WATER QUALITY

Thursday 7 July: Session 1

Water quality issues for groundwater and their relationship to sanitation and health.

Dr. L Katiyo (IWSD)

WHO Definition

Defines safe drinking water as water that "*does not represent any significant risk to health over the lifetime of consumption, including different sensitivities that may occur between life stages*."

Guidelines vs. Standards

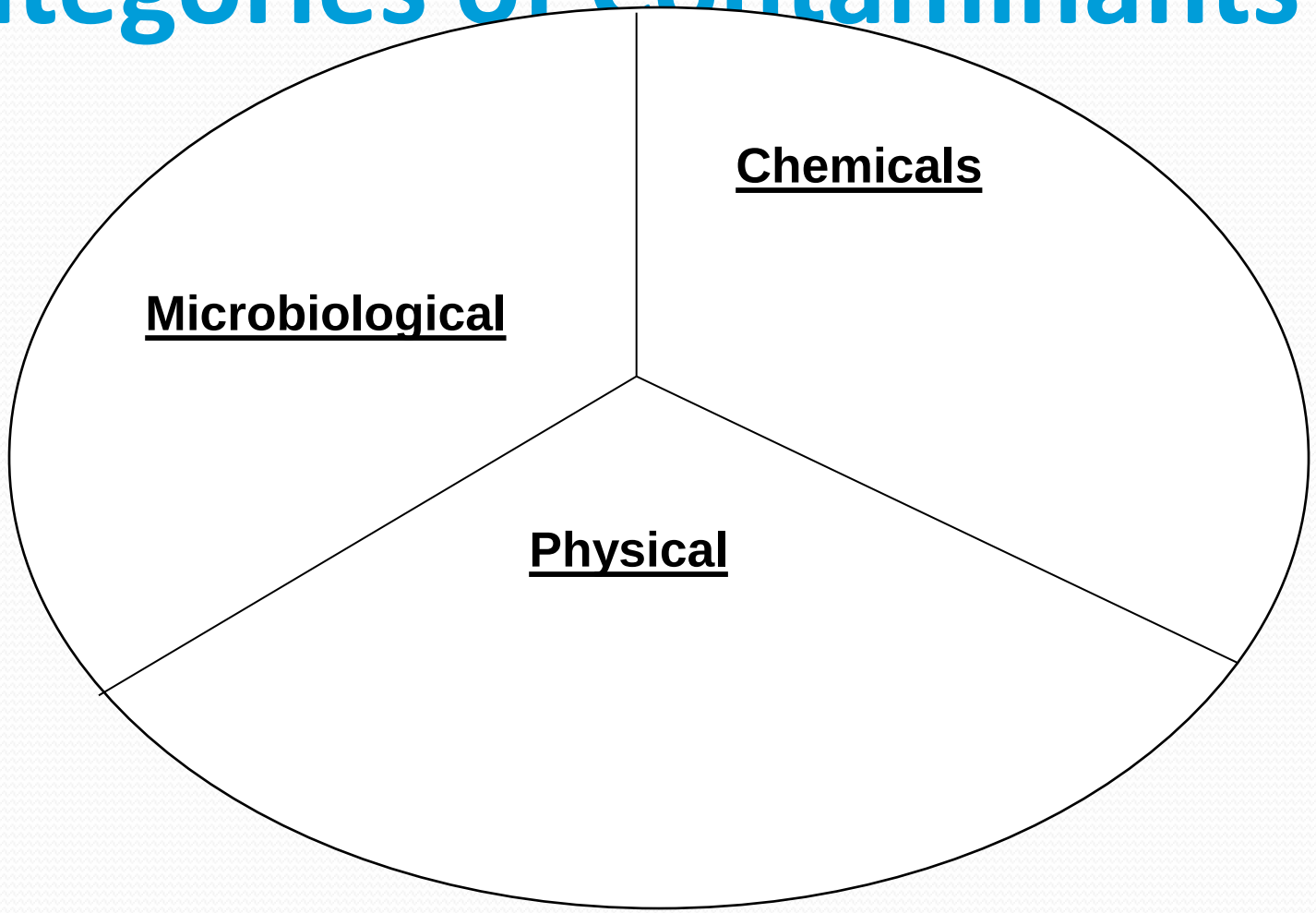
- Guideline: a recommended limit that should not be exceeded
- Standard: a mandatory limit that must not be exceeded (often reflects legal duty or obligation)

- WHO Guidelines for Drinking Water Quality (2006)
  - Guideline values to ensure safety of drinking water
- Standards vary among countries and regions

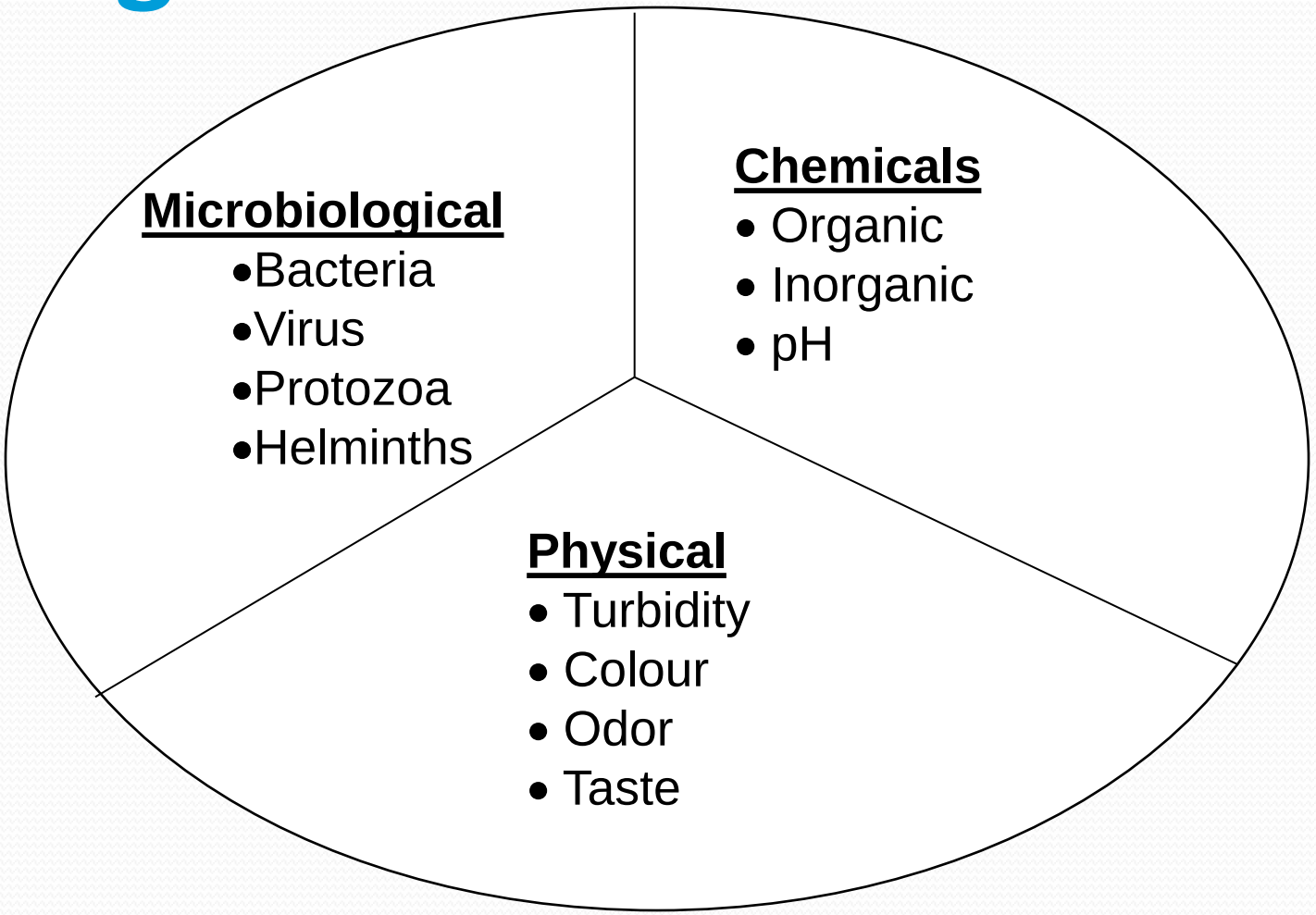
Why Do We Do Water Quality Testing?

- Ensure safe drinking water
- Identify problems
- Adopt precautionary measures
- Raise awareness
- Determine the effectiveness of water treatment technologies
- Select an appropriate water source
- Influence policies to supply safe water

Categories of Contaminants



Categories of Contaminants



Water Sampling

-**Microbiological sampling**

-Indicator organisms for pathogen presence

Physical sampling

-turbidity, conductivity, total dissolved solids etc

Chemical sampling

- pH, dissolved oxygen, phosphates, chemical oxygen demand, biological oxygen demand, mineral impurities (iron, manganese, chloride, lead, sodium etc)

Types of Testing

- Observation
  - Advantages:
    - Quick and easy
    - Inexpensive
  - Limitations:
    - Qualitative – low precision and accuracy
- Field testing
  - Advantages:
    - Easy to use and portable
    - Rapid results
    - Less expensive
  - Limitations:
    - Less precision and accuracy
    - Less quality assurance

Types of Testing

- Mobile laboratories
  - Advantages:
    - Controlled environment,
    - High level of precision and accuracy
  - Limitations:
    - Relatively expensive
    - Requires skilled laboratory technicians
- Laboratory testing
  - Advantages:
    - Controlled environment,
    - High level of precision and accuracy
  - Limitations:
    - Expensive
    - Lack of flexibility to conduct own testing

Selecting Test Methods

Depends on:

- Objectives
- Range of concentration
- Required accuracy and precision
- Time period between sampling and analysis
- Technical skills and equipment required
- Familiarity with the method
- Availability of resources

Where Do We Sample?

