UNIVERSITY OF ALBERTA
SCHOOL OF PUBLIC HEALTH

Risk-Based Targets for Design & Management of On-site Systems

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Clean Water Act and Safe Drinking Water Act: Costly and Outdated

- **Fundamental problem:** focus is on centralized system impacts
  - Poorly addresses 'secondary' upstream (on-site) impacts
    - E.g. Cape Cod is reinvoking an old 208 wastewater management planning process to deal with on-site caused eutrophication
  - From a health point of view – focus is on coliforms, which can easily be removed but leave pathogens (enteric viruses, protozoa & post-treatment environmental pathogens and antibiotic-resistance gene issues)

Solution – System's Understanding so:

1. Promote more sustainable systems, and
2. Manage safe water (reuse)

Current water quality targets for water reuse

Californian Title 22 (1978, 2007)

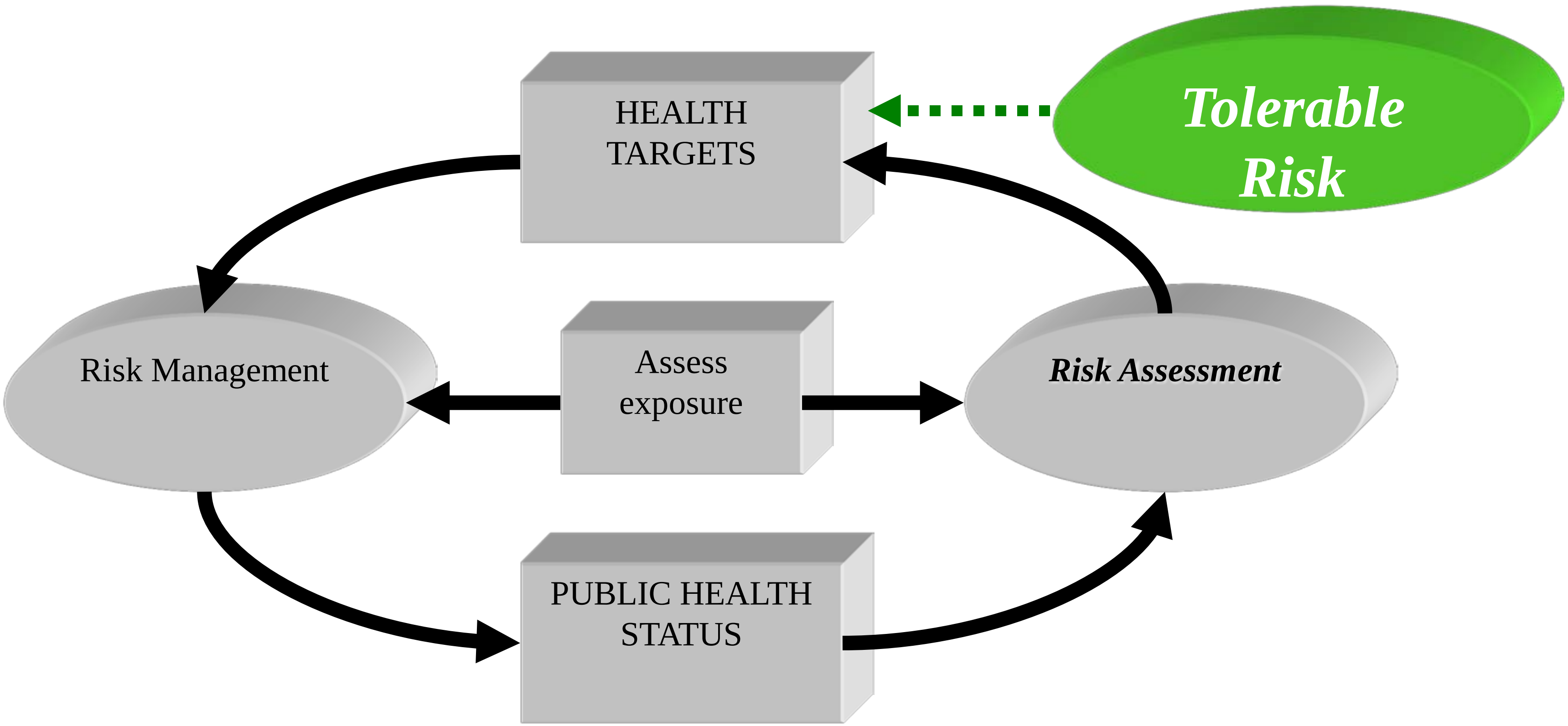
- Specifies treatment steps (with described log-reductions by unit processes), requiring:
  - 5-$\log_{10}$ virus reduction based on piking studies[1]
    - **Performance-based but by process type, not on-site**
  - NTU <2 (daily average) & chlorine 1 mg/L
    - **i.e. process-based targets**
  - Total Coliforms (<2.2 MPN/100 mL) as a **[poor]** overall index of treatment performance

