

# Evaluation of cancer incidence among Marines and Navy personnel and civilian workers exposed to contaminated drinking water at USMC Base Camp Lejeune: a cohort study

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The author declares he has nothing to disclose.

## 1 Abstract

### 2 Background

3 Drinking water at U.S. Marine Corps Base Camp Lejeune, North Carolina was contaminated  
4 with trichloroethylene and other industrial solvents from 1953 to 1985.

### 6 Methods

7 A cohort cancer incidence study was conducted of Marines/Navy personnel who, between 1975  
8 and 1985, began service and were stationed at Camp Lejeune, North Carolina (N=154,821) or  
9 Camp Pendleton, California (N=163,484), and civilian workers employed at Camp Lejeune  
10 (N=6,494) or Camp Pendleton (N=5,797) between October 1972 and December 1985. Camp  
11 Pendleton's drinking water was not known to be contaminated between 1972 and 1985.  
12 Individual-level information on all primary invasive cancers and in-situ bladder cancer  
13 diagnosed from 1996 to 2017 was obtained from data linkages with 54 cancer registries in the  
14 U.S. Survival methods were used to calculate hazard ratios (HRs) comparing cancer incidence  
15 between the Camp Lejeune and Camp Pendleton cohorts. Precision of effect estimates were  
16 evaluated using the 95% confidence interval (CI) ratio.

### 18 Results

19 Cancers among Camp Lejeune Marines/Navy personnel and civilian workers totaled 12,083  
20 (354/100,000) and 1,563 (1,301/100,000), respectively. Cancers among Camp Pendleton  
21 Marines/Navy personnel and civilian workers totaled 12,144 (335/100,000) and 1,416  
22 (1,372/100,000), respectively.

23  
24 Compared to Camp Pendleton, Camp Lejeune Marines/Navy personnel had adjusted HRs  $\geq 1.20$   
25 with 95% CI ratios (CIRs)  $\leq 3$  for acute myeloid leukemia (HR=1.38, 95% CI: 1.03, 1.85), all  
26 myeloid cancers including polycythemia vera (HR=1.24, 95% CI: 1.03, 1.49), myelodysplastic  
27 and myeloproliferative syndromes (HR=1.68, 95% CI: 1.07, 2.62), polycythemia vera alone  
28 (HR=1.41, 95% CI: 0.94, 2.11), cancers of the esophagus (HR=1.27, 95% CI: 1.03, 1.56), larynx  
29 (HR=1.21, 95% CI: 0.98, 1.50), soft tissue (HR=1.21, 95% CI: 0.92, 1.59) and thyroid  
30 (HR=1.22, 95% CI: 1.03, 1.45). Compared to Camp Pendleton, Camp Lejeune civilian workers  
31 had adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$  for all myeloid cancers including polycythemia vera

32 (HR=1.40, 95% CI: 0.83, 2.36), squamous cell lung cancer (HR=1.63, 95% CI: 1.10, 2.41) and  
33 female ductal breast cancer (HR=1.32, 95% CI:1.02, 1.71). Sensitivity analyses indicated that  
34 confounding bias due to unmeasured risk factors (e.g., smoking and alcohol consumption) is  
35 unlikely to significantly impact the findings.

36

### 37 **Conclusion**

38 Increased risks of several cancers were observed among Marines/Navy personnel and civilian  
39 workers likely exposed to contaminated drinking water at Camp Lejeune compared to personnel  
40 at Camp Pendleton.

41

42 (word count = 363)

43

### 44 **Keywords**

45 USMC Base Camp Lejeune, USMC Base Camp Pendleton, Marines/Navy personnel, civilian  
46 workers, cancer incidence, drinking water, trichloroethylene, tetrachloroethylene, benzene, vinyl  
47 chloride, hazard ratio

48

### 49 **Abbreviations**

50 ATSDR: Agency for Toxic Substances and Disease Registry

51 AML: acute myeloid leukemia

52 BOQ: bachelor officer quarters

53 CDC: Centers for Disease Control and Prevention

54 CI: confidence interval

55 CIR: confidence interval ratio

56 COPD: chronic obstructive pulmonary disease

57 DCE: t-1,2-dichloroethylene

58 DMDC: Defense Manpower Data Center

59 DOD: US Department of Defense

60 EPA: US Environmental Protection Agency

61 HB: Holcomb Boulevard treatment plant

62 HP: Hadnot Point treatment plant

63 HR: hazard ratio

64 IARC: International Agency for Research on Cancer

65 ICD-O-3: third edition of the International Classification of Diseases for Oncology

66 MCL: EPA maximum contaminant level in drinking water

67 MZBCL: marginal zone B-cell lymphoma

68 NHL: non-Hodgkin lymphoma

69 NOS: not otherwise specified

70 NTP: National Toxicology Program

71 µg/L: micrograms per liter

72 PCE: tetrachloroethylene (also known as perchloroethylene)  
73 RR: risk ratio  
74 SEER: Surveillance, Epidemiology, and End Results Program  
75 SIR: Standardized incidence ratio  
76 SSA: Social Security Administration  
77 SSN: Social security number  
78 TCE: trichloroethylene  
79 TT: Tarawa Terrace treatment plant  
80 USMC: United States Marine Corps  
81 VA: U.S. Department of Veteran Affairs  
82 WHO: World Health Organization

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## 99 Background

100 Distribution system drinking water samples collected between 1980 and 1985 at United States  
101 Marine Corps (USMC) Base Camp Lejeune, North Carolina found industrial solvents in the  
102 drinking water supplied by two of the base's eight treatment plants. Each drinking water  
103 treatment plant served a different area of the base. The Tarawa Terrace (TT) treatment plant  
104 began operating in 1952 and served approximately 1,850 family housing units. The TT  
105 distribution system was contaminated by an off-base dry-cleaning business. Tetrachloroethylene  
106 (PCE) was the primary contaminant in the TT distribution system with measured concentrations  
107 of 104 micrograms per liter ( $\mu\text{g/L}$ ) in July 1982 and a maximum level of 215  $\mu\text{g/L}$  in January  
108 1985. Much lower levels of trichloroethylene (TCE), trans-1,2-dichloroethylene (DCE), and  
109 vinyl chloride occurred in the distribution system due to PCE degradation in groundwater [1].

110  
111 The Hadnot Point (HP) treatment plant began operation in 1942 and served the base's  
112 "mainside" including most of the workplaces, a majority of the bachelor's quarters ("barracks"),  
113 a small number of family housing units, field training areas (via mobile "water buffaloes") and  
114 eating establishments. The HP distribution system was contaminated by on-base sources –  
115 leaking underground storage tanks, industrial area spills, and waste disposal sites. TCE and PCE  
116 were the primary contaminants, with maximum measured levels in the distribution system of  
117 1,400  $\mu\text{g/L}$  and 100  $\mu\text{g/L}$ , respectively during 1982. A TCE concentration of 1,148  $\mu\text{g/L}$  was  
118 measured in drinking water from the HP treatment plant in January 1985. Also detected in the  
119 drinking water at the HP treatment plant during 1984 and/or 1985 were benzene, from fuel spills  
120 and leaks, and DCE and vinyl chloride from the degradation of PCE and TCE in ground water  
121 [2].

122  
123 The Holcomb Boulevard (HB) treatment plant began operation in 1972 and served  
124 approximately 2,100 family housing units and a bachelor officer quarters (BOQ). The HB  
125 service area was uncontaminated except for intermittent dry periods when the HP system  
126 provided supplementary water. During a two-week period starting in late-January 1985, the HB  
127 plant was shut down for repairs and the HP system provided water to the HB service area [2].

128

129 No drinking water samples for volatile organic compounds were collected at Camp Lejeune prior  
130 to 1980, and there were a limited number of samples taken between 1982 and 1985. Therefore,  
131 ATSDR conducted historical reconstruction modeling to estimate the monthly average  
132 contaminant levels in the TT and HP distribution systems. Details of the methodology have been  
133 summarized elsewhere [1-2]. Based on historical reconstruction modeling estimates, the TT and  
134 HP systems were contaminated by the mid-1950s. The highly contaminated supply wells serving  
135 the TT and HP systems were shut down by mid-February 1985, although levels of benzene above  
136 its maximum contaminant level (MCL) of 5 µg/L were detected on 11/19/1985 (2,500 µg/L) and  
137 on 12/10/1985 (38 µg/L) in the HP distribution system. In each system, water from supply wells  
138 was mixed together at the treatment plant prior to distribution. Contamination levels in each  
139 system varied depending on the wells in use, their levels of contamination, and their pumpage  
140 rates [1-2].

141  
142 Estimated monthly average concentrations of PCE in the TT distribution system between January  
143 1975 and February 1985 ranged from 0 to 158 µg/L with a median of about 85 µg/L [1].

144 Estimated monthly average concentrations of TCE in the HP distribution system between  
145 January 1975 and February 1985 ranged from 0 to 783 µg/L, with a median level of about 366  
146 µg/L [2]. In addition, estimated monthly average levels of PCE and vinyl chloride in the HP  
147 distribution system between January 1975 and February 1985 ranged from 0 to 39 µg/L and 0 to  
148 67 µg/L, respectively, with medians of the estimates of 15 µg/L and 22 µg/L, respectively [2].

149  
150 The United States Environmental Protection Agency (EPA) MCLs are 5 µg/L for TCE, PCE, and  
151 benzene; 2 µg/L for vinyl chloride; and 100 µg/L for DCE. EPA and the International Agency  
152 for Research on Cancer (IARC) classified TCE as a human carcinogen [3-5]. The EPA classified  
153 PCE as a “likely human carcinogen” [6] and IARC classified PCE as “probably carcinogenic to  
154 humans” [4-5]. Both benzene and vinyl chloride are known human carcinogens [7-9]. The  
155 carcinogenicity of DCE is not classified by EPA.

156  
157 The drinking water exposures at Camp Lejeune include contributions to total internal body dose  
158 from three routes: ingestion, inhalation and dermal. A Marine in training may consume as much  
159 as 6 liters/day of drinking water [10]. The combined dose from the inhalation and dermal routes

160 may be as high or higher than the dose from the ingestion route. For example, an internal dose  
161 via inhalation to TCE during a 10-minute shower may equal the internal dose via the ingestion of  
162 2 liters of TCE-contaminated drinking water [11].

163  
164 The ATSDR previously conducted cohort mortality (not cancer incidence) studies of Camp  
165 Lejeune Marines/Navy personnel and civilian workers [12-13], and a case-control study of male  
166 breast cancer incidence among Camp Lejeune Marines [14]. The mortality studies compared  
167 Marines and civilian workers at the base from 1975 to 1985 and 1973 to 1985, respectively, with  
168 similar cohorts over the same periods at USMC Base Camp Pendleton, California. Both cohort  
169 studies found elevated risks of mortality from cancers of the kidney, rectum, lung, prostate,  
170 leukemias, and multiple myeloma [12-13]. Male breast cancer incidence was elevated in the  
171 case-control study comparing Camp Lejeune Marines with Marines at other bases [14].

172  
173 Based on the published ATSDR studies at Camp Lejeune as well as a literature review of  
174 occupational and environmental studies conducted elsewhere, an ATSDR report assessed the  
175 strength of the evidence supporting causality of cancers from exposures to TCE, PCE, vinyl  
176 chloride, and benzene [15]. The assessment integrated findings from ATSDR's Camp Lejeune  
177 mortality studies and male breast cancer study and studies of other populations exposed  
178 occupationally or via drinking water to these chemicals. The assessment found sufficient causal  
179 evidence for linking TCE and kidney cancer and non-Hodgkin lymphoma (NHL), and "equipoise  
180 and above evidence" (i.e., evidence that was as likely as not or greater, but less than sufficient  
181 evidence) for TCE and multiple myeloma, leukemias, and liver cancer. Sufficient causal  
182 evidence was found for PCE and bladder cancer, and "equipoise and above evidence" for PCE  
183 and NHL. Sufficient causal evidence was found for benzene and NHL and leukemias, and  
184 "equipoise and above evidence" for benzene and multiple myeloma. Sufficient evidence was  
185 found for associating vinyl chloride and liver cancer.

186  
187 Two epidemiological studies have evaluated cancer incidence and drinking water exposures to  
188 TCE or PCE. A New Jersey study observed associations between NHL and TCE and PCE, and  
189 leukemia and TCE [16]. A study in Cape Cod, Massachusetts found associations between PCE  
190 and cancers of the lung, bladder, rectum, female breast, and leukemia [17-19].

191 The purpose of this cancer incidence cohort study of Camp Lejeune Marines/Navy personnel and  
192 civilian workers was to determine if being stationed or employed at Camp Lejeune between 1975  
193 and 1985 (Marines/Navy personnel) or between October 1972 and December 1985 (civilian  
194 workers), a portion of the period when the drinking water was contaminated, increased the risk  
195 of cancer incidence ascertained between 1996 and 2017 compared to being stationed or  
196 employed at Camp Pendleton. Camp Pendleton was not known to have contaminated drinking  
197 water during the years prior to 1986 [20].

198

## 199 Methods

### 200 Study Populations

201 ATSDR obtained quarterly personnel data from the Defense Manpower Data Center (DMDC) for  
202 full time civilian workers who were employed during any quarter between October 1972 and  
203 December 1985 at Camp Lejeune or Camp Pendleton. The DMDC data did not contain  
204 information on part-time employees. The DMDC began collection of personnel data for civilian  
205 workers in the last quarter of 1972. The end of the year 1985 was selected because drinking water  
206 distribution system samples taken at Camp Lejeune from 1986 onward indicated no  
207 contamination above the contaminants' MCLs. The study included a cohort of 6,494 workers  
208 employed at Camp Lejeune and a comparison cohort of 5,797 workers employed at Camp  
209 Pendleton, who were known to be alive as of January 1, 1996. The DMDC data included base  
210 location of employment (state, city and zip codes), social security number, full name (started in the  
211 last quarter of 1981), date of birth, paygrade, education level, race, sex, and occupation code. Based  
212 on the DMDC data, the average duration of employment at Camp Lejeune between October 1972  
213 and December 1985 was 56 months.

214

215 ATSDR also obtained quarterly personnel data from the DMDC for Marines and Navy personnel  
216 stationed at Camp Lejeune and Camp Pendleton for the years 1975 to 1985. Although drinking  
217 water contamination preceded 1975, the code for unit (e.g., regiment, battalion, company, etc.),  
218 necessary to determine the base where the individual was stationed, was not available in the  
219 DMDC database until the second quarter of 1975. In addition to the unit code, the DMDC data  
220 included date of birth, marital status, rank (paygrade), date active duty started, military



221 occupation code, education level at the start of service, race, sex, full name, and social security  
222 number. The USMC provided a list of the unit codes for the units that were stationed at each  
223 base. Based on the DMDC data, Marines/Navy personnel in the Camp Lejeune cohort were  
224 stationed at the base on average for 18 months.

225  
226 The full cohort of Marines/Navy personnel for this study included 211,023 at Camp Lejeune and  
227 224,419 at Camp Pendleton, who were known to be alive as of January 1, 1996. Some members  
228 of the full cohort began active duty prior to 1975 when information on base location (i.e., unit  
229 code) was not available in the DMDC data. For these Marines/Navy personnel, it would be  
230 unknown whether those stationed at Camp Pendleton between 1975 and 1985 were stationed at  
231 Camp Lejeune prior to 1975. Since it was not unusual for Marines/Navy personnel to be  
232 stationed at both bases, it was likely that some who began active duty prior to 1975 and were  
233 stationed at Camp Pendleton between 1975 and 1985, were stationed at Camp Lejeune prior to  
234 1975. To address this problem, a subgroup of the full cohort was identified consisting of  
235 Marines/Navy personnel who began active duty between 1975 and 1985 when information on  
236 base location was available in the DMDC database. This subgroup consisted of 154,821 at Camp  
237 Lejeune and 163,484 at Camp Pendleton, who were known to be alive as of January 1, 1996.  
238 Comparisons between the Camp Lejeune and Camp Pendleton subgroup are the main focus of  
239 the evaluation of cancer incidence among Marines and Navy personnel.

240  
241 Camp Pendleton Marines/Navy personnel and civilian workers were chosen as the comparison  
242 groups in this study because the base's finished drinking water was not known to be  
243 contaminated prior to 1986 [20]. Moreover, Camp Pendleton's Marines/Navy personnel and  
244 civilian workers were similar to Camp Lejeune in terms of demographics, socioeconomic factors,  
245 training activities, personnel trained, and types of civilian employee occupations. Biases due to  
246 the "healthy veteran effect" [21-23] or the "healthy worker effect" [24], or due to unmeasured  
247 confounders, should be reduced by having comparison cohorts with similar risk factor  
248 characteristics as the Camp Lejeune cohorts.