- Source water
- Transport container (before treatment)
- Treated water
- Stored water (after treatment)
- Point of use

MICROBIOLOGY OF WATER

Pathogens

micro-organism that cause disease

- 4 types of pathogens
  - Bacteria
  - Virus
  - Protozoa
  - Helminths

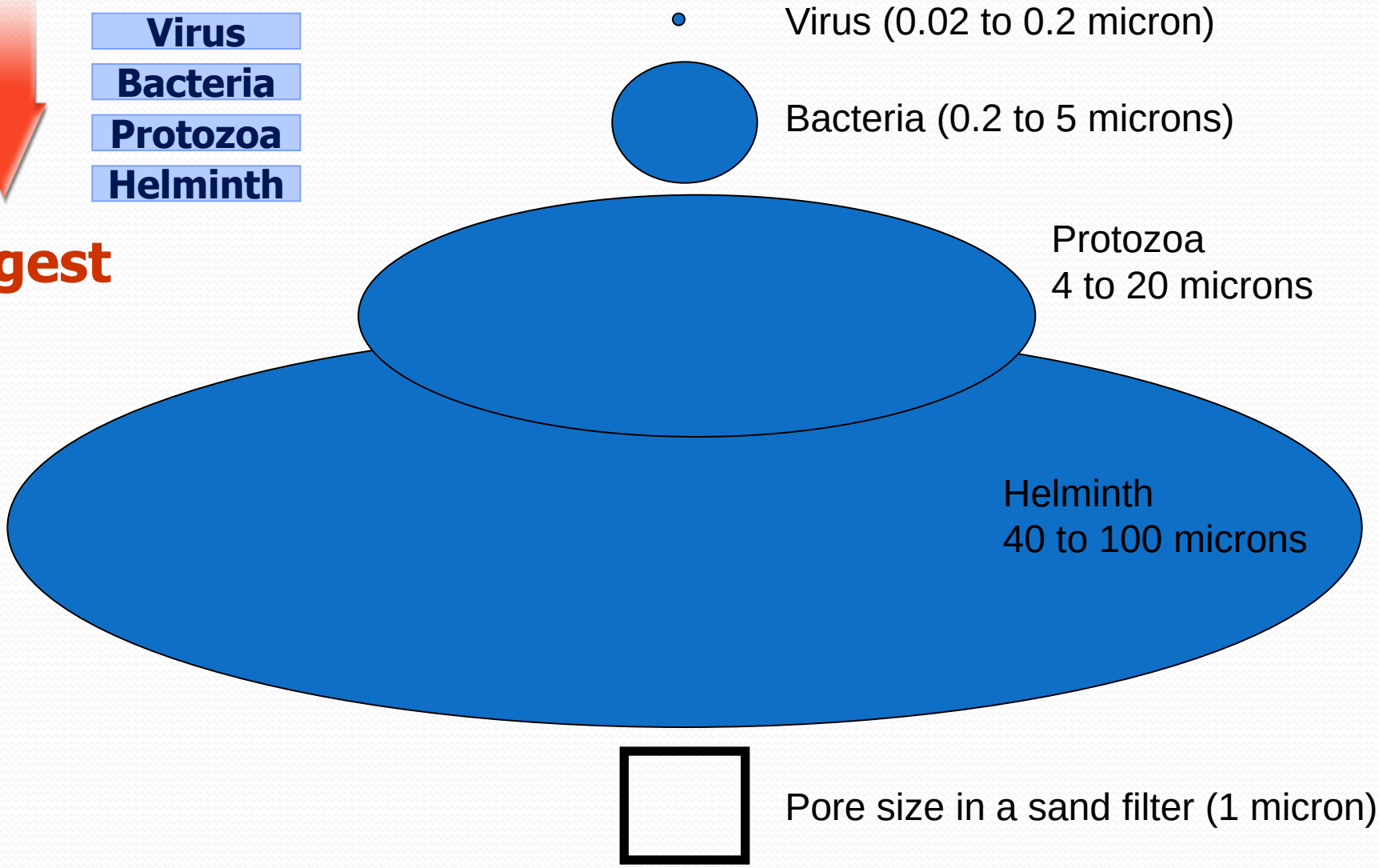
Zoom: Bacteria on the tip of a pin

Size Comparison

Smallest

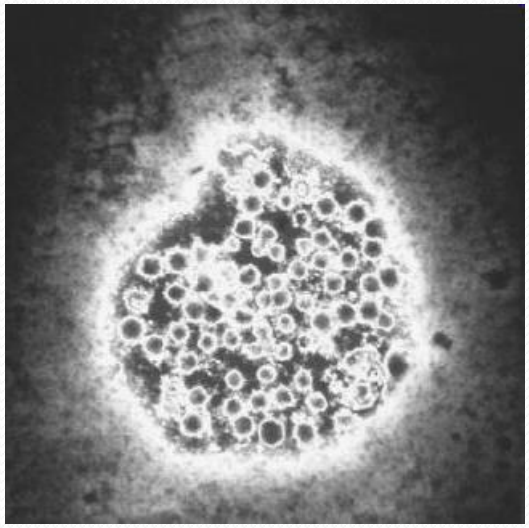
- Virus
- Bacteria
- Protozoa
- Helminth

Largest



Viruses

- Hepatitis (A and E are faecal-oral)
- Dengue Fever
- Polio

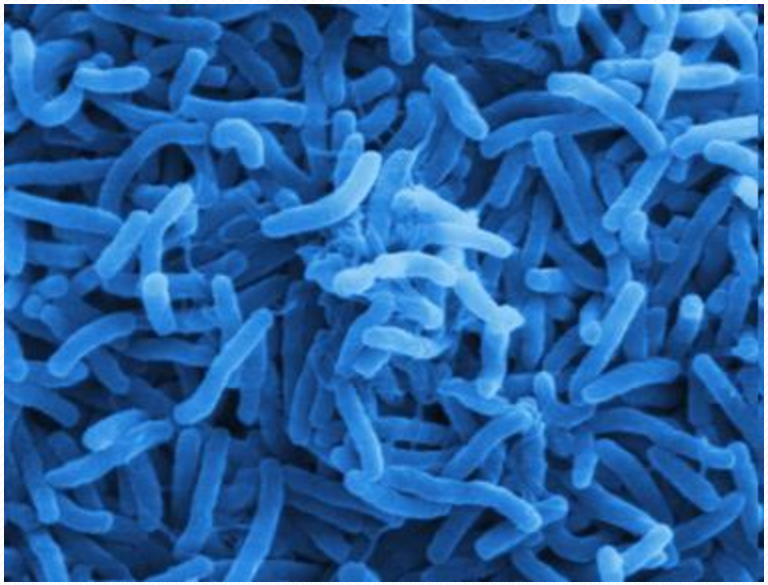


Hepatitis A

• Viruses depend on the host cells that they infect to replicate
• When stimulated, new viruses are formed, and burst out of the host cell, killing it and going on to infect other cells
• Some viruses can remain viable outside of a host for long periods, also in dry conditions
• Viruses can survive but will not grow in food

Bacteria

- Cholera
- E-Coli
- Salmonella
- Shigella
- Typhoid
- Trachoma



Cholera

- Most dominant organism found in faeces
- Most diverse group of micro-organisms
- Simplest, wholly contained life system
- Abundant in faeces (1g = billions of bacteria)

FACTORS AFFECTING NUMBER AND TYPE OF BACTERIA IN WATER

- Type of water:
  - Surface or deep
  - Mineral springs

- Presence of organic matter
- Temperature
- Light
- pH
- Dissolved oxygen
- Rainfall
- Season
- Storage
- Filtration

Protozoa

- Single celled organisms
- Able to form cysts which are resistant to chlorine
- Some can stay alive outside of a host

- Giardia
- Cryptosporidium
- Malaria

Helminths

- Roundworm
- Hookworm
- Guinea Worm
- Schistosomiasis (Bilharzia)

Worm from a human intestine (20 feet in length)

- Can live for many years in the body
- Most do not multiply within the human host
- Derives sustenance at hosts expense
- Most helminths are passed in faeces

Fecal pollution:

Introduces varieties of pathogens.

Bacterial:

- Cholera
- Typhoid fever
- Shigellosis
- Diarrhoea
- E.coli
- Y.enterocolitica
- C.fetus
- Leptospirosis

Viral:

- Hepatitis A , E
- Rota viral diarrhoea
- Poliomyelitis

Helminthes:

- Round worm
- Thread worm
- Whip worm
- Hydatid disease
- Guinea worm disease
- Fish tape worm
- Schistosomiasis

Protozoal:

- Amoebiasis
- Giardiaisis
- Balantidiasis

Microbiological Testing

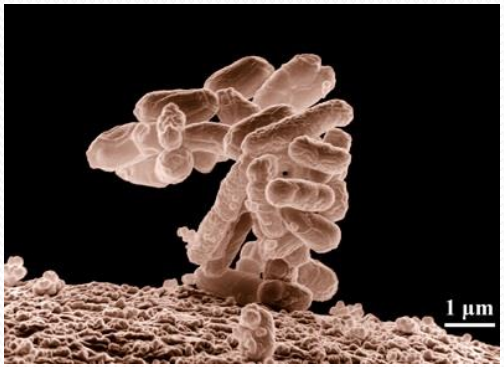
- Testing for every pathogen is time consuming and expensive

Bacterial Indicator Organisms

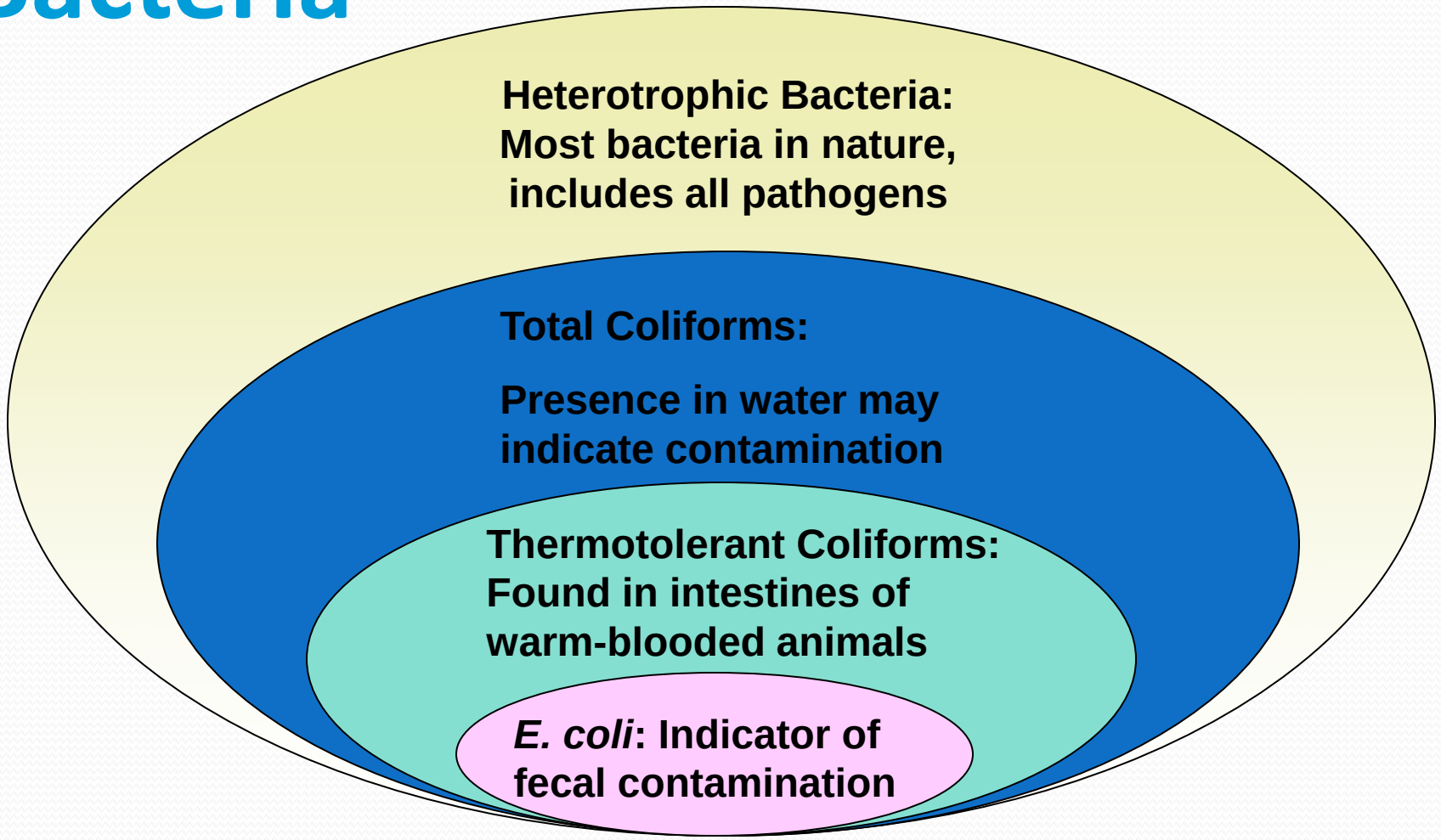
- Test for bacterial indicator organisms instead:
  - Cheaper
  - Easier to perform
  - Faster results
  - Does not require highly trained personnel

