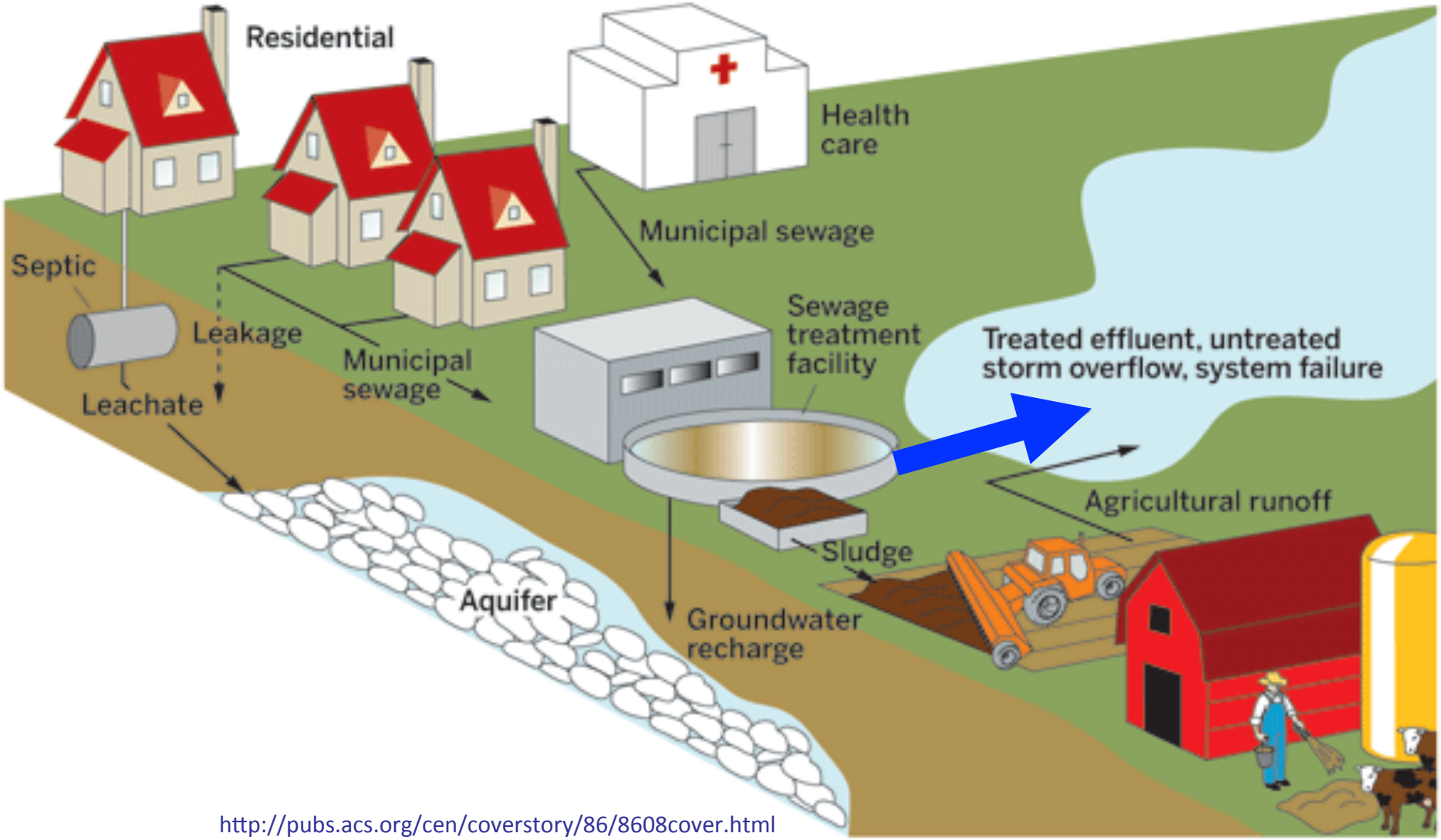
Inputs of Contaminants of Emerging Concern into the Cape Cod Aquifer from Onsite and Centralized Wastewater Treatment Systems

Laurel Schaider, Ph.D.
Research Scientist, Silent Spring Institute

NEWEA Microconstituents Specialty Conference
October 29, 2014

SILENT SPRING INSTITUTE

How do pharmaceuticals and other CECs get into the environment?



http://pubs.acs.org/cen/coverstory/86/8608cover.html

How do pharmaceuticals and other CECs get into the environment?

http://pubs.acs.org/cen/coverstory/86/8608cover.html

Septic systems and other onsite systems:

- Serve 25% of U.S. population
- One-third of new development

Yet little research on CECs focuses on septic systems

How do pharmaceuticals and other CECs get into the environment?

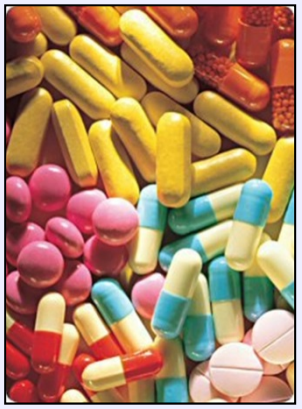
http://pubs.acs.org/cen/coverstory/86/8608cover.html

Cape Cod drinking water supplies are vulnerable

- 85% of homes have septic systems
- Sand and gravel sole source aquifer
- Rapid development

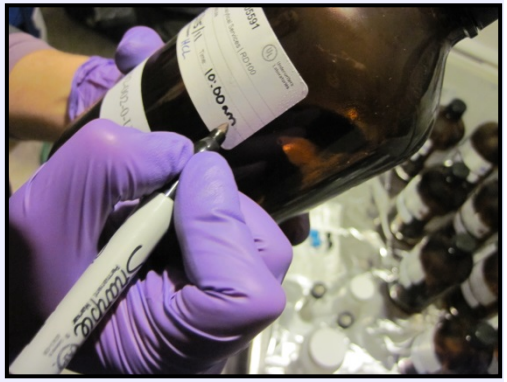
Examples of CECs

- Pharmaceuticals, personal care products, hormones, perfluorinated chemicals, consumer product chemicals
- Not currently regulated in drinking water, some are candidates
  - Candidate Contaminant List 3
  - Unregulated Contaminant Monitoring Rule 3
- Growing set of occurrence data
- Our understanding of human, ecological health effects vary among CECs



Cape Cod water quality research objectives

- Measure endocrine disruptors and other CECs in drinking water and groundwater
- Evaluate septic systems as sources of contaminants and characterize subsurface transport
- Inform Cape wastewater management and drinking water protection decision-making



Silent Spring Institute
Cape Cod water research

Septic systems

- First study to identify estrogen-mimicking alkylphenols in household wastewater, groundwater, and drinking water

Environ. Sci. Technol. **1998**, *32*, 861–869

Identification of Alkylphenols and Other Estrogenic Phenolic Compounds in Wastewater, Septage, and Groundwater on Cape Cod, Massachusetts

RUTHANN A. RUDEL,*,† STEVEN J. MELLY,† PAUL W. GENO,‡ GANG SUN,‡ AND JULIA G. BRODY†

Silent Spring Institute, 29 Crafts Street, Newton, Massachusetts 02158, and Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78228-0510

Silent Spring Institute
Cape Cod water research

Groundwater

- Some endocrine disruptors and other CECs are persistent in groundwater
- Persistence of CECs depends on dissolved oxygen levels

Environ. Sci. Technol. **2006**, *40*, 4894−4902

Steroid Estrogens, Nonylphenol Ethoxylate Metabolites, and Other Wastewater Contaminants in Groundwater Affected by a Residential Septic System on Cape Cod, MA

CHRISTOPHER H. SWARTZ,*,†,‡ SHARANYA REDDY,§ MARK J. BENOTTI,§ HAIFEI YIN,§ LARRY B. BARBER,⊥ BRUCE J. BROWNAWELL,§ AND RUTHANN A. RUDEL†

Silent Spring Institute
Cape Cod water research

Ponds

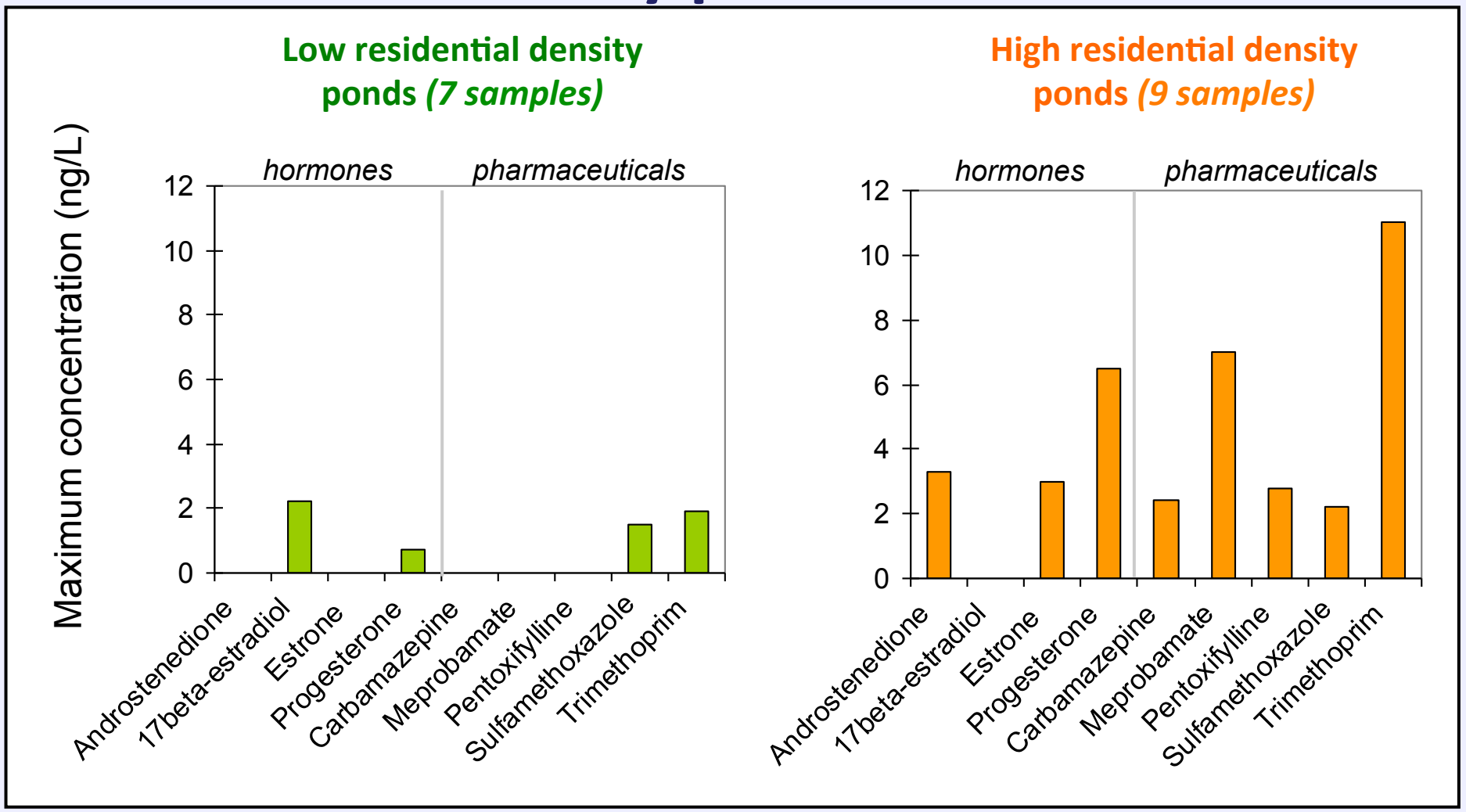
- Ponds more impacted by residential development have more hormones and pharmaceuticals
- Highest hormone levels approached ecological levels of concern

