

***Historical Reconstruction of  
Single and Multispecies PCE-Contaminated  
Drinking Water at U.S. Marine Corps Base  
Camp Lejeune, NC***

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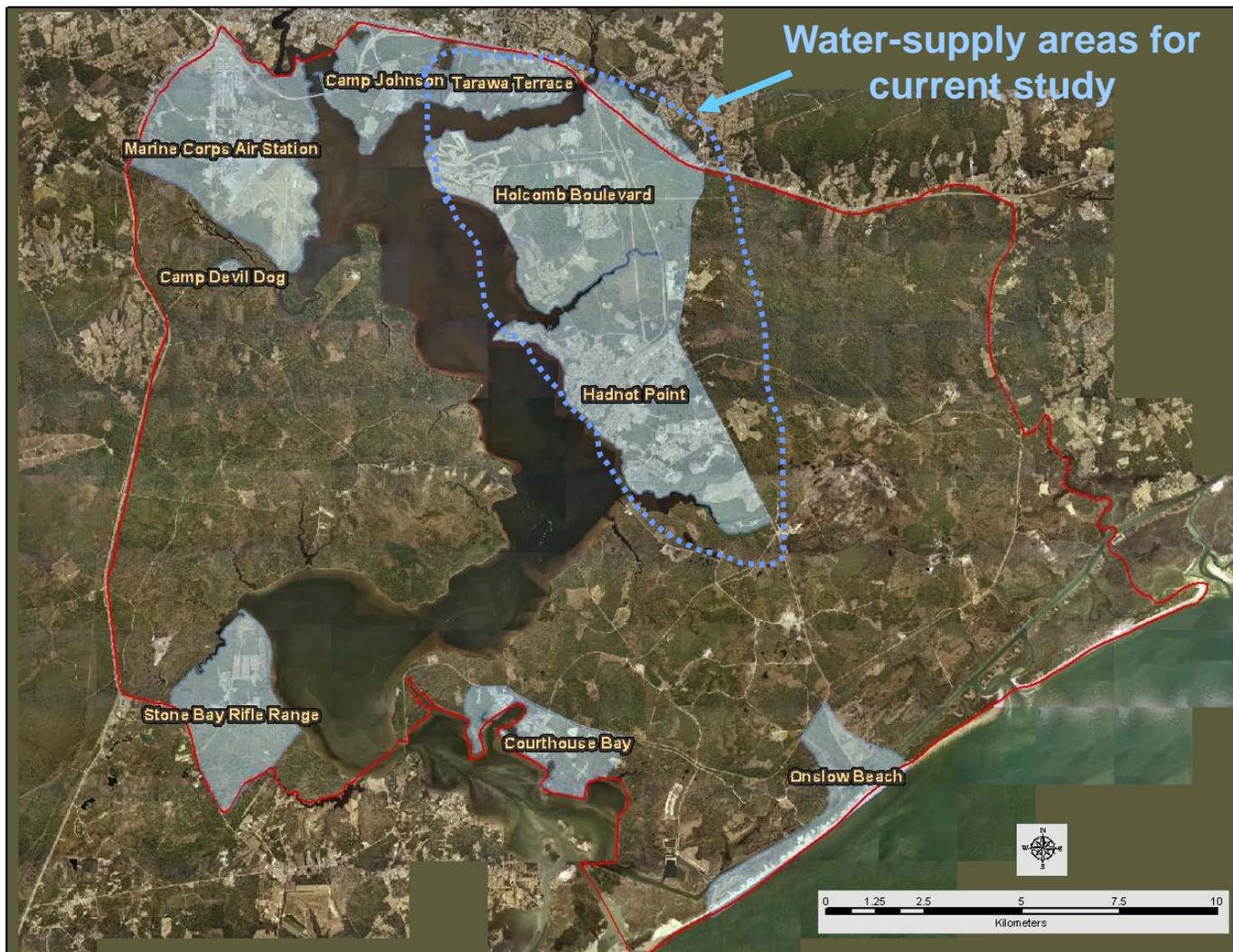
***May 12-16, 2008***

*The findings and conclusions in this presentation are those of the author and do not necessarily represent the views of the Agency for Toxic Substances and Disease Registry or the U.S. Department of Health and Human Services*

