THE NATIONAL ACADEMIES
REPORT IN BRIEF

Public Summary and Context

Contaminated Water Supplies at Camp Lejeune

Assessing Potential Health Effects

In the early 1980s, two water-supply systems on the Marine Corps Base Camp Lejeune in North Carolina were found to be contaminated with the industrial solvents trichloroethylene (TCE) and perchloroethylene (PCE). The water systems were supplied by the Tarawa Terrace and Hadnot Point water-treatment plants, which served enlisted-family housing, barracks for unmarried service personnel, base administrative offices, schools, and recreational areas. The Hadnot Point water system also served the base hospital and an industrial area and supplied water to housing on the Holcomb Boulevard water system (full-time until 1972 and periodically thereafter).

This report examines what is known about the contamination of the water supplies at Camp Lejeune and whether the contamination can be linked to any adverse health outcomes in former residents and workers at the base. Because of the technical nature of the report, this public summary is being provided to explain the committee's approach and reasoning, so that people who are not scientists can understand what was done and why. It attempts to place the committee's analysis and findings into the context of a larger discussion about environmental health issues at Camp Lejeune in a way that will be helpful to people who have personal concerns about the situation at the base. It also provides perspective on why the committee was unable to answer some questions.

Courtesy U.S. Marine Corps.

The Charge to the Committee

The National Research Council (NRC) conducted this review in response to a request from the U.S. Navy, the department under which the Marine Corps operates. The Navy was mandated by the U.S. Congress (Public Law 109-364, Section 318) to request a review by the NRC to address the evidence on whether adverse health outcomes are associated with past contamination of the water supply at Camp Lejeune. The NRC developed specific instructions for the scope of the review ("the charge"). It then recruited and appointed a committee of scientists with diverse but pertinent backgrounds and perspectives to carry out the review.

The charge had several elements. One was to review the scientific evidence about the kinds of adverse health effects that could occur after exposure to TCE, PCE, and other contaminants. The second was to

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evaluate studies that were performed or that are under way on former residents of the base and to consider how useful it will be to conduct additional studies. The third element was to identify scientific considerations that could help the Navy set priorities on future activities. The responsibility of the committee was to address its charge in a dispassionate, expert, and unbiased way. Analyses and findings were neither subject to oversight nor influenced by the agenda of any of the entities with responsibilities for Camp Lejeune, former or current residents of Camp Lejeune, or any other entity.

The Concerns of Former Residents and Workers

The committee held three public meetings over the course of its study, two in Washington, DC (September 24, 2007, and September 12, 2008) and one in Camp Lejeune, NC (November 15, 2007). Former residents and other concerned individuals presented oral and written testimonies about their experiences at Camp Lejeune at those meetings. The committee also sought comments from consultants working with community groups seeking answers to questions about the water contamination. Although these encounters were not exhaustive in identifying all issues of concern or all perspectives, they gave the committee a chance to hear firsthand from people who have concerns. The committee sincerely appreciates the time and effort that went into the presentations, testimonies, and materials that were provided.

On the basis of the public input, the committee understands that some people believe that the Marine Corps has not responded appropriately to the contamination since it was first discovered. Some believe that the military leadership has not been fully forthcoming in providing data and information about the contamination and about the people who lived in affected areas. Some have concerns about whether information was disclosed or released in timely and appropriate ways. Questions have also been raised about the pace at which investigations have been conducted and whether the investigations are the most appropriate ones. Many expressed an interest in an unbiased and credible review.

Many of the people who addressed the committee have suffered from serious diseases or have family members or friends who have suffered. The committee was moved by the testimonies it heard and understands that some may have been looking for the committee to make a judgment on their particular case. However, science does not allow the committee to determine the cause of a specific case of disease. This may be hard to understand. Why would scientific experts not be able to determine whether a child's birth defect or a parent's cancer diagnosis was due to a chemical exposure? Unfortunately, for diseases that can have multiple causes and that develop over a long period of time, it is generally impossible to establish definitively the cause in individual cases. It was beyond the scope of the committee's charge to try to determine whether any particular case of a disease or disorder is associated with exposure to the water supply at Camp Lejeune.

Some parties contend that the Marine Corps has not done what it should to compensate them or to provide medical care for the harm they believe was caused by their exposure to the contaminated water supplies. In 2007, the U.S. Government Accountability Office (GAO) reported that former residents and employees of Camp Lejeune had filed more than 750 claims against the federal government related to the contamination. GAO also reports that the federal government is awaiting the results of a study on childhood cancers and birth defects before adjudicating claims. It was beyond the scope of the committee's charge to judge whether the military authorities acted appropriately from a legal or ethical perspective or fulfilled their responsibilities to those under their charge. It was also beyond the scope of the committee's charge to determine whether or how the military authorities should address claims made.

