Water Quality Testing Everything You Always Wanted to Know about Managing Water Safety

Mark D. Sobsey, PhD

Kenan Distinguished Professor

University of North Carolina

Gillings School of Global Public Health

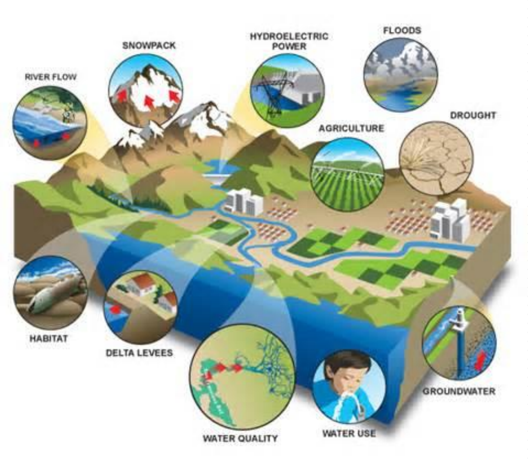
Dept. of Env. Sci. and Eng.

Chapel Hill, NC

Email: Mark_Sobsey@unc.edu

Why Test Drinking and Other Waters?

- Nearly all surface and many ground waters contain contaminants of health concern
- Dissolved minerals, organic compounds, microbes and other particles (turbidity) find their way into water. **The hydrologic cycle drives** contaminant presence and transport
- Natural and anthropogenic sources
- Contaminants in waters impact beneficial uses and human health. Waterborne disease occurs, both endemic and as outbreaks
- The safety of water is best ensured by regular monitoring as part of a **Water Safety Plan** as per the World Health Organization



http://distart119.ing.unibo.it/albertonew/?q=node/73

Need for Testing: Improved’ ≠ ‘Safe’ Water

- Water Safety Plans are the basis of the WHO GDWQ
  - Source water classification and selection
  - Choice and effectiveness of treatment
  - Collected, distributed and stored water in communities
  - Drinking water in households/where consumed

- JMP (WHO & UNICEF) used “improved”/”unimproved” classification of sources as proxy for safe/unsafe water under the MDGs

UNRELIABLE & NOT PREDICTIVE OF HEALTH RISK

We will need actionable microbial water quality data for the water target of the Sustainable Development Goals (Goal 6)

The UN SDGs include a Goal (#6) to Improve Access to Safe Water and Sanitation

6.1 By 2030, **achieve universal and equitable access to safe & affordable drinking water for all**

6.2 By 2030, **achieve access to adequate and equitable sanitation and hygiene** for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3 By 2030, **improve water quality** by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4 By 2030, substantially **increase water-use efficiency** across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5 By 2030, **implement integrated water resources management** at all levels, including through transboundary cooperation as appropriate

6.6 By 2020, **protect and restore water-related ecosystems,** including mountains, forests, wetlands, rivers, aquifers and lakes

6.a By 2030, **expand international cooperation and capacity-building** support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies

6.b Support and strengthen the participation of local communities in improving water and sanitation management

Physical Water Quality Testing Parameters (and their Measurement)

- **pH value -** measures hydrogen ion activity. Values are from 1 to 14. Most natural and drinking waters are pH 6 to 9. Low pH values can indirectly impact health by leaching toxic metals. (Meter)

- **Alkalinity -** a measure of buffering capacity, as quantified by reaction with a strong acid to a target pH. High alkalinity is harmful for irrigation, causing soil damage and reduced crop yields (pH Titration)

- **Conductivity or Total Dissolved Solids -** Measures of the capacity to convey an electric current and of solute levels. Water of conductivity/TDS is not drinkable and impacts agricultural use (Meter)

- **Turbidity -** Measures the concentration of particulate matter, such as clay or silt, organic matter and microorganisms, in water by the extent of light scattering (Meter)

Chemicals of Major Health Concern in Water (and their Measurement Difficulty)

