Using Environmental Engineering Tools, Scientific Analyses, and Epidemiological Studies to Quantify Human Exposure to Contaminated Drinking Water and to Benefit Public Health

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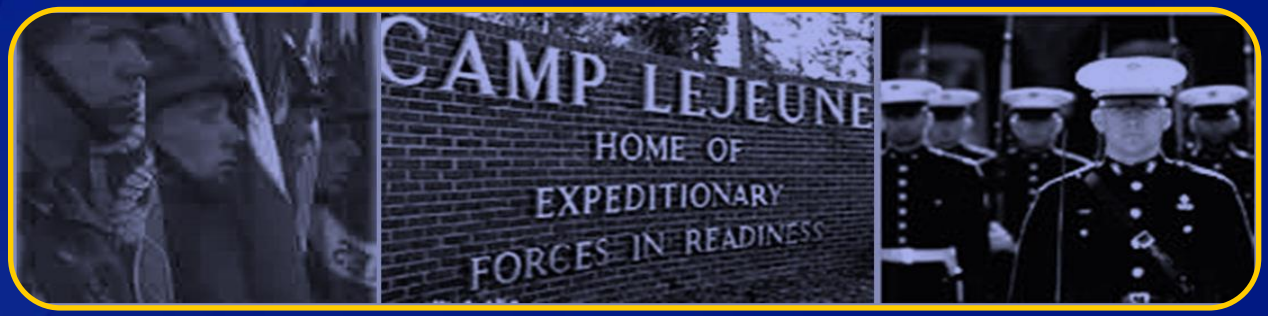

American Academy of Environmental Engineers & Scientists

2015 Excellence in Environmental Engineering & Science Awards Luncheon & Conference

National Press Club, Washington, DC – April 23, 2015

ATSDR

U.S. Department of Health and Human Services

Agency for Toxic Substances and Disease Registry

Partners and team members (Listed in alphabetical order by organization)

- **CDC-ATSDR**
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  - F.J. Bove
  - S.M. Moore
  - P.Z. Ruckart
  - J.B. Sautner
  - R.J. Suárez-Soto
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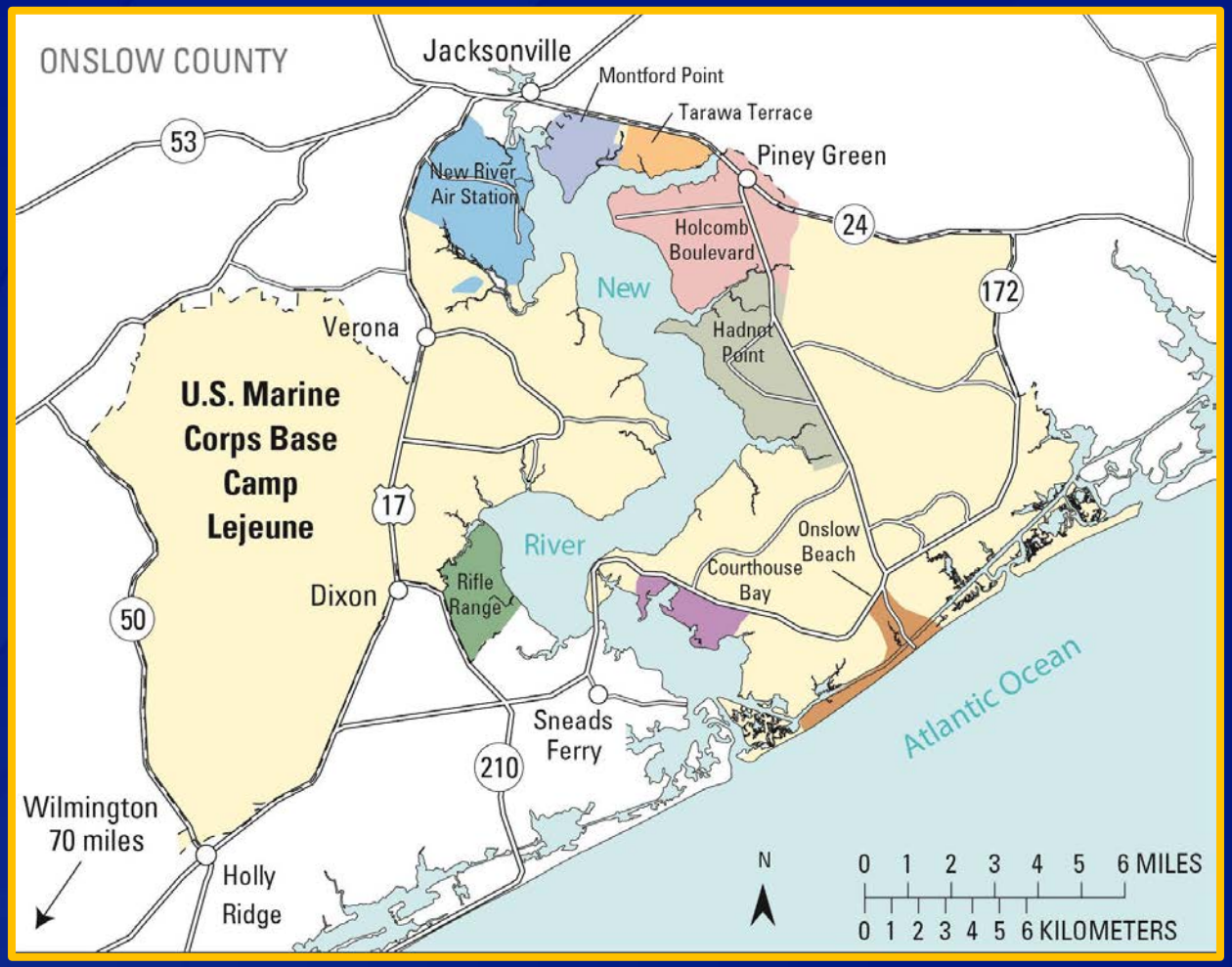
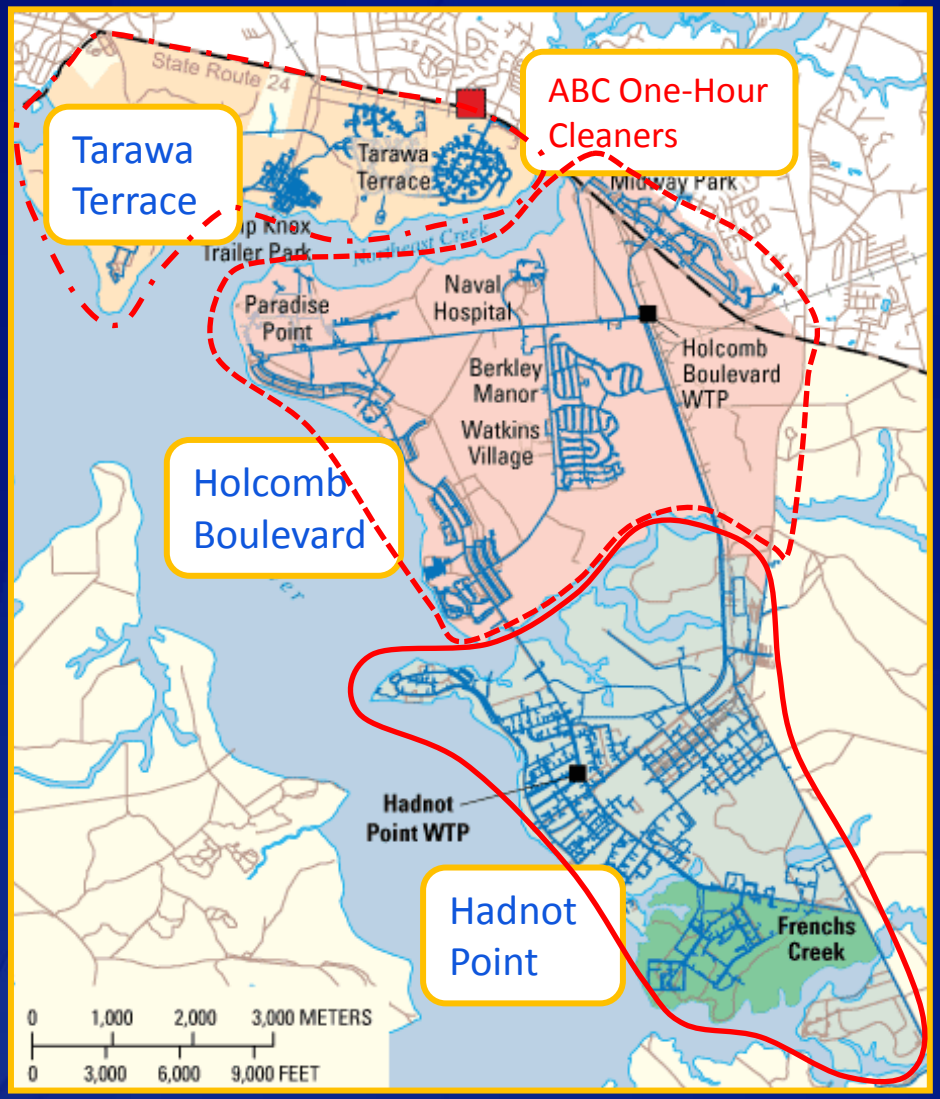
Water-supply areas