The Committee's Review and Findings

The committee divided its review into two major categories: (1) evaluating the exposures of former residents and workers to the contamination of the Tarawa Terrace and Hadnot Point water-supply systems, and (2) evaluating the potential health effects associated with the water contaminants. The assessments were then considered together to ascertain whether conclusions could be drawn about whether any adverse health outcomes could be attributed to the water contaminants.

Exposures to Former Residents and Workers

The term "exposure" refers to contact with contaminants in air, water, or food that may occur through inhalation, ingestion, or dermal absorption (through the skin). In this case, it refers to drinking water that contains contaminants or using it for other purposes. Bathing and showering are relevant, as well

as drinking, because TCE and PCE (and other solvents) can evaporate into the air (volatilize) when present in hot water used for bathing, showering, or washing dishes or clothing and can then be inhaled. All of these routes of exposure affect how the body metabolizes TCE and PCE, how the metabolites are distributed and cleared by the body, and how organ systems respond.

It is also important to understand the duration of exposure, which is the length of time a person is exposed. An understanding of individual behaviors helps to estimate the degree of exposure that occurred. Water-related behaviors include water-consumption and showering or bathing patterns, but whether such information can be accurately recalled is questionable. The contaminated water systems also supplied nonresidential areas of the base, including schools, workplaces, recreational areas, and a hospital. Water-use patterns and behaviors in these settings are expected to vary substantially from those in residential areas. In addition, residential and nonresidential exposures could overlap, thus, exposing individuals to contaminated water at multiple locations.

The Water Systems at Camp Lejeune

Figure 1 provides a simplified illustration of a water-supply system at Camp Lejeune. Water-supply wells collected groundwater and pumped it to a water-treatment plant when the wells were turned on. The wells were "cycled," meaning that only a few wells pumped water to the treatment plant at any given time. A few wells that supplied water to the Tarawa Terrace and Hadnot Point systems were contaminated by solvents from sources on and off the base. When the contaminated wells were in service, contaminated water was delivered to the water-treatment plant where water from several wells was mixed and processed before being distributed in the pipes that supplied water to the base. Thus, the contamination of the water supplies varied and was

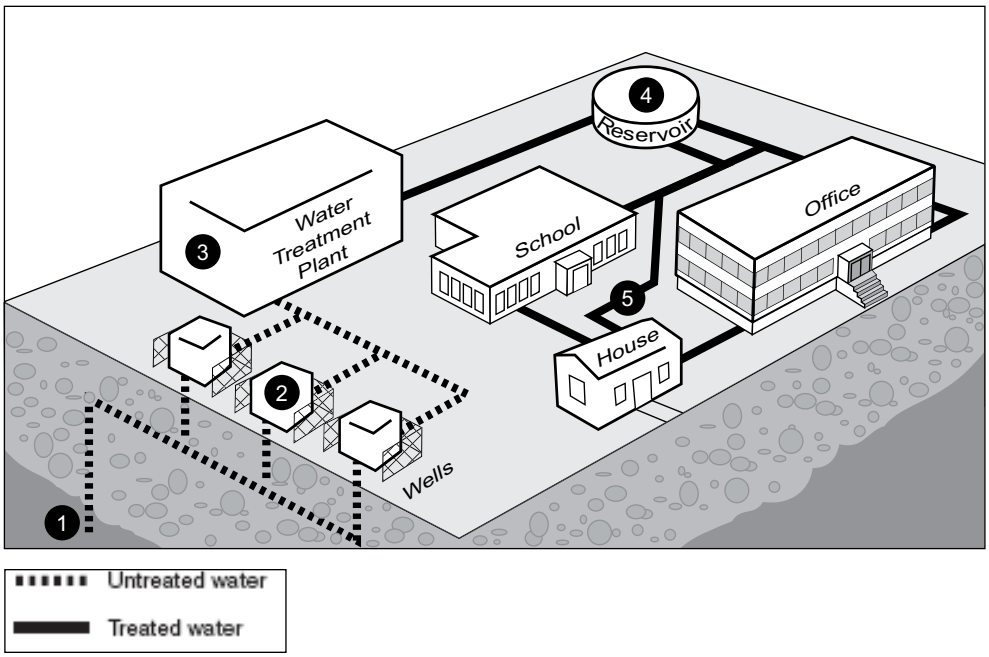

FIGURE 1 Conceptual model of a Camp Lejeune water system. (1) The drinking water at Camp Lejeune is obtained from groundwater pumped from a freshwater aquifer located approximately 180 feet below the ground. (2) Groundwater is pumped through wells located near the water-treatment plant. (3) In the water-treatment plant, the untreated water is mixed and treated through several processes: removal of minerals to soften the water, filtration through layers of sand and carbon to remove particles, chlorination to protect against microbial contamination, and fluoride addition to help to prevent tooth decay. (4) After the water is treated, it is stored in ground and elevated storage reservoirs. (5) When needed, treated water is pumped from the reservoirs and tanks to facilities such as offices, schools, or houses on the base. Source: GAO. 2007. Defense Health Care: Activities Related to Past Drinking Water Contamination at Marine Corps Base Camp Lejeune. GAO-07-276. Washington, DC: U.S. Government Accountability Office.

dependent on many factors, such as the time of operation of the contaminated wells, the water treatments used, and the rate at which water was supplied to the base.