Environmental Toxicology and Chemistry, Vol. 27, No. 12, pp. 2457–2468, 2008

WASTEWATER-CONTAMINATED GROUNDWATER AS A SOURCE OF ENDOGENOUS HORMONES AND PHARMACEUTICALS TO SURFACE WATER ECOSYSTEMS

LAUREL J. STANDLEY,*† RUTHANN A. RUDEL,† CHRISTOPHER H. SWARTZ,‡ KATHLEEN R. ATTFIELD,†
JEFF CHRISTIAN,§ MIKE ERICKSON,§ and JULIA G. BRODY†
†Silent Spring Institute, 29 Crafts Street, Suite 150, Newton, Massachusetts 02458, USA
‡Stockholm Environment Institute, 11 Curtis Avenue, Somerville, Massachusetts 02144, USA
§Columbia Analytical Services, 1317 South 13th Avenue, Kelso, Washington 98626, USA

Higher concentrations in high residential density ponds



Ibuprofen detected, not shown on graphs

Standley et al., ET&C, 2008

Silent Spring Institute
Cape Cod water research

Public wells

- Pharmaceuticals, perfluorinated chemicals, and flame retardants found in public wells
- Nitrate, boron, and unsewered development all correlated with extent of CECs

Science of the Total Environment 468–469 (2014) 384–393

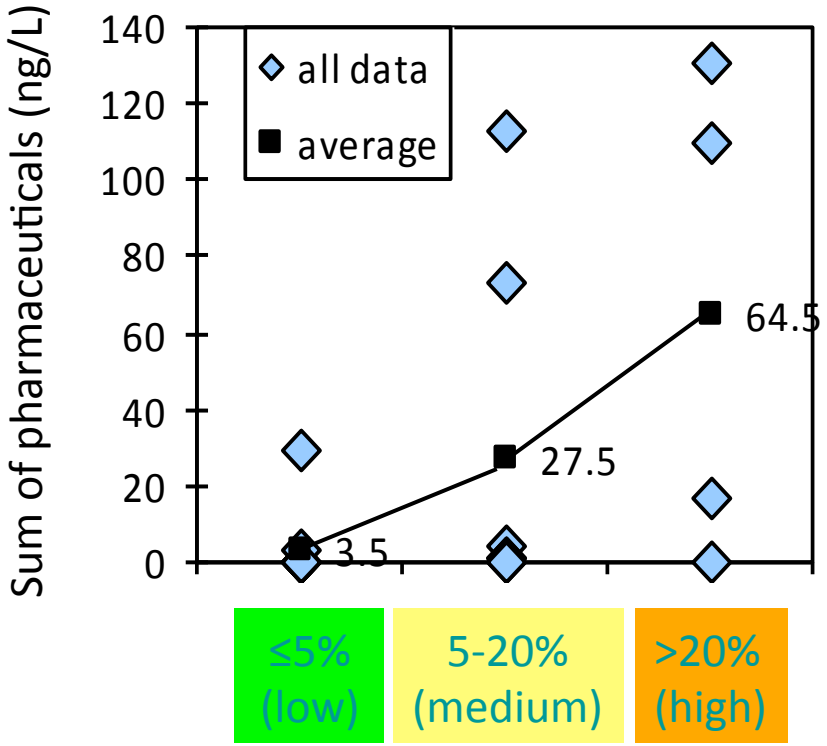
Pharmaceuticals, perfluorosurfactants, and other organic wastewater compounds in public drinking water wells in a shallow sand and gravel aquifer☆

Laurel A. Schaider *, Ruthann A. Rudel, Janet M. Ackerman, Sarah C. Dunagan, Julia Green Brody

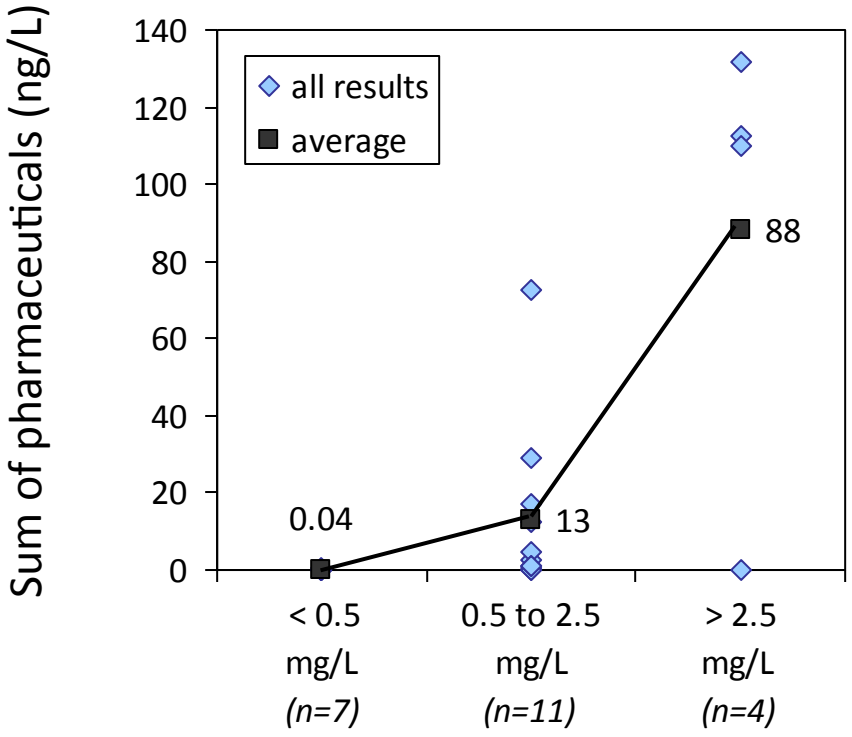
Silent Spring Institute, 29 Crafts Street, Newton, MA 02458, USA

Wells with more residential development and higher nitrate had more emerging contaminants

Total pharmaceutical concentration (ng/L)



Percent of recharge areas used for residential development



Silent Spring Institute
Cape Cod water research

Private wells

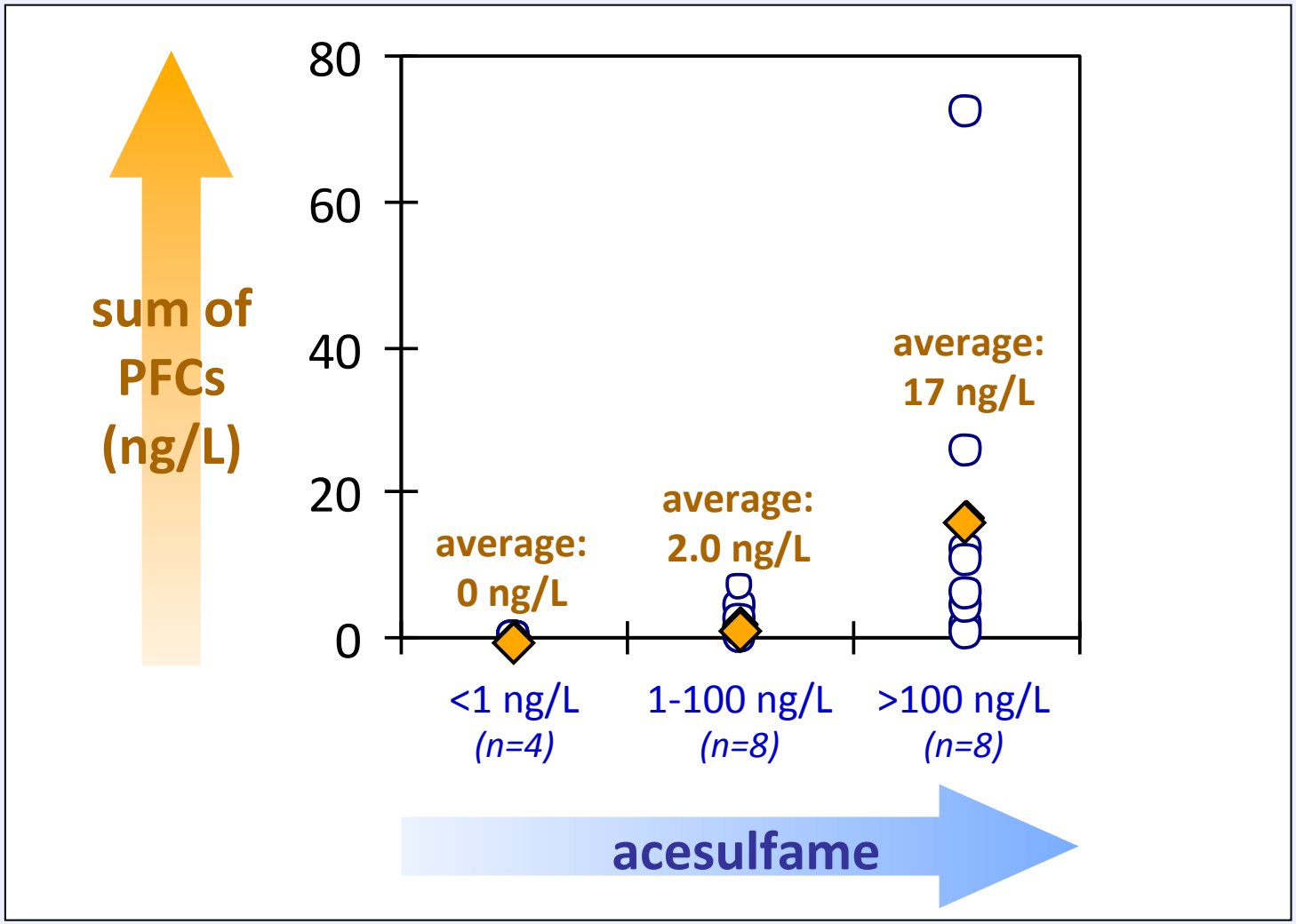
- Pharmaceuticals and perfluorinated chemicals found in many private wells
- Artificial sweetener (acesulfame) sensitive wastewater marker and CEC indicator