- **Nitrate (NO_3)and Nitrite (NO_2)** – oxidized, inorganic nitrogen from fecal contamination and overuse of fertilizer. NO_2 health risks to infants and NO_3 in surface; can cause harmful algal blooms (easy)
- **Arsenic** – Mostly natural (geohydrological) contaminant of ground water causing toxicity (arsenicosis) (hard)
- **Fluoride** – Mostly natural (geohydrological) contaminant of ground water causing toxicity (fluorosis) (hard)
- **Lead** – Mostly anthropogenic contaminant of water from lead pipes and plumbing fixtures causing toxicity in children, neurological and developmental disorders (easy)
- **Pesticides** – Many chemical pesticides used in agriculture and can cause water contamination due to overuse and misuse. (hard)

Other Health Related Chemical Measurements of Drinking Water Quality

- **Chlorine residual**
  - Measure chlorine concentration of water where is used as a drinking water disinfectant
  - Achieve target chlorine dose, e.g., 3 mg/L
  - Maintain a minimum acceptable chlorine residual through the water supply system (at use), e.g., 0,2 mg/L

- **Chlorine disinfection by-products (DBPs)**
  - Some are known or suspected carcinogens
  - Manage water quality and chlorine use to maintain DBP concentrations below allowable limits

Microbial Water Quality Testing

- Testing microbial quality is essential to identify (un)safe water
  - You can not judge or estimate the microbial quality of water without microbially testing it
  - Water that looks clean could be fecally contaminated and contain disease-causing microorganisms (pathogens)
- Many drinking waters are not microbially tested or only rarely
  - Their microbial quality is essentially unknown
  - Many waters classified as “improved” are microbially contaminated
- When microbial testing is done, it is usually only for community water supplies; it is done only rarely or not at all in user homes
- Many water supplies are remote from testing labs, so testing can not be done within specified sample holding times. So, not done.
- Some field testing systems are available; most have drawbacks

Microbial Water Quality Testing

- Almost always for **fecal bacteria.** Many **fecal pathogens** are bacteria
  - Examples*: Vibrio cholera* (cholera) & *Salmonella typhi* (typhoid fever)
- Pathogens are rarely tested for directly – too may different ones, low levels in water, require difficult, multi-step and costly analytical methods
- **Fecal indicator bacteria** are tested for regularly in water instead
  - Bacteria that are always present at high concentrations in feces
  - Considered fecal indicators of possible pathogen presence
  - Recommended FIB testing is for *Escherichia coli* (*E. coli*)
    - The key member of the so-called coliform group of bacteria
    - Can be tested for directly by culture based methods (overnight)
      - Grow to detect (presence-absence) or quantify (number/100 mL)
- ***E. coli* should be absent consistently** from 100 mL samples of drinking water to be considered safe (World Health Organization)

Key Question for Practitioners

How can we monitor microbial quality of water without a lab, equipment or specialized analyst … in the field?

Microbial Water Testing in Resource-limited Settings

- Equipment often not accessible, too complicated and too costly
- When tested, only rarely (≤1X/year); often poorly
  - Often only at Rx works; often not at sources, taps, in HHs
- Test results are not used for rational or timely decision making for water safety management
- Testing is not done for the right reasons or within a health risk-based framework
  - Only the end-product testing after treatment; (WRONG!)
- Some RIGHT reasons (WHO GDWQ):
  - Risk assessments of water supplies/systems
  - Support Water Safety Plans
  - Support local management systems and decisions
  - Get data to monitor progress toward Goal 6 of the SDGs

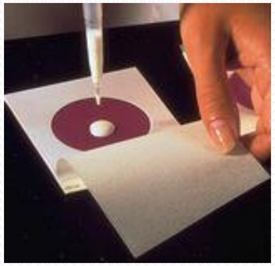
Desirable Goals for Microbial Testing in Low Resource Settings: at Point-of-Need

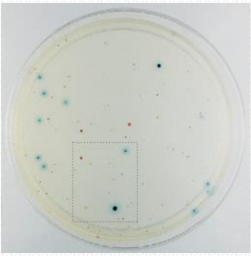
- Simple: anybody should be able to do it
- Self-contained: open the box and run the test
- Portable
- Lab-free
- Electricity-free
- No cold chain
- Low cost
- Globally available and accessible; supply chain
- Local to global water data collection and communication
- Save, convey and use the data to make decisions!
- Education and behavior change tool
  - Educate and mobilize stakeholders - especially youth

Typical Options for Microbial Water Testing

- **Static laboratories**
  - Expensive facilities and equipment, high overhead, consumables need high calibre staff
  - Long chain to get samples from field to lab

