Water Safety Plan

Water & Waste Engineering

2019/05/10

名古屋大学減災連携研究センター
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Partial Revision of the Waterworks Act, 2018

> The objectives of partial revision of the Waterworks Act are to reinforce the waterworks management bases, and to respond the subjects which waterworks in Japan are faced with, for example decreasing water demand due to depopulation, deterioration of water supply facilities, a critical shortage of human resources.

1. Clarification of the accountability of the person concerned
2. Promotion of the wide area cooperation
3. Promotion of appropriate asset management
4. **Promotion of the public-private partnership**
5. Improvement of system for designated water pipe plumber

Public-Private Partnership

- **Private Finance Initiative (PFI)**
- **Concession Agreement**
  - In the case of a public service concession, a private company enters into an agreement with the waterworks to have the exclusive right to operate, maintain and carry out investment in a public utility for a given number of years. Other forms of contracts between public and private entities, namely lease contract and management contract (in the water sector often called by the French term affermage), are closely related but differ from a concession in the rights of the operator and its remuneration. A lease gives a company the right to operate and maintain a public utility, but investment remains the responsibility of the public. Under a management contract the operator will collect the revenue only on behalf of the government and will in turn be paid an agreed fee.

Water Supply Cost and Water Charge in Japan

- **Water Supply Cost**
  - 1 cubic meter : 164.40 JPY
  - Domestic usage of 20 cubic meter/month: 3,288 JPY
- **Water Charge**
  - Domestic usage of 20 cubic meter/month: 3,192 JPY

Discussion

Imagine;

You are a resident of the A city.

A private enterprise will manage the water utility of the A city.

A. Agreement

B. Objection

Water facts

- 663 million people are still without access to clean drinking water, despite the Millennium Development Goal target for clean water being met in 2010.
- 8 out of 10 people without access to clean water live in rural areas.
- 159 million people use untreated water from lakes and rivers, the most unsafe water source there is.
- Since 1990, 2.6 billion people have gained access to improved drinking water and today, 91% of the world's population drink clean water.

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Sanitation facts

- 1 in 3 people don't use improved sanitation.
- 1 in 7 people practice open defecation.
- Since 1990, 2.6 billion people have gained access to improved sanitation.
- 5 countries, India, Indonesia, Nigeria, Ethiopia, Pakistan, account for 75% of open defecation.
- We must double our current efforts in order to end open defecation by 2030.

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Water and sanitation

- **1.1 billion** population **CANNOT** access clean and safe drinking water, 63% of which are in Asia-Pacific Region (UNICEF/WHO).
- 7.9 % of water supply systems in Asian cities retain appropriate residual chlorine over 0.1 mg/L, 21. 5% **CANNOT** comply with national standards (UNEP).
- **2.6 billion** people **CANNOT** use appropriate sanitation systems, 3/4 of which are in Asia-Pacific Region (UNICEF/WHO)

QMRA (Quantitative Microbial Risk Assessment)

- Quantitative Microbial Risk Assessment (QMRA) has been used to quantify the microbial safety of drinking water (Hass et al., 1999; Medema et al., 2006).
- The microbial exposure or dose is calculated based on the pathogen concentration in the drinking water and the consumption of unboiled drinking water.
- The risk of infection is calculated based on the chance of ingesting pathogens and developing an infection from this exposure (dose-response relation).

QMRA (Quantitative Microbial Risk Assessment)

- a framework and approach
  - ✓ brings information and data together with mathematical models to address the spread of microbial agents through environmental exposures and to characterize the nature of the adverse outcomes.
- Ultimately the goal in assessing risks is to develop and implement strategies that can monitor and control the safety and allows one to respond to emerging diseases, outbreaks and emergencies that impact the safety of water, food, air, fomites and in general our outdoor and indoor environments.

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QMRA
(Quantitative Microbial Risk Assessment)

- Hazard identification
- Dose response
- Exposure assessment
- Risk characterization
- Risk management

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Hazard identification

- The hazard identification is both identification of the microbial agent and the spectrum of human illness and disease associated with the specific microorganism.
  - ✓ Establish parameters associated with the pathogen. Case fatality ratios, transmission routes, incubation times, etc.
  - ✓ Research pathogen like before. In addition, there have been large outbreaks of E. coli associated with spinach in the past. It may be useful to research them for reference. Factors like attack rate and corrective actions will be valuable to know.
  - ✓ You should first identify the strain you are dealing with. Different strains have different attack rates, effect different population etc. Knowing these unique qualities is important.

Dose response

- The dose response analysis provides a quantitative relationship between **the likelihood of adverse effects** and **the level of microbial exposure**. The dose response assessment phase is arguably the most important phase in the QMRA paradigm.
  - Assuming we are dealing with Enterohemorrhagic E. coli O157:H7, the recommended model based on our criteria uses the exponential equation with a k value of 2.18E-04 and an LD50 of 3.18E+03.
  - The recommended dose-response model according to our criteria would be the beta-poisson equation with an α value of 5.81E-01 and N50 of 9.45E+05.

Exposure assessment(1)

- The exposure assessment identifies affected population, determines the exposure pathways and environmental fate and transport, calculates the amount, frequency, length of time of exposure, and estimates dose or distribution of doses for an exposure.
  - ✓ Questions to be answered include; How much water will the child ingest over a period of time? Is the pathogen traveling from a source, is there die-off or grow while the pathogen is in the environment? What is the concentration of pathogen in the water at the time of ingestion?

Exposure assessment(2)

- ✓ What kind of concentrations of organisms are seen in surface waters in rural farmlands? What concentrations could be expected should these crops be irrigated with this water. How is the crop processed, will there be any growth or die off during this process? What about during shipping and storage? What temperature will it be stored in? How much will the population eat?
- ✓ How many times will a sick individual cough during the day? How many organisms will the ill person excrete with each cough? When they touch a fomite (surface), what concentration of organism will be deposited on that surface? If someone touches a contaminated surface, how many organisms will be transferred to their hands and then be ingested?

Risk characterization(1)

– The risk characterization Integrates dose-response analysis and exposure assessment to estimate the magnitude of risk, uncertainty and variability of the hazard. Assuming you find a range of values for each parameter risk characterization is the process of determining which values within these ranges to use, or how to use the ranges as a probability.

- ✓ If there is a range of concentration in the water, you may consider using a conservative one considering the potential severity of outcome and the relative unimportance of recreational water (i.e. closing a beach does not incur significant economic cost).

Risk characterization(2)

- ✓ You may wish to use software to calculate doses based on a probability range as there will be many many potential interactions between pathogen and host, all with possibly slightly different exposure scenarios.
- ✓ There will inherently be wide ranges in excretion rates associated with coughing and other habits. As well as the amount each person coughs or touches objects. The particular scenario may require probability estimates. Or if it's not too serious, a liberal estimate may be acceptable with authorities.

Risk management

– Risk can be managed using many different strategies and is most effective when it is informed through risk characterization.

- ✓ Should the lake/beach be closed to swimmers? What is the source of the contamination, can it be stopped?
- ✓ Should there be a product recall? Can you better regulate irrigation of crops? Can you end the source of contamination of the source waters? Can you disinfect the crop during processing?
- ✓ Should you quarantine the office? Improve disinfection techniques by the janitorial staff? Disable the air conditioning? Or perhaps just prepare to absorb the cost of multiple sick days.

Microbial risk from the Philadelphia water supply

- Problem
  - ✓ Cryptosporidium presents in surface water, it cause Cryptosporideosis.
  - ✓ What is the risk of Cryptosporideosis caused by drinking water in Philadelphia?

