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Evaluation of Military Field-Water Quality

Volume 9. Data for Assessing Health Risks in Potential Theaters of Operation for U. S. Military Forces

Jeffrey I. Daniels and D. W. Layton (Editors)

Environmental Sciences Division
Lawrence Livermore National Laboratory
University of California
P. O. Box 5507
Livermore, CA 94550-0617

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Project Officer: S. A. Schaub

L. R. Anspaugh, J. I. Daniels, and D. W. Layton
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Data are presented in this volume for assessing the health risks in populations of military personnel that could result as a consequence of exposure to field waters containing constituents or infectious organisms of military concern, which are from natural and anthropogenic sources, at levels above those recommended as field-water-quality standards (i.e., above safe levels). Turbidity and color are the physical properties that are of military concern in field water. The other constituents that are of military concern in field water are (1) total dissolved solids, (2) chloride, (3) magnesium, (4) sulfate,. (5) arsenic, (6) cyanide, (7) the pesticide lindane, and (8) metabolites of algae and associated bacteria. Bacteria, viruses, and parasites (e.g., protozoa and helminths) are categories of water-related infectious organisms that are of military concern. Figures were developed from dose-response data to enable military risk managers to quickly assess the potential performance-degrading effects in personnel exposed to a measured concentration

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DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED of a particular constituent in field water. The general physical, chemical, and biological quality of field waters in geographic regions worldwide, representing potential theaters of operation for U.S. military forces, also are evaluated. This analysis is based on available water-quality monitoring data and indicators of likely water-quality conditions (e.g., geohydrology, climate, sanitation, industrialization, etc.). Accompanying our evaluation are maps and tables alerting military planners and risk managers to the physical, chemical, or biological quality of field water that can be expected generally in geographic regions of concern.

This report is the last volume of a nine-volume study entitled *Evaluation of Military Field-Water Quality*. Titles of the other volumes are as follows: Vol. 1, *Executive Summary*; 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*; and 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*.

FOREWORD

This report is the last volume of a nine-volume study entitled Evaluation of Military Field-Water Quality. Titles of the other volumes are as follows: Vol. 1, Executive Summary; 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; and 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.

As indicated by the titles listed above, 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 researchers on topics related to field water and the U.S. military community.

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Volume 9. Data for Assessing Health Risks in Potential Theaters of Operation for U.S. Military Forces

ABSTRACT

Data are presented in this volume for assessing the health risks in populations of military personnel that could result as a consequence of exposure to field waters containing constituents or infectious organisms of military concern, which are from natural and anthropogenic sources, at levels above those recommended as field-water-quality standards (i.e., above safe levels). Turbidity and color are the physical properties that are of military concern in field water . The other constituents that are of military concern in field water are (1) total dissolved solids, (2) chloride, (3) magnesium, (4) sulfate, (5) arsenic, (6) cyanide, (7) the pesticide lindane, and (8) metabolites of algae and associated bacteria. Bacteria, viruses, and parasites (e.g., protozoa and helminths) are categories of water-related infectious organisms that are of military concern. Figures were developed from dose-response data to enable military risk managers to quickly assess the potential performance-degrading effects in personnel exposed to a measured concentration of a particular constituent in field water. The general physical, chemical, and biological quality of field waters in geographic regions worldwide, representing potential theaters of operation for U.S. military forces, also are evaluated. This analysis is based on available water-quality monitoring data and indicators of likely water-quality conditions (e.g., geohydrology, climate, sanitation, industrialization, etc.). Accompanying our evaluation are maps and tables alerting military planners and risk managers to the physical, chemical, or biological quality of field water that can be expected generally in geographic regions of concern.

CHAPTER 1. INTRODUCTION

J.I. Daniels* and D.W. Layton*

The chemical substances, infectious organisms, and physical properties of field-water supplies that could directly or indirectly cause performance-degrading health effects to military personnel were identified in the three parts of Volume 2, and in Volumes 5 and 6 of this study.[1-5] Turbidity and color are the physical properties of field water of military concern. Field water chemical constituents that are of concern are (1) total dissolved solids, (2) chloride, (3) magnesium, (4) sulfate, (5) arsenic, (6) cyanide, (7) the pesticide lindane, and (8) metabolites of algae and associated bacteria. Bacteria, viruses, and parasites (e.g., protozoa and helminths) are categories of water-related infectious organisms that could be hazardous to the military. 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, and infectious organisms.[4-6] 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. Thus, concentrations of the aforementioned chemical substances and infectious organisms at or below those recommended as field-water-quality standards can be considered safe levels.

In this volume 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 Volumes 4 through 6. Figures that summarize the toxicity data are presented to enable military risk managers to quickly assess the potential performance-degrading effects that a measured concentration of a particular constituent of military concern in field water can have on exposed personnel.

Additionally, this volume 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

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* Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550.

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. Important geographical locations that lack meaningful water-quality data also are identified to indicate the need for monitoring water quality especially in these areas.

In summary, the purpose of this volume is to provide military planners and risk managers with two types of information for assessing the relationship between field-water quality and the accomplishment of military objectives. The first type of information consists of health-effects summaries for evaluating the potential impact that measured levels of the physical properties, chemical substances, and infectious organisms of military concern in field water might have on the performance of exposed military personnel. The second type of information describes the quality of field water generally expected in geographic regions worldwide and is essential for (1) anticipating water-treatment and monitoring capabilities needed for a particular region, and (2) estimating the possible performance-degrading health risks that could result from the absence or failure of those capabilities. 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.

REFERENCES

1. Layton, D.W., B.J. Mallon, T.E. McKone, Y.E. Ricker, and P.C. Lessard, Evaluation of Military Field-Water Quality. Volume 2. Constituents of Military Concern from Natural and Anthropogenic Sources. Part 1. Organic Chemicals, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 2, Part 1 (1988).

2. Scofield, R., J. Kelly-Reif, F. Li, T. Awad, W. Malloch, P. Lessard, and D. Hsieh, Evaluation of Military Field-Water Quality. Volume 2. Constituents of Military Concern from Natural and Anthropogenic Sources. Part 2. Pesticides, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 2, Part 2 (1988).

3. Daniels, J.I., J.M. Hirabayashi, N.B. Crow, D.W. Layton, and Y.E. Ricker, Evaluation of Military Field-Water Quality. Volume 2. Constituents of Military Concern from Natural and Anthropogenic Sources. Part 3. Inorganic Chemicals and Physical Properties, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 2, Part 3 (1988).

4. Cooper, R.C., A.W. Olivieri, R.E. Danielson, P.G. Badger, R.C. Spear, and S. Selvin, Evaluation of Military Field-Water Quality. Volume 5. Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 5 (1986).

5. Cooper, R.C., A.W. Olivieri, R.E. Danielson, and P.G. Badger, Evaluation of Military Field-Water Quality. Volume 6. Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 6 (1986).

6. Daniels, J.I., Ed., Evaluation of Military Field-Water Quality. Volume 4. Health Criteria and Recommendations for Standards. Part 1. Chemicals and Properties of Military Concern Associated with Natural and Anthropogenic Sources, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 4, Part 1 (1988).

CHAPTER 2. HEALTH RISKS ASSOCIATED WITH PHYSICAL PROPERTIES AND CHEMICALS OF MILITARY CONCERN IN FIELD WATER

J.I. Daniels,* L.B. Gratt,† M. Lyon,† and B. Perry†

Turbidity and color are the physical properties of field water that can be of military concern. Total dissolved solids (TDS), magnesium (Mg^{+2}), sulfate (SO_4^{-2}), arsenic (As), cyanide (CN^-), and the pesticide lindane [common name for the gamma-isomer of 1,2,3,4,5,6-hexachlorocyclohexane (HCH)], are among the chemicals that can be of military concern in field water. As mentioned in Chapter 1 of this volume, these physical properties and chemicals can be of military concern in field water because they were identified as those that could be present at high enough concentrations to cause performance-degrading health effects in exposed military personnel. Thus criteria and recommendations for field-water-quality standards have been developed for these physical properties and chemicals. These criteria and standards are applicable to military personnel consuming up to 5 or 15 L/d of field water for exposure periods up to either 7 d or 1 y. Levels of these physical properties and chemicals at or below those recommended as field-water-quality standards can be considered safe.

In this chapter we identify the safe levels for each of the previously mentioned substances in field water and present data for assessing the health risks for military personnel drinking water containing concentrations of these substances that are above recommended levels. These data are summarized in figures that are visual guides for quickly assessing the relationship between the concentration of a particular substance of concern in field water and the corresponding health risks for military personnel as a function of consumption rate and exposure period.

TURBIDITY AND COLOR

Turbidity in water is caused by suspended material such as clay, silt, finely divided organic matter, and microorganisms.[1] Turbidity may result from natural processes such as erosion, or it may result from the discharge of domestic and industrial waste to surface waters. For example, suspended material derived from mining, dredging, logging, pulp and paper manufacturing, and other industrial activities will contribute to water turbidity.[2]

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* Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550.

† IWG Corp., 3065 Rosecrans Place (Suite 210), San Diego, CA 92110.

Color in water may result from the presence of metallic ions (e.g. iron and manganese), humus and peat materials, plankton, and industrial wastes.[1] The term "true color," in water treatment practice, means the color of water remaining after the turbidity has been removed. The term "apparent color" includes color resulting from substances in solution as well as suspended materials. The color of water with low turbidity is basically the same as that of clear water.[2]

Turbidity measurements derived by nephelometry (determining the intensity of light scattered by a sample) are expressed as nephelometric turbidity units (NTU). Color measurements made by visual comparison of a sample with tinted glass discs calibrated to correspond to standardized platinum-cobalt solutions in water are expressed as color units and not as mg/L. These are standard procedures for determining the turbidity and color content of water,[1] and unless otherwise stated, the units associated with these procedures are used in this volume of the report.

Recommended Field-Water-Quality Standards

Part 1 (Chemicals and Properties of Military Concern Associated With Natural and Anthropogenic Sources) of Volume 4 (Health Criteria and Recommendations for Standards)[3] contains our recommendations for field-water-quality standards for turbidity and color, along with the data and analyses we used to derive them. The recommended field-water-quality standard for turbidity is 1 NTU for exposure periods of up to either 7 d or 1 y and for any water consumption rate, including ones of 5 and 15 L/d. This level should diminish the interfering effect that turbidity can have on disinfection processes and should minimize the number of military personnel who could reject field water for organoleptic reasons and who would consequently become susceptible to dehydration. The recommended field-water-quality standards for color are 50 color units for exposure periods up to 7 d and 15 color units for exposure periods up to 1 y at water consumption rates of both 5 and 15 L/d. These color levels do not signify any health risks, and although they are noticeable, they should be tolerated by military populations.

The recommendations just mentioned are based on an assessment of the degree to which the objectionable appearance that could be imparted to field water by turbidity or color might lead indirectly to degraded performance in exposed military personnel. However, turbidity composed of organic material can also decrease disinfection efficiency (i.e., the organic material increases chlorine demand), which thereby improves the chances for survival of the infectious organisms in disinfectant-treated water. Thus, high chlorine demand in field waters, whether turbid or reasonably clear (i.e., turbidity ≤ 5 NTU), is a good indication that the risk of infectious disease for military personnel consuming the disinfected water could be higher than that which would ordinarily be expected.

Health Risks

There is no evidence indicating any direct relationship between human health effects and turbidity and color in water. However, as previously stated, turbidity that is composed of organic material can increase chlorine demand and thereby reduce disinfection efficiency. Nevertheless, high chlorine demand in field water is only useful as an indicator that the risk of illness for military personnel consuming the disinfected water could be higher than that which would ordinarily be expected. For these reasons, turbidity and color are accepted generally as aesthetic standards. High levels of turbidity or color can make water visually objectionable to many individuals, causing them to reduce consumption or to refuse to drink it. In arid environments particularly, where large volumes of water must be consumed to replace sweat losses, military personnel who refuse to drink field water or reduce their consumption of it would be susceptible to dehydration, which could result in performance degradation. The actual debilitating effects of dehydration, described by Adolph et al.,[4] progress in the following sequence: (1) discomfort, (2) weariness, (3) muscle weakness, (4) apathy, (5) impaired coordination, (6) delirium, and (7) heat stroke. Additionally, Walker et al.[5] state that intense thirst is experienced over the first two days of water deprivation; weakness and confusion occur during the third day of abstention, and death results within approximately 10 days.

As discussed in the second chapter of Part 1 of Volume 4, Harris[6] performed a study designed to systematically relate combinations of turbidity, color, and odor values in drinking water to the percentage (from 0 to 100) of the public accepting the water. He obtained acceptability ratings for 125 water samples containing different combinations of color, odor, and turbidity from three different consumer populations (i.e., consumers of bottled water, unfiltered tapwater, and filtered tapwater). In assessing a sample the respondent observed and smelled the sample, then indicated the degree to which he or she could accept the water by selecting the appropriate rating on the action-tendency (i.e., likely behavioral response) scale shown in Table 1. According to Harris,[6] the borderline between acceptance and rejection for the population surveyed was located between rating statements 5 and 6 on the action-tendency scale.

Table 1. Action-tendency scale for rating water on the basis of color, turbidity, and odor.

Rating	Statement
1	I would be very happy to accept this water as my everyday drinking water.
2	I would be happy to accept this water as my everyday drinking water.
3	I am sure that I could accept this water as my everyday drinking water.
4	I could accept this water as my everyday drinking water.
5	Maybe I could accept this water as my everyday drinking water.
General Population	
6	I don't think I could accept this water as my everyday drinking water.
Military Population	
7	I could not accept this water as my everyday drinking water.
8	I could never drink this water.

From our analysis of Harris's[6] data we derived the following multiple regression equation:

$$A = 86 - 0.5(C) - 1(T) - 0.1(S)\,, \tag{1}$$

where

A = percentage of public rating water acceptable,
C = color units,
T = nephelometric turbidity units (NTU), and
S = threshold odor number (TON).

The derivation of this equation is explained in Part 1 of Volume 4.

We can adapt this equation to describe the response of military populations in the following manner. As we discuss in Part 1 of Volume 4, a population of military personnel is assumed to be less sensitive to the organoleptic characteristics (e.g., taste, odor, or appearance) of water than a civilian population such as Harris[6] surveyed. Therefore, we shift the threshold for acceptance and rejection for military populations on the action-tendency scale from between rating statements 5 and 6 to between rating statements 6 and 7 (see Table 1). According to the analyses we performed in Volume 4, this shift corresponds to about a 15% increase in the percentage of the population accepting water with any combination of color, turbidity, or odor in it.[3] Consequently, the coefficients in Eq. 1 should be increased by a factor of 15% (i.e., multiplied by 1.15) for Eq. 1 to be applicable to military populations. Then a mathematical expression can be derived for estimating the percentage of the military population (MP) that may refuse to drink water containing any combination of turbidity, color, or odor:

$$MP = 1.1 + 0.575\,(C) + 1.15\,(T) + 0.115\,(S).^{*} \qquad (2)$$

Note that even if color, turbidity, and odor were absent there might still be a small background of individuals who would reject the water (i.e., 1.1%). Table 2 shows an example of the relationship between turbidity and the percentage of a military population that might refuse to drink the water when color and odor were absent. As stated in the section on turbidity and color in Part 1 of Volume 4, color levels at 50 color units or 15 color units for short-term ($\leq$ 7-d) or long-term ($\leq$ 1-y) exposure, respectively, in combination with a TON of three for odor, can be considered safe and tolerable, particularly when mandatory water consumption is enforced for combat-situations in hot, arid environments. Table 3 shows an example of the relationship between color and the percentage of a military population that might refuse to drink the water when turbidity was equal to 1 NTU and the TON for odor was equivalent to three. A turbidity level of 1 NTU should optimize the disinfection efficiency for most pathogenic microorganisms (Giardia and Cryptosporidium are notable exceptions) and minimize the percentage of a military population that would find the appearance of water to be objectionable. Additionally, a TON of up to three is considered by the U.S. Environmental Protection Agency to be acceptable to most of the general population,[7] and therefore it should be acceptable to military populations as well.

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[*] $MP = 100 - 1.15\,(86 - 0.5[C] - 1[T] - 0.1[S])$

Table 2. Predicted water rejection for military populations based on turbidity; color and odor are considered to be absent.

Turbidity (NTU)	Percentage of a military population finding water unacceptable[a]
1[b]	2
5	7
10	13
15	18
20	24
25	30
30	36
35	41
40	47
45	53
50	59

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[a] Determined using Eq. 2: $MP = 1.1 + 0.575\ (C) + 1.15\ (T) + 0.115\ (S)$.

[b] Field-water-quality standard recommended for turbidity for both short- ($\leq$7-d) and long-term ($\leq$ 1-y) exposure periods and any consumption rate, including ones of 5 and 15 L/d

The standards for turbidity and color proposed in Volume 4 reflect a balance between desire to minimize water rejection by troops and a realistic health assessment of field-water turbidity and color levels. Turbidity and color levels high enough to cause troops to reject water supplies will increase the susceptibility of the troops to the performance-degrading effects associated with dehydration. What level of rejection should be termed "significant" is contingent on several variables, including the risk of dehydration and the workforce-allocation needs of the field commander for accomplishing missions.

Figures 1 and 2 are visual guides for quickly assessing the impact of various levels of turbidity and color, respectively, on the susceptibility of a population of military personnel to dehydration and subsequent performance-degrading health effects. Specifically, the information presented in this figure, or resulting from the application of Eq. 2, allows the percentage of a population of military personnel potentially at risk for suffering from dehydration to be estimated for concentrations of turbidity or color in field water at or above recommended safe levels.

Table 3. Predicted water rejection for military populations based on color; turbidity is fixed at 1 NTU and odor is considered to be absent.

Color (color unit)	Percentage of military population finding water unacceptable[a]
3[b]	4
6	6
9	7
12	9
15[c]	11
20	14
30	20
40	25
50[d]	31
60	37

[a] Determined using Eq. 2: MP = 1.1 + 0.575 (C) + 1.15 (T) + 0.115 (S).

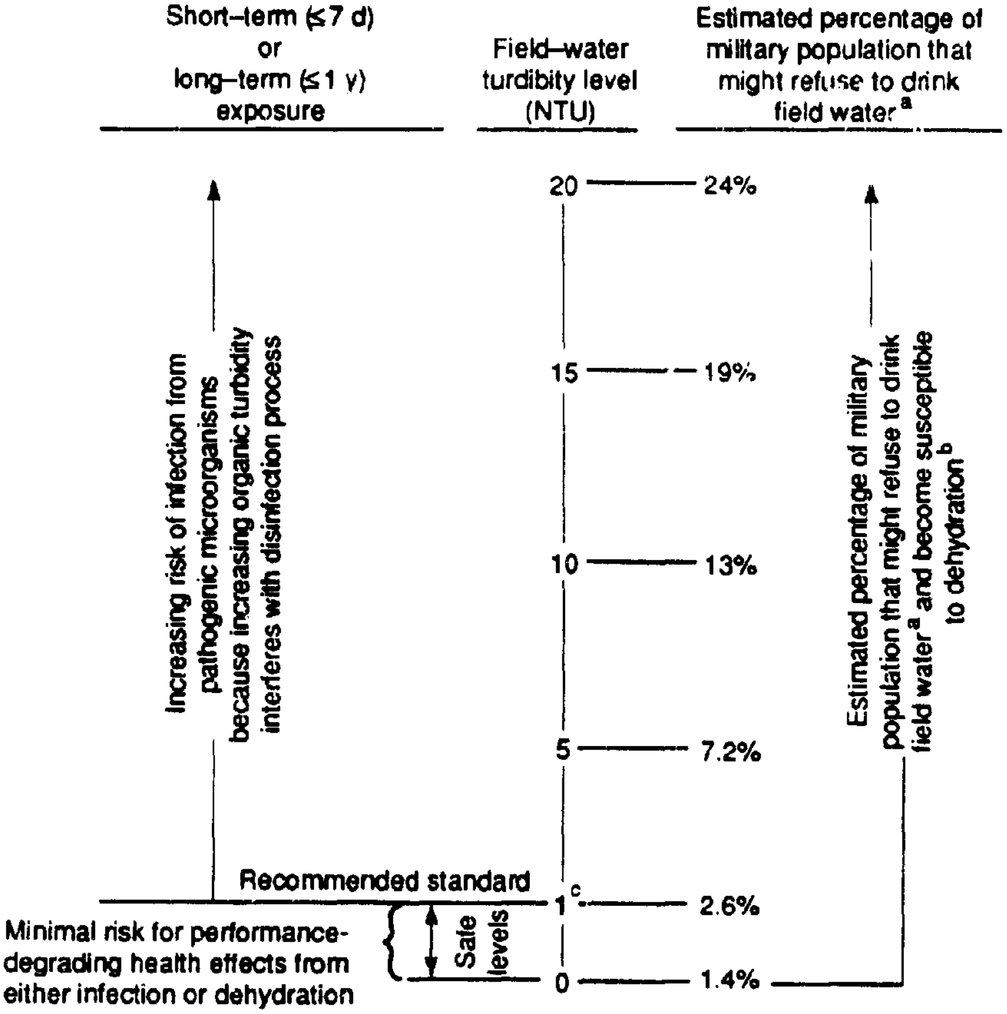
[b] Color level indicated by the U.S. Environmental Portection Agency[7] to be undetectable by many individuals in the general population. Also, the general population would be more likely to complain about color if it changes rapidly, rather than remaining high constantly.

[c] Field-water-quality standard recommended for color for long-term exposure ($\le$ 1 y) for any consumption rate, includings ones of 5 and 15 L/d. Safe and tolerable color levels should not impact the performance of military personnel, but may require acclimation by the exposed military population.

[d] Field-water-quality standard recommended for color for short-term exposure ($\le$ 7 d) for any consumption rate, includings ones of 5 and 15 L/d. Safe and tolerable color levels should not impact the performance of military personnel, but may require acclimation by the exposed military population.

Conclusions

Health effects stemming from the presence of turbidity or color in field-water supplies center on the risk of 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 (A-T scales), which attempt to quantify behavioral responses to stimuli. The actual debilitating effects of dehydration progress in sequence, including discomfort, weariness, apathy,



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

impaired coordination, delirium, and heat stroke. Turbidity levels greater than 1 NTU can 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 aversive 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 may require turbidity removal by filtration processes to levels less than or equal to 0.1 NTU, as explained in Part 1 of Volume 4).

TOTAL DISSOLVED SOLIDS

Mineral salts and small amounts of other inorganic and organic substances constitute the filterable residue content of water. The concentration of filterable residue is expressed commonly as milligrams per liter (mg/L) of total dissolved solids (TDS).[1,8] Typically, the ions of the mineral salts are the main constituents of the dissolved material; consequently, TDS generally refers to salinity.[9] The principal cations constituting TDS are calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^+), and sodium (Na^+); the chief anions are bicarbonate (HCO_3^-), carbonate (CO_3^{-2}), chloride (Cl^-), sulfate (SO_4^{-2}), and in ground waters, nitrate (NO_3^-).[8]

The dissolved substances that constitute TDS are encountered in all natural waters, and they enter the water from natural as well as man-made processes. The composition and concentration of TDS vary geographically. The relative proportions of TDS constituents in natural waters are a function of geochemical processes (e.g., weathering) acting on local geological strata.[10]

Worldwide distribution of water with high TDS content is based on two general factors: the ratio of precipitation to evaporation and proximity to the ocean. Locally high TDS concentrations can result from contact of water with deposits of soluble evaporite rocks (i.e., sedimentary rocks formed from the deposition of precipitates of evaporating lakes, oceans, etc.).

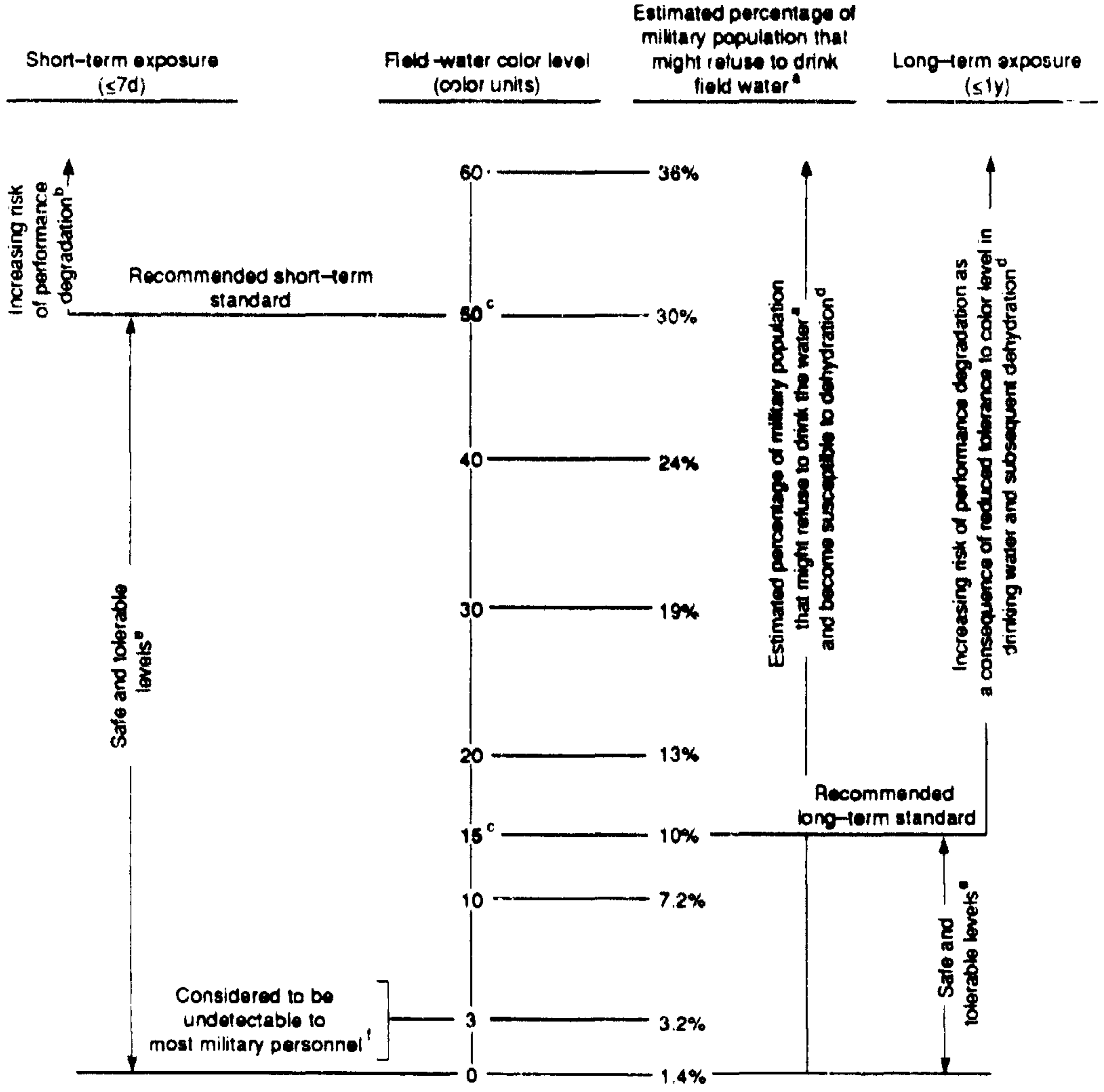


Figure 2. Health-effects summary for color with turbidity absent (i.e., zero) and a threshold odor number (TON) equal to three.

FOOTNOTES FOR FIGURE 2. Health-effects Summary for Color with Turbidity Absent and a 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.[7]

The TDS concentration of drinking water commonly ranges from levels below 500 mg/L to amounts exceeding 2000 mg/L. Seawater is considered to be the typical worst-case challenge for military reverse osmosis water purification equipment because of its high TDS concentration (approximately 35,000 mg/L).

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4, a military field-water-quality standard for TDS of 1000 mg/L is recommended. This recommendation is applicable to both short-term (≤7 day) and long-term (≤1 year) exposure periods and is based on an assessment of the degree to which the objectionable taste that can be imparted to field water by TDS can lead indirectly to degraded performance in exposed military personnel.

Health Risks

Health risks due to high TDS concentrations in drinking water fall into two general categories: the risk of dehydration caused by refusal to drink water and the possibility of laxative effects. These two categories of health risks are summarized next.

The primary problem with a high TDS concentration is its effect on taste. As the TDS content of a water exceeds approximately 1000 mg/L, its taste becomes increasingly worse.[7,11] At very low TDS concentrations (e.g., a distilled water) water can be objectionable because of a lack of taste. One consequence of bad water taste is decreased consumption.[12] As mentioned in the section concerning turbidity and color, decreased consumption, in arid environments particularly, could make some military personnel susceptible to dehydration. The debilitating effects of dehydration that could subsequently result progress in the following sequence: (1) discomfort, (2) weariness, (3) muscle weakness, (4) apathy, (5) impaired coordination, (6) delirium, and (7) heat stroke.[4]

The laxative effect of high TDS concentrations may be produced because the osmotic pressure in the intestinal tract is high enough to prevent absorption of water through the intestinal wall. The large volume of fluid retained in the intestine increases the motility of the smooth muscle lining the intestinal wall and this helps to flush the large intestine.[13,14] However, the laxative effects of elevated TDS levels may actually be due to the action of specific ions,[15] such as of Mg^{+2} and SO_4^{2}, which are addressed later in this volume, and not necessarily from the collective effect of all constituents of TDS. As discussed in Volume 4 of this study, the relationship between TDS concentration and laxative effects is confounded even more by evidence that TDS levels exceeding

2000 mg/L can be tolerated without any ill effects if populations are acclimated to such concentrations. Therefore, the principal problem of a high TDS concentration in field water is considered to be its effect on taste.

In order to define the relationship between TDS and field-water acceptability, the technique and data of Bruvold and Ongerth[11] were employed. These researchers examined taste panel responses to California water supplies made on an action-tendency (AT) scale. Such scales are used to measure behavioral response. By extrapolating from this analysis, we predict the percentage of military personnel that may refuse to drink field-water supplies (and hence can become susceptible to dehydration) as a consequence of the TDS concentration.

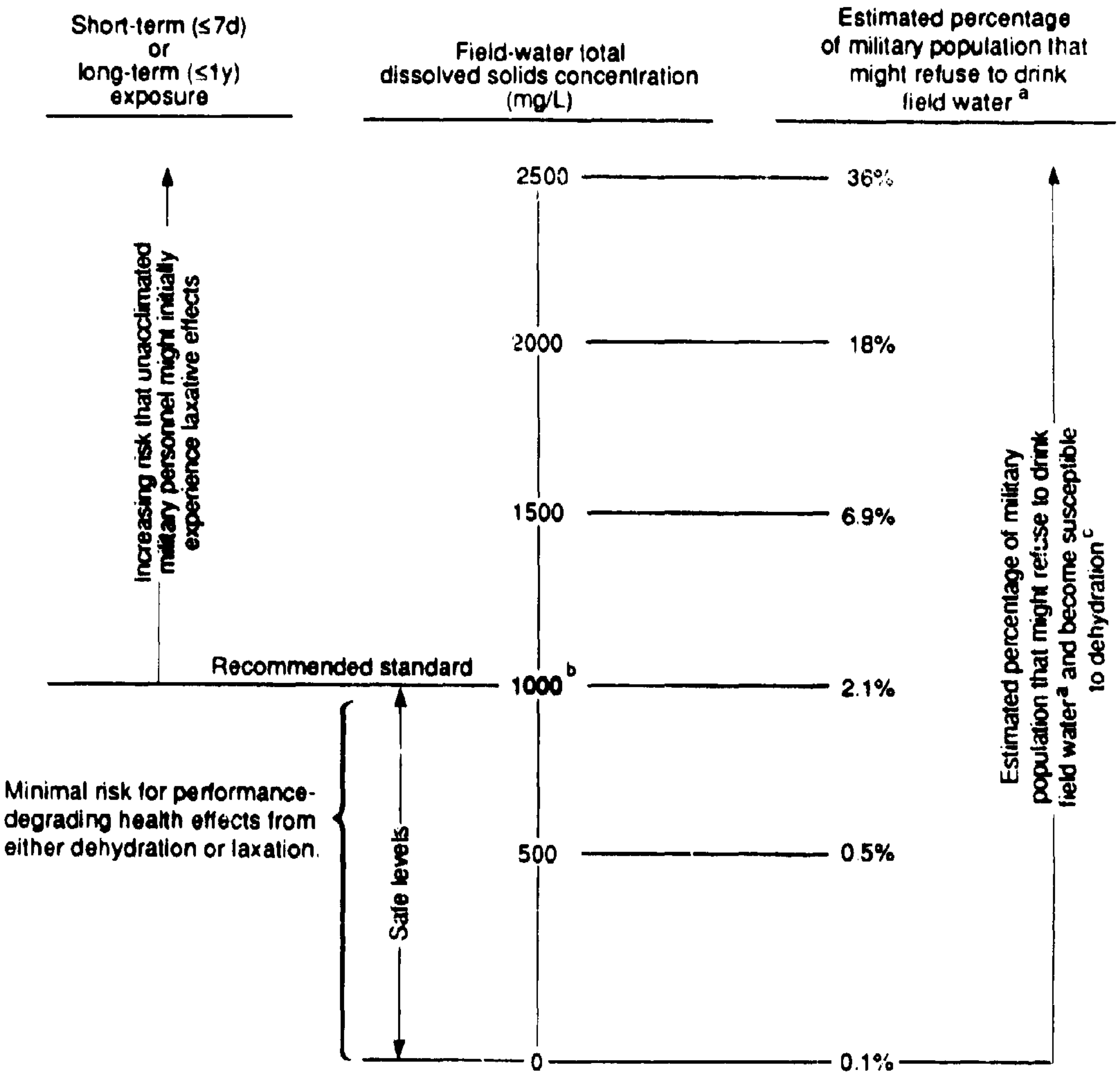
Table 4 shows the relationship between TDS concentration and water rejection by military personnel. From Table 4, it can be seen, for example, that if the TDS concentration were 1000 mg/L, then only about 2% of the exposed military population would be at risk of dehydration.

Figure 3 is a visual guide for quickly assessing the impact of various levels of TDS on the susceptibility of military personnel to dehydration and related performance- degrading health effects. Specifically, the information presented in this figure allows the percentage of a population of military personnel potentially at risk of suffering from dehydration to be estimated for concentrations of TDS in field water at or above recommended safe levels.

Table 4. Comparison between TDS concentrations in field water and corresponding proportions of a military population that might refuse to drink the water.

TDS concentration in field water (mg/L)	Proportion of military population that might refuse to drink the water (%)
1000[a]	2.1
1500	6.9
1800	13
2200	25
2800	50

[a] Recommended field-water quality standard for exposure periods of up to either 7 d or 1 y.



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[a] Determined using the z-score equation for Action-Tendency ratings, and a table of values for the standard normal distribution (see Part 1 of Volume 4).[3]

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

Conclusions

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 if not treated, can result in performance degradation. The relationship between TDS concentration and water rejection has been documented through the use of action-tendency scales (A-T scales), which attempt to quantify behavioral responses to stimuli. 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

The chloride anion (also denoted Cl^-) is a constituent of virtually all natural waters, and it contributes to the total dissolved solids (TDS) content of these waters.[2,10,16] Typically, brine and seawater contain high TDS concentrations that are composed primarily of chloride anions (about 55% of TDS by weight) and sodium cations (about 30% of TDS by weight). In comparison, the TDS concentration in fresh water is much lower and the chloride anion constitutes a smaller proportion of this TDS concentration (about 10% or less of TDS by weight). Other anions such as sulfate and bicarbonate are the predominant anionic constituents of TDS in fresh water.

Sources of the chloride ion in natural waters include (1) drainage from mineral deposits; (2) seawater intrusion or the deposition of sea spray; (3) sewage contamination; (4) runoff from agricultural areas, and (5) effluent from industrial projects such as oil wells, galvanizing plants, and paper plants.[2,17] Evaporite deposits such as halite (NaCl) and sylvite(KCl) are the predominant sources for chloride in fresh water.[17]

Recommended Field-Water-Quality Standards

The standard for chloride ion concentration in field-water supplies recommended in Part 1 of Volume 4 is 600 mg/L. This recommended standard is applicable to both short-term ($\leq$7 day) and long-term ($\leq$1 year) exposure periods. This recommendation is based on an assessment of how the objectionable taste that can be imparted to field water by the chloride ion can lead indirectly to degraded performance in exposed military personnel.

Health Risks

The health risks associated with elevated levels of chloride ion in field-water include the possibility of reduced water consumption and increased susceptibility to dehydration as a consequence of the poor taste of the water; and laxative effects and hypertension as a consequence of consumption of the water. These health risks are described next.

The major health risk associated with the presence of the chloride ion in drinking water is dehydration that could result from water rejection based on taste. Bruvold[18] conducted a study in which civilian panelists indicated whether or not they would accept two solutions of NaCl as their everyday drinking water. The mean behavioral response of the panelists to the taste of water with 600 mg/L of chloride ion (1000 mg/L NaCl) was that they might be able to accept such water as an everyday drinking water. However, at 1200 mg/L of chloride (2000 mg/L NaCl) in water, the mean behavioral response of the panelists was that they might not be able to accept the water as their everyday supply. As discussed previously, bad tasting water will be consumed in smaller quantities than good tasting water.[12] Despite the inherent uncertainty involved in extrapolating civilian tests to a military population, these studies suggest that concentrations of chloride greater than 1200 mg/L in water may make the taste of water so objectionable that soldiers might not want to drink it. Such individuals could become susceptible to dehydration, especially in desert environments, where large quantities of water must be consumed to replace sweat losses. As noted earlier, dehydration can lead to discomfort, weariness, muscle weakness, apathy, impaired coordination, delirium, and heat stroke.

In an effort to quantify the relationship between chloride-ion-induced objectionable taste and water rejection, we employed the technique and data of Bruvold and Ongerth.[11] These researchers examined taste panel responses to California water supplies made on an action-tendency scale. However, in order to apply this methodology to the taste problem that can be produced by chloride ions, it was assumed that chloride ions make up approximately 60% of the total dissolved solids (TDS). This assumption is based on the fact that Na^+ and Cl^- ions are the predominant constituents of the TDS content of field water, particularly seawater, that has been processed through a reverse osmosis water purification unit (ROWPU) to achieve potability.[19] Thus, on the basis of this assumption, we employed a procedure similar to that used for TDS to describe the relationship between the chloride concentration and the proportion of the military population that might refuse to consume the water.

Table 5 shows a comparison between three chloride concentrations and the corresponding percentages of military personnel that might refuse to drink the water. At

Table 5. Comparison between chloride concentrations in field water and corresponding proportions of a military population that may refuse to drink the water.

Chloride concentration in field water[a] (mg/L)	Proportion of military population that may refuse to drink the water (%)
600[b]	2.1
900	6.9
1000	11

[a] Computed by assuming that sodium and chloride ions constitute almost all of the TDS content of the water, which is likely for ROWPU product water.[19]

[b] Current and recommended chloride field-water quality standard for military.[3,20]

the current U.S. Army field-water standard for chloride of 600 mg/L,[20] the corresponding percentage of the military population that would consider this water unacceptable for consumption would be about 2%. Increasing the chloride concentration to 900 mg/L means that the proportion of military personnel that might refuse to consume the water would increase to nearly 7%. Finally, at a chloride concentration of 1000 mg/L, approximately 11% of military personnel would refuse to drink the water.

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. For example, the presence of a high concentration of chloride in the intestinal tract probably causes extracellular fluids to flow into the intestinal tract osmotically. This osmotic effect increases both the fluid volume in the large intestine and the motility of the smooth muscle lining the large intestine. Both factors help to flush the large intestine and thereby cause diarrhea.[13] Cass[21] 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 in humans. Such laxative effects may be eliminated in some cases if a period of physiological adjustment to high-chloride water is permitted, or if water that contains a low concentration of TDS is ingested soon after consumption of the high-chloride water.[22]

Unfortunately, the previous data are insufficient to derive quantitatively a no-effects threshold level and comprehensive dose-response relationship for the quantity of chloride that would induce laxative effects. However, the evidence[18,21,22] does suggest that military personnel will probably find the taste objectionable when chloride is present in concentrations substantially less than those reported to cause laxative effects.

A recent study by Kurtz and Morris[23] suggested that hypertension in humans may be related to dietary intake of salt (i.e., NaCl). Military populations, however, would have to consume high levels of NaCl in field-water supplies for periods longer than one year and have minimal sweat loss during the exposure period to experience any performance-degrading symptoms related to hypertension.

Figure 4 is a visual guide for quickly assessing the impact of various levels of Cl^- on the susceptibility of military personnel to dehydration and related performance-degrading health effects. Specifically, the information presented in the figure allows the percentage of a population of military personnel at risk of dehydration to be estimated for concentrations of chloride ion in field water at or above recommended safe levels.

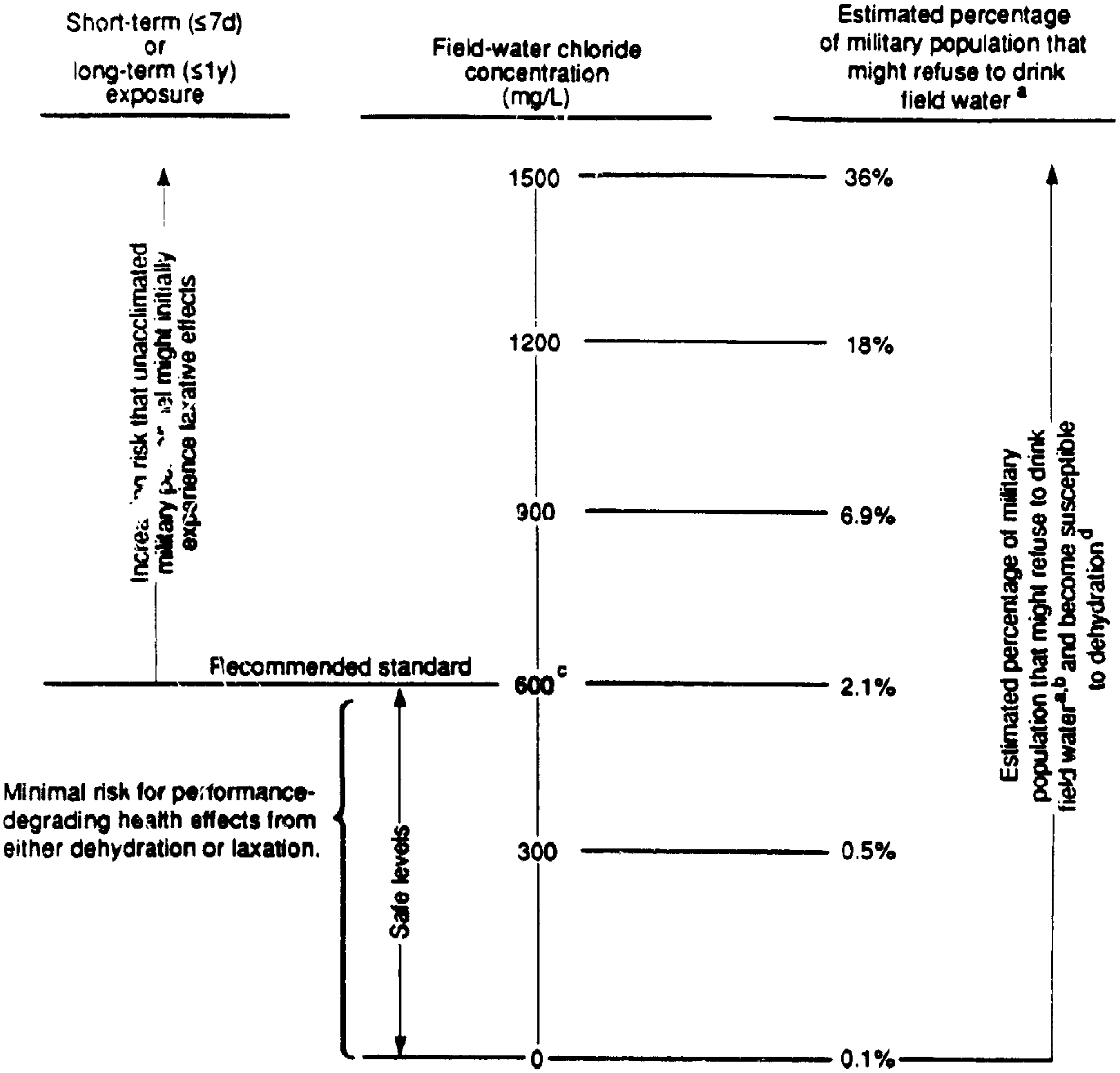
Conclusions

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. Additionally, data were not available in the literature to assess the laxative effects of water containing concentrations of chloride in combination with other laxative producing solutes such as magnesium and sulfate. Therefore, the solutes of military concern that can produce laxative effects--chloride, magnesium, and sulfate--are all addressed separately.

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.

MAGNESIUM

Magnesium is one of the most abundant elements in the earth's crust, but because it is so chemically active it is not found in nature in the elemental state. It is widely distributed in crustal minerals, commonly existing in combination with carbonate and silicate.[24] Magnesium ions (usually Mg^{+2}) and salts (except for the hydroxide) are highly water soluble.[24] Elevated levels of magnesium in field-water supplies generally can be



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[a] Determined using the z-score equation for Action-Tendency ratings, and a table of values for the standard normal distribution (see Part 1 of Volume 4).[3]

[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.

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

Figure 4. Health-effects summary for chloride.

attributed at the regional scale to contact of the water with outcrops of rocks containing soluble magnesium salts.

Magnesium salts are used commonly as laxatives and cathartics; in clinical medicine, a dose of 40 meq (480 mg) is the recommended dose when a laxative effect is desired.[14] Futhermore, a single 15-g dose of epsom salts ($MgSO_4 \cdot 7H_2O$) will produce a cathartic response including a semifluid or watery evacuation in 3 h or less.[14] Doses lower than 15 g produce a laxative effect with a longer latency period. However, as with other saline laxatives, it appears that humans can develop a tolerance to magnesium's laxative effects.[25]

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4 we recommend that the military field-water-quality standard for Mg^{+2} be 30 mg/L for a water consumption rate of 15 L/day. We also recommend a standard for Mg^{+2} of 100 mg/L for a water consumption rate of 5 L/day. Both recommended levels for Mg^{+2} in water are applicable to exposure periods of up to either 7 d or 1 y because of the body's ability to achieve and maintain a constant level of magnesium, and because there is no evidence of chronic toxicity from continued exposure to elevated Mg^{+2} concentrations. The basis for the recommended field-water-quality standards is dose-response data concerning the laxative effects from ingestion of magnesium ions.

Health Risks

The ability of magnesium to cause laxative effects is well established: it is widely prescribed as a laxative and cathartic.[14] In addition, magnesium is associated with other health effects, including hypermagnesemia, and it can have adverse effects on the palatability of water.

The World Health Organization (WHO) states that one possible undesirable effect of water with high magnesium content is gastrointestinal irritation, especially in the presence of sulfate.[26] Additionally, drinking-water supplies high in magnesium have been associated with elevated levels of laxative problems.[27,28] However, magnesium concentrations high enough to cause laxative effects may not be above the threshold for poor taste. Therefore, water containing magnesium concentrations below the threshold for poor taste may be consumed and the resulting laxative effects might be sufficiently dangerous to the soldier to be incapacitating. They could also be harmful before that point by disrupting normal water balance and accelerating the process of dehydration. It is the degree of laxative effect that should be protected against to ensure no performance degradation to a soldier.

The symptoms of hypermagnesemia (elevated plasma levels of magnesium) include muscle weakness, hypotension, sedation, confusion, and respiratory paralysis; electrocardiogram changes have also been reported.[29,30] No evidence was found to indicate that large oral intakes of magnesium are harmful to people with normal renal (kidney) function.[25] Thus, toxic effects following oral administration of magnesium are rare, attributable primarily to the body's ability to sustain remarkably constant serum-magnesium levels.[30] However, one of the possible causes of reduced renal function and the appearance of hypermagnesemia is dehydration.[29]

Palatability of drinking water is important to military personnel because an objectionable taste could lead to voluntary dehydration, especially in a hot and arid environment. It is generally recognized that at high concentrations, magnesium and other ions will give an unpleasant taste to water. However, the relationship between ion concentrations, drinking water acceptability, and the phenomenon of voluntary dehydration is not understood well enough to predict the concentration of magnesium that will begin to exacerbate voluntary dehydration in military personnel. This difficulty results because ions cannot be tested individually in water and the effect that individual ions have on the taste of water when present together is poorly understood. For example, it appears that the level of magnesium reported as having an objectionable taste is affected by the anion with which it is associated.[31-34] In addition to the concentration and combination of ions, other variables such as acclimation and water temperature can affect the acceptability of a mineralized water.[33,35,36] A wide range of difference exists among individuals in subjective taste intensities reported for a given water,[35,37] and in concentrations that are assessed as acceptable for one's daily drinking water.[11] Some rough guidance as to the acceptability of water containing magnesium salts can be found in the report that water with 1000 mg/L of magnesium salts was rated as acceptable by a group tasting the water even though they also reported that the taste was not good.[32]

Figure 5 is a visual guide for quickly assessing the impact of magnesium concentration on performance-degrading health effects in military personnel. The figure shows that magnesium concentrations in field water above recommended safe levels can increase the incidence of laxative effects and therefore the susceptibility of exposed populations of military personnel to dehydration. Unfortunately, at levels of magnesium above the recommended standards neither the proportion of the exposed population likely to exhibit laxative effects, nor the severity of those effects, can be estimated from the available data.