[1]F-RNA coliphage MS2 (ATCC 15597B1, grown on *E. coli* ATCC 15597), poliovirus or other that is at least as resistant as poliovirus (based on Pomona Virus Study [Nellor *et al*. 1994])

Major international microbial criteria for non-potable reuse (by 1995)

Parameter	Title 22	Arizona	NSW - Australia	Israel
Designated treatment train	Yes	Yes	Multiple barriers	No
Total coliforms / 100 mL	< 2.2 MPN		<10 (90%ile) into distribution <2.5 (50%ile) at point of use	< 1000
Fecal coliforms/100 mL			< 1	-
Viruses	5-$\log_{10}$ reduction in spiking studies[5]	<125/40 L restricted <1/40 L open use	<2/50 L	-
Parasites		<1/40 L	<1/50 L	< 1 ova/L
Turbidity (NTU)	<2 (daily average)		<2 50%ile <5 95%ile	-
Color (total color)	-	-	<15	-
Chorine residual	1 mg/L	-	5 mg/L at first reservoir, 2 mg/L at customers	-

WHO & Australian Risk management framework (post 2000)

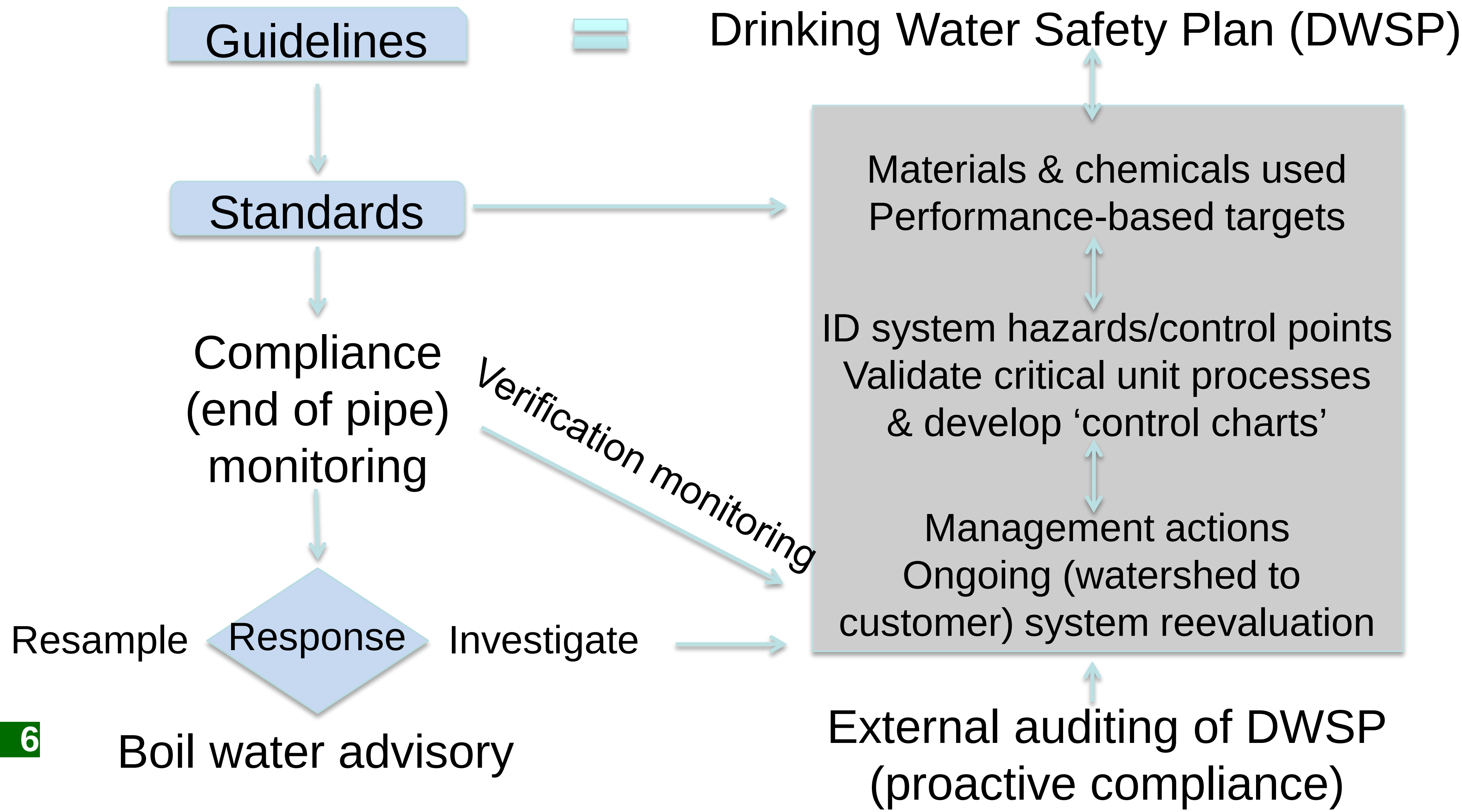


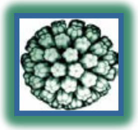
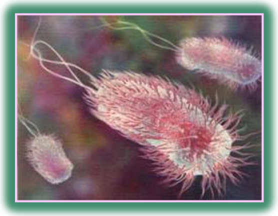
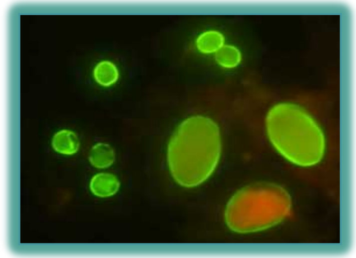
Fewtrell & Bartram (2001) Water Quality: Guidelines, Standards and Health. Risk Assessment and Management for Water Related Infectious Diseases, WHO, Geneva

Transitioning from Stds & Guidelines to WSP framework

Current reactive management of Drinking Water

WSP proactive management of Drinking Water (Alberta)



Key issue: Hazardous events