- **Field labs and "portable" labs**
  - Cheaper, but still expensive, supply chain issues, need for trained staff; not really portable if you are on the move





- **Disposable field tests (low sample volume)**
  - Compact dry plates or films (volume: 1 mL)
  - Easygel plates for colonies (cold chain); 5-ml
  - Presence/absence by H_2S (often only 20 mL)
  - Most are too costly; limited access; cold chain

Clear Plastic Compartment Bag (CBT) Test: A Lab-free, Portable, Disposable Field Test

- 5-compartments = 100ml:
  - 1, 3, 10, 30, and 56 ml
- Detects *E. coli*/100 ml in WHO low to high risk ranges: 0, 1-10, >10-100, >100
- Easily read color (blue) as positive with chromogenic *E. coli* medium
- No cold chain
- Simple to perform
- Portable
- Low-Cost
- No other equipment or supplies
- Built-in decontamination
- Now available commercially for global use

CBT Test of *E. coli* in water
www.aquagenx.com

How the CBT Works

- Collect 100 mL sample
- Dissolve growth medium in sample for ~15 min.
- Pour sample with added medium into compartment bag
- Squeeze and tilt bag to adjust compartment sample volumes to fill lines
- Incubate 24-48 hours depending on ambient temperature
- Score and record test results
- Find Most Probable Number concentration of E. coli/100 mL in table provided with the test
- Decontaminate the bag and its liquid by adding the chlorine tablets provided and wait 45 minutes before disposal

Common Positive CBT Compartment Combinations and their Most Probable Number (MPN) Concentrations/100 mL

	Compartment Volume, mL						
Bag	1	3	10	30	56	MPN/100 mL	95% CI
1	-	+	+	+	+	48.3	[7, 352]
2	-	-	+	+	+	13.6	[2.2, 83.1]
3	-	-	-	+	+	4.7	[0.9, 22.8]
4	-	-	-	-	+	1.5	[0.2, 7.8]

All positive: >48.3 MPN/100 mL; None positive: <1.5 MPN/100 mL

Most Probable Number of *E. coli*/100 mL

Compartment # 1 (10mL)	2 (30mL)	3 (56mL)	4 (3mL)	5 (1mL)	MPN/100mL	Upper 95% Confidence Interval/100mL	Health Risk Category Based on MPN and Confidence Interval
Yellow	Yellow	Yellow	Yellow	Yellow	0.0	2.87	Low Risk/Safe
Yellow	Yellow	Yellow	Green	Yellow	1.0	5.14	Intermediate Risk/ Probably Safe
Yellow	Yellow	Yellow	Yellow	Green	1.0	4.74	
Green	Yellow	Yellow	Yellow	Yellow	1.1	5.16	
Yellow	Green	Yellow	Yellow	Yellow	1.2	5.64	
Yellow	Yellow	Green	Yellow	Yellow	1.5	7.81	
Yellow	Yellow	Yellow	Green	Green	2.0	6.32	
Green	Yellow	Yellow	Green	Yellow	2.1	6.85	
Green	Yellow	Yellow	Yellow	Green	2.1	6.64	
Yellow	Green	Yellow	Green	Yellow	2.4	7.81	
Yellow	Green	Yellow	Yellow	Green	2.4	8.12	
Green	Green	Yellow	Yellow	Yellow	2.6	8.51	
Green	Yellow	Yellow	Green	Green	3.2	8.38	
Yellow	Green	Yellow	Green	Green	3.7	9.70	
Yellow	Yellow	Green	Yellow	Green	3.1	11.36	Intermediate Risk/ Possibly Safe
Yellow	Yellow	Green	Green	Yellow	3.2	11.82	
Green	Yellow	Green	Yellow	Yellow	3.4	12.53	
Green	Green	Yellow	Yellow	Green	3.9	10.43	
Green	Green	Yellow	Green	Yellow	4.0	10.94	
Yellow	Green	Green	Yellow	Yellow	4.7	22.75	
Yellow	Yellow	Green	Green	Green	5.2	14.73	
Green	Green	Yellow	Green	Green	5.4	12.93	
Green	Yellow	Green	Yellow	Green	5.6	17.14	
Green	Yellow	Green	Green	Yellow	5.8	16.87	
Green	Yellow	Green	Green	Green	8.4	21.19	
Yellow	Green	Green	Yellow	Green	9.1	37.04	
Yellow	Green	Green	Green	Yellow	9.6	37.68	
Green	Green	Green	Yellow	Yellow	13.6	83.06	High Risk/Possibly Unsafe
Yellow	Green	Green	Green	Green	17.1	56.35	
Green	Green	Green	Yellow	Green	32.6	145.55	High Risk/Probably Unsafe
Green	Green	Green	Green	Yellow	48.3	351.91	
Green	Green	Green	Green	Green	>100	9435.10	Unsafe