Bacterial Indicator Organisms

- Good indicators should:
  - Be present whenever pathogens are present
  - Present in the same or higher numbers than pathogens
  - Specific for faecal contamination
  - Non-pathogenic (harmless)
  - Have a survival time equal to pathogens
  - Not reproduce in water



Bacteria


Heterotrophic Bacteria:
Most bacteria in nature,
includes all pathogens
Total Coliforms:
Presence in water may
indicate contamination
Thermotolerant Coliforms:
Found in intestines of
warm-blooded animals
E. coli: Indicator of
fecal contamination

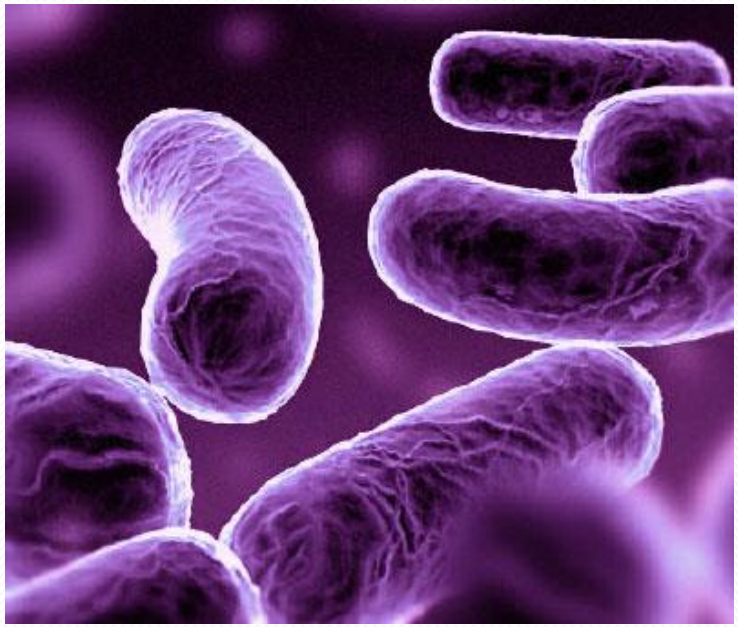
Indicator organisms:

Esch.coli.

Faecal coliforms

Faecal streptococci.

Clostridium perfringens.



Presence of fecal streptococci along with coliforms in the absence of E.coli is also confirmatory of fecal pollution.

Escherichia coli (E. coli)

- Found mainly in faeces of warm-blooded animals
- Majority of *E. coli* is harmless (non-pathogenic)

- Meets criteria for a good indicator and is the most important
  - Most specific for faecal contamination
  - Limited ability to survive and reproduce in water
  - Non-pathogenic

WHO Guidelines

Number of *E. coli* Present (CFU/100 mL)	**Risk**
0 - 10	Reasonable Quality
11 - 100	Polluted
101 - 1,000	Dangerous
> 1,000	Very Dangerous

Source: WHO, 1997; Harvey, 2007

Microbiological Testing Methods

- 3 methods to determine presence of bacteria in water:
  - Presence-Absence (P-A)
  - Most Probable Number (MPN)
  - Membrane Filtration

Presence-Absence (P-A)

- Simplest method
- Add water sample to a bottle containing broth and let it sit for 24-48 hours
- Color will change if indicator organism is present
- Does not show numbers of bacteria!
- If the sample is positive, the water should be re-tested using membrane filtration to determine the number of bacteria
- Not recommended by WHO for analysis of surface water and untreated community water supplies
- Not recommended for testing the efficiency of household water treatment technologies (e.g. biosand filter)

Presence-Absence

Positive for *E. coli*

Positive for Coliforms

Negative

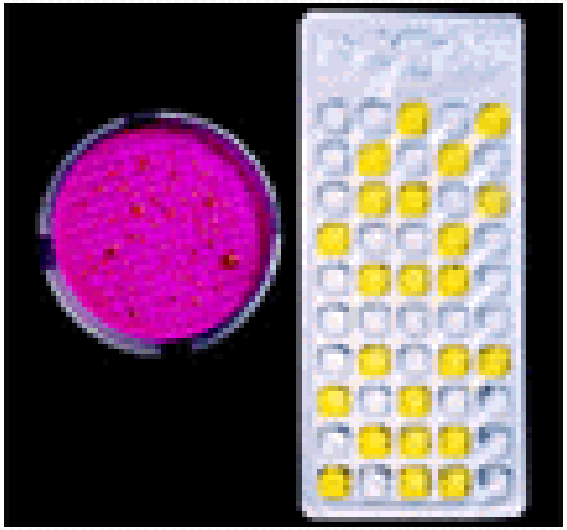
Most Probable Number (MPN)

- Tells the number of bacteria that are most likely to be in the water sample
- Add water sample or diluted sample to 5 or 10 or test tubes (or larger tray 50 – 96 tubes)
- Incubate for 24-48 hours
- Gas production and/or cloudiness will be visible if the indicator organism is present
- Using a table provided, report the number of positive tubes as number of colonies per 100 mL of sample
- Typically used for wastewater or turbid samples

Most Probable Number (MPN)

# Positive Tubes	MPN Index (CFU/100mL)
0	<1.1
1	1.1
2	2.2
3	3.6
4	5.1
5	6.9
6	9.2
7	12.0
8	16.1
9	23.0
10	>23.0

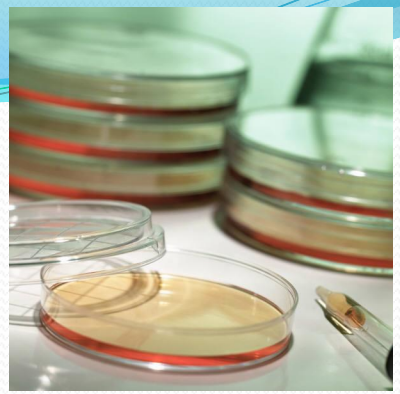
Sample Table for 10 tube test



Most Probable Number (MPN)

- Characteristics:
  - Quantitative results
  - Simple to understand and use
  - Relatively inexpensive
  - Can be used with turbid water
  - More labor-intensive than P-A
  - Requires some training
  - Requires incubator & other equipment

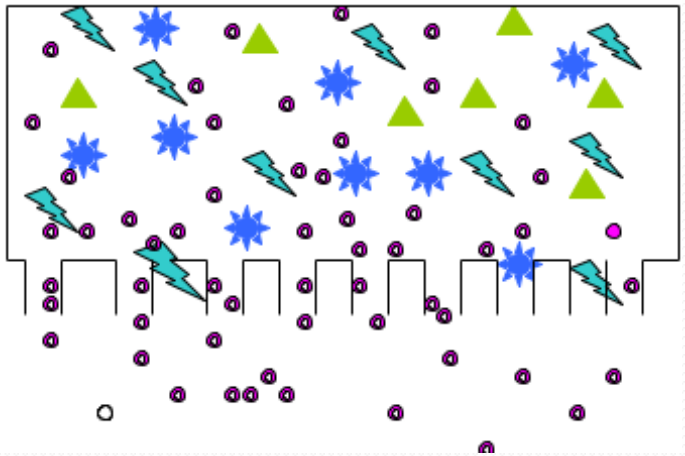
Membrane Filtration

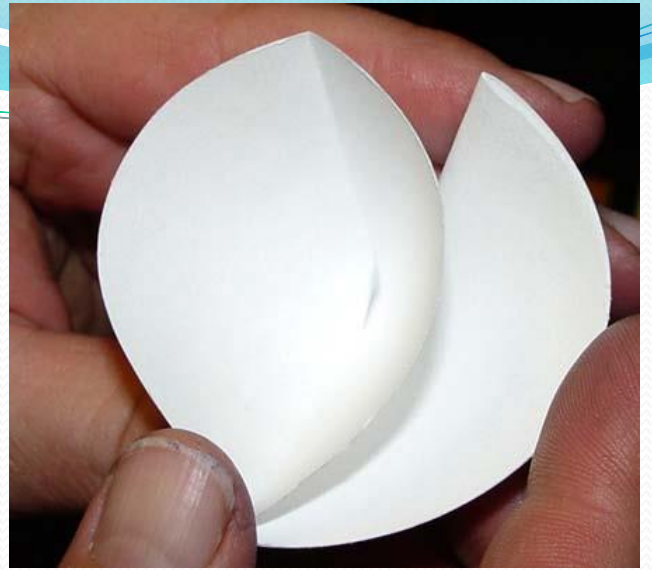


- Most accurate method to count bacteria
- Filter 100 mL of a water sample
  - Add broth to a Petri dish which provides nutrients for the indicator organism to grow
  - Filter the water using the filtration equipment
  - Transfer the filter paper to the Petri dish
  - Incubate for 24-48 hours depending on the broth
- If the indicator organism is present, colonies will appear on the filter paper and can be counted
- Results are reported as the number of colonies per 100 mL of water sample (CFU/100mL)
  - CFU = colony forming units

Membrane Filter Technology

- A membrane is a thin material that has pores (holes) of a specific size
- Membranes trap larger particles that won't fit through the pores of the membrane, letting water and other smaller substances through to the other side





Transporting Samples

- Bacteria do not survive well in water
- Temperature can affect bacteria die off
- Samples should be placed on ice in an insulated container if they cannot be tested right away
- Ideally – all samples should be tested within 6 hours of sampling
- If the time exceeds 6 hours, note this in your report
- Samples exceeding 30 hours (between collection and testing) should not be tested

Membrane Filtration Equipment

Field Kits

Membrane Filtration Equipment

Incubator

Membrane Filtration Equipment

Nalgene Testing Kit

Membrane Filtration

- Advantages:
  - Able to count the number of bacteria
  - Most accurate test method
  - Ability to test many samples at once
  - Internationally recognized method
  - Rapid
  - Easy & Economical.
  - Gives direct result.
  - Useful in rural areas.
  - Samples can be tested in the field

Membrane Filtration

- Limitations:
  - More labour intensive than MPN, P-A
  - Requires more training
  - Requires additional equipment
  - Cost of consumables can be high in many countries
  - Turbid water interferes with bacterial growth.
  - Noncoliforms interferes with counting of coliforms.
  - Toxic substances in the water may be absorbed by filter and interferes with bacterial growth.