Exposure Review

The committee's exposure evaluation involved identifying the contaminants of concern, their sources, and the concentrations estimated to be present in the water supplies over time. For Tarawa Terrace, the committee relied on work by the Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR compiled the available information on the Tarawa Terrace water system and used computer models to simulate how contaminants moved underground, entered water-supply wells, and were distributed in the water supply. Contaminant measurements were only available from 1980 to 1985, so models were needed to make estimates of the concentrations of contaminants in the water supply in the preceding decades.

A similar historical reconstruction has not yet been performed for the Hadnot Point water system. To identify contaminants of concern there, the committee reviewed information on historical activities on the base (for example, building and chemical uses and sites of hazardous-waste storage or disposal) and findings from site investigations and plans for remedial action at waste sites. The committee also reviewed data available from testing records and other documents to get a preliminary characterization of the exposures that occurred. For some of its analyses, the committee focused on samples taken from "mixed water," that is, water mixed from several supply wells at the treatment plant, because those measurements were probably the most representative of the contaminant concentrations that were delivered to the taps on base. As was the case with Tarawa Terrace, contaminant measurements of the Hadnot Point system were only available from 1980 to 1985.

The major contaminants of the Tarawa Terrace and Hadnot Point systems are of a particular form that tends to serve as a continuing source of contamination even after the contaminants are underground. These are called "DNAPLs," which stands for dense nonaqueous phase liquids. DNAPLs are dense, so they have the potential to sink into the deeper aquifers. Such chemicals get trapped in the soil and dissolve slowly into groundwater. The geology of the area makes it probable that DNAPLs that were spilled on the ground or that were leaked or disposed of in the soil got into the groundwater that supplied some of the wells of the two systems.

The dry-cleaning solvent PCE is the primary contaminant of the Tarawa Terrace water-supply system. Spills and improper disposal of PCE by an off-base dry-cleaner contaminated the groundwater collected by on-base supply wells. Other contaminants detected in water-supply wells were TCE, 1,1-dichloroethylene (DCE), *cis*-1,2-DCE, *trans*-1,2-DCE, benzene, toluene, and vinyl chloride. Several of the contaminants (TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and vinyl chloride) may be the result of degradation of PCE in the soil and groundwater. There was some on-base contamination of the Tarawa Terrace supply system as well.

Sophisticated computer modeling techniques were used by ATSDR to make predictions about the monthly concentrations of PCE to which residents of Tarawa Terrace were exposed. To provide perspective on its estimates, ATSDR compared its monthly estimates with the U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) for PCE in drinking water of 5 µg/L, which was established in 1985. The model estimated that starting in November 1957, the concentration of PCE delivered to residents exceeded that MCL and remained well above it until the wells were closed in 1985.

Some of the modeling approaches used by ATSDR were "cutting-edge," meaning that they used computer codes and modeling techniques that are still in the research stage and have yet to be validated. Furthermore, the absence of measurement data for the first 30 years of the contamination period means the predictions, even if based on validated codes and models, cannot be evaluated for accuracy. The actual concentrations may have been higher or lower than the predictions, but that cannot be assessed. Other uncertainties were introduced into the models because assumptions had to be made about how the water system was operating. For example, little information was available on which wells were supplying water at specific time periods, so assumptions had to be made about when the contaminated wells were operating. Another uncertainty is that the models did not take into account the DNAPL form of pollutants. Given the multiple uncertainties and likely variation in contaminant concentrations, the committee concluded that the Tarawa Terrace modeling predictions should only be used to provide a general estimate of the timeframe and magnitude of exposure.

The contamination of the Hadnot Point system was more complex than Tarawa Terrace. There were multiple sources of pollutants, including an industrial area, a drum dump, a transformer storage lot, an industrial fly ash dump, an open storage pit, a former fire training area, a site of a former on-base dry cleaner, a liquids disposal area, a former burn dump, a fuel-tank sludge area, and the site of the original base dump. The available data on contaminant measurements taken in the 1980s show that TCE and *trans*-1,2-DCE were the contaminants found most often in mixed-water samples, with a few detections of PCE, methylene chloride, and vinyl chloride. The nature of the hazardous-waste sites in the vicinity of the Hadnot Point supply wells suggests that other contaminants may have been present. For example, tests of samples taken from special monitoring wells installed after the contamination was discovered have detected fuel constituents and metals, compounds that were not routinely analyzed in the water samples taken in the 1980s.

Photo by Bruce Muhlenberg.