- Match color sequence of bag compartments to one of 32 possible outcomes
- Chart provides MPN for sample combination and indication of risk, based on WHO categories
- Make informed decisions about water quality, even in intermediate risk ranges where many decisions about safety are often made
- 95% CL is highest likely MPN value detected if the same sample was repeatedly tested; a worst case 95th percentile MPN estimate

Water Institute at UNC: Water Quality Portable Field Kit for MEL

- **Ideal when resources are lacking** or samples must be analyzed from different locations over time
- **Includes key water quality tests** that are small and portable enough to fit in a backpack (Most other kits come in a hard case)
- **Avoids preparing media and reagents** and allows teams on motorbikes to carry enough supplies to analyze dozens of (50) samples for a few critical parameters without refilling
- **Includes CBTs for *E. coli* and validated commercial tests** for arsenic, fluoride, free chlorine, turbidity, pH, and total dissolved solids/electrical conductivity in a backpack-sized field kit
- **Includes collapsible containers** for measuring flow rates, mobile phones for rapid data collection, field chargers to avoid running out of power, and barcoded asset tags to link samples, sources, and surveys using mobile barcode scanner apps

Materials in UNC Water Institute Portable Water Quality Field Kit and

Quantity	Item	Description	Manufacturer	Part #
1	Backpack	Super-sturdy ballistic nylon backpack	Ful	
50	CBT	Compartment Bag with Test Bud	Aquagenx, LLC	
20	Clip	Plastic clip for Compartment Bag Test	Aquagenx, LLC	
50	Whirlpak Bags	Sterile 100 mL Whirlpak bag with sodium thiosulfate	Nasco	B01040WA
1	Plastic asset tags	Adhesive plastic asset tags for sample tracking (pack of 100 tags)	Intelli-scanner®	ISTAGS-S100
1	Arsenic Test Kit	Econo-Quick II Arsenic Test Kit (100 tests)	ITS, Inc	481304
1	Fluoride Meter	Digital fluoride meter	Extech Instruments	FL700
1	Fluoride Reagents	TISAB tablets (tube of 100)	Extech Instruments	FL704
1	Chlorine Meter	Digital Residual Chlorine Meter	Extech Instruments	FL200
1	Chlorine Reagents	DPD tablets (pack of 100)	Extech Instruments	FL204
1	pH/Conductivity meter	Digital pH/conductivity/TDS meter	Hanna Instruments	HI 98129
2	Stopwatch	Digital sports stopwatch	Champion Sports	910
1	Collapsible bucket	20L collapsible bucket	Sea to Summit	
1	Turbidimeter	Portable Turbidimeter (Optional)	Hanna Instruments	HI9803
1	Mobile phone	Mobile phone suitable for data collection	Various Mfrs.	
1	Power bank	Mobile power bank (>10,000 mAh)	Various Mfrs.	

WaSH MEL project Virtual Learning Center www.washmel.org , or Kaida Liang (kliang@email.unc.edu)

What are the Costs of Water Quality Testing?

- Some tests are self-contained, portable and require no or little equipment or other material.
  - Cost US$ 1-10 each, depending on analyte(s)
  - Microbiological tests are ~US$ 1-10, if self-contained; quantitative ones US$ 5-10 (some are more)
  - Chemical tests are US$ <1 to ~5, depending on parameter
- Some tests are in a system or modular kit with instruments, supplies and materials. Typical costs ~US$ 1000-5000
  - Recurrent costs for consumable supplies and materials are similar to costs for self-contained tests