Sampling from a dugwell:

A suitable size stone has to be attached to the sampling bottle.

A 20 meter length of clean string is tied on the bottle and a stick.

Bottle is immersed completely in the water and lowered down to the bottom of the well.

Once the bottle is filled ,it is pulled out.

Little water is discarded to provide air space.

Sampling bottles and bags

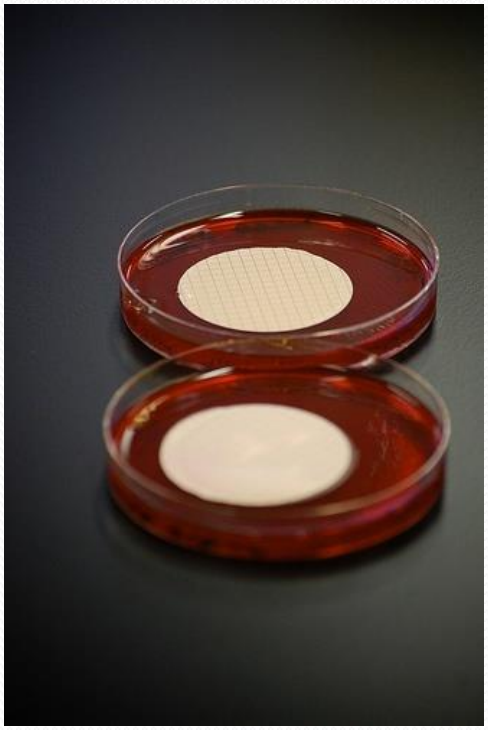
Whirl-pak® bag
(from 120 to 720mL)

- Convenient
- Single Use

Plastic Sample Bottles
(from 200mL to 1500mL)

- More robust
- Re-usable

Processing of the sample:

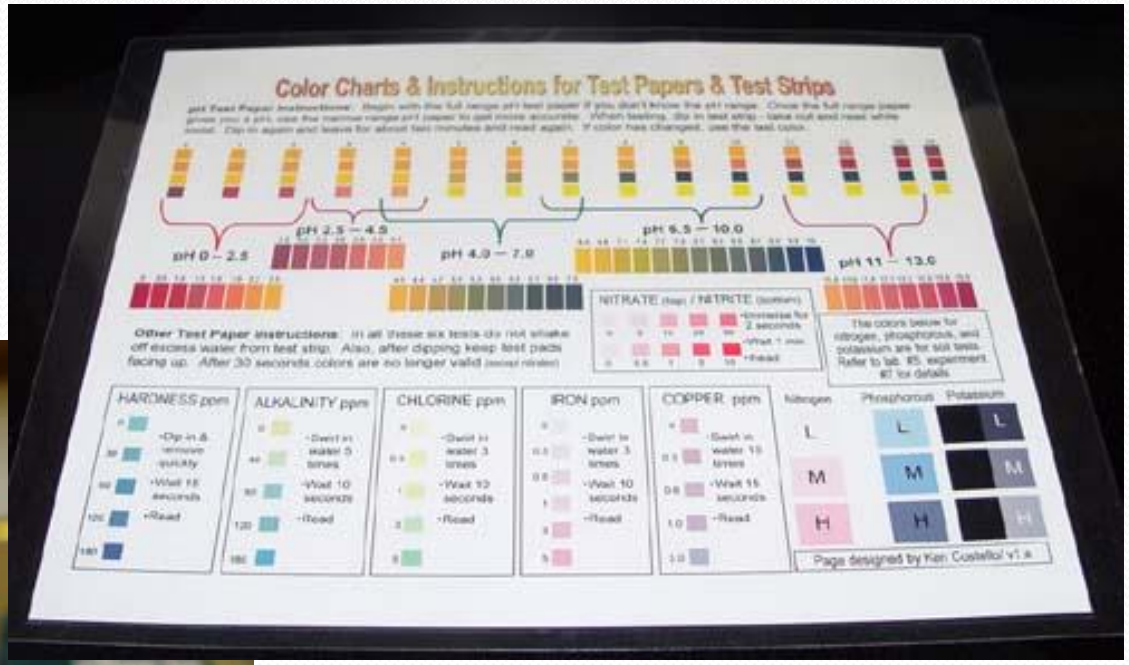


Should be processed within 6 hours.

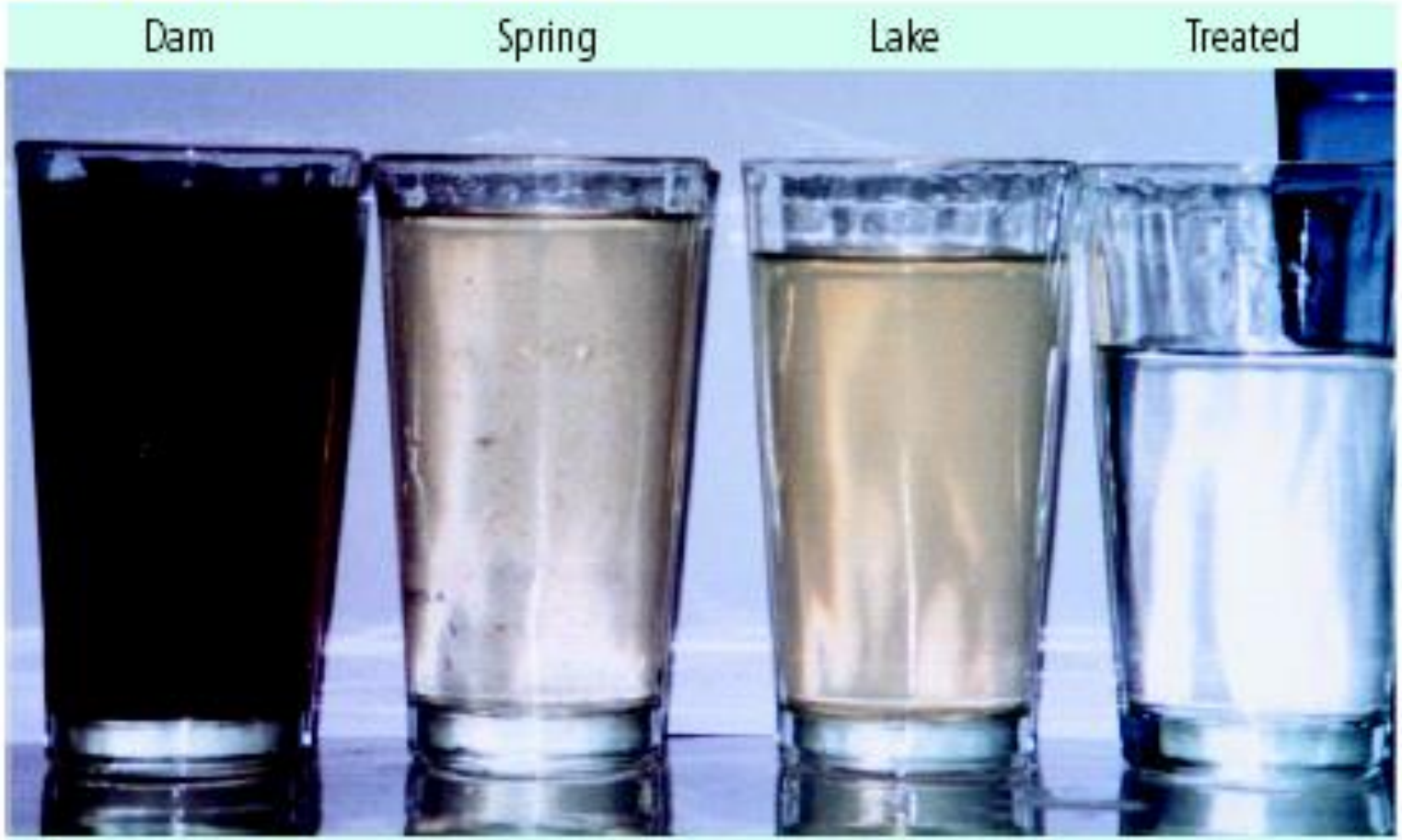
In case of delay ,water can be filtered by using a ***membrane filter***.

Filter paper has to be transported on an absorbent pad saturated with **transport medium.**

Physical sampling:



Kenyan Drinking Water Samples



http://www.pghsi.com/images/PUR_kyoto.pdf

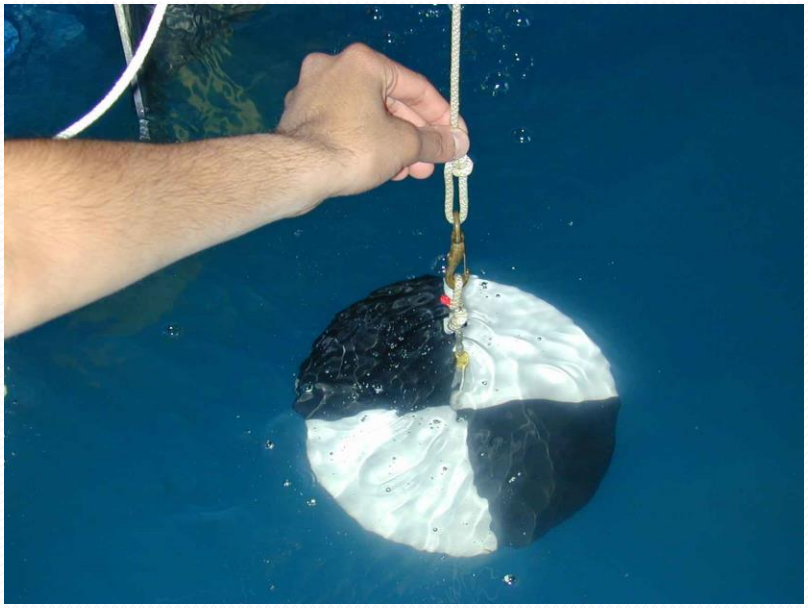
What is Turbidity?

- A measure of water clarity
- The murkier the water, the higher the turbidity.
- Turbidity reduces the transmission of light into water.
- Turbidity increases as a result of suspended solids in the water.

Sources of Turbidity

- Phytoplankton blooms
- Soil erosion
- Waste discharge
- Urban runoff
- Abundant bottom feeders

How is Turbidity Measured?