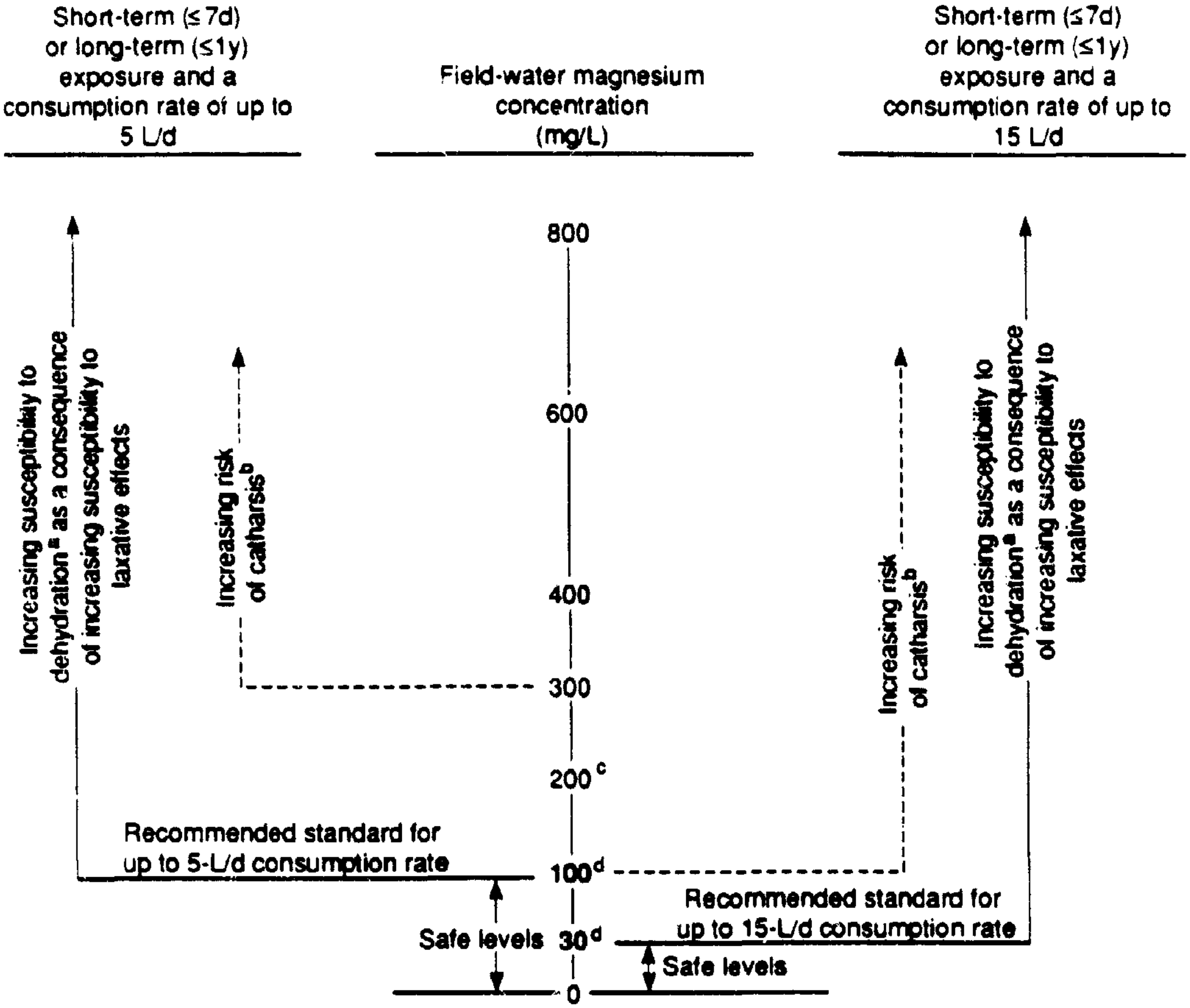

Figure 5. Health-effects summary for magnesium.

FOOTNOTES FOR FIGURE 5. Health-effects Summary for Magnesium.

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

[b] Based on a cathartic 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 possible 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.

Conclusions

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.[14] 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.

As noted in Vol. 4, Part 1, the standards we recommend for magnesium may be conservative because we assume that accumulated individual doses of magnesium totaling a toxic dose from repetitive drinks of water would exert the same effect as a single toxic dose of magnesium administered clinically as a laxative. This assumption was made because the data needed to resolve this uncertainty were not available. As mentioned previously, synergisms between laxative producing solutes such as chloride, magnesium, and sulfate are not addressed because of a lack of data.

SULFATE

The sulfate ion (SO_4^{-2}) is one of the major anions occurring in virtually all natural waters[38] and may be associated with a variety of different cations. Most inorganic sulfates are quite soluble, with the exception of those of lead and barium. Sulfate ions can be present in water that has been in contact with sulfur-bearing minerals or they can be present as the result of several different human activities.

One of the most common sources of sulfate in field-water supplies is leaching of sulfate salts from evaporite sediments comprised of the sulfates of sodium, magnesium, or calcium.[2,25] Metal sulfides (e.g., iron pyrite), common in igneous or sedimentary rocks, can be oxidized and can also contribute to a water's sulfate load; this is frequently a problem with drainage water from mines.[25] The degradation of natural or anthropogenic organic matter is another source of sulfate in water.[25] For example, the degradation of detergents is known to add substantial quantities of sulfate to waste waters.[2] Finally, sulfate contamination is known to come from the waste waters of tanneries, pulp mills, textile mills, and other industrial processes that use sulfates or sulfuric acid.[25]

The ability of sulfate salts to cause laxative effects is well established; like magnesium salts, they are widely prescribed as laxatives and cathartics. In fact, sulfate ions are administered clinically as saline laxatives and in fasted individuals single doses of 1490 mg of sulfate ion are cathartic.[14]

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4, the recommended field-water-quality standards for sulfate are 100 mg/L for a water-consumption rate of 15 L/d and 300 mg/L for a water-consumption rate of 5 L/d. These standards are applicable to exposure periods of up to either 7 d or 1 y because no chronic effects have been associated with sulfate concentrations in drinking water. The recommended standards are the result of an analysis of the available dose-response data concerning the laxative effects from ingestion of sulfate ions.

Health Risks

The health risks related to the consumption of field water supplies that have high sulfate concentrations center on the potentially performance degrading effects of dehydration. Sulfate contributes to the risk of dehydration in two ways: through fluid losses induced by laxation and through insufficient water consumption to make up for sweat losses because of the refusal to drink water with elevated levels of sulfate.

A 15-g dose of epsom salt ($MgSO_4 \cdot 7H_2O$) or Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) will produce a cathartic response, including a semifluid or watery evacuation in 3 h or less.[14] Doses lower than 15 g produce a laxative effect with a longer latency period. For example, a single 5-g dose of epsom salt or Glauber's salt (i.e., 1950- or 1490-mg dose of sulfate ions, respectively) administered in dilute solution to a fasting individual is reported to produce "a significant laxative effect."[14] New users of a water supply high in sulfate may report diarrhea and a feeling of heaviness in the stomach.[39,40] Table 6 contains sulfate concentrations in drinking water that have been reported to cause laxative effects. Multiplication of the range of sulfate levels from Table 6 (about 700 to 1000 mg/L) by a 2-L/d drinking-water consumption rate (typically associated with the general public) yields a range of daily doses of sulfate (1400 to 2000 mg) comparable to the

Table 6. Sulfate levels in drinking water associated with increased incidence of laxative effects.

Laxative concentration (mg/L)	Type of data	Reference
720	Case report	28
>750	Survey	40
>1000	Survey	41

range of single doses of sulfate already mentioned as being sufficient to cause laxative effects (1450 to 1950 mg).

The cation associated with the sulfate appears to have some effect on a sulfate salt's potency as a laxative. For example, calcium sulfate is reported to be much less potent as a laxative than sodium sulfate or magnesium sulfate[42]; and magnesium sulfate is reported to be a better purgative than sodium sulfate.[28] This may result partly from laxative properties of the cations themselves or from differences in the solubility products of the salts.

Sulfate is one of the weakest anions with respect to its ability to elicit a taste sensation.[31,33,43] Nonetheless, it is widely accepted that sulfates can contribute to the undesirable taste of water with a high TDS content. In fact, this taste consideration is the basis for most of the recommended standards for sulfates in drinking water.[11,25,26,42,44,45] Taste panels have been used to determine the levels of ions, including sulfate, that have an objectionable taste. For example, the mean rating from a panel that tasted water with 1000 mg/L and 2000 mg/L of $MgSO_4$ indicated that both concentrations could be accepted by a large portion of the panel as a daily drinking water supply even though the taste was not good.[32] The objectionable level for sulfate, and probably most other ions, is well above the taste-threshold level.

The ion levels that give water an objectionable taste appear to be influenced by several factors, making the measurement of objectionable taste levels difficult. For example, acclimation is an important factor influencing the sulfate levels at which people report an objectionable taste. Daily users of water high in sulfate (and other ions) apparently become accustomed to a taste that new or occasional consumers find close to intolerable.[42] Evidence that people adapt to the taste of water with high levels of sulfate comes primarily from reports of regular use of drinking water supplies that have high sulfate concentrations. For example, water from several small supplies of public drinking water in South Dakota had sulfate levels of 1000 to 1200 mg/L and these supplies were being consumed by residents of the area without extensive physiological effects.[27] Also, there are reports of regularly used drinking-water supplies that have sulfate levels ranging from 2000 mg/L[46] up to 4400 mg/L.[41]

Figure 6 is a visual guide for quickly assessing the impact of sulfate concentration on performance-degrading health effects in military personnel. The figure shows that sulfate concentrations in field water above recommended safe levels might increase the incidence of laxative effects and therefore the susceptibility of exposed populations of military personnel to dehydration. 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.

Conclusions

Health effects stemming from levels of sulfate ion above recommended standards in field-water supplies center on 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, except for data concerning clinical administration of sulfate ions in saline laxatives.

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.

As noted in Vol. 4, Part 1, a laxative administered clinically would be given in a single dose; however, a laxative dose of sulfate consumed in repetitive drinks of water over the course of a day might not exert the same response because of elimination from the gastrointestinal tract. We assume that accumulated individual doses of sulfate totaling a toxic dose at the end of a day would elicit the same response as a single toxic dose because data are not available to resolve this uncertainty. Therefore, the standards we recommend for sulfate might be conservative. As mentioned previously, synergisms between laxative producing solutes such as chloride, magnesium, and sulfate are not addressed because of a lack of data.

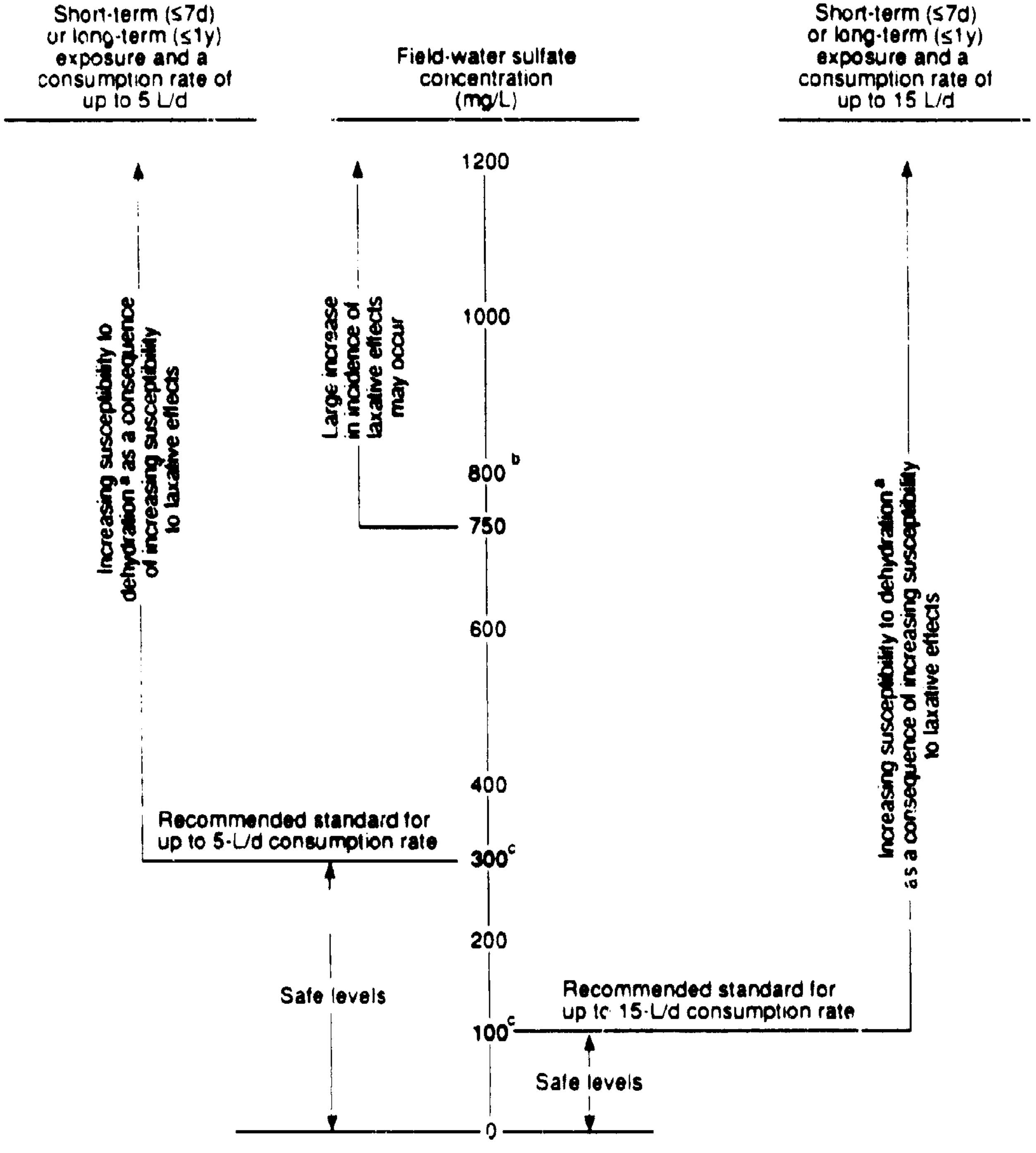

Figure 6. Health-effects summary for sulfate.

FOOTNOTES FOR FIGURE 6. Health-effects Summary for Sulfate.

[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 possible 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.

ARSENIC

Arsenic (As) is a semi-metallic element[47] that is capable of forming numerous different organic and inorganic compounds,[48] many of which can be found in water. The oxidation state of arsenic and the water solubilities of the various arsenic compounds affect the toxicity of arsenic in drinking water. Solubility affects the likelihood that an arsenic compound will be present in water and the extent to which it will be absorbed from the gut.[49]

Trivalent arsenic or arsenite (As(III)) and pentavalent arsenic or arsenate (As(V)) are the most stable oxidation states in most natural waters.[50] In oxygenated waters As(V) is more stable than As(III), but a large fraction of the total arsenic may still be present as As(III) because the rate of oxidation to As(V) is slow at neutral pH.[50]

In addition to the inorganic forms of arsenic, several organic forms can exist in water. These compounds include methylarsines, alkylchloroarsines, methylarsenic acids, and many other more complex compounds.

Arsenic can be present in a wide variety of different natural waters. Typically, arsenic concentrations are well below levels of concern for health effects. For example, Durum et al.[51] found that 79% of 727 water samples taken from U.S. rivers and lakes had less than 0.01 mg/L of total arsenic; only 2% had levels exceeding 0.05 mg/L.

Arsenic can enter the water as the result of a variety of natural processes and human activities. For example, arsenic-bearing minerals are one possible source of arsenic in natural waters. Arsenic compounds can also enter water as a result of their use in many pesticides and herbicides (e.g., Agent Blue).[52] Finally, waters can be contaminated with arsenic from industries that use arsenic compounds; such as glass, metallurgy, industrial chemicals manufacturing, pharmaceuticals, and electronics.[48,52-54]

Recommended Field-Water Quality Standards

As noted in Part 1 of Volume 4, animal studies suggest trivalent arsenic is more toxic than the pentavalent form. However, a difference in potency between these two forms of arsenic has not been shown in humans. Moreover, there is no evidence that the human health effects produced by one form of arsenic could even be distinguished from those produced by the other. In fact, human exposure data for ingestion of inorganic arsenic generally include doses that are expressed only in terms of total inorganic arsenic. For these reasons we recommended standards for total inorganic arsenic in field water. For daily water consumption of up to 15 L, the recommended arsenic standards are

0.1 mg/L for an exposure period up to 7 d and 0.02 mg/L for an exposure period up to 1 y. For daily water consumption of up to 5 L, the recommended arsenic standards are 0.3 mg/L for an exposure period up to 7 d and 0.06 mg/L for an exposure period up to 1 y.

Health Risks

As mentioned previously, the health effects associated with the ingestion of inorganic arsenic depend on the form of inorganic arsenic, its solubility, and valence state. Most studies on the health effects of inorganic arsenic have involved exposure to incompletely characterized mixtures of arsenic species.

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 effects, several different organ systems were affected, including the circulatory, gastrointestinal, integumentary, nervous, hepatic, renal, and immune systems.

Table 7 summarizes the doses and effects reported in several different cases of acute, subacute, and chronic exposures. The doses listed are, in most cases, rough estimates of total inorganic arsenic, made after the exposure took place. The effects reported are those from cases severe enough to come to the attention of the public health authorities. Particularly in the cases of water or food contamination, the total number of people exposed is not generally known.

As shown in Table 7, the highest arsenic level reported in water that is not associated with any adverse health effects is 1 mg/L. According to Goudey,[56] the people in this study were exposed to drinking water containing 0.05 to 1.0 mg/L of arsenic. Thus, this report suggests that people may be able to tolerate levels of arsenic up to 1 mg/L for short periods of time without serious effects.[56] The third incident listed in Table 7 is a report of severe arsenic poisoning caused by contaminated beer. Some of the affected individuals may have consumed as little as 2 mg/d of arsenic; however, this is considered a rough estimate because of difficulties in reconstructing the daily doses (this result is based on a study reported in 1901).

In the fourth incident listed in Table 7, 417 people developed serious arsenic poisoning after exposure to an estimated 3 mg/d from an accidental contamination of soy sauce in Japan.[59] The average duration of exposure was estimated to be 2 to 3 wk. The primary symptoms exhibited by the affected individuals included facial edema (>80%) and gastrointestinal symptoms such as anorexia (>80%), nausea (50%), epigastric fullness (50%), vomiting (35%), and abdominal pain (40%). Skin lesions, upper respiratory symptoms (e.g., headache, chill, sore throat, rhinorrhea), and signs of neuropathy also

Table 7. Relationship between dose of inorganic arsenic and health effects as reported in several literature sources.

Daily dose of total inorganic arsenic (mg)	Source	Acute health effects reported	Exposure conditions	Ref.
0.324 (high-dose group)	Drinking water	No clinical or hematological abnormalities	Long-term exposure[a]	55
0.1 to 2.0	Drinking water with 0.05 to 1.0 mg/L	No "noticeable effect"	Several months exposure	56
~2 to 32	Contaminated beer with 2 to 4 mg/L	Digestive, circulatory, nervous, and integumentary systems affected; some deaths	Estimated consumption was ~1 to 8 L/d for several months	57,58
~3	Contaminated soy sauce	Digestive, circulatory, nervous, and integumentary systems affected; no deaths	2- to 3-wk exposure period	59
3.8	Arsenical medicine	Skin symptoms (cited as example of sensitive individual)	2-d exposure	60
20	Various	Acute intoxication	Single dose	61
70 to 180	Various	Fatal	Single dose	62

[a] The exposure period is described as "long-term," but the authors of the paper noted that it may have been shorter than the exposure period in other studies in which chronic arsenic intoxication was found (e.g., studies in Chile[63] and Taiwan[64]). Eighty-five percent of the residents in the study area had lived there for less than 10 y.[55]

developed in about 20% of the affected cases.[59] These effects would certainly interfere with a soldier's ability to perform any kind of task.

Because the actual number of people exposed is not available, it is not known what percent of the population would be affected to the extent described. However, Holland's comment, that a patient reacting to a daily dose of 3.8 mg of arsenic in the form of As_2O_3 was an example of a sensitive individual, suggests that it would not be a large percentage.[60] A single oral dose of 20 mg is reported to produce severe acute intoxication,[61] and 70 to 180 mg can result in human death.[62]

Table 8 presents incidents of chronic health effects that resulted from exposure to inorganic arsenic in drinking water and which were reported in the literature. The information contained in Table 8 suggests that chronic exposures above 0.40 mg/L cannot be tolerated for prolonged periods without producing performance-degrading effects such as skin changes, respiratory symptoms, cardiovascular effects, and gastrointestinal disturbances.

Additionally, cancer and some nervous disorders may develop long after the period of exposure has ended.[72] In one case, a woman ingested larger than normal (~14 cups of coffee per day) amounts of well water with 1.2 mg/L of arsenic; after 4 months, she developed skin, gastrointestinal, and peripheral nervous symptoms characteristic of arsenic intoxication. Twelve years later she began to develop multiple skin carcinomas of the type associated with arsenic (basal-cell carcinomas and squamous-cell carcinomas).[73]

The first two studies in Table 8 found no increase in the incidence of skin cancer[65] or peripheral neuropathy[66] at mean total arsenic levels under 0.05 mg/L. Hindmarsh et al. examined 92 people in Nova Scotia who were using well water with more than 0.05 mg/L of arsenic.[67] As noted in Table 8, the group with wells containing between 0.05 and 0.10 mg/L had a higher prevalence of clinical symptoms and of abnormal electromyograph (EMG) readings than did the control group. The group exposed to drinking water with arsenic levels above 0.10 mg/L (0.10 to 1.40 mg/L) had an even higher prevalence of clinical symptoms and abnormal EMG readings. The clinical findings and EMG readings for the 0.05 to 0.10 mg/L group were all considered to be very mild effects, not severe enough to interfere with a person's ability to perform a complicated task such as driving a car.[74] The shortest exposure period for a person with abnormal EMG readings was 2 y.[67] Thus, it appears that a year of exposure to less than 0.10 mg/L would not produce a performance-degrading neuropathy. However, the delayed appearance of nervous system problems, as documented in other cases, cannot be ruled out.[72]

Table 8. Relationship between dose of inorganic arsenic and chronic health effects reported in the literature.

Arsenic level in drinking water	Chronic health effects reported	Exposure period	Ref.
0.004 to 0.017 mg/L average (5% of samples >0.10 mg/L)	No increase in incidence of skin cancer	Not determined	65
0.04 mg/L median (range, 0.001 to 4.80 mg/L; mean = 0.35)	No dose response for arsenic ingestion; no signs of peripheral neuropathy	≥2 y[a]	66
0.05 mg/L (range, to 1.40 mg/L)	Increase in arsenic accumulation in hair; no specific illness	Not stated	64
0.05 to 0.10 mg/L	Abnormal clinical findings in 16% of population, 10% in controls; abnormal EMG[b] in 17%, 0% controls	≥2 y[b]	67
>0.10 mg/L (range, to 1.40 mg/L)	Abnormal clinical findings in 40% of population; abnormal EMG[b] in 50%	≥2 y[b]	67
0.18 mg/L and 0.21 mg/L average[c] (range, 0.05 to 0.75 mg/L)	No typical signs or symptoms	≥5 y	68
0.22 mg/L average (range, 0.001 to 2.45 mg/L)	No effects	Long term[d]	55
0.41 mg/L (range, 0.16-0.59 mg/L)	Skin symptoms 21.6%, 2.2% in controls; higher prevalence of gastrointestinal symptoms in exposed population	≥8 y[e]	69
0.40 to 0.60 mg/L (range, 0.01 to 1.82 mg/L)	Prevalence rates for hyperpigmentation, keratosis, skin cancer, and gangrene of extremities were 183.5, 71.0, 10.6, and 8.9/1000, respectively	Population was using contaminated well for ~50 y	63,70
0.60 mg/L average (range, 0.05 to 0.96 mg/L)[f]	Skin changes, respiratory symptoms, cardiovascular effects, gastrointestinal symptoms	15 y	71

Table 8. (Continued)

Arsenic level in drinking water	Chronic health effects reported	Exposure period	Ref.
0.80 mg/L average	Skin changes, respiratory symptoms, cardiovascular effects, gastrointestinal symptoms; 12 y exposure	12 y	63

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[a] Two out of the 147 participants were kept in the study because they had a high arsenic level in their drinking water (2.65 mg/L) even though they had lived in the study area for only 13 months.

[b] The minimum time a patient with electromyographic (EMG) abnormalities had used a well with high arsenic concentration was 2 y. Exposure period for other study subjects not reported.

[c] Two "exposed" communities were studied, one with a mean arsenic concentration of 0.18 mg/L and one with a mean of 0.21 mg/L.

[d] The exposure period is described as "long-term," but the authors of the paper noted that it may have been shorter than the exposure period in other studies in which chronic arsenic intoxication was found (e.g., studies in Chile[63] and Taiwan[64]). Eighty-five percent of the residents in the study area had lived there for less than 10 y.[55]

[e] The shortest period of exposure after which lesions were detected was 8 y for hypopigmentation. Other skin symptoms had longer minimum exposure periods. No exposure periods were reported for the appearance of nonspecific symptoms (e.g., gastrointestinal symptoms).

[f] Average represents weighted mean from 1955 to 1970; range applies to same period.

In another study, signs of arsenic intoxication were looked for in two "exposed" groups of Utah residents: one with a mean total arsenic concentration of 0.18 mg/L in its water supply and another with a mean concentration of 0.21 mg/L.[68] No evidence was found of arsenic intoxication in the form of statistically significant increases in the prevalence of anemia, dermatological symptoms, or neurological symptoms in the exposed groups. Southwick et al. did note among the exposed group, however, a slightly increased proportion of people with a slowing of nerve conduction.[68] A similar study in an Alaskan community that had been exposed to a slightly higher level of arsenic (0.22 mg/L) also found no evidence of anemia, dermatological symptoms, or neurological symptoms.[55]

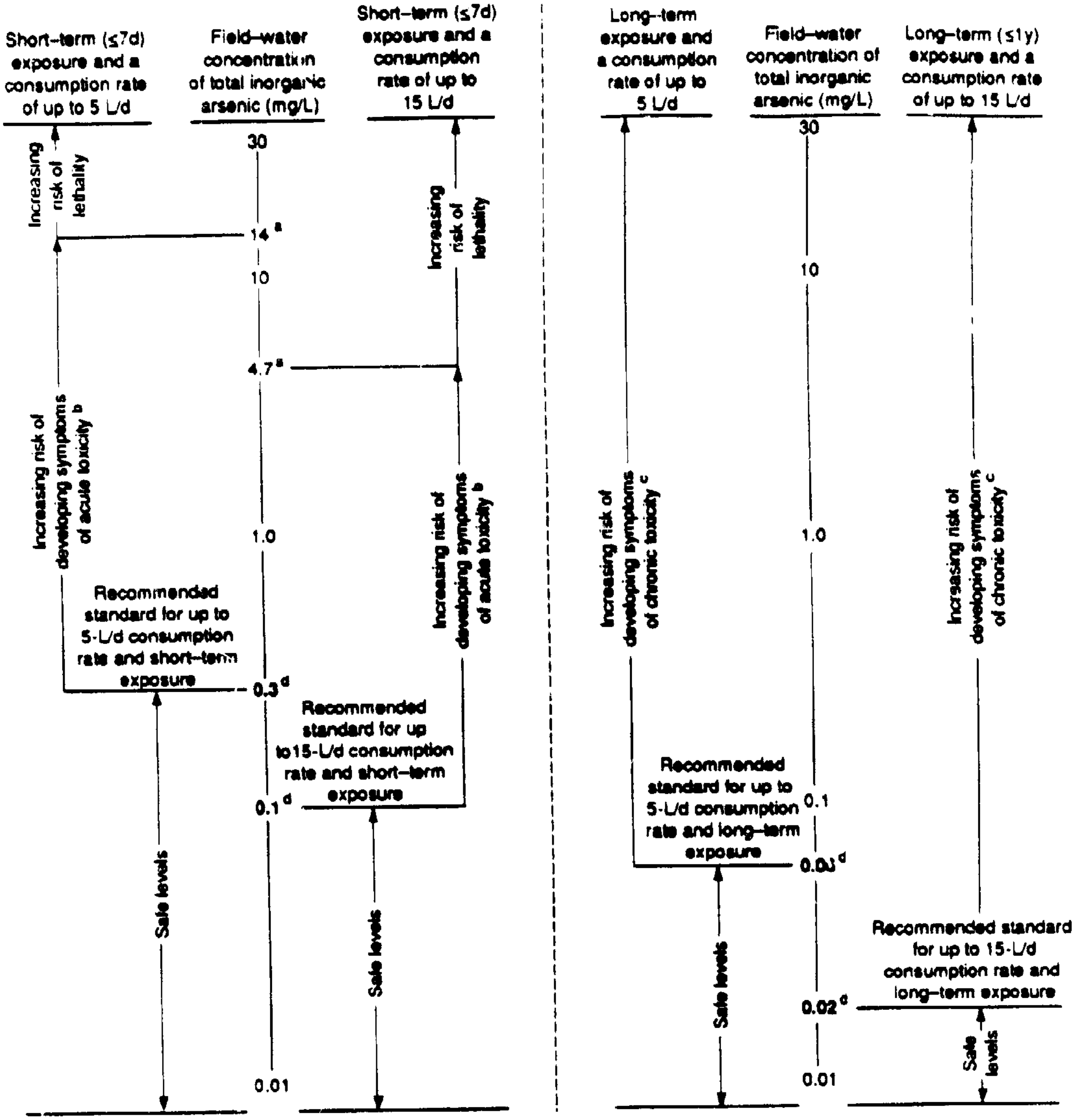
The last four epidemiological studies in Table 8 document effects occurring when levels of arsenic in water exceed 0.40 mg/L. In all of these studies, adverse effects typical of chronic arsenic intoxication were found; and in all four of these studies, the communities had been exposed to arsenic in their drinking water for several years. In Chile, Zaldivar documented the appearance of arsenic intoxication in babies after as few as 2 years of exposure.[71]

Figure 7 is a visual guide for quickly assessing the impact of total inorganic arsenic concentrations in field water on the performance of exposed military personnel for the consumption rates and exposure periods just mentioned. The figure shows that total inorganic arsenic concentrations in field water above recommended safe levels can lead to an increased risk of performance-degrading health effects in exposed military personnel. Consequently, the higher the arsenic concentration is above th[illegible] level, the greater the risk will be that many of the exposed military personnel will deve[illegible]nptoms that can be performance degrading or even lethal. Unfortunately, the pro[illegible]on of the exposed military population that could be affected by performance-degra[illegible]ymptoms, at levels of arsenic above the recommended standards, cannot be estimated f[illegible] the available data.

Conclusions

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.

While the literature suggests that people may be able to tolerate levels of arsenic in drinking water approaching 1 mg/L for short periods,[56] higher concentrations could cause facial edema and gastrointestinal symptoms such as anorexia, nausea, epigastric fullness, vomiting, and abdominal pain. Skin lesions, upper respiratory symptoms (e.g., headache, chill, sore throat, rhinorrhea), and signs of neuropathy are among the chronic symptoms that might also occur.[59] 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.[3]



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

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

[c] Characteristic symptoms 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 periods.

Figure 7. Health-effects summary for arsenic.

CYANIDE

According to Jenks,[75] the simplest inorganic cyanides are the cyanide salts, including the commonly used industrial salts, NaCN, KCN, and $Ca(CN)_2$. These salts are very soluble in water and are hydrolyzed to release free CN^- ions.[76,77] Other simple cyanide salts have varying solubilities in water.[77] Cyanide complexes can also form with some of the metals, including iron, nickel, cobalt, zinc, silver, cadmium, and mercury. In water, these complexes dissociate to different degrees and release metallocyanide anions, which can dissociate further into the metals and cyanide ions.[78,79] An example is the ferrocyanide complex, which is relatively nontoxic and which slowly releases CN^- into an aqueous solution. Two factors limit the aqueous transport of cyanide: hydrogen cyanide is quite volatile, not staying in solution, and the cyanide ion is highly reactive, tending to form low toxicity complexes in water.[76,80,81]

Chlorination of water that contains HCN results in the formation of the highly toxic cyanogen chloride (CNCl),[79] as well as the much less toxic cyanates (OCN^-).[2] Cyanogen chloride can persist for more than 24 hours and slowly hydrolyzes to the cyanate ion.[82] Cyanide (as hydrogen cyanide) is commonly known to have the odor of burnt almonds. However, anecdotal reports of individuals unable to detect their own exposure to dangerous levels of cyanide suggest that odor cannot be relied on as a warning against cyanide poisoning.[83]

Cyanide can contaminate drinking water in several ways. The most important of these appears to be the discharge of cyanide-containing wastewater from industrial processes, particularly those associated with the metals processing industry. For example, industrial discharges have been implicated in most of the cyanide-pollution events serious enough to cause fish kills or to threaten human health.[82,84-86]

Cyanide is used in the metals processing industry for electroplating, heat treating (case hardening), and metal polishing.[2,75] Coal carbonization for the production of coal gas or in coke ovens generates large amounts of cyanide, which can reach water supplies.[82,87] Another source of cyanide in natural waters is wastewaters from many mining operations, as they contain cyanides that are used in the extraction of metals, such as gold and silver, from ore.[75,87]

Photograph and blueprint developing may also be sources of cyanide contamination for natural waters because they frequently use solutions of iron-cyanide complexes.[2] Another industry with a potential to release cyanides into the environment is chemical manufacturing, because cyanides are used in the production of dyes and pigments, agricultural chemicals, plastics, pharmaceuticals, and several other products.[75] Cyanides and their derivatives are also used in agriculture and could enter water as pest fumigants, herbicides (cyanuric chloride), and fertilizers (calcium cyanamide).[75,78]

Microbial metabolism of nitrogenous compounds by bacteria, fungi, and algae can also be responsible for the presence of cyanide in water.[79,80] Microbial decomposition of cyanide-containing plant material and domestic sewage constitutes a constant source of cyanide for some bodies of water.[85] Levels attributed to these sources, however, are much lower than those resulting from industrial or agricultural contamination.

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4, field-water-quality standards for cyanide are recommended to be 2 mg/L for an assumed water-consumption rate of 15 L/d, and 6 mg/L for a 5-L/d consumption rate. These recommended levels are applicable to exposure rates of up to either 7 d or 1 y because there is no reason to expect that chronic health effects will appear in an adequately nourished military population that is not subjected to repeated acute cyanide toxicity. The recommended standards are based on the correlation between whole-blood concentrations of cyanide and physiological effects, and the use of a one-compartment pharmacokinetic model to estimate the concentrations of cyanide in whole blood that can result from the consumption of cyanide-containing water.

Health Risks

Cyanide is known to cause acute health effects by blocking electron transport, thus preventing the body from using oxygen. In addition, cyanide has been associated with a few chronic conditions (e.g., neuropathies, goiter, and diabetes) in some susceptible populations (e.g., those with dietary deficiencies, malnutrition, or hereditary sensitivity). These chronic conditions may be related to long-term exposure to low levels of cyanide.

The cyanide ion is detoxified rapidly to thiocyanate (detoxification is mediated by the enzyme rhodanese); therefore, the accumulation of an acutely toxic level of cyanide will occur when the rate of dosing exceeds the rate of detoxification plus excretion. The effects produced by an acute exposure to cyanide will be influenced strongly by the period of time over which the dose is administered. Once a toxic concentration is accumulated, the cyanide exerts its effects rapidly, acting as a chemical asphyxiant and preventing the use of oxygen in cellular respiration. The nervous and respiratory systems are the first to fail in severe cyanide poisoning.

As mentioned previously, the major health effects associated with chronic exposure to cyanide are neuropathies, goiter, and diabetes. The primary evidence linking these conditions to cyanide are reports of high incidences of these diseases in regions of high cyanide consumption, particularly regions of Africa and the Caribbean where the cyanide-containing cassava root is the staple food.[88-93] Also, reports have been made of neuropathies and goiter developing in occupationally exposed populations.[94,95] Although, these conditions appear to occur in populations with dietary deficiencies or hereditary sensitivities, they may have occurred as a result of repeated acute anoxias caused by exposures to high levels of cyanide.

Table 9 shows the relationship between cyanide ion concentration in drinking water and acute health effects. Symptoms of cyanide intoxication include headache, breathlessness, weakness, palpitation, nausea, giddiness, and tremors, and these symptoms are considered performance degrading. A one-compartment pharmacokinetic model that is based on first-order absorption and elimination was used to compute the doses of cyanide that are used to estimate concentrations in drinking water for the different consumption rates.[96] This model is discussed in detail in Volume 4, along with the parameters used to derive the concentrations presented in Table 9.

Figure 8 is a visual guide for quickly assessing the impact of cyanide concentrations in field water on the performance of exposed military personnel. The figure shows that cyanide concentrations in field water above recommended safe levels can lead to an increased risk of performance-degrading health effects in exposed military personnel. Consequently, the higher the cyanide concentration is above the safe level, the greater the risk will be that many of the exposed military personnel will develop symptoms that can be performance degrading or even lethal. Unfortunately, the proportion of the exposed military population that could be affected by performance-degrading symptoms, at levels of cyanide above those recommended as standards, cannot be estimated from the available data.

Conclusions

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.

Table 9. Cyanide in drinking water: dose-effect relationships.

Concentration in drinking water (mg/L)		
5 L/d	15 L/d	Health effects
0 to 6	0 to 2	No effects
6 to 12	2 to 4	Possible changes in blood chemistry,[a] but no clinical effects likely
12 to 24	4 to 8	Detectable changes in blood chemistry,[a] but no clinical effects likely
24 to 48	8 to 16	Metabolic acidosis, with severe, but reversible clinical symptoms[b]
>48	>16	Life-threatening toxicity, with increasing likelihood of death as concentrations of cyanide increase

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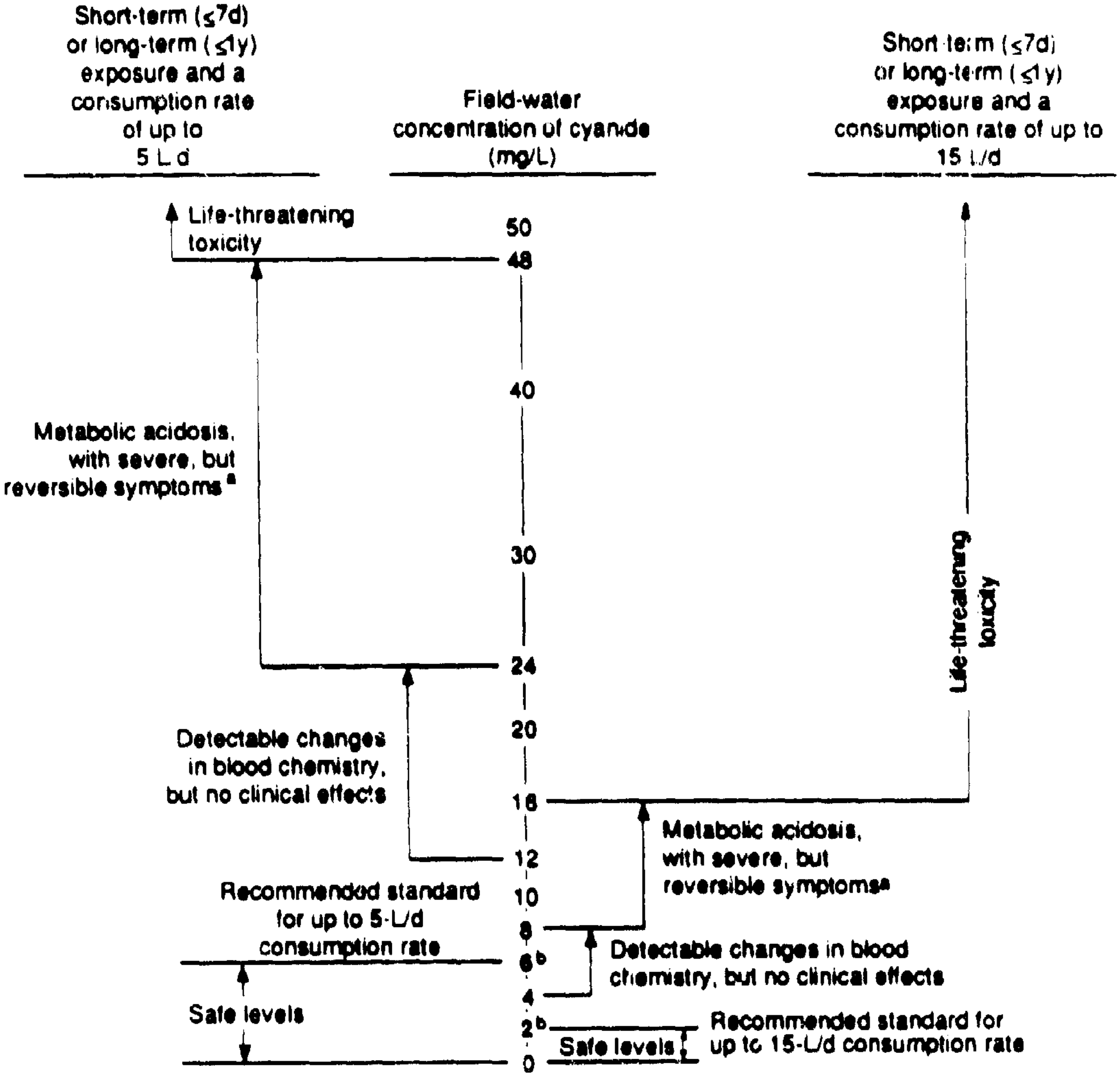
[a] Changes appear in base deficit, oxygen content of mixed venous blood, ATP content, and lactate pyruvate ratios.

[b] Typical symptoms of cyanide intoxication include headache, weakness, palpitation, nausea, breathlessness, 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.

THE PESTICIDE LINDANE

A great variety of pesticides are used worldwide. In the screening analysis we performed on pesticides in worldwide use, the basic conclusion was that while pesticide contamination is widespread, it is only rarely severe enough to threaten troop health.[97] Of the many pesticides we examined (see Ref. 97 for details), lindane, a halogenated hydrocarbon, appears to have the greatest potential for being found at dangerous levels in



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[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 periods up to either 7 d or 1 y..

Figure 8. Health-effects summary for cyanide.

field water. This conclusion was based on data related to its use, production, occurence in natural waters, and toxicity. As such, the health risks associated with lindane contamination of drinking water are presented.

Lindane is the common name for the gamma-isomer of the chemical 1,2,3,4,5,6-hexachlorocyclohexane (HCH). The gamma-isomer is the main insecticidal component of the HCH mixture[98,99]; technical-grade HCH contains approximately 13 to 14% of the gamma isomer. This fraction is isolated to a high degree of purity during production.[100] To be designated as "lindane," it must have at least 99% gamma-HCH.[98,101]

Lindane is known worldwide by several other names. Some of the most commonly used names are Gamaphex, gamma-HCH, Gamma-BHC, Gammalin, Gammex, Isotox, Lindafor, Lintox, Nexit, Novigam, Silvanol, Agromexit, Gammexane, Exagama, Forlin, Gallogama, Inexit, Lindagam, Lindagrain, Lindagramox, Lindalo, Lindamul, Lindapoudre, and Lindaterra.[98,102,103]

Lindane is a colorless solid with a slightly musty odor, a melting point of 112 to 113°C, and a vapor pressure of 9.4×10^{-6} mm Hg at 20°C.[98,103,104] It is slightly soluble in water, with reported solubilities of 7.3 to 10 ppm at 20 to 25°C, 12.0 ppm at 35°C, and 14.0 ppm at 45°C.[98,103] It has an odor-detection threshold of 12.0 ppm.[105]

Lindane is used widely as an agricultural and household insecticide, scabicide, pediculicide, parasiticide, and in baits for rodent control.[98,106] As an insecticide, it is effective against soil-dwelling and plant-eating insects found on fruit, rice, cereal, vegetable, sugarcane, sugarbeet, oil seed, and cotton crops.[98,102,107] As such, it is likely to be encountered any place in the world. Lindane is also used as a public health measure against the mosquito vector of malaria and the triatomid vectors (reduviid bugs) that transmit Chagas' disease.[103,108,109]

Lindane is reported to be moderately persistent in natural water, with a half-life of 6 to 25 wk.[110] Biodegradation/biotransformation appears to be the most important process involved in the degradation of lindane in the aquatic environment.[111]

Lindane has been found in a variety of waters throughout the world. Most of the reported occurrences were in samples of surface waters, primarily rivers. Levels up to 2.0 µg/L have been detected occasionally in surface waters, but most monitored concentrations of lindane are well below 1.0 µg/L. High concentrations (1920 µg/L) of lindane were detected in rice-paddy water in Iran[112] and in canal water in Germany (7.1 µg/L).[113] However, concentrations at or near these levels have been measured only in water near agricultural activities. Groundwater samples from Israel and Egypt contained only low levels of lindane.[114,115]

Lindane is believed to enter water systems via rainfall, runoff, leaching, direct application for mosquito control, or from its use on rice.[109,112,116,117] Because lindane is adsorbed by upper soil layers, it does not appear that significant amounts of lindane reach the water by runoff or leaching.[116] However, since lindane has been known to persist in soil for 10 y or more (95% disappears in 3 to 10 y), the possibility of its presence in a soil environment should be noted.[118]

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4, military field-water-quality standards for lindane are recommended. For 5- and 15-L/d water consumption rates, the recommended standards are 0.6 and 0.2 mg/L, respectively, for exposure periods up to either 7 d or 1 y. These recommendations are based on an evaluation of the daily dose of lindane that produced no effects in rats in one lifetime feeding study and slight liver enlargement in another, and the lowest daily dose reported to cause adverse effects in humans. From this evaluation we concluded that a dose of 3 mg/d should be used as the maximum allowable daily dose of lindane for humans. This daily dose is a factor of 10 lower than the smallest one reported to cause adverse effects in humans over a period of three days.

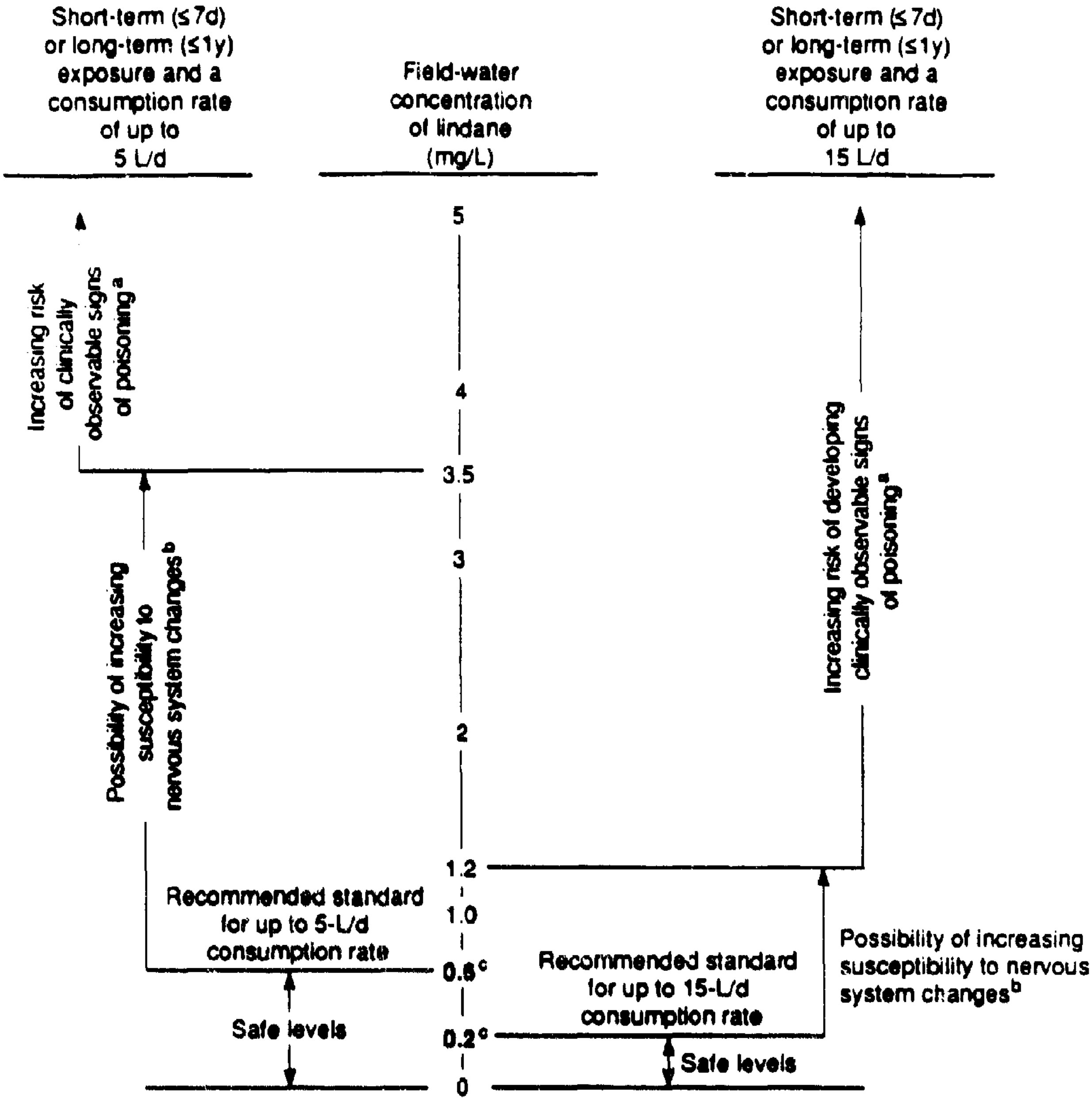
Health Risks

A variety of symptoms have been reported following the ingestion of gamma-HCH (lindane) and technical-grade HCH. With increasing dose, the reported symptoms include a burning sensation of the tongue, nausea, dizziness, restlessness, frontal headaches, vomiting, upper abdominal pain accompanied by diarrhea, enhanced urination, increased or decreased heart and respiration rate, muscle fasciculation, equilibrium disorders, tremors, ataxia, and reflex slowing or loss.[119-121] At higher doses, severe epileptiform seizures can occur,[122] as well as acute renal failure and pancreatitis,[123] followed by eventual central respiratory failure and acute cardiovascular collapse, stupor, confusion, metabolic acidosis, coma, and death.[123,124]

Characterizing a dose-response function for exposure to lindane, including the identification of a no-effects level, is very difficult. This is due, at least in part, to (1) the fact that reported incidents and experiments have involved a variety of carriers, and carriers appear to substantially influence toxicity; (2) an apparently large amount of individual variability in response to lindane; and (3) very approximate estimates of doses in some cases that are reported to cause health effects. For example, the short-term dose regimens for lindane that produced no adverse reaction in humans included: (1) 45 mg/d in a lipid carrier, administered for 3 d[121]; (2) 90 mg/d in a lipid carrier, administered apparently for 3 d[121]; (3) 40 mg/d as a solid, administered for 14 d[120]; and (4) 100 mg/d as a solid administered for 14 d.[120] In contrast to these, a single dose of 45 mg caused convulsions in one patient, and 30 mg/d for 3 d caused nausea, stomach pains, and diarrhea in three patients, as well as dizziness and vision problems in a fourth patient.[121] Additionally, although health effects have been observed in populations occupationally exposed to HCH for long periods,[125-130] and in general populations following prolonged consumption of contaminated grain,[131] the exposure levels for these incidents were not estimated. Therefore, to arrive at an acceptable daily dose for military personnel who will be exposed to field water for periods up to 7 d or 1 y, we applied a safety factor of 10 to the lowest daily dose of lindane reported to cause adverse health effects in humans (30 mg/d).[121] This dose (i.e., 3 mg/d) is then divided by the assumed daily rate of water consumption for military personnel, either 5 or 15 L/d, to arrive at corresponding safe levels of lindane in field water. Military personnel consuming field water containing levels of lindane above those considered to be safe are subject to the possibility of increasing susceptibility to significant nervous system changes. Such changes were observed in laboratory animals (i.e., rats) administered lindane in daily doses of 5 mg/kg of body weight over 3 months.[132]

Based on a minimum-effects-level dose of 2.5 mg/(kg•d) of lindane administered to rats in a lifetime feeding study,[133] and applying a 10-fold safety factor to this daily dose, the estimated daily dose for 1 y for a 70-kg adult is 17.5 mg/d. Because this dose is over half of the minimal dose that produced adverse effects in humans (30 mg/d), we did not consider it a conservative enough estimate upon which to base safe levels for lindane in field water. Therefore, in our judgment should military personnel consume field water containing lindane at concentrations above those based on a dose of 17.5 mg/d (3.5 mg/L for 5 L/d; 1.2 mg/L for 15 L/d), they will be subject to an increasing risk of developing clinically observable signs of poisoning.