Hach


Delagua


Wagtech Palintest

Water Quality Testing is Best Done for Water Safety Plans

An Overview

Water Safety Plans for Drinking Water

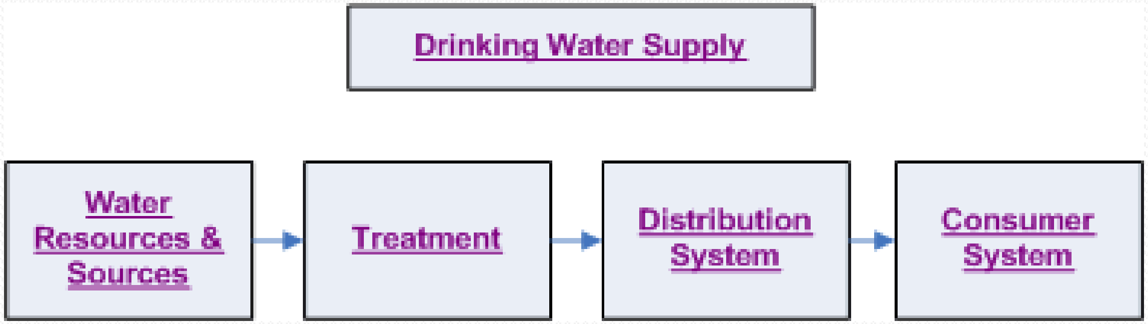
Overview

- Comprehensive risk assessment and risk management approach
- Includes all steps from catchment to consumer
- Based on principles and practices of the multiple barrier approach and HACCP
  - (HACCP = Hazard Analysis at Critical Control Points)

Main objectives

- Minimize contamination of source waters
- Reduce or remove contamination through treatment processes
- Prevent contamination in the source, during collection, storage, distribution and handling of the water

Drinking Water Supplies & Water Safety Plans



Water resources and sources

- Sources of raw water, including surface sources, groundwater, harvested rain water, the sea or other brackish sources

Treatment

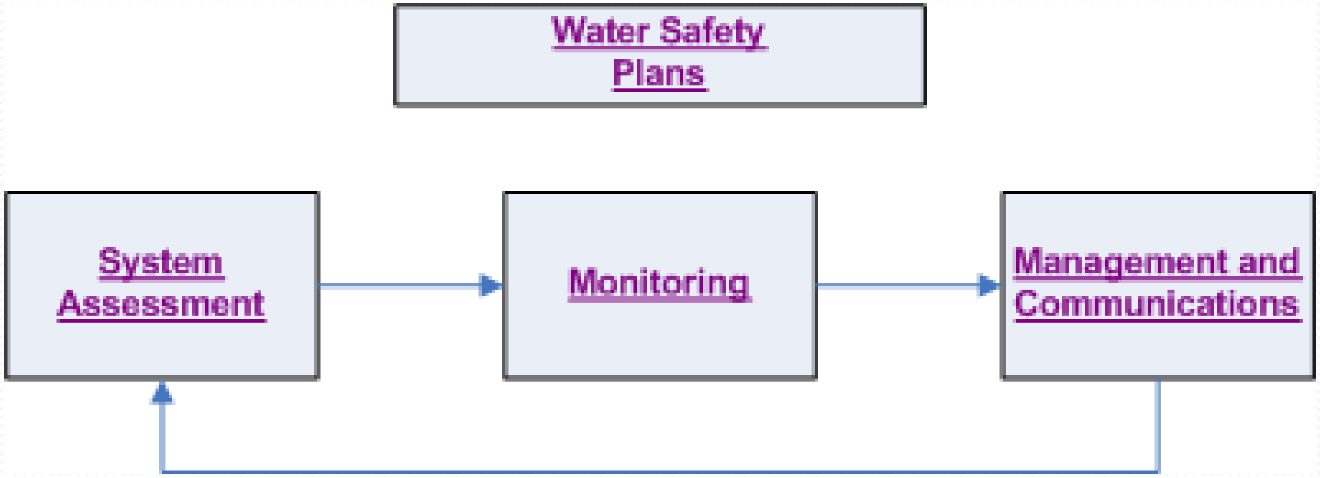
- Any chemical, biological of physical treatment of raw water.

Distribution system

- Distribution through piping/other structures from storage to consumer

Consumer system

- The systems used to provide water to a household or other user beyond the point of delivery from the water supplier.