RESEARCHING THE ENVIRONMENT AND WOMEN'S HEALTH

Emerging Contaminants in Cape Cod Private Drinking Water Wells

November 2011

Wastewater appears to be primary source of perfluorinated chemicals in private wells



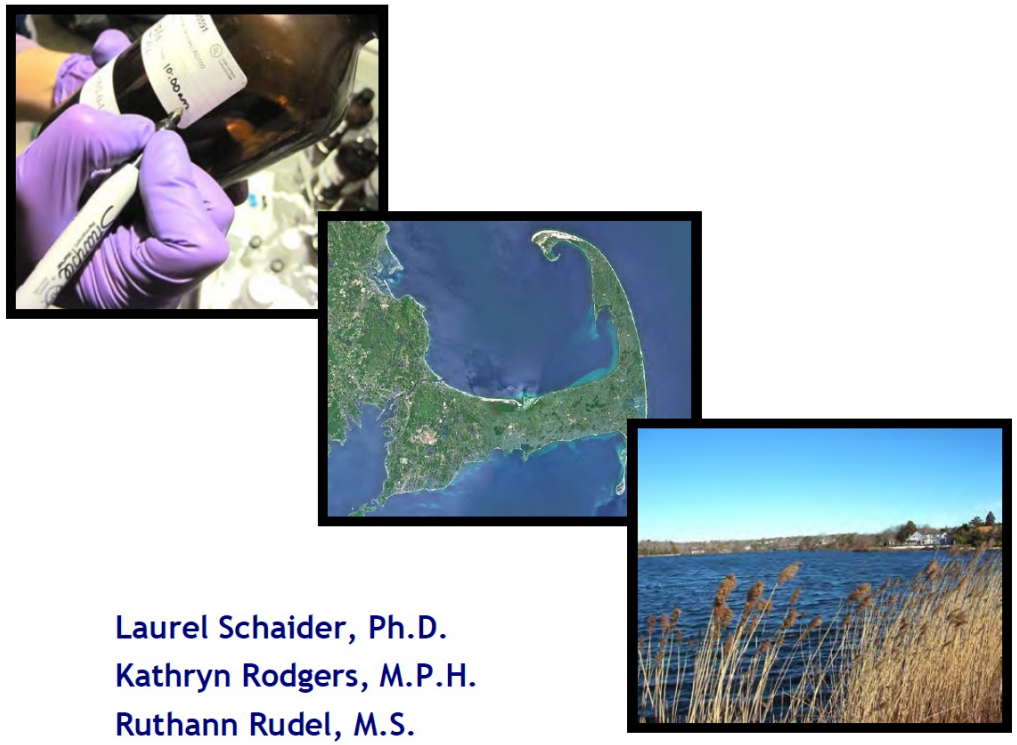
Septic systems are impacting Cape Cod groundwater quality.

25% of Americans have a septic system.

But what do we know about CEC discharges from septic systems?

Contaminants of Emerging Concern and Septic Systems:

A Synthesis of Scientific Literature and Application to Groundwater Quality on Cape Cod



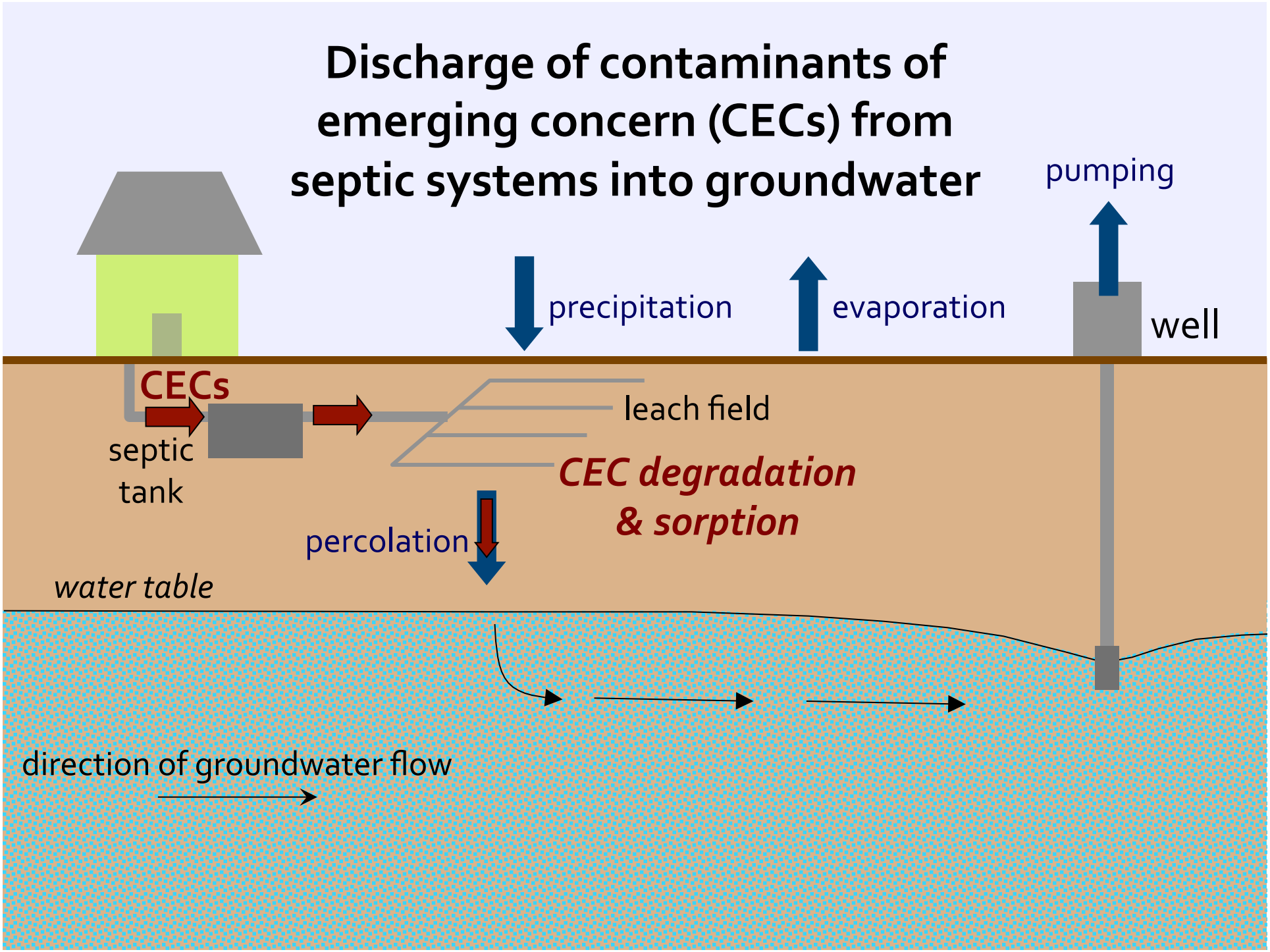
Laurel Schaider, Ph.D.
Kathryn Rodgers, M.P.H.
Ruthann Rudel, M.S.

Silent Spring Institute
Newton, MA
September 2013

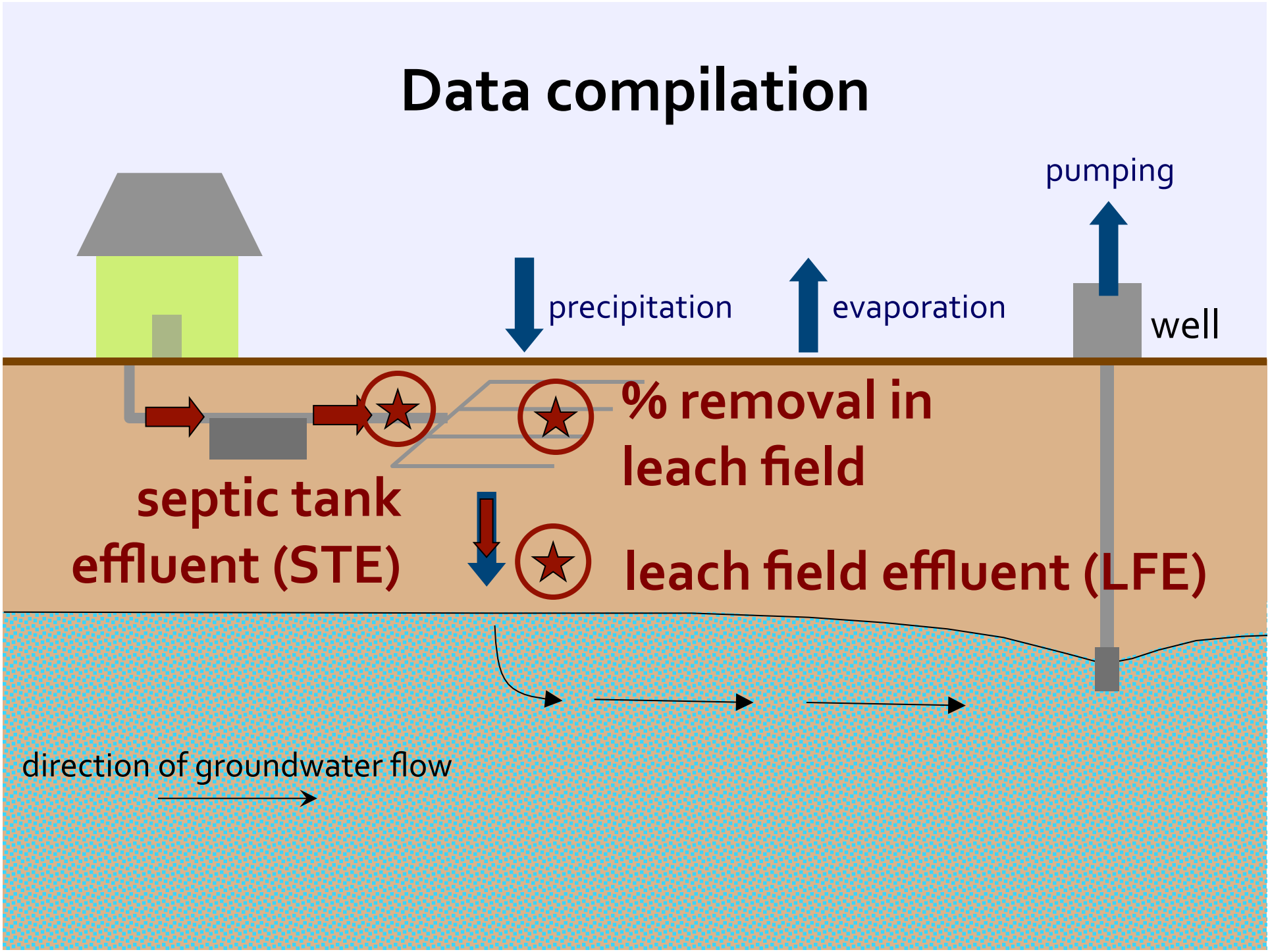
Emerging contaminants in septic systems and inputs into Cape Cod groundwater

