Principles of water treatment

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TODAY
REVISION!
1.
2.
3.

increasing contamination of water supplies

increasing rate of technological development

increasing sophistication of treatment facilities

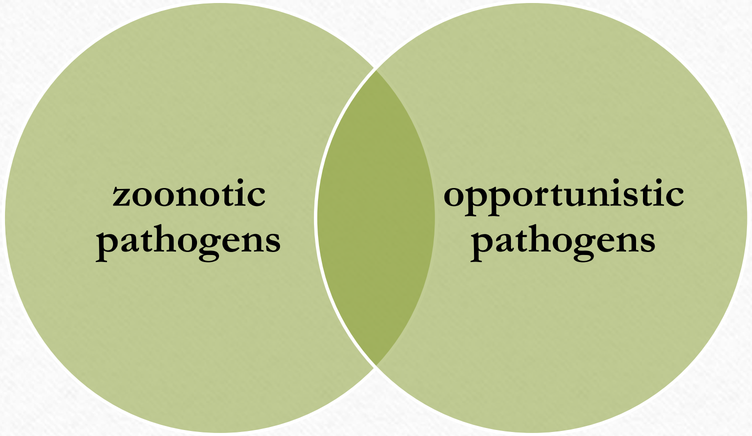
Gives the engineer

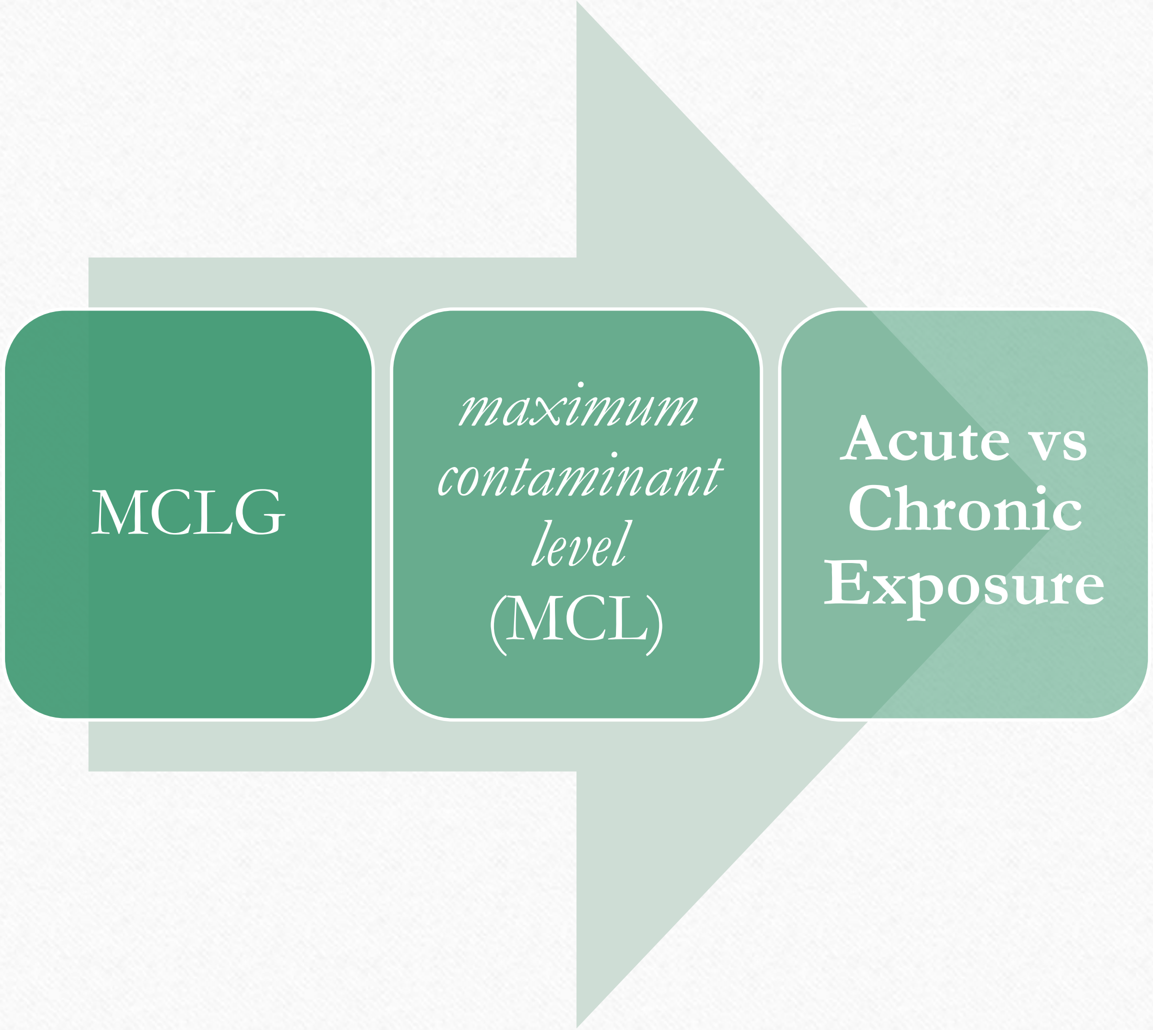
a basis for evaluating process innovations

