

Principles and Practices of Drinking-water Chlorination



*A guide to strengthening chlorination practices in
small- to medium-sized water supplies*



**World Health
Organization**

Regional Office for South-East Asia

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Part 2. Practical Chlorination

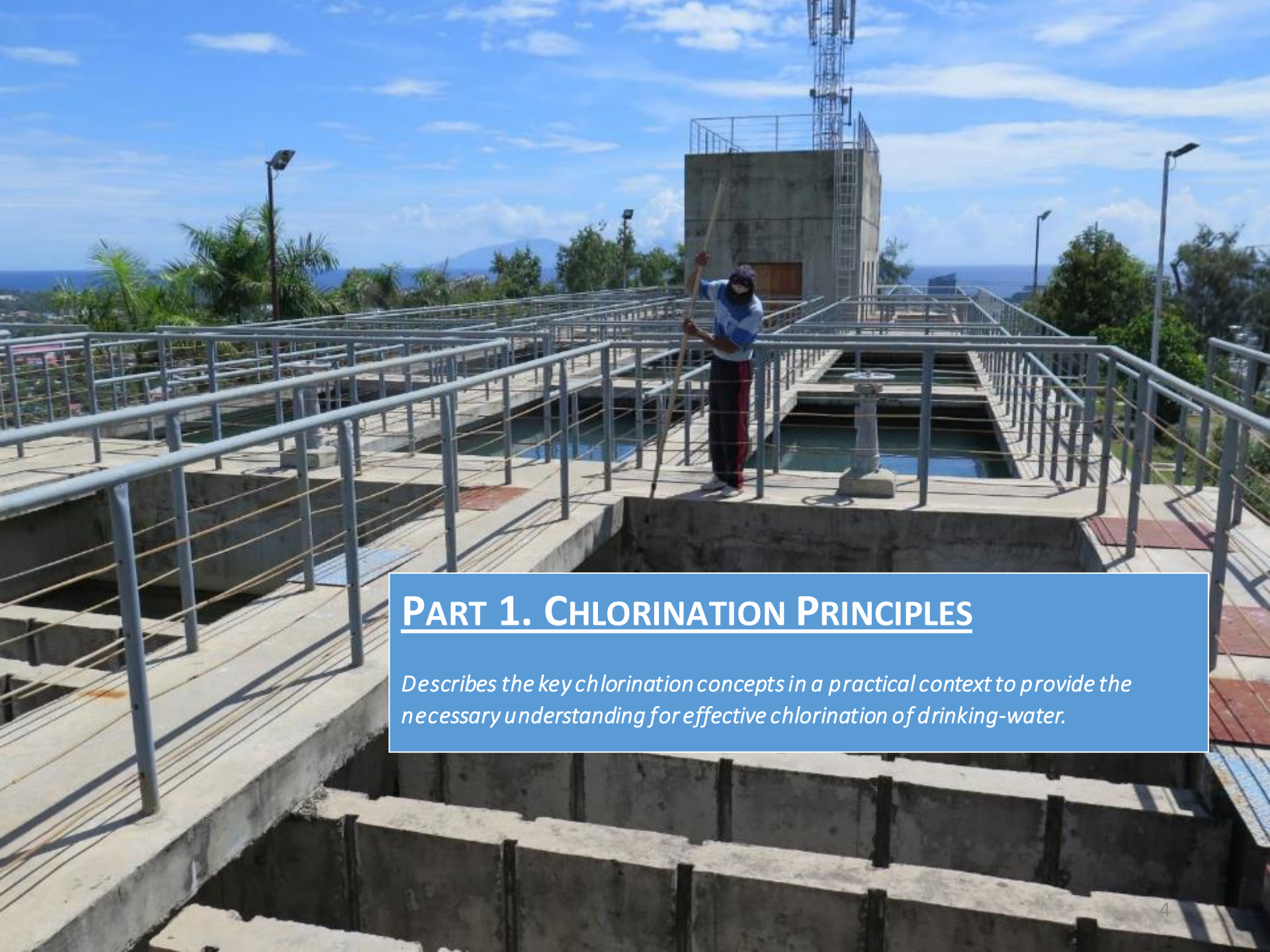
- **Safe handling and storage of chlorine**
- **Chlorine liquid dosing systems**
- **Chlorine dosing calculations**
- **Developing standard operating procedures**
- **Chlorine monitoring**

General Summary

Aim of this training programme

Upon completion of this training course, you will be able to:

- ✓ **understand the key principles of drinking-water chlorination**
- ✓ **apply these principles practically in the field**
- ✓ **perform the basic calculations required to support effective drinking-water chlorination**
- ✓ **develop standard procedures to correctly and consistently chlorinate drinking-water**
- ✓ **store and handle chlorine safely**



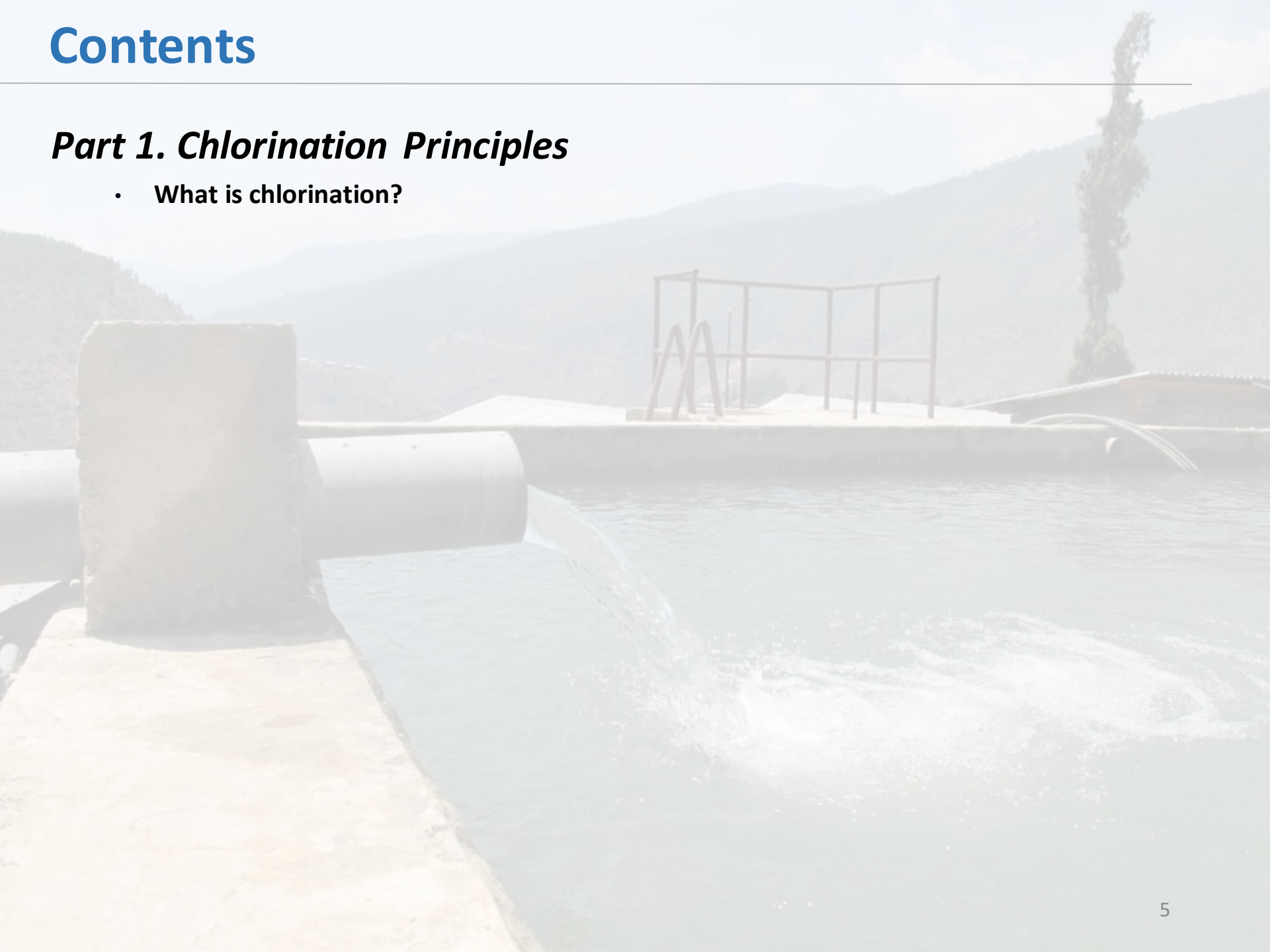
PART 1. CHLORINATION PRINCIPLES

Describes the key chlorination concepts in a practical context to provide the necessary understanding for effective chlorination of drinking-water.

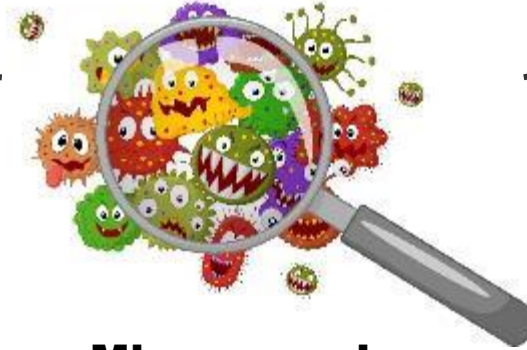
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Part 1. Chlorination Principles

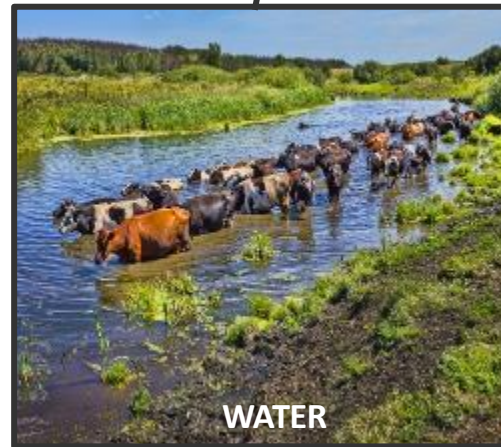
- What is chlorination?



Microorganisms – Found in almost all environments



Microorganisms



Microorganisms in drinking-water may cause illness

Microorganisms commonly associated with waterborne disease include:

- bacteria (e.g., *Escherichia coli*, *Vibrio cholerae*)
- viruses (e.g., Hepatitis A, poliovirus A)
- protozoa (e.g., *Cryptosporidium*, *Giardia*).



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VIRUSES



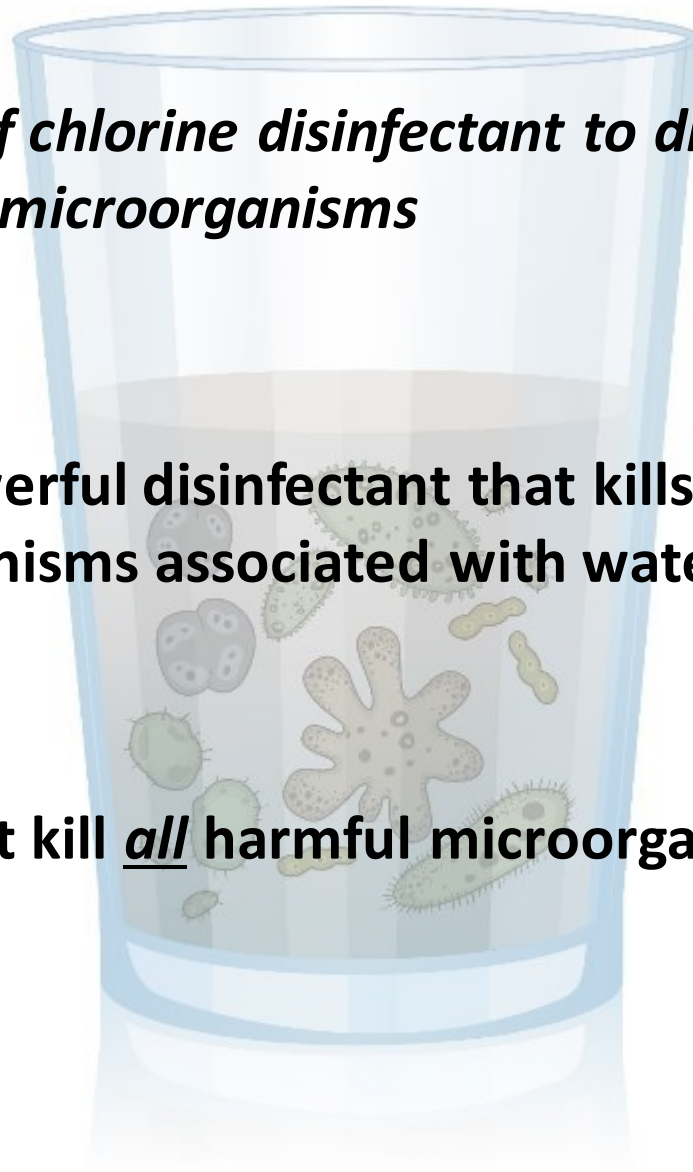
PROTOZOA

Chlorination

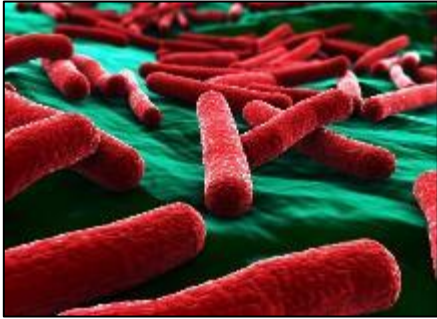
⇒ ***Addition of chlorine disinfectant to drinking-water to kill or inactivate microorganisms***

Chlorine is a powerful disinfectant that kills most harmful microorganisms associated with waterborne disease

Chlorine does not kill all harmful microorganisms



Relative effectiveness of chlorine



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MOST EFFECTIVE

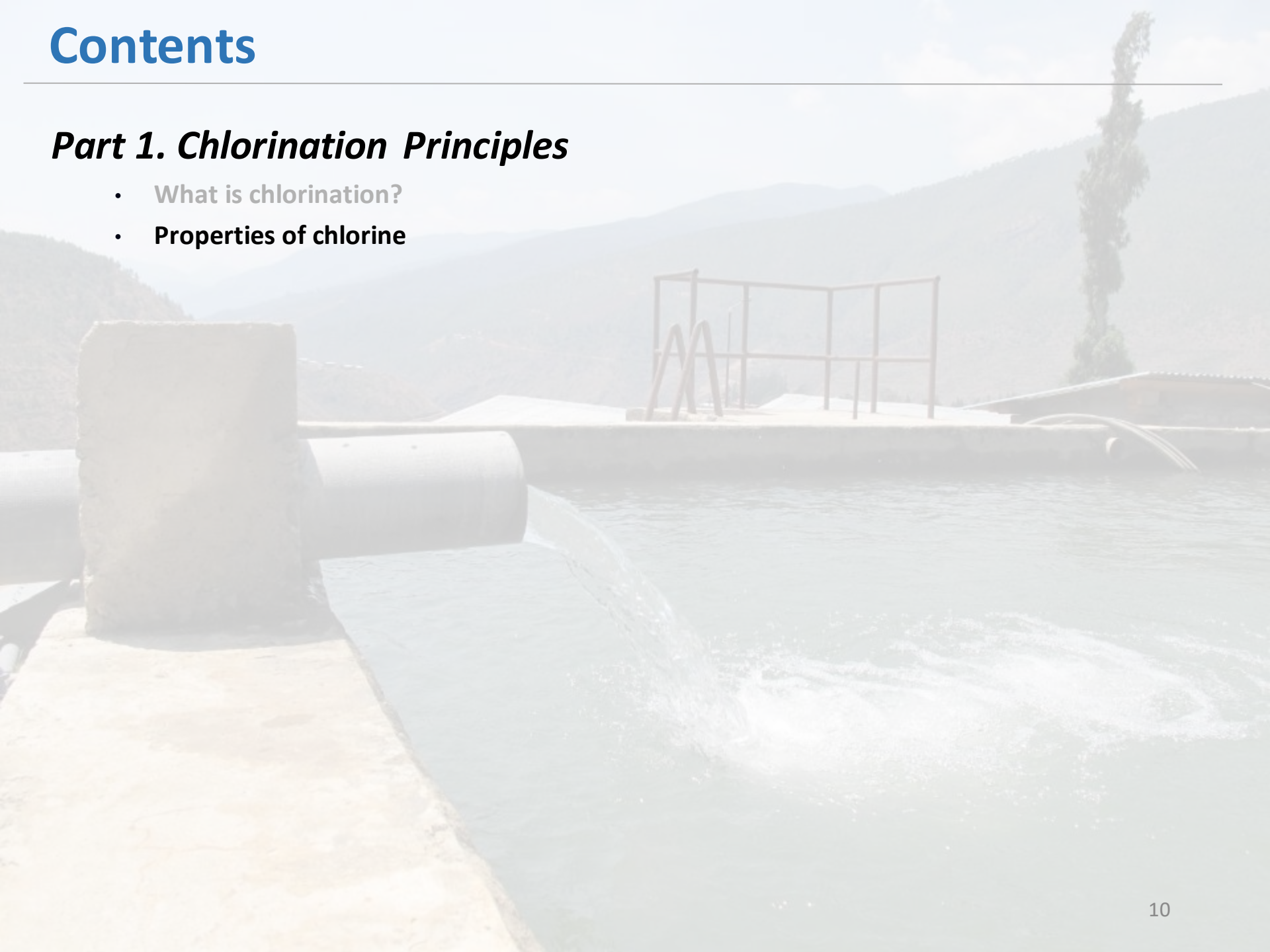
EFFECTIVENESS OF CHLORINE

LEAST EFFECTIVE

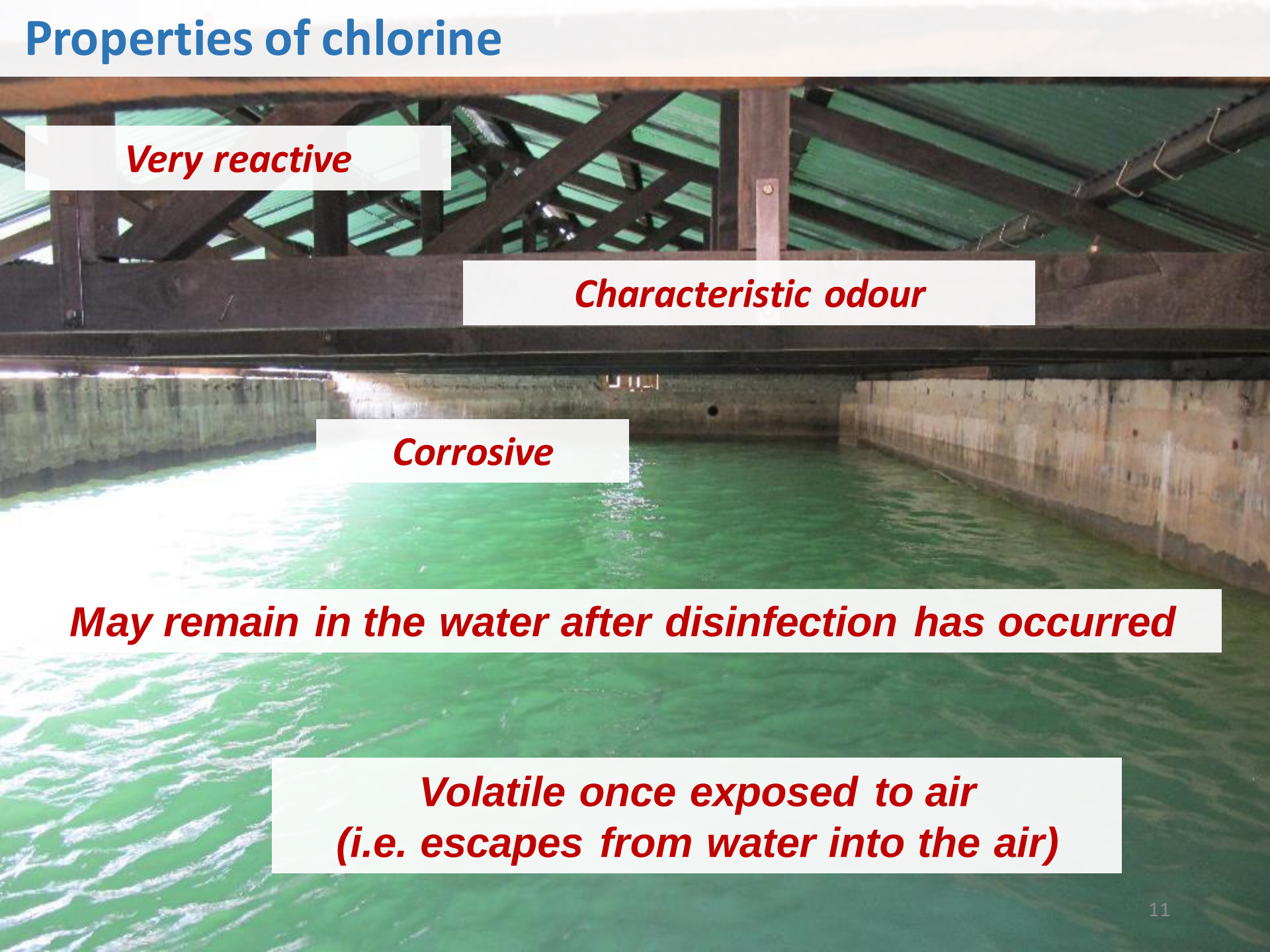
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Part 1. Chlorination Principles

- What is chlorination?
- Properties of chlorine



Properties of chlorine

The background image shows a large industrial tank, likely for wastewater treatment. The water inside is a distinct green color. The tank is supported by a complex network of dark metal beams and girders. The lighting is somewhat dim, with a brighter area on the left side of the tank.