Objectives

- Synthesize available studies of CEC removal and discharge from septic systems
- Compare CEC concentrations in effluent from septic systems and centralized treatment plants
- Model CEC inputs into Cape Cod groundwater


Discharge of contaminants of emerging concern (CECs) from septic systems into groundwater
pumping
precipitation
evaporation
well
CECs
leach field
septic tank
CEC degradation & sorption
percolation
water table
direction of groundwater flow

Data compilation



Studies in compilation

- 16 studies measured CECs in septic tank effluent, leach field effluent, or % removal in leach fields
- Some systems serve one household or more households, others serve institutional sources
- Some leach field effluent concentrations were estimated based on septic tank effluent and % removal

Initial list of chemicals of interest

Pharmaceuticals

Prescription

- **carbamazepine**
- diclofenac
- **gemfibrozil**
- naproxen
- **sulfamethoxazole**
- **trimethoprim**

Non-prescription

- acetaminophen
- caffeine
- cotinine
- ibuprofen
- paraxanthine

Hormones

- 17β-estradiol
- estriol
- estrone

Personal care products

- **bisphenol A**
- **DEET**
- **salicylic acid**
- triclosan

*** detected in Cape Cod drinking water**

Flame retardants

- **TBEP**
- **TBP**
- **TCEP**
- **TCPP**
- **TDCPP**

Alkylphenols

- **nonylphenol (NP)**
- NP ethoxylates
- NP1EC
- octylphenol (OP)
- OP ethoxylates

9 chemicals for further study

Pharmaceuticals

Prescription

- carbamazepine
- diclofenac
- gemfibrozil
- naproxen
- sulfamethoxazole
- trimethoprim