- System's approach to identifying & managing **enteric pathogen** risks depends upon:
  - **ID and control of short-duration hazardous events throughout the system; via**
  - **Surrogate target levels (at control points)**

Percent of exceedances missed for different sampling frequencies

Sampling frequency	Missed exceedances (%)
5 days per week (weekdays)	20%
3 times per week	45%
Once per week	75%
Once per moth	95%

Leecaster and Weisberg (2001) Marine Pollut Bull 42(11): 1150–1154

What is appropriate for on-site systems?

Possible Questions:

1. Use a Title 22-like approach and characterize system types for pathogen reduction?
2. What is the end-point of acceptability based on?
   – Current coliform criteria not health-based
3. How to administer on-site performance?

Possible answer:

- **Risk-based criteria based on a water safety plan approach**

Quantitative Microbial Risk Assessment (QMRA): Regulatory & operational uses

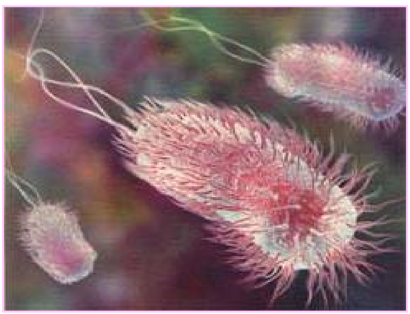
- Recently WHO & EPA have set water criteria and/or treatment requirements based on QMRA

  e.g. 3 & 4 log reductions in Drinking Water (DW) parasites & viruses, respectively

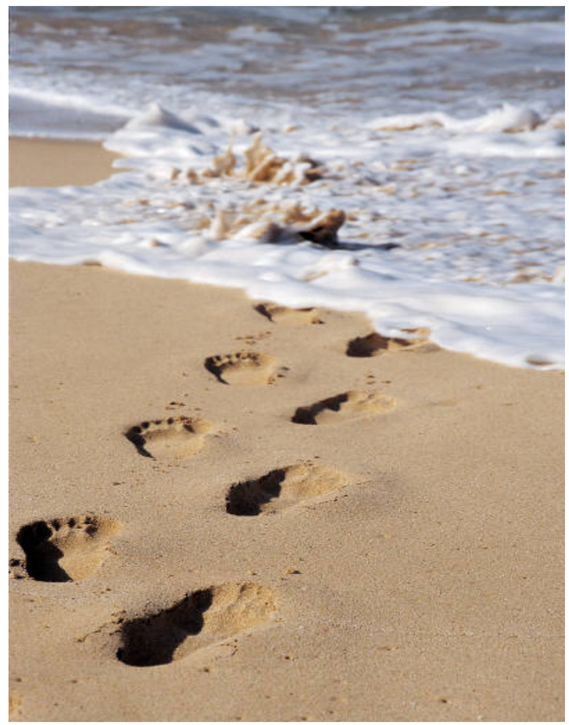
- Risk-based targets (also provide QMRA goal)
  - **Not current EPA policy:** DW < 1 infection 10^{-4}/year
  - **WHO/Australia: DW & reuse:** < 10^{-6} DALY/year
  - **EPA policy:** rec water < 32-36 NGI/1000 people.day