U.S. Marine Corps Base Camp Lejeune, North Carolina

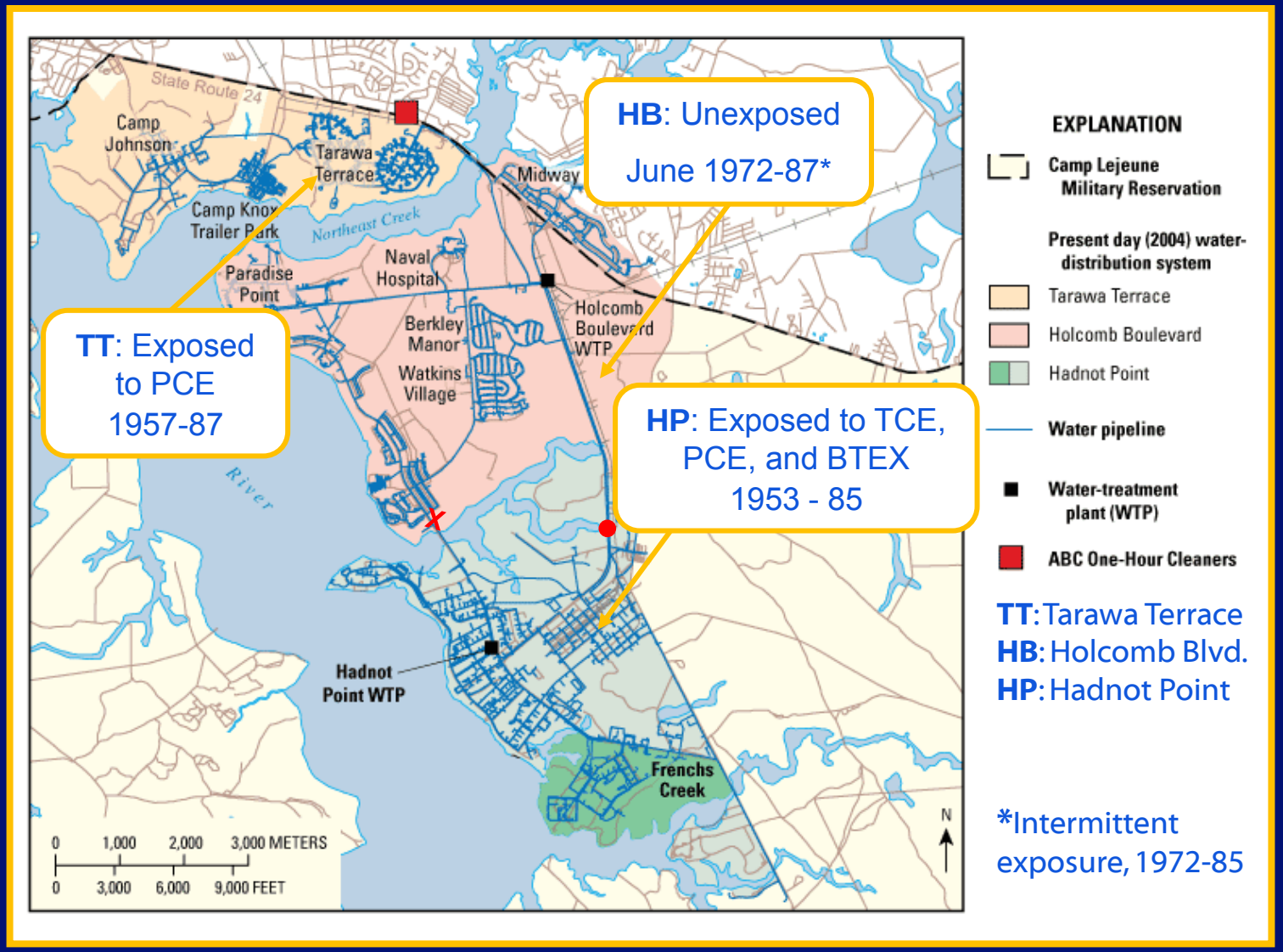


Events related to water-supply and contamination



- **1941:** Hadnot Point water treatment plant comes on-line
- **1952:** Tarawa Terrace water treatment plant comes on-line
- **1972:** Holcomb Boulevard water treatment plant comes online in June of 1972
- **Nov 1984-Feb 1985:** Several supply wells shut down due to VOC contamination
- **Jan 27-Feb 4 1985:** Marston Pavilion interconnection valve opened continuously (8 day period)
- **1987:** Holcomb Boulevard water treatment plant expanded to provide water to Tarawa Terrace and Camp Johnson water-distribution system areas
- **March 1987:** Tarawa Terrace water treatment plant taken out-of-service (March) and demolished
- **1989:** ABC One-Hour Cleaners and Camp Lejeune placed on EPA's National Priorities List (NPL) of sites.

Family housing and ATSDR health study areas



Questions posed by ATSDR health study scientists requiring monthly mean, contaminant-specific drinking-water concentrations

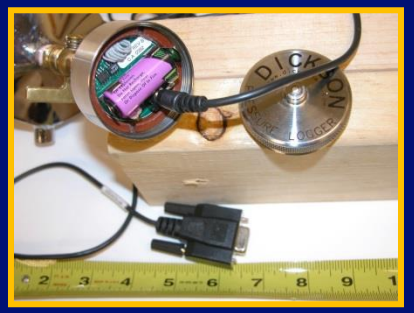
- What chemical compounds contaminated the drinking water (contaminants of concern)?
- When did contaminated groundwater reach water-supply wells and what was the duration of the contamination (arrival dates)?
- What were the monthly mean drinking-water concentrations?
- How was contaminated water distributed to housing areas (water transfers)?
- What were the ranges of concentration values (based on modeling results) for a specific month (uncertainty)?

Contaminants of potential concern

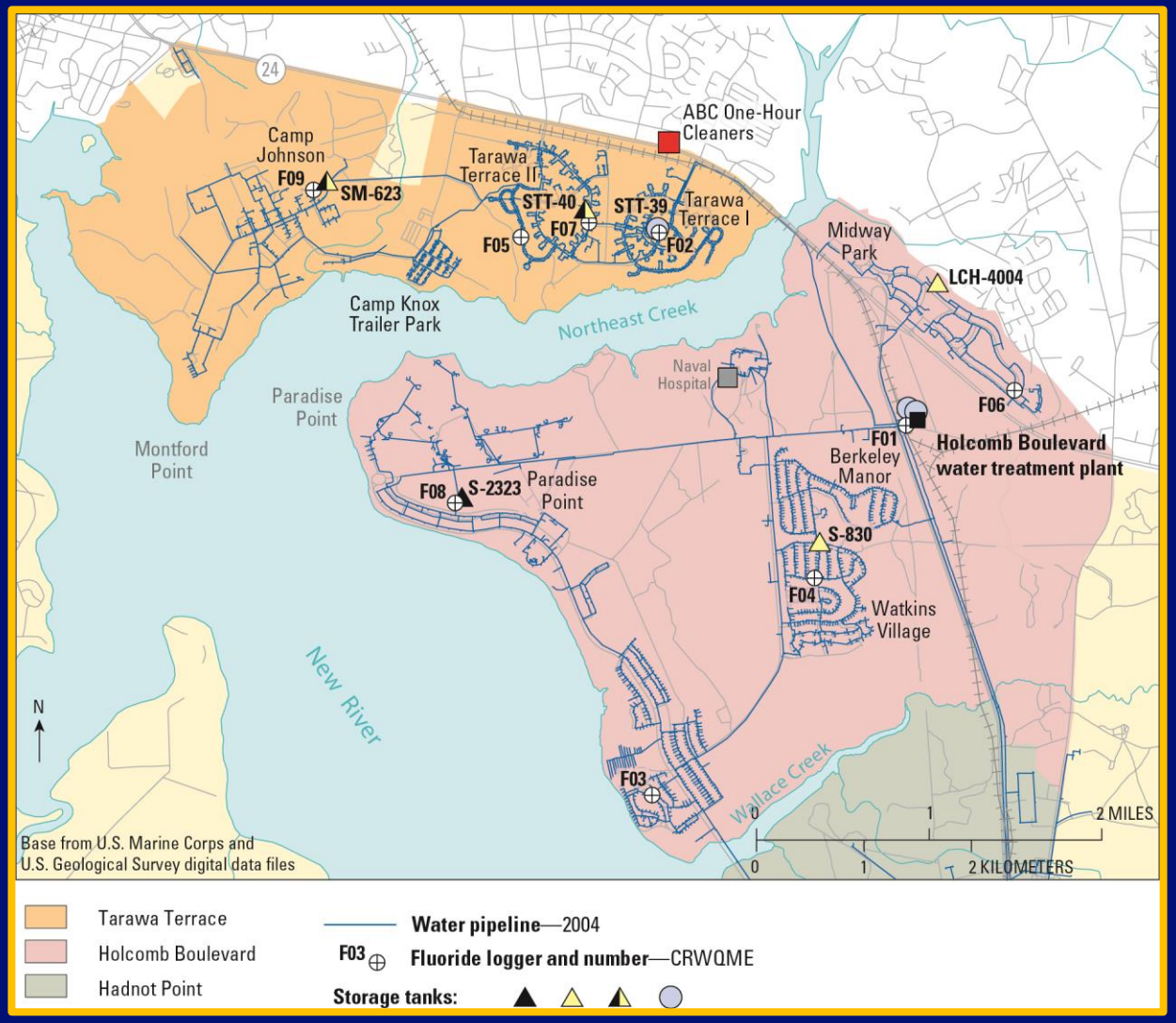
Contaminant	MCL (µg/L)+	Effective date*	Cancer classification	Reference
PCE	**5**	July 30, 1992	**Probably carcinogenic to humans**	Guha et al. 2012; USEPA 2012
TCE	**5**	January 9, 1989	**Carcinogenic in humans**	USEPA 2011
1,1-DCE	7	January 9, 1989	Possible human carcinogen	ATSDR 1994
Cis-1,2- DCE	70	July 30, 1992	Inadequate information to assess the carcinogenic potential	USEPA - IRIS
Trans-1,2-DCE	100	July 30, 1992	Inadequate information to assess the carcinogenic potential	USEPA - IRIS
Vinyl chloride	**2**	January 9, 1989	**Known human carcinogen**	NTP 2011
Benzene	**5**	January 9, 1989	**Known human carcinogen**	IARC 1982; NTP 2011
Toluene	1,000	July 30, 1992	Cannot be classified	ATSDR 2000
Ethylbenzene	700	July 30, 1992	Possibly carcinogenic to humans	IARC 2000
Xylenes (total)	10,000	July 30, 1992	Cannot be classified	IARC 1999

+USEPA (2003, 2009); *40 CFR, Section 141.60, Effective Dates, July 1, 2002, edition; IARC, International Agency for Research on Cancer; IRIS, Integrated Risk Information System; MCL, maximum contaminant level; NTP, National Toxicology Program, US Department of Health and Human Services.