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251

## 252 Cancer Ascertainment

253 Linkage between the cohort data and a commercial tracing service was used to correct discrepant  
254 names, social security numbers, and dates of birth and to obtain the most recent five residential  
255 street addresses and vital status. Vital status and date of death were obtained via linkage with the  
256 Social Security Administration (SSA) Data for Epidemiological Researchers and the National  
257 Death Index. The resulting information was used in the data linkages with cancer registries.

258  
259 Individual-level information on all primary invasive cancers and in situ bladder cancer from  
260 1996 to 2017 was obtained from data linkages with 49 state cancer registries, the cancer  
261 registries of Puerto Rico and the Pacific Islands, the District of Columbia cancer registry, and the  
262 cancer registries at the Department of Defense (DOD) and the Department of Veterans Affairs  
263 (VA). Due to state law restrictions requiring consent of the living patient, the West Virginia  
264 Cancer Registry provided aggregate data on specific cancers by age group, sex, whether Marine  
265 or civilian employee, and base stationed or employed. The aggregate data did not distinguish the  
266 1975-1985 subgroup of Marines/Navy personnel from the full cohort. The Kansas Cancer  
267 Registry had a similar state law restriction but was able to obtain consent from, and provide  
268 individual-level data for, most of the patients that matched to the cohorts. For those who matched  
269 but did not provide consent, the Kansas Cancer Registry provided similar aggregate data as the  
270 West Virginia Cancer Registry.

271  
272 The start of follow-up was January 1, 1996, because all registries were operating by 1996 (some  
273 registries were not operating prior to 1996). December 31, 2017 was chosen as the end date for  
274 data collection from the registries because some of the registries did not have complete and  
275 verified data beyond 2017 at the time the linkages were scheduled to be performed. In situ  
276 bladder cancers were included in the study "...because the information needed to distinguish  
277 between *in-situ* and invasive bladder cancers is not always available or reliable" (see  
278 [https://www.cdc.gov/cancer/uscs/technical\\_notes/data\\_sources/incidence.htm](https://www.cdc.gov/cancer/uscs/technical_notes/data_sources/incidence.htm)).

279  
280 All cancer registries except the DOD cancer registry utilized the same linkage software  
281 (Match\*Pro, a Java-based application developed by Information Management Services, Inc).  
282 Similar manual review procedures were performed at all the registries except the VA and DOD

283 registries which did not perform manual review. The matching parameters used by the linkage  
284 software were first, middle, and last name (using a Soundex algorithm that matches names that  
285 have similar pronunciation but may have different spellings) for both the cancer registry data and  
286 the cohort personnel data), social security number, date of birth, and street address. Blocking  
287 parameters (first name, last name, social security number, and date of birth) were used to limit  
288 the number of comparisons to those records for which two or more blocking parameters  
289 matched.

290  
291 The linkage software produced three classes of matches: high quality, uncertain, and non-  
292 matches. The thresholds for these three classes were based on pilot tests with three of the cancer  
293 registries and were consistent across all linkages. Registries manually reviewed all uncertain  
294 matches to identify any missed cases. Most registries also reviewed all high-quality matches for  
295 potential false positives. Based on this review, about 0.1% of the high-quality matches were  
296 identified as false positives. Many registries also reviewed records in the unmatched category for  
297 any false negatives. Once all the cancer data were received, duplicate records were removed.

298  
299 Cancer registries provided the following information for each matched tumor record: primary site of  
300 the cancer, histologic type, laterality, behavior code (benign, in situ, malignant), grade, diagnostic  
301 confirmation, cancer stage (Surveillance, Epidemiology and End Results Program (SEER)  
302 summary stage-1977 for 1977 to 2000; SEER summary stage-2000 for 2001 to 2017), sequence  
303 number, state of diagnosis, age at diagnosis, date of diagnosis, and whether the cancer was  
304 identified solely by death certificate (“DCO” case). Histological subtypes were defined using the  
305 SEER site recode definitions based on the cancer site and International Classification of Diseases  
306 for Oncology, 3<sup>rd</sup> edition (ICD-O-3) histology codes, updated for hematopoietic codes based on  
307 the World Health Organization (WHO) Classification of Tumours of Hematopoietic and  
308 Lymphoid Tissues [25]. The histology coding schemes for the histological subtypes are provided  
309 in Supplemental file 1, Table S1-1.

310

## 311 Data Analyses

312 The analyses focused on comparisons between the Camp Lejeune and Camp Pendleton cohorts.  
313 For the Marines/Navy personnel, the analyses focused on comparisons between the Camp

314 Lejeune and Camp Pendleton 1975-1985 subgroup. Analyses of the full cohort of Marines/Navy  
315 personnel are presented in Supplemental file 1, Tables S1-2 to S1-4.

316  
317 Follow-up began on January 1, 1996, and continued until date of death or December 31, 2017,  
318 whichever was earlier. Because exposures among the Camp Lejeune cohorts occurred more than  
319 10 years before the start of follow-up, the data analyses did not lag exposures to account for a  
320 latency period. Data analyses evaluated each primary cancer site as well as the histological  
321 subtypes for some primary cancer sites.

322  
323 Descriptive analyses included the calculation of standardized incidence ratios (SIRs) for each  
324 base and primary cancer site. The sex, race and five-year age-specific cancer incidence statistics  
325 for 1999-2017 for the United States and Puerto Rico from the CDC WONDER online database  
326 were used as the basis for calculating the SIRs. Poisson regressions comparing the sex, race, and  
327 five-year age-specific cancer incidence rates for Camp Lejeune versus Camp Pendleton were  
328 conducted as part of the descriptive analyses because comparisons of the SIRs between the two  
329 bases could be impacted by residual confounding bias due to differences in the distributions of  
330 age, sex and/or race.

331  
332 To calculate the SIRs and conduct the Poisson regressions, person-years at risk were  
333 accumulated during the follow-up period from 1996 to 2017 and were stratified by base, sex,  
334 race and 5-year age categories. Person-years at risk were assigned to Camp Lejeune if the  
335 individual was stationed or employed at the base anytime between 1975 and 1985  
336 (Marines/Navy personnel) or between October 1972 and 1985 (civilian workers), regardless of  
337 whether the individual was also stationed or employed at Camp Pendleton during these periods.  
338 Person-years at risk were assigned to Camp Pendleton only if the individual was stationed or  
339 employed at that base between 1975 and 1985 (Marines/Navy personnel) or October 1972 to  
340 1985 (civilian workers) and not stationed at Camp Lejeune during these periods.

341  
342 The aggregate data from the Kansas and West Virginia registries did not identify Marines and  
343 Navy personnel belonging to the subgroup, so the aggregate data were only used in the SIR and  
344 Poisson regression analyses comparing the Camp Lejeune and Camp Pendleton full cohort. In

345 addition to the individual-level cancer data, a total of 510 cancers from the aggregate data  
346 obtained from the West Virginia and Kansas cancer registries were included in the SIR and  
347 Poisson regression analyses of the full cohort. For the civilian workers, the SIR and Poisson  
348 regression analyses included the individual-level cancer data as well as 21 cancers from the  
349 aggregate data obtained from the West Virginia and Kansas cancer registries.

350  
351 The main analysis evaluated individual-level data using Cox proportional hazards (Cox)  
352 regression to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for each cancer  
353 site and histological subtype. Age was the time variable. Marines/Navy personnel, and civilian  
354 workers stationed or employed at Camp Lejeune were compared to those stationed or employed  
355 at Camp Pendleton. For the analyses of Marines/Navy personnel, the adjusted models included  
356 sex, race, rank, and education level (not a high school graduate, high school graduate, college  
357 graduate and higher). For the analyses of civilian workers, the adjusted models included sex,  
358 race, blue collar work (y/n), and education level. Blue collar work included manual jobs such as  
359 maintenance workers, mechanics, construction workers, laundry and dry-cleaning workers, pest  
360 control workers and water treatment plant workers. Evaluation of Schoenfeld residuals was used  
361 to check the proportional hazards assumption. The Schoenfeld residuals are calculated for all  
362 covariates for each individual experiencing an event at a given age and consist of the differences  
363 between that individual's covariate values at the age when the event occurred and the  
364 corresponding risk-weighted average of covariate values among all those then at risk at that age.  
365 The proportional hazards assumption is met if there is no pattern in the residuals over age.

366  
367 The main analyses of the Marines/Navy personnel focused on comparisons between the Camp  
368 Lejeune and Camp Pendleton 1975-1985 subgroup. Secondary analyses evaluated the full cohort  
369 comparing Camp Lejeune and Camp Pendleton. For civilian workers, the main analyses also  
370 focused on comparisons between Camp Lejeune and Camp Pendleton.

371  
372 In the previous Camp Lejeune mortality studies, residential cumulative exposure to each  
373 contaminant was evaluated based on linking the estimated monthly concentrations in the TT, HP  
374 and HB water systems from the historical reconstruction modeling and Camp Lejeune base  
375 family housing records and information on the barrack location of each military unit [12-13]. In

376 this study, cumulative residential exposure to each contaminant was not conducted because  
377 drinking water exposures during training and other base activities would likely contribute  
378 significantly to overall cumulative exposure. Since information on training and other base  
379 activities was not available, the study focused instead on duration of assignment (Marines/Navy  
380 personnel) or duration of employment (civilian workers) at Camp Lejeune as a surrogate for  
381 overall cumulative exposure. Duration at Camp Lejeune is defined as the number of quarters in  
382 the DMDC database an individual is stationed or employed at Camp Lejeune during 1975-1985  
383 for Marines/Navy personnel and during October 1972 and December 1985 for civilian workers.  
384 Cox regression analyses using categorical variables for duration were conducted with Camp  
385 Pendleton Marines/Navy personnel and civilian workers as the comparison groups.

386  
387 In the Cox regression analyses, an individual could contribute cancers at more than one cancer  
388 site but not more than one per site. For example, if a person had recurrent lung cancer records  
389 during the follow-up period, only the first lung cancer during the period was included in the  
390 analysis of the lung cancer site. However, an individual could contribute to more than one  
391 subtype of a particular cancer site. For example, an individual who had a lung cancer  
392 adenocarcinoma histology and later had a lung cancer squamous cell histology would be  
393 included in the analysis of each of these histological subtypes.

394  
395 Information on smoking and alcohol consumption was not available. Occupational history prior  
396 to or after active-duty service or employment at Camp Lejeune or Camp Pendleton was also  
397 unavailable.

398  
399 To assess the possible confounding effects of smoking and alcohol consumption, the study  
400 evaluated “negative control” diseases that are associated with the unmeasured risk factor (i.e., the  
401 potential confounder) but were not known to be associated with the exposures of interest, i.e.,  
402 exposure to the drinking water contaminants at Camp Lejeune [26]. Negative controls were used to  
403 estimate prevalence differences in smoking and alcohol consumption between Camp Lejeune and  
404 Camp Pendleton. The negative control diseases for smoking were mortality due to chronic  
405 obstructive pulmonary disease (COPD) and cardiovascular disease. Several smoking-related  
406 cancers, such as cancers of the lung, larynx, and bladder [27], were included in the study but were

407 not considered negative controls because there was at least some evidence in the scientific literature  
408 linking these cancers to one or more of the contaminants in the drinking water [15, 18, 28-33]. The  
409 negative control diseases included for alcohol consumption were mortality due to alcoholism,  
410 alcoholic liver disease and chronic liver disease. Several alcohol-related cancers, such as cancers of  
411 the oral cavity and pharynx (“oral cancers”), larynx, liver, esophagus, colon and female breast [34]  
412 were included in the study but were not considered negative controls because there was at least  
413 some evidence in the scientific literature linking these cancers to one or more of the contaminants in  
414 the drinking water [15, 18, 30-31, 35-36].

415  
416 Quantitative bias analyses were conducted to estimate quantitatively, and adjust the HR estimates  
417 for, the systematic errors (or biases) due to unmeasured confounding factors and exposure  
418 misclassification. The analyses focused on the dichotomous subgroup comparisons between Camp  
419 Lejeune and Camp Pendleton, and used Excel spreadsheets included with the textbook, Applying  
420 Quantitative Bias Analysis to Epidemiologic Data, Second Edition [37]. A quantitative bias  
421 analysis involves choosing a bias model (e.g., exposure misclassification), an analytic technique  
422 (e.g., a multidimensional analysis), and values for the parameters of the bias model (e.g., for  
423 exposure misclassification, the bias parameters could be the sensitivity and specificity of the  
424 exposure classification). The values of the bias parameters are applied to the observed data using  
425 bias adjustment equations to calculate what the data would have been if the bias were absent. The  
426 quantitative bias analyses of the impacts of unmeasured confounding due to smoking and alcohol  
427 consumption used the negative control results to determine the values for the bias parameters of the  
428 bias model.

429  
430 Quantitative bias analyses of exposure misclassification assumed that the misclassification was non-  
431 differential and independent because: (1) the base assignments derived from the unit codes for  
432 Marines/Navy personnel were completed over ten years prior to cancer data collection, and (2) the  
433 base location of employment for civilian workers was recorded in the DMDC database more than  
434 thirty years prior to cancer data collection [37].

435  
436 For Camp Lejeune Marines/Navy personnel, the sources of possible exposure misclassification  
437 were due to using unit assignment to a base as a proxy for exposure to the drinking water. First,

438 errors were possible in the historical research conducted by the DMDC and USMC to determine the  
439 base where each unit was located. Second, even if the base assignment of the unit was correct, some  
440 individuals may not have been exposed to the contaminated drinking water because they were  
441 deployed to a different base (e.g., outside the country) or trained at a different base. Third, some  
442 individuals stationed at Camp Lejeune may not have been exposed because all their water  
443 consumption (including showering and other water uses) occurred off-base (e.g., in off-base  
444 housing) or in areas of the base not served by the HP or TT drinking water systems. On the other  
445 hand, most of those classified as stationed at Camp Pendleton likely were truly unexposed to the  
446 contaminated drinking water.

447  
448 For Camp Lejeune civilian workers, the main source of exposure misclassification was due to water  
449 consumption (including showering and other water uses) occurring mostly or entirely off-base (e.g.,  
450 at their residences). In addition, the workplaces of some of the Camp Lejeune civilian workers may  
451 have been located in areas not served by the contaminated drinking water. All civilian workers at  
452 Camp Pendleton were assumed to be truly unexposed to contaminated drinking water during the  
453 study period.

454  
455 To conduct the quantitative bias analyses, it was assumed that the sensitivity of the exposure  
456 classification for the Marines/Navy personnel and civilian workers, i.e., the probability that the truly  
457 exposed individuals were correctly classified as exposed (i.e., assigned to Camp Lejeune) was near  
458 1.0. The specificity of the exposure classification, i.e., the probability that the truly unexposed  
459 individuals were correctly classified as unexposed (i.e., assigned to Camp Pendleton) was assumed  
460 to range from 0.81 to 0.91. The chosen values for sensitivity and specificity used in the quantitative  
461 bias analysis reflected the assumptions that between 75% and 90% of those stationed or employed  
462 at Camp Lejeune were truly exposed, and all (or virtually all) of those stationed or employed at  
463 Camp Pendleton were truly unexposed.

464  
465 Interpretation of study findings was based primarily on the magnitude of the adjusted HR, its  
466 precision, and whether a finding was supported by other studies published in the scientific  
467 literature of occupational or drinking water exposures to the chemicals found in the drinking  
468 water at Camp Lejeune. Because many of the meta-analyses published in the scientific literature



469 for TCE occupational exposures and kidney cancer, NHL and liver cancer observed summary  
470 risk ratios between 1.20 and 1.40 [15], the present study emphasized HRs  $\geq 1.20$ . A HR of 1.20  
471 implies that the cancer occurs 1.2 times more often in the Camp Lejeune cohort compared to the  
472 Camp Pendleton cohort.

473  
474 For Marines/Navy personnel, the interpretation of the findings for rare cancers that primarily  
475 occur among older populations, such as male breast cancer, was supplemented by the findings  
476 from the Cox regression analyses of the Camp Lejeune and Camp Pendleton full cohort. The  
477 analyses of duration stationed or employed at Camp Lejeune provided additional information  
478 that was used in the interpretation of the findings. Emphasis was on monotonic trends, i.e., when  
479 every change in the adjusted HR with increasing duration is in the same direction (e.g., the HR  
480 increases), although the trend could have flat segments but never reverse direction [38].

