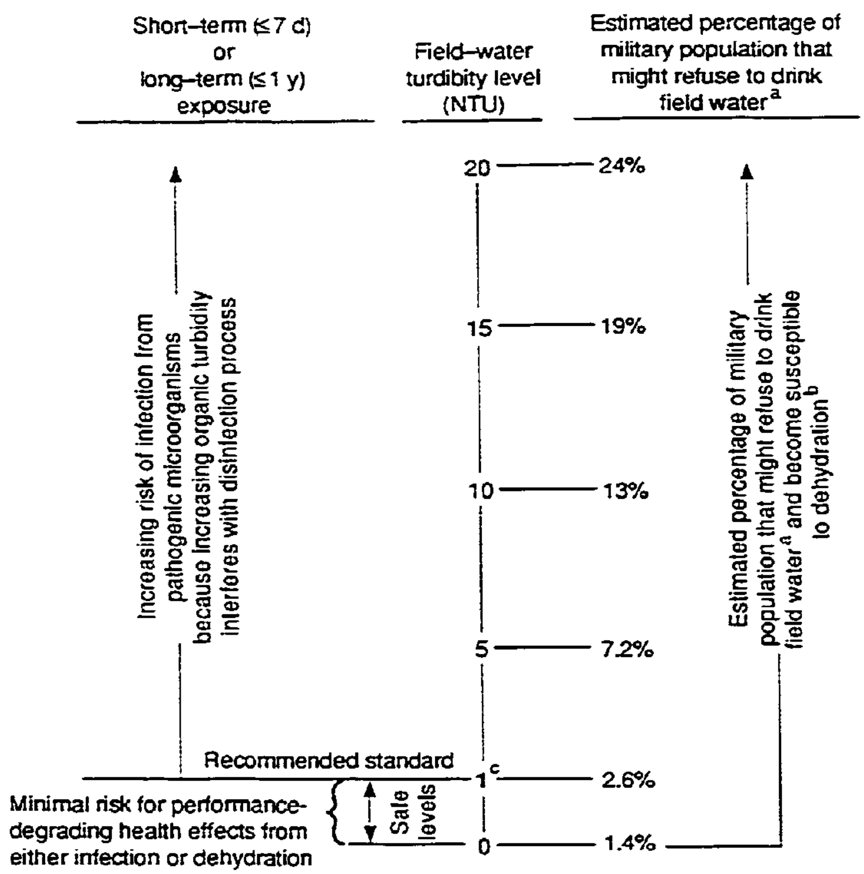
Table 1-1. Summary of recommended and interim field-water-quality standards.

	Recommended standards			
	≤7 d		≤1 y	
Constituents	5 L/d	15 L/d	5 L/d	15 L/d
PHYSICAL PROPERTIES:				
Turbidity	1	1	1	1
Color (color units)	50	50	15	15
Total dissolved solids (mg/L)	1000	1000	1000	1000
CHEMICAL CONSTITUENTS:				
Chloride (mg/L)	600	600	600	600
Magnesium (mg/L)	100	30	100	30
Sulfate (mg/L)	300	100	300	100
Total inorganic arsenic (mg/L)	0.3	0.1	0.06	0.02
Cyanide (mg/L)	6	2	6	2
Lindane (mg/L)	0.6	0.2	0.6	0.2
Organoleptic metabolites of algae and associated aquatic bacteria (ng/L)	10	10	10	10
Hydrogen cyanide (mg/L)	6	2		
Trichothecene mycotoxin, T-2 (µg/L)	26	8.7		
Radioactivity[a]				
Gross alpha and/or gross beta	8 µCi/L	3 µCi/L	0.1 µCi/L	0.05 µCi/L
Specific radionuclides	ALI/35[a]	ALI/105[a]	ALI/1825[a]	ALI/5475[a]
OP threat agents (µg/L)	12	4		
Lewisite (mg/L) (arsenic fraction)[b]	0.08	0.027		
Total coliforms (CFU/100mL)[c]	1	1	1	1

[a]If specific radionuclides are known to be present, then the annual limits on intake (ALI) published in Vol. 4, Part 2 should be divided by the factors stated above.

[b]Based on detection of the arsenic fraction of lewisite in water; the corresponding concentration of lewisite is about 2.75 times greater.

[c]Corresponds to coliform-organism colony-forming units (CFU) used as an indicator of the presence of pathogenic microorganisms in water and determined using membrane-filter technique.

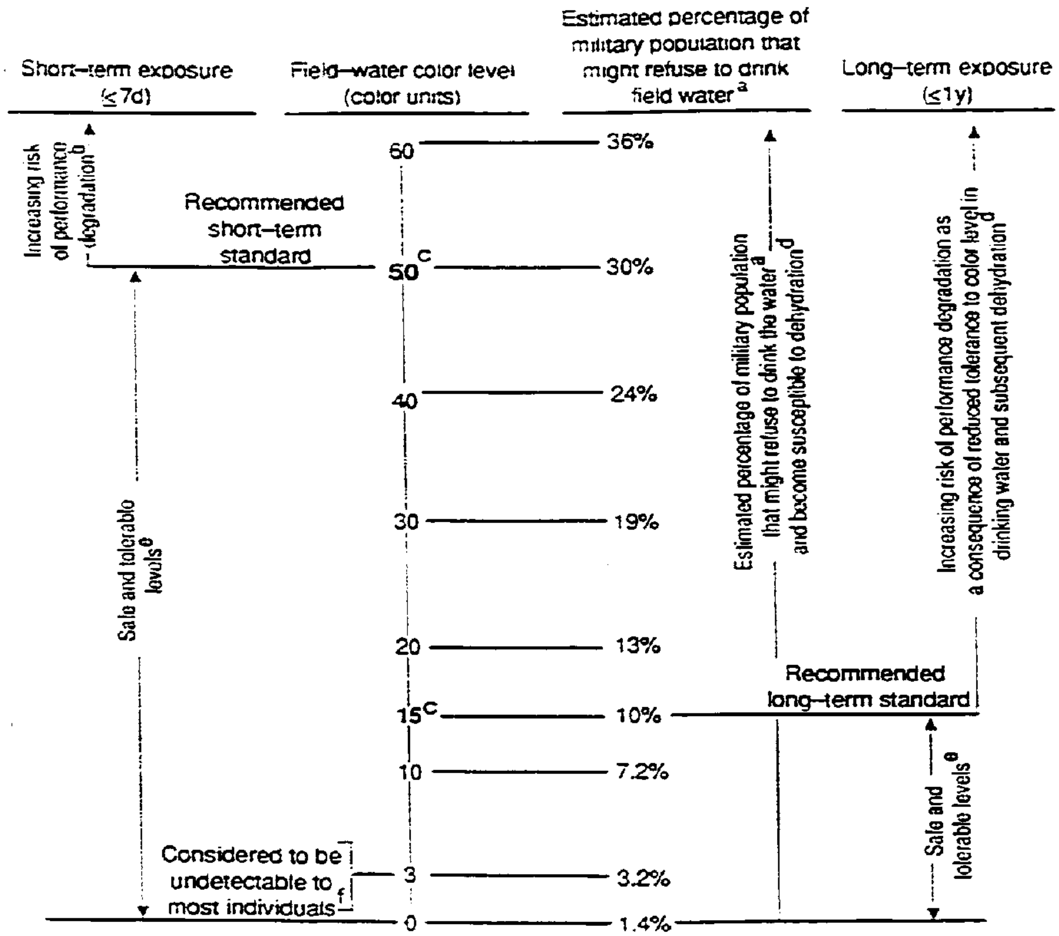


[a]For any combination of color, turbidity, and odor values:
MP = 1.1 + 0.575(c) + 1.15(T) + 0.115(S), where MP = percent of military population that might refuse to drink field water and thereby become susceptible to the performance-degrading effects of dehydration; C = color units; T = nephelometric turbidity units (NTU); and S = threshold odor number (TON). Estimates presented are computed on the basis of zero color units (C) and a TON (S) of three.

[b]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

[c]Because turbidity is an organoleptic property of water (i.e., appearance), the recommended field-water-quality standard for both short- and long-term exposure is applicable to any consumption rate, including ones of 5 and 15 L/d.

Figure 1-1. Health-effects summary for turbidity with color absent (i.e., zero) and a threshold odor number (TON) equal to three.



[a]For any combination of color, turbidity, and odor values:
MP = 1.1 + 0.575(c) + 1.15(T) + 0.115(S), where MP = percent of military population that might refuse to drink field water and thereby become susceptible to the performance-degrading effects of dehydration: C = color units: T = nephelometric turbidity units (NTU): and S = threshold odor number (TON). Estimates presented are computed on the basis of zero turbidity (T) and a TON (S) of three.

[b]Performance degradation results from decreased tolerance to color level in drinking water and subsequent dehydration.

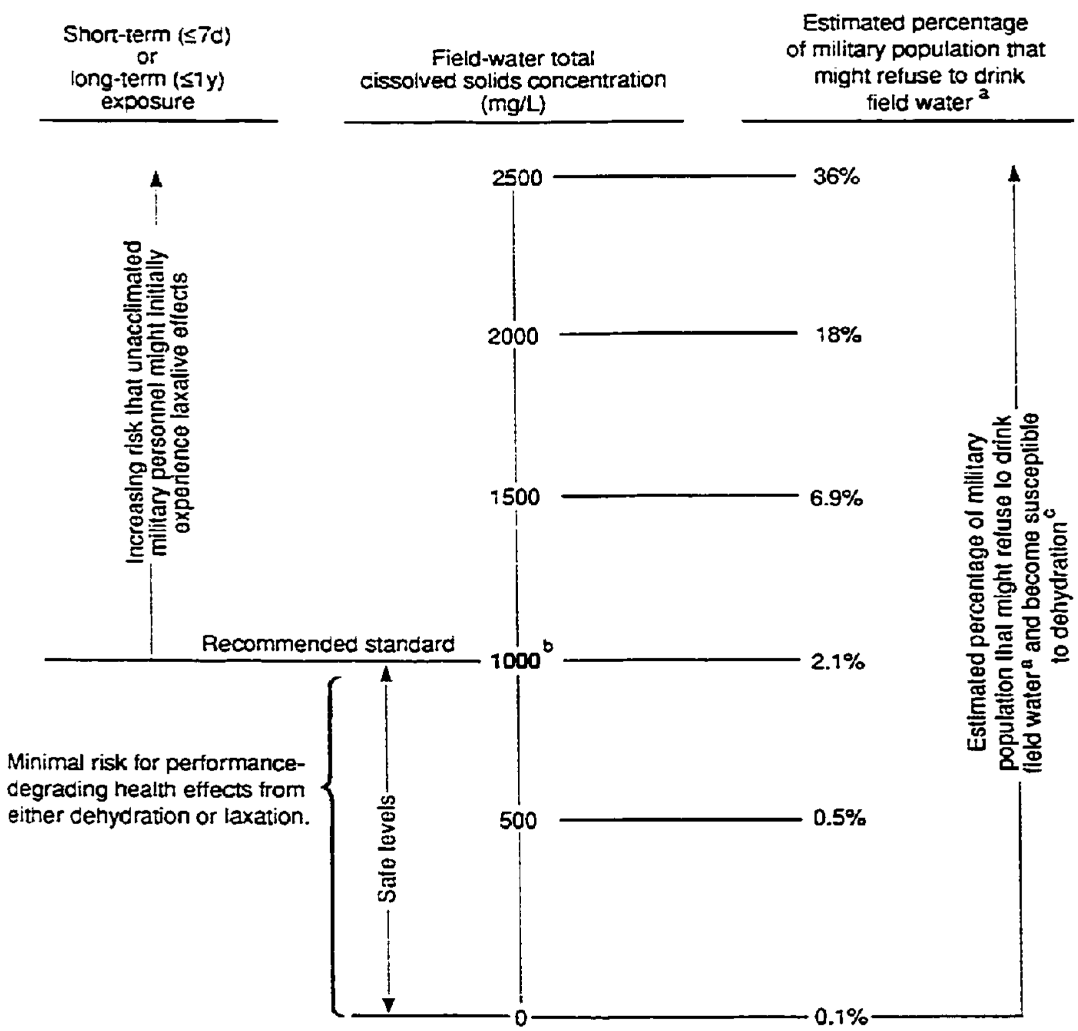
[c]Because color is an organoleptic property of water (i.e., appearance), the recommended field-water-quality standards are applicable to any consumption rate, including ones of 5 and 15 L/d.

[d]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

[e]Safe and tolerable color levels are ones that should not impact the performance of military personnel, but which may require acclimation.

[f]The U.S. Environmental Protection Agency cites evidence indicating that a color level of three color units will not be detectable to many individuals.

Figure 1-2. Health-effects summary for color with turbidity absent (i.e., zero) and a threshold odor number (TON) equal to three.

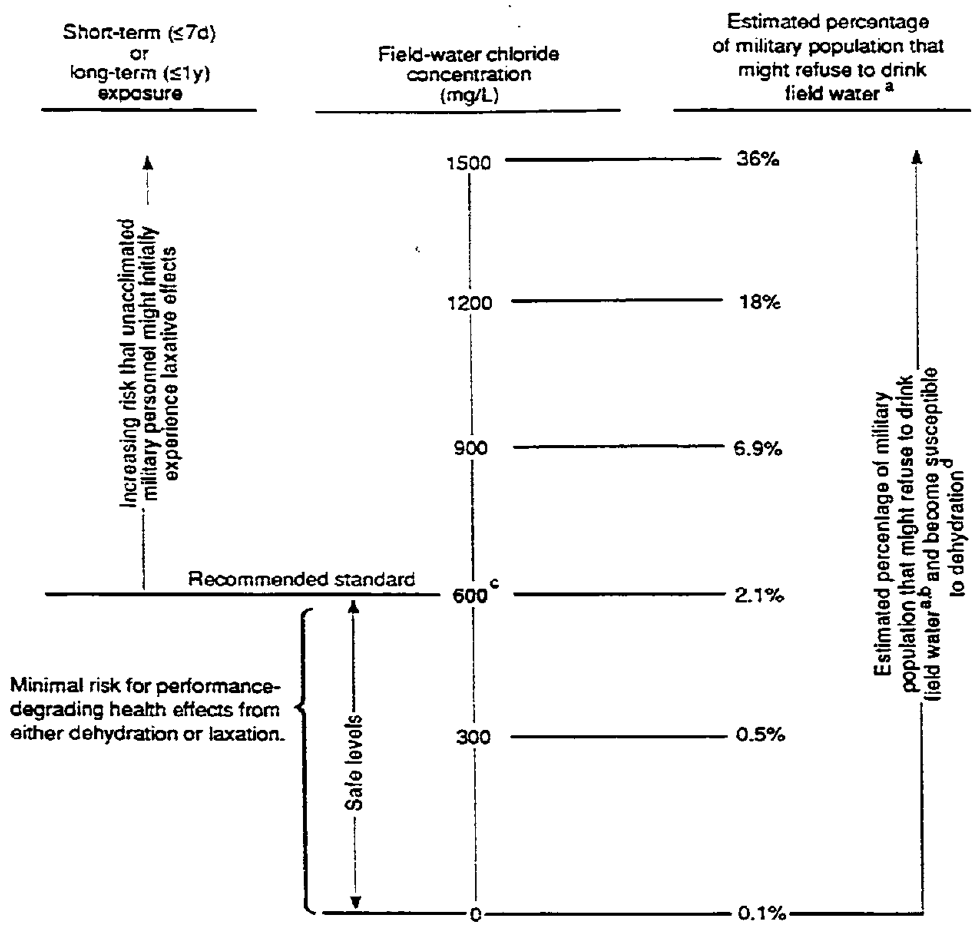


[a]Determined using the z-score for Action-Tendency ratings and a table of values for the standard normal distribution (see Part 1 of Volume 4).

[b]Because total dissolved solids at concentrations less than or equal to 1000 mg/L are only organoleptically of concern (i.e., affect taste), the recommended field-water-quality standard for both short- and long-term exposures is applicable to any consumption rate, including ones of 5 and 15 L/d.

[c]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

Figure 1-3. Health-effects summary for total dissolved solids (TDS).



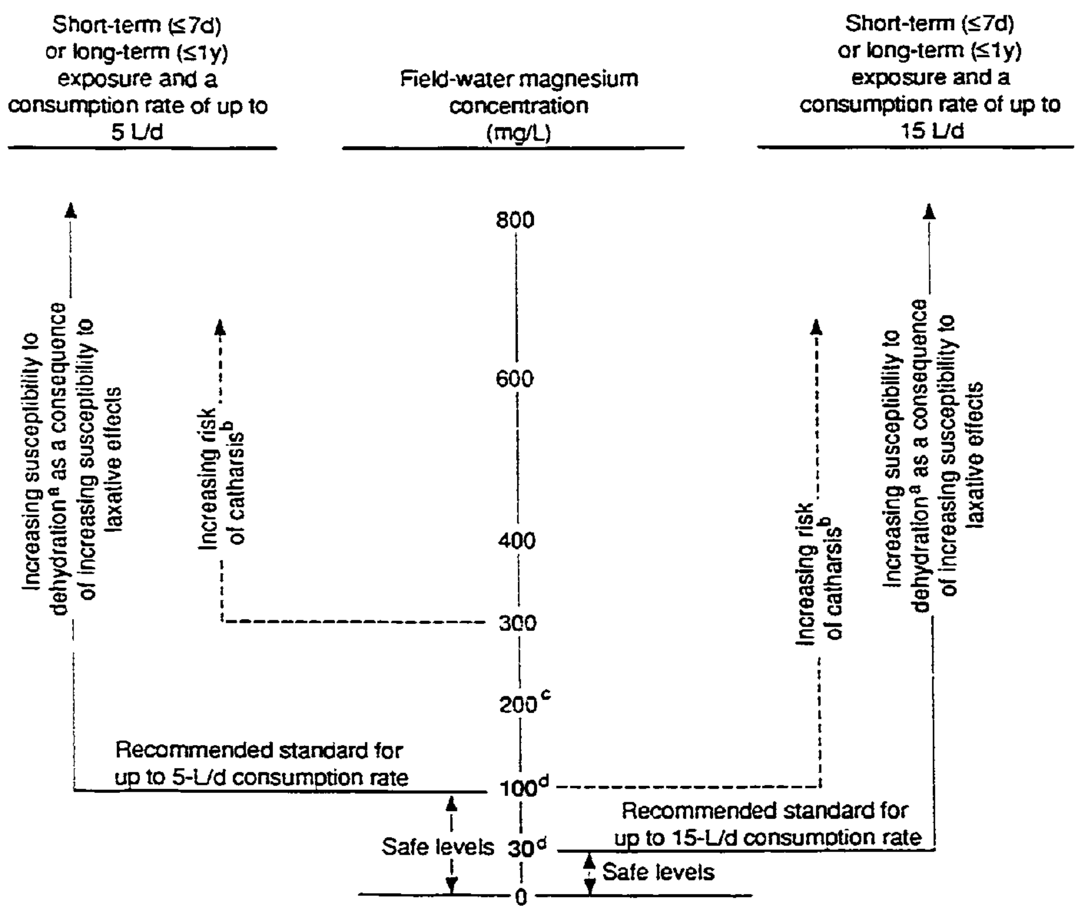
[a] Determined using the z-score for Action-Tendency ratings and a table of values for the standard normal distribution (see Volume 9).

[b] Estimates are made assuming chloride ion constitutes 60% of total dissolved solids (TDS) concentration because sodium and chloride ions are considered to be the predominant constituents of the TDS content of most field waters, particularly seawater processed through the reverse osmosis water purification unit (ROWPU).

[c] Because chloride ions at concentrations less than or equal to 600 mg/L are only organoleptically of concern (i.e., affect taste), the recommended field-water-quality standard for both short- and long-term exposures is applicable to any consumption rate, including ones of 5 and 15 L/d.

[d] Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

Figure 1-4. Health-effects summary for chloride.



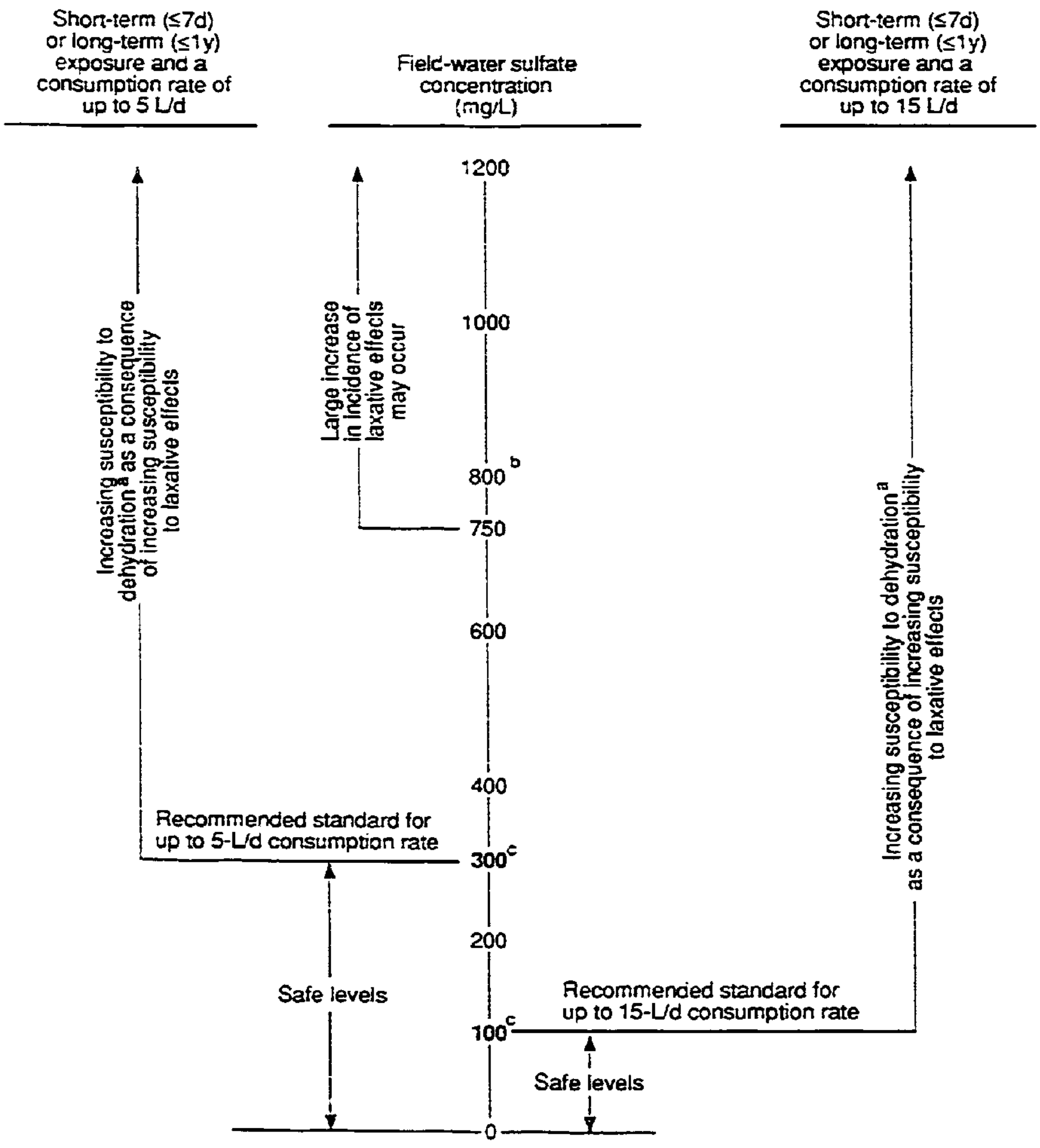
[a]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

[b]Based on a laxative dose of 15 g of epsom salts ($MgSO_4 \cdot 7H_2O$), effects include semifluid or watery evacuation in 3 h or less. Doses lower than 15 g produce laxative effects with a longer latency period.