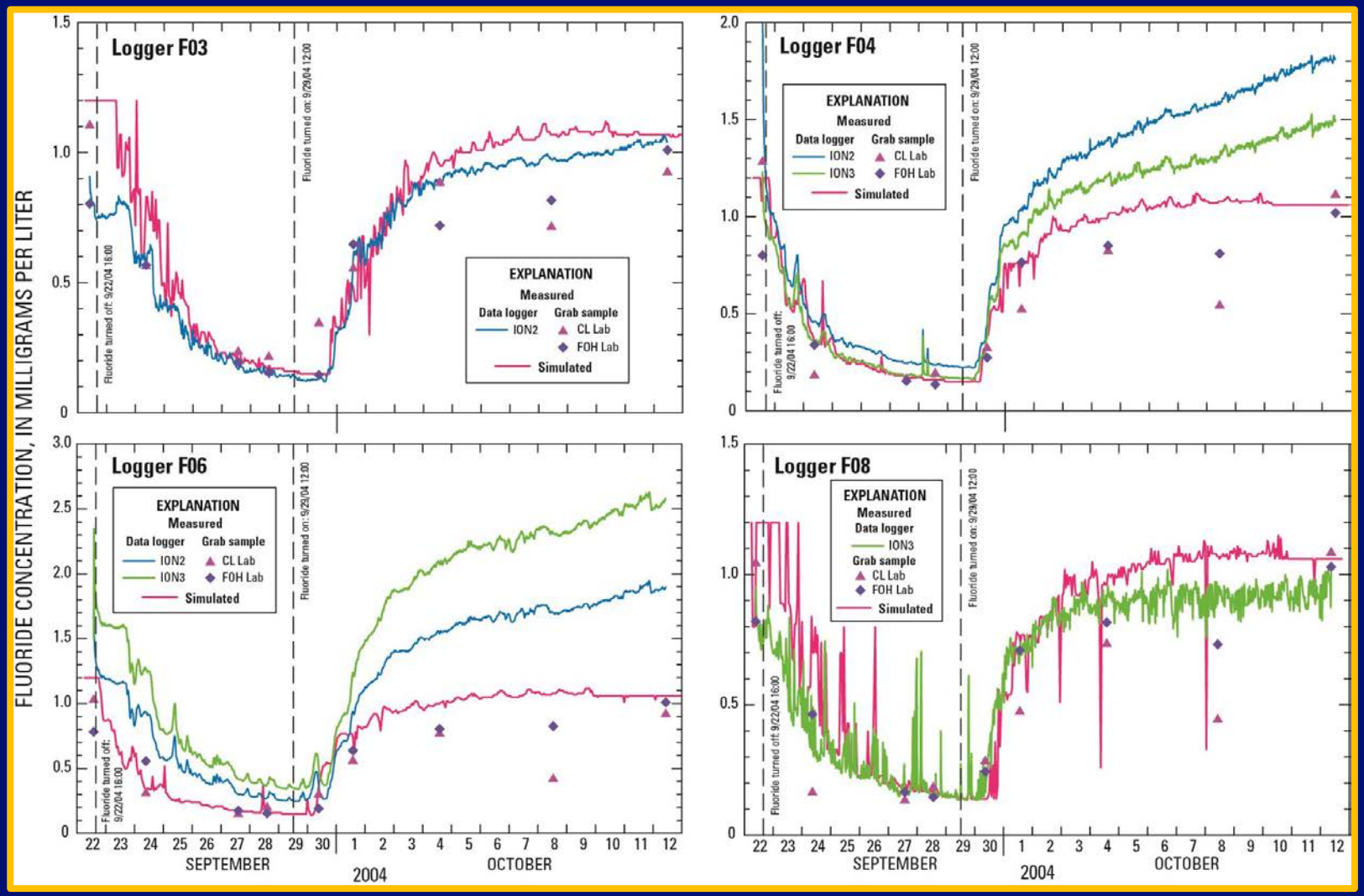
Water-distribution system hydraulic and tracer tests, May-October 2004



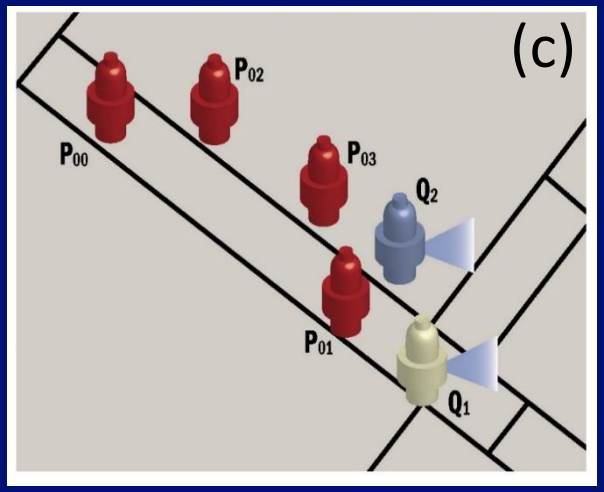
Location of continuous-reading, ion-specific data loggers used to conduct tracer tests

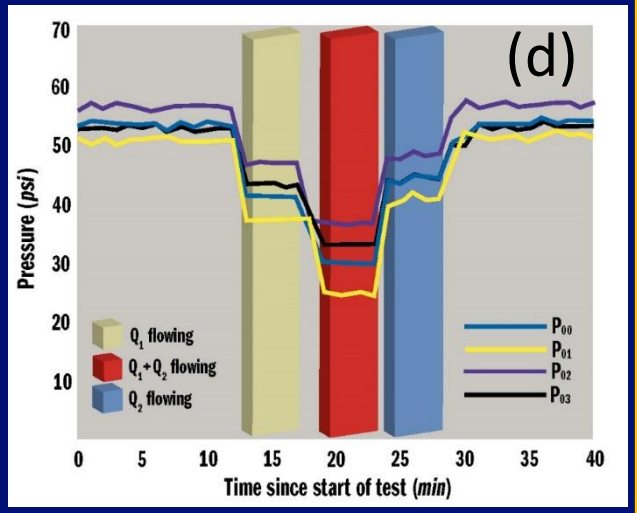


Measured (data loggers and grab samples) and simulated fluoride concentrations



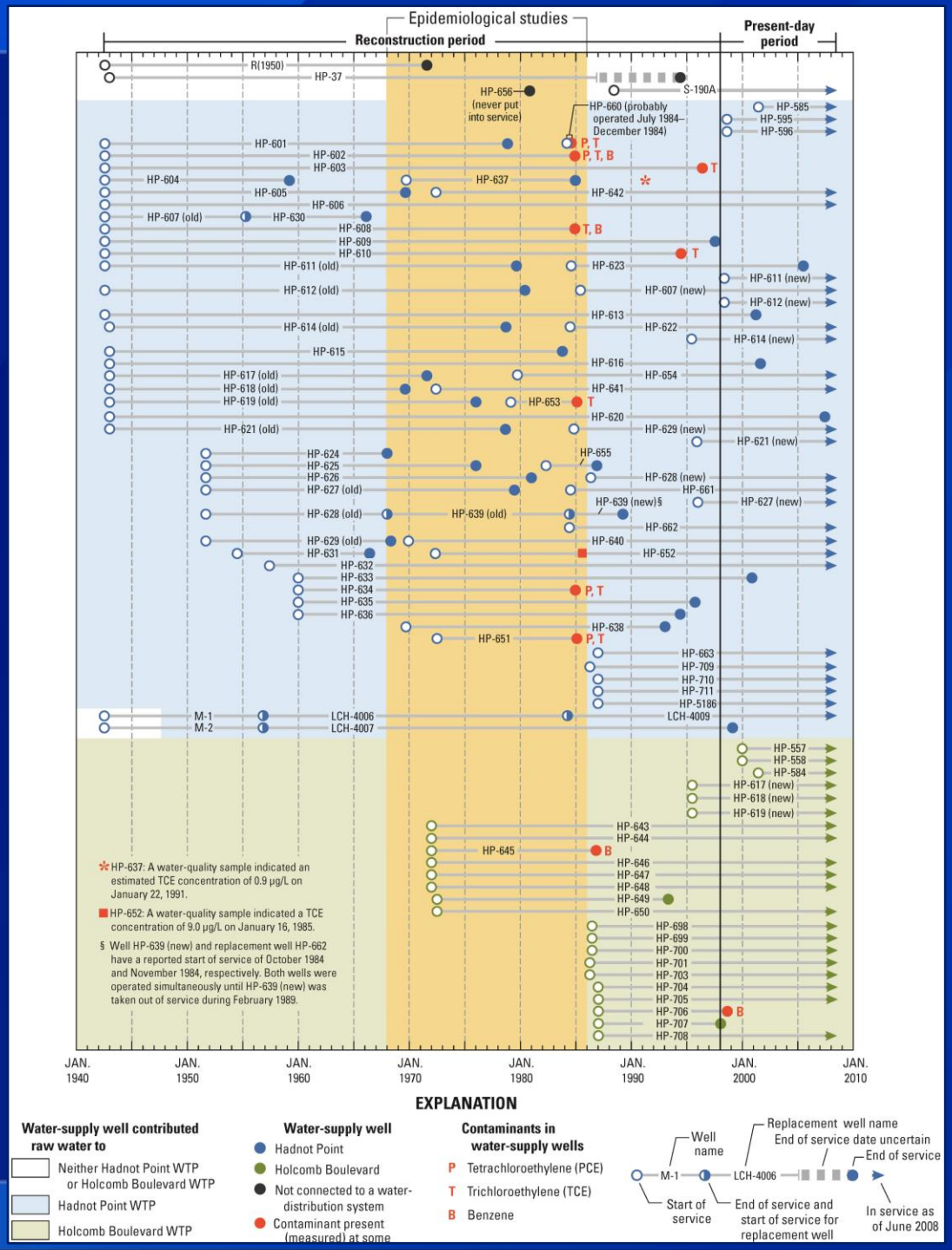
An innovative, effective and efficient fire-flow test method for model calibration