481  
482 The 95% confidence interval ratio (CIR), measured by the quotient of the upper to lower limit,  
483 was used to indicate the precision (or degree of random variability) of the effect estimates i.e.,  
484 the SIR, the risk ratio (RR) and the HR estimates [39-40]. The ratio is primarily impacted by the  
485 level of the confidence interval (e.g., a 95% CI) and the number of cases of a cancer in the  
486 groups being compared. The smaller the number of cases, the wider the confidence interval and  
487 therefore the larger the CIR. The study emphasized adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$ .

488  
489 Because p-values and statistical significance testing are “commonly misused and misinterpreted”  
490 [41], significance testing was not used to interpret findings [38, 42]. Instead, the interpretation of  
491 findings was based on: (1) the magnitude of the adjusted HR estimate (i.e.,  $\geq 1.20$ ), (2) the  
492 precision of the estimate (i.e., the 95% CIR  $\leq 3$ ), (3) the quantitative impacts of unmeasured  
493 potential confounders (e.g., smoking and alcohol consumption) and exposure misclassification  
494 on the adjusted HR estimate, and (4) supporting information from the scientific literature on the  
495 health effects of TCE, PCE, vinyl chloride and benzene [40, 42-43]. Analyses were conducted  
496 using SAS 9.4 and STATA 16, and SPSS was used for data management.

497  
498 This study was approved by the Centers for Disease Control and Prevention Institutional Review  
499 Board.

500

## 501 Results

502 Demographic information for the civilian workers and the subgroup of Marines/Navy personnel  
503 is provided in Tables 1a and 1b. Tables providing demographic information and all statistical  
504 results for the Camp Pendleton and Camp Lejeune full cohort of Marines/Navy personnel are  
505 included in the Supplemental file 1, Tables S1-2 to S1-4.

506

507 The median age of the Camp Lejeune and Camp Pendleton Marines/Navy personnel subgroup at  
508 the start of follow-up was 35 years, and the median age at the end of follow-up was 57 years  
509 (Table 1a). Most of the Marines/Navy personnel were male (95.6%), White (75.7%), and ranged  
510 in rank from E1 to E4 (81.5%). The average length of follow-up was 20 years, and the total  
511 number of person-years was approximately 7.04 million (Camp Lejeune: 3.42 million, Camp  
512 Pendleton: 3.63 million). The total number of malignancies (including bladder cancer in situ)  
513 was 24,227 (Camp Lejeune: 12,083 and Camp Pendleton: 12,144). The total number of  
514 individuals with a malignancy or with bladder cancer in situ was 22,536 (Camp Lejeune: 11,207,  
515 Camp Pendleton: 11,329). The incidence rates were 354 per 100,000 person-years for Camp  
516 Lejeune and 335 per 100,000 person-years for Camp Pendleton.

517

518 For civilian workers (Table 1b), the percentages of women in the workforce at Camp Lejeune  
519 and Camp Pendleton were 53.4% and 48.4%, respectively. Most of the workforce at both bases  
520 were white (77%). A much higher percentage of the Camp Lejeune workforce was African  
521 American (18.1%) compared to Camp Pendleton (8.0%). A higher percentage of workers at  
522 Camp Lejeune graduated from college (16.1%) compared to Camp Pendleton (7.4%). Over half  
523 of the workers in the study were above 70 years of age at the end of follow-up. The average  
524 length of follow-up was slightly over 17 years, and the total amount of person-years was  
525 223,382. The total number of malignant cancers (including bladder cancer in situ) was 2,979  
526 (Camp Lejeune: 1,563, Camp Pendleton: 1,416). The total number of individuals with a  
527 malignancy or with bladder cancer in situ was 2,599 (Camp Lejeune: 1,359, Camp Pendleton:  
528 1,240). The incidence rates were 1,301 per 100,000 person-years for Camp Lejeune and 1,372  
529 per 100,000 person-years for Camp Pendleton.

530

531 The results of the SIR and Poisson regression analyses for the Camp Lejeune and Camp  
532 Pendleton Marines/Navy personnel subgroup are shown in Table 2. The SIRs for many of the  
533 cancers evaluated were less than 1.00, consistent with a “healthy veteran effect.” [21-23]. The  
534 healthy veteran effect is due to several factors including the initial physical screening for healthy  
535 recruits, physical fitness standards during military service, and access to quality health care  
536 during and after service. The healthy veteran effect may have been especially strong in the  
537 subgroup because over three-quarters of the members of the subgroup were less than 60 years of  
538 age at the end of follow-up (Table 1a). However, SIRs were above 1.00 at both Camp Lejeune  
539 and Camp Pendleton for melanoma, oral cancers and cancers of the brain and central nervous  
540 system, and female breast (Table 2).

541

542 The Poisson regression analyses comparing the Camp Lejeune and Camp Pendleton  
543 Marines/Navy personnel subgroup observed RRs  $\geq 1.20$  (i.e., an increase in risk of  $\geq 20\%$ ) with  
544 95% CIRs  $\leq 3$  for acute myeloid leukemia (AML) (RR=1.41, 95% CI: 1.17, 1.69), and cancers of  
545 the esophagus (RR=1.24, 95% CI: 1.09, 1.41), larynx (RR=1.24, 95% CI: 1.06, 1.46) and thyroid  
546 (RR=1.23, 95% CI: 1.06, 1.43) (Table 2). In the Poisson regression analyses comparing the  
547 Camp Lejeune and Camp Pendleton full cohort, most of the results were similar to the subgroup  
548 results. However, for male breast cancer, the number of cases in the full cohort was nearly  
549 double that in the subgroup and the RR was 1.39 (95% CI: 1.05, 1.85) (Supplemental file 1,  
550 Table S1-3). For comparison, the RR for male breast cancer was 1.19 (95% CI: 0.85, 1.68) in the  
551 subgroup (Table 2).

552

553 The results of the SIR and Poisson regression analyses for the civilian workers are shown in  
554 Table 3. Compared to Camp Pendleton, civilian workers at Camp Lejeune had RRs  $\geq 1.20$  with  
555 95% CIR  $\leq 3$  for NHL (RR=1.24, 95% CI: 0.91, 1.68), female breast cancer (RR=1.23, 95% CI:  
556 0.96, 1.58), oral cancers (RR=1.65, 95% CI: 1.00, 2.72) and AML (RR=1.30, 95% CI: 0.77,  
557 2.19). Thyroid cancer and male breast cancer had RRs  $\geq 1.20$  but with 95% CIRs  $> 3$ .

558 In the analyses using Cox regression methods, the unadjusted and adjusted HRs comparing the  
559 Camp Lejeune and Camp Pendleton Marines/Navy personnel subgroup are shown in Table 4.

560 (The Cox regression results for the comparisons between the Camp Lejeune and Camp Pendleton

561 full cohort are provided in Supplemental file 1, Table S1-4). The Cox regressions included age as  
562 the time variable, base where the individual's unit was stationed, sex, race, rank, and education  
563 level during the study period. Adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$  were observed for AML  
564 (HR=1.38, 95% CI: 1.03, 1.85), all myeloid cancers including polycythemia vera (HR=1.24,  
565 95% CI: 1.03, 1.49) and cancers of the esophagus (HR=1.27, 95% CI: 1.03, 1.56), larynx  
566 (HR=1.21, 95% CI: 0.98, 1.50), soft tissue (HR=1.21, 95% CI: 0.92, 1.59) and thyroid  
567 (HR=1.22, 95% CI: 1.03, 1.45). Adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$  were also observed for  
568 lung cancer histological subtypes, non-small cell carcinoma (HR=1.23, 95% CI: 0.97, 1.56),  
569 large cell lung cancer (HR=1.38, 95% CI: 0.84, 2.28) and adenocarcinoma (HR=1.25, 95% CI:  
570 1.10, 1.41). In addition, adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$  were observed for  
571 myelodysplastic and myeloproliferative syndromes (HR = 1.68, 95% CI: 1.07, 2.62),  
572 polycythemia vera (HR=1.41, 95% CI: 0.94, 2.11), marginal zone B-cell (MZBCL) lymphoma  
573 (HR=1.45, 95% CI: 0.92, 2.28), and squamous cell esophageal cancer (HR=1.47, 95% CI: 0.96,  
574 2.25).

575  
576 Most of the Cox regression adjusted results for the Camp Lejeune and Camp Pendleton  
577 Marines/Navy personnel full cohort appeared similar to the subgroup results (Supplemental file  
578 1, Table S1-4), except for male breast cancer. In the subgroup analysis, the HR for male breast  
579 cancer was 0.99 with a 95% CIR  $>3$ , whereas the HR in the full cohort was 1.24 with a 95% CIR  
580  $\leq 3$ .

581  
582 For civilian workers, the Cox regression analysis comparing Camp Lejeune to Camp Pendleton  
583 is presented in Table 5. Adjusted hazard ratios (HRs)  $\geq 1.20$  with 95% CIRs  $\leq 3$  were observed for  
584 all myeloid cancers including polycythemia vera (HR=1.40, 95% CI: 0.83, 2.36) and squamous  
585 cell lung cancer (1.63, 95% CI: 1.10, 2.41). NHL had an adjusted HR of 1.19 (95% CI: 0.83,  
586 1.71) and female breast cancer had an adjusted HR of 1.19 (95% CI: 0.95, 1.49). The female  
587 breast cancer histological subtype ductal carcinoma had an adjusted HR of 1.32 (95% CI: 1.02,  
588 1.71). Several cancers and histological subtypes had adjusted HRs  $\geq 1.20$  but with 95% CIRs  $>3$   
589 including male breast cancer, oral cancers, thyroid cancer, acute myeloid leukemia,  
590 myelodysplastic and myeloproliferative syndromes, follicular and diffuse large B-cell  
591 lymphomas, and non-papillary transitional cell bladder carcinoma.

592 The Marines/Navy subgroup analysis of duration stationed at Camp Lejeune between 1975 and  
593 1985 as a categorical variable is presented in Table 6. The reference group consisted of those  
594 Marines/Navy personnel stationed at Camp Pendleton and not Camp Lejeune between 1975 and  
595 1985. The levels of duration were approximately quartiles of the data after removal of the  
596 reference group. Since the DMDC data was quarterly, the levels of the categorical variable  
597 consisted of the number of quarters the individual was stationed at Camp Lejeune: “low”  
598 duration (1 – 2 quarters), “medium” duration (>2 – 6 quarters), “medium/high” duration (>6 – 10  
599 quarters) and “high” duration (>10 quarters). A monotonic trend for thyroid cancer was  
600 observed, with the adjusted HR at the highest duration level of 1.32 (95% CI: 1.00, 1.75). No  
601 other monotonic trends were identified, and further results are reported in Table 6.

602  
603 For civilian workers, analysis of duration of employment between October 1972 and December  
604 1985 at Camp Lejeune with Camp Pendleton as the referent group is shown in Table 7. The  
605 levels of duration were approximately tertiles of the data after removal of the reference group.  
606 The levels of the categorical variable consisted of the number of quarters the worker was  
607 employed at Camp Lejeune between October 1972 and December 1985: “low” duration (1 – 4  
608 quarters), “medium” duration (5 – 21 quarters), and “high” duration (22– 53 quarters). A  
609 monotonic trend was observed for diffuse large B-cell lymphoma with a HR of 1.99 though this  
610 estimate was imprecise with a 95% CIR >3.

611  
612 The results of the Cox regression analyses of the negative control non-cancer diseases comparing  
613 the Camp Lejeune and Camp Pendleton civilian workers and the Marines/Navy personnel  
614 subgroup are shown in Supplemental file 2, Tables S2-1a and S2-1b. For the Marines/Navy  
615 personnel subgroup, adjusted HRs for underlying and contributing causes of death due to  
616 alcoholism, alcohol liver disease, chronic liver disease and cardiovascular disease were  $\leq 1.00$ .  
617 For COPD, the adjusted HRs for underlying and contributing causes of death were 1.08 and 1.02,  
618 respectively.

619  
620 Using a range of RRs from 3.00 to 5.50 for smoking and COPD [44], to fully explain the HR of  
621 1.08 for COPD, the difference in smoking prevalence between Camp Lejeune and Camp  
622 Pendleton Marines/Navy personnel would be about 6% (Supplemental file 2, Figure 1).

623 Adjusting for a smoking prevalence difference of 6% and assuming RRs for smoking and lung  
624 cancer and laryngeal cancer between 7.00 and 12.00, the HR of 1.16 for lung cancer would  
625 decrease to between 1.05 and 1.06 and the HR of 1.21 for laryngeal cancer would decrease to  
626 between 1.10 and 1.11 (Supplemental file 2, Figures 2 and 3). Assuming RRs for smoking and  
627 esophageal cancer around 2.5 [27, 45], the HR of 1.27 for esophageal cancer would decrease to  
628 between 1.18 and 1.25 (Supplemental file 2, Figure 4).

629  
630 For the subgroup of Marines/Navy personnel, the adjusted HRs for chronic liver disease  
631 mortality as an underlying and contributing cause were 0.93 and 0.88. A recent systematic  
632 review of alcohol consumption and mortality due to liver cirrhosis found RRs of 2.65, 6.83 and  
633 16.38 for drinking 25g/day (2 drinks/day), 50g/day (4 drinks/day) and 100g/day (8 drinks/day)  
634 compared to those who never drank alcoholic beverages [46]. A military survey conducted in  
635 1980 found that about 30% of Marines were heavy drinkers [47].

636  
637 To determine what prevalence differences in alcohol consumption between Camp Lejeune and  
638 Camp Pendleton Marines/Navy personnel would be necessary to fully explain the chronic liver  
639 disease mortality HRs of 0.93 and 0.88, a quantitative bias analysis was conducted assuming that  
640 at least 2/3 of Marines/Navy personnel at Camp Lejeune consumed  $\geq 1$  drink/day. It was also  
641 assumed that the RRs for alcohol consumption and chronic liver disease mortality ranged  
642 between 2.5 and 10 [46]. To fully explain the HRs of 0.93 and 0.88, the prevalence differences  
643 would range between 6% and 10% and between 11% and 16%, respectively (Supplemental file  
644 2, Figures 5-6). (Assuming a lower percentage of Camp Lejeune drinkers would decrease the  
645 prevalence difference range, e.g., if only half the Marines/Navy personnel at Camp Lejeune were  
646 drinkers, then the percentage difference ranges would be 5% - 9% and 9% - 15% for chronic  
647 liver disease mortality as underlying cause and as contributing cause, respectively.)

648  
649 Adjusting for an alcohol use prevalence difference of 10% between Camp Lejeune and Camp  
650 Pendleton Marines/Navy personnel, the HR of 1.47 for squamous cell esophageal cancer would  
651 increase to between 1.51 and 1.64 (Supplemental file 2, Figure 7). Adjusting for alcohol use, the  
652 HR of 1.27 for esophageal cancer would increase to between 1.30 and 1.41 (Supplemental file 2,

653 Figure 8). Adjusting for an alcohol use prevalence difference of 10% would increase the HR of  
654 1.21 for laryngeal cancer to between 1.22 and 1.32 (Supplemental file 2, Figure 9).

655  
656 The impact of non-differential exposure assessment on the adjusted HRs for base assignment,  
657 comparing the Camp Lejeune and Camp Pendleton Marines/Navy personnel subgroup was  
658 evaluated assuming that between 10% and 25% of those assigned to Camp Lejeune were truly  
659 unexposed and virtually none of those assigned to Camp Pendleton were truly exposed  
660 (Supplemental file 2, Table S2-2a). Adjusted for exposure misclassification, the HR of 1.16 for  
661 lung cancer would increase to between 1.18 and 1.22. For laryngeal cancer the HR of 1.21 would  
662 increase to between 1.24 and 1.28. For esophageal cancer, the HR of 1.27 would increase to  
663 between 1.30 and 1.36. For AML, the HR of 1.38 would increase to between 1.42 and 1.50.