Non-prescription

- acetaminophen
- caffeine
- cotinine
- ibuprofen
- paraxanthine

Hormones

- 17β-estradiol
- estriol
- estrone

Personal care products

- bisphenol A
- DEET
- salicylic acid
- triclosan

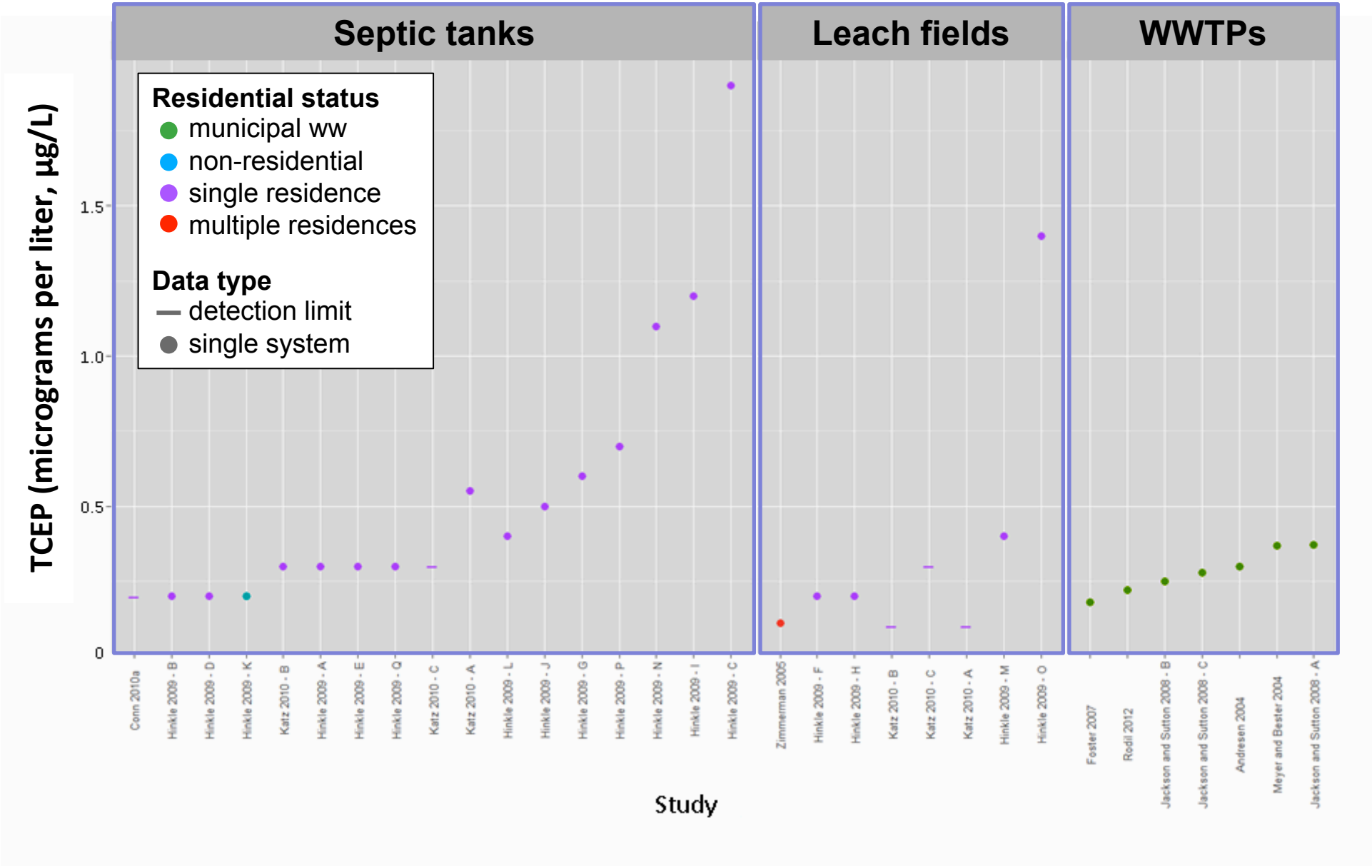
Flame retardants

- TBEP
- TBP
- TCEP
- TCPP
- TDCPP

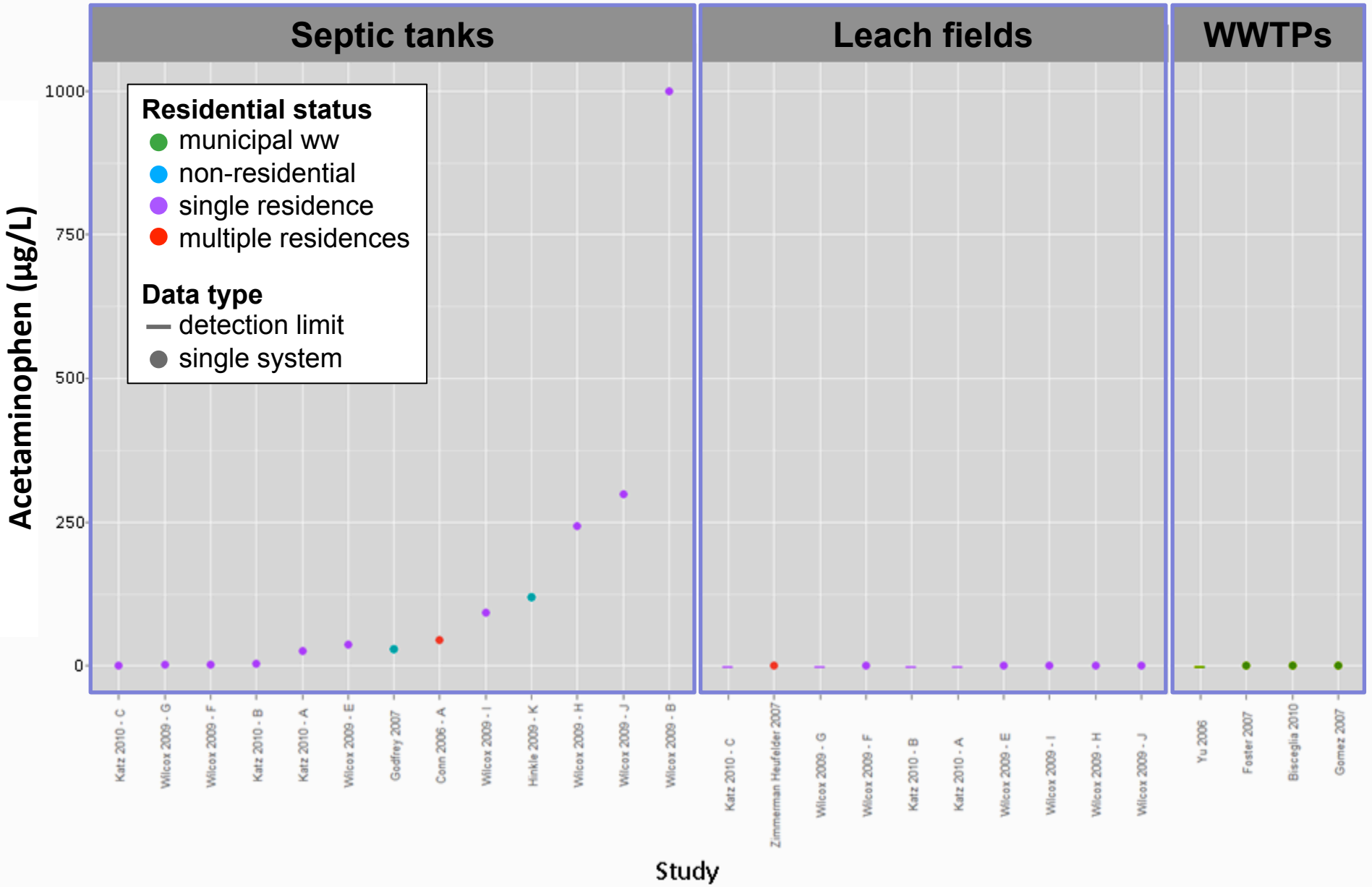
Alkylphenols

- nonylphenol (NP)
- NP ethoxylates
- NP1EC
- octylphenol (OP)
- OP ethoxylates

TCEP (flame retardant) – poorly removed



Acetaminophen (Tylenol) – well removed



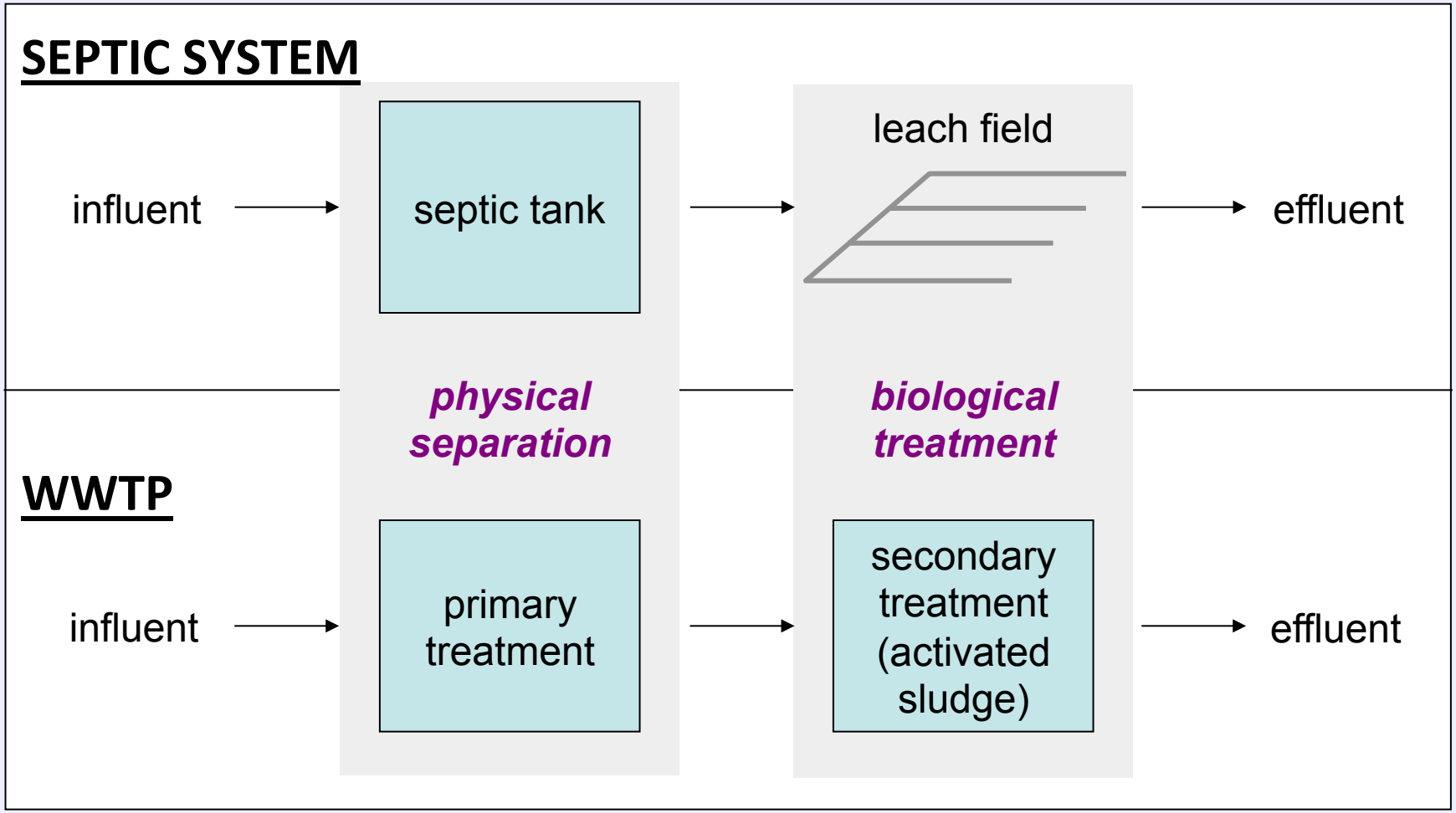
	Median concentration in septic tank effluent (µg/L)	Median concentration in leach field effluent (µg/L)	Median concentration in WWTP effluent (µg/L)	Median percent removal in leach fields (%)
Well removed in WWTPs (>80% removal)				
acetaminophen	40	0.1	0.1	>99%
caffeine	40	0.1	1	>99%
nonylphenol	30	7	0.3	80%
triclosan	1	0.1	0.2	90%
Moderately removed in WWTPs (50-80% removal)				
DEET	1	0.2	0.1	80%
sulfamethoxazole	0.03	0.2	0.1	40%
trimethoprim	0.6	0.01	0.03	70%
Poorly removed in WWTPs (<50% removal)				
carbamazepine	0.9	0.08	0.5	40%
TCEP	0.3	0.2	0.3	30%

	Median concentration in septic tank effluent (µg/L)	Median concentration in leach field effluent (µg/L)	Median concentration in WWTP effluent (µg/L)	Median percent removal in leach fields (%)
Well removed in WWTPs (>80% removal)				
acetaminophen	40	0.1	0.1	>99%
caffeine	40	0.1	1	>99%
nonylphenol	30	7	0.3	80%
triclosan	1	0.1	0.2	90%
Moderately removed in WWTPs (50-80% removal)				
DEET	1	0.2	0.1	80%
sulfamethoxazole	0.03	0.2	0.1	40%
trimethoprim	0.6	0.01	0.03	70%
Poorly removed in WWTPs (<50% removal)				
carbamazepine	0.9	0.08	0.5	40%
TCEP	0.3	0.2	0.3	30%

	Median concentration in septic tank effluent (µg/L)	Median concentration in leach field effluent (µg/L)	Median concentration in WWTP effluent (µg/L)	Median percent removal in leach fields (%)
Well removed in WWTPs (>80% removal)				
acetaminophen	40	0.1	0.1	>99%
caffeine	40	0.1	1	>99%
nonylphenol	30	7	0.3	80%
triclosan	1	0.1	0.2	90%
Moderately removed in WWTPs (50-80% removal)				
DEET	1	0.2	0.1	80%
sulfamethoxazole	0.03	0.2	0.1	40%
trimethoprim	0.6	0.01	0.03	70%
Poorly removed in WWTPs (<50% removal)				
carbamazepine	0.9	0.08	0.5	40%
TCEP	0.3	0.2	0.3	30%

	Median concentration in septic tank effluent (µg/L)	Median concentration in leach field effluent (µg/L)	Median concentration in WWTP effluent (µg/L)	Median percent removal in leach fields (%)
Well removed in WWTPs (>80% removal)				
acetaminophen	40	0.1	0.1	>99%
caffeine	40	0.1	1	>99%
nonylphenol	30	7	0.3	80%
triclosan	1	0.1	0.2	90%
Moderately removed in WWTPs (50-80% removal)				
DEET	1	0.2	0.1	80%
sulfamethoxazole	0.03	0.2	0.1	40%
trimethoprim	0.6	0.01	0.03	70%
Poorly removed in WWTPs (<50% removal)				
carbamazepine	0.9	0.08	0.5	40%
TCEP	0.3	0.2	0.3	30%