Very reactive

Characteristic odour

Corrosive

May remain in the water after disinfection has occurred

***Volatile once exposed to air
(i.e. escapes from water into the air)***

Properties of chlorine

Chlorine may be found in three forms



Powder



Liquid



Gas

How to express the strength of chlorine

Chlorine gas typically contains pure chlorine

Chlorine powder and liquid do not contain pure chlorine

⇒ are mixed with other substances (e.g., calcium, sodium or water)

The strength of chlorine in chlorine powder or chlorine liquid is referred to as the ‘*concentration*’ of chlorine in that substance

Typically, this is expressed as the percentage (%) of active chlorine present

Properties of chlorine: Powder

Appearance: White powder, granules or tablet

Strength: Typically 30 to 70 % active chlorine
Requires mixing with water to make a liquid solution before use (see '*Chlorine liquid*' below)

Stability: May lose strength over time; more stable than chlorine liquid

Application: Typically used for small-sized water treatment plants (< 5 000 cubic meters per day)



Examples: => Bleaching powder (approx. 35 % active chlorine)

=> High test hypochlorite (approx. 70 % active chlorine)

Properties of chlorine: Liquid

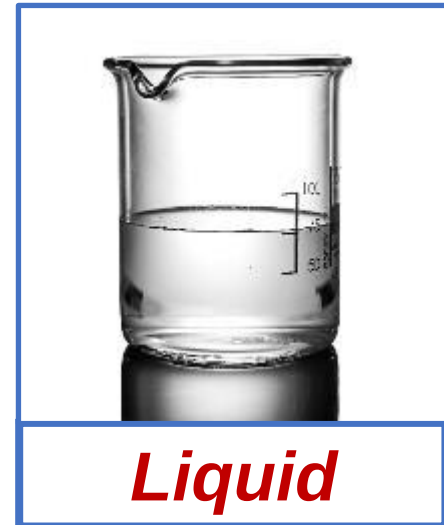
Appearance: Pale yellow to clear liquid

Strength: Typically 1 to 15 % active chlorine

Stability: May lose strength over time; less stable than chlorine powder

Application: Typically used for small- to medium-sized water treatment plants (i.e., <10 000 cubic meters per day)

Examples: => Sodium hypochlorite (10 to 15 % active chlorine)
=> Domestic bleach (5 to 10 % active chlorine)
=> Chlorine liquid solution prepared from chlorine powder (typically 1 to 5 % active chlorine)



Properties of chlorine: Gas

Appearance: Green-yellow gas

Strength: Approx. 100 % active chlorine

Stability: Most stable

Application: Typically used for medium- to large-sized water treatment plants (i.e., >10, 000 cubic meters per day)



Example: Chlorine gas (liquefied)

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- What is chlorination?
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 - *Chlorine dose*

Chlorine dose

How much chlorine is added to the drinking-water (or, the concentration of chlorine in the drinking-water)

Usually expressed as milligrams per litre (mg/L).

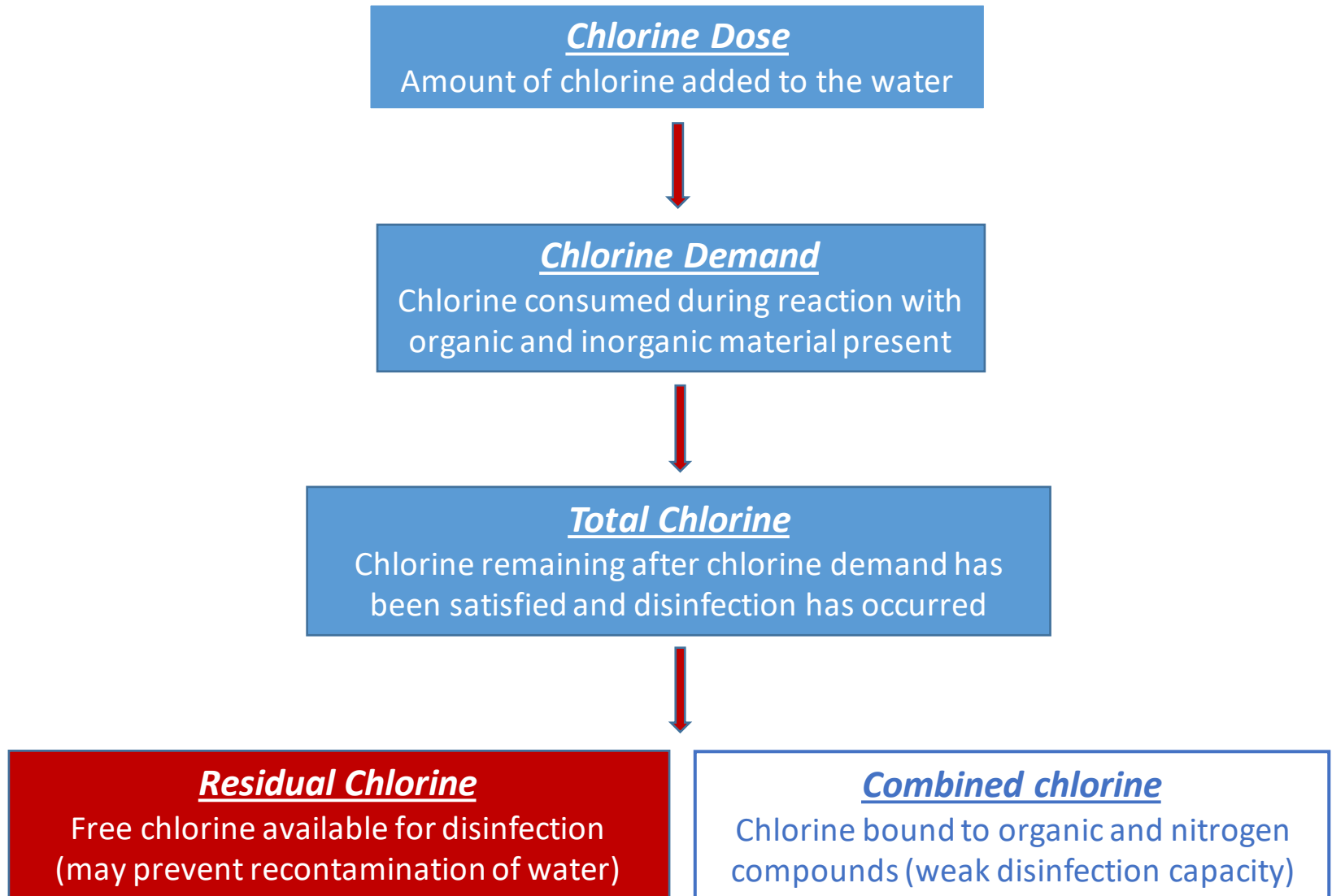
⇒ *for example, if drinking-water has a chlorine concentration of 1 mg/L, this means that there is 1 milligram of chlorine present in 1 litre of water*

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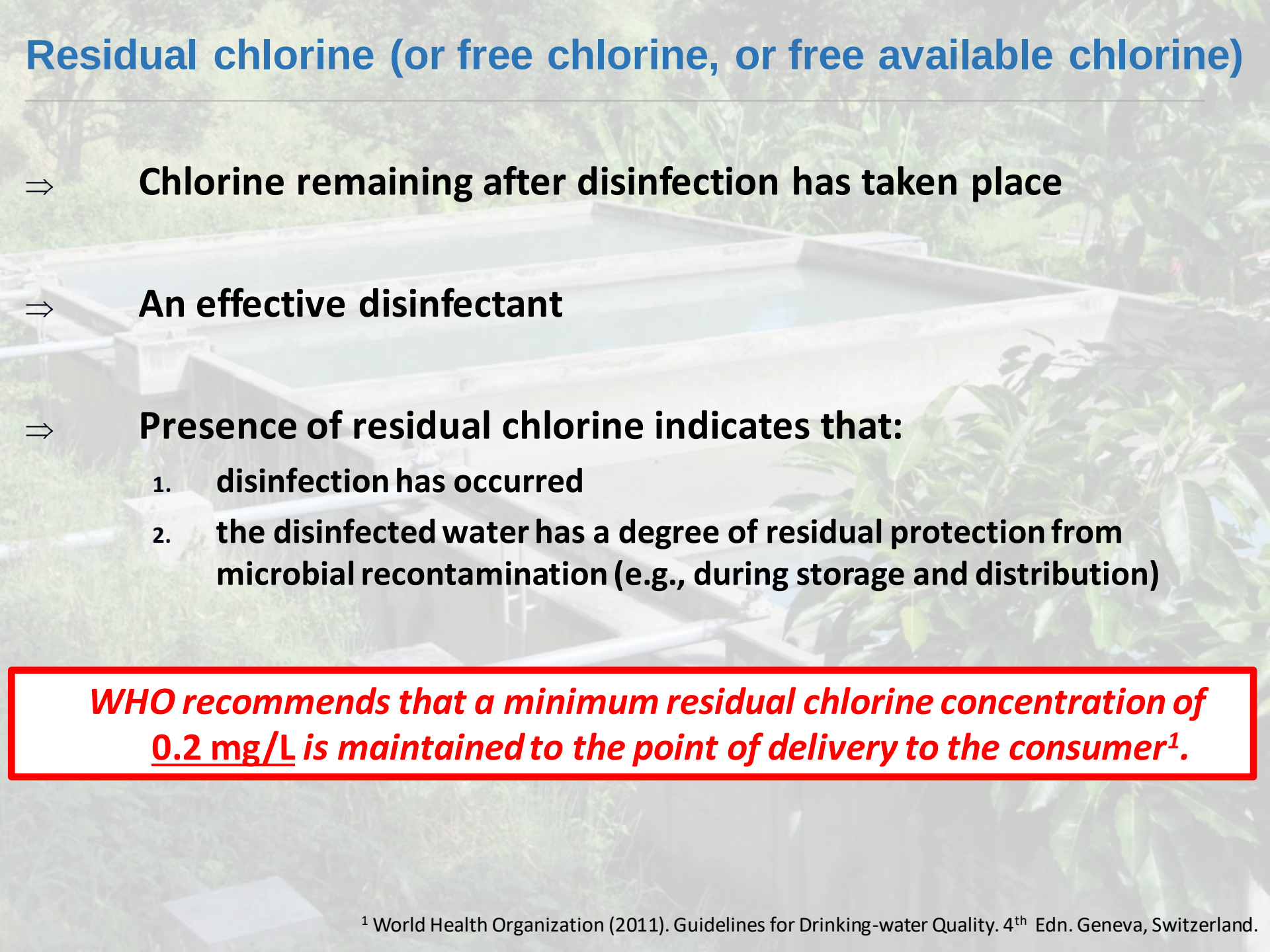
Part 1. Chlorination Principles

- What is chlorination?
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Chlorine reactions in drinking-water



Residual chlorine (or free chlorine, or free available chlorine)

- 
- ⇒ Chlorine remaining after disinfection has taken place
 - ⇒ An effective disinfectant
 - ⇒ Presence of residual chlorine indicates that:
 1. disinfection has occurred
 2. the disinfected water has a degree of residual protection from microbial recontamination (e.g., during storage and distribution)

WHO recommends that a minimum residual chlorine concentration of 0.2 mg/L is maintained to the point of delivery to the consumer¹.

¹ World Health Organization (2011). Guidelines for Drinking-water Quality. 4th Edn. Geneva, Switzerland.

Chlorine demand

When chlorine is added to water, it reacts with any organic and inorganic material (*chlorine reactive substances*)

- ⇒ during these reactions, chlorine is consumed
referred to as the 'chlorine demand'
- ⇒ as chlorine is consumed during these reactions, the concentration of chlorine decreases

Chlorine demand

It is important to understand how much chlorine will be consumed during the disinfection process:

- ⇒ **This allows you to estimate how much chlorine you need to add to the drinking-water at the water treatment plant to ensure there will be sufficient residual chlorine present in the water to protect the water during storage and distribution**

Chlorine demand

Understanding the chlorine demand of the raw water is important for effective disinfection

- ⇒ if the water has a **higher concentration** of chlorine reactive substances, the chlorine demand will be **higher**
- ⇒ if the water has a **lower concentration** of chlorine reactive substances, the chlorine demand will be **lower**

Relationship between chlorine demand & chlorine dose

DIRTY WATER

High concentration of organic & inorganic material



***High chlorine demand
(i.e. high chlorine consumption)***

CLEAN WATER

Low concentration of organic & inorganic material



***Low chlorine demand
(i.e. low chlorine consumption)***

Chlorine demand

Chlorine demand of water is constantly changing



Changes as water quality changes

Examples of events that influence the chlorine demand include....

***Seasonal changes in the raw water quality
(e.g. dry/wet season, algal blooms, floods, landslides, bushfires)***



Failure of a water treatment process (e.g. sedimentation, filtration)



Introduction of contamination post treatment (e.g. leaking/bust water main, accumulation of sediment or microbial biofilm within water mains)



Chlorine demand

Consideration of the chlorine demand is most important at the water treatment plant, immediately prior to the addition of chlorine

Where practical, chlorine demand is a useful parameter to monitor

- ⇒ **Where routine monitoring is not practical, you should be aware of the impact of changing raw water quality (i.e. changing chlorine demand) on the required chlorine dose**
- ⇒ **E.g. poorer water quality => higher chlorine demand => higher chlorine dose required**

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Chlorine decay

=> The decrease (or reduction) in the concentration of chlorine in drinking-water as it passes from the water treatment plant, through the distribution system, to the point of consumer delivery

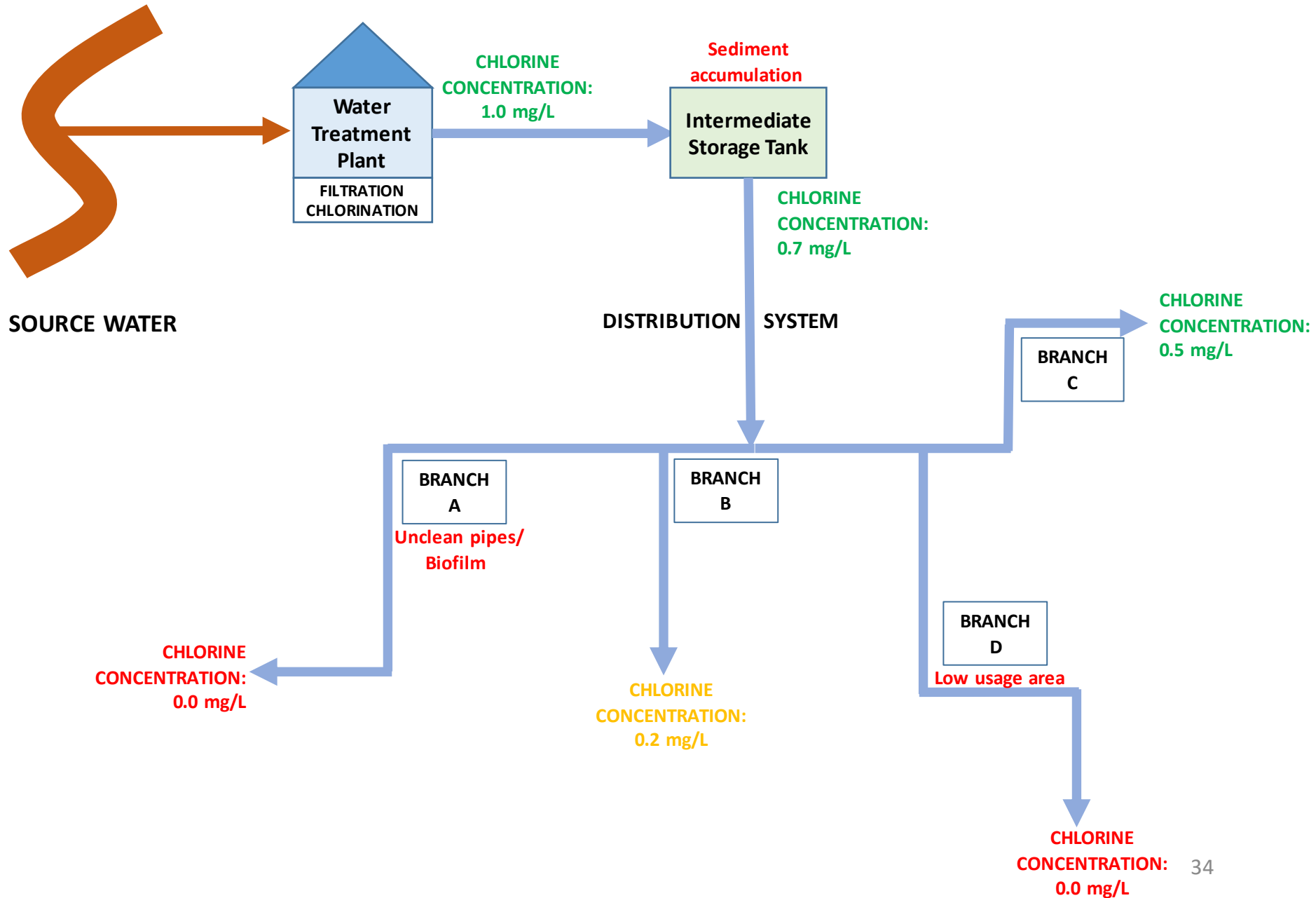
Due to chlorine decay, the concentration of chlorine at the end of the distribution system will usually be less than the concentration at the water treatment plant

Chlorine decay

The rate and extent of chlorine decay may be influenced by:

- ⇒ **the level of chlorine reactive substances that are present in the treated water as well as the distribution tanks and pipes (i.e., organic and inorganic material)**
- ⇒ **the type of material used in the distribution network tanks, pipes and fittings**
- ⇒ **how long the water remains in the distribution system (or the 'water age')**

Chlorine decay



Understanding the *chlorine demand* and *chlorine decay* of your water supply system is important:

⇒ helps you to determine the correct chlorine dose at the water treatment plant

Remember, must dose enough chlorine at the water treatment plant to ensure you have ≥ 0.2 mg/L at the point of consumer delivery.

