IN THE UNITED STATES DISTRICT COURT

FOR THE EASTERN DISTRICT OF NORTH CAROLINA

Civil Action No.: 7:23-CV-00897

IN RE: CAMP LEJEUNE WATER LITIGATION **This Pleading Relates to:** **ALL CASES.**	)))))))	**PLAINTIFFS' LEADERSHIP GROUP'S OPPOSITION TO UNITED STATES' MOTION TO EXCLUDE EXPERT TESTIMONY OF MUSTAFA ARAL**

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I. INTRODUCTION

Plaintiffs' Leadership Group ("PLG") submits this Opposition to the United States' Motion to Exclude Unreliable and Irrelevant Expert Testimony of Mustafa Aral. The United States asks this Court to believe that Dr. Aral, an internationally renowned environmental engineer who spent a decade working on the historical water modeling of Camp Lejeune's contaminated water systems—alongside and at the request of Defendant's own expert environmental agency, ATSDR—could not utter one helpful word about the quality of their joint work to this Court at trial. In its Motion, the United States glosses over Dr. Aral's ten years of work on Camp Lejeune, recasts his substantial contributions to ten chapters of ATSDR's peer-reviewed, published reports as having been "limited," and tells this Court he now has nothing "helpful" to say at the forthcoming trials.

In his years working with ATSDR on historical water modeling for Tawara Terrace and Hadnot Point, Dr. Aral had significant involvement in many aspects of both projects. Nevertheless, as to be expected with such large-scale engineering projects, he did not touch every single aspect of the agency's work spanning this time—or even every aspect of data collection for the chapters he did author. That fact does not render him unable to testify about ATSDR's overall work under Federal Rule of Evidence 703. Were it so, Defendant's *own* experts would lack any basis to opine on ATSDR's work because they, too, were "not involved in collecting data that the ATSDR used in all relevant steps of the water modeling projects at Camp Lejeune..." Def.'s Mot. at 12. Further, under Defendant's argument—that Dr. Aral's testimony is irrelevant because he is not an epidemiologist who can opine on the sufficiency of the water modeling data—no expert in this case would be able to testify unless he or she could testify across all of the sciences, connecting A to Z. Rule 702 and its caselaw impose no such requirement; in fact, courts around the country have rejected that exact notion.

As set forth below, Dr. Aral's substantial contributions to the water modeling conducted alongside ATSDR for ten years at Camp Lejeune surely qualify as sufficient facts and data under Rule 702 to opine on the quality of the work produced. And Defendant's argument that Dr. Aral's

testimony is irrelevant because he "knows nothing about the level of exposure detail needed for the epidemiological studies" should likewise be rejected. Def.'s Mot. at 12. Plaintiff's other causation experts can and will address the sufficiency of the contaminant data required to find causation. For these reasons, this Court should deny Defendant's misplaced Motion to Exclude.

II. FACTUAL BACKGROUND

Mustafa Aral Ph.D., P.E., is a Professor Emeritus of Civil and Environmental Engineering at the Georgia Institute of Technology and an independent consultant. Ex. 1, Report at 3. Dr. Aral has more than 50 years of professional experience in environmental modeling and forensic analysis, including the development and application of mathematical model techniques to assess the origin, fate, and transport of contaminants in natural and engineered environments. *Id.* He has conducted environmental forensic evaluations of chemical release timing and developed enviro-geochemical models within multimedia systems in compliance with regulatory guidance and directives. *Id.*

Dr. Aral holds a Ph.D. in Environmental Water Resources Management and Modeling (1971) and a Master of Science in Water Resources Engineering (1969)—both from the Georgia Institute of Technology. *Id.* He earned his Bachelor of Science in Civil Engineering in 1967 from the Middle East Technical University in Ankara, Turkey. Over the course of his academic and professional career, Dr. Aral has authored more than 100 peer-reviewed technical publications, five books, ten book chapters, and numerous conference papers and technical reports. *Id.* Dr. Aral is a Fellow of the American Society of Civil Engineers (ASCE) and a Past President of the American Institute of Hydrology (AIH). *Id.* He founded the International Journal on Water Quality, Exposure and Health in 2009 and served as its Editor-in-Chief until 2014. *Id.*

Dr. Aral has received twenty-eight honor citations from scientific and professional organizations. *Id.* His awards include, *inter alia*, the ASCE Cuming Medal (2000), two American Academy of Environmental Engineers Best Environmental Health Research Awards (2003 and 2015), the Centers for Disease Control and Prevention (CDC) Excellence in Applied Environmental Health Research Award (2006), and the ASCE-EWRI James R. Croes Medal

(2011). *Id.* Notably, in 2015, Dr. Aral received the Grand Prize in Environmental Engineering Research from the American Academy of Environmental Engineers, based on his work in the historical reconstruction of the Camp Lejeune water contamination and modeling project. *Id.*

Here, based on his education, experience, and training, Dr. Aral offers several opinions,

see Ex. 1, Report at 12–13, which include:

> The models and techniques used by the ATSDR for historical reconstruction, including fundamental equations, input parameters, parameter estimates, calibration, uncertainty and sensitivity analyses, were and remain reliable, scientifically valid and state of the art procedures that are consistent with standard practices used and are generally accepted in this field.
>
> The simulated monthly mean concentrations of TCE, PCE, 1,2-tDCE, benzene and vinyl chloride at Tarawa Terrace, Hadnot Point and Holcomb Boulevard included (tabulated or in figures) in ATSDR reports are reliable and represent, within a reasonable degree of scientific and engineering certainty, the contaminant levels in finished water at Camp Lejeune from 1953 to 1987
>
> The analyses published in all ATSDR chapter reports (ATSDR, 2007; ATSDR, 2013) and supplemental information regarding Camp Lejeune (see Figure 2), including the conclusions and monthly concentration data, were all done applying proper scientific and engineering methodologies and remain to this day to be mathematically reliable, statistically accurate and correct.

Id.

III. LEGAL STANDARD

Federal Rule of Evidence 702 permits a qualified expert to testify if their knowledge will assist the trier of fact, the testimony is grounded in sufficient facts or data, that testimony is the product of reliable principles and methods, and those principles and methods have been reliably applied to the case. *Daubert v. Merrell Dow Pharm., Inc.*, 509 U.S. 579, 588 (1993). Evidence is relevant if "it has any tendency to make a fact more or less probable than it would be without the evidence" and "the fact is of consequence in determining the action." Fed. R. Evid. 401. And the "basic standard of relevance ... is a liberal one." *Daubert*, 509 U.S. at 587.

Federal Rule of Evidence 703 permits an expert to opine regarding data that he has not personally observed. ("An expert may base an opinion on facts or data in the case that the expert has been made aware of or personally observed."). Moreover, "[i]f experts in the particular field

would reasonably rely on those kinds of facts or data in forming an opinion on the subject, they need not be admissible for the opinion to be admitted." *Id.*

IV. ARGUMENT

A. Defendant fails to present *any* evidence that environmental engineers such as Dr. Aral do not reasonably rely on data collected by other engineering professionals.

Defendant argues that, because Dr. Aral "was not involved in collecting data that the ATSDR used in all relevant steps of the water modeling projects at Camp Lejeune," he cannot opine on the reliability of ATSDR's work, and thus he must be "parroting" ATSDR's work as well as other experts (who are not identified by Defendant). Def.'s Mot. at 12. In support, Defendant cherry-picks irrelevant deposition questions concerning ATSDR's work—which spanned more than a decade, involved dozens of government officials, and manifested in thousands of pages of reports—such as "why the ATSDR needed operational histories for the 96 supply wells in the Hadnot Point system, of which only a few were contaminated." *Id.* Such a question has no bearing on whether ATSDR's reports or Dr. Aral's testimony were reliable; it may most charitably be characterized as an historical factoid.

And in reality, Defendant's argument is, at heart, a question of whether Dr. Aral's opinions comply with Federal Rule of Evidence 703, which permits an expert such as Dr. Aral to offer opinions based upon data that he has not personally observed. Defendant argues that because Dr. Aral didn't personally observe, collect, or review all of the data in ATSDR's reports, his opinion cannot satisfy Rule 702's requirement that his opinions be based on "sufficient facts or data" and is inadmissible hearsay. But Rule 703 envisions, and permits, that exact scenario: "If experts in the particular field would reasonably rely on those kinds of facts or data in forming an opinion on the subject, they need not be admissible for the opinion to be admitted." Fed. R. Evid. 703; *see also United States v. Vandivere*, No. 5:15-HC-2017-D, 2015 WL 13689051, at *1 (E.D.N.C. Dec. 14, 2015) ("Thus, the fact that Dr. Zinik may not have firsthand knowledge of information upon which he relied does not provide a basis for striking evidence of his opinions.").

In *OmniSource Corp. v. Heat Wave Metal Processing, Inc.*, the plaintiff made a similar argument as Defendant here: that an expert's opinions "do not rely on sufficient facts or data connected to this case because he has not independently investigated the matter." No. 5:13-CV-772-D, 2015 WL 3452918, at *8 (E.D.N.C. May 29, 2015) (Dever, J.). This Court rejected that argument in observing that under Rule 703, if such information is a type reasonably relied upon by experts in the field, "[i]ndividual investigation is not necessarily required." *OmniSource Corp.*, 2015 WL 3452918, at *8. This Court held that such "concerns go to the weight of [the expert's] testimony and not to its admissibility." *Id.*; *see also Collins v. Cottrell Contracting Corp.*, 733 F. Supp. 2d 690, 701 (E.D.N.C. 2010) (Flanagan, J.) (finding expert physician's reliance on other physicians' records was reasonable under Rule 703); *Verona v. U.S. Bancorp*, No. 7:09-CV-057-BR, 2011 WL 1252935, at *18 (E.D.N.C. Mar. 29, 2011) (stating that expert testimony is excludable if it is "speculative or conjectural," "based on assumptions that are so unrealistic and contradictory as to suggest bad faith," or an "apples and oranges comparison," but other contentions that the assumptions are unfounded go to the weight, not the admissibility, of the testimony) (internal quotations omitted).

Defendant completely fails to show that environmental engineers such as Dr. Aral do not regularly rely on data collected by other professionals when conducting their professional work. And the few cases that Defendant cites that it claims support exclusion are too far afield from the facts here. For example, Defendant cites *Funderburk v. S.C. Elec. & Gas Co.* for the proposition that expert testimony "that seeks merely to parrot other evidence or vouch for the work of another expert" is prohibited. 395 F. Supp. 3d 695, 717 (D.S.C. 2019). But a closer read of that decision reveals that the concerns meriting exclusion there are not applicable here. In *Funderburk*, as Defendant highlights, the court excluded an expert's testimony that "parroted manufacturer's hearsay on culvert life expectancy." Def.'s Mot. at 14. The court wrote what is reflected in Rule 703: "Generally, it is permissible for an expert to rely upon the opinions and findings of other experts to reach his or her expert conclusion, but only if experts in their respective field would reasonably rely on the other expert's opinions and findings." *Funderburk*, 395 F. Supp 3d at 717..

(internal quotations omitted). The court continued, "[i]n some instances, a proffered expert … should address the validity of the opinions of the experts he relied upon and not just show an unblinking reliance upon the opinions of other experts." *Id.* (citing *In re TMI Lit.*, 193 F.3d 613, 716 (3d Cir. 1999)). But the expert in *Funderburk* was excluded because he simply recited, verbatim, a blanket statement from the culvert manufacturer's materials, and thus did nothing more than provide an "unblinking reliance" without conducting any analysis or testing himself. 395 F. Supp. 3d at 719. Critically, the sole reliance for his opinion about the life expectancy of a culvert was that statement from the manufacturer's materials, and because that statement was not peer-reviewed or published, that fact "significantly undermin[ed] its reliability." *Id.*at 718.[1]

Defendant cites a bankruptcy case, *Matter of James Wilson Assocs.*, as additional, but again misplaced support for its argument. 965 F.2d 160, 173 (7th Cir. 1992). There, a party retained an expert architect who was to opine on the physical state of the building that was the subject of the bankruptcy. *Id.* The expert architect hired an engineer (who was not called as an expert witness) who personally inspected the building—while the architect never did. *Id.* The Seventh Circuit observed, again consistent with Rule 703, that "[a]n expert is of course permitted to testify to an opinion formed on the basis of information that is handed to rather than developed by him—information of which he lacks first-hand knowledge and which might not be admissible in evidence no matter by whom presented." *Id.* at 172. But, importantly, the court wrote that "the judge must make sure that the expert isn't being used as a vehicle for circumventing the rules of evidence." *Id.*at 713. The Seventh Circuit found exactly that: "The issue was the state of the building, and the expert who had evaluated that state—the consulting engineer—was the one who should have

[1] Defendant cites another decision that quotes the *Funderburk* decision, *In re Zetia (Ezetimibe) Antitrust Litig.*, No. 2:18-MD-2836, 2022 WL 3337796, at *10 (E.D. Va. Aug. 3, 2022). Def.'s Mot. at 14. But in *In re Zetia*, the court actually permitted the at-issue expert's testimony, and wrote that Rule 703 permits such reliance on another expert, as the court observed that "an expert is not required to reprove the other expert's opinions." 2022 WL 3337796, at *10 (emphasis in original). The court also wrote: "Furthermore, Federal Rules of Evidence 702 and 703 do not require that an expert rely upon the best evidence, and certainly not upon what the opposing party considers to be the best evidence." *Id.* at *14 (citation omitted).

testified." *Id.* The expert architect "could use what the engineer told him to offer an opinion within the architect's domain of expertise, but he could not testify for the purpose of vouching for the truth of what the engineer had told him—of becoming in short the engineer's spokesman." *Id.* Thus, the Seventh Circuit concluded that such a maneuver is an improper "screen against cross-examination." *Id.* Here, by contrast, Dr. Aral is not being used simply to introduce the data collected by ATSDR, but rather to offer an expert opinion based upon his review of that data.

In any event, Defendant has failed to show that Dr. Aral has a sole, "unblinking reliance" on anyone or that his testimony is being used to "screen" against cross-examination. Dr. Aral spent 10 years working on water modeling for Camp Lejeune and co-authored 10 chapters as part of ATSDR's work. That is not the "unblinking reliance" on unpublished, un-peer-reviewed hearsay that the *Funderburk* court excluded. Dr. Aral *has* relied on the data collection of his fellow co-authors at ATSDR with whom he worked hand-in-hand for a decade to opine on the reliability of ATSDR's work here. But that is quite different from what *Funderburk* says and what Defendant claims has happened here. Nor is Dr. Aral's years-long work at Camp Lejeune akin to the architect in *James Wilson*, whose entire opinions amounted to vouching for the work of a non-testifying consultant engineer.

In scientific and engineering fields, often work is conducted as a team effort, with participants working on specialized aspects of a project, based on their particular expertise. Dr. Aral contributed directly to certain aspects of model development and specifically focused on the very complex field of three-dimensional multiphase flow and transport. This is common and standard practice in the groundwater field. Basic data collection can often be collected by technicians, and it is not economically feasible, practical, nor scientifically necessary for professors, scientists, and model developers to be intimately or directly involved in the collection of data used to support a model. And here, Dr. Aral is not opining that the underlying data collection was correct, but that based on his decades of experience in water modeling, the methods that ATSDR used to evaluate that data were sound—an opinion that is permissible under Rules 702 and 703. *See Vandivere*,2015 WL 13689051, at *1 ("Thus, the fact that Dr. Zinik may not

have firsthand knowledge of information upon which he relied does not provide a basis for striking evidence of his opinions."). Moreover, other experts who did participate in the data collection related to Camp Lejeune, such as Morris Maslia, are named as experts for Plaintiffs here and can testify to the methods and accuracy of that data collection.

Defendant's questions regarding Dr. Aral's knowledge of specific data related to the water modeling are matters for cross-examination rather than a basis for exclusion under *Daubert*. As this Court wrote in *OmniSource*, if an expert has reasonably relied upon data as other experts in the field would have, then the questions regarding the expert's independent investigation "go to the weight of [the expert's] testimony and not to its admissibility." 2015 WL 3452918, at *8 ("OmniSource can cross-examine Kerlin at trial about the depth of his investigation, and the jury will decide how much weight to afford Kerlin's testimony."); *see also Verona*, 2011 WL 1252935, at *18 (stating that contentions that factual assumptions are unfounded go to the weight, not the admissibility, of the testimony).

Under Rules 702 and 703, Dr. Aral is clearly permitted to testify that based on his education, experience, and training, the "models and techniques used by ATSDR … were and remain reliable, scientifically valid and state of the art procedures that are consistent with standard practices used and are generally accepted in this field," that the calculated concentrations of the contaminants are reliable, and that the "analyses … were all done applying proper scientific and engineering methodologies." Ex. 1, Report at 12–13. As Dr. Aral wrote in his report: "The basis of my opinions outlined in this expert report is my 50 years of work in this field and my fifteen years of Camp Lejeune related work providing technical assistance to ATSDR under a cooperative agreement established between the Centers for Disease Control and Prevention (CDC) and Georgia Tech and my fifty years of expertise and knowledge in this area of research as an educator, researcher and engineer." Ex. 1, Report at 13. Importantly, Dr. Aral, continued: "The documents and information that I considered are of the type that can be reasonably relied upon to support my opinions and are regularly relied upon by practitioners in my field." *Id.* at 4. "The materials that I reviewed include, but are not limited to, published technical literature, reports, historic data

sources, correspondence and meetings with state and regulatory agencies, participation in workshops and review of documents provided by independent experts at these gatherings." *Id.* Those statements remain unrebutted by Defendant, which has entirely failed to show that Dr. Aral has impermissibly relied on other engineering professionals to arrive at his opinions. The Court should thus reject Defendant's argument.

B. Defendant invents a standard for expert "fit" that its own experts could not satisfy.

Defendant next argues that because Dr. Aral "knows nothing about the level of exposure detail needed for the epidemiological studies that the ATSDR's water modeling projects were intended to support," that his opinions that ATSDR's water modeling work was reliable must be excluded. Def.'s Mot. at 16. Specifically, Defendant argues: "Without any reference to the purpose of the model, however, Dr. Aral's opinion is unhelpful in determining the exposure issue in this case." *Id.* Tellingly, Defendant fails to cite any authority for its proposition that Dr. Aral must have experience in epidemiology to deliver a helpful opinion about water modeling. That is because none exists. Dr. Aral disclaims any opinions regarding epidemiology; he is not an epidemiologist—he *is* a recognized authority on water modeling, he has had a long career teaching at a world-class university, he was the head of a research institute at that university, and his assessments of groundwater models at Camp Lejeune are highly relevant to the follow-up epidemiological studies at Camp Lejeune. But he does not need to be an expert in epidemiology or to be aware of the details of the epidemiological studies to qualify as an expert for the water models.

Defendant in essence argues that Dr. Aral must be an expert in epidemiology to deliver a helpful opinion to this Court. Courts around the country have soundly rejected such an argument positing that experts must prove a party's entire case:

> The Court must pause at the outset to acknowledge that no single expert provides a self-sufficient opinion that an identified defect or defects in fact caused the *St. John* collision. This is not dispositive. The case law does not . . . require each expert to present the complete decision tree leading from defect to collision. Reliable expert

testimony need only be relevant, and need not establish every element that the plaintiff must prove, in order to be admissible.

In re Toyota Motor Corp. Unintended Acceleration Mktg., Sales Pracs., & Prods. Liab. Litig., 978 F. Supp. 2d 1053, 1066–67 (C.D. Cal. 2013) (citation omitted); *Kassman v. KPMG LLP*, 416 F. Supp. 3d 252, 272 (S.D.N.Y. 2018) ("Dr. Golberg's failure to address causation does not make her opinion irrelevant, as no single expert must prove a party's entire case."); *Chen-Oster v. Goldman, Sachs & Co.*, 114 F. Supp. 3d 110, 125 (S.D.N.Y. 2015), *objections overruled*, 325 F.R.D. 55 (S.D.N.Y. 2018) ("But it is not necessary for each expert to provide evidence establishing every element of a party's case . . . ."); *Hix v. Zimmer Biomet Holdings, Inc.*, No. 3:18-CV-00437-RCJ-WGC, 2022 WL 946914, at *4 (D. Nev. Mar. 29, 2022) ("The argument fails because Hix is not limited to meeting his burden of proof through a single expert."); *Nationwide Agribusiness Ins. Co. v. Munters Corp.*, No. 15-CV-1362, 2018 WL 3769846, at *5 (E.D. Wis. Aug. 8, 2018) ("[W]hile I agree with defendants that there is no single expert that 'connects all the dots,' because no 'Grand Unified Theory of causation' is required, I find that plaintiffs have put forth sufficient evidence to defeat defendants' motion for summary judgment."); *Schmucker v. Johnson Controls, Inc.*, No. 3:14-CV-1593 JD, 2019 WL 718553, at *12 (N.D. Ind. Feb. 19, 2019) ("The Plaintiffs offer no reason why a witness must be an expert in every discipline that could possibly bear on a question before offering an opinion on that question, and the Seventh Circuit has expressly rejected such a suggestion."); *Smith v. Ford Motor Co.*, 215 F.3d 713, 720 (7th Cir. 2000) ("[E]xpert testimony need only be relevant to evaluating a factual matter in the case. That testimony need not relate directly to the ultimate issue that is to be resolved by the trier of fact.").

Moreover, in Defendant's zeal to exclude Dr. Aral because his work purportedly did not make reference to the purpose of the water modeling, Defendant overlooks a thorny fact in its argument: Defendant's own expert hydrogeologist, Dr. Alexandros Spiliotopoulos, whose work in this case is "only to critique the quality of the modeling work and outcome of that modeling," testified that *he* does not know whether or how ATSDR epidemiologists used the results of the water modeling in their studies. Ex, 2, Dep. Tr. 152:20–22; *id.* 152:5–13. In fact, Dr.

Spiliotopoulos called the epidemiological studies "irrelevant to my opinions on this matter." *Id.* at 152:24–9. So irrelevant are they, that Dr. Spiliotopoulos did not even read them:

> Q. Have you reviewed the published epidemiology studies regarding Camp Lejeune?
>
> A. I have not.
>
> Q. Do you know whether in any of the published epidemiology studies they document that the epidemiologist used the modeling in order to calculate the level and duration of exposure to contaminants?
>
> [objection omitted]
>
> Q. Do you know whether it says that in the published studies?
>
> A. No. I have not read those studies.
>
> …
>
> Q. Do you know if ATSDR epidemiologists had used the mean monthly levels of contaminants predicted by ATSDR's models to calculate the cumulative exposure for any individuals who lived at Camp Lejeune?
>
> [objection omitted]
>
> A. I do not know that. I'm not familiar with the epidemiological studies at Camp Lejeune.
>
> Q. So if the modeling was sent to support the epidemiology studies and the epidemiologists used the modeling to calculate cumulative exposure to individuals, you don't know that; right?
>
> [objection omitted]
>
> A. My work here is only to critique the quality of the modeling work and outcome of that modeling.
>
> Q. So you don't know whether ATSDR's work was used for the purpose of making exposure assessments in individuals? You don't know either way, do you?
>
> [objection omitted]
>
> Q. By the ATSDR epidemiologists. Do you know?
>
> A. This is irrelevant to my opinions on this matter.

…

Q. Did you do any research to determine how ATSDR's modeling studies were used by the epidemiologists?

A. That was not my role in this case.

Id. at 151:13–154:18. Defendant's argument thus falls flat given Dr. Spiliotopoulos's testimony that the purpose of the water modeling was irrelevant to his own opinions on the reliability of that modeling. It cannot be the case that Dr. Aral's lack of familiarity with epidemiological studies is grounds for his exclusion, when the testimony of Defendant's hydrogeologist expert suffers from precisely the same deficiency.

Defendant also erroneously argues: "Reliability for individual exposure is also not included in the models' intended purpose, which was to support epidemiology studies concerned with relative, not absolute, exposure levels." Def.'s Mot. at 17. In fact, use of the mean monthly levels was not limited to estimating relative exposures among groups, as shown in ASTDR's Childhood Birth Defects and Cancer Study and 2017 Public Health Assessment. Plaintiffs incorporate by reference their Opposition on this very subject, which details Plaintiffs' response more fully. *See* Pls.' Opp. To Mot. to Exclude Pls.' Phase 1 Expert Testimony in Supp. of Using ATSDR's Water Models to Determine Exposure Levels for Individual Plaintiffs at 4–7, 16–20.

An assessment of the accuracy, reliability, and correctness of water models depends on hydrogeological factors and principles; it does not depend on how someone else would use the results of the model after it is developed. The models are used to compute the contaminant concentrations at water-supply wells and water treatment plants. An expert like Dr. Aral is qualified to assess how well the model does that. Dr. Aral does not need to have expertise in epidemiological studies to assess the accuracy, reliability, and correctness of the modeling, and the lack of such expertise does not logically disqualify him from using his groundwater and modeling expertise to assess the development and accuracy of the ATSDR groundwater models. It was not his job to assess whether these models supported individual exposure levels; that responsibility falls to other plaintiff experts.

Likewise, an epidemiologist would not have the training or expertise to assess whether hydrogeological data were collected properly or sufficiently, nor whether numerical methods used in solving the equations governing groundwater flow or transport were appropriate and sufficiently accurate. And an expert epidemiologist should not be excluded from testifying about the epidemiological studies because they did not have expertise in groundwater methods, models, and studies.

Additionally, Defendant argues that "it does not matter whether science and engineering could do any better than the ATSDR's water modelers did because relevance is independent of scientific validity." Def.'s Mot. at 16. But Defendant again misses the mark: *Daubert* does not require the use of the "best" modeling methodology or data; rather, the choice of methodology or data must be based on *good grounds, based on what is known*. *See Hartle v. FirstEnergy Generation Corp.*, 7 F. Supp. 3d 510, 515, 522–23, 525 (W.D. Pa. 2014) (allowing modeler to testify because he had good ground for selecting and applying the model and considered the model's limitations). Neither Rule 702 nor *Daubert* hold experts to a standard of "absolute" certainty – *i.e.*, they are not required to be "irrefutable or certainly correct." *See Westberry v. Gislaved Gummi AB*, 178 F.3d 257, 261 (4th Cir. 1999); *see also Daubert*, 509 U.S. at 590 ("Of course, it would be unreasonable to conclude that the subject of scientific testimony must be 'known' to a certainty; arguably, there are no certainties in science.")."

Both in his expert report and in the foreword to Chapter G of the Tawara Terrace ATSDR Report, Dr. Aral wrote:

> Historical water contamination data needed for the epidemiological study were limited. To obtain estimates of historical exposure, ATSDR used water-modeling techniques and the process of historical reconstruction of contamination levels at the base. These methods are used to quantify concentrations of contaminants in finished water at the base and to compute the level and duration of human exposure to contaminated drinking water.

Ex. 1, Report at 14. This is a clear statement of the purpose of the water models and is consistent with Dr. Aral's statement that he was aware that the groundwater models would supply "estimates

of historical exposures" for the epidemiological studies. It is the role of Plaintiff's other experts to then assess whether the data that Dr. Aral's models generated is sufficient for causation. Plaintiffs are not limited to meeting their burden of proof through a single expert, and Dr. Aral's opinions are simply one piece of the larger causation puzzle. Because the Federal Rules of Evidence do not require Dr. Aral to opine on epidemiology as a water modeling expert, Defendant's argument that his testimony would not be helpful under Rule 702 should be rejected.

V. CONCLUSION

For the foregoing reasons, the PLG respectfully requests the Court to deny Defendant's Motion to Exclude the Testimony of Mustafa Aral. Dr. Aral's opinions are grounded in sufficient facts and data based on his decade of work on water modeling for Camp Lejeune. He is not required to offer opinions on what epidemiological studies may require to prove causation, as he is not an epidemiologist. Dr. Aral is a well-respected environmental engineer with decades of experience, and his report and deposition testimony fully support his admission as an expert in that field.

DATED this 4th day of June 2025.

/s/ J. Edward Bell, III

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CERTIFICATE OF SERVICE

I, J. Edward Bell, III, hereby certify that the foregoing document was electronically filed on the Court's CM/ECF system on this date, and that all counsel of record will be served with notice of the said filing via the CM/ECF system.

This the 4th day of June 2025.

/s/ J. Edward Bell, III

J. Edward Bell, III

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF NORTH CAROLINA
SOUTHERN DIVISION
Civil Action No.: 7:23-CV-897

IN RE:	)
	)
CAMP LEJEUNE WATER LITIGATION	)
	)
This Pleading Relates to:	)
	)
ALL CASES.	)
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TABLE OF EXHIBITS
PLAINTIFFS' LEADERSHIP GROUP'S OPPOSITION TO UNITED STATES' MOTION TO EXCLUDE EXPERT TESTIMONY OF MUSTAFA ARAL

Ex. 1 – October 23, 2024 Expert Report of Prof. Mustafa M. Aral

Ex. 2 – March 18, 2025 Deposition of Alexandros Spiliotopoulos, Ph.D. transcript excerpts

EXHIBIT 1

Expert Report

Prof. Mustafa M. Aral

Date: 10/23/2024

Prepared by,

Prof. Mustafa M. Aral, *GA-PE 15254*

Consultant, Environmental Modeling and Health Risk Analysis

https://www.researchgate.net/profile/M-Aral

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1. Background and Qualifications

I am a Professor Emeritus from the School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta Georgia USA and an independent consultant residing in 270 17th St NW, Unit 809, Atlanta, Georgia USA. I hold a Ph.D. degree in Environmental Water Resources Management and Modeling (1971) and a master's degree in water resources engineering from the School of Civil and Environmental Engineering (1969), Georgia Institute of Technology. I have a bachelor's degree in civil engineering (1967) from the Middle East Technical University, Ankara, Turkey. I am a Professional Engineer registered in the State of Georgia (PE-15254).

I joined the Georgia Institute of Technology faculty in 1978 where I served until 2018 as Professor and the Director of Multimedia Environmental Simulations Laboratory (MESL), a research center established in 1993. In 2018 I was appointed as Professor Emeritus at Georgia Institute of Technology. During my career I have published over 100 technical publications in peer reviewed journals, five books, ten book chapters, and numerous conference papers and technical reports. I served as the Chair of several International Conferences. Among these the most noteworthy activities are the NATO Advanced Study Institute that I organized in Antalya, Türkiye in 1995; the Environmental Exposure and Health Conference held in Atlanta, GA, USA in 2005 which I co-organized; and I was the Technical Chair of the ASCE/EWRI IPWE 2013 International Conference held in Izmir, Türkiye in January 7-9, 2013. I am the Past-President of the American Institute of Hydrology (AIH), and a Fellow of the American Society of Civil Engineers (ASCE), a professional organization that represents over 190,000 civil and environmental engineers in the USA. During 2009 I established the International Journal on "Water Quality, Exposure and Health" published by Springer Publishers. I was the Editor-in-Chief of this journal from 2009 to 2014. I am also on the Editorial Board of several technical journals and serve as a consultant and reviewer on European Framework programs.

During my career I received twenty-eight honor citations from scientific organizations. Among these the most noteworthy national (USA) and international recognitions are American Society of Civil Engineers (ASCE), Cuming Medal (2000); two times the recipient of American Academy of Environmental Engineers Best Environmental Health Research Award (2003 and 2015); Centers for Disease Control and Prevention (CDC) Excellence in Applied Environmental Health Research (2006); and ASCE-Environmental Water Resources Institute (EWRI) James R. Croes Medal (2011). Among these, the Grand Prize Award received in Environmental Engineering in Research category given by the American Academy of Environmental Engineers (AAEE, 2015) is particularly important to this case since it is based on the quality and substance of the research work done in the Camp Lejeune water modeling historical reconstruction project.

My expertise includes the development and application of mathematical modeling techniques to environmental and engineered systems to evaluate the origins and fate and transport of contaminants in natural and engineered environments. I have more than 50 years of relevant professional experience evaluating the timing of chemical releases, developing enviro-geochemical models in multimedia environments and conducting environmental forensic analysis in the context of mathematical modeling techniques, regulations and guidance or directives established by the relevant agencies. My Curriculum Vitae and a list of my publications are provided in Exhibit A of this report. I have not testified by deposition or at trial in the last four years.

2. Assignment

In August 2022, I was retained by Bell Legal Group on behalf of the *Camp Lejeune Water Litigation* Plaintiffs as an environmental modeling expert to testify regarding the ATSDR Environmental Water Modeling Study conducted at U.S. Marine Corps Base Camp Lejeune, North Carolina and such other opinions as may become relevant. I am being compensated $600 per hour for my work on this matter.

As an environmental modeling expert, I was tasked with the following:

- Provide a high-level explanation of the ATSDR's historical reconstruction process for both the Tarawa Terrace and Hadnot Point-Holcomb Boulevard study sites, including my involvement in it.
- Provide an explanation of the reported concentrations of contaminants in finished water at Camp Lejeune from 1953 to 1987.
- Provide an explanation of the calibration, sensitivity analysis, uncertainty analysis, and validation techniques used in the ATSDR study of the Camp Lejeune site.
- Summarize the conclusions and opinions included in the published ATSDR Reports.
- Provide additional opinions beyond those already included in the ATSDR published works.

Around the year 2000, the Multimedia Environmental Simulations Laboratory (MESL), a research center at the School of Civil and Environmental Engineering, Georgia Institute of Technology entered into a cooperative agreement with the Agency for Toxic Substances and Disease Registry (ATSDR)/Centers for Disease Control and Prevention (CDC) to provide technical support to ATSDR in all aspects of the Camp Lejeune study for all three study areas on an as-needed basis. As the MESL research center director, I oversaw all aspects of this cooperative agreement at the Georgia Institute of Technology side. The cooperative agreement was extended to three five-year periods and ended in 2015. My involvement in the ATSDR Historical Reconstruction Project was supported by my graduate students at the MESL research center. There was no other faculty member involvement in the cooperative agreement from the Georgia Tech side. Over the 15-year period from 2000 to 2015, I and my team members worked with the other team members of the Exposure Dose Reconstruction Program (EDRP) at ATSDR to perform an analysis of the Tarawa Terrace, Holcomb Boulevard, and Hadnot Point study sites of the U.S. Marine Corps Base Camp Lejeune.

To conduct my evaluation and render my expert opinions, I relied on my education, research, professional experience, and the information base I accumulated over the years while working on the ATSDR Camp LeJeune study and other matters. The documents and information that I considered are of the type that can be reasonably relied upon to support my opinions and are regularly relied upon by practitioners in my field. The materials that I reviewed include, but are not limited to, published technical literature, reports, historic data sources, correspondence and meetings with state and regulatory agencies, participation in workshops and review of documents provided by independent experts at these gatherings. The list of documents I have considered and/or relied upon to render my opinions is provided in Section 8 of this Expert Report.