Recreational water quality criteria: The only health-based water criteria i.e. from epidemiology studies

Indicator

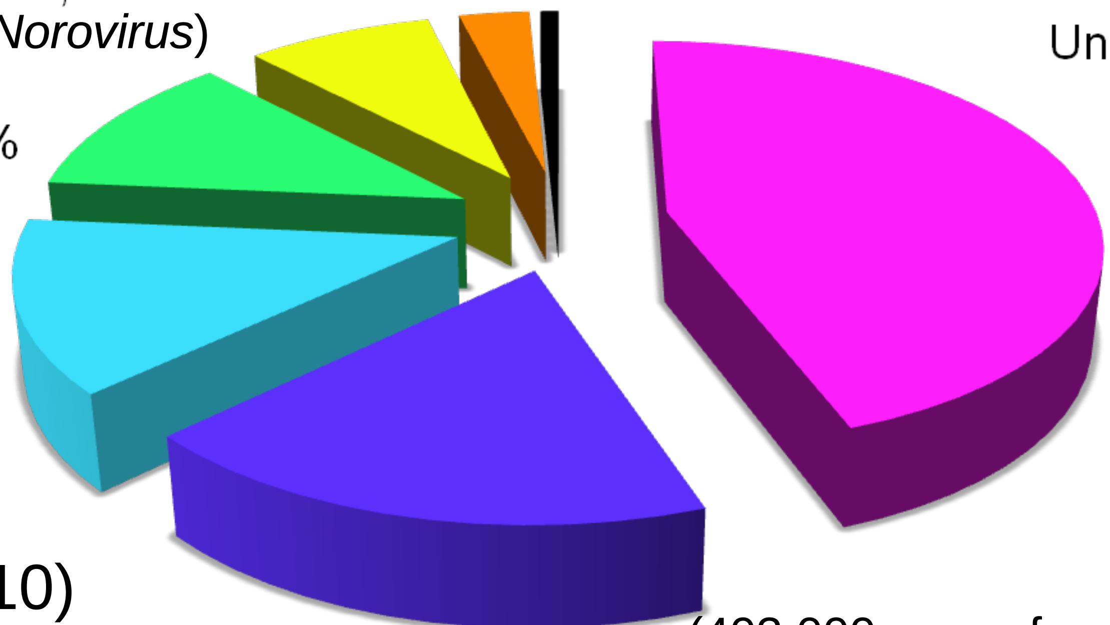


Exposure



Outcome

Etiologic agents & percentages for 780 drinking water outbreaks, 1971-2006 USA



Craun *et al*. (2010)
CMR 23:507-528

Public health hospital costs from USA drinking water exposures

- CDC estimate drinking water disease costs > $970 m/y
  - Less so fecal pathogens, largely Legionnaires’ disease, *otitis externa*, and non-tuberculous mycobacterial causing >40 000 hospitalizations/year

Disease	Annual costs
Cryptosporidiosis	**$46M**
Giardiasis	**$34M**
Legionnaires’ disease	**$434M**
NTM infection/Pulmonary	**$426M/ $195M**

Collier *et al.* (2012) Epi Inf 140: 2003-2013

Quantitative microbial risk assessment (QMRA)

STEP 1
SETTING

Problem formulation & Hazard identification
Describe physical system, selection of reference pathogens and identification of hazardous events

STEP 2
EXPOSURE

Source water
Ref pathogen densities

Treatment
Ref pathogen removals

Distribution
Pathogen loss (biofilm/death)

Environmental Pathogens
Pipe biofilm growth

($P_{env\text{-}path}$)

Human exposures
Vol water intake

STEP 3
HEALTH EFFECTS

Dose-Response (P_{inf})
Selection of appropriate models for each ref pathogen and groups exposed

STEP 4
RISK

Risk Characterisation
Simulations for each pathogen baseline and event infection risks with variability & uncertainty identified