Strategies to minimize chlorine decay in a water supply system

- **Optimize water treatment process to ensure high quality treated water (i.e., water entering the distribution system has a low chlorine demand)**
- **Maintain intermediate storages and distribution pipes (e.g., for removal of accumulated sediment and microbial biofilms)**
- **Optimize the hydraulic regime during distribution (i.e., minimise water age and low-flow/stagnant areas)**
- **Minimize unaccounted water (i.e., leaks, illegal connections) which may be vulnerable points for entry of contamination**
- **Aim for 24 hours supply (where feasible) to maintain positive pressure in the system to minimize risks of contamination entry**

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Ct concept for disinfection

Chlorine requires time to kill or inactive microorganisms during disinfection

⇒ this is referred to as '*contact time*'

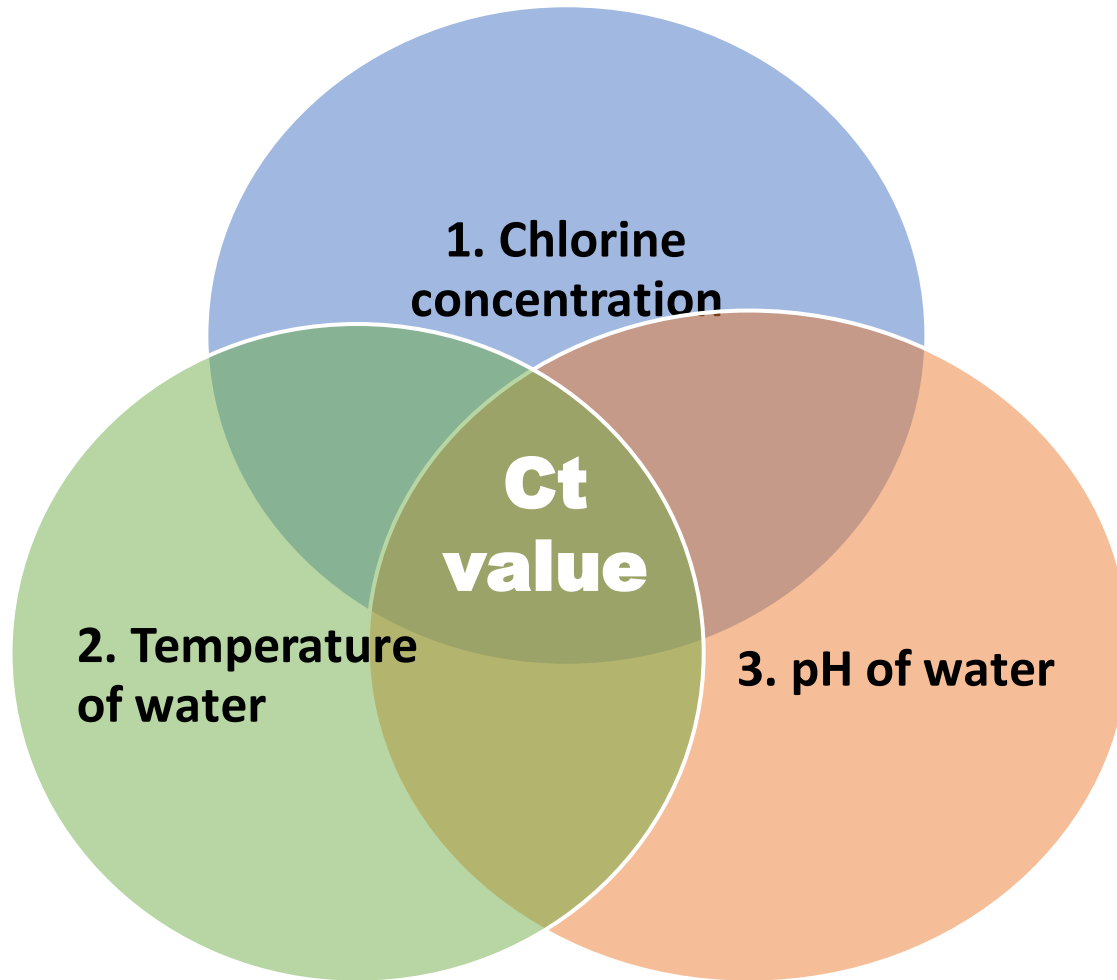
The contact time must be considered in conjunction with the chlorine concentration and other factors, to ensure that effective disinfection of drinking-water occurs

⇒ this is referred to as the '*Ct*' concept for disinfection

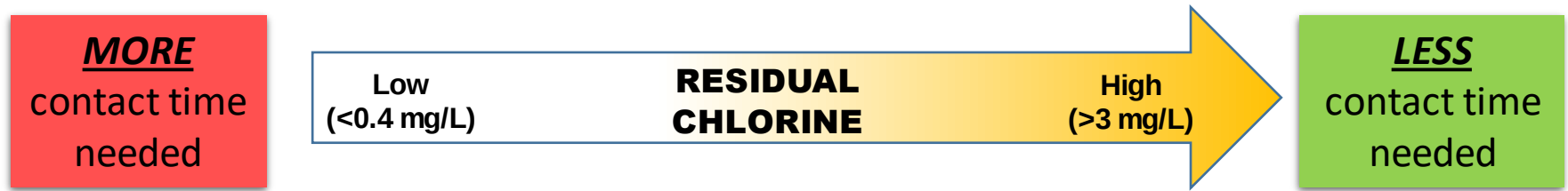
The Ct value is the product of disinfectant concentration and contact time with the drinking-water

$Ct = \text{Residual Chlorine Concentration (mg/L)} \times \text{Time of Contact (min)}$

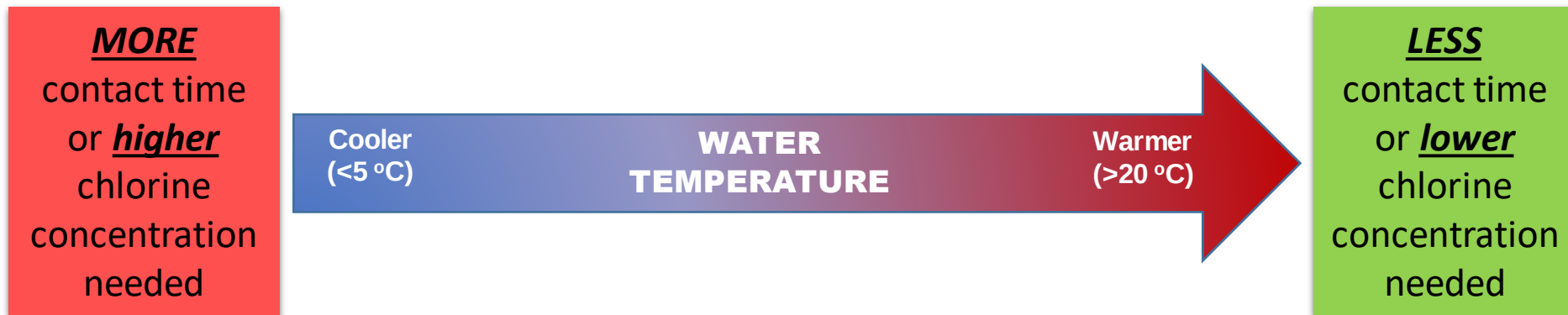
Factors influencing the Ct value



Influence of chlorine concentration on disinfection



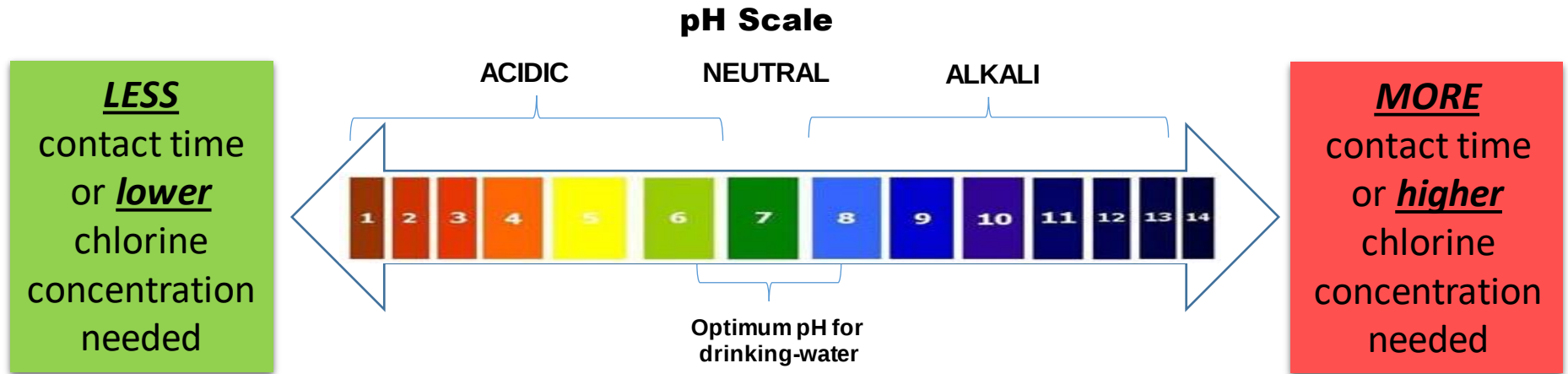
Influence of water temperature on disinfection



Influence of pH on disinfection

pH measures if the water is acid or alkaline (or basic)

- ⇒ measured on a scale of pH 0 to pH 14
- ⇒ pH 7 considered neutral, pH <7 considered acidic and pH >7 considered alkali



Influence of pH on disinfection

For effective chlorination, the pH of the water should be < pH 8.0

However

To balance water quality considerations, including chlorination, the optimum pH of drinking-water is generally between pH 6.5 and pH 8.5

⇒ **Where water is >pH 8.0, higher chlorine concentrations or more contact time will be required!**

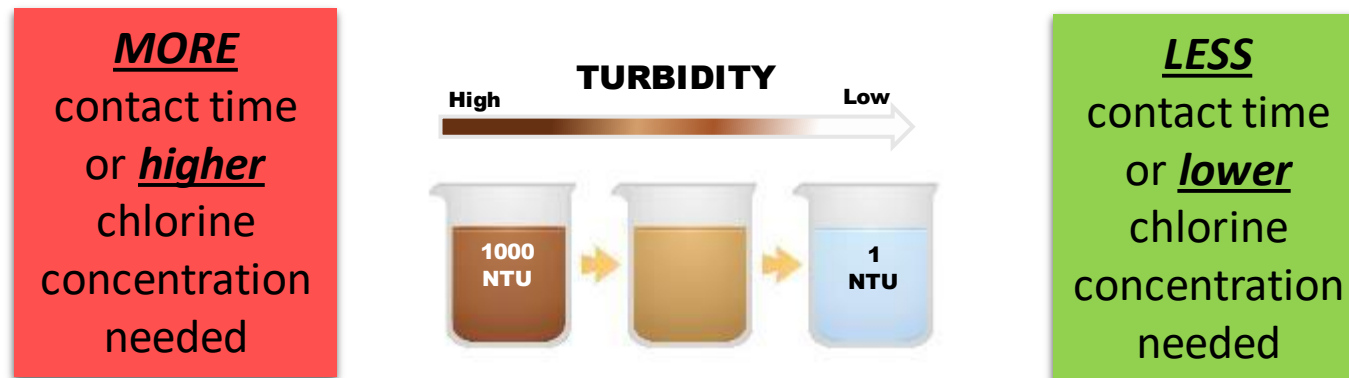
Turbidity may also indirectly impact contact time

Suspended organic/inorganic particles in water

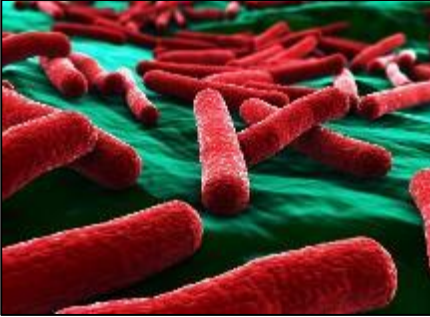
⇒ gives water an opaque (or cloudy) appearance

Turbidity may influence the effectiveness of chlorine disinfection

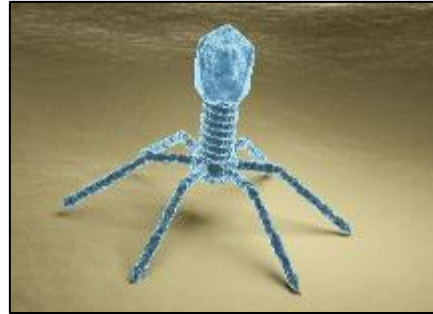
- ⇒ indicates the presence of chlorine reactive substances, which may react with and consume chlorine, thereby increasing the chlorine demand
- ⇒ May also 'shields' microorganisms from the lethal/inactivating effects of chlorine



Type of microorganism and chlorine disinfection



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LESS
contact time
or **lower**
chlorine
concentration
needed

MOST EFFECTIVE

LEAST EFFECTIVE

MORE
contact time
or **higher**
chlorine
concentration
needed

Minimum required contact time for effective disinfection

How much contact time is needed for effective disinfection?

For effective disinfection, the WHO¹ recommends at least 30 minutes contact time, where the residual chlorine concentration is ≥ 0.5 mg/L and the pH of the water is $< \text{pH } 8$.

⇒ *Minimum recommendation only – should be determined on a site-specific basis (more to follow on this in Part 2...)*

¹ World Health Organization (2011). Guidelines for Drinking-water Quality. 4th Edn. Geneva, Switzerland.

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 - *Aesthetic considerations for chlorination*

Aesthetic considerations (i.e. relating to taste or odour)

Chlorine may result in a distinctive taste & odour in drinking-water

- ⇒ different individuals vary in their ability to detect chlorine taste/odour
- ⇒ in general, chlorine has a taste/odour threshold $>0.3 \text{ mg/L}$



If chlorine is present in drinking-water at concentrations that are unacceptable to consumers:

- ⇒ may result in an individual using alternative, less safe, water sources

Aesthetic considerations (i.e. relating to taste, odour, appearance)

For this reason the aesthetic impact of chlorine on drinking-water should be considered when optimizing the chlorine dose

HOWEVER...

⇒ ***Disinfection should always be prioritized over aesthetic considerations!!!***

Aesthetic considerations

To balance effective disinfection against aesthetic considerations:

⇒ **a residual chlorine concentration of between 0.2 to 0.5 mg/L**
should be targeted at all points in the distribution network

However, this may need to be higher in certain circumstances, to ensure a minimum residual chlorine concentration of 0.2 mg/L is maintained to the point of consumer delivery