Cryptosporidium

- First described by Ernest Tyzzer in 1907
- Protozoan parasite infecting the intestinal tract of vertebrates
- Currently 26 known species infecting humans, other mammals, birds, reptiles, fish
- *C. parvum* and *C. hominis* are the primary species that infect humans

Cryptosporidiosis

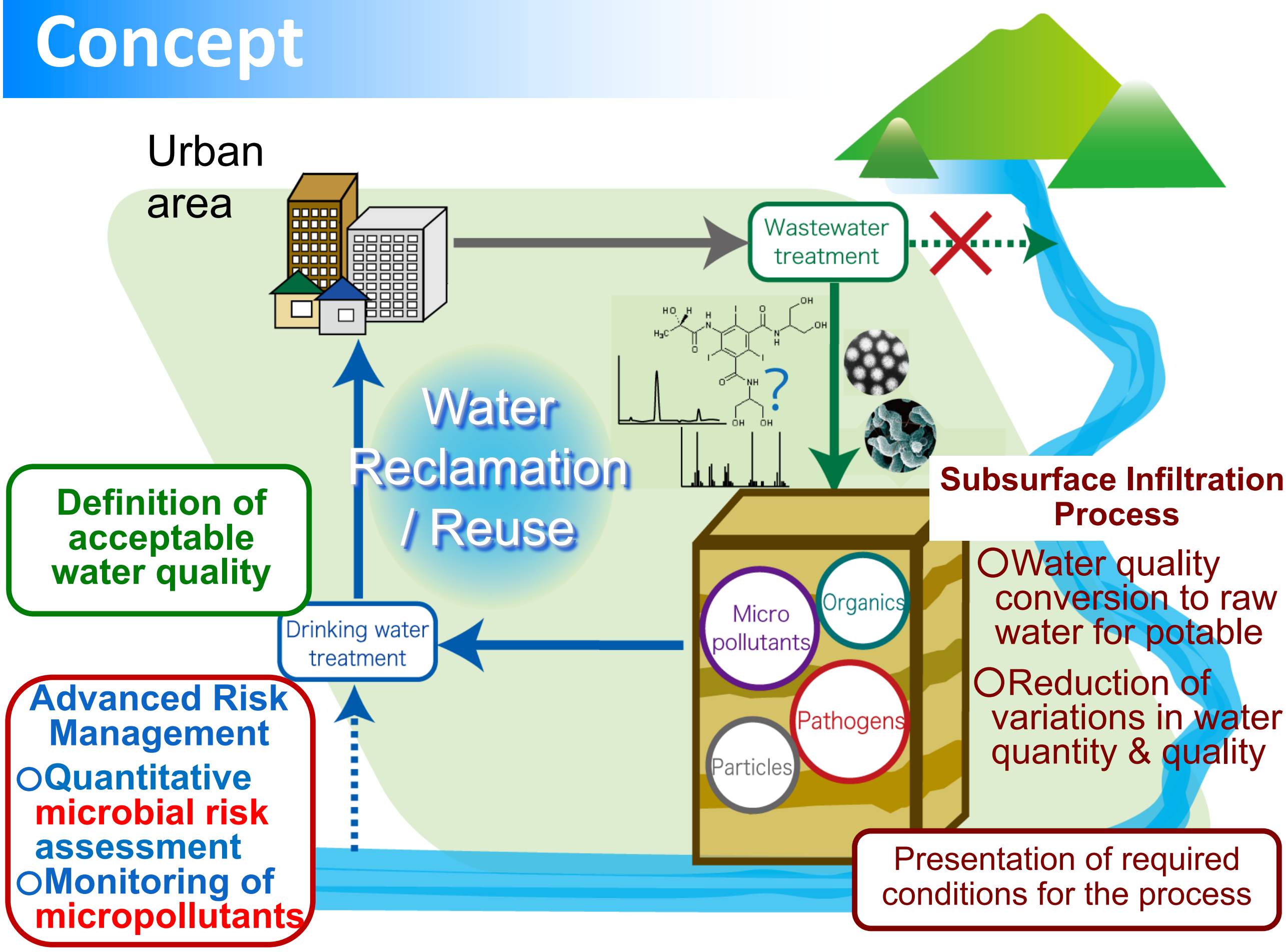
- Gastrointestinal disease caused by Cryptosporidium
- Most common symptom is watery diarrhea but other clinical symptom may include: stomach cramps, nausea, vomiting, fever, dehydration
- Clinical symptoms appear 2 to 10 days after infection and last 1 to 2 weeks.
- Immune compromised, children and the elderly are most vulnerable to infection
- Infection is by fecal-oral route

Cryptosporidium in drinking water supplies

- Cryptosporidium has become a significant pathogen in drinking water outbreaks since the 1980's
- Oocysts are resistant to being killed by the standard chlorine disinfection
- Cryptosporidium pathogens enters water through the infected feces of animals and humans

Quantitative risk management for Water Reuse System

Concept



Modern risk science

	Microbial risk	Chemical risk
Target level	Infection rate 10^{-4} /year	Cancer-causing rate 10^{-5} /life
Approach	✱Quantitative microbial risk assessment (QMRA)	✱ Toxicological assessment ✱ Precautionary principle

DALYs (Disability-Adjusted Life Years)

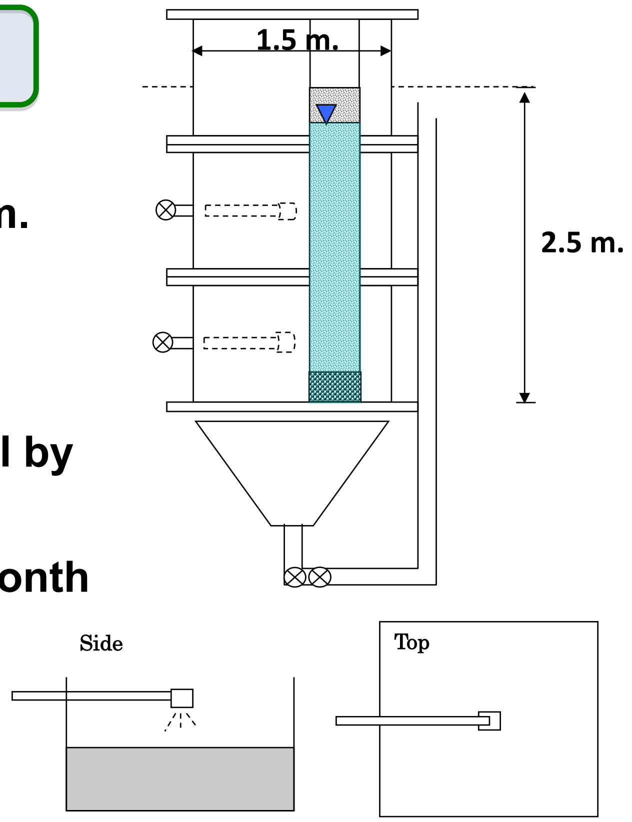
Experimental System

Pilot Plant Scale
(Toba Treatment Plant in Kyoto City)

Cullum Scale

Pilot reactor of SAT

- L x W x H = 1.5 x 1.5 x 3.0 m.
- Total Volume = 6.75 m^3
- Materials = Stainless steel (SUS304)
- Water level = below top soil by 0.3 m.
- Retention time = 1 and 6 month
- Soil depth = 2.5 m.