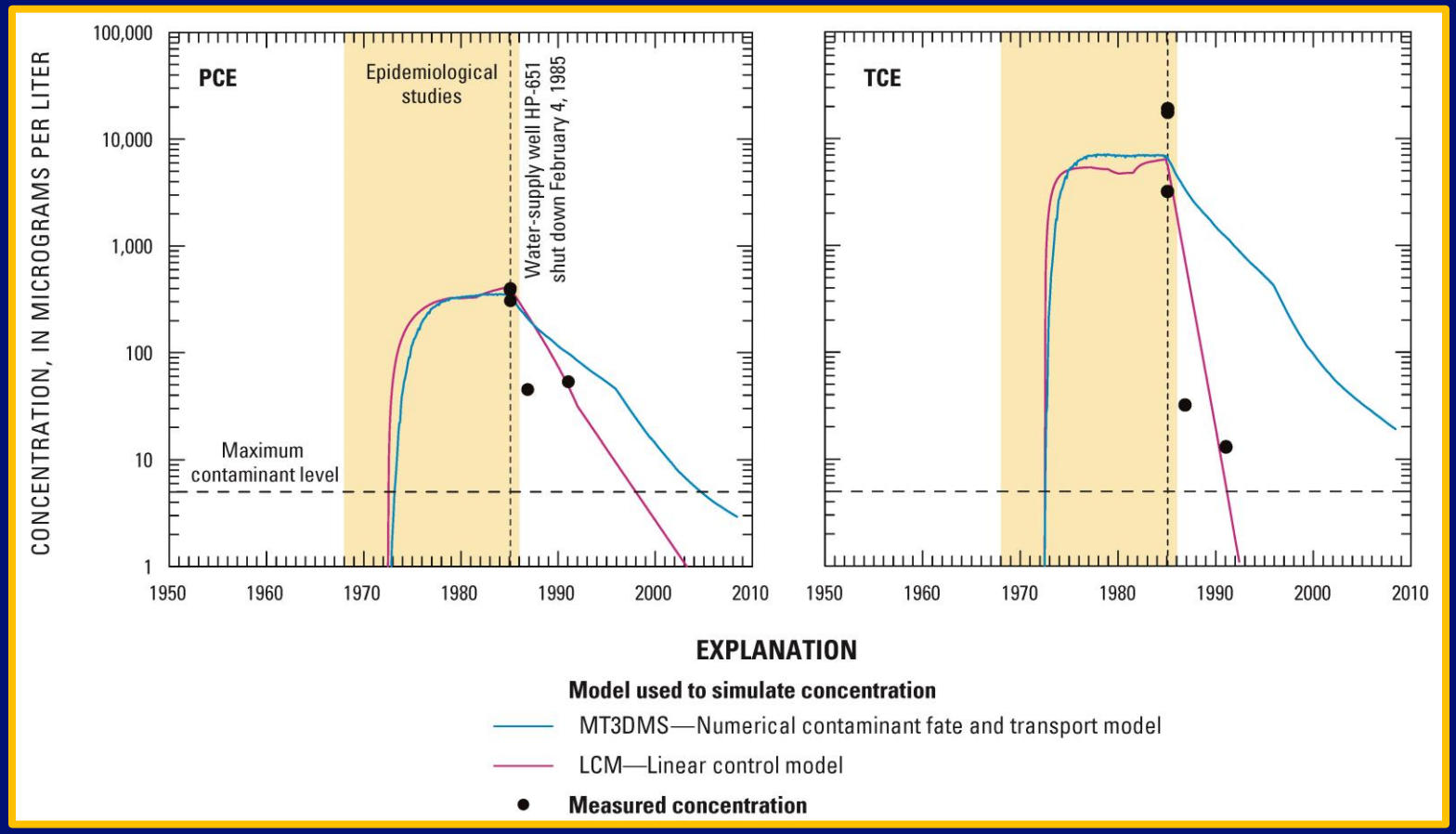


Reconstructing Hadnot Point and Holcomb Boulevard water-supply well operational chronology

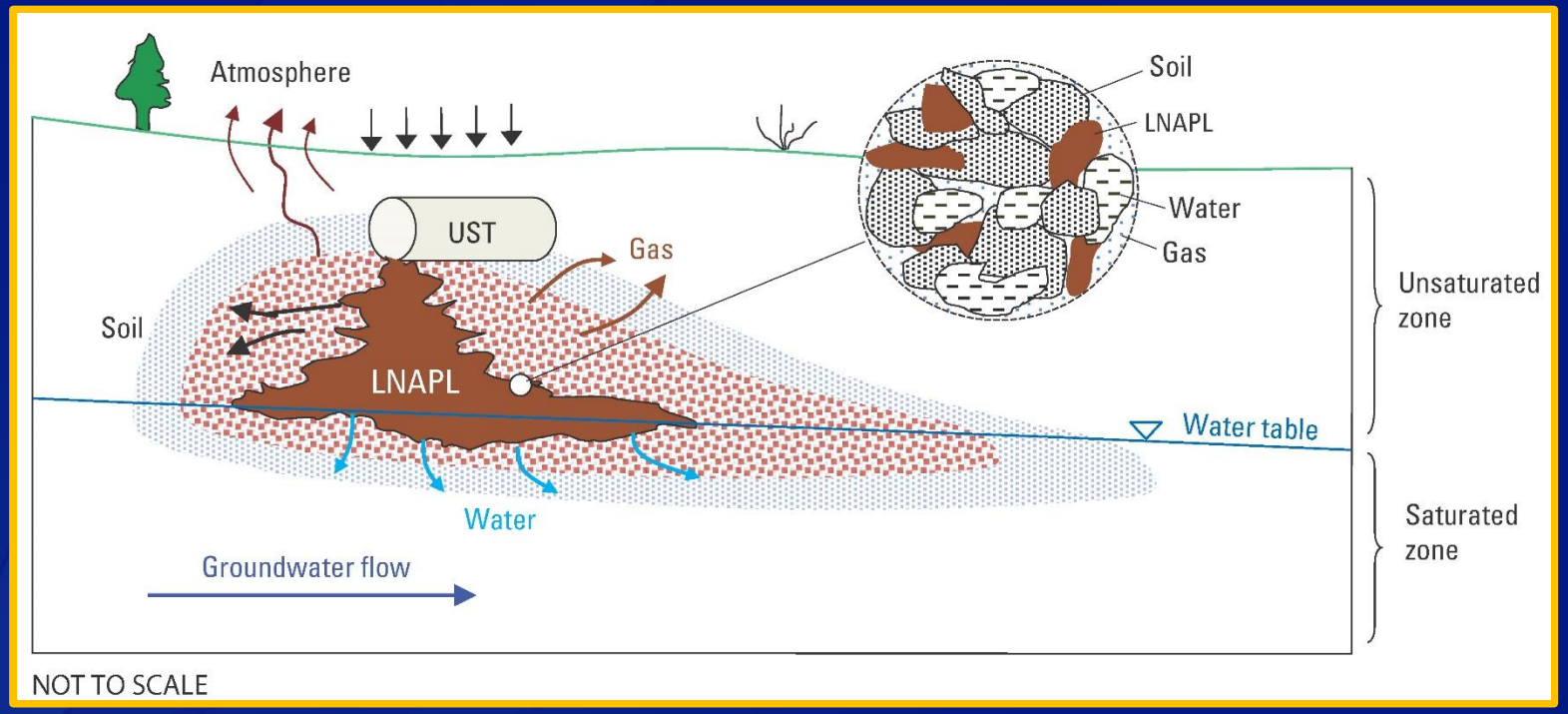
- Hadnot Point: 72 wells
- Holcomb Blvd.: 24 wells
- Golf course: 2 wells
- Emergency: 1 well
- Not connected: 1 well



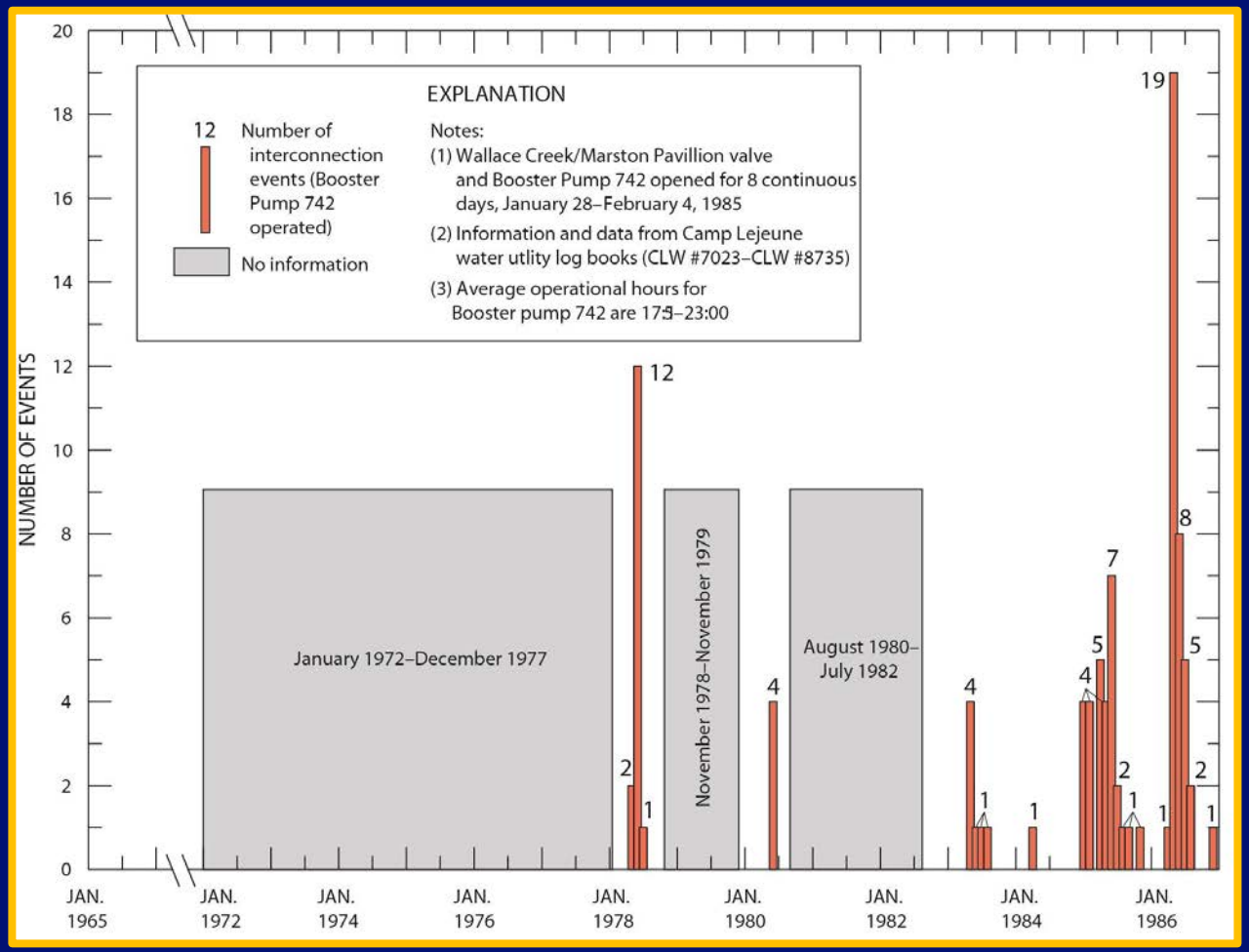
An innovative method (linear control model) to reconstruct concentrations at water-supply wells