On-site QMRA model

STEP 1

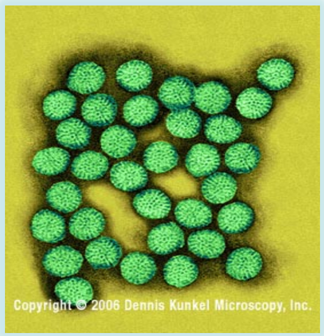
SETTING

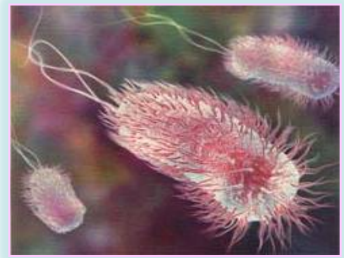
Hazard identification & its setting

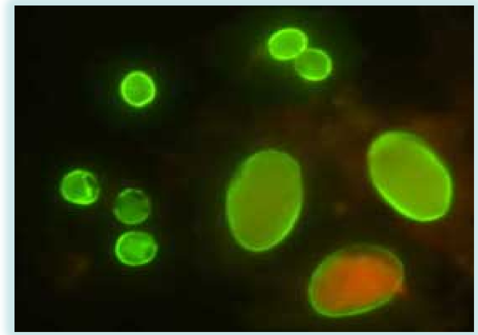
Describe physical system, selection of **reference pathogens** & identification of **hazardous events**

‘Pathogens’ versus specific system surrogates

Pathogens







Viruses
Reference: (*Norovirus*)

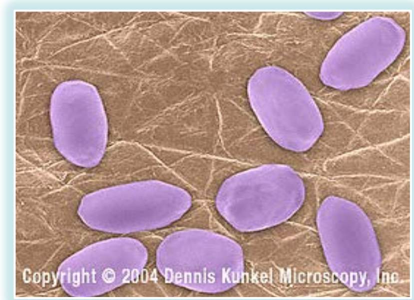
Bacteria
(*Campylobacter*)

Parasitic protozoa
(*Cryptosporidium*)

Surrogates for different system barriers

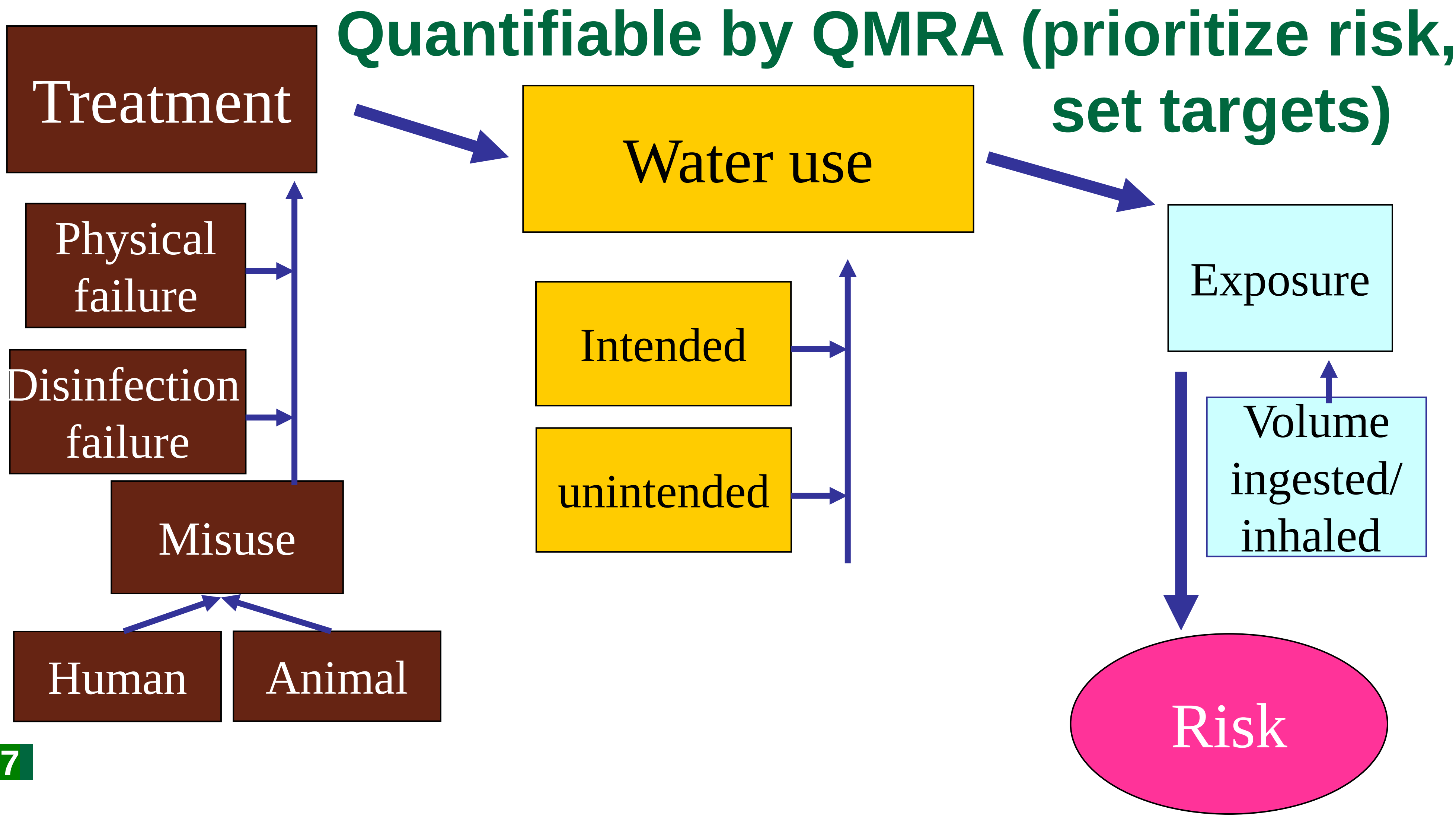
Phages
(e.g. *Bacteroides*)