Conventional septic system vs. conventional WWTP

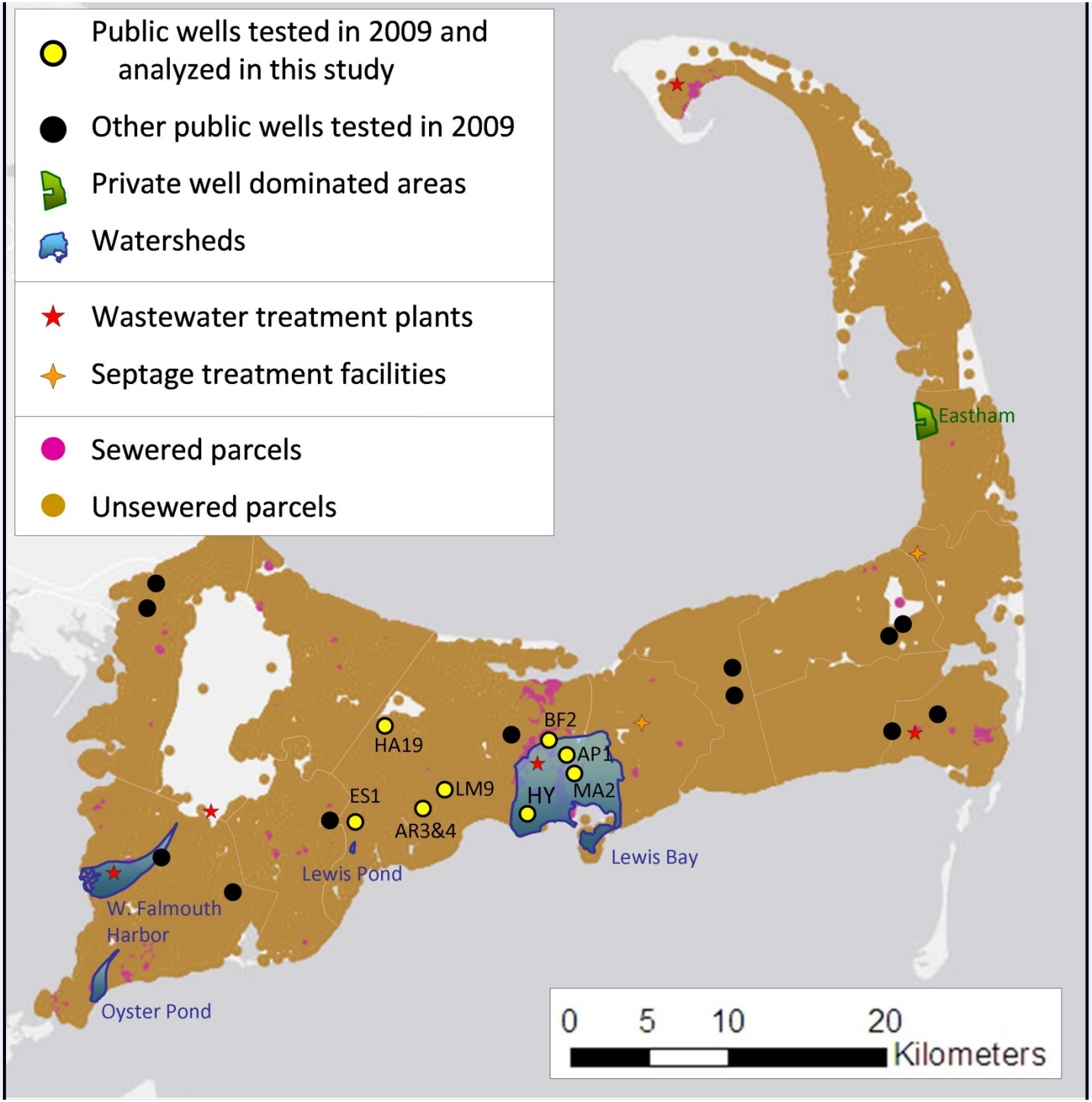


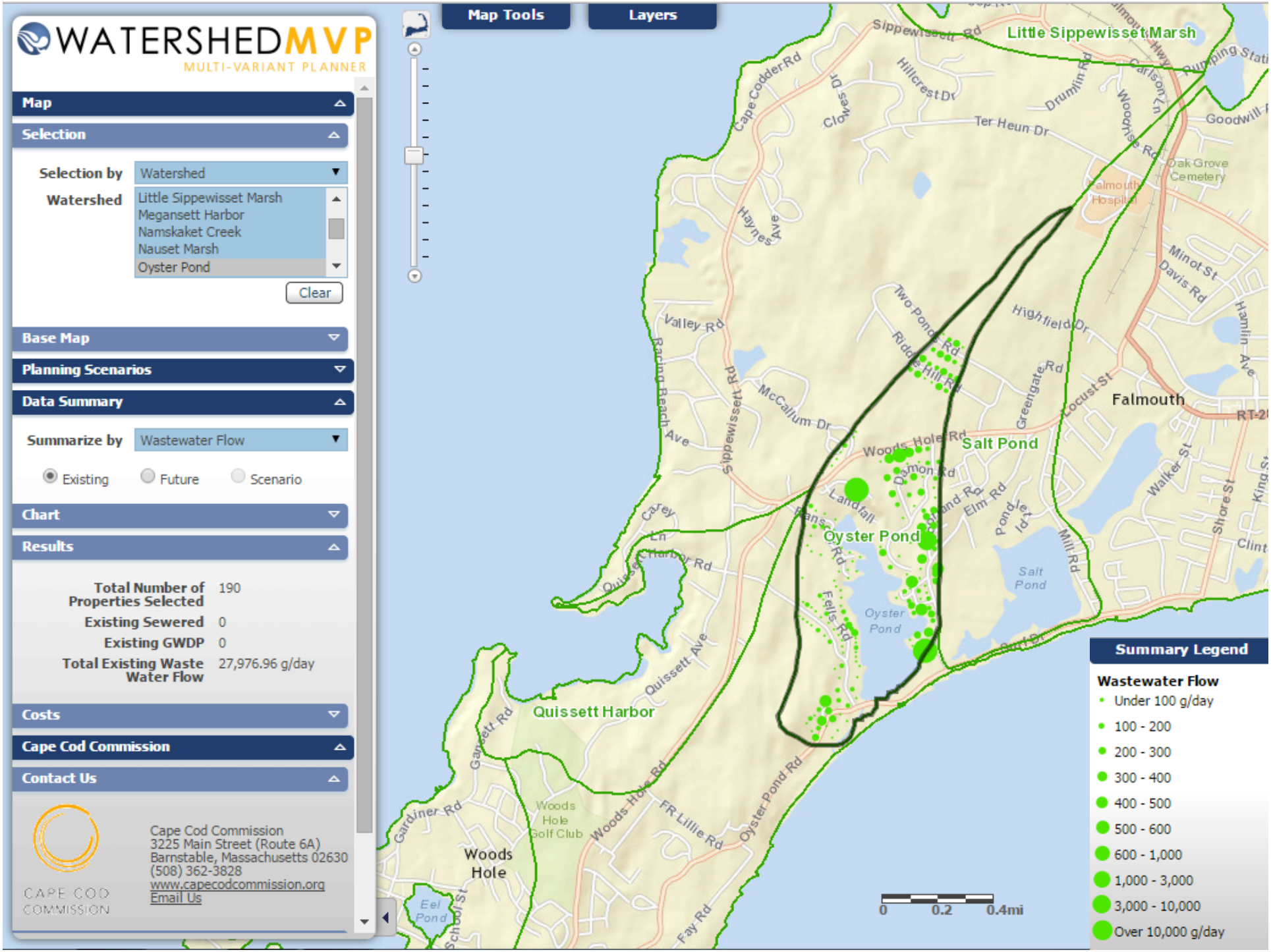
Next steps for data compilation

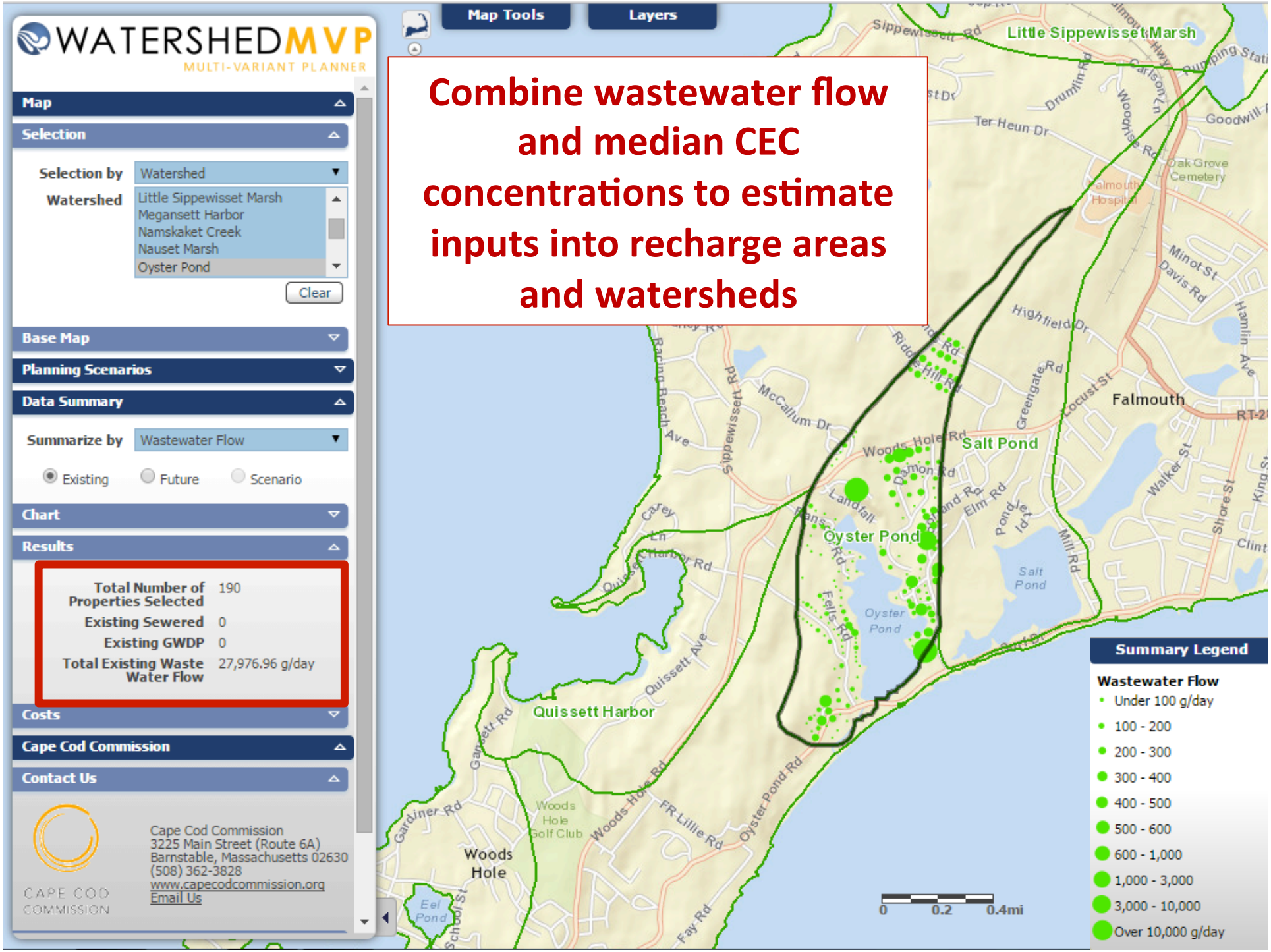
- Incorporate new studies
- Include advanced onsite systems
- Additional statistical approaches for datasets with many non-detects (Helsel)

Estimating CEC inputs to groundwater

- Which areas of Cape Cod receive most concentrated CEC inputs?
- Areas of interest
  - Public wells recharge areas
  - Areas served by private wells
  - Coastal and freshwater watersheds


Public wells tested in 2009 and analyzed in this study
Other public wells tested in 2009
Private well dominated areas
Watersheds
Wastewater treatment plants
Septage treatment facilities
Sewered parcels
Unsewered parcels
Eastham
HA19
BF2
AP1
MA2
HY
LM9
ES1
AR3&4
Lewis Pond
Lewis Bay
W. Falmouth Harbor
Oyster Pond
0 5 10 20
Kilometers


WATERSHEDMVP
MULTI-VARIANT PLANNER
Map
Selection
Selection by
Watershed
Watershed
Little Sippewisset Marsh
Megansett Harbor
Namskaket Creek
Nauset Marsh
Oyster Pond
Clear
Base Map
Planning Scenarios
Data Summary
Summarize by
Wastewater Flow
Existing
Future
Scenario
Chart
Results
Total Number of Properties Selected 190
Existing Sewered 0
Existing GWDP 0
Total Existing Waste Water Flow 27,976.96 g/day
Costs
Cape Cod Commission
Contact Us
Cape Cod Commission
3225 Main Street (Route 6A)
Barnstable, Massachusetts 02630
(508) 362-3828
www.capecodcommission.org
Email Us
CAPE COD COMMISSION
Map Tools
Layers
Little Sippewisset Marsh
Falmouth
Salt Pond
Oyster Pond
Quissett Harbor
Woods Hole
Woods Hole Golf Club
Eel Pond
Salt Pond
Oyster Pond
Falmouth Hospital
Oak Grove Cemetery
0 0.2 0.4mi
Summary Legend
Wastewater Flow
Under 100 g/day
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 1,000
1,000 - 3,000
3,000 - 10,000
Over 10,000 g/day


WATERSHEDMVP
MULTI-VARIANT PLANNER
Map
Selection
Selection by
Watershed
Watershed
Little Sippewisset Marsh
Megansett Harbor
Namskaket Creek
Nauset Marsh
Oyster Pond
Clear
Base Map
Planning Scenarios
Data Summary
Summarize by
Wastewater Flow
Existing
Future
Scenario
Chart
Results
Total Number of Properties Selected 190
Existing Sewered 0
Existing GWDP 0
Total Existing Waste Water Flow 27,976.96 g/day
Costs
Cape Cod Commission
Contact Us
Cape Cod Commission
3225 Main Street (Route 6A)
Barnstable, Massachusetts 02630
(508) 362-3828
www.capecodcommission.org
Email Us
CAPE COD COMMISSION
Map Tools
Layers
Combine wastewater flow and median CEC concentrations to estimate inputs into recharge areas and watersheds
Little Sippewisset Marsh
Falmouth
Salt Pond
Oyster Pond
Quissett Harbor
Woods Hole
Woods Hole Golf Club
Eel Pond
Summary Legend
Wastewater Flow
Under 100 g/day
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 1,000
1,000 - 3,000
3,000 - 10,000
Over 10,000 g/day
0
0.2
0.4mi