[c]Although many individuals would perceive water to have an inferior taste, a few individuals might consider water consumable and for them taste alone might not be an effective warning of laxative effects.

[d]Recommended field-water-quality standard for magnesium-ion concentration for indicated daily consumption rate and exposure periods up to either 7 d or 1 y.

Figure 1-5. Health-effects summary for magnesium.

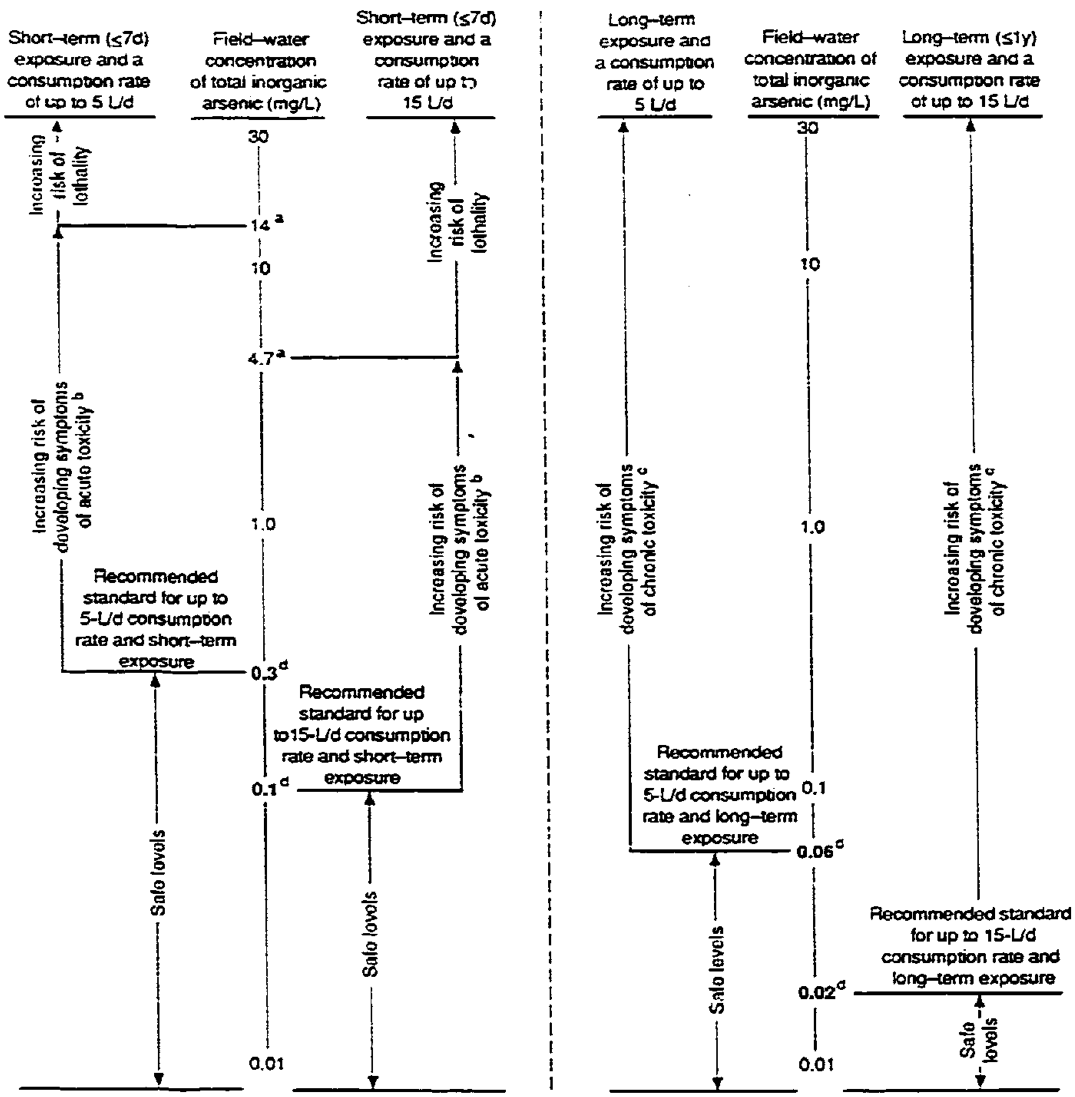


[a]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

[b]Although many individuals would perceive water to have an inferior taste, a few individuals might consider water consumable and for them taste alone may not be an effective warning of laxative effects.

[c]Recommended field-water-quality standard for sulfate-ion concentration for indicated daily consumption rate and exposure periods up to either 7 d or 1 y.

Figure 1-6. Health-effects summary for sulfate.



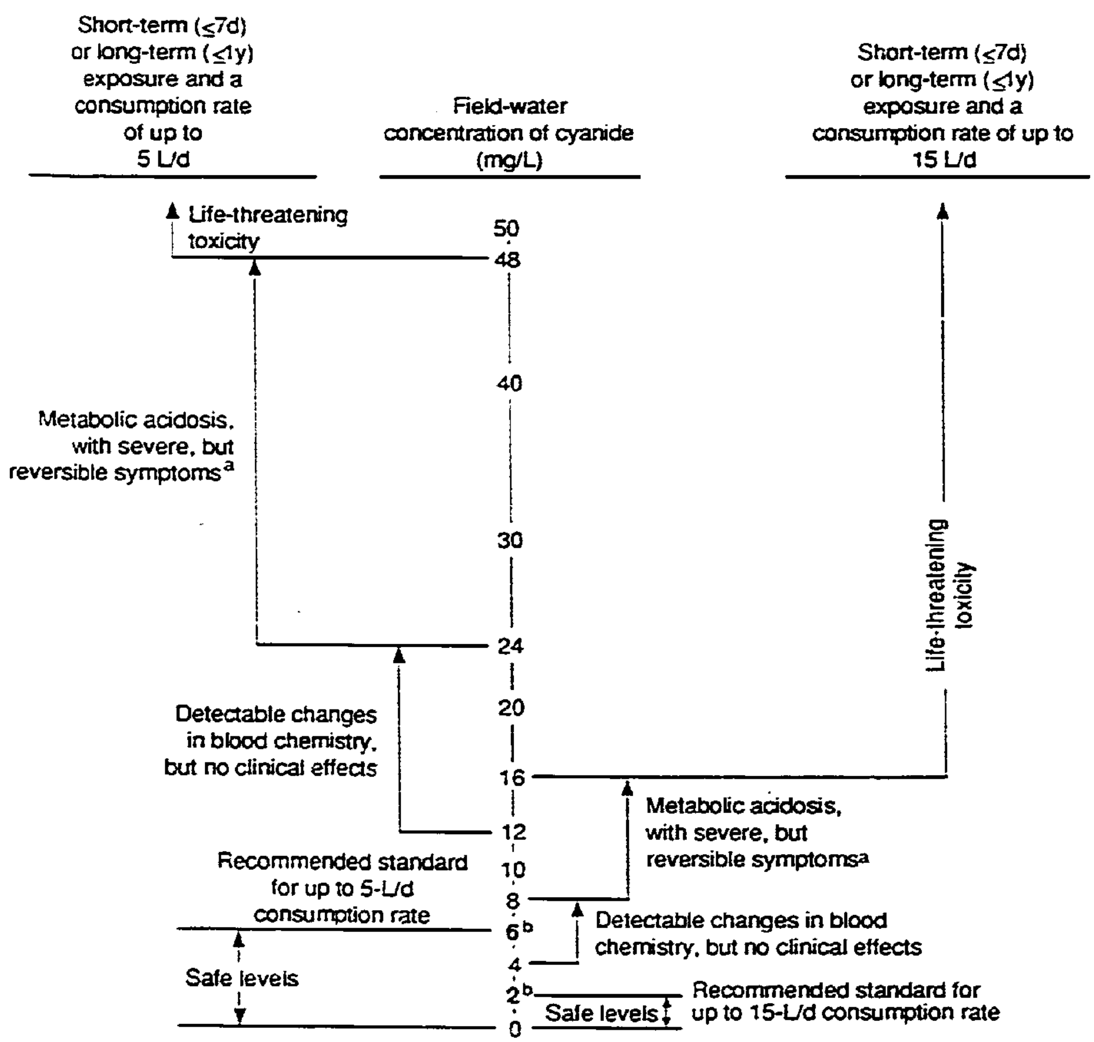
[a]Concentration corresponding to an increasing risk of lethality was calculated based on a single, oral does of 70 mg of arsenic.

[b]Symptoms of acute arsenic toxicity may include edema, nausea, vomiting, headache, and abdominal pain.

[c]Characteristic symptions of chronic arsenic toxicity include skin effects (pigmentation changes, keratosis, and skin cancer), gastrointestinal problems, peripheral vascular disease, and neurological changes.

[d]Recommended field-water-quality standard for indicated daily consumption rate and exposure period.

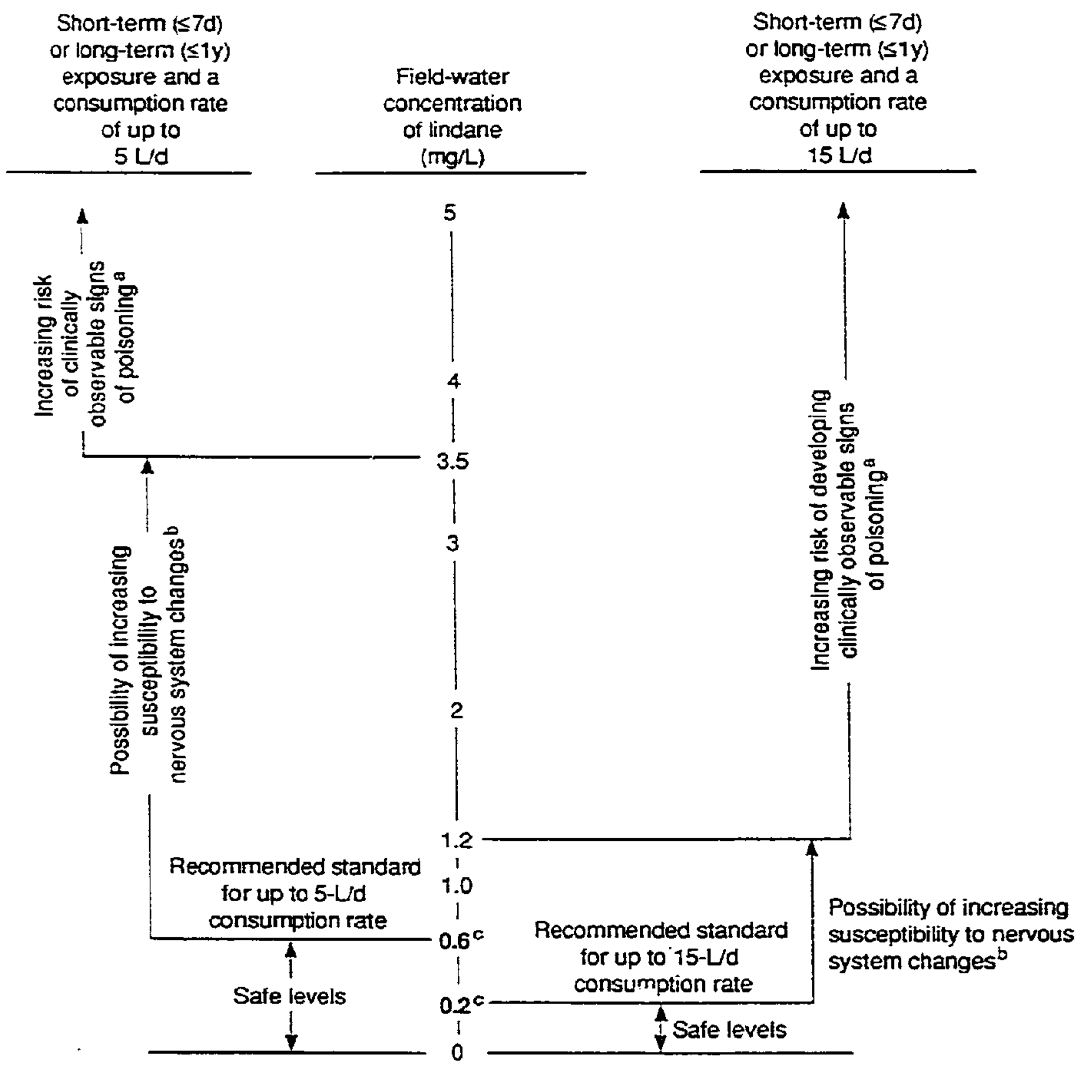
Figure 1-7. Health-effects summary for arsenic.



[a]Symptoms of acute cyanide toxicity can include headache, weakness, palpitation, nausea, giddiness, and tremors.

[b]Recommended field-water-quality standard for indicated daily consumption rate and exposure period.

Figure 1-8. Health-effects summary for cyanide and hydrogen cyanide.

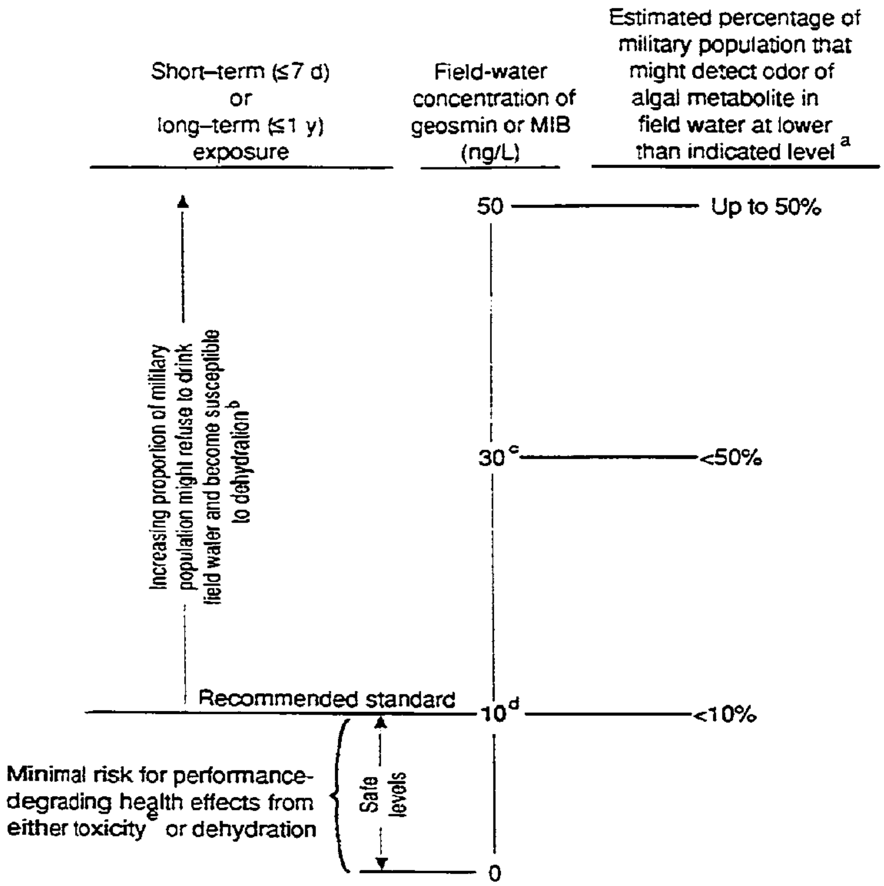


[a]Based on extrapolation to humans from a minimal-effects dose reported in a lifetime feeding study of laboratory animals and the applicaiton of a 10-fold safety factor.

[b]Evidence from long-term feeding studies of laboratory animals indicates that low doses of lindane may be associated with subclinical effects on the nervous system.

[c]Recommended field-water-quality standard for indicated daily consumption rate and exposure periods up to either 7 d or 1 y. Based on human data and the application of a 10-fold safety factor.

Figure 1-9. Health-effects summary for lindane.



[a]Estimates for a military population are based on information available in the literature on the predicted response of the general public to geosmin and MIB in drinking water.

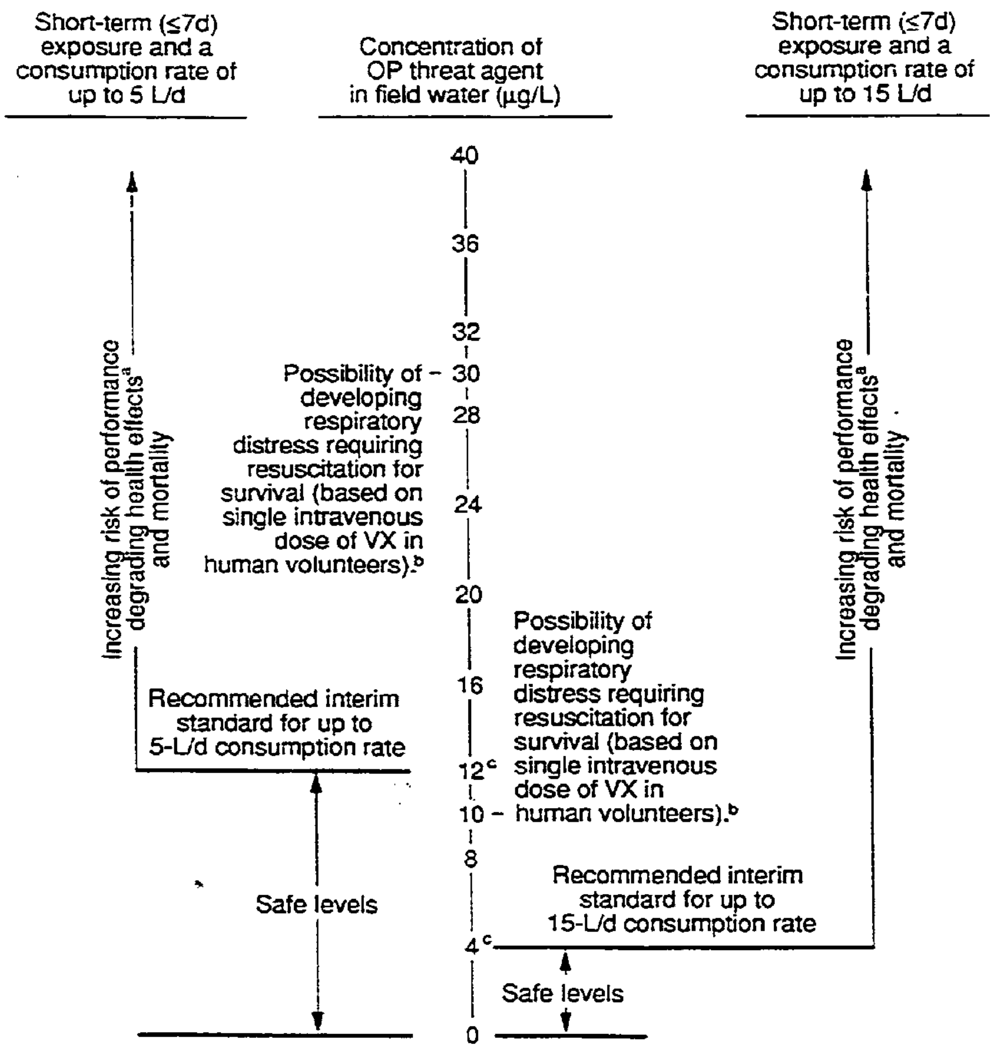
[b]Symptoms of dehydration may include weariness, apathy, impaired coordination, delirium, and heat stroke.

[c]The greatest number of complaints from the general public appear to occur at concentrations of geosmin above 30 ng/L. This is not recommended as a standard for military personnel because it has been reported that concentrations exceeding 10 ng/L may be associated with the presence of toxins released by cyanobateria (see Volume 4, Part 1).

[d]Because geosmin and MIB affect the organoleptic quality of water (i.e., taste and odor), the recommended field-water-quality standards are applicable to any consumption rate, including 5 and 15 L/d.

[e]Poisoning from toxins released by cyanobacteria is considered unlikely at concentrations of geosmin and MIB less than or equal to 10 ng/L. WARNING: Risk of poisoning from toxins released by cyanobacteria increases at levels above the recommended standard for geosmin and MIB, especially if an algal bloom is present and earthy/musty odors are detectable.

Figure 1-10. Health-effects summary for the organoleptic metabolites of algae and associated aquatic bacteria.

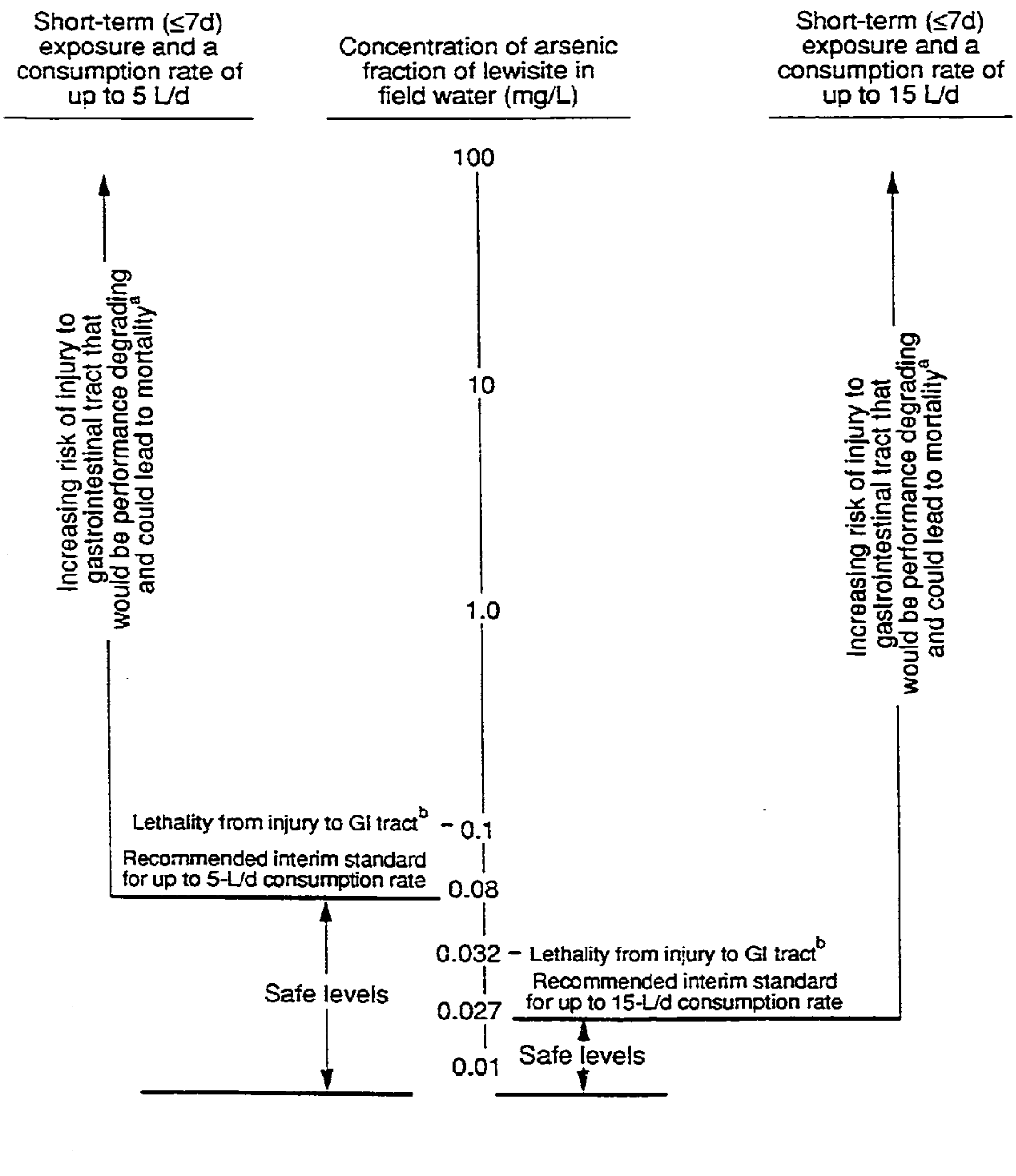


[a]Performance-degrading health effects can include abdominal cramps, vomiting, diarrhea, and headache.