E. coli +
coliphages



Clostridium perfringens
spores

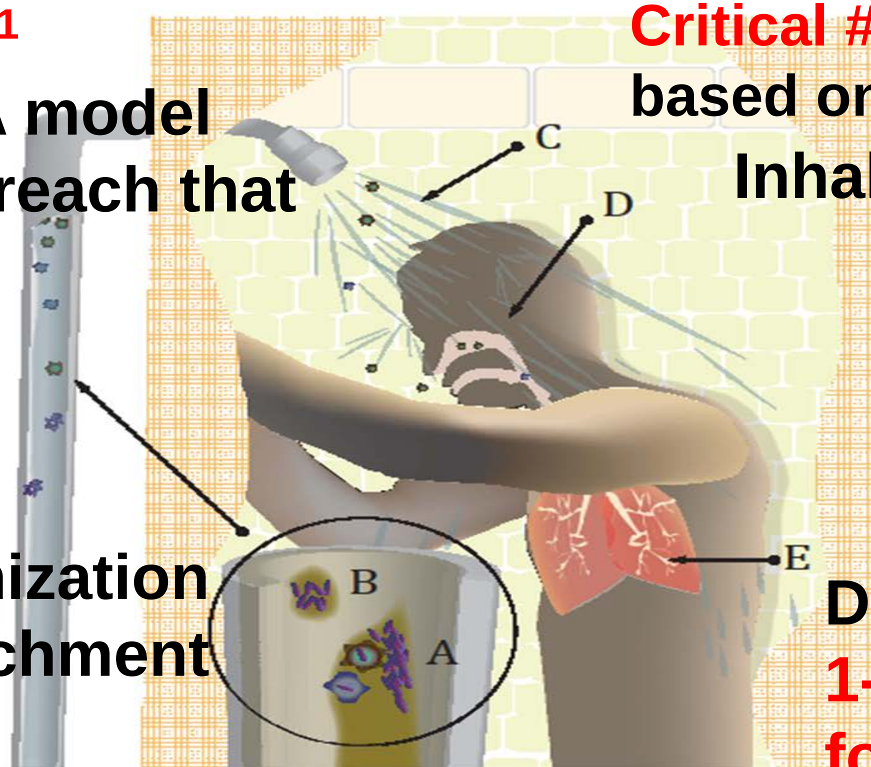
Hazardous events at on-site system:



Example: QMRA for critical *Legionella* densities

Critical # in DW
10^6 – 10^8 CFU L^{-1}
based on QMRA model
Needs hosts to reach that

Aerosolization
Critical # 35 – 3,500 CFU m^{-3}
based on QMRA model
Inhalation



Biofilm colonization and detachment

Deposition
1-1,000 CFU in lung for potential illness

Schoen & Ashbolt (2011) Water Research 45(18): 5826-5836

Rationale for indicator qPCR vs pathogen detection – a numbers game (~ 100-fold)