664  
665 For civilian workers, the adjusted HRs for underlying and contributing causes of death due to  
666 alcoholism, alcoholic liver disease, chronic liver disease, and cardiovascular disease were  $\leq 1.00$ .  
667 For COPD mortality, the underlying cause HR was  $\leq 1.00$  but the contributing cause HR was  
668 1.05. Using a range of RRs from 3.00 to 5.50 for smoking and COPD [44], to fully explain the  
669 HR of 1.05 for COPD, the difference in smoking prevalence between Camp Lejeune and Camp  
670 Pendleton would be about 4% (Supplemental file 2, Figure 10).

671  
672 Adjusting for a smoking prevalence difference of 4% between Camp Lejeune and Camp  
673 Pendleton civilian workers, and assuming RRs for smoking and lung cancer and laryngeal  
674 between 7.00 and 12.00 [27], the HR of 1.15 for lung cancer would decrease to between 1.08 and  
675 1.09, and the HR of 1.18 for laryngeal cancer would decrease to 1.11 (Supplemental file 2,  
676 Figures 11-12). Adjusting for a smoking prevalence difference of 4% and RRs for smoking and  
677 oral cancers between 3.50 and 7.00 [27], the HR of 1.67 for oral cancers (oral cavity and  
678 pharynx) would decrease to between 1.57 and 1.59 (Supplemental file 2, Figure 13). Finally,  
679 assuming RRs for smoking and kidney cancer of between 1.20 and 1.60 [27, 48], adjusting the  
680 kidney cancer HR of 1.12 for a 4% smoking prevalence difference would decrease the HR to  
681 between 1.10 and 1.11 (Supplemental file 2, Figure 14).

682 For the civilian workers, the adjusted HR for chronic liver disease mortality as an underlying  
683 cause was 0.74. To determine what prevalence differences in alcohol consumption between

684 Camp Lejeune and Camp Pendleton workers would be necessary to fully explain the HR of 0.74  
685 for chronic liver disease mortality, a quantitative bias analysis was conducted. It was assumed  
686 that about 1/3 of the Camp Lejeune workers consumed  $\geq 1$  drink/day. Using a range of RRs  
687 between 2.5 and 10 for alcoholic consumption and chronic liver disease mortality [46], the  
688 prevalence differences would need to range between 15% and 25% (Supplemental file 2, Figure  
689 15). (Assuming that only 20% of Camp Lejeune workers consumed  $\geq 1$  drink/day, the prevalence  
690 difference would range from 11% to 21%. Assuming a higher percentage of Camp Lejeune  
691 drinkers would increase the prevalence difference range, e.g., if 50% of Camp Lejeune workers  
692 consumed  $\geq 1$  drink/day, the prevalence difference would range from 21% to 31%.) Adjusting for  
693 an alcohol use prevalence difference of 15% between Camp Lejeune and Camp Pendleton  
694 workers, the HRs of 1.19 for female breast cancer and laryngeal cancer would increase to  
695 between 1.20 and 1.27, and between 1.20 and 1.39, respectively (Supplemental file 2, Figures  
696 16-17). For oral cancers, the HR of 1.67 would increase to between 1.73 and 2.11 (Supplemental  
697 file 2, Figure 18).

698  
699 The analysis of the impact of non-differential exposure assessment on the adjusted HRs  
700 comparing Camp Lejeune and Camp Pendleton civilian workers used sensitivity values of 0.99  
701 and 1.00 and specificity values ranging from 0.81 to 0.91. The chosen values for sensitivity and  
702 specificity reflected the assumptions that between 75% and 90% of those stationed or employed at  
703 Camp Lejeune were truly exposed, and all (or virtually all) of those stationed or employed at Camp  
704 Pendleton were truly unexposed. Based on these values for sensitivity and specificity, the HRs for  
705 oral cancers and cancers of the lung, larynx, kidney, female breast and NHL were adjusted for  
706 non-differential exposure misclassification (Supplemental file 2, Table S2-2b). Adjusted for  
707 exposure misclassification, the HR for lung cancer of 1.15 would increase to between 1.16 and  
708 1.19. For laryngeal cancer, the HR of 1.18 would increase to between 1.20 and 1.23. For oral  
709 cancers, the HR of 1.67 would increase to between 1.73 and 1.85. For kidney cancer, the HR of  
710 1.12 would increase to between 1.14 and 1.16, and the HRs of 1.19 for NHL and female breast  
711 cancer would increase to between 1.21 and 1.24.

712

713



## 714 Discussion

715 This cohort study evaluated whether Marines/Navy personnel and civilian workers stationed or  
716 employed at Camp Lejeune during a portion of the period when the drinking water was  
717 contaminated had increased risks of cancers during the period from 1996 to 2017 compared to  
718 being stationed or employed at Camp Pendleton. Additional analyses evaluated duration  
719 stationed or employed at Camp Lejeune with Camp Pendleton as the reference group. These  
720 analyses of duration assumed that contamination levels did not fluctuate greatly from month to  
721 month between 1972 and 1985 for the workers and between 1975 and 1985 for the  
722 Marines/Navy personnel. However, the estimated monthly average contaminant levels in the  
723 Hadnot Point and Tarawa Terrace distribution systems varied widely. Therefore, the results of  
724 the duration analyses should be interpreted with caution.

725  
726 In the Cox regression analyses of the Marines/Navy personnel subgroup, several cancers had  
727 HRs  $\geq 1.20$  with 95% CIR  $\leq 3$ , including AML, cancers of the esophagus, larynx, thyroid, and  
728 soft tissue, all myeloid cancers (including polycythemia vera), and the lung cancer histological  
729 subtypes, non-small cell, large cell, and adenocarcinoma. HRs  $\geq 1.20$  with 95% CIR  $\leq 3$  were also  
730 observed for myelodysplastic and myeloproliferative syndromes, polycythemia vera, MZBCL,  
731 and squamous cell esophageal cancer. A monotonic trend for thyroid cancer with longer duration  
732 at Camp Lejeune was consistent with the elevated HR for thyroid cancer observed in the  
733 Marines/Navy personnel subgroup.

734  
735 In the Cox regression analysis comparing Camp Lejeune and Camp Pendleton civilian workers,  
736 cancers with HRs  $\geq 1.20$  with 95% CIR  $\leq 3$  were observed for all myeloid cancers (including  
737 polycythemia vera), squamous cell lung cancer and female ductal breast cancer. Several other  
738 cancers had HRs  $\geq 1.20$  but with 95% CIRs  $> 3$ . These included oral cancers, cancers of the  
739 thyroid and male breast, and acute myeloid leukemia, myelodysplastic and myeloproliferative  
740 syndromes, follicular and diffuse large B-cell lymphomas, and non-papillary transitional cell  
741 bladder carcinoma.

742  
743 In the comparisons between Camp Lejeune and Camp Pendleton workers and Marines/Navy  
744 personnel, the HRs for AML and myelodysplastic and myeloproliferative syndromes were

745 greater than 1.20. The grouping of all myeloid cancers (including polycythemia vera) had HRs  
746 greater than 1.20 in the comparisons between Camp Lejeune and Camp Pendleton workers and  
747 Marines/Navy personnel. AML is known to be caused by benzene exposure [8]. ATSDR  
748 previously concluded that the evidence for a causal association between TCE and AML was at  
749 least as likely as not based on TCE's effects on the immune system [15]. Benzene exposure has  
750 also been associated with myelodysplastic syndrome [49-50]. Another blood cancer,  
751 polycythemia vera, had a HR greater than 1.20 for Marines/Navy personnel, but the HR for  
752 civilian workers could not be calculated because there were 3 cases among Camp Lejeune  
753 workers and no cases among Camp Pendleton workers. Benzene exposure is possibly associated  
754 with polycythemia vera [51].

755  
756 Thyroid cancer had HRs  $\geq 1.20$  for Camp Lejeune Marines/Navy personnel and civilian workers  
757 compared to Camp Pendleton. The finding for the subgroup of Marines/Navy personnel was  
758 supported by a monotonic trend with duration at Camp Lejeune. Thyroid cancer has been  
759 associated with occupational exposures to solvents (e.g., benzene), particularly in the footwear  
760 industry, among women but not men [52]. However, a review of occupations and thyroid cancer  
761 concluded that the findings for solvents were "largely null" but recommended additional study  
762 [53].

763  
764 Although NHL had a HR of 1.01 for Marines/Navy personnel, several of its histological subtypes  
765 had HRs  $\geq 1.20$ . In the analysis of civilian workers, NHL had a HR of 1.19. Adjusting for non-  
766 differential exposure misclassification in the civilian workers analysis, the HR for NHL would  
767 have increased above 1.20 (Supplemental file 2, Table S2-2b). In addition, HRs  $> 1.20$  were  
768 observed for follicular and diffuse large B-cell lymphomas, though 95% CIRs were  $> 3$ . ATSDR  
769 previously concluded that the evidence for a causal association between TCE and NHL and  
770 between benzene exposure and NHL was sufficient [15]. Both TCE and benzene exposures have  
771 also been associated with some of the histological subtypes of NHL [54-56].

772  
773 Soft tissue cancer had a HR of 1.21 with 95% CIR  $\leq 3$  in the subgroup analyses comparing Camp  
774 Lejeune and Camp Pendleton Marines/Navy personnel. Soft tissue cancer had a HR of 1.38 (95%  
775 CI: 0.73, 2.64) in the previous Camp Lejeune mortality study of Marines/Navy personnel [12].

776 Studies of occupational exposures to PCE or TCE and soft tissue cancer have generally included  
777 a small number of cases. Two studies found elevated risks among females only for TCE [57] and  
778 working as a dry cleaner [58]. Two other studies that did not conduct sex-specific analyses  
779 observed elevated risks for soft tissue cancer and PCE exposure [59] and both PCE and TCE  
780 exposures [60], but these findings were based on few cases.

781  
782 Kidney cancer is known to be associated with TCE exposure [5]. In the current study the HRs  
783 were  $\leq 1.20$  in the comparisons between Camp Lejeune and Camp Pendleton. Papillary cell  
784 kidney cancer had a HR of 1.18 with 95% CIR  $\leq 2$  (95% CI 0.86-1.60) in the Marines/Navy  
785 personnel subgroup, and renal cell carcinoma NOS had a HR of 1.18 with 95% CIR  $> 3$  in the  
786 analysis of civilian workers.

787  
788 Male breast cancer had a HR  $\geq 1.20$  with 95% CIR  $\leq 3$  only in the full cohort analysis of  
789 Marines/Navy personnel (HR=1.24, 95% CI: 0.79, 1.93) which had almost double the number of  
790 cases than the subgroup analysis. A possible reason for the greater number of male breast cancer  
791 cases in the full cohort was that a much greater percentage (41.3%) in the full cohort were  $\geq 60$   
792 years of age at the end of follow-up compared to the subgroup (23.6%). In the U.S., about 75%  
793 of male breast cancers are diagnosed at age  $\geq 60$  years [61]. In the analysis of civilian workers,  
794 there were seven cases of male breast cancer among Camp Lejeune workers compared to one  
795 case among Camp Pendleton workers. Occupational TCE exposure has been associated with  
796 male breast cancer in three studies [57, 62-63]. In a case-control study of male breast cancer  
797 using data from the U.S. Department of Veterans Affairs cancer registry, men stationed at Camp  
798 Lejeune had an odds ratio of 1.14 (95% CI: 0.65, 1.97) compared to Marines at all other bases  
799 [14].

800  
801 Female breast cancer had a HR of 1.00 in the analysis of Marines and Navy personnel, but its  
802 histological subtype duct-lobular carcinoma had a HR  $\geq 1.20$ . In the analysis of civilian workers,  
803 female breast cancer had a HR of 1.19. Adjusting for non-differential exposure misclassification,  
804 the HR for female breast cancer would increase to above 1.20 (Supplemental file 2, Table S2-  
805 2b). Moreover, the female breast cancer HR of 1.19 would also increase if adjusted for possible

806 confounding due to alcohol consumption (Supplemental file 2, Figure 16). The female ductal  
807 carcinoma breast cancer had an adjusted HR of 1.32 with 95% CIR  $\leq 3$ .

808  
809 Some occupational studies of female breast cancer incidence and mortality have not supported a  
810 causal association with exposures to TCE, PCE, vinyl chloride, or benzene [15]. However, one  
811 case-control study found an increased risk of female breast cancer among pre-menopausal  
812 women who predominantly worked in dry cleaning [64]. A study of exposure to PCE-  
813 contaminated drinking water in Cape Cod, MA found an increased risk for breast cancer among  
814 women with the highest cumulative exposures [65]. Two recently published occupational studies  
815 of female breast cancer provide support for a causal association with TCE and/or PCE exposure  
816 [35-36]. A study in Taiwan found elevated risks for female breast cancer among workers  
817 exposed to TCE/PCE and benzene [35]. A case-control study of postmenopausal women found  
818 increased ORs for occupationally ever exposed to benzene and PCE and postmenopausal breast  
819 cancer ranging between 1.18 and 1.32 and between 1.92 and 2.83, respectively, (with the ranges  
820 depending on the adjustment model), but with 95% CIRs  $> 3$  [36].

821  
822 Several smoking associated cancers that have also been linked to exposures to TCE, PCE, and/or  
823 benzene were evaluated in this study including oral cancers and cancers of the esophagus,  
824 bladder, larynx, and lung. Meta-analyses have found relative risks for these cancers associated  
825 with smoking  $\geq 2.50$ . [27, 48].

826  
827 Oral cancers had a HR  $\geq 1.20$  in the analysis of civilian workers (95% CI 0.93, 3.00). There is  
828 some evidence linking PCE and TCE occupational exposures and oral cancers among females [30],  
829 but the evidence is much weaker for males [31]. Dry cleaning workers had a standardized mortality  
830 ratio of 1.10 for mortality due to cancers of the buccal cavity and pharynx [66]. Occupational  
831 benzene exposure has not been associated with oral cancers [67-68].

832  
833 In the subgroup analyses of Marines/Navy personnel, the HR for esophageal cancer was 1.27  
834 with 95% CIR  $\leq 3$ , and the HR for squamous cell esophageal cancer was 1.47 with 95% CIR  $\leq 3$ .  
835 Three occupational cohort studies have found associations between TCE exposures and  
836 esophageal cancer [15]. In addition, a previous cohort mortality study comparing Marines/Navy

837 personnel stationed at Camp Lejeune versus Camp Pendleton obtained a HR of 1.43 (95% CI:  
838 0.85, 2.38) for esophageal cancer [12].

839  
840 In the analysis of civilian workers, the bladder cancer histological subtype non-papillary  
841 transitional cell carcinoma had a HR  $\geq 1.20$  with 95% CIR  $>3$  (HR=1.30, 95% CI 0.70, 2.40). In  
842 the Marines/Navy personnel subgroup analysis of duration at Camp Lejeune, a HR  $\geq 1.20$  with  
843 95% CIR  $\leq 3$  (HR=1.33, 95% CI 0.99, 1.79) was only observed in the high duration category for  
844 bladder cancer in situ. Occupational exposure to PCE is associated with bladder cancer [15].

845  
846 For laryngeal cancer, HRs were 1.21 with 95% CIR  $\leq 3$  (95% CI 0.98, 1.50) for the  
847 Marines/Navy personnel subgroup and 1.18 with 95% CIR  $>3$  (95% CI 0.49, 2.82) for civilian  
848 workers. Laryngeal cancer has been associated with occupational exposure to PCE in men [31]  
849 and with occupational PCE and TCE exposure in women [30]. In a previous study, an odds ratio  
850 of 1.29 was found for men who were ever occupationally exposed to PCE or who were exposed  
851 to the low PCE cumulative exposure index [31].

852  
853 The lung cancer histological subtypes large cell, non-small cell, and adenocarcinoma had HRs  
854  $\geq 1.20$  with 95% CIR  $\leq 3$  in the analysis of the Marines/Navy personnel subgroup. Non-small cell  
855 lung cancer also had a HR  $\geq 1.20$  in the high duration category. In the analysis of civilian  
856 workers, squamous cell lung cancer had a HR  $\geq 1.20$  with 95% CIR  $\leq 3$ . Occupational exposure to  
857 PCE in dry cleaning has been associated with lung cancer in three cohort studies and one case-  
858 control study with relative risks in the range of 1.3 and 1.4 [28, 58, 69-70]. Two case-control  
859 studies of occupational exposure to PCE also found associations with lung cancer, especially in  
860 women [29, 71]. In addition, a study of drinking water exposures to PCE at Cape Cod, MA  
861 found an odds ratio of 3.7 for lung cancer among those with the highest cumulative exposure  
862 [18]. A case-control study of lung cancer and occupational exposures to benzene, toluene and  
863 xylene found an association for benzene with an odds ratio of 1.35 (95% CI: 0.99, 1.84) [32].