[b]Response considered possible on the basis of a single intravenous dose of VX in humans of 2.12 µg/kg converted to a drinking water concentration. This response and corresponding concentration are presented because lethality data for repeated ingestion of OP threat agents over time are not available for humans. Furhermore, VX is the most toxic OP threat agent when administered intravenously in a single dose to humans, but appears to be less toxic than GD when ingested in several divided doses over time.

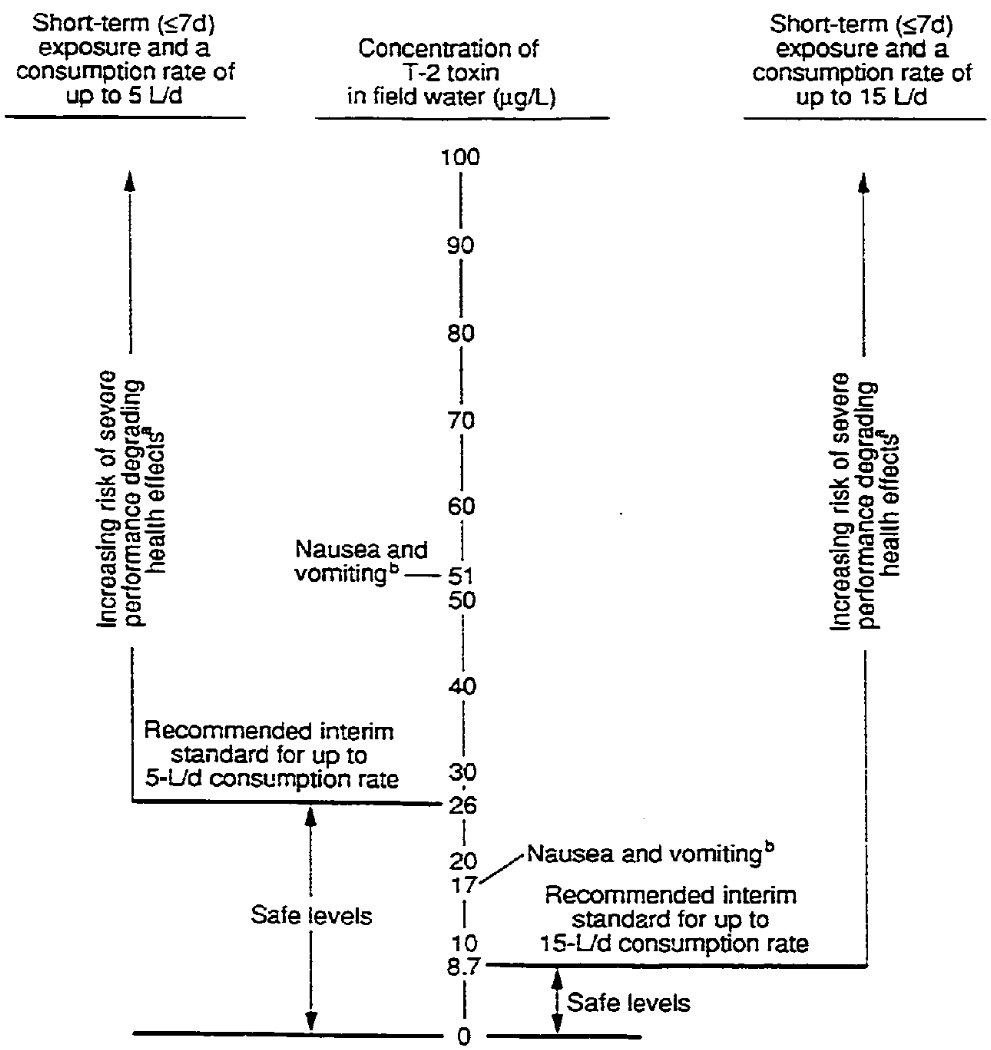
[c]Interim standards for OP threat agents are based on the MPC for GD because GD appears to be the most toxic OP threat agent where a total dose from field water is ingested in several drinks separated in time over the course of a day for an exposure period lasing up to 7 d.

Figure 1-11. Health-effects summary for the organophosphorus nerve agents.



[a]Based on extrapolation from effect of doses above NOEL for rabbits.
[b]Based on lowest dose reported to produce mortality in rabbits (0.07 mg/kg x 0.1 x 70kg/5 or 15 L/d).

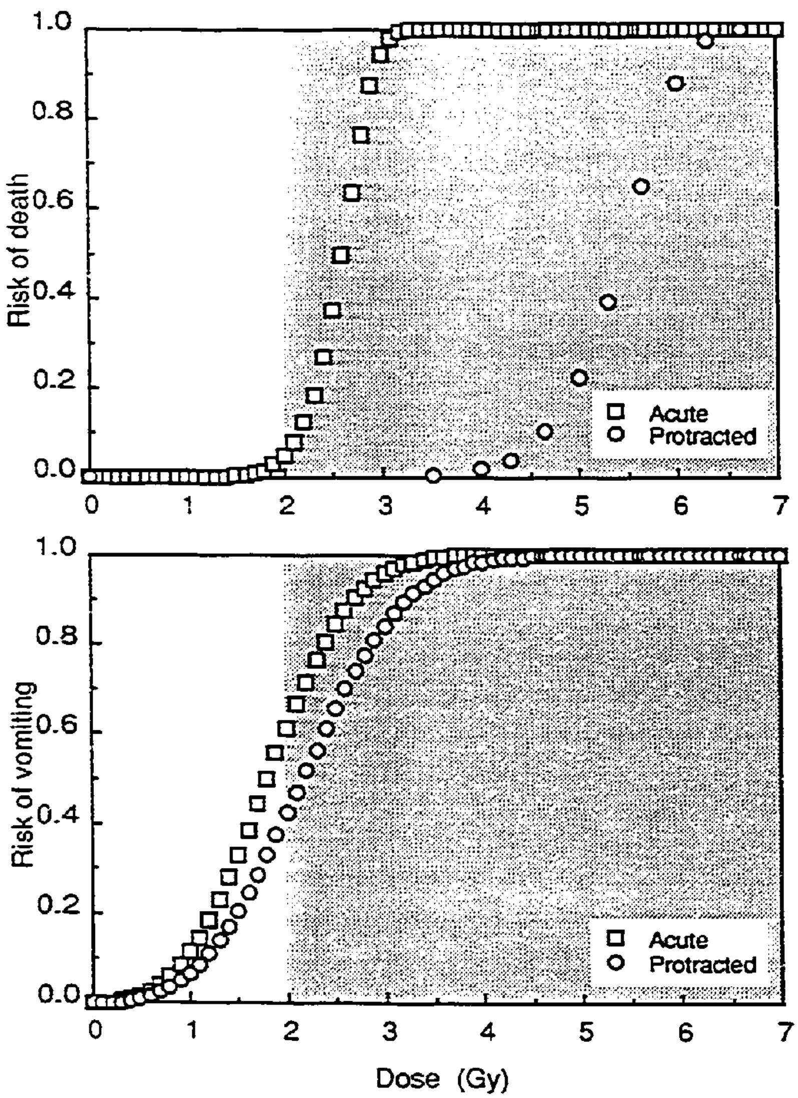
Figure 1-12. Health-effects summary for lewisite.



[a]Potentially performance-degrading health effects may include nausea, vomiting, diarrhea, generalized burning erythema, and mental confusion according to studies with where patients were treated with a chemotherapeutic agent considered analogous to trichothecene mycotoxin, T-2.

[b]Based on lowest daily intravenous dose of a chemotherapeutic agent considered analogous to T-2 that caused nausea and vomiting in cancer patients. Most severe health effects were reported in cancer patients administered a daily dose of the agent by rapid intravenous infusion for 5 d that was about 30 times greater than the one used to calculate the standards. Therefore, concentrations of T-2 toxin that are 30 times grater than the recommended interim filed-water-quality standards are expected to produce the most severe toxic symptoms.

Figure 1-13 Health-effects summary for the trichothecene mycotoxin, T-2.



DISCUSSION. A limit of 1.0 Sv (100 rem) committed dose equivalent to an individual organ or tissue of the GI tract is the basic standard. (For the purpose of this assessment we assume that 1.0 Gy equals 1.0 Sv.) This should carry essentially zero risk of acute lethality,* and no more than 10% of the affected troops should suffer performance degradation.† Under extreme emergency conditions, this basic limit might be increased to as much as 2.0 Sv (200 rem).* This emergency standard should still result in zero incidence of lethality (based on curve to the right in the upper graph), but might yield significant performance degradation (based on curve to the right in lower graph). The recommended standards for radionuclides in military field-water supplies to protect against both lethality and significant performance degradation are based on a limit of 1.0 Sv to the organs of the GI tract and are achieved by dividing 1.0 Sv by an exposure-to-dose conversion value to arrive at an Annual Limit on Intake (ALI). By dividing the ALI by the amount of water to be consumed over the relevant time period (5 and 15 L/d over 7 d, or 35 and 105 L, for short-term exposure; and 5 and 15 L/d over 365 d, or 1825 and 5475 L, for long-term exposure), a recommended standard is achieved for military field-water supplies. For ex-ample, we recommend 10 MBq as the ALI (equivalent to 1.0 Sv) to be used to protect against unidentified individual gross alpha or beta activity. For short-term exposure (up to 7 d), 10 MBq (270 µCi) is divided by 35 and 105 L to obtain recommended standards of 300 kBq/L (8 µCi/L) and 100 kBq/L (3 µCi), for 5 and 15 L/d consumption rates, respectively. Similary, for long-term exposure (up to 1 y) 10 MBq (270 µCi) is divided by 1825 and 5475 L to arrive at recommended standards of 5 kBq (0.1 µCi) and 2 kBq (0.05 µCi).

FOOTNOTES:

* If exposure is occurring via external exposure and the inhalation of radionuclides in addition to exposure by ingestion, such exposure must be considered as part of the total exposure discussed here.

† The assumption is being made that a committed dose equivalent to an organ or tissue of the GI tract has the same effect as a dose to the whole body. This assumption is considered to be conservative, but is not verified.

Figure 1-14. Risk of death or performance degradation (vomiting) from radiation.

Table 1-2. Summary of the risk-assessment results for populations of up to 20 military personnel exposed to field water containing one of the 11 waterborne infectious organisms considered to be of military concern. Probability (P_i) that the percentage of ill troops is greater than 10 or 90%, respectively, was determined for conditions considered representative of high- and low-risk situations.

	Probability (P_1) that the percentage of ill troops is greater than 10%			Probability (P_2) that the percentage of ill troops is greater than 90%			
Pathogen	Developed country (High risk)[a]	Developing country (Low risk)[b]	Developed country (Low risk)[b]	Developed country (High risk)[a]	Developing country (Low risk)[b]	Developed country (Low risk)[b]	Latency (d)[c]
BACTERIAL:							
Shigella spp.	0.88	0.86	0.50	0.86	0.56	0.18	3 to 6
Vibrio cholerae Classical	0.53	0.00	0.00	0.35	0.00	0.00	<1 to 2
Vibrio cholerae El Tor	0.68	0.00	0.00	0.56	0.00	0.00	<1 to 2
Campylobacter	0.87	0.90	0.50	0.87	0.69	0.18	1 to 4
Escherichia coli	1.00	0.99	0.96	0.04	0.04	0.00	0.1 to 3
Salmonella spp.	0.87	0.73	0.70	0.82	0.35	0.30	3 to 22
Salmonella typhi	0.78	0.03	0.03	0.47	0.02	0.02	3 to 22
Yersenia spp.	0.89	0.87	0.72	0.80	0.72	0.35	<1
VIRAL:							
Enteroviruses[d]	0.95	0.86	0.76	0.55	0.04	0.00	2 to 35
PROTOZOAN:							
Entamoeba hystolytica	0.88	0.82	0.30	0.84	0.50	0.00	7 to 98
Giardia lamblia	0.88	0.90	0.90	0.83	0.62	0.62	3 to 56

[a] A 15 L/d consumption rate and the absence of treatment constitute the principal parameters for a high-risk situation.

[b] A 10 L/d consumption rate and a treatment efficiency between 99 and 99.999% removal constitute the principal parameters for a low-risk situation.

[c] Latency is defined to be the time (in days) from ingestion to the onset of symptoms.

[d] Norwalk agent, Rotavirus, and Hepatitis A were also investigated, but dose-response data and concentration data were not available for these organisms and a risk assessment could not be made.

EXAMPLE: A military unit is operating in a developed country and the only drinking water available is untreated surface water from mountain streams. The microorganism considered to be present in such surface water is the protozoan *Giardia lamblia*, which can produce severe diarrhea. Examination of Table 1-2 reveals that there is in 88% chance that more than 10% of a population of 20 military personnel will become infected and could exhibit symptoms as early as three days after exposure. Table 1-2 also shows that there is an 83% chance that more than 90% of the exposed military population could develop symptoms as early as three days after exposure. The conclusion to be drawn is that a significant risk exists that any mission lasting up to 7 d and requiring more than one individual to complete could be jeopardized should troops consume the field water without adequate filtration followed by disinfection.

RESEARCH RECOMMENDATIONS

A number of research recommendations are made throughout the eight volumes of this study. The following is a list of several major groups of these recommendations.

- Volunteer military personnel should be employed for tests to quantify the relationship between increasing concentrations of the organoleptic substances for which standards have been developed and various behavioral responses. Volunteers should also be used to evaluate water temperature, pH, odor, and color for their individual or synergistic effects on consumption.
- Those substances that cause laxative effects, i.e., TDS, magnesium, and sulfate need to be analyzed more fully to clearly define the dose-response relationships that induce laxation and perhaps identify means to mediate any laxative effects.
- The degree to which excessive salt (NaCl) can cause cardiovascular impairment, decreased work capacity, impaired heat acclimation, and other health effects needs to be determined.
- Those substances that are of concern because of toxic effects (e.g., arsenic, lewisite, cyanide, lindane, metabolites of algae and associated aquatic bacteria, OP threat agents, and trichothecene mycotoxin T-2) need to be studied more fully in animal models to understand their metabolism and dose response.
- Studies are needed to define the relationships between the turbidity of various natural waters, the physical and chemical properties of the turbidity, chlorine demand, and the impact on disinfection efficiency for pathogens. A related topic is research to develop improved field techniques for assessing the chemical or physical characteristics of turbidity, e.g., organic versus inorganic constituents.
- Research should be performed to develop reasonable quantitative techniques for recovery, concentration, and enumeration of important pathogenic agents in water.
- Research is needed to better define the nature of protozoal pathogens and helminths and human dose responses as well as determination of their occurrence and concentration in water, and indicator organism/pathogen relationships.
- More information is also needed on the survival of bacterial, viral, and protozoan pathogens, and helminths under varying environmental conditions, such as pH, temperature, salinity, and organic loading.

- All categories of research for the more recently identified etiologic agents of water-washed or water-based disease organisms, such as *Aeromonas* spp. and non-*cholerae Vibrio* spp., need to be explored and improved.
- Studies should be performed to determine the effect that oil and grease as well as other opportunity poisons could have on the operation of a ROWPU. The suggested priority for research is petroleum products first and then solvents; coolants; insecticides, rodenticides, and repellents; and herbicides and defoliants.
- Documentation of the removal rate of microorganisms by military water-treatment equipment under field operating conditions is needed to improve confidence in risk estimates.
- Detailed analyses of the chemicals, particularly toxins, released as the metabolites of algae and associated aquatic bacteria should be undertaken so that updated water-quality criteria and recommendations for standards can be derived for these substances. Also the worldwide significance of the algal metabolites needs to be defined.
- Techniques for detecting classes of pesticides, as well as techniques for determining individual pesticides that are in wide use and of high toxicity, should be developed, and the treatability of pesticides most likely to be water contaminants should be carefully evaluated.

CONCLUSIONS

This comprehensive study of military field-water quality has taken over six years to complete. It includes more than 2500 pages of information and was developed by an integrated, interdisciplinary team of scientific and military participants.

The field-water-quality standards derived in this study are recommendations to the Office of the Surgeon General of the U.S. Army. Adopted standards will be incorporated into updated versions of military training and field manuals, such as TB MED 577.

In the past, there was little documentation to provide the basis for field-water-quality standards. This study provides defensible analyses for recommendations for standards; it also provides guidance for generating new studies. This Executive Summary volume represents a road map for locating the detailed information presented in the other eight volumes.

CHAPTER 2. SCREENING

Water that may be obtained and used by the military in the field can contain many different organic and inorganic chemical constituents. These chemicals may exist in a dissolved or colloidal state or absorbed on suspended material, and they are present as a consequence of either natural geochemical and hydrological processes or the industrial, domestic, or agricultural activities of man.

The health risk to military personnel from a chemical constituent or physical property of field water is largely a function of the frequency with which it occurs at concentrations that are high enough to produce a toxic or organoleptic (e.g., detectable and objectionable color, taste, or odor) effect. Of particular concern are health effects that lead to the diminished ability of exposed military forces to perform their assigned missions. Such diminished ability can result from health effects caused by the constituent directly or from heat illnesses caused by dehydration resulting from the reduced consumption of aesthetically unappealing water.

To minimize adverse performance-related effects in military personnel using field-water supplies, the high-risk chemical constituents producing high performance-degrading effects must be identified and analyzed. (For example, a substance that is toxic at low concentrations in water but is found only rarely in surface and ground waters would not be considered a high-risk substance.) The objective of the three parts of Volume 2 is to yield a prioritized index of the chemical constituents and physical properties of field water that are of military concern and to describe the screening methodology and supporting data that we used to identify them. The general approach consists of comparing the maximum likely concentration of each possible chemical constituent in field water with a corresponding concentration estimated to be the threshold above which toxic effects, are likely to occur. Our analyses are based on the average 70-kg soldier consuming field water at a maximum rate of 15 L/d. Maximum likely concentrations for each chemical in field water are derived from our compilation of available U.S. and worldwide water-quality monitoring data.

The screening methodology is comprised of two phases. In the first phase of screening, we make conservative assumptions to extrapolate the threshold concentration above which toxic effects could occur in military forces from either oral-mammalian LD50 (lethal dose to 50% of a population) data or, better yet, Acceptable Daily Intake (ADI) values for humans. The result of this screening procedure is to exclude from further consideration those chemical constituents that are not calculated to be of military concern. Although the conservative assumptions incorporated into the initial screening exercise minimize the omission of substances that may actually be of concern, some substances may be identified incorrectly as high risk. Therefore, where possible, to refine the results of the initial screening effort, we reexamine the available monitoring data and review the published human-toxicity data more carefully for each chemical indicated to be of possible military concern. Next, we use any more appropriate human-toxicity data (e.g., dose-response information from reported accidental poisonings, occupational exposures, or therapeutic administrations) and apply it in the second phase of screening. Then, as in the initial screening procedure, any ratio greater than unity between the maximum likely concentration for a chemical in field water and the concentration above which it could produce toxic or organoleptic effects in 70-kg military personnel consuming field water at a maximum rate of 15 L/d indicates that the chemical or physical attribute really could be of military concern. Because impaired performance can occur as a result of indirect health effects, especially from heat illnesses caused by dehydration resulting from reduced consumption of poor-tasting water, we also screen the initial list of chemicals by comparing maximum likely concentration data for each one with available data corresponding to the concentration of the substance that represents the taste- or odor-detection threshold in water.

To facilitate data acquisition, analysis, and review, as well as application of the screening methodology, we separated the potential chemical constituents of field water into three categories: organic solutes, except pesticides (Vol. 2, Part 1); pesticides (Vol. 2, Part 2); and inorganic chemicals and physical properties (Vol.2, Part 3).

OVERVIEW OF THE BASIC SCREENING METHODOLOGY

The basic procedure for screening a substance, as shown schematically in Fig. 2-1 for organic compounds, is to compare its measured or predicted concentration in water against a screening concentration that represents a no-health-effect level; that is, the concentration found in screening has a low probability of degrading performance or of causing an adverse organoleptic response. Figure 2-2 depicts the various comparisons that can result. This solute concentration is below the screening concentration perceived to induce toxic effects and the adverse organoleptic concentration (comparison A), then the substance does *not* constitute a high *potential* health risk because the toxic effects are below the organoleptic-warning threshold for possible danger. However, if the concentration is above either of these screening concentrations (i.e., comparisons B to E),

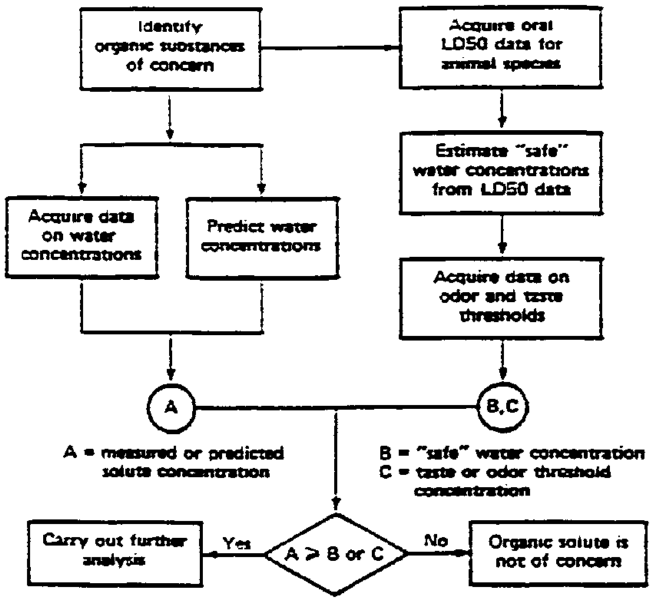


Figure 2-1. Diagram of the methodology for identifying organic solutes that could pose health risks to military personnel consuming field waters. The basic procedure for screening a chemical is to compare measured or predicted concentrations in water with concentrations that represent a no-effect level. Solutes whose concentrations in water are above toxic or organoleptic thresholds are potentially high-risk compounds.