Figure 9 is a visual guide for quickly assessing the impact of lindane concentrations in field water on the performance of exposed military personnel. The figure shows that lindane concentrations in field water above recommended, safe levels can lead to an increased risk of performance-degrading health effects in exposed military personnel. Consequently, the higher the lindane concentration is above the safe level, the greater the risk will be that many of the exposed military personnel will develop symptoms that can be performance degrading. Symptoms can range from the possibility of subclinical nervous



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[a] Based on extrapolation to humans from a minimal-effects dose reported in a lifetime feeding study of laboratory animals and the application 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 9. Health-effects summary for Lindane (gamma-isomer 1, 2, 3, 4, 5, 6-hexachlorocyclohexane).

system changes, which might not be performance degrading, at concentrations just above the recommended levels to clinically observable signs of poisoning, including significant nervous system changes, at much higher concentrations above the recommended levels. 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.

Conclusions

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.[119-121] At high doses, epileptiform seizures can occur, followed by major systemic failure and even death.[122-124]

ALGAE AND ASSOCIATED AQUATIC BACTERIA

Algae and associated aquatic microorganisms are commonly found in fresh and marine waters. Many of these aquatic microorganisms have been identified as the source of taste and odor (organoleptic) problems, particularly in drinking-water reservoirs.[134-136] Cyanobacteria (blue-green algae) and actinomycetes (gram-positive filamentous bacteria) are the most important of these microorganisms from a military field-water-quality perspective because they can release the compounds geosmin and 2-methylisoborneol (MIB) into water.[135,137-142] These substances are persistent and cause taste and odor (organoleptic) problems at extremely low concentrations. For example, detection thresholds for the taste and odor of geosmin and MIB vary from 1 to 10 ng/L, depending on the sensitivity of the individual.[135,143,144]

Fresh-water cyanobacteria may also produce other biochemicals (i.e., alkaloid, lipopolysaccharide, and polypeptide compounds) of potential military concern. For example, poisonings of livestock and domestic animals have been attributed to ingestion of water containing these substances and/or concentrated masses of the microorganisms that produce them.[145-147] Moreover, there is circumstantial evidence that indicates a causal relationship between otherwise unexplainable outbreaks of adverse health effects in human populations and the presence of cyanobacteria and their toxic biochemicals in public drinking water supplies.[148-155] In natural waters, especially fresh surface waters, cyanobacteria grow in close association with actinomycetes and are a postulated source of nutrition for the actinomycetes, which peak in population when the cyanobacteria population starts its decline.[137]

Recommended Field-Water-Quality Standards

In Part 1 of Volume 4, a field-water-quality standard of 10 ng/L is recommended for geosmin and MIB, the taste- and odor-causing metabolites of cyanobacteria and actinomycetes. The recommended standard is based on the organoleptic properties (i.e., taste and odor) of these biochemicals. The standard was developed almost entirely from data presented in the literature that address the relationship between possible rejection of drinking water and taste and odor produced by geosmin and MIB.[135,136,156] Although no evidence exists to indicate that these substances are toxic, especially at such an extremely low concentration, higher concentrations might indicate the presence of other potentially toxic biochemicals produced by cyanobacteria, particularly if algal blooms are present.

Unfortunately, the data are too limited to permit recommendation of standards for the toxic compounds associated with cyanobacteria in algal blooms. As pointed out by Bourke et. al.,[150] human aversion to discoloured, foul-tasting, malodorous water accounts for the scant information concerning human algal intoxication. These biochemicals are toxic to livestock and domestic and laboratory animals, but interspecies extrapolation, especially to humans, is made difficult by confounding variables (e.g., differences in digestive systems, responses, and dosage equivalents). Consequently, we suggest that field waters containing algal blooms and detectable odors be avoided by military personnel or be used only after treatement with activated carbon to remove performance-degrading natural biological substances.

Health Effects

Virtually all the reported incidents of animal or possible human poisonings, and most of the accounts of organoleptic problems, correlate with the presence of heavy blooms of cyanobacteria and actinomycetes (an algal bloom is the accumulation of dense masses of algae and accompanying bacteria along shore lines as a consequence of wind and wave action) in drinking water. Usually, blooms occur as part of the eutrophication process (i.e., the increase in biological productivity of a water body, and, subsequently, its detritus content, as a result of favorable temperature and nutrient enrichment introduced naturally or as a consequence of pollution from human activities) in surface waters. Thus, the biochemicals of military concern are most likely to be at critical levels when algal blooms are present.

The biochemicals of military concern that are released into water by cyanobacteria and actinomycetes can be grouped into two categories: (1) those that impair the organoleptic properties of the water and (2) those that produce toxic effects following ingestion or nonconsumptive exposure. Geosmin and MIB belong to the first category and the alkaloid, lipopolysaccharide (LPS), and polypeptide toxins belong to the second one. Geosmin and MIB are produced by a wide variety of cyanobacteria and actinomycetes,[135-141,142,157-159] whereas, the toxins generally are attributed to only a few species of cyanobacteria, Microcystis aeruginosa, Anabaena flos-aquae, and Schizothrix calcicola.[145-147,155,160,161]

The implication for military personnel in the field is that two different types of performance-degrading health effects might result from the presence of high concentrations of cyanobacteria and actinomycetes in a field water: (1) direct effects associated with the toxicity of alkaloid, LPS, and polypeptide compounds released by cyanobacteria, and (2) indirect effects related to the release of the organoleptic metabolites geosmin and MIB by both cyanobacteria and actinomycetes.

The most chemically and pharmacologically understood alkaloid toxin is anatoxin-a.[146] It is a potent neuromuscular blocking agent.[146,162] However, no human deaths have been directly correlated with the ingestion of water containing alkaloid toxins. Lipopolysaccharides (endotoxins) have been isolated from common gram-negative bacteria and cyanobacteria.[153,155] Characteristic responses by humans to LPS from gram-negative bacteria are endotoxemia (the presence of endotoxin in the blood) and pyrogenicity (fever).[153] However, the effect on human populations of ingestion of drinking water containing LPS of cyanobacterial origin is a controversial subject because there is little evidence to suggest that a normal population would be affected by ingesting drinking water containing LPS.[146] Nevertheless, gastroenteritis and "travellers diarrhea" have been attributed to elevated concentrations of LPS in drinking water supplied to Sewickley, PA (2.5 mg/L or 10 to 100 times what is found in normal conditions) and Mexico City (0.8 mg/L).[153,155]

Information about the polypeptide toxins is limited. However, evidence presented by Falconer et al.,[163] indicates that a bloom of Microcystis aeruginosa in a reservoir containing drinking water for the city of Armidale, Australia, was probably responsible for increased liver damage among members of the population using that water. According to Falconer et al.,[163] the pentapeptide hepatotoxin of Microcystis aeruginosa enters water

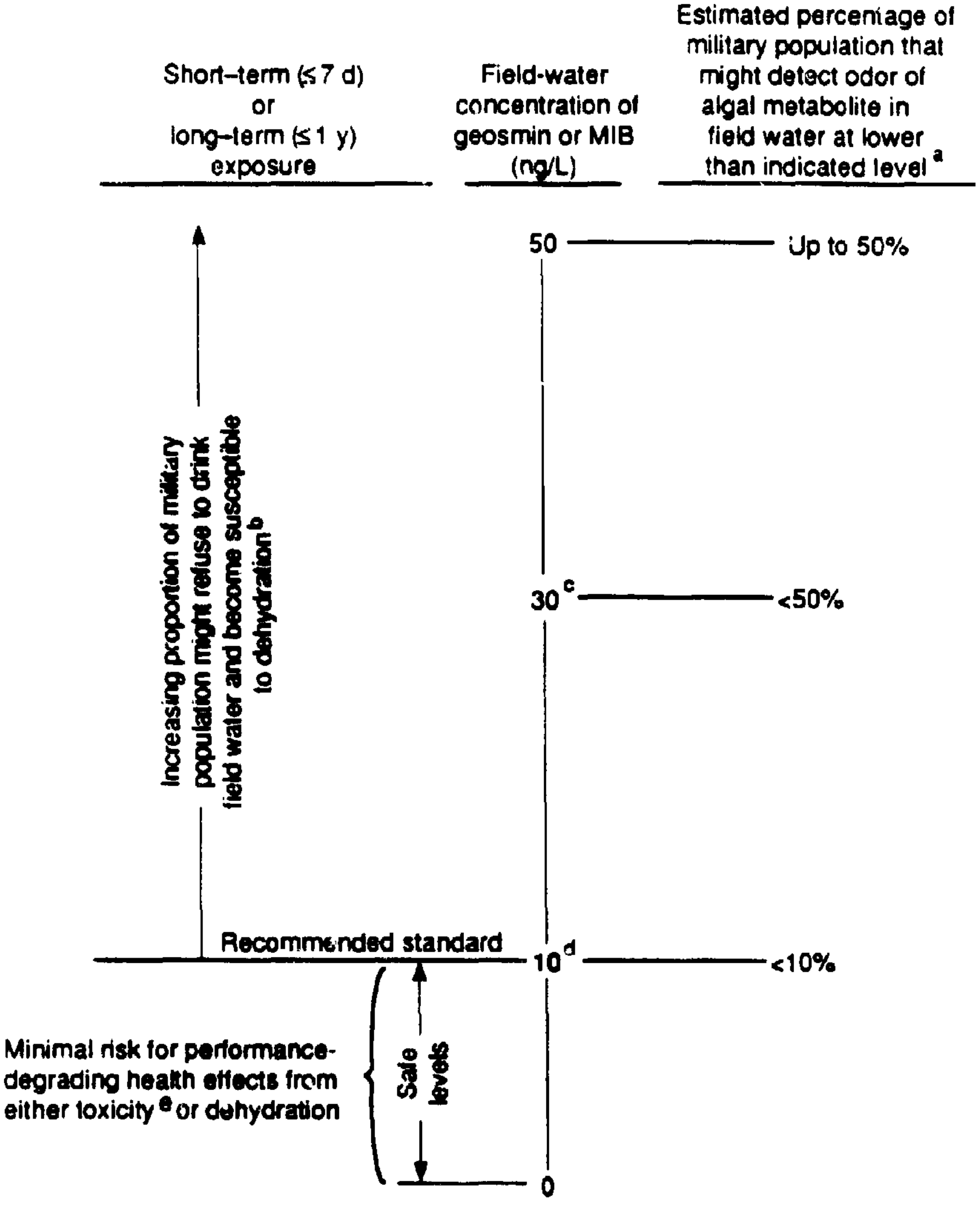

Figure 10. Health-effects summary for the organoleptic metabolites (geosmin and MIB) of algae and associated aquatic bacteria.

FOOTNOTES FOR FIGURE 10. Health-Effects Summary for the Organoleptic Metabolites (geosmin and MIB) of Algae and Associated Aquatic Bacteria.

[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.[135,136,156]

[b] Symptoms of dehydration 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 exceeds the minimum background level of 10 ng/L reported by Burlingame *et al.*[3] upstream from an algal bloom, indicating that concentrations exceeding 10 ng/L may be associated with the presence of toxins released by cyanobacteria.

[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.

when these cells are damaged. Consequently, the toxin may be released in the stomach of humans or rumen of livestock following ingestion of drinking water containing the alga or it may be present in the water following lysis of the cells in the course of treatment of the water with an algicide or it may travel through a distribution system.

The indirect effects could occur when military personnel reduce or reject consumption of water with the objectionable taste and odor of geosmin and MIB. In many operating regions, especially deserts where large amounts of water are needed to replace sweat losses, this could lead to dehydration and the performance-degrading effects associated with it.

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.[136,156,164] This standard should protect military populations from performance-degrading health effects from either poisoning or dehydration. Figure 10 is a visual guide for quickly assessing the impact to military personnel if the concentration of geosmin and MIB exceed the recommended standard. 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 increasing possibility that cyanobacteria might produce critical levels of a toxin produced by an algal bloom. This concern is even more relevant given the possibility that sensory fatigue might be experienced after exposure to geosmin and MIB.[136,165]

Conclusion

We conclude by noting 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.[166] Consequently, waters that have obvious algal masses and detectable earthy/musty odors should be avoided.

REFERENCES

1. American Public Health Association, Standard Methods for the Examination of Water and Wastewater (American Public Health Association, American Water Works Association, Water Pollution Control Federation, Washington, DC, 1981), 15th ed.

2. California State Water Resources Control Board, Water Quality Criteria, J. E. McKee and H. W. Wolf, Eds., California State Printing Office, Sacramento, CA, Publication No. 3A (1963), 2nd ed.

3. Daniels, J.I., Ed., Evaluation of Military Field-Water Quality. Volume 4. Health Criteria and Recommendations for Standards. Part 1. Chemicals and Properties of Military Concern Associated with Natural and Anthropogenic Sources, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 4, Part 1 (1988).

4. Adolph, E.F., A.H. Brown, D.R. Goddard, R.E. Gosselin, J.J. Kelly, G.W. Molnar, H. Rahn, A. Rothstein, E.J. Towbin, J.H. Wells, and A.V. Wolf, "Signs and Symptoms of Desert Dehydration", in Physiology of Man in the Desert (Interscience Publishers, Inc., New York City, NY, 1947), pp. 226-240.

5. Walker, B.S., W.C. Boyd, and I. Asimov, Biochemistry and Human Metabolism (Williams and Wilkins Co., Baltimore, MD, 1954), pp. 630-719.

6. Harris, D.H., Assessment of Turbidity, Color and Odor in Water, (Anacapa Sciences, Inc.,Santa Barbara, CA, Technical Report 128 prepared for U.S. Department of the Interior. Washington, DC 1972)

7. U.S. Environmental Protection Agency, National Secondary Drinking Water Regulations, U.S. Government Printing Office, Washington, DC, EPA-570/9-76-000 (1979), pp. 34-35.

8. U.S. Environmental Protection Agency, Quality Criteria for Water, U.S. Government Printing Office, Washington, DC (1976), pp. 205-210.

9. Drever, J.I., The Geochemistry of Natural Waters (Prentice-Hall, Inc., Englewood Cliffs, NJ, 1982), p. 12.

10. Faust, S.D., and O.M. Aly, Chemistry of Natural Waters (Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1981), pp. 2-3.

11. Bruvold, W.H., and H.J. Ongerth, "Taste Quality of Mineralized Water," J. Am. Water Works Assoc. 61, 170-174 (1969).

12. Zoeteman, B.C.J., G.J. Piet, and C.F.H. Morra, "Sensorily Perceptible Organic Pollutants in Drinking Water," in Aquatic Pollutants: Transformation and Biological Effects, O. Huntzinger, I. H. Lelyveld, and B. C. J. Zoeteman, Eds. (Pergamon Press, New York, 1978), pp. 359-368.

13. Vander, A.J., J.H. Sherman, and D.S. Luciano, Human Physiology: The Mechanism of Body Function (McGraw-Hill Book Company, San Francisco, CA, 1970), pp. 367-401.

14. Fingl, E., "Laxatives and Cathartics," Goodman and Gilman's The Pharmacological Basis of Therapeutics, A.G. Gilman, L.S. Goodman, and A. Gilman, Eds. (Macmillan Publishing Co., Inc., New York, 1980), 6th ed., pp. 1002-1012.

15. Harvey, R.F., and A.E. Read, "Mode of Action of the Saline Purgatives," Am. Heart J. 89, 810-812 (1975).

16. National Research Council Safe Drinking Water Committee, Drinking Water and Health, Volume 3 (National Academy Press, Washington, DC, 1980), pp. 298-302.

17. Moore, E.W., "Sanitary Analysis of Water," in Rosenau Preventive Medicine Public Health, K. F. Maxcy, Ed. (Appleton-Century-Crofts, Inc., New York, NY, 1956), 8th ed., pp. 1152-1187.

18. Bruvold, W.H., "Scales for Rating the Taste of Water," J. Appl. Psych. 52, 245-253 (1968).

19. Marinas, B.J., Z.G. Ungun, and R.E. Selleck, Evaluation of Military Field-Water Quality. Volume 7. Performance Evaluation of the 600-GPH Reverse Osmosis Water Purification Unit (ROWPU): Reverse Osmosis (RO) Components, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 7 (1985).

20. Department of the Army, Sanitary Control and Surveillance of Supplies at Fixed and Field Installations Technical Bulletin, U.S. Army Headquarters, Washington, DC, TB MED 229 (1975).

21. Cass, J.S., Report on the Physiological Effects of Some Common Inorganic Salts in Waters on Man and Domestic Animals, The Kettering Laboratory, University of Cincinnati, College of Medicine, Cincinnati, OH (1953).

22. Murray, R.H., F.C. Kuft, R. Bloch, and A.E. Weyman, "Blood Pressure Responses to Extremes of Sodium Intake in Normal Man," Proc. Soc. Exp. Biol. Med. 159, 432-436 (1978).

23. Kurtz, T.W., and R.C. Morris, Jr., "Dietary Chloride as a Determinant of Sodium-Dependent Hypertension," Science 22, 1139-1140 (1983).

24. Browning, E., "Magnesium," in Toxicity of Industrial Metals (Appleton-Century-Crofts, New York City, NY, 1969), pp. 206-212.

25. National Research Council Safe Drinking Water Committee, Drinking Water and Health, Volume 1 (National Academy Press, Washington, DC, 1977).

26. World Health Organization (WHO), International Standards for Drinking Water (World Health Organization, Geneva, Switzerland, 1971), 3rd ed.

27. Moore, E.W., "Physiological Effects of the Consumption of Saline Drinking Water," in A Progress Report to the 16th Meeting of Subcommittee on Water Supply of the Committee on Sanitary Engineering and Environment, January 1952 (National Academy of Sciences, Washington, DC, 1952), Appendix B.

28. Peterson, N.L., "Sulfates in Drinking Water," Off. Bull. N.D. Water Sewage Works 18(10/11), 11 (1951).

29. Mudge, G.H., "Agents Affecting Volume and Composition of Body Fluids," in Goodman and Gilman's The Pharmacological Basis of Therapeutics, A.G. Gilman, L.S. Goodman, and A. Gilman, Eds. (Macmillan Publishing Co., Inc., New York, NY, 1980), 6th ed., pp. 848-884.

30. Hammond, P.B., and R.P. Beliles, "Metals," in Casarett and Doull's Toxicology, J. Doull, C. D. Klaasen, and M. O. Amdur, Eds. (Macmillan Publishing Co., New York, NY, 1980), 2nd ed., pp. 409–467.

31. Zoeteman, B.C.J., F.E. deGrunt, E.P. Koster, K.G.J. Smit, and P.H. Punter, "Taste Assessment of Individual Salts in Water. Methodology and Preliminary Findings by a Selected National Panel," Chem. Senses Flavor 3(2), 127–139 (1978).

32. Bruvold, W.H., and R.M. Pangborn, "Rated Acceptability of Mineral Taste in Water," J. Appl. Psych. 50, 22–32 (1966).

33. Pangborn, R.M., I.M. Trabue, and R.E. Baldwin, "Sensory Examination of Mineralized, Chlorinated Water," J. Am. Water Works Assoc. 62,572–576 (1970).

34. Bruvold, W.H., and W.R. Gaffey, "Evaluative Ratings of Mineral Taste in Water," Percept. Mot. Skills 28, 179–182 (1969).

35. Pangborn, R.M., and L.L. Bertolero, "Influence of Temperature on Taste Intensity and Degree of Liking of Drinking Water," J. Am. Water Works Assoc. 64, 511–515 (1972).

36. Bruvold, W.H., H.J. Ongerth, and R.C. Dillehay, "Consumer Assessment of Mineral Taste in Domestic Water," J. Am. Water Works Assoc. 61, 575–580 (1969).

37. Bruvold, W.H., and W.R. Gaffey, "Subjective Intensity of Mineral Taste in Water," J. Exp. Psychol. 69, 369–374 (1965).

38. Sawyer, C.N., and P.L. McCarty, "Sulfate," in Chemistry for Environmental Engineers (McGraw-Hill Book Company, San Francisco, CA, 1978) 3rd ed., pp. 476–481.

39. Chien, L., H. Robertson, and J.W. Gerrard, "Infantile Gastroenteritis Due to Water with High Sulfate Content," Can. Med. Assoc. J. 99, 102–104 (1968).

40. An, A.S., V.A. Dudina, and N.I. Nedostupova, "Outbreaks of Intestinal Disorders Due to High Sulfate Concentration in Drinking Water," Hyg. Sanit. 32(5), 264–266 (1967).

41. MacFadyen, W.A., "Sulphates in African Inland Waters," Nature 172, 595 (1953).

42. U.S. Public Health Service, Public Health Service Drinking Water Standards--1962, U.S. Department of Health, Education, and Welfare, Washington, DC, Public Health Service Publication No. 956 (1969), pp. 32-36.

43. Cohen, J.M., L.J. Kamphake, E.K. Harris, and R.L. Woodward, "Taste Threshold Concentrations of Metals in Drinking Water," J. Am. Water Works Assoc. 52, 660-670 (1960).

44. World Health Organization (WHO), European Standards for Drinking Water (World Health Organization, Geneva, Switzerland, 1970), 2nd ed., p. 37.

45. Welsh, G.B., and J.F. Thomas, "Significance of Chemical Limits in USPHS Drinking Water Standards," J. Am. Water Works Assoc. 52, 289 (1960).

46. Moore, E.W., "The Desalting of Saline Waters. A Review of the Present Status," in Bull. Subcomm. Water Supply, Comm. Sanit. Eng. Environ., Interim Report (National Academy of Sciences, Washington, DC, 1950), Appendix A, pp. 100-117.

47. Ucko, D.A., "The Periodic Table," in Basics for Chemistry (Academic Press, Inc., New York, NY, 1982), pp. 128-154.

48. Doak, G.O., G.G. Long, and L.D. Freedman, "Arsenic Compounds," in Kirk-Othmer Encyclopedia of Chemical Technology (Interscience Publishers, New York, NY, 1978), Vol. 3, pp. 251-266.

49. Done, A.K., and A.J. Peart, "Acute Toxicities of Arsenical Herbicides," Clin. Toxicol. 4, 343-355 (1971).

50. Ferguson, J.F., and J. Gavis, "A Review of the Arsenic Cycle in Natural Waters," Water Res. 6, 1259-1274 (1972).

51. Durum, W.J., J.D. Hem, and S.G. Heidel, Reconnaissance of Selected Minor Elements in Surface Waters of the United States, October 1970, U.S. Department of the Interior, Washington, DC, Geological Survey Circular 643 (1971).

52. World Health Organization, Arsenic, Environmental Health Criteria 18, World Health Organization, Geneva, Switzerland (1981).

53. Hampel, C.A., and G.G. Hawley, "Arsenic and Compounds," in The Encyclopedia of Chemistry (Van Nostrand Reinhold Co., New York, NY, 1973), pp. 109-110.

54. Wickstrom, G., "Arsenic in the Ecosystem of Man," Work Environ. Health 9, 2-8 (1972).

55. Harrington, J.M., J.P. Middaugh, D.L. Morse, and J. Houseworth, "A Survey of a Population Exposed to High Concentrations of Arsenic in Well Water in Fairbanks, Alaska," Am. J. Epidemiol. 108, 337 385 (1978).

56. Goudey, R.F., "From the Operator's Viewpoint," J. Am. Water Works Assoc. 35, 1416-1424 (1943).

57. Reynolds, E.S., "An Account of the Epidemic Outbreak of Arsenical Poisoning Occurring in Beer-Drinkers In the North of England and the Midland Counties," Lancet, 166-170 (1901).

58. Reynolds, E.S., "Epidemic of Arsenical Poisoning in Beer-Drinkers in the North of England During the Year 1900," Lancet, 98-100 (1901).

59. Mizuta, N., M. Mizuta, F. Ito, T. Ito, H. Uchida, Y. Watanabe, H. Alsama, T. Murakami, F. Hayashi, K. Nakamura, T. Yamaguchi, W. Mizuia, S. Oishi, and H. Matsumura, "An Outbreak of Acute Arsenic Poisoning Caused by Arsenic Contaminated Soy Sauce: A Clinical Report of 220 Cases," Bull. Yamaguchi Med. Sch. 4, 131-150 (1956).

60. Holland, J.W., "Inorganic Poisons," in Textbook of Legal Medicine and Toxicology, F. Peterson and W. S. Haines, Eds. (W. B. Saunders and Company, Philadelphia, PA, 1904), pp. 340-446.

61. Luh, M., R.A. Baker, and D.E. Henley, "Arsenic Analysis and Toxicity - A Review," Sci. Total Environ. 2, 1-12 (1973).

62. Vallee, B.L., D.D. Ulmer, and W.E.C. Wacker, "Arsenic Toxicology and Biochemistry," AMA Arch. Ind. Health 21, 56/132 to 75/151 (1960).

63. Borgono, J.M., and R. Greiber, "Epidemiological Study of Arsenicism in the City of Antofagasta," in Trace Substances in Environmental Health, V. Proc. of Univ. Missouri 5th Annu. Conf. Trace Subst. Environ. Health, June 29-July 1, 1971, Univ. Missouri, Columbia, MO (1972), pp. 13-24.

64. Tseng, W.P., "Effects and Dose-Response Relationships of Skin Cancer and Blackfoot Disease with Arsenic," Environ. Health Perspect. 19, 109-119 (1977).

65. Morton, W., G. Starr, D. Pohl, J. Stoner, S. Wagner, and P. Weswig, "Skin Cancer and Water Arsenic in Lane County, Oregon," Cancer 37, 2523-2532 (1976).

66. Kreiss, K., M.M. Zack, R.G. Feldman, C.A. Niles, J. Chirico-Post, D.S. Sax, P.J. Landrigan, M.H. Boyd, and D.H. Cox, "Neurologic Evaluation of a Population Exposed to Arsenic in Alaskan Well Water," Arch. Environ. Health 38, 116-121 (1983).

67. Hindmarsh, J.T., O.R. McLetchie, L.P.M. Heffernan, O.A. Hayne, H.A. Ellenberger, R.F. McCurdy, and H.J. Thiebaux, "Electromyographic Abnormalities in Chronic Environmental Arsenicalism," J. Anal. Toxicol. 1, 270-276 (1977).

68. Southwick, J.W., A.E. Western, M.M. Beck, T. Whitley, R. Isaacs, J. Petajan, and C.D. Hanson, Community Health Associated with Arsenic in Drinking Water in Millard County, Utah, Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH, PB82-108374 (1981).

69. Cebrian, M.E., A. Albores, M. Aguilar, and E. Blakely, "Chronic Arsenic Poisoning in the North of Mexico," Hum. Toxicol. 2, 121-133 (1983).

70. Tseng, W.P., H.M. Chu, S.W. How, J.M. Fong, C.S. Lin, and S. Yeh, "Prevalence of Skin Cancer in an Endemic Area of Chronic Arsenicism in Taiwan," J. Natl. Cancer Inst. 40, 453-463 (1968).

71. Zaldivar, R., "Arsenic Contamination of Drinking Water and Foodstuffs Causing Endemic Chronic Poisoning," Beitr. Pathol. 151, 384-400 (1974).

72. National Research Council, Medical and Biological Effects of Pollutants -- Arsenic, (National Academy of Sciences Printing and Publishing Office, Washington, DC, 1977).

73. Wagner, S.L., J.S. Maliner, W.E. Morton, and R.S. Braman, "Skin Cancer and Arsenical Intoxication From Well Water," Arch. Dermatol. 115, 1205-1207 (1979).

74. Heffeman, L.P.M., Victoria General Hospital, Halifax, Nova Scotia, Canada, private communication (August 1983)

75. Jenks, W.R., "Cyanides," in Kirk-Othmer Encyclopedia of Chemical Technology (John Wiley and Sons, New York, NY, 1979), 3rd. ed., Vol. 7, pp. 307-334.

76. Weast, R.C., Handbook of Chemistry and Physics (CRC Press, Boca Raton, FL, 1980), 61st ed.

77. Durrant, P.J., and B. Durrant, Introduction to Advanced Inorganic Chemistry (William Clewes and Sons, Ltd., London, 1970), 2nd ed., pp. 614.

78. Cotton, F.A., and B. Wilkinson, Advanced Inorganic Chemistry, A Comprehensive Text (John Wiley and Sons, New York, NY, 1980) 4th ed., pp. 113-114 and pp. 367-371.

79. Leduc, G., "Ecotoxicology of Cyanides in Freshwater," in Cyanide in Biology, B. Vennesland, E.E. Conn, C.J. Knowles, J. Westley, and F. Wissing, Eds. (Academic Press, San Francisco, CA, 1981), pp. 487-494.

80. Knowles, C.J., "Microorganisms and Cyanide," Bact. Rev. 40, 652-680 (1976).

81. Dean, J.A., Lange's Handbook of Chemistry (McGraw-Hill, Inc., San Francisco, CA, 1972), 12th ed.

82. Pettet, A.E.J., and G.C. Ware, "Disposal of Cyanide Wastes," Chem. Ind. 40, 1232-1238 (1955).

83. Gonzalez, E.R., "Cyanide Evades Some Noses, Overpowers Others," J. Am. Med. Assoc. 248, 2211 (1982).

84. Carlson, P.R., "Cyanide Waste Disposal Survey," Sewage Ind. Wastes 24, 1541-1543 (1952).

85. Krutz, H., "Different Origins of Cyanide Contamination in Small Rivers," in Cyanide in Biology, B. Vennesland, E. E. Conn, C. J. Knowles, J. Westley, and F. Wissing, Eds. (Academic Press, San Francisco, CA, 1981), pp. 479-485.

86. Canela, R., J. Molins, J. Oromi, and F. Gonzales Fuste, "El Problema Sanitario de los Cianuros Presentes en el Medio Acuatico," Circ. Farm. 276, 267-280 (1982).

87. Towill, L.E., J.S. Drury, B.L. Whitefield, E.B. Lewis, E.L. Golyan, and A.S. Hammons, Reviews of the Environmental Effects of Pollutants: V. Cyanides, Health Effects Research Laboratory, U.S. Environmental Protection Agency, Cincinnati, OH, PB-289 920 (1978).

88. Haddock, D.R.W., C.J. Ebrahim, and B.B. Kapur, "Ataxic Neurological Syndrome Found in Tanganyika," Br. Med. J. 2(5317), 1442-1443 (Dec. 1, 1962).

89. Monekosso, G.L., and J. Wilson, "Plasma Thiocyanate and Vitamin B_{12} in Nigerian Patients with Degenerative Neurological Disease," Lancet 1(7446), 1062-1064 (May 14, 1966).

90. Osuntokun, B.O., "An Ataxic Neuropathy in Nigeria," Brain 91, 215-248 (1968).

91. Osuntokun, B.O., "Cassava Diet and Cyanide Metabolism in Wistar Rats," Br. J. Nutr. 24, 797-800 (1970).

92. Osuntokun, B.O., and O. Osuntokun, "Tropical Amblyopia in Nigerians," Am. J. Ophthalmol. 72, 708-716 (1971).

93. Makene, W.J., and F. Wilson, "Biochemical Studies in Tanzanian Patients with Ataxic Tropical Neuropathy," J. Neurol. Neurosurg. Psychiatry 35, 31-33 (1972).

94. El Ghawabi, S.H., M.A. Gaafar, A.A. El-Saharti, S.H. Ahmed, K.K. Malash, and R. Fares, "Chronic Cyanide Exposure: A Clinical, Radioisotope, and Laboratory Study," Br. J. Ind. Med. 32, 215-219 (1975).

95. Hardy, H.L., W. McK. Jeffries, M.M. Wasserman, and W.R. Waddell, "Thiocyanate Effect Following Industrial Cyanide Exposure," New Engl. J. Med. 242, 968-972 (1950).

96. Gehring, P.J., P.G. Watanabe, and G.E. Blau, "Pharmacokinetic Studies in Evaluation of the Toxicological and Environmental Hazards of Chemicals," in Advances in Modern Toxicology, Vol. 1 New Concepts in Safety Evaluation, M.A. Mehlman, R.E. Shapiro, and H. Blumenthal, Eds. (Hemisphere Publishing Corporation, John Wiley and Sons, New York, 1976), pp. 195-270.

97. Scofield, R., J. Kelly-Reif, F. Li, T. Awad, W. Malloch, P. Lessard, and D. Hsieh, Evaluation of Military Field-Water Quality. Volume 2. Constituents of Military Concern from Anthropogenic Sources. Part 2. Pesticides, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 2, Part 2 (1988).

98. Worthing, C.R., The Pesticide Manual--A World Compendium (British Crop Protection Council, Croydon, 1979), 6th ed., p. 290.

99. Demozay, D., and G. Marechal, "Introduction," in Lindane: Monograph of an Insecticide, E. Ulmann, Ed. (Verlag K. Schillinger, Freiburg im Breisgau, W. Germany, 1972), pp. 13-16.

100. Bodenstein, G., "Lindane in the Environment," in Lindane: Monograph of an Insecticide, E. Ulmann, Ed. (Verlag K. Schillinger, Freiburg im Breisgau, W. Germany, 1972), pp. 115-135.

101. U.S. Environmental Protection Agency (EPA), Lindane: Position Document 1, Lindane Working Group, Washington, DC (1977).

102. Thomson, W.T., Agricultural Chemicals Book 1. Insecticides, Acaricides, and Ovicides (Thomson Publications, Fresno, CA, 1982-1983).

103. Meister, R.T., G.L. Berg, C. Sine, S. Meister, and J. Poplyk, The Farm Chemicals Handbook (Meister Publishing Co., Willoughby, OH, 1984).

104. Windholz, M., S. Budavari, R.F. Blumetti, and E.S. Otterbein, The Merck Index (Merck, Rahway, NJ, 1983), 10th ed.

105. Verschueren, K.V., Handbook of Environmental Data on Organic Chemicals (Van Nostrand Reinhold Company, New York City, NY, 1983), 2nd ed.

106. Saleh, F.Y., K.L. Dickson, and J.H. Rodgers, "Fate of Lindane in the Aquatic Environment: Rate Constants of Physical and Chemical Processes," Environ. Toxicol. Chem. 1, 289-297 (1982).

107. Ferrell, G.T., "Lindane Residue in the Environment," in Lindane in Forestry...A Continuing Controversy, T. W. Koerber, Ed., USDA Forest Serv. Gen. Tech. Rep. PSW-14, Pac. Southwest For. Range Exp. Stn., Berkeley, CA (1976), p. 6.

108. World Health Organization/Food and Agriculture Organization (WHO/FAO), Data Sheets on Pesticides: No. 12. Lindane, VBC/DS/75.12, WHO, Geneva, Switzerland, (1975).

109. Hayes, W.J., Jr., Pesticides Studied in Man (Williams & Wilkins, Baltimore, MD, 1982), pp. 211-228.

110 McEwen, F.L., and G.R. Stephenson, The Use and Significance of Pesticides in the Environment (Wiley, New York, NY, 1979), pp. 282.

111. U.S. Environmental Protection Agency (EPA), Water-Related Environmental Fate of 129 Priority Pollutants. Vol. 1: Introduction and Technical Background, Metals and Inorganics, Pesticides and PCBs, U.S. Department of Commerce, NTIS PB80-204373 (1979), EPA-440/4-79-029a, Office of Water Planning and Standards, Washington, DC.

112. Teimoory, S., and M. Hosseiny-Skekarabi, "Residue Estimation of Some Insecticides Used against Rice Stem Borer in Paddy Fields in the Field Water," Entomol. Phytopathol. Appl. 47, 79-95 (1979).

113. Herzel, F., "Organochlorine Insecticides in Surface Waters in Germany--1970 and 1971," Pestic. Monit. J. 6, 179-187 (1972).

114. Lahav, N., and Y. Kahanovitch, "Lindane Residues in the Southern Coastal Aquifer of Israel," Water, Air, Soil Pollut. 3, 253-259 (1974).

115. El-Zanfaly, H.T., M.R. Lasheen, M.M. El-Abagy, S.A. El-Hawaary, and M.I. Badawy, "Assessment of El-Salaam Underground Water for Poultry Use," Environ. Int. 9, 313-317 (1983).

116. Leber, G., "Lindane-Behaviour in the Environment," in Proc. European Symposium on Lindane, Centre Int. d'Etude du Lindane (CIEL), Brussels, Belgium, 1976, pp. 102-112.

117. Anderson, A., "It's Raining Pesticides in Hokkaido," Nature 320, 478 (1986).

118. Edwards, C.A., "Insecticide Residues in Soils," Residue Rev. 13, 83-132 (1966).

119. Herbst, M., and G. Bodenstein, "Toxicology of Lindane," in Lindane: Monography of an Insecticide, E. Ulmann, Ed. (Verlag K. Schillinger, Freiburg im Breisgau, W. Germany, 1972), pp. 23-77.

120. Klosa, J., "DISKUSSIONEN: Zur Toxikologie der Hexachlorcyclohexane," Pharmazie 5, 615-616 (1950).

121. Graeve, K., and G. Hermring, "Über die Toxizität des Gamma-Hexachlorcyclohexan," Arch. Int. Pharmacodyn. Ther. 85, 64-72 (1951).

122. Starr, H.G., Jr., and N.J. Clifford, "Acute Lindane Intoxication," Arch. Environ. Health 25, 374-375 (1972).

123. Munk, Z.M., and A. Nantel, "Acute Lindane Poisoning with Development of Muscle Necrosis," Can. Med. Assoc. J. 117, 1050-1054 (1977).

124. Eskenasy, J.J., "Status Epilepticus by Dichlorodiphenyltrichlorethane and Hexachlorcyclohexane Poisoning," Rev. Roum. Neurol. 9, 435-442 (1972).

125. Baumann, K., K. Behling, H.-L. Brassow, and K. Stapel, "Occupational Exposure to Hexachlorocyclohexane. III. Neurophysiological Findings and Neuromuscular Function in Chronically Exposed Workers," Int. Arch. Occup. Environ. Health 48, 165-172 (1981).

126. Brassow, H.-L., K. Baumann, and G. Lehnert, "Occupational Exposure to Hexachlorocyclohexane. II. Health Conditions of Chronically Exposed Workers," Int. Arch. Occup. Environ. Health 48, 81-87 (1981).

127. Milby, T.H., and A.J. Samuels, "Human Exposure to Lindane: Comparison of an Exposed and Unexposed Population," J. Occup. Med. 13(5), 256-258 (1971).

128. Samuels, A.J., and T.H. Milby, "Human Exposure to Lindane: Clinical, Hematological and Biochemical Effects," J. Occup. Med. 13(3), 147-151 (1971).

129. Czegledi-Janko, G., and P. Avar, "Occupational Exposure to Lindane: Clinical and Laboratory Findings," Brit. J. Ind. Med. 27, 283-286 (1970).

130. Mayersdorf, A., and R. Israeli, "Toxic Effects of Chlorinated Hydrocarbon Insecticides," Arch. Environ. Health 28, 159-163 (1974).

131. Khare, S.B., A.G. Rizvi, O.P. Shukla, R.R. Singh, O. Perkash, V.D. Misra, J.P. Gupta, and P.K. Sethi, "Epidemic Outbreak of Neuro-Ocular Manifestations Due to Chronic BHC Poisoning," J. Assoc. Phys. Ind. 25, 215-222 (1977).

132. Desi, I., "Neurotoxicological Investigation of Pesticides in Animal Experiments." Neurobehav. Toxicol. Teratol. 5, 503-515 (1983).

133. Truhaut, R. (1954), Communication au symposium international de la prevention du cancer. Sao Paulo. Cited by M. Herbst, "Toxicology of Lindane," in Proc. European Symposium on Lindane, Lyon-Chazay, 1976, p. 46.

134. Lalezary, S., M. Pirbazari, M. J. McGuire, and S. W. Krasner, "Air Stripping of Taste and Odor Compounds from Water," J. Am. Water Works Assoc. 76(3), 83-87 (1984).

135. Means, E. G. III, and M. J. McGuire, "An Early Warning System for Taste and Odor Control," J. Am. Water Works Assoc. 78(3), 77-83 (1986).

136. Burlingame, G. A., R. Dann, and G. L. Brock, "A Case Study of Geosmin in Philadelphia's Water," J. Am. Water Works Assoc. 78(3), 56-61 (1986).

137. Faust, S. D., and O. M. Aly, "Chapter 3. Tastes and Odors in Drinking Water," in Chemistry of Water Treatment (Butterworth Publishers, Woburn, MA, 1983), pp. 131-185.

138. Gerber, N. N., and H. A. Lechevalier, "Geosmin, an Earthy-Smelling Substance Isolated from Actinomycetes," Appl. Microbiol. 13, 935-938 (1965).

139. Safferman, R. S., A. A. Rosen, C. I. Mashni, and M. E. Morris, "Earthy-Smelling Substance from a Blue-Green Alga," Environ. Sci. Technol. 1, 429-430 (1967).

140. Medsker, L. L., D. Jenkins, and J. F. Thomas, "Odorous Compounds in Natural Waters: An Earthy-Smelling Compound Associated with Blue-Green Algae and Actinomycetes," Environ. Sci. Technol. 2, 461-464 (1968).

141. Medsker, L. L., D. Jenkins, J. F. Thomas, and C. Koch, "Odorous Compounds in Natural Waters: 2-Exo-hydroxy-2-methylbornane, the Major Odorous Compound Produced by Several Actinomycetes," Environ. Sci. Technol. 3, 476-477 (1969).

142. Rosen, A. A., C. I. Mashni, and R. S. Safferman, "Recent Developments in the Chemistry of Odour in Water: The Cause of Earthy/Musty Odour," Water Treat. Exam. 19(Part 2), 106-119 (1970).

143. Tourila, H., T. Pyysalo, T. Hirvi, and A. K. Vehvilainen, "Characterization of Odours in Raw and Tap Water and Their Removal by Ozonization," Vatten 3, 191-199 (1980).

144. Persson, P.-E., "Off Flavours in Aquatic Ecosystems—An Introduction," Water Sci. Technol. 15, 1-7 (1983).

145. Carmichael, W. W., P. R. Gorham, and D. F. Biggs, "Two Laboratory Case Studies on the Oral Toxicity to Calves of the Freshwater Cyanophyte (Blue-Green Alga) Anabaena flos-aquae NRC-44-1," Can. Vet. J. 18, 71-75 (1977).

146. Carmichael, W. W., "Freshwater Blue-Green Algae (Cyanobacteria) Toxins--A Review," in The Water Environment: Algal Toxins and Health, W. W. Carmichael, Ed. (Plenum Press, New York City, NY, 1981), pp. 1-13.

147. Mahmood, N. A., W. W. Carmichael, and D. Pfahler, "Anticholinesterase Poisonings in Dogs from a Cyanobacterial Blue-Green Algae Bloom Dominated by Anabaena flos-aquae," Am. J. Vet. Res. 49, 500-503 (1988).

148. Aziz, K. M. S., "Diarrhea Toxin Obtained from a Waterbloom-Producing Species, Mycrocystis aeruginosa Kutzing," Science 183, 1206-1207 (1974).

149. Billings, W. H., "Water-Associated Human Illness in Northeast Pennsylvania and its Suspected Association with Blue-Green Algae Blooms," in The Water Environment: Algal Toxins and Health, W. W. Carmichael, Ed. (Plenum Press, New York City, NY, 1981), pp. 243-255.

150. Bourke, A. T. C., R. B. Hawes, A. Neilson, and N. D. Stallman, "An Outbreak of Hepato-Enteritis (The Palm Island Mystery Disease) Possibly Caused by Algal Intoxication," Toxicon Suppl. 3, 45-48 (1983).

151. Falconer, I. R., M. T. C. Runnegar, A. R. B. Jackson, and A. McInnes, "The Occurrence and Consequences of Blooms of the Toxic Blue-Green Alga Microcystis aeruginosa in Eastern Australia," Toxicon Suppl. 3, 119-121 (1983).

152. Dean, A. G., and T. C. Jones, "Seasonal Gastroenteritis and Malabsorption at an American Military Base in the Philippines. I. Clinical and Epidemiologic Investigations of the Acute Illness," Am. J. Epidemiol. 95, 111-127 (1972).

153. Sykora, J. L., G. Keleti, R. Roche, D. R. Volk, G. P. Kay, R. A. Burgess, M. A. Shapiro, and E. C. Lippy, "Endotoxins, Algae and Limulus Amoebocyte Lysate Test in Drinking Water," Water Res. 14, 829-839 (1980).

154. Hashimoto, Y., H., H. Kamiya, K. Yamazato, and K. Nozawa, "Occurrence of a Toxic Blue-Green Alga Inducing Skin Dermatitis in Okinawa," in *Animal, Plant, and Microbial Toxins*, A. Ohsaka, K. Hayashi, and Y. Sawai, Eds. (Plenum Press, New York City, NY, 1976), pp. 333-338.

155. Keleti, G., J. L. Sykora, E. C. Lippy, and M. A. Shapiro, "Composition and Biological Properties of Lipopolysaccharides Isolated from *Schizothrix calcicola* (Ag.) Gomont (Cyanobacteria)," *Appl. Environ. Microbiol.* *38*, 471-477 (1979).

156. Lillard, D. A., and J. J. Powers, *Aqueous Odor Thresholds of Organic Pollutants In Industrial Effluents*, National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency, Corvallis, OR, 660/4-75-002 (1975).

157. Persson, P.-E., "The Source of Muddy-Odor in Bream (*Abramis brama*) from the Porvoo Sea Area (Gulf of Finland)," *J. Fish. Res. Board Can.* *36*, 883-890 (1979).

158. Tabachek, J. L., and M. Yurkowski, "Isolation and Identification of Blue-Green Algae Producing Muddy Odor Metabolites Geosmin, and 2-Methylisoborneol in Saline Lakes in Manitoba," *J. Fish. Res. Board Can.* *33*, 25-35 (1976).

159. Lalezary, S., M. Pirbazari, and M. J. McGuire, "Oxidation of Five Earthy-Musty Taste and Odor Compounds," *J. Am. Water Works Assoc.* *78*(3), 62-69 (1986).

160. Shoptaugh, N. H., and E. J. Schantz, "Algal Toxins," in *CRC Handbook of Foodborne Diseases of Biological Origin*, M. Rechcigl, Jr., Ed. (CRC Press, Inc., Boca Raton, FL, 1983), pp. 271-275.

161. Collins, M., "Algal Toxins," *Microbiol. Rev.* *42*, 725-746 (1978).

162. Mahmood, N. A., and W. W. Carmichael, "The Pharmacology of Anatoxin-a(s), A Neurotoxin Produced by the Freshwater Cyanobacterium *Anabaena flos-aquae* NRC 515-17," *Toxicon* *24*, 425-434 (1986).

163. Falconer, I. R., A. M. Beresford, and M. T. C. Runnegar, "Evidence of Liver Damage by Toxin from a Bloom of the Blue-green Alga, Mycrocystis aeruginosa," Med. J. Aust. 1, 511-514 (1983).

164. Zoeteman, B. C. J., and G. J. Piet, "Cause and Identification of Taste and Odour Compounds in Water," Sci. Total Environ. 3, 103-115 (1974).

165. Piet, G. J., B. C. J. Zoeteman, and A. J. A. Kraayeveld, "Earthy Smelling Substances in Surface Waters of the Netherlands," Water Treat. Exam. 21(Part 4), 281-286 (1972).

166. Krasner, S. W., C. J. Hwang, and M. J. McGuire, "Chapter 38: Development of a Closed-Loop Stripping Technique for the Analyusis of Taste- and Odor-Causing Substances in Drinking Water," in Advances in the Identification & Analysis of Organic Pollutants in Water. Volume 2, L. H. Keith, Ed. (Ann Arbor Science Publishers Inc., Ann Arbor, MI, 1981), pp. 689-710.

CHAPTER 3. REGIONS OF CONCERN WITH REGARD TO INORGANIC CHEMICAL CONSTITUENTS OF FIELD WATER

N.B. Crow*

Several inorganic constituents of field waters could pose health risks to mi personnel (see Chapter 2), mainly in hot, arid regions or areas where natural waters in contact with exposed mineral deposits, such as salt, gypsum, or metal ores. In t chapter we identify those regions where water resources are likely to contain elevate levels of dissolved inorganic substances. Our analyses are meant to provide informatio indicative of water quality. These overviews can be used to identify where in the worl water-quality monitoring is most needed.

AFRICA AND THE MIDDLE EAST

Several countries in Africa and the Middle East have surface and ground water supplies with high levels of dissolved constituents. Surface water quality there is affected by the low rainfall. Figures 1 and 2 show extensive areas where annual rainfall does not exceed 400 mm. Ground water resources, as expected, vary considerably across the region in both volume and concentration of dissolved solids.