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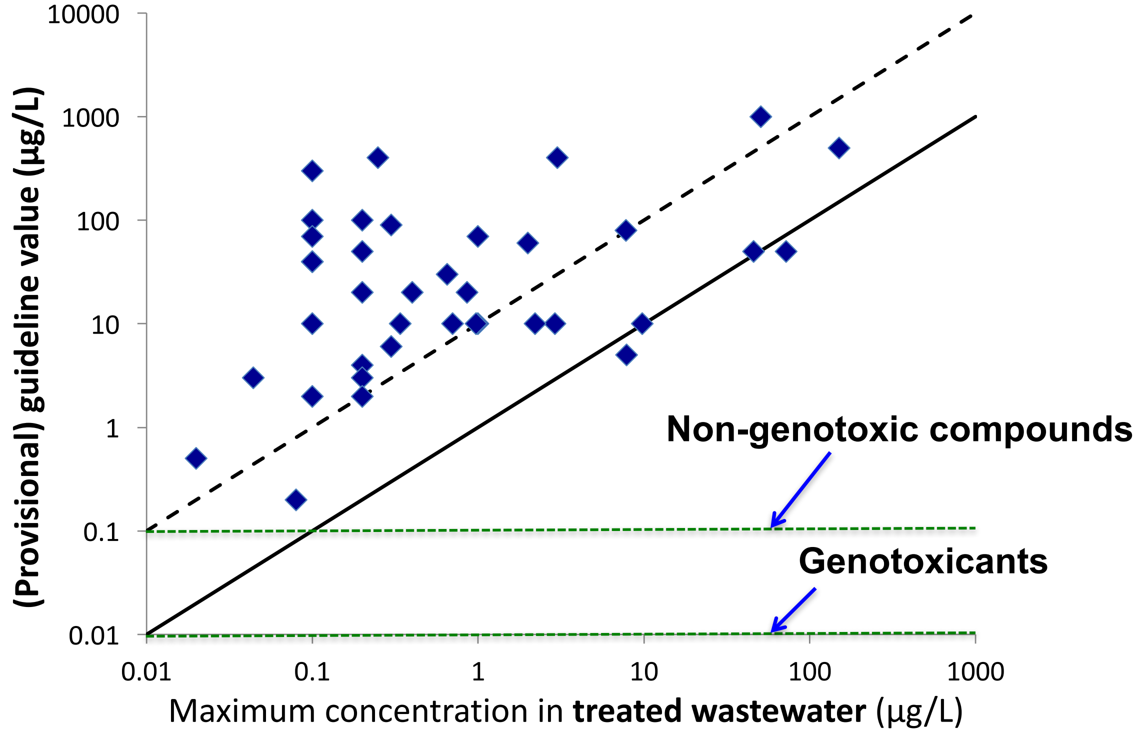
Management of toxic compounds

Compounds regulated by Pollutant Release and Transfer Register (**PRTR**)



Target chemicals

Risk assessment based on the concentrations in treated sewage and health-based standard values

Micropollutants･･･Perfluoro compounds, Estrogenic compounds, 1,4’-Dioxane

Disinfection by-products･･･Trihalomethane, Haloacetic acid, Haloacetnitrile, Halonitromethane, N-Nitrosodimethylamine

Metals･･･Nickel, Lead

Others･･･Cyanogen, Ethylene diamino tetra acetic acid, 1,3-dichloro-2-propanol

Multicomponent simultaneous analysis and search for transformation products

Pharmaceuticals and personal care products

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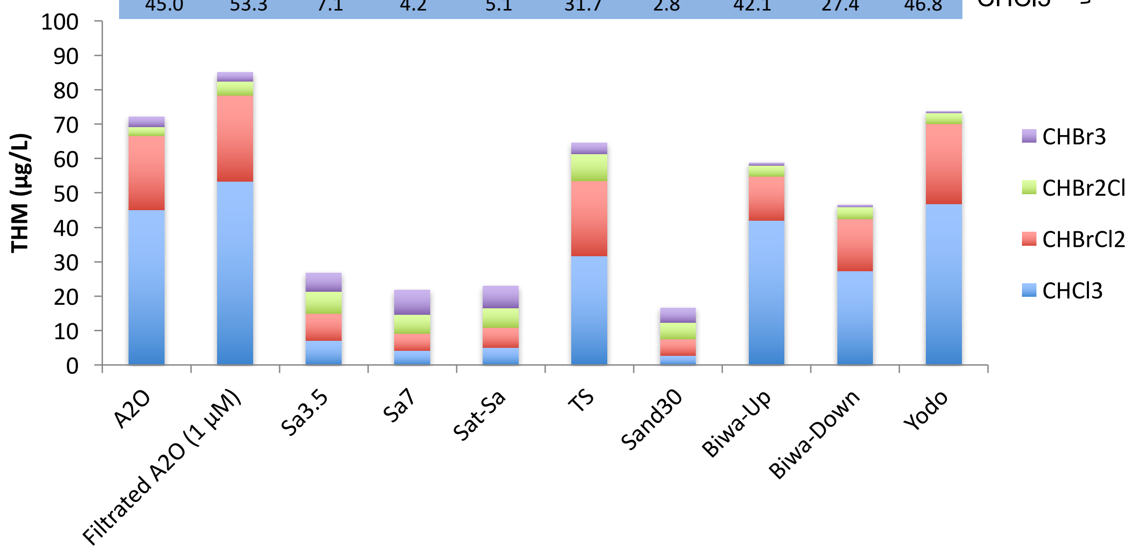
THM Formation Potential (THMFP)

	A2O	Filtrated A2O (1 μM)	Sa3.5	Sa7	Sat-Sa	TS	Sand30	Biwa-Up	Biwa-Down	Yodo
CHBr3	3.1	2.7	5.5	7.2	6.4	3.4	4.3	0.9	0.9	0.6
CHBr2C	2.6	4.0	6.5	5.6	5.7	7.8	4.9	3.3	3.4	3.2
CHBrCl2	21.6	25.1	7.8	4.9	5.8	21.7	4.7	12.7	15.1	23.3
CHCl3	45.0	53.3	7.1	4.2	5.1	31.7	2.8	42.1	27.4	46.8

THM4

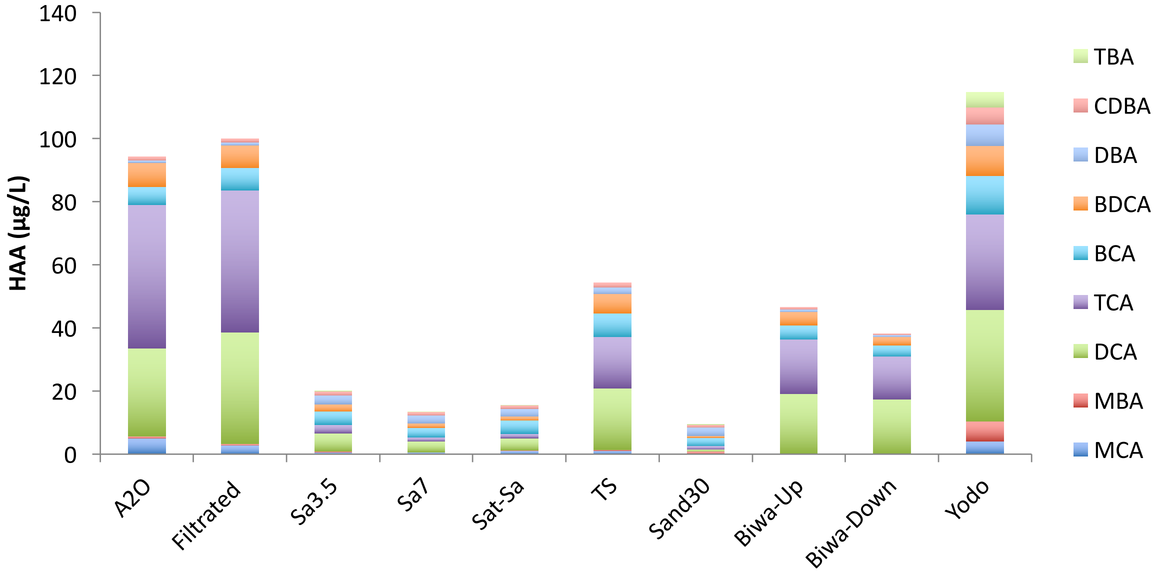


- Effects on THMFP: SAT significantly reduced THMFP by more than 65% (except TS by 10%).
- All THM conc. for waters after SAT were below the regulation.