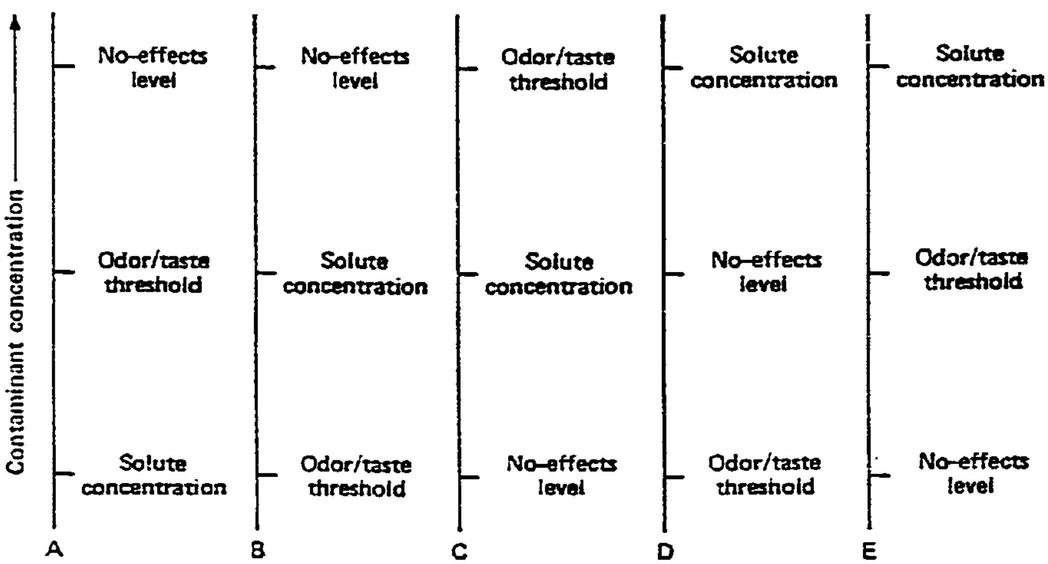


Figure 2-2. Possible comparisons between water concentrations and threshold concentrations for toxic and organoleptic responses.

then the substance is considered a potential high-risk contaminant. The highest potential health risk occurs when the odor or taste threshold is above the no-health-effect threshold, because there is no organoleptic warning of possible danger (comparison E). The second phase of the screening methodology is a more detailed analysis of the toxicity and occurrence of these high-risk solutes to ensure that they are identified correctly.

The presence of solutes in natural waters is a complex function of usage, pollution controls, environmental chemistry (e.g., solubility, volatility, decomposition rates, etc.), and transport (i.e., dilution and diffusion) in surface and ground waters. Measured concentrations of a solute reflect all of the above factors. If we knew all of the relevant parameters for different compounds, as well as site-specific hydrologic characteristics, we could conceivably predict concentrations in various water supplies. Unfortunately, these data are incomplete for most chemicals. Therefore, to estimate the probable occurrence of chemicals in field-water supplies, we have relied principally on measured concentrations in treated and untreated waters obtainable from some foreign countries and the United States.

IDENTIFICATION OF CONTAMINANTS FOR PRELIMINARY SCREENING

The differences in the availability of information for the three categories of contaminants lead to the development of three different methods for the identification of contaminants for the screening process. For organic contaminants, the substances identified for screening analyses included substances for which health standards had been established by domestic or foreign governments or scientific organizations and substances that appeared on hazardous material lists. Our premise was that such standards and lists reflect objective and subjective evaluations of the health risks of various solutes in water supplies worldwide. We supplemented this set of compounds with substances that have been reported in foreign water supplies and substances that were measured frequently in U.S. water supplies. The final screening list consisted of over 200 potentially hazardous organic substances (see Appendix A of Vol. 2, Part 1).

To identify the pesticides likely to be present in water supplies, we examined three different kinds of data: monitoring data, production and use data, and literature reports of illnesses caused by pesticide-contaminated drinking water. Monitoring data showed which pesticides have been identified in various drinking-water supplies and their concentrations. Production and use data disclosed which pesticides have been manufactured and applied in the greatest amounts. Literature reports were used to evaluate the nature and extent of illnesses attributed to pesticide contamination of drinking water. We used the three different sources of data to create a list of 50 pesticides to be screened.

To identify the common and trace inorganic chemicals that could be present as constituents of field drinking-water supplies, we surveyed two types of literature: reports reviewing the chemical composition of natural waters and reports concerning water-related priority pollutants. These references also provided information about the typical valences (or oxidation states) and chemical species of the inorganic substances that can be present in natural waters. We identified 40 possible inorganic substances and total dissolved solids as potential areas for concern.

After development of these lists, the above-mentioned screening process was applied.

OPPORTUNITY POISONS

Independently from the screening just discussed, we also considered the possibility that opportunity poisons would be used to deliberately contaminate water supplies (Vol. 3). The term "opportunity poison" refers to any substance that in military situations might be intentionally added to field water by an adversary to deny its use or that if consumed will cause infectious disease or chemical toxicity; it implies that such contamination will be introduced as a spontaneous action, rather than as part of a preconceived military capability. There are many different substances in military inventories and the civilian marketplace that because of their availability and toxic or adverse organoleptic properties can be considered potential opportunity poisons for field water. To identify these substances and indicate their relative importance from a military perspective, we considered the probable availability from military or civilian sources, the possible water-related health or aesthetic effects, and the potential impacts on water-treatment equipment of the principal constituents of each class of compounds. We found that 20 classes of substances are potential opportunity poisons. Awareness of potential contamination with opportunity poisons and avoidance of obvious contamination are the primary precautions in the management of health risks from this type of field-water contamination. We have recommended a procedure to assure vigilance at water-supply points as the best method for early warning of the presence of these indeterminate, randomly used contaminants.

SUMMARY AND RESEARCH RECOMMENDATIONS

ORGANIC CHEMICAL CONSTITUENTS

Our screening effort addressed substances in field water that could potentially be toxic or cause adverse organoleptic effects. Moreover, we assumed that no water treatment would occur prior to water consumption. From our comparison between reported maximum-observed concentrations and threshold concentrations for toxicity (based on a 15-L/d consumption rate for a 70-kg individual), we conclude that there is a very low probability that organic solutes in field water will cause direct, debilitating effects in troops. However, this assumes that troops follow existing doctrine regarding the placement of water-supply points and use of sanitary surveys. Siting a water-supply point directly below a sewage or industrial waste outfall on a stream or river, for example, greatly enhances the risk of health effects. Likewise, the use of a well that is in the immediate vicinity of actual or possible surface industrial contamination poses an increased health risk. Avoiding these obvious situations is a key precaution in the management of health risks from all contaminants of field water.

Nonetheless, we did identify several organic solutes that could cause taste and odor problems. Among the most important compounds in this group are trichloromethane, ethylbenzene, toluene, and tetrachloroethene because they have the greatest worldwide distribution. In addition, chlorinated phenols, as well as oil and grease, could impair the potability of field water. Our screening for organoleptic effects, however, used chemical concentrations representing taste- and odor-detection thresholds instead of concentrations related to a behavioral response, such as refusal to drink poor-tasting water. We therefore recommend research in which taste panels comprised of groups of soldiers be used to quantify the relationship between the likely concentrations of these substances, an organoleptic property, and various behavioral responses. This research could provide a data base that would support a more definitive analysis for determining the organic chemicals likely to impair the potability of field water and for which standards should be established. An important issue that has emerged is the effect that oil and grease could have on the operation of a ROWPU. Studies are needed to determine the concentrations of oil and grease that could impair the efficiency and life of reverse osmosis membranes.

We also indicate that compounds released into water by the aquatic microorganisms, cyanobacteria and actinomycetes, can also be of particular military concern. These substances fall into two categories: (1) those that impair the taste and odor of drinking water and (2) those that could produce toxins that induce health effects following ingestion or nonconsumptive exposure. Geosmin and 2-methylisoborneol fall into the first category, and alkaloid, lipopolysaccharide, and polypeptide toxins belong to the second one. Because of the potential for algal blooms in impounded surface waters, we recommend that available data on the organoleptic and toxic properties of these metabolites be evaluated carefully so that consideration can be given to developing criteria and recommendations for their standards in field water.

PESTICIDES

For pesticides, we found that contamination of large bodies of water (e.g., lakes, rivers, and oceans) does not generally occur at levels that threaten troop health or performance. Consequently, these water supplies need not be routinely treated specifically to remove pesticides. The greatest threat to troop health from pesticides in water appears to come from infrequent, transient occurrences of extreme contamination, particularly in small bodies of water with little potential for dilution, such as ponds, irrigation ditches, and rice patties. The challenge to military preventive-medicine personnel is to detect and avoid the apparently rare cases of extremely contaminated water.

Nevertheless, because severe pesticide contamination is known to occur, and because such contamination would seriously affect the health and performance ability of troops, it is recommended that the military develop field techniques to detect certain classes of pesticides and a few highly important individual pesticides. Because pesticide-contaminated water may be the only available source of drinking water, it is also recommended that the treatability of pesticides in water be investigated for Army equipment. It must be recognized that, by accident or intent, any pesticide can be present in water at levels that would render water unacceptable for use. Lindane is the pesticide with the greatest known potential to be found at dangerous levels in water as a result of its normal use. The most widely used organophosphates (e.g., malathion and parathion) appear to present a less likely hazard, but these compounds should also be considered for the development of detection techniques and for treatability studies.

INORGANIC CONTAMINANTS AND PHYSICAL PROPERTIES

For inorganic contaminants and physical properties, the screening and survey of the review literature revealed that only arsenic, chloride, cyanide, magnesium, sulfate, total dissolved solids (TDS), and turbidity and color are likely to be of concern to military personnel consuming field water. We also determined that, with the possible exception of cyanide, inorganic constituents of field water will not produce performance-degrading health effects in military personnel exposed externally as a result of routine swimming, showering, or bathing activities. However, further research is still required to reduce important sources of uncertainty associated with the recommended standards. This research will either improve the scientific basis for the recommendations or provide data supporting revisions.

Our analysis that there is a very low probability that most inorganic constituents of field water will cause direct, debilitating health effects in troops is based on the assumption that troops follow existing doctrine regarding the placement of water-supply points. Siting a water-supply point directly below a sewage outfall on a stream or river, or in waters expected to have been sabotaged by opportunity poisons or chemical warfare agents, for example, greatly enhances the risk of health effects. Likewise, the use of a well that is in the immediate vicinity of actual or possible surface industrial contamination poses an increased health risk. Avoiding these obvious situations is a key precaution in the management of health risks from field-water contaminants.

The data base on occurrence in water for several inorganic chemicals was insufficient to ultimately determine if standards were needed. Further development of water resource data should be conducted.

OPPORTUNITY POISONS

The water sources mostly likely to be affected by opportunity poisons are small bodies of water, wells, cisterns, storage tanks, tactical pipelines, and/or distribution systems. The training of commanders, specialists, and troops to be aware of potential contamination with opportunity poisons is the best defense against the problem. We make the following recommendations to meet the threat of opportunity poisons: (1) develop and distribute technical bulletins, training manuals, and field manuals on the threat of opportunity poisons, (2) develop and implement in existing training programs for U.S. Engineer, Quartermaster, and Medical Corps personnel and troop commanders appropriate literature, practical exercises, and detailed training scenarios and appropriate responses, and (3) conduct research quantifying the effects of the various classes of opportunity poisons on military water-treatment equipment, particularly the reverse osmosis water purification unit (ROWPU); the suggested priority for research is petroleum products; solvents; coolants; insecticides, rodenticides, and repellents; and herbicides and defoliants.

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CHAPTER 3. STANDARDS

The standards developed for field-water quality can be placed in two major categories: recommended final standards and interim standards. The recommended final standards are presented for those substance of concern for which sufficient data are available to determine the appropriateness of the standard. Interim standards are presented for those substances of concern for which the data are not sufficient for the setting of a definite standard.

RECOMMENDED STANDARDS FOR SUBSTANCES OF CONCERN

Drinking-water standards were developed for field-water constituents and properties of military concern that are naturally occurring or anthropogenically introduced i... water. The recommended standards are applicable only to military personnel deployed in the field, and they are meant to protect against performance-degrading effects resulting from the ingestion of field water. Standards are recommended that address both short-term (≤7 d) and long-term (≤1 y but >7 d) field-water consumption at rates of 5 and 15 L/d. Turbidity, color, and total dissolved solids (TDS) are the physical properties of concern because they can adversely impact the organoleptic quality of field water, and thereby lead to reduced water consumption and subsequent voluntary dehydration, which can degrade performance. Certain metabolites of aquatic algae and associated bacteria, geosmin and 2-methylisoborneol also affect organoleptic quality and can lead to reduced water consumption. Chloride, magnesium, sulfate, inorganic arsenic, cyanide, the pesticide lindane, and other metabolites of aquatic algae and associated bacteria (i.e, alkaloid, lipopolysaccharide, and polypeptide toxins) are the chemical constituents of concern because they can be responsible for degrading performance directly as a consequence of their toxic properties.

Field-water-quality standards have previously been adopted for several of these parameters, including turbidity, color, TDS, chloride, magnesium, sulfate, arsenic and cyanide. However, comprehensive review and revision of such standards have not been performed since the 1960's. In Volume 4, Part 1, we present reviews and assessments of the potential health effects associated with each of the chemical constituents and properties of interest, define applicable criteria for establishing standards, and then recommend revised or new standards that protect against performance-degrading effects. Finally, we present recommendations for research that can provide data and results for reducing uncertainties related to the standards developed.

TURBIDITY AND COLOR

Water quality limits for turbidity and color are accepted generally as aesthetic standards; no evidence indicates that a direct relationship exists between human health effects and turbidity and color in water. However, high levels can make the water objectionable to many individuals, causing them to refuse to drink it. Additionally, turbidity can affect the efficacy of disinfection, and consequently may increase exposure to infectious microorganisms in field water that can pose a significant risk to health.

The data we reviewed suggest that approximately a third of military personnel might reject field water that meets existing military standards (5 units of turbidity and 50 units of color). A turbidity level less than or equal to 1 nephelometric-turbidity unit (NTU) not only would tend to improve the efficacy of disinfection for most infectious microorganisms (the protozoa *Giardia* and *Cryptosporidium* are notable exceptions), but also would reduce to levels as low as about 2%, the percentage of military personnel that may refuse to drink the water and become susceptible to the performance-degrading effects of dehydration, provided color and odor are absent. Thus, we recommend that the existing turbidity standard of 5 units be changed to 1 NTU. We also recommend that the existing color standard be changed to 15 color units for long-term ($\leq$ 1-y) exposure and 50 color units for short-term ($\leq$ 7-d) exposure because (1) color is not directly associated with health effects, and (2) these color levels, although noticeable, can be considered tolerable for military populations under field conditions from an organoleptic or aesthetic standpoint.

TOTAL DISSOLVED SOLIDS

After assessing health-effects literature, we concluded that intermediate TDS concentrations (~1000 – 2500 mg/L) are not clearly linked with specific health effects. However, these intermediate TDS concentrations in water will make the taste of the water objectionable to many individuals, causing them to reject it. Moreover, TDS concentrations higher than those causing organoleptic effects may cause laxative effects.

After our review, we concluded that consideration should be given to lowering the present military field-water-quality standard for TDS from 1500 mg/L to 1000 mg/L. This reduction would lower the percentage of the military population that might refuse to drink the water from approximately 7% for a 1500-mg/L TDS standard to about 2% for the 1000-mg/L TDS standard. A 1000-mg/L TDS standard should also reduce the incidence of laxative effects from elevated TDS among the military population consuming the water and possibly ameliorate the adaptation process for those individuals accustomed to the taste of water with lower TDS.

CHLORIDE

The relationship between health effects and chloride concentrations in drinking-water supplies is poorly documented. However, the available evidence suggests that chloride will give water an objectionable taste for many individuals at concentrations well below those that cause laxative effects.

Because chloride is a constituent of the TDS content of water (particularly field water that has been processed through a reverse osmosis water purification unit [ROWPU]), and because both TDS and chloride cause an objectionable taste, we assume the TDS is dominated by sodium chloride (sodium chloride predominates TDS following the ROWPU process). Then, we estimate quantitatively the proportion of the military population that will refuse to drink water, based on that TDS concentration. According to our calculations, the present field-water-quality standard for chloride, 600 mg/L for both short-term (7-d) and long-term (1-y) exposure periods, could be retained because we estimate that only about 2% of the military population will refuse to drink such water.

MAGNESIUM

High levels of magnesium in water are of concern because they can produce diarrhea and thereby disrupt the normal water balance of military personnel, particularly in hot climates. We determined a no-effects concentration by estimating a single no-effect dose and calculating the concentration that would result if the dose were diluted into 5 and 15 L of water that was consumed over the course of a day. Thus, the recommended standard for magnesium is 100 mg/L for a water consumption rate of 5 L/d, and 30 mg/L for a water consumption rate of 15 L/d for both short-term (≤7 d) and long-term (≤1 y) exposure periods.

SULFATE

Like high levels of magnesium, high levels of sulfate are of concern because they can produce diarrhea and thereby disrupt the normal water balance of military personnel, particularly in hot climates. We determined recommended standards by the same method as for magnesium, with the result that the recommended standard for sulfate is 300 mg/L for a water-consumption rate of 5 L/d, and 100 mg/L for a water-consumption rate of 15 L/d for both short-term and long-term exposure periods.

ARSENIC

The most common arsenic species in natural waters are the trivalent, As^{+3}, and pentavalent, As^{+5}, forms. "Total aresenic," which includes both the trivalent and pentavalent forms, typically is reported from analysis of water quality; however, As^{+3} is the most prevalent, as well as the most toxic, species in natural waters. Human health effects that occur following the ingestion of inorganic arsenic are varied. Where exposures were high enough to cause observable effects, the reports show that the most commonly affected systems include the circulatory, gastrointestinal, integumentary, nervous, hepatic, renal, and immune systems. Also, a sufficiently high dose can be fatal. The recommended standards are intended to prevent performance degradation or irreversible effects in troops who will be exposed to water that contains arsenic for up to 7 d or up to 1 y. For an assumed daily water consumption of 5 L, the recommended standards are 300 μg/L for a period up to 7 d and 60 μg/L for a period up to 1 y. For an assumed daily water consumption of 15 L, the recommended standards are 100 μg/L for a period up to 7 d and 20 μg/L for a period up to 1 y.

CYANIDE

Cyanide is known to cause acute health effects by blocking electron transport, thus preventing the body from using oxygen. The recommended standards are based on the assumption that 0.5 mg/L is the maximum tolerable concentration of cyanide in whole blood. For both short-term and long-term exposures, the recommended standard is 6 mg/L for a 5-L/d consumption rate and 2 mg/L for a water-consumption rate of 15 L/d.

LINDANE

Lindane is an organochlorine pesticide, and a variety of symptoms have been reported following its ingestion. At low doses, some of the acute effects include nausea, dizziness, headaches, diarrhea, changes in heart rate and respiration rate, and tremors. At higher doses, severe seizures can occur, as well as acute renal failure and pancreatitis, followed by eventual central respiratory failure and acute cardiovascular collapse, stupor, confusion, metabolic acidosis, coma, and death. The recommended standards are intended to prevent performance-degrading or irreversible effects in troops who will be exposed to lindane-containing water for up to either 7 d or 1 y. For both of the exposure periods, the recommended standard is 0.6 mg/L for a daily water-consumption rate of 5 L/d and 0.2 mg/L for a daily water-consumption rate of 15 L/d.

METABOLITES OF ALGAE AND ASSOCIATED AQUATIC MICROORGANISMS

Algae and associated aquatic microorganisms are commonly found in fresh and marine waters. Many of these microorganisms have been identified as the source of taste and odor problems in surface waters, particularly drinking-water reservoirs. Two of these microorganisms, cyanobacteria (blue-green algae) and actinomycetes (gram-positive filamentous bacteria that grow in close association with cyanobacteria), are important from the perspective of military field-water quality because they can release the compounds geosmin and 2-methylisoborneol (MIB) into water. These substances are persistent and can cause taste and odor problems at extremely low concentrations. Furthermore, cyanobacteria are the source of other biochemicals (i.e., alkaloid, lipopolysaccharide, and polypeptide compounds) that are toxic to animals and therefore to man. Field-water-quality standards of 10 ng/L are recommended for the taste- and odor-causing biochemicals, geosmin and MIB, for both short-term and long-term exposures. Unfortunately, data are too limited for recommending standards for the toxic substances associated with the presence of cyanobacteria in algal blooms. Although the toxic agents have been shown to produce toxicity in livestock, domestic, and laboratory animals; interspecies extrapolation is made difficult by too many confounding variables (e.g., differences in digestive systems, responses, and dosage equivalents). The practical recommendation is that field waters containing algal blooms be avoided by military personnel or be used only after treatment with activated carbon.

RECOMMENDATIONS FOR FIELD-WATER-QUALITY STANDARDS

The recommended field-water-quality standards are summarized in Table 3-1. For comparison, Table 3-1 also contains the analogous standards for drinking water published in the last (i.e., 1975) edition of U.S. Army Technical Bulletin No. TB MED 229, the 1986 edition of U.S. Army Technical Bulletin No. TB MED 577, the most recent version of Quadripartite Standardization Agreement (QSTAG) 245, and a recent article summarizing drinking-water standards internationally. The standards for constituents of drinking water that are summarized in Table 3-1 have been divided into two categories: those related primarily to the physical condition or organoleptic quality (e.g., taste, odor, appearance) of the water and those related to the chemical quality of the water.

The recommended field-water-quality standards summarized in Table 3-1 and discussed earlier were not developed on the basis of detection capabilities available to military forces nor on the treatment efficiency attainable by military water-purification equipment. Moreover, the methodologies used to develop the recommended field-water-quality standards were not the same for all the constituents of field water identified to be of concern. Nevertheless, the recommended standards were developed to be consistent with each other. Each standard provides protection against performance-degrading effects in military personnel, and is applicable to all military occupational specialties. The standards recommended do not address health effects such as carcinogenesis or teratogenesis. Furthermore, a temperature of 60°F ±10° F (16°C ± 5°C), a pH between 5 and 9, and a threshold odor number (TON) between 0 and 3 represent optimum tolerable limits for these attributes of field water for military personnel. Consequently, standards that are recommended for other chemicals and properties of field water take into consideration the aforementioned optimum limits for temperature, pH, and odor. In fact, a potential source of drinking water may not be consumed if the temperature, pH, and/or odor of the water were outside the optimum limits, independent of the concentration of other chemicals or properties of military concern.

RESEARCH RECOMMENDATIONS

These recommended field-water-quality standards were developed in the face of limited and sometimes discordant data. Research is necessary to reduce important sources of uncertainty or to strengthen the scientific basis of the recommended standards. This research should include human studies with military personnel under field conditions so that the relationship between the organoleptic properties of water and

Table 3-1. Summary of recommended field-water-quality standards and other selected drinking-water standards.