In the western part of the Middle East (see Fig. 3), from Libya to Saudi Arabia and Western Iraq, regional aquifers contain rather large amounts of ground water. Water quality in these aquifers varies, depending upon aquifer lithology and proximity to the ocean. In Libya and Egypt, the aquifers are largely sandstones with few soluble minerals; inland from the coast, the water is normally of low salinity. However, reducing conditions dominate these aquifers and the water may contain exceptionally high levels of iron and manganese, which can cause a strongly objectionable taste. Near the coast, the water becomes too saline for use.

Further east, in Lebanon, Jordan, Syria and Israel, the aquifers are largely limestone, and the water is relatively hard, though usually potable. In the eastern part of Syria and adjacent Iraq, gypsum (hydrated calcium sulfate) becomes an important constituent in the limestone aquifers. Water in contact with the soluble gypsum develops high equilibrium concentrations of sulfate.

The Middle-Eastern regions with fairly serious water quality problems include central and eastern Iraq and most of Iran south of the Elburz Mountains (see Fig. 3). The

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* Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550.

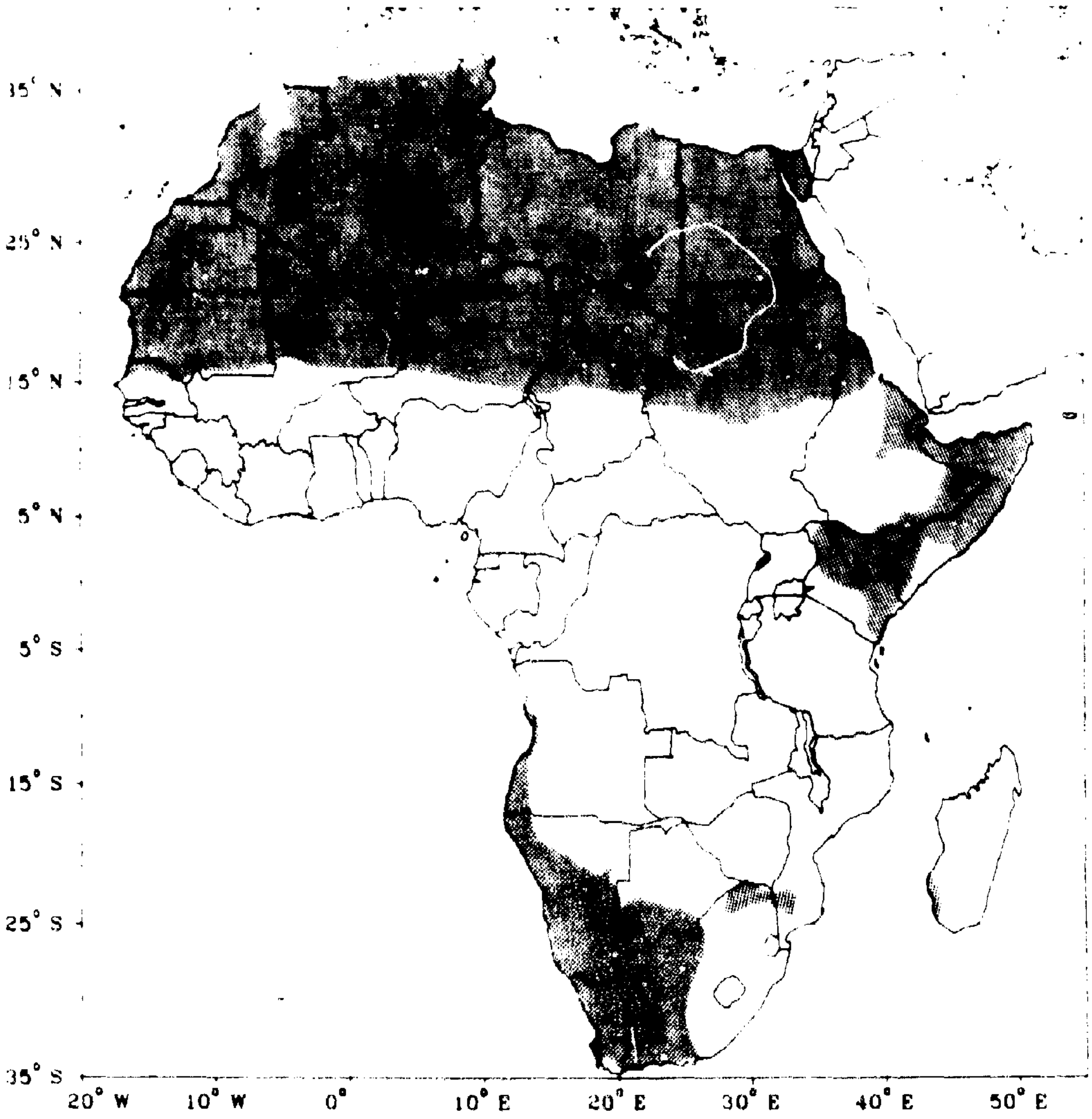

Figure 1. Areas of low annual precipitation (≤400 mm) in Africa (shaded). Based on data appearing in The Times Atlas of the World.[1]

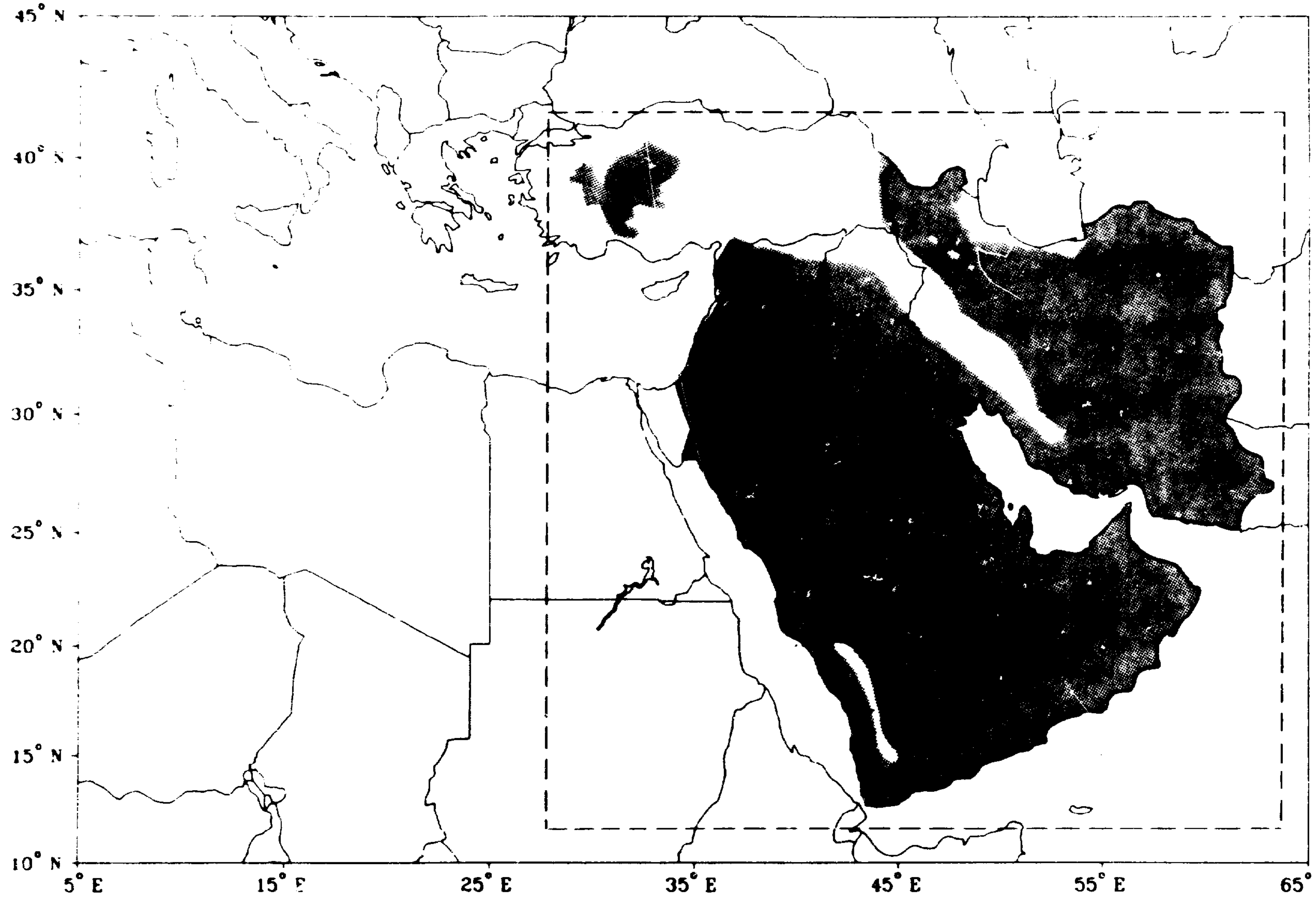

Figure 2. Areas of low annual precipitation (≤400 mm) in the Middle East (shaded). Based on data appearing in <u>The Times Atlas of the World.</u>[1]

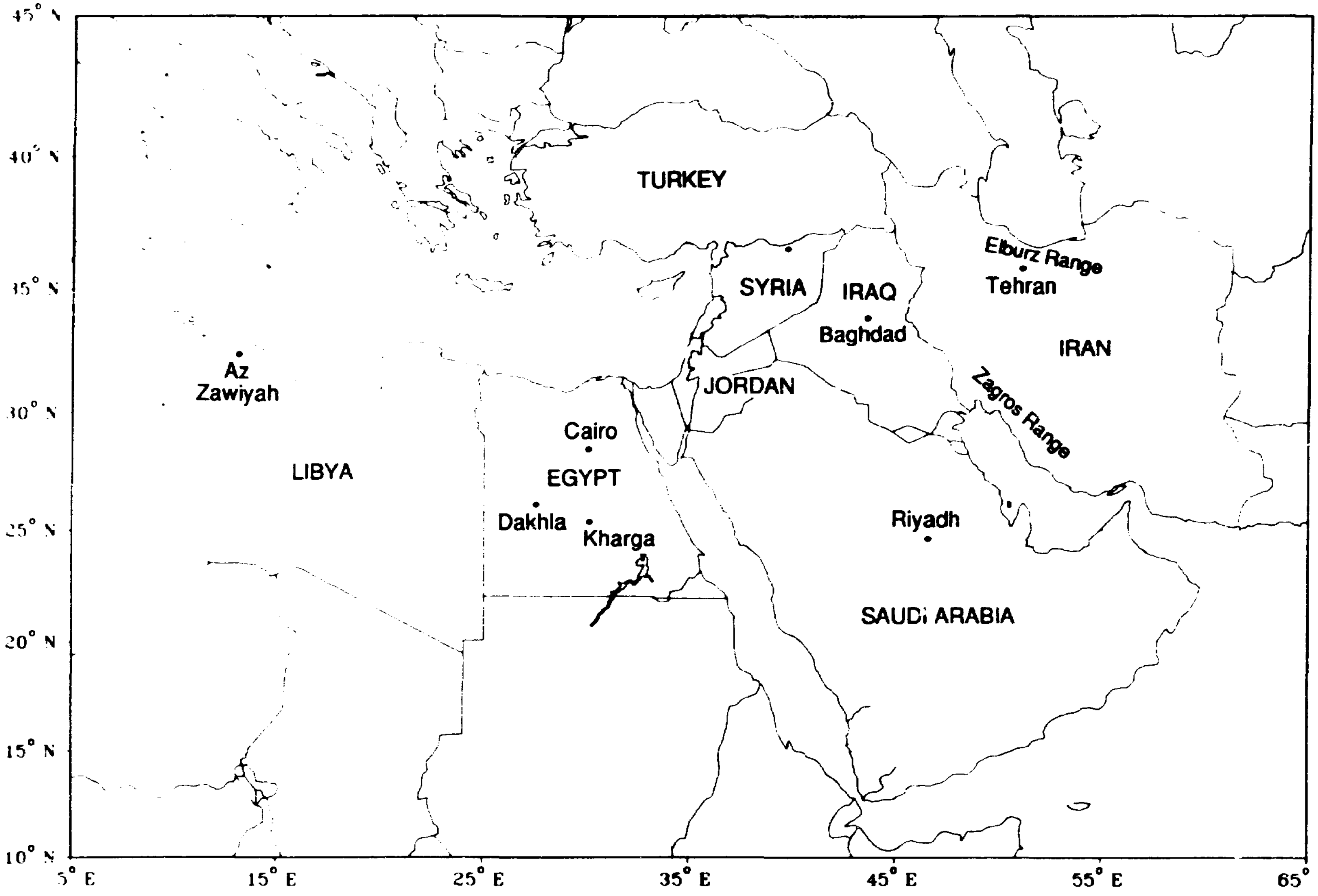

Figure 3. Map of pertinent regions of the Middle East.

climate is hot and arid, and evaporation generally exceeds precipitation, causing high-salinity water supplies. In addition, abundant outcrops of evaporites--gypsum and salt--occur in much of the region. In Iraq salt outcrops are found largely in the northern mountains, which are extensions of the Zagros Range of Iran. In Iran, south of the Elburz Range and north of the coast along the Indian Ocean, evaporite deposits are common. There are relatively large amounts of brackish to highly saline waters available that could be desalinated by reverse osmosis equipment. Because of the likelihood of poor-quality water and the lack of detailed water-quality data, site-specific hydrogeological reconnaissance would be necessary to determine reliably the characteristics of any location of interest.

Iran

A number of studies of the bedrock geology of Iran have been conducted in conjunction with the exploration of petroleum resources. Colman-Sadd[2], Dunnington,[3] and Stöcklin[4] reviewed much of the work on Iran and adjacent northern Iraq. In our discussion below we rely on these sources to identify areas that could have waters with high levels of dissolved solids--expecially those areas where salt-bearing formations could affect ground-water supplies.

The geology of Iran is complex. It is characterized by several episodes and locales of mountain-building. Over large regions, the rocks are deformed, folded and faulted. The major ranges are the east-west trending Elburz range to the north of Tehran, which divides the more-humid north from the semi-arid to arid south; and the Zagros Range, a series of linear fold ridges that trend from north-central Iraq southeasterly as far as the Gulf of Hormuz (Fig. 3). Other, less well-studied mountain complexes and basins occur east of the Zagros Range and south of the Elburz Range. Because the bedrock in Iran is largely deformed, folded, and faulted, there are virtually no major regional bedrock aquifers.

Sedimentary salt layers are a major feature of several horizons in the geologic section affected by mountain-building. These layers, most notably the lowest-lying Hormuz formation, have been mobilized by tectonic forces and forced up into the cores of many anticlines (upward-arching folds). The salt sometimes breaches the sedimentary layers originally lying above it, piercing the crests of anticlines and in some places extruding salt at the surface.[4,5]

The Fars formation is younger than the folded rocks, and was deposited after mountain-building was complete. Thus it is not strongly folded and faulted. It consists of interbedded salt, anhydrite, gypsum, and gypsiferous marls and redbeds. It crops out a the surface in many basins over an area some 1200 km (750 miles) long and 150 km (95 mi) wide, extending from central Iraq, Syria and southern Turkey southeastward to southern Iran.[4,6] In addition, salt is accumulating today in closed basins within the great central desert of Iran, the Dasht-i-Kavir. Figure 4 shows the generalized extent of all these salt formations. These large accumulations of salt and gypsum near the surface provide abundant soluble material that will dissolve in the water that comes into contact with it.

The physiography of Iran also has an important effect on the geohydrology. Because of the aridity of much of the country south of the Elburz Range, rainfall and runoff are very small and there are relatively few perennial streams. The terrain is mountainous, with uplands frequently separated by basins with internal drainage. The lack of abundant water and the presence of many closed drainage basins are favorable to the formation of high-salinity water supplies.

The climate of Iran south of the Elburz Mountains is generally arid to sub-arid and is characterized by cold winters with occasional storms and very hot, dry and windy summers. Thus, the region has scanty rainfall, poor leaching of salts weathered from rocks, and high evaporation rates. These characteristics correlate well with saline water supplies.[7]

Because low rainfall and high evaporation are characteristic of Iran south of the Elburz range, surface water sources are few in number and largely confined to the slopes of the Elburz Range and a few scattered perennial rivers elsewhere in the country. Moreover, many surface water resources have been in contact with salt or gypsum outcrops and are not potable. Most of the potable water in Iran is ground water provided either by conventional wells or by qanats, which are shallow-dug tunnels for transporting water. Most of the water-quality data used in this report are for ground water; however, a few data are included for mountain streams near the Elburz Range and for the Minab River, an unusual perennial river near Bandar Abbas, at the "choke point" of the Persian Gulf.

North of the Elburz mountains is the coastal plain of the Caspian Sea. The Elburz mountains and coastal plains contain very few areas with salt or evaporite outcrops, the physiography is not characterized by closed drainage basins, the climate is humid, and the water supplies generally would be of reasonably good chemical quality.

Figure 5 shows selected locations in Iran where water-quality data are available for several inorganic chemical constituents (i.e., chloride, magnesium, sulfate, and total dissolved solids). Table 1 contains the results of a statistical analysis we performed on the water-quality monitoring data obtained at the sampling locations. The sampling data were presented in reports prepared for the government of Iran by U.S. engineering firms during the 1950's and 1960's and were found to be lognormally distributed. According to our

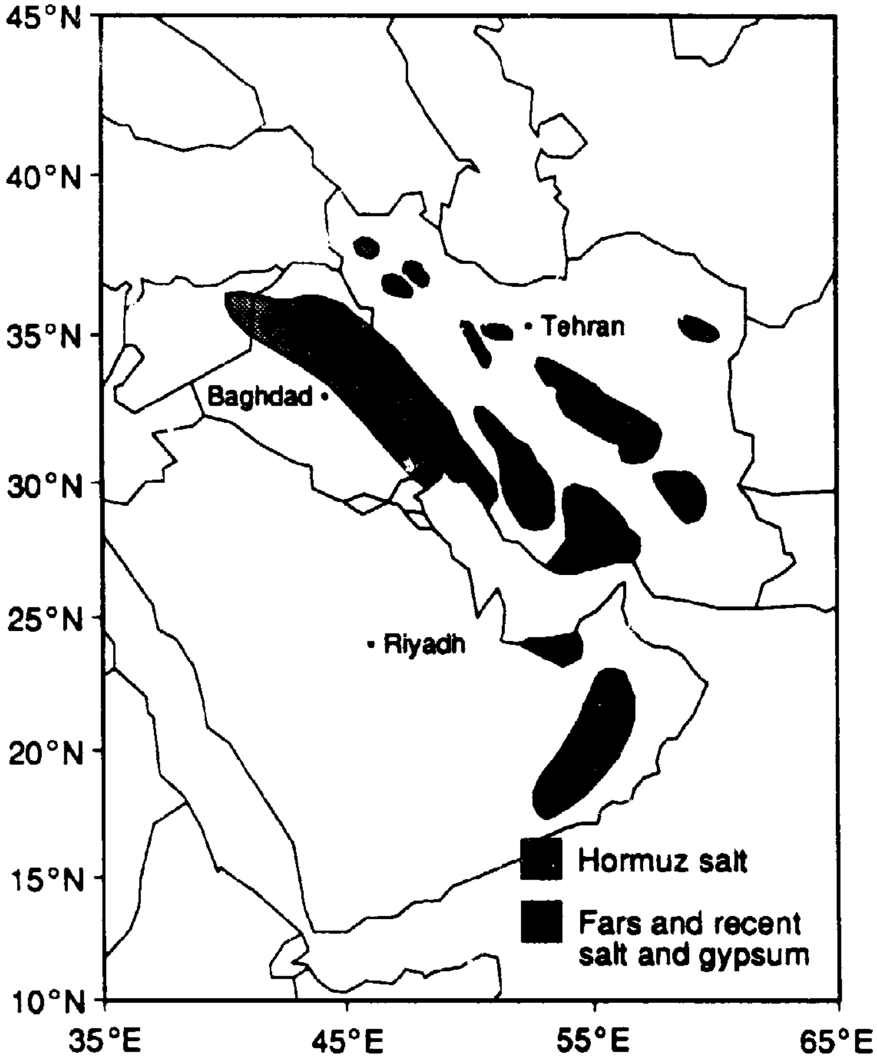

Figure 4. Map of onshore salt deposits in the Persian Gulf region of the Middle East. Taken from information presented by Stöcklin.[4]

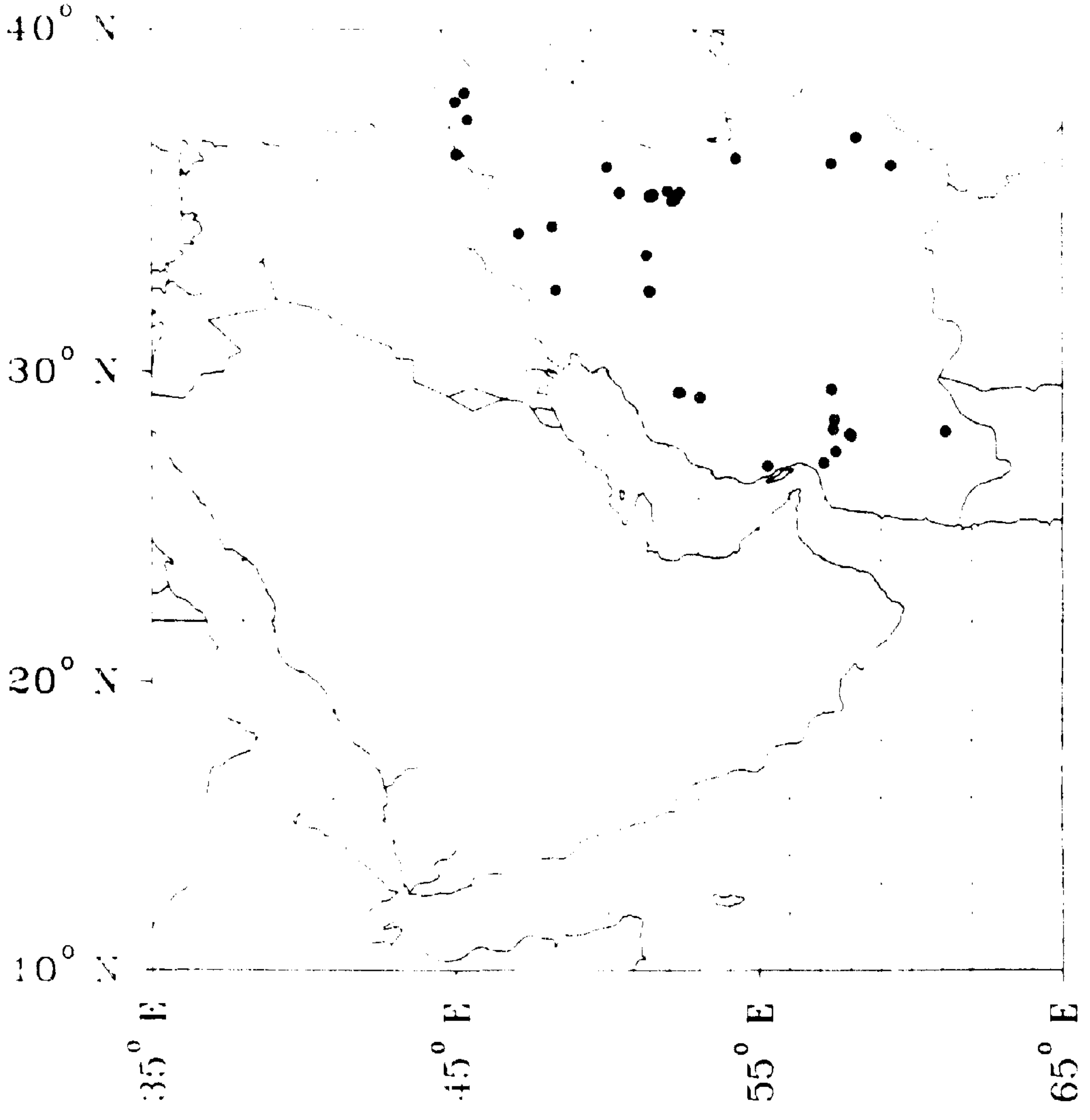

Figure 5. Water-quality sampling locations in Iran at which concentrations of chloride, magnesium, sulfate, and total dissolved solids were measured. (Compiled from original data contained in reports prepared by U.S. engineering firms for the government of Iran during the 1950's and 1960's.)

Table 1. Results of a statistical analysis of water-quality monitoring data for selected inorganic chemical constituents from sampling locations in Iran. (Compiled from original data contained in reports prepared by U.S. engineering firms for the government of Iran during the 1950's and 1960's.)[a]

Inorganic chemical constituent	No. of samples	Geometric mean concentration (mg/L)[b]	Geometric standard deviation	95th cumulative percentile concentration (mg/L)[c]
Chloride	42	77.2	3.43	590
Magnesium	42	37	2.35	150
Sulfate	44	142	3.91	1300
Total dissolved solids (TDS)	43	685	2.15	2400

[a] Most water quality data for Iran are for ground water. Data for a few rivers are available and are included in the statistical analysis.

[b] Sampling data fit a lognormal distribution and the geometric mean concentration is equivalent to the 50th cumulative percentile concentration.

[c] 95th cumulative percentile concentration is equivalent to the geometric mean concentration (X_g) multiplied by the geometric standard deviation (σ_g) raised to the 1.645 power (i.e., $X_g \bullet \sigma_g^{1.645}$). There is a cumulative probability of 95% that the monitored values will be less than or equal to the 95th cumulative percentile concentration.

analysis of the data, there is a 95% cumulative probability that the concentrations of chloride, magnesium, sulfate, and total dissolved solids (TDS) in this region will be less than or equal to 590, 150, 1300, and 2400 mg/L, respectively. These levels approach or exceed the recommendations for field-water-quality standards for these chemicals discussed in Chapter 2.

Because the geohydrology, physiography and climate of Iran south of the Elburz Range all favor the development of saline water supplies, it seems probable that relatively few potable water supplies will be available. However, the Elburz Range and the Caspian coastal plain are likely to have adequate water supplies.

Additional potable-water supplies would be found most likely in regions without bedrock salt formations, on mountain ranges without salt outcrops, and high on the slopes of alluvial fans on mountain ranges. If Reverse Osmosis Water Purification Units (ROWPU's) are available, it should be possible to produce potable water from water supplies of greater salinity in this region than that generally used by civilian populations due to the ability of ROWPU's to desalinate water.

Iraq

Water-quality data for Iraq are very sparse; only a few data points for the Tigris River and irrigation canals near Baghdad are available.[8-10] These data indicate the water of the Tigris River to be of moderately good chemical quality (see Table 2). The sodium chloride content is relatively low. Sulfate concentrations are undoubtedly the result of dissolution of the Fars formation rocks that crop out along the tributaries of the Tigris.

The linear fold mountains of the Zagros Range extend into Iraq, primarily in the eastern and northern portions. The Fars formation, containing gypsum and salt, crops out in these mountains as well (see Figs. 3 and 4).

The climate of northern Iraq is generally similar to that of adjacent Iran. The major physiographic difference between Iran and Iraq is the presence in south-central Iraq of the alluvial plain of the Tigris and Euphrates Rivers. Although no data are available, there is the possibility that potable ground water of moderate to high salinity exists in buried stream channels beneath the alluvial plain.

Table 2. Water-quality monitoring data for irrigation canals and the Tigris River in the vicinity of Baghdad, Iraq.

Inorganic chemical constituent	Concentration (mg/L)		
	Al-Jaysh canal[a]	Al-Khair canal[a]	Tigris River[b]
Calcium (Ca^{+2})	80.1	70.0	64.5
Bicarbonate (HCO_3^-)[c]	196.7	234.0	---
Chloride (Cl^-)	119.5	109.7	82.6
Magnesium (Mg^{+2})	48.2	61.1	21.7
Potassium (K^+)	12.7	10.0	---
Sodium (Na^+)	78.5	78.6	47.7
Sulfate (SO_4^{-2})	120.0	131.4	65.5
Total dissolved solids (TDS)	636.3	575.3	437
pH	7.78	7.63	8.12

[a] From Ref. 8.

[b] From Ref. 10.

[c] Reported as alkalinity and recalculated.

Saudi Arabia

The geology of most of the Saudi Arabian peninsula is characterized by relatively homogeneous sedimentary rocks--primarily limestones and evaporites, with some salt layers--gently dipping eastward off the granitic basement complex that crops out in the west.[11,12] Some of the world's largest petroleum and natural gas occurrences are found in geologic structures that form reservoirs in the older sediments of this sedimentary section.

Above the stratigraphic zones that contain petroleum-bearing reservoirs, tabular bedrock aquifers contain relatively large amounts of ground water of varying quality. Some of these aquifers contain rocks with high sulfate content. Water quality has a regional pattern; generally the best quality water is found near the center of the Arabian peninsula, and the salinity increases eastward toward the coast of the Persian Gulf. Scattered data[13] show that the waters from the regional aquifers often contain relatively high sulfate concentrations; in regions where the water is not potable, waters have high sodium chloride concentrations as well. Bakiewicz et al.[14] present a regional study of one of the major aquifers, the Umm er Radhuma formation. The report includes a map showing the total dissolved solids (TDS) concentration of the water in this formation regionally (see Fig. 6). The map shows that the waters near the [illegible]st of Saudi Arabia in the Umm er Radhuma formation generally exceed 1500 mg/L and therefore are above the recommended field-water-quality standard for TDS of 1000 mg/L (see Chapter 2). Nonetheless, local populations of this area have apparently acclimated to water up to about 2500 mg/L of total salinity, because there is no better quality water available.

Aquifers are probably scarce in the granitic highlands in the west of the Arabian peninsula and in the folded mountains extending along the south coast to Oman; most water sources are probably in the overlying alluvium and are likely to be relatively small in extent. These water sources are likely to be of reasonably high quality.

Syria, Lebanon, Israel, and Jordan

The situation in these four countries is generally similar. They are underlain by more or less gently-dipping sedimentary rocks, predominantly limestones.[12] The western and northern areas--the Mediterranean coastal areas of Israel and Lebanon and the "Fertile Crescent" highlands in northern Syria and adjacent Turkey--are relatively well-watered--approximately 500 mm/y--and water supply is unlikely to be a serious problem. The eastern portions of Syria, all of Jordan, and the West Bank are desert country and are likely to have both a general shortage of water and a salinity problem.

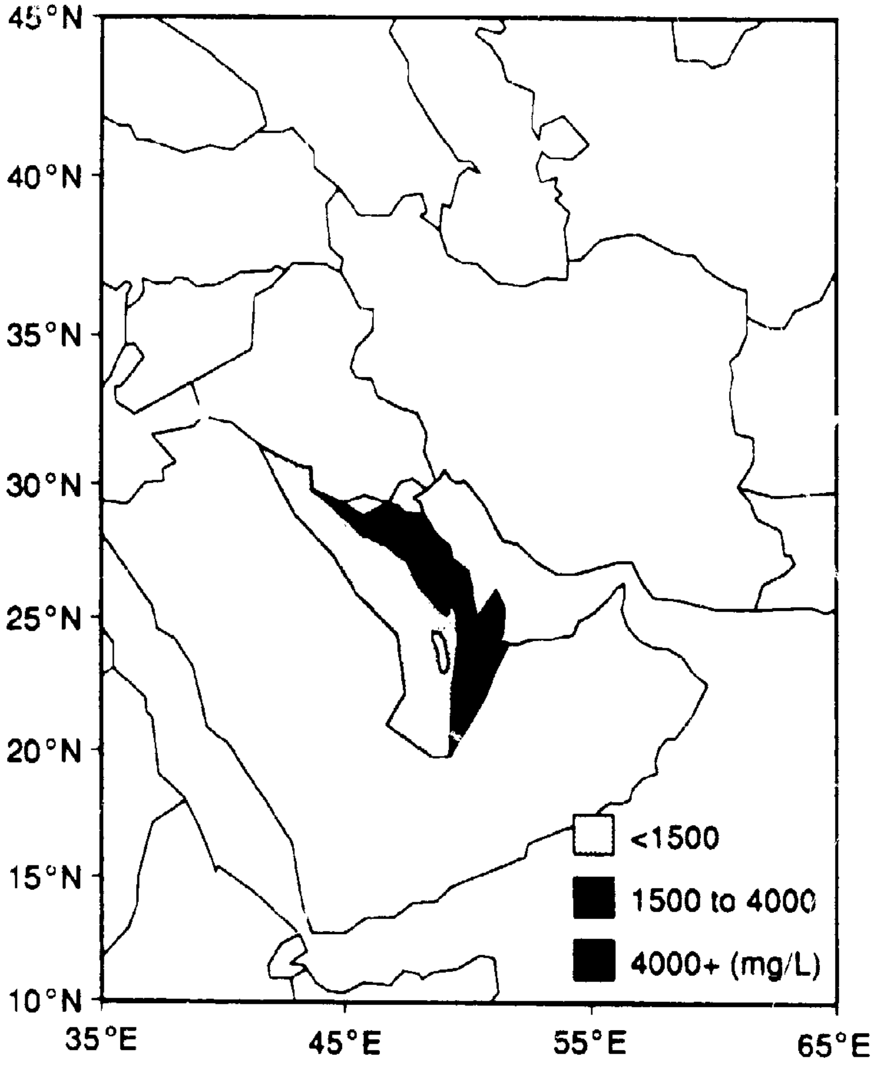

Figure 6. Map showing regional water salinity (TDS) concentrations associated with Umm er Radhuma Aquifer, Saudi Arabia. From information pressented by Backiewicz et al.[14]

The water in the Jordan River/Dead Sea basin is quite saline, unlike the remainder of the region.

We found considerable but scattered data covering Jordan and Israel, fewer about Lebanon and Syria. There is one report by Burden and Safadi[15] that includes water-quality data for a relatively large number of wells completed in karst aquifers in Syria (see Table 3). Karst aquifers are found in the widespread limestone beds of the region, and the available data indicate that the groundwater does not have a high dissolved solids content. In areas where the karst aquifers are in rocks high in sulfate minerals, the sulfate concentration in the water is much higher and the water is less desirable as drinking water.

Egypt

Northern Egypt is a very arid region; along the coast the only dependable water supply is the Nile River, which has been used for thousands of years to support both agriculture and the population. Table 4 shows water chemistry data compiled by Talling[16] for the Nile River at Lake Victoria and Cairo. The river water is supplied by rainfall in the southern highlands of Egypt, the Sudan, and Ethiopia; because the rocks in this region contain few soluble minerals, the water is usually of excellent chemical quality. The salinity of the Nile increases downstream. At Cairo the water is of moderate salinity. At the mouth of the Nile below Alexandria, the water is brackish. Despite reasonably good chemical quality in most of the Nile River, biological pollution is quite severe, and there are high levels of algae in the water as well. For these reasons pretreatment of the water is necessary for drinking and for using in boilers.[17,18]

Near the coast, water quality is generally poor. During the Egyptian and Libyan campaign of World War II, the British army survived in coastal strongholds on shallow ground water with salinities as high as 4000 mg/L. Troops using water of such high salinities were not usually able to fight vigorously and tanks and other vehicles were dependent on treated Nile River water transported by rail.[17,18]

Another major source of water in much of inland Egypt is the Nubian sandstone aquifer.[19,20] This sandstone lies at the base of a relatively thin, undeformed section of sedimentary rocks; it overlies a granitic basement from which the sand is largely derived. The rock contains few soluble salts. Studies indicate that most of the water in the aquifer entered it from granitic and volcanic highlands adjacent to the southern part of the aquifer during Pleistocene pluvial periods about 10,000 to 15,000 years ago.[19,20] Because few soluble salts entered the water, the water is of remarkably low salinity for this highly arid region (see Table 5).

Table 3. Water-quality monitoring data for the karst aquifers in Syria.[a]

Inorganic chemical constituent	Concentration (mg/L)	
	Springs	Wells
Calcium (Ca^{+2})	47.1	78.2
Bicarbonate (HCO_3^-)	231	220
Chloride (Cl^-)	13.8	70.9
Magnesium (Mg^{+2})	20.7	25.3
Sodium and potassium (Na^+ and K	16.3	40.5
Sulfate (SO_4^{-2})	30.7	85.5
Total dissolved solids (TDS)	386	543

[a] Averaged data from Ref. 15.

Table 4. Water-quality monitoring data for the Nile River at Lake Victoria and Cairo, Egypt.[a]

Inorganic chemical constituent	Concentration (mg/L)	
	Lake Victoria	Cairo
Calcium (Ca^{+2})	5.6	27.6
Bicarbonate (HCO_3^-)	68.4	200
Chloride (Cl^-)	3.9	14.5
Magnesium (Mg^{+2})	2.6	10.0
Potassium (K^+)	3.9	6.6
Sodium (Na^+)	10.4	27.6
Sulfate (SO_4^{-2})	2.4	17.8
Conductivity (μmho/cm)	97	307

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[a] From Ref. 16.

Table 5. Water-quality monitoring data for the Nubian Aquifer at Kharga and Dakhla Oases, Egypt.[a]

Inorganic chemical constituent	Concentration (ppm)			
	Wells at Kharga		Wells at Dakhla	
	el Maheriq	Baris 15	Mut	Rashda
Calcium (Ca^{+2})	19.2	44.8	21.6	24.8
Bicarbonate (HCO_3^-)	89.5	95.0	55.5	53.0
Chloride (Cl^-)	67.0	98.0	49.0	62.0
Free CO_2	89.5	36.6	42.6	36.0
Iron (Fe^{+2})	1.2	45.0	4.6	6.1
Magnesium (Mg^{+2})	9.2	17.5	9.7	10.6
Potassium (K^+)	34.5	34.0	21.5	12.5
Sodium (NA_+)	81.5	60.0	30.0	33.0
Sulfate (SO_4^{-2})	14.5	76.0	32.5	53.5
Total dissolved solids (TDS)	378.0	432.0	226.0	294.0
Eh (millivolts)	+125[b]	-4.6[c]	+99.7[b]	+64.7[b]
pH	6.6	6.7	6.3	6.4
Temperature (°C)	38.0	33.0	34.0	34.0

[a] From Ref. 20.

[b] Oxidizing environment.

[c] Mildly reducing environment.

While salinity of the water is low, conditions in the aquifer can be strongly reducing. The water has a high temperature, can be high in iron and manganese, and is highly corrosive.[20] High concentrations of iron may make the water unpalatable. The Nubian aquifer covers a large area; Shata[19] describes its geographic extent and its water salinity contours (see Fig. 7). Note that near the Mediterranean coast the water in the aquifer is not potable because of high salinity.

As part of an agricultural development program, the Egyptian government has developed the water resources of the Nubian aquifer in several inland oases areas where the water is sufficiently shallow to allow economical pumping of the water to the

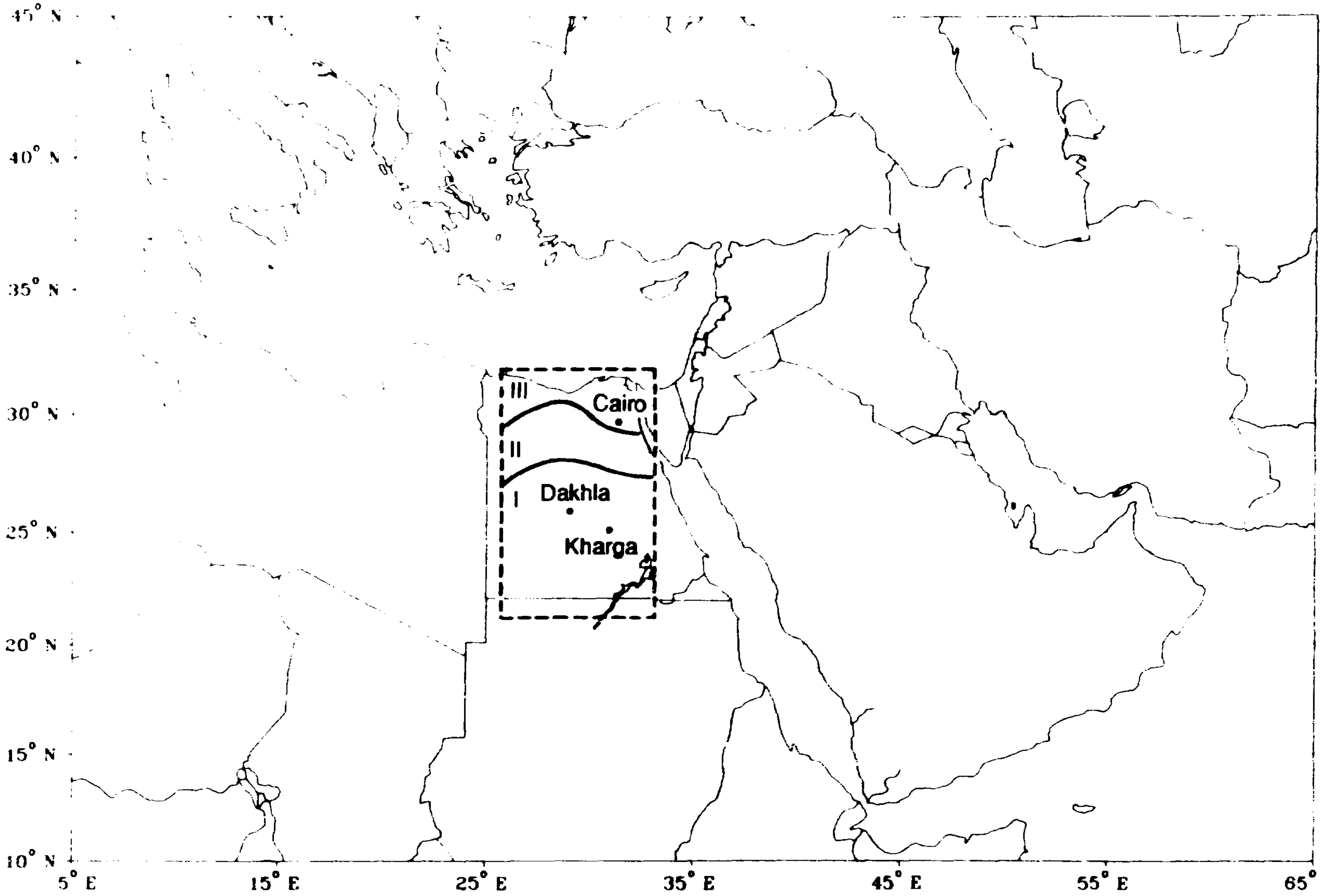

Figure 7. Salinity zones for the Nubian Aquifer in Eqypt. Zone III = Highly saline brine, Zone II = Brackish water, and Zone I = Fresh water (≤1000 ppm TDS).

surface.[19,20] In areas not presently used for agriculture, adequate water could be developed from the Nubian aquifer for use; however, special construction techniques for wells and some pre-treatment for the strong iron taste could be necessary.

Libya

There are some data about Libya, but not sufficient for a detailed analysis. In general the geology is similar to that of western Egypt, with gently dipping sedimentary layers overlying a granitic basement. Water supplies control population, which is confined largely to those parts of the coast with potable water (i.e., the city of Tripoli), as well as scattered inland oases. The information available[21,22] suggests that adequate water supplies from deep aquifers could be developed inland, but that near the coast ground waters would require treatment by ROWPU. Table 6 shows indicative analyses of Libyan groundwater based on monitoring data from 28 wells in the area of Az Zawiyah (see Fig. 3).

EUROPE AND THE U.S.S.R.

The temperate climate of most of Europe has produced an abundance of surface water supplies with generally low levels of dissolved constituents. However, there are

Table 6. Averaged water-quality monitoring data for 28 wells located in the Az Zawiyah area of Libya.[a]

Inorganic chemical constituent	Concentration (ppm)
Calcium (Ca^{+2})	68.0
Bicarbonate (HCO_3^-)	193.0
Chloride (Cl^-)	135.6
Magnesium (Mg^{+2})	30.4
Potassium (K^+)	6.0
Sodium (NA_+)	93.1
Sulfate (SO_4^{-2})	95.7
Total dissolved solids (TDS)	554
pH	7.6

[a] From Ref. 21.

areas with low amounts of rainfall (less than 400 mm/year) that may have surface or ground waters with elevated levels of dissolved solids (see Fig. 8). More geohydrological data are needed on these areas in order to assess the potential for water of inferior quality. Data are also needed on sources of anthropogenic pollution of water supplies.

ASIA

As shown in Fig. 9 large areas of Asia have annual precipitation that is less than or equal to 400 mm and could have mainly high-salinity water supplies. We were unable to acquire water-quality data indicative of these areas, and we recommend further work on the subject. However, water-quality monitoring data compiled in the GEMS/Water Data Summary for 1979 through 1981[23] may be helpful for assessing the water quality in some specific surface and groundwaters of the region. These data were not sufficient to indicate water quality because the monitoring data for the various sites were inconsistent.

LATIN AMERICA

While quantitative surveys of inorganic surface water constituents in Central America are rare, a comprehensive water-quality survey has been done in Guatemala.[24] The results from that survey are discussed below to provide a general characterization of the inorganic constituents of water of other tropical regions.

The generally high water quality in Guatemala can be attributed to the geohydrology of the region. Guatemalan bedrock is largely volcanic rock with few soluble minerals. The climate is tropical and the rainfall high; materials leached from the rocks are readily moved into the rivers. Thus, surface water in Guatemala is of quite low salinity and of good chemical quality. For example, Weiss[24] carried out a survey of the water quality in many of the rivers of Guatemala. The data from that survey show that the water quality is high in these rivers (see Table 7). Based on the similarity of waters in this type of climate, it is not unreasonable to think that the excellent water quality in Guatemala may also be representative of humid tropical regions elsewhere, so long as soluble salts are not present at the land surface.

Figure 10 shows the low annual precipitation pattern (less than 400 mm) for Central and South America. From the figure, it can be seen that the region is characterized by generally high precipitation; areas of lowest precipitation are along the west coast of South America.

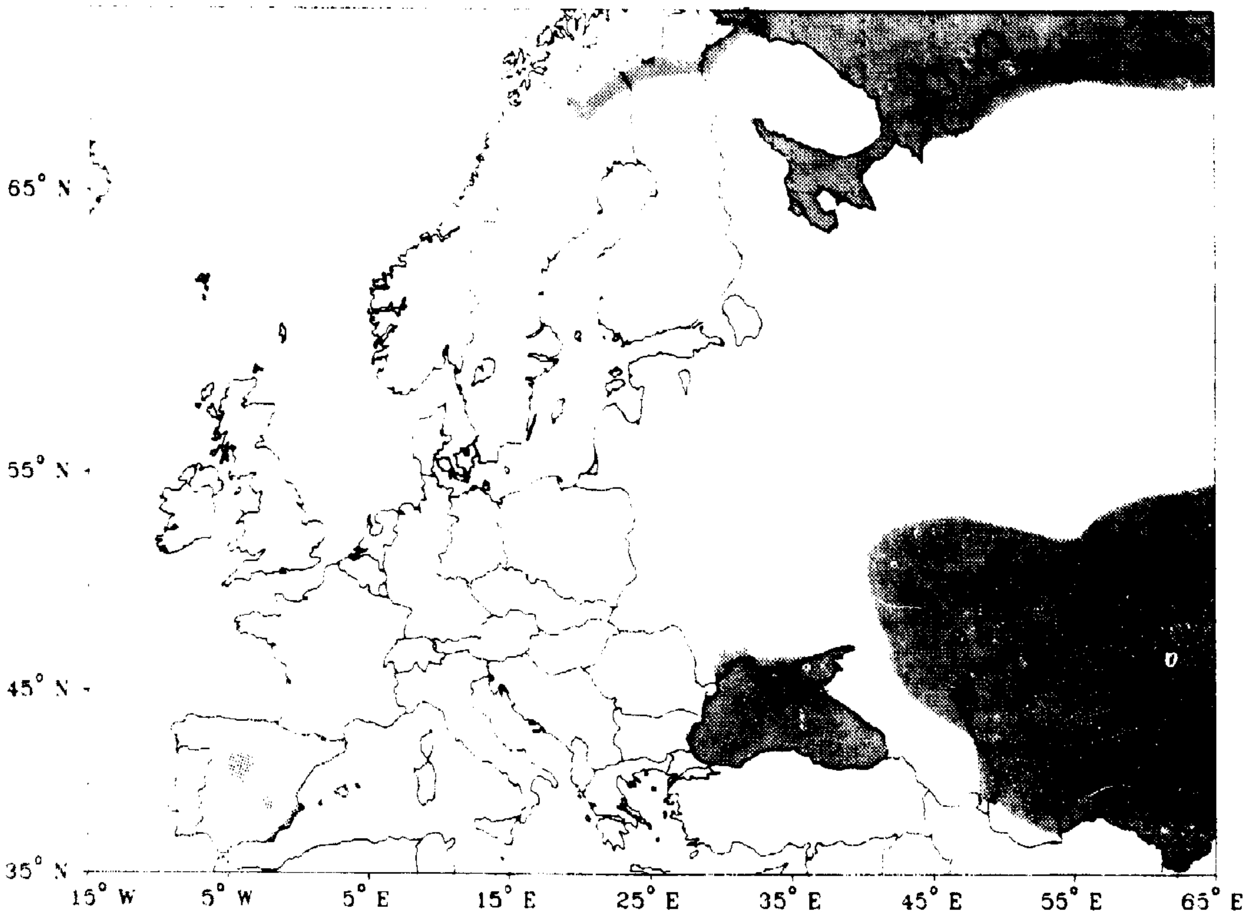

Figure 8. Areas of low annual precipitation (≤400 mm) in Europe and the Western Soviet Union (shaded). Based on data appearing in The Times Atlas of the World.[1]

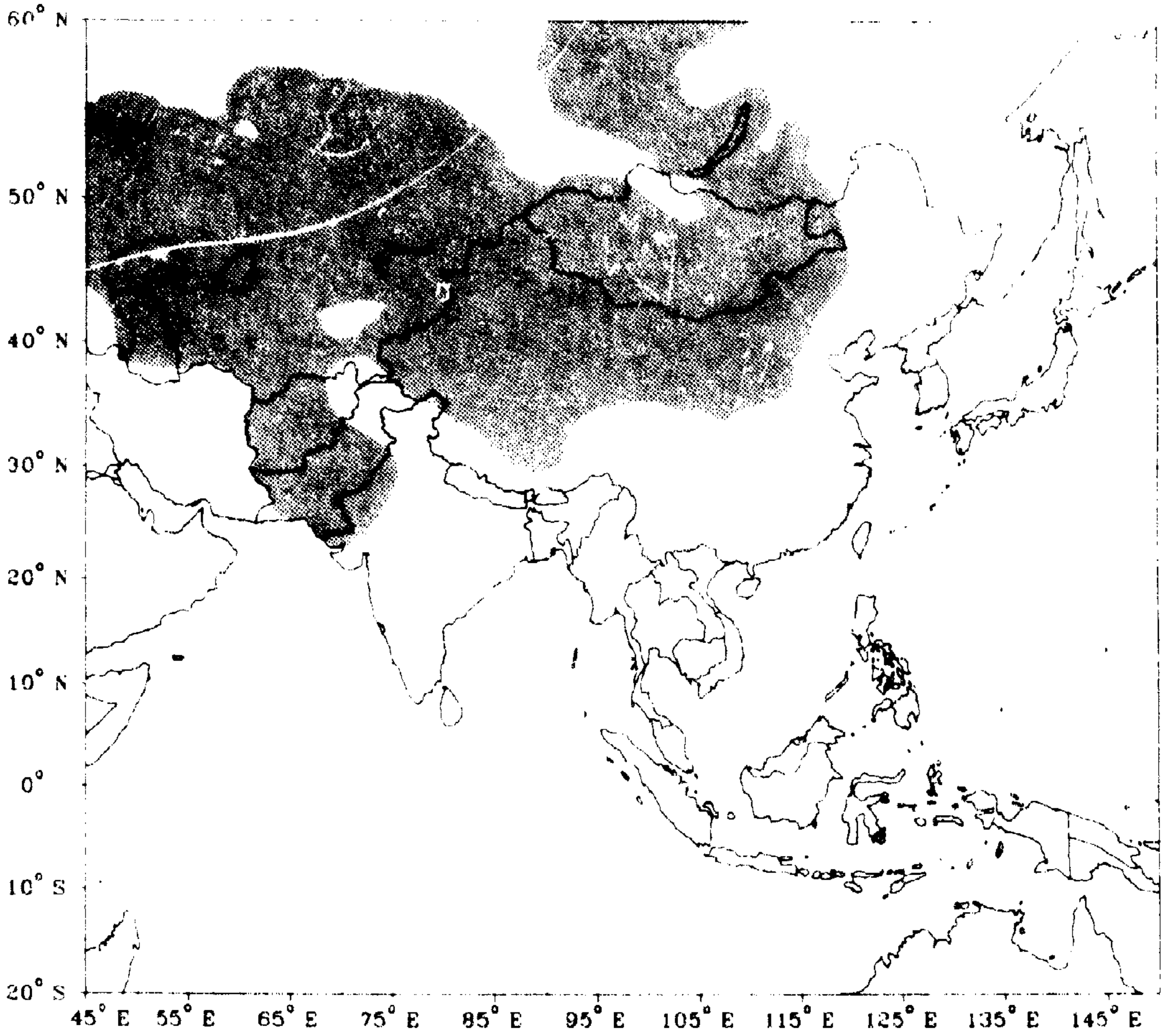

Figure 9. Areas of low annual precipitation (≤400 mm) in Asia (shaded). Based on data appearing in The Times Atlas of the World.[1]

Table 7. Results of a statistical analysis of water-quality monitoring data for selected inorganic chemical constitutents from surface-water sampling locations in Guatemala.