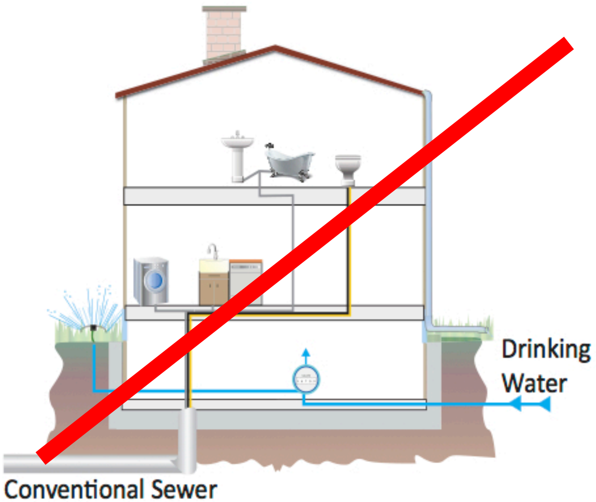
Ashbolt *et al*. (2010) Wat Res **44:**4692-4703

- Target pathogen density (rec water 0.03 GI risk swim^{-1})
  - e.g. for one of the most numerous known pathogens:

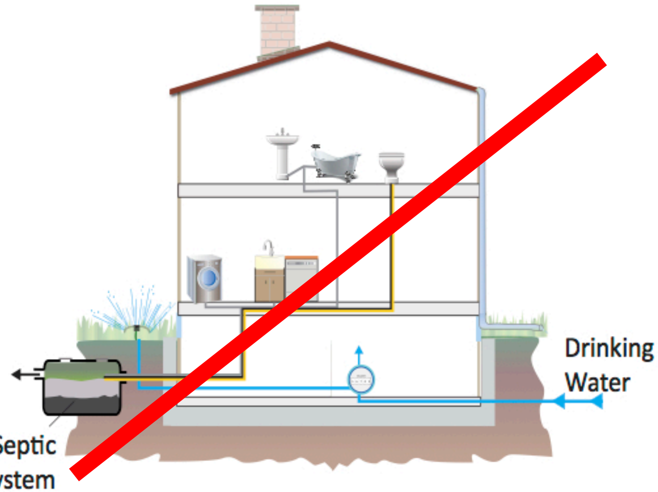
    9 *Norovirus* genomes L^{-1} of rec water ➡ 0.03 GI risk

    Changing *Norovirus* morbidity based on infection from best estimate 0.6 to 0.1 increases the target density **to 80 *Norovrius* genomes L^{-1}** (half to a tenth if recovery accounted for)
- *Bacteroides* HF183 target for same level of contamination from sewage to cause the benchmark (0.03 GI) illness:
  - **8600 *Bacteroides* HF183 genome copies L^{-1}**

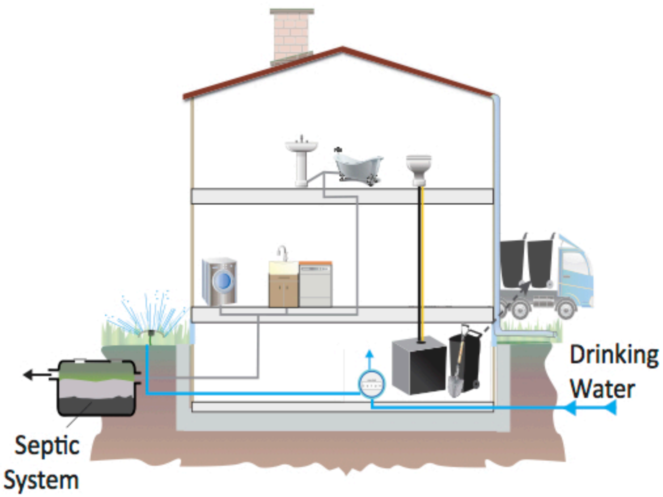
Alternatives to BAU-Septic/leachfield



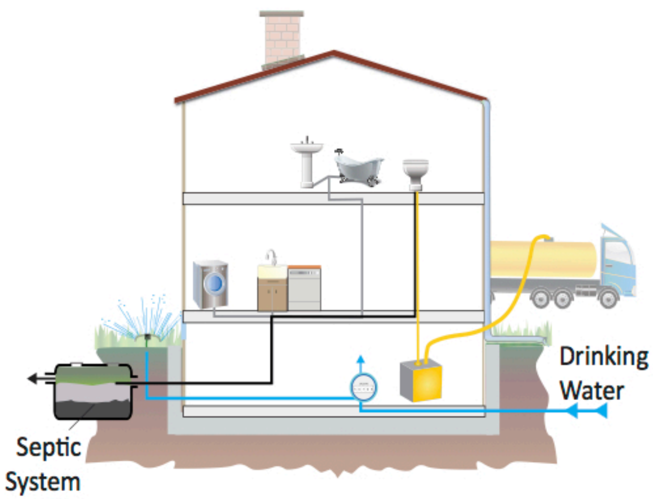
(BAU) Business as usual: Conventional municipal wastewater sewer & water supply