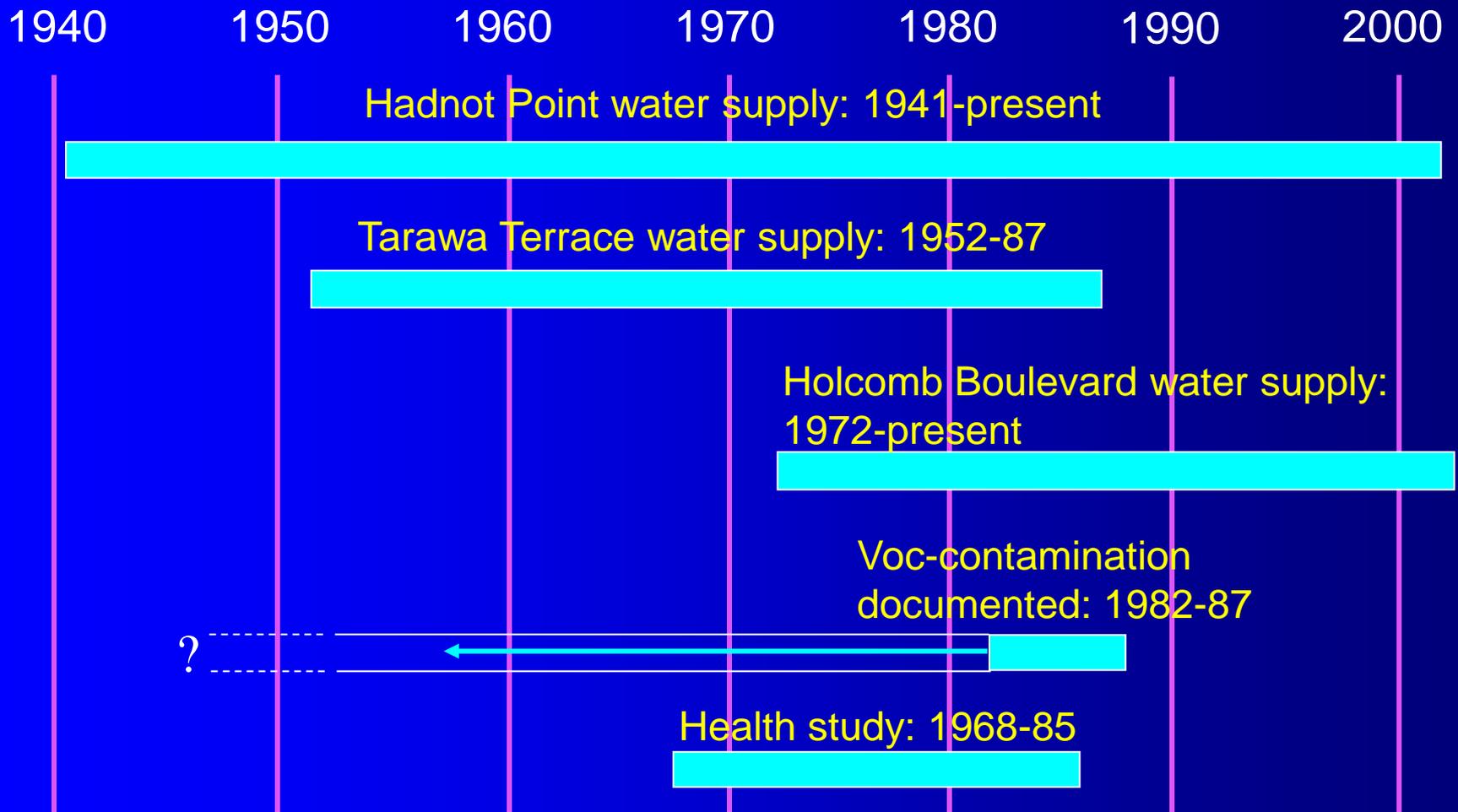
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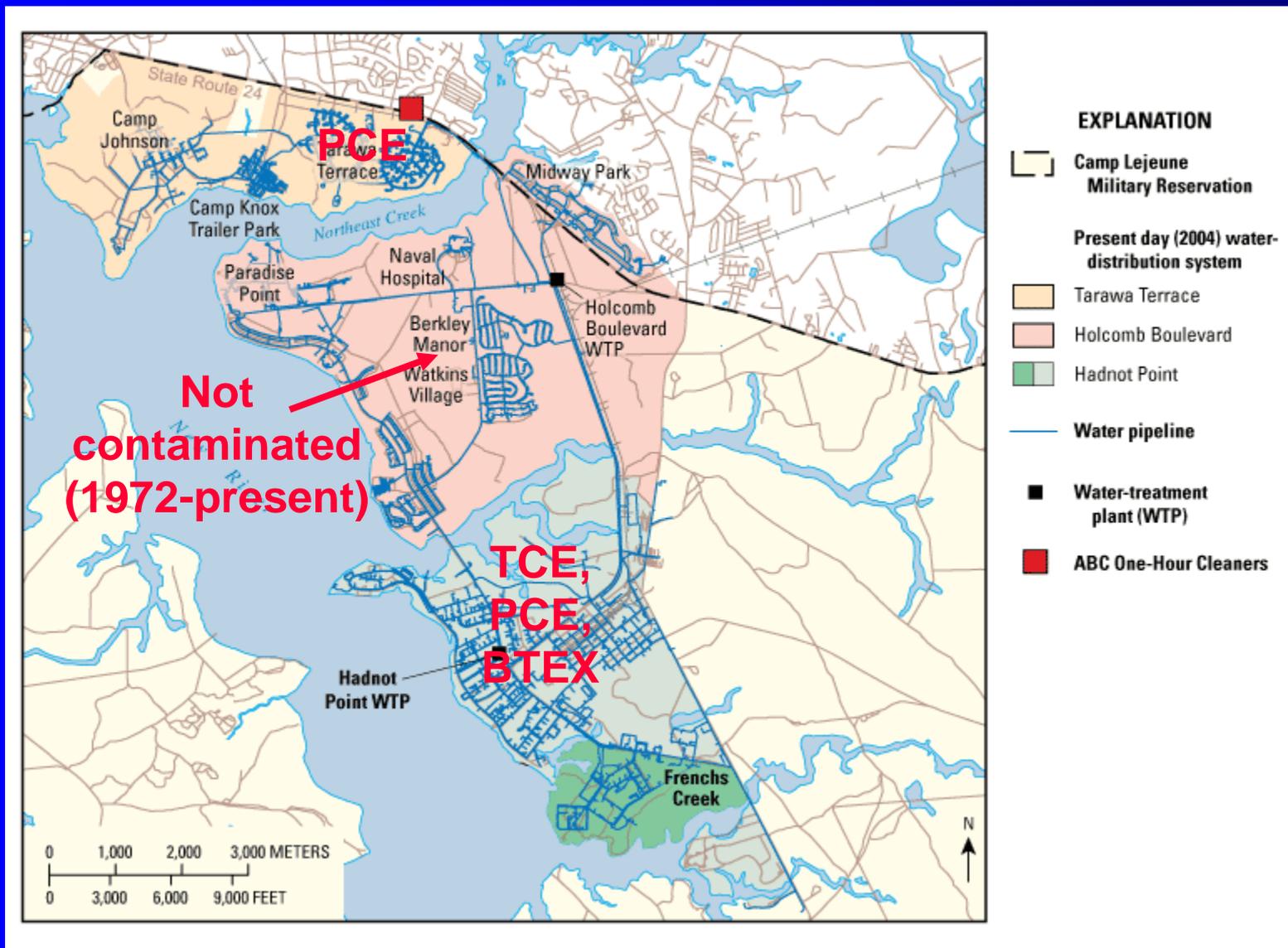
# Water-supply areas



# Base housing drinking-water supplied at Camp Lejeune



# VOC-contaminated water systems



# *Exposure to volatile organic compounds in drinking water and specific birth defects and childhood cancers (case-control study)*

- **Multi-step process**

- Review scientific literature to identify specific birth defects and childhood cancers associated with drinking water contaminated with chlorinated solvents
- Conduct telephone survey to ascertain potential cases
- Obtain medical records to verify diagnoses of reported cases
- Conduct a case-control study
  - ▲ interview parents
  - ▲ **obtain estimates of exposure from the water modeling component**

# *Health effects being studied*

## ● Birth defects

- Spina bifida: failure of the spine to close
- Anencephaly: absence of most of the brain
- Cleft lip: one or two vertical fissures (cleft) in the upper lip
- Cleft palate: opening in the roof of the mouth