864  
865 This study did not have information on important risk factors such as smoking and alcohol  
866 consumption since these are not routinely collected by cancer registries. However, confounding  
867 due to failure to adjust for unmeasured risk factors was likely to be minor because of the

868 demographic and socio-economic similarity of the Camp Lejeune and Camp Pendleton cohorts.  
869 The prevalence of smoking and “heavy alcohol” consumption among Marines in 1980 was  
870 estimated at 53.4% and 28.6%, respectively [47]. Marines had a smoking prevalence slightly less  
871 than the Navy and Army but had the highest heavy alcohol consumption prevalence among the  
872 services [47]. Smoking and alcohol consumption among Marines were encouraged by the  
873 military culture, the stress of service, targeted advertising by the tobacco and alcoholic beverage  
874 industry, and the lower cost and tax-free availability of these products on base at both Camp  
875 Lejeune and Camp Pendleton compared to off-base civilian stores [47, 72].

876  
877 In the subgroup analysis of Marines/Navy personnel, the HRs for COPD and cardiovascular  
878 mortality were 1.08 and 0.99, suggesting minor if any difference in smoking behavior between  
879 Camp Lejeune and Camp Pendleton (Supplemental file 2, Table S2-1a). On the other hand, the  
880 HRs for mortality due to alcoholism, alcoholic liver disease and chronic liver disease as  
881 underlying causes were 0.90, 0.86, and 0.93 suggesting that the prevalence of alcohol use among  
882 Camp Lejeune Marines/Navy personnel may be lower than among Camp Pendleton  
883 Marines/Navy personnel (Supplemental file 2, Table S2-1a). For civilian workers, the HRs for  
884 COPD as an underlying and contributing cause of mortality were 0.91 and 1.05, and the HRs for  
885 cardiovascular disease were  $\leq 1.00$  suggesting minor if any difference in smoking behavior  
886 between Camp Lejeune and Camp Pendleton workers. On the other hand, the HRs for mortality  
887 due to alcoholism, alcoholic liver disease, and chronic liver disease were 0.62, 0.54 and 0.74,  
888 suggesting the prevalence of alcohol use among Camp Lejeune workers may have been lower  
889 than among Camp Pendleton workers.

890  
891 For smoking to fully explain the HRs observed for cancers of the lung and larynx in the analyses  
892 of Marines/Navy personnel and civilian workers, a difference of  $\geq 10\%$  in smoking prevalence  
893 would be necessary (see Supplemental file 2, Figures 2-3, 11-12). Given the similarity of the two  
894 bases, a percentage difference of this magnitude in the prevalence of smoking was unlikely.  
895 Based on the findings for COPD mortality, it is more likely that the difference in smoking  
896 prevalence between Camp Lejeune and Camp Pendleton Marines/Navy personnel and civilian  
897 workers is between 4% and 6% (Supplemental file 2, Figures 1, 10). Adjusting for a smoking

898 prevalence difference of 4% or 6% would reduce the HRs for the smoking-related cancers by  
899 less than 10% (Supplemental file 2, Figures 2-4, 11-14).

900

901 The findings for the negative control diseases for alcohol consumption, i.e., mortality due to  
902 alcoholism, alcoholic liver disease and chronic liver disease, suggest that Camp Lejeune  
903 Marines/Navy personnel and civilian workers had a lower prevalence of alcohol use than Camp  
904 Pendleton. The findings for these negative controls suggest that possible confounding due to  
905 alcohol consumption might have biased HRs towards the null for alcohol-related cancers such as  
906 oral cancers and cancers of the esophagus, larynx, and female breast. For laryngeal cancer,  
907 adjusting for possible differences in alcohol consumption between the two bases might cancel  
908 out the impact of adjusting for possible smoking differences between the two bases  
909 (Supplemental file 2, Figures 3, 9, 12, 17.). Similarly, for oral cancers among workers, and  
910 esophageal cancer among Marines/Navy personnel, the impact on the HRs of adjusting for  
911 alcohol use might cancel out the impact of adjusting for smoking. (Supplemental file 2, Figures  
912 4, 8, 13 and 18).

913

914 To evaluate the potential impact of non-differential and independent exposure misclassification,  
915 the sensitivity of the exposure classification, i.e., the probability that the truly exposed were  
916 correctly classified as exposed (i.e., assigned to Camp Lejeune) was assumed to be near 1.0. The  
917 specificity of the exposure classification i.e., the probability that the truly unexposed were correctly  
918 classified as unexposed (i.e., assigned to Camp Pendleton) was assumed to range between 0.81 to  
919 0.91. Adjusting for exposure misclassification using these values for sensitivity and specificity  
920 would increase the HRs by no more than 10% (Supplemental file 2, Tables 2a-2b). These results  
921 suggested that for cancers that are smoking-related, the bias due to non-differential exposure  
922 misclassification in this study may cancel out the potential confounding bias due to smoking.

923

924 Overall, the results of the quantitative bias analyses suggested that in this study, the impacts of  
925 adjusting for confounding by smoking or alcohol consumption, and adjusting for non-differential  
926 exposure misclassification, would likely be minor and may cancel each other. In particular, for  
927 cancers that are both smoking-related and alcohol-related, the impact of potential confounding

928 bias due to smoking may be more than counteracted by the impact of potential confounding bias  
929 due to alcohol consumption as well as the bias due to exposure misclassification.

930  
931 A major strength of this study was the collection of cancer incidence data from every state and  
932 territorial cancer registry, the D.C. registry, the VA cancer registry, and the DOD cancer registry.  
933 Collecting data from all these cancer registries was necessary because the Marines/Navy  
934 personnel resided in every state. Moreover, unlike the National Death Index, there is no central  
935 cancer incidence registry in the US that can provide individual-level cancer incidence data linked  
936 to the personal identifier information of persons in a study.

937  
938 Another major strength was the evaluation of histological subtypes for several of the cancer  
939 types including hematopoietic cancers and cancers of the lung, esophagus, oral cavity, kidney,  
940 bladder, and female breast cancer. The epidemiological findings of associations with exposures  
941 to certain chemicals such as those found in the drinking water at Camp Lejeune have differed  
942 among the histological subtypes of hematopoietic cancers [55, 73], lung cancer [74], and head  
943 and neck cancers [31]. It is possible that differences in associations may also occur among the  
944 histological subtypes of other cancers. In this study, both cancer types and histological subtypes  
945 were evaluated.

946  
947 Weaknesses of this study included several sources of non-differential exposure misclassification  
948 bias as well as the lack of information on smoking, alcohol consumption, and the occupations  
949 prior to and after active-duty service or employment at Camp Lejeune and Camp Pendleton. In  
950 addition, many of the HRs in the analyses had 95% CIRs >3 due predominantly to the small  
951 numbers of cases for the rare cancers and histological subtypes. In particular, many HRs in the  
952 analyses of the civilian workers had 95% CIRs >3 due to small numbers of cases.

953  
954 Many of the HRs observed in this study were less than 1.50. This result was not unexpected  
955 because the exposures to the drinking water contamination at Camp Lejeune were likely lower  
956 and of shorter duration than occupational exposures to these chemicals. Nevertheless, risk  
957 estimates for many of these cancers from occupational exposures to these chemicals also tend to  
958 be less than 1.50. For example, the HR of 1.21 for laryngeal cancer in the subgroup analysis



959 comparing Camp Lejeune and Camp Pendleton Marines/Navy personnel was similar in size to  
960 the odds ratio of 1.29 for ever/never occupational exposure to PCE among males in a case-  
961 control study conducted in France [31]. Three meta-analyses of occupational exposures to TCE  
962 and kidney cancer found relative risks in the 1.3 to 1.4 range [15]. A meta-analysis of TCE and  
963 NHL observed a summary relative risk of 1.32 [75]. The meta-analysis of occupational exposure  
964 to PCE and bladder cancer found a RR of 1.08 for PCE-exposed workers and a RR of 1.47 for  
965 employment as a dry cleaner [76]. A meta-analysis of occupational benzene exposure and NHL  
966 found a summary relative risk of 1.27 for those studies that had quantitative exposure  
967 assessments [77].

968  
969 An additional factor affecting both the magnitude of the HRs and the 95% CIRs in the subgroup  
970 analyses of the Marines/Navy personnel was that at the end of follow-up, the median age was 57  
971 years and over 75% of the subgroup members were under the age of 60 years. According to the  
972 NCI's SEER Program, between 2014 and 2018 the median age of a cancer diagnosis was 66  
973 years [78]. For cancers of the bladder, lung, pancreas, and gallbladder, as well as chronic  
974 lymphocytic leukemia and myelodysplastic syndrome, the median age at diagnosis is  $\geq 70$  years.  
975 For cancers that have been associated with occupational TCE exposure such as NHL, and  
976 cancers of the kidney and liver, the median ages at diagnosis are 67, 64, and 65 years,  
977 respectively. For several other cancers that have been associated with occupational exposures to  
978 TCE or benzene, such as AML and multiple myeloma, the median ages at diagnosis are 68 and  
979 69 years, respectively [78].

980

## 981 Conclusion

982 In the analyses of the Marines/Navy personnel subgroup, adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$   
983 were observed for all myeloid cancers including polycythemia vera, AML, myelodysplastic and  
984 myeloproliferative syndromes, polycythemia vera, cancers of the esophagus, larynx, thyroid, and  
985 soft tissue, and the histological subtypes marginal zone B-cell lymphoma, squamous cell  
986 esophageal cancer and the lung cancer subtypes large cell, non-small cell and adenocarcinoma.  
987 The finding for thyroid cancer was supported by a monotonic trend for duration at Camp  
988 Lejeune. In the full cohort of Marines/Navy personnel, male breast cancer had an adjusted HR  
989  $\geq 1.20$  with a 95% CIR  $\leq 3$ .

990 In the analyses of civilian workers, adjusted HRs  $\geq 1.20$  with 95% CIRs  $\leq 3$  were observed for all  
991 myeloid cancers including polycythemia vera, and the histological subtypes squamous cell lung  
992 cancer and female ductal breast cancer. Adjusted HRs  $\geq 1.20$  that did not meet the criterion for  
993 precision (i.e., 95% CIRs  $> 3$ ) due to small numbers of cases included oral cancers, thyroid  
994 cancer, AML, myelodysplastic and myeloproliferative syndromes, follicular and diffuse large B-  
995 cell lymphomas, and non-papillary transitional cell bladder carcinoma. NHL and female breast  
996 cancer had adjusted HRs of 1.19 with 95% CIRs  $\leq 3$ .

997  
998 Few studies have evaluated drinking water exposures to these chemicals and cancer incidence.  
999 The adult cancer incidence of the family members of the Marines and Navy personnel who  
1000 resided in base family housing at Camp Lejeune has not been evaluated. Families living in base  
1001 housing that received contaminated drinking water may have had exposure durations that were  
1002 longer than most Marines and Navy personnel on base. The results of this study are relevant to  
1003 all individuals exposed to the contaminated drinking water at Camp Lejeune and add to the  
1004 literature on the health effects of these contaminants. It is hoped that this study encourages future  
1005 research on the health effects of drinking water exposure to these chemicals.

1006

#### 1007 **Competing interests**

1008 The author declares no actual or potential competing financial interest.

1009

#### 1010 **Authors' contributions**

1011 FJB designed the study, oversaw the data collection, managed, analyzed and interpreted the data,  
1012 and prepared the manuscript. Battelle and NAACCR staff recruited the cancer registries,  
1013 designed and oversaw the data collection, conducted data linkages for some of the registries and  
1014 managed the data.

1015

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1037

1038 **ATSDR/CDC Disclaimer**

1039 The findings and conclusions in this manuscript are those of the author and do not necessarily  
1040 represent the official position of the Centers for Disease Control and Prevention/Agency for  
1041 Toxic Substances and Disease Registry.  
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1373 **Tables**

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1402 Table 1a. Demographic information for the Marines/Navy personnel subgroup:  
 1403 Marines/Navy personnel at risk during the follow-up period who began active duty  
 1404 and were stationed at Camp Lejeune or Camp Pendleton between 1975 and 1985

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Factor	Camp Lejeune N=154,821 (48.6%)	Camp Pendleton (ref) N=163,484 (51.4%)	Total N=318,305
Male	146,772 (94.8%)	157,617 (96.4%)	304,389 (95.6%)
Female	8,049 (5.2%)	5,867 (3.6%)	13,916 (4.4%)
White	113,525 (73.3%)	127,385 (77.9%)	240,910 (75.7%)
African American	37,138 (24.0%)	27,599 (16.9%)	64,737 (20.3%)
Other or unknown race	4,158 (2.7%)	8,500 (5.2%)	12,658 (4.0%)
Rank E1 – E4	126,471 (81.7%)	132,874 (81.3%)	259,345 (81.5%)
Rank E5 – E9	22,662 (14.6%)	23,051 (14.1%)	45,713 (14.4%)
WO or CO	5,688 (3.7%)	7,559 (4.6%)	13,247 (4.2%)
Not a high school graduate	19,035 (12.3%)	26,039 (15.9%)	45,074 (14.2%)
High school graduate	129,843 (83.9%)	129,419 (79.2%)	259,262 (81.5%)
College graduate	5,943 (3.8%)	8,026 (4.9%)	13,969 (4.4%)
Age at start of follow-up (1/1/1996)			
Mean (years)	35.0	35.2	35.1
Median (years)	35	35	35
Age at end of follow-up (12/31/2017 or date of death)			
Mean	56.3	56.5	56.4
Median	57	57	57
Age ≥60 years	35,426 (22.9%)	39,734 (24.3%)	75,160 (23.6%)
Age >69 years	292 (0.2%)	277 (0.2%)	569 (0.2%)
Died during 1/2/1996 – 12/31/2017	13,632 (8.8%)	14,904 (9.1%)	28,536 (9.0%)
Length of follow-up (years)			
Mean (years)	20.3	20.3	20.3
Median (years)	21	21	21
Total person-years of follow-up	3,417,738 (48.5%)	3,626,570 (51.5%)	7,044,308

Quarters in the DMDC data, 1975-1985*	Camp Lejeune	Camp Pendleton	
Mean	7.7	7.2	
Median	7.0	6.0	
Minimum	1	1	
Maximum	41	42	
Interquartile range (25 <sup>th</sup> -75 <sup>th</sup> percentiles)	8 (3 – 11)	8 (3 – 11)	
Cancers	Camp Lejeune	Camp Pendleton	Total
Total number of malignancies (including bladder cancer in situ)	12,083	12,144	24,227
Total number of individuals with any malignancy or bladder cancer in situ	11,207	11,329	22,536

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1409 Abbreviations: E1 – E4: private to corporal;

1410 E5 – E9: sergeant to sergeant major;

1411 WO: warrant officer;CO: commissioned officer

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1413 The table does not include aggregate cancer data obtained from the West Virginia and Kansas

1414 cancer registries.

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1416 \* Number of quarters at either Camp Lejeune or Camp Pendleton during 1975-1985. Some  
 1417 members of the Camp Lejeune cohort, who were stationed at least one quarter at Camp Lejeune  
 1418 during 1975-1985, were also stationed at Camp Pendleton during 1975-1985. So, the statistics  
 1419 for the Camp Lejeune cohort include quarters at Camp Pendleton during 1975-1985. The Camp  
 1420 Pendleton cohort members were not stationed at Camp Lejeune during 1975-1985.