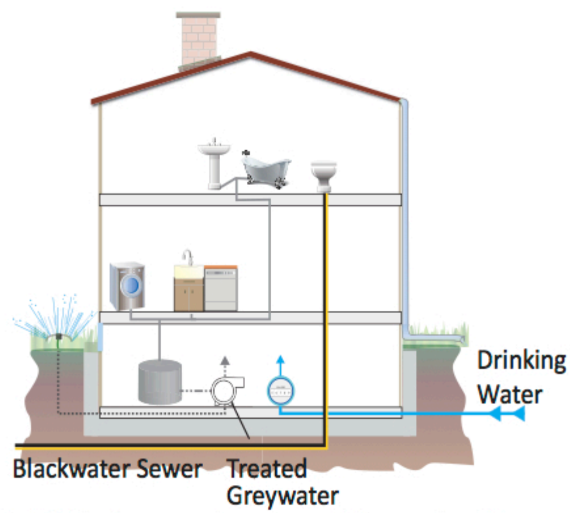
(BAU-SS) Business as usual: Conventional septic system & water supply



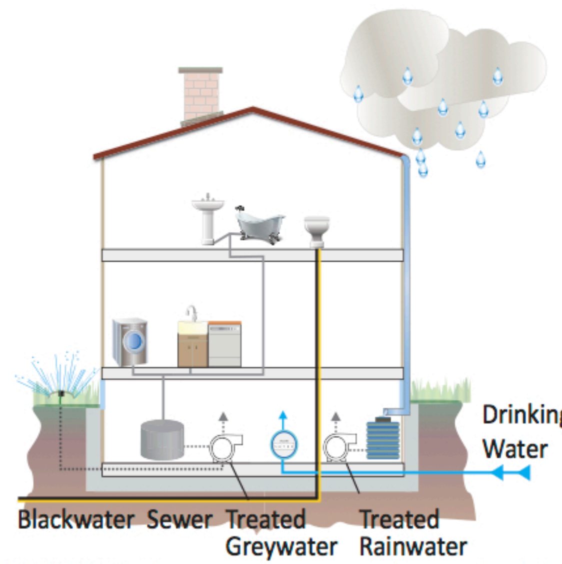
(CT-SS) Composting toilet w/ greywater-only septic system, municipal water supply



(UD-SS) Urine diversion toilet w/ blackwater & greywater septic system, municipal water supply



(BE-GR) Blackwater-only sewer w/ biogas electricity generation, treated greywater reuse for washing & irrigation



(BE-GRR) Blackwater-only sewer w/ biogas electricity generation, treated greywater & rainwater reuse for washing & irrigation

Human Health RA

- **Pathogens**
  - –Three reference pathogens selected for Cape Cod: Human norovirus, *Campylobacter, & Cryptosporidium*
  - –Dose estimates: household & recreational exposure routes
  - –Infection risks to disability-adjusted life years (DALYs)
- **Disinfection by-products (DBPs)**
  - –The highest-risk class of chemicals associated with water & urban living (bladder cancer)
  - –Focus on chloroform & bromodichloromethane
- Key human health risk trade-off:
  - –Use of rainwater with no DBP via hot water, but increased potential risk from pathogens

Example annual risks by ref. pathogen Illness (DALY) for on-site systems

	Norovirus	*Campylo-bacter*	*E. coli* O157:H7	*Crypto-sporidium*
DALY/illness	1.6×10^{-3}	4.6×10^{-3}	5.5×10^{-2}	1.7×10^{-3}
BAU rec water	6.1×10^{-2} (2.2×10^{-3})	-	-	-
Greywater reuse	5.2×10^{-4}	-	-	-
Rainwater use	-	7.9×10^{-8} (negligible)	1.3×10^{-4} (7.7×10^{-2})	1.4×10^{-3} (2.3×10^{-2})

Pathogen risks >> DBP, and most risk via GI illness

Assuming 10% of pop of 10,000 swim in nearby waters, 22% consume salad crops with reuse. EPA health threshold for rec water GI is 7×10^{-3}

L. pneumophila only 2.7×10^{-7} annual probability of illness with RWH but not assessed via household plumbing (could be similar risk to that with potable water.

Summary

- Risk-based targets can be established by QMRA, backed up by epi information
- QMRA has been used to set critical limits at points of exposure and at upstream control points for surrogates (WSP)
- Pathogen surrogates need to be used as **performance criteria** (viral, bacterial, protozoan)
- Should allow for innovation, not limit on-site technologies to specific systems/controls

Acknowledgements

Mary Schoen (EPA)