Recommendations

- For the purposes of epidemiologic studies, the results of the Tarawa Terrace historical reconstruction can be used to characterize people as being exposed or unexposed on the basis of date and location of residence or workplace. The monthly estimates imply more accuracy than is appropriate and should not be used to characterize exposure of individual people.
- Because any groundwater modeling of the Hadnot Point system will be fraught with considerable difficulties and uncertainties, simpler modeling approaches should be used to assess exposures from the Hadnot Point water system. Simpler modeling will not reduce the uncertainty associated with the estimates, but they have the advantage of providing a broad picture of the timeframe and magnitude of exposure encountered by people who used water from that system more quickly and with less resources than complex modeling exercises.
- To facilitate better understanding of the contamination on the base, the Marine Corps should develop a comprehensive and accessible database of water-quality measurements taken from the base.

Potential Health Effects

The committee undertook four kinds of reviews to determine what kinds of diseases or disorders (adverse health effects) have been found to result from exposure to TCE and PCE: (1) review of epidemiologic studies of solvents and their effects, including studies in occupational and industrial settings and community studies; (2) review of epidemiologic studies of other communities with solvent-contaminated water supplies; (3) review of toxicologic studies conducted in animals and humans to test for health effects of TCE and PCE; and (4) review of studies conducted specifically on the Camp Lejeune population.

Review of Epidemiologic Evidence on Solvents

Epidemiologic studies examine whether people with greater exposure to particular chemicals have greater frequency of disease than people with lesser or no exposure (also referred to as greater incidence or greater risk of disease). To manage the review of the vast amount of peer-reviewed scientific literature on TCE and PCE, the committee began with a comprehensive review of the epidemiologic studies of those solvents that was conducted by the Institute of Medicine (IOM) in 2003. IOM categorized the evidence according to an established scheme accepted by the Department of Veteran's Affairs in evaluating risks to veterans of the Vietnam War and the Gulf War. These categories are shown in Box 1. The committee identified new studies published from

BOX 1—Five Categories Used by IOM to Classify Associations

Sufficient Evidence of a Causal Relationship

Evidence from available studies is sufficient to conclude that a causal relationship exists between exposure to a specific agent and a specific health outcome in humans, and the evidence is supported by experimental data. The evidence fulfills the guidelines for sufficient evidence of an association (below) and satisfies several of the guidelines used to assess causality: strength of association, dose-response relationship, consistency of association, biologic plausibility, and a temporal relationship.

Sufficient Evidence of an Association

Evidence from available studies is sufficient to conclude that there is a positive association. A consistent positive association has been observed between exposure to a specific agent and a specific health outcome in human studies in which chance and bias, including confounding, could be ruled out with reasonable confidence. For example, several high-quality studies report consistent positive associations, and the studies are sufficiently free of bias, including adequate control for confounding.

Limited/Suggestive Evidence of an Association

Evidence from available studies suggests an association between exposure to a specific agent and a specific health outcome in human studies, but the body of evidence is limited by the inability to rule out chance and bias, including confounding, with confidence. For example, at least one high-quality study reports a positive association that is sufficiently free of bias, including adequate control for confounding. Other corroborating studies provide support for the association, but they were not sufficiently free of bias, including confounding. Alternatively, several studies of less quality show consistent positive associations, and the results are probably not due to bias, including confounding.

Inadequate/Insufficient Evidence to Determine Whether an Association Exists

Evidence from available studies is of insufficient quantity, quality, or consistency to permit a conclusion regarding the existence of an association between exposure to a specific agent and a specific health outcome in humans.

Limited/Suggestive Evidence of No Association

Evidence from well-conducted studies is consistent in not showing a positive association between exposure to a specific agent and a specific health outcome after exposure of any magnitude. A conclusion of no association is inevitably limited to the conditions, magnitudes of exposure, and length of observation in the available studies. The possibility of a very small increase in risk after exposure studied cannot be excluded.

Source: IOM (Institute of Medicine). 2003. Gulf War and Health, Vol. 2, Insecticides and Solvents. Washington, DC: National Academies Press.

2003 to 2008 and considered whether they changed the conclusions in the IOM report. The studies included people exposed in occupational situations and in community settings.

IOM's approach to evaluating the literature is to determine whether a "statistical association" exists between the chemicals and diseases and disorders. When studies are conducted properly, a statistical association means that people who are exposed to the chemicals are more likely to have or develop the disease or disorder than people who are not exposed. A statistical association, however, does not establish that the chemicals cause the diseases or disorders. Judgment about the quality of each study and additional supporting evidence from other studies are needed. Statistical associations are often represented by numeric estimates, known as "relative risks" or "odds ratios." The estimates describe the relative frequency of disease in groups with higher exposures compared with groups with lower or no exposure. For example, in a study in which individuals are classified as either exposed or unexposed, a relative risk of 2 means that exposed people in the study were twice as likely to develop the disease as people who were not exposed.

As shown in Box 2, all the health outcomes reviewed were placed into one of two categories.