HAA Formation Potential (HAAFP)

0.7	1.0	2.8	2.5	2.5	2.1	2.6	0.8	0.7	6.8	DBA
45.6	45.0	2.7	1.2	1.4	16.2	1.0	17.2	13.6	30.2	TCA
27.9	35.4	5.8	3.4	3.9	19.5	0.7	19.2	17.4	35.4	DCA
0.7	0.5	0.3	0.1	0.2	0.3	0.9	0.0	0.0	6.3	MBA
5.0	2.7	0.6	0.6	1.1	1.1	0.0	0.0	0.0	4.1	MCA

HAA5



- Effects on THMFP: SAT significanty reduced HAAFP by more than 80% (except TS by 42%).
- All HAA conc. for waters after SAT were below the regulation.

Microbial Transformation Products (TPs) of PPCPs

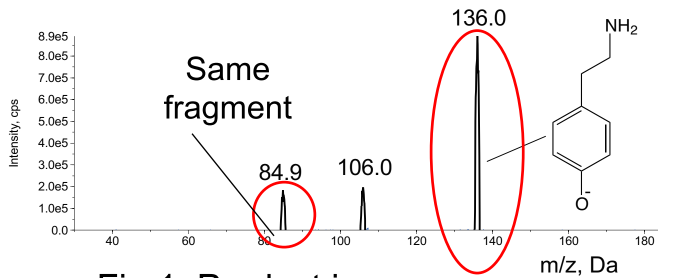


Fig.1: Product ion scan (ESI+, Concentrated sample)

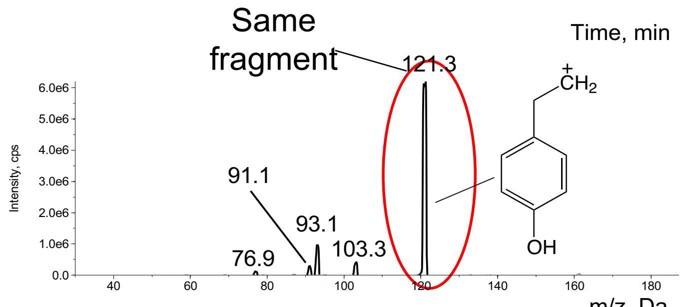
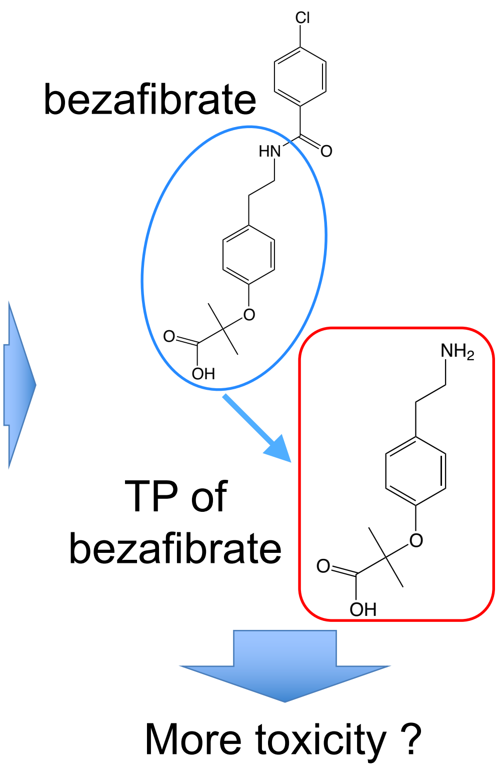


Fig.2: Product ion scan (ESI-, Concentrated sample)



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Target pathogens

Bacteria : *Campylobacter jujuni*

Viruses : Rotavirus, Adenovirus

Protozoan oocysts : *Cryptosporidium, Giardia*

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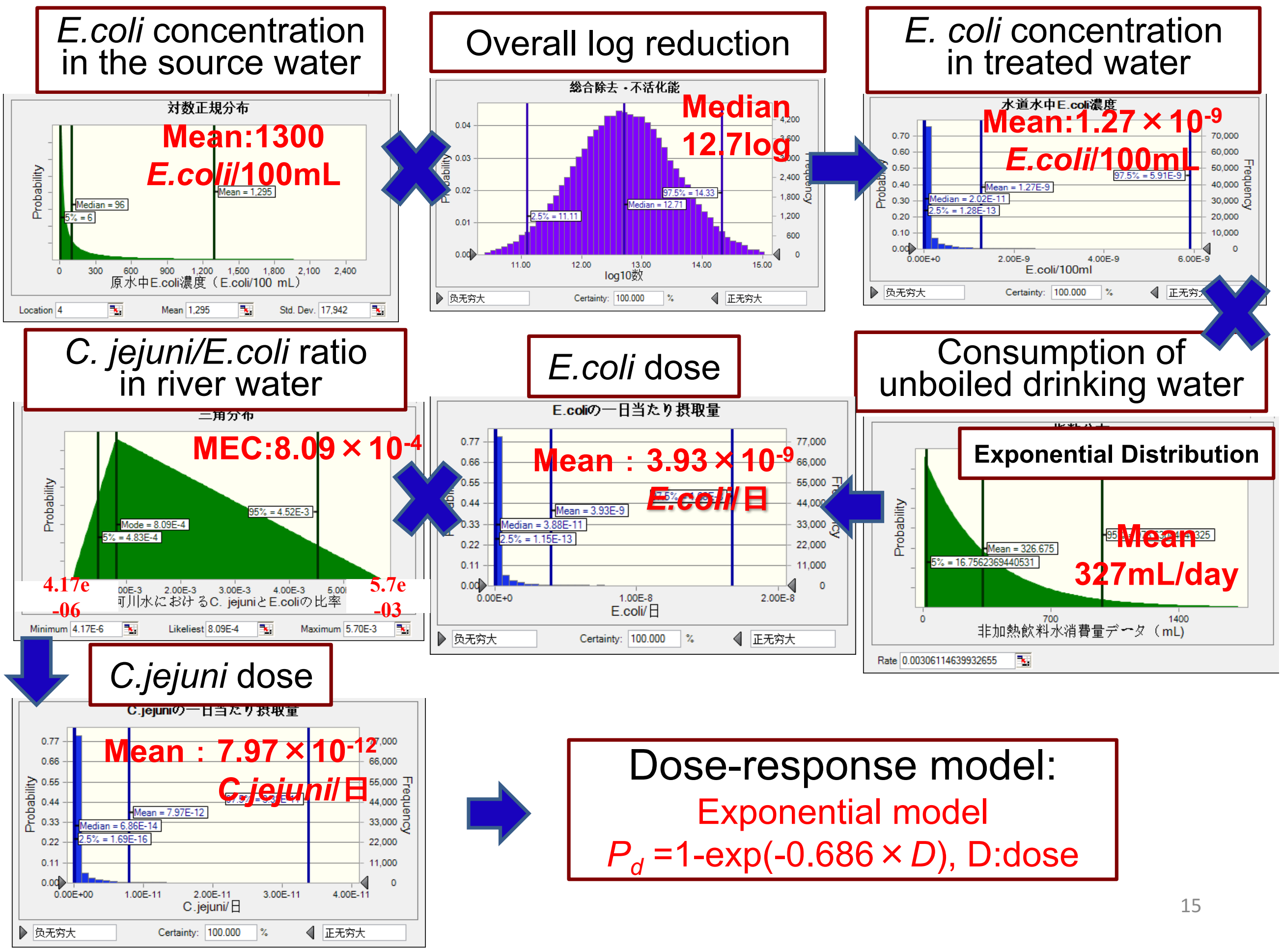