Inorganic chemical constituent	No. of samples	Geometric mean concentration (mg/L)[a]	Geometric standard deviation	95th cumulative percentile concentration (mg/L)[b]
Chloride (Cl^-)	26	13.9	1.76	35
Magnesium (Mg^{+2})	25	6.27	2.33	25
Total dissolved solids (TDS)	26	264	1.57	550

[a] Sampling data fit a lognormal distribution and the geometric mean concentration is equivalent to the 50th cumulative percentile concentration.

[b] 95th cumulative percentile concentration is equivalent to the geometric mean concentration (X_g) multiplied by the geometric standard deviation (σ_g) raised to the 1.645 power (i.e., $X_g \cdot \sigma_g^{1.645}$). There is a cumulative probability of 95% that the monitored values will be less than or equal to the 95th cumulative percentile concentration.

ARCTIC REGIONS

Although arctic regions are technically deserts, any naturally occurring fresh waters that do occur and are not frozen are likely to be quite potable. This potability can be attributed to the small amount of evaporation that takes place in these regions, which would otherwise tend to increase the salt concentration of such waters. It should also be noted that streams containing glacial runoff can be highly turbid.

GENERALIZATIONS

Studies of the correlations between water salinity and both climate and geohydrology indicate a causal relationship.[7,25] 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 scanty water supplies with 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.

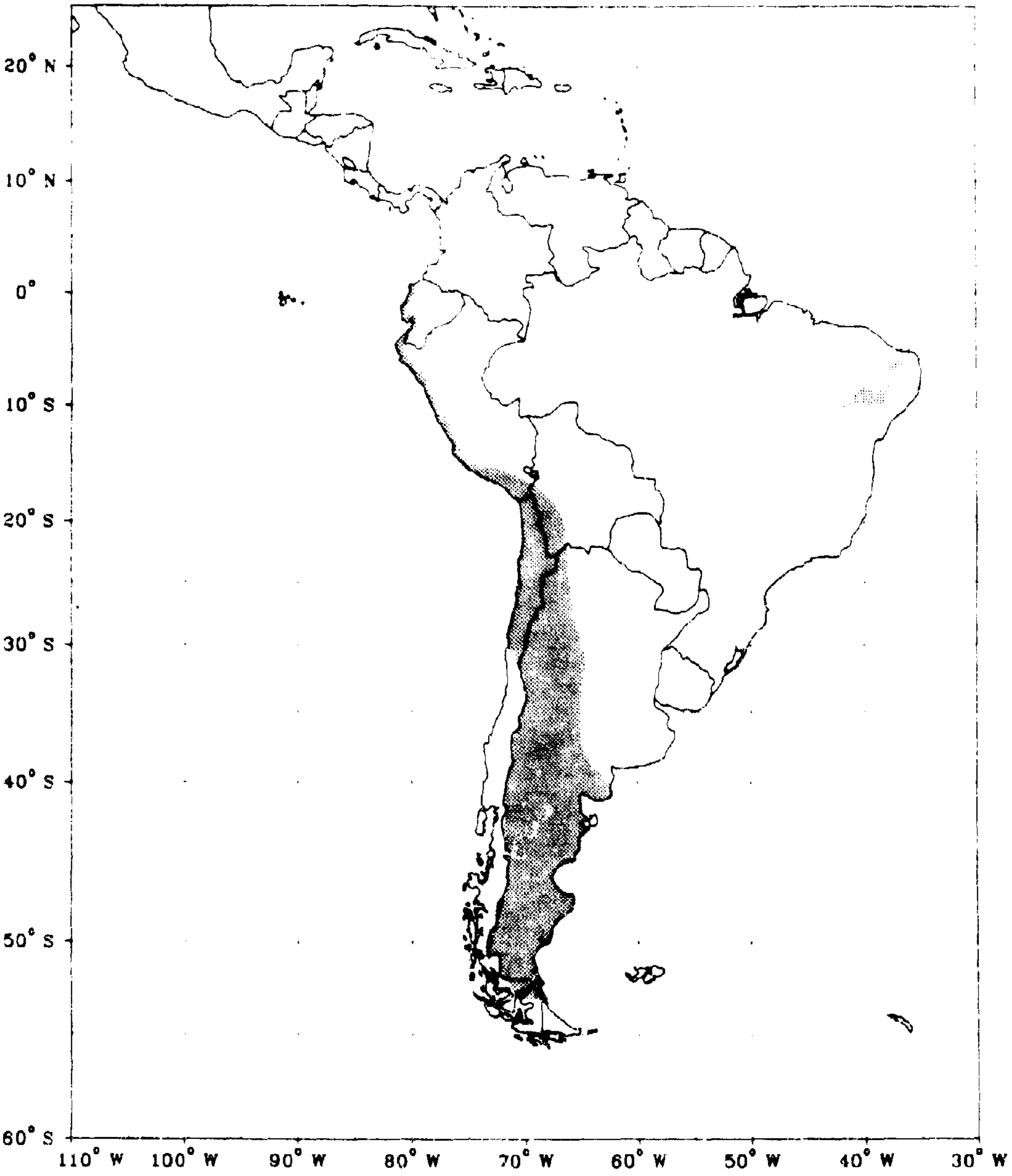

Figure 10. Areas of low annual precipitation (≤400 mm) in Latin America (shaded). Based on data appearing in The Times Atlas of the World.[1]

The largest trade-wind deserts are the North African Sahara and Middle Eastern desert of Eurasia. Because of the impact of man's development, human populations in the area, and the size of the Eurasian land mass, the latter desert is somewhat more extensive than the other trade-wind deserts. To its north are the semi-arid regions of Turkey and southern Soviet Central Asia.

Generally similar climate and conditions characterize the deserts of northwestern Mexico and the adjacent U.S. Southwest. To the north of this trade-wind desert lies the arid to semi-arid region of eastern California, Nevada, and southern Oregon.

In the Southern Hemisphere, similar regions are found on the west coasts of South Africa, South America, and most of Western Australia. We think that water supplies will be scanty in these regions and the general likelihood of encountering saline water will be high.

In addition to these regions, there is a likelihood that highly saline waters will be encountered in regions with outcrops of bedrock containing such soluble minerals as salt 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,[26] and the Salzkammergut near Salzburg, Austria. The Colorado River has a reach underlain by gypsum and anhydrite near the headwaters of the stream 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.

In order to obtain information reliable enough for assessment of areas of critical interest, fairly detailed site-specific hydrogeologic studies by the best available techniques are essential. However, in the absence of such data this evaluation can be used to identify locations in the regions of military concern with waters that could contain elevated concentrations of inorganic chemicals and where it is important for monitoring to be performed.

REFERENCES

1. Times Books, The Times Atlas of the World (Times Books, New York City, NY, 1983) plate 4.

2. Colman-Sadd, S.P. Fold Development in Zagros Simply Folded Belt. Southwest Iran," Am. Assoc. Pet. Geol. Bull. 62, 984-1003 (1978).

3. Dunnington, H. V., "Salt-Tectonic Features of Northern Iraq," in Geological Society of America Special Paper 88. Geological Society of America, New York City, NY (1968), pp. 183-227.

4. Stöcklin, J., "Salt Deposits of the Middle East," Geological Society of America Special Paper 88, Geological Society of America, New York City, NY (1968), pp. 157-181.

5. Ala, M.A., "Salt Diapirism in Southern Iran," Am. Assoc. Pet. Geol. Bull. 58, 1758-1770 (1974).

6. Gill W. D. and M. A. Ala, "Sedimentology of Gachsaran Formation (Lower Fars series), Southwest Iran," Am. Assoc. Petrol. Geol. Bull. 56, 1965-1974 (1972).

7. Gibbs, R. J., "Mechanisms Controlling World Water Chemistry: Evaporation-Crystallization Process," Science 172 870-872 (1971).

8. Al-Shawani, M. F., M. W. Ishaq, A. K. Al-Hindawi, S.A. Ali, and N. Muthafar, "Quality Change in Baghdad Canals and Irrigation," J. Environ. Sci. Health A18, 773-785 (1983).

9. Jazrawi, S. F. and M. W. Ishaq, "Occurrence of Some Indicator Bacteria in the Waters of Al-Khair Stream and Al-Jaish Canal Passing Through Baghdad City," J. Environ. Sci. Health A18, 673-684 (1983).

10. Mutlak, S. M., B. M. Salih, and S. J. Tawfiq, "Quality of Tigris River Water Passing through Baghdad for Irrigation," Water Air Soil Pollut. 13, 9-16 (1980).

11. Powers, R. W., L. F. Ramirez, C. D. Redmond, and E. L. Elberg, Geology of the Arabian Peninsula. Sedimentary Geology of Saudi Arabia, U.S. Geological Survey, Washington, DC, Prof. Paper 560-D (1966).

12. Burdon, D. J., "Hydrogeological Conditions in the Middle East," Q. J. Eng. Geol. 15, 71-82 (1982).

13. United Nations Food and Agriculture Organization, Survey and Evaluation of Available Data on Shared Water Resources in the Gulf States and the Arabian Peninsula Vol. 1 of 3, United Nations Food and Agriculture Organization, Rome, Italy (1979), restricted distribution. Published as map with tables.

14. Bakiewicz, W., D. M. Milne, and M. Noori, "Hydrology of the Umm Er Radhuma Aquifer, Saudi Arabia, with Reference to Fossil Gradients," Q. J. Eng. Geol., London 15, 105-126 (1982).

15. Burden, D. J., and C. Safadi, "The Karst Groundwater of Syria," J. Hydrol. 2, 324-347 (1964).

16. J. F. Talling, "Chapter 26. Water Characteristics," in The Nile, Biology of an Ancient River, J. Rzoska, Ed. (Dr. W. Junk B.V., Publishers, The Hague, The Netherlands, 1976), pp. 357-384.

17. Armstrong, S. J., "Water Supply Problems in Egypt During the War, 1939-45," R. Eng. J. 62, 178-182 (1948).

18. Fryer, W. C., "The Military Water Problem in the Western Egyptian Desert, 1940-1943," R. Eng. J. 64, 140-147 (1950).

19. Shata, A. A., "Hydrology of the Great Nubian Sandstone Basin, Egypt," Q. J. Eng. Geol. 15, 127-133 (1982).

20. Clarke, F. E., The Corrosive Well Waters of Egypt's Western Desert, U.S. Geological Survey, Washington, DC, Water-Supply Paper 1757-O (1979).

21. Ogilbee, W., R. C. Vorhis, and H. A. Tarhuni, Ground Water Resources of the Az Zawiyah Area, Tripolitania, United Kingdom of Libya," (Ogilbee and Vorhis with the U.S. Geol. Survey, Tarhuni with the Nazarat of Agriculture, Province of Tripolitania, Libya). Published in Tripoli, Libya, by U.S. Geol. Survey (1962).

22. Wright, E. P., A. C. Benfield, W. M. Edmunds, and R. Kitching, "Hydrogeology of the Kufra and Sirte Basins, Eastern Libya," Q. J. Eng. Geol. 15, 83-103 (1982).

23. United Nations Environmental Programme, World Health Organization, United Nations Educational, Scientific and Cultural Organization, and World Meteorological Organization, GEMS: Global Environmental Monitoring System Water Data Summary (WHO Collaborating Center for Surface and Groundwater Quality, Canada Center for Inland Waters, Burlington, Ontario, Canada, 1983).

24. Weiss, C. M., Water Quality Investigations, Guatemala. Guatemalan Rivers 1969-1971, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, NC, ESE Pub. No. 282 (1971).

25. Gibbs, R. J., "Mechanisms Controlling World Water Chemistry," Science 170, 1088-1092 (1970).

26. Rex, R. W., E. A. Babcock, S. Biehler, J. Combs, T. B. Coplen, W. A. Elders, R. B. Furgerson, Z. Garfunkel, T. Meidav, and P. T. Robinson, Cooperative Geological-Geophysical-Geochemical Investigations of Geothermal Resources in the Imperial Valley, University of California at Riverside, Institute of Geophysics and Planetary Physics, Riverside, CA, Report No. 71-2 (1971).

CHAPTER 4. REGIONS OF CONCERN WITH REGARD TO ORGANIC CHEMICAL CONTAMINATION OF FIELD WATER

J. Kelly-Reif*

Organic chemicals, both industrial and agricultural, are found throughout the world in all types of natural waters. In part one of Volume 2 of this study, we made a comprehensive survey of organic chemicals found in natural waters. Our analysis of the available data showed that organic compounds are typically detected at concentrations that are not high enough to cause systemic effects or adverse organoleptic responses. 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. Nevertheless, transient releases from industrial facilities storing large quantities of organic chemicals and from transshipment points could result in elevated levels of organic contaminants in surface waters. Additionally, 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. We also describe in this chapter the geographic regions worldwide that might contain water with elevated levels of pesticides, especially lindane. These levels, particularly that of lindane, occur as a consequence of agricultural application procedures.

ORGANIC CHEMICAL PRODUCTION CENTERS AND PETROLEUM REFINERIES

The geographic regions considered possible theaters of operation for U.S. military forces are (1) Latin American (Central and South America), (2) Europe (including the U.S.S.R.), (3) Africa and the Middle East, and (4) Asia. A map of each region is presented in Appendix A showing the location of major organic chemical production centers (see Figs. A-1 through A-5). These maps are intended to assist military risk managers in determining where troops under battlefield conditions might be exposed to elevated concentrations of organic chemicals in field water. High concentrations of organic

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* Department of Environmental Toxicology, University of California at Davis, Davis, CA 95616.

chemicals in field water could cause performance-degrading effects to its military consumers.

Organic chemical production centers could be important sources of water pollution because they are often situated near major water supplies needed for manufacturing processes and shipping. Such centers are often near major land routes to further accommodate transportation needs and improve accessibility Thus, under combat conditions, these production centers could be destroyed and nearby waters could become highly contaminated. The latitude, longitude and production capacities for major organic chemical production centers worldwide are provided in Tables A-1 through A-5 in Appendix A.

The production capacities given for the major centers are for the combined total of the following chemicals: benzene, phthalic anhydride, methanol, phenol, ethylene, polyvinyl chloride (PVC), polyamides (nylon), polyethylene, styrene, butadiene, and carbon black. This information is based on 1970 statistics. As such, it should be viewed as only an indicator of potential pollution sources. The actual production volumes are greater today and should increase well into the future. For example, the average annual increase in output of industrial chemicals (defined as organic chemicals, particularly petrochemicals, chloralkalies, other inorganic chemicals, fertilizers, pesticides, plastics, synthetic fibers, and synthetic rubber) by developing nations worldwide was 10.7% between 1970 and 1979, 7.0% in 1986, and (estimated) 6.8% for 1987.[2] This rise in chemical production is attributed to the industrialization of these countries and the need for them to produce more of the chemicals required by their domestic industries. Furthermore, estimates of industrial chemical production also suggest that developing countries will rapidly be increasing their output of fertilizers and pesticides, and that the geographic concentration of output will be changing as well (e.g. growth in industrial chemical production appears to be slowing in southeast Asia but expanding on the Indian subcontinent).[2]

Locations of major petroleum refineries and their refining capacities are presented in Table A-6 of Appendix A. Capacities are given in barrels per calendar day (b/cd). Refineries are usually located near large bodies of water, in part to supply cooling water but also for access to shipping tankers.[3] Normally, cooling systems are major sources of water pollution at these facilities. Offshore platform accidents and on-shore well leaks can also be responsible for water contamination.[4]

Africa and the Middle East

As can be seen in Figs. A-1 and A-2 of Appendix A, several of the chemical production centers in these areas of the world are located near coastal waters, especially in South Africa and Israel. Inland sites include Helwan, Egypt (near the Nile River), and Sasolburg/Modderfontein/Germiston, South Africa. At the regional scale, low production levels would indicate that an extensive pollution problem is unlikely. Production figures for 1970 did not exceed 850,000 metric tons for any given country (see Tables A-1 and A-2 in Appendix A). At the local level, Sasolburg, South Africa produces the largest quantity of organic chemicals (500,000 metric tons) in the region. The potential for growth of production capacity in this part of the world is great.

No country in Africa or the Middle East has more than 10 petroleum refineries. Furthermore, in the Middle East there are only five petroleum refineries with capacities of over 200,000 b/cd (see Table A-6 in Appendix A). The largest of these is in Saudi Arabia, with a capacity of 415,000 b/cd.

Europe and the U.S.S.R.

Europe has more organic chemical production centers than any of the other regions described in this analysis (see Fig. A-3 in Appendix A). Western Europe, in particular, has numerous sites, with the largest output in West Germany (over 14,000,000 metric tons), and Italy (7,400,000 metric tons) according to Table A-3. In West Germany, most of the centers are along the Rhine River. Italy has numerous sites along its coastlines. Eastern Europe, on the other hand, has most of its production centers near inland rivers. In Poland, for example, the largest center is in Plock, on the Vistula River. There are numerous petroleum refineries in Europe (see Table A-6 in Appendix A), 23 with capacities of at least 200,000 b/cd (see Table A-6 in Appendix A). There are undoubtedly heavily polluted streams and rivers in this region, but our review of English-language publications contained little definitive data on the nature and magnitude of such contamination. Specialized studies may eventually be required to identify those heavily polluted water resources.

Asia

As shown in Fig. A-4 of Appendix A, most organic chemical production sites are near coastal waters. Japan is the biggest producer in the area, with centers dispersed along much of its coastline, and with a total production capacity of over 16,000,000 metric tons (see Table A-4).

The major oil refineries (crude capacity ≥ 200,000 b/cd) in this region of the world are in the far east: Japan, South Korea, and Taiwan (see Table A-6 in Appendix A). Japanese crude oil refining capacity is by far the greatest of any country in the region.

Latin America

In Latin America and the Antilles, most organic chemical production centers occur along the Atlantic and Pacific Oceans (see Fig. A-5 in Appendix A). Brazil is the largest organic chemical producer in the region (2,400,000 metric tons) (see Table A-5 in Appendix A). For its small size, Puerto Rico produces a relatively large amount of organic chemicals (1,850,000 metric tons).

Brazil has the most petroleum refineries (13) followed by Argentina (12). All other countries in the region have less than 10 petroleum refineries. The major regional oil refineries (crude capacities ≥ 200,000 b/cd) are in Argentina, Brazil, Mexico, and Venezuela (see Table A-6 in Appendix A).

PESTICIDE CONTAMINATION IN AGRICULTURAL AREAS

An earlier review of the worldwide extent of pesticide contamination of surface and gound waters showed that only limited data were available on actual pesticide concentrations in natural waters (see part 2 of Volume 2).[5] That information suggested that low, non-toxic 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. To identify locations of potential concern, we have shown major food-producing areas (Figures B-1 through B-5 of Appendix B) in possible theaters of operation for U.S. military forces. These maps indicate where elevated levels of pesticides might be present in water supplies, and where monitoring should be performed.

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 µg/L was reported in rice paddy water.[6] Areas of rice production, which are principally located in Third World countries (see Figs. B-1 to B-5 in Appendix B), are at considerable risk for contamination of water by pesticides, particularly by lindane.

Africa and the Middle East

Figs. B-1 and B-2 in Appendix B show the primary areas of general agriculture and rice production in Africa and the Middle East. Agricultural activity is fairly ubiquitous throughout the subcontinent south of the Sahara, and around the Mediterranean Sea.

Europe and the U.S.S.R.

Fig. B-3 in Appendix B shows the primary areas of general agriculture and rice production in Europe and the U.S.S.R. Most of Europe should be considered agricultural; however, there is little rice production in this region.

Asia

Fig. B-4 in Appendix B shows the primary areas of general agriculture and rice production in Asia. More than half of the cultivated areas in this region are in rice production; they have the greatest potential for containing water contaminated with high levels of lindane.

Latin America

Fig. B-5 in Appendix B shows the primary areas of general agriculture and rice production in Latin America. Agricultural activity is concentrated in the coastal areas of South America.

REFERENCES

1. Layton, D.W., B.J. Mallon, T.E. McKone, Y.E. Ricker, and P.C. Lessard, Evaluation of Military Field-Water Quality. Volume 2. Constituents of Military Concern from Natural and Anthropogenic Sources. Part 1. Organic Chemicals, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008, Vol. 2, Part 1 (1988).

2. Anderson, E., "Third World Leads in Chemical Growth," Chem. Eng. News 65(11), 18 (1987).

3. Jahnig, C. E., Kirk-Othmer Encyclopedia of Chemical Technology, M. Grayson, and D. Eckroth, Eds. (Wiley, New York City, NY, 1982), Vol. 17, pp. 185, 238.

4. Sax, N. I., Industrial Pollution (Van Nostrand Reinhold, Chicago, IL, 1974), pp. 559.

5. Scofield, R., J. Kelly-Reif, F. Li, T. Awad, W. Malloch, P. Lessard, and D. Hsieh, Evaluation of Military Field-Water-Quality. Volume 2. Constituents of Military Concern from Natural and Anthropogenic Sources. Part 2. Pesticides, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008. Vol. 2, Part 2 (1988).

6. Teimoory, S., and M. Hooseiny-Skekarabi, "Residue Estimation of Some Insecticides Used Against Rice Stem Borer in Paddy Field in the Field Water," Entomol. Phytopathol. Appl. 47, 79-97 (1979).

CHAPTER 5. HEALTH RISKS FROM WATERBORNE, WATER-WASHED AND WATER-BASED INFECTIOUS ORGANISMS OF MILITARY CONCERN

A.W. Olivieri,* R.E. Danielson,* and P.G. Badger*

Diseases caused by water-related infectious organisms have always been a major concern for planners of military operations. Many water-related diseases can completely disable the soldier for long periods. The infectious organisms responsible for most water-related diseases can be classified into three groups: bacteria, viruses, and parasites (e.g. protozoa and helminths). The routes of transmission to humans that these disease agents can take 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 other than water that is closely associated with water.

Table 1 lists the more important water-related diseases, along with the responsible infectious organisms and the routes of transmission. Water-related disease is usually associated with an absence or compromise of good hygienic practice and sanitary conditions. In all cases the 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 infect another individual. It follows that two methods of controlling waterborne and water-washed infectious disease are (1) to keep infected individuals and their wastes away from water supplies and (2) to eliminate the infectious organisms from the water by treatment (e.g., chlorination). Controlling water-based disease can be accomplished by eradication of the aquatic vector (e.g., the snails which carry the larval forms of Schistosomes).

RECOMMENDED FIELD-WATER-QUALITY STANDARDS

As discussed in Volume 5 of this report, Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks and Recommendations for Establishing Related Standards,[1] there are no relatively simple field tests for measuring the specific concentration of any of the variety of infectious organisms listed in Table 1. Until such tests are available for determining either directly or indirectly (based on

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* Sanitary Engineering and Environmental Health Research Laboratory (Building 112), University of California, Richmond Field Station, Richmond, CA 94804.

Table 1. Water-related diseases and route of transmission.

Water-related disease (responsible infectious organism)	Waterborne	Water-washed	Water-based
Bacterial diseases:			
Bacillary dysentery (*Shigella* spp.)	X	X	--
Cholera (*Vibrio Cholera*)	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:			
Entero viruses	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	--
Balantidial dysentery (*Balantidium coli*)	X	X	--
Dracontiasis (*Dracunculus medinensis*)	--	--	X
Giardiasis (*Giardia lamblia*)	X	--	--
Meningoencephalitis (*Naegleria* spp. and *Acanthamoeba* spp.)	--	X	--
Schistosomiasis (*Schistosoma* spp.)	--	--	X

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. 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)[2] can be considered indicative of a safe level for infectious organisms in field water. Nevertheless, the consumption of specific concentrations of the infectious organisms of military concern in field water can be evaluated. This evaluation can be accomplished by using the risk-assessment model we presented in Volume 5 in combination with (1) the dose-response equation for the particular infectious organism that yields the most conservative estimate of the risk of illness; (2) an estimate of the concentration of the infectious organism in the field water;

(3) an approximation of the daily volume of field water the population of military personnel is likely to consume, and (4) the expected efficiency of any water treatment process that may be used for removing the infectious organisms from the water prior to its consumption. The risk of illness for military personnel from consumption of 11 waterborne infectious organisms is discussed next. Additionally, the health risks are described for exposure to water-washed and water-based infectious organisms. 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.

HEALTH RISKS FROM WATER-RELATED INFECTIOUS ORGANISMS

This section is divided into two parts. In the first part we discuss the results of application of our risk-assessment model for determining probabilistically the risk of illness for a fraction of a military population of up to 20 military (representing a platoon-sized group--see Volume 5 for assumptions) personnel consuming waterborne infectious organisms in field water, based on representative high- and low-risk conditions. In the second part we describe the evaluation of the health risks posed by water-washed and water-based infectious organisms and identify the efficacy of control strategies for minimizing these health risks.

Waterborne Infectious Organisms

The health effects caused by infectious waterborne agents are quite varied. Table 2 lists some of the major effects of each disease. 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 risk-assessment model described in Volume 5 was used to develop a probabilistic description of the percentage of an exposed military population that would be ill after drinking water contaminated with specific infectious organisms. The model was applied

Table 2. Health effects associated with water-related infectious organisms.

Waterborne infectious organisms	Health effects
BACTERIA:	
Shigella	Diarrhea, bloody stools, ulceration.
Vibrio cholera (Classical and El Tor)	Diarrhea, vomiting, dehydration, death.
Campylobacter	Diarrhea, vomiting, malaria.
Escherichia coli	Diarrhea
Salmonella spp.	Diarrhea
Salmonella typhi	Fever, constipation, malaria, anorexia, ulceration, septicemia.
Yersinia spp.	Diarrhea, enterocolitis, abscess, septicemia, colonic ulceration, arthritis.
VIRUSES:	
Enteroviruses	Viral gastroenteritis.
Norwalk agent	Gastroenteritis, vomiting.
Rotavirus	Diarrhea, vomiting, fever, dehydration.
Hepatitis A	Fever, jaundice, abdominal discomfort.
PROTOZOA:	
Entamoeba histolytica	Bloody diarrhea, constipation, fulminating dysentery.
Giardia lamblia	Chronic diarrhea, cramps, anorexia.

Water-washed and water-based infectious organisms	Health effects
BACTERIA:	
Non-cholera vibrio spp.	Skin ulcer and sepsis; fever, chills, nausea, occasionally death.
Pseudomonas spp.	Skin ulcers, sepsis, nosocomial infections.

Table 2. (continued).

Water-washed and water-based infectious organisms	Health effects
Staphylococcus spp.	Impetigo, ecthyra, folliculitis, boils, carbuncle, abscesses, cellulitus, erysipedas.
Leptospira spp.	Jaundice, flu like illness.
Aeromonas spp.	Wound infections, gastroenteritis.
PROTOZOA:	
Acanthamoeba spp.	Amoebic meningoencephalitis.
Naegleria spp.	Primary amoebic meningoencephalitis.
Balantidium spp.	Diarrheal disease, abdominal pain, colonic ulceration.
HELMINTHS:	
Dracunculus medinensis	Temporary crippling disease.
Ascaris lumbricoides	Pneumonitis, labored breathing, cough, chest pain, fever, anorexia, vomiting, diarrhea, constipation.
Schistosoma spp.	Dysenteric, pulmonary, and abdominal symptoms, rigors, itching skin, and dermatitis.

to 11 waterborne infectious organisms and used three representative exposure 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. An equivalent expression for this treatment efficiency is 2 to 5 log removals, where log removal corresponds to the logarithm of the factor of reduction in the number of organisms per liter of water (e.g., if the initial concentration of organisms is 10^6/L and treatment reduces this concentration to 250 organisms/L, about a 99.98% treatment efficiency, then $\log_{10}$ [10^6/250] equals 3.6 log removals). The second scenario represents a high risk situation in a developed country. This situation might be encountered during a military conflict. 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 3 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. Risk curves that reflect much of the data contained in Table 3 are presented in Appendix C of this document. These curves can be used to estimate probabilities other than those expressed in Table 3 for the percentages of troops that may become ill.

The exponential dose-response equation provided the most conservative estimate of risk for five of the pathogens evaluated (i.e., Shigella spp., Vibrio cholerae Classical, Salmonella spp., Entamoeba hystolytica, and Giardia lamblia); the logistic dose-response equation provided the most conservative estimate of risk for three of the pathogens evaluated (i.e., Vibrio cholerae El Tor, Escherichia coli, and Salmonella typhi); and the lognormal dose-response equation provided the most conservative estimate of risk for Campylobacter and was used for Yersenia spp. and enteroviruses because dose-response data for the latter organisms were too limited for use with other dose-response equations.

A comparison between the risk assessment results presented in Table 3 for developed and developing countries reveals that for all 11 waterborne infectious organisms the risk of illness is greatest in developing countries. These results indicate that the risk-assessment model is sensitive to changes in the mean concentration of pathogens in water. For example, for each of the infectious organisms examined with the risk assessment model the mean pathogen concentration is greater in developing countries than in developed countries. It also was noted from a sensitivity analysis described in Volume 5 that the volume of water consumed (10 to 15 L/d) has little effect on the risk estimates. Consequently, the applicability of the risk curves presented in Appendix C and in Volume 5 to specific field combat situations can be improved dramatically if accurate measurements of the concentrations of the pathogenic organisms that are present in the water are made and introduced into the risk assessment model.

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. For example, the latency period for the pathogenic microorganisms of concern generally is one to three days (see Table 4). 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, the need to complete a 1-d mission successfully may be so important in a hot, arid environment that the risk of infection occurring 1- to 3-d after exposure to field water containing pathogenic microorganisms is academic, no matter what proportion of the population is likely to be affected.

Two examples of how Table 3 and corresponding figures in Appendix C might be used for risk assessment purposes with respect to estimating the success of military missions are presented next. However, we emphasize that Table 3 and the figures presented in Appendix C, which are adapted from figures in Volume 5, are constructed from the risk-assessment model and assumptions and data presented and discussed in Volume 5. More refined situation-specific risk tables and figures can be constructed by using the risk-assessment model with site-specific data, particularly monitoring data that identifies the concentration of microorganisms in a field water.

> EXAMPLE 1: 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 waters is the protozoan Giardia lamblia, which can produce a severe diarrheal illness (i.e., giardiasis). Thus, this field water is considered to be one of high risk to the military population. The possible impact of this water on mission accomplishment can be assessed by using the applicable information for Giardia lamblia in developed countries that is contained in Table 3.
>
> Examination of Table 3 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 (see Table 4). Table 3 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 (see Table 4). Figure C 11 in Appendix C displays these relationships graphically and indicates the inelastic nature of the risk.
>
> The conclusion to be drawn from this analysis is that a significant risk exists (> 80%) that any mission lasting up to 7 d and requiring more than one individual to complete (i.e., > 90% of the population of 20 military personnel could become ill) could be jeopardized should troops consume the field water without adequate filtration followed by disinfection.

Table 3. 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.

Pathogen	(Fig.)[f]	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]		
		Developed country[d] (High risk)[g]	Developing country[e] (Low risk)[h]	Developed country[d] (Low risk)[h]	Developed country[d] (High risk)[g]	Developing country[e] (Low risk)[h]	Developed country[d] (Low risk)[h]
BACTERIAL:							
Shigella spp.	(C-1)	0.88	0.86	0.50	0.86	0.56	0.18
Vibrio cholerae Classical[i]		0.53	0.00	0.00	0.35	0.00	0.00
Vibrio cholerae El Tor	(C-2)	0.68[j]	0.00	0.00	0.56[j]	0.00	0.00
Campylobacter	(C-3)	0.87	0.90	0.50	0.87	0.69	0.18
Escherichia coli	(C-4)	1.00	0.99	0.96	0.04	0.04	0.00
Salmonella spp.	(C-5)	0.87	0.73	0.70	0.82	0.35	0.30
Salmonella typhi	(C-7)	0.78	0.03	0.03	0.47	0.02	0.02
Yersenia spp.	(C-8)	0.89	0.87	0.72	0.80	0.72	0.35
VIRAL:							
Enteroviruses	(C-9)	0.95	0.86	0.76	0.55	0.04	0.00
PROTOZOAN:							
Entamoeba hystolytica	(C-10)	0.88	0.82	0.30	0.84	0.50	0.00
Giardia lamblia	(C-11)	0.88	0.90	0.90	0.83	0.62	0.62

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[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.

FOOTNOTES FOR TABLE 3. (continued).

[d] A developed country is considered to be an industrialized one like the United States or a nation in Europe.

[e] A developing country is a nation that is predominantly agrarian, with only recent industrialization.

[f] Other probabilities and corresponding percentages of ill troops can be determined using the indicated figures, which appear in Appendix C.

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

[h] 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.

[i] Figure not presented in Appendix C, but would be similar in appearance to Fig. C-2.

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

Table 4. Latency[a] for disease symptoms produced by common waterborne pathogens.

Organism	Latency (d)[b]
Shigella dysenteriae	3 to 6
Campylobacter jejuni	1 to 4
Vibrio cholerae	<1 to 2
Escherichia coli	0.1 to 3
Salmonella typhi	3 to 22
Yersinia	<1
Enteroviruses	2 to 35
Norwalk agent	0.42 to 2.1
Rotavirus	1 to 4
Entamoeba histolytica	7 to 98
Giardia lamblia	3 to 56

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

[b] Based on data contained in Appendices of Volume 5.[1]

EXAMPLE 2: A military unit is operating in a developed country and the drinking water available is from a surface water that has undergone treatment by reverse osmosis water purification followed by disinfection. The microorganism considered to be present in such surface water is the bacteria *Escherichia coli*, which can produce an intestinal illness. Thus, this field water is considered to be one of low risk to the military population. The possible impact of this treated and disinfected field water on mission accomplishment can be assessed by using the applicable information for *Escherichia coli* in developed countries that is contained in Table 3

Examination of Table 3 reveals that there is a 96% chance that more than 10% of a population of 20 military personnel will become infected and could exhibit clinical symptoms of intestinal illness in less than one day after exposure (see Table 4). However, Table 3 also shows that there is little chance that more than 90% of the exposed military population could develop an intestinal illness. Figure C-4 in Appendix C shows graphically the relationship between level of risk and percentage of military population that could become ill from exposure to *E. coli* in field water.

The conclusion to be drawn from this analysis is that there is virtually no risk (i.e., zero) that a military mission lasting up to 7 d and requiring at least one individual to complete (> 90% of the population of 20 military personnel could become ill) could be jeopardized should troops consume the treated field water. However, there is a significant risk (> 95%) that more than 10% of the exposed population could become ill in less than 1 d (see Table 4)

> as a consequence of exposure to the treated field water. Nevertheless, the level of risk decreases for percentages that are greater than 10%. Therefore, military missions lasting up to 7 d and requiring up to about 18 individuals to complete should not be in jeopardy and can be performed.

From the results of the two examples just presented, it is evident 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. This procedure is described in Volume 6 of this report, Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks and Recommendations for Establishing Related Standards,[3] and summarized here for the infectious organisms shown in Table 5.

Feachem et al.[4] and Bradley and Feachem[5] defined five categories of infection, as shown in Table 6. These categories are based on environmental features discussed in detail in Chapter 14 of Volume 6 that include latency, infectivity, infective dose, and mode of transmission. Control measures appropriate to each category also are shown in Table 6.

Table 5. Water-washed and water-based infectious organisms selected for review.

Bacteria	Protozoa	Helminths
Non-cholerae Vibrio spp.	Acanthamoeba spp.	Dracunculus medinensis
Pseudomonas spp.	Naegleria spp.	Ascaris lumbricoides
Staphylococcus spp.	Balantidium spp.	Schistosoma spp.
Leptospira spp.		Trichobilharzia spp.
Aeromonas spp.		

Table 6. 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	Water (ingested), person-to-person contact	Treated-water supply.[a]
II.	Immediately infective, medium or high infective dose, moderately persistent, short latent period	Naegleria	Skin and eye meningoencephalitis	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).

There is a clear difference between the first two categories and the last three, which require an animal host or intermediate aquatic host as part of the mode of transmission. Furthermore, the most important major control measures for the last three categories involve limiting contact between the potential host and untreated water (i.e., ponds, lakes, standing water, etc.) and the provision of toilets. If a treated-water supply is provided, independent of other control methods, the likely effect on minimizing health risks in exposed military populations 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.

According to the classification scheme just mentioned, the immediate risk posed to military personnel is the highest from pathogens in Category I and generally the lowest from pathogens in Category V. This evaluation 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, comparison of risk from the organisms can be made from the data shown in Table 7. Review of Table 7 indicates that the pathogens can be roughly grouped as follows: short latency (i.e., few days to 10 days), 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 (Group I), relative to health effects occurring over a short period of time (i.e., $\leq$ 7 d), appear to be Staphylococcus spp., Leptospira spp., B. coli, and Ascaris lumbricoides. The group of pathogens that present the highest risk of serious infection (Group II), relative to health effects developing over a long time period (i.e., $\leq$ 1 y), appear to be Schistosoma spp., and Dracunculus medinensis. The final group of pathogens (Group III) are those with a medium to high infective dose and a short latency period. Unless the concentration of these pathogens in water is quite high, it appears that they present the lowest overall risk of infection.

Table 7. Grouping of pathogens based on latency and infective dose.

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

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

[b] See text for definition.

The focus of the previous discussion is on the risk of infection assuming no treatment of the water supply. 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 I: slight,
Group II: negligible for Schistosomiasis, but great for Dracontiasis, and
Group III: slight to moderate.

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

REFERENCES

1. Cooper, R.C., A.W. Olivieri, R.E. Danielson, P.G. Badger, R.C. Spear, and S. Selvin, Evaluation of Military Field-Water Quality. Volume 5. Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008, Vol. 5 (1986).

2. Headquarters, Department of the Army, Sanitary Control and Surveillance of Supplies at Fixed and Field Installations, Department of the Army, Washington, DC, TB MED 229 (1975).

3. Cooper, R.C., A.W. Olivieri, R.E. Danielson, and P.G. Badger, Evaluation of Military Field-Water Quality. Volume 6. Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 6 (1986).

4. Feachem, R.G., D.J. Bradley, H. Garelick, and D.D. Mara, Sanitation and Disease: Health Aspects of Excreta and Wastewater Management (John Wiley and Sons, New York City, NY, 1983).

5. Bradley, D.J., and R. Feachem, "Environmental Epidemiology and Sanitation," in Proceedings of ASCE Convention and Exposition, (ASCE, Chicago, IL, 1978), pp. 134-161.

CHAPTER 6. REGIONS OF CONCERN WITH REGAR TO WATER-RELATED INFECTIOUS ORGANISMS

A.W. Olivieri,* R.E. Danielson,* and P.G. Badger*

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. Nevertheless, in this chapter we describe two indicators useful as warnings that high concentrations of infectious organisms may exist in the field water of a particular region. We also present data that were available for determining specific locations of Schistosoma spp. and Dracunculus medinensis in water of different regions globally.

INDICATORS OF HIGH CONCENTRATIONS OF INFECTIOUS ORGANISMS

A summary of the distribution of the common aquatic infectious organisms is shown in Tables 1 and 2. These infectious organisms are ubiquitous, but are found in higher concentrations in some areas, particularly those with poor sanitation such as developing countries. Figure 1 presents a map indicating the developing countries with poor sanitation. These countries appear as shaded areas in the figure.

Infant mortality rates (deaths in infants less than 1 y old) also can be used as an indicator of areas where military personnel would be at risk of water-related infectious disease. 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 produced by the organisms listed in Tables 1 and 2. Figure 2 is a map showing ranges for infant mortality in locations worldwide. Because of the direct relationship between high levels of infant mortality and poorest sanitary conditions, Figures 1 and 2 should be used together to locate the geographic areas with the greatest likelihood of having high concentrations of infectious organisms in their natural waters.

It should be noted that very little information concerning waterborne disease outbreaks in the U.S.S.R. and other Soviet Bloc countries was available. However, it may be assumed that the commonly occurring waterborne pathogens that occur worldwide would also be present in these countries.

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* Sanitary Engineering and Environmental Health Research Laboratory (Building 112), University of California, Richmond Field Station, Richmond, CA 94804.

Table 1. Global distribution of waterborne infectious organisms.

Waterborne infectious organisms	Distribution
BACTERIA:	
Shigella spp.	Worldwide
Vibrio cholera (Classical and El Tor)	Coastal areas in Asia, East and West Africa, and isolated from coastal waters of developed countries.
Campylobacter	Worldwide
Escherichia coli	Worldwide
Salmonella spp.	Worldwide
Salmonella typhi	Worldwide
Yersinia spp.	Worldwide
VIRUSES:	
Enteroviruses	Worldwide
Norwalk agent	Worldwide
Rotavirus	Worldwide
Hepatitis A	Worldwide
PARASITES:	
Entamoeba histolytica	Worldwide
Giardia lamblia	Worldwide

WORLDWIDE DISTRIBUTION OF DISEASE FROM SCHISTOSOMA SPP. AND DRACUNCULUS MEDINENSIS

Data were available for the preparation of maps illustrating the distribution of disease from Schistosoma spp. and Dracunculus medinensis. The distribution of these organisms and related diseases is described next. As discussed in Volume 6 of this study, Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risks and Recommendations for Establishing Related Standards,[1] schistosomiasis is the infection caused by a trematode (blood fluke), Schistosoma spp., the

Table 2. Global distribution of water-washed and water-based infectious organisms.

Water-washed and water based infectious organisms	Distribution
BACTERIA:	
Non-cholera *vibrio* spp.	Coastal areas worldwide
Pseudomonas spp.	Worldwide
Staphylococcus spp.	Worldwide
Leptospira spp.	Worldwide
Aeromonas spp.	Worldwide
PROTOZOA:	
Acanthamoeba spp.	Worldwide
Naegleria spp.	Worldwide
Balantidium spp.	Worldwide
HELMINTHS:	
Dracunculus medinensis	India, Africa, Middle East, and South America.
Ascaris lumbricoides	Worldwide
Schistosoma spp.	Africa, Middle East, India, Southeast Asia, and Central and South America.

waterborne larvae of which enter the body directly by penetrating the skin; dracontiasis is the infection produced by the large nematode *Dracunculus medinensis* (commonly called Guinea worm) that enters the body when waterborne *Cyclops* copepods infected with its larvae are consumed in drinking water and these larvae subsequently are liberated in the digestive system.

Schistosoma mansoni, as shown in Figs. 3 and 4, occurs in Africa, predominately between the 15°N and 25°S parallels and has been reported in the Middle East.[2,3] It is believed that African slaves brought this organism to South America where it has established a foothold along the eastern coastal regions north to Puerto Rico (see Fig. 4). Schistosomiasis has also been reported in the interior of Brazil and Ecuador, as indicated in Fig. 4.

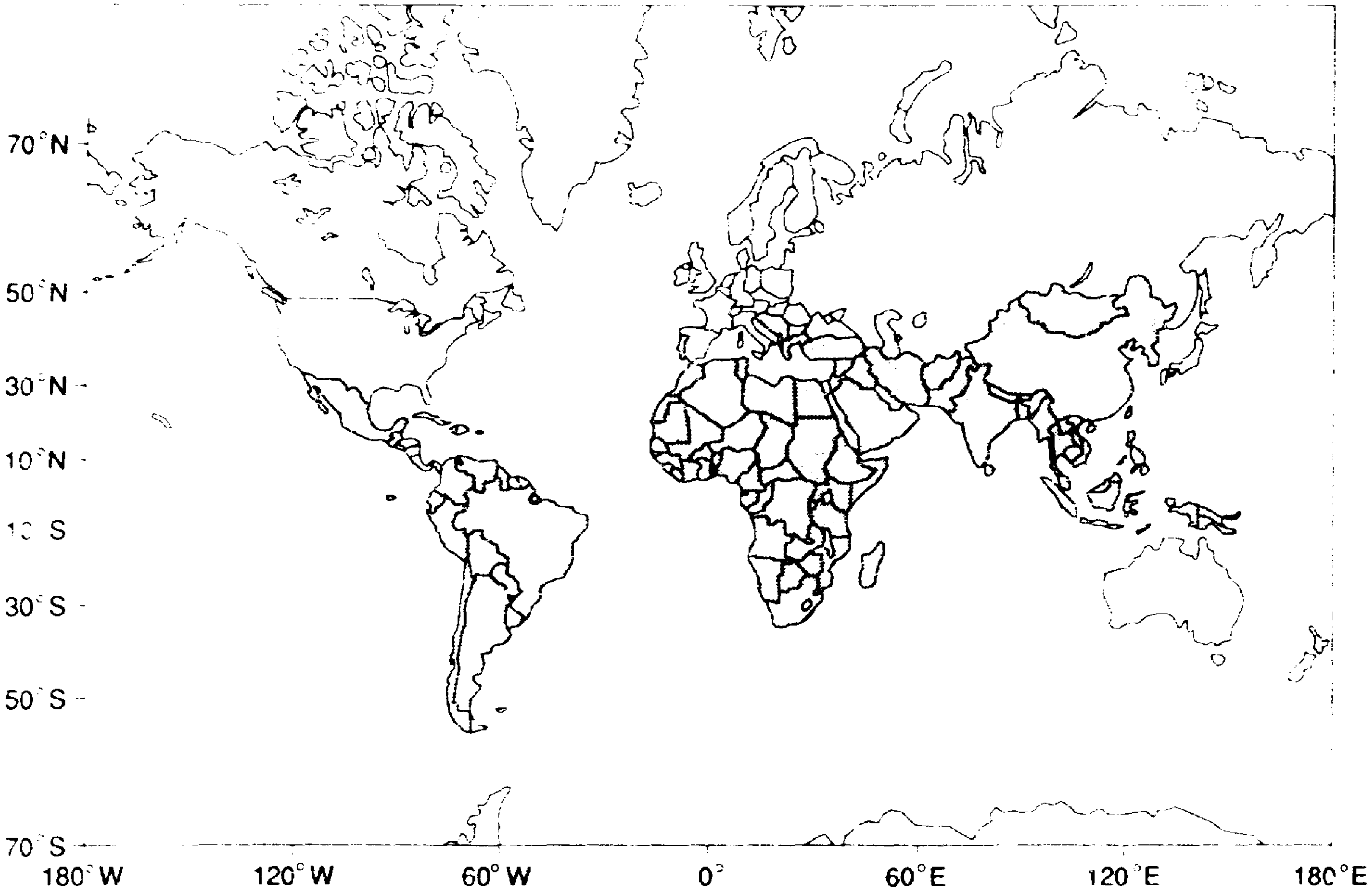

Figure 1 Map indicating the developing countries with poor sanitation as shaded areas.