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1434 Table 1b. Demographic information for civilian workers  
 1435 Civilian workers at risk during the follow-up period who were employed at Camp  
 1436 Lejeune or Camp Pendleton between October 1972 and December 1985

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Factor	Camp Lejeune N = 6,494 (52.8%)	Camp Pendleton (ref) N = 5,797 (47.2%)	Total N=12,291
Male	3,026 (46.6%)	2,992 (51.6%)	6,018 (49.0%)
Female	3,468 (53.4%)	2,805 (48.4%)	6,273 (51.0%)
White	4,998 (77.0%)	4,483 (77.3%)	9,481 (77.1%)
African American	1,178 (18.1%)	461 (8.0%)	1,639 (13.3%)
Other or unknown race	318 (4.9%)	853 (14.7%)	1,171 (9.5%)
Blue collar	2,251 (34.7%)	2,260 (39.0%)	4,511 (36.7%)
White collar	4,243 (65.3%)	3,537 (61.0%)	7,780 (63.3%)
Not a high school graduate	700 (10.8%)	483 (8.3%)	1,183 (9.6%)
High school graduate	4,746 (73.1%)	4,887 (84.3%)	9,633 (78.4%)
College graduate	1,048 (16.1%)	427 (7.4%)	1,475 (12.0%)
Age at start of follow-up (1/1/1996)			
Mean (years)	52.9	55.1	53.0
Median (years)	50	53	51
Age at end of follow-up (12/31/2017 or date of death)			
Mean	72.1	73.4	72.7
Median	71	73	71
Age >65 years	4,728 (72.8%)	4,288 (74.0%)	9,016 (73.4%)
Age >70 years	3,288 (50.6%)	3,270 (56.4%)	6,558 (53.4%)
Age >75 years	2,228 (34.3%)	2,415 (41.7%)	4,643 (37.8%)
Died during 1/2/1996 – 12/31/2017	2,251 (34.7%)	2,433 (42.0%)	4,684 (38.1%)
Length of follow-up (years)			
Mean (years)	17.7	17.0	17.4
Median (years)	21	21	21
Total person-years of follow-up	120,148 (53.8%)	103,234 (46.2%)	223,382

Quarters in the DMDC data, 10/1972-12/1985*	Camp Lejeune	Camp Pendleton	
Mean	19.5	17.6	
Median	12.0	10.0	
Minimum	1	1	
Maximum	53	53	
Interquartile range (25 <sup>th</sup> -75 <sup>th</sup> percentiles)	32 (3 – 35)	24 (4 – 28)	
Cancers	Camp Lejeune	Camp Pendleton (ref)	Total
Total number of malignancies (including bladder cancer in situ)	1,563	1,416	2,979
Total number of individuals with any malignancy or with bladder cancer in situ	1,359	1,240	2,599

1439

1440 The table does not include aggregate cancer data obtained from the West Virginia and Kansas  
1441 cancer registries.

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1443 \* Number of quarters employed at either Camp Lejeune or Camp Pendleton during 10/72-  
1444 12/1985. Some members of the Camp Lejeune cohort, who were employed at least one quarter at  
1445 Camp Lejeune during 10/72-12/1985, were also employed at Camp Pendleton during 10/72-  
1446 12/1985. So, the statistics for the Camp Lejeune cohort include quarters at Camp Pendleton  
1447 during 10/72-12/1985. The Camp Pendleton cohort members were not employed at Camp  
1448 Lejeune during 10/72-12/1985.

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Table 2. Standardized incidence rates and Poisson regression results:  
Marines/Navy personnel subgroup

CANCER	Camp Lejeune			Camp Pendleton			RR (CL vs CP)*
	N	SIR	95% CI	N	SIR	95% CI	
Oral Cavity and Pharynx	751	1.13	(1.05, 1.21)	792	1.09	(1.02, 1.17)	1.07 (0.98, 1.16)
Esophagus	196	0.93	(0.80, 1.07)	177	0.78	(0.67, 0.90)	1.24 (1.09, 1.41)
Stomach	173	0.75	(0.64, 0.86)	188	0.77	(0.66, 0.88)	0.97 (0.84, 1.12)
Liver and bile duct	322	0.88	(0.78, 0.98)	411	1.05	(0.94, 1.15)	0.89 (0.78, 1.00)
Gallbladder	7	0.47	(0.12, 0.82)	12	0.77	(0.34, 1.21)	0.54 (0.33, 0.88)
Pancreas	285	0.91	(0.80, 1.02)	291	0.88	(0.78, 0.98)	1.05 (0.91, 1.21)
Larynx	199	0.95	(0.81, 1.08)	176	0.80	(0.68, 0.92)	1.24 (1.06, 1.46)
Lung and Bronchus	1,302	0.88	(0.83, 0.93)	1,229	0.79	(0.74, 0.83)	1.15 (1.05, 1.25)
Melanoma	909	1.35	(1.26, 1.44)	1,043	1.33	(1.25, 1.41)	1.00 (0.93, 1.08)
Urinary Bladder	442	0.90	(0.82, 0.99)	463	0.84	(0.76, 0.91)	1.08 (0.98, 1.18)
Kidney and Renal Pelvis	732	1.03	(0.95, 1.10)	737	0.97	(0.90, 1.04)	1.08 (0.99, 1.18)
Brain and CNS	414	1.71	(1.54, 1.87)	445	1.67	(1.51, 1.82)	1.02 (0.90, 1.17)
Thyroid	286	0.93	(0.82, 1.04)	249	0.75	(0.66, 0.85)	1.23 (1.06, 1.43)
NHL	554	0.86	(0.79, 0.93)	597	0.86	(0.79, 0.93)	1.01 (0.92, 1.11)
Multiple Myeloma	186	0.92	(0.79, 1.05)	165	0.81	(0.68, 0.93)	1.13 (0.97, 1.32)
Leukemias	316	0.87	(0.77, 0.97)	320	0.81	(0.72, 0.90)	1.08 (0.96, 1.22)
Colon and rectum	1,093	0.79	(0.74, 0.84)	1,151	0.79	(0.74, 0.83)	1.01 (0.93, 1.09)
Colon	656	0.77	(0.71, 0.82)	714	0.79	(0.73, 0.85)	0.97 (0.88, 1.06)
Rectum	449	0.86	(0.78, 0.94)	452	0.79	(0.72, 0.87)	1.07 (0.95, 1.19)
Anus	63	0.87	(0.65, 1.08)	96	1.30	(1.04, 1.56)	0.67 (0.55, 0.82)
Soft Tissue Sarcoma	111	0.94	(0.76, 1.11)	102	0.81	(0.65, 0.97)	1.18 (0.96, 1.44)
Hodgkin	107	0.89	(0.72, 1.06)	114	0.91	(0.75, 1.08)	1.00 (0.81, 1.23)
ALL	23	0.84	(0.50, 1.18)	25	0.84	(0.51, 1.17)	0.97 (0.71, 1.32)
CLL	114	0.93	(0.76, 1.10)	122	0.89	(0.74, 1.05)	1.03 (0.87, 1.21)
AML	105	1.05	(0.85, 1.26)	82	0.76	(0.60, 0.92)	1.41 (1.17, 1.69)
CML	39	0.63	(0.43, 0.83)	56	0.85	(0.63, 1.07)	0.76 (0.59, 0.97)
Mesothelioma	14	0.78	(0.37, 1.18)	13	0.65	(0.30, 1.00)	1.17 (0.88, 1.54)
Breast Cancer - male	26	0.79	(0.49, 1.09)	23	0.67	(0.39, 0.94)	1.19 (0.85, 1.68)
Breast Cancer - female	340	1.15	(1.03, 1.27)	271	1.19	(1.05, 1.34)	0.95 (0.83, 1.08)
Prostate	2,850	0.93	(0.89, 0.96)	2,679	0.83	(0.80, 0.86)	1.08 (1.02, 1.15)
Testis	185	0.85	(0.73, 0.98)	220	0.90	(0.79, 1.02)	0.96 (0.82, 1.13)
Cervix	24	0.94	(0.56, 1.31)	17	0.92	(0.48, 1.36)	1.07 (0.70, 1.68)
Uterus	31	0.62	(0.40, 0.83)	50	1.23	(0.89, 1.57)	0.52 (0.39, 0.69)
Ovary	21	0.86	(0.49, 1.23)	19	0.99	(0.54, 1.43)	0.88 (0.55, 1.42)

Abbreviations: N: number; CL – Camp Lejeune; CP – Camp Pendleton; SIR – standardized incidence ratio; CI – confidence interval; RR – risk ratio; CNS – central nervous system; NHL – non-Hodgkin lymphoma; ALL – acute lymphocytic leukemia; CLL – chronic lymphocytic leukemia; AML – acute myeloid leukemia; CML – chronic myeloid leukemia



\* Poisson regression controlling for sex, race and 5-year age groups.

SIRs calculated relative to sex, race and five-year age-specific cancer incidence statistics for 1999-2017 for the United States and Puerto Rico from the CDC WONDER.

Includes cancer cases from the aggregate data provided by the West Virginia and Kansas cancer registries.

Table 3. Standardized incidence rates (SIR) and Poisson regression results:  
Civilian workers

CANCER	Camp Lejeune			Camp Pendleton			RR (CL vs CP)*
	N	SIR	95% CI	N	SIR	95% CI	
Oral Cavity and Pharynx	31	0.88	(0.57, 1.20)	19	0.58	(0.32, 0.85)	1.65 (1.00, 2.72)
Esophagus	8	0.48	(0.15, 0.81)	16	1.01	(0.52, 1.51)	0.49 (0.29, 0.85)
Stomach	17	0.75	(0.39, 1.11)	23	0.99	(0.59, 1.40)	0.67 (0.40, 1.13)
Colon and rectum	106	0.76	(0.61, 0.90)	113	0.85	(0.70, 1.01)	0.89 (0.68, 1.18)
Colon	77	0.76	(0.59, 0.93)	76	0.79	(0.62, 0.97)	0.94 (0.69, 1.27)
Rectum	31	0.79	(0.52, 1.07)	38	1.02	(0.72, 1.37)	0.83 (0.53, 1.31)
Liver and bile duct	14	0.65	(0.31, 1.00)	20	0.82	(0.48, 1.25)	0.74 (0.43, 1.29)
Pancreas	33	0.84	(0.55, 1.13)	47	1.27	(0.91, 1.63)	0.72 (0.47, 1.12)
Larynx	13	0.92	(0.42, 1.41)	10	0.83	(0.32, 1.35)	1.15 (0.62, 2.15)
Lung and Bronchus	262	1.14	(1.00, 1.28)	227	1.07	(0.94, 1.22)	1.12 (0.92, 1.37)
Melanoma	55	1.07	(0.80, 1.37)	55	1.04	(0.78, 1.33)	1.02 (0.74, 1.37)
Urinary Bladder	88	1.28	(1.03, 1.57)	85	1.14	(0.90, 1.38)	1.10 (0.87, 1.39)
Kidney and Renal Pelvis	59	1.18	(0.90, 1.50)	50	1.12	(0.83, 1.45)	1.10 (0.80, 1.50)
Brain and CNS	9	0.60	(0.21, 1.00)	17	1.22	(0.64, 1.81)	0.47 (0.28, 0.81)
Soft Tissue Sarcoma	7	0.92	(0.24, 1.60)	10	1.37	(0.52, 2.22)	0.66 (0.32, 1.34)
Thyroid	32	1.23	(0.81, 1.66)	14	0.64	(0.31, 0.98)	1.88 (1.04, 3.38)
NHL	72	1.29	(1.01, 1.60)	60	1.08	(0.80, 1.35)	1.24 (0.91, 1.68)
Multiple Myeloma	18	0.78	(0.42, 1.15)	16	0.81	(0.41, 1.20)	1.02 (0.62, 1.68)
Leukemias	36	0.99	(0.66, 1.31)	43	1.17	(0.82, 1.53)	0.83 (0.56, 1.22)
CLL	11	0.72	(0.29, 1.14)	16	1.04	(0.53, 1.55)	0.58 (0.34, 0.98)
AML	14	1.30	(0.62, 1.99)	11	1.02	(0.42, 1.62)	1.30 (0.77, 2.19)
CML	6	1.30	(0.26, 2.33)	9	1.96	(0.68, 3.24)	0.71 (0.32, 1.57)
Mesothelioma	5	1.51	(0.19, 2.83)	5	1.40	(0.17, 2.63)	0.99 (0.50, 1.97)
Breast Cancer - female	210	1.02	(0.89, 1.17)	134	0.83	(0.69, 0.97)	1.23 (0.96, 1.58)
Prostate	304	1.15	(1.03, 1.29)	248	1.02	(0.90, 1.15)	1.06 (0.89, 1.25)
Uterus	41	0.91	(0.65, 1.22)	34	0.99	(0.66, 1.32)	0.92 (0.64, 1.33)
Ovary	24	1.25	(0.75, 1.75)	26	1.69	(1.04, 2.33)	0.77 (0.50, 1.20)

Abbreviations: N: number; CL – Camp Lejeune; CP – Camp Pendleton; SIR – standardized incidence ratio; CI – confidence interval; RR – risk ratio; CNS – central nervous system; NHL – non-Hodgkin lymphoma; ALL – acute lymphocytic leukemia; CLL – chronic lymphocytic leukemia; AML – acute myeloid leukemia; CML – chronic myeloid leukemia

\* Poisson regression controlling for sex, race and 5-year age groups.

SIRs calculated relative to sex, race and five-year age-specific cancer incidence statistics for 1999-2017 for the United States and Puerto Rico from the CDC WONDER.

Includes cancer cases from the aggregate data provided by the West Virginia and Kansas cancer registries.

Cancers not listed in Table 3 because the number of cases at either Camp Lejeune or Camp Pendleton were less than 5 were: gallbladder, anus, male breast cancer, testis, cervix, Hodgkin lymphoma and ALL.

Table 4. Comparison of base location at Camp Lejeune vs Camp Pendleton: Marines/Navy personnel subgroup

Cancer Outcome	Cases	Camp Lejeune				Camp Pendleton Cases
		Unadjusted HR	(95% CI)	Adjusted HR	(95% CI)	
Any malignant cancer (and bladder in-situ)	11,207	1.07	(1.04, 1.10)	1.05	(1.02, 1.08)	11,329
Oral Cavity and Pharynx	709	1.00	(0.90, 1.10)	1.03	(0.93, 1.15)	766
Oropharynx	423	1.02	(0.90, 1.17)	1.06	(0.93, 1.21)	446
Hypopharynx	25	0.72	(0.43, 1.19)	0.72	(0.44, 1.20)	38
Nasopharynx	24	0.99	(0.57, 1.73)	1.10	(0.63, 1.93)	26
Oral cavity only	132	0.99	(0.78, 1.25)	1.03	(0.81, 1.30)	144
Overlapping/other	42	1.10	(0.72, 1.69)	1.14	(0.74, 1.75)	41
Squamous cell oral cancer	640	1.01	(0.90, 1.12)	1.05	(0.94, 1.17)	686
Esophagus	195	1.23	(1.00, 1.51)	1.27	(1.03, 1.56)	172
Adenocarcinoma	126	1.11	(0.86, 1.42)	1.19	(0.93, 1.53)	123
Squamous cell	52	1.57	(1.02, 2.40)	1.47	(0.96, 2.25)	36
Stomach	169	0.98	(0.80, 1.21)	0.97	(0.78, 1.19)	186
Liver and bile duct	321	0.85	(0.74, 0.99)	0.91	(0.78, 1.05)	410
Gallbladder	7	0.76	(0.29, 2.00)	0.62	(0.23, 1.63)	10
Pancreas	287	1.07	(0.91, 1.27)	1.05	(0.89, 1.24)	289
Larynx	185	1.20	(0.98, 1.48)	1.21	(0.98, 1.50)	166
Lung and Bronchus	1,295	1.16	(1.07, 1.25)	1.16	(1.08, 1.26)	1,214
Large cell	36	1.38	(0.84, 2.26)	1.38	(0.84, 2.28)	28
Small cell	181	1.11	(0.90, 1.37)	1.14	(0.92, 1.40)	177
Non-small cell	145	1.22	(0.96, 1.55)	1.23	(0.97, 1.56)	128
Squamous cell	277	1.10	(0.93, 1.30)	1.11	(0.94, 1.32)	275
Adenocarcinoma	562	1.26	(1.11, 1.42)	1.25	(1.10, 1.41)	487
Colon and Rectum	1,016	1.03	(0.94, 1.12)	1.00	(0.92, 1.09)	1,066
Adenocarcinoma	864	1.00	(0.91, 1.10)	0.99	(0.90, 1.08)	929
Colon	601	0.99	(0.89, 1.11)	0.96	(0.86, 1.07)	655
Rectum only	353	1.12	(0.96, 1.30)	1.10	(0.94, 1.28)	339