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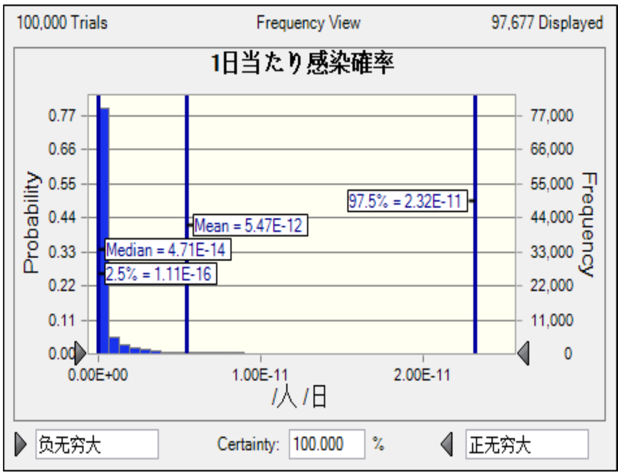
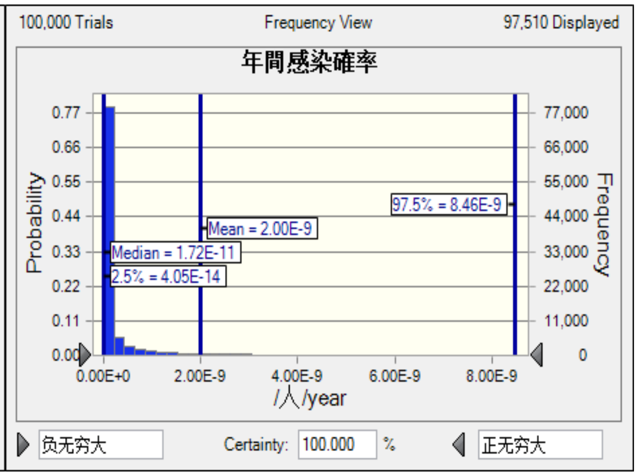
Daily risk of infection (/person/day)
$P_d = 1 - \exp(-0.686 \times D)$

Yearly risk of infection (/person /year)
$P_y = 1 - (1 - P_d)^{365}$





Mean : 5.47×10^{-12} /person/day
Median : 4.71×10^{-14} /person/day

Mean : 2.0×10^{-9} /person /year
Median : 1.72×10^{-11} /person /year

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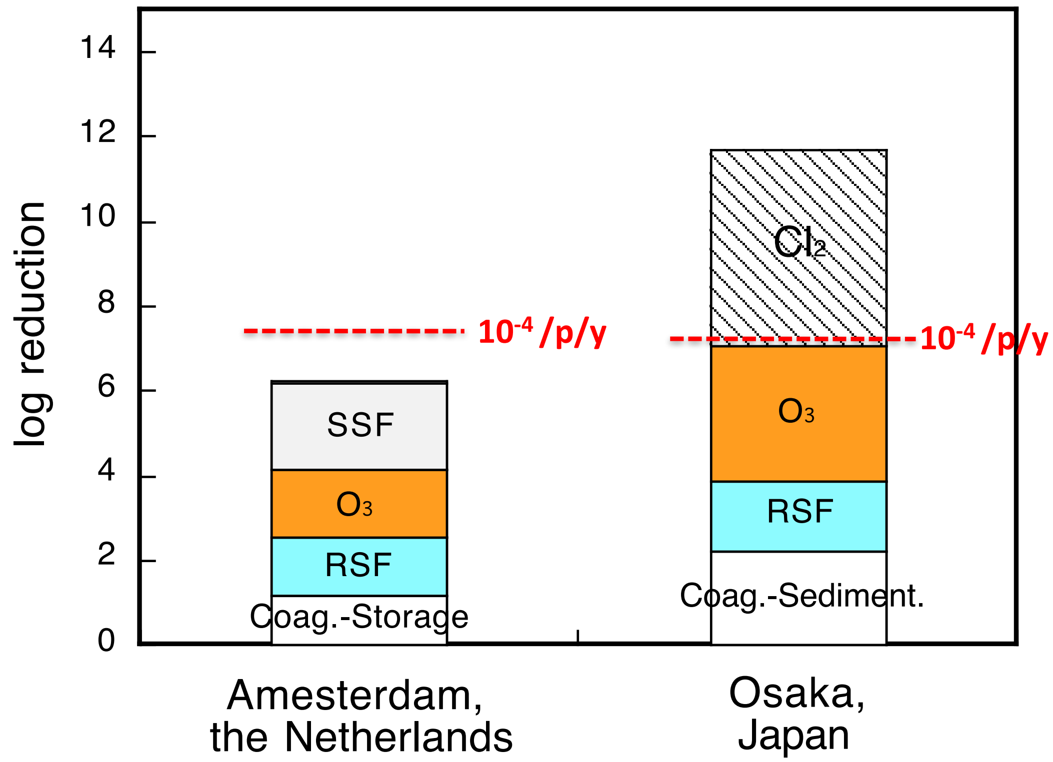
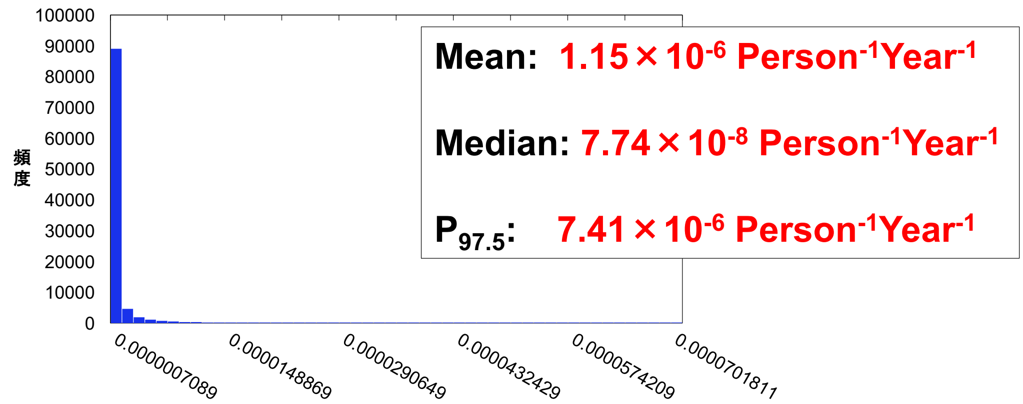
Examples of Quantitative Microbial Risk Assessment (QMRA) of *Campylobacter*