Opinions presented in this report were reached by applying accepted methods and information in the fields of hydrogeology, geochemistry, environmental sciences and mathematical and stochastic computational modeling. The opinions expressed in this report are my own and are based on my education, training, and experience, as well as the documents, public information, diagrams, data, and

facts that were available to me at the time of writing. I hold these opinions to a reasonable degree of scientific and engineering certainty. I reserve the right to supplement and/or amend my opinions on this matter as necessary as additional documents, depositions or information are made available to me.

3. Introduction

U.S. Marine Corps Base Camp Lejeune, North Carolina was established in 1942. Groundwater is the sole source of water supply for Camp Lejeune. In the 1980s, Navy water testing at Camp Lejeune detected Volatile Organic Compounds (VOCs) in some water-distribution systems at the base. In 1982 and 1983, continued testing identified two VOCs—trichloroethylene (TCE), a metal degreaser, and tetrachloroethylene (PCE), a dry-cleaning solvent—in two water-distribution systems that served base housing areas, Hadnot Point and Tarawa Terrace. In 1984 and 1985 a Navy environmental program identified VOCs, such as TCE and PCE, in some of the individual wells serving the Hadnot Point and Tarawa Terrace water-distribution systems. Ten wells were subsequently removed from service.

The extent of subsurface contamination, its impact on groundwater, and the associated potential health risks of water contamination prompted the U.S. Environmental Protection Agency (USEPA or EPA) to place Camp Lejeune on the EPA CERCLA (Superfund) National Priority List for cleanup (remediation) in 1989, leading to Remedial Investigations / Feasibility Studies and ultimately to Records of Decisions (RODs) for remedial action (EPA, 1993 for Tarawa Terrace / ABC One Hour Cleaners; EPA, 1993 for Hadnot Point Industrial Area; and EPA 1994 for Hadnot Point Landfill).

Hadnot Point was the original water-distribution system, serving the entire base with finished water beginning in the early 1940s. The Hadnot Point water treatment plant (WTP) was constructed and began operations in the 1941–1942 timeframe. The Tarawa Terrace WTP began delivering finished water during 1952, and the Holcomb Boulevard WTP began delivering finished water during June 1972, Figure 1. The Tarawa Terrace WTP was closed in March 1987 due to contamination, leaving Hadnot Point WTP to supply water to the Hadnot Point area, and the Holcomb Boulevard WTP to supply water to the Holcomb Boulevard and Tarawa Terrace base housing areas. The Holcomb Boulevard water-distribution system is connected to the Hadnot Point water-distribution system at the Marston Pavilion valve and at booster pump 742. While booster pump 742 was removed during 2007, the two systems can still be interconnected by opening a valve at the same location based on water supply demand. For operational reasons, the two water-distribution systems were occasionally connected—exceptions being some connections that occurred during late spring and summer months of 1972–1986 and a continuous 8-day period of 28 January to 4 February 1985 (ATSDR, 2007a). Tarawa Terrace, Hadnot Point, and Holcomb Boulevard water-distribution systems historically supplied finished water to most family housing units, enlisted personnel barracks, workplaces, and other facilities at the base (ATSDR, 2013a).

Department of Defense (DOD) and North Carolina officials concluded that on and off-base sources were likely to have caused contamination (GAO, 2007). With respect to Tarawa Terrace, PCE contamination of finished water occurred because PCE, a common dry-cleaning solvent, leaked into groundwater that supplied the Tarawa Terrace drinking water system from a dry-cleaner (One-Hour ABC Cleaners) located outside the Camp Lejeune base. In 1987, the military base shut down the Tarawa Terrace water treatment plant because of PCE contamination of the drinking water (ATSDR, 2007a, e). The Hadnot Point water system, which provided water to both the Hadnot Point and Holcomb Boulevard service areas, was contaminated with TCE, PCE and refined petroleum products because of waste disposed of at a landfill and activities within an industrial area, including vehicle service and maintenance, warehousing, auto body painting and maintenance, and heavy equipment maintenance. Active underground storage tanks (USTs) and solvent storage areas were in the Hadnot Point Industrial Area (HPIA), where substantial volumes of liquid hydrocarbon fuels were lost due to leakage to the subsurface.

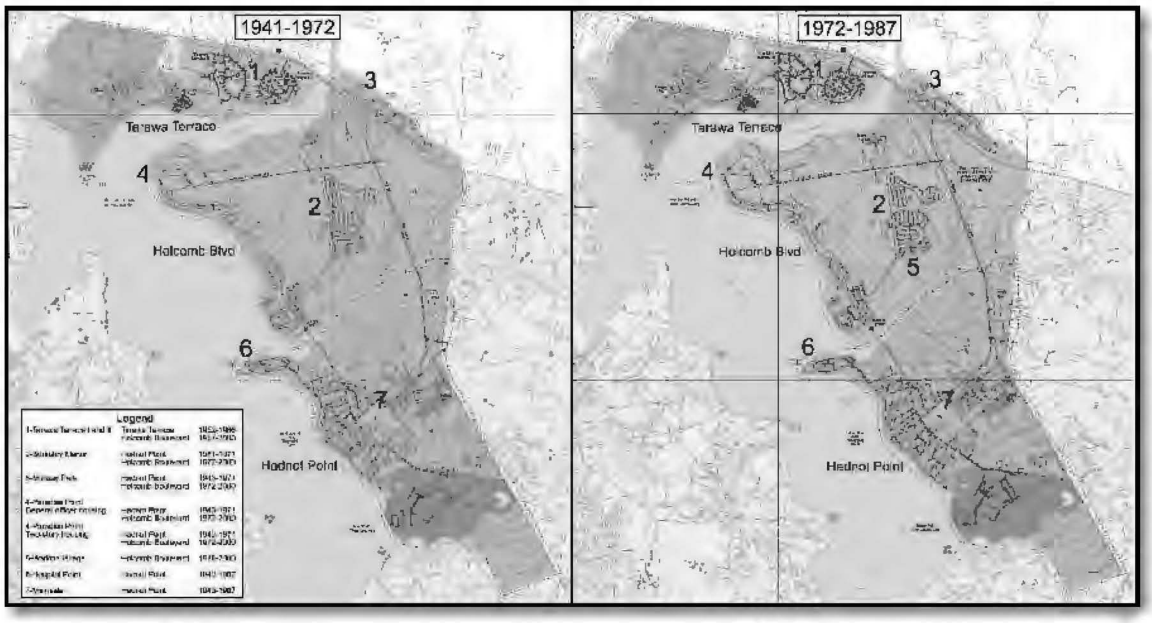

Figure 1: General map of U.S. Marine Corps Base Camp Lejeune in North Carolina (ATSDR, 2007a; ATSDR, 2013a)

The Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services, conducted several studies to help Marines, civilians, health officials, and other interested parties understand more about the drinking water contamination at Camp Lejeune and whether it affected the health of persons living or working on the base during the period 1953-1987. The first was an epidemiological study to evaluate whether in-utero and infant exposures to volatile organic compounds in contaminated drinking water at Camp Lejeune were associated with specific birth defects and childhood cancers. The study included births occurring during the period 1968-1985 to women who were pregnant while residing in family housing at the base. Later, the epidemiologic studies were extended to cover other health effects as well. These epidemiologic studies and their findings are not within my expertise area.

Historical exposure data needed for the epidemiological case-control study were limited. To obtain estimates of historical exposure, ATSDR used water modeling techniques and the process of historical reconstruction to determine the extent of VOC-contamination at the site, to quantify historical concentrations of contaminants in the finished water, and to compute the level and duration of human exposure to the contaminated drinking water. The findings of the study were grouped in two series of reports: (a) Tarawa Terrace and Vicinity Study Reports (ATSDR-a/b/c/d/e/f/g/h/i, 2007); (b) Hadnot Point and Vicinity Study Reports (ATSDR-a/b/c/d/e/f/g/h/i/j/k/l, 2013), Figure 2. From this point forward these references will be quoted as (ATSDR, 2007) and (ATSDR, 2013) in bulk. From the context of the discussion, it will be clear which chapter is under consideration. In some references specific chapter references will also be given when necessary.

The ATSDR water modeling team was guided by an external ATSDR Expert Panel, whose members contributed significantly to the quality of the modeling effort. The members of the ATSDR Expert Panels are well-known and respected scientists in the field; their names are listed in the Expert Panel reports

(Maslia, 2005; Maslia, 2009). These are also available on the ATSDR website (https://www.atsdr.cdc.gov/sites/lejeune/expert-panels.html).

Water modeling enabled ATSDR to estimate monthly mean contaminant levels in drinking water within the Tarawa Terrace, Hadnot Point and Holcomb Boulevard water treatment plant service areas for the period 1942-2008. This work in turn helped ATSDR epidemiologists determine if populations were exposed to contaminants, at what levels and when they were exposed during the period 1953-1987 (ATSDR, 2007; ATSDR, 2013).

Table A2. Summary of ATSDR chapter reports on topical subjects of water-modeling analyses and the historical reconstruction process, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[ATSDR, Agency for Toxic Substances and Disease Registry; VOC, volatile organic compound; PCE, tetrachloroethylene; WTP, water treatment plant]

Report chapter	Author(s)	Chapter title and reference citation	Topical summary
A	Maslia ML, Sautner JB, Faye RE, Suárez-Soto RJ, Aral MM, Grayman WM, Jang W, Wang J, Bove FJ, Ruckart PZ, Valenzuela C, Green JW Jr, and Krueger AL	Summary of Findings; Maslia et al. 2007 (this report)	Summary of detailed technical findings (found in Chapters B–K) focusing on the historical reconstruction analysis and present-day conditions of groundwater flow, contaminant fate and transport, and distribution of drinking water
B	Faye RE	Geohydrologic Framework of the Castle Hayne Aquifer System; Faye (In press 2007a)	Analyses of well and geohydrologic data used to develop the geohydrologic framework of the Castle Hayne aquifer system at Tarawa Terrace and vicinity
C	Faye RE, and Valenzuela C	Simulation of Groundwater Flow; Faye and Valenzuela (In press 2007)	Analyses of groundwater flow including developing a predevelopment (steady state) and transient groundwater-flow model
D	Lawrence SJ	Properties of Degradation Pathways of Common Organic Compounds in Groundwater; Lawrence (In press 2007)	Describes and summarizes the properties, degradation pathways, and degradation by-products of VOCs (non-trihalomethane) commonly detected in groundwater
E	Faye RE, and Green JW Jr	Occurrence of Contaminants in Groundwater; Faye and Green (In press 2007)	Describes the occurrence and distribution of PCE and related contaminants within the Tarawa Terrace aquifer and the Upper Castle Hayne aquifer system at and in the vicinity of the Tarawa Terrace housing area
F	Faye RE	Simulation of the Fate and Transport of Tetrachloroethylene (PCE); Faye (In press 2007b)	Historical reconstruction of the fate and transport of PCE in groundwater from the vicinity of ABC One-Hour Cleaners to individual water-supply wells and the Tarawa Terrace WTP
G	Jang W, and Aral MM	Simulation of Three-Dimensional Multispecies, Multiphase Mass Transport of Tetrachloroethylene (PCE) and Associated Degradation By-Products; Jang and Aral (In press 2007)	Descriptions about the development and application of a model capable of simulating three-dimensional, multispecies, and multiphase transport of PCE and associated degradation by-products
H	Wang J, and Aral MM	Effect of Groundwater Pumping Schedule Variation on Arrival of Tetrachloroethylene (PCE) at Water-Supply Wells and the Water Treatment Plant; Wang and Aral (In press 2007)	Analysis of the effect of groundwater pumping schedule variation on the arrival of PCE at water-supply wells and the Tarawa Terrace WTP
I	Maslia ML, Suárez-Soto RJ, Wang J, Aral MM, Sautner JB, and Valenzuela C	Parameter Sensitivity, Uncertainty, and Variability Associated with Model Simulations of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water; Maslia et al. (In press 2007b)	Assessment of parameter sensitivity, uncertainty, and variability associated with model simulations of groundwater flow, contaminant fate and transport, and the distribution of drinking water
J	Sautner JB, Valenzuela C, Maslia ML, and Grayman WM	Field Tests, Data Analyses, and Simulation of the Distribution of Drinking Water; Sautner et al. (In press 2007)	Field tests, data analyses, and simulation of the distribution of drinking water at Tarawa Terrace and vicinity
K	Maslia ML, Sautner JB, Faye RE, Suárez-Soto RJ, Aral MM, Grayman WM, Jang W, Wang J, Bove FJ, Ruckart PZ, Valenzuela C, Green JW Jr, and Krueger AL	Supplemental Information; Maslia et al. (In press 2007a)	Additional information such as synoptic maps showing groundwater levels, directions of groundwater flow, and the distribution of PCE based on simulation; a complete list of references; and other ancillary information and data that were used as the basis of this study

Table A1. Summary of ATSDR chapter reports and supplemental information sections, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[ATSDR, Agency for Toxic Substances and Disease Registry; PCE, tetrachloroethylene; TCE, trichloroethylene; LNAPL, light nonaqueous phase liquid; IRP, Installation Restoration Program; WTP, water treatment plant; RCRA, Resource Conservation and Recovery Act of 1976; BTEX, benzene, toluene, ethylbenzene, and xylenes]

[1]Report chapter	[2]Authors and reference	Chapter or supplemental information section title	Topical summary
A	Maslia ML, Suarez-Soto RJ, Sautner JB, Anderson BA, Jones LE, Faye RE, Aral MM, Guan J, Jang W, Telci IT, Grayman WM, Bove FJ, Ruckart PZ, and Moore SM (Maslia et al. 2013)	Summary and Findings	Summary of detailed technical findings (found in Supplements 1–8 and Chapters B–D) focusing on historical reconstruction analyses and present-day conditions of groundwater flow, contaminant fate and transport, and distribution of finished water
A–Supplement 1	Sautner JB, Anderson BA, Suarez-Soto RJ, and Maslia ML (Sautner et al. 2013a)	Descriptions and Characterizations of Data Pertinent to Water-Supply Well Capacities, Histories, and Operations	A comprehensive listing and analysis of historical through June 2008 water-supply wells, their capacities, operational histories, and supply of finished water
A–Supplement 2	Telci IT, Sautner JB, Suarez-Soto RJ, Anderson BA, Maslia ML, and Aral MM (Telci et al. 2013)	Development and Application of a Methodology to Characterize Present-Day and Historical Water-Supply Well Operations	Describes a method that uses recorded data, other ancillary information, and a training algorithm to synthesize monthly water-supply well operations, 1942–2008
A–Supplement 3	Faye RE, Jones LE, and Suarez-Soto, RJ (Faye et al. 2013)	Descriptions and Characterizations of Water-Level Data and Groundwater Flow for the Brewster Boulevard and Castle Hayne Aquifer Systems and the Tarawa Terrace Aquifer	Describes water-level data for the Brewster Boulevard and Castle Hayne aquifer systems and Tarawa Terrace aquifer, analyzes water-level trends, and presents a potentiometric surface map derived from the water-level data and resulting groundwater-flow directions
A–Supplement 4	Suarez-Soto RJ, Jones LE, and Maslia ML (Suarez-Soto et al. 2013)	Simulation of Three-Dimensional Groundwater Flow	Describes the application and calibration of a three-dimensional groundwater-flow model used to simulate steady-state (predevelopment) and transient groundwater flow for the period 1942–2008

Table A1. Summary of ATSDR chapter reports and supplemental information sections, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.—Continued

[ATSDR, Agency for Toxic Substances and Disease Registry; PCE, tetrachloroethylene; TCE, trichloroethylene; LNAPL, light nonaqueous phase liquid; IRP, Installation Restoration Program; WTP, water treatment plant; RCRA, Resource Conservation and Recovery Act of 1976; BTEX, benzene, toluene, ethylbenzene, and xylenes]

[1]Report chapter	[2]Authors and reference	Chapter or supplemental information section title	Topical summary
A–Supplement 5	Guan J, Anderson BA, Aral MM, and Maslia ML (Guan et al. 2013)	Theory, Development, and Application of Linear Control Model Methodology to Reconstruct Historical Contaminant Concentrations at Selected Water-Supply Wells	Describes the model developed using linear control theory that is capable of reconstructing historical contaminant concentrations using limited geohydrologic and aquifer information; model is applied to water-supply well HP-651 in the Hadnot Point landfill area
A–Supplement 6	Jones LE, Suarez-Soto RJ, Anderson BA, and Maslia ML (Jones et al. 2013)	Source Characterization and Simulation of Fate and Transport of Selected Volatile Organic Compounds in the Vicinities of the Hadnot Point Industrial Area and Landfill	Describes the application and calibration of three-dimensional models of contaminant fate and transport used to reconstruct historical groundwater concentrations of PCE, TCE, and benzene in the vicinity of the Hadnot Point Industrial Area and landfill area for the period 1942–2008
A–Supplement 7	Jang W, Anderson BA, Suárez-Soto RJ, Aral MM, and Maslia ML (Jang et al. 2013)	Source Characterization and Simulation of the Migration of Light Nonaqueous Phase Liquids (LNAPLs) in the Vicinity of the Hadnot Point Industrial Area	Describes the estimation of LNAPL volume in the subsurface and the development and application of a three-dimensional contaminant fate and transport model used to simulate LNAPL and dissolved-phase benzene in the vicinity of the Hadnot Point Industrial Area for the period 1942–2008
A–Supplement 8	Sautner JB, Grayman WM, Telci IT, Maslia ML, and Aral MM (Sautner et al. 2013b)	Field Tests, Data Analyses, and Simulation of the Distribution of Drinking Water with Emphasis on Intermittent Transfers of Drinking Water Between the Hadnot Point and Holcomb Boulevard Water-Distribution Systems	Describes field tests conducted and data gathered during 2004 for the Hadnot Point and Holcomb Boulevard water-distribution systems and simulations of the intermittent supply of Hadnot Point finished water to the Holcomb Boulevard water-distribution system during the period 1972–1985
B	Faye RE (Faye 2012)	Geohydrologic Framework of the Brewster Boulevard and Castle Hayne Aquifer Systems and the Tarawa Terrace Aquifer	Describes detailed analyses of well, borehole, and geophysical data used to develop the geohydrologic framework of the Brewster Boulevard and Castle Hayne aquifer systems and the Tarawa Terrace aquifer; hydraulic characteristics for several geohydrologic units are tabulated; hydraulic conductivity maps are included
C	Faye RE, Anderson BA, Suarez-Soto RJ, and Sautner JB (Faye et al. 2010)	Occurrence of Selected Contaminants in Groundwater at Installation Restoration Program Sites	Detailed accounting of the occurrences of contaminants of concern and their related degradation products in groundwater at IRP sites within the service areas of the Hadnot Point and Holcomb Boulevard WTPs
D	Faye RE, Suarez-Soto RJ, and Maslia ML (Faye et al. 2012)	Occurrence of Selected Contaminants in Groundwater at Above-Ground and Underground Storage Tank Sites	Summaries of RCRA investigations with detailed accounting of the occurrence and distribution of BTEX components, such as benzene, within the soil and groundwater at selected RCRA sites within the service areas of the Hadnot Point and Holcomb Boulevard WTPs

[1]Letter designation of chapters for series, "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina," supplemental information sections are part of Chapter A, provided on CD–ROM.

[2]See References section for complete reference citation

Figure 2. Summary of ATSDR reports on Camp Lejeune site (ATSDR, 2007; ATSDR, 2013)

Over the past years several agencies and organizations have reviewed ATSDR's studies and the outcomes that were reported by ATSDR (ATSDR, 2007; ATSDR, 2013). One review was provided by the National Academy of Sciences - National Research Council (NRC, 2009a), which was sponsored by the U.S. Department of the Navy. My contemporaneous response to this review was submitted to ATSDR on June 27, 2009, which became an internal document for ATSDR. The contents of this document is set forth in Section 7 of this report.

The government accountability office also reviewed the ATSDR studies and the NRC review. In their conclusions the following point was referenced (GAO, 2007).

- Members of the expert panel that the National Academy of Sciences convened generally agreed that many parameters of ATSDR's current study are appropriate, including the study population, the exposure time frame, and the selected health effects (GAO, 2007).

At the time (GAO, 2007), ATSDR's epidemiology studies were ongoing. Since then, these studies have been concluded. The findings of these studies are given in ATSDR epidemiology reports which are beyond my expertise area.

ATSDR study of the Camp Lejeune site also went through the critical review of an Expert Panel organized by another branch of CDC outside the EDRP/ATSDR group working on the study. The Tarawa Terrace ATSDR study underwent extensive external peer review by an expert panel of leading scientists as documented in Maslia et al. 2009 (Appendix B, P. 46, (https://www.atsdr.cdc.gov/sites/lejeune/expert-panels.html)), as was the Hadnot Point and Holcomb Boulevard study (Maslia et al., 2009; Maslia et al., 2013, P. A98). The scientists on these panels have international reputations as leaders in this field. EDRP/ATSDR program took several steps to respond and adapt to the recommendations of the Expert Panel throughout the study.

The rigorous peer review done by the ATSDR expert panels was followed with another level of peer review in the published journal articles, and a major national award by American Academy of Environmental Engineers (AAEE, 2015) which recognized the quality of ATSDR work product completed at the Camp Lejeune site. This further substantiates the general acceptance of ATSDR's modeling and reconstruction methodology in the pertinent scientific community.

As stated above, an additional level of scrutiny of ATSDR's modeling work came from publication of the Tarawa Terrace and the Hadnot Point/Holcomb studies in two separate peer-reviewed articles published in high quality Q1 (top quartile) journals as given below:

- Maslia, M.L. et al. 2009(b). "Reconstructing Historical Exposures to Volatile Organic Compound-Contaminated Drinking Water at a U.S. Military Base." *Water Quality, Exposure, and Health*. 2009, 1, 49-68.
- Maslia, M.L. et al., 2016. "Reconstructing Historical VOC Concentrations in Drinking Water for Epidemiological Studies at a U.S. Military Base: Summary of Results." *Water*. 2016, 8, 449, 1-23.

This is the summary background of the water modeling studies that have been conducted at the Camp Lejeune site by ATSDR.

4. Principles of Water Modeling and Application at Camp Lejeune

4.1 Water Modeling

In the absence of historical and continuous water quality sampling data, environmental scientists commonly rely on modeling to both predict future contaminant levels and to reconstruct historical contamination at a site. The use of modeling for historical reconstruction is an accepted methodology to predict past exposure or contamination levels, as demonstrated both in the scientific literature (Reif et al. 2003; Maslia et al., 2005; Sahmel et al., 2010) and in site specific studies such as Jacksonville, FL Naval Air Station (USGS, 2003); Tucson International Airport / Hughes Aircraft Facility (EPA, 1988); Oak Ridge National Lab (ATSDR/ChemRisk, 2000); Hanford Site (PNL, 1991); and Toms River / Dover Township (ATSDR, 2000). In its study of the Camp Lejeune site, the ATSDR created four interlinked models using scientifically valid, state of the art modeling tools that are based on fundamental groundwater flow and contaminant migration principles that are widely accepted and routinely utilized in practice for predicting contaminant movement (e.g., during natural spread or enhanced cleanup scenarios) and/or for historical reconstruction efforts such as at Camp Lejeune and other sites (Sahmel et al., 2010; Anderson et al., 2015; Bedient et al., 1999).

My opinions, within a reasonable degree of scientific and engineering certainty, on modeling techniques, their principles, and their application to the Camp Lejeune site include the following:

- Water Modeling (environmental modeling) is a science-based approach to describe and develop domain-based knowledge on contaminant migration within and across domains to understand environmental responses to natural or human perturbations.
- A scientific model (in this case Water Modeling) can be defined as an abstraction of some real system - an abstraction that can be used for decision making and management purposes. Development of a scientific model may include physical, mathematical and statistical procedures. In ATSDR studies of the Camp Lejeune site both mathematical and statistical procedures were used.
- Since all models are an abstraction of the real system, they need to be presented and analyzed in a computational or physical environment which may include an analysis of calibration, validation (section 6.7), uncertainty and variability before they are used in simulation to predict future or past conditions at a site. In ATSDR studies of the Camp Lejeune site all aspects of these computational procedures were successfully employed using computational methods.
- As such, Water Modeling is a reliable and widely accepted method of reconstructing historical contamination in natural and engineered environmental systems. Natural environmental systems may include surface, subsurface and air media; and engineered systems may include water distribution systems, constructed water ways and harbors, etc.
- Under all circumstances, trying to fit a physical system to an available off-the-shelf model approach should be avoided in water modeling. In all cases the best models that describe the system adequately should be used or developed when necessary (USEPA 2009, p. 31).
- The models and techniques used by the ATSDR for historical reconstruction, including fundamental equations, input parameters, parameter estimates, calibration, uncertainty and sensitivity analyses, were and remain reliable, scientifically valid and state of the art procedures that are consistent with standard practices used and are generally accepted in this field.
- The model results show finished water at U.S. Marine Corps Base Camp Lejeune was contaminated with varying levels of TCE, PCE, 1,2-tDCE, benzene and vinyl chloride from 1953 to 1987.

- The simulated monthly mean concentrations of TCE, PCE, 1,2-tDCE, benzene and vinyl chloride at Tarawa Terrace, Hadnot Point and Holcomb Boulevard included (tabulated or in figures) in ATSDR reports are reliable and represent, within a reasonable degree of scientific and engineering certainty, the contaminant levels in finished water at Camp Lejeune from 1953 to 1987.
- The analyses published in all ATSDR chapter reports (ATSDR, 2007; ATSDR, 2013) and supplemental information regarding Camp Lejeune (see Figure 2), including the conclusions and monthly concentration data, were all done applying proper scientific and engineering methodologies and remain to this day to be mathematically reliable, statistically accurate and correct.

4.2 Basis of Opinions

The basis of my opinions outlined in this expert report is my 50 years of work in this field and my fifteen years of Camp Lejeune related work providing technical assistance to ATSDR under a cooperative agreement established between the Centers for Disease Control and Prevention (CDC) and Georgia Tech and my fifty years of expertise and knowledge in this area of research as an educator, researcher and engineer. I have reviewed and relied on published literature, reports, historic data sources, correspondence and participation in meetings with state and regulatory agencies, participation in workshops and the review of documents provided by independent experts at these gatherings, as documented in this report (Section 8).

My opinions are based on my understanding of sound science, engineering, mathematical and statistical formulations that follow the current technology, scientific and engineering methodology that is used in archival literature.

5. Models used in ATSDR Study at Camp Lejeune

The Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services, was requested to conduct an epidemiological study to evaluate health issues at U.S. Marine Corps Base Camp Lejeune, North Carolina. The scientific protocol on these studies received approval from the Centers for Disease Control and Prevention Institutional Review Board and the U.S. Office of Management and Budget.

Historical water contamination data needed for the epidemiological study were limited. To obtain estimates of historical exposure, ATSDR used water modeling techniques and the process of historical reconstruction of contamination levels at the base. These methods are used to quantify concentrations of contaminants in finished water at the base and to compute the level and duration of human exposure to contaminated drinking water.

Owing to the complexity, uniqueness, and the number of topical subjects included in the historical reconstruction process of each study area, several reports were prepared that provide comprehensive descriptions of information, data, and methods used to conduct historical and present-day analyses at both Tarawa Terrace (TT) and Hadnot Point–Holcomb Boulevard (HP-HB), Figure 2.

These reports provide comprehensive descriptions of modeling results used to reconstruct historical contaminant concentration levels and timing of contaminant movement at Camp Lejeune. The study represents the efforts of about 20 experts whose combined expertise from a variety of scientific and engineering disciplines spans every relevant area and specialty involved in water modeling. This body of work forms the foundation for many of the opinions I have included in this report. In this report, I am also offering a more in-depth level of detail on some of those opinions when necessary. To allow the reader the easiest access to this extensive body of work as it relates to this expert report, some of the figures and tables were copied/reproduced from these reports and included here with proper references to the source of the information.

5.1 Modeling Tools

The methods and approaches used to complete the historical reconstruction process for the Tarawa Terrace, Hadnot Point and Holcomb Boulevard study areas, the ATSDR study included the following steps of analysis:

i. Information discovery, field study, data mining and data analysis.
ii. Three dimensional, steady-state (predevelopment) and transient groundwater-flow modeling application using **MODFLOW**-2005. This study included a trial-and-error calibration of the model which also included the use of objective parameter estimation technique using **PEST-12**.
iii. Determining historical water-supply well scheduling and operations using **TechWellOp** and **PSOpS**, a sub-model developed by MESL, Ga Tech.
iv. Three-dimensional dissolved phase groundwater fate and transport modeling of VOCs using **MT3DMS**-5.3.
v. Estimating the volume of light nonaqueous phase liquid (LNAPL) released to the subsurface at the Hadnot Point Industrial Area using **TechNAPLVol**, a sub-model developed by MESL, Ga Tech.
vi. LNAPL and dissolved phase fate and transport analysis using **TechFlowMP**, a sub-model developed by MESL, Ga Tech.

vii. Reconstruction of water-supply well concentrations at the Hadnot Point landfill area using the linear control theory model (LCM) **TechControl**, a sub-model developed by MESL, Ga Tech.
viii. Computation and analysis of flow-weighted average concentrations of VOCs assigned to finished water delivered by the water treatment plants using a volumetric mass balance analysis (simple mixing).
ix. Extended period simulation of hydraulics and water quality in the water-distribution system using **EPANET 2**.
x. Probabilistic analysis of intermittent connections (1972–1985) of the Hadnot Point and Holcomb Boulevard water-distribution systems using the **TechMarkovChain**, a sub-model developed by MESL, Ga Tech.
xi. Calibration and sensitivity analysis of hydraulic and fate and transport models, and numerical-model parameters.
xii. Uncertainty analysis of model simulations.
xiii. The result of the historical reconstruction process included the estimation of monthly mean concentrations of selected VOCs in finished water distributed to Tarawa Terrace housing areas and vicinity, and for the Hadnot Point and Holcomb Boulevard study areas of Camp Lejeune served by the TTWTP, HPWTP and HBWTP.

The models and techniques used by the ATSDR to complete the historical reconstruction process for the Tarawa Terrace, Hadnot Point, and Holcomb Boulevard study areas were and remain reliable, state of the art and consistent with standard engineering practices used in the field of water modeling. The governing mathematical and statistical methods and models used in these applications are standard techniques that are used in technical literature and are well established (Anderson et al., 2015; Aral, 2010; Bedient et al., 1999, Rao, 1996).

Modeling tools (software) used for multiphase flow and multi-species transport in the subsurface and engineered systems at the site include the following public-domain applications developed by the US government agencies:

- The **MODFLOW**-2005.5 application, a three-dimensional finite-difference groundwater-flow model developed by the U.S. Geological Survey (USGS) that is used in groundwater modeling, (https://igwmc.princeton.edu/modflow/).

- **MT3DMS**, a public domain application developed by USGS. **MT3DMS** is a three-dimensional multi-species solute transport model used for solving advection, dispersion, and chemical reactions of contaminants in saturated groundwater flow systems. **MT3DMS** interfaces directly with the U.S. Geological Survey finite-difference groundwater flow model **MODFLOW** for the groundwater flow solution and supports the hydrologic and discretization features of **MODFLOW**. **MT3DMS** contains multiple transport solution techniques in one code, which can often be important, including for model calibration. (https://pubs.usgs.gov/publication/70189204).

- The **HSSM.5** application, a one-dimensional semi-analytical model developed by the U.S. Environmental Protection Agency to estimate volume of spills at contaminated sites. (https://www.epa.gov/water-research/hydrocarbon-spill-screening-model-hssm).

- Developed by USEPA, **EPANET** application is a software application that is used throughout the world to model water distribution systems. It was developed as a tool for understanding

the movement and fate of drinking water constituents within water distribution systems and can be used for many different types of applications in water distribution systems analysis. It can also be used to model contamination threats and evaluate resilience to security threats or natural disasters relevant to water distribution systems. (https://www.epa.gov/water-research/epanet).

The applications listed above are all in the main core of tools used in the ATSDR studies of the Camp Lejeune site. They are all accepted methodologies and software that were used in similar studies at other sites by government agencies and consulting firms.

In addition to the above listed standard applications used in the water modeling field, ATSDR needed to investigate in more detail some of the questions that were raised by the expert panel convened by ATSDR/CDC. For that purpose, MESL research program capabilities were used to supplement the main core applications described above.

These supportive (sub-model) applications used in the ATSDR study of the Camp Lejeune site include:

- The **TechFlowMP** application is a multiphase flow and multispecies contaminant transport model developed in MESL studies (Jang, W. and Aral, MM, 2005; Jang, W. and Aral, MM, 2007; ATSDR 2007h; Jang, W. and Aral, MM, 2008: a, b; Jang, W. and Aral, MM, 2011). In **TechFlowMP** model the coupled equations for flow of water, gas, and NAPL phases and transport of multispecies contaminants in saturated and unsaturated subsurface systems and heat energy transport were formulated and analyzed. To solve those equations, a three-dimensional finite element numerical model (software) was developed. The origin of these studies at MESL research program dates to 1997. **TechFlowMP** model has been verified using analytical solutions and experimental data that are published and available in the literature. To investigate the fate and transport of VOCs in the subsurface, the model was used in conducting numerical analysis on the following other topics in other MESL studies: (i) multiphase flow and contaminant transport in subsurface environments; (ii) biological transformations of contaminants in multiphase environments; (iii) in-situ air sparging analysis (IAS); and, (iv) thermally enhanced venting (TEV) that is used in contaminated groundwater treatment processes. In these numerical studies, the **TechFlowMP** model successfully simulated the migration of contaminants between phases and between the unsaturated/saturated zones of a subsurface system, the dynamic movements of gas phases in the unsaturated zone, and remedial processes under in-situ air sparging (IAS) and thermally induced remediation (TEV) studies of the MESL program.

  This application was used to explore saturated and unsaturated zones and vapor phase contaminant distributions at the Camp Lejeune site. It also served the purpose of independent reconfirmation of the predictions of the calibrated multiphase subsurface models used by ATSDR at the Camp Lejeune site as described above (Figure 11). The ATSDR water modeling team first utilized the **MODFLOW** and **MT3DMS** codes in its groundwater simulations and analysis at the Camp Lejeune site. These two models are widely accepted public domain codes that have been tested and verified in other studies and are universally used in the modeling field for the analysis of groundwater flow and fate and transport of contaminants in subsurface systems (see above cited web sites). In addition to these studies, to enhance the understanding of conditions at the site, ATSDR extended its analysis. The ATSDR water modeling team applied the **TechFlowMP** software to understand and evaluate the unsaturated zone injection and migration conditions at

the site. **TechFlowMP** is a public domain code that can be accessed from the Georgia Tech website for individual use (http://mesl.ce.gatech.edu/, MESL 2017).