## ● Childhood Leukemia

- A cancer affecting white blood cells

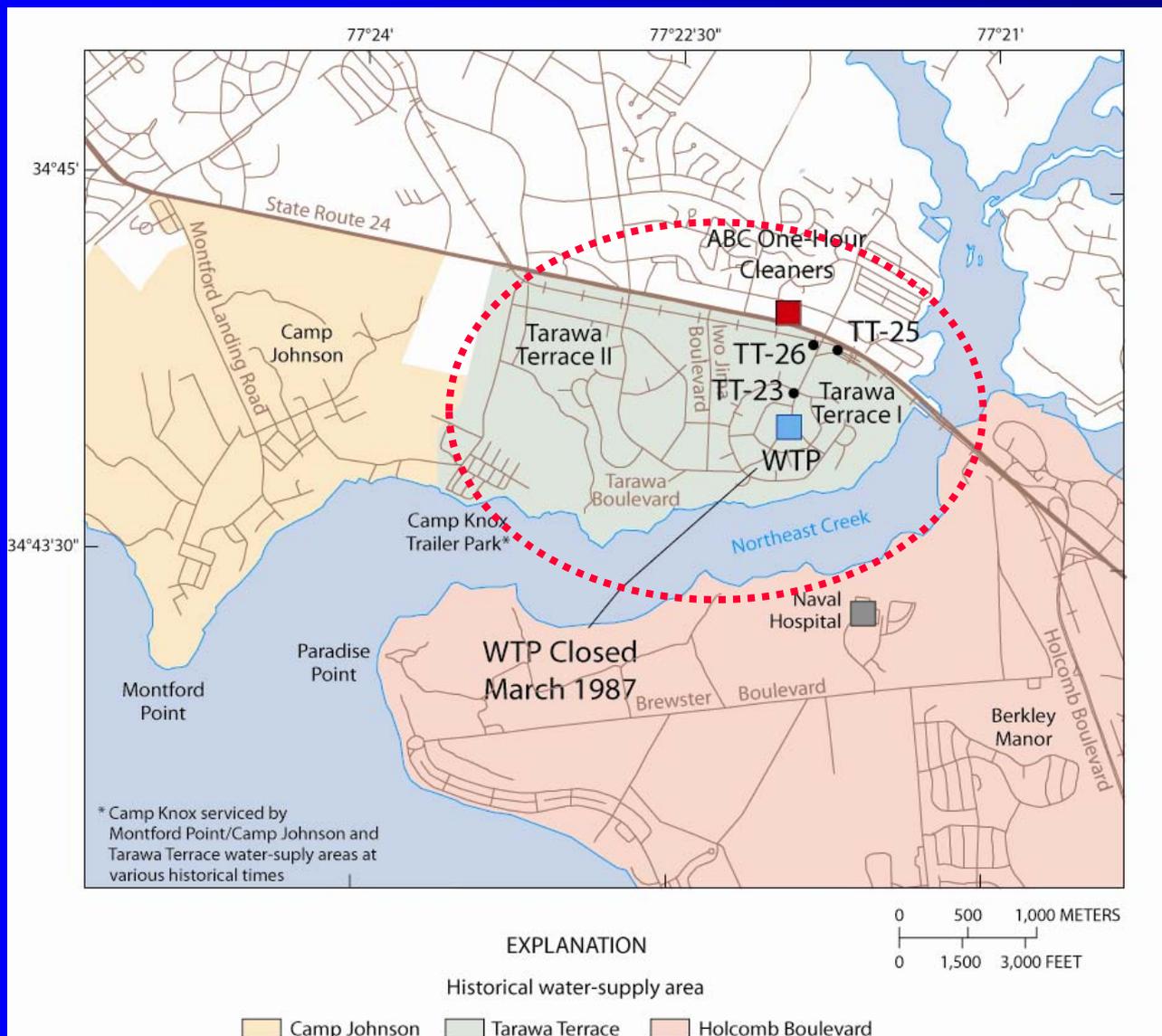
## ● Childhood non-Hodgkin's lymphoma

- a cancerous growth of white blood cells in the lymphatic system

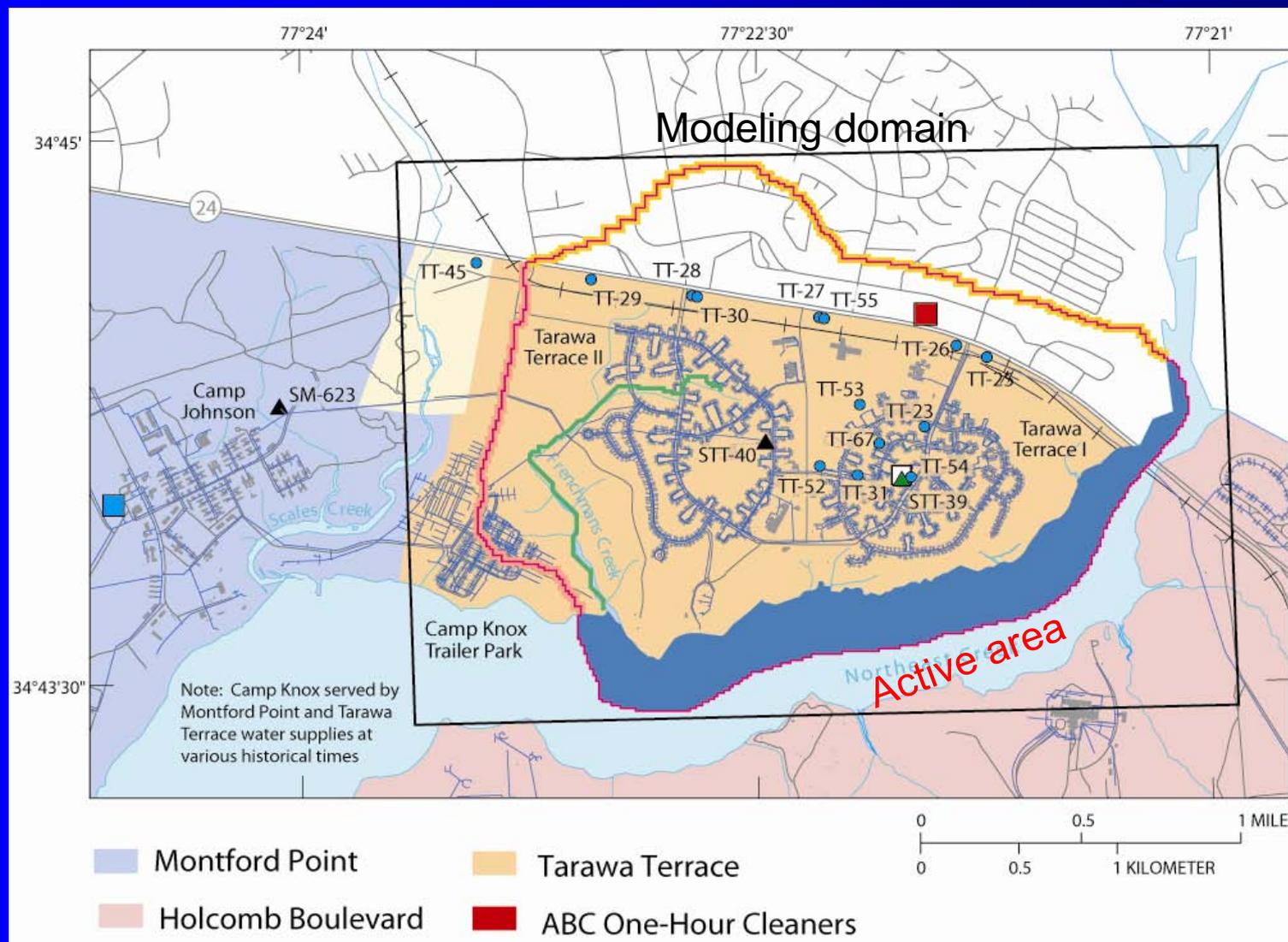
# *Exposure characterization*

- the **monthly** average level of contamination in the drinking water serving the child's residence will be assigned to each month of gestation up to the child's first year of life.

# Tarawa Terrace and vicinity



# Tarawa Terrace water-modeling area



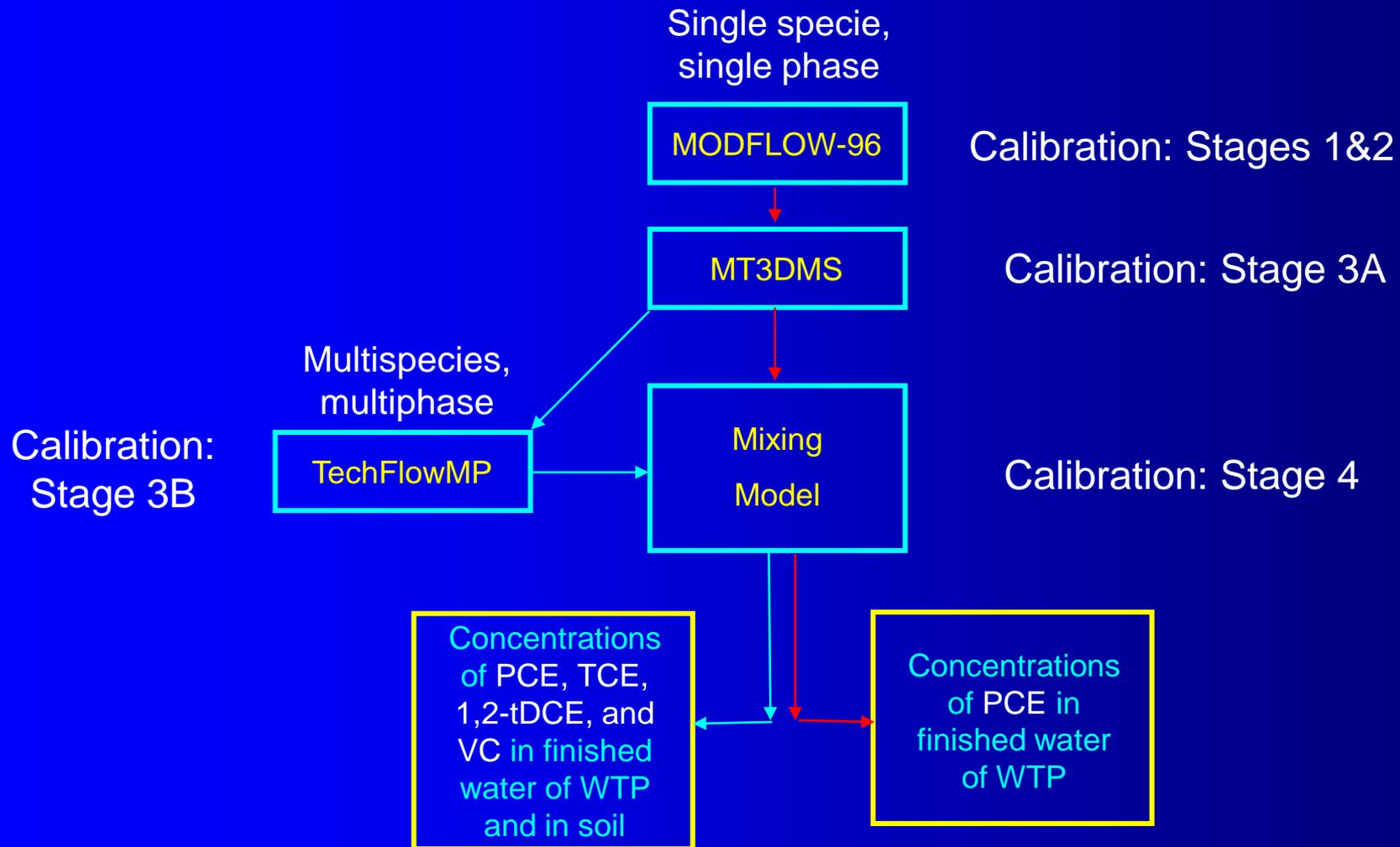
# Geologic, hydrogeologic, and model units