Yearly risk of *Campylobacter jejuni* infection

Water source
River：SAT＝1：1 → Water Treatment Process

Yearly risk of infection



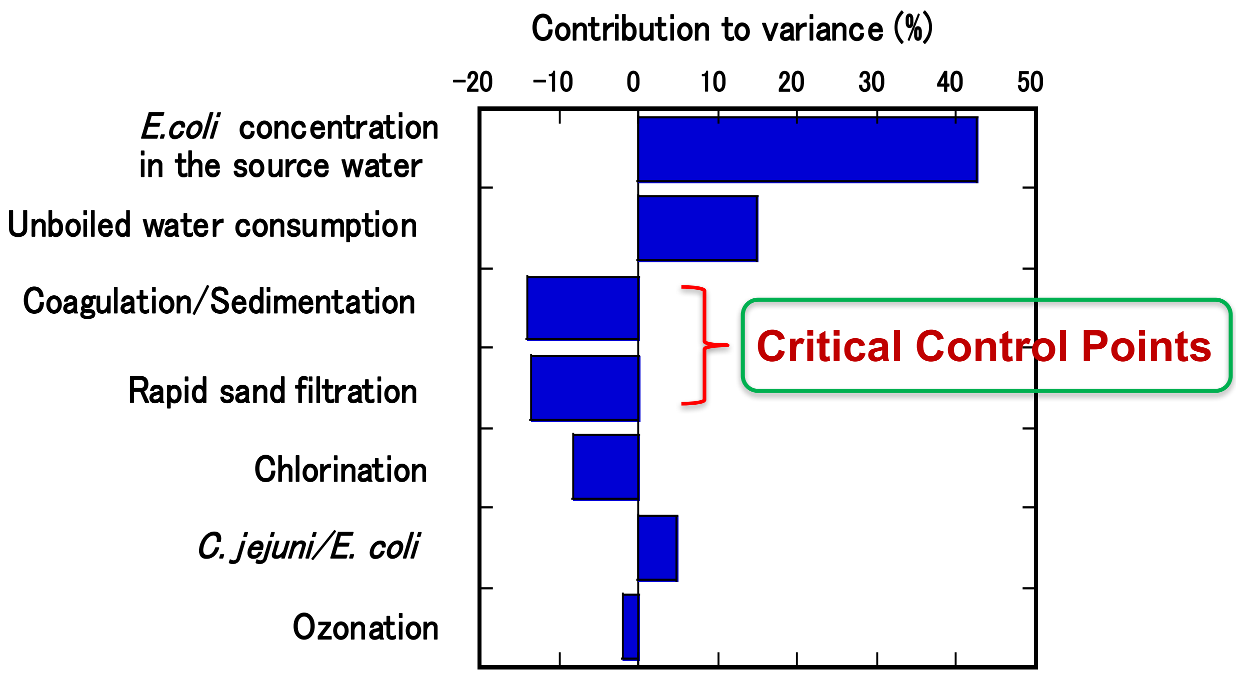
Mean: 1.15×10^{-6} Person^{-1}Year^{-1}

Median: 7.74×10^{-8} Person^{-1}Year^{-1}

$P_{97.5}$: 7.41×10^{-6} Person^{-1}Year^{-1}

Estimated yearly risk of infection < Acceptable risk level: 10^{-4}

Sensitivity Analysis



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Estimation approach of DALYs

QMRA

- *E.coli* in the source water (*E.coli*/100mL)
- ↓
- Treatment efficacy of *E.coli* — Water treatment steps: ① Coagulation-sedimentation ② Rapid sand filtration ③ Chlorination
- ↓
- *E.coli* in the treated water (*E.coli*/100mL)
- ↓ ← Water consumption (mL/day)
- *E. coli dose* (*E.coli/day*)
- ↓ ← *C. jejuni / E. coli* ratio for surface water
- *Campylobacter dose* (*Campylobacter /day*)
- ↓ ← Dose-response model (P_d=1-exp(-0.686×D), D:dose)
- Daily risk of infection ($person^{-1}d^{-1}$)
- ↓
- Yearly risk of infection: P_y ($person^{-1}yr^{-1}$)
- ↓ ← Illness to infection rate (DALYs = P_y × $P_{inf\text{-}ill}$ × 4.6/1000)
- DALYs ($person^{-1}yr^{-1}$)

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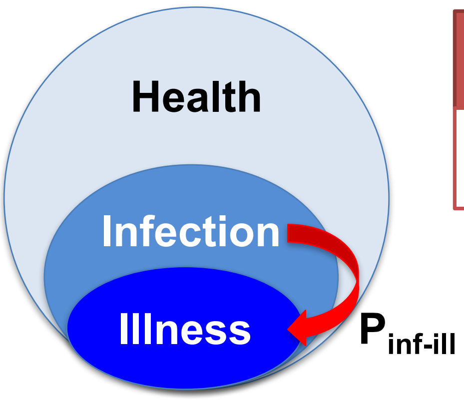
Uncertainty factor (Illness-to-Infection Rate)



$P_{inf\text{-}ill}$ →Base case: 1.0 (Conservation value)
Min. : 0.01

DALYs obtained in Min. was 98 times smaller than that obtained in base case.

↓

Important uncertainty factor: $P_{inf/ill}$

Estimation method

Seroepidemiological survey	Patient data with *C. jejuni* in Kobe
Rate of asymptomatic infections: P_{inf}	Rate of symptomatic infections: P_{ill}

Estimation of illness-to-infection rate: $P_{inf/ill}$

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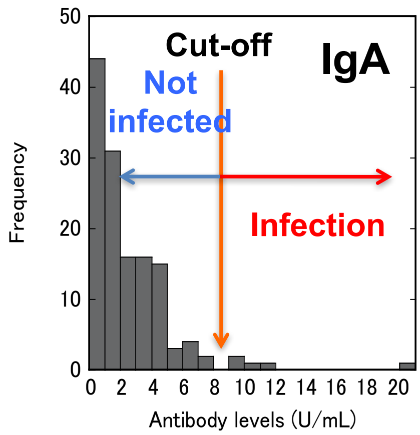
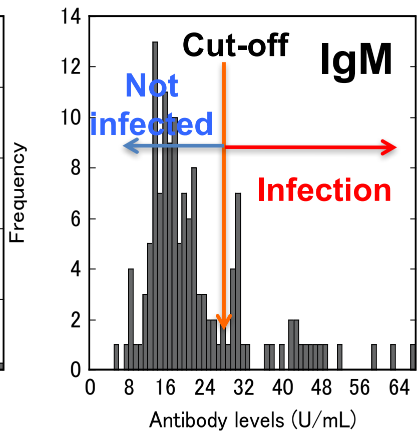
Estimation of Illness-to-Infection Rate

Distributions of the antibody levels (140 serum samples)





Rate of asymptomatic infection: P_{inf}

Medical data
7.9～35.0%

Statistical methods
12.1～23.6%

Correction factors

Population coverage rate: 31.7%

Fecal examination rate :10.9%

Consultation rate :32.0%

Rate of symptomatic infection: P_{ill}

4.3%

Illness-to-infection rate: $P_{inf\text{-}ill}$

Medical data
12.1～53.8%

Statistical methods
31.3～35.1%

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Contribution to the uncertainty of the DALYs