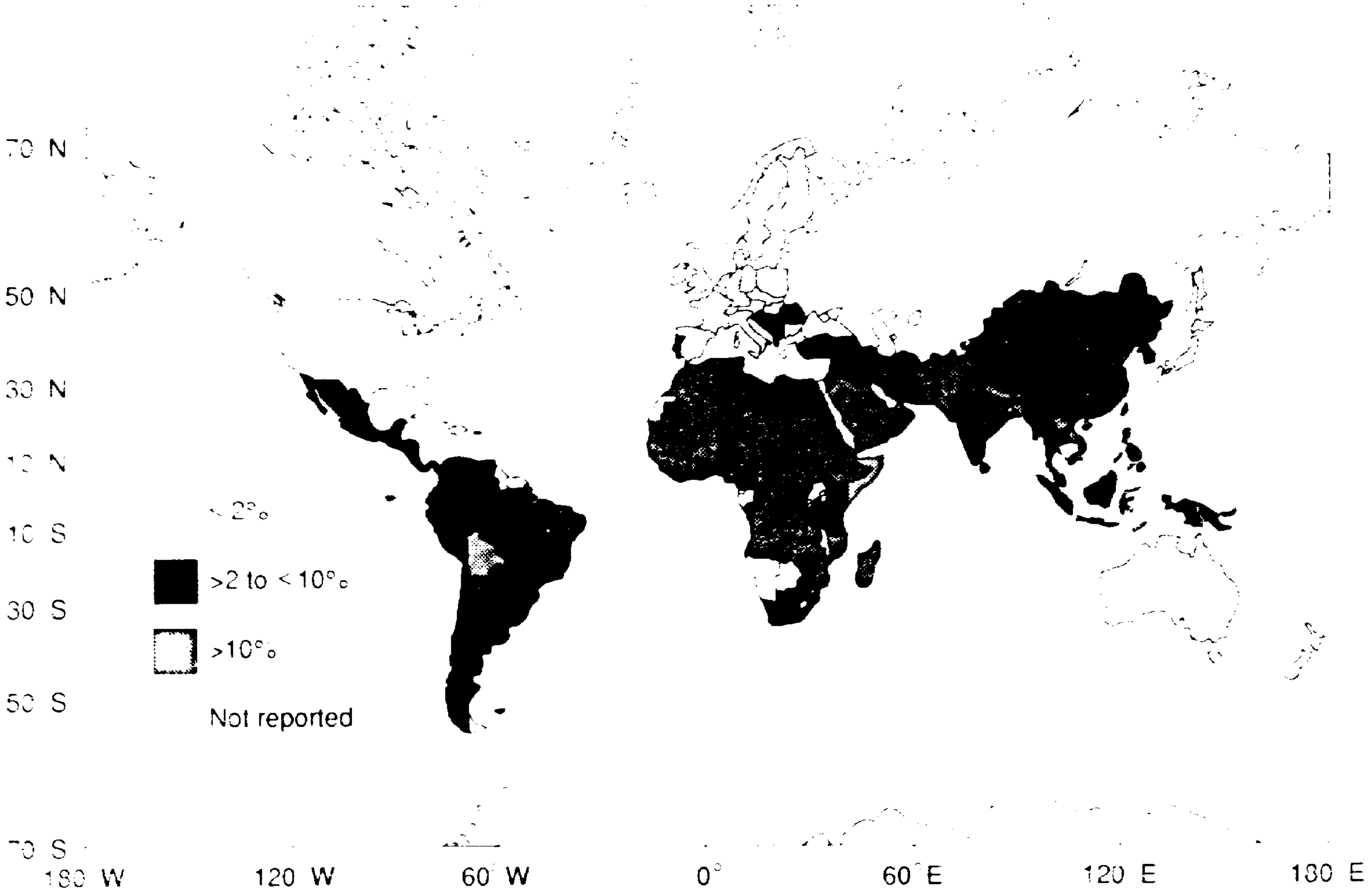

Figure 2. Map indicating ranges of infant mortality worldwide.

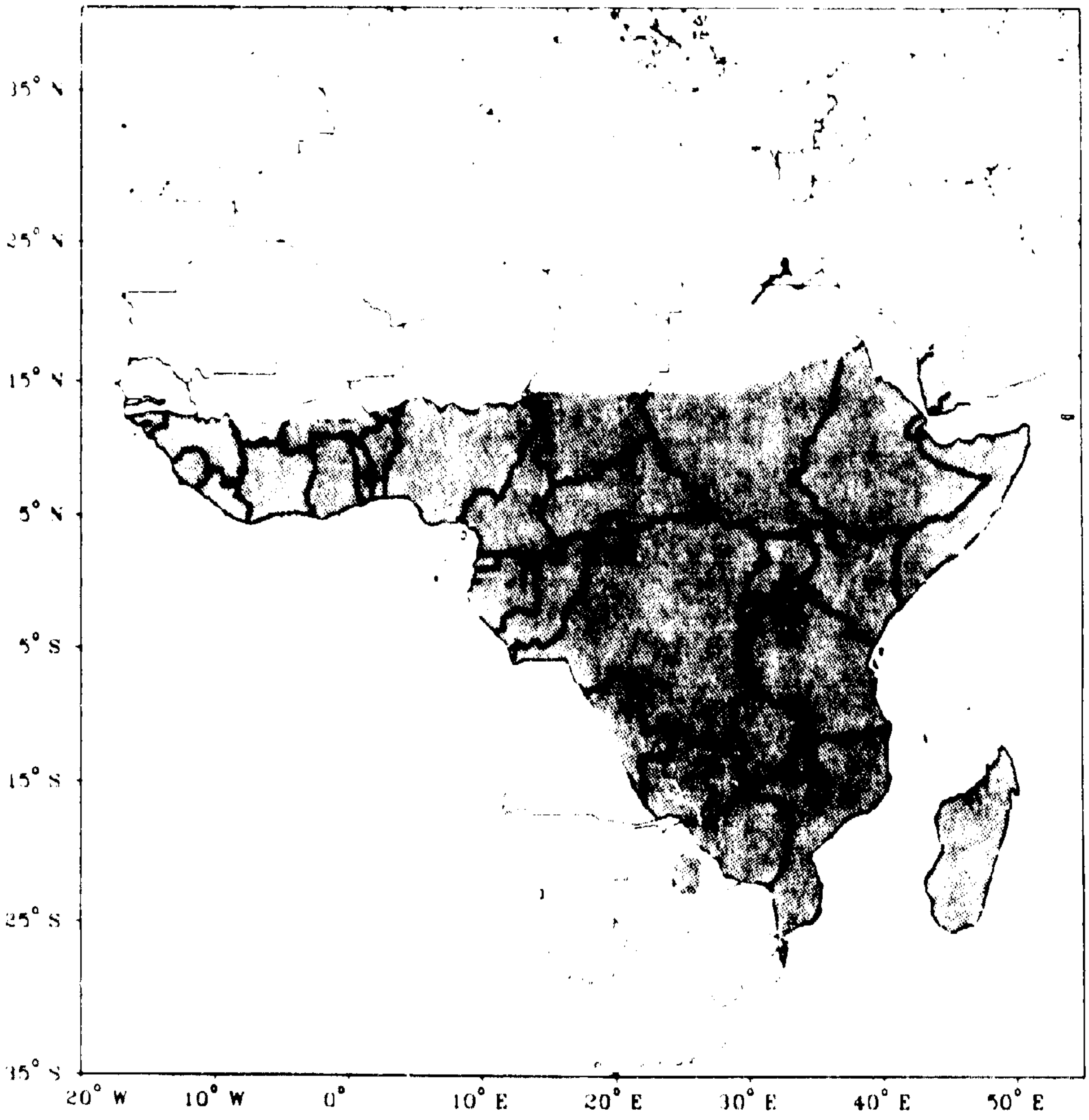

Figure 3. Distribution of S. mansoni in Africa (shaded areas).

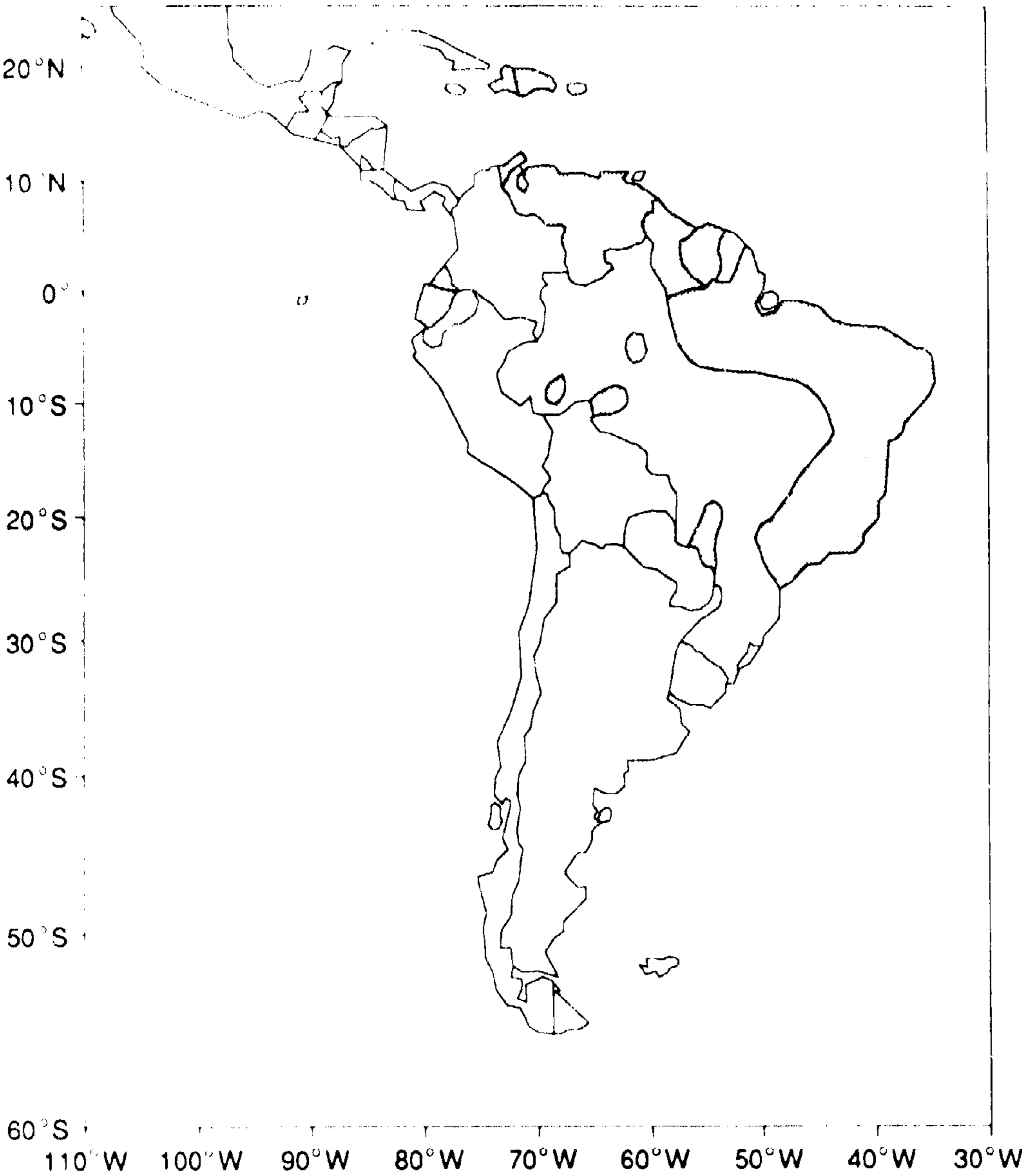

Figure 4. Distribution of S. mansoni in Latin America (shaded area).

Schistosoma japonicum, as shown in Fig. 5, can be found in China, Japan, Celebes, the Philippines, Laos, Cambodia, and the southern portion of Viet Nam.[2,4-8]

Schistosoma mekongi, as shown in Fig. 6, is found in Southeast Asia. The organism is present in the Mekong River from Pakse in southern Laos, to Khong Island, Laos, and south to Strung Teng and Kratie, Cambodia (Kampuchea). Some areas west of the Mekong River are infected in Thailand and Cambodia (Kampuchea). Isolated cases have been reported in Southern Thailand, Java, Indonesia, and Malaysia.[9-15]

Schistosoma haematobium, as shown in Fig. 7, is found throughout most of Africa, particularly in Central and Southeastern Africa and the Nile River Basin. It is also found in parts of the Middle East, with foci in Jordan, Syria, Iraq, Iran, Arabia, and Yemen.[2-4,16-19] There is a small focus in India.

Dracunculus medinensis, as shown in Fig. 8, is found in Central and West Africa, most of India, and portions of the Middle East. Seven states in India are endemic for D. medinensis, putting a population of 10 million persons at risk of adverse health effects in that country alone. Nigeria is the next most afflicted country.[9]

Data concerning the concentrations in worldwide waters of the other water-related infectious organisms should be obtained. This information would assist military planners and risk managers in identifying the geographic regions of the world that are of most concern from the perspective of particular infectious organisms in field water. Furthermore, the impact of specific infectious organisms in field water on exposed populations of military personnel could be assessed in terms of both the known latency of disease symptoms and accomplishment of military missions.

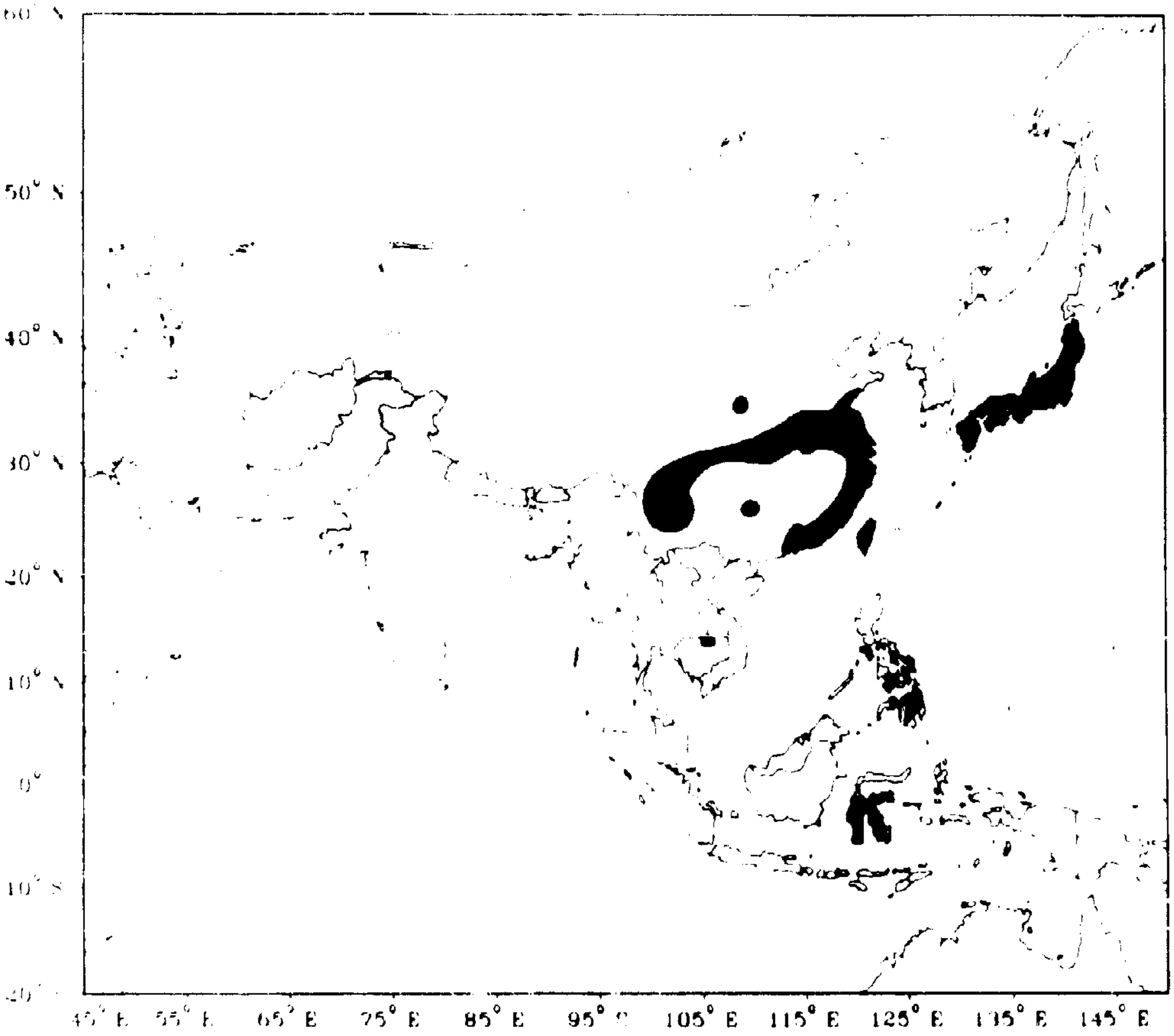

Figure 5. Distribution of S. japonicum in Asia (shaded area).

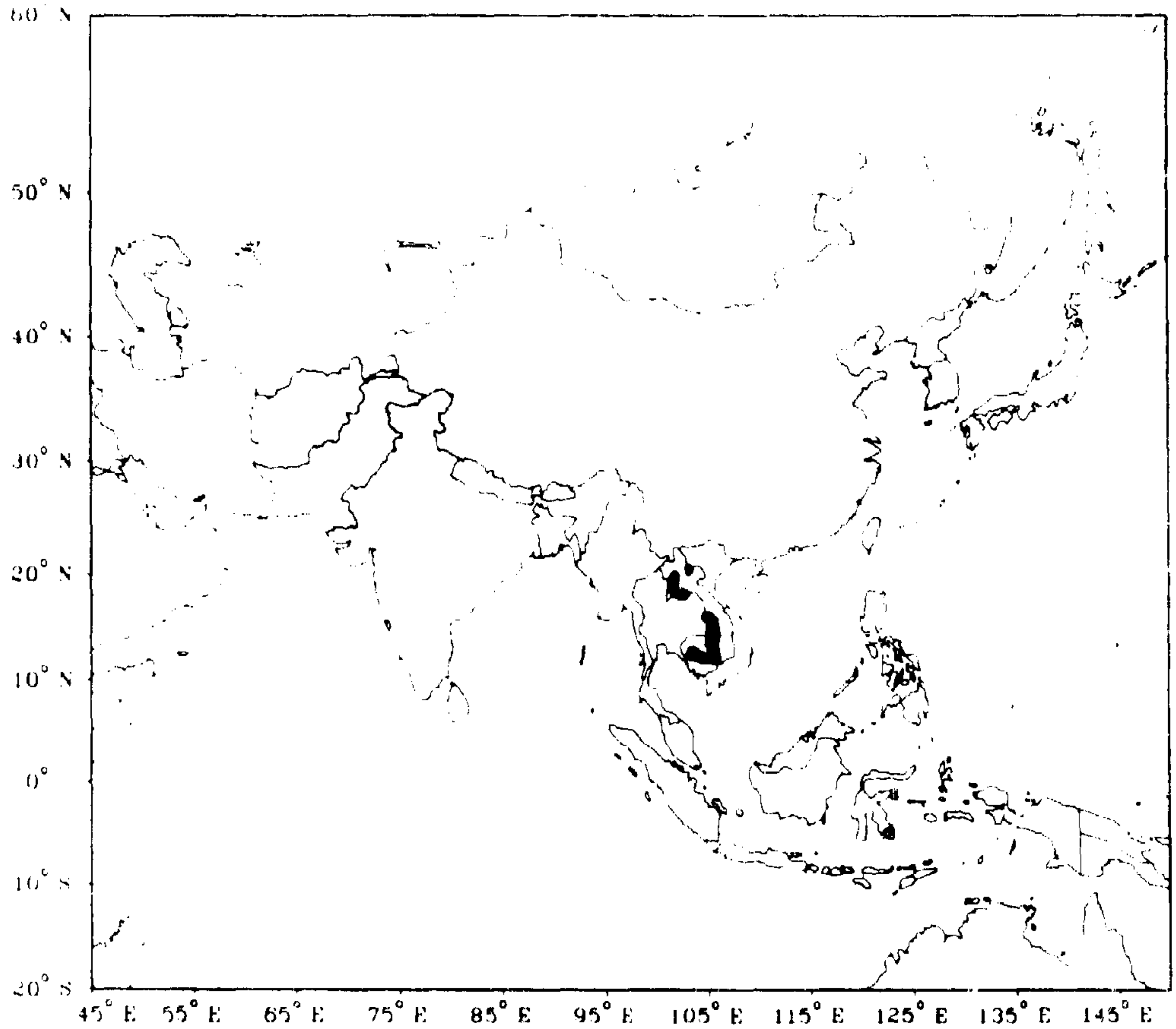

Figure 6. Distribution of S. melongi in Asia (shaded area).

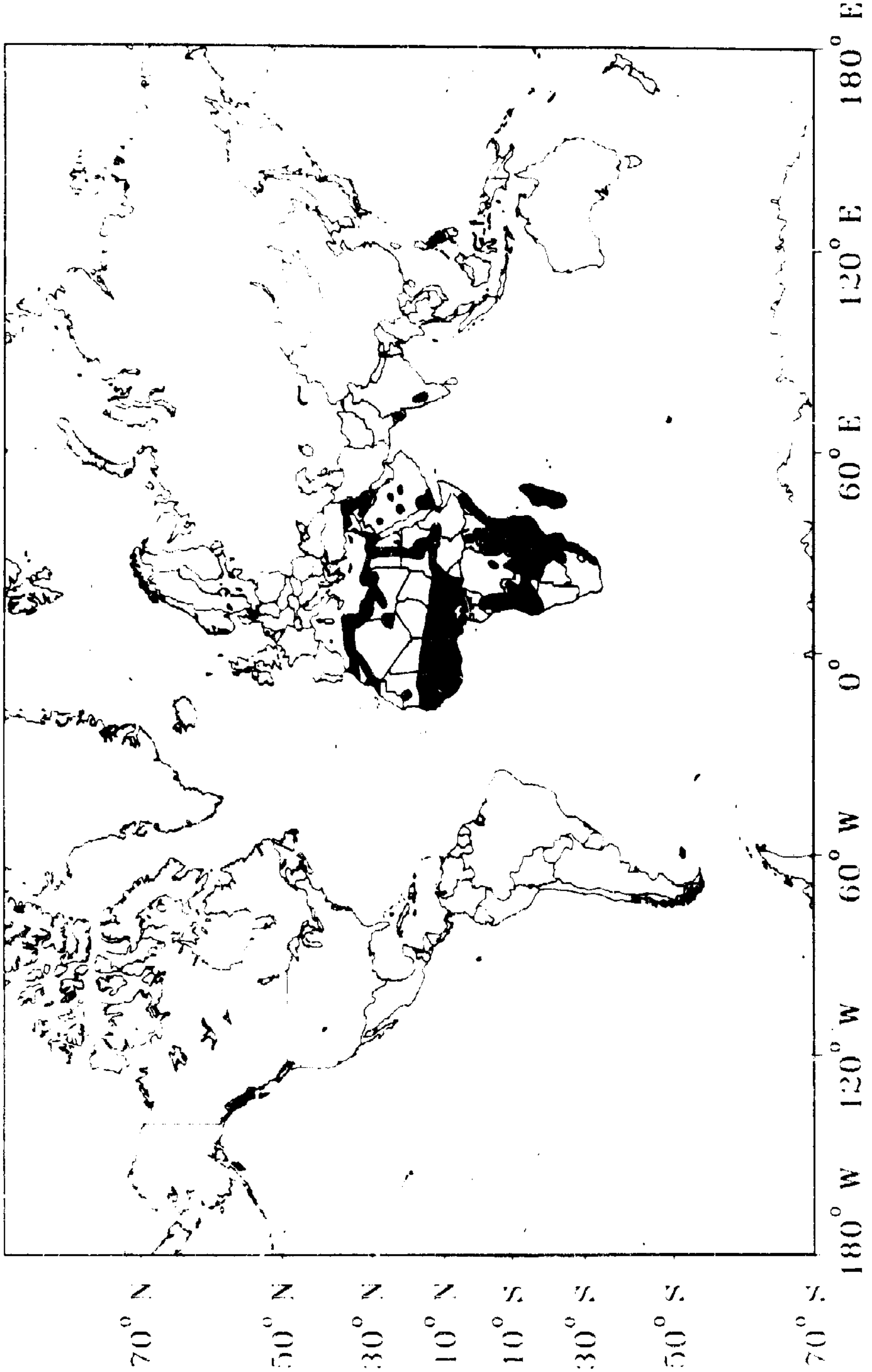

Figure 7. Distribution of S. haematobium worldwide (shaded area).

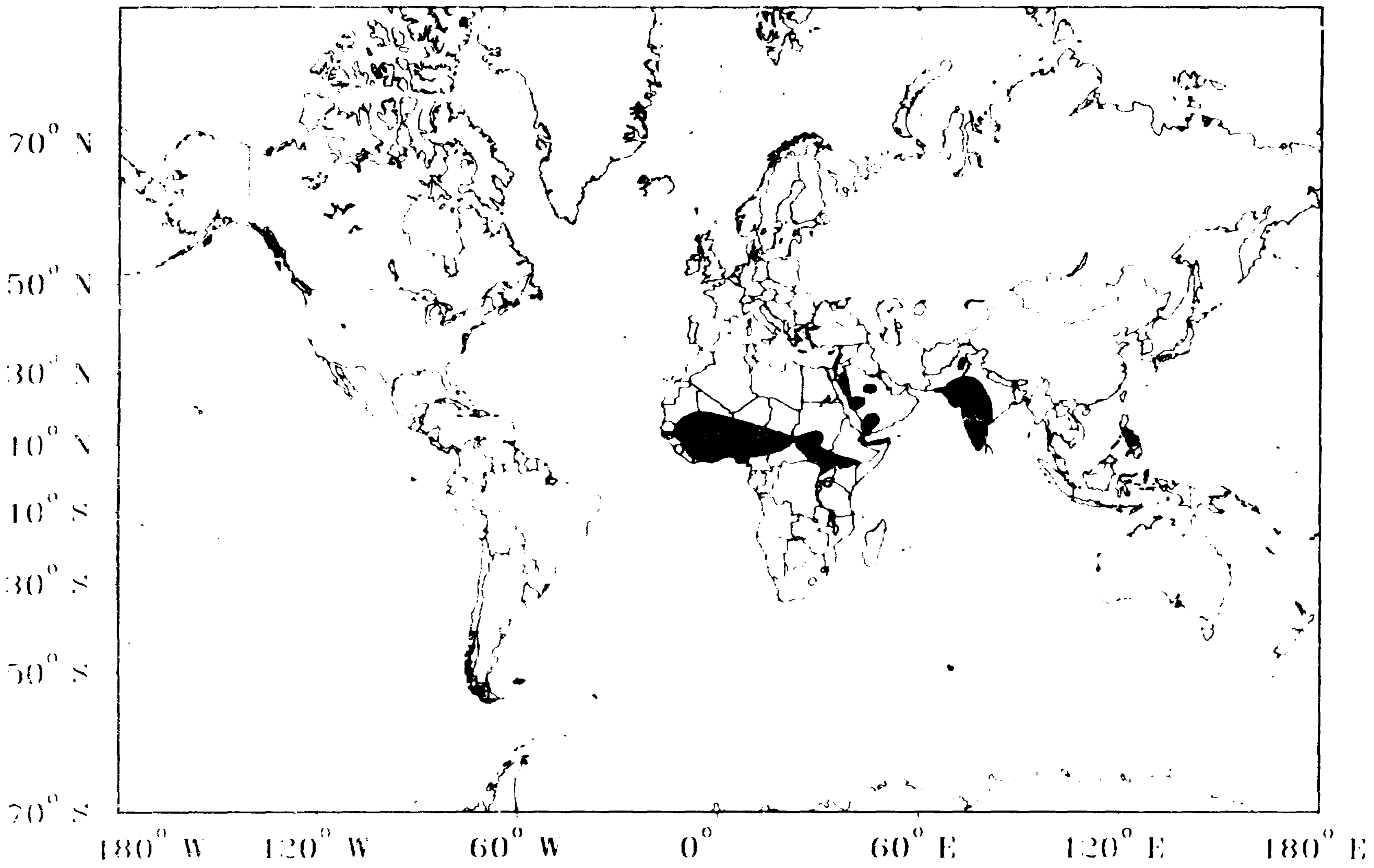

Figure 8. Distribution of *Dracunculis medinensis* (shaded area).

REFERENCES

1. Cooper, R.C., A.W. Olivieri, R.E. Danielson, and P.G. Badger, Evaluation of Military Field-Water Quality. Volume 6. Infectious Organisms of Military Concern Associated with Nonconsumptive Exposure: Assessment of Health Risk and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008 Vol. 6 (1986).

2. Feachem, R.G., D.J. Bradley, H. Garelick, and D.D. Mara, Sanitation and Disease: Health Aspects of Excreta and Wastewater Management (John Wiley and Sons, New York City, NY, 1983).

3. Howe, M., A World Geography of Human Diseases (Academic Press, London, UK, 1977).

4. Brown, H.W., and F.A. Neva, Basic Clinical Parasitology (Appleton-Century- Crofts, Norwalk, CT, 1983), 5th ed.

5. Yokogawa, M., "Review of Prevalence and Distribution of Schistosomiasis in Japan," Southeast Asian J. Trop. Med. Public Health 7, 137-143 (1976).

6. Sommani, S., "Current Status of Schistosomiasis in Laos, Thailand and Malaysia," Southeast Asian J. Trop. Med. Public Health 7, 149-154 (1976).

7. Pesigan, T.P., M. Fraooq, N.G. Hairston, J.J. Jaurequi, E.G. Garcia, A.T. Santos, B.C. Santos, and A.A. Besa, "Studies on Schistosoma japonicum. Infection in the Philippines. I. General Considerations and Epidemiology," Bull. WHO 18, 345-355 (1958).

8. Lewart, R.M., M.G. Yogore, and B.L. Blas, "Schistosomiasis japonica in Barrio San Antonio, Basey, Samar, The Philippines. I. Epidemiology and Morbidity," Am. J. Trop. Med. Hyg. 28, 1010-1025 (1979).

9. California State Department of Health Services, Control of Communicable Diseases in California, California Dept. of Health Services, Health and Welfare Agency, Sacramento, CA (1983).

10. Sommani, S., "Current Status of Research on the Biology of Mekong Schistosoma," Southeast Asian J. Trop. Med. Public Health 7, 208-213 (1976).

11. Schneider, C.R., "Schistosomiasis in Cambodia: A Review," Southeast Asian J. Trop. Med. Public Health 7, 155-166 (1976).

12. Wittes, R., J.D. MacLean, C. Law, and J.O. Lough, "Three Cases of Schistosomiasis Mekongi from Northern Laos," Am. J. Trop. Med. Hyg. 33, 1159-1165 (1984).

13. Keittivuti, B., A. Keittivuti, T. O'Rourke, and T. D'Agnes, "Treatment of Schistosoma mekongi with Praziquantel in Cambodian Refugees in Holding Centres in Prachinburi Province, Thailand," Trans. R. Soc. Trop. Med. Hyg. 78, 477-479 (1984).

14. Kitikoon, V., C.R. Schneider, S. Sommani, C. Harinasuta, and G.R. Lanza, "Mekong Schistosomiasis: 2. Evidence of the Natural Transmission of Schistosoma japonicum, Mekong Strain, at Khong Island, Laos," Southeast Asian J. Trop. Med. Public Health 4, 350-358 (1973).

15. Keittivuti, B., A. Keittivuti, and T.F. O'Rourke, "Parasitic Diseases with Emphasis on Schistosomiasis in Cambodian Refugees, in Prachinburi Province, Thailand," Southeast Asian J. Trop. Med. Public Health 14, 491-494 (1983).

16. American Public Health Association, Control of Communicable Diseases in Man, A.S. Benenson, Ed. (American Public Health Association, Washington, DC, 1985), 14th ed.

17. Nash, T.E., A.W. Cheever, E.A. Ottesen, and J.A. Cook, "NIH Conference: Schistosome Infections in Humans: Perspectives and Recent Findings," Ann. Intern. Med. 97, 740-754 (1982).

18. Browning, M.D., S.I. Nardoz, G.T. Strickland, N.A. El-Masry, and M.F. Abdel-Wahab, "Clinical Characteristics and Response to Therapy in Egyptian Children Infected with Schistosoma haematobium," J. Infect. Dis. 149, 998-1004 (1984).

19. Warren, K.S., A.A. F. Mahmoud, J.F. Muruka, L.R. Whittaker, J.H. Ouma, and T. K. Arap Siongokm "*Schistosomiasis haematobium* in Coast Province Kenya: Relationship Between Egg Output and Morbidity," *Am. J. Trop. Med. Hyg.* **28**, 864-870 (1979).

CHAPTER 7. SUMMARY AND CONCLUSIONS

J.I. Daniels* and D.W. Layton*

This volume can help military risk managers to assess the potential performance-degrading health effects of particular constituents of field water (physical, chemical, or biological) on exposed personnel. Accompanying these data is an evaluation of the general physical, chemical, and biological quality of field water throughout the world. The evaluations alerts military decision makers to high-risk locations in potential theaters of operation.

PHYSICAL PROPERTIES AND CHEMICALS

Turbidity and color are the main physical properties of field water of military significance. Total dissolved solids, chloride, magnesium, and sulfate are among the inorganic constituents of most concern. At concentations in field water above recommended safe levels, all these constituents can increase the risk of performance-degrading health effects in the military, effects resulting from dehydration and catharsis.

Not only does the taste or appearance of high concentrations of these constituents make the water undrinkable, but consumption of field water with high concentrations of some of these chemicals produces laxative effects. In either case, water loss and subsequent dehydration can degrade performance. Magnesium and sulfate are of most concern because they can induce laxative effects at concentrations below their taste thresholds in unacclimated individuals.

Arsenic and cyanide are also among the inorganic chemicals of military concern. People who ingest too much arsenic in field water can experience nausea and abdominal pain. Cyanide above recommended safe levels in drinking water can adversely affect the nervous and respiratory systems.

Except for arsenic and cyanide, high levels of inorganic chemicals in field-water supplies are to be expected in some parts of the world. Critical regions are those with (1) high degrees of evaporation relative to precipitation, (2) areas near oceans, and (3) locations where water comes in direct contact with geological formations of soluble salts. Elevated concentrations of arsenic and cyanide in field water would most likely

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* Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550.

occur through industrial contamination, although naturally high arsenic concentrations in ground water occur infrequently. Rapid detoxification and volatilization in bodies of water make only the areas immediately around industrial sources of particular concern with regard to cyanide.

Organic chemicals are likely to be found in many field water supplies. Except for pesticides, they are rarely found in concentrations high enough to degrade the health and performance of exposed military personnel. However, should chemical factories be destroyed in military operations, high levels of organic chemicals could contaminate nearby field-water supplies. Hence, chemical manufacturing centers and oil refineries considered to be military targets, or adjacent to military targets, represent potential sources of field-water contamination.

Among the pesticides of particular concern is lindane because it may occur at elevated levels in field waters near agricultural areas, and it has been found where rice is grown. Ingestion of field water containing excessive levels of lindane can produce such performance-degrading health effects as nausea, dizziness, restlessness, headache, vomiting, and abdominal pain.

INFECTIOUS ORGANISMS

Bacteria, viruses, and parasites (e.g., protozoa and helminths) are the groups of water-related pathogens of greatest military concern. These infectious organisms cause a variety of performance-degrading diseases. They are found at highest concentrations in developing countries with poor sanitation and high infant mortality, particularly in equatorial Africa and Asia.

CONCLUSIONS

The information presented in this volume of the report 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.

APPENDIX A
LOCATIONS AND PRODUCTION CAPACITIES OF MAJOR ORGANIC CHEMICAL PRODUCTION CENTERS AND PETROLEUM REFINERIES WORLDWIDE

Maps indicating the general location of major chemical production centers (Fig. A-1 through A-5) throughout the world (except in the U.S. and Canada) are presented in this appendix. This appendix also contains six tables that identify the locations of these facilities and major petroleum refineries (crude capacity $\geq$ 200,000 b/cd), along with estimates of their production capacities. Specifically, Tables A-1 through A-5 indicate the latitude, longitude and production capacities of the major organic chemical production centers (i.e., combined total production of benzene, phthalic anhydride, methanol, phenol, ethylene, polyvinyl chloride (PVC), polyamides, polyethylene, styrene, butadiene, and carbon black), and Table A-6 contains such data for the major petroleum refineries worldwide.

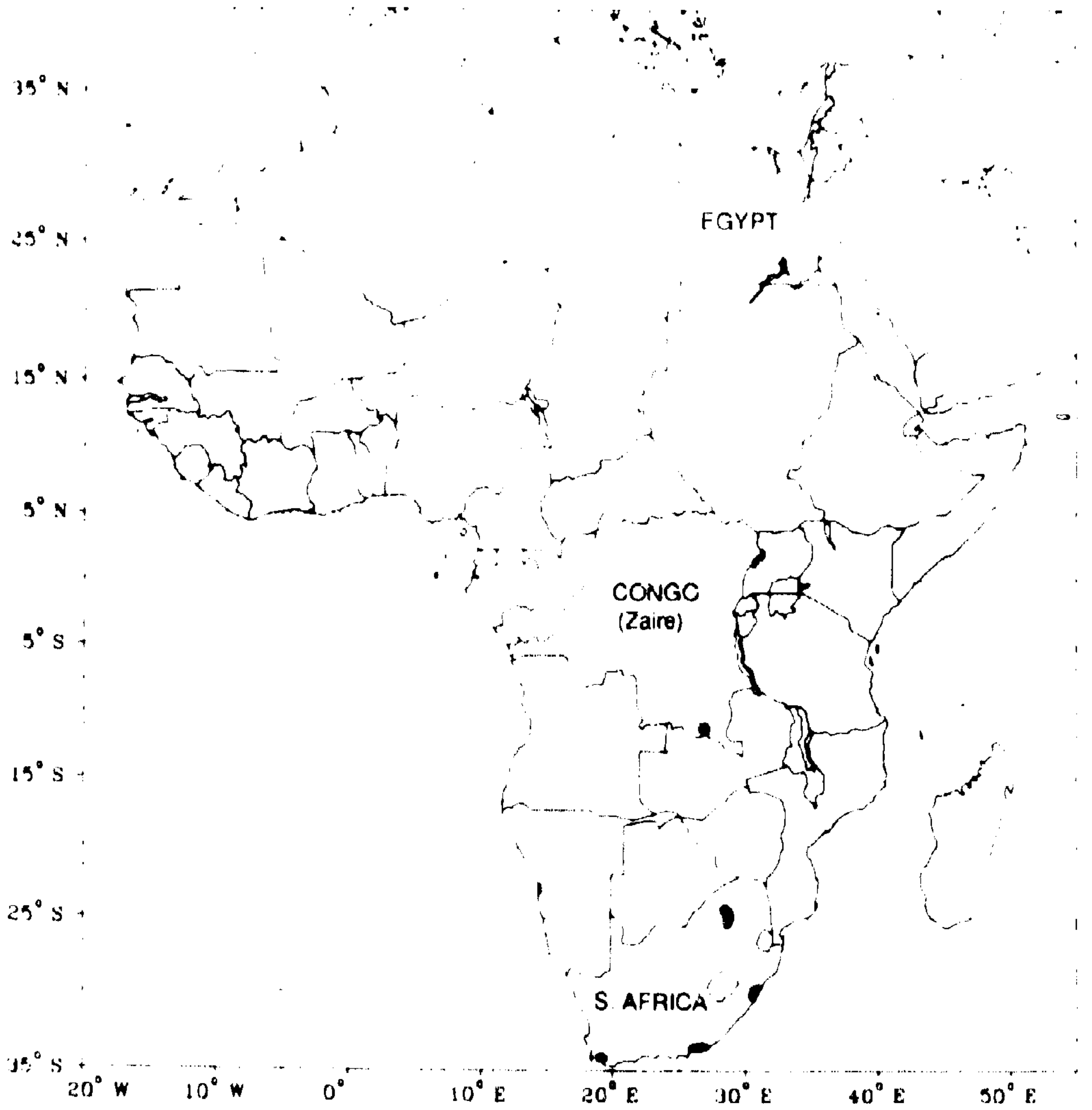

Figure A-1. Major organic chemical production centers in Africa (darkened areas). Based on information in Ref. 1.

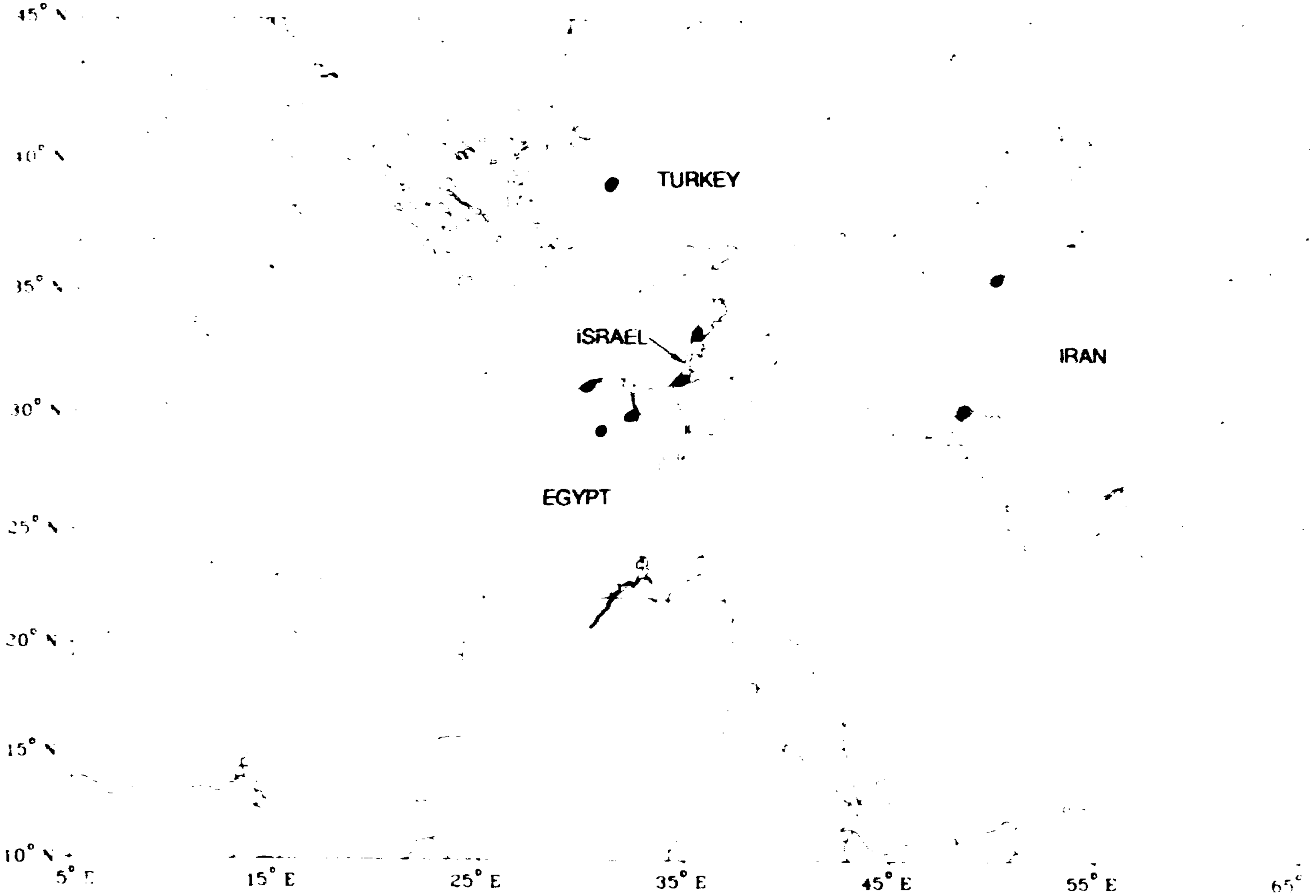

Figure A-2. Major organic chemical production centers in the Middle East (darkened areas). Based on information in Ref. 1.

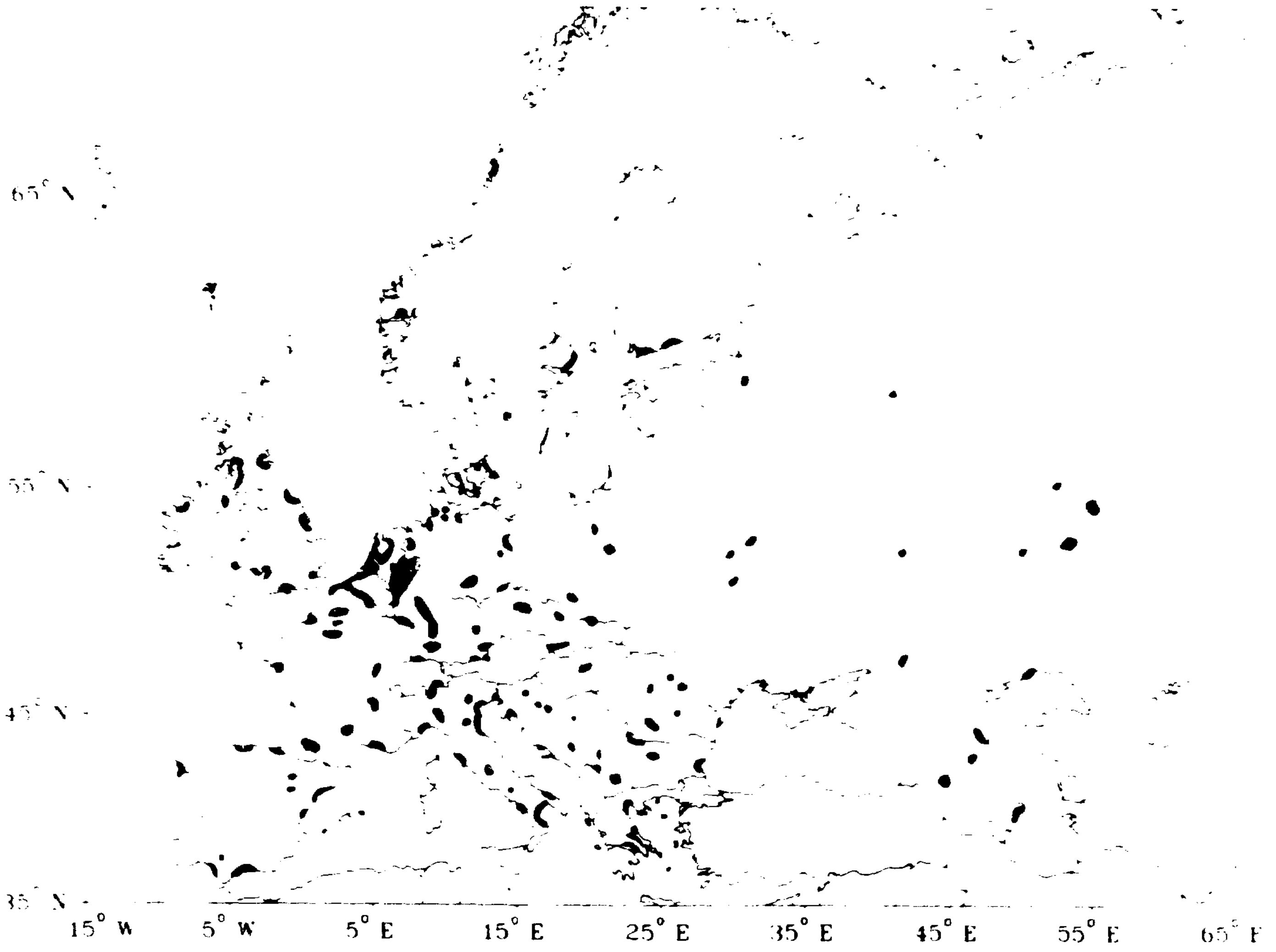

Figure A-3. Major organic chemical production centers in Europe and the U.S.S.R. (darkened areas). Based on information in Ref. 1.

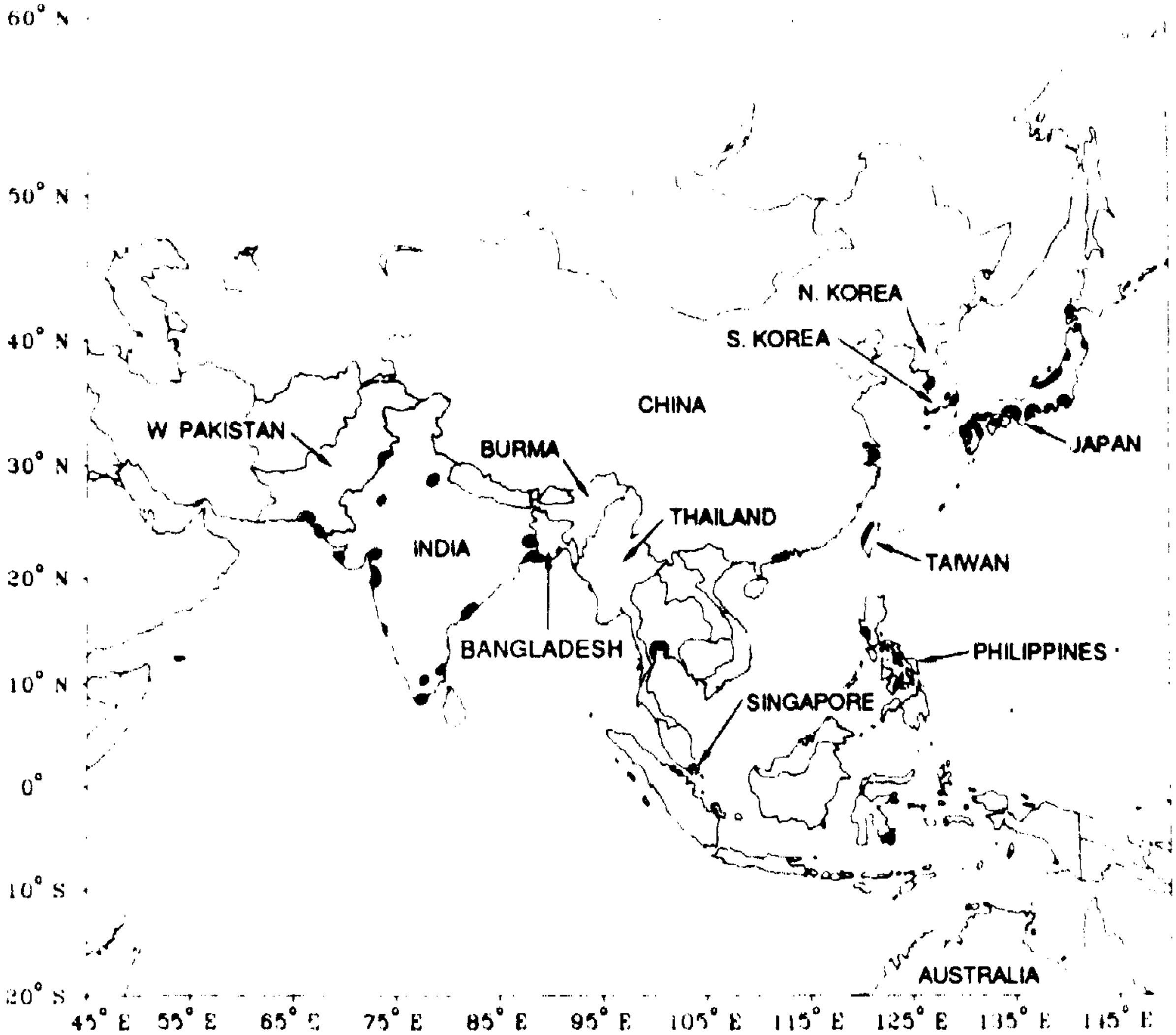

Figure A-4. Major organic chemical production centers in Asia (darkened areas). Based on information in Ref. 1.