Geologic units			Hydrogeologic units	Thickness		Model layers		
System	Series	Formation	Aquifer and confining unit	Range		MODFLOW-96 and MT3DMS	TechFlowMP	
				Feet	Meters			
Quaternary	Holocene	Undifferentiated						
	Pleistocene							
Tertiary	Pliocene	Absent						
	Miocene	Belgrade Formation	Absent					
			Brewster Boulevard aquifer			Absent		
			Brewster Boulevard confining unit			Absent		
			Tarawa Terrace aquifer	10–60	3–18	1	VSZ1–VSZ5	
			Tarawa Terrace confining unit	5–20	2–6	1		
	Oligocene	River Bend Formation	Upper Castle Hayne aquifer– River Bend unit	10–55	3–17	1	1	
	Eocene	Castle Hayne Formation	Local confining unit	6–16	2–5	2	2	
			Upper Castle Hayne aquifer– Lower unit	10–45	3–14	3	3	
			Middle Castle Hayne confining unit	8–30	2–9	4	4	
			Middle Castle Hayne aquifer	30–90	9–27	5	5	
			Lower Castle Hayne confining unit	10–30	3–9	6	6	
			Lower Castle Hayne aquifer	25–85	8–26	7	7	
Paleocene	Beaufort Formation	Beaufort confining unit	—	—	Base of model			

# *Water-modeling analyses*

- Steady and transient groundwater flow
  - MODFLOW-96 model
- Fate and transport of PCE, **single species**, single phase
  - MT3DMS
- **Multispecies**, multiphase mass transport of PCE
  - TechFlowMP model
  - PCE→TCE→1,2-*t*DCE→VC
  - Dissolved and vapor-phase constituents
- Complete, steady, uniform mixing
  - Mixing model based on principles of continuity and conservation of mass