Secchi disk

- Measures water transparency
- Measures depth at which disk is no longer visible
- Useful for deep water

Turbidity in the lab and field

Turbidimeter

- optical device that measures scattering of light (most accurate)
- Measure in NTU (nephelometric turbidity units) or JTU (Jackson turbidity units)

Typical Turbidity Data

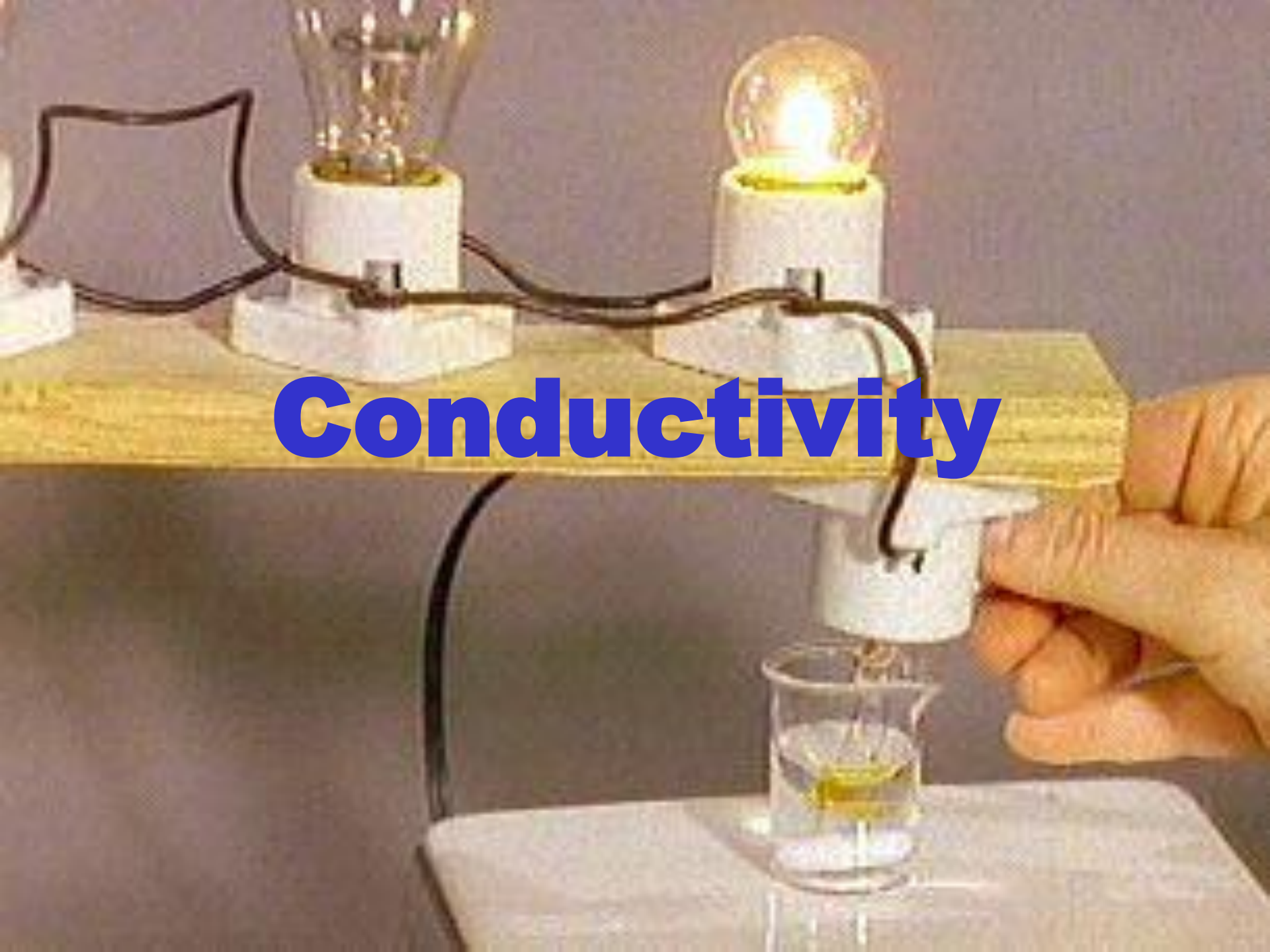
Water Source	Turbidity Level
Water bodies with sparse plant and animal life	0 NTU
Drinking water	<0.5 NTU
Typical groundwater	<1.0 NTU
Water bodies with moderate plant and animal life	1 - 8 NTU
Water bodies with large plumes of planktonic life	10 – 30 NTU
Muddy water or winter storm flows in rivers	20 - 50 NTU

So what?

- Degrades drinking water quality.
- Water treatment costs increase.
- Decreases light penetration in water.

Conductivity

- Conductivity is the measure of water's ability to conduct an electric current.
- Estimates amount of total dissolved minerals (ions).


Conductivity

Conductivity in water

- Dissolved salts (ions) conduct electrical current in water.
- Absolutely pure water is a poor electrical conductor.

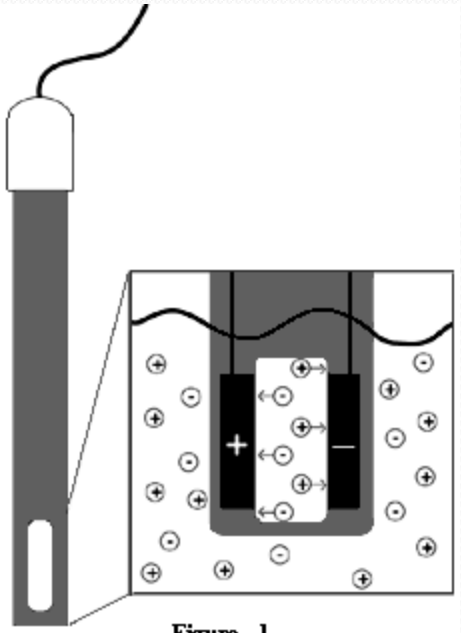


Figure - 1

http://www.humboldt.edu/~dp6/chem110/cond/cond.html

How do we measure Conductivity?

- Test with a Conductivity meter
- Measured in Siemens or mhos/cm

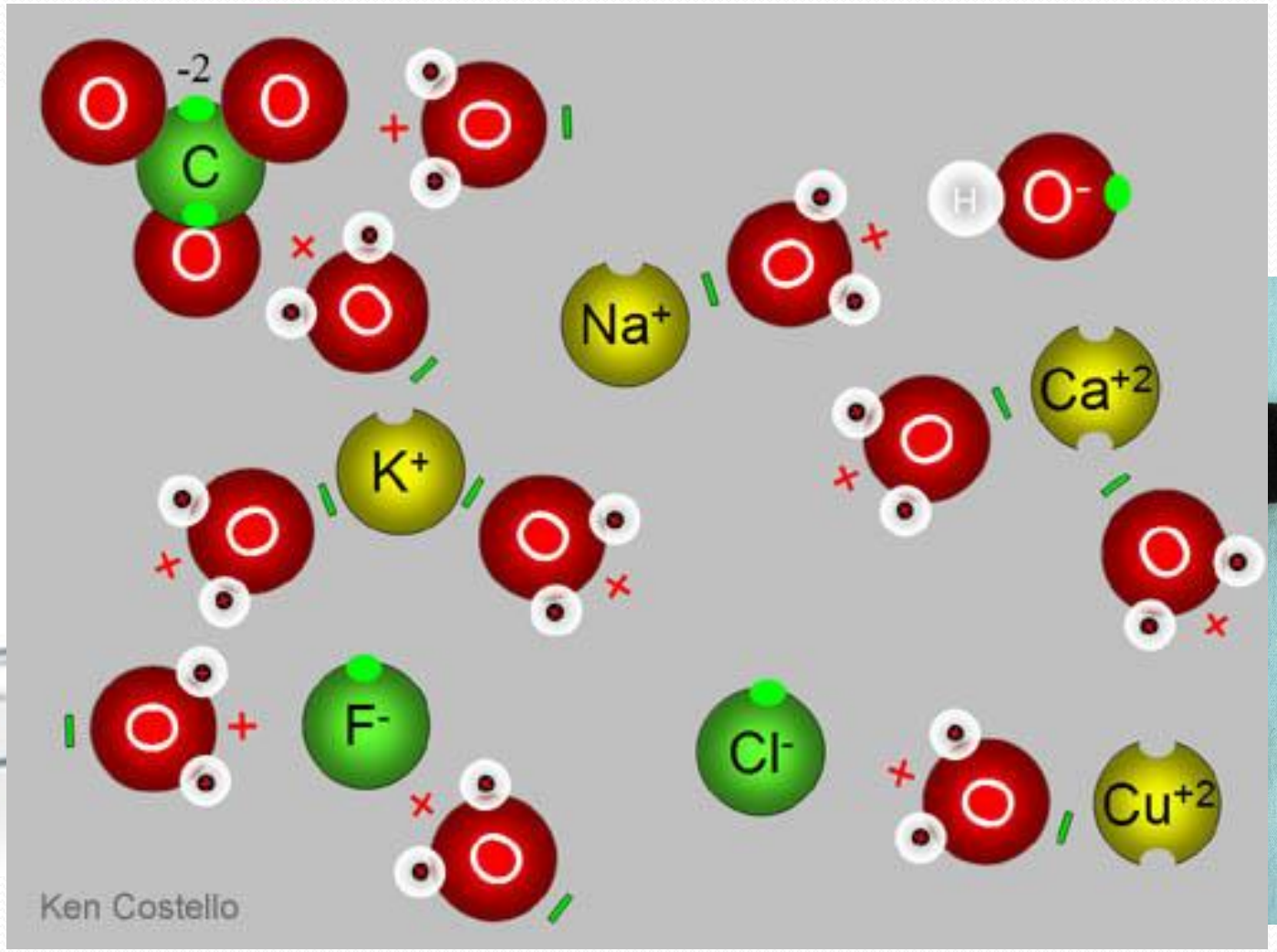
Conductivity Units

- Mhos is ohms backwards! (Mhos is the reciprocal of ohms –if you have to know)
- So….ohms is a measure of the *resistance* to a current.
- The less the *resistance*, the greater the *conductivity.*
- Conductivity in drinking water is *low*, so we use µmhos/cm or 1×10^{-6} mhos/cm!
- Units are sometimes expressed as microsiemens (µS).

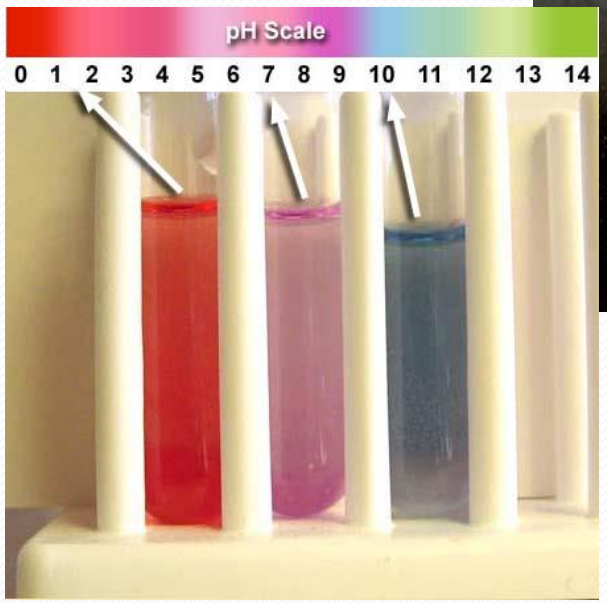
So What?