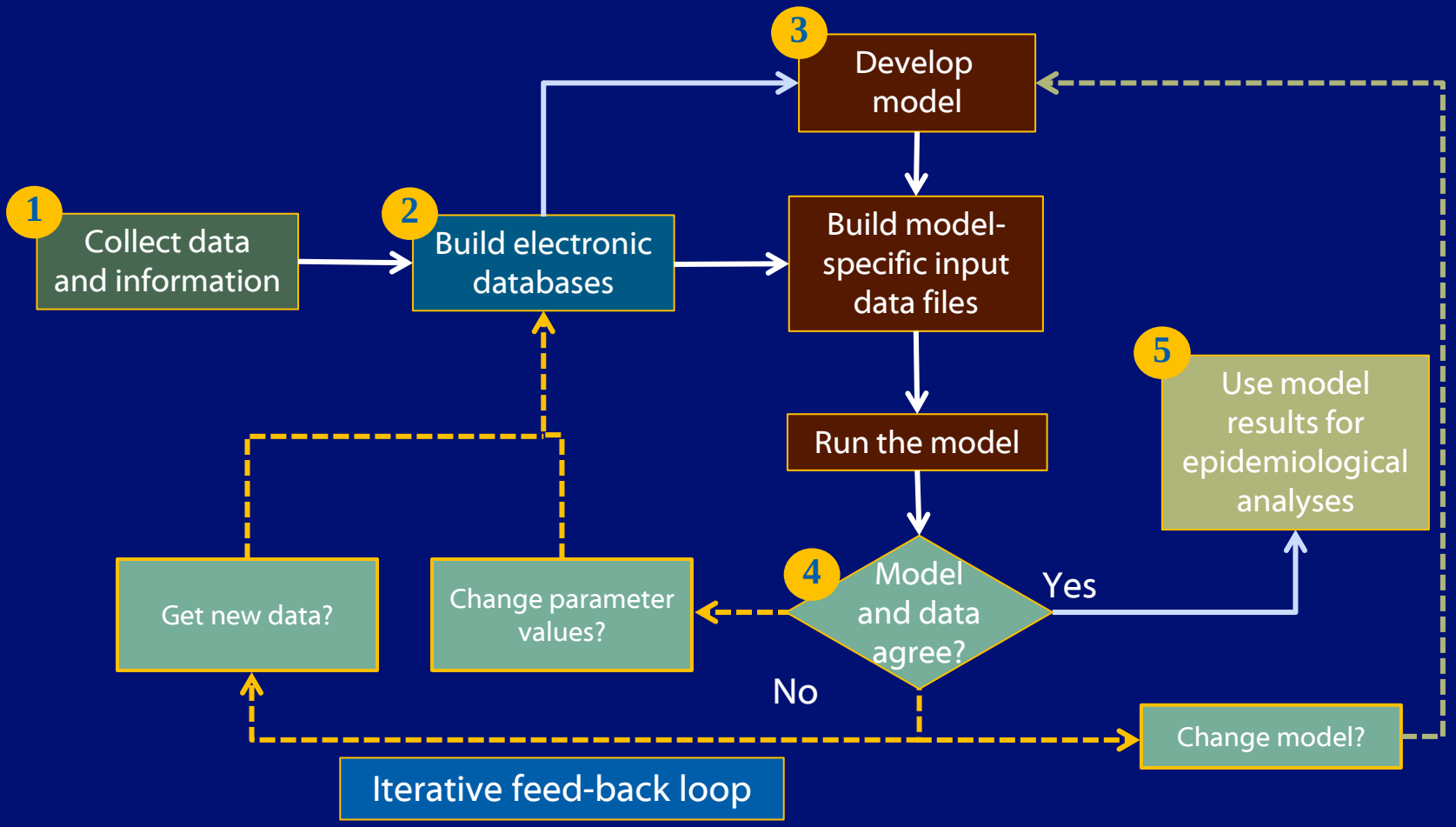
Subsurface light nonaqueous phase liquid (LNAPL) scenario



Interconnection events: transfer of Hadnot Point water to the Holcomb Boulevard water-distribution system, 1972-1986

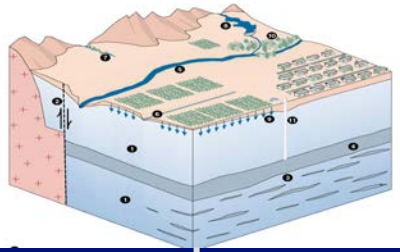


Water modeling process used to reconstruct historical drinking-water concentrations

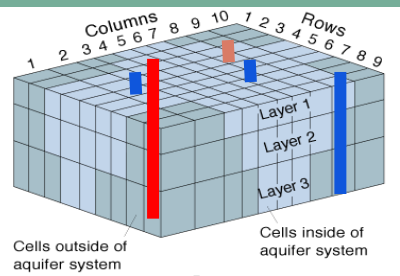


Application of "water models" to reconstruct monthly contaminant-specific concentrations

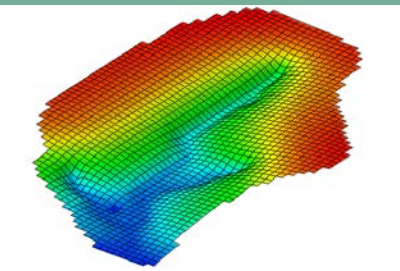
TT, HP-HB study areas



Groundwater flow



Fate and transport

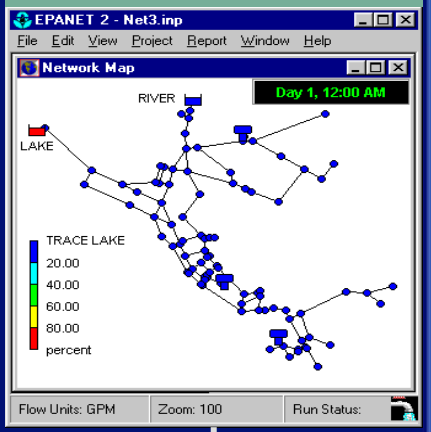


Flow-weighted mixing

Reconstructed monthly mean concentrations at Tarawa Terrace and Hadnot Point water treatment plant

Intermittent water transfers from Hadnot Point to Holcomb Boulevard

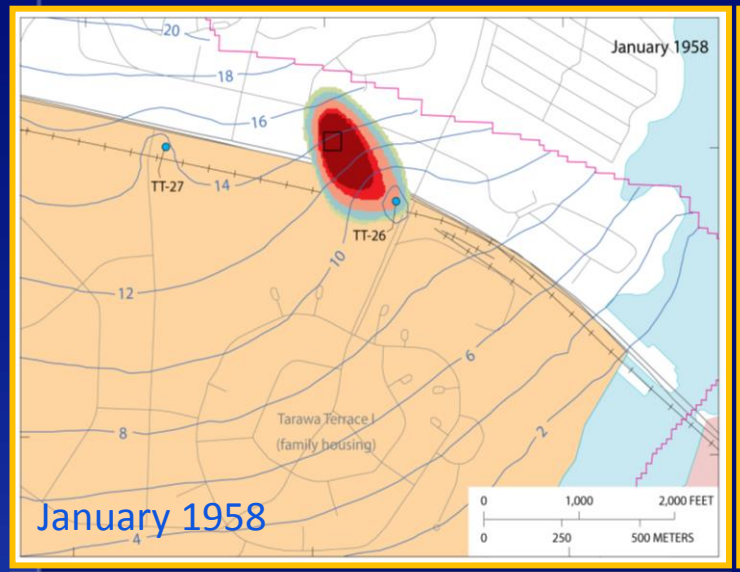
Water distribution

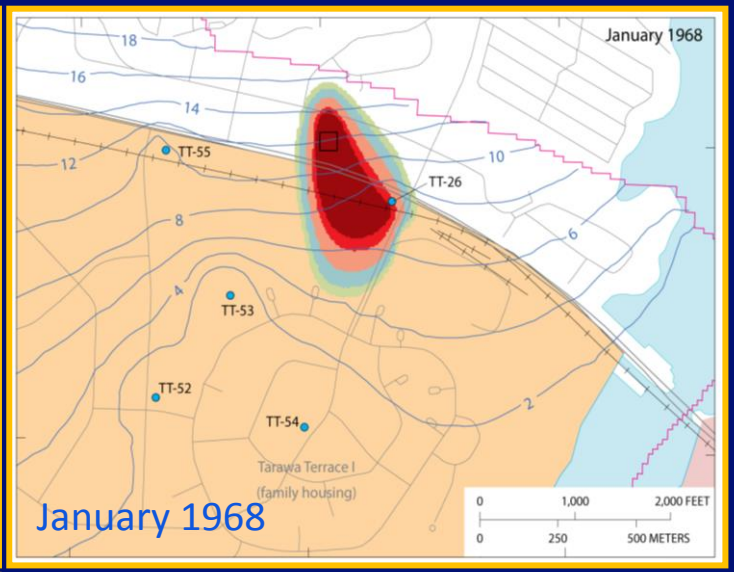


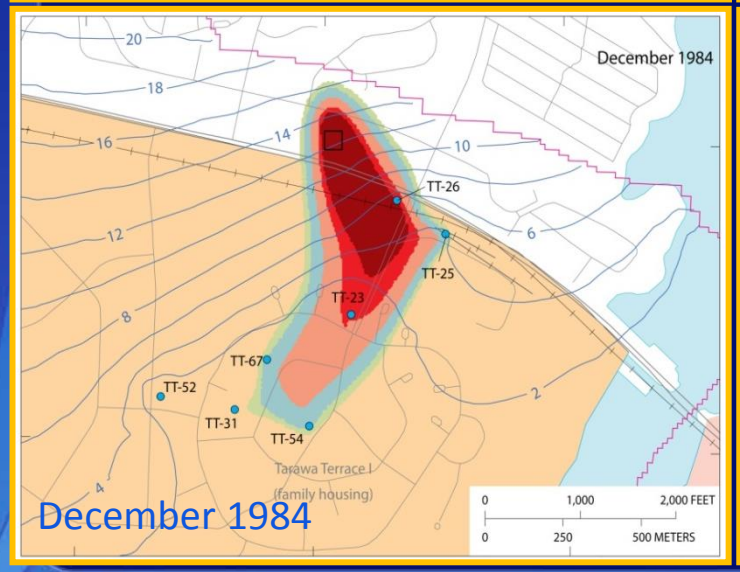
Reconstructed monthly mean concentrations at Holcomb Boulevard housing areas