System Assessment ***(KNOW YOUR SYSTEM!)***

- Determines if the whole supply chain can deliver water of adequate quality

Monitoring ***(PAY ATTENTION TO IT AND KEEP DOING THAT!)***

- Monitoring of the control measures in the supply chain that are of particular importance in securing water safety

Management and communications ***(HAVE A PLAN, USE & SHARE IT!)***

- Management plans describing the actions to be undertaken from normal conditions to extreme events

Applying WSPs to Your Water System

Ask:

- **What are the hazards?**
- **What events could occur?**
- **What adverse consequences could occur on public health?**

Applying WSPs to Your Water System

For each event consider:

- **Severity: How severe would the public health consequences be?**
- **Frequency: How likely is the event to happen ?**

Severity Example – Your System

HAZARD → EVENT → CONSEQUENCE

HAZARD	EVENT	CONSEQUENCE
Salmonella In raw water	Chlorinator fails	People become ill

Frequency

Likelihood ranking	Description
Rare	May occur only in exceptional circumstances (once in 1000 years)
Unlikely	Could occur (once in 100 years)
Possible	Might occur at some time (once in 10 years)
Likely	Will probably occur (once in 1 or 2 years)
Almost certain	Is expected to occur in most circumstances

WHO Guidelines For Drinking-water Quality (4th edition) System Assessment Scoring

Table 5.4 Example of assessment of priority of remedial action for household drinking-water systems based on a grading system of microbial quality and sanitary inspection rating or scores[a]

		Sanitary inspection risk score (susceptibility of supply to contamination from human and animal faeces)			
		0–2	3–5	6–8	9–10
E. coli classification (as decimal concentration/100 ml)	< 1				
	1–10				
	11–100				
	> 100				

Low risk: no action required	Intermediate risk: low action priority	High risk: higher action priority	Very high risk: urgent action required

[a] Where there is a potential discrepancy between the results of the microbial water quality assessment and the sanitary inspection, further follow-up or investigation is required.

http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/

WSPs for Drinking Water: A Summary

- Provides a rational, practical and holistic basis for **sound and effective management** *for the purpose of continuously delivering safe drinking water*
- Intended to be:
  - Tailored or fit to the local context and conditions
  - Actionable
  - Adaptable
  - Proactive
- Scalable to any size and kind drinking water supply
- Based on sound science, technology and practice
- Embraces and implements the basic principles of HACCP (Hazard Analysis at Critical Control Points)
  - Identify, anticipate, respond to, monitor and document on-going conditions and be prepared to react to changing conditions and risks that might compromise water safety

Key Monitoring and Testing Tools for WSPs

- Sanitary Inspection/Survey Tools
  - System maps, diagrams and descriptions
  - Check list for system components and actors
  - Check list for grading system components and their vulnerabilities
  - Inventory of system data, reporting and accountability
- Testing Entities and their Tools
  - Who tests the water? For what purposes? How often?
  - What tests are performed? By what methods? How often?
    - Who is responsible for maintaining testing capabilities and resources?
    - Is there a Data Management System and QA/QC?
  - What happens to testing data? Who gets it? What actions may be triggered by it? By whom? Are there auditing systems?

Some Resources

- www.who.int/water_sanitation_health/dwq/en/ and http://www.who.int/wsportal/en/
- WHO Water Safety Plan Manual: http://www.wsportal.org/wspmanual
- Sustainable Development Goals – Goal 6 (WaSH): http://www.un.org/sustainabledevelopment/water-and-sanitation/
- Centre for Affordable Water and Sanitation Technology (CAWST). Water Quality Testing Guide: https://resources.cawst.org/manual/cfd38f83/drinking-water-quality-testing-manual
- Others:

Bain R, Bartram J, Elliott M, Matthews R, McMahan L, Tung R, Chuang P, Gundry S. Int J Environ Res Public Health. 2012 May;9(5):1609-25. doi: 10.3390/ijerph9051609. Epub 2012 May 4. PMID: 22754460

Mahmud, S.G., S.A. Shamsuddin, M.F. Ahmed, A. Davison, D. Deere and G. Howard (2007) Development and implementation of water safety plans for small water supplies in Bangladesh: benefits and lessons learned. J. Water & Health 5(4): 585–597

Thank You!

Questions?