⇒ **discussed further in next section...**

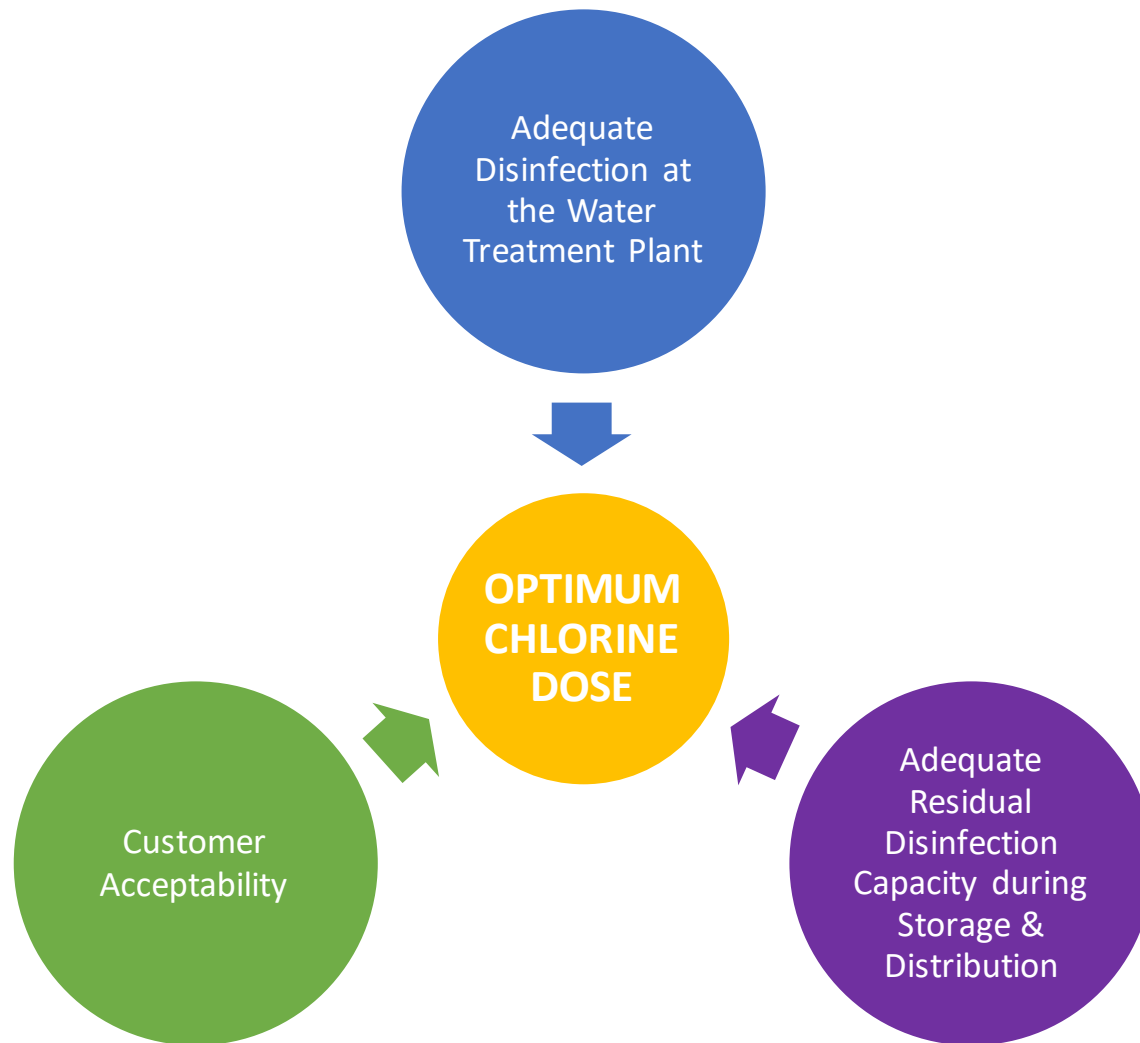
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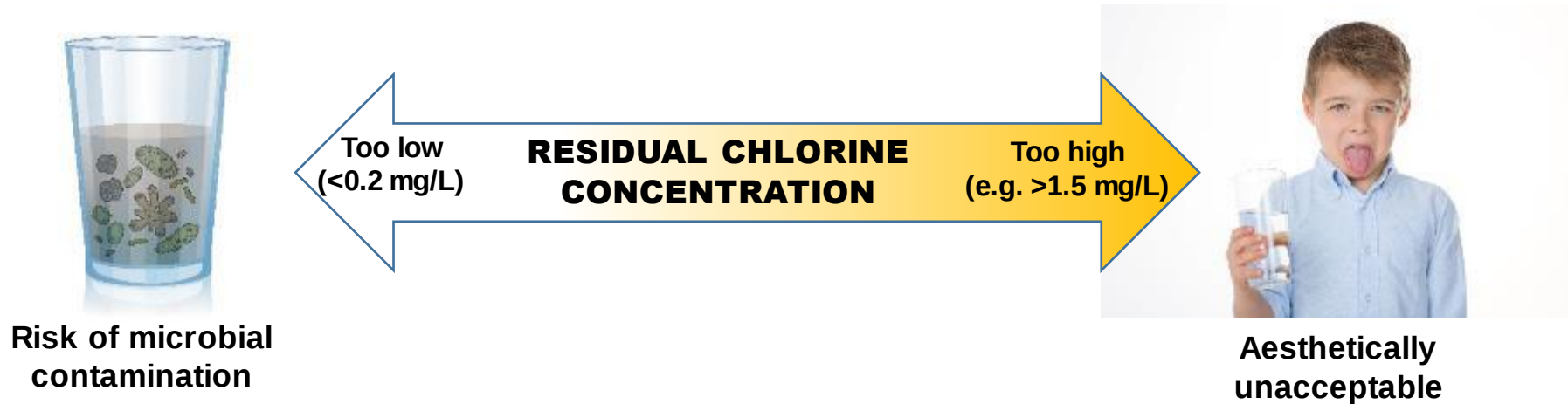
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 - *Optimizing the chlorine concentration in a water supply system*

Optimizing the chlorine dose

Requires balancing the following key considerations...



Optimizing the chlorine dose



Optimizing the chlorine dose

Priority must always be to add sufficient chlorine such that:

- ⇒ The minimum required contact time for effective disinfection is achieved
- ⇒ The residual chlorine concentration at all points in distribution system is $\geq 0.2 \text{ mg/L}$

To balance effective disinfection against consumer acceptability considerations:

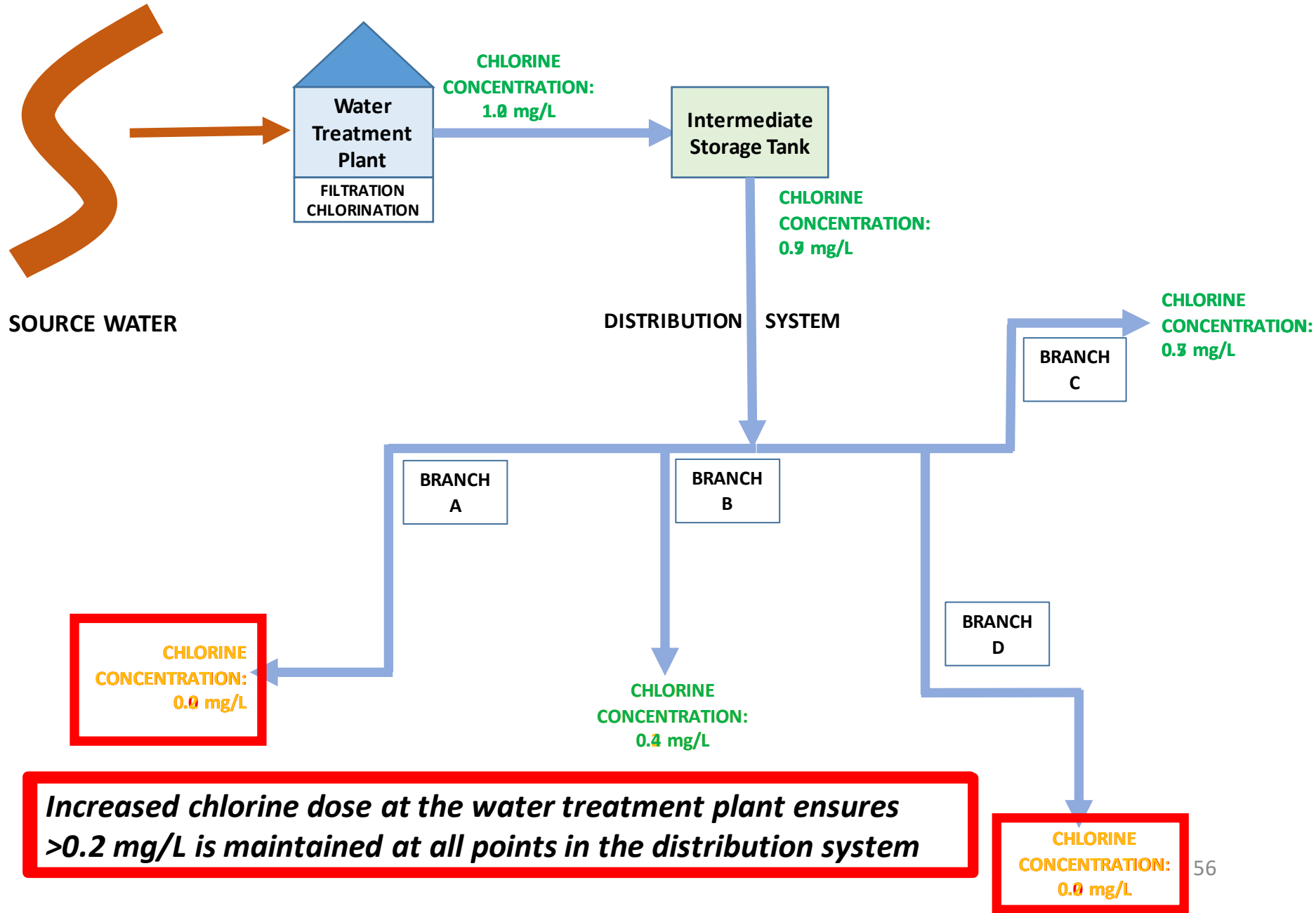
- ⇒ a residual chlorine concentration of between 0.2 to 0.5 mg/L in the distribution network should be targeted
- ⇒ ***Effective disinfection and residual protection should always be prioritized over aesthetic considerations***

Optimizing the chlorine dose

May need to maintain a higher residual chlorine concentration in some parts of the distribution system to ensure a minimum residual chlorine concentration of 0.2 mg/L is achieved throughout the entire system

- ⇒ for example, having a higher residual chlorine earlier in the system
- ⇒ this may be needed to maintain an adequate residual chlorine concentration at the very end of the distribution system

Optimizing the chlorine dose



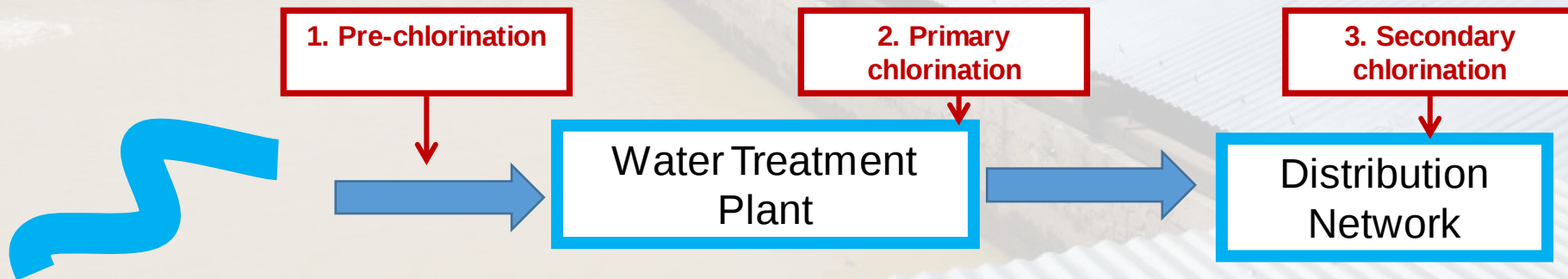
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Points of chlorine dosing

Chlorine may be added:

1. Pre-chlorination (before water treatment plant)
2. Primary chlorination (after water treatment process)
3. Secondary chlorination (during distribution)



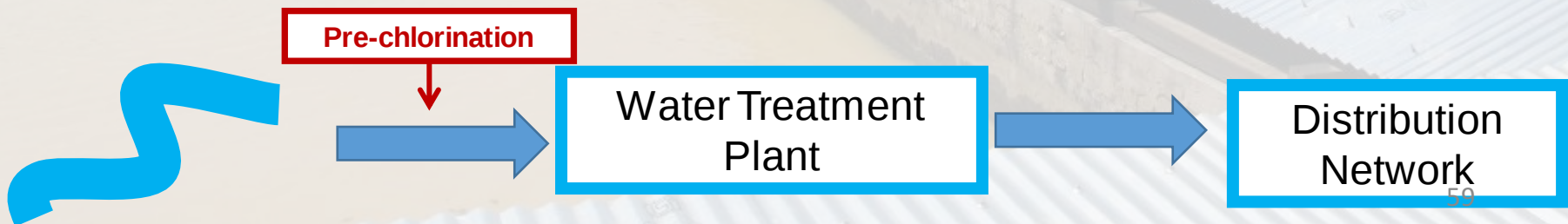
Points of chlorine dosing

1. Pre-chlorination (before water treatment plant)

- ⇒ used to remove minerals (e.g. Iron, manganese)
- ⇒ chlorine makes them insoluble (particulate)
- ⇒ can be removed during water treatment (filtration)
- ⇒ can also remove taste/odour

Potential issues:

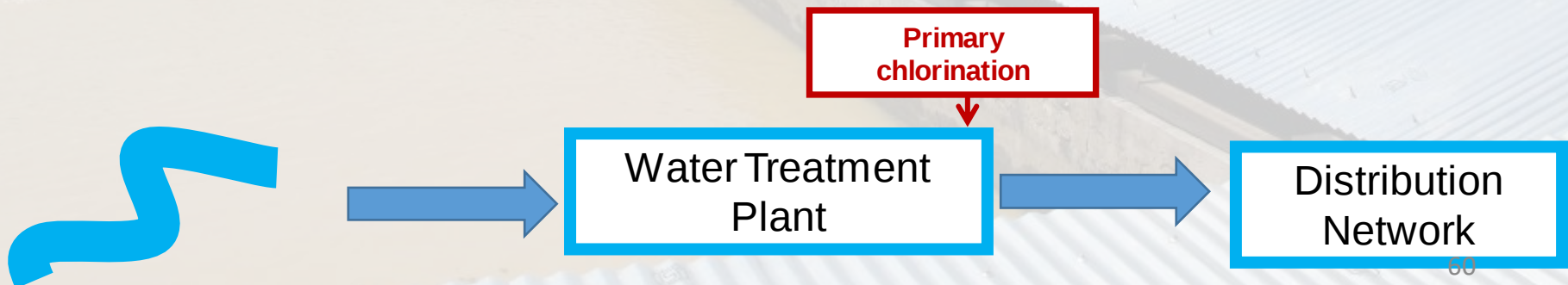
- ⇒ raw water may have a high chlorine demand which requires high chlorine dose (high operational cost)
- ⇒ formation of disinfection by-products in high organic waters



Points of chlorine dosing

2. Primary chlorination (after water treatment)

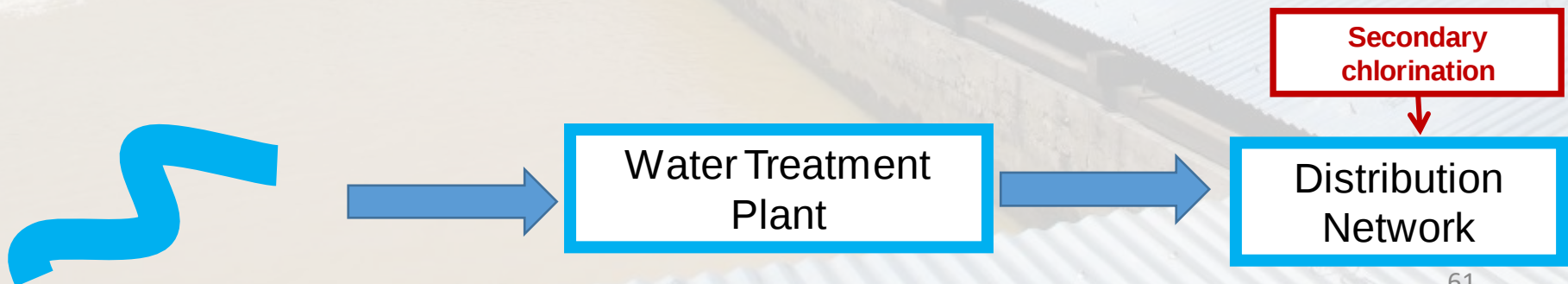
- ⇒ used for disinfection; most common & effective point of application
- ⇒ most effective to add chlorine when turbidity is as low as possible – ideally <1 NTU (i.e., after clarification, filtration)
- ⇒ clean, filtered water so lower chlorine demand
 - ⇒ use less chlorine
 - ⇒ less risk of disinfection by-product formation
- ⇒ *Disinfection should not be compromised in attempting to control disinfection by-products*



Points of chlorine dosing

3. Secondary ('booster') chlorination

- ⇒ used to maintain sufficient chlorine concentration during distribution to protect the water from recontamination i.e. $\geq 0.2 \text{ mg/L}$
- ⇒ 'booster station' adds more chlorine to the water at strategic points during distribution when the chlorine concentration is too low i.e. $< 0.2 \text{ mg/L}$
- ⇒ helps keep the water safe to the very end of the distribution system
- ⇒ common in large distribution networks



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- **Summary**

Summary of the optimal conditions required for effective chlorination

- Turbidity:** <1 NTU (lower where possible)
(where < 1 NTU is not possible, <5 NTU should be the aim; above 5 NTU, disinfection should still be practised, but higher chlorine doses or contact times will be required to inactivate harmful microorganisms)
- pH:** <pH 8.0
(Above pH 8.0, chlorination should still be practised but higher chlorine doses or contact times will be required to inactivate harmful microorganisms)
- Minimum contact time:** 30 minutes contact time with a minimum residual chlorine concentration of 0.5 mg/L, where the pH of the water is <pH 8.

Summary of the optimal conditions required for effective chlorination

A minimum residual chlorine concentration of 0.2 mg/L must always be maintained to the point of consumer delivery

The residual chlorine concentration during distribution to the point of delivery should aim to be between 0.2 to 0.5 mg/L

⇒ **may need to be higher than 0.5 mg/L in particular circumstances to ensure that a minimum residual chlorine concentration of 0.2 mg/L is always maintained**

The concentration of chlorine in water supplied to consumers should always be <5 mg/L

PART 2. PRACTICAL CHLORINATION

Applies key chlorination principles into practice, describing safe and effective procedures for drinking-water chlorination.



Part 2. Practical Chlorination

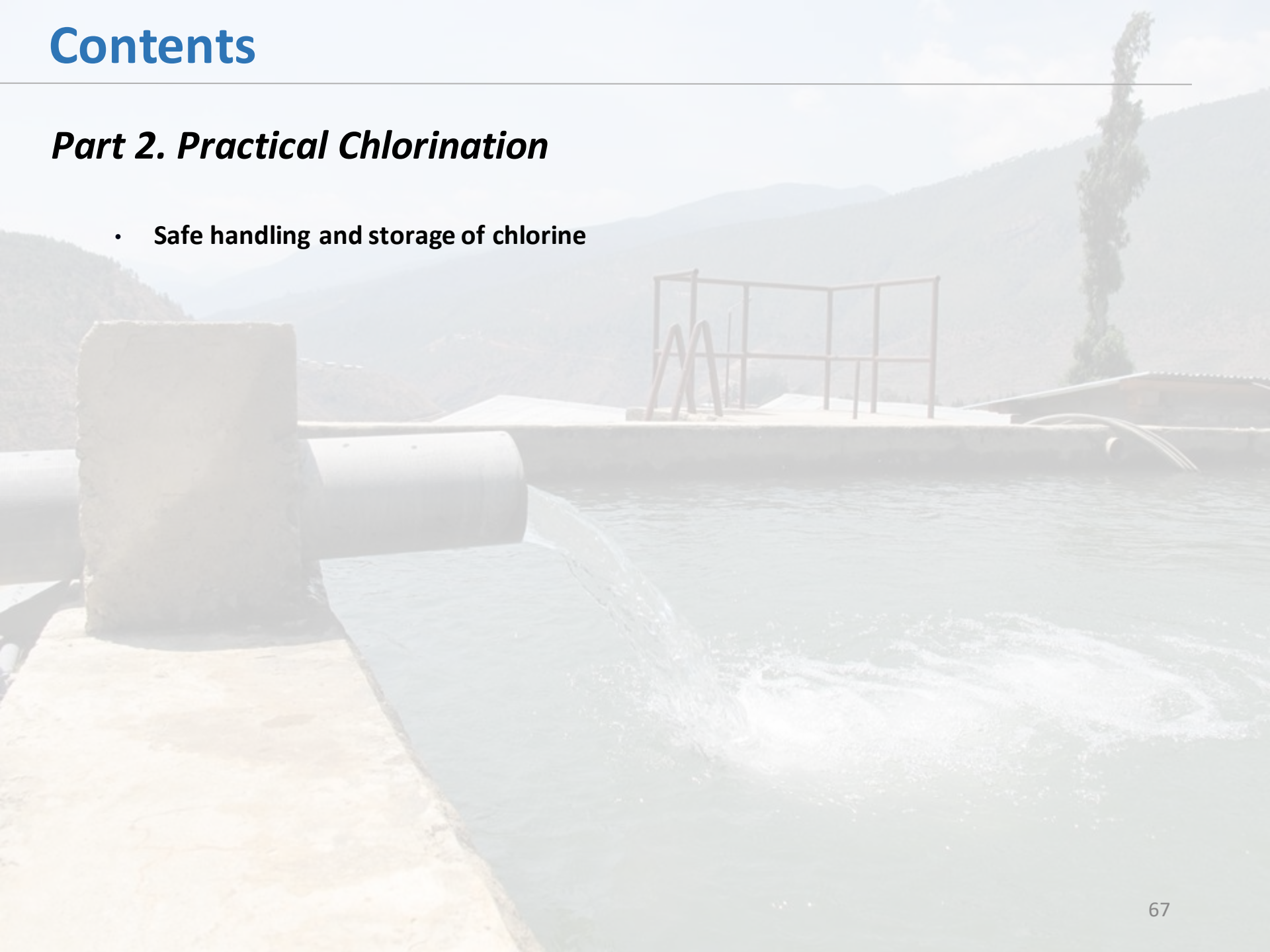
- **Safe handling and storage of chlorine**
- **Chlorine liquid dosing systems**
- **Chlorine dosing calculations**
 - *How to calculate the chlorine demand*
 - *How to calculate the Ct value*
 - *How to calculate the required chlorine dose*
 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*
 - *How to calculate the chlorine dose rate*
- **Developing standard operating procedures**
- **Chlorine monitoring**

General Summary

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Part 2. Practical Chlorination

- **Safe handling and storage of chlorine**



Remember...Properties of chlorine

Very reactive

Characteristic odour

Corrosive

*May remain in the water after disinfection has occurred
(i.e. residual protection)*

Volatile once exposed to air

Safe handling and storage of chlorine powder & liquid

Contact with concentrated forms of chlorine may result in irritation, chemical burns and even death

=> contact includes clothes, skin, eyes, mouth and inhalation into the lungs

=> Protecting the health and safety of staff is critical

All staff in contact with chlorine must receive basic training in:

- 1. the required personal protective equipment (PPE)**
- 2. precautions to be exercised when handling and storing different forms of chlorine, alongside**
- 3. basic first-aid measures in the event of accidental contact**

Chlorine powder: Protective personal equipment required for handling

- **Wear gloves**



GLOVES

- **Wear overalls**



OVERALLS

- **Wear a dust mask**



DUST MASK

- **Wear safety glasses**



SAFETY GLASSES



Chlorine liquid: Protective personal equipment required for handling

- **Wear gloves**
- **Wear overalls**
- **Wear a face shield**



GLOVES



OVERALLS



FACE SHIELD



Any enclosed building used for storage or preparation of chlorine should always be well ventilated.