BOX 2—Categorization of Health Outcomes[a] Reviewed in Relation to TCE, PCE, or Solvent Mixtures

Sufficient Evidence of a Causal Relationship

- No outcomes

Sufficient Evidence of an Association

- No outcomes

Limited/Suggestive Evidence of an Association

- Esophageal cancer (PCE)
- Lung cancer (PCE)
- Breast cancer (PCE)
- Bladder cancer (PCE)
- Kidney cancer
- Adult leukemia (solvent mixtures)
- Multiple myeloma (solvent mixtures)
- Myleodysplasic syndromes (solvent mixtures)
- Renal toxicity (solvent mixtures)
- Hepatic steatosis (solvent mixtures)
- Female infertility (with concurrent exposure to solvent mixtures)
- Miscarriage (with exposure to PCE during pregnancy)
- Scleroderma (solvent mixtures)
- Neurobehavioral effects (solvent mixtures)

Inadequate/Insufficient Evidence to Determine Whether an Association Exists

- Oral/pharyngeal cancer
- Nasal cancer
- Laryngeal cancer
- Esophageal cancer (TCE)
- Stomach cancer
- Colon cancer
- Rectal cancer
- Pancreatic cancer
- Hepatobiliary cancer
- Lung cancer (TCE)
- Bone cancer
- Soft tissue sarcoma
- Melanoma
- Non-melanoma skin cancer
- Breast cancer (TCE)
- Cervical cancer
- Ovarian/uterine cancer
- Prostate cancer
- Bladder cancer (TCE)
- Cancer of the brain or central nervous system
- Non-Hodkin lymphoma
- Hodgkin disease
- Multiple myeloma
- Adult leukemia
- Myelodysplasic syndromes
- Childhood leukemia
- Childhood neuroblastoma
- Childhood brain cancer
- Aplastic anemia
- Congenital malformations
- Male infertility
- Female infertility (after exposure cessation)
- Miscarriage, preterm birth, or fetal growth restriction (from maternal preconception exposure or paternal exposure)
- Preterm birth or fetal growth restriction (from exposure during pregnancy)
- Cardiovascular effects
- Liver function or risk of cirrhosis
- Gastrointestinal effects
- Renal toxicity
- Amyotrophic lateral sclerosis
- Parkinson disease
- Multiple sclerosis
- Alzheimer disease
- Long-term reduction in color discrimination
- Long-term hearing loss
- Long-term reduction in olfactory function

Limited/Suggestive Evidence of No Association

- No outcomes

[a]Outcomes for TCE and PCE unless otherwise specified.

The strongest evidence was in the category of *limited/suggestive of an association,* which means that there is some evidence that people who were exposed to TCE or PCE were more likely to have the disease or disorder but that the studies were either few in number or had important limitations. In many cases, the studies could not separate out the effects of individual chemicals because the people were exposed to mixtures. Some of these studies were of highly exposed groups of workers where detection of effects would be expected if present. Such studies might reach conclusions about solvents in general but not about TCE or PCE specifically. For diseases and disorders where the evidence is limited/suggestive of an association, the committee has concluded that the epidemiologic studies give some reason to be concerned that sufficiently high levels of the chemical may cause the disease, but the studies do not provide strong evidence that they actually do so.

The majority of the health outcomes reviewed by the committee were placed into the category of *inadequate/insufficient evidence to determine whether an association exists,* which means that the studies were too few in number, limited in quality, inconsistent, or inconclusive in results to make an informed assessment. It also means that such an association cannot be ruled out. For diseases and disorders in this category, the committee has concluded that the epidemiologic studies cannot tell us whether exposure to the chemicals is associated with the disease or not.

The committee is aware that some health outcomes reported by former residents of the base (for example, male breast cancer and second-generation effects) are not cited in Box 2. The absence of inclusion of specific health outcomes does not mean that such effects are unrelated to exposures from the contaminated water supplies at Camp Lejeune. Rather, those outcomes have not been specifically investigated or, if they were considered, the studies were too small or of insufficient quality to allow conclusions to be drawn.

Review of Epidemiologic Evidence from Community Studies

The committee decided to consider the subset of epidemiologic studies that were conducted in communities exposed to solvents in their water supplies in more detail. Because these studies involved populations and exposure situations that more closely resemble those at Camp Lejeune, some relevant implications might be learned. A few studies reported certain diseases and disorders, such as congenital heart defects, spontaneous abortions, and very low birth weight. However, the studies reported differing effects, so generally they did not confirm each other. In general, the studies had limitations in their design that are unavoidable because of the circumstances that gave rise to them. The limitations include lack of data on levels of contaminants in the water, lack of adequate information about diseases and disorders in the population, and relatively small populations. These factors limit the capacity of such studies to detect associations even if they exist. Limitations in such studies often mean that people in the study communities can only be classified into two groups to reflect exposure to contamination—those exposed and those considered unexposed. Such classification is a crude way to address exposure because it can make it more difficult to detect any effects that might occur. Another common limitation of community studies in general is that they are not able to account for other factors that may affect the likelihood of disease. Furthermore, the studies face the difficult task of addressing diseases that are relatively uncommon. It is harder to find enough cases of uncommon diseases to make comparisons when studying relatively small populations. The committee concluded that the evidence provided by this subset of epidemiologic studies needs further support and confirmation before they can be considered significant on their own.