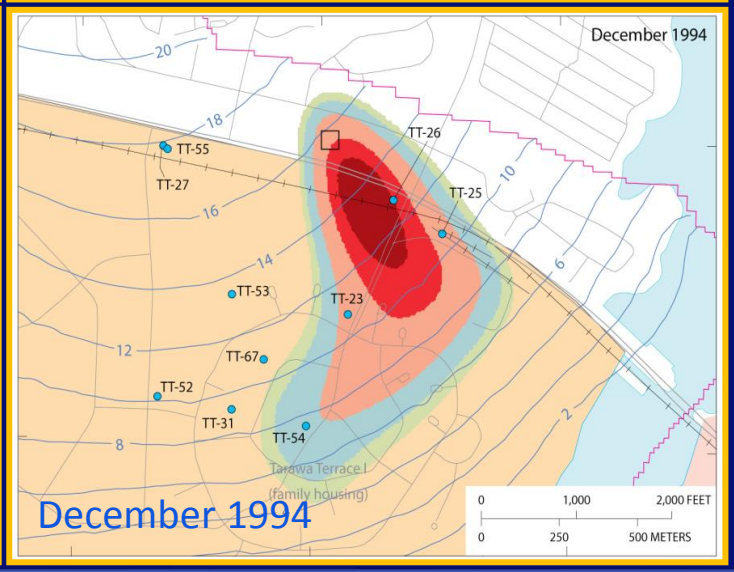
TT, Tarawa Terrace; HP, Hadnot Point; HB, Holcomb Boulevard

Fate and transport of PCE at Tarawa Terrace (model layer 1)