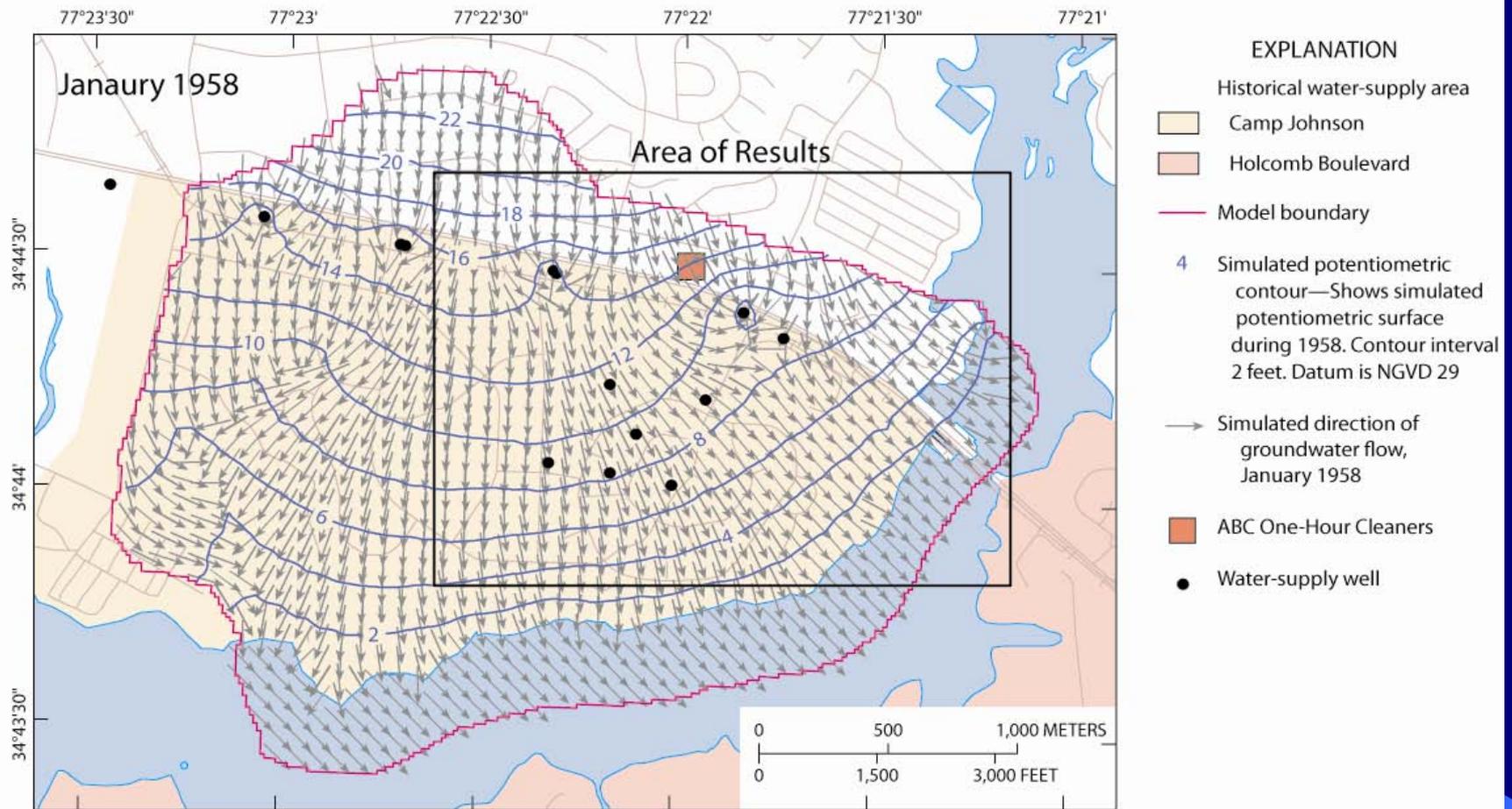
# Tarawa Terrace water modeling



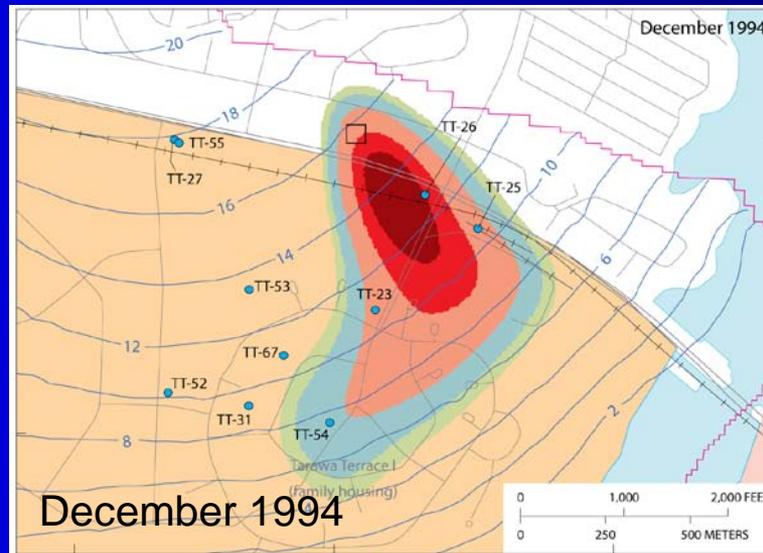
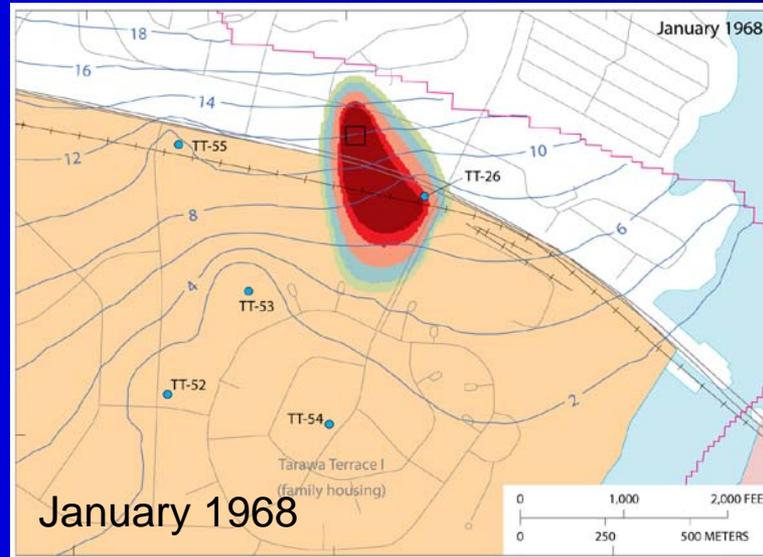
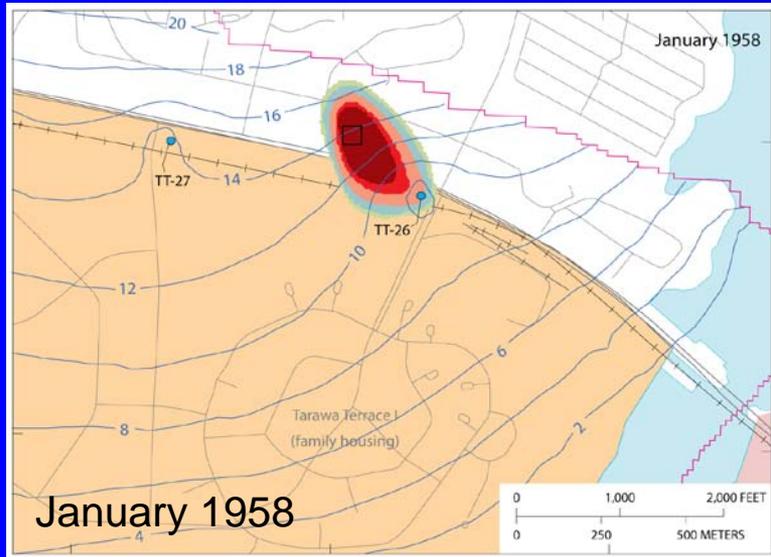
# *Final Results for Tarawa Terrace and Vicinity*

26 MAR 08

# Examples of simulation results: Model layer 1



# Single-specie PCE fate and transport



- EXPLANATION**
- Historical water-supply area
  - Tarawa Terrace
  - Holcomb Boulevard
  - Model boundary
  - Frenchmans Creek
  - 4— Simulated potentiometric contour—Shows simulated potentiometric surface during January 1958. Contour interval 2 feet. Datum is National Geodetic Vertical Datum of 1929
  - Simulated direction of groundwater flow, January 1958
  - ABC One-Hour Cleaners
  - Pumping water-supply well and identification
  - TT-26
  - PCE concentration, in micrograms per liter
  - 1 to 5
  - Greater than 5 to 50
  - Greater than 50 to 500
  - Greater than 500 to 1,500
  - Greater than 1,500

December 1984  
26 MAR 08

# Mixing model for Tarawa Terrace water treatment plant

$$Q_T = \sum_{i=1}^{NWP} Q_i$$

$$C_{WTP} = \frac{\sum_{i=1}^{NWP} C_i Q_i}{Q_T}$$

NWP: number of wells pumping for month

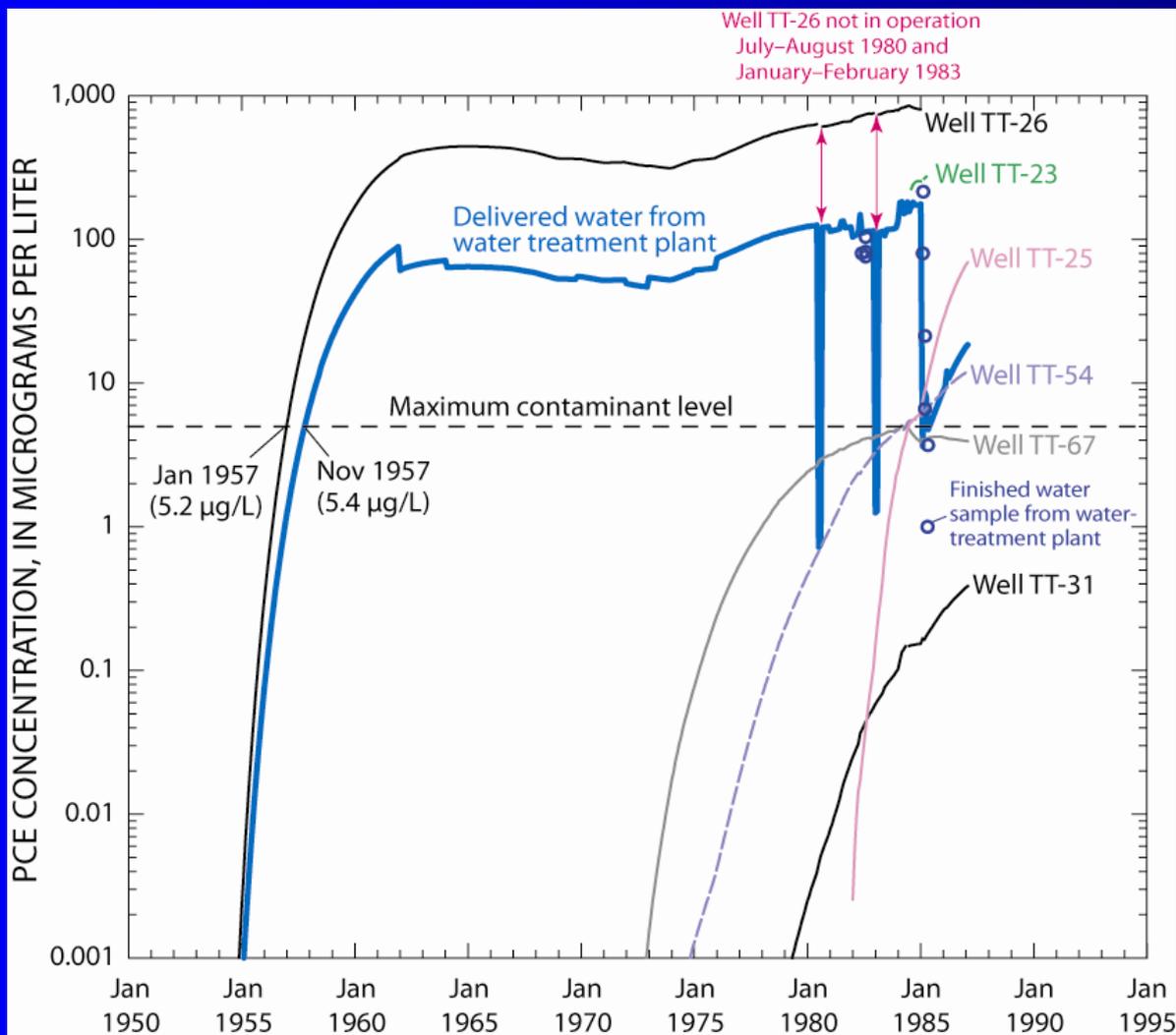
$Q_i$ : simulated pumping rate for well  $i$