Review of the Toxicologic Evidence

Toxicologic studies are mainly laboratory experiments, usually conducted on animals. The committee's review on TCE and PCE were in part based on previously published toxicologic reviews but were mainly based on analyses of recently published studies. The studies were analyzed using criteria for good study design and degree of agreement between the conclusions and the data presented. Further, the committee took into consideration the quality and reliability of studies, consistency of findings of similar studies, understanding of the biologic processes, toxicologic significance, dose- and duration-dependence, and understanding of whether effects observed in animals are predictive of human risks. Each chemical was reviewed for effects on the major organ systems—for example, liver, kidneys, lungs, reproductive system, nervous system, and immune system.

In animal experiments, TCE was reported to cause kidney and testicular cancers in rats and liver and lung cancers in mice. PCE was reported to cause

liver cancer in mice and mononuclear cell leukemia and kidney cancer in rats. Differences in how these chemicals are handled in the body by rodents and humans, as well as current scientific understanding of how these tumors develop, led the committee to the conclusion that kidney cancer is the most relevant to humans.

For other kinds of adverse health effects, kidney toxicity and liver toxicity were observed in rodents given high doses of TCE and PCE. Effects on male rodent fertility, but not female fertility, were observed. Neither chemical caused birth defects in rats. There were some adverse effects on offspring of pregnant female rats exposed to PCE but to not TCE. Adverse changes in some nervous system measurements were seen in some TCE and PCE studies. TCE causes some effects on the immune system of sensitive strains of mice, but there are few immunotoxicity studies on PCE.

When possible, the committee identified the lowest dose of TCE or PCE at which adverse effects were observed in animal studies (the dose is called the lowest-observed-adverse-effect level or LOAEL). To put these doses in perspective, the committee did a comparison of the doses with approximated doses to former residents that were estimated from concentrations of TCE and PCE measured in mixed water.[1] Because of the known variation in contaminant concentrations, the range used for the comparison included the highest measured concentrations of TCE and PCE in mixed water, one-half those concentrations, and twice the highest measured concentrations. The adverse health effects considered for this comparison were those thought to be most relevant to humans (kidney cancer, renal toxicity, and immunosuppression for TCE, and renal toxicity and neurotoxicity for PCE). This comparison is not an assessment or prediction of risk and can only give a general indication of the degree of difference between doses that caused a response in laboratory animals and doses to former residents of Camp Lejeune. The comparison reflects estimated combined daily doses from all three routes of exposure (ingestion, inhalation, and skin contact) that could have occurred for adults and children at Camp Lejeune. Results of the comparison suggest that the highest levels of either TCE or PCE measured in the mixed-water samples at Camp Lejeune were much lower than the lowest dose that caused adverse effects in the most sensitive strains and species of laboratory animals. The lower levels of exposure may be of some concern for effects on neurotoxicity and immunotoxicity, but further research is needed to evaluate the specific effects of TCE and PCE and whether they are relevant to humans.

[1] A dissenting viewpoint from one committee member on this evaluation is provided in Chapter 4.

Consideration of the Epidemiologic and Toxicologic Evidence Together

The committee considered collectively what is known about adverse health effects that are associated with exposure to TCE and PCE from human epidemiologic and animal toxicologic studies. Evidence on similar outcomes reported in animal and human studies were compared to see whether the data were supportive of the potential health consequences of exposure to TCE and PCE in the water supply.

Review of epidemiologic studies on cancer outcomes provided limited/suggestive evidence for an association between chronic exposure to TCE or PCE and kidney cancer and to PCE and cancers of the esophagus, lungs, breast, and bladder. For these outcomes, the toxicologic evidence was strongest for kidney cancer.

Noncancer effects that were found to be similar in humans and laboratory animals included adverse effects on the liver, kidneys, and nervous and immune systems. In the epidemiologic literature, toxic effects on the liver and kidneys appeared to be related to short-term inhalation of high concentrations of solvents as opposed to longer-term exposure at lower concentrations. Support for these effects observed in toxicologic studies come from rodents exposed to high concentrations of TCE and PCE. For kidney effects, adverse findings were only found in male rats. Epidemiologic studies of occupational exposure to mixed solvents showed limited/suggestive evidence of neurobehavioral effects, and toxicologic studies of TCE showed some decrements in neurobehavioral outcomes. For effects on the immune system, epidemiologic studies showed limited/suggestive evidence for an association with mixed solvent exposure for certain immunologically mediated diseases. Toxicologic studies also showed that TCE can affect the immune system, as shown by immunosuppression and worsening of preexisting autoimmune diseases. These findings are shown in Table 1. The absence of other diseases and disorders in the table does not mean that such outcomes are irrelevant or unworthy of study, but that the findings for them were inconsistent between the toxicologic and the epidemiologic evidence or were not addressed in the available studies.