improve performance

Solving problems

Relationship between Water Quality and Public Health






INTRODUCTION
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Evolving Trends and Challenges in Drinking Water Treatment

Challenges & competing issues

a solid grasp

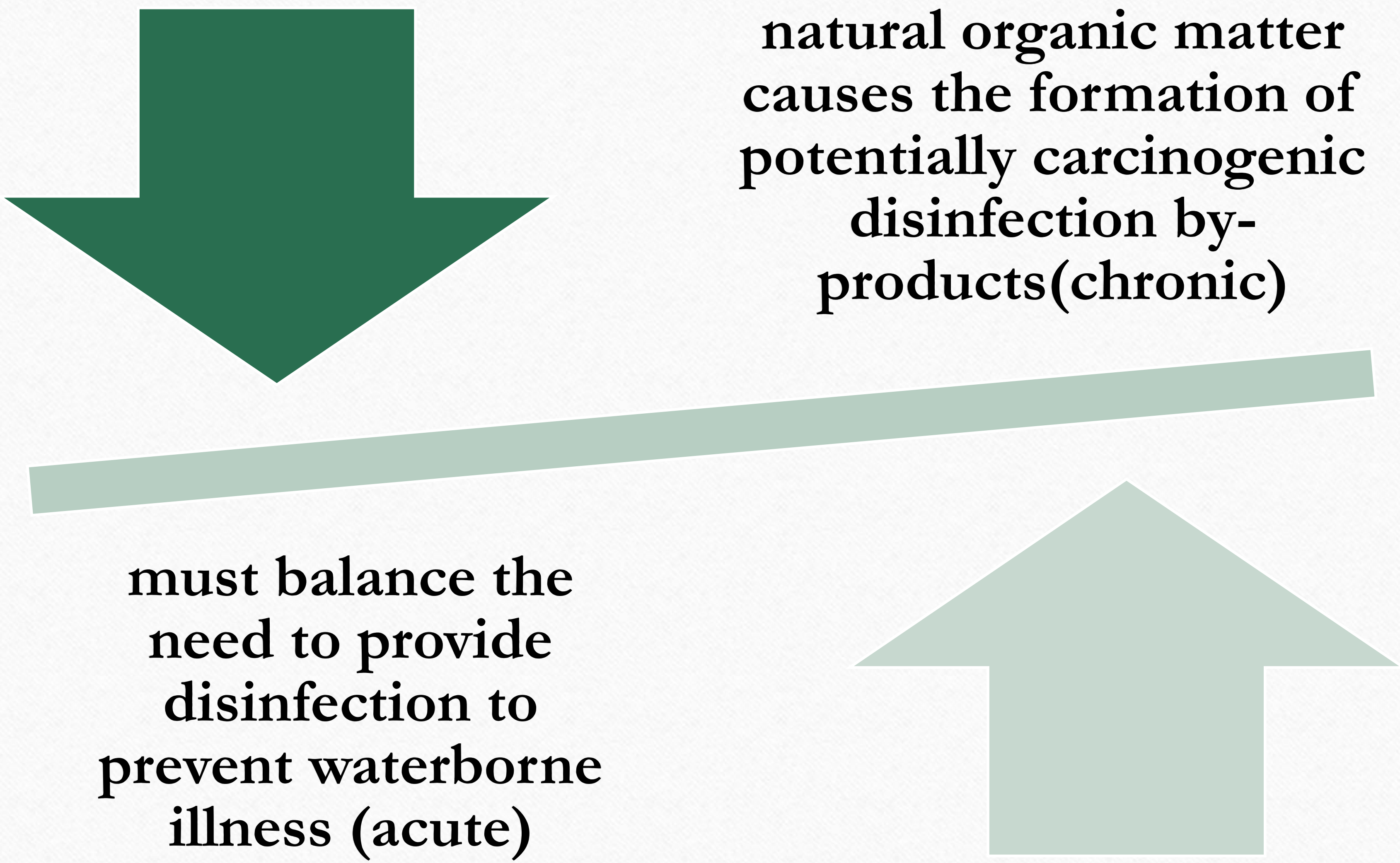
the scientific principles

fundamental

water is a vehicle for transmitting disease

water quality management

to protect against and provide treatment for a wider array of potential sources of microbial contamination.