$Q_T$ : Total simulated pumping rate for month

$C_i$ : simulated concentration for well  $i$

$C_{WTP}$ : concentration in finished water delivered from Tarawa Terrace WTP

# Concentration of finished water delivered from Tarawa Terrace WTP



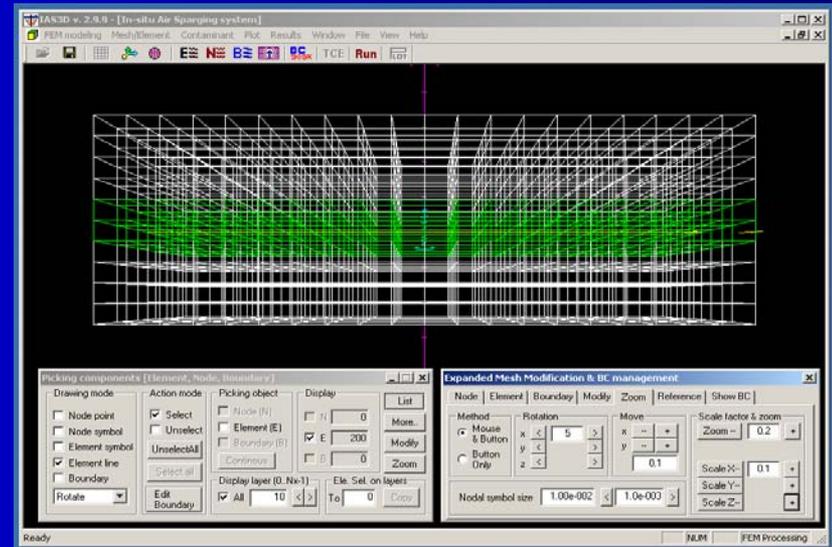
# *Simulation of PCE degradation by-products*

- TechFlowMP model
  - Developed by Multimedia Environmental Simulations Laboratory (MESL) at Ga. Tech
  - Three-dimensional, mass transport
  - Multispecies
    - ▲  $\text{PCE} \rightarrow \text{TCE} \rightarrow 1,2\text{-tDCE} \rightarrow \text{VC}$
  - Multiphase
    - ▲ Dissolved in groundwater
    - ▲ Vapor phase in unsaturated zone

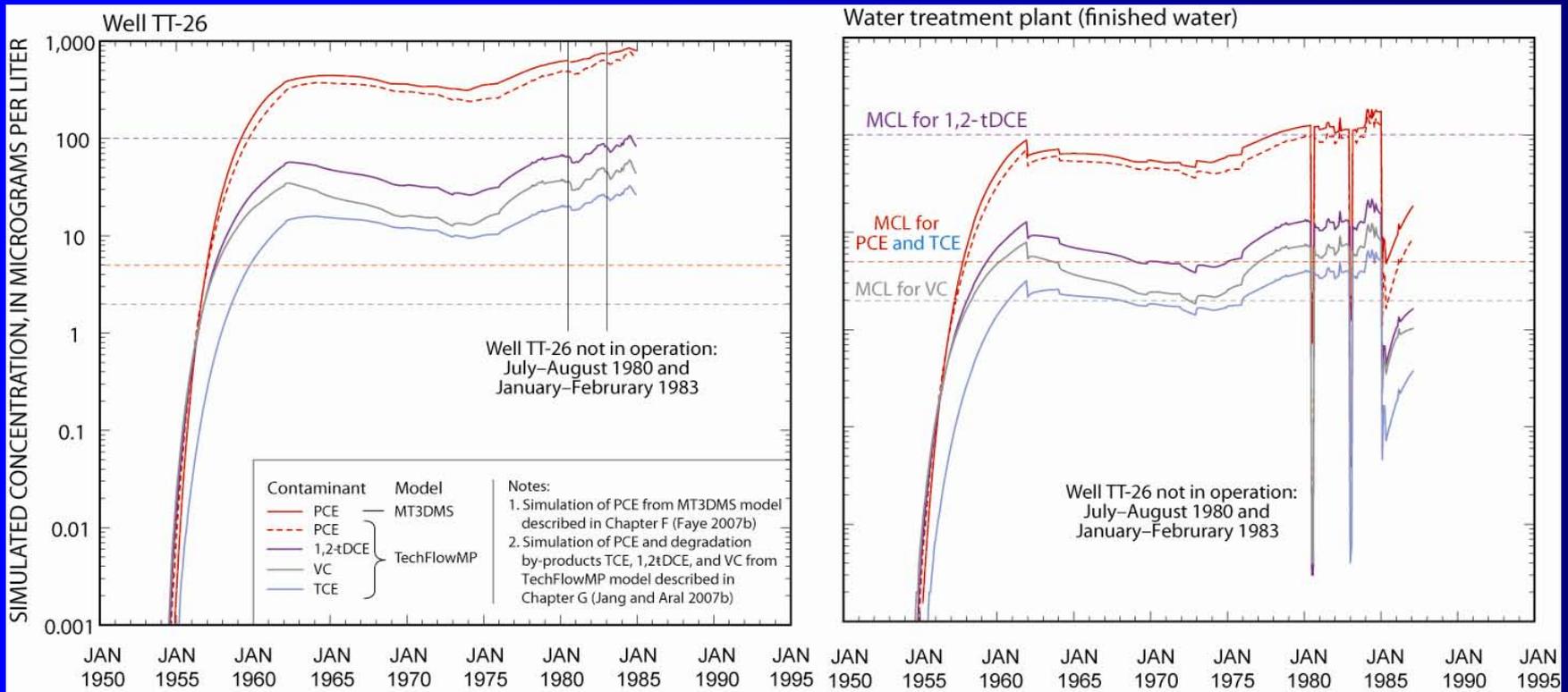
# Numerical method

- Galerkin Finite Element Method
  - Modified Picard method
  - Element of domain
    - ▲ Rectangular prism (8 nodes each element)
- Material balance calculation
  - Accuracy and error checking
- Numerical codes
  - TechFlowMP: 3D multiphase flow and multispecies transport codes.
  - Program language: C++/Microsoft Visual C++
  - Supporting platform: Linux, Unix with OpenMP, and Microsoft Windows