Review of Camp Lejeune Studies

Only a few studies have been conducted on the Camp Lejeune population, and these have focused on health effects in people who were exposed as children or while their mothers were pregnant with them. One study evaluated pregnancy outcomes among women who lived in base housing from 1968 to 1985.

Although the water contamination probably began before 1968, ATSDR selected 1968 as its starting point because electronic birth certificates became available that year. ATSDR compared data on premature births, births of babies who were small relative to other babies from pregnancies of similar duration (small for gestational age), and birth weights between mothers who were exposed and those who were unexposed. Whether mothers were exposed was determined by where they lived on the base when the child was born, not taking into account whether they moved during the pregnancy. Two analyses were performed; one that evaluated residents of Hadnot Point and Tarawa Terrace and one that focused only on Tarawa Terrace residents.

In both analyses, no clear associations were found between mean birth weight, preterm birth, or small for gestational age. However, a comparison of subgroups within the Tarawa Terrace population found a weak association between PCE exposure and small-for-gestational-age births for children of women over 35 or of women who had prior miscarriages. However, a limitation of this conclusion is that the decision to perform this analysis was added after the original design of the study. It was not one of the hypotheses or theories set out before the study. Therefore, scientists give this finding less weight.

The findings from these analyses are no longer valid. After the study was completed, ATSDR discovered that a residential area it classified as unexposed (Holcomb Boulevard) received water from the Hadnot Point system for the first 4 years of the study period, and the study results must be reanalyzed to correct for this mistake in classification. ATSDR has indicated that it will reanalyze the results of the study using exposure estimates from its groundwater modeling of the Tarawa Terrace and Hadnot Point systems.

ATSDR also has a study under way on prenatal exposure to water-supply contaminants and birth defects and childhood cancer. The specific outcomes being studied are childhood leukemia, childhood non-Hodgkin lymphoma, spina bifida, anencephaly, cleft lip, and cleft palate. These outcomes are rare, and given the number of study participants, it appears that the statistical power of this study could limit its ability to detect associations. The study is also awaiting the completion of groundwater modeling of the Hadnot Point water system so that differences in exposure can be assessed.

Recommendations

- The committee recommends that ATSDR go forward with reanalyzing its study of birth

TABLE 1 Similar Health Effects Found in Epidemiologic and Toxicologic Studies

Effects	Epidemiologic Evidence	Toxicologic Evidence
Kidney cancer	Limited/suggestive for TCE and PCE	TCE and PCE (limited to male rats)
Liver toxicity	Limited/suggestive for solvents and hepatic steatosis[a]	TCE and PCE (liver damage)
Kidney toxicity	Limited/suggestive for solvents	TCE and PCE (limited to male rats)
Neurobehavioral effects	Limited/suggestive for solvents (effects on visuomotor and motor function, fatigue, headache, deficits in concentration)	TCE: central nervous system depression, attention deficits, deficits in visual discrimination, altered visual evoked potentials[b] PCE: anesthetic effects; changes in behavior and neurochemical markers
Immunologic effects	Limited/suggestive for solvents and glomerulonephritis[c] and scleroderma[d]	TCE: sensitization, immunosuppression, influence autoimmune disease (in sensitive strains of mice)

[a] Hepatic steatosis is fatty accumulation in the liver.
[b] Electrical response recorded by a skull electrode after a visual stimulus (e.g., a flash).
[c] Glomerulonephritis is a disease that affects kidney function.
[d] Scleroderma is a disease resulting in abnormal growth of connective tissue.

outcomes to correct for errors in exposure classification without awaiting the results of groundwater modeling of the Hadnot Point system. For the reasons given earlier, such modeling is unlikely to yield reliable quantitative estimates of exposure that would refine exposure classification for epidemiologic study.

- Despite the committee's concerns about the statistical power of the study of birth defects and childhood cancer, it recommends that the study be completed as soon as possible. Simpler approaches to groundwater modeling should be performed to support the exposure classification in the study rather than performing the same type of complex groundwater modeling that was performed for Tarawa Terrace.

The Feasibility and Utility of Future Studies of the Camp Lejeune Population

ATSDR has evaluated the feasibility of conducting three additional studies of the Camp Lejeune population, including a health survey and studies that would evaluate deaths from all causes and cancer incidence among former residents and workers. ATSDR identified some of the same diseases and disorders identified in the committee's review as being of interest. These included kidney cancer, lung cancer, breast cancer, scleroderma, liver disease, kidney disease, and spontaneous abortion. ATSDR also identified additional outcomes of possible interest for its study.

Difficulties with performing the studies are identifying, locating, and recruiting the study participants and obtaining reliable health information on them in an efficient manner. The committee found that although ATSDR did consider the major issues bearing on the feasibility of the proposed studies and proposed reasonable approaches to conducting the studies, there remain serious, unresolved questions about the feasibility and ultimate value of the studies. For example, it is not clear that the cancer incidence study could be performed successfully, because it is contingent on the cooperation of many state cancer registries. Even with cooperation, the statistical power to compare groups of interest across the range of outcomes has yet to be assessed. Statistical power is also an issue with the mortality study.