If chlorine aerosols, mists, vapours or dust are not adequately controlled by ventilation, appropriate respiratory protection should be considered.

Powder & liquid chlorine may lose strength over time

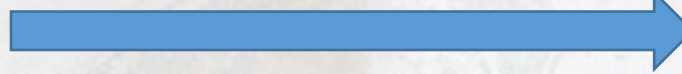
For example...



**New bag
35 % chlorine**

**0
months**

**12
months**



**Old bag
e.g. 30 % chlorine**

Powder & liquid chlorine may lose strength over time

Chlorine liquid solutions are generally less stable than chlorine powder (i.e., lose strength more quickly)

Type of chlorine (approx. % active chlorine concentration)		Loss of initial active chlorine concentration (%) ^{1, 2, 3}
Chlorine powder	Bleaching powder (35 %)	5 to 18 % after 40 days
	High test hypochlorite (70 %)	
Chlorine liquid	Sodium hypochlorite (15 %)	50 % after 100 days
	Sodium hypochlorite (10 %)	50 % after 220 days
	Sodium hypochlorite (5 %)	50 % after 790 days

Source:

¹World Health Organisation. Calcium hypochlorite. Fact Sheet 2.19. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_19.pdf?ua=1 visited on 13 July, 2015.

²World Health Organisation. Sodium hypochlorite. Fact Sheet 2.20. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_20.pdf?ua=1 visited on 13 July, 2015.

³American Water Works Association (2006). Chlorination/chloramination practices and principles. AWWA Manual M20. 2nd Edn. Colorado, United States of America.

Powder & liquid chlorine may lose strength over time

May have important implications for water quality:

- ⇒ if the chlorine powder or liquid is less concentrated, the risk of chlorine under-dosing may exist (i.e., not adding enough chlorine for effective disinfection)
- ⇒ may present a microbiological water quality risk

Appropriate chlorine storage practices must be in place to:

- 1. minimize the rate and extent of chlorine degradation during storage, and***
- 2. protect staff safety***

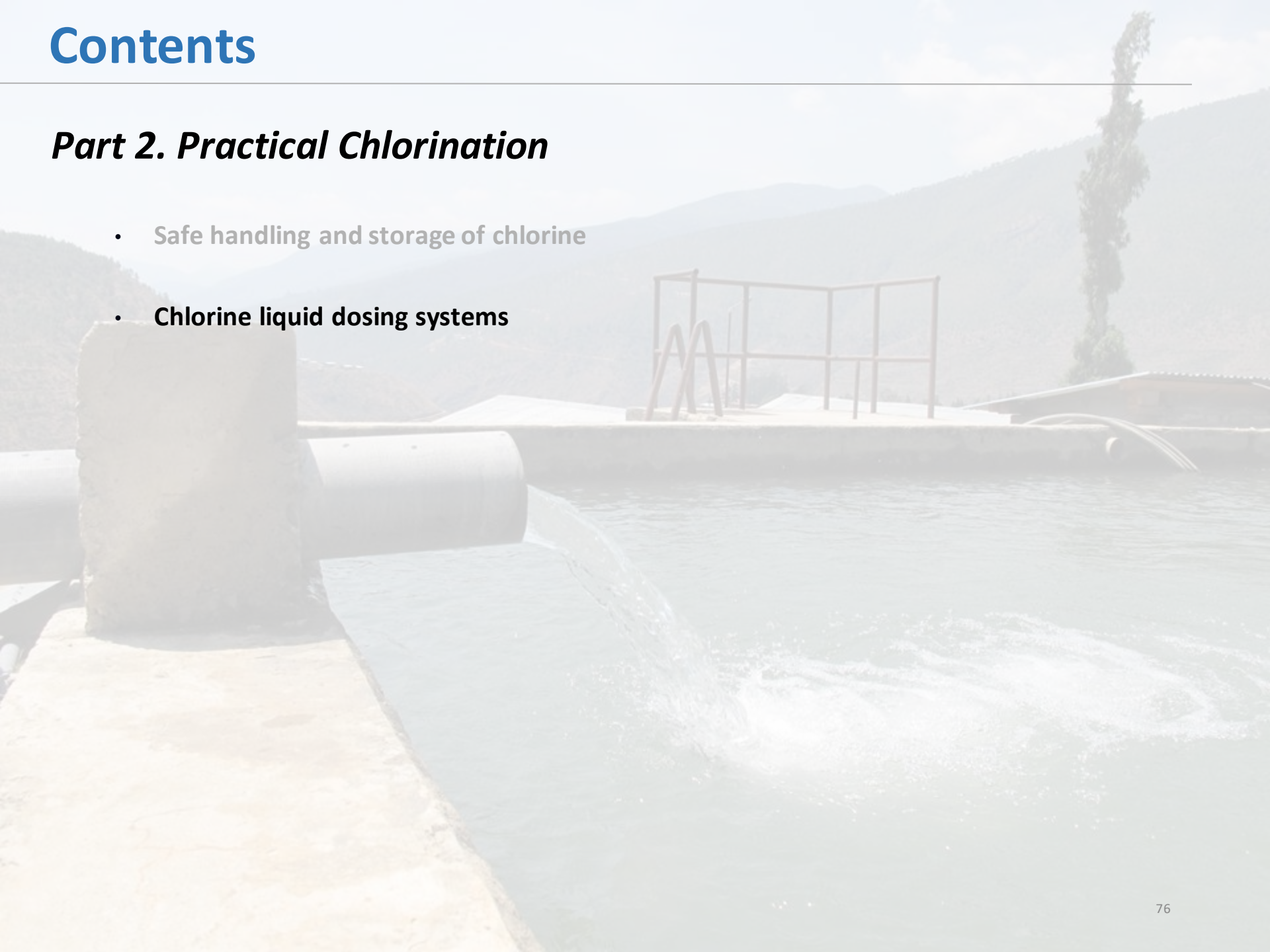
Chlorine powder and liquid: Appropriate storage practices

- ✓ **Store in a cool, dry, well ventilated place in air-tight containers**
- ✓ **Store away from sunlight**
- ✓ **Do not store for excessive periods of time (i.e., many months, years)**
- ✓ **Store in chlorine resistant containers**
- ✓ **Keep containers closed/sealed when not in use**
- ✓ **Check for container leaks/spills regularly**
- ✓ **Avoid contact and breathing in chlorine powder dust or chlorine liquid splashes/mists/aerosols**
- ✓ **Always mark and date new chlorine stock individually**
- ✓ **Use '*First In First Out*' stock management principles**

Contents

Part 2. Practical Chlorination

- Safe handling and storage of chlorine
- Chlorine liquid dosing systems



Chlorine liquid dosing systems

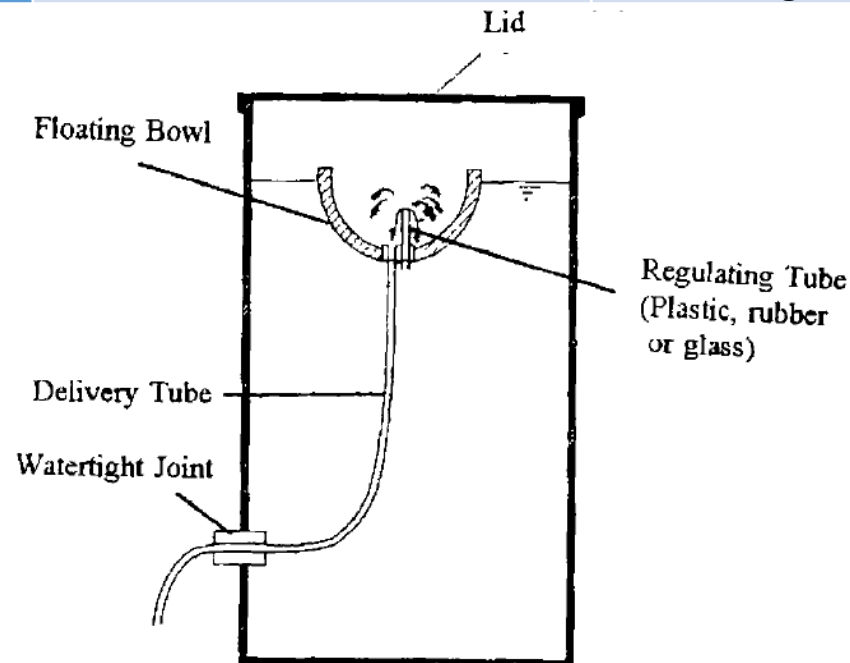
Used to dose chlorine liquid into the drinking-water

Two options:

1. Non-pump-based systems (e.g., gravity)
2. Pump-based systems

1. Non-pump based dosing systems

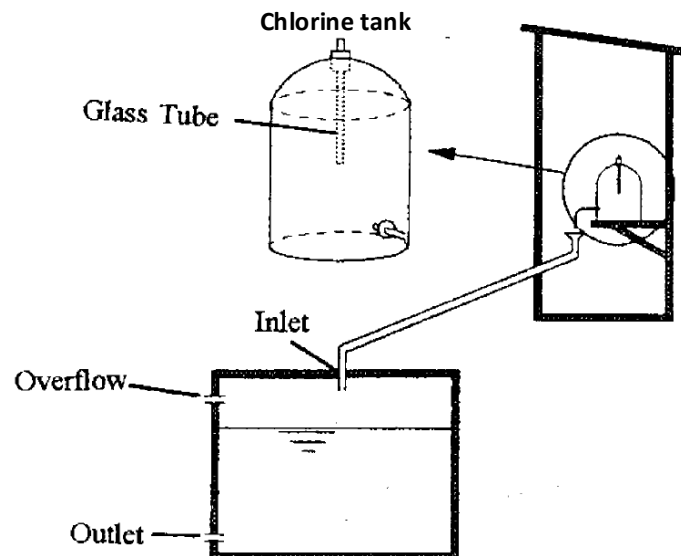
System ¹	Basis	Comments
Drip-feed chlorinators	Feeds a constant rate of drops of chlorine liquid solution using a constant head device to maintain the drip feed	- Assume constant water flow rate (inaccurate dosing if flow rate changes) - Suitable for small supplies - Risk of siphoning must be managed



¹World Health Organisation. Dosing hypochlorite solutions. Fact Sheet 2.22. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_22.pdf?ua=1 visited on 12 August, 2015.

1. Non-pump based dosing systems

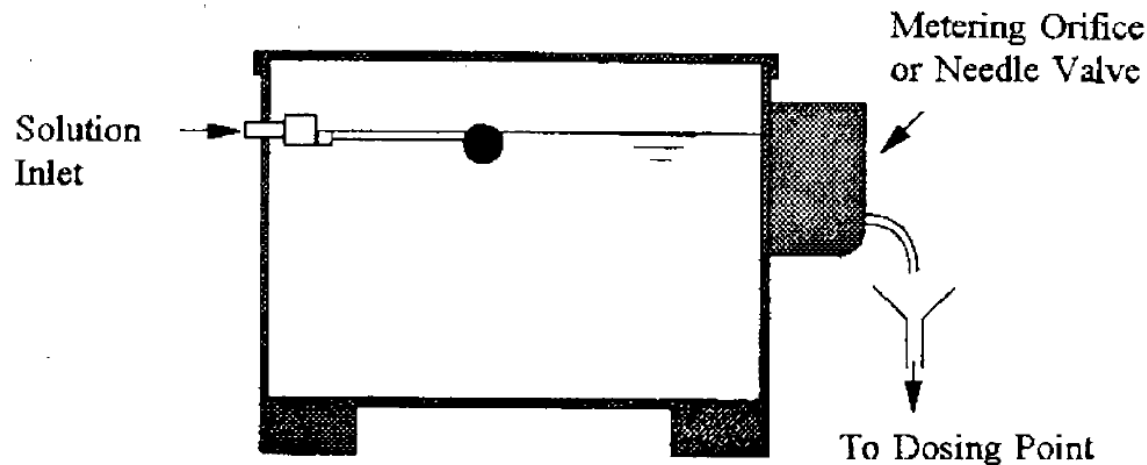
System ¹	Basis	Comments
Constant head aspirator	Drips a constant rate of chlorine liquid solution using an aspirator and glass tube	- Simple, robust device - Durable if given appropriate basic maintenance - Easy installation - Coarse and fine drip-rate control possible - Assume constant water flow rate (inaccurate dosing if flow rate changes)



¹World Health Organisation. Dosing hypochlorite solutions. Fact Sheet 2.22. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_22.pdf?ua=1 visited on 12 August, 2015.

1. Non-pump based dosing systems

System ¹	Basis	Comments
Gravity feeder	Relies on gravity and a metering orifice/valve to control the flow of chlorine liquid solution	- Requires a second tank and ball valve to maintain constant head pressure



¹World Health Organisation. Dosing hypochlorite solutions. Fact Sheet 2.22. http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_22.pdf?ua=1 visited on 12 August, 2015.

1. Non-pump based dosing systems

Lower cost

Simple to operate and maintain (no mechanical parts, servicing)

Not suitable for larger capacity water supply systems

Less accurate and less operational control

=> greater risk of chlorine under-/over-dosing

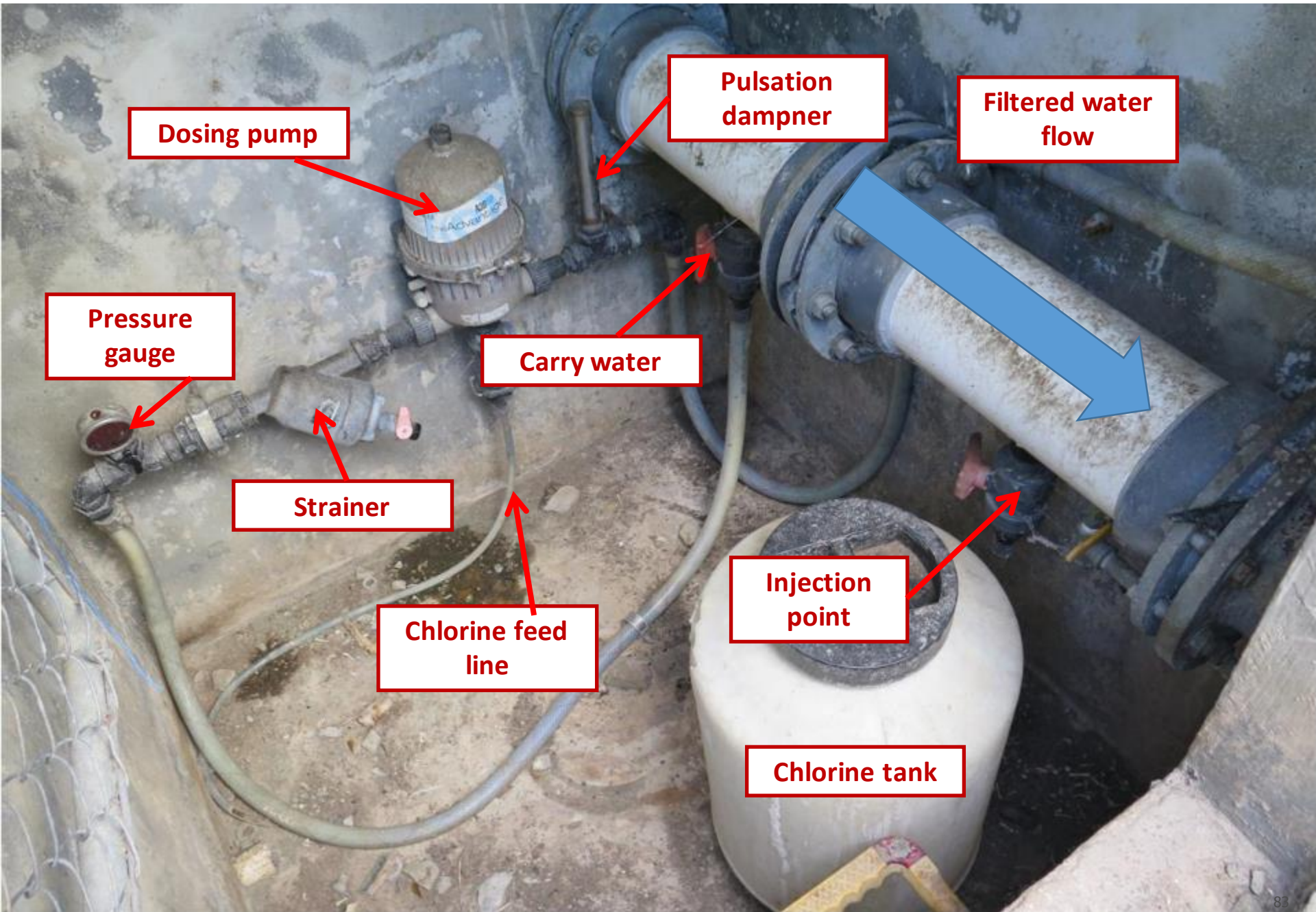
Suitable for small supplies, limited resource settings