The **TechFlowMP** code has been tested and verified against other applications in the literature. The details of verification analysis developed for **TechFlowMP** model can be found in the following references (Jang, W. and Aral, MM, 2005; Jang, W. and Aral, MM, 2007; ATSDR 2007h; Jang, W. and Aral, MM, 2008: a, b; Jang, W. and Aral, MM, 2011). This list of peer reviewed publications provides detailed information on the verification of this model in subsurface application. The application of the **TechFlowMP** model to Camp Lejeune site and calibration, sensitivity and reliability analysis can be found in the references (ATSDR, 2007g; ATSDR, 2013a) and in, http://mesl.ce.gatech.edu/PUBLICATIONS/Publications.html).

- The **TechNAPLVol** sub-model: This is a spilled LNAPL volume estimation model which is based on the USEPA **HSMM.5** analysis mentioned above. In this case the USEPA **HSSM.5** procedures are extended to three-dimensional analysis and used to estimate the volume of spilled BTEX compounds at the Camp Lejeune site.

  For the overall project, the area of interest was the entire Hadnot Point–Holcomb Boulevard (HPHB) study area (Figures A1 and A12 in ATSDR, 2013a, Figure 1). The focus for the modeling and analyses of LNAPL volume estimates is in an area of the Base designated as the Hadnot Point Industrial Area (HPIA). Various fuels, solvents, and other chemicals were stored, used, and inadvertently released to the environment during routine operations at the HPIA. Of particular interest in this study was the historical presence and subsequent fate and transport of subsurface light nonaqueous phase liquid (LNAPL) associated with fuel storage system releases at the HPIA. Results from the analyses are integrated with the results from other models and approaches as a part of the overall project objective to produce estimates and uncertainty bounds for the concentration of contaminants over time in selected water-supply wells and water-distribution systems.

  The objectives of the LNAPL volume estimate analysis were to:

  i. Investigate the migration and distribution of fuel-related LNAPL released into the unsaturated zone above a shallow aquifer for a hypothetical scenario.
  ii. Estimate the volume and distribution of LNAPL in the subsurface at the HPIA using historical field data for LNAPL (free product) thicknesses measured over time in site monitoring wells; and,
  iii. Analyze the dissolution of benzene and total xylenes from the LNAPL source areas and the subsequent dissolved phase fate and transport of these contaminants under unsteady hydrologic and variable water supply well pumping conditions in the underlying groundwater system at the HPIA.

  The purpose of the hypothetical scenario used is to illustrate and explore the behavior of LNAPL in a multiphase environment and provide insight about the potential variability of results involving LNAPL movement. LNAPL movement is just one component of the overall fate and transport process for the applied analysis at the HPIA. For the HPIA analysis, LNAPL movement and estimates of LNAPL distribution in soil were also integrated with the **TechFlowMP** model including the LNAPL dissolution process and subsequent transport of

the dissolved phase contaminants in the groundwater. The goal of the integrated analysis is to evaluate contaminant arrival over time at water-supply wells in the area.

The **HSSM** and **TechFlowMP** models were used in parallel to investigate the migration of LNAPL in the unsaturated zone and at the water table and to explore the distribution of LNAPL saturation in soil over time. Using LNAPL thickness data measured in monitoring wells, the **TechNAPLVol** model code was used to estimate the spatial distribution of LNAPL saturation and the volume of LNAPL in a three-dimensional subsurface domain within the HPIA. The **TechFlowMP** model used saturation profiles from the LNAPL analysis as a starting point for modeling the dissolution of benzene and total xylenes from free-phase LNAPL and the subsequent fate and transport of dissolved phase benzene and total xylenes in the underlying groundwater system.

Technical details of this analysis which follows the USEPA methods of analysis (Farr et al, 1990; USEPA, 1986) are given in (ATSDR, 2013, Chapter A–Supplement 7), Figure 3. This approach is used in ATSDR study to estimate volume of spilled contaminants at the Camp Lejeune site. As indicated in the ATSDR study reports the results confirm the observed data at the site (ATSDR, 2013a, Tables A15, A16). These comparisons are given in Figure 3.

Table A15. Estimates of fuel loss, free product in the subsurface, and fuel recovery at the Hadnot Point Industrial Area fuel farm, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[USMCB, U.S. Marine Corps Base; HPFF, Hadnot Point fuel farm; ATSDR, Agency for Toxic Substances and Disease Registry]

Type of estimate	Volume, in gallons	Reference
Fuel-loss estimates		
USMC documentation of known release from underground fuel line in 1979	20,000–50,000	Water and Air Research, Inc. (1983)
USMC documentation of known fuel releases and inventory losses during 1979–1987	23,150–33,150	O'Brien and Gere Engineers, Inc. (1988, 1990), CH2M HILL (2001)
Model-derived estimates		
[1]SpillCAD™ model estimate of free product (LNAPL) in the subsurface using free product measurements collected during 1988–1995	830,324–1,061,901	UST Management Web Portal Files (2010–2012)[2]
Order-of-magnitude estimate of total fuel in the subsurface based on available documentation as of 2001 (specific methodology not described)	400,000–1,100,000	CH2M HILL (2001)
Fuel recovery estimate		
Reported total fuel recovery from HPFF/Building 1115 area remediation systems as of July 2010	414,118	[3]USMCB Camp Lejeune (July 2010)

[1]SpillCAD™ was developed by Environmental Systems & Technologies (1993)

[2]Draft report by Baker Environmental, Inc., contained in UST Management Web Portal File #01185, p. 526–562

[3]From information presented at the ATSDR-DON Data Mining & Discovery Technical Work Group Meeting, USMCB Camp Lejeune, July 21–22, 2010

Table A16. Estimated volumes of light nonaqueous phase liquid in the subsurface, using semi-analytical solutions and numerical integration, Hadnot Point Industrial Area fuel farm, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.[1]

[1]Method and model (scheme number)	[2]Light nonaqueous phase liquid (LNAPL) volume, in gallons		
	Minimum	Maximum	Mean
[3]Analytical solution using depth of LNAPL in wells; TechNAPLVol model; (Scheme 1)	939,000	1,408,000	1,174,000
Numerical integration of three-dimensional domain using LNAPL depth in wells (apparent thickness); TechNAPLVol model; (Scheme 2)	939,000	1,409,000	1,174,000
Numerical integration of three-dimensional domain using LNAPL depth in soil (actual thickness); TechNAPLVol model; (Scheme 3)	1,079,000	1,618,000	1,348,000

[1]Results listed are a summary of multiple simulation scenarios. Refer to Jang et al. (2013) for details and descriptions of each scheme; see Jang et al. (2013, Tables S7.6 and S7.7) for full range of results and seven different simulation scenarios; also see Jang et al. (2013, Figure S7.12)

[2]Volumes reported are for fresh gasoline; for aged gasoline, minimum volumes increase about 20 percent

[3]Analytical solution derived by Farr et al. (1990)

Figure 3. Spill volumes reported by other agencies (Table A15, pp. A49, ATSDR, 2013a) and Spill volumes estimated by **TechNAPLVol** application (Table A16, pp. A50, ATSDR, 2013a)

- The **Pumping Schedule Optimization System, PSOpS** sub-model: To complement ATSDR's historical contamination reconstruction studies, the pumping schedule variation analysis was conducted to describe the effect of groundwater pumping schedule variations on the arrival times of Tetrachloroethylene (PCE) and other by-products at water-supply wells and the water treatment plant (WTP).

  During the historical reconstruction study, the groundwater flow and fate-and-transport of contaminants in the Tarawa Terrace area of the Camp Lejeune base and its vicinity have been simulated to evaluate the contaminant concentration in the WTP. Due to the uncertainty residing in the reconstructed input data used in these simulations, uncertainty may be present in the simulated contaminant concentrations in the water-supply wells and the WTP, and hence in the times for contaminant concentrations to reach the maximum contaminant level (MCL) at these locations. A contributor to this uncertainty is the uncertainty in pumping schedules used in the ATSDR model, therefore, in this study the focus was on the uncertainty associated with the pumping schedules. The study included the development of a simulation and optimization (S/O) procedure identified as **PSOpS** (**P**umping **S**chedule **Op**timization **S**ystem), which combines field data, simulation models and optimization techniques to optimize the pumping schedules to identify maximum or minimum contaminant concentrations in the WTP consistent with the reported pumping schedules. Based on the optimized pumping schedules, variations of PCE concentration and the maximum contaminant level (MCL, PCE) arrival time at water-supply wells and the WTP were evaluated (Wang and Aral, 2008).

  The MESL-Georgia Tech research group developed **PSOpS** sub-model, an optimization application to yield answers to specialized uncertainty-related question raised by the ATSDR Expert Panel (March 2005) (https://www.atsdr.cdc.gov/sites/lejeune/expert-panels.html). The analysis is based on the **MODFLOW** family of codes in the generation of the database used to solve an optimization problem. The question ATSDR Expert Panel members raised in this case was related to the uncertainty of a pumping-schedule operation that may be implemented at the site and the characterization of its effects on the study outcome. The **PSOpS** model that was developed for the purposes of this analysis and used in the ATSDR water modeling study to address this question became part of the peer reviewed PhD thesis of a graduate student at Georgia Tech. The detailed documentation of this model, which uses the principles of optimization (Rao, 1996) can be found in the PhD thesis of Dr. J. Wang, which is public domain information (Wang, 2008). The overall methodology that used these applications are set forth in detail in the series of reports published by ATSDR, (ATSDR, 2007a, h; ATSDR, 2013a and S2).

- The **TechMarkovChain** sub-model: As described earlier (see Section 3), the Tarawa Terrace WTP was closed in March 1987 due to contamination. During this period, Hadnot Point WTP supplied water to the Hadnot Point area, and Holcomb Boulevard WTP supplied water to the Holcomb Boulevard and Tarawa **T**errace base housing areas. The Holcomb Boulevard water-distribution system is connected to the Hadnot Point water-distribution system at the Marston Pavilion valve and at booster pump 742. While booster pump 742 was removed during 2007, the two systems can still be interconnected by opening a valve that exists at the same location based on water demand conditions. For operational reasons, the two water-distribution systems were occasionally connected (depending on water demand)—exceptions being connections that

occurred during late spring and summer months of 1972–1986 and a continuous 8-day period of 28 January to 4 February 1985 (ATSDR, 2007a, ATSDR, 2013 S8). Because the information pertaining to times when interconnection events occurred is limited and for some years unknown (e.g., 1972–1977, Figure S8.37; ATSDR, 2013), a Markov process (Ross, 1997) was applied by using available field data and information to estimate the probability and number of monthly interconnection events that occurred during the months of April–August for 1972–1985.

A Markov process (a stochastic process) analyzes the tendency of one event to be followed by another event based on the data available on a sequence of events during a calibration period. By using this analysis, one can generate a new sequence of random but related events, which will be statistically correlated to the original calibration data. The stream of events generated is called a Markov Chain.

In this study, a probabilistic approach based on Markov Chain simulations was used to estimate the yearly numbers of booster pump/valve openings. For the calculation of transition probabilities of this Markov Chain model, the conditional probabilities of transfer events given the temperature, precipitation, or delivered finished-water volume value in a day were calculated using Kernel density estimator and Bayes' theorem. Also, the probabilities of transfer were conditioned on the values of pairs of parameters by using the Copula concept. The Markov analysis first estimates the number of historical booster pump opening events on a yearly basis. Next, the numbers of events are distributed among the dry months (April–August) during each year. Graphical techniques and data analyses (of daily recordings of temperature, precipitation, and raw-water volume in the HBWTP) were then used to estimate the occurrence of daily finished-water transfers during individual months. Table S8.20 (ATSDR, 2013, S8) lists the number of recorded interconnection events, and the number of monthly events predicted by using a Markov Chain analysis for the period 1972–1985.

This methodology is an efficient and effective way of utilizing the available data to predict the number of booster pump/valve openings monthly (Ross, 1997; Rao, 1996). The results show that predictions made using the Markov methodology analysis are statistically correlated and mimic the historical operations within a statistical confidence interval (Table S8.20, ATSDR, 2013, S8). These outcomes are used in contaminant fate and transport simulations for the Holcomb Boulevard and Hadnot Point water-distribution systems in ATSDR study. The details of the Markov analysis methodology are given in Appendix S8.4 (ATSDR, 2013a, S8).

- **TechControl** sub-model: A linear control theory model and software developed by MESL, Ga Tech. It is used to address the question of the application of simpler models to predict contaminant concentrations at certain locations of the Camp Lejeune site (HPLF) (ATSDR,2013, S5). The development of the software was based on a request that was initiated by the ATSDR Expert Panel of scientists (Expert Panel 2005) (https://www.atsdr.cdc.gov/sites/lejeune/expert-panels.html).

- The **Linear Control Theory**, **LCT** analysis**:** Linear Control Theory is a scientific methodology of the field of control engineering and applied mathematics. The methodology deals with the control of dynamical systems in engineered processes. In the case of ATSDR study of the Camp Lejeune site, the methodology was applied to groundwater contaminant transport analysis as a simple application to predict concentration values at a specific point in space and time based on limited data available at the site (ATSDR,2013, S5). This study was requested by the expert panel (Expert Panel 2005) which reviewed the ATSDR Camp Lejeune site study and provided scientific advice.

- The **TechWellOp** sub-model**:** A subsurface pumping well estimation model and software developed by MESL, Ga. Tech. The methodology uses the daily data in the Training Period to determine the monthly operational behavior of the water supply wells at the Camp Lejeune site that would satisfy the total water volume delivered to the water treatment plants. Once the average monthly working days in the Training Period are estimated for each calendar month, they are utilized in the prediction stage which is based on the same principle of satisfying the total monthly flow delivered to the treatment plant at those periods. This methodology is an efficient and effective way of integrating the available data in recent years to the prediction process for the past years. The development of the software was based on a discussion that was initiated by the ATSDR Expert Panel of scientists (Maslia, et al., Expert Panel 2005, ATSDR, 2007a; ATSDR, 2013, S2).

The use and application of specialized codes to address specific problems that standard codes such as **MODFLOW** and **MT3DMS** cannot address is an accepted methodology. As stated in the U.S. Environmental Protection Agency report, "Guidance on the Development, Evaluation, and Application of Environmental Models" (USEPA 2009, p. 31): "However, the Agency acknowledges there will be times when the use of proprietary models provides the most reliable and best-accepted characterization of a system." The point being made in this statement is that the most appropriate model should be applied to characterize a system, not necessarily, the most popular or often-used off-the-shelf models. This is the modeling philosophy and approach that ATSDR took when applying the **TechFlowMP**, **TechNAPLVol, TechWellOp, TechControl**, **TechMarkovChain** and **PSOpS** models that were used at the Camp Lejeune site.

5.2 Multimedia Environmental Simulation Laboratory (MESL) involvement in the ATSDR study

In Figure A2, the first in Figure 4 below (ATSDR, 2007; ATSDR, 2013), the components of the Tarawa Terrace modeling study are shown. The red arrows on this figure indicate the areas where the MESL team was involved, and the yellow arrows indicate where the MESL team provided an oversight of the study components. In Figure A2, the second in Figure 4 below (ATSDR, 2007; ATSDR, 2013), the components of the Hadnot Point – Holcomb Boulevard modeling study are shown. The red arrows on this figure indicate the areas where the MESL team was involved, and the yellow arrows indicate where the MESL team provided an oversight of the study components.

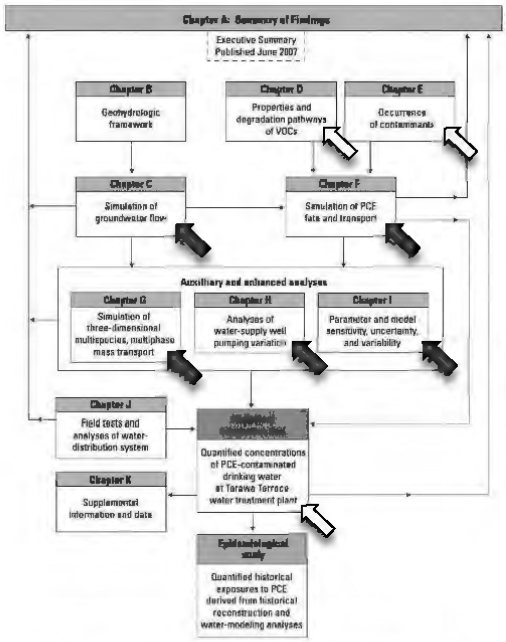

Figure A2. Relation among Chapter A report (Summary of Findings), Chapters B–K reports, historical reconstruction process, and the ATSDR epidemiological case-control study, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina. (VOCs, volatile organic compounds; PCE, tetrachloroethylene.)

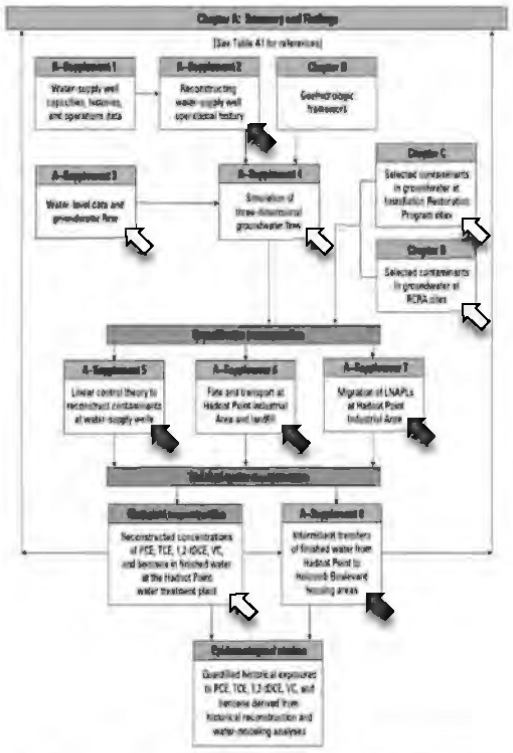

Figure A2. Relation among Chapter A report (Summary and Findings), Chapter A supplements (1–8), Chapters B–D reports, historical reconstruction process, and the ATSDR epidemiological studies, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina. (RCRA, Resource Conservation and Recovery Act of 1976; LNAPL, light nonaqueous phase liquid; PCE, tetrachloroethylene; TCE, trichloroethylene; 1,2-tDCE, trans-1,2-dichloroethylene; VC, vinyl chloride)

Figure 4. MESL involvement in ATSDR modeling tasks at TT and HP/HB Camp Lejeune site (ATSDR, 2007; ATSDR, 2013)

6. Evaluation of ATSDR Camp Lejeune Study Results

6.1 Environmental Modeling Processes used in ATSDR Study

A scientific model can be defined as being an abstraction of some real system - an abstraction that can be used for prediction and management purposes. Thus, the purpose of a scientific model is to make some predictions on the modeled system. While making these predictions, a scientific model also enables the analyst to determine how one or more changes in various aspects of the modeled system may affect the other aspects of the system, the system itself, and the results predicted, in a cost-effective manner. Because models are an abstraction of the real system and cannot be a complete depiction of the real system, they need to be presented and analyzed in a computational environment which includes an analysis of uncertainty, variability, calibration and validation.

Uncertainty analysis may take the form of sensitivity analysis, or for more complicated applications, statistical uncertainty analysis may be utilized. It is important to distinguish the difference between the terms "uncertainty" and "variability." As expected, they refer to two different and distinct concepts (Aral, 2010).

Uncertainty is a measure of knowledge of the magnitude of a parameter. Thus, uncertainty can be reduced by further research, i.e. the parameter value can be refined through further experimentation or further data collection. Variability on the other hand is a measure of the heterogeneity of a parameter, event or the inherent variability in a chemical property at a site. Variance cannot be reduced by further research, but a model can be developed such that it would mimic the variability of the parameter or event used in the model. Statistical variability analysis is a common approach used in modeling studies to envelope these variations at a site and understand its effects on the outcome. This analysis provides some degree of confidence in model output.

Models include parameters that need to be associated with values. These parameter values are used as input to mathematical models to produce numerical output. Ideally, these parameters should have a good definition and a physical basis for the environmental system under study. Usually, these parameters either are calculated using the mathematical representation of their physical basis, or they are measured in field or laboratory studies. Often, however, the values of these parameters are unknown or only known approximately. Thus, a range of these parameters can be input into a model to yield the best outcome when compared to an observation made in a field or laboratory study. Appropriate values of the parameters are needed in the model to achieve the appropriate output that is observed at a site. Thus, calibration of models is necessary. Calibration of a model can then be defined as the stage where we adjust the parameters of the mathematical model such that the model agreement is maximized with respect to the observation data we have on the modeled system output. In this sense, model calibration is fine tuning the model to a set of parameter data on the modeled system. Calibration procedures used in the ATSDR study for all models considered adhere to the standards used in the technical literature (Bedient, 2003; Anderson, 2015, Mei 2023).

The calibration process followed by validation of complex systems is another important aspect of model development and use as it is implemented in ATSDR studies. The seemingly complex definitions of these two terms may get further complicated when several models are used in environmental applications where overlapping models are necessary to describe the behavior of the complex system. In complex system analysis several interlinked modeling phases are used to describe the behavior of the system

modeled. Thus, as a typical example, the calibration and validation procedures used in a simple steady state groundwater modeling application will be different than an interlinked study of a complex system. A complex system may include a steady/unsteady groundwater flow model that is linked to a transient contaminant transport model which is further linked to a water treatment plant condition that is linked to a water distribution system analysis. Since these phases are not independent and occur within the same envirosphere and time frame of analysis, one should not ignore the integrated calibration and validation processes involved in these applications. In complex systems the interlinked behavior of the models used is the key response that is in question which is sometimes ignored, overlooked or not properly understood. The ATSDR study of the Camp Lejeune site represents such a complex system where steady groundwater flow, unsteady groundwater flow, unsteady multispecies multiphase contaminant transport and the engineered water treatment and water distribution system applications are all components of the same envirosphere and operate within the same time frame. As such, calibration and validation processes should be considered as interlinked processes.

Having described the definition of the calibration process above, validation is another contended modeling concept that was and still is debated in scientific literature. For example, in Konikow and Bredehoeft (1992) it is stated that: "Ground-water models are embodiments of scientific hypotheses. As such, the models cannot be proven or validated, but only tested and invalidated," or "…The absolute validity of a model can never be determined" (NRC, 1990). This is partly a semantic issue and partly a philosophical one. In the main text of this report, I will not go into the details of the philosophical discussions on this subject although I believe they have merit within the context the authors describe the process in their scientific discussions. However, I will evaluate this process within the context of complex systems analysis in Section 6.7 of this expert report to bring clarity to the definition of this process as it is used in the Camp Lejeune study. In this expert report I will adopt the standard (traditional) definition of validation of a model. In traditional definition, validation is understood as a process that results in an explicit statement about the behavior of a model in an application. That is, the common definition of validation is the demonstration that a model, within its domain of applicability, possesses satisfactory accuracy consistent with the intended application of the model (Sargent, 1984; Curry et al., 1989; Konikow and Bredehoeft, 1992). This demonstration builds confidence in the model and indicates that the model is acceptable for use. As such, validation procedures used in the ATSDR study for all models considered adhere to the standards used in technical literature (Aral, 2010, Bedient, 2003; Anderson, 2015, Sargent, 1984; Curry et al., 1989; Konikow and Bredehoeft, 1992; Mei, 2003).

The calibration, validation, uncertainty and sensitivity analysis concepts used in the ATSDR study are clearly described on page 23 of Chapter A report (ATSDR, 2007a; Fig. A9) Figure 5. In these definitions, the hierarchical approach to calibration and validation is conceptually described in terms of the Venn or set diagrams (Borowski and Borwein 1991), Figure 5. Such diagrams are useful for showing logical relations between sets or groups of like items and are shown in Figure A9 for each hierarchical calibration level. What is meant by this description is that at level 1 (Figure *A9a, Figure 5),* there may be many combinations of parameters that yield solutions to the predevelopment groundwater-flow calibration conditions. However, only a smaller set of these feasible solutions, the subset of solutions indicated by circle "A" in Figure A9a yields an acceptable combination of parameters for a calibrated transient groundwater flow condition. Viable solutions are indicated by circle "B" (Figure *A9b*, ATSDR, 2007a), Figure 5. Only those solutions that successfully simulate both predevelopment and transient groundwater flow conditions can be accepted and classified as resulting in calibrated transient and predevelopment groundwater flow models. As such, the next level modeling used not only serves as the independent validation of the previous level application, but it is also used in the iterative recalibration process of the previous system if validation process does not yield satisfactory outcome. Similarly, the

next level of modeling phase, which is the transient contaminant transport analysis serves as the next independent validation of groundwater flow models, but it is also used in the recalibration of the complete system up to that stage. Thus, in all levels, the last level serves as an independent validation of the previous level and sometimes necessitates the recalibration of all the previous system levels. This is an important distinction which needs to be considered in complex system analysis and modeling as opposed to simple modeling applications.

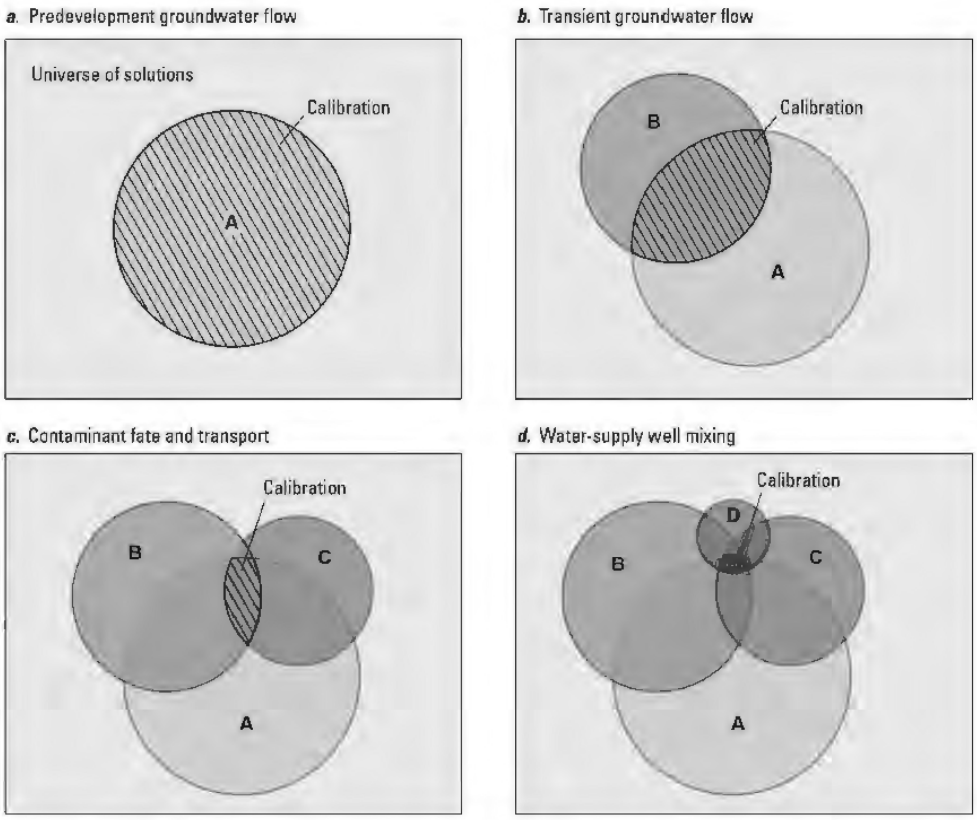

Figure A9. Venn diagrams showing hierarchical approach of model calibration used to estimate concentration of finished water: *(a)* predevelopment groundwater flow, *(b)* transient groundwater flow, *(c)* contaminant fate and transport, and *(d)* water-supply well mixing, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Figure 5. Venn diagram representations (Figure A9, page A23, ATSDR, 2007a)

The ATSDR study of the Camp Lejeune site falls into the category of a "Complex System" as defined above. Thus, iterative calibration and validation of all models used in the ATSDR study adhere to the standards used in the technical literature within the concept of complex system analysis (Aral, 2010).

It is my opinion that these concepts are properly and successfully developed and employed in the models that are used in ATSDR studies for the Camp Lejeune site (ATSDR, 2007a; ATSDR, 2013a).

6.2 Contaminants Studied at the Camp Lejeune Site

The specific VOCs that ATSDR studied at the Camp Lejeune site (TT, HP-HB sites), include:

- trichloroethylene (TCE),
- tetrachloroethylene (PCE),

- *trans* 1,2-dichloroethylene, (1,2-tDCE),
- vinyl chloride (VC), and
- benzene or BTEX compounds.

Trichloroethylene: Trichloroethylene (TCE) is a volatile, colorless liquid organic chemical. TCE does not occur naturally in the environment and is created by chemical synthesis. It is used primarily to make refrigerants and other hydrofluorocarbons and as a degreasing solvent for metal equipment. TCE is also used in some household products, such as cleaning wipes, aerosol cleaning products, tool cleaners, paint removers, spray adhesives, carpet cleaners and spot removers. Commercial dry cleaners also use trichloroethylene as a spot remover. (extracted from: https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/trichloroethylene).

Tetrachloroethylene: Tetrachloroethylene is a nonflammable colorless liquid. It is widely used for dry cleaning of fabrics; hence it is sometimes called "dry-cleaning fluid". It also has its uses as an effective automotive brake cleaner. Other names for tetrachloroethylene include perchloroethylene, PCE, PERC, tetrachloroethene, and perchlor. (extracted from: https://en.wikipedia.org/wiki/Tetrachloroethylene).

Trans-1,2-dichloroethylene: Trans-1,2-dichloroethylene is a colorless liquid, with a sharp, harsh odor, and is highly flammable. The primary uses for trans-1,2-dichloroethylene are as a solvent in processing and in formulations for cleaning and degreasing.

Vinyl chloride: Vinyl chloride is a colorless gas that burns easily. It does not occur naturally and must be produced industrially for its commercial uses. Vinyl chloride is used primarily to make polyvinyl chloride (PVC), a hard plastic resin used to make a variety of plastic products, including pipes, wire and cable coatings, and packaging materials (extracted from: https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/vinyl-chloride).

BTEX: A group of VOCs, collectively known as BTEX, comprising benzene (**B**), toluene (**T**), ethylbenzene (**E**) and xylene (**X**) (often expressed as total xylenes) are important industrial solvents and frequently encountered in petroleum products.

Benzene: Benzene is a colorless or light-yellow liquid chemical at room temperature. It is used primarily as a solvent in the chemical and pharmaceutical industries, as a starting material and an intermediate in the synthesis of numerous chemicals, and in gasoline. Benzene is produced by both natural and man-made processes (extracted from: https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/benzene).

The contamination conditions based on these chemicals at the Tarawa Terrace, Hadnot Point and Holcomb Boulevard areas will be examined in more detail in the following sections of this expert report.

6.3 Contaminants Observed at the Camp Lejeune Site

Contamination vs *Pollution* are two synonymous terms that are commonly used in technical literature and in the common language that is associated with environmental studies and health risk analysis. Contamination that is present in the environment at low concentrations and thus does not cause adverse environmental or health effects should not be confused with pollution. It is when these contaminant levels exceed a certain threshold and cause health effects is of concern in health studies. When that happens, contaminants at a site are classified as environmental pollution (Meharg, 2005; Aral, 2010).

In this context it is important to reference the reported (observed) PCE concentrations in water supply wells in Tarawa Terrace study area reports. In Table A9, page A27, we see the elevated PCE concentrations in water supply wells (ATSDR, 2007a), Figure 6. In this table, the numbers in the fourth column are all observed PCE levels in water supply wells; the MCL level for PCE is 5 µg/L.

Table A9. Summary of model-derived values and observed data of tetrachloroethylene at water supply wells, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina.[1]

(PCE, tetrachloroethylene; µg/L, microgram per liter; J, estimated; ND, nondetect)

Model-derived value		Observed data				
Month and year	PCE concentration in µg/L	Sample date	PCE concentration in µg/L	Detection limit, in µg/L	Calibration target, in µg/L	Sample number
			Supply well TT-23			
January 1985	254	1/16/1985	132	10	41.7–417	1
February 1985	253	2/12/1985	37	10	41.7–417	2
February 1985	253	2/19/1985	26.2	2	8.3–82.9	3
February 1985	253	2/19/1985	ND	10	1–10	4
March 1985	265	3/11/1985	14.9	10	4.7–47.1	5
March 1985	265	3/13/1985	16.6	2	5.2–52.5	6
March 1985	265	3/12/1985	40.6	10	12.8–128	7
March 1985	265	3/12/1985	48.8	10	15.4–154	8
April 1985	274	4/9/1985	ND	10	1–10	9
September 1985	279	9/25/1985	40	2	1.3–12.6	10
July 1991	191	7/11/1991	ND	10	1–10	11
			Supply well TT-25			
February 1985	7.3	2/5/1985	ND	10	1–10	12
April 1985	9.8	4/9/1985	ND	10	1–10	13
September 1985	18.1	9/25/1985	0.43J	10	0.14–1.4	14
October 1985	20.4	10/29/1985	ND	10	1–10	15
November 1985	22.8	11/4/1985	ND	10	1–10	16
November 1985	23.0	11/13/1985	ND	10	1–10	17
December 1985	25.5	12/3/1985	ND	10	1–10	18
July 1991	7.7	7/11/1991	23	10	7.5–75	19
			Supply well TT-26			
January 1985	804	1/16/1985	1,580.0	10	309–3,096	20
January 1985	804	2/12/1985	5.6	10	1.3–13	21
February 1985	798	2/19/1985	64.0	10	20.2–202	22
February 1985	798	2/19/1985	55.2	10	17.5–175	23
April 1985	801	4/9/1985	630.0	10	199–1,992	24
June 1985	799	6/24/1985	1,160.0	10	367–3,668	25
September 1985	788	9/25/1985	1,490.0	10	548–5,478	26
July 1991	670	7/11/1991	350.0	10	111–1,107	27
			Supply well TT-30			
February 1985	0.0	2/6/1985	ND	10	1–10	28
			Supply well TT-31			
February 1985	0.17	2/6/1985	ND	10	1–10	29
			Supply well TT-53			
February 1985	0.0	2/6/1985	ND	10	1–10	30
			Supply well TT-54			
February 1985	6.6	2/6/1985	ND	10	1–10	31
July 1991	30.4	7/11/1991	ND	5	1–5	32
			Supply well TT-67			
February 1985	4.4	2/6/1985	ND	10	1–10	33
			Supply well RW1			
July 1991	0.0	7/12/1991	ND	2	1–2	34
			Supply well RW2			
July 1991	879	7/12/1991	790	2	240–2,403	35
			Supply well TW2			
July 1991	0.0	7/12/1991	ND	2	1–2	36

[1]Model-derived values for water-supply wells based on simulation results obtained from the finite-element transport model MT3DMS (Zheng and Wang 1999); see the Chapter B report (Clive in prep. 2007b) for details

[2]Calibration targets are 0.5 order of magnitude for observed data when observed data are reported as ND; upper calibration target is detection limit and lower calibration target is 1 µg/L

[3]See Figure A1

Figure 6. The reported (observed) PCE concentrations at the Tarawa Terrace study area water supply wells (column four Table A9, page A27, Tarawa Terrace site, ATSDR, 2007a.)