Cancer Outcome	Camp Lejeune				Camp Pendleton Cases	
	Cases	Unadjusted HR	(95% CI)	Adjusted HR		(95% CI)
Rectosigmoid Junction	82	0.97	(0.72, 1.30)	0.98	(0.72, 1.32)	91
Small Intestine	57	0.78	(0.55, 1.09)	0.77	(0.55, 1.08)	79
Anus	46	0.71	(0.49, 1.04)	0.69	(0.48, 1.01)	69
Urinary Bladder (malignant and in-situ)	444	1.06	(0.93, 1.20)	1.09	(0.95, 1.24)	456
Papillary Transitional Cell Carcinoma	319	1.04	(0.89, 1.21)	1.08	(0.92, 1.26)	333
Non-papillary Transitional Cell Carcinoma	109	1.11	(0.85, 1.44)	1.11	(0.85, 1.46)	107
Urothelial	428	1.05	(0.92, 1.20)	1.09	(0.95, 1.24)	440
Bladder – malignant	217	1.02	(0.85, 1.23)	1.04	(0.87, 1.26)	230
Bladder – in-situ	232	1.07	(0.90, 1.29)	1.12	(0.93, 1.34)	234
Kidney and Renal Pelvis	710	1.06	(0.96, 1.18)	1.06	(0.95, 1.18)	721
Renal cell and clear cell carcinoma	524	1.01	(0.90, 1.14)	1.03	(0.91, 1.16)	558
Renal cell carcinoma, NOS	250	1.13	(0.95, 1.35)	1.12	(0.94, 1.34)	237
Clear cell only	277	0.92	(0.79, 1.08)	0.97	(0.82, 1.14)	324
Papillary	92	1.34	(0.99, 1.83)	1.18	(0.86, 1.60)	74
Brain and other CNS	231	1.02	(0.85, 1.22)	1.04	(0.86, 1.24)	241
Gliomas	203	1.02	(0.84, 1.24)	1.04	(0.86, 1.26)	212
Soft Tissue Sarcoma	112	1.21	(0.93, 1.59)	1.21	(0.92, 1.59)	99
Melanoma	607	0.94	(0.84, 1.05)	1.00	(0.89, 1.11)	695
Thyroid	284	1.23	(1.04, 1.46)	1.22	(1.03, 1.45)	247
Mesothelioma	14	1.16	(0.54, 2.47)	1.15	(0.54, 2.46)	13
Leukemias	314	1.06	(0.91, 1.24)	1.07	(0.91, 1.25)	319
Lymphoid cancers	979	1.03	(0.95, 1.13)	1.02	(0.94, 1.12)	1,018
Hodgkin lymphoma	108	1.01	(0.78, 1.31)	1.01	(0.77, 1.31)	114
Non-Hodgkin lymphoma	550	1.00	(0.89, 1.13)	1.01	(0.90, 1.14)	588
Mantle Cell	27	1.21	(0.70, 2.09)	1.27	(0.73, 2.21)	24
Follicular	130	1.03	(0.81, 1.31)	1.07	(0.84, 1.36)	135
Diffuse Large B-cell	160	0.88	(0.72, 1.09)	0.89	(0.72, 1.10)	194
Burkitt	15	1.33	(0.62, 2.84)	1.53	(0.71, 3.30)	12
Marginal Zone B-cell	43	1.41	(0.89, 2.21)	1.45	(0.92, 2.28)	33
Multiple Myeloma	185	1.22	(0.99, 1.51)	1.13	(0.91, 1.40)	163

Cancer Outcome	Camp Lejeune				Camp Pendleton Cases	
	Cases	Unadjusted HR	(95% CI)	Adjusted HR		(95% CI)
Acute lymphocytic leukemia	23	0.97	(0.55, 1.70)	0.94	(0.53, 1.67)	25
Chronic lymphocytic leukemia	114	1.01	(0.78, 1.30)	1.02	(0.79, 1.32)	122
Myeloid cancers (including polycythemia vera, myelodysplastic and myeloproliferative syndromes)	239	1.21	(1.00, 1.45)	1.24	(1.03, 1.49)	213
Myeloid cancers (including myelodysplastic and myeloproliferative syndromes)	186	1.19	(0.96, 1.46)	1.19	(0.97, 1.47)	169
Acute myeloid leukemia <sup>¥</sup>	104	1.36	(1.02, 1.81)	1.38	(1.03, 1.85)	82
Chronic myeloid leukemia	39	0.75	(0.50, 1.12)	0.74	(0.49, 1.12)	56
Myelodysplastic and Myeloproliferative Syndromes	49	1.66	(1.07, 2.60)	1.68	(1.07, 2.62)	32
Polycythemia Vera	53	1.29	(0.87, 1.93)	1.41	(0.94, 2.11)	44
Female Breast	266	1.00	(0.83, 1.19)	1.00	(0.83, 1.20)	208
Ductal carcinoma	202	1.04	(0.84, 1.28)	1.03	(0.83, 1.28)	151
Lobular carcinoma	20	0.72	(0.39, 1.32)	0.82	(0.45, 1.52)	22
Duct-Lobular carcinoma	14	1.34	(0.56, 3.20)	1.41	(0.58, 3.40)	8
Male Breast	21	1.05	(0.57, 1.90)	0.99	(0.54, 1.81)	22
Cervix	24	1.02	(0.55, 1.90)	1.01	(0.54, 1.89)	17
Uterus	30	0.49	(0.31, 0.78)	0.49	(0.31, 0.78)	49
Ovary	19	0.84	(0.44, 1.60)	0.85	(0.44, 1.63)	18
Prostate	2,844	1.18	(1.12, 1.25)	1.08	(1.02, 1.13)	2,661
Testis	184	0.90	(0.74, 1.10)	0.94	(0.77, 1.14)	220
Penis	18	1.31	(0.66, 2.59)	1.31	(0.66, 2.61)	15

Abbreviations: HR – hazard ratio; CNS – central nervous system; NOS – not otherwise specified

<sup>¥</sup> includes acute monocytic leukemia

HRs adjusted for sex, race, rank and education level; age was the time variable.

Totals:

Camp Lejeune = 154,821

Females = 8,049

Males = 146,772

Camp Pendleton = 163,484

Females = 5,867

Males = 157,617

Table 5. Comparison of Camp Lejeune versus Camp Pendleton civilian workers

Cancer Outcome	Camp Lejeune			Camp Pendleton Cases
	Cases	Unadjusted HR (95% CI)	Adjusted HR (95% CI)	
Any malignant cancer (and bladder in-situ)	1,359	1.02 (0.95, 1.10)	1.02 (0.95, 1.11)	1,240
Oral Cavity and Pharynx	31	1.49 (0.84, 2.64)	1.67 (0.93, 3.00)	19
Oropharynx	11	1.21 (0.49, 3.01)	1.32 (0.53, 3.28)	8
Hypopharynx	3	0.90 (0.18, 4.45)	-	3
Oral cavity only	7	2.09 (0.54, 8.11)	2.05 (0.52, 8.04)	3
Overlapping/other	8	1.31 (0.45, 3.82)	1.37 (0.47, 4.02)	6
Squamous cell oral cancer	28	1.85 (0.97, 3.52)	1.99 (1.04, 3.82)	14
Esophagus	8	0.48 (0.21, 1.12)	0.48 (0.20, 1.16)	16
Adenocarcinoma	5	0.41 (0.14, 1.19)	0.43 (0.15, 1.27)	11
Squamous cell	2	0.74 (0.12, 4.46)	-	3
Stomach	17	0.71 (0.38, 1.34)	0.67 (0.35, 1.31)	23
Liver	9	0.55 (0.24, 1.25)	0.64 (0.27, 1.50)	16
Liver, Bile duct, and Gallbladder	18	0.72 (0.39, 1.34)	0.79 (0.42, 1.49)	24
Pancreas	33	0.65 (0.42, 1.02)	0.68 (0.43, 1.08)	47
Larynx	13	1.22 (0.53, 2.78)	1.18 (0.49, 2.82)	10
Lung and Bronchus	261	1.13 (0.95, 1.35)	1.15 (0.95, 1.38)	226
Large cell	7	1.35 (0.43, 4.26)	1.09 (0.33, 3.62)	5
Small cell	42	1.10 (0.70, 1.72)	1.13 (0.72, 1.79)	36
Non-small cell	23	0.92 (0.52, 1.64)	0.92 (0.51, 1.65)	24
Squamous cell	72	1.66 (1.14, 2.42)	1.63 (1.10, 2.41)	43
Adenocarcinoma	93	1.12 (0.83, 1.51)	1.15 (0.84, 1.56)	80
Colon and Rectum	106	0.91 (0.70, 1.19)	0.93 (0.70, 1.22)	112
Adenocarcinoma	102	0.96 (0.73, 1.27)	0.99 (0.75, 1.32)	102
Colon	77	0.98 (0.71, 1.35)	0.97 (0.70, 1.35)	76
Rectum and Rectosigmoid Junction	31	0.79 (0.49, 1.28)	0.87 (0.53, 1.44)	37
Rectum only	25	0.94 (0.54, 1.65)	1.02 (0.57, 1.83)	25
Small Intestine	1	0.09 (0.01, 0.70)	-	10

Cancer Outcome	Cases	Camp Lejeune				Camp Pendleton Cases
		Unadjusted HR	(95% CI)	Adjusted HR	(95% CI)	
Anus	3	0.41	(0.11, 1.59)	0.41	(0.11, 1.60)	7
Urinary Bladder (malignant and in-situ)	87	1.02	(0.75, 1.37)	1.10	(0.81, 1.50)	85
Papillary Transitional Cell Carcinoma	60	0.96	(0.67, 1.37)	1.07	(0.74, 1.56)	61
Non-papillary Transitional Cell Carcinoma	24	1.28	(0.70, 2.34)	1.30	(0.70, 2.40)	19
Urothelial	84	1.04	(0.76, 1.41)	1.13	(0.82, 1.55)	80
Bladder – malignant	49	1.04	(0.70, 1.54)	1.14	(0.76, 1.73)	49
Bladder – in-situ	40	1.00	(0.64, 1.56)	1.09	(0.69, 1.73)	38
Kidney and Renal Pelvis	58	1.07	(0.73, 1.56)	1.12	(0.76, 1.67)	49
Renal cell and clear cell carcinoma	43	1.04	(0.67, 1.62)	1.05	(0.67, 1.66)	37
Renal cell carcinoma, NOS	28	1.24	(0.70, 2.20)	1.18	(0.65, 2.13)	20
Clear cell only	15	0.81	(0.40, 1.63)	0.89	(0.44, 1.82)	17
Papillary	3	0.89	(0.18, 4.45)	0.96	(0.18, 5.27)	3
Brain and other CNS	9	0.49	(0.22, 1.11)	0.49	(0.22, 1.11)	17
Gliomas	9	0.62	(0.27, 1.46)	0.62	(0.26, 1.47)	13
Soft Tissue Sarcoma	7	0.62	(0.24, 1.64)	0.67	(0.25, 1.81)	10
Melanoma	54	0.93	(0.64, 1.37)	1.03	(0.70, 1.52)	53
Thyroid	32	1.90	(1.01, 3.56)	1.91	(1.01, 3.63)	14
Mesothelioma	5	0.98	(0.28, 3.41)	0.96	(0.26, 3.61)	5
Leukemias	36	0.81	(0.52, 1.26)	0.86	(0.54, 1.36)	43
Lymphoid cancers	104	1.00	(0.76, 1.32)	1.03	(0.77, 1.38)	98
Lymphoid excluding Hodgkin	101	1.03	(0.77, 1.36)	1.07	(0.80, 1.43)	93
Hodgkin lymphoma	3	0.55	(0.13, 2.31)	0.53	(0.12, 2.26)	5
Non-Hodgkin lymphoma	71	1.13	(0.80, 1.60)	1.19	(0.83, 1.71)	60
Follicular	15	1.38	(0.62, 3.08)	1.41	(0.63, 3.17)	10
Diffuse Large B-cell	27	1.30	(0.73, 2.32)	1.48	(0.81, 2.70)	20
Burkitt	1	0.22	(0.02, 1.98)	-	-	4
Marginal Zone B-cell	2	0.32	(0.06, 1.61)	0.33	(0.06, 1.72)	6
Multiple Myeloma	18	1.02	(0.52, 2.01)	1.04	(0.51, 2.10)	16
Acute lymphocytic leukemia	1	0.27	(0.03, 2.63)	-	-	3
Chronic lymphocytic leukemia	11	0.68	(0.31, 1.47)	0.60	(0.27, 1.33)	16



Cancer Outcome	Camp Lejeune				Camp Pendleton Cases	
	Cases	Unadjusted HR	(95% CI)	Adjusted HR		(95% CI)
Myeloid cancers (including polycythemia vera, myelodysplastic and myeloproliferative syndromes)	35	1.20	(0.73, 1.96)	1.40	(0.83, 2.36)	29
Myeloid cancers (including myelodysplastic and myeloproliferative syndromes)	32	1.10	(0.66, 1.82)	1.27	(0.75, 2.16)	29
Acute myeloid leukemia <sup>¥</sup>	14	1.24	(0.56, 2.73)	1.35	(0.59, 3.09)	11
Chronic myeloid leukemia	6	0.60	(0.21, 1.70)	0.69	(0.24, 2.01)	9
Myelodysplastic and Myeloproliferative Syndromes	14	1.70	(0.73, 3.94)	1.97	(0.79, 4.90)	9
Female Breast	208	1.22	(0.98, 1.51)	1.19	(0.95, 1.49)	134
Ductal carcinoma	167	1.33	(1.04, 1.72)	1.32	(1.02, 1.71)	97
Lobular carcinoma	12	0.93	(0.40, 2.16)	0.91	(0.38, 2.20)	10
Duct-lobular carcinoma	7	0.42	(0.17, 1.06)	0.36	(0.14, 0.93)	13
Male Breast	7	7.51	(0.92, 61.2)			1
Cervix	2	0.50	(0.08, 2.99)			3
Uterus	40	0.91	(0.57, 1.44)	0.90	(0.56, 1.44)	34
Ovary	24	0.74	(0.42, 1.28)	0.71	(0.40, 1.28)	26
Prostate	303	1.25	(1.06, 1.48)	1.06	(0.89, 1.27)	247

<sup>¥</sup> includes acute monocytic leukemia

HR: hazard ratio CI: confidence interval

CNS: central nervous system

HRs adjusted for sex, race, blue collar work (y/n) and education level; age was the time variable.

The table does not include mantle cell lymphoma, polycythemia vera and cancers of the nasopharynx, testis and penis because both Camp Lejeune and Camp Pendleton had less than three cases of these cancers. Because of small numbers, gallbladder cancer was included with liver and bile duct cancers, and rectosigmoid junction cancer was combined with rectal cancer.