2. Pump-based dosing systems

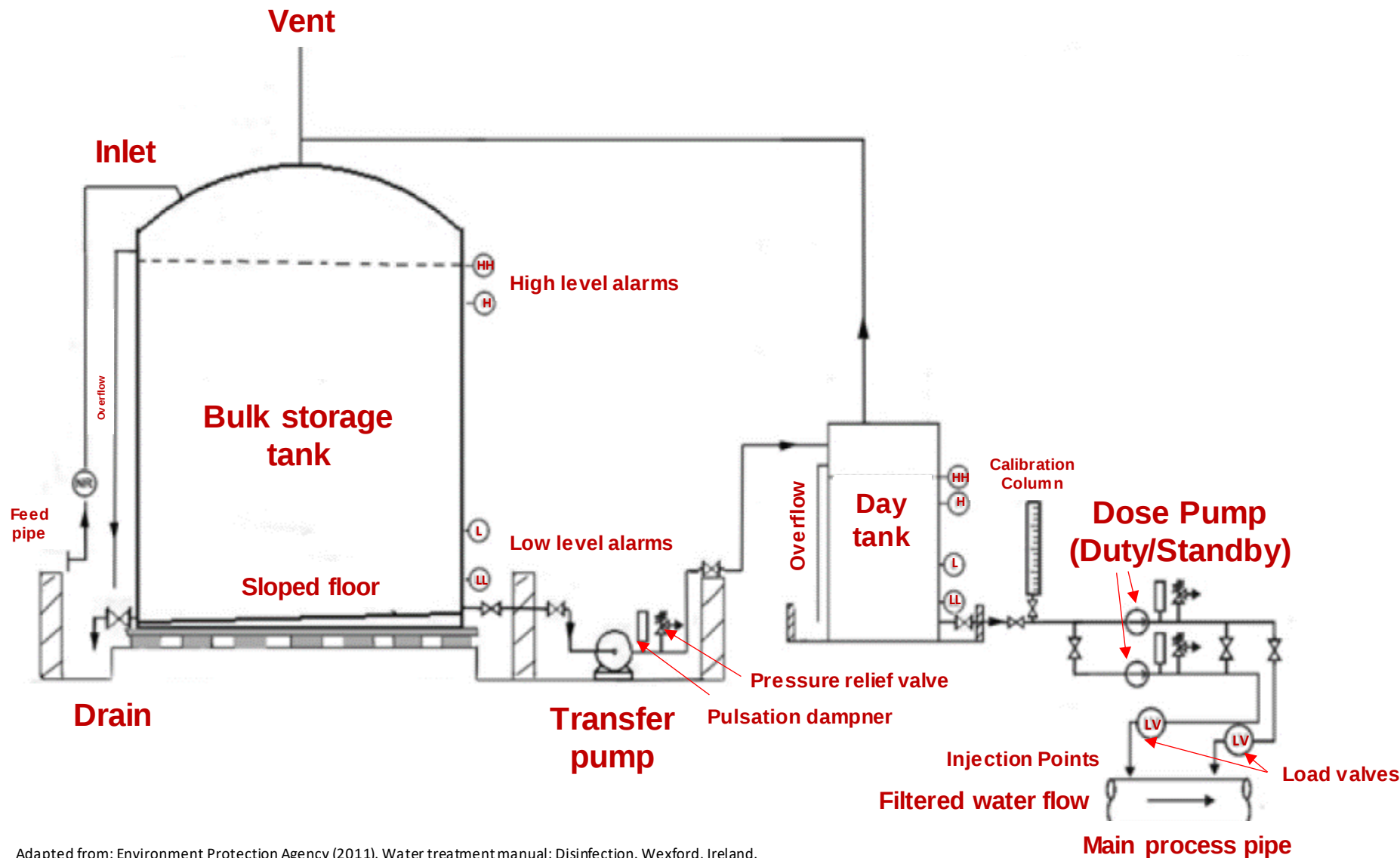
Vary in their complexity and design....



2. Pump-based dosing systems: More basic



2. Pump-based dosing systems: More advanced



Adapted from: Environment Protection Agency (2011). Water treatment manual: Disinfection. Wexford, Ireland.

Credit: Environment Protection Agency, Ireland

2. Pump-based dosing systems

Allow much greater accuracy and operational control

- ⇒ may be linked to control signals (e.g. flow-paced, residual trim and associated alarming)
- ⇒ less risk of chlorine under-/over-dosing

More costly

Require maintenance, servicing and parts

- ⇒ may require specialised technician and supply chain for parts

Recommended where resources permit

Part 2. Practical Chlorination

- Safe handling and storage of chlorine
- Chlorine liquid dosing systems
- Chlorine dosing calculations
 - *How to calculate the chlorine demand*

Remember....Chlorine demand

Reaction between chlorine and any organic and inorganic material (*chlorine reactive substances*) present in the water

⇒ **During these reactions, chlorine is consumed**

⇒ **Residual chlorine in the water decreases**

Important to understand the chlorine demand of the raw (untreated) water to optimise the chlorine dose

How to calculate the chlorine demand (Eq. 1)

$$\text{Chlorine Demand (mg/L)} = \text{Actual Chlorine Dose (mg/L)} - \text{Total Residual Chlorine (mg/L)}$$

Example:

⇒ If the actual chlorine dose is 3 mg/L

⇒ The total residual chlorine is 1 mg/L (after 30 minutes contact time), then using Eq. 1:

$$\begin{aligned} \text{Chlorine Demand (mg/L)} &= 3 \text{ mg/L} - 1 \text{ mg/L} \\ &= 2 \text{ mg/L} \end{aligned}$$

Contents

Part 2. Practical Chlorination

- Safe handling and storage of chlorine
- Chlorine liquid dosing systems
- Chlorine dosing calculations
 - *How to calculate the chlorine demand*
 - *How to calculate the Ct value*

Remember.... Ct value

Ct is calculated as follows:

Residual chlorine concentration (C) x Contact time (t)

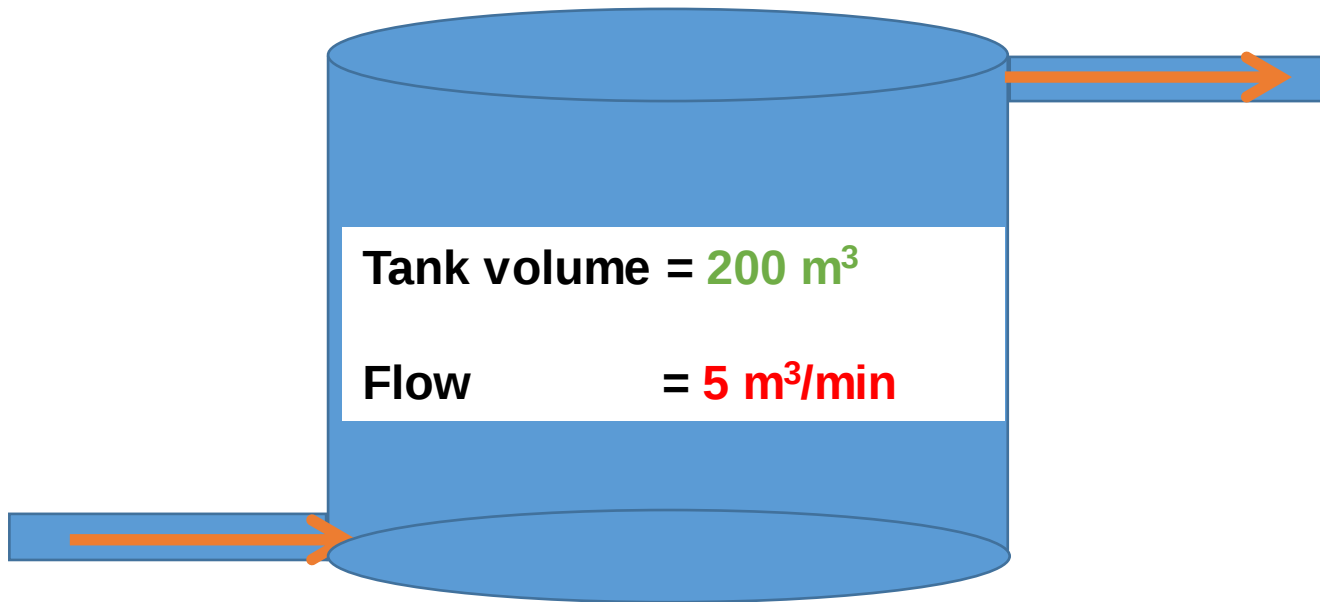
Where:

Residual chlorine: **Concentration of residual chlorine (in mg/L)**

Contact time: *Amount of time (in minutes) there is contact between the chlorine and the water (e.g. detention time in a storage tank, reservoir, or pipe)*

How to calculate the detention time for a storage

$$\text{Detention time (min)} = \text{Storage volume (m}^3\text{)} \div \text{Flow (m}^3\text{/min)}$$



$$\begin{aligned} \text{Detention time} &= 200 \text{ m}^3 \div 5 \text{ m}^3\text{/min} \\ &= 40 \text{ min} \end{aligned}$$

How to calculate the Ct value (Eq. 2)

$$\text{Ct (min.mg/L)} = \text{Residual chlorine concentration (mg/L)} \times \text{Contact time (min)}$$

Example:

⇒ Residual chlorine concentration is **0.5 mg/L**

⇒ Tank has a detention time of **40 minutes**, then using Eq. 2:

$$\begin{aligned} \text{Ct (min.mg/L)} &= 0.5 \text{ mg/L} \times 40 \text{ min} \\ &= 20 \text{ min.mg/L} \end{aligned}$$

Minimum recommended Ct value

***WHO¹ recommends a minimum contact time of 30 minutes where the residual chlorine is 0.5 mg/L and the pH is <8
(i.e., 15 min.mg/L)***

However, Ct values should be determined on a site specific basis, considering:

- the temperature of the water
- the pH of the water
- turbidity of the water
- 'short-circuiting' within the storage (that is, the potential for preferential flow and reduced mixing/detention time)

A more detailed example for accurately determining the minimum required Ct value using Ct tables is presented in Toolbox C of the accompanying guide

¹ World Health Organization (2011). Guidelines for Drinking-water Quality. 4th Edn. Geneva, Switzerland.

Part 2. Practical Chlorination

- Safe handling and storage of chlorine
- Chlorine liquid dosing systems
- Chlorine dosing calculations
 - *How to calculate the chlorine demand*
 - *How to calculate the Ct value*
 - *How to calculate the required chlorine dose*

How to calculate the required chlorine dose (Eq. 3)

$$\text{Required Chlorine Dose (mg/L)} = \text{Chlorine Demand (mg/L)} + \text{Desired Residual Chlorine (mg/L)}$$

Example:

⇒ The chlorine demand is known to be 2 mg/L

⇒ The desired residual chlorine is 1 mg/L, then using Eq. 3:

$$\begin{aligned} \text{Required chlorine dose (mg/L)} &= 2 \text{ mg/L} + 1 \text{ mg/L} \\ &= 3 \text{ mg/L} \end{aligned}$$

Part 2. Practical Chlorination

- Safe handling and storage of chlorine
- Chlorine liquid dosing systems
- **Chlorine dosing calculations**
 - *How to calculate the chlorine demand*
 - *How to calculate the required chlorine dose*
 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*

Preparing chlorine liquid from chlorine powder

Establish which type of chlorine powder is in use:

- 1. bleaching powder – typically 35 % active chlorine, or**
- 2. high test hypochlorite typically 70 % active chlorine**

=> if unsure, contact supplier or manufacturer

Consider the age and storage conditions of the chlorine powder

⇒ concentration of active chlorine in the chlorine powder may be less than expected if old stock is in use and/or stock has been stored inappropriately

Preparing chlorine liquid from chlorine powder

Determine what concentration you wish to prepare the chlorine liquid solution:

- ⇒ typically chlorine liquid solutions are made between 1 and 5 % active chlorine
- ⇒ higher concentrations of liquid solutions may be prepared in certain circumstances (e.g., pump or bulk storage capacity limitations)
 - may result in accumulation of undissolved sediment (or 'sludge') from inert material present in the powder (risk of blockages)
 - requires appropriate settling time for undissolved sediment and decanting
- ⇒ **Appropriate concentration and volume of chlorine liquid solution to be prepared must be determined on a specific basis**

How to calculate the required amount of chlorine powder (Eq. 4)

Weight of chlorine powder (mg/L) =

$$\frac{1\,000 \times \text{Volume of chlorine liquid required (L)} \times \text{Desired chlorine liquid concentration (\%)}}{\text{Active chlorine concentration in the chlorine powder (\%)}}$$

Example:

⇒ Require 500 L of chlorine liquid solution

⇒ Require chlorine liquid concentration to be 2 % active chlorine

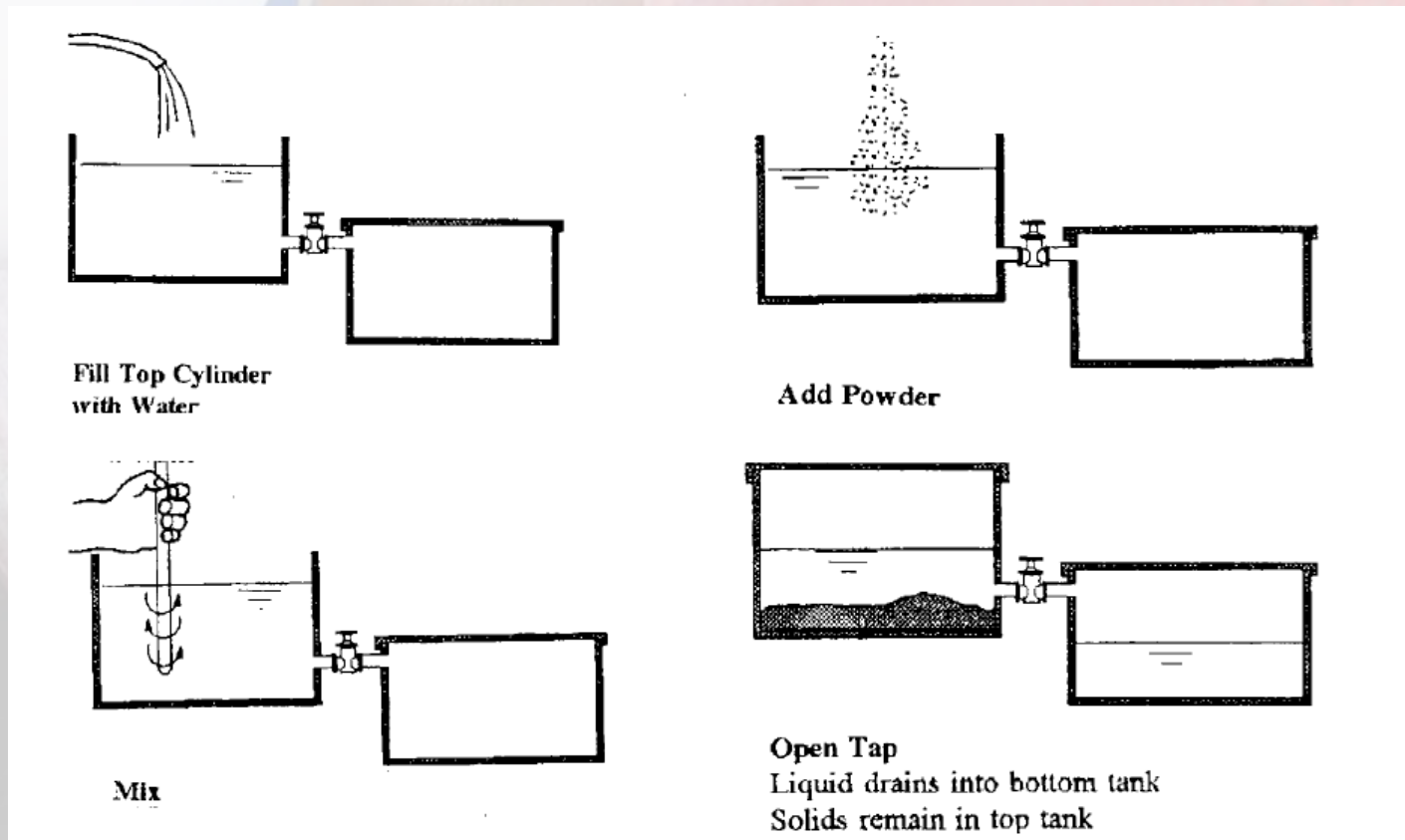
⇒ Using bleaching powder (35 % active chlorine), then using Eq. 4:

$$\begin{aligned} \text{Weight of chlorine powder (mg/L)} &= \frac{1\,000 \times 500 \text{ L} \times 2 \%}{35 \%} \\ &= 28\,571 \text{ g (or 28.6 kg) per 500 L of water} \end{aligned}$$

Preparing chlorine liquid from chlorine powder

Generally require two containers:

1. **One for mixing and settling of undissolved sediment (e.g., up to 24 hours settling time)**
2. **One for decanting settled solution into for storage and dosing**



Summary of Steps for Preparing Chlorine Liquid from Chlorine Powder

1. Determine what strength chlorine powder you are using

- Bleaching powder ~35 % active chlorine, or
- High test hypochlorite ~ 70 % active chlorine

2. Determine the concentration you want the chlorine liquid solution to be

- Typically liquid chlorine solutions between 1 to 5 % active chlorine is used
- May be higher in certain situations

3. Determine how much chlorine powder must be added to prepare the desired chlorine solution

- Determine the total volume of liquid chlorine solution required
- Calculate amount of chlorine powder required for this volume using Equation 4

4. Mix chlorine powder in the desired volume of water in an appropriate container

- Allow sufficient time for the undissolved powder to settle
- Pour off (decant) the liquid chlorine solution
- Ready to use 😊