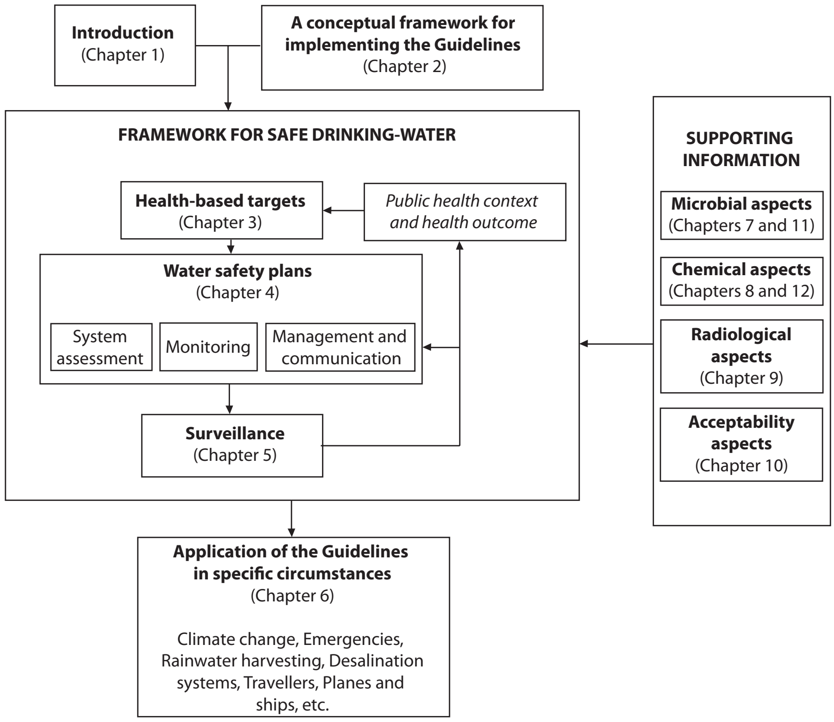
	$P_{inf\text{-}ill}$	Median	Mean	Upper 95% CI boundary
DALYs (person^{-1}yr^{-1})	Min.=12.1%	9.37×10^{-9}	1.39×10^{-7}	8.97×10^{-7}
	Max.=53.8%	4.16×10^{-8}	6.19×10^{-7}	3.97×10^{-6}

The uncertainty of the DALYs

- This study: **4.4 times**
- Previous study: **98 times**

Estimation of illness-to-infection rate contributes to decrease the uncertainty.

Framework for safe drinking water



©Guidelines for Drinking-water Quality - 4th ed., WHO, 2011

HACCP
Hazard analysis and critical control points

- **a systematic preventive approach to food safety from biological, chemical, and physical hazards in production processes**
- **to design measurements to reduce these risks to a safe level.**
  - The HACCP system can be used at all stages of a food chain, from food production and preparation processes including packaging, distribution, etc.

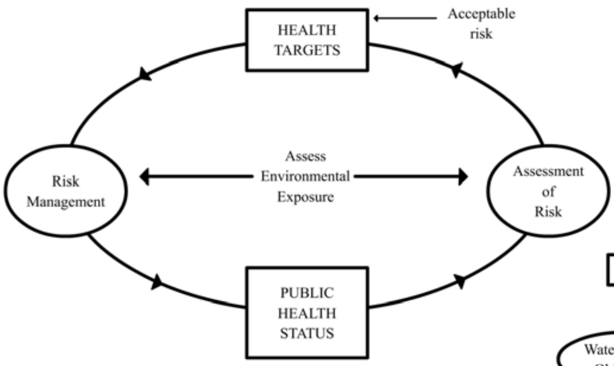
Principles

- Conduct a hazard analysis
- Identify critical control points
- Establish critical limits for each critical control point
- Establish critical control point monitoring requirements
- Establish corrective actions
- Establish procedures for ensuring the HACCP system is working as intended
- Establish record keeping procedures

Water quality management

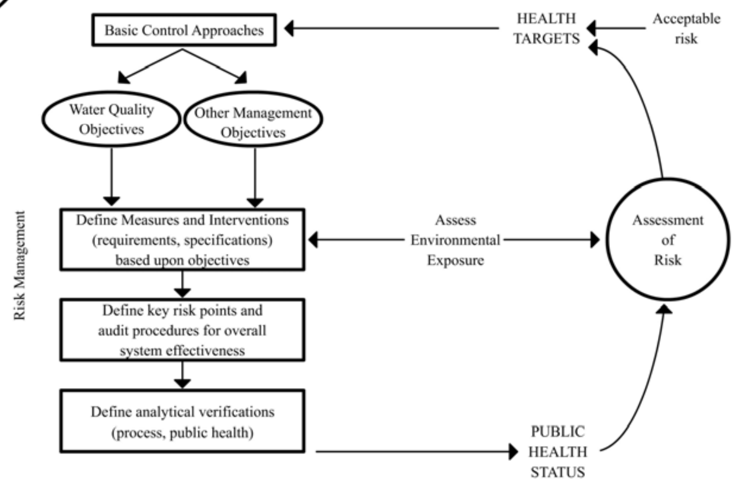
- The use of HACCP for water quality management was first proposed nearly 20 years ago.
- a number of water quality initiatives applied HACCP principles and steps to the control of infectious disease from water, and provided the basis for the Water Safety Plan
- Water Safety Plan is a way of adapting the HACCP approach to drinking water systems

Risk management framework for safe drinking water



Simplified framework

Expanded framework



©Bartram et al. , 2001

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Current management approaches

- aimed at assuring the safety of drinking water
- preventing pollution of source waters
- selective water harvesting
- controlled storage
- treatment prior to distribution
- protection during distribution
- safe storage within the home and in some circumstances, treatment at the point of use

The basis for water safety

- Know your catchment
- Know your source water quality
- Control the treatment
- Protect your distribution
- Safe drinking water

Health-based targets

- Health outcome targets: the specification of water quality targets
- Water quality targets: a health risk from long-term exposure, guideline values (concentrations) of the chemicals of concern
- Performance targets: short-term exposure represent public health risk, required reduction of the substance of the concern or effectiveness in preventing contamination
- Specified technology targets:

Water safety plan

- To prevent contamination of source waters
- To treat the water to reduce or remove contamination that could be present to the extent necessary to meet the water quality targets
- To prevent re-contamination during storage, distribution and handling of drinking-water

Development of a water safety plan

- system assessment
- operational monitoring
- management plans
- documentation and communication

Intended water use

Example 1
Water utility X provides water to the general population.
The water supplied is intended for general consumption by ingestion. Dermal exposure to waterborne hazards through washing of bodies and clothes, and inhalation from showering and boiling are also routes for waterborne hazards.
Foodstuffs may be prepared with the water.
The intended consumers do not include those who are significantly immunocompromised or industries with special water quality needs. These groups are advised to provide additional point-of-use treatment.

Example 2
Utility Y provides water to approximately half the population.
The water is intended for general consumption by ingestion. Dermal exposure to waterborne hazards through washing of bodies and clothes, and inhalation from showering and boiling are also routes for waterborne hazards.
Foodstuffs may be prepared from the water and market sellers use the water for freshening produce.
About half the population served rely of water supplied from public taps, with a further significant proportion relying on tanker services filled from hydrants.
The socio-economic level of the population served by public taps is low and vulnerability to poor health is consequently high.
A significant proportion of the population is HIV positive, which increases vulnerability further.