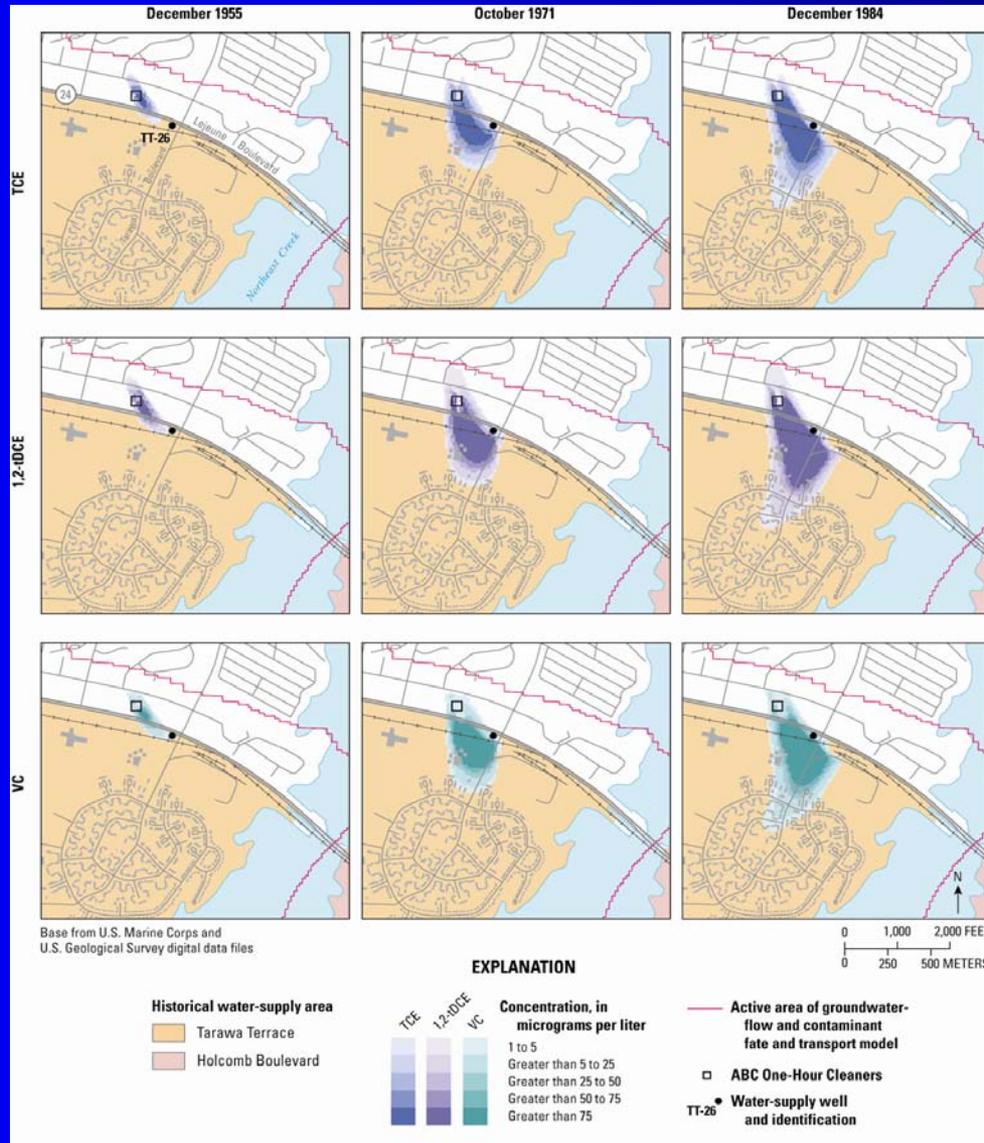
**TechFlowMP**  
(Graphical user interface and 3D mesh)



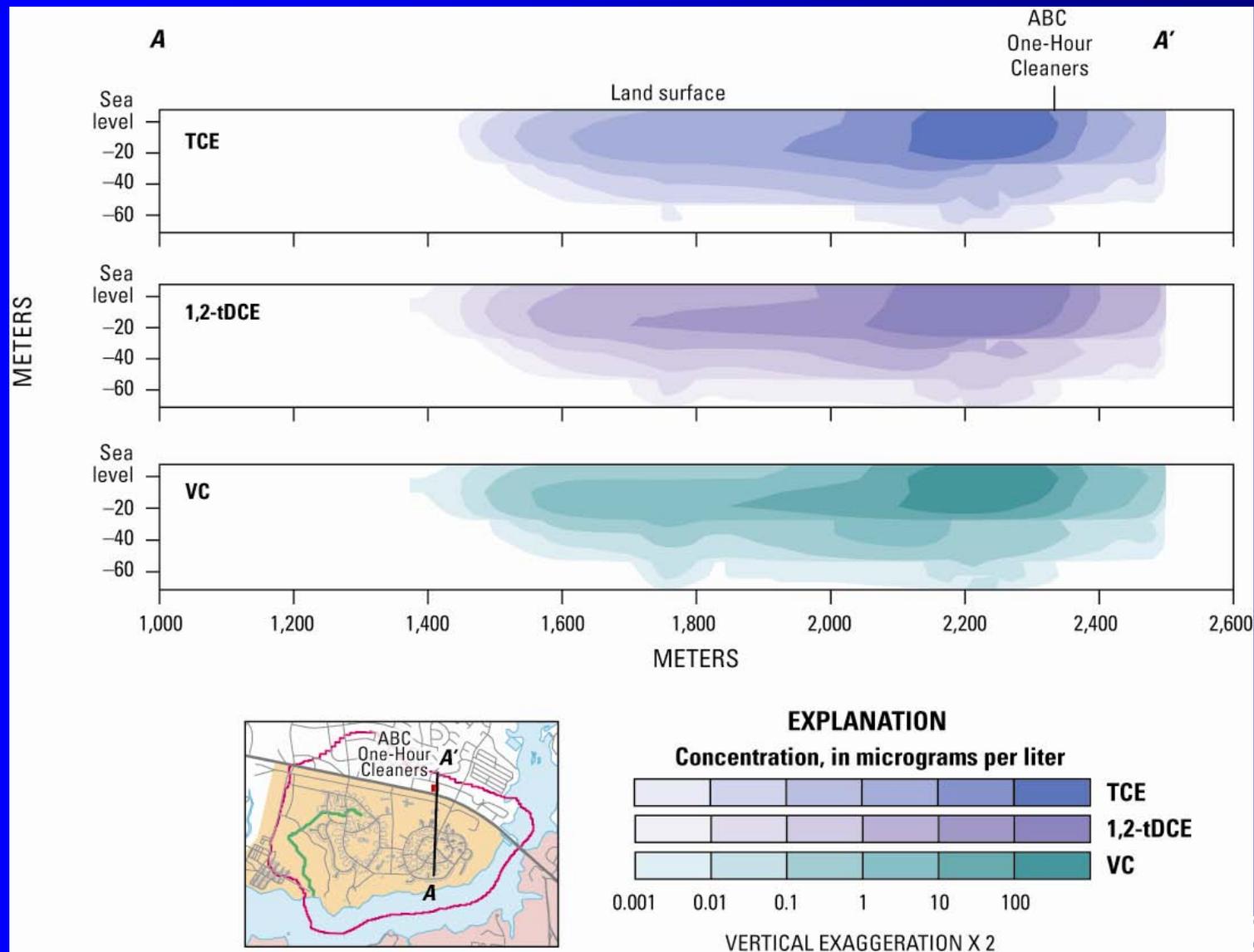
# Simulated PCE and PCE degradation by-products