		4-NONYLPHENOL		TCEP		SULFAMETHOXAZOLE	
		grams per year	grams per sq. mile per year	grams per year	grams per sq. mile per year	grams per year	grams per sq. mile per year
Whole Cape		200,000	500	8,000	20	7,000	20
Public wells							
BFD2 (BF2)	ZOC	50	300	2	9	2	9
(Barnstable)	Zone 2	700	100	30	4	20	4
Arena 3&4	ZOC	200	1,000	6	50	6	50
(C-O-MM)	Zone 2	3,000	800	80	30	90	30
Electric Station 1	ZOC	100	700	4	20	4	20
(Cotuit)	Zone 2	300	600	10	20	10	20
Lumbert Mill 9	ZOC	300	900	9	30	9	30
(C-O-MM)	Zone 2	2,000	1,000	70	30	70	40
Hyannisport	ZOC	900	1,000	30	60	30	50
(Hyannis)	Zone 2	2,000	2,000	300	200	100	70
Private well areas							
Eastham		1,000	2,000	40	70	40	80
Watersheds							
Lewis Bay system		10,000	900	900	70	500	40
West Falmouth Harbor		1,000	500	200	60	60	20
Lewis Pond		20	200	0.6	7	0.6	7
Oyster Pond		200	400	8	10	8	10

Challenges and limitations

- Few studies available
- Some chemicals not studied at all
  - e.g., perfluorinated chemicals
- Many non-detects
- Leach field “effluent” difficult to assess
- Cape Cod wastewater may be different
- Only modeling inputs, not fate and transport

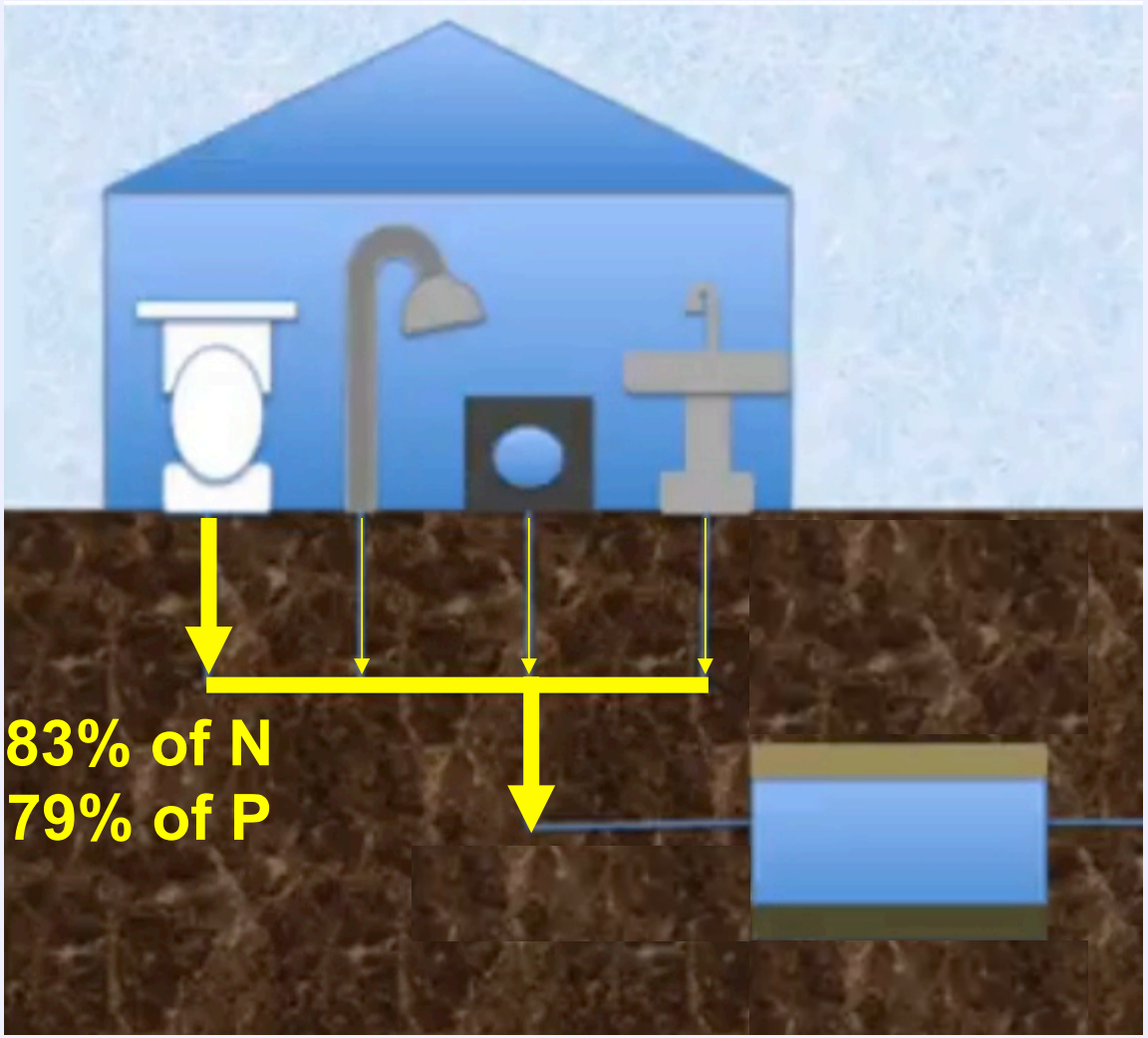
Sewers vs. septic systems

- WWTPs may not do a better job of removing CECs than septic systems
- Additional considerations:
  - Advanced onsite and centralized treatment will remove more ↑
  - Failing or old septic systems and leaky sewers will remove less ↓
  - WWTPs can add disinfection by-products ↑
- What about alternatives ...

Eco-toilets

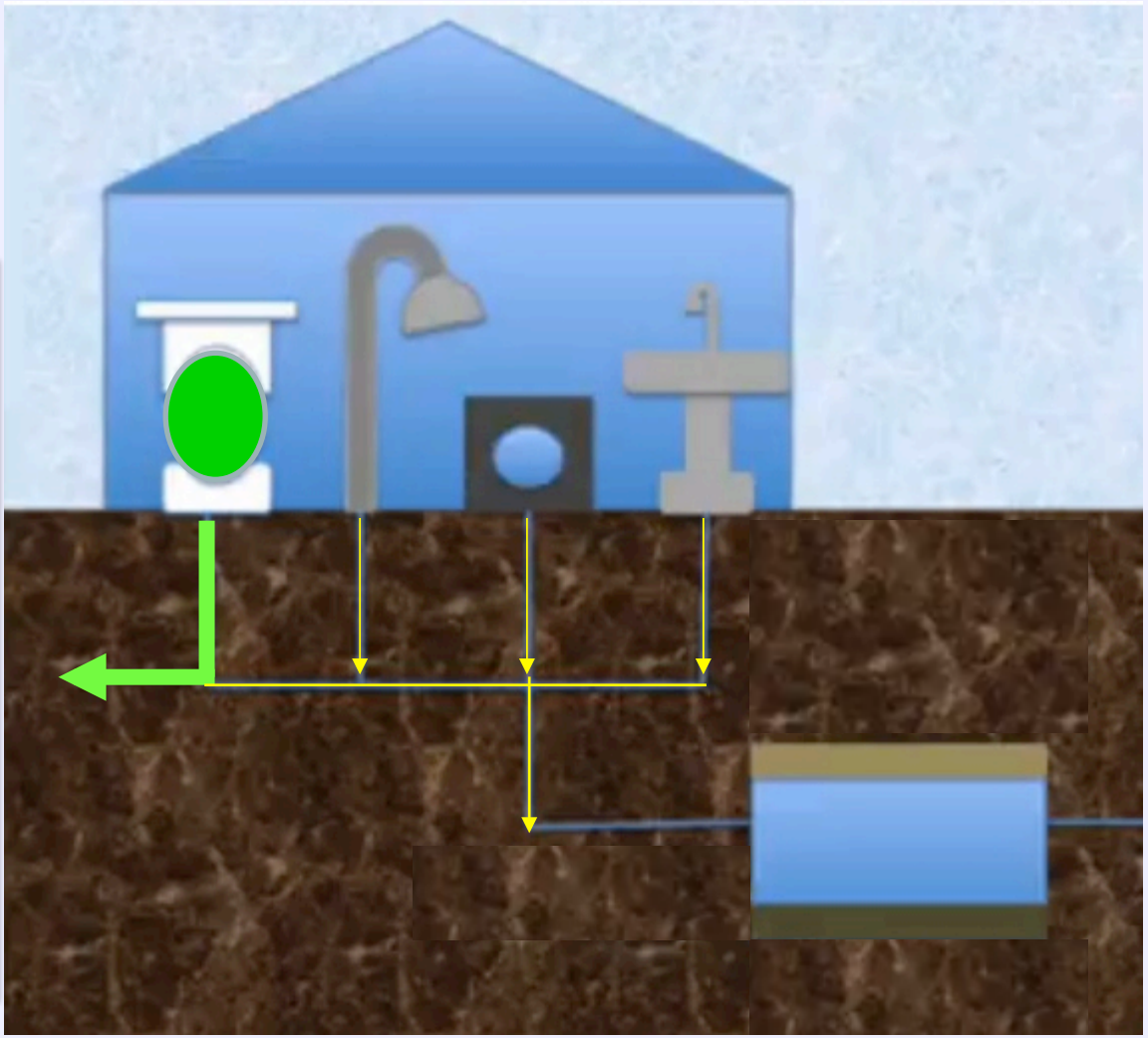
- Composting or urine diverting
- Town of Falmouth, MA:
  pilot project to measure nitrogen in septic systems after eco-toilet installation
- What happens to CECs?