	Recommended standards[a]				TB MED 229[b]		TB MED 577[c]		QSTAG 245[d]		International[g]			
	≤7 d		≤1 y		≤7 d	≥7 d	≤7 d	≥7 d	≤7 d[e]	≥7 d[f]				
Constituents	5 L/d	15 L/d	5 L/d	15 L/d	5 L/d	5 L/d	5 L/d	5 L/d	5 L/d[h]	5L/d[h]	US	CAN	EEC	WHO
PHYSICAL PROPERTIES:														
Turbidity (NTU, unless otherwise noted)	1	1	1	1	RC	5	RC	5	5	1	1 to 5[i]	5	4[j]	5
Color (color units, unless otherwise noted)	50	50	15	15	—	50	—	50	—	15	15[k]	15	20[j,l]	15
Total dissolved solids (mg/L)	1000	1000	1000	1000	—	1500	—	1500	1500	1500	500[k]	500	400[m,n]	1000
pH	—	—	—	—	—	—	—	5.0 to 9.0	5.0 to 9.2	5.0 to 9.2	6.5 to 8.5	6.5 to 8.5	—	6.5 to 8.5
Temperature (°F)	—	—	—	—	—	—	—	—	39.2° to 95°	59 to° 71.6°	—	59°	77°	—
CHEMICAL CONSTITUENTS														
Chloride (mg/L)	600	600	600	600	—	600	—	600	—	600	250[k]	250	25[m]	250
Magnesium (mg/L)	100	30	100	30	—	150	—	150	—	150	—	—	50[j]	—
Sulfate (mg/L)	300	100	300	100	—	400	—	400	—	400	250[k]	500	25[m]	400
Total inorganic arsenic (mg/L)	0.3	0.1	0.06	0.02	2.0	0.2	2.0	0.2	2	0.05	0.05[i]	0.05	0.05[j]	0.05
Cyanide (mg/L)	6	2	6	2	20	2	20	2	20	0.5	—	0.2	0.05[j]	0.1
Lindane (mg/L)	0.6	0.2	0.6	0.2	—	—	—	—	—	—	—	0.004	0.001	0.003
Organoleptic metabolites of algae and associated aquatic bacteria (ng/L)	10	10	10	10	—	—	—	—	—	—	—	—	—	—

[a] Field-water-quality standards recommended in this document for adoption by the Armed Forces of the United States are consistent with a pH between 5 and 9, an optimum drinking-water temperature of 60°F ± 10°F (16°C ± 5°C), and a threshold odor number (TON) between 0 and 3.

[b] U.S. Army Technical Bulletin No. TB MED 229 (1975).

[c] U.S. Army Technical Bulletin No. TB MED 577 (1986).

[d] Minimum treatment requirements for assuring potability as presented in Table A of Quadripartite Standardization Agreement (QSTAG) 245 (1985).

[e] Short-term consumption provisions that according to Quadripartite Standardization Agreement (QSTAG) 245 are for "emergency or field operational conditions" and may lead to degraded troop performance and reduced combat efficiency each day they remain in effect.

[f] Long-term consumption provisions, which according to QSTAG 245, are designed to assure the health and maintain the performance of troops provided their health is good and their rations are adequate.

[g] Sayre, I.M., "International Standards for Drinking Water," *J. Am. Water Works Assoc. 80*, 53-60 (1988). These rates are assumed to be applicable to a 2L/d consumption rate.

FOOTNOTES TO TABLE 1 (continued)

[h] For consumption rates exceeding 5 L/d, QSTAG 245 states that the permitted level for toxic substances (e.g., arsenic and cyanide) be based on the maximum daily dose that would be ingested at the 5 L/d consumption rate.

[i] Enforceable U.S. primary drinking water regulation.

[j] European Economic Community (EEC) maximum admissible concentration.

[k] Nonenforceable U.S. secondary drinking water regulation.

[l] Measured in units of mg Pt-Co/L.

[m] Guidance level.

[n] Measured as conductivity (mS/cm).

[o] Optimum drinking-water temperature for palatability identified in U.S. Army Technical Bulletin No. TB MED 577 as being 60°F ± 10°F (16°C ± 5°C), but not specified as a field-water-quality standard.

the desire to consume such water is made more clear. Also, toxicological and pharmacological studies employing suitable animal models should be performed to explain the mechanisms of action of the more toxic substances such as arsenic and cyanide. Finally, future research should examine the synergistic effects that combinations of constituents in field water can have on military performance. Among the most important research studies recommended are those addressing (1) the complex relationship between temperature, pH and odor, and the influence these factors can have on fluid consumption, especially in a hot, arid environment, (2) the relationship between turbidity and disinfection effectiveness, (3) the relationship between the concentrations of magnesium and sulfate and the organoleptic and laxative properties of total dissolved solids, (4) the precise implications of chloride concentration in water as it relates to ingestion of salt (NaCl) obtained from military rations and with respect to operation of reverse osmosis water purification units, (5) the nature of the human health effects associated with different chemical species of arsenic, (6) the importance of excretion pathways, such as sweating, with regard to cyanide detoxification and elimination, (7) the dose-response relationship for lindane with regard to subtle neurological changes and military performance, and (8) the consequences of ingesting water containing toxins released by cyanobacteria.

INTERIM STANDARDS FOR SELECTED THREAT AGENTS

Drinking-water standards for field water were also developed for selected threat agents of concern, including radioactivity (see Volume 4, Part 2). The threat agents of concern in addition to radioactivity are the classical chemical-warfare compounds hydrogen cyanide, organophosphorus nerve agents (i.e., GA, GB, GD, and VX), and lewisite (an arsenical vesicant), as well as a fungal metabolite identified only recently as a possible threat agent, the trichothecene mycotoxin T-2. All of these substances are of concern because they could appear in water during war time and they can be responsible for degrading performance due to their toxic properties. The recommended standards are applicable only to military personnel deployed in the field, and they are meant to protect against performance-degrading effects resulting from the ingestion of the substances in field water consumed at rates of up to 5 and 15 L/d but only for a period lasting up to 7 d. However, due to the nature of radioactivity and because radioactive material could be dispersed over a very wide geographic area following a military exchange with nuclear weapons, standards are also recommended for up to 1-y exposure in a radioactive environment. Additionally, the standards recommended for all the threat agents, except hydrogen cyanide, are interim ones because (1) in the case of radioactivity, the regulatory basis upon which they were developed is under review and could change, and (2) for the other compounds, the toxicological data are from limited studies with human volunteers and laboratory animals. To compensate for the absence of definitive data, these interim standards were developed using conservative assumptions. The standards recommended for hydrogen cyanide are not assigned an interim status because there is no reason to believe that the standards recommended for cyanide in field water cannot be applied to the threat agent hydrogen cyanide and also because the data from which the standards for cyanide were developed are not quite so limited.

HYDROGEN CYANIDE

Hydrogen cyanide (HCN), also referred to as hydrocyanic acid, is a rapidly acting poison that exerts its toxic effects by inhibiting certain enzymes that play a critical role in the use of oxygen for cellular respiration. Once such chemical asphyxiation begins, the nervous and respiratory systems start to fail, and this leads to adverse health effects that can include headache, breathlessness, weakness, tremors, and even death. However, because cyanide can be detoxified in the body and because HCN is very volatile, massive amounts of the gas are probably needed for it to be effective as a threat agent in chemical warfare.

HCN vapor dispersed as a threat agent will dissolve in water. Field-water-quality standards were initially derived for cyanide nonagent standards because cyanide compounds, including HCN, could be found in field water as a result of contamination by industrial wastewaters. Because no evidence indicates that the mode of introduction of HCN into field water affects its toxicity following ingestion, the short-term field-water-quality standards for cyanide of 6 and 2 mg/L for drinking-water consumption rates of up to 5 and 15 L/d are applied to the threat agent hydrogen cyanide, as well.

RADIOACTIVITY

Radioactivity in water may be derived from a variety of sources. These sources include fallout from nuclear weapons explosions, leaching of naturally occurring radionuclides, and sabotage. Acute effects of radioactivity depend on the level of dose and range from fatigue, nausea, vomiting, and diarrhea at lower dose levels to death at higher levels. Delayed effects of radiation include carcinogenesis and the induction of genetic defects. A limit of 1.0 Sv (100 rem) committed dose equivalent to an individual organ or tissue of the GI tract is the basic standard to protect against significant performance degradation. This standard should carry essentially zero risk of acute lethality,* and no more than 10% of the affected troops should suffer performance degradation.† Under extreme emergency conditions, this basic limit might be increased to as much as 2.0 Sv (200 rem).* This emergency standard should still result in zero incidence of lethality but might yield significant performance degradation. Recommended standards for radionuclides in military field-water supplies to protect against both lethality and significant performance degradation are therefore based on a limit of 1.0 Sv (100 rem) to the organs of the GI tract and are achieved by dividing 1.0 Sv by an exposure-to-dose conversion value to arrive at an Annual Limit on Intake (ALI). By dividing the ALI by the expected amount of water to be consumed over the relevant time period (5 and 15 L/d over 7 d, or 35 and 105 L, respectively, for short-term exposure; and 5 and 15 L/d over 365 d, or 1825 and 5475 L, respectively, for long-term exposure), a recommended standard is achieved for military field-water supplies. For example, we recommend 10 MBq as the ALI (equivalent to 1.0 Sv) to be used to protect against unidentified individual gross alpha or beta activity. Therefore, for short-term exposure (up to 7 d), 10 MBq (270 μCi) is divided by 35 and 105 L to obtain recommended standards of 300 kBq/L (8 μCi/L) and 100 kBq/L (3 μCi/L), for 5 and 15 L/d consumption rates, respectively. Similary, for long-term exposure (up to 1 y) 10 MBq (270 μCi) is divided by 1825 and 5475 L to arrive at recommended standards of 5 kBq (0.1 μCi/L) and 2 kBq (0.05 μCi/L).

* If exposure is occurring via external exposure and the inhalation of radionuclides in addition to exposure by ingestion, such exposure must be considered as part of the total exposure discussed here.
† The assumption is being made that a committed dose equivalent to an organ or tissue of the GI tract has the same effect as a dose to the whole body. This assumption is considered to be conservative, but is not verified.

ORGANOPHOSPHORUS COMPOUNDS

The organophosphorus (OP) compounds that are nerve agents possess properties that make them superior chemical warfare (CW) munitions for military forces. These properties include (1) relatively fast-acting acute toxicity, (2) effectiveness whether inhaled or absorbed through the skin, (3) ease of dispersal, (4) stability in storage, and (5) fairly low manufacturing costs. There are four OP nerve agents that have received the greatest amount of consideration as threat agents: tabun (GA), which is O-ethyl N-dimethylphosphoramidocyanidate; sarin (GB), which is O-isopropylmethylphosphonofluoridate; soman (GD), which is O-1,2,2-trimethylpropyl methylphosphonofluoridate; and agent VX, which is O-ethyl S-[2-(diisopropylamino)ethyl]-methylphosphono-thioate.

The inhibition of the enzyme acetylcholinesterase (AChE) and the subsequent rapid accumulation of acetylcholine at cholinergic synapses (junctions between nerves or nerves and muscles in the tissues across which acetylcholine transmits the nerve impulse) is considered the principal mechanism by which the four OP nerve agents induce acute toxicity. Among the acute symptoms that can occur as a consequence of excessive accumulation of acetylcholine are uncontrollable vomiting and defecation, convulsions, loss of reflexes, coma, and central respiratory failure, which leads to death. The standards recommended for drinking water consumption rates of 5 and 15 L/d for exposure lasting up to 7 d are 12 and 4 μg/L for organophosphorus nerve agents.

MYCOTOXINS

Mycotoxins are metabolites of fungi that are produced by secondary biochemical pathways. These pathways are active when changes in chemical and physical conditions restrict fungal growth. Mycotoxins have been implicated as the causative agents of adverse health effects in humans and animals that have consumed fungus-infected agricultural products and plants. Additionally, one chemical group of mycotoxins, the trichothecenes, may also represent a problem from a military perspective because of their potential use as a threat agent.

In 1981, the trichothecene mycotoxin T-2 was claimed to be the lethal ingredient in "yellow rain" dispersed in Laos and Kampuchea. T-2 was found as the yellow spots that appeared on some rocks and leaves and in the water samples taken from locations near the battlefields. This trichothecene mycotoxin purportedly was aerially dispersed as a chemical weapon—yellow rain—described by inhabitants from these combat zones in Southeast Asia, and from places in Afghanistan where military engagements had also taken place, as aerial attacks where yellow granules or mists were released that "fell like rain" and produced disease. Yet, the evidence for the use of chemical weapons comprised of trichothecene mycotoxins, particularly T-2, remains controversial. The statements about yellow rain by alleged victims are ambiguous and conflicting; the results from the analyses of the environmental samples collected in the field and then analyzed by different research laboratories and at different times are contradictory; and most important of all, the physical composition of the yellow spots themselves indicates they could be of natural origin—excrement released by Asian honeybees in fecal showers as they swarm unheard and unseen overhead.

Despite this controversy, T-2 toxin is one of the most toxic trichothecenes, particularly if ingested. Moreover, our review of the literature revealed that (1) trichothecene mycotoxins possess chemical, physical, and toxicological properties that make them candidates for use as chemical weapons; (2) the technology to manufacture significant quantities of the compounds is available; and (3) studies have been performed with trichothecene mycotoxins at research facilities outside the United States that are linked to research on chemical and biological weapons. Thus, we developed recommendations for interim field-water-quality standards for the trichothecene mycotoxin T-2 of 26 and 8.7 μg/L for drinking-water consumption rates of 5 and 15 L/d for exposure lasting up to 7 d.

LEWISITE

Lewisite is the organic trivalent-arsenic compound, 2-chlorovinyl-dichloroarsine. This threat agent is not only a potent vesicant (i.e., blister agent), but also a lung irritant and systemic poison. Because trivalent arsenic is considered the component of lewisite that is principally responsible for its vesicant and systemic toxicity at the cellular level, arsenic-based field-water-quality standards for lewisite (i.e., standards expressed in terms of the arsenic fraction of lewisite) were derived. Furthermore, such arsenic-based standards for lewisite are practical because the water-quality test for lewisite currently used by the military does not detect lewisite directly, instead the presence of lewisite in water is based on detection of its arsenic component. The standards recommended for drinking-water consumption rates of 5 and 15 L/d for exposure lasting up to 7 d are 0.08 and 0.027 mg/L for lewisite.

RECOMMENDATIONS FOR INTERIM FIELD-WATER-QUALITY STANDARDS

The recommended interim field-water-quality standards are summarized in Table 3-2. For comparison, Table 3-2 also contains the analogous standards for drinking water published in the last (i.e., 1975) edition of U.S. Army Technical Bulletin No. TB MED 229, the 1986 edition of U.S. Army Technical Bulletin No. TB MED 577, and the most recent version of Quadripartite Standardization Agreement (QSTAG) 245. As is the case for the recommended field-water-quality standards summarized in Table 3-1, the recommended interim field-water-quality standards summarized in Table 3-2 also were not developed on the basis of detection capabilities available to military forces, nor on the treatment efficiency attainable by military water-purification equipment.

RESEARCH RECOMMENDATIONS

Research can be performed to help reduce important sources of uncertainty and strengthen confidence in the recommended standards for the OP nerve agents, trichothecene mycotoxin T-2, and lewisite. Research recommendations for hydrogen cyanide are the same as presented in the discussion of cyanide; i.e., the importance of excretion pathways, including sweating, with regard to cyanide detoxification and elimination, should be investigated. There is sufficient confidence in the standards recommended for radioactivity on the basis of the available data that additional research is not recommended. However, the basis for radioactivity standards is constantly under review and this review process should be monitored for changes that affect the standards stated here. For this reason, the recommendations on standards for radioactivity should be regarded as interim.

The research we recommend for the OP nerve agents, lewisite, and the trichothecene mycotoxin T-2 involve the testing of specific laboratory animals for evidence and mechanisms of toxicity. We propose that the respective compounds be administered orally in repetitive doses to the animals at various concentrations in water (or an appropriate vehicle) over an exposure period of 7 d. Dose-response data from such studies can then be extrapolated to military personnel for drinking-water consumption rates up to 5 or 15 L/d over the same exposure period. These results should be compared to the recommended interim standards so that such interim standards can be verified or revised accordingly. The acute health effects, especially the neurotoxic and behavioral effects, that can result from short-term exposure to repetitive oral doses of threat agents

Table 3-2. Summary of (1) recommended interim field-water-quality standards for selected threat agents of concern for ingestion up to 7 d, (2) recommended standards for radioactivity for ingestion up to 7 d and for up to 1 y,[a] and (3) comparable standards.

	Recommended standards[b]		TB MED 229[c]	TB MED 577[d]	QSTAG 245[e]
Constituent	5 L/d	15 L/d	5 L/d	5 L/d	5 L/d
Hydrogen cyanide (mg/L)	6[f]	2[f]	20	20	20
Radioactivity[a] (µCi/L)					
Short-term:			--[g]	--[g]	--[g]
Gross alpha and/or gross beta	8	3			
Specified	ALI/35[h]	ALI/105[h]			
Long-term		–	–	0.06[i]	
Gross alpha and/or gross beta	0.1	0.05			
Specified	ALI/1825[h]	ALI/5475[h]			
OP threat agents (µg/L)[j]	12	4	20	20	20
T-2 toxin (µg/L)	26	8.7	–	–	–
Lewisite (mg/L) (arsenic fraction)[k]	0.08	0.027	2	2	2

[a]Long-term (≤1 y) as well as short-term (≤7 d) standards were developed because of the nature of radioactivity and the possibility that radioactive material could be dispersed over a very wide geographic area following a military exchange with nuclear weapons.

[b]Field-water-quality standards recommended in this document for adoption by the Armed Forces of the United States are consistent with a pH between 5 and 9, an optimum drinking-water temperature of 60°F ± 10°F (16°C ± 5°C), and a threshold odor number (TON) between 0 and 3. (See Volume 4, Part 1 for further discussion of these parameters.)

[c] U.S. Army Technical Bulletin No. TB MED 229 (1975).

[d] U.S. Army Technical Bulletin No. TB MED 577 (1986).

[e]Minimum treatment requirements for assuring potability from Table A of Quadripartite Standardization Agreement (QSTAG) 245 (1985). These are short-term consumption provisions that are for "emergency or field operational conditions" and may lead to degraded troop performance and reduced combat efficiency each day they remain in effect.

[f]Recommendations for field-water-quality standards for cyanide from industrial wastewater discharge have been presented previously and there is no evidence to indicate that such standards for cyanide cannot be applied to the threat agent hydrogen cyanide.

[g]If external radiation permits military personnel to occupy a location, then water is considered suitable for consumption for a period lasting up to 7 d.

[h]If specific radionuclides are known to be present, then the annual limit of intake (ALI) should be divided by the factors stated above.

[i]A long-term standard (≤1 y) for mixed fission products.

[j]If pretreatment with pyridostigmine bromide is enforced, the rates are 4.7 and 1.6 µg/L for 5 and 15 L/d consumption rates.

[k]Based on detection of the arsenic fraction of lewisite in water; the corresponding concentration of lewisite is about 2.75 times greater.

are of particular concern. Additionally, the research may indicate if field-water-quality standards should be considered for the environmental degradation products of the threat agents of concern.

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CHAPTER 4. MICROORGANISMS

Considerable interest exists in establishing realistic standards for water quality that will reduce transmission of infectious disease. The development of such standards is a complicated task that involves the concept of risk assessment. In the context of our study, risk assessment involves the relationship between the concentration of a pathogen in water and the likelihood of disease occurring in individuals who drink the water. A mathematical model was developed to take into account the variability of the pathogen concentration in water, and hence the dose, as well as the biological variability inherent in the dose-response relationship. An interactive computer program was developed that allows the user to select the organism of interest, its concentration, the amount of water consumed, the treatment-alternative removal rate, the dose-response model, and the number of susceptible individuals (up to 20). Based on the users' selections, a computer-generated risk curve is produced.

In Volumes 5 and 6, we developed the screening methodology to identify high-priority water-related pathogens. The mathematical model was developed to assess the health risks associated with water-related pathogens. In cases where information on an infectious agent is lacking, ambiguous, or contradictory, the most conservative data were used.

The first step in quantifying health risk required the development of a detailed description of the risk and consideration of known factors contributing to this risk. Ideally, the risk could be calculated based on exposing a user population to various concentrations of the pathogens of interest. The incidence of adverse reactions would then be measured and the level of risk calculated. Obviously, such studies cannot be performed. However, an approximation can be made by using data from outbreak reports, epidemiological studies, and animal or human feeding studies.

SCREENING OF WATER-RELATED DISEASES

The first step in the screening of water-related pathogens involves the identification of, as well as the gathering of data on, the prevalence, morbidity, and mortality associated with all water-related diseases. In general, water-related diseases affecting man's health occur throughout the world but are most abundant in developing countries. To identify those pathogens that present the greatest risk to military personnel, a list was compiled of the communicable diseases in man that are transmitted via water. Data on the prevalence, mortality, and morbidity of water-related diseases were acquired.

Water-related diseases were then classified by route of transmission. The routes of transmission to humans for these water-related diseases can be described as (1) waterborne, where the infected water must be consumed; (2) water-washed, where an indirect exposure to contaminated water causes the disease (e.g., hand-washing, bathing, eating food cleaned in contaminated water); and (3) water-based, where the infectious agent is carried by a vector that is closely associated with water. Water-related disease is usually associated with an absence or compromise of good hygienic practice and sanitary conditions. In all cases, the infectious organisms must enter water supplies (or a vector closely associated with water) from an infected individual and survive long enough (in the water or the vector) to be transmitted to another individual.

The final screening task was to compare the reported prevalence, mortality, and morbidity data against the list of diseases and to identify those diseases requiring study. In our screening analysis, we identified 20 water-related diseases and their routes of transmission. These are presented in Table 4-1.

The evaluation of the 11 waterborne infectious organisms of greatest concern appears in Vol. 5. This is followed by a discussion of our evaluation of water-washed and water-based infectious organisms, which appears in Vol. 6. However, the method for evaluating the risks from the latter group of infectious organisms is not as quantitative as that used for waterborne infectious organisms. The reason for this is that only a limited amount of data are available concerning the dose-response relationships, environmental concentrations, and persistence of the water-washed and water-based infectious organisms.

WATERBORNE DISEASES

We identified a data format appropriate for the use of an interactive computer model for waterborne diseases. In this instance, the data are separated into two groups: one describing the likelihood that an individual would encounter a given dose of a pathogen in water, and one describing the capability of the exposed individual to withstand a challenge dose (i.e., dose response). Basically, for given levels of pathogens in water, water volume consumed, treatment efficiency, and a pathogen dose-response relationship, a prediction of the number (or percentage) of affected individuals can be made.

Table 4-1. Water-related diseases and routes of transmission.