Totals:

Camp Lejeune =	6,494	Females =	3,468	Males =	3,026
Camp Pendleton =	5,797	Females =	2,805	Males =	2,992

Table 6. Duration stationed at Camp Lejeune (Camp Pendleton as reference): Marines/Navy personnel subgroup: Hazard ratios and 95% confidence intervals (CIs)

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	Med/high duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Oral Cavity and Pharynx	1.08	0.93	1.26	1.00	0.86	1.18	1.13	0.95	1.33	0.91	0.75	1.10
Oropharyngeal	1.20	0.99	1.45	0.97	0.79	1.20	1.12	0.90	1.39	0.95	0.74	1.21
Hypopharyngeal	0.96	0.48	1.94	0.61	0.26	1.44	0.53	0.19	1.50	0.77	0.30	1.99
Nasopharyngeal	0.85	0.35	2.07	1.59	0.76	3.32	0.90	0.31	2.61	1.11	0.38	3.26
Oral cavity only	0.97	0.68	1.38	1.03	0.72	1.48	1.31	0.91	1.90	0.77	0.47	1.26
Overlapping/other	0.99	0.49	1.98	1.10	0.57	2.15	1.49	0.79	2.78	0.99	0.46	2.13
Squamous cell	1.12	0.95	1.31	1.01	0.86	1.20	1.15	0.96	1.37	0.89	0.73	1.10
Esophagus	1.43	1.07	1.91	1.00	0.71	1.39	1.32	0.95	1.83	1.35	0.96	1.91
Adenocarcinoma	1.27	0.88	1.82	1.02	0.68	1.52	1.29	0.87	1.92	1.21	0.78	1.86
Squamous cell	1.77	1.00	3.14	1.00	0.49	2.02	1.25	0.61	2.52	1.83	0.96	3.51
Stomach	0.99	0.73	1.35	1.01	0.74	1.39	0.89	0.62	1.29	0.99	0.68	1.44
Liver and bile duct	0.93	0.75	1.16	1.01	0.82	1.25	0.86	0.66	1.11	0.76	0.57	1.03
Gallbladder	0.53	0.11	2.44	0.33	0.04	2.58	1.29	0.35	4.69	0.46	0.06	3.69
Pancreas	1.00	0.78	1.28	1.03	0.80	1.33	0.97	0.73	1.28	1.23	0.93	1.61
Larynx	1.12	0.82	1.53	1.42	1.06	1.90	1.37	0.98	1.90	0.91	0.60	1.39
Lung and Bronchus	1.15	1.03	1.30	1.20	1.07	1.34	1.16	1.02	1.32	1.10	0.96	1.27
Large cell	1.03	0.47	2.27	1.39	0.67	2.87	1.96	0.97	3.95	1.37	0.59	3.18
Small cell	1.09	0.80	1.49	1.39	1.04	1.86	1.06	0.74	1.51	0.90	0.60	1.35
Non-small cell	1.22	0.87	1.72	1.20	0.84	1.71	1.09	0.72	1.66	1.39	0.92	2.10
Squamous cell	1.16	0.91	1.48	1.03	0.80	1.33	1.16	0.88	1.53	1.06	0.78	1.45
Adenocarcinoma	1.23	1.03	1.47	1.31	1.10	1.56	1.21	0.99	1.48	1.19	0.95	1.47
Colon and Rectum	1.00	0.88	1.14	1.05	0.92	1.20	0.93	0.80	1.08	1.02	0.88	1.19
Adenocarcinoma	0.99	0.86	1.14	1.09	0.95	1.25	0.92	0.78	1.07	0.94	0.79	1.11
Colon	0.99	0.84	1.17	0.99	0.83	1.17	0.82	0.67	1.00	1.02	0.84	1.23
Rectum only	1.04	0.83	1.31	1.19	0.96	1.48	1.08	0.84	1.38	1.07	0.81	1.38
Rectosigmoid Junction	0.82	0.51	1.33	1.28	0.84	1.93	1.18	0.74	1.89	0.64	0.34	1.21

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	Med/high duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Small Intestine	0.51	0.27	0.96	1.03	0.64	1.67	0.77	0.43	1.39	0.81	0.44	1.50
Anus	0.66	0.37	1.18	0.63	0.34	1.17	0.92	0.51	1.67	0.58	0.26	1.28
Soft Tissue Sarcoma	1.19	0.79	1.77	1.54	1.06	2.24	0.81	0.48	1.36	1.19	0.75	1.90
Urinary Bladder (malignant and in-situ)	1.16	0.96	1.41	0.86	0.69	1.08	1.18	0.95	1.45	1.19	0.95	1.49
PTCC	1.12	0.89	1.41	0.83	0.64	1.08	1.23	0.96	1.57	1.18	0.91	1.54
NPTCC	1.27	0.86	1.86	0.97	0.63	1.49	1.06	0.68	1.65	1.13	0.71	1.78
Urothelial	1.16	0.95	1.41	0.87	0.69	1.08	1.19	0.96	1.47	1.17	0.93	1.47
Bladder – malignant	1.13	0.87	1.49	0.86	0.63	1.17	1.17	0.87	1.57	1.00	0.72	1.41
Bladder – in-situ	1.17	0.90	1.54	0.85	0.62	1.16	1.19	0.89	1.59	1.33	0.99	1.79
Kidney and Renal Pelvis	1.19	1.03	1.39	1.08	0.92	1.26	1.00	0.84	1.19	0.91	0.75	1.10
RCC and Clear cell	1.11	0.93	1.32	1.08	0.90	1.29	0.95	0.77	1.17	0.94	0.75	1.17
RCC-NOS	1.02	0.77	1.33	1.25	0.97	1.62	1.16	0.86	1.55	1.02	0.74	1.41
Clear cell only	1.17	0.93	1.47	0.95	0.74	1.22	0.80	0.60	1.08	0.89	0.66	1.19
Papillary	1.75	1.17	2.62	0.88	0.53	1.47	1.15	0.70	1.87	0.88	0.51	1.53
Brain and other CNS	1.06	0.81	1.39	1.13	0.86	1.48	1.16	0.87	1.54	0.70	0.48	1.02
Gliomas	1.01	0.75	1.36	1.08	0.80	1.45	1.30	0.97	1.75	0.73	0.49	1.09
Melanoma malignant	1.08	0.92	1.28	0.93	0.78	1.12	1.02	0.86	1.22	0.94	0.78	1.15
Thyroid	1.15	0.89	1.48	1.23	0.95	1.59	1.24	0.94	1.64	1.32	1.00	1.75
Mesothelioma	0.63	0.14	2.79	0.94	0.27	3.31	1.40	0.45	4.34	1.76	0.61	5.11
Lymphoid	1.01	0.89	1.16	1.12	0.98	1.27	1.02	0.88	1.18	0.92	0.78	1.08
Hodgkin Lymphoma	1.00	0.68	1.47	1.05	0.71	1.56	0.96	0.61	1.52	0.96	0.59	1.57
Non-Hodgkin lymphoma	0.94	0.78	1.12	1.15	0.97	1.36	1.00	0.82	1.21	0.94	0.76	1.16
Mantle Cell	1.58	0.73	3.44	0.71	0.25	2.07	1.77	0.82	3.82	1.05	0.40	2.79
Follicular	1.06	0.74	1.53	1.06	0.73	1.53	1.09	0.73	1.62	1.01	0.65	1.56
Diffuse Large B-Cell	0.64	0.44	0.92	1.26	0.94	1.67	0.95	0.67	1.35	0.73	0.48	1.13
Burkitt	2.10	0.82	5.40	1.43	0.46	4.46	-	-	-	2.40	0.75	7.67
Marginal Zone B-Cell	1.21	0.61	2.40	1.78	0.96	3.29	1.51	0.74	3.07	1.25	0.55	2.86
Multiple Myeloma	1.21	0.89	1.64	1.23	0.90	1.67	1.24	0.89	1.72	0.79	0.53	1.19
Myeloid	1.38	1.02	1.87	1.00	0.70	1.41	0.98	0.67	1.44	1.27	0.88	1.84

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	Med/high duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Leukemias	1.25	1.00	1.56	0.99	0.77	1.27	0.90	0.68	1.19	1.09	0.83	1.44
ALL	1.18	0.54	2.56	0.75	0.29	1.96	0.96	0.37	2.53	0.90	0.31	2.64
CLL	1.23	0.85	1.77	0.95	0.63	1.42	0.94	0.60	1.46	0.95	0.60	1.51
AML (myeloid/monocytic)	1.67	1.13	2.47	1.09	0.68	1.73	1.07	0.64	1.78	1.68	1.06	2.68
CML	0.90	0.50	1.63	0.57	0.27	1.20	0.68	0.32	1.42	0.83	0.40	1.69
Myelodysplastic and Myeloproliferative Syndromes	1.85	0.99	3.43	1.55	0.79	3.03	1.70	0.85	3.40	1.56	0.73	3.32
Polycythemia Vera	2.02	1.22	3.33	1.02	0.53	1.99	1.11	0.54	2.28	1.32	0.63	2.73
Female Breast	0.92	0.72	1.18	1.03	0.78	1.37	1.06	0.78	1.43	1.09	0.79	1.50
Ductal carcinoma	0.92	0.69	1.23	1.10	0.80	1.51	1.10	0.77	1.57	1.12	0.77	1.63
Lobular carcinoma	0.99	0.43	2.31	0.54	0.16	1.82	0.91	0.34	2.41	0.78	0.27	2.28
Ductal-lobular	1.80	0.60	5.45	1.88	0.56	6.37	0.50	0.06	3.99	1.43	0.37	5.49
Male Breast	1.06	0.43	2.63	1.16	0.43	2.62	0.82	0.28	2.38	1.08	0.40	2.92
Cervix	1.03	0.48	2.23	1.50	0.66	3.40	0.78	0.23	2.67	0.34	0.04	2.54
Uterus	0.27	0.12	0.61	0.77	0.40	1.46	0.64	0.29	1.42	0.42	0.15	1.19
Ovary	1.09	0.48	2.48	0.88	0.32	2.41	0.24	0.03	1.83	0.87	0.25	3.01
Prostate	1.10	1.01	1.19	1.07	0.99	1.16	1.03	0.95	1.13	1.10	1.01	1.20
Testis	1.05	0.79	1.39	1.07	0.80	1.43	0.86	0.61	1.22	0.69	0.46	1.04
Penis	1.49	0.57	3.89	0.77	0.22	2.68	1.63	0.59	4.53	1.49	0.48	4.60

Abbreviations: PTCC - papillary transitional cell carcinoma, NPTCC – non-papillary transitional cell carcinoma, RCC – renal cell carcinoma, NOS – not otherwise specified, CNS – central nervous system, ALL – acute lymphocytic leukemia, CLL – chronic lymphocytic leukemia, AML – acute myeloid leukemia, CML – chronic myeloid leukemia

\*Hazard Ratios adjusted for sex, race, rank and education level; age was the time variable.

CI: 95% confidence interval

“low” duration (1 – 2 quarters), “medium” duration (>2 – 6 quarters), “medium/high” duration (>6 – 10 quarters) and “high” duration (>10 quarters).

Number of quarters potentially exposed to the contaminated drinking water at Camp Lejeune, 1975 - 1985:

Mean = 6.1

Median = 5.0

Maximum = 38

Interquartile range = 7 (25<sup>th</sup> percentile = 2; 75<sup>th</sup> percentile = 9)

Table 7. Duration employed at Camp Lejeune, October 1972 - December 1975 (Camp Pendleton as reference):  
Civilian workers: Hazard ratios and 95% confidence intervals (CIs)

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Oral Cavity and Pharynx	1.82	0.76	4.34	2.20	1.07	4.53	1.23	0.56	2.70
Oropharyngeal	2.43	0.70	8.50	2.39	0.82	6.95	0.24	0.03	1.94
Hypopharyngeal <sup>‡</sup>	1.19	0.12	11.73	0.95	0.10	9.15	0.69	0.07	6.67
Oral cavity only	2.16	0.33	14.11	0.94	0.09	9.32	2.70	0.60	12.20
Overlapping/other	0.66	0.07	5.89	1.53	0.37	6.29	1.64	0.45	5.93
Squamous cell	2.32	0.90	6.00	2.91	1.35	6.25	1.23	0.51	2.96
Esophagus	-	-	-	0.41	0.09	1.83	0.75	0.27	2.05
Adenocarcinoma	-	-	-	0.26	0.03	2.08	0.78	0.24	2.55
Stomach	0.34	0.08	1.49	0.55	0.19	1.64	0.94	0.43	2.04
Liver	0.82	0.18	3.78	0.71	0.20	2.49	0.54	0.17	1.68
Liver, bile duct, and gallbladder	0.78	0.26	2.37	1.00	0.42	2.38	0.65	0.27	1.56
Pancreas	0.62	0.29	1.36	0.65	0.32	1.31	0.74	0.40	1.36
Larynx	2.78	0.93	8.32	1.05	0.28	3.93	0.64	0.19	2.16
Lung and Bronchus	1.05	0.76	1.43	1.23	0.95	1.59	1.15	0.91	1.44
Large cell	1.46	0.27	7.92	0.55	0.06	4.81	1.25	0.30	5.11
Small cell	1.49	0.76	2.94	1.14	0.60	2.17	0.95	0.52	1.74
Non-small cell	0.48	0.14	1.66	0.78	0.32	1.94	1.24	0.63	2.45
Squamous cell	1.58	0.83	3.02	1.87	1.12	3.14	1.52	0.95	2.41
Adenocarcinoma	0.85	0.49	1.47	1.41	0.93	2.15	1.14	0.77	1.69
Colon and Rectum	1.09	0.70	1.68	0.97	0.65	1.44	0.82	0.57	1.18
Adenocarcinoma	1.19	0.76	1.86	1.05	0.70	1.58	0.87	0.59	1.26
Colon	1.11	0.66	1.86	1.03	0.64	1.65	0.86	0.56	1.33
Rectum only	1.31	0.54	3.18	1.06	0.46	2.41	0.86	0.40	1.85
Rectum and Rectosigmoid Junction	1.03	0.46	2.31	1.00	0.50	2.00	0.72	0.37	1.42

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Soft Tissue Sarcoma	-	-	-	1.83	0.63	5.29	0.25	0.03	2.04
Urinary Bladder (malignant and in-situ)	1.76	1.07	2.88	1.04	0.66	1.65	0.94	0.64	1.38
Papillary Transitional Cell Carcinoma	1.66	0.93	2.97	1.04	0.60	1.80	0.90	0.56	1.44
Non-papillary Transitional Cell Carcinoma	2.08	0.74	5.84	1.36	0.57	3.26	1.11	0.53	2.32
Urothelial	1.76	1.06	2.91	1.11	0.70	1.77	0.95	0.64	1.41
Bladder – malignant	1.86	0.95	3.62	1.06	0.57	1.99	0.99	0.59	1.64
Bladder – in-situ	1.77	0.88	3.58	1.01	0.51	1.99	0.93	0.52	1.65
Kidney and Renal Pelvis	0.96	0.49	1.85	1.08	0.62	1.89	1.25	0.77	2.03
Renal cell and clear cell carcinoma	0.93	0.43	1.99	0.90	0.46	1.76	1.23	0.71	2.14
Renal cell carcinoma, NOS	1.43	0.58	3.53	0.90	0.37	2.17	1.26	0.62	2.56
Clear cell only	0.38	0.08	1.70	0.96	0.34	2.68	1.28	0.53	3.11
Papillary	-	-	-	1.03	0.09	11.16	1.59	0.22	11.41
Brain and other CNS	-	-	-	0.76	0.27	2.13	0.58	0.19	1.78
Melanoma	1.17	0.66	2.08	0.77	0.43	1.41	1.15	0.70	1.90
Thyroid	1.89	0.84	4.26	1.86	0.82	4.20	2.01	0.84	4.82
Mesothelioma	0.89	0.10	8.21	0.71	0.08	6.40	1.14	0.24	5.40
Lymphoid	1.03	0.65	1.64	1.09	0.73	1.63	0.99	0.68	1.43
Lymphoid excluding Hodgkin Lymphoma	1.11	0.70	1.78	1.17	0.78	1.75	0.98	0.67	1.43
Non-Hodgkin lymphoma	1.37	0.79	2.36	1.22	0.75	2.01	1.08	0.68	1.72
Follicular	2.99	1.01	8.83	1.77	0.63	4.96	0.62	0.17	2.24
Diffuse Large B-Cell	1.01	0.36	2.83	1.21	0.50	2.95	1.99	0.98	4.04
Multiple Myeloma	0.89	0.28	2.80	1.36	0.54	3.43	0.90	0.35	2.32
Myeloid cancers	1.41	0.61	3.25	1.19	0.55	2.58	1.54	0.82	2.89
Leukemias	0.67	0.27	1.61	0.86	0.44	1.70	0.94	0.53	1.65
Chronic lymphocytic leukemia	0.26	0.03	2.07	0.77	0.25	2.34	0.64	0.24	1.72
Acute myeloid leukemia <sup>¥</sup>	0.55	0.07	4.49	1.52	0.51	4.56	1.53	0.59	3.95

Outcome	Low duration	Lower CI	Upper CI	Medium duration	Lower CI	Upper CI	High duration	Lower CI	Upper CI
Chronic myeloid leukemia	1.05	0.26	4.29	-	-	-	0.97	0.25	3.82
Myelodysplastic and Myeloproliferative Syndromes	2.46	0.69	8.84	1.56	0.40	6.15	1.90	0.63	5.76
Female Breast	1.18	0.88	1.59	1.29	0.97	1.72	1.05	0.74	1.48
Uterus	1.09	0.59	1.98	0.73	0.37	1.43	0.86	0.41	1.79
Ovary	0.22	0.06	0.74	1.00	0.48	2.08	1.18	0.53	2.65
Prostate	0.97	0.71	1.34	0.84	0.64	1.11	1.22	0.99	1.49

HRs adjusted for sex, race, blue collar work (y/n) and education level; age was the time variable.

\* Includes bladder in situ.

¥ includes acute monocytic leukemia

£ Unadjusted results only are presented because of small numbers of cases.

- No cases.

CNS: central nervous system

“low” duration (1 – 4 quarters), “medium” duration (5 – 21 quarters), and “high” duration (22– 53 quarters).

Number of quarters potentially exposed to the contaminated drinking water at Camp Lejeune, October 1972 – December 1985:

Mean = 18.6

Median = 11.0

Maximum = 53

Interquartile range = 30 (25<sup>th</sup> percentile = 3; 75<sup>th</sup> percentile = 33)