Toilets are major source of nutrients

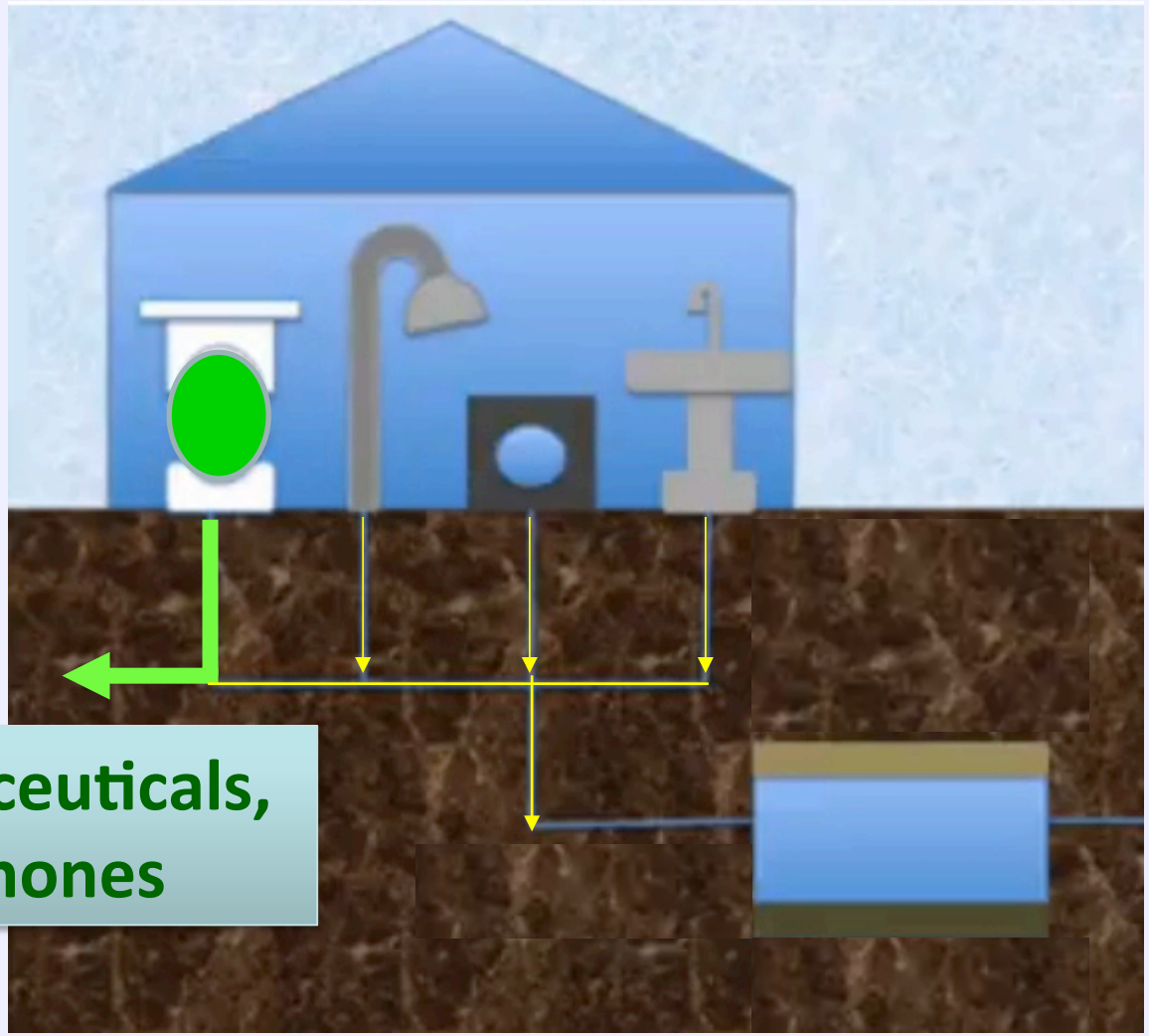


Eco-toilets divert nutrients

Divert nutrients from ground water, allow for beneficial reuse

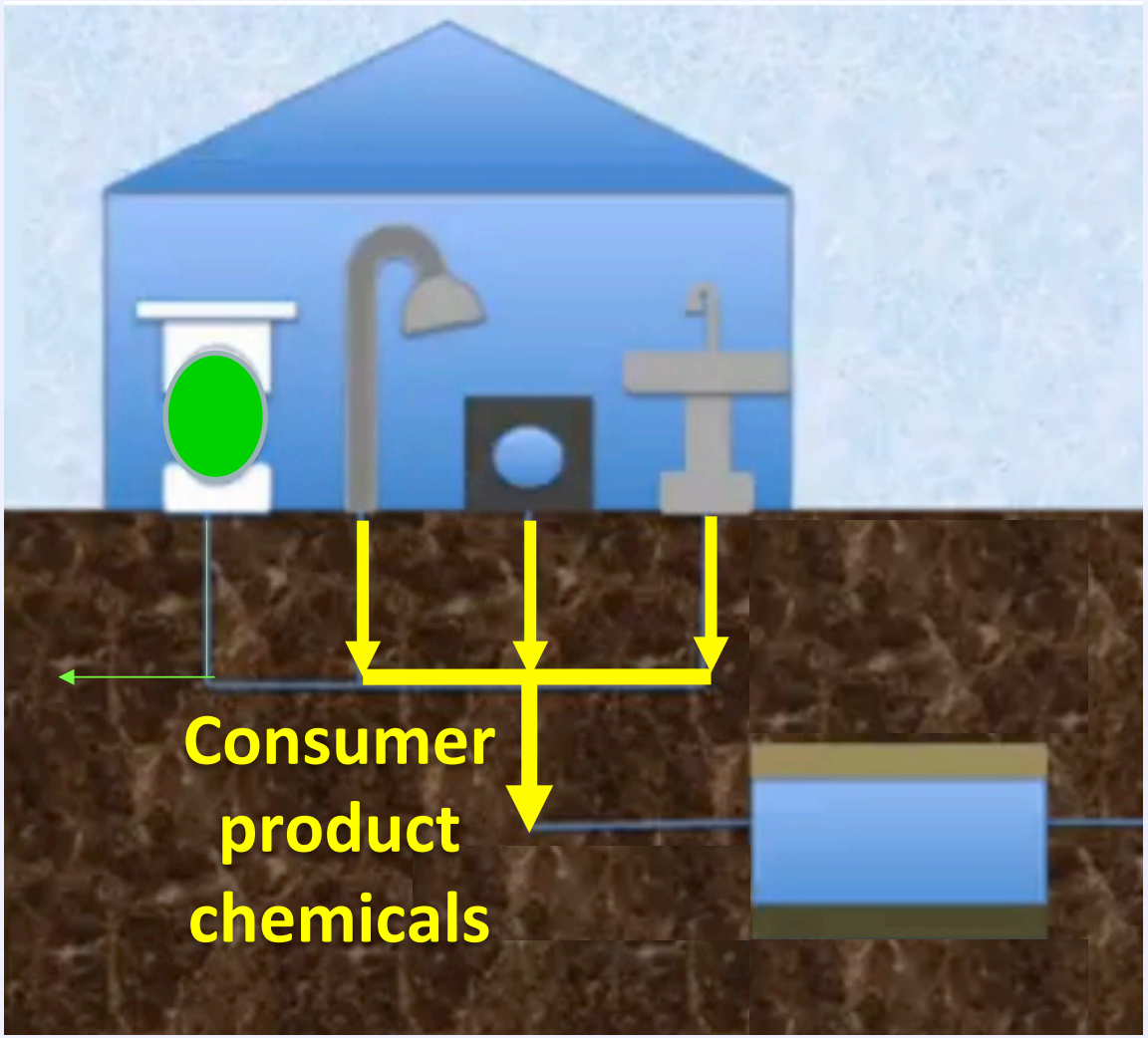


Can eco-toilets reduce CEC pollution?

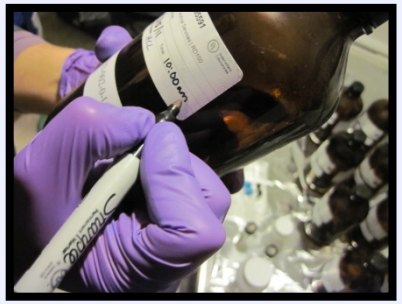


Pharmaceuticals, hormones

Can eco-toilets reduce CEC pollution?



Implications and future work



- Presence of CECs in Cape Cod groundwater raises health concerns
- Strategies for managing nutrients may alter location and amount of CECs entering Cape groundwater
- Eco-toilets study will provide information about CEC contributions from blackwater
- Further study needed of sources and fate of perfluorinated chemicals

Acknowledgements

- Ruthann Rudel, Julia Brody, Kathryn Rodgers

- Commonwealth of Massachusetts
- Mass. Environmental Trust
- Private donations
- Tom Cambareri

MASSACHUSETTS ENVIRONMENTAL TRUST

Contact information:

Laurel Schaider, Ph.D.

Research Scientist

schaider@silentspring.org

www.silentspring.org/water

SILENT SPRING INSTITUTE

Press Room | FAQs | Support Our Work | Contact Us | Home

ABOUT US | BREAST CANCER AND THE ENVIRONMENT | OUR RESEARCH | OUR PUBLICATIONS | OUR TOOLS | TAKE ACTION

Search

Home » Our Research » Water Research

- Everyday Chemical Exposures
  - Household Exposure Study
  - Household Exposure Study in Richmond and Bolinas, California
  - Testing Exposure Reduction Strategies
  - Flame Retardants
  - Ethics in Community Research
    - Reporting Individual Exposure Results
    - Data Sharing and Privacy Protection
- Chemicals and Breast Cancer
  - Chemical Effects on Mammary Gland Development
  - Tools for Green Chemistry: High Throughput Screening
  - Mammary Gland Carcinogens List
  - Science Reviews and Database
  - Guide to Cohort Studies
- Environmental Justice
- **Water Research**
  - **Wastewater from Septic Systems**
  - **Ponds**
  - **Public Drinking Water Supplies**
  - **Private Drinking Water Wells**
  - **Alternative Wastewater Solutions**

Water Research

To protect Cape Cod's coastal marine sanctuary, wastewater is disposed on land, primarily in septic systems that allow pollutants to seep through porous soils, often reaching shallow drinking water wells. Silent Spring Institute is undertaking a number of initiatives aimed at understanding the role that such polluted water may play in the disproportionately high levels of breast cancer on Cape Cod.

Estrogens And Other Hormonally Active Pollutants In Groundwater And Drinking Water

Drinking water for Cape Cod residents comes from a sole-source aquifer. Because the Cape has a shallow water table and sandy, porous soil, the aquifer is particularly vulnerable to land use activity. Silent Spring Institute's study*Tracking Estrogens and Other Hormonally Active Pollutants in Cape Cod Groundwater and Drinking Water* focuses on measuring degradation to groundwater quality from wastewater leaching from septic systems and into the aquifer. This

RELATED SCIENTIFIC RESOURCES

Additional Resource

What are Emerging Contaminants? Endocrine Disruptors & Chemicals of Concern in Drinking Water

National media brings attention to hormones in drinking water and consumer products

Invited Talk

Pharmaceuticals and Other Emerging Contaminants in Public and Private Drinking Water Wells on Cape Cod, Massachusetts.

Wastewater and Emerging Contaminants of Concern

Scientific Article or Summary

Historical reconstruction of wastewater and land use impacts to groundwater used for public drinking water: exposure assessment using chemical data and GIS

Identification of alkylphenols and other estrogenic phenolic