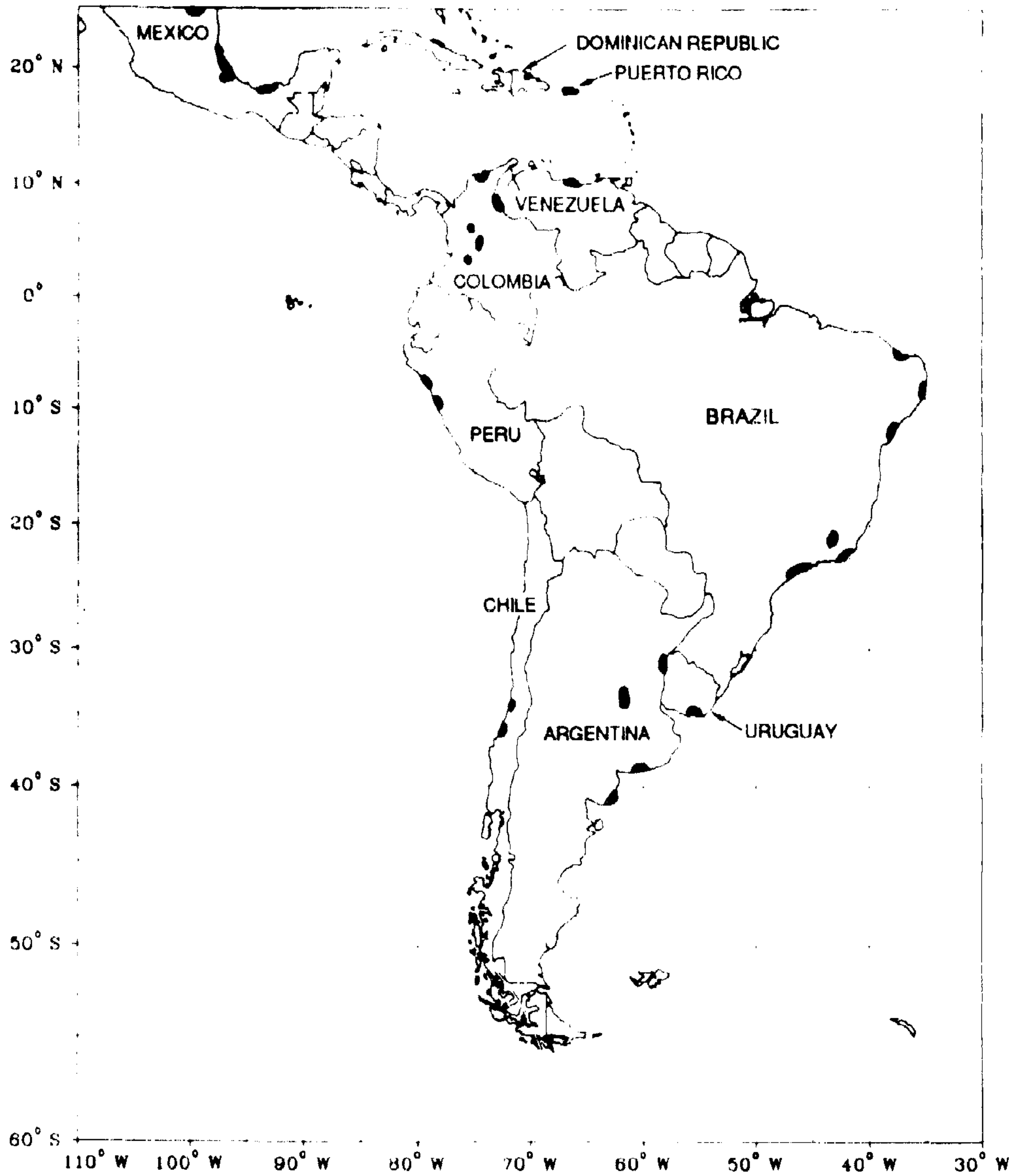

Figure A-5. Major organic chemical production centers in Latin American (darkened areas). Based on information in Ref. 1.

Table A-1. Organic Chemical Production Centers: Africa.[1]

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
Congo, D.R. (Zaire)	Lubumbashi	11.41 S	27.29 E	50
				Total: 50
S. Africa	Modderfontein	26.05 S	28.10 E	150
	Germiston	26.15 S	28.10 E	100
	Sasolburg	26.50 S	27.51 E	500
	Umbogintwini	30.01 S	30.55 E	+
	Paarl/Bellville	33.45 S	18.58 E	50
	Port Elizabeth	33.58 S	25.36 E	50
				Total: 850

+ Data unavailable.

Table A-2. Organic Chemical Production Centers: The Middle East.[1]

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
Egypt (United Arab Republic)	Helwan	29.51 N	31.20 E	50
	As Suways	29.58 N	32.33 E	150
	Kafr El Dawwar	31.08 N	30.08 E	50
				Total: 250
Iran	Abadan	30.20 N	48.15 E	50
	Tehran	35.40 N	51.26 E	50
				Total: 100
Israel	Ashdod	31.45 N	34.40 E	50
	Haifa	32.49 N	34.59 E	100
	Akko	32.55 N	35.04 E	50
				Total: 200
Turkey	Derince	40.40 N	29.47 E	50
		40.48 N	29.55 E	400
				Total: 450

Table A-3. Organic Chemical Production Centers: Europe and the U.S.S.R.[1]

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
Austria	Schwechat	48.09 N	16.29 E	500
				Total: 500
Belgium	Jemeppe	50.11 N	5.19 E	100
	Tertre	50.28 N	3.48 E	50
	Liege	50.38 N	5.34 E	50
	Ronsarj	50.42 N	3.41 E	50
	Zandvoorde	50.49 N	2.58 E	150
	Zwijaarde	51.00 N	3.43 E	50
	Gent	51.03 N	3.43 E	50
	Temeuzen	51.04 N	3.44 E	1000
	Willebroek	51.04 N	4.22 E	50
	Zandvliet	51.09 N	5.08 E	100
	Beek	51.09 N	5.36 E	700
	Zelzate	51.12 N	3.49 E	150
	Antwerpen	51.13 N	4.25 E	1600
				Total: 4100
Bulgaria	Dimitrovgrad	42.03 N	25.34 E	50
	Burgas	42.30 N	27.29 E	300
	Kameno	42.33 N	27.17 E	100
	Pleven	43.25 N	24.40 E	400
	Vidin	44.00 N	22.05 E	50
				Total: 900
Czechoslovakia	Bratislava	48.10 N	17.08 E	450
	Novaky	48.43 N	18.33 E	50
	Humenne	48.57 N	21.54 E	50
	Pana Nad Lyznici	49.22 N	14.43 E	+
	Valasske Mezirici	49.29 N	17.57 E	100
	Pardubice	50.03 N	15.45 E	50
	Kralupy Nad Vltavau	50.14 N	14.19 E	100
	Most/Zalyzi	50.31 N	13.39 E	100
				Total: 900
Denmark	Nyborg	55.19 N	10.48 E	50
	Kobenhavn/Kasttkup	55.43 N	12.34 E	150
				Total: 200
England	Fawley	50.49 N	1.20 W	800
	Hythe	51.05 N	1.05 E	100
	Wilton	51.05 N	7.52 W	1750
	Avonmouth	51.31 N	2.42 W	100
	Ilford	51.33 N	0.06 E	50
	Basildon	51.34 N	0.25 E	50
	Port Talbot	51.36 N	3.47 W	50
	Cheltenham	51.54 N	2.04 W	50

Table A-3. (Continued)

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
	Spondon	52.26 N	1.25 W	100
	Briston	52.52 N	1.05 E	50
	Chesterfield	53.15 N	1.25 W	50
	Stanlow/Ellesmere	53.17 N	2.52 W	300
	Runcorn	53.20 N	2.44 W	100
	Carrington/ Warrington	53.26 N	2.24 W	650
	Aintree	53.29 N	2.57 W	50
	Stallingbourough	53.36 N	0.11 W	100
	Scumthrope	53.36 N	0.38 W	100
	Immingham	53.37 N	0.14 W	300
	Cleckheaton	53.44 N	1.43 W	50
	Kingston Upon Hull	53.45 N	0.20 W	100
	Heysham	54.02 N	2.54 W	300
	Stavelly	54.04 N	1.26 W	150
	Ravenscrar	54.24 N	0.30 W	50
	Middlesbrough	54.35 N	1.14 W	600
	Aycliffe	54.36 N	1.34 W	50
	Hillhouse	Uncertain	Uncertain	300
				Total: 6350
Finland	Helsinki	60.08 N	25.00 E	50
	Turku	60.27 N	22.15 E	50
				Total: 100
France	Mont	42.49 N	0.26 E	150
	Lannemezan	43.08 N	0.22 E	100
	Saint-Menet	43.17 N	5.27 E	100
	Pardies	43.22 N	0.34 W	300
	Cite de Lavera	43.23 N	5.02 E	450
	Lacq	43.25 N	0.37 W	300
	Berre l'Etang	43.27 N	5.05 E	300
	Toulouse	43.37 N	1.26 E	50
	Saint-Auban	44.17 N	5.25 E	50
	Le Peage	44.29 N	5.02 E	100
	Le Point-de-Claix	45.07 N	5.42 E	50
	Brignoud	45.15 N	5.54 E	100
	Saint Fons	45.42 N	4.51 E	100
	Feyzin	45.40 N	4.51 E	500
	Balan	45.50 N	5.05 E	200
	Montlucon	46.20 N	2.36 E	100
	Besancon	47.14 N	6.02 E	100
	Donges	47.19 N	2.04 W	50
	Saint Nabord	48.03 N	6.35 E	50
	Bezons	48.56 N	2.12 E	50
	Sarralbe	49.00 N	7.01 E	100
	Carling	49.10 N	6.43 E	550

Table A-3. (Continued)

		Map Location		Production (metric tons x 1000)
Country	City	Latitude	Longitude	
	Marienay	49.11 N	6.52 E	50
	Villers	49.19 N	0.00	100
	Ebange	49.19 N	6.08 E	50
	Port Jerome	49.28 N	0.32 E	500
	Gonfreville L'Orcher	49.30 N	0.14 E	900
	Chauny	49.37 N	3.14 E	100
	Tavaux	49.44 N	3.55 E	300
	Tertry	49.52 N	3.04 E	50
	Saint-Laurent-Blangy	50.18 N	2.48 E	50
	Vendrin/Drocourt	50.23 N	2.55 E	50
	Mazingarbe	50.28 N	2.42 E	50
	Coquelles	50.56 N	1.48 E	100
				Total: 6150
Germany (East), DR	Leuna	51.19 N	12.01 E	300
	Schokopau	51.24 N	11.59 E	200
	Bitterfeld	51.37 N	12.19 E	100
	Guben	51.57 N	14.43 E	50
	Erkner	52.25 N	13.45 E	50
	Schwedt	53.04 N	14.17 E	200
				Total: 900
Germany (West), FR	Rheinfelden	47.34 N	7.48 E	100
	Waldshut	47.37 N	8.13 E	50
	Rheinburg	47.42 N	8.44 E	100
	Bremen	47.44 N	9.56 E	100
	Oberhausen	47.47 N	11.08 E	50
	Homberg	47.52 N	8.55 E	100
	Hessen	47.54 N	10.18 E	50
	Amberg	47.56 N	9.39 E	50
	Hochst/Kelsterbach	47.57 N	8.16 E	1100
	Neumunster	47.58 N	11.50 E	50
	Freiburg im Breis	48.00 N	7.51 E	50
	Ahlen/Kamen	48.08 N	9.39 E	100
	Burghausen	48.10 N	12.50 E	600
	Munchen	48.42 N	13.28 E	50
	Hurth	48.56 N	10.56 E	50
	Brebach	49.13 N	7.02 E	100
	Ostringen	49.13 N	8.43 E	50
	Saarbrucken	49.14 N	7.00 E	100
	Rorscbach	49.15 N	8.07 E	+
	Ludwigshafen	49.29 N	8.27 E	2100
	Frankfurt	49.41 N	10.32 E	50

Table A-3. (Continued)

Country	City	Map Location Latitude	Map Location Longitude	Production (metric tons x 1000)
	Raunhein	50.01 N	8.27 E	50
	Grossauheim	50.06 N	8.57 E	50
	Linz	50.34 N	7.18 E	50
	Troisdorf	50.49 N	7.10 E	100
	Kohlscheid	50.50 N	6.06 E	50
	Wesseling	50.50 N	6.58 E	2600
	Kalscheurem	50.53 N	6.54 E	300
	Leverkusen/Koln	51.01 N	6.59 E	450
	Geisenkirchen	51.02 N	6.10 E	900
	Dormagen	51.06 N	6.50 E	800
	Holthausen	51.11 N	8.20 E	50
	Dusseldorf	51.13 N	6.46 E	150
	Wuppertal	51.16 N	7.11 E	100
	Recklinghausen	51.18 N	8.02 E	50
	Untrop	51.24 N	8.05 E	50
	Bochum/Wanne-eickel	51.29 N	7.13 E	300
	Kamp-Lintfort	51.30 N	6.32 E	50
	Bottrop	51.31 N	6.55 E	50
	Dortmund	51.31 N	7.27 E	250
	Dinslaken	51.34 N	6.44 E	100
	Gladbeck	51.37 N	9.57 E	300
	Erkenschwick	51.38 N	7.15 E	50
	Marl/Scholven	51.39 N	7.05 E	1200
	Datteln	51.40 N	7.23 E	50
	Drutte	52.09 N	10.27 E	50
	Osnabruck	52.16 N	8.03 E	50
	Heide	52.19 N	8.58 E	150
	Peine	52.19 N	10.14 E	50
	Misburg	52.23 N	9.51 E	50
	Lingen	52.32 N	7.19 E	50
	Essen/Aitenessen	52.42 N	7.55 E	100
	Bremerhaven	53.33 N	8.35 E	50
	Hamburg	53.33 N	10.00 E	150
	Lubeck	53.52 N	10.42 E	50
	Kohn/Lulsdorf	54.21 N	10.27 E	300
				Total: 14,150
Greece	Athinai	38.00 N	23.44 E	50
	Thessaloniki	40.38 N	22.58 E	50
	Diavata	40.42 N	22.47 E	50
				Total: 150
Hungary	Szolnok	47.10 N	20.11 E	50
				Total: 50

Table A-3. (Continued)

Country	City	Map Location Latitude	 Longitude	Production (metric tons x 1000)
Ireland	Sligo	54.17 N	8.28 W	50
	Antrim	54.43 N	6.13 W	50
				Total: 100
Italy	Ragusa	36.55 N	14.44 E	250
	Gela	37.04 N	14.15 E	150
	Priolo Gargallo	37.09 N	15.11 E	200
	Sarroch	39.04 N	9.00 E	100
	Cagliari	39.13 N	9.07 E	100
	Assemini	39.17 N	9.00 E	100
	Sibari	39.45 N	16.27 E	500
	Pisticci/Ferrandina	40.23 N	16.33 E	150
	Ferrandina	40.29 N	16.27 E	100
	Brindisi	40.38 N	17.56 E	550
	Porto Torres	40.50 N	8.24 E	900
	Napoli	40.50 N	14.15 E	100
	Camello	41.41 N	13.37 E	50
	Colleferro	41.44 N	12.59 E	50
	Cesano	42.05 N	12.21 E	100
	Terni	42.34 N	12.37 E	100
	Castezvecchio	42.53 N	13.01 E	50
	Rosignano Solvay	43.23 N	10.26 E	200
	Forli	44.13 N	12.03 E	50
	Cengio	44.23 N	8.12 E	100
	Ravenna	44.25 N	12.12 E	450
	Ferrara	44.50 N	11.35 E	500
	Fidenza	44.52 N	10.03 E	100
	Trecenta	45.02 N	11.28 E	50
	Mantova	45.09 N	10.48 E	100
	Crespiatica	45.21 N	9.34 E	50
	Padova	45.25 N	11.53 E	50
	Ivrea	45.28 N	7.53 E	50
	Marghera	45.28 N	12.14 E	1150
	Rho/Milano	45.32 N	9.02 E	250
	Castellanza	45.37 N	8.54 E	300
	Maderno	45.38 N	10.35 E	100
	Trieste	45.40 N	13.46 E	100
	Bergamo	45.41 N	9.43 E	100
	Trento	46.04 N	11.08 E	150
				Total: 7400
Luxembourg	Echternach	49.49 N	6.25 E	50
				Total: 50

Table A-3. (Continued)

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
Netherlands	Moerdijk	51.42 N	4.38 E	300
	Pernis	51.54 N	4.23 E	600
	Rozenburg	51.55 N	4.15 E	150
	Rotterdam	51.55 N	4.29 E	400
	Europoort	51.59 N	4.06 E	500
	Arnhem	52.00 N	5.53 E	100
	Uithoorn	52.14 N	4.50 E	100
	Amsterdam	52.21 N	4.54 E	600
	Ijuiden	52.23 N	4.38 E	50
	Emmer-Compascuum	52.49 N	7.03 E	50
				Total: 2850
Norway	Heroya	62.18 N	5.45 E	100
	Mo	66.19 N	14.10 E	50
				Total: 150
Poland	Oswiecim	50.02 N	19.11 E	100
	Plock	52.33 N	19.40 E	800
	Gorzow Wielkopolski	52.42 N	15.12 E	50
	Bydgoszcz	53.16 N	17.33 E	50
	Blachownia Slaska	Uncertain	Uncertain	250
				Total: 1250
Rumania	Pitesti	44.51 N	24.51 E	400
	Ploesti	44.57 N	26.01 E	100
	Hunedoara	45.45 N	22.54 E	50
	Fagaras	45.50 N	24.59 E	50
	Copsa Mica	46.06 n	24.25 E	50
	Turda	46.35 N	23.50 E	50
	Piatra Neamt	46.53 N	26.23 E	50
				Total: 750
Scotland	Stevenson	55.39 N	4.45 W	300
	Glasgow	55.53 N	4.15 W	50
	Grangemouth	56.01 N	3.44 W	1250
	Invergordon	57.42 N	4.10 W	300
				Total: 1900
Spain	San Roque	36.13 N	5.24 W	50
	Huelva	37.15 N	6.56 W	300
	Sevilla	37.24 N	5.59 W	100
	Aviles	37.54 N	1.48 W	50
	Puertollano	38.41 N	4.07 W	400
	Castellon de la Piana	39.59 N	0.02 W	50
	Alcala de Henares	40.29 N	3.22 W	50

Table A 3. (Continued)

Country	City	Map Location Latitude	 Longitude	Production (metric tons x 1000)
Spain	Tarrangona	41.07 N	1.15 E	300
	Barcelona	41.23 N	2.11 E	350
	Zaragoza	41.38 N	0.53 W	50
	San Celoni	41.41 N	2.29 E	50
	Monzon	41.55 N	0.12 E	50
	Porto	42.04 N	8.32 W	50
	Sobrado	42.19 N	7.14 W	50
	Sabinanigo	42.31 N	0.22 W	50
	Miranda de Ebro	42.41 N	2.57 W	150
	Andoain	43.13 N	2.01 W	50
	Billbao	43.15 N	2.58 W	50
	Mieres	43.15 N	5.46 W	50
	Luchana/Ortuella	43.17 N	2.59 W	50
	Torrelavega	43.21 N	4.03 W	150
	Limpias	43.22 N	3.25 W	50
	Santander	43.28 N	3.48 W	100
				Total: 2600
Sweden	Malmo	55.35 N	13.00 E	50
	Boras	57.44 N	12.55 E	50
	Goteborg	57.45 N	12.00 E	50
	Stenungsund	58.05 N	11.55 E	450
	Nynashamn	58.54 N	17.55 E	50
	Stockholm/Oxelosund	59.20 N	18.95 E	150
	Karlstad	59.24 N	13.32 E	50
				Total: 850
Switzerland	Grono	46.15 N	9.09 E	50
	Visp	46.18 N	7.53 E	50
	Domat	46.51 N	9.28 E	50
	Brugg	47 29 N	8.13 E	50
	Pratteln	47.32 N	7.42 E	50
				Total: 250
USSR	Rustavi	41.34 N	45.03 E	50
	Groznyy	43.21 N	45.42 E	100
	Furyev	47.08 N	51.59 E	50
	Novocherkassk	47.25 N	40.05 E	50
	Sverdlovsk	48.05 N	39.37 E	50
	Rubezhnoye	49.01 N	38.22 E	50
	Karaganda	49.56 N	73.11 E	50
	Saratov/Engel's	51.30 N	45.55 E	100
	Voronezh	51.40 N	39.13 E	50
	Mozyr	52.02 N	29.10 E	50
	Sterlitamak	53.04 N	55.59 E	50
	Novokuybyshevsk	53.06 N	49.59 E	50
	Yefremov	53.08 N	38.08 E	50

Table A-3. (Continued)

Country	City	Map Location Latitude	 Longitude	Production (metric tons x 1000)
	Barnaul	53.12 N	83.50 E	50
	Salavat	53.22 N	55.50 E	50
	Stavropol/Tolyatti	53.32 N	49.24 E	100
	Sterlitamak	53.40 N	55.59 E	50
	Dzerzhinsk	53.41 N	27.08 E	100
	Novomoskovsk	54.06 N	38.15 E	50
	Tula	54.11 N	37.38 E	300
	Ufa/Salavat	54.45 N	55.58 E	150
	Omsk	55.00 N	73.22 E	50
	Novosibirsk	55.04 N	83.00 E	50
	Polotsk	55.30 N	28.43 E	200
	Kazan	55.45 N	49.10 E	400
	Volzhsk	55.51 N	48.22 E	50
	Krasnoyarsk	56.10 N	93.00 E	50
	Yaroslavl	57.34 N	39.52 E	50
	Leningrad	59.55 N	30.25 E	100
	Not indicated	Uncertain	Uncertain	1600
				Total: 4150
Wales	Barry	51.24 N	3.18 W	300
	Port Talbot	51.36 N	3.47 W	50
	Swansea	51.38 N	3.57 W	50
	Pontypool	51.43 N	3.02 W	300
	Milford Haven	51.44 N	5.02 W	300
	Llanwnen	52.06 N	4.09 W	100
	Raubon	52.59 N	3.02 W	50
	Hawarden	53.11 N	3.02 W	50
	Baglan Bay	Uncertain	Uncertain	400
				Total: 1600
Yugoslavia	Skopje	42.00 N	21.29 E	100
	Leskoval	42.11 N	20.44 E	50
	Prizren	42.13 N	20.45 E	50
	Corazde	42.52 N	19.56 E	50
	Vitkovice	42.58 N	20.33 E	50
	Zenica	43.18 N	19.21 E	50
	Lukavac	43.33 N	21.16 E	100
	Teslic	44.37 N	17.52 E	50
	Kastel Sucurac	45.27 N	13.39 E	50
	Zagreb	45.48 N	16.00 E	100
	Moste	46.12 N	14.33 E	50
				Total: 700

Table A-4. Organic Chemical Production Centers: Asia[1]

Country	Island	City	Map Location Latitude	Map Location Longitude	Production (metric tons x 1000)
China		Tao-yuan	28.55 N	111.16 E	50
		Shang-hai	31.13 N	121.25 E	50
		Lan-chou	36.01 N	103.45 E	100
		T'ai-yuan	37.50 E	112.30 E	50
					Total: 250
India		Tutibrin	8.18 N	78.10 E	50
		Mettur	11.53 N	77.51 E	50
		Madras	13.05 N	80.18 E	150
		Vishakapatnam	17.42 N	83.24 E	100
		Thana/Bombay/ Hanvel/ Trombay	18.56 N	72.51 E	700
		Chembur	19.03 N	72.54 E	50
		Baroda	22.19 N	73.14 E	1300
		Calcutta	22.35 N	88.21 E	50
		Durgapur	24.47 N	87.44 E	100
		Kota	25.11 N	75.58 E	50
		Bareilly	28.20 N	79.24 E	150
					Total: 2750
Japan	Hokkaido	Muroran	42.18 N	140.56 E	100
		Tonatsu	43.16 N	141.54 E	50
		Shiga	44.06 N	143.28 E	100
	Honshu	Ube	33.56 N	131.16 E	50
	Honshu	Bofu	34.04 N	131.34 E	100
		Tokuyama	34.04 N	131.48 E	900
		Iwakuwi/Otake	34.10 N	132.10 E	450
		Nishiki	34.12 N	136.24 E	100
		Wakayami	34.14 N	135.10 E	50
		Mihara	34.24 N	133.06 E	50
		Sakai	34.34 N	135.28 E	800
		Okayama	34.40 N	133.54 E	100
		Takasago	34.41 N	134.48 E	100
		Amagaski/Suita	34.42 N	135.28 E	50
		Hirohata	34.48 N	134.38 E	50
		Himeji/Befu	34.50 N	134.42 E	800
		Uji	34.54 N	135.48 E	100
		Okazaki Aichi	34.58 N	137.10 E	150
		Yokkaichi	35.00 N	136.40 E	850
		Mishima	35.06 N	138.56 E	50
		Nagoya	35.08 N	136.56 E	300
		Kama Kuki	35.18 N	139.34 E	50
		Ofuna	35.20 N	139.32 E	100
		Ichihara	35.26 N	134.36 E	100

Table A-4. (Continued).

Country	Island	City	Map Location		Production (metric tons x 1000)
			Latitude	Longitude	
		Yokahama and Kawasaki	35.28 N	139.28 E	3300
		Goi/Anegasaki/ Sodegaura	35.30 N	140.06 E	1400
		Chiba	35.36 N	140.08 E	1400
		Tokyo	35.40 N	139.46 E	100
		Yoshiba	35.40 N	140.28 E	100
		Kashima	35.58 N	140.38 E	700
		Mizushima	36.28 N	136.32 E	850
		Takaoka	36.44 N	137.00 E	300
		Uozu	36.48 N	137.24 E	100
		Naoetsu/Omi	37.10 N	138.14 E	150
		Shibukawa	37.38 N	140.28 E	50
		Niigata	37.56 N	139.04 E	300
		Sakata	38.55 N	139.51 E	50
		Akita	39.42 N	140.08 E	100
		Kurosaki	40.00 N	141.56 E	150
		Osaka	40.36 N	141.14 E	250
	Kyushu	Minamata	32.12 N	130.24 E	100
		Nobeoka	32.34 N	131.40 E	50
		Omuta	33.02 N	130.28 E	150
		K.Kumoto/Oita/ Tsuraki	33.14 N	131.36 E	100
	Shikoku	Matsuyama	33.50 N	132.46 E	100
		Ohe/Niihama	33.58 N	133.16 E	400
		Tokushima	34.04 N	134.34 E	100
	Uncertain	Takeo	33.12 N	130.00 E	100
		Tsurusaki	33.14 N	131.42 E	300
		Tobata/Wakamatsu	33.54 N	130.50 E	400
					Total: 16,650
Malaysia (Singapore)		Singapore	1.20 N	103.50 E	50
		Chita-Hanto	Uncertain	Uncertain	50
					Total: 100
Pakistan, East (Bangladesh)		Chandraghona	22.27 N	92.09 E	50
					Total: 50
Pakistan, West		Karachi	24.51 N	67.02 E	50
		Lyallpur	31.25 N	73.09 E	50
					Total: 100
Phillipine Islands		Bataan	14.23 N	120.36 E	50
					Total: 50

Table A-4. (Continued).

Country	Island	City	Map Location Latitude	Map Location Longitude	Production (metric tons x 1000)
South Korea		Ulsan	35.32 N	129.21 E	300
		Taegu	35.52 N	128.36 E	50
		Anyang-ni	37.23 N	126.55 E	50
		Inch on	37.30 N	126.38 E	100
		Soul	37.32 N	127.00 E	100
					Total: 600
Taiwan		Kao-Hsiung	22.36 N	120.17 E	350
		Miao-Li	24.33 N	120.48 E	50
		Chi-Lung	25.10 N	121.43 E	50
		Tou-Fen	Uncertain	Uncertain	100
					Total: 550
Thailand		Bangkok/Krung Thep	13.44 N	100.30 E	50
		Sathani Don Chai	18.00 N	100.06 E	+
					Total: 50

+ Data unavailable.

Table A-5. Organic Chemical Production Centers: Latin America[1]

Country	City	Map Location		Production (metric tons x 1000)
		Latitude	Longitude	
Argentina	San Joaquin	31.57 S	58.42 W	50
	Rio Tercero	32.15 S	64.08 W	150
	San Lorenzo	32.45 S	60.45 W	550
	San Nicolas	33.25 S	60.15 W	300
	Mercedes	33.41 S	65.28 W	50
	Zarate	34.07 S	59.00 W	400
	Campana	34.10 S	59.55 W	100
	Pilar	34.28 S	54.48 W	100
	Rawson	34.34 S	60.05 W	+
	Ensenada/Jose Hernandez	34.50 S	57.54 W	50
	La Plata	34.52 S	57.55 W	50
	Bahia Blanca	38.45 S	62.15 W	400
	Moron	41.08 S	63.22 W	50
				Total: 2250
Brazil	Caxias	4.53 S	43.20 W	100
	Recife	8.06 S	34.53 W	100
	Maceio	9.34 S	35.47 W	100
	Camacari	12.44 S	38.16 W	300
	Candeias	20.44 S	45.18 W	50
	Rio de Janeiro	22.53 S	43.17 W	100
	Jundiai	23.10 S	46.54 W	50
	Sao Paulo/ Santo Andre	23.33 S	46.39 W	200
	Cubatao	23.53 S	46.26 W	600
	Piassaguera/Santos	23.56 S	46.22 W	100
	Capuava	24.00 S	48.00 W	700
				Total: 2400
Chile	San Vicente	34.27 S	71.05 W	100
	Concepcion	36.50 S	73.03 W	100
				Total: 200
Colombia	Cali	3.24 N	76.30 W	50
	Bogota	4.38 N	74.05 W	50
	Zula	4.57 N	75.28 W	300
	Medellin	6.15 N	75.36 W	100
	Barrancabermeja	7.06 N	73.54 W	200
	Cartagena/Mamonal	10.24 N	75.33 W	150
				Total: 850
Dominican Republic	San Juan	18.49 N	71.12 W	100
				Total: 100

Table A-5. (Continued)

Country	City	Map Location Latitude	 Longitude	Production (metric tons x 1000)
Mexico	Minatitlan	17.59 N	94.32 W	350
	Cortza Coalcos	18.10 N	94.25 W	50
	San Christobal	18.23 N	95.44 W	50
	Cuernavaca	18.57 N	99.15 W	50
	Puebla	19.03 N	98.10 W	100
	Tlaxcala	19.20 N	98.12 W	50
	Toluca	19.20 N	99.40 W	50
	Mexico City	19.25 N	99.10 W	250
	Poza Rica	20.34 N	97.26 W	400
	Salamanca	20.34 N	101.12 W	200
	Irapuato	20.40 N	101.40 W	50
	Madero	22.19 N	97.50 W	150
	Monterrey	25.40 N	100.20 W	50
				Total: 1800
Peru	Paramonga	10.42 S	77.50 W	50
	Lima	12.06 S	77.03 W	50
				Total: 100
Puerto Rico	Guayama	18.00 N	66.07 W	350
	Ponce	18.01 N	66.36 W	50
	Penuelas	18.03 N	66.43 W	750
	Arecibo	18.29 N	66.44 W	100
	Guayannila	Uncertain	Uncertain	600
				Total: 1850
Uruguay	Montevideo	34.55 S	56.10 W	50
				Total: 50
Venezuela	Valencia	10.14 N	67.59 W	100
	Caracas	10.35 N	66.56 W	50
				Total: 150

+ Data unavailable.

Table A-6. Major oil refineries worldwide, excluding USA and Canada (capacities as of January, 1982).[a]

Region	Country	City	Crude capacity (b/cd)[b]
Latin America	Argentina	Ensenada	216,000
	Brazil	Paulinia, Sao Paulo	325,700
	Brazil	Duque de Caxias/ Rio de Janeiro	256,900
	Mexico	Cadereyta	235,000
	Mexico	Cangrejera	200,000
	Mexico	Salamanila	200,000
	Venezuela	Amuay Bay	639,000
	Venezuela	Candon	325,210
Middle East	Bahrain	Awali	250,000
	Iran	Tehran	210,000
	Iran	Esfahan	200,000
	Kuwait	Mena Al-Ahmadi	250,000
	Saudi Arabia	Ras Tanura	415,000
Far East and Japan	Japan	Chiba	661,000[c]
	Japan	Yokkaichi	491,000[d]
	Japan	Mizushima	478,200[d]
	Japan	Negishi	330,000
	South Korea	Yosu	355,000
	South Korea	Ulsan	265,000
	Taiwan	Kaohsiung	425,000
Europe	Austria	Schwechat	244,000
	Belgium	Antwerpen	321,400
	Finland	Porvoo	243,000
	France	Berre L'Etang	210,000
	France	La Mede	200,000
	France	L' Orcher	454,000
	France	Petit Couronne	382,000
	Italy	Trecate, Novara	215,000
	Italy	Sicily	505,000
	Italy	Siracusa	481,200[d]
	Italy	Sarroch	360,000
	Italy	Ravenna	240,000
	Italy	Burgondi	230,000
	Italy	Melilli	220,000
	Netherlands	Pernis	790,000[d]
	Portugal	Sines	225,000
	Spain	Somorrostro, Vizcaya	240,000
	Spain	Cartagena, Marcia	220,000
	Sweden	Brofjorden-Lysekil	220,000
	United Kingdom	Fawley	294,000
	United Kingdom	Stanlow	250,000
	United Kingdom	Isle of Grain	211,000
	West Germany	Geilsenkirchen	267,000

Table A-6. (Continued)

Region	Country	City	Crude capacity (b/cd)[b]
Caribbean Islands and West Indies	Bahamas	Freeport	500,000
	Netherlands Antilles	Aruba	420,000
	Netherlands Antilles	Curacao	362,000
	Trinidad	Pointe-a-Pierre	356,000

---

[a] From Ref. 2.

[b] Crude capacity of 200,000 b/cd (barrels per calendar day) and over.

[c] Represents a total of three refineries.

[d] Represents a total of two refineries.

REFERENCES

1. Oxford University Press, Oxford Economic Atlas of the World (Prepared by Cartographic Dept. of Clarendon Press, London, UK, 1972), 4th ed., pp. 58,60.

2. International Petroleum Encyclopedia (Pennwell, Tulsa, OK, 1982), pp. 362, 366–380, 381, 384.

APPENDIX B

MAJOR FOOD PRODUCING AREAS WORLDWIDE: GENERAL AGRICULTURE AND RICE PRODUCTION

Maps indicating the major food-producing areas in the geographic regions considered possible theaters of operation for military personnel are presented in this appendix. Major food-producing areas are the most likely locations for elevated levels of pesticides to occur in water supplies. Both general agricultural areas and rice-producing regions are shown on the figures. Lindane is the pesticide frequently used for rice production. We note, however, that lindane use may vary greatly according to the cultural practices used to grow rice.

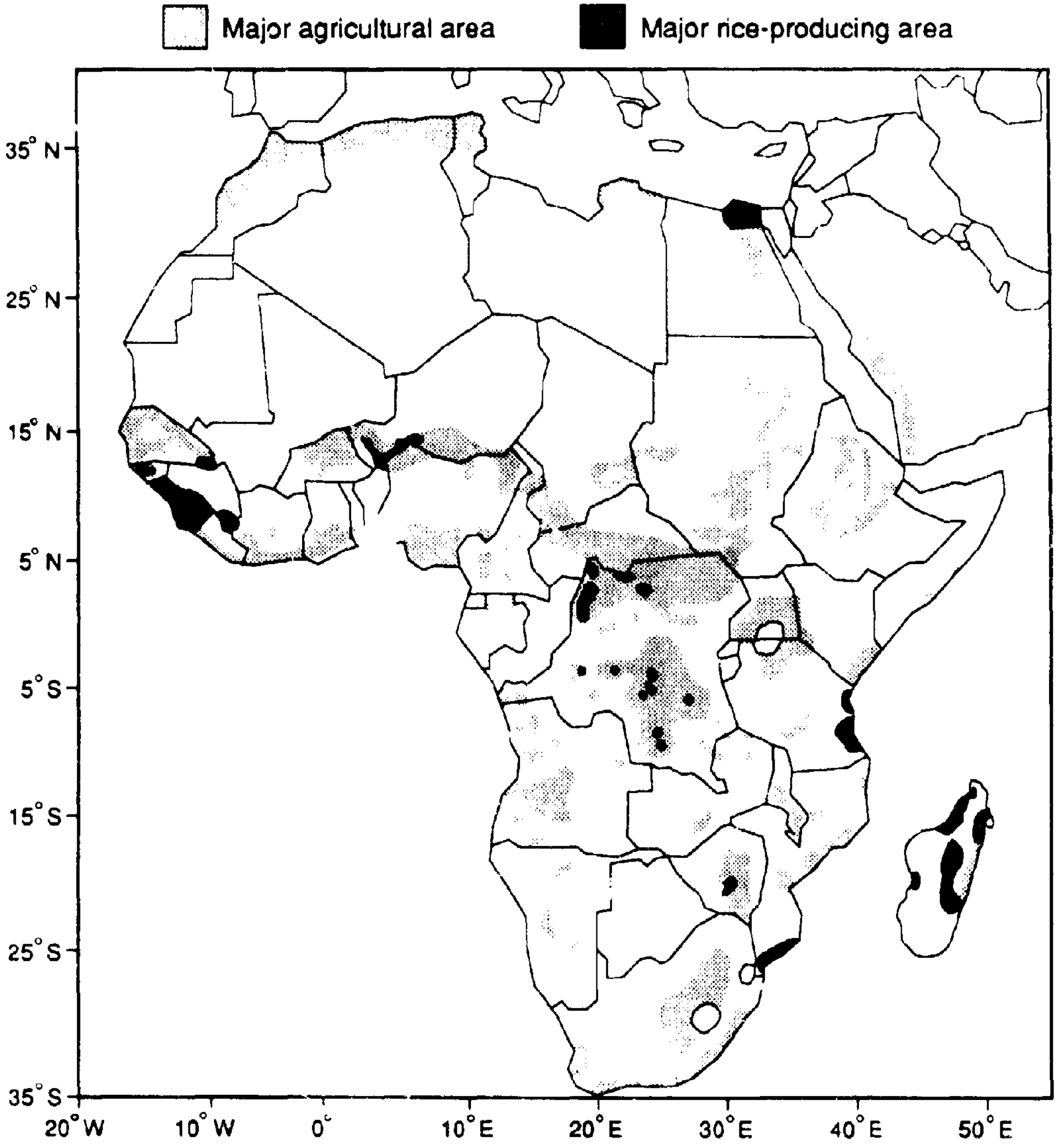

Figure B-1. Major agricultural and rice-producing areas in Africa. Based on information in Refs. 1 and 2.

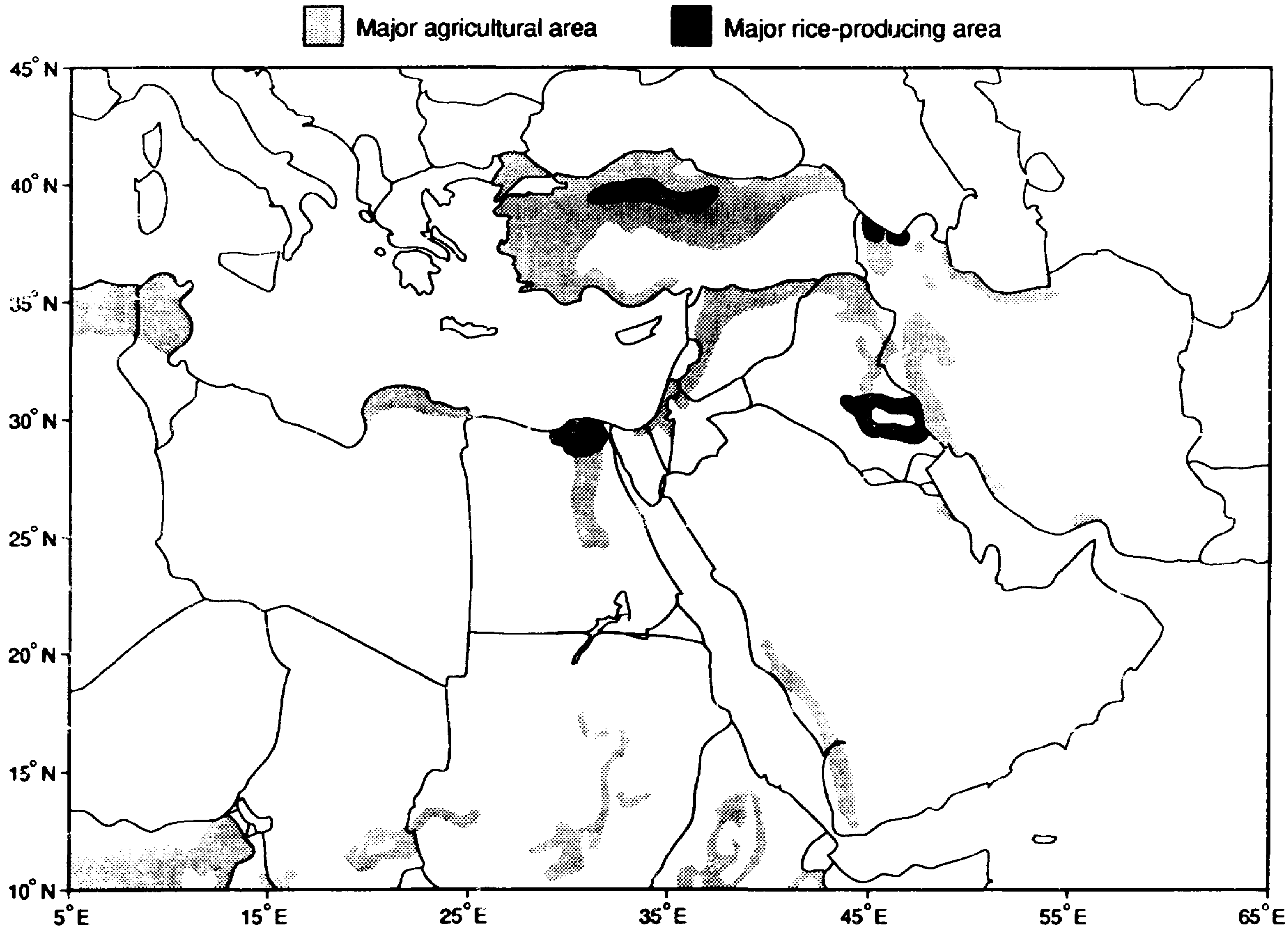

Figure B-2. Major agricultural and rice-producing areas in the Middle East. Based on information in Refs. 1 and 2.

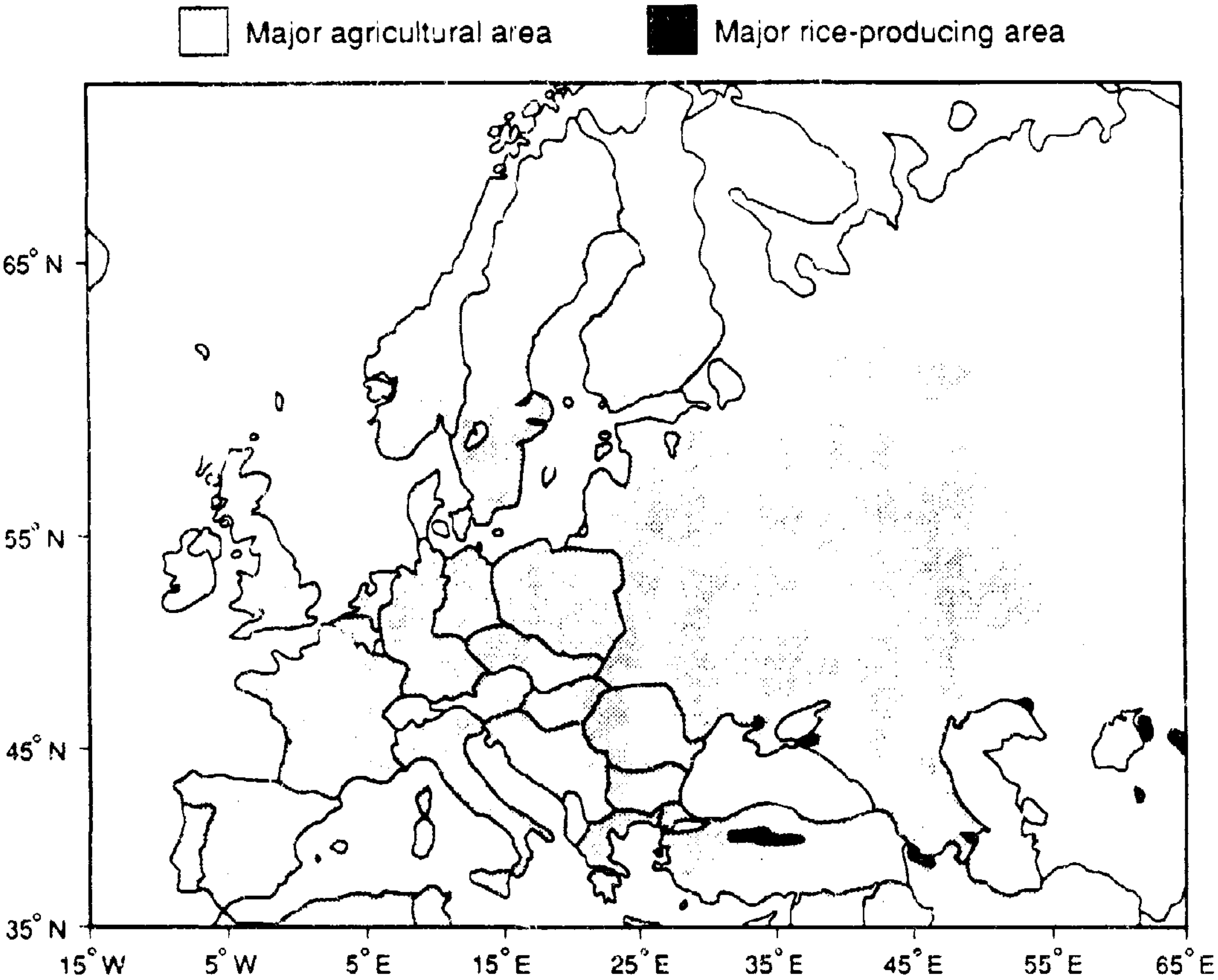

Figure B-3. Major agricultural and rice-producing areas in Europe and the U.S.S.R. Based on information in Refs. 1 and 2.

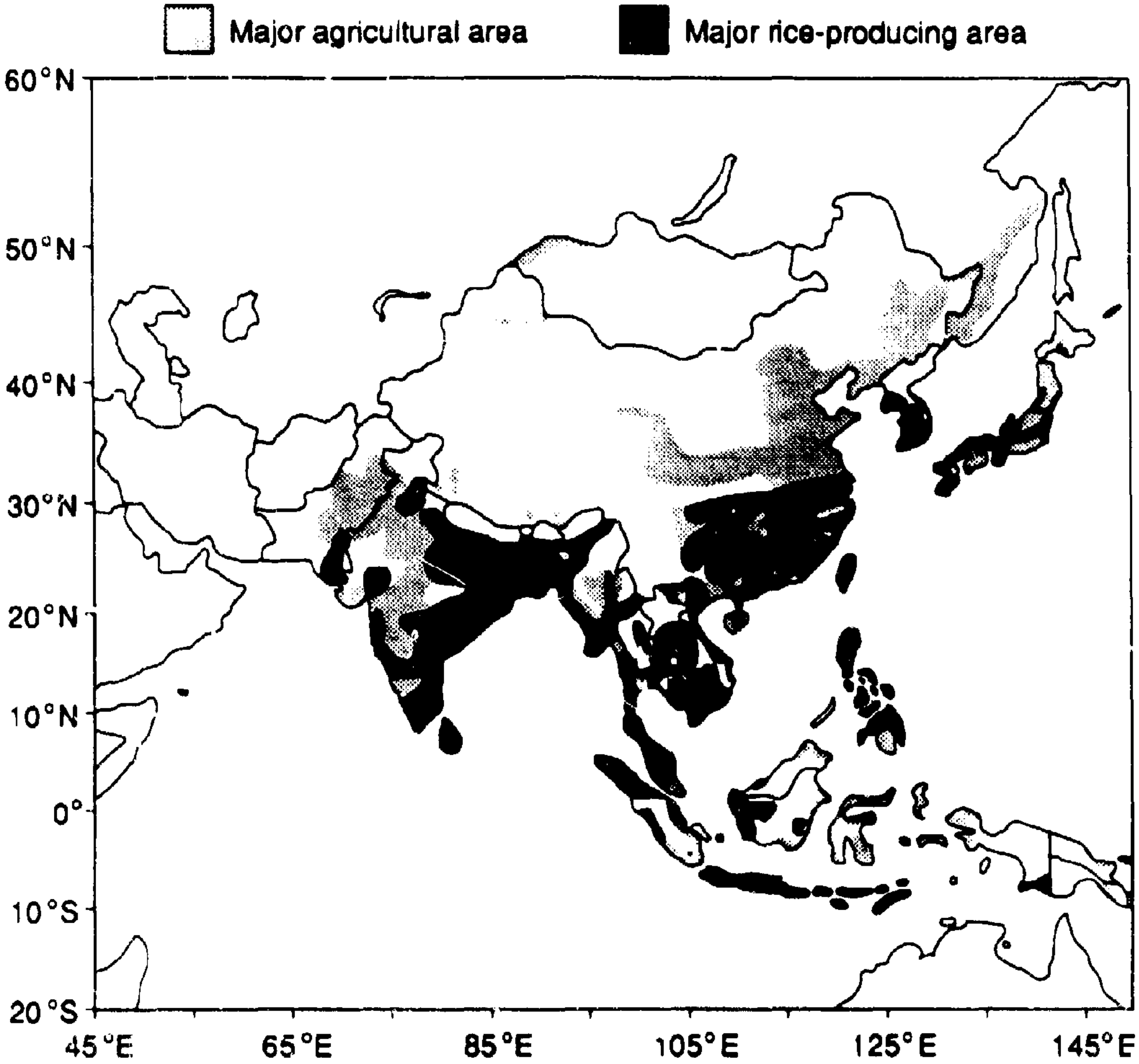

Figure B-4. Major agricultural and rice-producing areas in Asia. Based on information in Refs. 1 and 2.