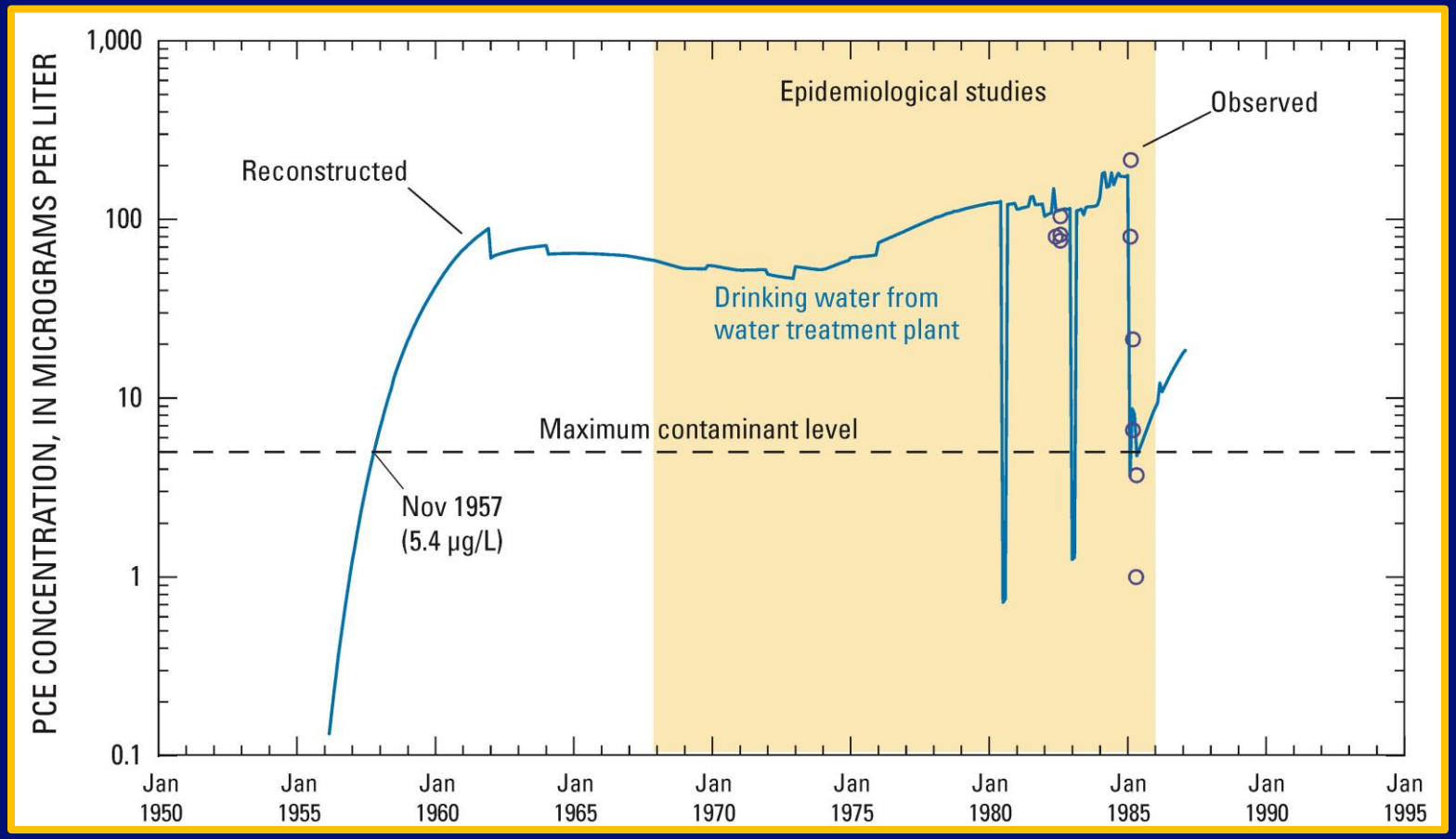




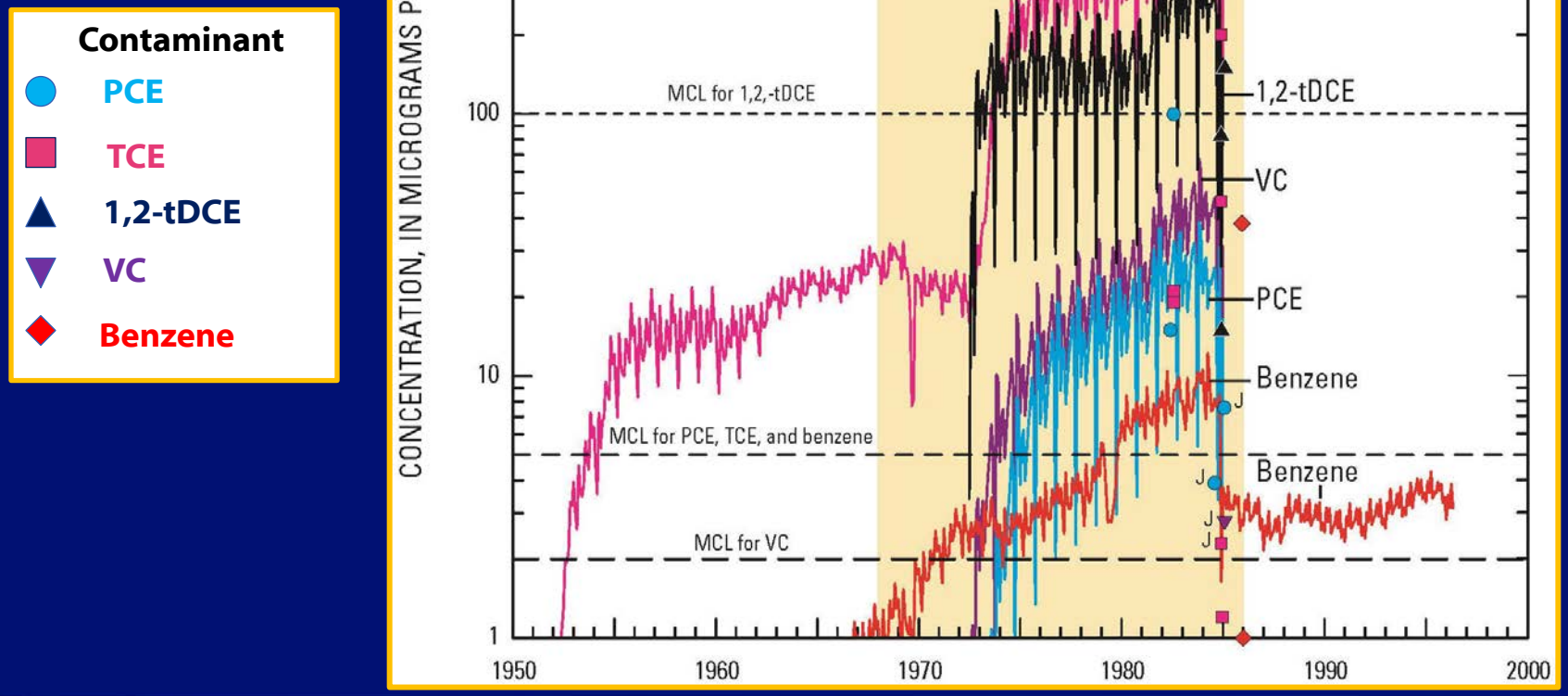
Concentration, in µg/L

- 1 to 5
- >5 to 50
- >50 to 500
- >500 to 1,500
- >1,500

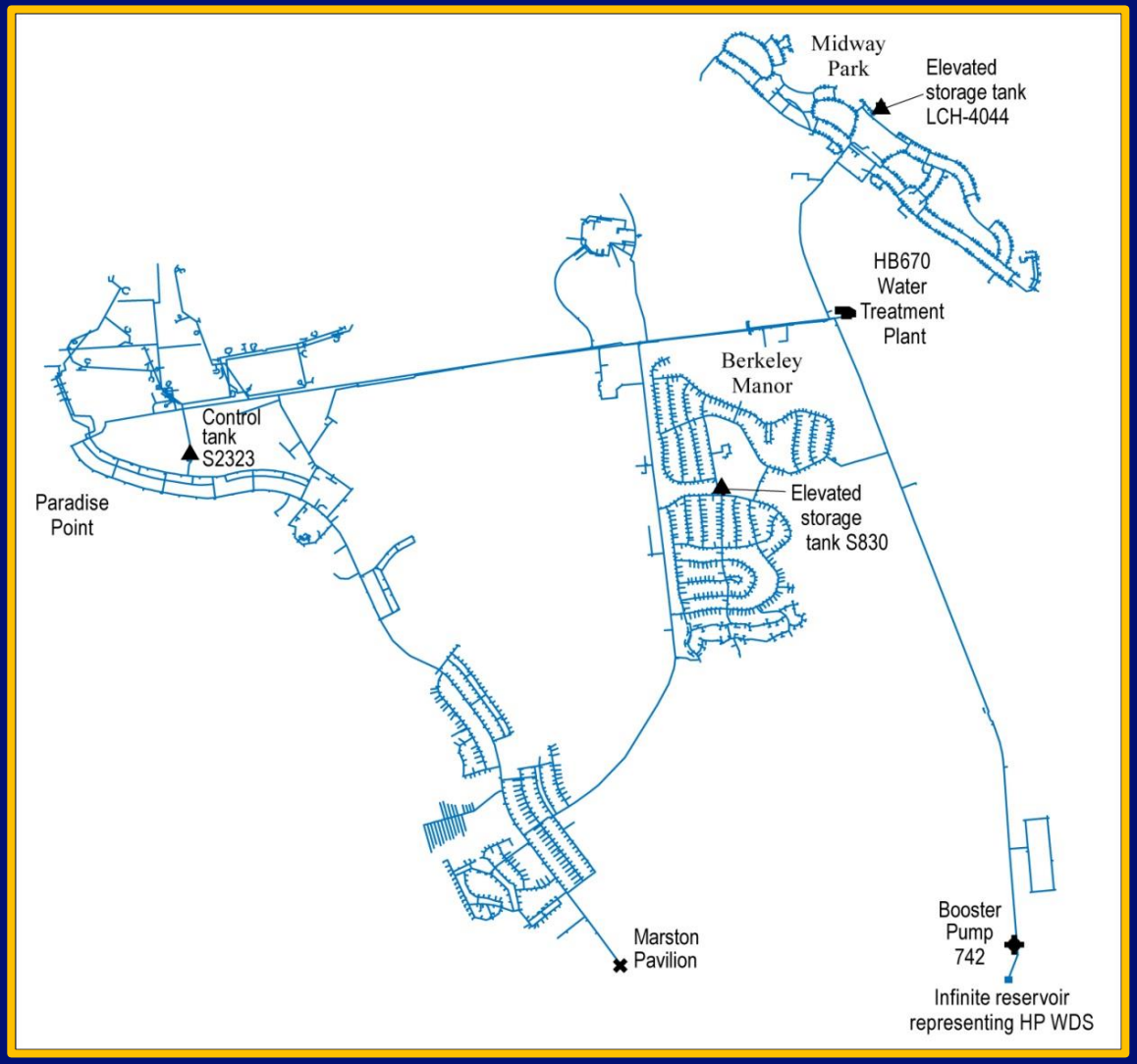
Reconstructed drinking-water concentrations for PCE, Tarawa Terrace water treatment plant



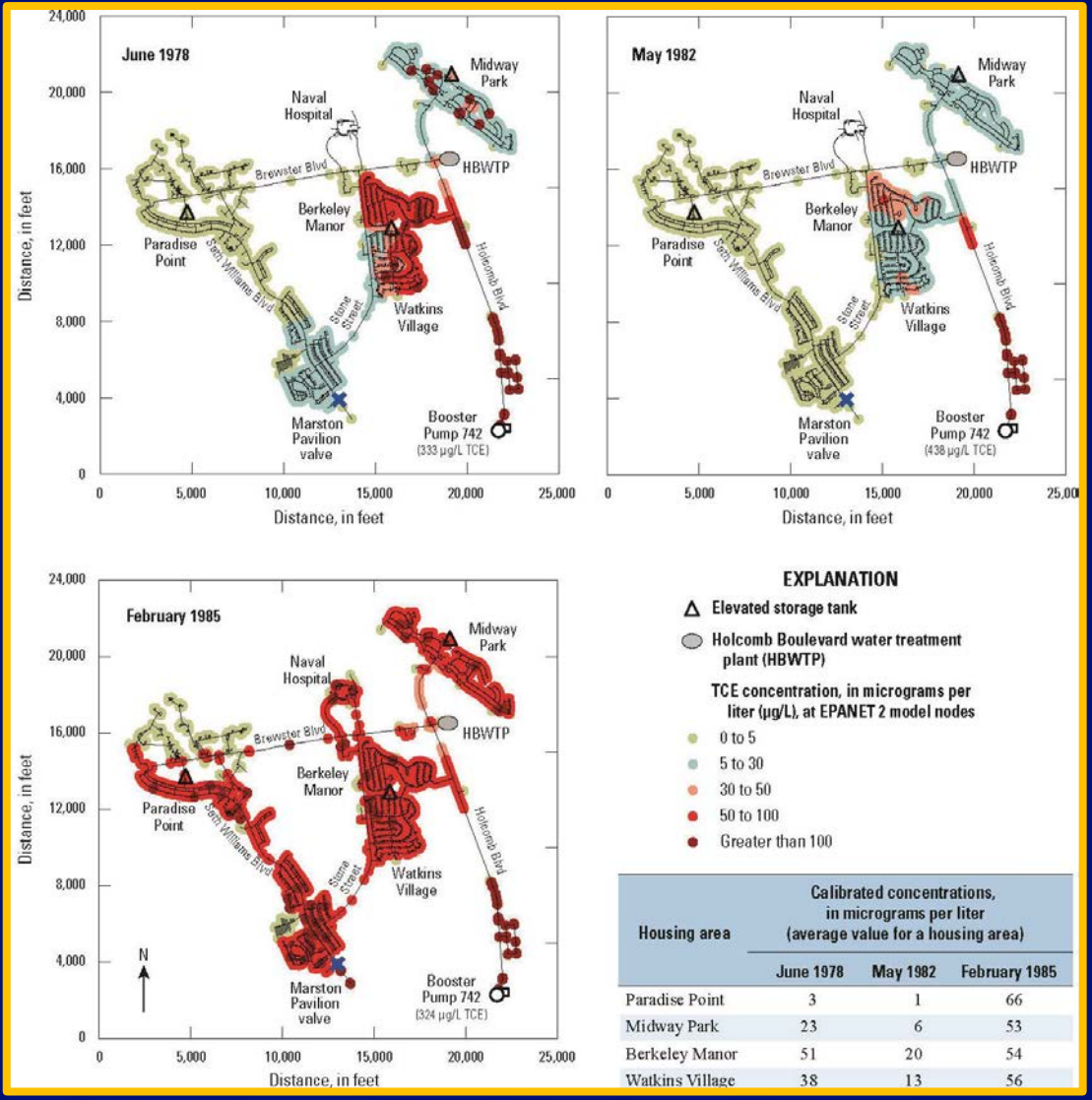
Reconstructed drinking-water concentrations Hadnot Point water treatment plant



Holcomb Boulevard water-distribution system: EPANET2 model network representation



Reconstructed TCE drinking-water concentrations: Holcomb Boulevard area



Housing area	Calibrated concentrations, in micrograms per liter (average value for a housing area)		
	June 1978	May 1982	February 1985
Paradise Point	3	1	66
Midway Park	23	6	53
Berkeley Manor	51	20	54
Watkins Village	38	13	56

Concentration, in µg/L

- 0 to 5
- >5 to 30
- >30 to 50
- >50 to 100
- >100

Summary of water-modeling findings

- **Tarawa Terrace water treatment plant**
  - Earliest MCL exceedance date for **PCE** is November 1957, but might have been as early as December 1956
- **Hadnot Point water treatment plant**
  - Earliest MCL exceedance date for **TCE** is August 1953, but might have been as early as November 1948
- **Holcomb Boulevard housing area**
  - **TCE** exceeded MCL during periods of intermittent supply (June 1972 – February 1985)