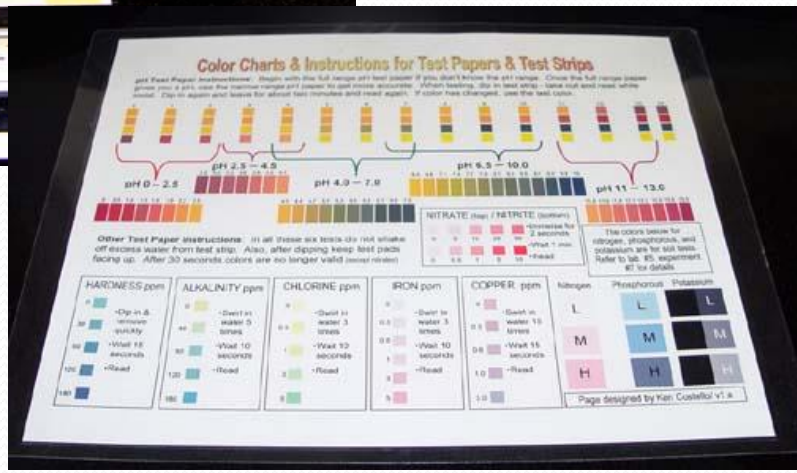
- Increased concentration of salts increases the conductivity
- Salts cannot be filtered out
- Higher conductivity can….
  - Foul irrigation water (leads to high salinity soils)
  - Kill wildlife
  - Create water shortages

Total dissolved solids



pH testing tap water



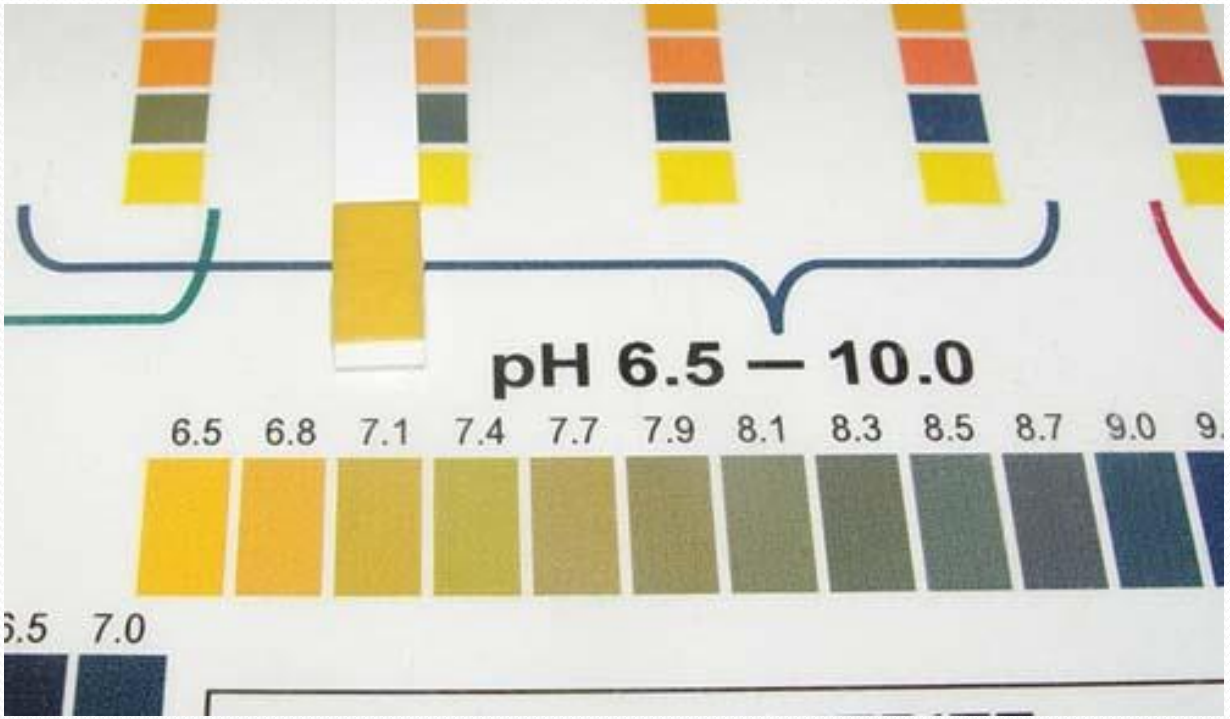


Tap water is probably close to being neutral (pH 7), so we will use the two test papers that include pH 7 in their range. pH 4.0-7.0 will be good if the water is somewhat acidic. pH 6.5-10 will be good if the water is very slightly acidic to somewhat alkaline.

pH testing tap water

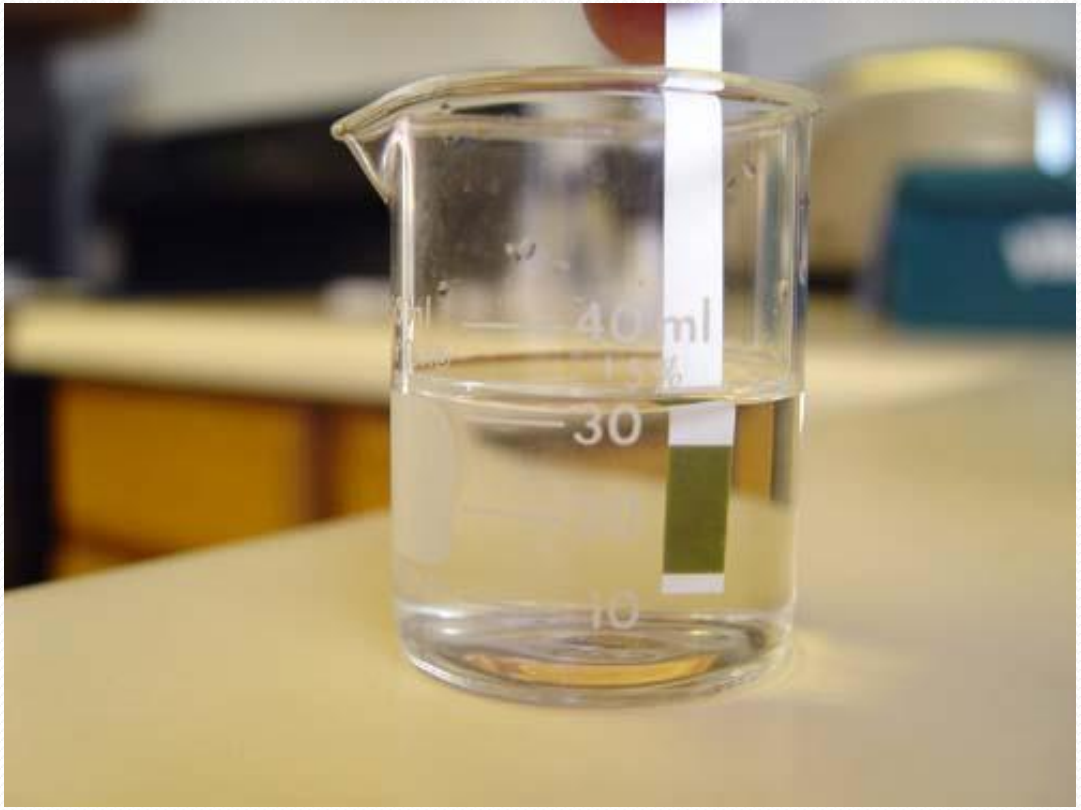
Let's say we start off with the pH 6.5-10 paper. Dip the paper into the beaker with the tap water for just a couple of seconds. Then take it to the chart.

pH testing tap water



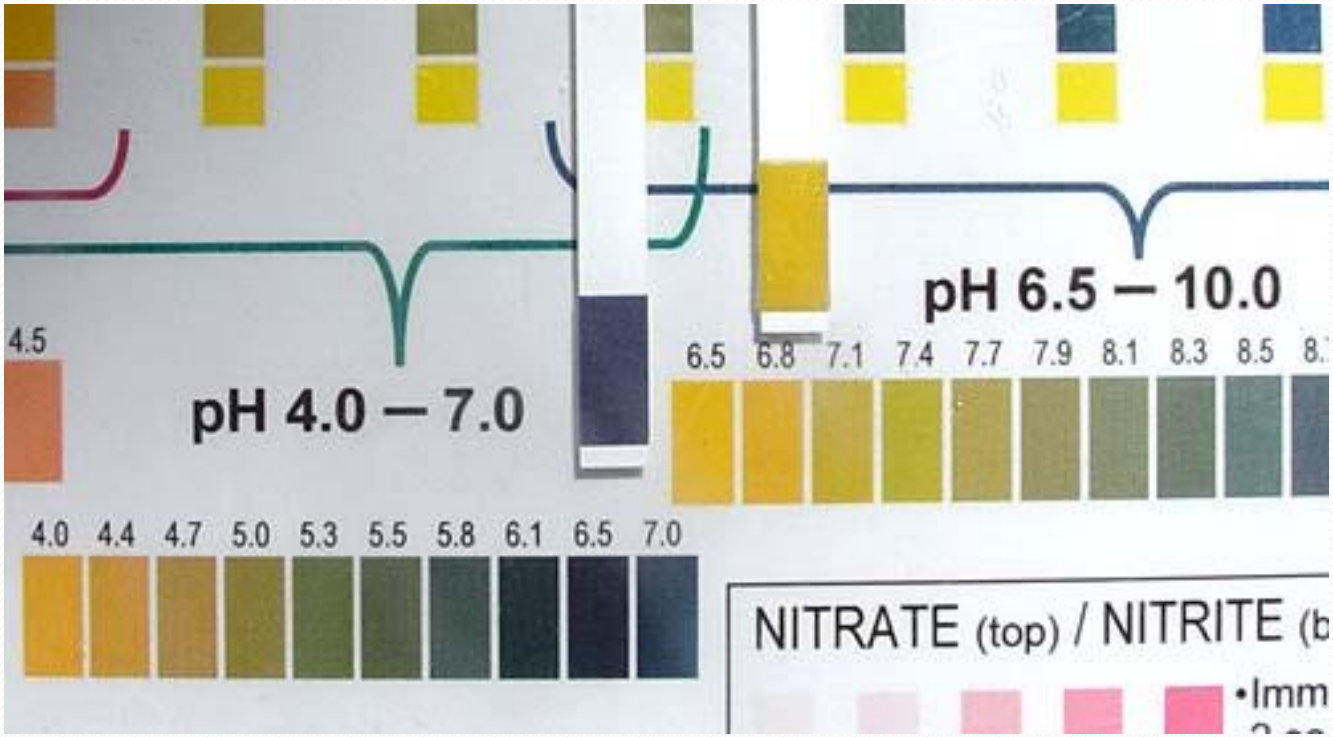
It looks like the pH is between 6.8 and 7.1. So it's looks pretty much neutral. We can now try the other test paper (pH 4.0-7.0) for confirmation.