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Similarly, the reported (observed) TCE, PCE, 1,1-DCE, 1,2-tDCE, 1,2-cDCE, Total 1,2-DCE, and VC concentrations at Hadnot Point – Holcomb Boulevard study area are given in Figure 7. In this table, the numbers highlighted in red are all observed levels that are above the detection limits for the compound identified in the header of the table; the MCL level for TCE and PCE is 5 µg/L.

Table A4. Water-supply wells with reported detections of tetrachloroethylene (PCE), trichloroethylene (TCE), 1,1-dichloroethylene (1,1-DCE), *trans*-1,2-dichloroethylene (1,2-tDCE), *cis*-1,2-dichloroethylene (1,2-cDCE), total 1,2-dichloroethylene (total 1,2-DCE), or vinyl chloride (VC), Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.[1]

[<, constituent is less than the detection limit. Number following the "<" is the detection limit; —, constituent concentration not determined in laboratory analysis; ND, constituent not detected; J, estimated concentration; D, sample diluted for analysis]

Well name	Sample date	Concentration of constituent (µg/L)						
		PCE	TCE	1,1-DCE	1,2-tDCE	1,2-cDCE	Total 1,2-DCE	VC
HP-602	7/6/1984	<1.0	<1.0	<1.0	7.0	—	—	<0.9
	11/30/1984	24	1,900	2.0J	550	—	—	0J
	12/10/1984	500	340	500	0J	—	—	500
	12/13/1984	3.0	300	—	110	—	—	—
	12/14/1984	50	340	50	200	—	—	50
	2/4/1985	1.0J	30	<10	7J	—	—	10
	11/12/1986	<4.1	2.2J	<2.0	2.4	—	—	<4.9
	1/22/1991	<5.0	0.77J	<5.0	—	—	2J	<10
HP-603	12/4/1984	<10	4.0J	<10	<10	—	—	<10
	12/12/1984	<10	<10	<10	<10	—	—	<10
	1/16/1985	<10	<10	<10	<10	—	—	<10
	8/11/1988	<10	<10	<10	<10	—	—	<10
	6/26/1990	<5.0	<5.0	<5.0	—	—	—	<10
	1/22/1991	<5.0	2.0J	<5.0	—	—	<5.0	<10
	9/20/1995	<0.50	5.0	<0.50	<0.50	2.4	—	<0.50
HP-608	12/4/1984	<10	11J	<10	4.4J	—	—	<10
	12/10/1984	<10	8J	<10	3.4J	—	—	<10
	2/4/1985	<10	7J	<10	<10	—	—	<10
	11/12/1986	<4.1	6J	<2.0	0J	—	—	<4.9
HP-610	2/4/1985	<10	<10	<10	<10	—	—	<10
	10/1/1992	<1.0	5J	—	—	—	—	<2.0
HP-634	12/4/1984	<10	<10	<10	<10	—	—	<10
	12/10/1984	<10	<10	<10	2.1J	—	—	<10
	1/16/1985	<10	1,300	<10	<10	—	—	6J
	11/12/1986	<4.1	1.9J	<2.0	2.0	—	—	<4.9
	1/22/1991	<5.0	<5.0	<5.0	—	—	1.5J	<10
HP-637	12/4/1984	<10	<10	<10	<10	—	—	<10
	12/10/1984	<10	<10	<10	<10	—	—	<10
	1/16/1985	<10	<10	<10	<10	—	—	<10
	1/22/1991	<5.0	0.80J	<5.0	—	—	<5.0	<10
	8/20/1992	<5.0	<5.0	<5.0	<5.0	<5.0	—	<5.0
HP-651	1/16/1985	180	5,000	180	3,400	—	—	660
	2/4/1985	307	17,000	200	2,000	—	—	1%
	2/4/1985	480	18,000	200	7,500	—	—	1,6
	11/12/1986	40	90	7.0	140	—	—	840
	1/22/1991	50	13	5.0J	—	—	2J	9J
HP-652	1/16/1985	<10	9J	<10	<10	—	—	<10
	11/12/1986	<4.0	<4.0	<2.0	<2.0	—	—	<4.9
	1/22/1991	<5.0	<5.0	<5.0	—	—	<5.0	<10
	9/20/1995	<0.50	<0.50	<0.50	<0.50	<0.50	—	<0.50
	12/11/2001	<0.50	0.5C	<0.50	<0.50	<0.50	—	<0.50
HP-653	1/16/1985	<10	5J	<10	<10	—	—	<10
	11/12/1986	<4.1	2.0	<2.0	<2.0	—	—	<4.9
	1/22/1991	<5.0	<5.0	<5.0	—	—	<5.0	<10
HP-660	12/4/1984	5.0J	14J	<10	8J	—	—	<10
	12/10/1984	4.6J	29J	<10	9J	—	—	<10
	1/16/1985	<10	2J	<10	0J	—	—	<10
	11/12/1986	<4.1	1.9	<2.0	<2.0	—	—	<4.9
	1/22/1991	<5.0	1.1J	<5.0	—	—	1.5J	<10

[1] See Faye et al. (2010) for a complete database of contaminants in water samples collected at water-supply wells in the Hadnot Point–Holcomb Boulevard study area

[2] Concentrations above the detection limit are highlighted in red

Figure 7. The reported (observed) TCE, PCE, 1,1-DCE, 1,2-tDCE, 1,2-cDCE, Total 1,2-DCE, VC concentrations at Hadnot Point – Holcomb Boulevard study area (Table A4, pp. A21, HP/HB Camp Lejeune site, ATSDR, 2013a)

Similarly, the reported (observed) BTEX concentrations at Hadnot Point – Holcomb Boulevard study area are given in Figure 8. The numbers highlighted in red are all concentrations above detection levels for the compound identified in the header of the table; the MCL level for Benzene is 5 µg/L.

Table A5. Water-supply wells with reported detections of benzene, toluene, ethylbenzene, or total xylenes, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.[1]

[<, constituent is less than the detection limit. Number following the "<" is the detection limit; —, constituent concentration not determined in laboratory analysis; ND, constituent not detected; E, estimated concentration]

Well number	Sample date	Concentration, in micrograms per liter			
		Benzene	Toluene	Ethylbenzene	Total xylenes
Hadnot Point Water Treatment Plant Service Area					
HP-602	7/6/1984	350	20	5.0	—
	11/30/1984	220	5.0E	<10	—
	12/10/1984	720	<500	<500	—
	12/13/1984	<1.0	<1.0	<2.0	—
	12/14/1984	20	0.1	50	—
	3/4/1985	10	<10	<10	—
	11/12/1986	10	0.0	7.2	<12
	1/23/1991	1*	<5.0	5.0	<5.0
HP-603	12/4/1984	10	0.0	<10	—
	12/10/1984	10	0.0	<10	—
	3/16/1985	10	0.0	10	—
	3/11/1988	10	0.0	10	<10
	8/26/1990	5.0	<5.0	<5.0	<5.0
	1/22/1991	<5.0	<5.0	<5.0	<5.0
	9/30/1995	<0.50	<0.50	<0.50	0.58
HP-604	12/4/1984	3.0	10	<10	—
	12/10/1984	<10	<10	<10	—
	3/4/1985	10	10	10	—
	11/12/1986	<8.4	<6.0	<7.2	<12
HP-621	1/16/1985	10	0.0	<10	—
	2/7/1985	10	0.0	<10	—
	11/12/1986	<8.4	<6.0	<7.2	12
	1/22/1991	5.0	0.0	<5.0	<5.0
Holcomb Boulevard Water Treatment Plant Service Area					
HP-645	2/4/1985	10	<10	<10	—
	11/6/1986	<8	7.5	ND	ND
	2/17/1987	<20	15	38	38
HP-706	9/19/1995	<0.50	<0.50	<0.50	<0.50
	1/13/1998	0.1	—	—	—

[1] See Faye et al. (2010) for a complete tabulation of contaminants in water samples collected at water-supply wells in the Hadnot Point–Holcomb Boulevard study area.

[2] Concentrations above the detection limit are highlighted in red.

Figure 8. The reported (observed) BTEX concentrations at Hadnot Point – Holcomb Boulevard study area (Table A5, pp. A22, HP/HB Camp Lejeune site, ATSDR, 2013a).

As seen in the tables above, the observed and modeled contaminant levels of TCE, PCE, their by-products and BTEX compounds at the Camp Lejeune site are all at elevated levels (ATSDR, 2007; ATSDR, 2013).

6.4 Dissolved phase pollution vs NAPL, LNAPL and DNAPL pollution.

Nonaqueous phase liquids (NAPLs) are hydrocarbons that exist in a subsurface environment as a separate, immiscible (nonmixing) phase when in contact with water and/or air. Differences in the physical and chemical properties of water and NAPL result in the formation of a physical interface between the liquids which prevents the two fluids from mixing. Nonaqueous phase liquids are typically classified as either light nonaqueous phase liquids (LNAPLs) which have densities less than that of water,

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or dense nonaqueous phase liquids (DNAPLs) which have densities greater than that of water (Newell et al., 1995).

Upon release to the environment, NAPL (i.e., LNAPL or DNAPL) will migrate downward under the force of gravity. If a small volume of NAPL is released to the subsurface, it will move through the unsaturated zone where a fraction of the hydrocarbon will be retained by capillary forces as residual globules in the soil pores, thereby depleting the contiguous NAPL mass until movement ceases. If sufficient LNAPL is released, it will migrate until it encounters a physical barrier (e.g., low permeability strata) or is affected by buoyancy forces near the water table. Once the capillary fringe is reached, the LNAPL may move laterally as a continuous, free-phase layer along the upper boundary of the water-saturated zone due to gravity and capillary forces (Newell et al., 1995). DNAPL pollution on the other hand, because its density is higher than that of water, will continue its downward motion under the force of gravity in a water saturated subsurface system.

Modeling techniques used for each of these contamination types and dissolved phase modeling techniques are distinctly different from one another. The governing equations, mathematical definitions of migration and diffusion-dispersion processes differ from one another and a model developed for one case cannot represent the contaminant fate and transport in the other case.

A NAPL phase which is in physical contact with ground water will dissolve (solubilize, partition) into the aqueous phase. The solubility of an organic compound is the equilibrium concentration of the compound in water at a specified temperature and pressure. For all practical purposes, solubility represents the maximum concentration of that compound in water at a given temperature. At the maximum concentration, the solution is said to be saturated and thus the NAPL phase exists. Thus, to distinguish NAPL pollution from dissolved phase pollution at a site, the relative magnitude of solubility of the alien substance and the concentrations observed at a site can be used. If the concentrations of the alien substance observed at a site is less than ~10% of the solubility range of the alien substance, then the alien substance plume can be identified as a dissolved phase plume rather than an NAPL plume (Hulling and Weaver, 1991).

Characterization of tetrachloroethylene (PCE) contamination in groundwater at the ABC One-Hour Cleaners site and at Tarawa Terrace base housing as a “free-phase” or “pure-phase” DNAPL plume (NRC 2009, p. 38) contradicts and misrepresents the concentration data presented in ATSDR and in other reports and documents in the water phase. Those reports and documents describe the PCE in groundwater in the vicinity of ABC One-Hour Cleaners as “dissolved-phase” PCE (Shiver 1985, Roy F. Weston, Inc. 1992, 1994, Faye and Green 2007). The solubility limit of PCE in water occurs at a concentration of at least 210,000 µg/L (Pankow and Cherry, 1996, Lawrence 2007). PCE solubility is given in the range 150,000 µg/L – 1,503,000 µg/L at 25 °C in (Fetter, 1998: page 163). PCE in groundwater that occurs at concentrations much less than the solubility limit is, by the definition given above, a dissolved-phase PCE plume. The ATSDR conceptualization of groundwater flow and of dissolved-phase PCE conditions at ABC One-Hour Cleaners and the Tarawa Terrace base housing area is shown below in Figure 9. PCE-concentration data presented in ATSDR reports (Faye and Green 2007, Tables E5 and E7) indicate that concentrations of PCE in groundwater at Tarawa Terrace and vicinity occur at much less than 10% of the solubility limit. Thus, the characterization of the PCE plume in the vicinity of ABC One-Hour Cleaners as a dissolved phase plume is the most appropriate characterization of conditions at the site.

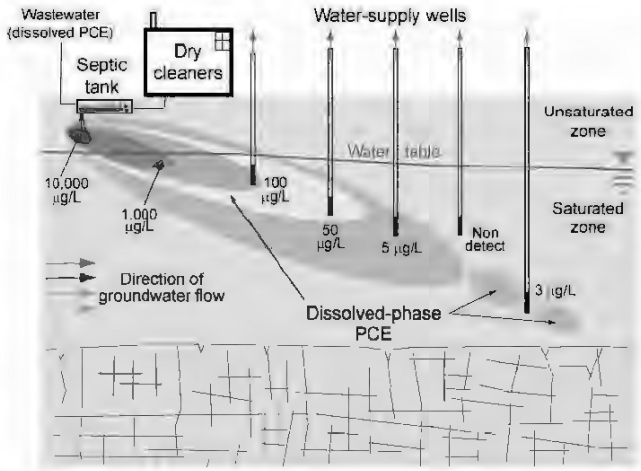

Figure 9. Conceptual model of groundwater flow and dissolved-phase PCE transport at, and in the vicinity of, ABC One-Hour Cleaners (solubility of PCE is at least 210,000 µg/L, Pankow and Cherry 1996, Lawrence 2007)

Further, the processes selected to remediate free-phase DNAPL PCE plume in groundwater are totally different from processes used to remediate dissolved-phase PCE plume in groundwater. The remediation process at the ABC One-Hour Cleaners and at Tarawa Terrace was coordinated under the auspices (directives) of the U.S. Environmental Protection Agency (USEPA). The remediation process selected was approved by the North Carolina Department of Environment and Natural Resources (NCDENR) and is correctly described as "groundwater extraction by wells and treatment by air stripping (i.e., pump-and-treat process)." This remediation process is appropriate only for dissolved phase PCE contamination and not for DNAPL phase PCE plume (NCDENR 2003, Weston Solutions Inc. 2005, 2007).

Given the definitions and data presented above, it is my opinion that the dissolved phase plume characterization used in the ATSDR study of the Tarawa Terrace area is appropriate and consistent with the definitions given above.

6.5 Tarawa Terrace Study

The construction of the Tarawa Terrace housing area dates to 1951. The area was subdivided into housing areas I and II which contained a total of 1,846 housing units and accommodated a resident population of about 6,000 people (fluctuating), Figure 10.

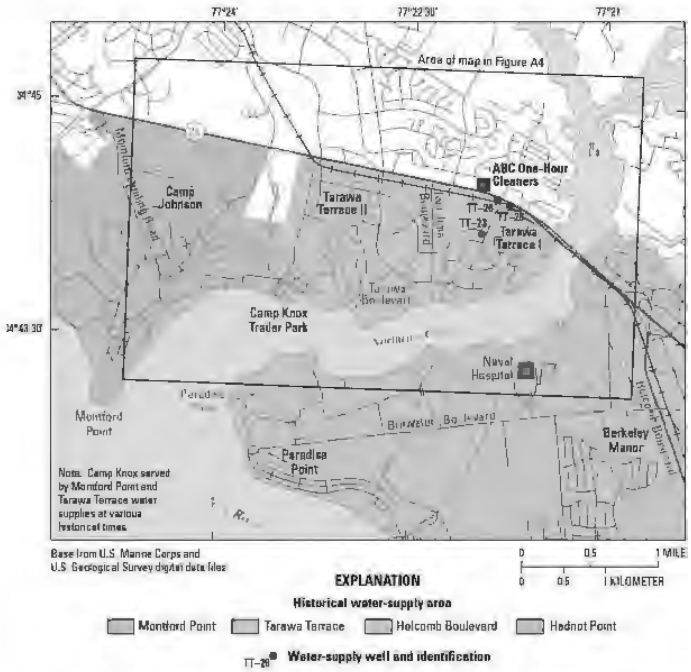

Figure A1. Selected base housing and historical water-supply areas, Tarawa Terrace and vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Figure 10. Tarawa Terrace study area, location of ABC One Hour Cleaners and geographic boundaries of the site. (Figure A1, page A3, ATSDR, 2007a)

Groundwater is the sole source of water supply at the Tarawa Terrace site. To analyze and reconstruct contaminant concentrations and the timeline of contaminant movement at the site, a series of modeling techniques were used by the EDRP/ATSDR modeling group. These are:

- The analysis of predevelopment (steady state) groundwater flow conditions at the site (**MODFLOW**);
- The analysis of transient (pumping) groundwater flow conditions at the site (**MODFLOW**);
- The analysis of fate and transport of PCE and its by-products from its source at ABC One-Hour Cleaners to water-supply wells (**MT3DMS and TechFlowMP**);
- The analysis of concentration of PCE and its by-products in finished water at the Tarawa Terrace WTP were determined by using a material mass balance model (**Mass Balance, simple mixing**), where the flow-weighted average concentration of the aforementioned contaminants was calculated. The water from the Tarawa Terrace WTP was delivered to residents living in family housing; and,
- Assessment of parameter sensitivity, variability, and uncertainty associated with model simulations of groundwater flow, contaminant fate and transport, and water-distribution system analyses were also conducted (ATSDR, 2007).

For the implementation of these stages proper sub-models developed by MESL were also used as appropriate. The details of these sub-models were described earlier in this report (see Section 5). The calibration and validation analyses were successfully completed for all the modeling stages given the

complex system analysis techniques described earlier in this expert report (see Section 6.1). The details of this analysis can be found in (ATSDR, 2007) which will not be repeated here.

After calibration and validation analyses were successfully completed the simulation results of PCE and its by-products at the WTP were generated. These results are summarized in Figure 11.

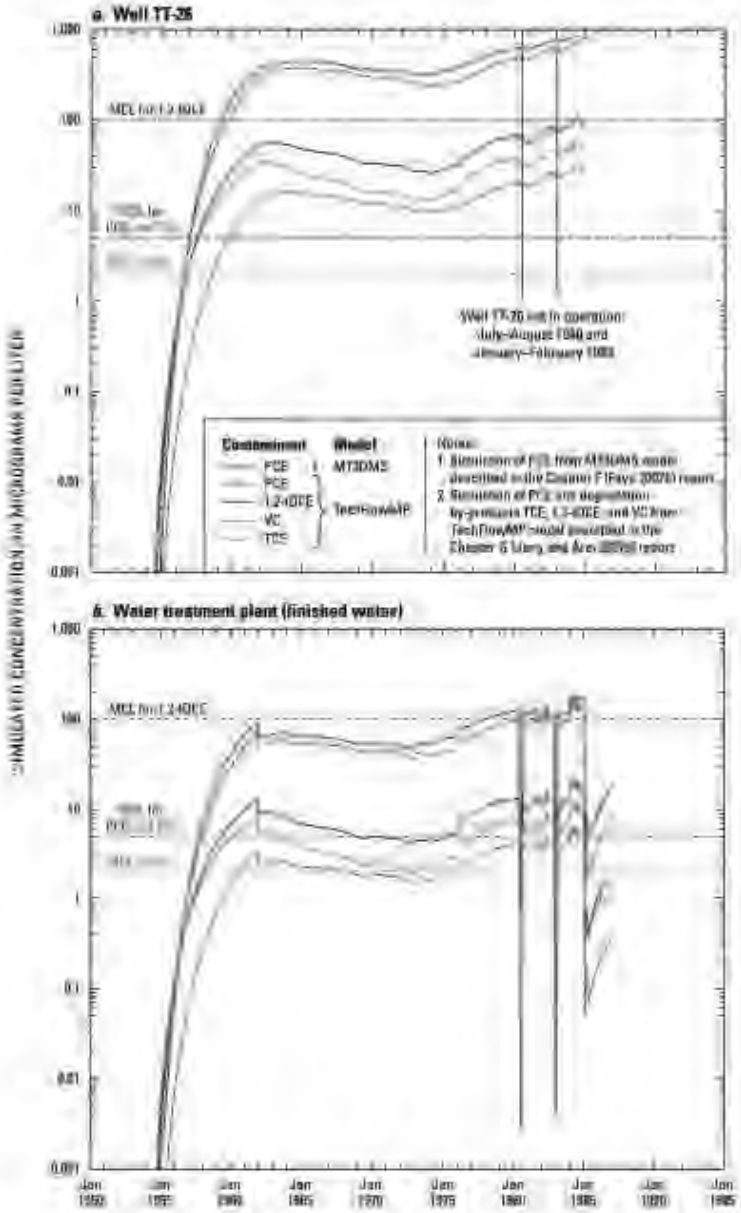

Figure A19. Simulated concentration of tetrachloroethylene (PCE) and degradation by-products trichloroethylene (TCE), *trans*-1,2-dichloroethylene (1,2-DCE), and vinyl chloride (VC) *(a)* at water-supply well TT-26 and *(b)* in finished water from water treatment plant, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina. (MCL, maximum contaminant level)

Figure 11. Simulated PCE concentrations and its by-products at water supply well TT-26 and the WTP of Tarawa Terrace site (Figure A19, page A43, ATSDR, 2007a)

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Uncertainty and sensitivity analyses were also successfully completed for the Tarawa Terrace study. The uncertainty analysis included the porous media parameter uncertainty, contaminant property uncertainty, model setup uncertainty and environmental factor uncertainty as described in Figure 12a. The parameter uncertainties were introduced using two stage Monte Carlo simulations (MCS). Pumping schedule uncertainties were introduced using sub-models developed by MESL program (see section 5.1) The results of this analysis yielded the outcome given in Figure 12b for PCE. In this figure the range of PCE concentrations derived from the probabilistic analysis using MCS is shown as a band of solutions and represents 95% of all possible results. The current MCL for PCE (5 µg/L) was first exceeded in finished water during October 1957-August 1958; these solutions include November 1957, the date determined using the calibrated fate and transport model (ATSDR, 2007b)-a deterministic modeling analysis approach. The PCE concentration in Tarawa Terrace WTP finished water during January 1985, simulated using the probabilistic analysis, ranges from 110-251 µg/L (95 percent of Monte Carlo simulations). This range includes the maximum calibrated value of 183 µg/L (derived without considering uncertainty and variability using MT3DMS (ATSDR, 2007b) and the maximum measured value of 215 µg/L. The red line trend includes the variability observed when pumping schedule uncertainty is included in the analysis. Therefore, the probabilistic analysis results-obtained by using two stage Monte Carlo simulation-provide a sense of confidence in the historically reconstructed deterministic PCE concentrations that were delivered to residents of Tarawa Terrace in finished water from the WTP.

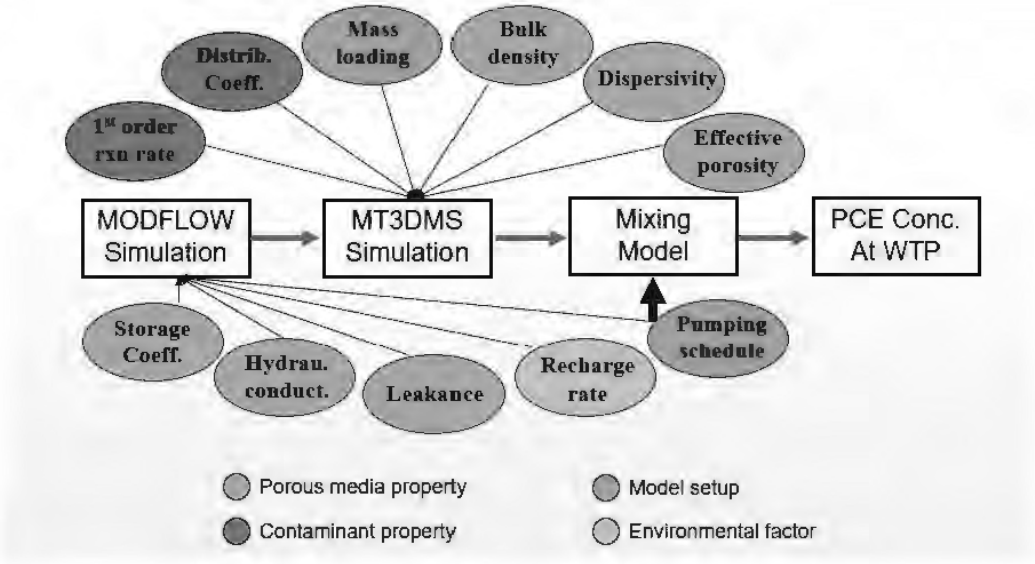

Figure 12a. The parameter uncertainty, model setup uncertainty and environmental factor uncertainty analysis structure used in ATSDR study of the Camp Lejeune site.

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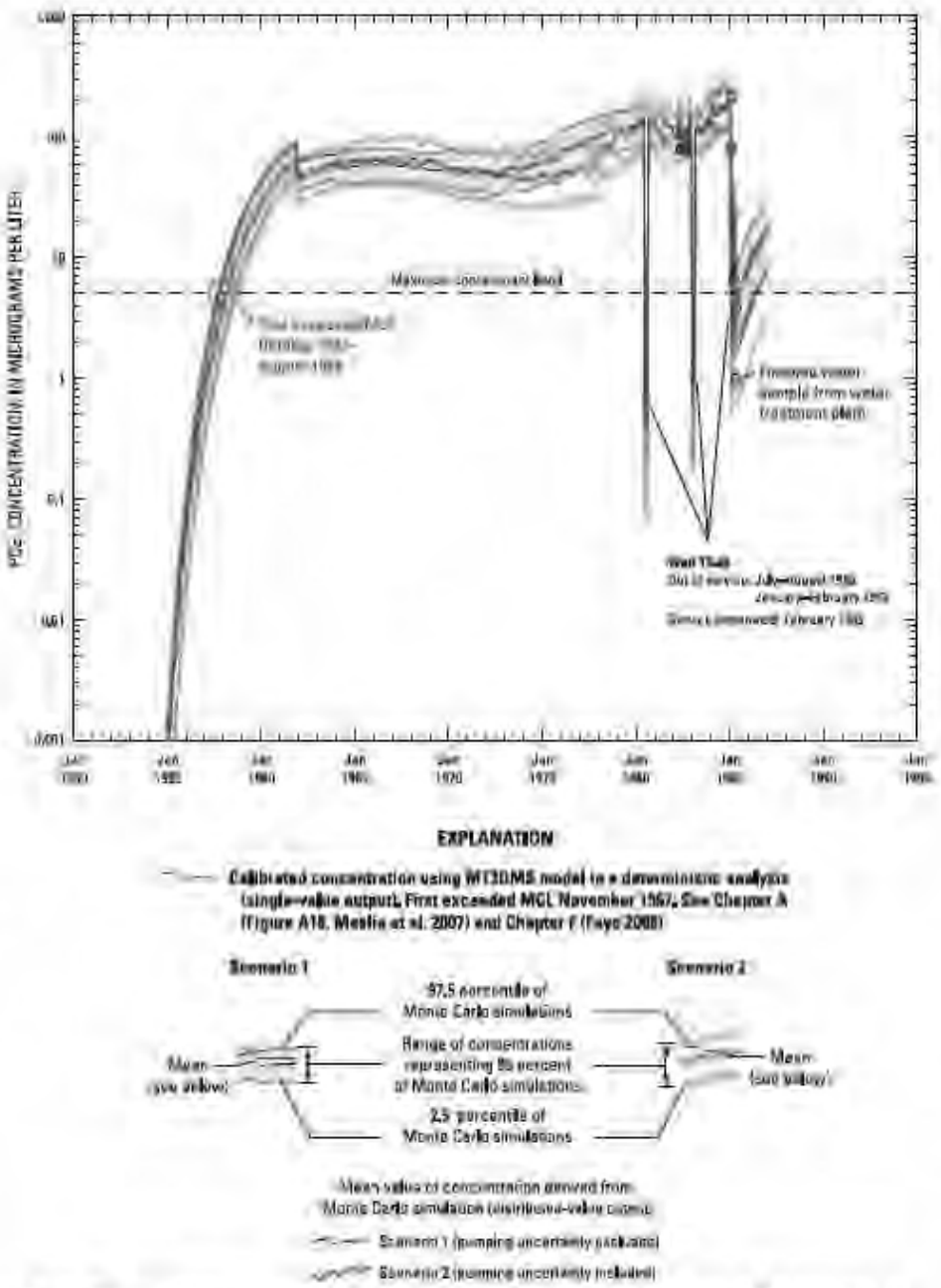

Figure I29. Concentrations of tetrachloroethylene in finished water at the water treatment plant derived from scenario 1 (pumping uncertainty excluded) and scenario 2 (pumping uncertainty included) probabilistic analyses using Monte Carlo simulation, Tarawa Terrace, U.S. Marine Corps Base Camp Lejeune, North Carolina. [See Appendix I5 for tabular listing; PCE, tetrachloroethylene; MCL, maximum contaminant level]

Figure 12b. Reconstructed drinking water concentrations at the Tarawa Terrace Water Treatment Plant including parameter uncertainty and pumping uncertainty, (Figure I29, page I55, ATSDR, 2007i)

Tabulated results of computed versus observed PCE concentrations at WTP were also given in Chapter F report, Figure 13. Third column in Table F14 indicates that the predicted values were all in calibration range except for four predicted values which indicates good capture of the observed values at the WTP. Detailed analysis of sensitivity analysis is also included in (ATSDR, 2007i) which will not be repeated here.

Table F14. Computed and observed tetrachloroethylene (PCE) concentrations in water samples collected at the Tarawa Terrace water treatment plant and calibration target range, U.S. Marine Corps Base Camp Lejeune, North Carolina.

[µg/L, microgram per liter; TTWTP, Tarawa Terrace water treatment plant; ND, not detected]

Date	PCE concentration, in µg/L		Calibration target range, in µg/L
	Computed[1]	Observed	
[2]TTWTP Building TT-38			
5/27/1982	148	180	25–253
7/28/1982	112	[3]104	33–329
7/28/1982	112	[3]76	24–240
7/28/1982	112	[3]82	26–259
2/5/1985	176	[3,4]80	25–253
2/13/1985	3.6	[3]ND	0–10
2/19/1985	3.6	[4]ND	0–2
2/22/1985	3.6	[3]ND	0–10
3/11/1985	8.7	[4]ND	0–2
3/12/1985	8.7	[4]6.6	2.1–21
3/12/1985	8.7	[4]21.3	6.7–67
4/22/1985	8.1	[3]1	0.3–3.2
4/23/1985	8.1	[3]ND	0–10
4/29/1985	8.1	[3]3.7	1.2–11.7
5/15/1985	4.8	[3]ND	0–10
7/1/1985	5.5	[3]ND	0–10
7/8/1985	5.5	[3]ND	0–10
7/23/1985	5.5	[3]ND	0–10
7/31/1985	5.5	[3]ND	0–10
8/19/1985	6.0	[3]ND	0–10
9/11/1985	6.0	[3]ND	0–10
9/17/1985	6.0	[3]ND	0–10
9/24/1985	6.0	[3]ND	0–10
10/29/1985	6.0	[3]ND	0–10
[2]TTWTP Tank STT-39			
2/11/1985	176	[3]215	0–10

[1]Weighted-average computation

[2]See Plate 1, Chapter A report, for location (Maslia et al. 2007)

[3]Detection limit is unknown

Figure 13. Reconstructed drinking water concentrations at the Tarawa Terrace Water Treatment Plant and a comparison with the observed concentrations at the WTP during the period (1982 – 1985), (Table F14, page F42, ATSDR, 2007f)

Modeling results for Tarawa Terrace show that former Marines and their families who lived in Tarawa Terrace family housing units from November 1957 through February 1987 received finished water primarily contaminated with Tetrachloroethylene (PCE), a dry-cleaning solvent. Levels of PCE in finished water during this period exceeded the amount currently allowed by the Environmental Protection Agency (USEPA) under the Safe Drinking Water Act, known as the Maximum Contaminant Level (MCL), which was set at 5 µg/L in 1992 (ATSDR, 2007a). PCE concentrations first exceeded the MCL in

November 1957 and routinely exceeded it, except for two "two-month" periods when Well TT-26 was not in operation, until February 1987, when the water treatment plant was finally decommissioned.

In summary, based on field data, modeling results, and the historical reconstruction process, the following observations can be made with respect to water contamination at Tarawa Terrace (ATSDR, 2007):

- Simulated PCE concentrations exceeded the current MCL of 5 µg/L at water-supply well TT-26 for 332 months—January 1957–January 1985; the maximum simulated PCE concentration was 775 µg/L; the maximum measured PCE concentration was 1,580 µg/L during January 1985.
- Simulated PCE concentrations exceeded the current MCL of 5 µg/L in finished water at the Tarawa Terrace WTP for 346 months—November 1957–February 1987; the maximum simulated PCE concentration in finished water was 176 µg/L; the maximum measured PCE concentration in finished water was 215 µg/L during February 1985 (Figure 13).
- Simulation of PCE degradation by-products—TCE, *trans*-1,2-dichloroethylene (1,2-tDCE), and vinyl chloride—indicated that maximum concentrations of the degradation by-products generally were in the range of 10 –100 µg/L at water-supply well TT-26; measured concentrations of TCE and 1,2-tDCE on January 16, 1985, were 57 and 92 µg/L, respectively (Figure A19, 2007a).
- Maximum concentrations of the degradation by-products in finished water at the Tarawa Terrace WTP generally were in the range of 2–15 µg/L; measured concentrations of TCE and 1,2-tDCE on February 11, 1985, were 8 and 12 µg/L respectively. Max TCE 7 µg/L and max 1,2 tDCE 22 µg/L levels were simulated as given in Table A13, page A44 (ATSDR, 2007a).
- PCE concentrations in finished water at the Tarawa Terrace WTP exceeding the current MCL of 5 µg/L could have been delivered as early as December 1956 and no later than December 1960. Based on probabilistic analyses, the most likely dates that finished water first exceeded the current MCL ranged from October 1957 to August 1958 (95 percent probability), with an average first exceedance date of November 1957.
- PCE and PCE degradation by-products contamination in finished water ceased after February 1987; the Tarawa Terrace WTP was closed March 1987.