Water-related diseases	Route of transmission		
	Waterborne	Water-washed	Water-based
Bacterial diseases			
Bacillary dysentery (*Shigella* spp.)	X	X	—
Cholera (*Vibrio choleraie*)	X	—	—
Diarrhea (*Campylobacter*)	X	—	—
Diarrhea (*Escherichia coli*)	X	X	—
Leptospirosis (*Leptospira* spp)	X	X	—
Salmonellosis (*Salmonella* spp.)	X	X	—
Typhoid fever (*Salmonella typhi*)	X	X	—
Skin infections (*Pseudomonas* spp. and *Staphylococcus* spp.)	—	X	—
Yersiniosis (*Yersinia* spp.)	X	—	—
Viral diseases			
Enteroviruses	X	X	—
Gastroenteritis, Norwalk agent, and rotavirus	X	—	—
Hepatitis A (hepatitis virus)	X	X	—
Parasitic diseases			
Acanthamebiasis (*Acanthamoeba* spp.)	X	—	—
Amebic dysentery (*Entamoeba histolytica*)	X		
Ascariasis (*Ascaris lumbricoides*)	X	X	
Balantidium dysentery (*Balantidium coli*)	X	X	—
Dracontiasis (*Dracunculus medinensis*)	—	—	X
Giardiasis (*Giardia lamblia*)	X	—	—
Meningoencephalitis (*Naegleria* spp. and *Acanthamoeba* spp.)	—	X	—
Schistosomiasis (*Schistosoma* spp.)	—	—	X

However, there are no relatively simple field tests for measuring the specific concentration of any of the variety of infectious organisms previously discussed. The present field-water quality standard based on the membrane-filter technique (i.e., coliform densities should not exceed one colony-forming unit (CFU) per 100 mL) is considered acceptable as both a short- and long-term standard for pathogenic organisms, including viruses and protozoa. Until such tests are available for determining either directly or indirectly (based on indicator organisms) the concentration of specific infectious organisms in field water, the military should continue to use the membrane-filter technique for the presumptive determination of the presence of coliform organisms in water. Moreover, further research should be performed with regard to the applicability of a coliform standard to viruses and protozoa as all of these organisms might differ in their survivability and treatability, particularly with respect to disinfection. Nevertheless, no better relationship between an indicator organism and pathogenic organisms in water exists at this time, and the coliform standard is practicable for field application because it eliminates the need to monitor for many different pathogenic organisms that may or may not be present.

To overcome any limitations associated with using a coliform standard for all pathogenic organisms, consideration should be given to transporting water samples collected in the field to a centrally located field laboratory where detailed microbiological analyses could be conducted. Such analyses would permit the concentration of specific infectious organisms to be determined. The data from such laboratory analyses could then be used in combination with the risk-assessment methodology discussed earlier to estimate the related health risks to military personnel exposed in the future.

A two-tier analytical approach might also be considered that would capitalize on the use of the membrane-filter technique in the field to first of all determine whether the concentration of pathogenic microorganisms, particularly those of fecal origin, are likely to be of concern and then, if indicated, employ the more sensitive analytical capabilities of a central field laboratory to quantify the concentration of specific infectious organisms in order to estimate health risks in the future. The two-tiered analytical strategy would be useful for prioritizing the locations requiring sample transport to a central laboratory for further analyses.

WATER-WASHED AND WATER-BASED DISEASES

Because of the lack of data on water-washed and water-based diseases, the approach to screening for these diseases is semiquantitative and limited to the presentation of an environmental classification scheme that allows for the relative comparison of pathogens based on their potential health risks and control strategies. The evaluation of the health risks posed by these pathogens and the identification and efficacy of control strategies require information in the following three main categories: (1) the presence of the agents that cause disease, (2) the dose-response characteristics of the agents, and (3) the probable mode of contact between the agent and susceptible individuals. These categories can be defined further to include information on pathogen concentration, latency, infectivity, persistence, infective dose, and reservoirs.

The term "latency" is defined as the time interval between infection and the onset of symptoms. The latency period for the bacteria and protozoa categories of pathogens is typically a few days and generally less than 10 d. Latency periods for the helminths is significantly longer, on the order of weeks and months.

"Infectivity" in this report is defined as the interval between the excretion of a pathogen by a host and its infection of a new host. The pathogens in the bacterial and protozoal categories are infective immediately. The helminths, however, generally all have a noninfective period.

"Persistence" of the organism in the environment is a measure of how quickly it dies after leaving the human host. Personal cleanliness, then, becomes an important factor for preventing the transmission of disease by pathogens with short environmental persistence. A pathogen with a relatively long persistence time in the environment is more likely to be transferred between a human host and a susceptible individual by other means (i.e., water). Control measures, which include providing a treated water supply and minimizing contact with raw water (i.e., lakes, ponds, etc.), are important in limiting the transmission of these persistent pathogens.

The median infective dose (ID_{50}) is used here as a gauge of pathogen infectivity and allows for a comparison between pathogens. Information about the doses required to infect half of the exposed population is limited. The ID_{50} values are estimates based on human and/or animal data and, in some cases, the opinions of researchers found in the literature we reviewed. Review of the data indicates that a wide range of infective doses exists. For some pathogens, the infective dose is a few organisms (e.g., *Leptospira* spp.: $<10^2$ organisms), while for others it is high (e.g., *Pseudomonas* spp.: $<10^6$ organisms). Generally, the estimates for bacterial infections, with or without the presence of preexisting wounds, indicate that the infective dose is on the order of 10^4 to 10^6 organisms. For the helminth infections, a single egg or larva can infect if ingested, even though the worms may fail to mature. Some viruses and encysted protozoa require ≤ 10 organisms to establish an infection.

Some diseases are almost exclusively infections of man. However, many of the pathogens involve animals as alternative hosts or as hosts for other stages in the organisms' life cycle. Because animals are a major reservoir for many of these pathogens, the proper collection, treatment, and disposal of waste, alone, will not provide the necessary controls to eliminate the transmission of disease associated with these pathogens.

Generally, the mode of transmission for the pathogens water-washed and water-based under review in Vol. 6 either is through person-to-person contact or is by direct contact of skin with contaminated water and/or soil. The two exceptions are for the pathogens *Balantidium coli* and *Dracunculus medinensis*, where transmission is achieved primarily through the ingestion of contaminated water.

Classification of Water-Based and Water-Washed Diseases

Five environmental categories of infection can be defined for the pathogens under review. These categories are based on the environmental features previously discussed, which include latency, infectivity, infective dose, and mode of transmission. These environmental categories of infection can be defined as follows:

Category I. The infections in this category have a low infective dose ($<10^2$ organisms ingested), are infective immediately upon excretion, and can be spread easily whenever water supplies are untreated and personal hygiene is not ideal. However, ingestion of water containing the organisms is required.

Category II. The infections in this category have a medium or high infective dose, are infective immediately upon excretion, and can be spread easily from person to person whenever water supplies are untreated and personal hygiene is not ideal. In addition, contact with untreated water (i.e., lakes, ponds) is associated with the transmission of these pathogens.

Category III. The infections in this category are similar to those in Categories I and II, except for one important difference. These organisms require an animal host as part of their life cycle. Also, limiting host contact with untreated water (i.e., lakes, ponds) is a significant factor in controlling these infections.

Category IV. The infections in this category have a low infective dose and are not immediately infective upon excretion. This category contains the soil-transmitted helminths. Provisions for the proper collection, treatment, and disposal of wastes and personal hygiene are important control measures for this category.

Category V. The organisms in this category are water-based helminths that require an aquatic host to complete their life cycles. Control is achieved by limiting host contact with untreated water (i.e., lakes, ponds, standing water), the provisirn of a treated-water supply (in the case of dracontiasis), and the control of the intermediate host.

A definite difference exists between the first two categories and the last three. For the last three categories, the major control measures involve limiting contact between the potential host and untreated water (i.e., ponds, lakes, standing water) and providing proper collection, treatment, and disposal of wastes.

Based on this type of classification, the immediate risk posed to military personnel is the highest from pathogens in Category I and the lowest from pathogens in Category V. However, if the assumption is made that all of these organisms will be present within water and also immediately infective, it would be more realistic to base the comparison of risk of infection on median infective dose of the pathogen and its latency. On this basis, the pathogens can be roughly grouped as follows: short latency (i.e., ≤7 d) and low infective dose (i.e., $\leq 10^2$ organisms), long latency and low infective dose, and short latency and medium-to-high infective dose. Based on this type of classification, it appears that the pathogens that present the highest risk of infection, relative to a short latency period (i.e., ≤7 d), appear to be *Staphylococcus* spp., *Leptospira* spp., *Balantidium coli*, and *Ascaris lumbricoides*. The pathogens that present the highest risk of infection for the long latency period (i.e., 1 y) appear to be *Schistosoma* spp. and *Dracunculus medinensis*. The pathogens that present the lowest risk are those with a medium-to-high infective dose and a short latency period.

The provision of a treated-water supply, in combination with an adequate supply of water and limiting the contact of personnel with untreated water (i.e., lakes, ponds, rivers), should adequately control the transmission of the above pathogens.

UNCERTAINTIES AND RESEARCH RECOMMENDATIONS

In performing this study, it became obvious that the analysis of risk is influenced strongly by the information available on the occurrence and concentration of the pathogen in water, as well as the level (i.e., efficiency) of water treatment. The lack of information on the occurrence and concentration of pathogens in water is disturbing. Better definition of this variable would improve the confidence of the risk estimates. For the most recently identified etiologic agents of water-washed, water-based disease organisms reviewed in this text, such as *Aeromonas* spp. and non-Cholerae *Vibrio* spp., all categories of research need to be explored or improved.

There are many instances in which no techniques exist that would allow for the measurement of pathogens in water. Therefore, it is strongly recommended that additional research be performed to develop reasonable quantitative techniques for the isolation and enumeration of important pathogenic agents in water. These methods could then be applied to determine the concentration of these infectious agents in specific sources of field drinking water in selected geographic areas.

One of the most important but neglected areas is the relationship between indicator-organisms and pathogens. Frequently, the correlation between coliform numbers in water and numbers of pathogens or the disease rate in those exposed to contaminated water is complicated and incomplete. We also note that a serious question exists as to the advisability of using coliforms as indicators of water quality in tropical areas of the world. Research is needed to (a) demonstrate which microorganism(s) would best serve as indicators of water quality under a variety of conditions; (b) determine the relationship between indicator-organisms and the numbers of specific infectious organisms that may be present; and (c) develop methods for the rapid detection and enumeration, in water, of appropriate indicators for specific pathogens or for the pathogens themselves. These data are essential to improving the confidence of disease-risk estimates based on water-quality criteria.

As for the level of treatment, the risk estimates made in this study assumed a maximum treatment-efficiency rate of 2 to 5 log removals, where log removal is defined as the base 10 logarithm of the factor of reduction in number of organisms per liter. Reducing the uncertainty associated with this variable by reducing the pathogen-removal range and/or increasing the removal rate was shown to improve the confidence of the risk estimate. For example, increasing the treatment-efficiency removal rate from 2 to 5 logs, to 4 to 5 logs, and 5 to 6 logs dramatically lowered the risk distribution. Documentation of the removal rates consistently obtained through the use of military water-treatment equipment would improve the confidence in the risk estimates.

Several other issues warrant further investigation. These issues include secondary infections (where the primary infected case transmits the disease via person-to-person contact), multiple exposure days, the relationship between infection rates and cases of clinical disease, and large numbers of troops at risk (i.e., >20).

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CHAPTER 5. TREATMENT

Volumes 7 and 8 of the series, *Evaluation of Military Field-Water Quality*, are concerned with the reverse osmosis (RO) components of the reverse osmosis water-purification unit (ROWPU) that were available in 1986 and with pretreatment, RO bypass, and other considerations related to field-water treatment. Together, these two volumes represent an assessment of the treatment, disinfection, and water-quality analysis procedures now used by U.S. military forces.

The primary purpose of this work is to ascertain whether the performance of the current 600-gph ROWPU is adequate to meet the water-quality standards recommended by this study. A secondary objective is to review the design of the treatment units used in the ROWPU, as well as the prescribed mode of operation, and to make constructive recommendations.

Reverse osmosis (hyperfiltration) is a complicated water-treatment process that is not described easily with a few process parameters. Furthermore, published literature on the type of membrane currently used in the ROWPU was scarce. Therefore, we required a mathematical model that could be used to extrapolate existing information to different operating conditions. It was successful for seawater and single-salt solutions, but it proved to be unsuccessful for just any mix of salts that might be encountered in nature.

BACKGROUND AND DESCRIPTION OF THE 600-GPH ROWPU

The mobile 600-gph ROWPU was designed to operate for two 10-h periods a day with interruption only to refuel, backwash filters, and perform routine maintenance and operational checks. The product-water flow rate was to be 600 gph when treating fresh water (less than 500 ppm total dissolved solids [TDS] at 77°F), and 400 gph when treating seawater (approximately 35,000 ppm TDS at 77°F). The actual potable-water production from seawater is greater than this because of optimal component configuration.

The ROWPU consists of (1) a 30-kW generator power source (only 22 kW is required), (2) a pretreatment system, (3) an RO system and (4) a post-treatment system. These parts are contained in a flatbed cargo trailer (see Fig. 5-1) with an overall weight of 6-1/2 tons, a length of 230 in., a width of 96 in., and a height of 97 in. These specifications allow for ROWPU transportation by train, road, or air. The system is also designed to

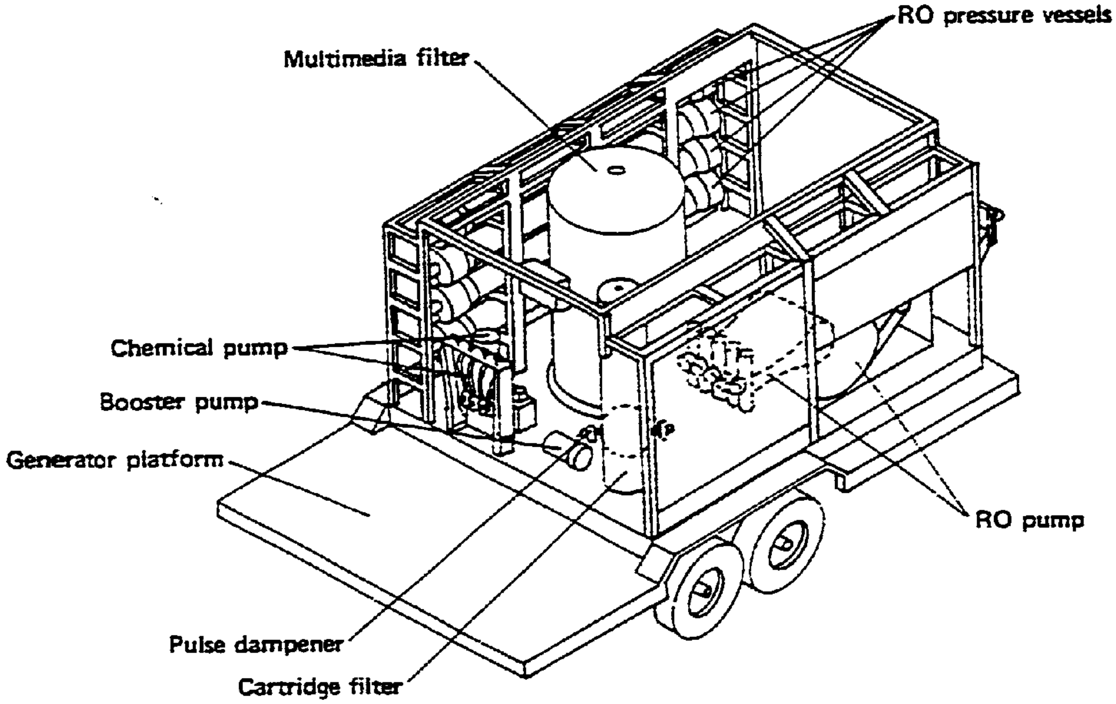

Figure 5-1. Rear view of 600-gph ROWPU (generator removed) and transport trailer used by U.S. Army. Reprinted from U.S. Army Training Manual, TM 5-4610-215-10, 1982.

withstand a 24-g deceleration for parachute delivery. A diagram of a typical field installation of the ROWPU is shown in Fig. 5-2.

Two raw-water pumps connected in series draw water from the source and pump it under pressure into the ROWPU pretreatment system. The suction lift of these pumps is limited to 10 ft. A float and strainer installed at the end of the water-intake hose keeps leaves, plants, stones, fish, and dirt out of the pumps and filters of the ROWPU.

Water-conditioning chemicals are pumped into the water just before it enters the filtration unit. A citric acid solution is used to keep acid-soluble substances, such as metal hydroxides and calcium carbonate which may foul the RO membrane, in solution. Sodium hexametaphosphate is used to remove organic substances and microbiological slimes that are not acid-soluble.

The RO system consists of four pressure vessels connected in series. Each pressure vessel contains two membrane elements.

In the event of chemical and/or radiological contamination, granular activated-carbon (GAC) and mixed-bed ion-exchange columns can be incorporated as post-treatment for the RO process. These columns are designed for an average 3-d operational capacity. If required, one of the two raw-water pumps is used to force the water through these two columns.

If nuclear and chemical warfare agents are not present in raw fresh water (TDS concentration is much less than that of seawater), ideally the feed would not require demineralization. A "freshwater bypass" of the RO system has been proposed for this situation. A main advantage of using such a bypass procedure allows a maximum flow rate of 1800 gph. This flow rate is three times greater than the design flow with the RO system included in the treatment chain. However, it is still uncertain whether the current cartridge filters can reliably remove cyst-sized microorganisms, and for this reason we do not recommend that the RO section be bypassed.

Finally, the product water coming out of the RO system is post-chlorinated. Two collapsible 1500-gal tanks connected in series permit a minimum of 5 h contact time for disinfection. If the RO elements are bypassed, the recommended contact time for the disinfection is 100 min. A distribution pump sends the product water to any point desired. The brine water is disposed of downstream from the raw-water intake, or it is stored for use in backwash.

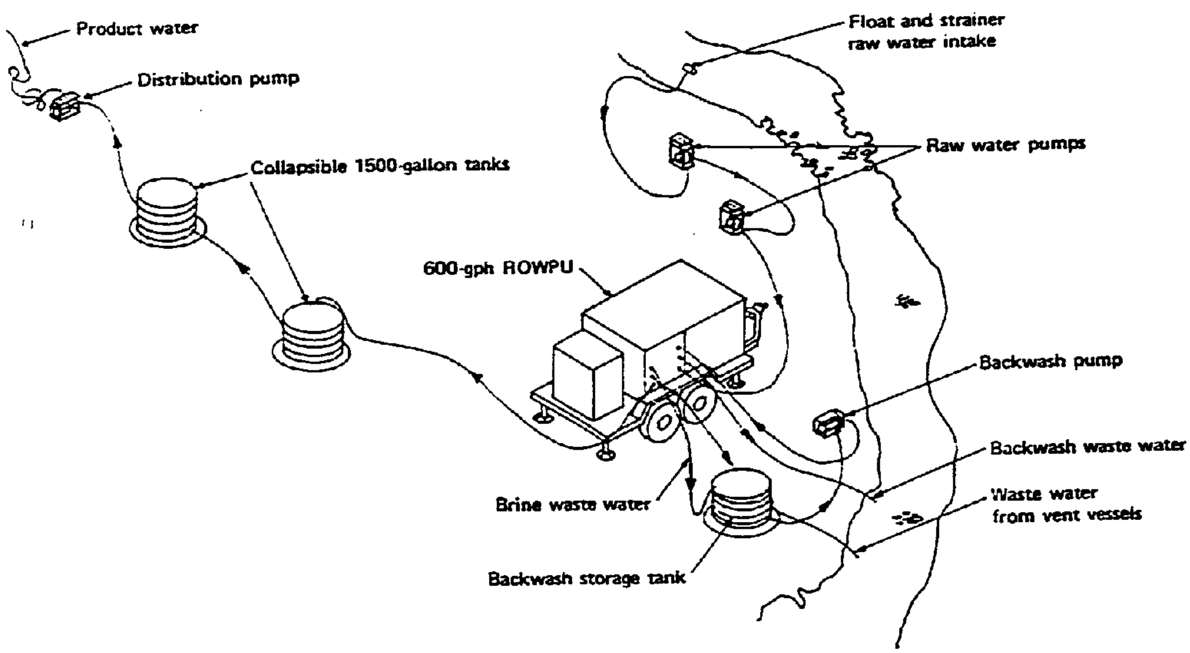

Figure 5-2. Typical field installation of 600-gph ROWPU. Reprinted from U.S. Army Training Manual, TM 5-4610-215-10, 1982.

PRINCIPLES OF HYPERFILTRATION

Reverse osmosis (RO) or hyperfiltration removes molecules in the size range of 1 to 10 Å (0.0001 to 0.001 μm) from water (molecules ranging from 1 to 10 times the size of water molecules). The RO membranes remove most electrolytes effectively. As a result, the difference between osmotic-pressures on either side of the membrane becomes appreciable, especially in the case of high initial salt concentration. Thus, the amount of external pressure applied to the upstream side may have to be significantly large to overcome the osmotic-pressure gradient across the membrane. The pressure applied across an RO membrane may range from about 20 to 100 bars (300 to 1500 psi), depending on the salt content of the water being demineralized.

The RO membranes are thin enough to obtain good water flows per unit area of membrane surface. These delicate membranes are supported usually by a backing of tough fibers. This backing may be in multiple layers with the layers having little or no RO properties. Membranes of this type are referred to as asymmetric, composite, or anisotropic.

Particles and molecules greater than about 10 Å (0.001 μm) in size are removed with asymmetrical membranes containing micropores. The mechanisms of removal are sieving and sorption; the process is called ultrafiltration (UF). Most of the dissolved salts pass through UF membranes; the decrease in osmotic pressure, which can be ascribed to the salts, is negligible. Thus, the pressures that have to be exerted across UF membranes are considerably less than those exerted across RO membranes. They range from about 0.5 to 5 bars (approximately 7 to 75 psi) in practice. The foregoing does not mean, however, that macromolecules or particle suspensions cannot exert osmotic pressures.

When the minimum size of the particles rejected is about 0.02 μm according to one report or 0.1 μm according to another, the sieving process is called microfiltration (MF). Microfiltration membranes are usually symmetric; the pressures exerted across the membrane commonly range from about 0.1 to 1 bar (approximately 1.5 to 15 psi) in practice.

Neither UF nor MF membranes contain pores of a uniform size, with the single exception of the Nuclepore MF membrane. Consequently, such membranes contain a spectrum of pore sizes; this means that the cutoff in the sizes of the particles and molecules passing through the membrane is not sharply defined.

SUMMARY AND CONCLUSIONS

SEA SALTS (STRONG ELECTROLYTES)

Water pumped from the ocean, ocean embayments, and estuaries essentially contains sea salt. In Volume 7, information is presented showing that of the typical substances comprising sea salt, the chloride ion is removed the least with RO membranes. The chloride standard is thus the critical standard; achieving this standard will ensure that the other standards TDS, Mg^{++}, and $SO_4^{=}$ are met. The same is true for achieving the recommended standards for these constituents that are presented in Vol. 4. The chloride standard of 600 mg/L should always be used to check compliance with the drinking-water standards for Mg^{++}, $SO^{=}_4$, and TDS.

In most cases with the 600-gph ROWPU, the greater the product-water flow, the less the chloride-ion concentration in the product water. This applies especially to operating temperatures of 45°C or less.