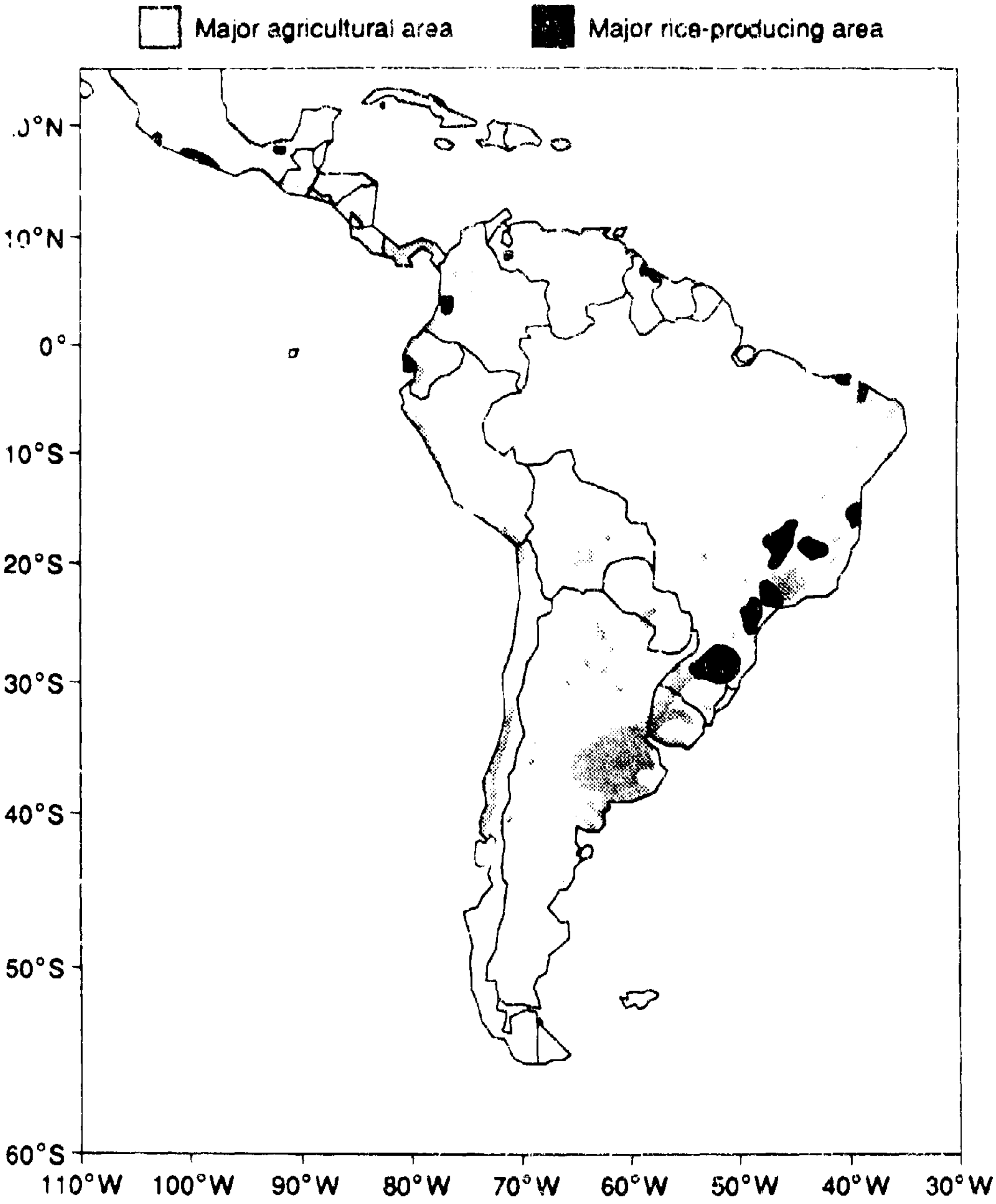

Figure B-5. Major agricultural and rice-producing areas in Latin America. Based on information in Refs. 1 and 2.

REFERENCES

1. The Times Atlas of the World (Times Books, New York City, NY, 1983), comprehensive ed., pp. xxii-xxiii.

2. Oxford University Press, Oxford Economic Atlas of the World (Prepared by Cartographic Department of Clarendon Press, London, UK, 1972), 4th ed., p. 11.

APPENDIX C

GRAPHS SHOWING THE RISK OF ILLNESS FOR MILITARY POPULATIONS CONSUMING FIELD WATER CONTAINING WATERBORNE INFECTIOUS ORGANISMS OF MILITARY CONCERN

Waterborne infectious organisms of military concern in the field water of developed and developing countries were evaluated in Volume 5 in terms of their risk of causing illness in exposed populations of up to 20 military personnel.[1] These evaluations were performed with the risk-assessment model described in Volume 5 for conditions considered representative for field-water consumption in high-risk and low-risk situations. Risk curves for assessing the probability that a fraction of the exposed military population could become ill were constructed from this analysis. We emphasize that the risk curves contained in this appendix were based on generalized assumptions and data, which are described in detail in Volume 5. Improved risk curves directly applicable to identified sources of field water can be derived by using the risk-assessment model in Volume 5 with measured values of the concentrations of specific infectious organisms.

The risk curves appearing in this appendix (Figs. C-1 through C-11) were adapted from Figs. 11, 13 through 18, and 20 through 23 of Volume 5. These adapted versions of the figures from Volume 5 facilitate interpretation. For example, in Fig. C-1 (adapted from Fig. 11 in Volume 5) there is a 50% probability (i.e., level of risk) that more than 8% of the exposed military population could become ill from exposure to <u>Shigella</u> spp. in the treated (i.e., 2- to 5-log removal, which corresponds to 99 to 99.999% treatment efficiency) field water of developed countries.

This is how the risk curves were derived from those in Volume 5. For each of the previously mentioned figures in Volume 5, the fraction of ill troops was converted to a percentage ill for plotting on the X-axis (instead of the Y-axis), and the corresponding cumulative probability was converted to a level of risk in units of percent for plotting on the Y-axis (instead of the X-axis). The percentage ill was calculated as the fraction ill multiplied by 100. The level of risk in units of percent was equal to one minus the cumulative probability, which was then multiplied by 100.

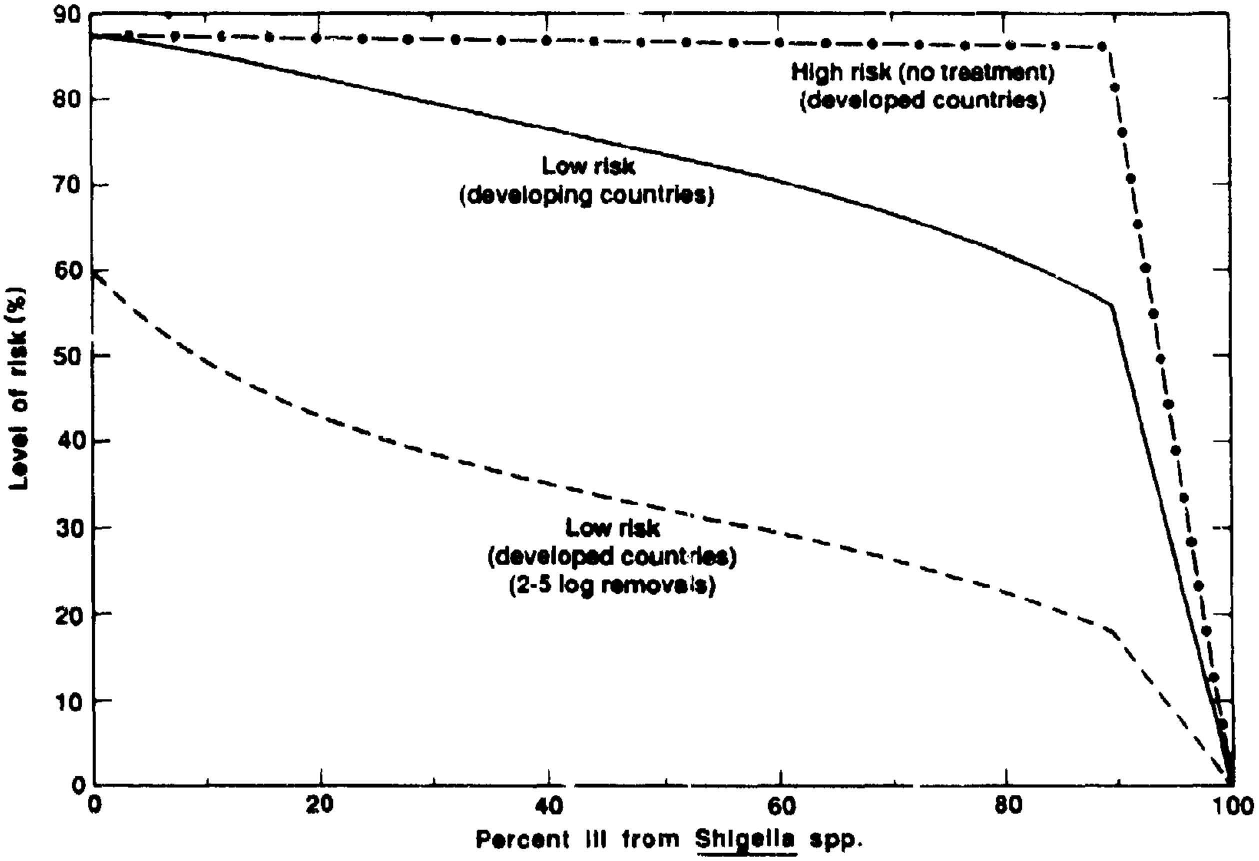

Figure C-1 (adapted from Fig. 11 in Vol. 5). Cumulative-risk curves showing effect of treatment efficiency, organism-concentration parameters, and volume of water consumed on the risk of becoming ill as a consequence of consumption of Shigella spp. in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms; (2) an exponential dose-response relationship; (3) a geometric mean (Gm) of 100 org/L and a geometric standard deviation (GSD) of 50 was used for organism concentrations in developed countries, and a GM = 1000 and a GSD = 500 was used for organism concentrations in developing countries; and (4) treatment efficiency equivalent to no treatment was used for constructing the high-risk curve and a treatment efficiency range of 2- to 5-log removals was used for constructing both low-risk curves.

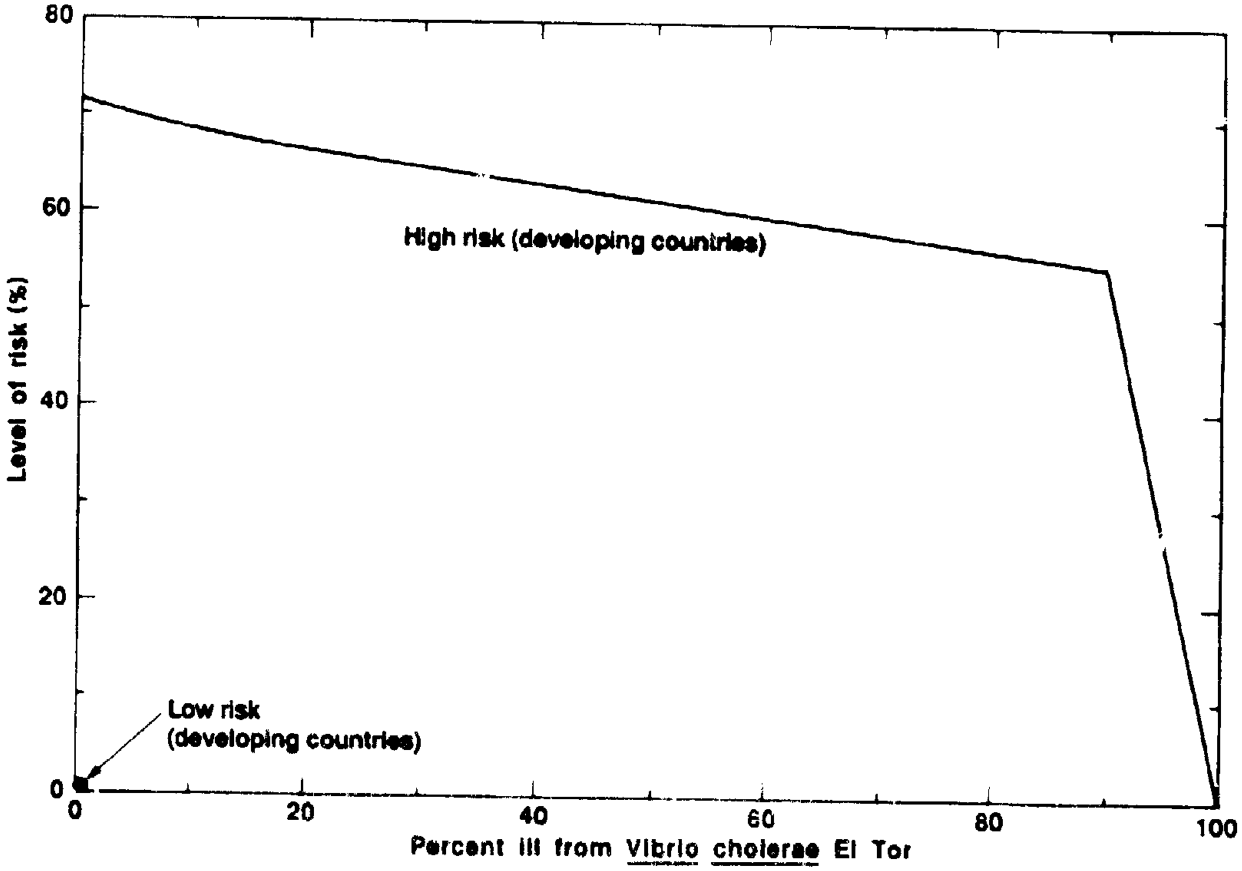

Figure C-2 (adapted from Fig. 13 in Vol. 5). Cumulative-risk curves showing effect of treatment efficiency on the risk of becoming ill as a consequence of consumption of Vibrio cholerae El Tor in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms; (2) an logistic dose-response relationship; (3) a dose distribution with GM = 32 organisms/L and a GSD = 15; and (4) treatment efficiency equivalent to either no treatment in high-risk curve, or 2- to 5-log removals at the low-risk point, which implies that no troops will be affected.

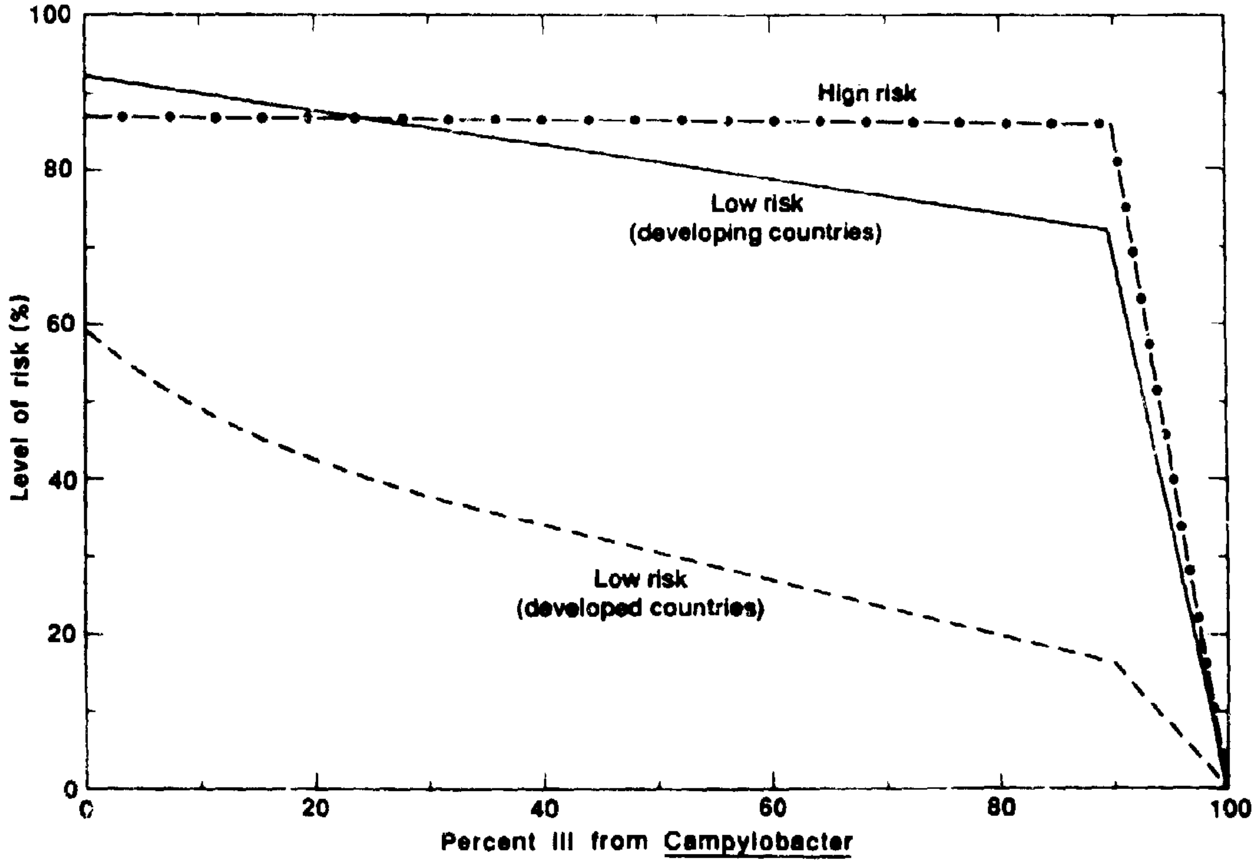

Figure C-3 (adapted from Fig. 14 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiency and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Campylobacter in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms; (2) a lognormal dose-response relationship. However, the GM of the organism concentrations for developed countries was 100 organisms/L with a GSD = 50, for developing countries, the GM = 300 organisms/L with a GSD = 150. A treatment efficiency equivalent to no treatment was used for the high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low risk curves.

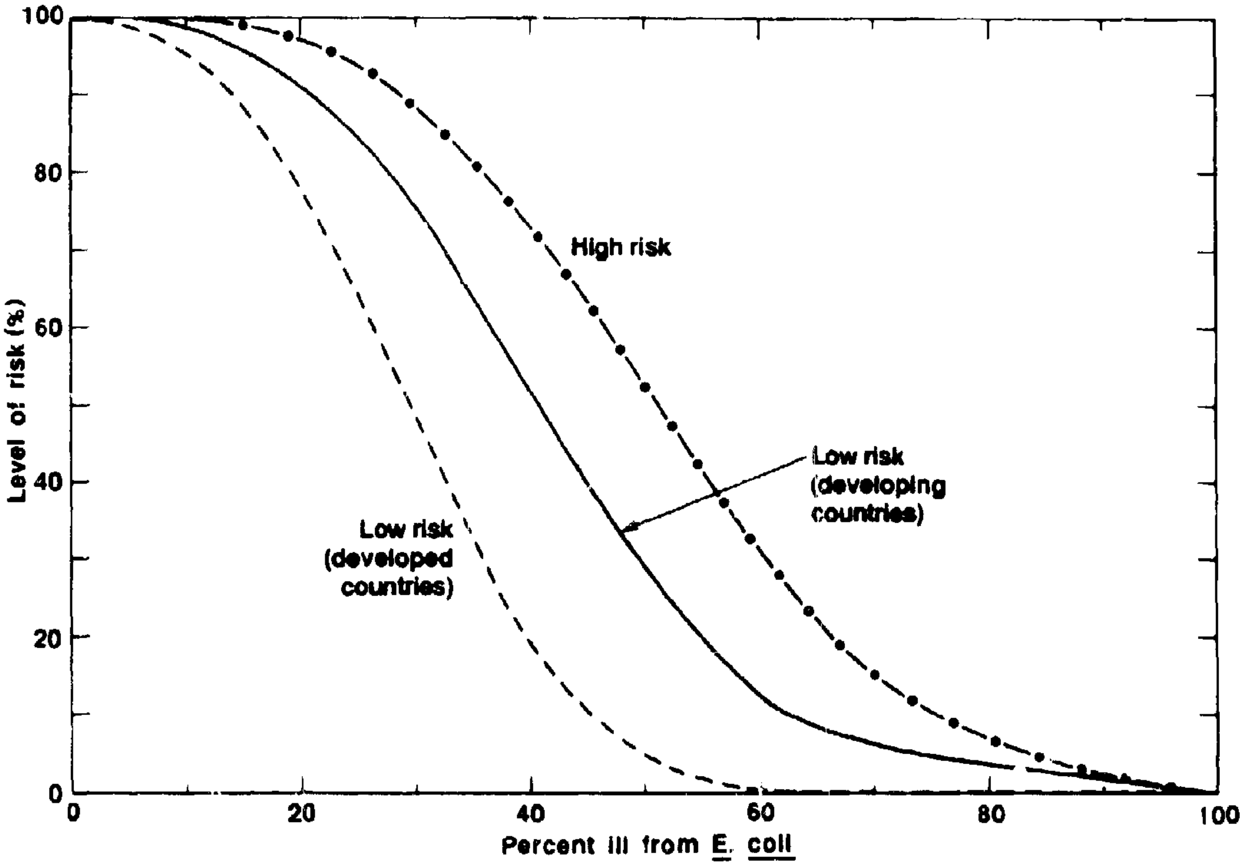

Figure C-4 (adapted from Fig. 15 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiency and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Escherichia coli in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms and (2) a lognormal dose-response relationship. However, a concentrations distribution with a GM = 2,000 organisms/L and a GSD = 7 was used for developed countries, and the concentration distribution with a the GM = 20,000 organisms/L and a GSD = 35 was used for developing countries. A treatment efficiency equivalent to no treatment was used for the high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low-risk curves.

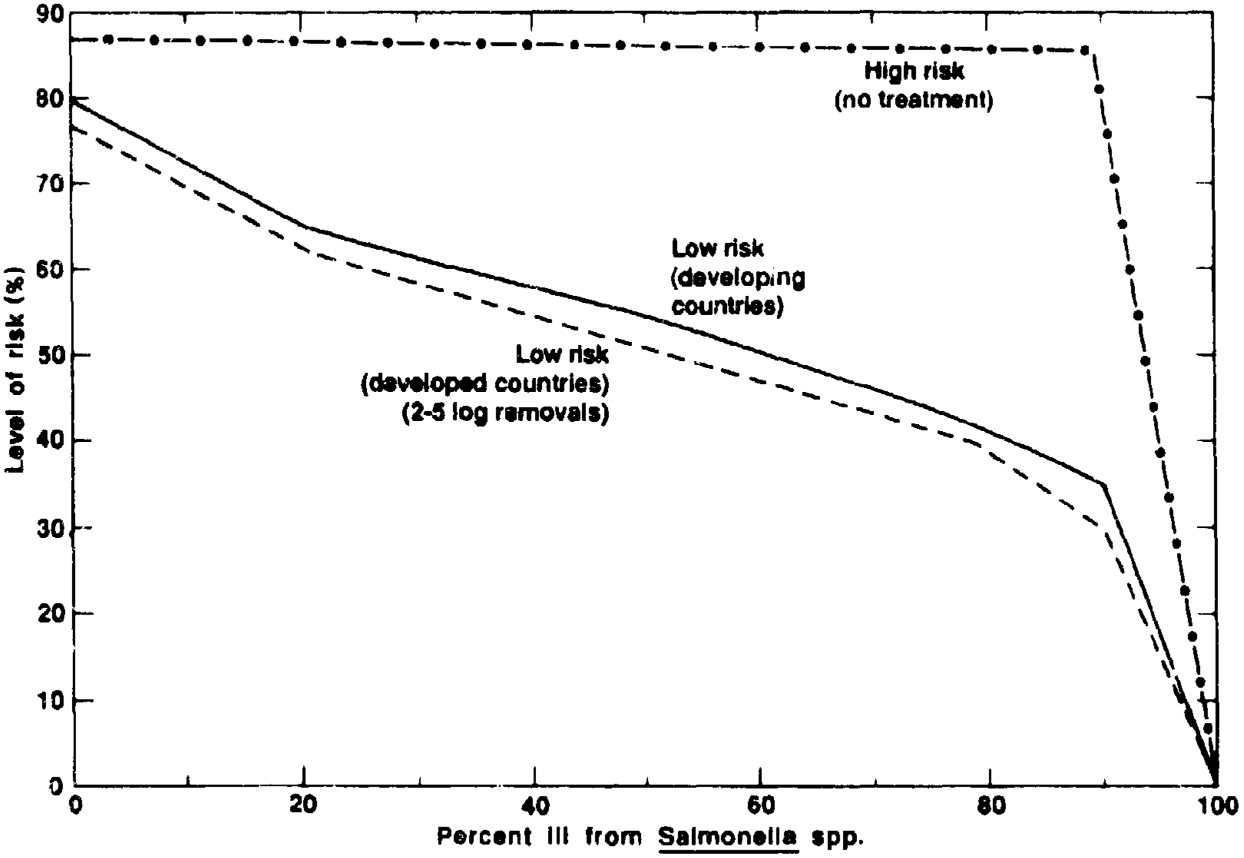

Figure C-5 (adapted from Fig. 16 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Salmonella spp. in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms, and (2) an exponential dose-response relationship. However, a concentrations distribution with a GM = 172 organisms/L and a GSD = 99 was used for developed countries, and the concentration distribution with a the GM = 221 organisms/L and a GSD = 100 was used for developing countries. A treatment efficiency equivalent to no treatment was used for the high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low-risk curves.

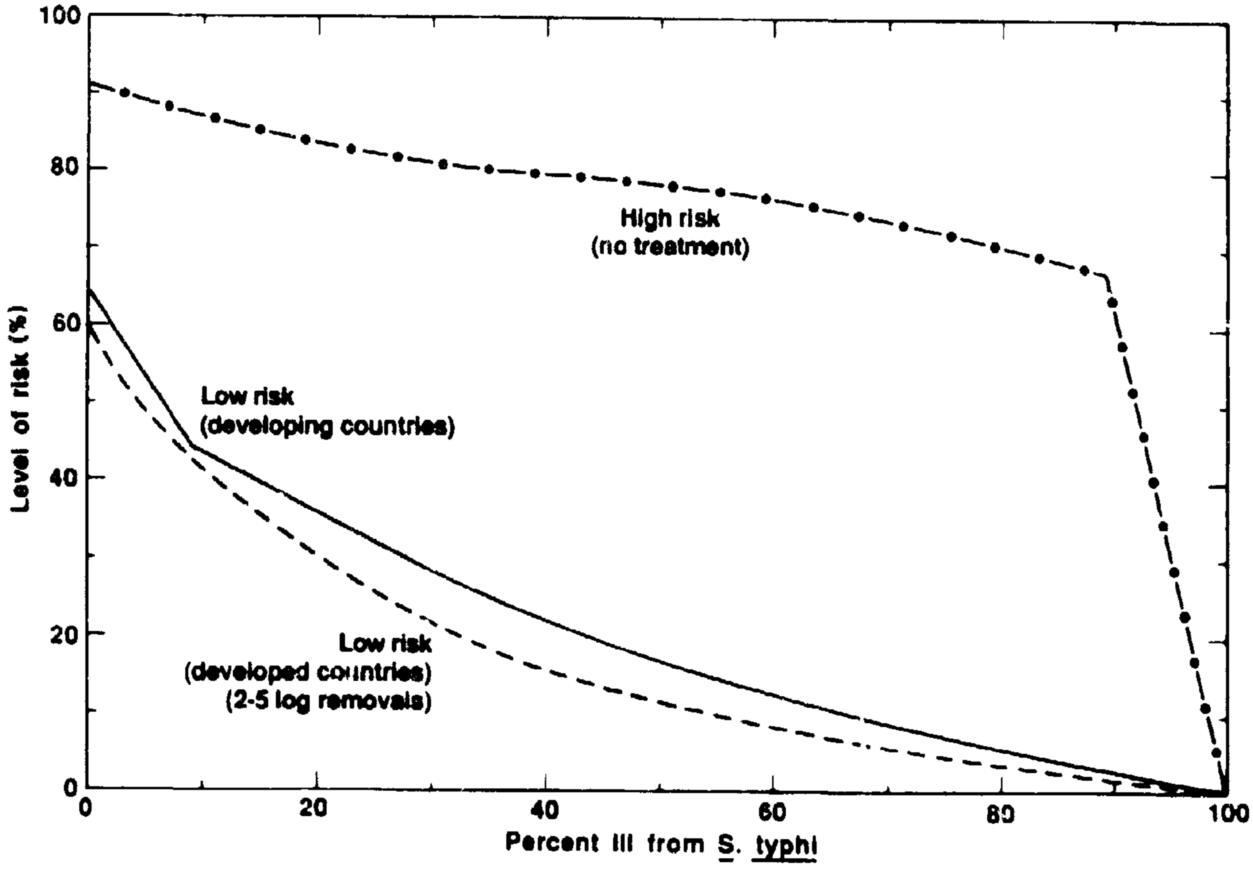

Figure C-6 (adapted from Fig. 16 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Salmonella typhi in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms, and (2) a logistic dose-response relationship. However, a concentrations distribution with a GM = 172 organisms/L and a GSD = 99 was used for developed countries, and a concentration distribution with a the GM = 221 organisms/L and a GSD = 100 was used for developing countries. A treatment efficiency equivalent to no treatment was used for the high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low-risk curves.

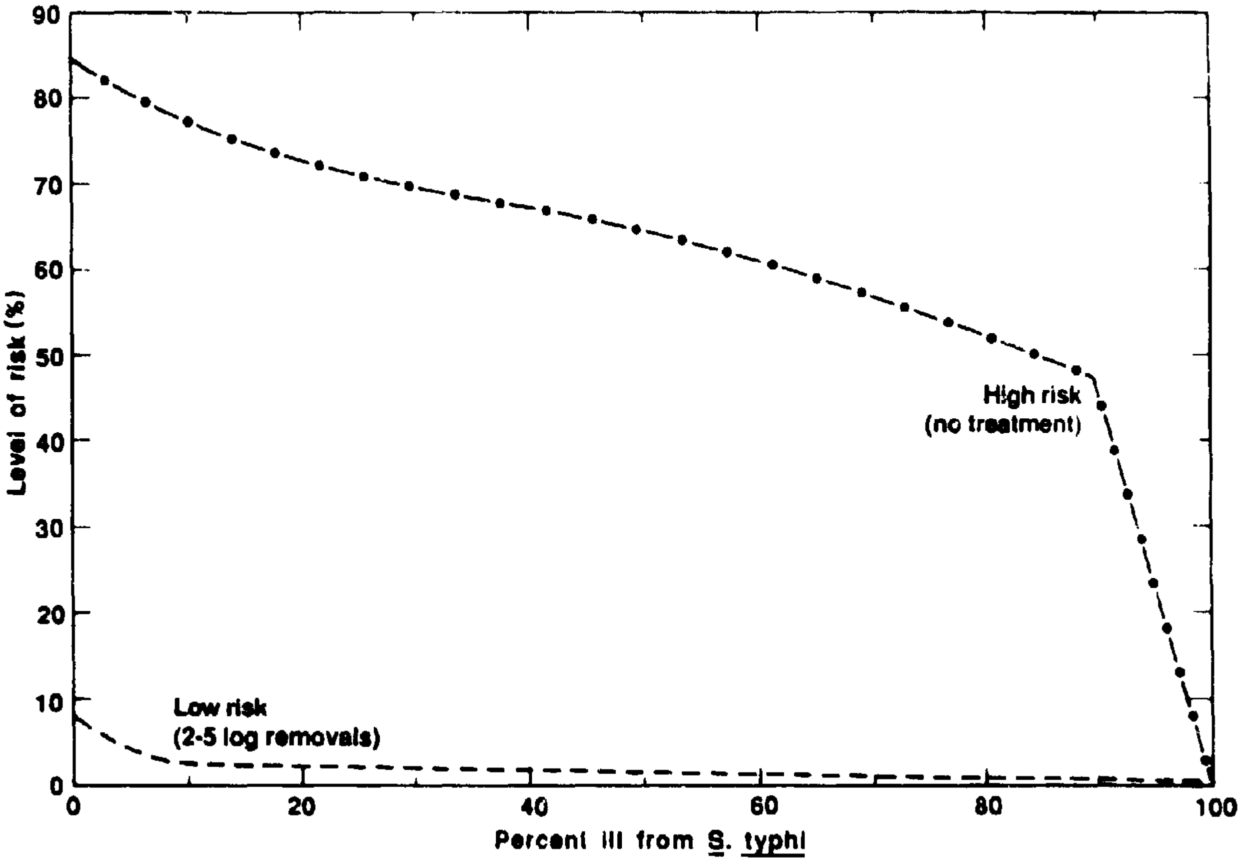

Figure C-7 (adapted from Fig. 18 in Vol. 5, and considered more reasonable than results in Fig. A-6, based on existing incidence of typhoid fever). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Salmonella typhi in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms, (2) a logistic dose-response relationship; (3) a concentration distribution with a GM = 17 organisms/L and a GSD = 9; and (4) treatment efficiency equivalent to no treatment for the high-risk curve and 2- to 5-log removals for low-risk curves.

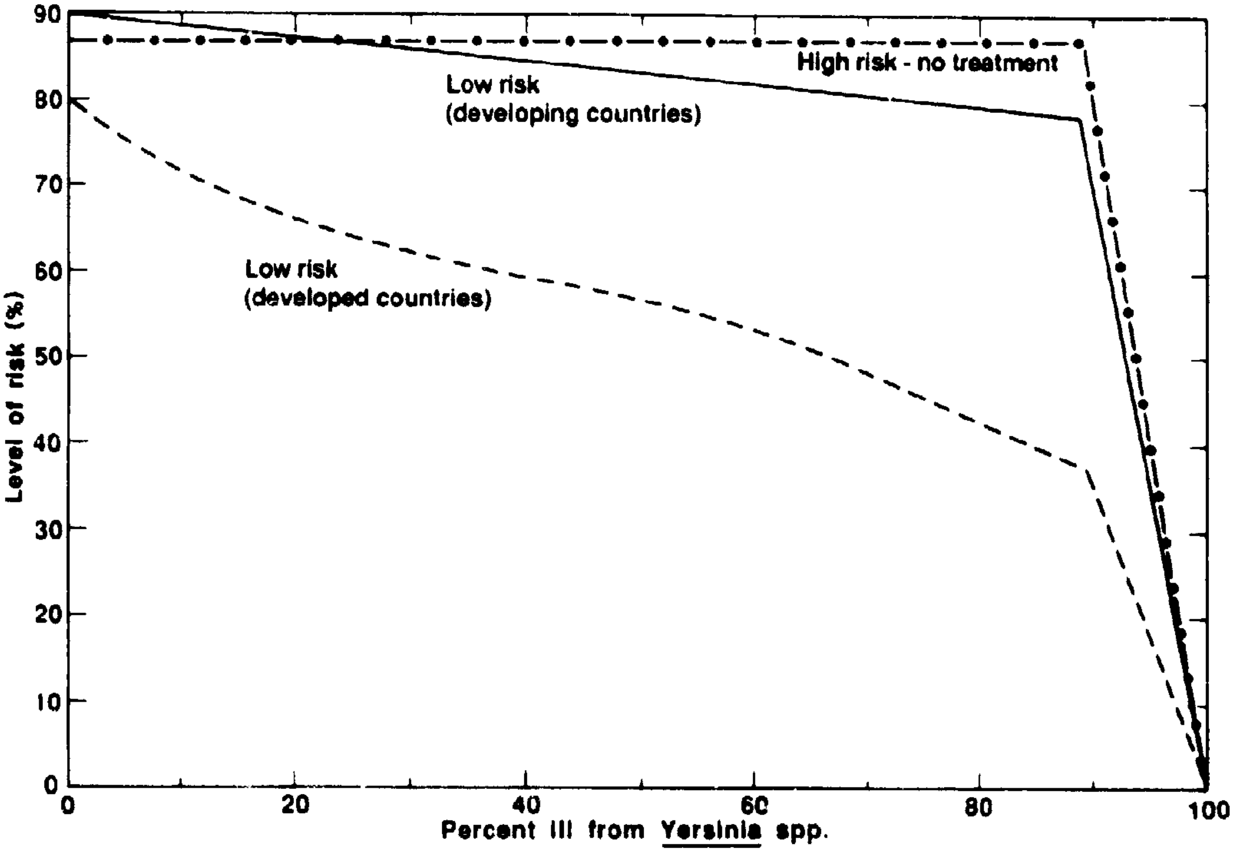

Figure C-8 (adapted from Fig. 20 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of *Yersinia* spp. in drinking water. Each curve was determined using (1) n = 20 troops and ill = disease symptoms, and (2) a lognormal dose-response relationship. However, a concentrations distribution with a GM = 100 organisms/L and a GSD = 50 was used for developed countries, and a concentration distribution with a the GM = 1000 organisms/L and a GSD = 500 was used for developing countries. A treatment efficiency equivalent to no treatment was used for the high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low-risk curves.

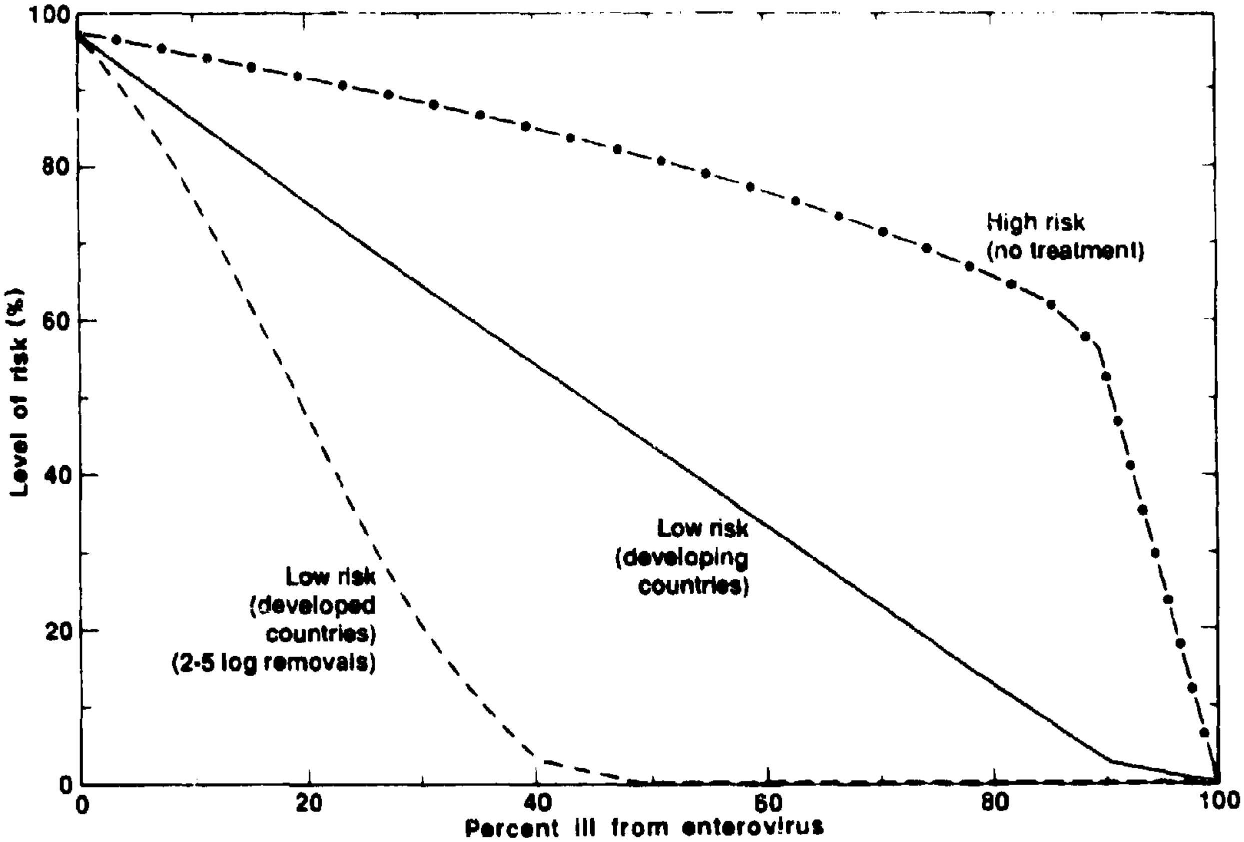

Figure C-9 (adapted from Fig. 21 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of enteroviruses in drinking water. The curve were determined using (1) n = 20 troops and ill = disease symptoms; (2) a lognormal dose-response relationship; (3) a dose distribution with a GM = 113 organisms/L and a GSD = 3; (4) treatment efficiency equivalent to no treatment in the high-risk curve and 2-to 5-log removals in both low-risk curves.

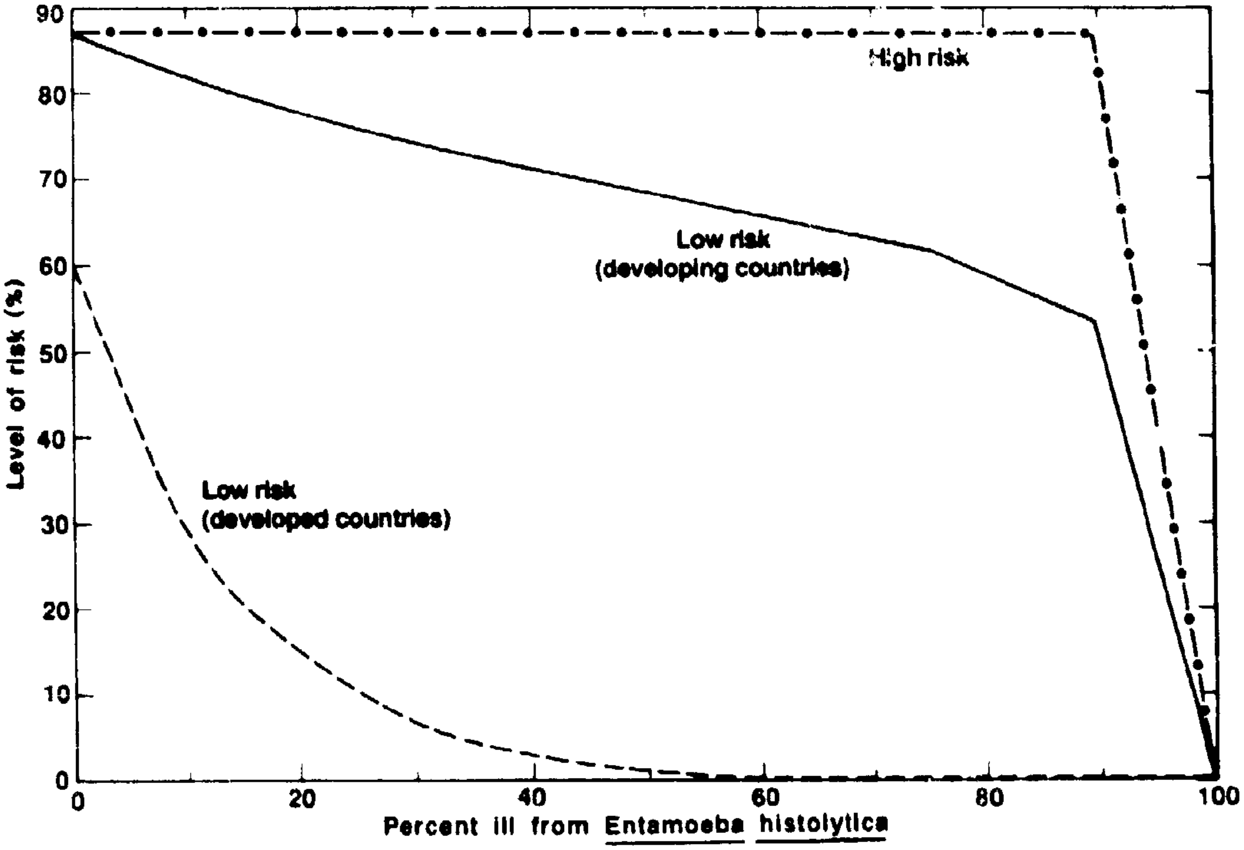

Figure C-10 (adapted from Fig. 22 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of Entamoeba histolytica in drinking water. The curve were determined using (1) n = 20 troops and ill = disease symptoms, and (2) an exponential dose-response relationship. However, a concentration distribution with a GM = 13 organisms/L and a GSD = 7 was used for developed countries, and a concentration distribution with a GM = 146 and a GSD = 73 was used for the low-risk curve in developing countries. A treatment efficiency equivalent to no treatment was used for high-risk curve, and a treatment efficiency equivalent to 2- to 5-log removals was used for both low-risk curves.

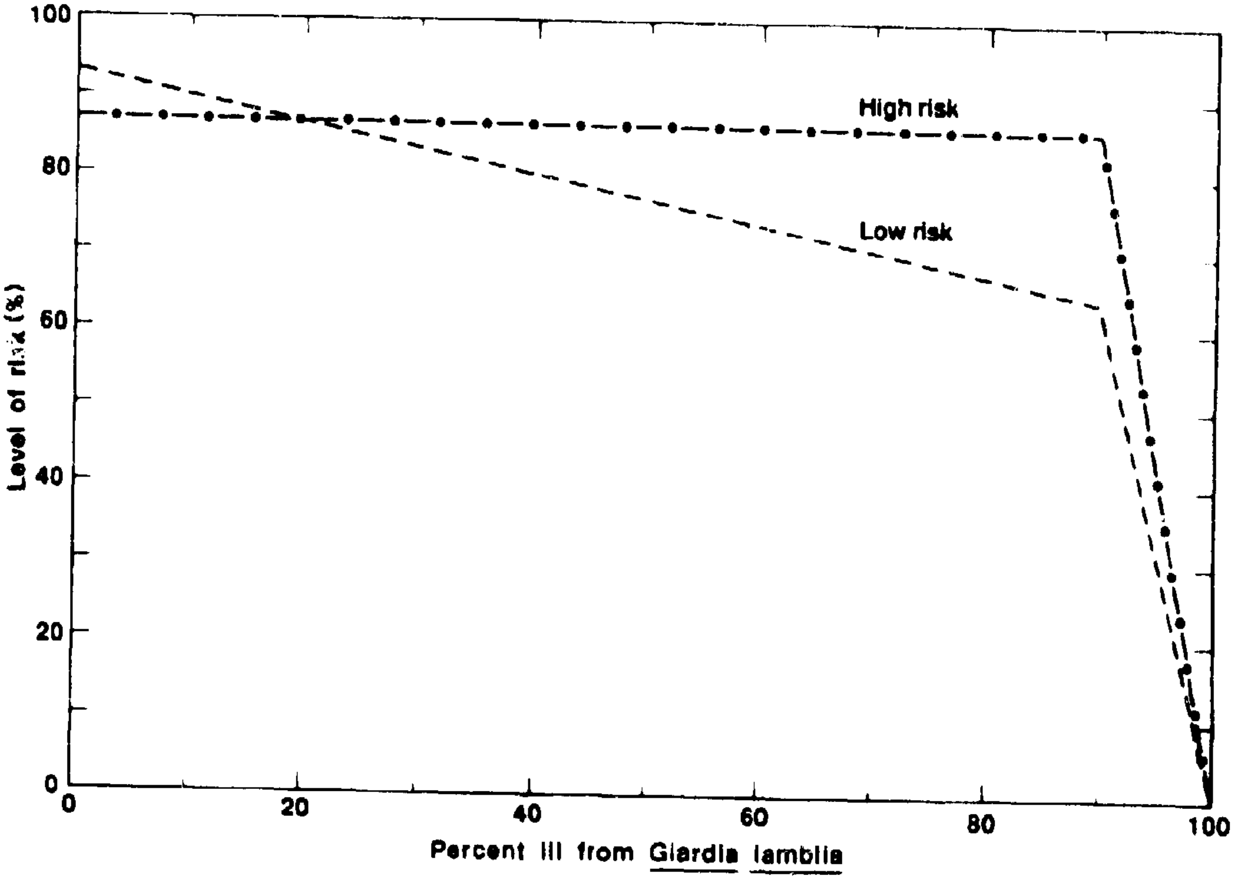

Figure C-11 (adapted from Fig. 21 in Vol. 5). Cumulative-risk curves showing effect of change in treatment efficiencies and organism-concentration parameters on the risk of becoming ill as a consequence of consumption of *Giardia lamblia* in drinking water. The curve were determined using (1) n = 20 troops and ill = disease symptoms; (2) an exponential dose-response relationship; (3) a concentration distribution with a GM = 100 organisms/L and a GSD = 50; (4) treatment efficiency equivalent to no treatment in the high-risk curve and 2- to 5-log removals in both low-risk curves.

REFERENCES

1. Cooper, R.C., A.W. Olivieri, R.E. Danielson, P.G. Badger, R.C. Spear, and S. Selvin, Evaluation of Military Field-Water Quality. Volume 5. Infectious Organisms of Military Concern Associated with Consumption: Assessment of Health Risks and Recommendations for Establishing Related Standards, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-21008, Vol. 5 (1986).

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