Part 2. Practical Chlorination

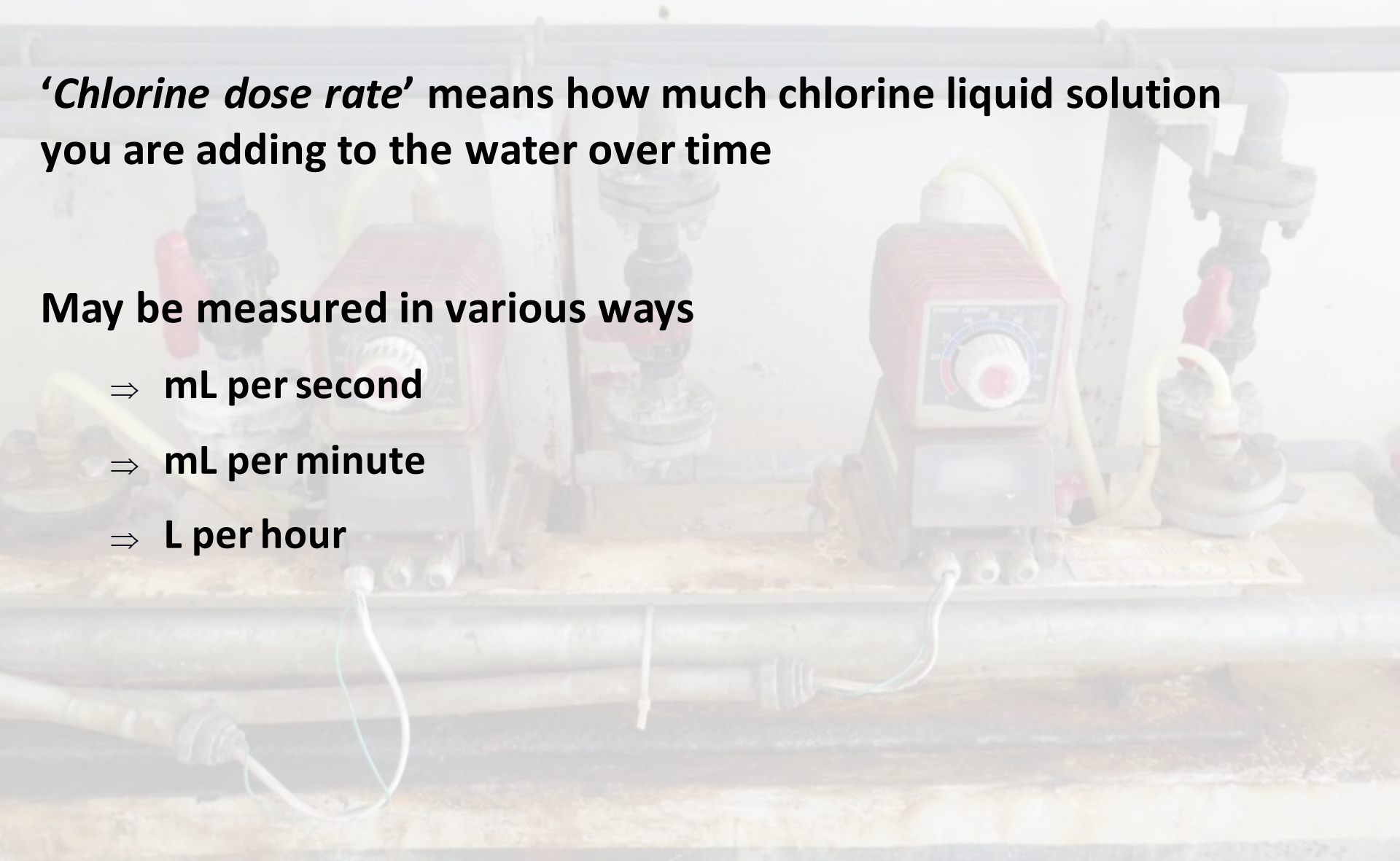
- **Safe handling and storage of chlorine**
- **Chlorine liquid dosing systems**
- **Chlorine dosing calculations**
 - *How to calculate the chlorine demand*
 - *How to calculate the Ct value*
 - *How to calculate the required chlorine dose*
 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*
 - *How to calculate the chlorine dose rate*

Chlorine dose rate

‘Chlorine dose rate’ means how much chlorine liquid solution you are adding to the water over time

May be measured in various ways

- ⇒ mL per second
- ⇒ mL per minute
- ⇒ L per hour



How to calculate the chlorine dose rate (Eq. 5)

$$\text{Chlorine Dose Rate (mL/h)} = \frac{\text{Required chlorine dose (mg/L)} \times \text{Treated water flow rate (m}^3\text{/h)}}{\text{Chlorine liquid concentration (\%)} \div 100}$$

Example:

- ⇒ Require **3 mg/L** chlorine dose (see Eq. 3)
- ⇒ Flow rate at the water treatment plant is **100 cubic meters per hour (100 m³/h)**
- ⇒ Chlorine liquid concentration is **2 %** (see Eq. 4), then using Eq. 5:

$$\begin{aligned}\text{Chlorine Dose Rate (mL/h)} &= \frac{3 \text{ mg/L} \times 100 \text{ m}^3\text{/h}}{2 \% \div 100} \\ &= 15\,000 \text{ mL/h (or 250 mL/min)}\end{aligned}$$

How to calculate the actual chlorine dose (Eq. 6)

May rearrange Eq. 5 to determine actual chlorine dose; useful for determining chlorine demand (Eq. 1)

Actual Chlorine Dose (mg/L) =

$$\frac{[\text{Chlorine dose rate (mL/h)} \times \text{Chlorine liquid concentration (\%)}] \div 100}{\text{Flow rate (m}^3\text{/h)}}$$

Example:

⇒ Chlorine dose rate is 6 000 mL/h

⇒ Chlorine liquid concentration is 2 % (see Eq. 4)

⇒ Flow rate at the water treatment plant is 100 cubic meters per hour (100 m³/h)
then using Eq. 6:

$$\begin{aligned} \text{Actual Chlorine Dose (mg/L)} &= \frac{(6\,000 \text{ mL/h} \times 2\%) \div 100}{100 \text{ m}^3\text{/h}} \\ &= 1.2 \text{ mg/L} \end{aligned}$$

Adjusting the chlorine dose

1) Always adjust stepwise (i.e., in small increments)

⇒ do not make large adjustments all at once or you risk over-/under-dosing

2) Always consider time taken for water to turn-over in the tank or pipe before additional adjustments are made

⇒ e.g. may take 2 days for higher chlorinated water to reach a particular monitoring point in the distribution system

⇒ make sure the tank/pipe/section of network is completely replenished with 'new' water with the adjusted chlorine dose

3) Increase the frequency of chlorine monitoring following:

⇒ changes in the chlorine dose

⇒ preparation/delivery of a new batch of chlorine liquid

Chlorine Dosing Cheat Sheet

For a quick and easy way to perform chlorine dosing calculations, see the '*Chlorine Dosing Cheat Sheet*' described in Toolbox B

⇒ prompts you to input the required information

⇒ automatically performs the calculation

Example:

How to determine the weight of chlorine powder required to prepare a chlorine liquid solution

1. Input the volume of liquid chlorine solution required in litres (L)

2. Input the desired active chlorine concentration in the final liquid chlorine solution in percentage (%)

3. Input the concentration of active chlorine in the chlorine powder in percentage (%)

Where possible, test the strength of the chlorine powder before use; if not possible to do this, check the estimated concentration with the manufacturer/supplier

In general, if using bleaching powder - use 35 %; if using high test hypochlorite - use 70 %

Total volume of liquid chlorine solution required 1 L

Desired concentration of final chlorine liquid solution 1 %

Active chlorine concentration in the chlorine powder 35 %

Weight of chlorine powder required 29 g

or

0.029 kg

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 - *How to calculate the required chlorine dose*
 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*
 - *How to calculate the chlorine dose rate*
- **Developing standard operating procedures**

Standard operating procedures (SOPs)

To be developed for any operational tasks that are performed routinely, including chlorination

Help operational staff perform duties safely, correctly and with consistency

Include important safety information

Examples of information that should be included within SOPs for chlorination....

Suggested SOPs for chlorination

1. Calculating the weight of chlorine powder required to make a chlorine liquid batch
2. Preparing a batch of chlorine liquid from chlorine powder
3. Calculating the chlorine dose

=> suggested content for each of this is presented on the following slides...

SOP: Calculating the weight of chlorine powder required to make a chlorine liquid batch

- ✓ PPE required for safe completion of the task
- ✓ The type of chlorine powder to be used (e.g., bleaching powder or high test hypochlorite)
- ✓ The desired solution strength of the chlorine liquid being prepared (e.g., 1 % chlorine liquid solution)
- ✓ The volume of chlorine liquid solution to be prepared
- ✓ The calculation used to determine the weight of chlorine powder required

=> For an example see Generic SOP 1 and 2 (Toolbox A)

SOP: Preparing a batch of chlorine liquid from chlorine powder

- ✓ PPE required for safe completion of the task
- ✓ The unit weight of chlorine powder required to prepare a batch of liquid chlorine (e.g., 35 g of bleaching powder per litre of water)
- ✓ The receptacle that the solution will be mixed in (e.g., dedicated concrete tank or a plastic container)
- ✓ The means by which the powder will be mixed with the water (e.g., a dedicated mixing device)
- ✓ The amount of settling time required following mixing and before use
- ✓ The appropriate chlorine storage conditions

=> For an example see Generic SOP 3 (Toolbox A)

SOP: Calculating the chlorine dose

- ✓ **PPE required for safe completion of the task**
- ✓ **The calculation used to determine the chlorine dose rate based on the strength of the chlorine liquid solution and the water treatment plant flow rate**
- ✓ **Precautions to be taken when adjusting the dose rate (including increased monitoring of the chlorine concentration in the drinking-water following adjustment)**

=> For an example see Generic SOP 4 (Toolbox A)

Other chlorination SOPs may include...

- Chlorine stock management
- Operation and maintenance of chlorine dose pumps
- Emergency response procedure in the event of accidental human contact or release to the environment
- Emergency response procedure in the event of accidental human contact or release to the environment

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 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*
 - *How to calculate the chlorine dose rate*
- Developing standard operating procedures
- **Chlorine monitoring (operational monitoring)**

Chlorine monitoring (operational monitoring)

Careful monitoring and optimization of the chlorine concentration through the water supply system is critical:

- ⇒ ensures that sufficient chlorine is added to the water for adequate disinfection and residual protection from recontamination
- ⇒ minimizing risks of consumer acceptability issues (i.e., taste, odour)



Risk of microbial contamination



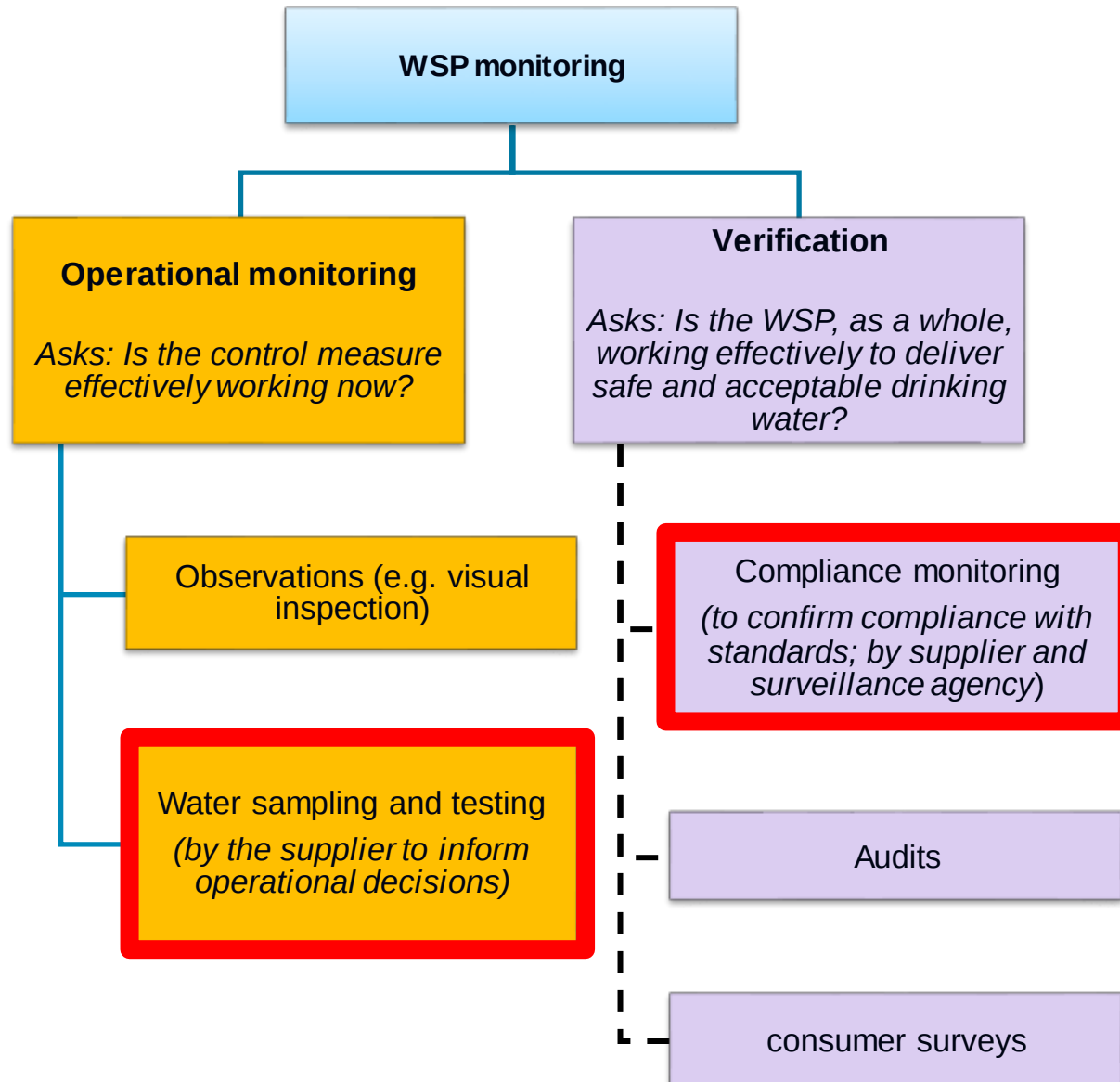
Aesthetically unacceptable

Chlorine monitoring

Should be performed as part of **Operational Monitoring**

- ⇒ simple, routine checks to confirm that the measures in place to manage water quality risk are operating effectively (i.e., **control measures**)
- ⇒ **critical limits** determine the point at which the control measures is no longer working within an acceptable range
- ⇒ **corrective actions** are then required to restore correction functioning of the control measure and minimise the risk of unsafe water supply

Operational monitoring is different to verification monitoring



Examples of equipment for chorine monitoring

Chlorine test strips



Chlorine comparator



Chlorine meter



ACCURACY / RESOLUTION

\$
\$
\$
\$
\$
\$
\$
\$
\$
\$
\$

Chlorine testing equipment

Test Equipment	Cost	Accuracy/Resolution	Advantages	Disadvantages
Chlorine test strips	M	L	- Easy to use, disposable - No calibration/servicing required	- Poor degree of resolution (e.g., may only measure in 0.5 mg/L increments) - Visual measurement (colour change); open to user interpretation - Requires supply chain for replacement strips
Chlorine comparator test kit	M	M	- Easy to use - Durable for field use - No calibration/servicing required	- Visual measurement (colour change); open to user interpretation - Requires reagents (DPD powder), supply chain
Chlorine meter	H	H	- High degree of resolution over a wide range (0.05 to 10 mg/L in 0.01 mg/L increments) - Easy to use	- Less durable for field use - Calibration/servicing required - Requires reagents, replacement parts (bulb), supply chain

Chlorine monitoring

Chlorine monitoring locations in the distribution system should include:

- ⇒ **the start, middle and end of the distribution network**
- ⇒ **known water quality trouble spots (that is, where poor water quality has been historically found, such as the end-points of the network, low-flow areas and dead legs)**

Number of sample points and the frequency of sampling will differ depending on the specific circumstances of the water supply system

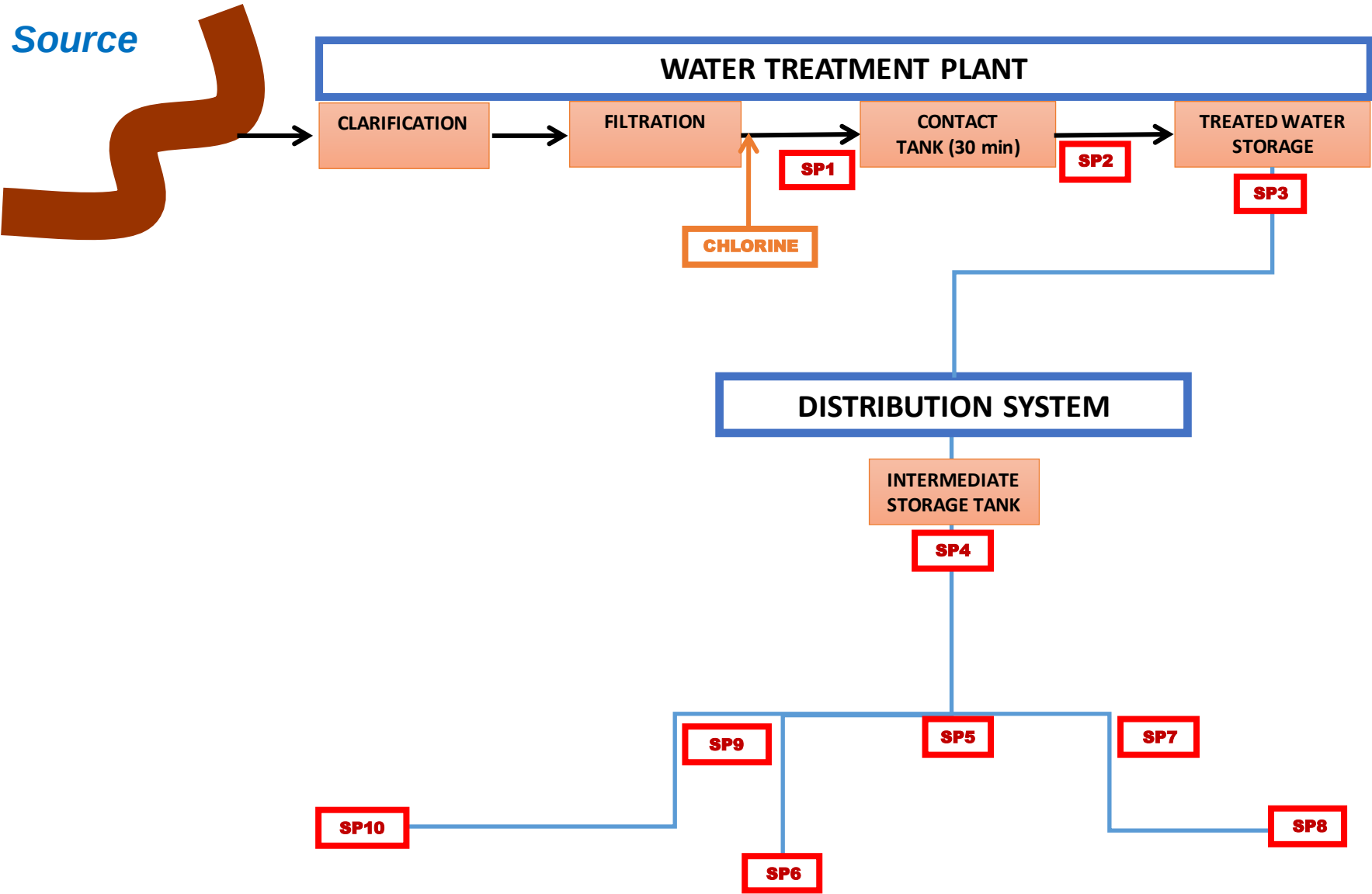
- ⇒ **should be sufficient to manage the risk of sub-optimal chlorination**

Chlorine monitoring

Chlorine monitoring should generally occur (**for sample point reference, see next slide**):

- ⇒ immediately after chlorine has been added to the water (dosed water; **SP1**)
- ⇒ after contact time has elapsed (**SP2**)
- ⇒ at the point of entry to the distribution system (**SP3**)
- ⇒ throughout the distribution system to the point of consumer delivery (including storage tanks, reservoirs; for example, **SP4 to 10**; Note - number of sample points will differ depending on the specific circumstances of the water supply system)
- ⇒ at a frequency that is appropriate to manage the risk of sub-optimal chlorine concentration in the particular drinking-water supply

Example chorine monitoring locations in a water supply system



Chlorine monitoring

Feedback of data from chlorine operational monitoring is essential to ensure that the chlorine dose is being optimized

Chlorine operational monitoring data will indicate if:

- ⇒ Chlorine dose at the water treatment plant needs to be optimized**
- ⇒ Potential changes in raw/treated water quality**
- ⇒ Potential presence of contamination in storage or distribution**
- ⇒ Likelihood of recontamination during delivery to consumer**

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 - *How to calculate the amount of chlorine powder required to make a chlorine liquid solution*
 - *How to calculate the chlorine dose rate*
- Developing standard operating procedures
- Chlorine monitoring

General Summary

Chlorine summary...