The brine-water flow should never be decreased much below 13.5 gpm for any 6-in. spiral-wound element. This gives a maximum permissible product-water flow of about 20 gpm, or about 60% product recovery for the ROWPU as presently configured. It may be noted that this is significantly greater than the 12 gpm established by the military for salt water. The maximum permissible applied pressure specified by the military is 800 psig for salt water. Increasing this limit to the maximum attainable of 980 psig for the ROWPU increases the product-water flow at temperatures less than 45°C, and this in turn decreases the concentration of chloride ions in the product water. Thus, increasing the permissible limits on product-water flow and applied pressure to 20 gpm and 980 psig, respectively, extends the range in feed-water quality that can be treated successfully with UOP TFC-1501 PA elements (former specifications).

The U.S. Army has stipulated that the useful life of a spiral-wound element in the 600-gph ROWPU should be at least 2000 h. Tests performed on UOP TFC-1501 PA elements indicated that the elements compacted and deteriorated rapidly at about 54°C and 600-psig pressure when such pressure was applied for 10 to 12 h daily for a total run time of about 200 h. The product-water flux dropped about 50%, and the ratio of salt passage to rejection increased about 80% during that time. This indicates that the elements would have been useless after 2000 h of operation. (It should be noted that the maximum feed-water temperature recommended by all the manufacturers of spiral-wound elements is 45°C.) Also, we recommend that the temperature of the product-water stream should be registered automatically on the control panel. This is needed to operate the ROWPU properly.

In summary, the performance of the RO components of the 600-gph ROWPU can be improved significantly for salt water simply by modifying the restrictions placed on maximum and minimum product-water flow, and the maximum applied pressure. The performance of the entire 600-gph ROWPU unit can be improved significantly by decreasing the feed-water flow to the unit. The advantages of this approach are manifest and include the following: a greater product-water recovery; longer run times on the multimedia and cartridge filters; improved multimedia filter removal efficiency; a smaller, lighter, and cheaper RO positive-displacement pump; and a decrease in the rate of consumption of the feed-water conditioning chemicals. Some thought should be given to the redesign of the RO portion of the ROWPU. This should include a complete evaluation of the effects of decreasing the feed-water flow and, possibly, the staging (i.e., arrangement of elements in ROWPU) of smaller elements to improve product-water recovery while maintaining the stipulated minimum brine flow.

MIXTURES OF STRONG ELECTROLYTES OTHER THAN SEA SALTS

No conclusions can be drawn concerning the performance of the ROWPU with fresh and brackish surface and ground water except to say that the rejections of TDS, Cl^-, Mg^{++}, and $SO_4^=$ should be adequate in nearly all cases to meet the recommended water-quality standards.

WEAK ELECTROLYTES (ARSENIC AND CYANIDE)

Published data on the subject of the removal of the weak electrolytes with noncellulosic thin-film composite membranes are scarce. Arsenic studies performed with cellulose acetate membranes and polyamide hollow fibers indicate that As(V) probably will be well rejected at most pH levels. As(III), on the other hand, may be poorly rejected if citric acid is added to the ROWPU feed water. Co-precipitation may also occur with other compounds, depending on the feed-water chemistry.

The rejection of hydrocyanic acid (HCN) apparently has not been investigated in any study. Cyanide probably will pass through a membrane with little or no rejection if citric acid is added to the ROWPU feed water, or it will precipitate out, depending on the feed-water chemistry.

BYPASS MODE

The U.S. Army is considering the use of the 600-gph ROWPU in an alternate configuration, identified as the "bypass mode." Only the multimedia and cartridge filters would be used, followed by chemical disinfection. The advantage of this is that the loss of approximately 1/2 of the filtered water as RO reject water would be avoided. A second benefit of this arrangement would be cutting the power requirements in half, because roughly 50% of the power supplied to the ROWPU is used in the high-pressure pump/RO process.

The current treatment system in the bypass mode would include the following components: (1) a garnet-sand-anthracite deep-bed multimedia pressure filter, (2) a 5-μm (nominal rating) cartridge filtration unit, and (3) chlorination with a chlorine dose equivalent to 5 to 10 mg/L of free-chlorine residual, depending on the pH, temperature, and other feed-water-quality parameters. Three criteria were suggested by the U.S. Army planners to be considered in the treatment of raw waters in the bypass mode. These criteria were as follows: (1) the water must be free of acutely toxic chemicals from industrial, agricultural, domestic, or natural resource contributions; (2) the water must satisfy potability requirements regarding NBC (nuclear, biological, and chemical) warfare agents; and (3) the water must meet palatability requirements.

Modifications to the treatment train have been considered by the U.S. Army planners. Two of the alternatives under consideration are (1) reducing the pore size of the cartridge filters from a nominal rating (defined by a military test) of 5 μm to an absolute rating (the diameter of the largest spherical particle passing through a filter) of 3 μm, and (2) using alternative disinfectants that might have viricidal and cysticidal properties superior to those of chlorine. A major concern expressed by the U.S. Army planners was the health risk inherent in the failure to remove pathogenic viruses and cysts when bypassing the RO section of the 600-gph ROWPU.

Disinfection bears the burden as the primary defender against the transmission of waterborne diseases. Filtration serves as a secondary barrier, but it never can be trusted to provide safe drinking water under all circumstances.

DIRECT FILTRATION

The main pretreatment unit of the 600-gph ROWPU represents a mode of operation called direct filtration without in-line flocculation. The filter is a deep-bed type containing several layers of media with different properties. Such filters are called mixed-media or multimedia filters.

The single-collector theory for deep-bed filtration is based on the assumption that completely destabilized particles always stick to the filter media, but do not flocculate as they move through the filter bed. The theory grossly underestimates the chances that the particle will be collected in a stacked bed of collectors, but the general change in the collector efficiency with particle size is believed to be correct.

Particles with sizes around 2 µm will be removed the least by the multimedia filter, and particles greater than about 20 µm should be removed almost completely. However, the cysts of pathogenic protozoans range in size from about 5 to 30 µm; consequently, the cysts may or may not be well removed. Finally, decreasing the filtration rate from 7.0 to 4.6 gal/(min • ft^2) (current feed rate to minimum feed rate) does not increase the ability of the filter to remove cyst-sized particles, although the filtered-water turbidity should be decreased somewhat.

CARTRIDGE FILTERS

Cartridge filters with a 5-µm size rating are installed downstream from the ROWPU multimedia filter. These filters are specifically intended to polish the water to protect the RO membranes; they do not remove viruses or bacteria adequately.

COAGULATION CONTROL

The failure to provide the optimal coagulant and water conditioner to the pretreatment units of the 600-gph ROWPU represents a good example of an "out-of-sight, out-of-mind" operation. The units are operated under pressure, and any turbidity escaping the pretreatment units is deposited on the RO membranes. The processed water is of good quality even when the pretreatment units are not functioning properly. This may seem to be a positive attribute of the ROWPU, but the life of the RO elements will be shortened significantly under such conditions of turbidity deposition on the membranes.

The amount of coagulant added to the water has to be just right, neither too large nor too small. Unfortunately, the effect of off-doses of coagulant on the performance of a deep-bed filter operated in the direct-filtration mode has not been investigated extensively.

EVALUATION OF ROWPU FILTRATION

According to specifications, the apparatus contained in the pretreatment section of the ROWPU should be able to treat a water with an initial turbidity ranging from 3 to 7 NTU adequately. However, our results, which are presented in Volume 8, did not support this conclusion. The multimedia filter removed on the average only 84% of the turbidity, and 74 to 98% of the bacteria. Cysts were not investigated, but the removal of the cysts probably would have proven better than the removal of the bacteria. Even so, the odds are that some of the cysts would have passed through the filter.

The performance of the ROWPU multimedia filter was less than one might expect for the relatively low-turbidity river water tested. The reasons for this may be an improper coagulant dose and inadequate mixing. However, considering the unusual hazards faced by Army personnel in all possible climates, it would seem reasonable that a filtering system should be provided to remove essentially all protozoan cysts and other large parasites. Theory and practice indicate that the multimedia filter installed in the ROWPU will never accomplish this task, even with perfect particle destabilization, also the performance of the cartridge filters appears to be unreliable at this time. Considering these factors, we recommend that the RO section of the ROWPU should not be bypassed until it is known for certain that the cartridge filters will remove cyst-sized particles reliably under all circumstances. This recommendation is even more important because of recent evidence strongly suggesting that the microorganism *Cryptosporidium*, a small (4 to 6 μm) protozoan parasite with oocysts (containing infective sporozoites) that appears to be (1) resistant to the disinfectants used routinely in hospitals and laboratories (e.g., in laboratory studies at Auburn University in Alabama, disinfection normally involves the use of full-strength commercial bleach) and (2) capable of deformation such that they can pass through cartridge-filter pore diameters greater than 2 to 3 μm in size, belongs on the list of waterborne organisms capable of producing outbreaks of gastroenteritis in humans (symptoms include diarrhea and abdominal cramps that can last from 1 to 2[illegible] d). If the ROWPU must be operated in the bypass mode, it is recommended that the dose of disinfectant used be made equal to that currently employed in the field for untreated raw water.

THE MOBILE WATER PURIFICATION UNIT

At this time, the Mobile Water Purification Unit (MWPU or Erdlator) is also available for water purification. The MWPU can decrease the turbidity of a river water from an average of 50 NTU to 0.2 NTU, provided that a well-defined sludge blanket is maintained. The corresponding decrease in the total-coliform bacteria was about 99.9%. No information was found in the literature relative to the removal of protozoan cysts with the MWPU, but in light of the findings of others concerning the removal of cysts with diatomaceous earth precoat filters, it can be safely assumed that nearly all of the cysts are removed. Thus, the MWPU provides an effective primary barrier against the transmission of waterborne diseases.

DIATOMACEOUS-EARTH (PRECOAT) FILTRATION

A number of studies performed on the removal of microorganisms and particles with the precoat-type filter demonstrates that the filter essentially strains the particles from the water when no coagulant is added to the precoat or the filter feed water. Large particles are well removed, but fine particles are not removed. Because most of these studies used very clean waters (tap water, distilled-deionized water, etc.), the problem of maintaining cake porosity with turbid waters was not addressed. The filtration rates investigated commonly were in the range of 1 to 2 gal/(min • ft^2).

It was noted early in the development of precoat filters that coating the diatomite with alum improved the removal of suspended solids. Cationic polyelectrolytes were eventually substituted for the alum and research proceeded in this vein for a number of years. Coagulant can be added to the feed water, instead of the filter media, with equally good results as long as the particles were completely destabilized.

DISINFECTION

There are three specific water-disinfection methods likely to be available today for field use by military personnel. The three methods of disinfection fall into two categories—physical and chemical treatment. Heating the water falls into the first category and adding iodine (as globaline, which contains tetraglycine hydroperiodide) or adding chlorine falls into the second category. The method selected for disinfection generally will depend on the quantity of water to be treated (e.g., a quart of water [960 mL] in a canteen for use by a single individual, or multiple gallons of water for use by a large number of individuals) and/or the availability of a treatment process.

Currently, chlorination remains the most effective and convenient proven method available to the military for disinfecting large quantities of water for consumption by military personnel in the field. If the reverse osmosis (RO) components of the ROWPU are bypassed and chlorine is available, then the dosage of chlorine used for disinfection should be in accordance with the maximum dosage recommended in the field for disinfecting untreated (raw) water in water-sterilizing bags (commonly referred to as Lyster bags) and in canteens under worst-case conditions. For example, military personnel currently are instructed to add sufficient chlorine to the raw water in Lyster bags so that the total-available residual chlorine, after 30 min of contact time, will be at least 5 mg/L. However, certain raw-water conditions such as the presence of especially resistant disease organisms, a pH of 8 or above, particularly cold water, or water containing large amounts of organic material may require more than normal chlorination for disinfection.

For individual canteens (1 qt or 960 mL), iodine is an acceptable disinfecting agent and military personnel should continue to add iodine (i.e., globaline) purification tablets to such water, as specified by current military doctrine. Each globaline tablet is designed to release 8 mg/L of iodine, and the minimum contact time required for disinfection is 25 min; two tablets are recommended to ensure adequate disinfection for turbid or colored water. When chlorine is not available as a disinfectant for water produced by ROWPU's operating in the bypass mode, the command surgeon should recommend the maximum dosage of iodine for the canteens being filled with such water. Also, it is important to recognize that the addition of iodine may introduce a slight taste and color change in the treated water that could affect its palatability for some individuals.

Boiling water may be the only effective alternative for disinfecting sources of drinking water in the event that neither chlorine nor iodine is available. Raising the temperature of water to its boiling point and then boiling it for 15 to 20 min is practical, but only on a small scale and in emergency situations.

The importance of efficient water disinfection is illustrated by recent data showing that the most resistant waterborne pathogens (e.g., Norwalk virus and Cryptosporidium) may be inactivated only by disinfecting chemicals, specifically high concentrations of free available chlorine in combination with long contact times. Additionally, even though the alternatives to chlorine disinfection now being investigated (e.g., N-halamine compounds) may be more stable than chlorine, particularly in the presence of organic demand, their effectiveness depends on even longer contact times than are required for a comparable concentration of free chlorine.

SUGGESTED IMPROVEMENTS

It is recognized that the U.S. Army will eliminate the MWPU during the next 10 years. Even so, its performance could be improved substantially by replumbing the chemical-feed lines in such a manner as to introduce the chemicals into the pipeline leading to it. The stability of the sludge blanket then will be increased significantly.

The current 600-gph ROWPU represents a much greater problem. A study should be conducted to determine just how the polyelectrolyte should be mixed with the feed water to obtain optimal pre-filter performance. The mean velocity gradient, G, can be altered by pipe inserts manufactured by several firms in the United States. The time required to obtain complete particle destabilization with each G should also be investigated, and the dimensionless number G • t, where t is time, should also be derived for each unit as a comparison.

It is not easy to judge the best method to obtain the optimal coagulant dose for the ROWPU as presently configured. All that can be encouraged here is the development and employment of a rugged and dependable zeta-potential meter.

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CHAPTER 6. EVALUATION OF RISK

The chemical substances, infectious organisms, and physical properties of field-water supplies that were likely to directly or indirectly produce performance-degrading health effects in military personnel on a worldwide basis were identified in the three parts of Vol. 2, and in Vols. 5 and 6 of this study. Turbidity, color, and total dissolved solids (TDS) are the physical properties that are of military concern in field water. The other chemical constituents that are of major military concern in field water are (1) chloride, (2) magnesium, (3) sulfate, (4) arsenic, (5) cyanide, (6) the pesticide lindane, and (7) metabolites of algae and associated bacteria. Bacteria, viruses, and parasites (e.g., protozoa and helminths) are categories of water-related infectious organisms that are also of great military concern. Radioactivity and the threat agents hydrogen cyanide, organophosphorous nerve agents, trichothecene mycotoxin, lewisite, mustard, and BZ incapacitant are also of concern. Volumes 4, 5, and 6 of this report present the health-effects criteria and recommendations for field-water-quality standards applicable to these physical properties, chemical substances, infectious organisms, and threat agents, except mustard and BZ incapacitant, which are available as separately authored reports and are not addressed in any of the other eight volumes of this series. The recommended field-water-quality standards were derived to protect populations of military personnel against performance-degrading health effects that could jeopardize the accomplishment of military missions.

In Vol. 9, we present criteria for assessing the health risks for populations of military personnel exposed to field water with the physical properties, chemical substances, or infectious organisms of military concern at concentrations exceeding safe levels. These criteria were developed from the dose-response relationships for physical properties, chemical substances, and infectious organisms described in Vols. 4, 5, and 6. Figures summarizing the toxicity data are presented in Vol. 9 for these likely constituents of untreated field water to enable military risk managers to quickly assess the potential performance-degrading effects that a measured concentration of a particular constituent can have on exposed personnel. In Vol. 4, Part 2, we present criteria for assessing the health risks for populations of military personnel exposed to field water contaminated with threat agents and radioactivity at levels exceeding the interim recommended standards. In Vols. 5 and 6, we present our criteria for evaluating risk associated with water-related infectious organisms.

In addition, Vol. 9 contains an evaluation of the general chemical and biological quality of the water resources in selected geographical regions of the world that represent potential theaters of operation for U.S. military forces. This evaluation is the result of an analysis of available water-quality monitoring data and various indicators of water-quality conditions (e.g., geohydrology, climate, sanitation, industrialization, etc.). Accompanying this evaluation are maps and tables alerting military planners to the chemical or biological quality of water supplies (i.e., ground and surface waters) that are indicative of major geographic regions such as (1) Africa, (2) the Middle East, (3) Europe and the Soviet Union, (4) Asia, and (5) Latin America, principally Central and South America. Additionally, important locations that lack meaningful field-water-quality monitoring data are identified to indicate the need for monitoring water quality especially in these areas.

HEALTH RISKS

TURBIDITY AND COLOR

Health effects stemming from the presence of turbidity or color in field-water supplies center on the risk of voluntary dehydration caused by refusal to consume water. The effects of dehydration can cause significant performance degradation and thereby jeopardize accomplishment of a mission. The relationship between turbidity and color and water rejection has been documented through the use of action-tendency scales, which are used to attempt to quantify behavioral responses to stimuli. The actual debilitating effects of dehydration progress in sequence, including discomfort, weariness, apathy, impaired coordination, delirium, and heat stroke. Turbidity levels greater than 1 NTU can also interfere with disinfection. This is particularly true when the turbidity is composed primarily of organic matter. Turbid waters are also aesthetically inferior, which can lead to decreased water consumption and possible dehydration. Color levels greater than 50 color units for short-term exposure and exceeding 15 color units for long-term exposure can also increase the risk of dehydration in the members of a military population, but these color levels are not associated directly with any adverse health effects. Thus, limiting turbidity to 1 NTU and color to either 50 color units for short-term exposures or 15 color units for long-term exposures will diminish averse responses to field water. Turbidity levels less than or equal to 1 NTU also tend to improve the efficiency of disinfection for most pathogenic microorganisms (*Giardia* and *Cryptosporidium*, which can cause severe diarrheal illness, are two notable exceptions and their elimination by disinfection chemicals may require turbidity removal by filtration processes to levels less than or equal to 0.1 NTU).

TOTAL DISSOLVED SOLIDS

As for turbidity and color, the health effects related to concentrations of TDS above the recommended standards in field-water center on the risk of dehydration caused by water rejection. Dehydration can result in performance degradation. The relationship between TDS concentration and water rejection has been documented through the use of action-tendency scales. For example, about 2% of a military population might refuse to drink water containing the recommended TDS standard of 1000 mg/L and thereby be at risk of dehydration. Moreover, at a TDS concentration above 2800 mg/L, about 50% of the exposed military population might refuse to drink the water.

CHLORIDE

Even though chloride might produce laxative effects at concentrations exceeding 600 mg/L, laxative effects are not the health effects of greatest concern for chloride. The health effects of greatest concern for military populations exposed to elevated concentrations of chloride ion in field-water are not direct; rather, they are associated with the dehydration of military personnel who reduced their consumption of field water because of its poor taste. The effects of dehydration can result in significant performance degradation. Only about 2% of a military population drinking water with the recommended chloride standard of 600 mg/L would be at risk of dehydration due to water rejection; however, more than 10% might refuse to drink field water containing a chloride concentration of 1000 mg/L.

Laxative effects that result from the consumption of water containing an elevated concentration of chloride appear to be associated with the process of osmoregulation of fluids in the intestinal tract. It has been reported that a single oral dose of 0.5 L water containing 7.4 g/L of NaCl (4.5 g/L of Cl^-) can induce a laxative effect. Synergisms between laxative producing solutes such as chloride, magnesium, and sulfate are not addressed because of a lack of data.

MAGNESIUM

The performance-degrading health effects stemming from elevated levels of magnesium ion above the recommended standards for field-water supplies center on the risk of dehydration caused by acute laxative action. However, the relationship between magnesium concentration in drinking water and such action is poorly documented except for data concerning clinical administration of magnesium ions in a saline laxative.

We recommend field-water-quality standards for 5 and 15 L/d consumption rates on the basis of the single oral dose of magnesium ions reported to cause laxative effects in fasted individuals when administered clinically as a saline laxative. This dose is 480 mg and the equivalent field-water-quality standards for 5 and 15 L/d for Mg^{+2} are 100 and 30 mg/L, respectively. Concentrations above these levels are considered to be associated with increasing incidence of laxative effects, which can lead to dehydration. The actual debilitating effects of dehydration include discomfort, weariness, apathy, impaired coordination, delirium, and heat stroke. Unfortunately, the proportion of the exposed military population that could be affected by performance-degrading symptoms at concentrations above recommended safe levels cannot be estimated from the available data.

SULFATE

Health effects stemming from levels of sulfate ion above recommended standards in field-water supplies also come about through the risk of dehydration caused by acute laxative action. This dehydration can cause significant performance degradation. The relationship between sulfate concentration in drinking water and laxative effects is poorly documented.

We recommend field-water-quality standards for sulfate based on the single oral dose of sulfate ions reported to cause laxative effects in fasted individuals when administered clinically as a saline laxative. This dose is 1490 mg and the equivalent field-water-quality standards for SO_4^{-2} are 300 mg/L and 100 mg/L for 5 and 15 L/d consumption rates, respectively, and exposure periods up to either 7 d or 1 y. The actual debilitating effects of dehydration include discomfort, weariness, apathy, impaired coordination, delirium, and heat stroke. Unfortunately, at levels of sulfate above the recommended standards, neither the proportion of the exposed military population affected by laxative effects, nor the severity of those effects, can be estimated from the available data.

ARSENIC AND LEWISITE

Reports of human exposure to inorganic arsenic via ingestion include several in which the arsenic was consumed in drinking water. Where exposures were high enough to cause observable health effects, several different organ systems are affected, including the circulatory, gastrointestinal, integumentary, nervous, hepatic, renal, and immune systems. These effects could be performance-degrading. Lewisite is an organic trivalent arsenic compound that is a threat agent; ingestion of lewisite can cause gastrointestinal injury and may be lethal.

Four epidemiological studies document adverse effects when the levels of arsenic exceed 0.40 mg/L over the long term. In addition, while the literature suggests that people may be able to tolerate levels of arsenic in drinking water approaching 1 mg/L for short periods, higher concentrations could cause facial edema and gastrointestinal symptoms such as anorexia, nausea, epigastric fullness, vomiting, and abdominal pain. Skin lesions, upper respiratory symptoms, headache, chill, sore throat, rhinorrhea, and signs of neuropathy are among the chronic symptoms that might also occur. These effects would certainly interfere with a soldier's performance. Consequently, the recommended standards for arsenic were derived to protect military personnel from both acute and chronic effects. For exposure periods of up to 7 d, we base the standards for 5 and 15 L/d consumption rates on a daily dose of 1.5 mg/d, and for exposure periods up to 1 y, we based the standards on a daily dose of 0.32 mg/d. No additional safety factor was applied to the lowest no effects level found for lewisite administered to laboratory rabbits to derive interim standards for 7-d exposure of 0.08 mg/L for 5L/d and 0.027 mg/L for 15L/d consumption rates.. Unfortunately, the proportion of the exposed military population that could be affected by performance-degrading symptoms at concentrations above recommended safe levels cannot be estimated from the available data.