Based on the Tarawa Terrace study results (ATSDR, 2007) the following conclusions can be drawn for the PCE contamination of finished water at Tarawa Terrace:

- PCE concentrations in the finished water at Tarawa Terrace first exceeded MCL level of 5 µg/L during the period 1957-1958.
- During the period 1957 – 1962, the PCE concentrations in the finished water at Tarawa Terrace continued to increase sharply from 5 µg/L to a range of 42 µg/L – 92 µg/L, Figures 11 and 12b.
- During the period 1962 – 1987, the PCE concentrations in the finished water at Tarawa Terrace continued to gradually increase from 42 µg/L – 92 µg/L range to a range of 110 µg/L – 250 µg/L, Figures 11 and 12b, except for two "two-month" periods when Well TT-26 was not in operation.
- Similar observations can be made for the degradation by-products of PCE from Figure 11.
- The simulated monthly mean concentrations and confidence boundaries given in ATSDR reports and the conclusions reported above are reliable and represent, within reasonable scientific and engineering certainty, the contaminant levels in finished water at Camp Lejeune from 1953 to 1987.

I confirm that the conclusions I summarized above and others that exist in ATSDR reports were reached by applying generally accepted methods in the fields of hydrogeology, geochemistry, environmental sciences, engineering and mathematical and stochastic computational modeling. These conclusions are my own and are based on my education, training, and experience, as well as the documents, public information, diagrams, data, and facts that were available to me at the time of writing. I hold these conclusions to a reasonable degree of scientific and engineering certainty. I reserve the right to supplement and/or amend my conclusions on this matter as necessary as additional documents or information are made available to me.

6.6 Hadnot Point – Holcomb Boulevard Study

The Hadnot Point Water Treatment Plant (HPWTP) (building 20) was likely constructed during 1941 and 1942, along with much of the original infrastructure of the Base, Figure 14.

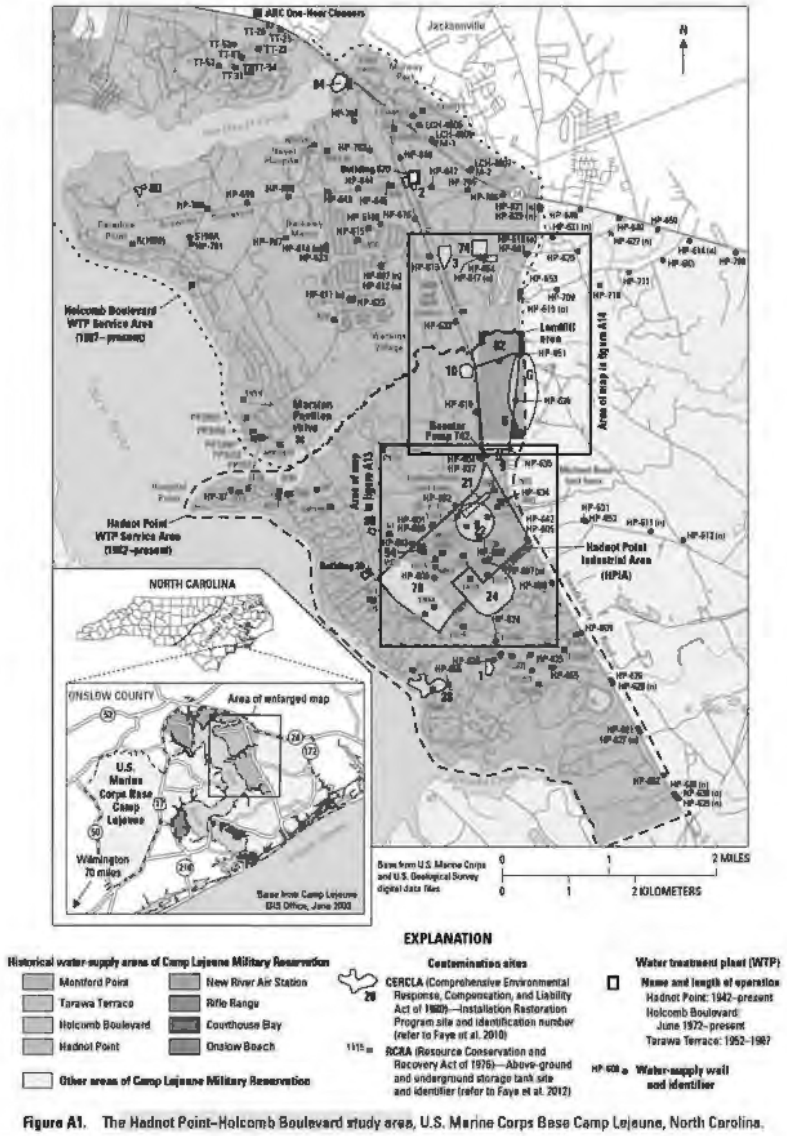

Figure A1. The Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.

Figure 14. Hadnot Point Holcomb Boulevard study area and geographic boundaries. (Figure A1, ATSDR, 2013a)

The original capacity of HPWTP is unknown. However, July 21, 1954, USMCB Camp Lejeune property record card indicates a capacity of 5 million gallons per day (MGD) (Scott R. Williams, USMCB Camp Lejeune, written ATSDR communication, February 22, 2012).

During 1942, the 21 original water-supply wells at Camp Lejeune (HP-601 to HP-621) were placed into operation and provided a total combined capacity of 7.3 MGD (CLHDW CDR File #2292, p. 1). Throughout the years, additional water-supply wells were brought online to increase system capacity or to replace abandoned wells. Some of the water-supply wells were removed from service and eventually were abandoned because of contaminants found in groundwater at nearby disposal sites and in the supply wells themselves (ATSDR, 2013a). As of June 2008, 27 wells were supplying groundwater to HPWTP with a total combined capacity of about 5.9 MGD and a delivered groundwater (raw water) flow rate of 2.2 MGD (ATSDR, 2013a).

Until the summer of 1972, all finished water distributed to bachelor and family housing units and all other facilities within the Hadnot Point-Holcomb Boulevard study area were supplied by the HPWTP (Building 20). After June 1972, finished water distributed to Berkeley Manor, Midway Park, Paradise Point, and Watkins Village family housing areas was supplied by the HBWTP. Also included in the HBWTP service area are the current U.S. Naval Hospital (from 1983), the USMCB Camp Lejeune high school, and the Brewster Boulevard junior high school. The Holcomb Boulevard water-distribution system is linked to the Hadnot Point water-distribution system near McHugh Boulevard and Wallace Creek (Marston Pavilion valve) and near Holcomb Boulevard and Wallace Creek at booster pump 742. For operational reasons, the two water-distribution systems were occasionally connected—exceptions being some documented connections that occurred during the late spring and early summer months of 1972–1986 (ATSDR, 2013a).

The historical reconstruction analysis of the Hadnot Point and Holcomb Boulevard area is more complex than the Tarawa Terrace study area described above. This is because there are multiple contamination sources and multiple contaminants at the site. The study also includes a water distribution system analysis, and the study area is much larger than the Tarawa Terrace study area. Accordingly, the historical reconstruction analyses discussed herein will focus on two general areas (within the Hadnot Point-Holcomb Boulevard study area) that contributed most substantially to water-supply well contamination. These are the Hadnot Point Industrial Area (HPIA) and the Hadnot Point landfill (HPLF) area.

The Hadnot Point-Holcomb Boulevard historical reconstruction covers the period 1942–2008. The first year, 1942, was chosen because operations at USMCB Camp Lejeune began in late 1941. The last year, 2008, was chosen to take advantage of more recent water-supply well operational data and contaminant concentration data to assist with model calibration.

As is the case with the Tarawa Terrace site, groundwater is the sole source of water at this site. Of critical need, in terms of historical reconstruction, was information and data on the monthly raw water production of supply wells (to enable computation of flow-weighted finished-water concentrations) and the distribution of finished water to family housing areas. The supply of finished water for the Hadnot Point-Holcomb Boulevard study area was composed of the following: (1) supply of water from groundwater wells to the HPWTP (1942–present) and the HBWTP (1972–present), (2) delivery of finished water from the WTPs through a network of pipelines and storage tanks to housing areas and other facilities, and (3) intermittent transfers of Hadnot Point finished (contaminated) water through connecting pipelines to the Holcomb Boulevard water-distribution system during late spring and early summer months for years 1972–1985.

Groundwater is the sole source of water supply at the site. To reconstruct contaminant concentrations and the timeline of contaminant movement at the site a series of modeling techniques were implemented. These are:

- To simulate predevelopment groundwater-flow conditions, the **MODFLOW** code was used. In addition to the trial-and-error calibration procedures, the estimates of model parameter values were supplemented using the objective parameter estimation code **PEST-12** (Doherty 2003, 2010).
- To simulate the transient (unsteady) effects caused primarily by the onset and continued operation of water-supply wells in the study area, historical water-supply well operating schedules were developed and again the **MODFLOW** code was used. The operating schedules of water supply wells was accomplished for the period 1942–2008 using **TechWellOp** and **PSOpS** sub-models described earlier (Section 5.1).
- Groundwater contaminant fate and transport analysis of TCE and benzene were simulated using **MT3DMS** and **TECHFLOWMP**. In addition, the fate and transport of PCE and TCE from source areas in the HPLF area to water-supply well HP-651 was simulated using the **MT3DMS**, **TechFlowMP**, and **LCM-TechCONTROL** code (Section 5.1).
- The occurrence of benzene as an LNAPL in the subsurface in the vicinity of the Hadnot Point Fuel Farm (HPFF) and HPIA is described in (ATSDR, 2013) and in Section 6.4. Estimates of subsurface LNAPL volume were developed using historical measurements of LNAPL thickness over time—monitor well data—in the HPIA combined with the **TechNAPLVol** code that uses semi-analytical and numerical methods in a three-dimensional domain (ATSDR, 2013). The resulting saturation profile from the LNAPL volume analysis was used within the **TechFlowMP** model code to simulate the dissolution of LNAPL constituents and the fate and transport of dissolved phase benzene (Section 5.1).
- An alternative method, a linear state-space representation of a contaminated aquifer system designated as the linear control model (**LCM**) methodology, was developed to reconstruct contaminant concentrations in water-supply wells (ATSDR, 2013). Using the model code **TechControl**, this simplified approach was used to reconstruct historical contaminant concentrations, including PCE, TCE, 1,2-tDCE, and VC, in water-supply well HP-651 in the HPLF area. A description of this code is given in Section 5.1 of this report. A more detailed description of the methodology can be found in (ATSDR, 2013; Guan, 2009). Results from the LCM application at water-supply well HP-651 were compared to simulated PCE and TCE concentrations obtained using the **MT3DMS** numerical fate and transport code later when the **MT3DMS** study was completed. The comparisons of these solutions and the analytical analysis of these comparisons are discussed extensively in (ATSDR, 2013, Chapter A supplement 5) for the results of the **TechControl** application at the HP-HB site which will not be repeated here.
- Reconstructed (simulated) monthly mean concentrations of PCE, TCE, 1,2-tDCE, VC, and benzene for finished water at the HPWTP were determined by using a materials mass balance model (**Mass Balance, simple mixing**) to compute the flow-weighted average concentration of the aforementioned contaminants. The use of the material mass-balance method is justified because all raw water from water-supply wells within the HPWTP service area was mixed at the HPWTP prior to treatment and distribution.
- Intermittent operations of booster pump 742 and the opening of the Marston Pavilion valve transferred contaminated Hadnot Point finished water to Holcomb Boulevard family housing areas and other facilities. Owing to missing data related to pump and valve operations, proba-bilistic analyses of the intermittent water transfers during the period 1972–1985 were conducted

using a Markov analysis (Ross 1977) and the code **TechMarkovChain** (Section 5.1). Results provided probabilistic estimates of the intermittent transfer of contaminated Hadnot Point finished water to the Holcomb Boulevard family housing areas.

- Using the reconstructed monthly mean concentrations of PCE, TCE, 1,2-tDCE, VC, and benzene in finished water from the HPWTP and the Markov analysis to estimate the occurrence of intermittent water transfers, extended period simulations of hydraulics and water quality for the water-distribution system serving the Holcomb Boulevard housing areas and other facilities were conducted. **EPANET 2** (Rossman 2000) was used for the water distribution system analysis.
- Assessment of parameter sensitivity, variability, and uncertainty associated with model simulations of groundwater flow, contaminant fate and transport, and water-distribution system analyses were also conducted (ATSDR, 2013).

The calibration and validation analyses were successfully completed for all these modeling stages following the complex system analysis techniques described earlier in this expert report (see Section 6). The details of this analysis can be found in (ATSDR, 2013) which will not be repeated here. After successful completion of calibration and validation analyses the simulation results of contaminants at WTP were generated. These results are summarized in Figure 15, 16 and 17 as Tables and Figures.

Table A18. Selected measured and reconstructed (simulated) concentrations of tetrachloroethylene (PCE), trichloroethylene (TCE), *trans*-1,2-dichloroethylene (1,2-tDCE), vinyl chloride (VC), and benzene at the Hadnot Point water treatment plant, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina

[µg/L, micrograms per liter; J, estimated]

Contaminant	[1]Measured data		[2]Reconstructed (simulated)		[2]Reconstructed (maximum value)	
	Sample date	Concentration, in µg/L	Simulation date	Concentration, in µg/L	Simulation date	Concentration, in µg/L
PCE	5/27/1982[3]	15	May 1982	21	Nov. 1983	39
	7/27/1982[4]	100	July 1982	27		
	12/4/1984[4]	3.9J	Nov. 1984	31		
	2/5/1985[5]	7.5J	Jan. 1985	16		
TCE	5/27/1982[3]	1,400	May 1982	438	Nov. 1983	783
	7/27/1982[4]	19	Aug. 1982	670		
	7/27/1982[6]	21	Aug. 1982	670		
	12/4/1984[3]	46	Nov. 1984	639		
	12/4/1984[4]	200	Nov. 1984	639		
	12/12/1984[6]	2.3J	Dec. 1984	43		
	12/19/1984	1.2	Dec. 1984	43		
	2/5/1985[5]	429	Jan. 1985	324		
1,2-tDCE	12/4/1984[4]	83	Nov. 1984	358	Nov. 1983	135
	12/4/1984[3]	15	Dec. 1984	26		
	12/12/1984[6]	2.3J	Dec. 1984	26		
	2/5/1985[5]	150	Jan. 1985	163		
VC	2/5/1985[5]	2.9J	Jan. 1985	31	Nov. 1983	67
Benzene	11/19/1985[7,8]	2,500	Nov. 1985	3	Apr. 1984	12
	12/10/1985[5]	38	Dec. 1985	3		
	12/18/1985[5]	1.0	Dec. 1985	3		

[1]Data from Faye et al. (2010, Tables C11 and C12)

[2]Simulation results represent the last day of each month (e.g., May 31); results reported for simulation month nearest the sample date; refer to Appendix A7 for complete listing of reconstructed finished-water concentrations

[3]Water sample collected at Building NH-1; data reported as unreliable

[4]Water sample collected at Building TC-530

[5]Untreated water

[6]Treated water

[7]Treatment status unknown

[8]Laboratory analysis noted with "Sample appears to have been contaminated with benzene, toluene, and methyl chloride" (ITC Environmental Consultants 1985)

[9]Data noted with "Not Representative" (U.S. Marine Corp Base Camp Lejeune Water Document CLW #1350)

Figure 15. Selected simulation results for TCE, PCE and other by-products at HPWTP. More detailed results and their analysis can be found in (ATSDR, 2013a).

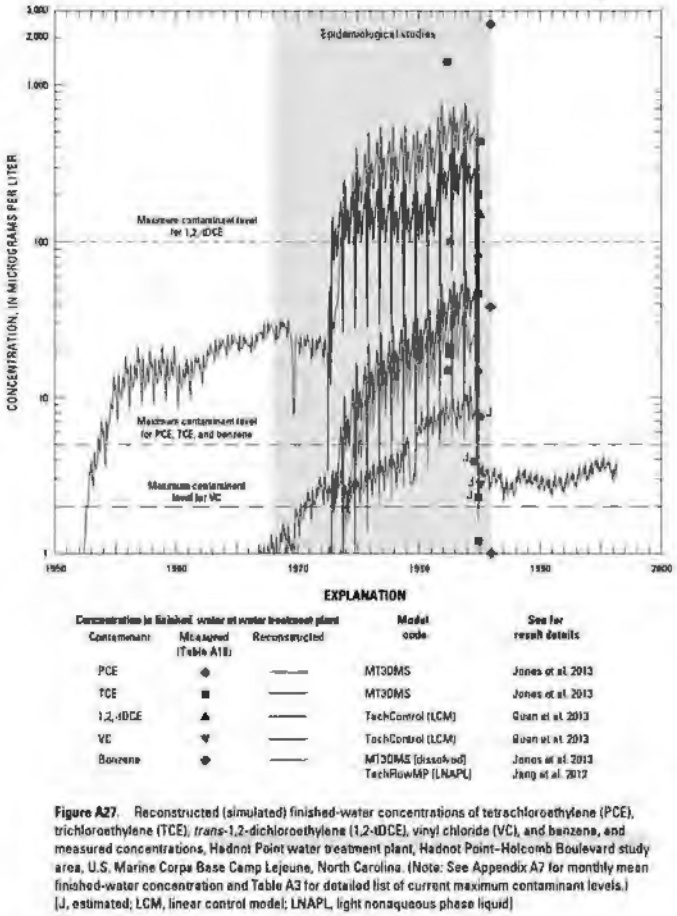

Figure A27. Reconstructed (simulated) finished-water concentrations of tetrachloroethylene (PCE), trichloroethylene (TCE), *trans*-1,2-dichloroethylene (1,2-tDCE), vinyl chloride (VC), and benzene, and measured concentrations, Hadnot Point water treatment plant, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina. (Note: See Appendix A7 for monthly mean finished-water concentration and Table A3 for detailed list of current maximum contaminant levels.) [J, estimated; LCM, linear control model; LNAPL, light nonaqueous phase liquid]

Figure 16. Selected simulation results for the HP and HB areas. More detailed results and their analysis can be found in (ATSDR, 2013a).

Results provided in Figure 16 and summary statistics provided in Figure 15 indicate a reasonable capture of the concentrations at the WTP.

Table A14. Summary statistics for reconstructed contaminant concentrations at selected water-supply wells and the Hadnot Point water treatment plant, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina.[1]

[MCL, maximum contaminant level; TCE, trichloroethylene; PCE, tetrachloroethylene; VC, vinyl chloride; 1,2-tDCE, *trans*-1,2-dichloroethylene; N/A, not applicable; µg/L, microgram per liter]

Water-supply identification (contaminant)	Reconstructed (simulated) concentrations, in micrograms per liter				[2]Duration in months exceeding MCL (month and year first exceeding MCL)	Date well stopped pumping in model
	July 1952–June 1985			Range during health study period of interest (January 1985–February 1985)		
	Maximum (date of maximum)	Mean	Standard deviation			
[3]Hadnot Point Industrial Area (HPIA)						
HP-602 (TCE)	658 (Jan. 1959)	399	222	357–499	390 (Oct. 1951)	Dec. 1984
HP-608 (TCE)	50 (Sept. 1972)	25	20	28–50	387 (Aug. 1957)	Dec. 1984
HP-634 (TCE)	659 (Oct. 1968)	391	170	215–659	283 (Aug. 1960)	Dec. 1984
HP-602 (benzene)	236 (Nov. 1984)	53	65	46–236	309 (July 1958)	Dec. 1984
HP-603 (benzene)	179 (May 1996)	29	43	6–129	345 (Aug. 1967)	June 1996
HP-608 (benzene)	11 (Sept. 1979)	4	4	0–11	301 (June 1966)	Dec. 1984
[3]Hadnot Point landfill (HPLF)						
HP-651 (PCE)	353 (Dec. 1982)	249	122	[4]0–353	142 (Apr. 1973)	Feb. 1985
HP-651 (TCE)	7,133 (Dec. 1978)	5,831	2,071	[4]3–7,133	150 (Aug. 1972)	Feb. 1985
HP-651 (1,2-tDCE)	4,037 (Dec. 1984)	3,284	572	[4]59–4,037	150 (Aug. 1972)	Feb. 1985
HP-651 (VC)	660 (Nov. 1984)	391	173	[4]8–660	151 (July 1972)	Feb. 1985
[3]Hadnot Point water treatment plant (HPWTP)						
HPWTP (PCE)	39 (Nov. 1983)	4	8	0–39	114 (Aug. 1974)	N/A
HPWTP (TCE)	783 (Nov. 1983)	107	180	0–783	374 (Aug. 1965)	N/A
HPWTP (1,2-tDCE)	431 (Nov. 1983)	53	95	0–431	128 (Nov. 1972)	N/A
HPWTP (VC)	67 (Nov. 1983)	6	13	0–67	144 (Nov. 1972)	N/A
HPWTP (benzene)	12 (Apr. 1984)	2	3	0–12	63 (Jan. 1979)	N/A

[1]For periods of time when concentrations are equal to or exceed the current MCLs for TCE, PCE, and benzene; non-rounded concentration values used to calculate statistics

[2]Current MCLs are as follows: vinyl chloride, 2 µg/L; PCE, TCE, and benzene, 5 µg/L; 1,2-tDCE, 100 µg/L (see Table A3)

[3]Statistics are computed solely for periods of operation

[4]See Appendix A3 for complete listing

[5]Water-supply well HP-651 did not start pumping until July 1972; values shown represent dates of July 1972–February 1985

[6]Finished-water concentration; see Appendix A7 for complete listing

Figure 17. Summary statistics for reconstructed contaminant concentrations at selected water-supply wells and the Hadnot Point water treatment plant, Hadnot Point–Holcomb Boulevard study area, U.S. Marine Corps Base Camp Lejeune, North Carolina

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Based on field data, uncertainty and sensitivity analyses, and the historical reconstruction process, the following conclusions are made with respect to groundwater and finished-water contamination of the Hadnot Point–Holcomb Boulevard (HPHB) study area.

For the Hadnot Point water treatment plant (HPWTP):

- Within the HPWTP, TCE routinely exceeded its current MCL during the period (1955–1985). TCE concentrations in finished water at the HPWTP ranged from about 10 to 30 µg/L for the period 1955–1972, prior to the onset of pumping from water-supply well HP-651 (Figure A27, ATSDR, 2013). After the onset of pumping of water-supply well HP-651 during July 1972, finished-water concentrations increased to a maximum computed value of 670 µg/L during August 1982 (Table A18, ATSDR 2013). Measured concentrations of PCE, TCE, 1,2-tDCE, VC, and benzene and historical reconstruction (simulated) results for the HPWTP are listed in Table A18 (ATSDR, 2013a).
- The reconstructed contamination of finished water exceeding the current maximum contaminant level (MCL) for TCE was 374 months (August 1953–January 1985) (Table A14, ATSDR, 2013a) Figure 17. With the onset of pumping at well HP-651 during July 1972, the concentration of TCE in well HP-651 affected the resulting finished-water concentrations of TCE at the HPWTP, which exceeded 750 µg/L during November 1983 (Table A14, ATSDR, 2013). Measured TCE concentrations in finished water at the HPWTP during the period May 1982 through February 1985 ranged from 1.2 µg/L to 1,400 µg/L (Faye et al. 2010, Table C11, ATSDR, 2013).
- The reconstructed contamination of finished water exceeding the current MCL for PCE was 114 months (August 1974–January 1985) (Table A14), Figure 17, also a consequence of the onset of pumping of well HP-651. The maximum reconstructed finished-water concentration of PCE was about 39 µg/L during November 1983 (Table A14, ATSDR, 2013a). Measured PCE concentrations at the HPWTP ranged from below detection limits (1–10 µg/L) to 100 µg/L during the period May 1982–February 1985 (Faye et al. 2010, Table C11, ATSDR, 2013).
- The reconstructed duration of contamination of finished water exceeding the current MCL for benzene was 63 months (January 1979–November 1984) (Table A14, ATSDR, 2013a), Figure 17.
- The maximum reconstructed finished water concentration of benzene was about 12 µg/L during April 1984 (Table A14, ATSDR, 2013). Measured benzene concentrations at the HPWTP ranged from below detection limits (10 µg/L) to 38 µg/L during the period December 1984–December 1985. An unexplained value of 2,500 µg/L of benzene was measured on November 11, 1985 (Faye et al. 2010, Table C12, ATSDR, 2013).

For the Holcomb Boulevard housing area:

- When this housing area was serviced by the HPWTP (prior to June 1972), the maximum reconstructed (simulated) monthly mean TCE concentration in finished water (January 1968–December 1985) was 32 µg/L during August 1968 and August 1969 (Appendix A7, ATSDR, 2013a). The minimum reconstructed (simulated) monthly mean TCE concentration in finished water (January 1968–December 1985) was 8 µg/L (September and October 1969). TCE concentrations in finished water first exceeded the MCL during August 1953 (Appendix A7, ATSDR, 2013).
- After June 1972 when the Holcomb Boulevard water treatment plant (HBWTP) came online to service this housing area, an interconnection analysis indicates that the maximum reconstructed

(simulated) TCE concentration in finished water was 66 µg/L during February 1985 for the Paradise Point area (Figure A29(H), ATSDR, 2013a).

- After June 1972 when the HBWTP came online to service this housing area, the maximum reconstructed (simulated) monthly concentrations for PCE, 1,2-tDCE, and VC in finished water for the Holcomb Boulevard housing area occurred during February 1985 and were 3 µg/L, 33 µg/L, and 6 µg/L, respectively (Table A21(H), ATSDR, 2013a). The maximum reconstructed (simulated) monthly concentration for benzene was 3 µg/L, occurring during January, February, April, May, and June 1972 (Table A21(H), ATSDR, 2013a).

For the Hadnot Point Industrial Area (HPIA):

- The maximum reconstructed (simulated) monthly mean TCE concentrations at water-supply wells HP-602, HP-608, and HP-634 were 658 µg/L during January 1959, 50 µg/L during September 1972, and 659 µg/L during October 1968, respectively (Table A14, ATSDR, 2013a). Measured TCE concentrations at well HP-602 ranged from an estimated 0.7 µg/L to 1,600 µg/L during the period of record, July 1984 to January 1991 (Table A4(H), ATSDR, 2013a). Corresponding concentrations at well HP-608 ranged from 9 µg/L to 110 µg/L during the period of record, December 1984 to November 1986. In well HP-634 between December 1984 and January 1991, TCE concentrations ranged from less than detection limits to 1,300 µg/L.
- Substantial volumes of liquid hydrocarbon fuels were lost due to leakage to the subsurface within the Hadnot Point Industrial Area (HPIA). This area contained as many as 10 active water-supply wells. Despite the large volumes lost, finished-water concentrations of benzene only exceeded the current MCL of 5 µg/L in some of the wells during the period 1980–1985.
- At water-supply wells with measured benzene concentrations exceeding detection limits (HP-602 and HP-608), the maximum reconstructed (simulated) monthly benzene concentration was 236 µg/L at well HP-602 during November 1984 and 11 µg/L at well HP-608 during September 1979 (Table A14, Appendix A3, ATSDR, 2013). Measured benzene concentrations at well HP-602 during the period of record, July 1984 to January 1991, ranged from less than 1.0 µg/L to 720 µg/L. Measured benzene concentrations at well HP-608 during the period of record, December 1984 to November 1986, ranged from 1.6 µg/L to an estimated 4.0 µg/L. All measured benzene concentrations in well HP-603 were below detection limits (Table A5(H), ATSDR, 2013a).

For the Hadnot Point landfill (HPLF) area:

- The maximum reconstructed (simulated) monthly mean TCE concentration at water-supply well HP-651 was 7,135 µg/L during December 1978 (Table A14, ATSDR, 2013a), Figure 17. Measured TCE concentrations during the period of record, January 1985 to January 1991, ranged from 13 µg/L to 18,900 µg/L (Table A4(H), ATSDR, 2013a).
- The maximum reconstructed (simulated) monthly PCE concentration at water-supply well HP-651 was 353 µg/L during December 1982 (Table A14, ATSDR, 2013), Figure 17. Measured PCE concentrations during the period of record, January 1985 through January 1991, ranged from 45 µg/L to 400 µg/L (Table A4(H), ATSDR, 2013a).
- The maximum reconstructed (simulated) monthly mean 1,2-tDCE concentration at water-supply well HP-651 was about 4,037 µg/L during December 1984 (Table A14), Figure 17. Measured 1,2-tDCE concentrations during the period of record, January 1985 to November 1986, ranged from 140 µg/L to 8,070 µg/L (Table A4(H), ATSDR, 2013a).

- The maximum reconstructed (simulated) monthly mean VC concentration at water-supply well HP-651 was 660 µg/L during November 1984 (Table A14, ATSDR, 2013), Figure 17. Measured VC concentrations during the period or record, January 1985 to January 1991, ranged from 70 µg/L to 655 µg/L (Table A4(H), ATSDR, 2013a).

In summary:

- The historical reconstruction process results show that finished water at U.S. Marine Corps Base Camp Lejeune was contaminated with varying levels of TCE, PCE, 1,2-tDCE, vinyl chloride and benzene from 1953 to 1987, (ATSDR, 2013).
- TCE contamination at the HP-HB finished water first exceeded MCL level of 5 µg/L during the period 1954 – 1955, Figure 16.
- During the period 1954 – 1973, the TCE contamination at the HP-HB finished water gradually increased from 5 µg/L to a range of 19 µg/L – 26 µg/L, Figure 16.
- During the period 1973 – 1985 there is a sharp increase in the TCE contamination at the HP-HB finished water from a range of 19 µg/L – 26 µg/L to a range of 380 µg/L – 620 µg/L, Figure 16.
- PCE contamination at the HP-HB finished water first exceeded MCL level of 5 µg/L during the period 1974 – 1975, Figure 16.
- During the period 1974 – 1985 there is a sharp increase in PCE contamination at the HP-HB finished water from 5 µg/L to a range of 20 µg/L – 30 µg/L, Figure 16.
- 1,2-tDCE contamination at the HP-HB finished water first exceeded MCL level of 100 µg/L during the period 1973 – 1974, Figure 16.
- During the period 1973 – 1985 there is a sharp increase in 1,2-tDCE contamination at the HP-HB finished water from 100 µg/L to a range of 220 µg/L – 390 µg/L, Figure 16.
- VC contamination at the HP-HB finished water first exceeded MCL level of 2 µg/L during the period 1972 – 1973, Figure 16.
- During the period 1972 – 1985 there is a sharp increase in VC contamination at the HP-HB finished water from 2 µg/L to a range of 34 µg/L – 52 µg/L, Figure 16.
- Benzene contamination at the HP-HB finished water first exceeded MCL level of 5 µg/L during 1980, Figure 16.
- During the period 1980 – 1985 there is a sharp increase in Benzene contamination at the HP-HB finished water from 5 µg/L to a range of 7 µg/L – 12 µg/L, Figure 16.
- The simulated monthly mean concentrations and confidence boundaries given in ATSDR reports and the conclusions reported above are reliable and represent, within reasonable scientific and engineering certainty, the contaminant levels in finished water at Camp Lejeune from 1953 to 1987.

I confirm that the conclusions I summarized above and others that exist in ATSDR reports were reached by applying generally accepted methods in the fields of hydrogeology, geochemistry, environmental sciences and engineering and mathematical and stochastic computational modeling. These conclusions are my own and are based on my education, training, and experience, as well as the documents, public information, diagrams, data, and facts that were available to me at the time of writing. I hold these conclusions to a reasonable degree of scientific and engineering certainty. I reserve the right to supplement and/or amend my conclusions on this matter as necessary as additional documents or information are made available to me.

6.7 Confidence in Validity of Historical Reconstruction Results

It is generally accepted that properly selected models that have been calibrated to site-specific conditions are appropriate for environmental management and decision-making – frequently there is no other form of guidance. While proper model calibration, sensitivity and uncertainty analyses improve confidence in model predictions, additional validation steps can increase confidence in simulation results. (Anderson et al., 1992; Bredehoeft and Konikow, 1993; Oreskes et al., 1994; Aral, 2010; Sahmel et al., 2010, Mei, 2003).

In an ideal world, the modeler would have an abundance of data. In that scenario, a portion of the data can be used to calibrate the model. The calibrated model can then be used to simulate values for comparison with the remaining independent data. This is the classical definition of model validation. In literature there are other definitions of validation as well. For example, IAEA (1982) defines validation as "A conceptual model and the computer code derived from it are validated when it is confirmed that the conceptual model and the computer code provide a good representation of the actual processes occurring in the real system." Or Schlesinger et al. (1979) defines validation as "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model." Or in Konikow and Bredehoeft (1992) it is stated that: "Ground-water models are embodiments of scientific hypotheses. As such, the models cannot be proven or validated, but only tested and invalidated." Or "…The absolute validity of a model can never be determined" (NRC, 1990).

Frequently, an abundance of data is unavailable (Maslia and Aral, 2004), and alternate validation means must be considered. In such situations, Sahmel et al. (2010) recommend alternative means to increase confidence (help validate) simulated exposure levels, including assessing:

i. ***Were the data used to formulate and calibrate the model taken from dependable and appropriate sources?***
   In my opinion, the ATSDR Camp Lejeune studies went to extraordinary measures to identify and collect all the dependable and appropriate sources of data for model calibration from Camp Lejeune archives.
ii. ***Has variability in the outcomes been considered?***
   There is abundant evidence in the ATSDR study that extensive analysis of stochastic uncertainty and sensitivity analysis was performed in the ATSDR study.
iii. ***Where possible, have multiple simulation approaches been utilized and generated similar results?***
   There were two additional modeling efforts employed in the ATSDR study which provided the reconfirmation of the results obtained from the standard applications that exist in public domain. These are the **TechControl** application that uses Linear control model and **TechFlowMP** application that is used to investigate the fate and transport processes at the Camp Lejeune site. These are two independent codes used in the analysis that satisfies the above criteria. One should also recognize the fact that two independent study groups implemented these parallel simulation approaches which yielded similar results. The comparisons of these solutions and the analytical analysis of these comparisons are discussed extensively in (ATSDR, 2013, Chapter A supplement 5) for the results of the **TechControl** application at the HP-HB site and in (ATSDR, 2007g) for the results of the **TechFlowMP** application (Figure 11) at the Tarawa Terrace site which will not be repeated here.

As philosophical discussion on validation concepts and definitions continues, as engineers working on the Camp Lejeune study, we believe being as close as possible to an observed system's behavior in modeling yields satisfactory answers to most practical problems that await immediate solutions. Having introduced some of the secondary philosophical discussions on validation concepts above, one must also recognize the following traditional validation step employed in ATSDR study as well. This step, described below, was completed for the models used in the ATSDR study of the Camp Lejeune site. I also notice that the completion of this step as an extra effort was not recognized or understood by some of the experts of the government in this case (see Dr. Dan Waddill's deposition, Tuesday, August 6, 2024).