The committee also reviewed ATSDR's plans for a health survey that was generated in response to a congressional directive. The survey would seek information on residential history and various health outcomes. Although the survey could contribute to designing future studies at Camp Lejeune, its success depends on getting adequate participation (at least 60%). Even if satisfactory participation is achieved, there are concerns that there could be bias in the reported data because people who have experienced disease or illness are more likely to participate in the survey.

After reviewing the study plans and feasibility assessments, the committee concluded that most questions about whether exposures at Camp Lejeune resulted in adverse health effects cannot be answered definitively with further scientific study. There are two main reasons for this. First, it is not possible to reliably estimate the historical exposures experienced by people at the base. Second, it will be difficult to detect any increases in the rate of diseases or disorders in the study population. Most of the health effects of concern are relatively rare, which means that very large numbers of people are needed to detect increased cases. Although the total number of people who have lived at Camp Lejeune while the Tarawa Terrace and Hadnot Point water supplies were contaminated is sizable, the population is still unlikely to be large enough to detect effects, other than common diseases or disorders, of concern. Another factor is that the population was relatively young, so many who would be studied are in an age range in which chronic diseases are rare. Yet another factor is that the people tended to live on the base for a relatively short time, resulting in a small increase in risk of disease at most, making it difficult to rule out other exposures or factors that could have contributed to disease or illness. All these factors make it unlikely that the proposed studies, even if the notable uncertainties about feasibility are resolved favorably, will produce results of sufficient certainty to resolve the question of whether Camp Lejeune residents suffered adverse health effects from exposure to contaminated water.

The available scientific information does not provide a sufficient basis for determining whether the population at Camp Lejeune has, in fact, suffered adverse health effects as a result of exposure to contaminants in the water supplies. On the one hand, several lines of scientific reasoning suggest such effects are unlikely to have occurred. The evidence includes a substantial body of research on the toxicology of TCE and PCE that indicates that the exposures required to cause adverse effects in laboratory animals were much larger than the highest

measurements available on the Camp Lejeune water supplies; evidence that humans have lower sensitivity to TCE and PCE than rodents; epidemiologic data largely from occupational settings with higher, longer-term exposures to TCE and PCE that has not generated compelling evidence of adverse health effects; and the relatively short-term, intermittent nature of the exposures incurred at Camp Lejeune. On the other hand, the possibility that health effects have been produced by the contaminant exposures at Camp Lejeune cannot be ruled out. Some effects of TCE or PCE exposure might have occurred below the level of detection in toxicologic studies, which focused on single contaminant exposures at high doses, used genetically homogeneous animal strains, and necessarily involved extrapolation across species. In addition, the population exposed at Camp Lejeune is more diverse and possibly more susceptible than those who have been exposed to TCE and PCE in occupational settings, and the actual concentrations of PCE and TCE and the presence of additional water contaminants are poorly documented and could thus be higher or more complex than the limited historical measurements suggest. There were divergent views among the committee members about the probability that each would assign to whether adverse health effects have in fact occurred, but there was consensus among them that scientific research is unable to provide more definitive answers to that question.

Conclusion and Recommendation

It cannot be determined reliably whether diseases and disorders experienced by former residents and workers at Camp Lejuene are associated with their exposure to contaminants in the water supply because of data shortcomings and methodological limitations, and these limitations cannot be overcome with additional study. Thus, the committee concludes that there is no scientific justification for the Navy and Marine Corps to wait for the results of additional health studies before making decisions about how to follow up on the evident solvent exposures on the base and their possible health consequences. The services should undertake the assessments they deem appropriate to determine how to respond in light of the available information.

Committee on Contaminated Drinking Water at Camp Lejeune: David A. Savitz (Chair), Mount Sinai School of Medicine; **Caroline L. Baier-Anderson,** Environmental Defense Fund; **James V. Bruckner,** University of Georgia; **Prabhakar Clement,** Auburn University; **Carole A. Kimmel,** Independent Consultant; **Francine Laden,** Harvard School of Public Health; **Bruce P. Lanphear,** Simon Fraser University; **Xiaomei Ma,** Yale University School of Medicine; **John R. Nuckols,** Colorado State University; **Andrew F. Olshan,** The University of North Carolina at Chapel Hill; **Lianne Sheppard,** University of Washington School of Public Health; **Elaine Symanski,** University of Texas School of Public Health; **Janice W. Yager,** The University of New Mexico; Susan Martel (*Study Director*), National Research Council.

The National Academies appointed the above committee of experts to address the specific task requested by the U.S. Navy. The members volunteered their time for this activity; their report is peer-reviewed and signed off by both the committee members and the National Academies.

For more information, contact the Board on Environmental Science and Technology at (202) 334-3060 or visit http://nationalacademies.org/best. *Copies of Contaminated Water Supplies at Camp Lejeune—Assessing Potential Health Effects* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.