©Water safety plan - managing drinking-water quality from catchment to consumer, WHO, 2005

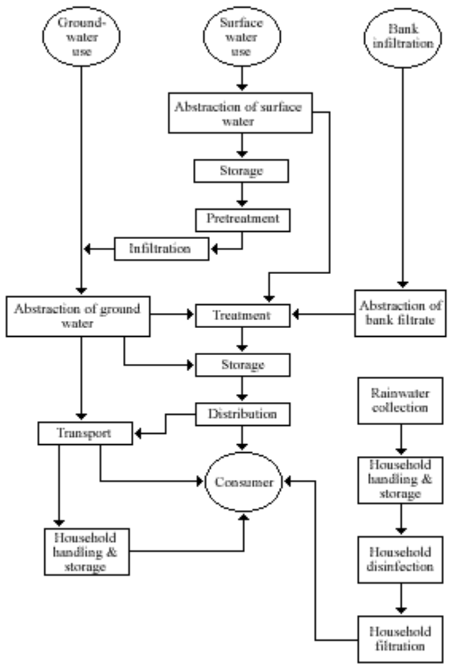
Describe the water supply(1)

- Catchments
  - ✓ Geology and hydrology, Meteorology and weather patterns, General catchment and river health, Wildlife, Competing water uses, Nature and intensity of development and land-use, Other activities in the catchment, Planned future activities
- Surface water
  - ✓ Description of water body type(e.g. river, reservoir, dam), Physical characteristics such size, depth, thermal stratification, altitude, Flow and reliability of source water, Retention times, Water constituents, Protection, Recreational and other human activity, Bulk water transport
- Groundwater systems
  - ✓ Confined or unconfined aquifer, Aquifer hydrogeology, Flow rate and direction Dilution characteristics, Recharge area, Well-head protection, Depth of casing, Bulk water transport

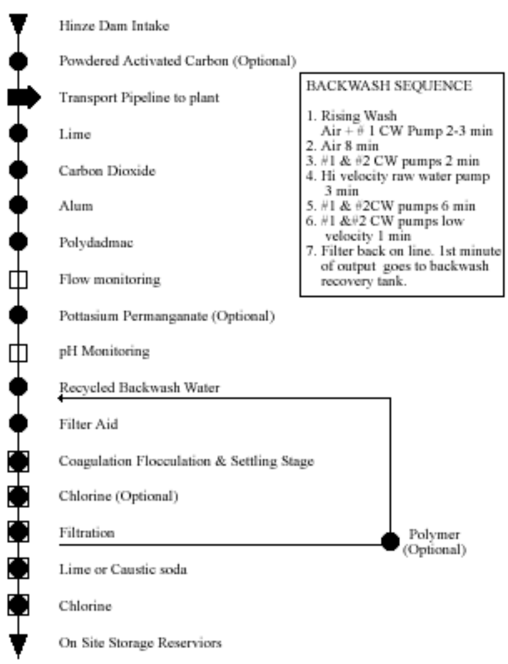
Describe the water supply(2)

- Treatment systems
  - ✓ Treatment processes, Equipment design, Monitoring equipment and automation, Water treatment chemicals used, Treatment efficiencies, Disinfection removals of pathogens, Disinfection residual/contact period time
- Service reservoirs and distribution systems
  - ✓ Reservoir design, Retention times, Seasonal variations, Protection (e.g. covers, enclosures, access), Distribution system design, Hydraulic conditions (e.g. water age, pressures, flows), Backflow protection, Disinfectant residuals

Flow diagram



Generic system flow diagram



flow chart for the Gold Coast Water (Australia)

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Understanding the hazards and threats

- A hazard is any biological, chemical, physical or radiological agent that has the potential to cause harm.
- A hazardous event is an incident or situation that can lead to the presence of a hazard.
- Risk is the likelihood of identified hazards causing harm in exposed population in a specified timeframe, including the magnitude of that harm and/or the consequences.

Melbourne water case study hazard analysis

Consequence/probability matrix

Ranking	Description, probability/frequency
Severity	
1	Insignificant
2	Minor impact for a small population
3	Minor impact for a big population
4	Major impact for a small population
5	Major impact for a big population
Likelihood	
1	0.001 or 1 in 1000 years
2	0.01 or 1 in 100 years
3	0.1 or 1 in 10 years
4	0.5 or 1 in 2 years
5	Almost certain

Significance scale

Significance	Likelihood				
	1	2	3	4	5
Severity					
1	negligible	negligible	negligible	negligible	low
2	negligible	negligible	low	medium	medium
3	low	low	medium	high	high
4	medium	high	high	very high	very high
5	high	very high	very high	very high	very high

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Control measures and priorities

- Control measures are those steps in supply that directly affect water quality and which, collectively, ensure that water consistently meets health based targets.
- To prevent or minimize hazards occurring
  - ✓ Actions
  - ✓ Activities
  - ✓ Processes

Melbourne water case study Control measures

Hazard	Hazardous event, source/cause	Control measures
Microbial	Inadequate disinfection method	Minimising ingress of contamination from humans and domestic animals to system (closed catchments) and long reservoir detention times. Source water specifications. Research programme underway to further quantify pathogen loads and disinfection method.
Chemical	Formation of disinfection by-products	Reducing water age through tanks downstream where possible in periods of low water demand. Upstream preventative measures and reservoir management to minimise disinfection by-product precursors (eg managing off takes to avoid higher coloured water) Levels of by-products researched and below guideline levels.
Microbial	Less effective disinfection due to elevated turbidity	None downstream of disinfection. Research programme underway to quantify effect of increased turbidity on disinfection effectiveness. Catchment research completed to show very low levels of bacterial pathogens in raw water.

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Limits and monitoring

- An operational limit (often defined as alert limit or action limit) is a criterion that indicates whether the control measure is functioning as designed.
- Exceeding the operational limit implies that action is required to prevent the control measure moving out of compliance.
- The term critical limit is often in some water safety plans to single out operational limit linked directly to absolute acceptability in terms of water safety.
- Monitoring is the act of conducting a planned series of observations or measurements of operational and/or critical limits to assess whether the components of the water supply are operating properly.

Monitoring parameters

	Treatment step/process					
Operational parameter	Raw water	Coagulation	Sedimentation	Filtration	Disinfection	Distribution system
pH		✓	✓		✓	✓
Turbidity (or particle count)	✓	✓	✓	✓	✓	✓
Dissolved oxygen	✓					
Stream/river flow	✓					
Rainfall	✓					
Colour	✓					
Conductivity (total dissolved solids)	✓					
Organic carbon	✓		✓			
Algae, algal toxins and metabolites	✓					✓
Chemical dosage		✓			✓	
Flow rate		✓	✓	✓	✓	
Net charge		✓				
Streaming current value		✓				
Headloss				✓		
CT					✓	
Disinfectant residual					✓	✓
Disinfection by-products					✓	✓
Hydraulic pressure						✓

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Monitoring example

	Animal control	Disinfection control
What?	Wild pig densities in catchment must be below 0.5 per km^2	Chlorine, pH, temperature and flow must provide for a CT of at least 15 with a turbidity of <5.0 NTU
How?	Scat (animal faeces) surveys in spatially stratified transects across the catchment	Measured via telemetry and on-line probes with alarms
When?	Annually	Telemetry is downloaded automatically and continuously monitored
Who?	Catchment officer	Telemetry engineer

Management procedures

- Corrective actions and incident response
  - ✓ A corrective action is defined as the action to be taken when the results of monitoring indicate a deviation from an operational or critical limit.
- Emergency management procedures
  - ✓ Emergency response plan: response actions, including increased monitoring; responsibilities and authorities internal and external to the organization; plans for emergency water supplies; communication protocols and strategies, including notification procedures; and mechanisms for increased public health surveillance.

Documentation and record keeping

- Documenting the water safety plan
- Record keeping and documentation
  - ✓ support documentation for developing the water safety plan
  - ✓ records generated by the water safety system
  - ✓ documentation of methods and procedures used
  - ✓ records of employee training programmes