CYANIDE AND HYDROGEN CYANIDE

Exposure to cyanide in drinking water can lead to a variety of performance-degrading health effects. Once a toxic level has accumulated in the blood, the cyanide exerts its effects rapidly, acting as a chemical asphyxiant. The nervous and respiratory systems are the first to fail. Typical symptoms of acute exposure to cyanide include headache, breathlessness, weakness, palpitation, nausea, giddiness, and tremors. Concentrations of cyanide in field water that could produce toxic levels in the blood and lead to performance-degrading health effects in military personnel consuming up to 5 or 15 L/d for periods up to either 7 d or 1 y are estimated to be greater than 6 and 2 mg/L, respectively. Moreover, the higher the cyanide concentration above the safe level, the greater the risk that many of the exposed military personnel will develop symptoms that can be performance degrading or lethal. Concentrations of 24 to 48 mg/L for a consumption of 5 L/d cause metabolic acidosis, and concentrations greater than 48 mg/L cause life-threatening toxicity.

Hydrogen cyanide is used as a threat agent. It is also referred to as hydrocyanic acid or prussic acid. Its effects are the same as those described for cyanide, and the recommended standards to prevent performance-degrading effects are considered to be the same.

LINDANE

Lindane, a representative pesticide in use worldwide, induces a wide variety of dose-dependent symptoms when ingested in drinking water. These symptoms include nausea, vomiting, frontal headache, restlessness, upper abdominal pain, diarrhea, tremors, ataxia, and reflex loss. At high doses, epileptiform seizures can occur, followed by major systemic failure and even death. The lowest daily dose of lindane reported to cause adverse health effects in humans was 30 mg/d. Unfortunately, the proportion of the exposed military population that could be affected by performance-degrading symptoms at concentrations above recommended safe levels cannot be estimated from the available data.

METABOLITES OF ALGAE AND RELATED AQUATIC BACTERIA

Although drinking water standards cannot be recommended for the toxic substances associated with cyanobacteria in algal blooms, a standard of 10 ng/L could be adopted for geosmin and MIB, based on human responses to objectionable taste or odor. This standard should protect military populations from performance-degrading health effects from either poisoning or dehydration. Even though concentrations of geosmin or MIB between 10 and 30 ng/L might be undetectable to more than half of an exposed population of military personnel, the 10 ng/L level is the recommended standard. This protects against the possibility that cyanobacteria might produce critical levels of a toxin introduced during an algal bloom. This concern is even more relevant given the possibility that sensory fatigue might be experienced after exposure to geosmin and MIB.

We also note that the taste- and odor-producing metabolites of algae might be increased by lysis of the algal cells, and, therefore, it is best not to use an algicide to eliminate the algal mass in hopes of immediately obtaining drinking water. Furthermore, the chemical nature of these odors makes them difficult to remove by standard methods of chlorination. Consequently, waters that have obvious algal masses and detectable earthy/musty odors should be avoided.

WATER-RELATED INFECTIOUS ORGANISMS

As discussed in Vol. 5 of this report, there are no relatively simple field tests for measuring the specific concentration of any of the variety of infectious organisms of concern. Until such tests are available for determining the concentration of specific infectious organisms in field water, the military should continue to use the membrane-filter technique for the presumptive determination of the presence of coliform organisms in water. The present field-water-quality standard based on this technique (i.e., coliform densities should not exceed one colony-forming unit (CFU) per 100 mL) can be considered indicative of a safe level of infectious organisms in field water.

Waterborne Infectious Organisms

The health effects caused by infectious waterborne agents are quite varied. For example, *Shigella*, *Salmonella*, and enteroviruses can cause vomiting and diarrhea symptoms, which can seriously degrade a soldier's ability to perform. However, these diseases are seldom fatal. On the other hand, cholera and some of the parasitic worms (helminths) can produce life-threatening diseases.

The evaluation of risk from waterborne infectious organisms is based on our risk-assessment model (presented in Vol. 5). The risk associated with exposure to 11 waterborne infectious organisms was evaluated for three scenarios. The first scenario represents a low-risk situation in a developed country: 10 L of water that are consumed daily have a pathogen concentration equal to the geometric mean of the dose data and a standard deviation equal to the standard deviation of the dose data. The treatment efficiency is assumed to remove between 99% and 99.999% of the infectious organisms from the field water. The second scenario represents a high-risk situation in a developed country. A daily consumption rate of 15 L of water is assumed. The pathogen concentration has a mean equal to the geometric mean of the dose data but the standard deviation is assumed to be 100 times the actual standard deviation of the dose data. There is no water treatment; the removal of infectious organisms is 0%. The third scenario represents the low-risk situation in a developing country. Water consumption and treatment efficiency are the same as in the first scenario but the pathogen concentration is somewhat higher.

The probability (P_i) that the percentage ill in a population of 20 military personnel will be greater than either 10% or 90% as a result of consuming field water containing infectious microorganisms is summarized in Table 6-1 for 11 of these waterborne pathogens. These probabilities were determined for conditions considered representative of high- and low-risk situations in developed and developing countries, as defined earlier. A comparison between the risk-assessment results presented in Table 6-1 for developed and developing countries reveals that for all 11 waterborne infectious organisms the risk of illness is greatest in developing countries.

Another important point to consider when interpreting the various results of the risk-assessment model is the relationship between latency (i.e., time from ingestion to the onset of symptoms) and illness. The latency period for the pathogenic microorganisms of concern generally is one to three days. This means that the expected percentage of troops that will become ill may still be capable of executing their military responsibilities for up to 1 d and maybe even for up to 3 d after ingesting field water containing any of the microorganisms of concern. Thus, the type of situation confronting a unit in the field may influence decisions regarding the use of water.

For example, Table 6-1 might be used for risk assessment purposes with respect to estimating the success of a military unit operating in a developed country where the only drinking water available is untreated surface water from mountain streams. The microorganism considered to be present in such surface waters is the protozoan *Giardia lamblia*, which can produce a severe diarrheal illness (i.e., giardiasis). Examination of Table 6-1 reveals that there is an 88% chance that more than 10% of a population of 20 military personnel will become infected and could exhibit clinical symptoms of giardiasis as early as three days after exposure. Table 6-1 also shows that there is an 83% probability that more than 90% of the exposed military population could develop giardiasis as early as three days after exposure. The conclusion to be drawn is that a significant risk exists (≥80%) that any mission lasting up to 7 d and requiring more than one individual to complete could be jeopardized should troops consume the field water without adequate filtration followed by disinfection (because ≥90% of the population of 20 military personnel could become ill).

Table 6-1. Summary of the risk-assessment results for populations of up to 20 military personnel exposed to field water containing one of the 11 waterborne infectious organisms considered to be of military concern. Probability (P_i) that the percentage of ill troops is greater than 10 or 90%, respectively, was determined for conditions considered representative of high- and low-risk situations.

	Probability (P_1) that the percentage of ill[a] troops is greater than 10%[b]			Probability (P_2) that the percentage of ill[a] troops is greater than 90%[c]			
Pathogen	Developed country (High risk)[d]	Developing country (Low risk)[e]	Developed country (Low risk)[e]	Developed country (High risk)[d]	Developing country (Low risk)[e]	Developed country (Low risk)[e]	Latency (d)[f]
BACTERIAL:							
Shigella spp.	0.88	0.86	0.50	0.86	0.56	0.18	3 to 6
Vibrio cholerae Classical	0.53	0.00	0.00	0.35	0.00	0.00	<1 to 2
Vibrio cholerae El Tor	0.68[j]	0.00	0.00	0.56[g]	0.00	0.00	<1 to 2
Campylobacter	0.87	0.90	0.50	0.87	0.69	0.18	1 to 4
Escherichia coli	1.00	0.99	0.96	0.04	0.04	0.00	0.1 to 3
Salmonella spp.	0.87	0.73	0.70	0.82	0.35	0.30	3 to 22
Salmonella typhi	0.78	0.03	0.03	0.47	0.02	0.02	3 to 22
Yersenia spp.	0.89	0.87	0.72	0.80	0.72	0.35	<1
VIRAL:							
Enteroviruses[h]	0.95	0.86	0.76	0.55	0.04	0.00	2 to 35
PROTOZOAN:							
Entamoeba hystolytica	0.88	0.82	0.30	0.84	0.50	0.00	7 to 98
Giardia lamblia	0.88	0.90	0.90	0.83	0.62	0.62	3 to 56

[a] Illness is defined as clinical presentation of disease symptoms for bacterial pathogens and as infection (i.e., multiplication of a microbial agent within a host, with or without presentation of clinical symptoms) for viral and protozoan pathogens.

[b] The cumulative probability that the percentage of ill troops is less than or equal to 10% is equivalent to the value of $1 - P_1$.

[c] The cumulative probability that the percentage of ill troops is less than or equal to 90% is equivalent to the value of $1 - P_2$.

[d] A 15 L/d consumption rate and the absence of treatment constitute the principal parameters for a high-risk situation.

[e] A 10 L/d consumption rate and a treatment efficiency between 99 and 99.999% removal constitute the principal parameters for a low-risk situation.

[f] Latency is defined to be the time (in days) from ingestion to the onset of symptoms. Times are based on data contained in the appendices of Vol. 5.

[g] Estimated for developing country and high-risk situation.

[h] Norwalk agent, Rotavirus, and Hepatitis A were also investigated, but dose-response data and concentration data were not available for these organisms and a risk assessment could not be made.

It is evident from this example that the reliability of the treatment and disinfection capability of a unit is important. This is especially true in developing countries where it is assumed that the concentrations of organisms could vary more widely than in developed countries and therefore at times are likely to be greater in concentration.

Water-Washed and Water-Based Infectious Organisms

The task of evaluating the health risks from exposure to the water-washed and water-based infectious organisms of military concern is not as straightforward as for waterborne organisms. Thus, a procedure different from the preceding one was used to evaluate the health risks from these water-related infectious organisms.

Five environmental categories of infection can be defined. These categories, along with representative organisms, types of infection, modes of transmission, and major control methods are presented in Table 6-2. The likely extent of minimization of health risks in exposed military populations from providing a treated-water supply, independent of other control methods, for each category would be as follows: Category I—great; Category II—slight to moderate; Category III—negligible; Category IV—negligible; and Category V—negligible for Schistosomiasis, but great for Dracontiasis.

The evaluation presented in Table 6-2 is based on the effectiveness of the treatment process being considered. However, if the assumption is made that all water-washed and water-based infectious organisms of concern will be present within water and also immediately infective, it would be more realistic to base the relative comparison of risk of infection on the median infective dose of the pathogen and its latency. Following this assumption, the pathogens of concern can be roughly placed in three groups: Group 1—short latency (i.e., few days to 10 days) and low infective dose (i.e., $\leq 10^2$ organisms); Group 2—long latency and low infective dose; and Group 3—short latency and medium-to-high infective dose (see Table 6-3). Based on this type of classification, the Group 1 and Group 2 pathogens are the pathogens of concern, while the Group 3 pathogens present the lowest overall risk of infection. However, if a treated-water supply is provided, the likely control of each of the aforementioned groups of water-washed and water-based organisms would be as follows: Group 1—slight; Group 2—negligible for Schistosomiasis, but great for Dracontiasis; and Group 3—slight to moderate. Unfortunately, the proportion of the exposed military personnel that could be affected by performance-degrading symptoms cannot be estimated from the available data.

The basis for the risk assessment just described has been a classification scheme based on the key environmental features and control strategies for the pathogens of concern. This risk assessment is semiquantitative because of the limited nature of the data for these microorganisms with respect to issues that include dose-response

Table 6-2. Environmental classification of excreted infections.

Environmental category	Representative organism	Infection	Mode of transmission	Major control measure
I. Immediately infective, low infective dose, short latent period	*Balantidium*	Balantidiasis person-to-person contact	Water (ingested).	Treated-water supply.[a]
II. Immediately infective, medium or high infective dose, moderately persistent, short latent period	*Naegleria*	Skin and eye meningo-encephalitis	Person to person, water (contact), soil contact	Health education, treated-water supply,[a] limit contact with water.
III. Immediately infective, low infective dose, persistent, animal host, moderate latent period	*Leptospira* spp.	Leptospirosis	Water (contact), person to person, soil contact	Limit contact with water, health education, provision of toilets, treated-water supply[a]
IV. Not immediately infective, low infective dose, moderately persistent, no intermediate host, long latent period	*Ascariasis lumbricoides*	Ascariasis	Person to person, soil, water contact	Health education, provision of toilets, treated-water supply.[a]
V. Not immediately infective, low infective dose, persistent, aquatic intermediate host, long latent period	*Schistosoma* spp., *et al.*	Schistosomiasis, dracontiasis, cercarial dermatitis	Water contact	Limit contact with water, treated-water supply,[a] control of intermediate host, improved sanitation (e.g., toilets), health education.

[a] Treatment could be provided by a reverse osmosis water-purification unit (ROWPU).

Table 6-3. Grouping of pathogens based on latency and infective dose.

Pathogen	Latency (time interval)	Median infective dose[a]
Group 1:		
Staphylococcus spp.	<1 d	Low to high
Leptospira spp.	<7 d	Low
Balantidium coli	Few d	Low
Ascaris lumbricoides	Few d to several months	Low
Group 2:		
Schistosoma spp.	4 to 6 wk or longer	Low
Cercarial dermatitis	4 to 6 wk or longer	Low
Dracunculus medinensis	10 to 14 months	Low
Group 3:		
Acanthamoeba spp.	>7 d	Medium
Naegleria spp.	3 to 7 d	Medium
Non-*cholerae Vibria* spp.	?	Medium to high
Pseudomonas spp.	2 d	Medium to high
Aeromonas spp.	1 d	High

[a] Median infective dose (organisms ingested and/or adsorbed): low $\leq 10^2$; medium = 10^4; high $\geq 10^6$.

relationships, correlation to indicator organism(s), and survival under different environmental conditions.

RADIOACTIVITY

There are many possible health effects that might result from exposure to radiation. These effects are described as either "stochastic" or "non-stochastic." Stochastic effects are those for which the probability of effect occurring, rather than its severity, is regarded as a function of dose, without threshold. Such stochastic effects are mainly those of carcinogenesis and mutagenesis; these occur with very low probability and might be evident only years after exposure. These effects are not regarded as performance degrading over the short-term (≤7 d) or long-term (≤1 y) as defined in this document. Non-stochastic effects are those for which the severity of the effect varies with dose, and for which a threshold may occur. Such effects include anorexia, nausea, fatigue, vomiting, diarrhea, and eventually death.

We presume that the the effects of anorexia, nausea, and fatigue are nuisances that are not incapacitating in the short term, but that vomiting and diarrheas are incapacitating. Authoritative sources have stated that vomiting would not be expected for whole-body doses less than 0.5 Gy (50 rad), and that vomiting would be expected at a frequency of 5% following a dose of 1 Gy (100 rad) and a frequency of 50% following a dose of 2 Gy (200 rad), with the expected time of occurrence of nausea and vomiting at 3 h post exposure. A 3-week symptom-free phase often follows the nausea and vomiting, which is then followed by the main illness (if any occurs) caused by depression of the number of circulating blood cells. Following doses of about 1.0 Gy (100 rad), complete recovery of virtually all personnel would be expected within 6 to 8 weeks after exposure. At supralethal doses in the range of 10 to 50 Gy (1000 to 5000 rad), death would occur in a week or less from denudation of the gastrointestinal tract. At doses above 50 Gy (5000 rad), survival time is inversely related to dose, and incapacitation is immediate due to disruption of the central nervous system.

Because some radiations, such as neutrons and alpha particles, produce greater biological effects than equal doses of others, such as beta particles or gamma rays, the unit "dose equivalent" was developed. The dose equivalent is expressed as rem or sievert (Sv). We recommend a limit of 1.0 Sv (100 rem) committed dose equivalent to an individual organ or tissue as the basic standard. This should carry essentially zero risk of lethality, and no more than 10% of affected troops should suffer performance degradation. Under emergency field conditions (e.g., nuclear warfare), this limit might be increased to as much a 2.0 Sv (200 rem). Under conditions of protracted exposure, this should still result in zero incidence of lethalities, but might result in significant performance degradation.

We also determined annual limits of intake (ALI) for target organs for over 400 radionuclides. If the sophisticated measurements necessary to identify individual radionuclides can be performed, the limits in water are calculated by dividing by the expected amount of water to be consumed over the relevant time period. The four cases of interest are 5 and 15 L/d over 7 d (35 and 105 L, respectively) and 5 and 15 L/d over 365 d (1825 and 5475 L, respectively). If more than one radionuclide is present, then fractions of ALIs should be calculated for each radionuclide and summed. This sum should not exceed 1.

It is unlikely that individual radionuclides will be identified in the field, so we developed a standard for gross beta or alpha activity based on the most limiting radionuclide. These calculations led to the following recommended standards: for exposures ≤7 d, 8 µCi/L (300 kBq/L) and 3 µCi/L (100 kBq/L) for 5 and 15 L/d consumption rates; and for exposures ≤1 y, 0.1 µCi/L (5 kBq/L) and 0.05 µCi/L (2 kBq/L) for 5 and 15 L/d consumption rates.

OP THREAT AGENTS

Concentrations of OP threat agents in field water greater than the recommended interim standards can produce performance-degrading health effects that can include abdominal cramps, vomiting, diarrhea, and headache. Sufficiently high levels consumed over the course of a 7-d period may even lead to death. However, the concentration of OP threat agents at which death might occur from repeated ingestion in drinking water over the course of several days is not reported in the literature. Consequently, an estimate of that level for exposure lasting up to 7 d is 12 µg/L for a consumption rate of 5L/d and 4 µg/L for a consumption rate of 15 L/d. Because OP threat agents are designed to be poisonous, there is probably a narrow margin between safe levels in water and those producing performance-degrading health effects, even under circumstances where an OP threat agent is ingested in several drinks separated in time over the course of a day for an exposure period lasting up to 7 d.

TRICHOTHECENE MYCOTOXIN T-2

The first performance-degrading effects to occur after ingestion of concentrations of trichothecene mycotoxin T-2 in field water greater than the recommended interim standards are nausea and vomiting. On the basis of data from clinical trials where cancer patients were treated with a chemotherapeutic agent considered analogous to trichothecene mycotoxin T-2, the mildest symptoms would be associated with concentrations just above the short-term (≤7 d) interim exposure limit of 26 µg/L for a consumption rate of 5L/d and 8.7 µg/L for a consumption rate of 15 L/d. The data from clinical tests also indicate that the most severe symptoms are associated with concentrations more than 30 times greater than these levels.

EVALUATION OF GEOGRAPHIC REGIONS

CLIMATE AND GEOHYDROLOGY

Studies of the correlations between water salinity and both climate and geohydrology indicate a causal relationship. Thus, climatic and geohydrologic information can be used to predict which regions are likely to have highly saline water supplies.

Regions with warm to hot, arid climates, and consequent high rates of water evaporation, very often have limited water supplies, and these have relatively high salinity. Such regions are virtually all located in the trade-wind deserts of the world and in the semi-arid regions that lie poleward of these deserts. Trade-wind deserts are located on the westward sides of continents between latitudes of about 20° and 30 to 35° both north and south of the equator. There is a potential for high salinity water poleward to about 40° latitude.

In addition to trade-wind desert areas, there is a likelihood that highly saline waters will be encountered in regions with outcrops of bedrock containing such soluble minerals as salt (NaCl) and gypsum/anhydrite. An example of major importance to this study is the region of Northern Iran and Iraq together with adjacent portions of Syria and Turkey. In Iran, the Hormuz salt pierces the overlying bedrock to form salt domes and salt glaciers, which can expose salt at the land surface. In an even wider area in the same region, the gypsum- and salt-bearing Fars formation underlies many of the intermontane valleys. Much of the water in this very large region is likely to be well above average in salinity.

Even in regions with reasonably high rainfall, areas underlain by salt and anhydrite can have waters with high salinity. Two examples are the Colorado River of west-central Colorado, and the Salzkammergut near Salzburg, Austria. The Colorado River has a reach underlain by gypsum and anhydrite near its headwaters in the high-altitude, moderately humid Rocky Mountains. The amount of calcium sulfate dissolved in the water is significant, and the salinity of the river water is markedly increased below the reach. The Salzkammergut is a high-rainfall area in the Eastern Alps of Central Europe. Salt (NaCl) occurs in the region; it has been mined there for thousands of years. Some water supplies in the region have unusually high levels of salt, undoubtedly as a result of leaching of salt by percolating waters.

ORGANIC CHEMICAL CONTAMINATION

Organic chemicals, both industrial and agricultural, are found throughout the world in all types of natural waters. Ordinarily, only pesticides, particularly lindane, may occur at a high enough concentration in potential sources of field water to be a threat to military health. Low, nontoxic levels of pesticides are likely to be associated with surface water supplies near major agricultural areas. Potential health risks from pesticides in those areas would result primarily from transient releases of pesticides from field applications or even spills. In general, any small body of water in the immediate vicinity of agricultural activities (i.e., irrigation canals, rice paddies, ponds, and reservoirs), with high potential for contamination and little potential for dilution, poses a real threat to troop health. In addition, military personnel should be alert to the possibility of extreme contamination levels in areas requiring the direct application of pesticides to water. For example, a concentration of lindane in water of 1920 mg/L was reported in rice paddy water. Areas of rice production, which are principally located in Third World countries, are at considerable risk for contamination of water by pesticides, particularly by lindane.

In addition, transient releases from industrial facilities storing large quantities of organic chemicals and from transshipment points related to these industries could result in elevated levels of organic contaminants in surface waters. Manufacturing areas could also contain factories that potentially could release contaminants, especially organic chemicals, into ground and surface waters. Although it is not possible to list all such facilities that could cause difficulties, we have identified major organic chemical production centers and petroleum refineries as the most significant possible sources of surface water contamination from a regional perspective. Information on the locations of these facilities can alert military planners to potential water-supply contamination by organic chemicals under battlefield conditions.

WATER-RELATED INFECTIOUS ORGANISMS

Data are not available for assessing the precise location globally of all the aquatic infectious organisms of military concern. In fact, most of the infectious organisms can be considered ubiquitous, especially in the Third World. However, two indicators are useful as warnings that high concentrations of infectious organisms may exist in the field water of a particular region. Poor sanitation is one indicator and infant mortality rates (deaths in infants less than 1 y old) is the other. In fact, locations of moderate to high infant mortality correspond to areas of poorest sanitary conditions and the majority of deaths in this age group are due to the infectious diseases.

CONCLUSIONS

The information presented on risk will aid military planners and risk managers to decide whether certain water constituents might reduce performance of exposed military personnel and thereby jeopardize mission accomplishment. Knowing the quality of field water generally expected in geographic regions worldwide allows military planners and risk managers to (1) anticipate water-treatment and monitoring capabilities needed for a particular region, and (2) estimate the possible performance-degrading health risks that could result from the absence or failure of those capabilities. Finally, monitoring of field-water quality should always be practiced in (1) densely populated areas, (2) locations of intense agricultural production, (3) sites near industrial manufacturing centers, and (4) areas where dissolved solids are likely to reach high concentrations.

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