pH testing tap water



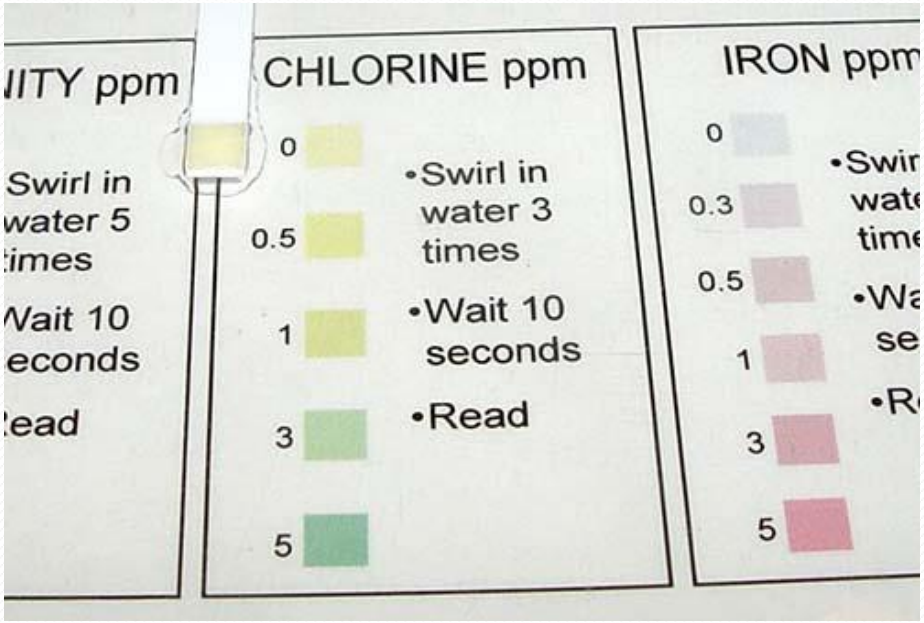
This is the pH paper for the 4.0-7.0 range. Dip in the tap water for a couple of seconds and take it to the chart.

pH testing tap water

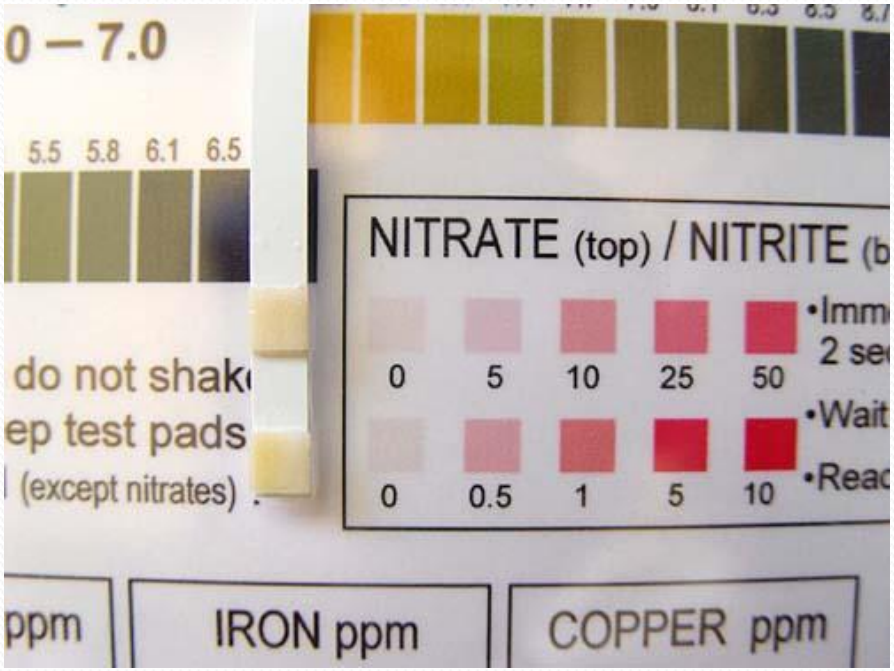


The 4.0-7.0 pH paper turns dark blue which indicates that it was close to the 7.0 pH reading. So it appears that the two different pH test papers both point to a pH close to the neutral pH of 7. This is usual for tap water unless there is something wrong with the water supply.