natural organic matter causes the formation of potentially carcinogenic disinfection by-products(chronic)
must balance the need to provide disinfection to prevent waterborne illness (acute)

A layperson’s view, water with no measurable contaminants is safe to drink.

- Chemicals have a threshold level below which they have no negative health effect
- People have different sensitivities to chemicals
- low concentrations essential minerals
- anthropogenic chemicals can be detected in most water source
- The last 30 to 40 years it possible to measure constituents at exceedingly low concentrations

find the appropriate concentration that reduces the probability of harm to an acceptable level

A challenge in future water treatment practice is balancing the level of treatment with actual health benefits

Pipes in some cases are decades old, full of deposits, corroded, or leaking.

Must consider the impact of water distribution on water quality and balance the objectives at the plant effluent with the objectives at the point of use.

Multi use of water

Only 3 to 4 percent of the water delivered to a residence is actually destined for human consumption

Future water management practices must balance the level of water quality achieved with the actual use of the water, potentially supplying drinking water separately from water for other uses.

Shortages of locally available high-quality water sources

Evaluate water treatment strategies from a holistic perspective that considers all benefits and impacts to the community, environment, and society

Process Selection

unit process

An individual process is known throughout environmental engineering and chemical engineering

Process train or treatment train

A series of unit processes

Contaminant Properties

Constituent properties and process capabilities are the cornerstone of process selection

if every physical, chemical, and biological property of a constituent were identical to those of water molecules, removal would be impossible.

The primary properties of interest include **size, density, charge, solubility, volatility, polarity, hydrophobicity, boiling point, chemical reactivity, and biodegradability**.

- water quality parameters that affect treatment depend heavily on local conditions of geology, climate, and human activity.
- Thus, water treatment facility processes must be tailored for the specific situation

Physicochemical properties (the collective physical and chemical properties of a substance).

This table is a starting point for deciding what processes might be appropriate for removing a particular constituent.

General trends of physicochemical properties of some classes of constituents in water

	Microorganisms	Inorganics	Synthetic Organics	Natural Organics	Radionuclides
Examples of compounds	Viruses, bacteria, protozoa	Na, Cl, Fe, Mn, As, Pb, Cu, NO_3^-	Pesticides, solvents, pharmaceuticals	Products of decaying plants and animals	Ra, U, radioactive inorganic chemicals
Size	Particles (0.0025–10 μm)	Small molecules (low MW)	Molecules (usually low MW)	Large molecules (high MW)	Small molecules
Density	Close to that of water	Varies (as a precipitate). Does not apply if dissolved.	Varies (as a liquid phase). Does not apply if dissolved.	Does not apply (is dissolved).	Does not apply (is dissolved).
Charge	Some negative surface charge	Positive or negative	Usually no	Negative charge	Varies
Soluble	No	Varies	Varies	Yes	Varies
Volatile	No	No	Varies	No	No (except radon)
Polar	N/A	Yes	Varies	Yes	No
Hydrophobic	No	No	Usually yes	No	No
Boiling point	N/A	Very high	Varies	Very high	Very high
Chemically reactive	Yes	Yes	Yes	Yes	No
Biodegradable	Yes	No	Usually yes	Usually no	No

the ability of a unit process to capitalize on differences in the properties of constituents.

EACH unit process relies on one or more key properties.

For instance,

- Air stripping relies on the difference in volatility between a constituent and water. The more volatile a chemical is, the easier it is to remove from water.
- Common processes for removing inorganic constituents include coagulation followed by filtration

Process selection can only proceed when the properties of the constituents and the principles of the unit processes are understood

the effectiveness of various unit processes at removing specific contaminants is founded in well-established scientific principles.