As discussed in Sections 5 and 6 of this report, the ATSDR reconstruction model is a complex system and consists of five stages: i. pre-development (pre-pumping); ii. transient (pumping); iii. contaminant migration; and iv. production well mixing at the treatment plant; and v. the water distribution system analysis. The reconstructed sequence of model's ability to fit the independent data available for finished water (supplied to the consumer) at WTP (see Figures 12, 13 and 15) provides internal model validation that all four levels are accurately capturing the system behavior. For example, only those solutions that successfully simulate predevelopment (pre-pumping) and transient groundwater flow conditions can successfully capture the contaminant migration processes that would yield the independent data values we have at the WTP. Thus, in the final stage when WTP data is captured accurately, it requires that all three previous stages have been accurately incorporated into the model and validated appropriately. Thus, successful capture of the independent measured data at the WTP, as occurred here for Tarawa Terrace and Hadnot Point/Holcomb Boulevard, provides an internal validation of the **MT3DMS** model and the coupled complex modeling ensemble.

In summary, as stated by Dr. Robert Clark, Chair of the Expert Review Panel for the ATSDR Camp Lejeune studies, the ATSDR appropriately used the data sets that were available to it, and validated its model using the best approach under the circumstances:

> *"From a scientific viewpoint it would be ideal to have independent data sets. One set could be used to calibrate the models, and the second data set used for validation. If one is developing a model based on experimental data this approach can be built into the combined experimental and modeling effort. However, it has been my experience that such an ideal situation rarely exists in "real world" situations. Therefore, in my opinion, the best approach is to use available datasets in conjunction with sound engineering principles and the investigator's best judgment to establish the validity of the exposure models."* Dr. Robert M. Clark, Chair Expert Review Panel, Maslia (Editor), 2009a, p. 76.

I concur with Dr. Clark's assessment given above. It is my opinion that ATSDR used the best available datasets, sound science and engineering principles, and professional judgment to establish the best possible reconstructed values of historical contaminant concentrations, and that, within a reasonable degree of scientific and engineering certainty, these were the contaminant levels delivered to Tarawa Terrace, Hadnot Point, and Holcomb Boulevard.

This assessment is reinforced by the successful peer review of ATSDR results in two top-tier journals (Maslia et al., 2009(b) for Tarawa Terrace and Maslia et al., 2016 for Hadnot Point-Holcomb Boulevard) along with the Grand Prize for Excellence in Environmental Engineering and Science Research (2015) from the prestigious American Academy of Environmental Engineering and Science for ATSDR's exemplary work at Camp Lejeune.

7. The NRC report

On June 27, 2009, I submitted a memorandum to EDRP/ATSDR which included my response to the NRC review comments on the Camp Lejeune study. The memorandum became an internal document for the Camp Lejeune study at ATSDR/CDC and was not released to the public. This section of my expert report includes both the contents of this memorandum and additional observations.

7.1 Comments on the NRC Report

The National Research Council (NRC) was requested to conduct a review by the Department of Navy (DON), under a mandate by the U.S. Congress (Public Law 109-364, Section 318). The U.S. Navy requested the NRC review to address whether adverse health outcomes are associated with past drinking-water contamination at U.S. Marine Corps (USMC) Base Camp Lejeune, North Carolina. The NRC review included an assessment of the Agency for Toxic Substances and Disease Registry's (ATSDR) overall study and in particular, the water modeling analyses and findings at Tarawa Terrace and vicinity. The NRC report released on July 13, 2009 (NRC 2009) covers a wide range of topics that include: (i) conceptual topics of exposure analysis and source characterization that are based on expert opinions of NRC committee members; (ii) water modeling based on observations of NRC committee and a critique of the science-based tools and analyses that are described in ATSDR technical reports on Tarawa Terrace and vicinity (Maslia et al., 2007; ATSDR, 2007); and, (iii) a critique of findings and interpretation of water-modeling study results that were completed by ATSDR at Tarawa Terrace and vicinity at Camp Lejeune.

On June 27, 2009, my responses to the NRC review were respectfully submitted to ATSDR to document my scientific evaluation of the findings of the NRC report. **Exhibit B** is the header of my original response to the NRC report.

To accurately respond to the comments made under each category I have identified above, the review comments I am providing below are grouped under two specific headings. This is in an effort so as not to confuse the reader and mix-and-match the review comments reported by the NRC committee which range from "conceptual topics" to the "comments on actual data reported" in the ATSDR water modeling study. I am confident that this approach will provide the reader with a clear picture of a range of topics critiqued in the NRC report. Accordingly, the discussion included in my review comments below will cover the range from "conceptual" perspectives on exposure analysis to "water modeling analysis" and "application specific" topics that are addressed in the NRC report.

It is important to note that the review comments I am providing below are only associated with the water modeling aspects of the ATSDR health study and the NRC report, and do not cover any epidemiologic study aspects since those topics are outside my expertise areas. All references to the "NRC report" refer to the NRC report titled, "Contaminated Water Supplies at Camp Lejeune: Assessing Potential Health Effects" and cited as NRC (2009) in the Reference section of this expert report. Furthermore, the reader should recognize that sentences in "italic font" under the heading "**Comment on…**" are extracted verbatim from the NRC report and statements in "regular font" under the heading "**Response**" are my responses to the specific NRC report statements.

7.2 Comments on the NRC report associated with conceptual topics of exposure analysis and site characterization.

Comment on p. 29: *Exposure assessment for epidemiologic studies of the effects of water-supply contamination includes two components. The first is estimation of the magnitude, duration, and variability of contaminant concentrations in water supplied to consumers. An important consideration is hydrogeologic plausibility: an association between a contaminant source and exposure of an individual or population cannot exist unless there is a plausible hydrogeologic route of transport for the contaminant between the source and the receptor (Nuckols et al., 2004). The second component is information on individual water use patterns and other water-related behaviors that affect the degree to which exposures occur, including drinking-water consumption (ingestion) and dermal contact and inhalation related to the duration and frequency of showering, bathing, and other water-use activities. Water use is an important determinant of variability of exposure to water-supply contaminants, particularly if it varies widely in the study population. Ideally, exposure-assessment strategies include both components, but in practice it may be difficult to obtain either adequately.*

Response: In this comment, which also includes a reference to the work of one of the committee members (Nuckols et al. 2004), the NRC committee is providing the reader with their understanding of the components of an exposure study that is associated with pollutants that may exist in an aquatic pathway at a contaminated site. The aquatic exposure analysis framework described in this statement is a conceptual statement and represents a very restrictive view of the exposure pathway analysis that needs to be considered at contaminated sites given the current understanding of the interaction between environmental pathways and the behavior of chemicals along those pathways. Current knowledge in this scientific field recognizes that in an aquatic exposure study the environment must be considered as a whole, and scientific and regulatory approaches alike must consider complex interactions between multimedia and intermedia interactions that exist in a multitude of potential environmental pathways at a site. In my opinion one should not emphasize only the concept of a "hydrogeologic connection" between the contaminant source and the exposure point as put forth by the NRC committee. This conceptual suggestion made by the NRC committee would be a very elementary and restrictive exposure analysis framework.

As specialists in this field, we know pollutants released to an aquatic environment are distributed among environmental media such as air, water, soil, vegetation etc., because of complex physical, chemical and biological processes. Thus, environmental pollution is a multi-pathway problem and environmental exposure assessment methods require that we carefully consider the transport, fate and accumulation of pollutants in the environment as a whole, (Cohen 1986; Aral, 2010). Methods that are proposed to evaluate environmental migration or exposure characterization in this envirosphere must consider all potential pathways and the interactions between these pathways. In scientific literature, the multi-pathway approach to environmental exposure analysis is identified as Total Exposure Characterization (TEC).

Elements of this multi-pathway analysis for an aquatic contamination source are imbedded in the ATSDR water modeling studies that were conducted for the Tarawa Terrace area of the Camp Lejeune site as much as possible. The specific pathways and processes considered in the ATSDR water modeling study are: (i) saturated groundwater; (ii) unsaturated groundwater; (iii) vapor emissions; (iv) multispecies analysis of contaminants in these three pathways; (v) mixing in the water treatment system; and (vi) estimates of contaminants in the water-distribution system. This was followed by proper epidemiologic studies that are not considered in this expert report.

In this analysis framework it is also important to recognize that one should not try to fit a physical problem to a model that may be readily available for use. Instead, appropriate models should be selected or developed that would fit the characterization of the physical problem at hand. Thus, selection of appropriate modeling tools to complete such an analysis is very important and is considered in sufficient detail in the ATSDR study. This is a very important point, which was either completely ignored in the NRC report or, steps taken by the ATSDR water modeling team to address these issues in a sound scientific and engineering manner were criticized by the NRC committee without providing any supporting evidence that is traceable to technical literature. I will revisit this issue in more detail in my comments below while providing case-specific public domain data and public domain information.

Comment on p. 33: *At a typical waste site, spent VOCs are present in the unsaturated zone (a partially saturated soil layer above the water table) in the form of dense nonaqueous-phase liquids (DNAPLs)..... (...* after a lengthy discussion of what DNAPL is and how DNAPL-based contaminants behave in the subsurface and what the consequences of such a source are, the NRC report continues in this section with the following remarks linking DNAPL presence to the aquifers at Camp Lejeune.*) ..... The presence of low-permeability units (such as the Castle Hayne confining unit or any clay units) would limit vertical migration of both DNAPL and dissolved contaminants.....*

Response: The NRC report does not provide any information for the justification of this conceptualization of the contamination source at the ABC One-Hour Cleaners site and Tarawa Terrace and vicinity other than providing a reference to a source concentration of 12,000 µg/L, reported in Chapter E of the ATSDR Tarawa Terrace report series (Faye and Green 2007, p. 38). This is followed by a reference to a number "110,000 µg/L" (p. 38 of the NRC report, second paragraph from bottom of page). As indicated in the NRC report, this is the highest possible concentration of tetrachloroethylene (PCE) in water. Because this reference value is given in the NRC report without a reference citation, I question the credibility of this reference value. The NRC report also does not discuss the importance of this number in their conceptualization of the contaminant source as a DNAPL. Furthermore, the NRC report does not refer to a data source on the solubility levels of PCE in water like those data sources reported in Chapter D of the ATSDR Tarawa Terrace report series (Lawrence, 2007). The NRC report does not refer to or cite a database that may exist in USMC files at Camp Lejeune, unknown to the ATSDR water modeling team, that NRC committee members may have had access to, that would indicate the presence of DNAPL-phase PCE at the site. The NRC report also does not refer to a systematic dry-cleaner disposal procedure that is reported in the documents they have reviewed for handling the disposal of the chemical PCE as a pure phase PCE at the ABC One-Hour Cleaners site.

In the NRC report, the highest concentration of dissolved PCE, 110,000 µg/L, must imply the NRC committee's understanding of the solubility level of PCE in water. Because a reference is not provided, I could not confirm this number. However, our references indicate that the solubility of PCE in water is around 200,000 µg/L (= 200 mg/L) at 15°C or higher. In Chapter D of the ATSDR Tarawa Terrace report series (Lawrence 2007, p. D12, Table D9), solubility of PCE is reported to be 210, 000 µg/L (=210 mg/L) at 25°C, which is the solubility number I would like to work with for my analysis below. There are other references in the literature that report the solubility of PCE at much higher concentrations as well, which are not referenced here. This is because I would like to focus on what is reported in the ATSDR Tarawa Terrace series of reports (ATSDR, 2007a).

The 12,000 µg/L concentration reported in NRC report (and in Chapter E of the ATSDR Tarawa Terrace report series [Faye and Green 2007]) as a justification for the presence of a DNAPL phase is about 5.7%

to 6% of the solubility level of PCE (12,000/200,000 = 6% or 12,000/210,000 = 5.7%). The 12,000 µg/L concentration is the dissolved-phase PCE concentration in the groundwater at ABC One-Hour Cleaners as reported by ATSDR (Faye and Green 2007). Although this is a high concentration, this value is much less than PCE's solubility limit in water (200,000 µg/L at 15°C or 210,000 µg/L at 25°C). Even at the lowest solubility value reported by USEPA 150,000 µg/L this concentration level is at 8% of the solubility level (USEPA, 2024). The location of the highest concentration sample within Tarawa Terrace and vicinity can be used to identify the source location at the site. High concentrations at a site may suggest the possibility of non-aqueous phase (NAPL) PCE (PCE in form of NAPL) presence but this does not guarantee a NAPL presence at the site, because in this case, 12,000 µg/L is 6% or less of the solubility limit of PCE (see Section 6.4 of this expert report).

Thus, the conceptual DNAPL contaminant source characterization that is provided in the NRC report without any justification and without any field data support is bothersome. This reference to the presence of a DNAPL-phase contaminant source at the site not only appears in this comment on NRC report page 33, but it is repeatedly referred to in other pages of the NRC report which is not clear and correct understanding of the source conceptualization (see discussion of "Dissolved phase pollution vs NAPL, LNAPL and DNAPL pollution" in Section 6.4). In my opinion the NRC committee needs to provide further technical and field data evidence in support of their DNAPL conceptualization. Also reporting the solubility of PCE in water at about half the value of the data reported in the ATSDR Chapter D report (Lawrence 2007) without providing a reference (page 38 of the NRC report) is not scientifically acceptable. Short of citing field data evidence and an appropriate reference for the solubility level of PCE as reported in the NRC report, I would question the scientific basis of this conceptualization. Further, without field data evidence, the NRC review is based on hypothetical conditions and assumptions that are extracted from the scientific work of others (Figure 2-3 of the NRC report) which is based on studies that are conducted at other sites. It is my opinion that these sites have no relevance to the ABC One-Hour Cleaners site or Tarawa Terrace and vicinity. The purpose of this assertion (PCE as DNAPL source conceptualization) and misrepresentation of the site data by the NRC committee is not clear to me.

During the NRC committee review process, the question of the characterization of the source was brought to the attention of ATSDR water modeling team members in a request for information by an NRC committee member (Email communication from P. Clement to M.L. Maslia, ATSDR, May 5-11, 2008). At that time, ATSDR water modeling team members provided the NRC with data ATSDR had on the subject matter clearly showing why the modeling team elected to simulate the PCE source as a dissolved-phase source.

Furthermore, the modeling team clearly identified why the dissolved-phase injection procedure applied in the models used for the ATSDR water modeling analyses. The information that was provided to the NRC was based on data from several remedial investigation reports, site reports, and other DON and USMC files (Shiver 1985, Roy F. Weston 1992, 1994). In these field study reports, there is no recorded data reported by DON and USMC consultants that would provide evidence of, or substantiate the existence of, the presence of a DNAPL source at ABC One-Hour Cleaners or Tarawa Terrace. If the DNAPL source conceptualization that appears in the NRC report is based solely on the data source and information we provided to the NRC committee, then I do not agree with the NRC's source characterization. I, therefore, consider this to be a misinterpretation of the conditions at the site. If this conceptualization is based on any other information or data that I was not aware of, and if this information was provided to NRC by DON, the USMC, or their consultants, the modeling team should have been provided with that information and data. Because the reference to a DNAPL-phase in the

aquifers underlying ABC One-Hour Cleaners and Tarawa Terrace and vicinity appears in several places within the NRC report, I will revisit this topic again in my discussions below.

In the statement on page 33 of the NRC report, I also noticed that the NRC committee acknowledged that the PCE source was discharged to the unsaturated zone of the aquifer underlying ABC One-Hour Cleaners and Tarawa Terrace and vicinity. However, given that observation, the NRC committee fails to provide a justifiable critique of the use of the **MODFLOW** family of codes that only considers a saturated groundwater zone to analyze the physical problem at the site. On the contrary, the NRC committee considers the **MODFLOW** family of codes to be an acceptable modeling choice throughout the NRC report. This is probably because the NRC committee considers the **MODFLOW** codes as accepted state-of-the-art tools for typical groundwater pathway modeling. This is an example of a typical case of fitting a physical problem to a code "concept" I referenced in my response statement "7.2" above, which the ATSDR water modeling team tried to avoid as much as possible (see the discussion in section 6.1 and **TechFlowMP** application in section 5.1).

In recognition of this problem and in recognition of the general perception that prevails in the scientific community that the **MODFLOW** family of codes is an accepted procedure, the ATSDR water modeling team first utilized the **MODFLOW** and **MT3DMS** codes in their simulations. In addition, to enhance our understanding of conditions at the site, ATSDR extended its analyses. The ATSDR water modeling team applied the **TechFlowMP** software to understand and evaluate the unsaturated zone injection conditions that are implemented at the site. **TechFlowMP** is a public domain code that can be accessed from the Georgia Tech website for individual use without a fee (http://mesl.ce.gatech.edu/). The NRC report attempts to discredit this extra effort and the steps taken by the ATSDR water modeling team to simulate the proper source disposal conditions at the ABC One-Hour Cleaners site by classifying: (i) **TechFlowMP** code as a research tool; and (ii) as a proprietary code that is not verified. Again, this is very puzzling and a misrepresentation of the scientific and public domain facts of this case by the NRC committee. These NRC statements that appear in several places in the NRC report ignore a scientifically sound attempt by the ATSDR water modeling team to properly evaluate a physical problem, above and beyond a traditional **MODFLOW** and **MT3DMS** application which the NRC review committee accepts (NRC 2009, p. 43). Further, the NRC committee failed to check current technical literature and scientific publications containing substantial evidence of publications involving the **TechFlowMP**. The evidence that the **TechFlowMP** code has been tested and verified against other applications (see section 5.1) exists in this technical literature. (web site: http://mesl.ce.gatech.edu/PUBLICATIONS/Publications.html). This lack of due diligence by the NRC committee is puzzling.

It is equally important to note that the use and application of specialized codes to address specific problems that codes, such as **MODFLOW** and **MT3DMS**, cannot address, is not shunned by government-based scientific organizations, but rather, it is recognized and encouraged. As stated in the U.S. Environmental Protection Agency report, "Guidance on the Development, Evaluation, and Application of Environmental Models" (USEPA 2009, p. 31): **"However, the Agency acknowledges there will be times when the use of proprietary models provides the most reliable and best-accepted characterization of a system."** The point being made in this statement is that the most appropriate model should be applied to characterize a system, not necessarily, the most popular or most often-used model; and this is the exact modeling philosophy and approach that ATSDR took when applying the **TechFlowMP** and **PSOpS** and other sub-models at ABC One-Hour Cleaners and Tarawa Terrace and vicinity (see discussion of this topic in section 5.1).

7.3 Comments on the NRC report associated with science-based tools, analysis and interpretation of study results.

Comment on p. 43: *For example, **MT3DMS** can predict the transport only of dissolved contaminants, so a key approximation was made to represent the mass dissolved from the DNAPL source. To apply **MT3DMS**, ATSDR replaced the highly complex DNAPL contaminated source zone with a hypothetical model node where PCE was injected directly into the saturated aquifer formation at a constant rate (1.2 kg/day).*

Response: This NRC report statement relies on their unsubstantiated and undocumented source characterization concept (see my review comment above and in section 6.4). Using this conceptualization as an undisputable fact, the NRC committee then attempts to discredit the groundwater-modeling study conducted by ATSDR at the ABC One-Hour Dry Cleansers site and Tarawa Terrace and vicinity. This statement is a hyperbole, wherein first an "assumption" is made which is wrong and then that "assumption" is considered to be a "fact" to critique the findings of a study. This approach in a scientific critique is puzzling.

Comment on p. 43: *Unlike the MODFLOW and MT3DMS codes, the PSOpS and TechFlowMP codes lack validation by a broad spectrum of practicing geoscientists in an open-source environment.*

Response: I have addressed the point the NRC committee chose in reference to the misrepresentation of **TechFlowMP** as an unverified code in my response above. I will not repeat that here. In reference to the **PSOpS** and other sub-model developed by the Georgia Tech research group (see section 5.1), the following needs a clear answer: Can a reference to a public domain code be provided by the NRC committee members that is available through the published literature that provides the analysis performed by **PSOpS** and other sub-models? Has such a public domain code been developed for, and applied to, any study that they are aware of to manage pumping-schedule operations in an optimal manner for a complex system such as the one at Tarawa Terrace? The answer to these questions is obvious and the answer is: "This type of public domain model does not exist in the literature and needed to be developed to complete the study in appropriate scientific confidence bounds."

PSOpS is an optimization application that was developed by the MESL-Georgia Tech research group participating in the ATSDR water modeling analysis to yield answers to specialized uncertainty-related questions pertinent to the current health study conducted at Camp Lejeune site. The analysis is based on the **MODFLOW** family of codes in the generation of the database used to solve an optimization problem. The development of this optimization model was necessary to respond to scientific questions raised by the ATSDR Expert Panel (March 2005) whose members guided our study and contributed significantly to its quality. The members of this ATSDR Expert Panel are well known and respected scientists in the field and their names are listed in the Expert Panel report (Maslia 2005) that is also available on the ATSDR website. The question ATSDR Expert Panel members raised in this case was related to the uncertainty of a pumping-schedule operation that may be implemented at the site and the characterization of its effects on the study outcome. The **PSOpS** model that was developed for the purposes of this analysis and used in the ATSDR water modeling analyses to address this question became part of the peer reviewed PhD thesis of a graduate student at Georgia Tech. In that sense, the theoretical background of the model is reviewed and accepted by independent PhD thesis committee members at Georgia Tech and the detailed documentation of this model can be found in the PhD thesis of Dr. J. Wang, which is public domain information (Wang, 2008).

In conclusion, the NRC committee is most likely aware of the following: (1) specialized models such as **PSOpS** are not available in the technical public-domain literature; and (2) codes such as **PSOpS** only are developed for the specialized purposes of the current study to find answers to specialized questions that are raised by the current water modeling analysis. The concept of using an optimization algorithm that is fed by a database through the **MODFLOW** family of models, which is a common and routine procedure, is both scientifically sound and scientifically necessary in a study such as the one ATSDR conducted at Camp Lejeune site. If a public domain model existed that can be used for this study, that would serve the same purpose, instead of the **PSOpS** model, we would have used that model instead of the **PSOpS** model. To my knowledge, such a model is not available. In my opinion, the NRC committee also should recognize that the ATSDR water modeling effort is not a run-of-the-mill work-product and the problem at hand is not a routine problem that can be or should be analyzed using routine models. In such cases it is expected that specialized methods can be developed and implemented; this should not be shunned by the NRC, but instead, it should be encouraged (see USEPA comment and reference above) (USEPA 2009, p. 31).

Comment on p. 44: *The DNAPL source zone was represented by using a model node where PCE was injected continuously into the unconfined model layer-1 of the saturated zone at a constant rate of 1.2 kg/day (Faye 2008).*

Response: Again, in this statement, the NRC committee is asserting that the DNAPL source zone was misrepresented in the current study. I refer to the reader to my previous comments in my response to the DNAPL source mischaracterization by the NRC committee also see section 6.4 of this expert report.

To reiterate, we have not represented a DNAPL source zone as an injection point in our models because there is no DNAPL source zone in the aquifer underlying the ABC One Hour Dry Cleaners site at Tarawa Terrace and vicinity. If the claim of the NRC committee can be substantiated by any field data, I stand corrected. Not only I would stand corrected, but also, I would strongly recommend that the U.S. Environmental Protection Agency (USEPA), their consultants, and the North Carolina Department of Environment and Natural Resources (NCDENR) should immediately abandon their remediation efforts at the ABC One-Hour Dry Cleaners site at Tarawa Terrace and vicinity and adopt remediation strategies that would yield more effective results for a DNAPL source contaminant. The U.S. Environmental Protection Agency (USEPA), their consultants, and the North Carolina Department of Environment and Natural Resources (NCDENR) conducted remediation efforts at the ABC One-Hour Dry Cleaners site at Tarawa Terrace and vicinity using remediation strategies directed toward a dissolved phase contaminant. The fact that USEPA and NCDENR field consultants did not implement DNAPL remediation technologies at the site is additional evidence that these agencies and their consultants also do not agree with the NRC committee as to the characterization of the contamination source as DNAPL phase PCE.

Comment on p. 48: *Because insufficient historical pumping data were available to constrain the model predictions from 1953 to 1980, the ability of the advanced optimization models to estimate the dates accurately is questionable.*

Response: There are obvious uncertainties in the physical problem being studied at ABC One-Hour Dry Cleaners and Tarawa Terrace and vicinity. The NRC committee would most likely agree with this statement. If we accept this statement, then the question becomes, should one completely ignore uncertainty in the analysis or should one try to develop techniques that would provide an estimate of the effects of uncertainty on the solution in a systematic way? In this study we have chosen the second route, which is the sound science alternative which documents the inherent level of uncertainty.

The NRC committee should accept the fact that answers to uncertainty questions cannot be answered "**accurately**" as the NRC report states in the above statement. Expecting that from an uncertainty analysis outcome would be scientifically irresponsible. Our uncertainty analyses are not provided to give "accurate" answers to the problem studied. Instead, our uncertainty analyses are used as estimates that would indicate the variability range of deterministic results provided earlier. The domain of uncertainty analysis is a scientific field which is not in the realm of the traditional groundwater fate and transport analysis expertise and should be viewed using a different microscope and expertise. ATSDR's uncertainty analysis is a reliable and accepted methodology in the field of environmental modeling.

Comment on p. 48: *(5) there is no spatial variation in the microbiologic or geochemical characteristics.*

Response: The NRC committee correctly identified that in the application of the TECHFLOWMP model to the aquifers underlying the ABC One-Hour Dry Cleaners site and Tarawa Terrace and vicinity, we assumed no spatial variation of microbiologic characteristics. If the NRC committee is familiar with the finite element procedures used in the **TechFlowMP** model, they would acknowledge that this is not a restriction of the model but a restriction on the available field data for the site. If the microbial distribution in an aquifer can be accurately characterized, which we doubt can be accomplished in this case or in any case, we can certainly include that heterogeneity in our modeling effort.

Having pointed out this fact, I would also like to question issues pertaining to levels of acceptable homogeneity considered in our modeling effort and compare it with levels of unacceptable homogeneity that are shunned in our modeling analysis based on the critique presented in the NRC report. For example, the assumption of uniform infiltration across the model domain when the MODFLOW family of model codes is utilized was not critiqued in the NRC report, but the assumption of uniform microbial distribution in the multilayer aquifer domain is critiqued. Between these two processes, which would be the easier process to characterize and implement? I think the answer to this question is obvious, the infiltration process would be easier. Thus, although both processes are characterized by heterogeneity in the aquifer, accepting the homogeneity assumption for the infiltration case but not accepting homogeneity assumption for the microbial distribution case would be setting the bar too high and would be scientifically irresponsible considering the levels of data that may be available to characterize either process. A scientific review committee should be able to make these distinctions easily and come up with appropriate conclusions in their review comments.

Comment on p. 49: *However, there are some important limitations in ATSDR's modeling efforts because of the sparse set of water quality measurements, the need to make unverifiable assumptions, and the complex nature of the PCE source contamination.*

Response: There are limitations of the modeling analyses conducted by ATSDR water modeling team. We would be the first to acknowledge these limitations. This is evident by the level of detail of the uncertainty analysis conducted as part of the water modeling analysis to envelope the effect of those uncertainties on the outcome presented. However, in my opinion, characterizing the uncertainty analysis outcome as not "**accurate**" as previously stated (see response above) or, that uncertainty analysis should only be conducted in "**verifiable**" cases as stated above is not a scientifically sound assessment or procedure. As we all agree, **an uncertainty that can be verified would be no longer uncertain**.

Regarding the lack of historically measured values of contamination, it was not required to measure these contaminants in the timeframe of interest, according to regulatory agencies. It was when

trihalomethane (THM) measurements were first required, those analytical techniques were utilized that could detect the presence of other halogenated (e.g., chlorinated) compounds like PCE and TCE. The lack of such measured values points to the need for historical reconstruction efforts – the NRC report offers no better alternative.

I fully agree with the NRC observation that "ATSDR applied best practices and cutting-edge modeling approaches to predict the complex groundwater-contamination scenario" (NRC, 2009; p 65) necessary for establishing reconstructed exposure levels. ATSDR conducted sensitivity analyses in both the 2009 Tarawa Terrace study (ATSDR, 2009) and the later 2013 Hadnot Point / Holcomb Boulevard study (ATSDR, 2013) that generated a range of possible exposure levels at a given point in time. Thus, in my opinion ATSDR not only satisfied but also built upon input from the NRC report to produce the best-possible engineering and scientifically valid information for assessing historical exposure levels at Camp Lejeune.

Comment on p. 49 first bullet: *The effects of the DNAPL in both unsaturated and saturated zones have not been included in the studies.*

Response: The NRC report brings back the DNAPL issue here again. Please see my response in the comments above.

Comment on p. 49 second bullet: *Constant values of dispersivity (longitudinal dispersivity of 25 ft and transverse 2.5 ft) were used in the transport model.*

Response: Although dispersivity is constant, based on the definition of the hydrodynamic diffusion coefficient, the hydrodynamic diffusion coefficients are variable because they depend on the velocity field at the site. This is a common assumption in most studies where field data are not available to support spatially variable dispersion/diffusion coefficients. This comment again is related to my discussion of acceptable homogeneity and unacceptable homogeneity conditions at a site study above.

Comment on p. 49 bullet four: *The numerical codes **TechFLowMP** and **PSOpS** used in the modeling are research tools and are not widely accepted public-domain codes, such as **MODFLOW** and **MT3DMS**, so their validation is important.*

Response: This characterization is a misrepresentation of the models, as clearly identified in my response above. The availability of codes with the capabilities of these models is very limited. In my opinion the use of these models in complex analysis should not be shunned by NRC, but instead, it should be encouraged since these models provide supplemental information beyond **MODFLOW** family of code applications (USEPA 2009, p. 31).

Comment on p. 49 bullet five: *The **PSOpS** modeling study is based on the premise that an optimization model can be used to evaluate pumping stresses. Without site-specific pumping and water-quality data, the results will be nonunique and uncertain.*

Response: PSOpS modeling concept is based on the effort of estimating the effects of uncertainty on the modeling outcome. This analysis is approached in a systematic manner following accepted processes such as an optimization analysis based on some constraints to satisfy the demands. The **PSOpS** model uses the **MODFLOW** family of codes as its database engine. We are not claiming that the outcome provides the exact conditions representing the problem at the site. But the outcome of the analysis provides us with an envelope which bounds our deterministic analysis. This is a standard uncertainty

analysis procedure like, for example, Monte Carlo analysis that is routinely used in uncertainty analysis. Monte Carlo analysis, according to a well-established procedure, systematically evaluates the effects of uncertainty on the problem solution based on random synthetic data generation. In such an application, it is not certain that the random numbers generated would exactly represent the actual conditions for the problem at the site. However, the bounding limits of the analysis are the goal of the analysis. The application of **PSOpS**, in essence, is very similar to that analogy.

As I have stated earlier, this goes back to the NRC report statement about the "**accuracy**" of the uncertainty analysis results that cannot be justified scientifically. Also, I must emphasize again what I stated earlier: The domain of uncertainty analysis is a scientific field which is not in the realm of the traditional groundwater fate and transport analysis expertise and should be viewed using a different microscope and expertise.

Comment on p. 49 bullet seven: *The **TechFlowMP** model predicted very high vapor concentrations. For example, **TechFlowMP** predicted that the PCE vapor concentration in the top 10 ft of soil beneath the Tarawa Terrace elementary school should be 1,418 μg/L. Studies of PCE vapor concentrations in buildings that house or are near a drycleaning facility have reported measured concentrations around 55 μg/L.*

Response: This reference to a vapor concentration at 1,418 μg/L is another example of misrepresentation of the results of the modeling analyses conducted by the ATSDR water modeling team. This aforementioned information was taken from Chapter A of the ATSDR Tarawa Terrace report series (Maslia et al. 2007, p. A44). The statement provided in the ATSDR report reads as follows: ***"b. the maximum simulated PCE concentration in groundwater (model layer 1) at the Tarawa Terrace elementary school was 1,418 μg/L (Figure A15b), whereas the maximum simulated vapor-phase PCE (in the top 10 ft of soil) was 137 μg/L (Figure A20a)"***

The above sentence, taken directly from the ATSDR report submitted to NRC, clearly states that the groundwater (not vapor) concentration of PCE in layer "1" is at 1,418 μg/L concentration. Vapor concentration is given separately in the paragraph towards the end of that sentence. For the NRC report to represent this number (1,418 μg/L) as the vapor concentration that is simulated at the site to discredit a study is not appropriate for a scientific review. I will provide a more detailed analysis of this case using simulation results to bring clarity to the concern raised in the NRC report.

In this case, the work product referred to are the **TechFlowMP** modeling results and the analysis mentioned was conducted by the MESL - Georgia Tech research group participating in the ATSDR water modeling analysis of the ABC One-Hour Cleaners site and Tarawa Terrace and vicinity (Jang and Aral 2007). To provide the reader with clear evidence of scientific misrepresentation of the facts, the actual data reported in our report is presented below in sufficient detail, unlike the other responses I have provided to other comments in this document. In the numerical study of the multispecies, multiphase groundwater contamination at ABC One-Hour Dry Cleaners and Tarawa Terrace and vicinity, **TechFlowMP** simulations used two boundary-conditions to characterize the ground surface under the original pumping schedule: (1) GSBC = 0.01 and (2) GSBC = 1.0 (Jang and Aral 2007, p. G15). Here the acronym "GSBC" stands for the Ground Surface Boundary Condition. For the in-/out-flux of gas between the atmosphere and the unsaturated zone, if the ground surface does not have low-permeable zones or hindrances due to pavement, lakes, or buildings, the GSBC value is set to be 1.0. This implies that soil gas can be freely released into the atmosphere from the unsaturated zone. However, when some objects, including roads, buildings, ponds, or highly water-saturated areas, are present at the ground surface, the

soil gas cannot be released into the atmosphere freely. Under such a condition, GSBC is set to be 0.01 in the current study. In a typical application, any number between these two extremes can be considered in the analysis. However, just to show the bounds of the results, the discussion here will be confined to these two extreme cases.

To analyze the concentration distribution around the school area as it is referred to in the NRC report comment, the location of the school at Tarawa Terrace must be identified and is shown in Figure 1 (ATSDR, 2007; ATSDR 2013).