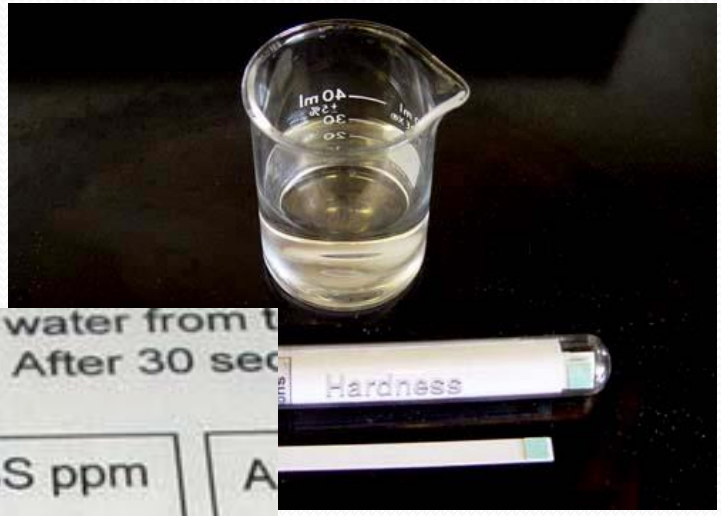
Testing Nitrite, Nitrate and Chlorine

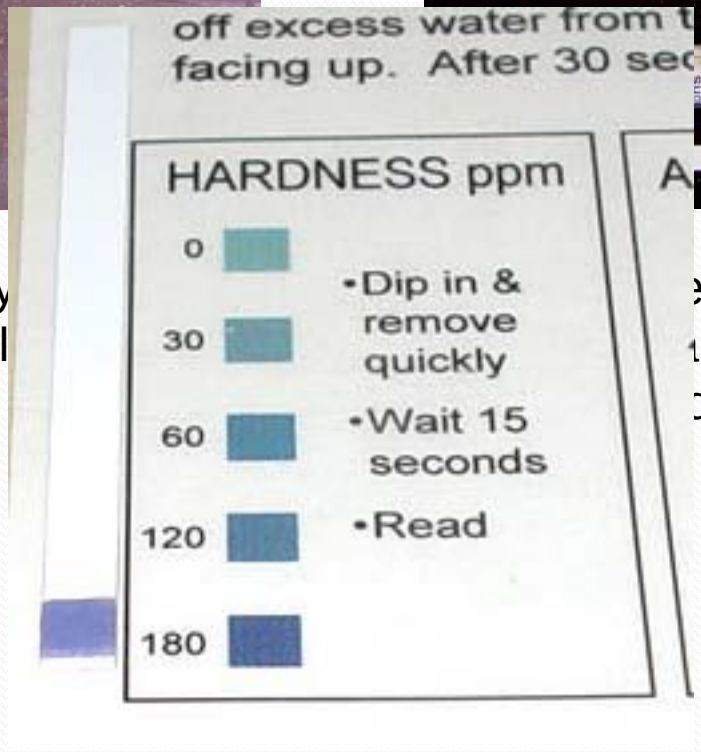


Negative test for nitrite



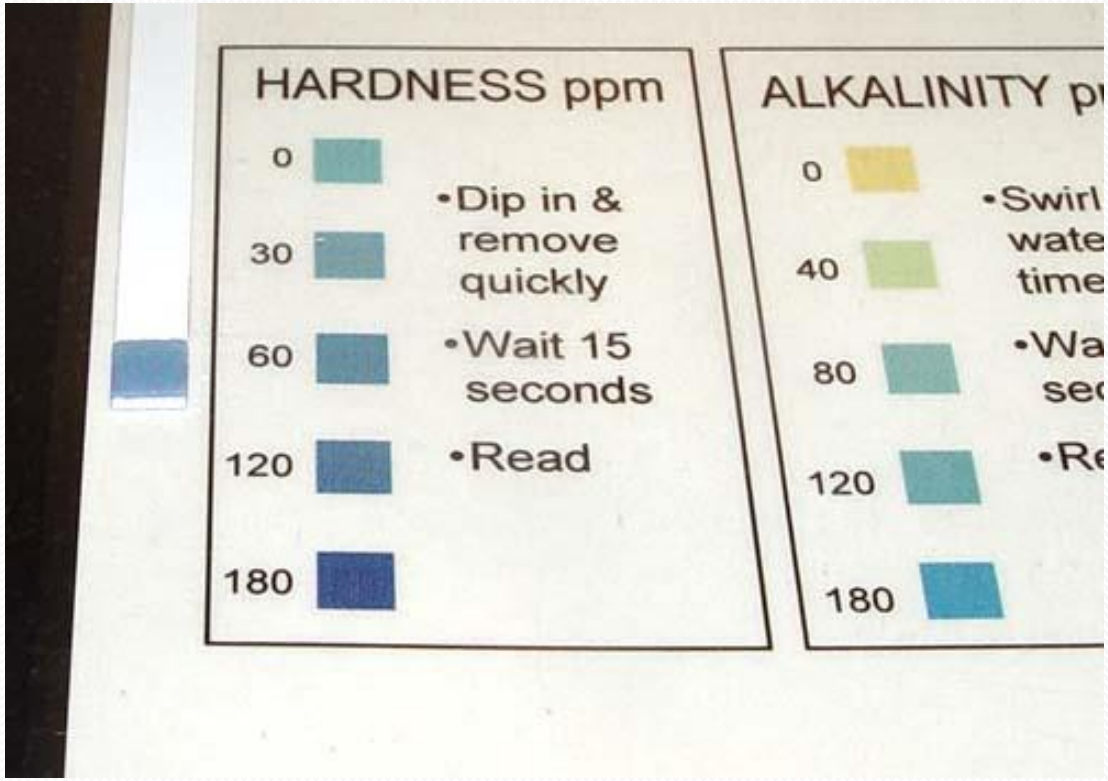
Hardness





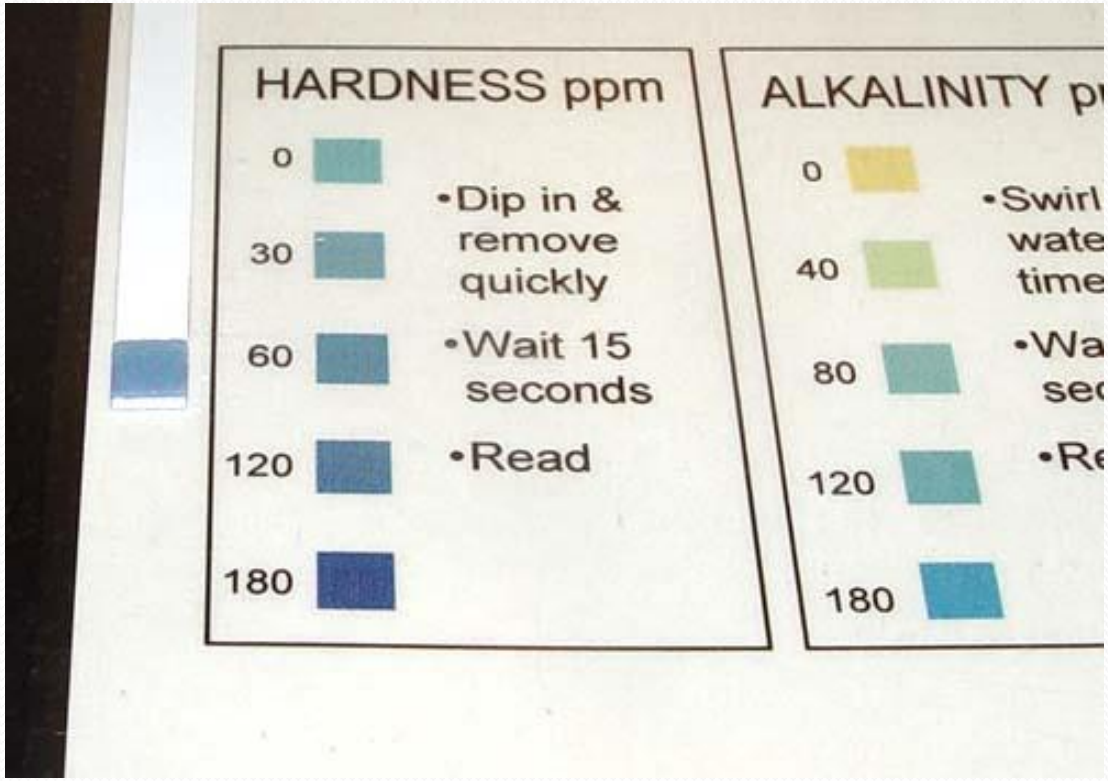
When hard water dries, y ehind. When it dries on a window, it's all lcium carbonate (chalk), calcium chloride de (french-fries salt).

Hardness and Alkalinity



A hardness test is mostly measuring the amount of calcium in the water. An alkalinity test is measuring the amount of carbonate in the water. So both tests are targeting calcium carbonate; one measuring calcium and the other measuring the carbonate. So they both are very similar.

Hardness and alkalinity



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Odor and Taste?

What are some common odors/tastes?

- Earthy, musty, moldy
  - Can be produced by some types of bacteria (actinomycetes)
  - May occur after adding chlorine
- Grass, hay, straw, wood
  - Associated with algal byproducts – decaying vegetation
- Marshy, swampy, septic, sewage, rotten egg
  - Sulphur – human or natural
- Chlorine
  - Residual from water treatment

How is it measured?

- Use your senses
- Do not breathe in the smell directly, use your hand to waft vapors towards your nose

Colour?

- Reddish, brown, or yellow
  - iron
- Black
  - bacteria growth
  - manganese
- Dark brown or yellow
  - Industrial waste from tanning industry, pulp and paper
  - Decaying vegetations
- Foam
  - detergents

Chemical testing of water

- Chemical Testing Methods
  - Test strips
  - Colour disc comparators
  - Colorimeters & photometers
  - Digital meters
  - Arsenic specific kits

Chemical Tests

- There are many different chemicals that can be found in our drinking water
- Difficult and expensive to test for all chemicals so we need to select a few that are a priority in the local area
  - Iron, Manganese
  - Arsenic, Fluoride
  - Chlorine
  - Total Dissolved Solids

Iron and Health

- Need small amounts of iron in food to be healthy
- No health impact, no WHO Guideline value
- > 0.3 mg/L of iron
  - Causes a bad taste
  - Stains water pipes and well aprons
  - Stains clothes during washing

Manganese

- Naturally found in groundwater
- Water has a black colour or black flakes
- Common to find manganese and iron together in water

Manganese and Health

- Need some manganese in food to be healthy
- Too much or too little manganese can make people sick
- WHO Guideline value < 0.4 mg/L
- > 0.15 mg/L of manganese
  - Causes a bad taste
  - Stains water pipes and creates a coating that comes off as small black flakes
  - Stains clothes during washing
  - Stains food during cooking

- Naturally occurring in groundwater

Arsenic

As: Where does it come from?

- Anthropogenic or Man-Made:
  - Drilling Wells
  - Mineral Extraction
  - Processing Wastes
  - Pesticides

- Levels of *As* in water depend on:
  - Level of human activity
  - Distance from pollution sources

Arsenic and Health

- Light or dark spots on skin
- Hardening skin on palms and feet
- Causes cancer
- Babies and young children are most vulnerable
- Biggest chemical issue in developing countries, high priority for WHO
- WHO Guideline < 0.01 mg/L
- Standards vary between countries

Non-Cancer Health Effects

- Long-term *As* exposure was found to be associated with cardiovascular effects (Utah and Taiwan)
- *As* exposure has also been reported to cause hypertension, anemia, liver disorders, kidney damage, headache, & confusion.
- Among children there have been reports of intellectual impairment when *As* in drinking water exceeded 50 µg/L (Bangladesh)

Arsenic and Health

Fluoride

- Naturally occurring in groundwater

Fluoride and Health

- Helps make teeth strong and prevents decay at low doses (0.5 – 1.0 mg/L)
- Higher doses are not good for teeth (1.5 – 4.0 mg/L)
- Very high doses harms the skeleton (> 10 mg/L)
- WHO Guideline < 1.5 mg/L

Chlorine

- Commonly use chlorine as a disinfectant to treat drinking water
- Not usually found naturally in water in amounts that can cause harm
- WHO Guideline < 5.0 mg/L
- High amounts of chlorine can hurt skin, eyes, throat and lungs if we touch it or breathe it

Chlorine for Disinfection

- Two things happen when we add chlorine to water:

1. Some chlorine reacts with organic matter to form new chemicals – Combined Chlorine
2. Some chlorine is left over – Free Chlorine

Total Chlorine = Combined + Free

Chlorine for Disinfection

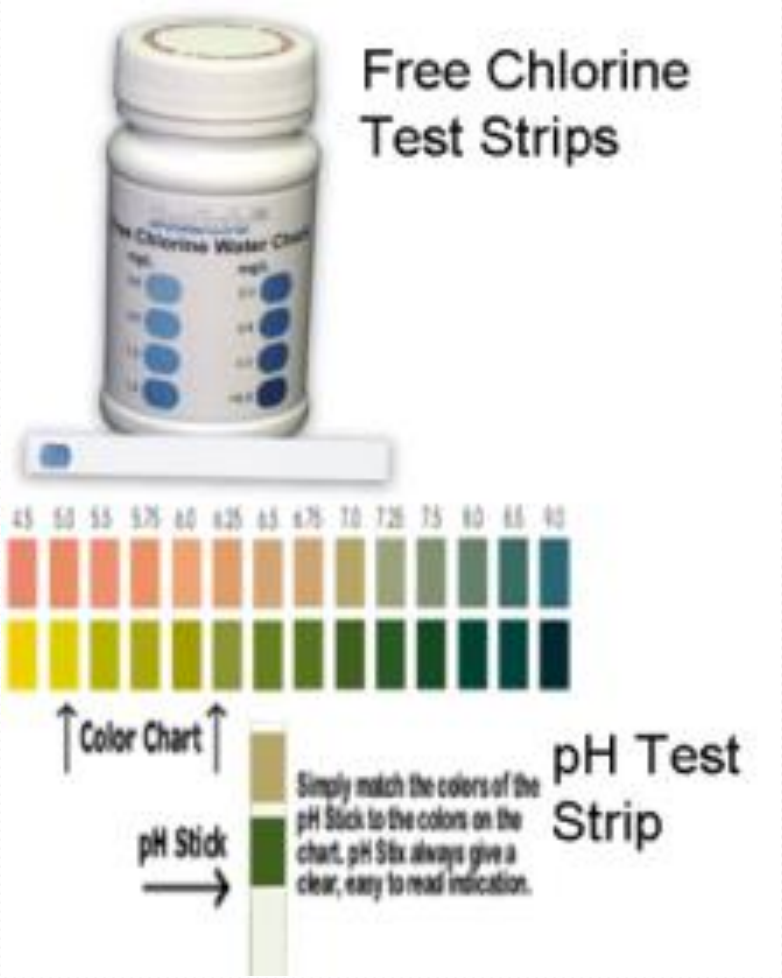
- Consumed chlorine is what kills pathogens in drinking water.
- Free chlorine is what protects drinking water from re-contamination.
- Ideal level of free chlorine in drinking water: 0.2 – 0.5 mg/L
- Typical levels of free chlorine in drinking water are 0.2 - 2.0 mg/L

Chemical Test Methods

- Test (reagent) strips
- Colour disc comparators
- Colorimeter and photometer
- Digital meters

Test (Reagent) Strips

- Designed to react with specific chemicals
  - pH, chlorine, hardness, etc.
- Compare colour on stick to colour chart



Advantages:

- Inexpensive
- Easy and simple
- Provides rough estimate

Limitations:

- Requires visual interpretation of colour
- Low accuracy +/- 10 %

Colour Disc Comparator

- Designed to react with specific chemicals
  - Chlorine, fluoride, nitrates, etc.
- Interchangeable colour discs

Advantages:

- Can be done in moderate field conditions
- Better accuracy

Limitations:

- Need reagents
- More expensive
- Requires visual interpretation of colour

Colour Disc Comparator for Chlorine (Wagtech)

Colorimeters & Photometers

- Uses light source to measure chemical concentration
- Test a range of chemicals

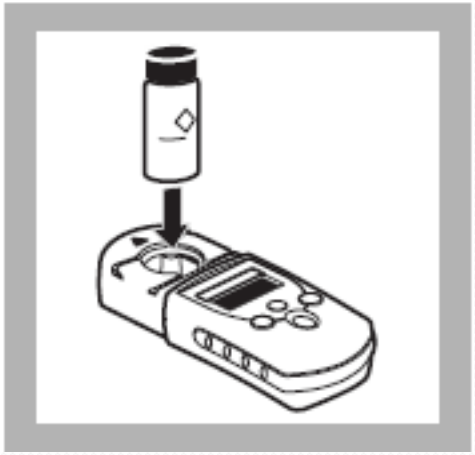
Photometer (Wagtech)

<u>Advantages</u>:

- More accurate

<u>Limitations</u>:

- More expensive
- Power source necessary
- Proper training required



Colorimeter (HACH)

Arsenic Test Kits

- Designed specifically for arsenic

Advantages:

- Fairly accurate – range 2 to 100 ug/L
- Portable
- Relatively easy to use

Limitations:

- Requires visual interpretation of colour
- Expensive

Digital Arsenator (Wagtech)

Sampling frequency…

Depends on…

- The quality of the water source and the type of treatment
- Size of the population served by the water source or distribution system
- Outbreak of diseases in the community served. If outbreaks occur frequently then the sampling frequency should also be higher.
- Resources available
- Type of water source
- Probability of contamination of water source
- Use of water

What is Safe Water?