Properties exploited by unit processes and the constituents in water for which each is commonly used

Process	Properties Exploited	Most Common Target Constituents
Adsorption	Polarity, hydrophobicity	Dissolved organics
Air stripping	Volatility	Dissolved organics
Disinfection	Chemical reactivity	Microorganisms
Granular filtration	Adhesive molecular forces	Particles
Ion exchange	Charge	Dissolved inorganics
Membrane filtration	Size	Particles
Oxidation	Chemical reactivity	Dissolved organics and inorganics
Precipitation	Solubility	Dissolved inorganics
Reverse osmosis	Size, charge, polarity	Dissolved inorganics
Sedimentation	Density, size	Particles

A final consideration is kinetics

In some cases, the rate of a reaction may be as important as the equilibrium condition.

- The importance of chemistry—the chemistry of the constituents, the chemistry of the processes, and the chemical composition of the water—should be evident to students who are studying water treatment.
- additional knowledge and understanding of chemistry is necessary to be an effective water treatment engineer.

Removal Efficiency

The objective of treatment processes is to remove contaminants.

- The fraction of a constituent removed by a process
- can be calculated with the equation
- $R = (1 - C_e/C_i)$
- where R = *removal expressed as a fraction, dimensionless*
- C_e = *effluent concentration, mg/L*
- C_i = *influent concentration, mg/L*
- used where the removal efficiency for a given constituent is three orders of magnitude or less (i.e., 99.9%)

three or more orders of magnitude less than the influent concentration.

For these situations, the removal is expressed in terms of base 10

log removal value (LRV)

$LRV = \log(Ci) - \log(Ce) = \log(Ci/Ce)$

used routinely to express the removals achieved with membrane filtration and for disinfection

- **Example**
- During testing of a prototype membrane filter, bacteriophage concentrations of 107 mL^{-1} and 13 mL^{-1} were measured in the influent and effluent, respectively. Calculate the removal and log removal value.
- 1. Calculate removal using
- $R = 1 -(Ce/Ci)$
- $= 1 - (13\ mL-1/107\ mL-1)= 0.9999987$
- Calculate the log removal value
- $LRV = \log Ci/Ce = \log 107\ mL-1/13\ mL-1 = 5.89$
- note that LRV = 5 corresponds to 99.999 percent and LRV = 6 corresponds to 99.9999 percent removal (i.e., the log removal value equals the "number of 9's").

Reliability

First: a process's ability to continuously meet the treatment objective.

Some processes are very reliable despite changes in raw water quality or operating parameters. Other processes are more sensitive to changes

Second: a process must have mechanical and hydraulic reliability.

- difference between process reliability and hydraulic reliability
- is the difference between granular filtration and membrane filtration.
- **Granular filters operate by gravity and are hydraulically very reliable**

but require operator attention and proper pretreatment du to changes in raw-water quality

- **The removal efficiency of *membrane filters* is independent of raw-water quality**;
- Changes in raw water quality, lead to membrane fouling and decreased passage of water through the filters.
- Thus, although water quality would be acceptable, the quantity of water produced may be insufficient

Multiple-Barrier Concept

The reliability of a treatment train increased by providing multiple barriers for the same contaminant in series.

Multiple barriers provide a factor of safety in the event one process fails even for a short period of time.

Is important for pathogens because acute effects

- Reduces the exposure to the risks that are associated with process failure.

Example

Consider two treatment train alternatives.

Train 1 has one unit process that reduces the target contaminant by six orders of magnitude (a 6 log reduction) when operating normally.

Train 2 has three unit processes in series, each of which reduces the target contaminant by two orders of magnitude (a 2 log reduction in each step) when operating normally.

For the purpose of this analysis, assume that each unit process fails about 1 percent of the time and that when it fails it achieves half the removal that it normally achieves.

With this information, estimate

(a) the overall removal for trains 1 and 2 when all the unit processes are operating normally

(b) the frequency (in days per year) of various levels of treatment for each train assuming that process failures occur randomly.

- Overall removal during normal operation:
- a. Train 1. Normal operation = 6 log removal.
- b. Train 2. Normal operation = 2 + 2 + 2 = 6 log removal.
- Frequency of various levels of removal:
- a. Train 1:

i. Provides 6 log removal 99 percent of time = $0.99 \times 365\ d = 361.35\ d$.

ii. Provides 3 log removal 1 percent of time = $0.01 \times 365\ d = 3.65\ d$.