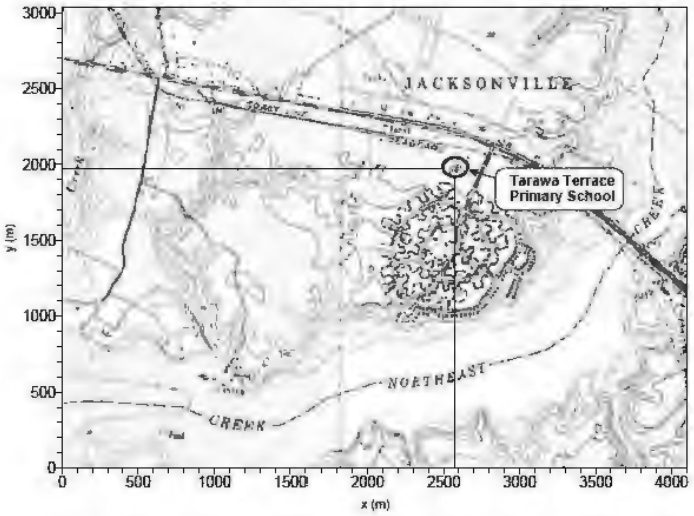

Figure 1. Location of the Tarawa Terrace Elementary School

In the school area, the groundwater table is near the ground surface (CH2MHILL 2007). In this study, the ground surface is at z = 7.6 meters (m, z = 25 ft), and the groundwater table is around z = 2.4 - 4 m (z = 8 - 13 ft) (Jang and Aral 2007, Figure G3, p. G10). Thus, the concentration distributions of the vaporized PCE at z = 6 m are presented below, where the unsaturated zone is at this location.

As shown in Figure 2 (ATSDR, 2007a), under GSBC = 0.01, which is more representative of an area where there are buildings and pavements, the predicted vaporized PCE concentrations in the pore space of the soil at the center of the school area (x = 2,580 m, y = 1,975 m) are about 15.5 μg/L during December 1984 (Figure 2a) and 3.7 μg/L during December 1994 (Figure 2b). Within the school area (marked with the circle in this figure), the PCE concentration ranges 0.1-100 μg/L during December 1984 (Figure 2a) and 0.1-50 μg/L during December 1994 (Figure 2b) (ATSDR, 2007a).

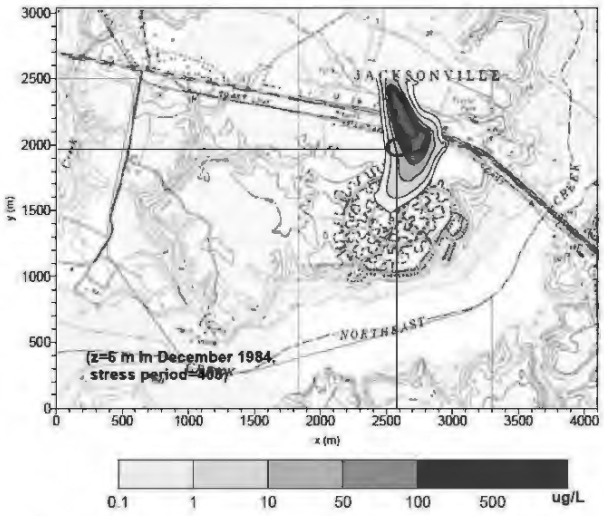

Figure 2a. Vaporized PCE concentrations in the gas phase under the original pumping schedule (PS-O) with GSBC=0.01, at z=6, December 1984.

In Figure 2, the vaporized PCE concentrations near the ABC One-Hour Cleaners site are very high where the contamination source is located. This is expected, but the vapor concentrations decrease sharply with the distance away from the ABC One-Hours Cleaners site. Furthermore, the simulated concentration of PCE in the gas phase, ranging from 0.1 to 100 µg/L, is not significantly different from the value of 55 µg/L, given in the NRC report.

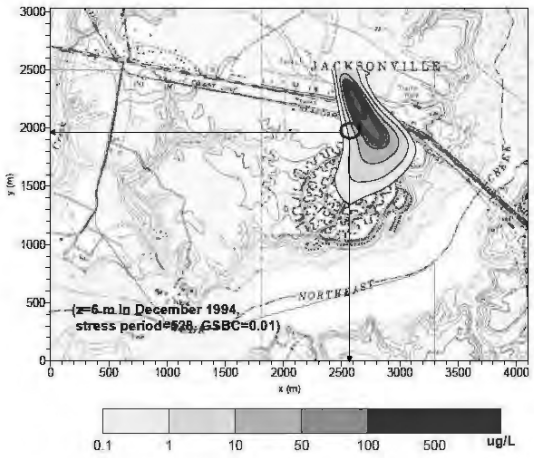

Figure 2b. Vaporized PCE concentrations in the gas phase under the original pumping schedule (PS-O) with GSBC=0.01, at z=6, December 1994.

Having provided this comparison, I also question the source of the reference number, 55 µg/L, that is used in the NRC report. The NRC report provides a reference for this case and this reference is McDermott et al. (2005). I was curious about this reference; therefore, I located and obtained a copy of the referenced paper. In the McDermott et al. (2005) study, the authors are analyzing and reporting data on the PCE vapor concentrations in a building where dry-cleaner operations are housed in New York City.

Does the NRC committee expect us to accept the concept that what is observed (measured) as vapor concentration in a building that houses a dry-cleaner facility in New York City should also apply to the subsurface pore space of the soil at the site of an elementary school area in Camp Lejeune, North Carolina? Or do they expect that what we have simulated in the pore space of the soils at a site in North Carolina should also confirm the observations made in New York City, 17-20 years beyond our final simulation date (2001-2003), in some dry-cleaner facility building? In my opinion, these types of comparisons, expectations, and assertions are scientifically not acceptable or credible.

In the groundwater contamination study that utilized TECHFLOWMP (Jang and Aral 2007), the local equilibrium of contaminant partitioning between the water and gas phases is implemented while calculating the contaminant distribution between the two phases (gas and liquid). Thus, we can use the Henry coefficient, H, in estimating PCE concentration in the gas phase from the concentration in the groundwater phase as follows:

$$C_{Vapor\_PCE} = HC_{GroundWater\_PCE}$$

For PCE, H is 0.35 (Jang and Aral 2007, Table G2). Using the dissolved PCE concentration in the groundwater shown in Figure G5 of Jang and Aral (2007) (in the unsaturated and saturated zones), the overall concentration distribution of the vaporized PCE within the gas phase in the unsaturated zone can also be estimated. This simple calculation could have been made by the NRC committee to confirm the vapor concentration numbers they are reporting in their statement. In Figure G5 of Jang and Aral (2007), the dissolved PCE concentration in the groundwater is 100-500 µg/L near the ground surface at the location of the elementary school (x = 2,580 m, y = 1,975 m). Therefore, the vaporized PCE concentration will be approximately 35-175 µg/L in the unsaturated zone near the school area. The cross-section line A-A, in Figure G5 is located at x = 2,606 m.

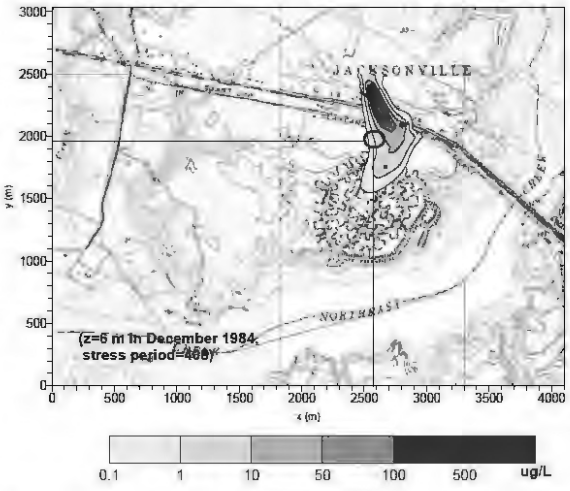

Figure 3a. Vaporized PCE concentrations in the gas phase under the original pumping schedule (PS-O) with GSBC=0.01, z=6, December 1984.

Let us also analyze the results of the other boundary condition that is used in the **TechFlowMP** model out of curiosity and see if the vapor concentration value of 1,418 µg/L reported in the NRC report was

referring to that case. The results reported in (Jang and Aral 2007) under the condition GSBC = 1 are shown in Figure 3 (ATSDR, 2007; ATSDR 2013). The predicted vaporized PCE concentrations at the center of the school area (x = 2580 m, y = 1975m) are about 0.99 during December 1984 (Figure 3a) and 0.1 μg/L during December 1994 (Figure 3b) (ATSDR, 2007; ATSDR 2013) (i.e. more PCE vapor is released to the atmosphere and less is remaining in the pore space when compared to the previous results). Within the school area (marked with the circle in the figure), the concentration ranges 0.1-10 μg/L in December 1984 (Figure 3a) and less than S μg/L in December 1994 (Figure 3b) (ATSDR, 2007).

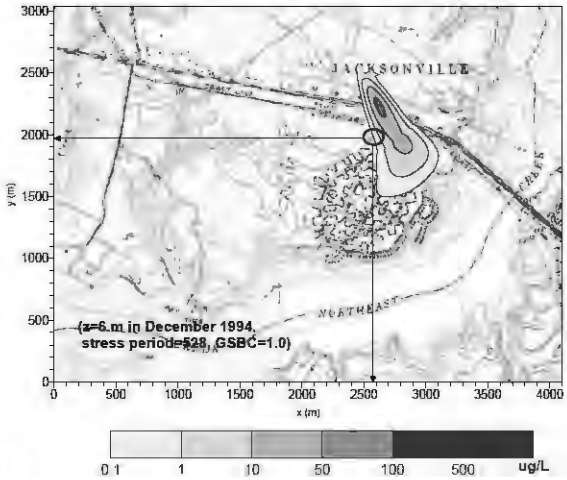

Figure 3b. Vaporized PCE concentrations in the gas phase under the original pumping schedule (PS-O) with GSBC=0.01. z=6. December 1994.

As can be seen from these results the number reported in the NRC report does not exist in the ATSDR water-modeling analysis as vapor concentration. This is a clear misrepresentation of the ATSDR water modeling results.

The field investigation during 2007 (CH2MHILL 2007) it was reported that the vaporized concentrations of PCE near the ground surface were below detection limits or very low, 3.9 ppbv (parts per billion volume), which is equivalent to 0.028 μg/L. Considering the time gap between the end of the historical simulation time (December 1994) and the field investigation time (July 2007), the simulation results that are provided in the Chapter G report of the ATSDR Tarawa Terrace report series (Jang and Aral 2007) provide reasonable modeling results and represent acceptable levels of expected vapor concentration near the Tarawa Terrace elementary school. Are we asserting that this is absolutely the case? The answer to that question is absolutely "No." This outcome is only an estimate based on the assumptions and limitations of the models considered and the boundary conditions used in the ATSDR water modeling analyses and the assumptions and limitations are based on our best judgment of the conditions that may exist at the ABC One-Hour Dry Cleaners site and Tarawa Terrace and vicinity.

The ATSDR water modeling reports do not report such high concentration of vaporized PCE concentration in the gas phase. The vaporized PCE concentration of 1,418 μg/L is equivalent to a dissolved PCE concentration of 4,051 μg/L, in the groundwater which does not exist in our results:

$$C_{Vapor,PCE} = HC_{GroundWater,PCE}$$

$$C_{GroundWater,PCE} = 1418/0.35 = 4051.4$$

I also note that the unsaturated zone is located at a very thin layer near the ground surface (z = 7.6 m (25 ft)) in Jang and Aral (2007, Figure G5) which is characterized in terms of several layers in water-modeling analysis. The maximum thickness of the unsaturated zone is about 7.6 m.

In conclusion the data, the associated discussion of the vapor levels near the Tarawa Terrace elementary school area, and the reference provided in the NRC report (McDermott et al. 2005) are far from the facts of the case and the results that are presented by the ATSDR water modeling team.

Comment on p. 49 bullet eight: *The biodegradation model used within the **TechFlowMP** code is based on an untested preliminary research model.*

and also,

Comment on p. 50: *The **TechFlowMP** simulations assumed that the biodegradation byproduct of TCE is trans-1,2-DCE. However, the scientific literature indicates that cis-1,2-DCE is the predominant product of TCE reduction under in situ groundwater conditions.*

Response: The detailed description of why trans-1,2-dichloroethylene is chosen as the representative byproduct of TCE bioreaction at the Tarawa Terrace area instead of cis-1,2-DCE is given in page G4 of the report, Chapter G (Jang and Aral, 2007). An additional explanation regarding this issue is given below.

As shown in Figure G2 of the report (Jang and Aral, 2007), the anaerobic biological degradation of trichloroethylene (TCE) generates three isomers, cis-1,2-dichloroethylene (cis-1,2-DCE), trans-1,2-dichloroethylene (trans-1,2-DCE), and 1,1-dichloroethylene (1,1-DCE). As discussed in the report (Jang and Aral 2007), cis-1,2-DCE (1,2-cDCE) is the most common byproduct among the three DCE isomers produced theoretically (Wiedemeier 1998). Even though cis-1,2-DCE has been often used as a primary byproduct of TCE-biodegradation under the anaerobic conditions in contaminant transport modeling of chlorinated ethenes (Clement et al., 2000; Jang and Aral, 2008), but the primary byproduct of the TCE bioreaction highly depends on the chemical-biological conditions (especially, microorganisms and nutrients) at the contaminated sites (Bradley, 2003), implying that the biological reaction of TCE is highly site-specific. For example, Christiansen et al. (1997) and Miller et al. (2005) reported the anaerobic biological degradation of TCE produced more trans-1,2-DCE than cis-1,2-DCE. At the TCE contaminated site in Key West, Florida, the ratio of trans-1,2-DCE to cis-1,2-DCE was greater than 2 (SWMU9, 2002). Griffin (2004) reported that the ratio could reach up to 3.5, based on field data for several sites, including Tahquamenon River, MI; Red Cedar River, MI; Pine River, MI; and Perfume River, Vietnam.

In the modeling of contaminant transport at a contaminated site, the field measurement data at the site are very important in validating the numerical models and in obtaining more accurate simulation results. For the numerical study at the Tarawa Terrace area, we had limited field data regarding the concentrations of PCE, TCE, and trans-1,2-DCE. This is indicated in the following statement of the ATSDR report: Review of degradation byproduct data analyses, provided to ATSDR by the Department of the Navy, U.S. Marine Crops, the North Carolina Department of Environment and Natural Resources, and others indicated that the predominant degradation byproduct of TCE at Tarawa Terrace and vicinity was trans-1,2-DCE (Faye and Green 2007, Tables E2 and E7).

As mentioned above, since the primary byproduct of the biological degradation of TCE depends on site-specific conditions, it is more reasonable to select trans-1,2-DCE instead of cis-1,2-DCE as a primary TCE-bioreaction-byproduct in the study on the groundwater contamination at the Tarawa Terrace area.

The NRC critique, therefore, ignores site-specific TCE degradation by-product data pertinent to Tarawa Terrace and vicinity, listed in Chapter E of the Tarawa Terrace report series. This statement again clearly demonstrates the lack of due diligence by the NRC review committee in their review of the data that exists at the Tarawa Terrace, Camp Lejeune site and their lack of understanding of the facts of the site-specific case based on this data.

Comment on p. 50 next to last bullet: *In the absence of data, historical reconstruction efforts that use groundwater models can only provide a general conceptual framework for what happened at the site and why.*

Response: Historical reconstruction is a procedure that is accepted in literature. It uses models to predict the past in a conceptually similar manner to the models that are routinely used to predict the future in other engineering studies. The ATSDR response document provides references to such historical reconstruction applications.

Comment on p. 65: *Therefore, the committee recommends the use of simpler approaches (such as analytic models, average estimates based on monitoring data, mass-balance calculations, and conceptually simpler **MODFLOW/MT3DMS** models) that use available data to rapidly reconstruct and characterize the historical contamination of the Hadnot Point water-supply system. Simpler approaches may yield the same kind of uncertain results as complex models but are a better alternative because they can be performed more quickly and with relatively less resources, which would help to speed-up the decision-making process.*

Response: Use of simpler models may be easier to implement. We have also proceeded in that direction as well for the Hadnot point study. However, how the detailed questions that are raised in the NRC report could be answered using simpler models is not clear to me. Further, simpler models will not necessarily reduce the level of uncertainty. Instead, they may introduce conceptual misrepresentation of the physical system modeled. The ATSDR's approach, which in my opinion is the correct approach, is to use the most appropriate model that can provide the needed information, rather than the simplest or an off the shelf model.

CONCLUSIONS:

The scientific and engineering evidence presented in this response statement (submitted to EDRP/ATSDR as a memorandum in 2009) and the discussion of this evidence herein clearly indicate that the data and the analysis presented in the NRC report (NRC, 2009) are misrepresentations and mischaracterizations of the findings of the ATSDR water modeling analyses conducted at the ABC One-Hour Cleaners site, Tarawa Terrace area and vicinity. The conceptual characterization of the contaminant source made by the NRC committee also does not fit available field data or reported field conditions by the USEPA, their consultants, or the NCDENR which guided remediation efforts at ABC One-Hour Cleaners and Tarawa Terrace and vicinity.

Thus, I believe, due to the presence of numerous errors, misrepresentations and mischaracterization of the scientific facts of the ATSDR water modeling analyses, the NRC report cannot be used as a reliable

rebuttal to ATSDR conclusions on water modeling or a guidance document in its entirety. I reserve the right to update this report should any additional evidence or deposition testimony be provided to me that calls into question the conclusions of the NRC report or that concerns any other topic in my report.

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8.2 Reliance Materials

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2. Faye, R.E. et al. 2007. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions - Chapter B: Geohydrologic Framework of the Castle Hayne Aquifer System." ATSDR, September 2007.
3. Faye, R.E. et al. 2007. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions - Chapter C: Simulation of Groundwater Flow." ATSDR, November 2007.
4. Lawrence, S.J. et al. 2007. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions -

Chapter D: Properties and Degredation Pathways of Common Organic Compounds in Groundwater." ATSDR, September 2007.
5. Faye, R.E. and Green, J.W. 2007. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions - Chapter E: Occurrence of Contaminants in Groundwater." ATSDR, December 2007.
6. Faye, R.E. et al. 2008. "Analyses of Groundwater Flow, Contaminant Fate, and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions - Chapter F: Simulation of the Fate and Transport of Tetrachloroethylene (PCE)." ATSDR, February 2008.
7. Jang, W. et al. 2008. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions - Chapter G: Simulation of Three-Dimensional Multispecies, Multiphase Mass Transport of Tetrachloroethylene (PCE) and Associated Degradation By-Products." ATSDR, April 2008.
8. Jang, W. and Aral, M.M. 2008. "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present Day Conditions - Chapter H: Effect of Groundwater Pumping Schedule Variation on Arrival of Tetrachloroethylene (PCE) at Water-Supply Wells and the Water Treatment Plant." ATSDR, February 2008.
9. Maslia, M.L. et al. 2009(a). "Analyses of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water at Tarawa Terrace and Vicinity, U.S. Marine Corps Base Camp Lejeune, North Carolina: Historical Reconstruction and Present-Day Conditions - Chapter I: Parameter Sensitivity, Uncertainty, and Variability Associated with Model Simulations of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water." ATSDR, February 2009.
10. Maslia, M.L. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A: Summary and Findings." ATSDR, March 2013.
11. Sautner, J.B. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 1 - Descriptions and Characterizations of Data Pertinent to Water-Supply Well Capacities, Histories, and Operations." ATSDR, March 2013.
12. Telci, I.T. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 2 - Development and Application of a Methodology to Characterize Present-Day and Historical Water-Supply Well Operations." ATSDR, March 2013.
13. Faye, R.E. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 3 - Descriptions

and Characterizations of Data Pertinent to Water-Level Data and Groundwater Flow for the Brewster Boulevard and Castle Hayne Aquifer Systems and the Tarawa Terrace Aquifer." ATSDR, March 2013.
14. Suarez-Soto, et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 4 - Simulation of Three-Dimensional Groundwater Flow." ATSDR, March 2013.
15. Guan, J. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 5 - Theory, Development, and Application of Linear Control Model Methodology to Reconstruct Historical Contaminant Concentrations at Selected Water-Supply Wells." ATSDR, March 2013.
16. Jones, L.E. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 6 Characterization and Simulation of Fate and Transport of Selected Volatile Organic Compounds in the Vicinities of the Hadnot Point Industrial Area and Landfill." ATSDR, March 2013.
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18. Sautner, J.B. et al. 2013. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter A–Supplement 8 - Field Tests, Data Analyses, and Simulation of the Distribution of Drinking Water with Emphasis on Intermittent Transfers of Drinking Water Between the Hadnot Point and Holcomb Boulevard Water-Distribution Systems." ATSDR, March 2013.
19. Faye, R.E. et al. 2012. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter B: Geohydrologic Framework of the Brewster Boulevard and Castle Hayne Aquifer Systems and the Tarawa Terrace Aquifer." ATSDR, January 2012.
20. Faye, R.E. et al. 2010. "Analyses and Historical Reconstruction of Groundwater Flow, Contaminant Fate and Transport, and Distribution of Drinking Water Within the Service Areas of the Hadnot Point and Holcomb Boulevard Water Treatment Plants and Vicinities, U.S. Marine Corps Base Camp Lejeune, North Carolina - Chapter C: Occurrence of Selected Contaminants in Groundwater at Installation Restoration Program Sites." ATSDR, October 2010.
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23. Maslia, M.L. (Editor). 2005. "Expert Peer Review Panel Evaluating ATSDR's Water-Modeling Activities in Support of the Current Study of Childhood Birth Defects and Cancer at U.S Marine Corps Base Camp Lejeune, North Carolina." ATSDR, Meeting March 28-29, 2005, published October 2005.
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25. March 28, 2005 Expert Peer Review Panel Meeting Transcript, available at https://www.atsdr.cdc.gov/sites/lejeune/panel_report_groundwater.html
26. March 29. 2005 Expert Peer Review Panel Meeting Transcript, available at https://www.atsdr.cdc.gov/sites/lejeune/panel_report_groundwater.html
27. April 29, 2009 Expert Peer Review Panel Meeting Transcript, available at https://www.atsdr.cdc.gov/sites/lejeune/expertpanels.html
28. April 30, 2009 Expert Peer Review Panel Meeting Transcript, available at https://www.atsdr.cdc.gov/sites/lejeune/expertpanels.html
29. February 8, 2012 Deposition of Elizabeth Ann Betz and any exhibits referenced therein
30. June 30, 2010 Deposition of Morris Maslia and exhibits referenced therein
31. May 28, 2024 Deposition of General Anthony Zinni; Zinni Deposition Exhibits 1-8
32. August 5, 2024 Deposition of Kim Henderson; Henderson Deposition Exhibits 1-18
33. August 6, 2024 Deposition of Dan Waddill; Waddill Deposition Exhibits 1-20
34. August 14, 2024 Deposition of Jason Barry Sautner; Sautner Deposition Exhibits 1-10
35. August 15, 2024 Deposition of Rene Suarez-Soto; Suarez-Soto Deposition Exhibits 1-5
36. August 22, 2024 Deposition of Dr. Chris Rennix; Rennix Deposition Exhibits 1-6
37. September 26, 2024 Deposition of Morris Maslia; Maslia Deposition Exhibits 1-22
38. ATSDR Camp Lejeune Project File: CLJA_ATSDRWM01-0000000001-CLJA_ATSDRWM01-0000189563; CLJA_WATERMODELING-0000000001-CLJA_WATERMODELING-0000209307; CLJA_WATERMODELING_01-0000000001-CLJA_WATERMODELING_01-0000854197; ATSDR_WATERMODELING_01-0000854198-ATSDR_WATERMODELING_01-0000936235; CLJA_WATERMODELING_01-0000936236-CLJA_WATERMODELING_01-0001118025; CLJA_WATERMODELING_04-0000000001-CLJA_WATERMODELING_04-0000117996; CLJA_WATERMODELING_05-0000000001-CLJA_WATERMODELING_05-0001394405; ATSDR_WATERMODELING_05-0001394406-ATSDR_WATERMODELING_05-0001394413; CLJA_WATERMODELING_07-0000000001-CLJA_WATERMODELING_07-0002316354; CLJA_WATERMODELING_08-0000000001-CLJA_WATERMODELING_08-0000193508; CLJA_WATERMODELING_09-0000000001-CLJA_WATERMODELING_09-0000547124; ATSDR_WATERMODELING_09-0000547125-ATSDR_WATERMODELING_09-0000568329;

CLJA_WATERMODELIING_09-0000568330-CLJA_WATERMODELIING_09-0000615612;
CLJA_WATERMODELING_09-0000615613-CLJA_WATERMODELING_09-0000745917

39. Georgia Tech Camp LeJeune Water Modeling Working Files
40. 00897_PLG_0000067113-00897_PLG_0000067132
41. 00897_PLG_0000339484-00897_PLG_0000339588
42. 00897_PLG_0000063393-00897_PLG_0000063594
43. 00897_PLG_0000065633-00897_PLG_0000065659
44. CLJA_ATSDR_BOVE-0000006959-CLJA_ATSDR_BOVE-0000006960

The forthcoming depositions of Frank Bove, Susan Martel, and Scott Williams, including any accompanying deposition exhibits and any other materials later produced in this litigation for which I reserve the right to read, review and rely upon.

9. Glossary of Abbreviations, and Definitions

Definitions of terms and abbreviations used throughout this report are listed below in alphabetical order.

ATSDR: Agency for Toxic Substances and Disease Registry.

BTEX: Benzene, toluene, ethyl benzene, and xylenes. These compounds are some of the VOCs found in petroleum derivatives such as gasoline. BTEX compounds typically occur near petroleum and natural gas production sites, gasoline stations, and other areas with underground storage tanks (USTs) or above-ground storage tanks (ASTs) containing gasoline or other petroleum-related products

CDC: Centers for Disease Control and Prevention.

DCE Dichloroethylene; an industrial chemical that is not found naturally in the environment. The USEPA has determined that 1,1-dichloroethylene is a possible human carcinogen

1,1-DCE 1,1-dichloroethylene or 1,1-dichloroethene

1,2-DCE 1,2-dichloroethylene or 1,2-dichloroethene

1,2-cDCE *cis*-1,2-dichloroethylene or *cis*-1,2-dichloroethene

1,2-tDCE *trans*-1,2-dichloroethylene or *trans*-1,2-dichloroethene

total 1,2-DCE total 1,2-dichloroethylene or total 1,2-dichloroethene

DNAPL: Nonaqueous Phase Liquids that are denser than water.

DOD: Department of Defense.

DON: Department of the Navy.

DPL: Liquids that mix with water, as opposed to nonmixing phase liquids NAPL.

EPANET 2: A water-distribution system (or network) model developed by the USEPA (Rossman 2000)

GAO: Government Accountability Office.

GSBC: Ground Surface Boundary Condition.

HBWTP: Holcomb Boulevard Water Treatment Plant.

HPWTP: Hadnot Point Water Treatment Plant.

HSMM: A one-dimensional NAPL volume estimator model and software developed by USEPA (Weaver et al. 1996).

LCT: Linear Control Theory. A scientific methodology of the scientific field of control engineering and applied mathematics. The methodology deals with the control of dynamical systems in engineered processes. In the case of ATSDR study of the Camp Lejeune site, the methodology was applied to groundwater contaminant transport analysis as a simple application to predict concentration values at a specific point in space and time based on limited data available at the site. This study was requested by the expert panel which reviewed the ATSDR Camp Lejeune site study and provided scientific advice.

LNAPL: Nonaqueous Phase Liquids that are lighter than water.

Markov process: A process that analyzes the tendency of one event to be followed by another event based on the sequence of events. Using this analysis, one can generate a new sequence of random but related events, which will look similar to the original; a stream of events is called a Markov Chain.

MCL: Maximum contaminant level; a legal threshold limit set by the USEPA on the amount of a hazardous substance that is allowed in drinking water under the Safe Drinking Water Act; usually expressed as a concentration in milligrams or micrograms per liter (USEPA 2003, 2009).

MESL: Multimedia Environmental Simulations Laboratory, a research center at Georgia Institute of Technology.

MODFLOW: A U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equations. Used worldwide in groundwater flow simulations in subsurface systems.

Monte Carlo analysis: Also referred to as Monte Carlo simulation; a computer-based method of analysis that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation or model (USEPA 1997).

MT3DMS: Three-dimensional mass transport, multispecies model developed on behalf of the U.S. Army Engineer Research and Development Center. MT3DMS-5.3 (Zheng and Wang 1999) is the specific version of MT3DMS code used for the Hadnot Point–Holcomb Boulevard study area analyses; references to MT3DMS in text, figures, tables, appendixes, and supplemental information refer to MT3DMS-5.3. It can be used linked to a **MODFLOW** model. Used worldwide in contaminant transport simulations in subsurface systems.

NAC: National Academy of Sciences.

NAPL: Nonaqueous phase liquids; hazardous organic liquids such as dry-cleaning fluids, fuel oil, and gasoline that do not readily dissolve in water. Dense NAPLs (DNAPLs), such as the chlorinated hydrocarbons (e.g., PCE, TCE) used in dry cleaning and industrial degreasing, are heavier than water and sink through the water column. Hydrocarbon fuels and aromatic solvents are described as light NAPLs (LNAPLs), which are less dense than water and float. These include lubricants and gasoline, pollutants often associated with leaking gasoline or oil storage tanks (e.g., benzene).

NRC: National Research Council.

PCE: Tetrachloroethylene, 1,1,2,2-tetrachloroethylene, or perchloroethylene; also known as PERC® or PERK®. PCE is a manufactured chemical used for dry cleaning and metal degreasing. In 2012, following its Guidelines for Carcinogen Risk Assessment (USEPA 2005), the USEPA characterized PCE as likely to be carcinogenic in humans by all routes of exposure (USEPA 2012).

PEST: Model independent, objective parameter estimation and uncertainty analysis code originally developed by Watermark Numerical Computing (Doherty 2003, 2010); the current version is PEST-12, available at *http://www.pesthomepage.org/Downloads.php.*

PSOpS: Pumping Schedule Optimization System application developed by MESL, Ga. Tech. The study included the development of a simulation and optimization procedure identified as PSOpS, which combines simulation models (MODFLOW, MT3DMS, TECHFLOWMP) and optimization techniques to optimize the pumping schedules to identify maximum or minimum contaminant concentrations in the WTP consistent with the reported pumping schedules and demanfs on finished water supply at Camp Lejeune site. Based on the optimized pumping schedules, variations of PCE concentration and the maximum contaminant level (MCL, PCE, TCE etc.) arrival times at water-supply wells and the WTP are evaluated (Wang and Aral, 2008, ATSDR, 2007; ATSDR, 2013).

Sensitivity Analysis: A method used to ascertain how a given model output (e.g., concentration) depends upon the input parameters (e.g., time-step size, pumping rate). Sensitivity analysis is an important method for assessing the quality of a given model and a powerful tool for analyzing the robustness and reliability model analyses.

TCE: 1,1,2-Trichloroethene; commonly referred to as 1,1,2-trichloroethylene or trichloroethylene. TCE is a colorless liquid which is used as a solvent for cleaning metal parts. In 2011, following its Guidelines for Carcinogen Risk Assessment (USEPA 2005), the USEPA characterized TCE as carcinogenic in humans by all routes of exposure (USEPA 2011).

TechControl: A linear control theory model and software developed by MESL, Ga Tech. It is used to address the question of application of simpler models to predicting contaminant concentrations

at certain locations of Camp Lejeune site. The development of the software was based on a request that was initiated by the ATSDR Expert Panel of scientists.

TechFlowMP: Three-dimensional multispecies, multiphase mass transport model developed by the Multimedia Environmental Simulations Laboratory at the Georgia Institute of Technology, Atlanta, Georgia.

TechMarkovChain: A model and software developed by MESL, Ga. Tech. It is based on a scientific mathematical methodology called Markov stochastic sequential processes (Ross, 1997). It is used to estimate intermittent connections (1972–1985) of the Hadnot Point and Holcomb Boulevard water-distribution systems based on the analysis of available field data collected at the Camp Lejeune site. The development of the software was based on a discussion that was initiated by the ATSDR Expert Panel of scientists (see section 5.9 for more details).

TechNAPLVol: A subsurface NAPL volume estimation model developed by MESL, Ga. Tech. It is a NAPL volume estimation model based on USEPA HSMM analysis described above. In this case the USEPA HSSM procedures are extended to three-dimensional analysis and used to estimate the volume of spilled BTEX compounds at the Camp Lejeune site. This software is an integral part of TECHFLOWMP (see section 5.10 for more details).

TechWellOp: A subsurface pumping well estimation model and software developed by MESL, Ga. Tech. The methodology uses the daily data in the Training Period to determine the monthly operational behavior of the water supply wells at the Camp Lejeune site that would satisfy the total water volume delivered to the water treatment plants. Once the average monthly working days in the Training Period are estimated for each calendar month, they are utilized in the prediction stage which is based on the same principle of satisfying the total monthly flow delivered to the treatment plant. This methodology is an efficient and effective way of integrating the available data in recent years to the prediction process for the past years. The development of the software was based on a discussion that was initiated by the ATSDR Expert Panel of scientists (see section 5.8 for more details and ATSDR, 2007).

Uncertainty: Lack of knowledge about specific factors, parameters, or models (for example, one is uncertain about the mean value of the concentration of PCE at the source).

Uncertainty analysis: Determination of the uncertainty (e.g., standard deviation) of the output variables' expected value (e.g., mean) due to uncertainty in model parameters, inputs, or initial state by stochastic modeling techniques (Schnoor 1996).

Unsaturated zone: Zone or area below ground in which the interconnected openings within the geologic medium contain a mixture of water under pressure less than atmospheric and air under atmospheric pressure; sometimes referred to as the vadose zone or the zone above the water table. The capillary fringe is part of the unsaturated zone and sometimes occurs as completely saturated.

USEPA: United States Environmental Protection Agency.

USMC: United States Marine Corps.

VC: Vinyl chloride or chloroethene; a colorless gas that burns easily, is not stable at high temperatures, and has a mild, sweet odor. It is a manufactured substance that does not occur naturally. It can be formed when other substances such as TCA, TCE, or PCE undergo biochemical degradation. The USEPA has characterized VC as a known human carcinogen (USEPA 2000). The NTP Report on Carcinogens (NTP 2011) has recognized vinyl chloride as a known human carcinogen based on sufficient evidence of carcinogenicity in humans.

VOC: Volatile organic compound; one of a group of carbon-containing compounds that evaporate readily at room temperature and can readily be inhaled. Examples of VOCs include tetrachloroethylene (PCE), trichloroethylene (TCE), vinyl chloride (VC), and benzene. These contaminants typically are generated from metal degreasing, printed circuit board cleaning, dry cleaning, gasoline, and

wood preserving processes. VOCs are environmental contaminants, and some are classified as known human carcinogens (e.g., TCE, VC, and benzene).

WTP: Water treatment plant.

Exhibit A

Mustafa M. Aral, PhD
Professor Emeritus, Georgia Institute of Technology
Email: mmaral@live.com
Address: 270 17th St. NW Unit 809 Atlanta, Georgia USA 30363
Research Gate: https://www.researchgate.net/profile/M-Aral

EDUCATION:

Ph.D. in Environmental Fluid Mechanics with minor in Numerical Analysis and Applied Mathematics, Sept. 1971, School of Civil Eng., Georgia Institute of Technology, USA.