Chlorine is added to water to kill microorganisms

=> kills most microorganisms in a short time

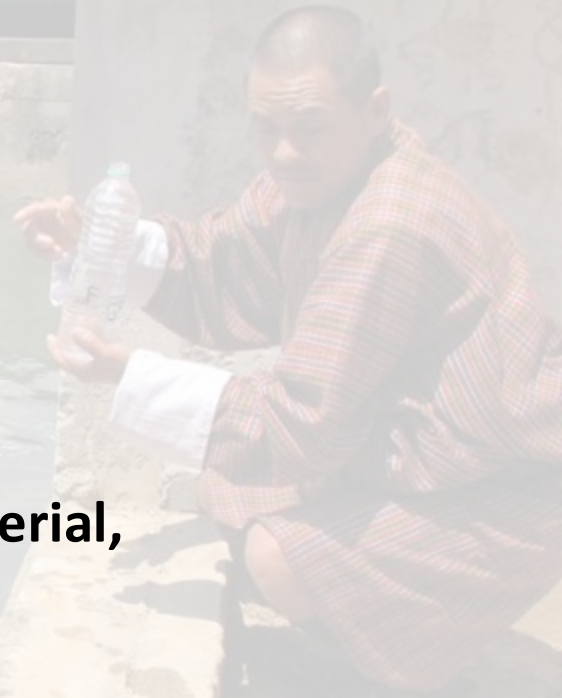
=> not all microorganisms will be killed by chlorine



Chlorine summary...

Chlorine is very reactive

**⇒ reacts with microorganisms, organic material,
sediment, pipe material**



Chlorine summary...

Chlorine decay is the decrease in the concentration of chlorine in a water supply system

⇒ for this reason, the chlorine concentration decreases in the distribution system

Chlorine summary...

Chlorine demand indicates how much chlorine will be consumed during chlorine reactions

- ⇒ helps inform what chlorine dose is required for effective disinfection
- ⇒ if water has high chlorine demand it consumes more chlorine and needs a high chlorine dose
- ⇒ if water has low chlorine demand it consumes less chlorine and needs a low chlorine dose

Chlorine summary...

Chlorine residual is the concentration of free chlorine remaining after the chlorine demand has been satisfied and disinfection has taken place

- ⇒ critically important water quality parameter for public health
- ⇒ implies that there is residual protection from recontamination from microorganisms during storage/distribution
- ⇒ residual chlorine concentration should always be ≥ 0.2 mg/L at the point of delivery to the consumer

Chlorine summary...

Chlorine contact time is the amount of time required for effective disinfection to take place

- ⇒ a minimum Ct value of 15 min.mg/L (where pH <8.0) is required in all cases**
- ⇒ this is 30 minutes contact time with a residual chlorine concentration of 0.5 mg/L**
- ⇒ minimum required Ct value should be determined on a case-by-case basis (see Appendix C of the accompanying manual)**

Chlorine summary...

Ct value is influenced by:

⇒ **pH**

⇒ **temperature**

⇒ **chlorine concentration**

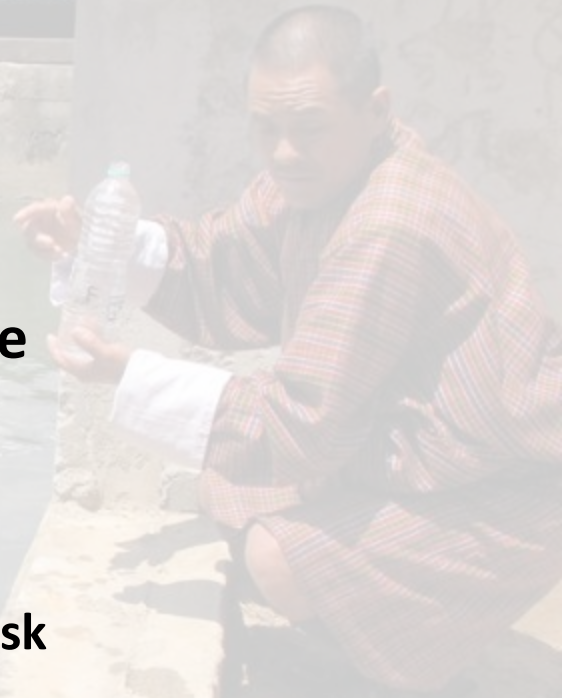
⇒ **turbidity**



Chlorine summary...

All forms of chlorine are dangerous to handle

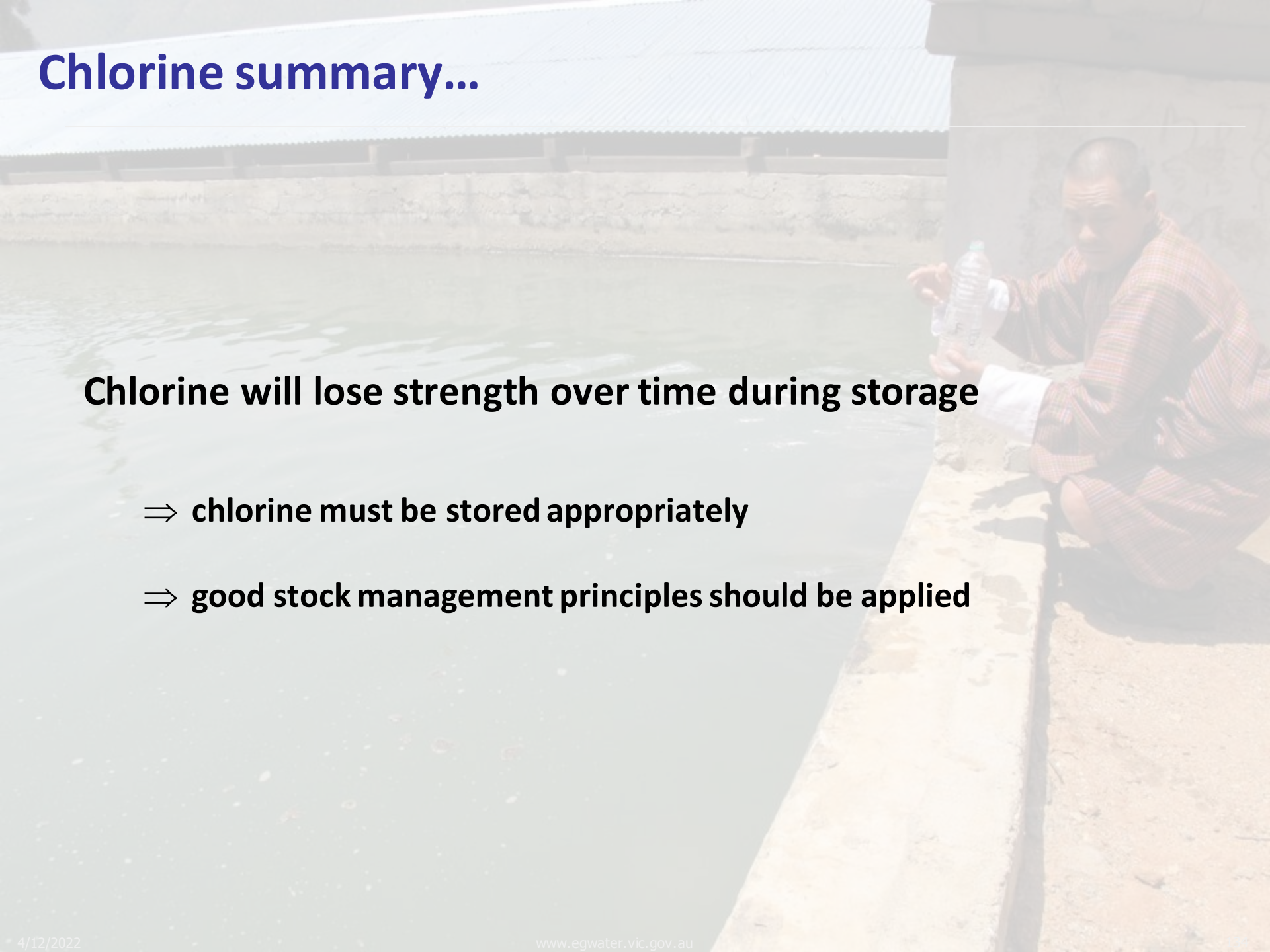
- ⇒ **must be handled safely**
- ⇒ **Powder: Overalls, gloves, safety glasses, dust mask**
- ⇒ **Liquid: Overalls, gloves and face shield**



Chlorine summary...

Chlorine will lose strength over time during storage

- ⇒ chlorine must be stored appropriately**
- ⇒ good stock management principles should be applied**



Chlorine summary...

Conditions required for effective disinfection

Turbidity:

<1 NTU (lower where possible)

(where < 1 NTU is not possible, <5 NTU should be the aim; above 5 NTU, disinfection should still be practised, but higher chlorine doses or contact times will be required to inactivate harmful microorganisms)

pH:

<pH 8.0

(Above pH 8.0, chlorination should still be practised but higher chlorine doses or contact times will be required to inactivate harmful microorganisms)

Minimum contact time: 30 minutes contact time with a minimum residual chlorine concentration of 0.5 mg/L, where the pH of the water is <pH 8.

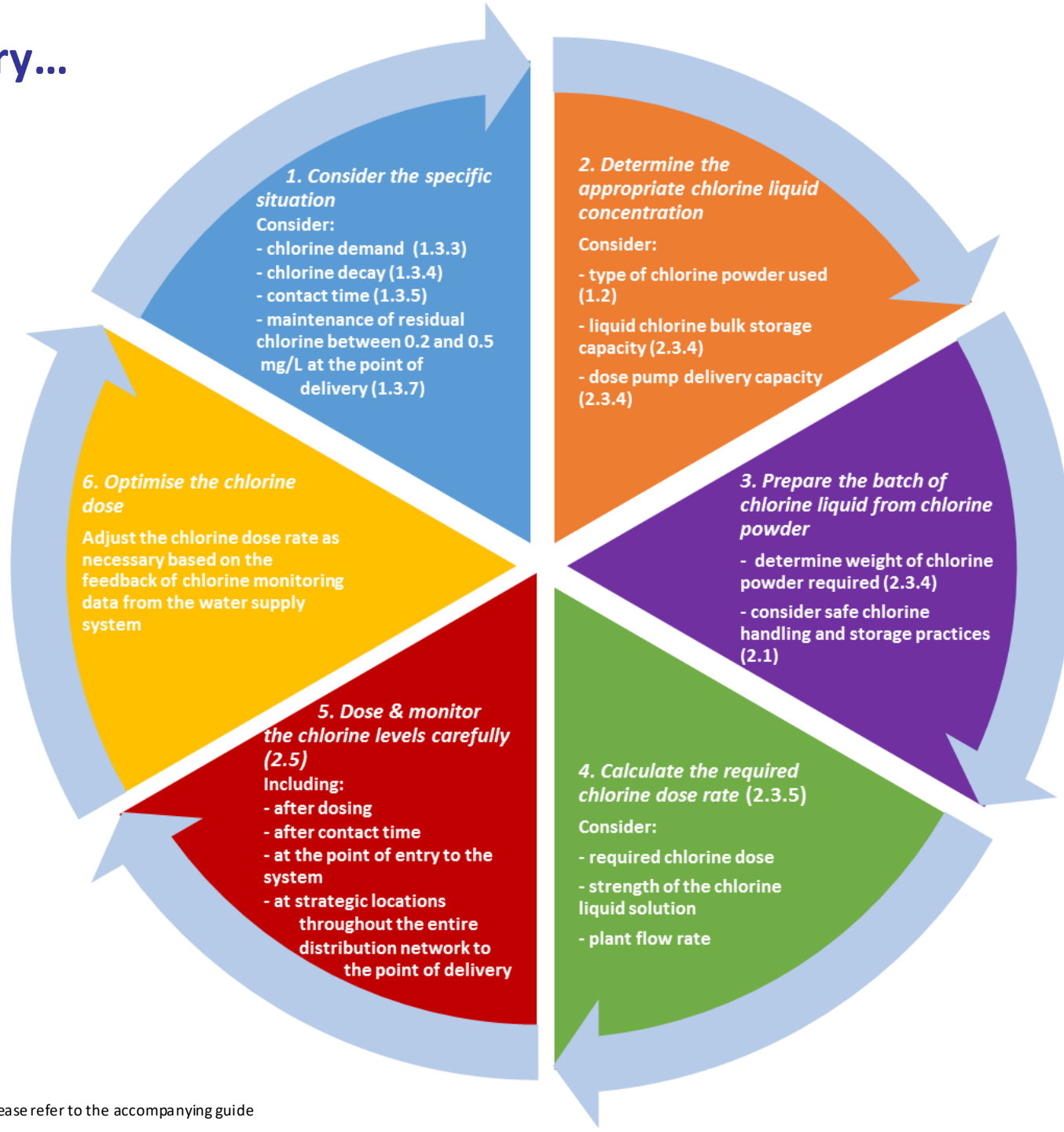
Chlorine summary...

Once chlorination at the water treatment plant is complete, the residual chlorine concentration during distribution to the point of delivery should aim to be between 0.2 to 0.5 mg/L.

⇒ **a minimum residual chlorine concentration of 0.2 mg/L must always be maintained at the point of delivery**

The concentration of chlorine in water supplied to consumers should always be <5 mg/L

Summary...



***any
questions...***



Quiz

Multiple choice.....

Quiz

Q.1) Chlorine is added to water to:

- a) Make it taste better***
- b) Kill/inactivate harmful microorganisms***
- c) Improve the pH***
- d) Remove turbidity***

Quiz

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Quiz

Q.2) Microorganisms may be found in:

a) Soil

b) Water

c) Sewage

d) All of the above

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b) Water

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Q.3) Chlorine will kill/inactivate:

- a) All microorganisms***
- b) Some microorganisms***
- c) Only bacteria***
- d) No microorganisms***

Chlorination Theory and Practice: Assessment

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Quiz

Q.4) Over time, chlorine powder and liquid will:

- a) Never lose strength***
- b) lose strength***
- c) Gain strength***
- d) Combine to give chlorine gas***

Quiz

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- a) Never lose strength***
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Q.5) Chlorine will react with:

- a) Microorganisms***
- b) Other organic material***
- c) Inorganic material***
- d) All of the above***

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Quiz

Q.6) Due to chlorine decay, the concentration of chlorine during distribution will:

- a) Increase***
- b) Decrease***
- c) Stay the same***
- d) Fluctuate up and down***

Quiz

Q.6) Due to chlorine decay, the concentration of chlorine during distribution will:

a) Increase

b) Decrease

c) Stay the same

d) Fluctuate up and down

Q.7) If water has high chlorine demand, it will:

- a) Consume more chlorine***
- b) Consume very little chlorine***
- c) Consume no chlorine***
- d) Produce chlorine***

Quiz

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- a) Consume more chlorine***
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Q.8) Chlorine residual is the concentration of chlorine:

- a) Before chlorine demand has been satisfied***
- b) After chlorine demand has been satisfied***
- c) Equal to the total chlorine***

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Q.9) Chlorine contact time is the amount of time needed for:

- a) Effective disinfection to occur***
- b) For chlorine concentration to decrease to zero***
- c) For chlorine to burn your skin***
- d) All of the above***

Q.9) Chlorine contact time is the amount of time needed for:

- a) Effective disinfection to occur***
- b) For chlorine concentration to decrease to zero***
- c) For chlorine to burn your skin***
- d) All of the above***

Q.10) Chlorine contact time depends on the:

- a) pH of the water***
- b) Temperature of the water***
- c) Chlorine concentration in the water***
- d) All of the above***

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Quiz

Q.11) Chlorine disinfection works best when turbidity is:

a) >1 NTU

b) <1 NTU

c) >5 NTU

d) Turbidity does not impact disinfection

Quiz

Q.11) Chlorine disinfection works best when turbidity is:

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c) >5 NTU

d) Turbidity does not impact disinfection

Q.12) The residual chlorine concentration in the distribution network should always be:

- a) Undetectable***
- b) $<0.2 \text{ mg/L}$***
- c) $\geq 0.2 \text{ mg/L}$***
- d) $>5 \text{ mg/L}$***

Q.12) The residual chlorine concentration in the distribution network should always be:

a) Undetectable

b) <0.2 mg/L

c) ≥ 0.2 mg/L

d) >5 mg/L

Q.13) If the residual chlorine concentration is <0.2 mg/L in distribution samples, the water is:

- a) Safe from recontamination by microorganisms***
- b) At risk from recontamination by microorganisms***
- c) Unpleasant taste and odor***
- d) None of the above***

Q.13) If the residual chlorine dose is <0.2 mg/L in the distribution network, the water is:

a) Safe from recontamination by microorganisms

b) At risk from recontamination by microorganisms

c) Unpleasant taste and odor

d) None of the above

Q.14) The chlorine dose at the water treatment plant should always be:

- a) 1 mg/L***
- b) <0.2 mg/L***
- c) 5 mg/L***
- d) Sufficient to ensure effective disinfection and a chlorine concentration ≥ 0.2 mg/L to the point of consumer delivery***

Q.14) The chlorine dose at the water treatment plant should always be:

- a) 1 mg/L***
- b) <0.2 mg/L***
- c) 5 mg/L***
- d) Sufficient to ensure effective disinfection and a chlorine concentration ≥ 0.2 mg/L to the point of consumer delivery***

Q.15) For effective chlorination, the pH of the water should always be:

a) >pH 8.5

b) <pH 8.5

c) pH does not impact chlorination

Quiz

Q.15) For effective chlorination, the pH of the water should always be:

a) >pH 8.5

b) <pH 8.5

c) pH does not impact chlorination