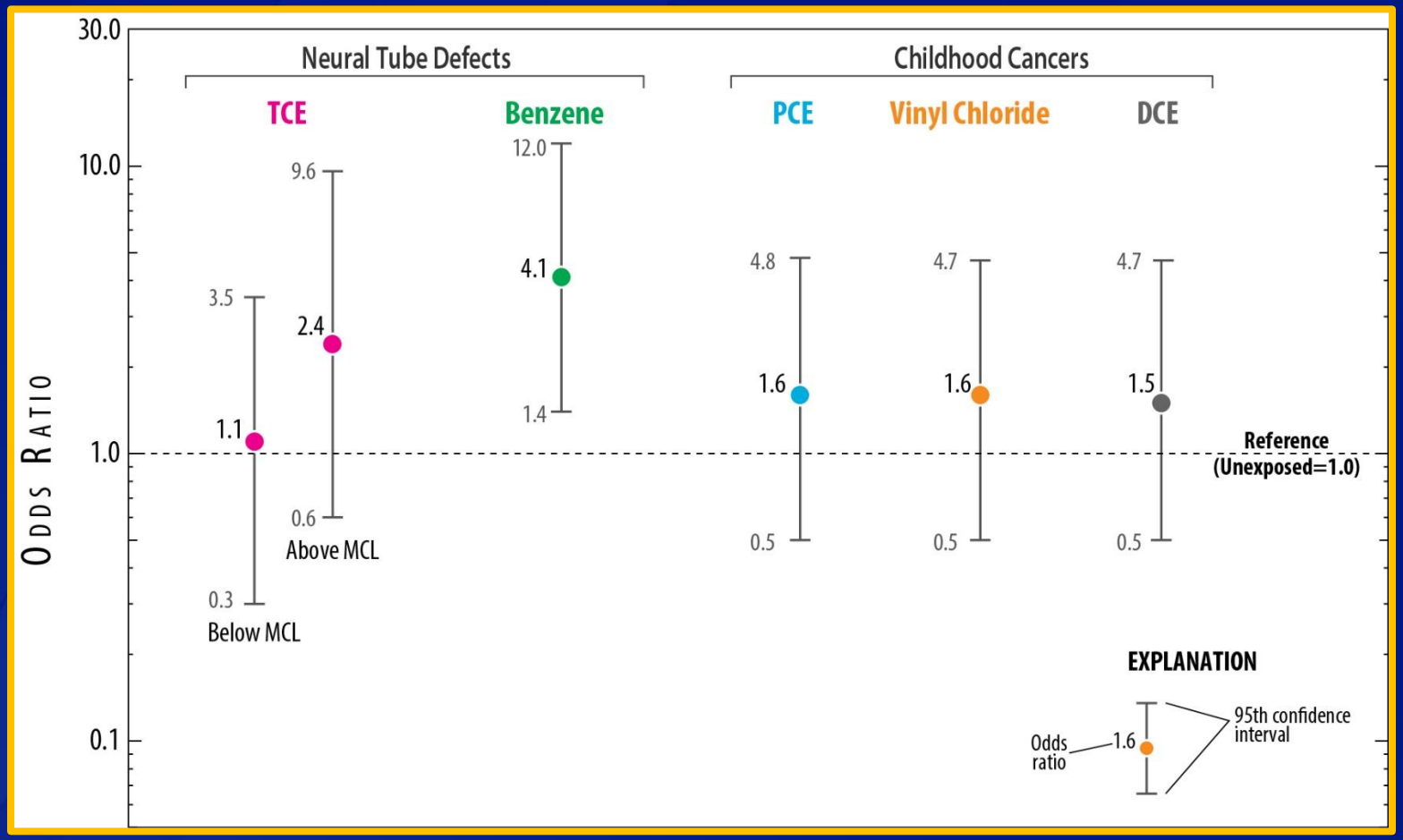
MCL: Maximum contaminant level

ATSDR health studies and results

- **Health studies conducted**
  - Specific birth defects and childhood cancers (case-control),
  - Mortality among marines and navy personnel and civilian employees (retrospective cohort), and
  - Adverse pregnancy outcomes (cross-sectional).

- **Associations found between VOC-contaminated drinking-water exposures and health outcomes for**
  - Neural tube defects,
  - Childhood leukemia,
  - Mortality from kidney cancer, rectal cancer, multiple myeloma, leukemias and other cancers, and
  - Preterm birth, small for gestational age, and low birth weight.

Epidemiological results using reconstructed monthly drinking-water concentrations*



*Average 1st trimester exposures

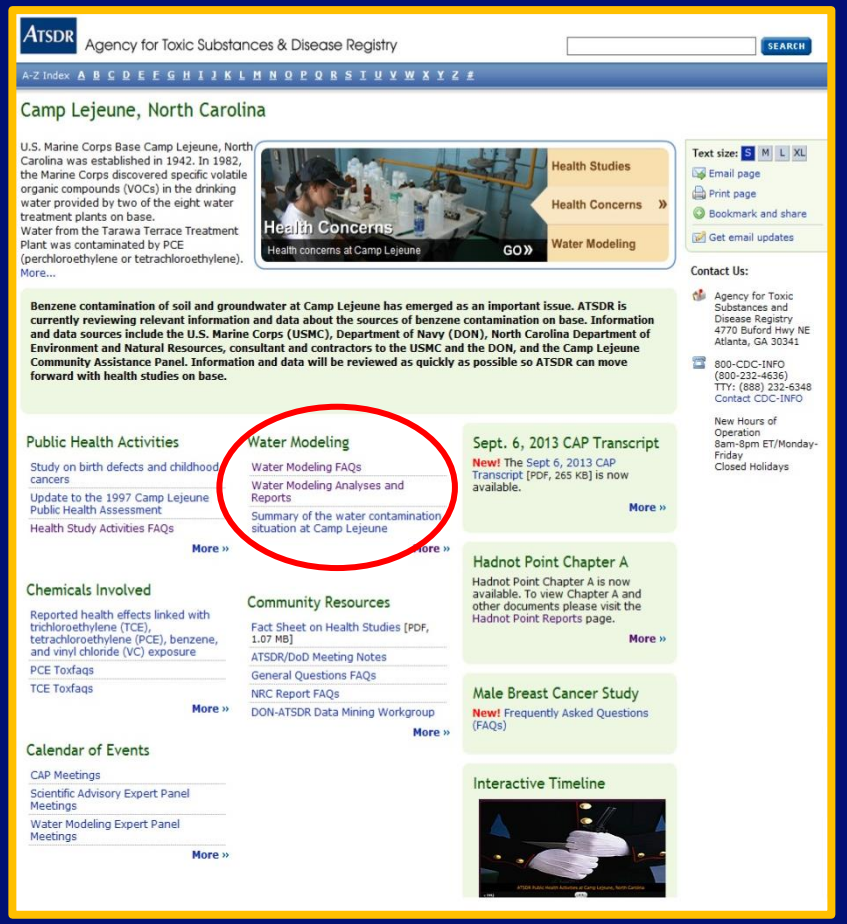
Benefits to Environmental Engineering and Public Health

- Project uniquely ties environmental engineering practice to health assessment and public health protections
- Epidemiological study results demonstrate the advantage of using contaminant-specific monthly concentrations instead of the classical exposed versus unexposed approach.
- Epidemiological study results contribute to the limited scientific knowledge of health effects from VOCs in drinking water, and inform the affected community and public health practitioners.
- Findings would not have been possible without the enhanced environmental engineering tools, novel approaches, and scientific analyses employed.

ATSDR Camp Lejeune information and data

- **ATSDR website**
  - http://www.atsdr.cdc.gov/sites/lejeune/index.html

  - Historical information and data
  - Health-related information
  - Water-modeling data and results



Published results in the public domain

- **All analyses and results (water modeling and epidemiological) have gone through external peer review**

- **ATSDR Reports**
  - Tarawa Terrace: **9**
  - Hadnot Point: **12**

- **Journal Articles**
  - Water Modeling: **2**
  - Epidemiology: **4**

Published results in the public domain

- Grayman, W. M., Maslia, M. L., and Sautner, J. B. (2006). "Calibrating distribution system models with fire-flow tests." *American Water Works Association, Opflow*, 32(4), 10-2. [Available from http://www.awwa.org/publications/opflow/abstract/articleid/18136.aspx]
- Maslia, M. L., Sautner, J. B., Faye, R. E., Suárez-Soto, R. J., Aral, M. M., Grayman, W. M., Jang, W., Wang, J., Bove, F. J., Ruckart, P. Z., Valenzuela, C., Green Jr., J. W., and Krueger, A. L. (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—Chapter A: Summary of Findings." *Agency for Toxic Substances and Disease Registry*, Atlanta, GA. [Cited 2 January 2015, available from http://www.atsdr.cdc.gov/sites/lejeune/docs/ChapterA_TarawaTerrace.pdf].
- Maslia, M. L., Aral, M. M., Faye, R. E., Suarez-Soto, R. J., Sautner, J. B., Wang, J., Jang, W., Bove, F. J., and Ruckart, P. Z. (2009). "Reconstructing historical exposures to volatile organic compound-contaminated drinking water at a U.S. Military Base." *Water Quality, Exposure and Health*, 1(1), 49–68. [Available from http://link.springer.com/article/10.1007%2Fs12403-009-0010-y].
- Maslia, M. L., Suárez-Soto, R. J., Sautner, J. B., Anderson, B. A., Jones, L. E., Faye, R. E., Aral, M. M., Guan, J., Jang, W., Telci, I. T., Grayman, W. M., Bove, F. J., Ruckart, P. Z., and Moore, S. M. (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." *Agency for Toxic Substances and Disease Registry*, Atlanta, GA. [Cited 2 January 2015, available from http://www.atsdr.cdc.gov/sites/lejeune/docs/chapter_A_hadnotpoint.pdf].
- Ruckart, P. Z., Bove, F. J., and Maslia, M. L. (2013). "Evaluation of exposure to contaminated drinking water and specific birth defects and childhood cancers at Marine Corps Base Camp Lejeune, North Carolina: A case-control study." *Journal of Environmental Health*, 12(104), 1–10. [Cited 2 January 2015, available from: http://www.ehjournal.net/content/12/104].
- Bove, F. J., Ruckart, P. Z., Maslia, M. L., and Larson, T. C. (2014a). "Evaluation of mortality among marines and navy personnel exposed to contaminated drinking water at USMC Base Camp Lejeune: A retrospective cohort study." *Journal of Environmental Health*, 13(10), 1-14. [Cited 2 January 2015, available from: http://www.ehjournal.net/content/13/1/10].
- Bove, F. J., Ruckart, P. Z., Maslia, M. L., and Larson, T. C. (2014b). "Mortality study of civilian employees exposed to contaminated drinking water at USMC Base Camp Lejeune: A retrospective cohort study." *Journal of Environmental Health*, 13(68), 1-13. [Cited 2 January 2015, available from: http://www.ehjournal.net/content/13/1/68].
- Ruckart, P. Z., Bove, F. J., and Maslia, M. L. (2014). "Evaluation of contaminated drinking water and preterm birth, small for gestational age, and birth weight at U.S. Marine Corps Base Camp Lejeune, North Carolina: a cross-sectional." *Journal of Environmental Health*, 13(99), 1–10. [Cited 2 January 2015, available from: http://www.ehjournal.net/content/13/1/99].

Questions and discussion

For more information please contact Agency for Toxic Substances and Disease Registry

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