M.S. in Civil Engineering with major in Environmental and Water Resources Engineering, June 1969, School of Civil Eng., Georgia Institute of Technology, USA.

B.S. in Civil Engineering, June 1967, Department of Civil Engineering, Middle East Technical University, Turkey.

EMPLOYMENT:

2018-present	Emeritus Prof.	School of Civil and Environmental Engineering, Ga. Tech., USA.
2018-2020	Dean	College of Engineering, Architecture and Design, Bartın Univ., Turkey.
2018-2020	Vice President	International Programs and Research, Bartın University, Turkey.
2018-2020	Professor	Department of Civil Engineering, Bartın University, Turkey.
1993-2018	Prof. Director	Multimedia Environmental Simulations Laboratory, Ga. Tech. USA
1983-1993	Assoc. Prof.	School of Civil and Environmental Engineering, Ga. Tech., USA
1979-1983	Visiting Prof.	School of Civil and Env. Engineering Ga. Tech. (On sabbatical), USA
1974-1982	Adjunct Prof.	Marine Sciences Dept., Civil Eng. Dept., Eng. Science Dept., Middle East Tech. Univ., Turkey.
1977-1982	Assoc. Prof.	Mathematics Dept., Middle East Tech. Univ., Turkey.
1974-1979	Asist Chairman	Mathematics Dept., Middle East Tech. Univ., Turkey.
1971-1977	Assistant Prof.	Mathematics Dept., Middle East Tech. Univ., Turkey.

PROFESSIONAL REGISTRATION:

Professional Engineer (PE): GA.USA. 15254

HONORS:

1973, **NATO, Science Fellowship**, September 1973.
1976, **Best Teacher Award**, Middle East Technical Univ., Mathematics Department, May 1976.
1976, **NATO, Science Fellowship**, September 1976.
1980, **Who is Who in Science, Engineering and Education** series since 1980.

1984, **Award of Appreciation**, in acknowledgment of contributions to the organization of the ASCE International Conference held in Atlanta, American Society of Civil Engineers, June 1984.

1986, **Outstanding Faculty Member**, Georgia Institute of Technology, May 1986.

1986, **Sigma Xi Research Society**.

1986, **Best Teacher Award**, Georgia Institute of Technology, June 1986.

1995, **Award of Recognition**, for the Organization of the East-West Advanced Study Institute on Environmental Issues, NATO, Scientific and Environmental Affairs Division, August 1995.

1996, **Engineering Technical Excellence Award**, Public Health Serv., USDHHS 1996 for the technical paper: "Estimating Exposure to VOCs from Municipal Water System Pipelines: Use and Application of a Computational Model, *Archives of Environmental Health*, May 1996 (with co-authors).

1997, **Research Program Development Award**, in Recognition for Developing a Consistent and Comprehensive Research Program in Environmental Health, School of Civil and Environmental Engineering, Georgia Institute of Technology, May 1997.

1997, **Science Publication Award**, ATSDR, US DHHS, for the technical paper: "Use of Computational models to Reconstruct and Predict Trichloroethylene Exposure," *in Toxicology and Industrial Health*, April 1997 (with co-authors).

1997, **Award of Appreciation and Recognition**, in acknowledgment of contributions to the organization of the International Conference on Geology and Environment (GeoEnv'97), September 1997.

1998, **Engineering Literary Excellence Award**, Public Health Serv., USDHHS for the technical paper: "Exposure Assessment Using Analytical and Numerical Models: A Case Study," *in ASCE Practice Periodical of Hazardous, Toxic, and Radioactive waste Management*, April 1998 (with co-authors).

1998, **Honorary Professor of Environmental Sciences**, Huazong University of Science and Technology, Wuhan, Peoples Republic of China.

2000, **Cuming Medal Award 2000**, The Society of American Military Engineers award to Dover Township Water Distribution System Modeling Research Team.

2000, **Best Practice Oriented Paper Award**, ASCE Environmental & Water Resources Institute Planning and Management Council, for the technical paper "Using Water-Distribution System Modeling to Assist Epidemiologic Investigations," *ASCE Journal of Water Res. Plan. and Man., Vol. 126, No. 4, 2000*.

2003, **Excellence in Environmental Engineering Award in Research Category**, American Academy of Environmental Engineers (AAEE). *Research Topic: "Enhancing Environmental Engineering Science to Benefit Public Health: Integrating Hydraulic Network Modeling, Spatial Analysis, and Genetic Algorithms with Epidemiologic Studies,"* Awarded to **M. M. Aral** for the Leadership of the ATSDR – MESL/GT Research Group.

2005, **Engineering Technical Excellence Award**, Public Health Service, USDHHS for the technical paper: "ACTS - A Multimedia Environmental Fate and Transport Analysis System." *in ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, published in 2004 (with co-authors).

2006, **Excellence in Applied Environmental Health Research**, National Center for Environmental Health (NCEH), Centers for Disease Control and Prevention (CDC), for our work in assisting NCEH/CDC in an epidemiological study of childhood leukemia and central nervous system cancers that occurred in the period 1979 through 1996 in Dover Township, New Jersey and Camp Lejeune (Air Force Army Base) at North Carolina.

2010, **Best Research Paper Award**, ASCE Water Resources Management Council, for the technical paper "Saltwater Intrusion Hydrodynamics in a Tidal Beach," *ASCE Journal of Hydrologic Engineering, Vol.* 13, No. 9: pp. 863-872*126* (with co-authors).

2010, **US Public Health Service Engineering Best Research Paper Award**, CDC, DHHS. "Reconstructing Historical Exposures to Volatile Organic Compound-Contaminated Drinking Water at a U.S. Military Ba

2010, **ASCE Outstanding Service Award**, ASCE EWRI, for Groundwater Hydrology Committee Chair activities under EWRI Groundwater Council.

2010, **Life Member**, ASCE EWRI.

2010. **Fellow ASCE**, ASCE, EWRI.

2011, **James R. Croes Medal**, ASCE EWRI, for the paper: "Optimal Design of Sensor Placement in Water Distribution Systems," ASCE Journal of Water Resources Planning and Management, Vol. 136, No. 1, pp.5-18, 2010.

2011, **Founders Award**, American Institute of Hydrology for dedicated contribution to the profession.

2011, **USPHS Engineering Literary Award**, for an outstanding Engineering Management Paper entitled "Stochastic Analysis of Pesticide Transport in the Shallow Groundwater of Oatland Island, Georgia." Published in the International Journal on Water Quality, Exp. and Health, Vol. 2, No. 1, pp. 47-64.

2013, **Sustained Interdisciplinary Research Award**, in Recognition for Developing a Consistent, Comprehensive and Integrated Research Program within CEE, Georgia Institute of Technology.

2015, **Panel Leadership and Organization Recognition, 68. Turkish Geology Conference.** "Groundwater Supplies and Drought" Panel, 68. Turkish Geology Conference, Organized by Turkish Maden Tetkik Arama Kurumu and Turkish Geology Engineers, 6 April 2015, Ankara, Turkey.

2015, **Invited Speaker in the opening session of the 68. Turkish Geology Conference.** "Evolution of Environmental and Geological Engineering Systems Analysis in Modern Day," 68. Turkish Geology Conference, Organized by Turkish Maden Tetkik Arama Kurumu and Turkish Geology Engineers, 6 April 2015, Ankara, Turkey.

2015, **Grand Prize in Environmental Engineering Award in Research Category by Am. Acad. of Env. Engineers (AAEE)**. *Research Topic: "Using Environmental Engineering Tools, Scientific Analyses, and Epidemiological Studies to Quantify Human Exposure to Contaminated Drinking Water and to Benefit Public Health,"* Awarded to **M. M. Aral** for the Leadership of the ATSDR – MESL/GT Research Group.

2018, **Best Teacher Award**, Center for Teaching and Learning, Ga. Institute of Tech., January 09, 2018.

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88. Morgan, W. and Aral, MM. (2015). "Modeling Hydraulic Fracturing in Pre-Fractured Rock Using the Discontinuous Deformation Analysis." 49th U.S. Rock Mechanics/Geomechanics Symposium, June 28 – July 1, 2015, San Francisco, USA.
89. Aral, M. M. (2015) "Concepts and development of modeling principles in environmental analysis," 68th National Geological Eng. Conf., 6 – 10 April 2015, MTA Kultur Sitesi, Ankara, Turkey (Keynote speech.)
90. Aral, M. M. (2015) "Integrated modeling of coupled watershed processes," 68th National Geological Engineers Conference, 6 – 10 April 2015, MTA Kultur Sitesi, Ankara, Turkey (invited).
91. Kentel, E., Gunduz, O. and Aral, M. M. (2015). "Critical Infrastructure Management: Risk, Resilience, Extent Concepts," The International Emergency Management Society 2015 Annual Conference, 30th September - 2nd October 2015, Rome, Italy.
92. Aral, M. M. (2016) "Transition from simple, complicated to complex systems," YTSAM, Yeni Türkiye Bilim ve Araştırma Merkezi International Conference, Ankara, Turkey, September 14, 2016.
93. Kentel, E., Gunduz, O., Bayar, M. and Aral, M. M. (2017). "Critical Infrastructure Management: Risk, Resilience, Extent Concepts," 12th Conference on Sustainable Development of Energy, Water and Environment Systems. Dubrovnic, Croatia.
94. Kizilaslan, M. A., Demirel, E., Aral, M. M. (2020). "Pathogen Inactivation and By-Product Formation in a Full-Scale Contact Tank," 2020 11th international Conference on Environmental Science and Development (ICESD 2020), Barcelona, Spain, February 10-12, 2020.
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96. Demirel, E. and Aral, M.M. (2020). "Batmış Kapağın Mansabındaki Vortekslerin İncelenmesi ve Sönümlenmesi," HİDRO 2020: Hidrojeoloji and Water Resources Sempozium, June 18-20, Bartın, Turkey.
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RESEARCH PROJECTS:

1. Principal investigator of the project titled, *Finite Element Analysis in Continuum Mechanics: FEMAC Computer Program*, (Funded by Middle East Technical Univ. Research funds - $18,000), 1972-73.
2. Principal investigator of the project titled, *An Analysis of Convective Diffusion Equation and Its Finite Element Solution*, (Funded by Turkish Sci. and Tech. Research Inst.- $ 12,000), 1976-77.
3. Principal investigator of the project titled, *Analytical and Numerical Study of Jet Deflection from Curved Boundaries*, (Funded by Middle East Technical Univ. Research funds - $ 19,000), 1976-77.
4. Principal investigator of the project titled, *Tsunami Study: Akkuyu Nuclear Power Plant*, (Funded by Turkish Electric Authority, Nuclear Energy Division - $ 75,000), 1977-79.
5. Principal investigator of the project titled, *Analysis of the Development of Shallow Ground Water Supplies by Pumping from Ponds*, (Funded by the Department of the Interior, Office of Water Resources Research and Technology - $ 48,000), 1979-80.
6. Principal investigator of the project titled, *Mathematical Modeling of Aquatic Dispersion of Effluents in Natural Rivers*, (Funded by the Health and Safety Division of the Oak Ridge National Laboratories, Oak Ridge Tennessee - $ 52,000), 1979-80.
7. Principal investigator of the project titled, *Aquifer Parameter Prediction by Numerical Modeling*, (Funded by the Department of the Interior, Office of Water Research and Tech. - $ 56,000), 1981-82.
8. Principal investigator of the proposal titled, *An Analysis of Rimming Condensate Flow*, (Funded by Beloit corporation, Beloit, Wisconsin - $ 68,000), 1981-83.
9. Principal investigator of the project titled, *Parameter Identification in Layered Aquifer Systems*, (Funded by the Department of the Interior, Office of Water Policy - $ 44,000), 1983-84.
10. Principal investigator of the project titled, *A Simplified Approach to Regional Multilayered Aquifer Analysis*, (Funded by the Department of the Interior, U.S. Geological Survey - $25,000), 1986-88.
11. Principal investigator of the project titled, *Modeling Transient Ground Water Flow in Multilayered Aquifer Systems*, (Funded by the Department of the Interior, USGS - $ 29,000), 1988-89.
12. Principal investigator of the project titled, *Multilayered Aquifer Modeling in a Landfill Site*, (Funded by the Waste Management, Inc., Geosyntec, Inc. - $ 42.000), 1990-91.
13. Principal investigator of the Research Program titled, *Exposure-Dose Reconstruction at Graton Massachusetts*, (Funded by: U.S. DHHS - $ 44,000), 1992.
14. Director, NATO Advanced Study Institute, *Recent Advances in Groundwater Pollution Control and Remediation*, (NATO - Directorate of Environmental Programs $ 111,000), 1994.
15. National Science Foundation, *Water, Sustaining A Critical Resource*, Joint Proposal with Dr. A. Zoporozec, University of Wisconsin, $ 30,000 1995.
16. Principal investigator of the Research Program titled, *Research Program on Exposure-Dose Reconstruction*, (Funded by: ATSDR/CDC- $ 2,500,000), 2000-2005.

17. Principal investigator of the Research Program titled, *Analysis of Coastal Georgia Ecosystem Stressors Using GIS Integrated Remotely Sensed Imagery and Modeling: A Pilot Study for the Lower Altamaha River Basin*, (Funded by: Sea Grant Program - $ 288,000), 2000-2003.
18. Principal investigator of the Research Program titled, *GIS Integrated Environmental Systems Modeling*, (Funded by: CDC - GT Bioengineering Center $ 30,000), 2000-2001.
19. Principal investigator of the Research Program titled, *Research Program on Exposure-Dose Reconstruction*, (Funded by: ATSDR/CDC- $ 2,500,000), 2005-2010.
20. Principal investigator of the research Program titled "*Potential n-Nitrosodimethylamine (NDMA) Formation at Water and Wastewater Treatment Plants and Exposure Pathway Analysis*," (Funded by: SNF FLOERGER, France, program period: 2004-2006. $ 550,432).
21. Principal investigator (co-investigator Prof. Ching-Hua Huang) of the research Program titled "*Potential n-Nitrosodimethylamine (NDMA) Formation at Water and Waste water Treatment Plants and Exposure Pathway Analysis*," (Funded by: SNF FLOERGER, France, program period: 2007-2009. $ 308, 821).
22. Principal investigator of the Research Program titled, *Research Program on Exposure-Dose Reconstruction*, (Funded by: ATSDR/CDC- $ 2,500,000), 2010-2015.
23. Principal investigator of the Research Program titled, Chinese Drywall Emission and Exposure through Inhalation, (Funded by: ATSDR/CDC- $ 500,000), 2012-2014.
24. Co-Principal investigator of the research program, "Combining Statistical Process Control and Optimization via Simulation for Robust Sensor Network Design in the Presence of Sensor Measurement Error," Funded by National Science Foundation, $ 350,000), 2016 – 2018.
25. Co-Principal investigator of the research program, "EU-Horizon 2020 Energy Efficiency Program-Eco-QUBE," Funded by EU Horizon 2020 program, €4.5 million, 2020-2023.

PROFFESIONAL ACTIVITIES:

National (USA):

1. **Member**, American Society of Civil Engineers, (ASCE). (1969 – present)
2. **Member**, Sigma Xi Research Society, (U.S.A.). (1971- present)
3. **Member**, American Geophysical Union, (U.S.A.) (1978-2010).
4. **Member**, National Water Well Association, (U.S.A.) (1978 – 2010).
5. **Member**, American Water Resources Association, (U.S.A.) (1978 – 1989).
6. **Member, Task Committee on Ground Water Strategy**, ASCE Hydraulics Division, 1983-85.
7. Listed in the directory of experts in Ground Water and Ground Water Contamination, Prepared by Edison Electric Institute and by Dames & Moore Consultants, Co.,1984
8. Listed in the directory in Who is Who in Science and Engineering.
9. **Member** of the organizing committee of the conference, *The Water Resources of Georgia and Adjacent Areas*, Sponsored by Ga. TECH and Georgia Geologic Survey, October 1983.
10. **Session Chairman**, ASCE. Spring Convention, Atlanta, 1984.
11. **Session Co-Chairman**, Engineering Mechanics Society, Blacksburg, 1984.
12. **Member**, American Water Resources Association, Publications Committee and Conference Organization Committee, 1987 – 1989.
13. **Member** of the Organizing Committee of the conference and Session Chairman, *Key Problems in Hydrology, Hazardous Waste*, Sponsored by American Institute of Hydrology, 1987.
14. **Member**, American Institute of Hydrology (1978-present).
15. **Session Chairman**, Int. Conference on Computational Eng. Sci., Atlanta, April 10-14, 1988.

16. **Chairman, Multidisciplinary Geohydrology Program,** Georgia Institute of Technology, College of Engineering, 1988-present (founding member).
17. **Invited Speaker - Board of Scientific Counselors**, Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services, 1990 - 1992.
18. **Member, Sci. Review Board**, Waste Policy Institute, U.S. Department of Energy, 1991 – present
19. **Director, Multimedia Environmental Simulations Lab.**, CEE, Ga. Tech., 1994-present.
20. **Member, Scientific Review Panel on program Analytical and Monitoring Methods in Subsurface Remediation**, USEPA, 1995 – 2001.
21. **Member, Scientific Review Panel on program STAR Program**, USEPA, 1995-present.
22. **Member, Scientific Review Panel on Eastern Research Group**, 1997-present.
23. **Member, International Society of Exposure Analysis,** 2002 – present.
24. **Member, International Association of Hydrogeology,** 2002 – present.
25. **Organizing Committee Member,** Achieving Sustainable Water Resources in Areas Experiencing Rapid Population Growth, 2003 AIH International Conf., Atlanta, GA.
26. **Vice President for International Affairs, American Institute of Hydrology,** 2004 – 2006.
27. **Elected to the Board of Dir. of the Buried Asset Man. Inst.– International**, (2004 – 2007).
28. **Chair** of the ASCE Groundwater Hydrology Technical Committee (2007 – 2009).
29. **Member** of the ASCE Groundwater Hydrology Technical Committee (2007 – present).
30. **Vice-Chair** of the ASCE, GWH Tech. Report Com. on Exp.-Dose Reconstruction (2007 – 2009).
31. **Member** of the ASCE, EWRI Ground Water Council (2007 – 2009).
32. **Vice President for Int. Affairs, American Institute of Hydrology, (**2009 – 2011).
33. **Member** of the ASCE, EWRI World Water Council, (2010 – present).
34. **Member of the ASCE EWRI International Council (2010 – Present).**
35. **Control Group Member, ASCE EWRI World Water Council (2012 – Present).**
36. **Member** of the ASCE, EWRI Env. Health and Water Quality Committee, (2008–present).
37. **FELLOW ASCE/EWRI**, elected by the ASCE Board of Directors to the rank of ASCE Fellow, 2010.
38. **Co-Chair of the organizing committee,** ASCE EWRI IPWE 2013 Conference Izmir, Turkey.
39. Short Course on **"Environmental Modeling and Health Risk Analysis,"** ATSDR/CDC Atlanta, GA (2010, 2011, 2012) and Izmir, Turkey (2012).
40. Invited Speaker ORLOB INTERNATIONAL SYMPOSIUM ON THEORETICAL HYDROLOGY. Presentation Title: "Climate Change and Spatial Variability of Sea Level Rise," University of California (Davis), August 4, 2013.
41. **PRESIDENT ELECT, 2013-2015 and PRESIDENT 2015 - 2017. American Institute of Hydrology (AIH).** Elected by the AIH membership.

International:

1. **Member**, Association for the Advancement of Mathematical Sciences. (1971 – 1978)
2. **Member**, Marine Sciences Research Institute, (Turkey, founding member). (1971 – 1978)
3. **Member**, Computer Sciences Research Institute, (Turkey, founding member). (1971 – 1978)
4. **Member**, International Engineering Analysts, Southampton, England.
5. **Member**, International Association for Computational Mechanics (1987 – 1990).
6. **Director, NATO Advanced Study Institute**, "Recent Advances in Ground Water Pollution Control and Remediation." June 1995.
7. **Session Chairman and Member** of the Organizing Committee of the conference, *International Conference on Geology and Environment*, Sponsored by Academy of Sciences of Turkey and other International Organizations, 1997.
8. **European Community FP6 – FP7 – FP8 proposal review panel member.** (2005 – present)

9. **Fulbright Senior Scientist.** (2005 – 2011).
10. **Short Course on ACTS/RISK** (Dec., 2011) Dokuz Eylul University, Izmir Turkey.
11. **Organization Committee Member,** ASCE/EWRI IPWE International Conference on Perspectives on Water Resources and Environment, Izmir, Turkey, 2013.
12. **Organizing Committee member, HydroEnv. Ist-2017.** International Association for Hydro-Environment Engineering and Research (IAHR).
13. **European Community Horizon 2020 panel member.** (2013 – Present).
14. **Austrian Science Fund review committee member.** (2015 – Present).

EDITORIAL AND REVIEWER WORK

Reviewer:

Journal of Pure and Applied Sciences, 1976 – 1985.
Environmental Protection Agency (review of proposals), 1980 – present.
U.S. Dept. of Int., Geological Survey (review of reports and proposals), 1980 – present.
TUBITAK Research Council, Turkey (review of reports and proposals), 1980 – present.
ASCE Committee on Computational Hydraulics, 1981 – 1995.
ASCE Journal of Engineering Mechanics Division, 1982 – 1995.
Journal of American Water Works Association, 1985 – 1995.
Water Resources Bulletin, American Water Resources Association, 1985 – 1995.
Journal of Hydrology, 1986 – present.
Journal of Computational Mechanics, 1986 – 1995.
Water Resources Research, 1985 – present.
ASCE, Water Resources Planning and Management Journal, 1998 – present.
Saudi Geologic Survey *for Scientific Research*, 2000 – present.
Turkish Scientific Research Council, 2000 – present.
Netherlands *Organization for Scientific Research*, 1999 – present.
Danish *Organization for Scientific Research*, 2000 – present.
NSF/NIH*, Engineering Centers of Excellence review committee member*. 2003 – 2004.
Advances in Water Resources, 2005 – present.
Water Resources Research, 1990 – present.
Journal of Contaminant Hydrology, 2004 – present.
European Community, *F6, F7, F8, Horizon 2020 committee member*. 2005 – present.
Journal of Transport in Porous Media, 2005 – present.
NSF, SBIR *review committee member*. 2005 – present.
USEPA, SBIR *review committee member*. 2005 – present.
Journal of Environmental Management, 2007 – present.
Journal of Water Quality, Exposure and Health, 2009 – 2016.
Journal of Environmental Monitoring and Assessment, 2007 – present.
Journal of Water Resources Management, 2007 – present.
Journal of Neural Networks, 2007 – present.
Environmental Science and Technology, 2008 – present.
Journal of Risk Assessment, 2008 – present.
Journal on Neural Networks, 2008 – present.
Journal on Water, Air and Soil Pollution, 2009 – present.
Journal of Environmental Modeling and Software, 2009 – present.
Journal of Environmental Engineering, 2010 – present.

***USEPA*, STAR Fellowship** *review committee member*. 2013 – 2014.
Water Journal, 2015 – present.
Processes Journal, 2015 – present.

Associate Editor:
Journal of Environmental Science and Health*, Am. Chem. Society*, 1989 – 99.
ASCE, Journal of Hydrologic Engineering, Associate Editor, 1985 – 1995.
ASCE, Journal of Hydrologic Engineering, International Associate Editor, 1995 – present.
International Journal of Hydroelectric Energy, International Editor, 1998 – present.
ISI Journal of Hydraulic Engineering*, Taylor & Francis,* 2011 – present.
Journal of Engineering Sciences*, (Turkey),* 2011 – present.
Journal of Engineering and Environmental Sciences*, (Turkey)*, 2013 – present.

Special Issue Editor:
Population Dynamics, Climate Change and Technology Nexus on Human Health (2019)
International Journal of Environmental Research and Public Health (Impact Factor: 2.47)
https://www.mdpi.com/journal/ijerph/special_issues/pdcctnhh

Water Quality Modeling (2019)
PROCESSES Journal (Impact Factor: 1.97)
https://www.mdpi.com/journal/processes/special_issues/Water_Model

Computational Methods in Water Resources (2020)
WATER Journal (Impact Factor: 2.53)
https://www.mdpi.com/journal/water/special_issues/computainal_methods

Chemical and Non-Chemical Water Treatment (2020)
WATER Journal. (Impact Factor: 2.53)
https://www.mdpi.com/journal/water/special_issues/ozone_treatment

Editor-in-Chief:
International Journal on Water Quality, Exposure and Health, Springer Publishers. 2008 – 2014.

ENGINEERING CONSULTING:

1. Allied Gulf Nuclear Services, (1978-80).
2. NATO, United Nations Development Program, (1979-present).
3. The Coca Cola Company, Corporate Engineering Department, (1983).
4. Georgia Geologic Survey, Department of Natural Resources, State of Georgia, (1983-85).
5. Dames and Moore (1987), Numerical study of flow through earth embankments, Sarasota reservoir.
6. Atlantic Richfield Co. (ARCO) (1990-92), Performance analysis of a cleanup operation in a vadose zone, numerical modeling of saturated-unsaturated flow pump-and-treat operation, Opa Locka, Florida and Numerical modeling of ground water flow and contaminant transport control in a multilayer aquifer with a slurry wall design at a Super Fund Site.
7. CHEVRON Products Co. USA (1992-2002), Numerical modeling of transport of NAPL

contamination, Cleves, Ohio and CHEVRON Chemical Products Co., USA (1996-1997), Investigation of Agricultural Pesticides pollution, Ortho-CHEM plant, Missouri.

8. Expert Testimony: Atlanta Gas Light -vs.- various Environmental Insurance Underwriters (1993), Numerical modeling of transport of petroleum products in aquifers, Georgia.
9. L&L Landfill Co. (1994), Transport of leachate through L&L landfill, Chicago, Illinois.
10. DOD, Mass. Military Reservation, EDB plume modeling and exp. risk analysis, (1997-1998).
11. GeoSyntec Consultants, Consultant (1994 - 2001) (subsurface resources and contaminant transport modeling support and expert testimony).
12. Globex Engineering & Development, Consultant (1998 - 1999) (subsurface resources and contaminant transport modeling support, risk analysis and expert testimony).
13. DOE, Waste Isolation Pilot Plant Project (WIPP), New Mexico (1998 - 1999) (Technical support for expert testimony).
14. Texas Education Board, State Proposal Reviews, (1999-2000).
15. Eastern Research Group, Subsurface Resources and Environmental Health related analysis and exposure assessment, (1998-2013).
16. Hydraulic Fracturing and shale gas extraction, Washington Law Group, (2010 – 2017).
17. Camp Lejeune Exposure Litigation, Bell Law Group, Atlanta, GA, USA. (2022 – Present).

SPECIALIZATION AREAS:

Research, teaching and engineering experience in the following specific areas:

- Groundwater flow and contaminant transport modeling in aquifers, aquifer remediation.
- Groundwater resources evaluation and management.
- Aerodynamic Analysis.
- Multimedia (air-surface water- groundwater) environmental simulations, risk based env. modeling.
- Exposure analysis, exposure-dose reconstruction.
- Environmental health.
- Renewable Energy.
- Climate Change, Water Resources and Environmental Health.
- Analytical and numerical analysis in aerodynamics, surface water, groundwater and air pollution.
- Evaluation of groundwater and surface water monitoring data, site assessment.
- Site characterization and surface water groundwater interaction.
- Saturated and unsaturated groundwater flow analysis.
- Miscible and immiscible groundwater flow analysis.
- Computational methods in environmental fluid mechanics.
- GIS applications in environmental systems.
- Optimization methods in environmental systems.
- Hydraulics and water resources engineering.
- Hydraulic Fracturing and shale gas extraction.
- Population Dynamics and Climate Effects.

PhD/MS Students:

Graduated 25 PhD students at Georgia Institute of Technology.
Graduated 68 M.S. students at Georgia Institute of Technology.

Exhibit B

MEMORANDUM

To: Morris Maslia, PE
Project Manager
Exposure-Dose Reconstruction Program
ATSDR, CDC

From: Prof. Mustafa M. Aral
Director, Multimedia Environmental Simulations Laboratory
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0355
Phone: 404 · 894 · 2243
Fax: 404 · 894 · 5111
E-mail: maral@ce.gatech.edu
WWW: http://mesl.ce.gatech.edu/

Date: June 27, 2009

Subject: **Response to Comments of the NRC Report on ATSDR Water Modeling Study.**

This memorandum was submitted to EDRP/ATSDR on June 27, 2009, and became an internal document for the Camp Lejeune study at ATSDR/CDC. Contents of this memorandum are now included in Section 7 of this expert report.

EXHIBIT 2

IN THE UNITED STATES DISTRICT COURT
FOR THE EASTERN DISTRICT OF NORTH CAROLINA
SOUTHERN DIVISION
NO. 7:23-CV-897

IN RE:)
)
CAMP LEJEUNE WATER LITIGATION)
)
)
This Document Relates to:)
ALL CASES)
_____)

VIDEOTAPED DEPOSITION OF
ALEXANDROS SPILIOTOPOULOS, PH.D.,
a witness herein, called by the Plaintiffs for examination, taken by and before Ann Medis, RPR, CLR, CSR-WA, and Notary Public in and for the Commonwealth of Pennsylvania, via Zoom Videoconference, at the offices of Department of Justice Civil Litigation 1100 L Street NW, Washington, DC 20005, on Tuesday, March 18, 2025, commencing at 9:22 a.m.

A P P E A R A N C E S

On behalf of Plaintiff
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On behalf of Defendant United States of America
U.S. DEPARTMENT OF JUSTICE
BY: HAROON ANWAR, ESQUIRE
KAILEY SILVERSTEIN, ESQUIRE
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1100 L Street NW
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Also present via Zoom
Jeff Davis
Allison O'Leary
Deanna Havai
Leonard Konikow
Morris Maslia
Remy Hennet

April Carter, videographer

Did I read that correctly?

A. Yes.

Q. So the ATSDR stated that its water modeling results can be used in combination with information from the mother on her water use to estimate the level and duration of her exposure to these contaminants; right?

MR. ANWAR: Object to form.

THE WITNESS: No. It clearly says it was to be used by the epidemiological study to estimate the level and duration of exposures to the mother. But there are caveats with respect to that.

BY MS. BAUGHMAN:

Q. Is that a caveat right there?

A. This is not the only quote in my opinions regarding what that did. This is just one piece. You cannot take it out of context.

Q. Does this not say that the ATSDR's work, the monthly mean concentrations can be used by the epidemiological study to estimate the level and duration of exposures to the mother? It says that; right?

MR. ANWAR: Object to form.

THE WITNESS: Even though that is said

there, Mr. Maslia has also provided responses to the expert panel, for example, with respect to how the results of these analyses will be used or the level of detail that would be required. Then, in fact, he said things like medium, high, medium, low rather than actual values, detailed concentrations.

So there is a caveat here with respect to how that should be interpreted.

MS. BAUGHMAN: I'm going to object as nonresponsive.

BY MS. BAUGHMAN:

Q. Let me ask you this: Have you reviewed the published epidemiology studies regarding Camp Lejeune?

A. I have not.

Q. Do you know whether in any of the published epidemiology studies they document that the epidemiologist used the modeling in order to calculate the level and duration of exposure to contaminants?

MR. ANWAR: Object to form.

BY MS. BAUGHMAN:

Q. Do you know whether it says that in the published studies?

A. No. I have not read those studies.
Q. Do you know if the ATSDR epidemiologists actually used ATSDR modeling of the historical concentration -- strike that.
Do you know if ATSDR epidemiologists had used the mean monthly levels of contaminants predicted by ATSDR's models to calculate the cumulative exposure for any individuals who lived at Camp Lejeune?
MR. ANWAR: Object to form.
THE WITNESS: I do not know that. I'm not familiar with the epidemiological studies at Camp Lejeune.
BY MS. BAUGHMAN:
Q. So if the modeling was sent to support the epidemiology studies and the epidemiologists used the modeling to calculate cumulative exposer to individuals, you don't know that; right?
MR. ANWAR: Object to form, foundation.
THE WITNESS: My work here is only to critique the quality of the modeling work and outcome of that modeling.
BY MS. BAUGHMAN:
Q. So you don't know whether ATSDR's work was used for the purpose of making exposure

assessments in individuals? You don't know either way, do you?

MR. ANWAR: Object to form and foundation.

BY MS. BAUGHMAN:

Q. By the ATSDR epidemiologists. Do you know?

A. This is irrelevant to my opinions on this matter.

MS. BAUGHMAN: I'm going to object as nonresponsive.

BY MS. BAUGHMAN:

Q. Page 23 of your report, you chose to put in your report a statement about this work being to support and epidemiologic study and not for purpose of making exposure assessments in individuals. You included that in your report; right?

A. I included that in my report because it provides context with respect to how this work was done, what it was intended to do, what the timeframe of that was and, therefore, support my work in looking at whether the modeling work that was done provided good results to rely on and support such evaluations.

Q. Can you tell me whether or not the ATSDR epidemiologist used the ATSDR's mean monthly concentrations from the modeling in order to make exposure assessments in individuals? Do you know whether they did that? Yes or no.

MR. ANWAR: Object to form and foundation.

THE WITNESS: I do not know that, but it's not relevant to work that I did and the opinions that I provide.

MS. BAUGHMAN: I'll object as nonresponsive to everything after "I do not know that."

BY MS. BAUGHMAN:

Q. Did you do any research to determine how ATSDR's modeling studies were used by the epidemiologists?

A. That was not my role in this case.

Q. Your report at 25 on a similar subject here, the last sentence on the first paragraph, you've written, "ATSDR further acknowledged this uncertainty by stating," quote, "'ATSDR's exposure assessment cannot be used to determine whether you or your family suffered any health effects as a result of past exposures to contaminated water at

Camp Lejeune.'"

You put that quote in your report; right?

A. Yes.

Q. And you're citing there two documents including ATSDR had Hadnot Point Chapter A; right?

A. Looks about right.

Q. Yes?

A. Yes.

(Spiliotopoulos Exhibit 9 was marked.)

BY MS. BAUGHMAN:

Q. I'm handing you what's marked as Exhibit 9 to your deposition, which is Chapter A, Summary and Findings from Hadnot Point. That's the document that you cited there; correct?

A. Yes.

Q. Let's turn to the page you cited page A182. The very first sentence under the bolded statement is your quote, right, what you quoted? But you left out a word, didn't you? What the ATSDR wrote was "ATSDR's exposure estimates cannot be used alone to determine whether you or your family suffered any health effects as a result of past exposure to TCE contaminated drinking water at U.S. Military Base Camp Lejeune." Right?