# PCE degradation by-product spatial and temporal distributions – Layer 1



# PCE degradation by-products vertical distributions



Model Stress Period	Simulation Date	Single species simulation using MT3DMS model <sup>1</sup>	Multispecies simulation using TechFlowMP model <sup>2</sup>			
		PCE, in µg/L <sup>3</sup>	PCE, in µg/L <sup>4</sup>	1,2-tDCE, in µg/L <sup>5</sup>	TCE, in µg/L <sup>6</sup>	VC, in µg/L <sup>7</sup>
385	Jan-83	1.25	0.10	0.04	0.00	0.05
386	Feb-83	1.29	0.12	0.05	0.01	0.07
387	Mar-83	111.76	88.43	11.55	3.65	6.37
388	Apr-83	112.66	86.39	10.85	3.43	5.77
389	May-83	113.97	87.67	11.04	3.52	5.88
390	Jun-83	106.10	82.26	10.54	3.33	5.70
391	Jul-83	116.70	92.03	11.95	3.75	6.52
392	Aug-83	117.72	94.46	12.45	3.87	6.87
393	Sep-83	117.83	96.92	12.94	3.99	7.21
394	Oct-83	117.97	96.60	12.82	3.96	7.12
395	Nov-83	118.63	95.49	12.58	3.89	6.95
396	Dec-83	120.78	95.52	12.60	3.89	6.96
397	Jan-84	132.87	111.52	15.09	4.61	8.43
398	Feb-84	180.39	145.48	19.20	5.94	10.56
399	Mar-84	183.02	155.54	21.34	6.47	11.97
400	Apr-84	151.46	132.07	18.23	5.52	10.26
401	May-84	153.42	132.19	18.09	5.49	10.13
402	Jun-84	182.13	158.14	21.85	6.60	12.28
403	Jul-84	156.39	140.96	19.72	5.92	11.14
404	Aug-84	170.47	118.88	16.05	4.81	8.94
405	Sep-84	181.22	149.36	19.60	6.17	11.20
406	Oct-84	173.73	136.04	17.33	5.56	9.39
407	Nov-84	173.77	131.63	16.46	5.34	8.87
408	Dec-84	173.18	128.47	15.83	5.18	8.46
409	Jan-85	176.12	127.80	15.48	5.12	8.20
410	Feb-85	3.64	1.10	0.29	0.05	0.22
411	Mar-85	8.71	3.88	0.68	0.17	0.47
412	Apr-85	8.09	3.70	0.68	0.16	0.49
413	May-85	4.76	1.65	0.44	0.07	0.35
414	Jun-85	5.14	1.88	0.50	0.08	0.41
415	Jul-85	5.54	2.10	0.56	0.09	0.47
416	Aug-85	6.01	2.34	0.63	0.10	0.52
417	Sep-85	6.50	2.62	0.71	0.12	0.59
418	Oct-85	7.06	2.91	0.79	0.13	0.65
419	Nov-85	7.64	3.24	0.87	0.15	0.71
420	Dec-85	8.27	3.58	0.95	0.16	0.76
421	Jan-86	8.85	3.95	1.04	0.18	0.82
422	Feb-86	9.42	4.24	1.08	0.19	0.83
423	Mar-86	12.14	5.40	1.34	0.24	1.01
424	Apr-86	10.83	4.93	1.20	0.22	0.89
425	May-86	11.56	5.25	1.25	0.23	0.91
426	Jun-86	12.28	5.61	1.30	0.25	0.92
427	Jul-86	13.06	5.97	1.35	0.26	0.94
428	Aug-86	13.84	6.36	1.39	0.28	0.96
429	Sep-86	14.61	6.75	1.44	0.30	0.97
430	Oct-86	15.42	7.12	1.48	0.31	0.99
431	Nov-86	16.21	7.52	1.52	0.33	1.00
432	Dec-86	17.03	7.89	1.56	0.34	1.01

Measured = ND

Detection Limit = 10 µg/L

# Summary of simulation results

Water supply	Date and duration, in months, MCL exceeded	Single Specie (MT3DMS) Max. PCE, in $\mu\text{g/L}$	Multispecies (TechFlowMP) Max. PCE, in $\mu\text{g/L}$
TT-23	Aug 1984–Apr 1985: 8 months	274	167
TT-25	Jul 1984-Feb 1985: 32 months	69	40
TT-26	Jan 1957-Jan 1985: 333 months	851	775
WTP	Nov 1957-Feb 1987: 346 months	183	158

# Summary of Findings

- PCE concentration exceeded the current MCL of 5  $\mu\text{g}/\text{L}$  in finished water at the Tarawa Terrace WTP for 346 months
  - November 1957-February 1987
  - Maximum **simulated** value: **158-183**  $\mu\text{g}/\text{L}$
  - Maximum **measured** value: **215**  $\mu\text{g}/\text{L}$  (Feb 1985)

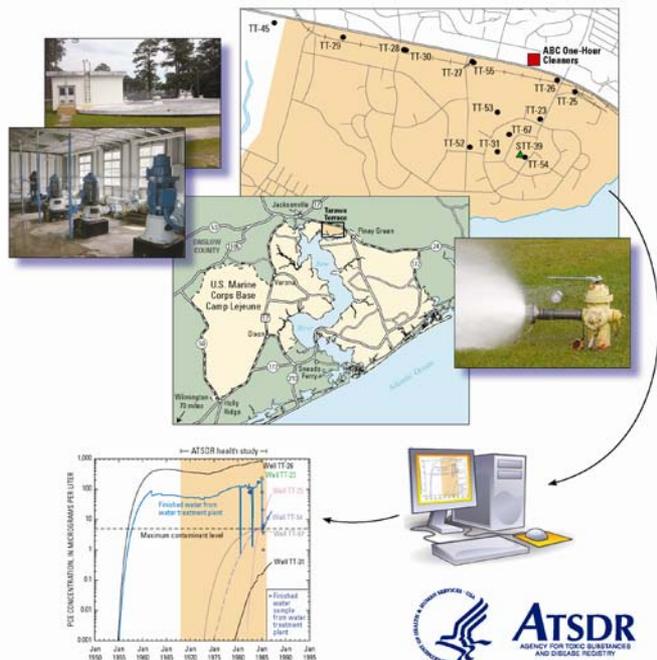
# Summary of Findings--continued

- PCE degradation by-products **TCE** and **1,2-tDCE** in finished water at the Tarawa Terrace WTP:
  - **Simulated** concentrations: **2-15**  $\mu\text{g/L}$
  - **Measured** concentration (TCE): **8**  $\mu\text{g/L}$  (Feb 11, 1985)
  - **Measured** concentration (1,2-tDCE): **12**  $\mu\text{g/L}$  (Feb 11, 1985)

# Published Tarawa Terrace reports

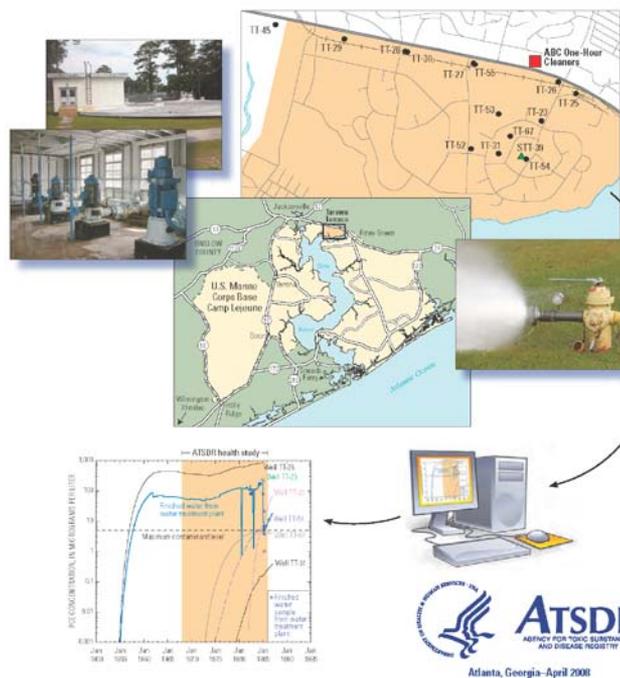
## Summary of Findings

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 A: Summary of Findings



## Multispecies Modeling

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







***Thank you for the opportunity to  
present information on ATSDR's  
current health study and water-  
modeling results at Marine Corps  
Base Camp Lejeune, NC***

For questions or additional information,  
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