- Provides 6 log removal when all three processes are operating normally = $0.99 \times 0.99 \times 0.99 \times 365\ d = 354.16\ d$.
- 5 log removal: $0.99 \times 0.99 \times 0.01 \times 3 \times 365\ \mathrm{d} = 10.73\ d$.
- 4 log removal: = $0.99 \times 0.01 \times 0.01 \times 3 \times 365\ \mathrm{d} = 0.11\ d = 2.6\ h$.
- 3log removal= $0.01 \times 0.01 \times 0.01 \times 365\ d = 0.00037\ d = 32\ s$.
- that multiple barriers (train 2) are more robust

Flexibility

PROCESS and process trains need to accommodate changes in:

- . Raw-water quality
- Regulations so that utilities are not forced to upgrade or replace processes every time a new regulation is passed.
- An increase in capacity as the water demand in the community increases over time.

Successful operating history

AVOID marketing claims to improve equipment sales.

New equipment and processes must be considered cautiously—public health depends on a properly working treatment facility.

- THE newer processes should be considered only when the water treatment engineer can validate the claims of superior performance.

Utility experience

The unit processes in a treatment facility must be within the ability of the utility to properly operate and maintain them.

- Small water utilities often do not have the resources to hire and pay experienced operators who can be dedicated to proper operation of complex processes. In those cases, simple and automated processes may be more appropriate.

Cost

Since potable water is a utility provided at a municipal scale, costs must be affordable by the public.

- Both construction and operating costs are important, and many times the operating cost of a process will be a more significant factor than the construction cost.

Sustainability and Energy Considerations

Our Common Future

“the ability of a society to meets their needs without compromising the ability of future generations to meet their own needs”

- our society should not consume resources at such a rate that they would be unavailable in the future nor degrade the environment to such an extent that it would be unusable in the future.
- Institute (EPRI) (2009) reports that the water and wastewater industry in the United States used 123.45 billion kWh of electricity in 2000
- small changes in design criteria can have significant impacts on the energy consumed over the lifetime of a treatment plant.

Life-Cycle Assessment

An LCA is a cradle-to-grave analysis,

examining the total environmental impact of a product through every step of its life, from raw material acquisition, manufacturing, distribution, use by consumers, and ultimate disposal.

- LCA has four components
- **First**, the goals and scope of the assessment
- **Second**: an inventory assessment in which the relevant inputs and outputs to the system are quantified.
- **Third,** the potential environmental impacts associated with those inputs and outputs are calculated.
- **Finally**, the results are interpreted and opportunities to reduce the environmental impact are identified

LCAs may consider a number of potential environmental impact categories, such as

- ❑ Global warming
- ❑ Stratospheric ozone depletion
- ❑ Acidification potential (refers to the compounds that are precursors to acid rain)
- ❑ Eutrophication potential (the potential to cause over-fertilisation of water. and soil, which can result in increased growth of biomass)
- ❑ Photochemical smog formation (nitrogen oxides and volatile organic compounds (VOCs) react to sunlight, creating a brown haze above cities)
- ❑ Terrestrial toxicity (the effects of a chemical substance to terrestrial organisms and terrestrial plants)
- ❑ Aquatic toxicity (the effects of a chemical on organisms living in water)
- ❑ Human health
- ❑ Resource depletion

Overall environmental indicators have been developed so that a single final score can be reported

Eco-Indicator 99 and Eco-Points 97 are two examples of overall environmental indicators used in LCA.

Software packages are available to assist with the collection and interpretation of **LCA data. SimaPro by Pre Consultants (2011) and GaBi by PE International (2011)** ´are two commonly used software packages.

Life-Cycle Assessment of Water Treatment Facilities

Over the past 10 to 15 years. Analyses have considered the impacts of

constructing the facility (5 to 20)

operating the treatment facility (80 %)

decommissioning the plant after its useful life(1 %)

potential sources of environmental impact from water treatment plant operation are

- energy consumption,
- obtaining chemicals and other consumable materials
- waste production

Energy consumption can be used as an overall environmental indicator.

pumping

From raw water to treatment processes, and distribution,

is between 0.37 and 0.50 kWh/m3.

$$P_W = \frac{Q_F P}{e}$$

where P_W = power, W (or rate of energy consumption, kWh/d)
Q_F = feed water flow rate, m^3/d or ML/d
P = pressure, Pa
e = efficiency

$$P = \rho g h$$

where ρ = density of fluid, kg/m^3
g = gravitational constant, 9.81 m/s^2
h = head, m

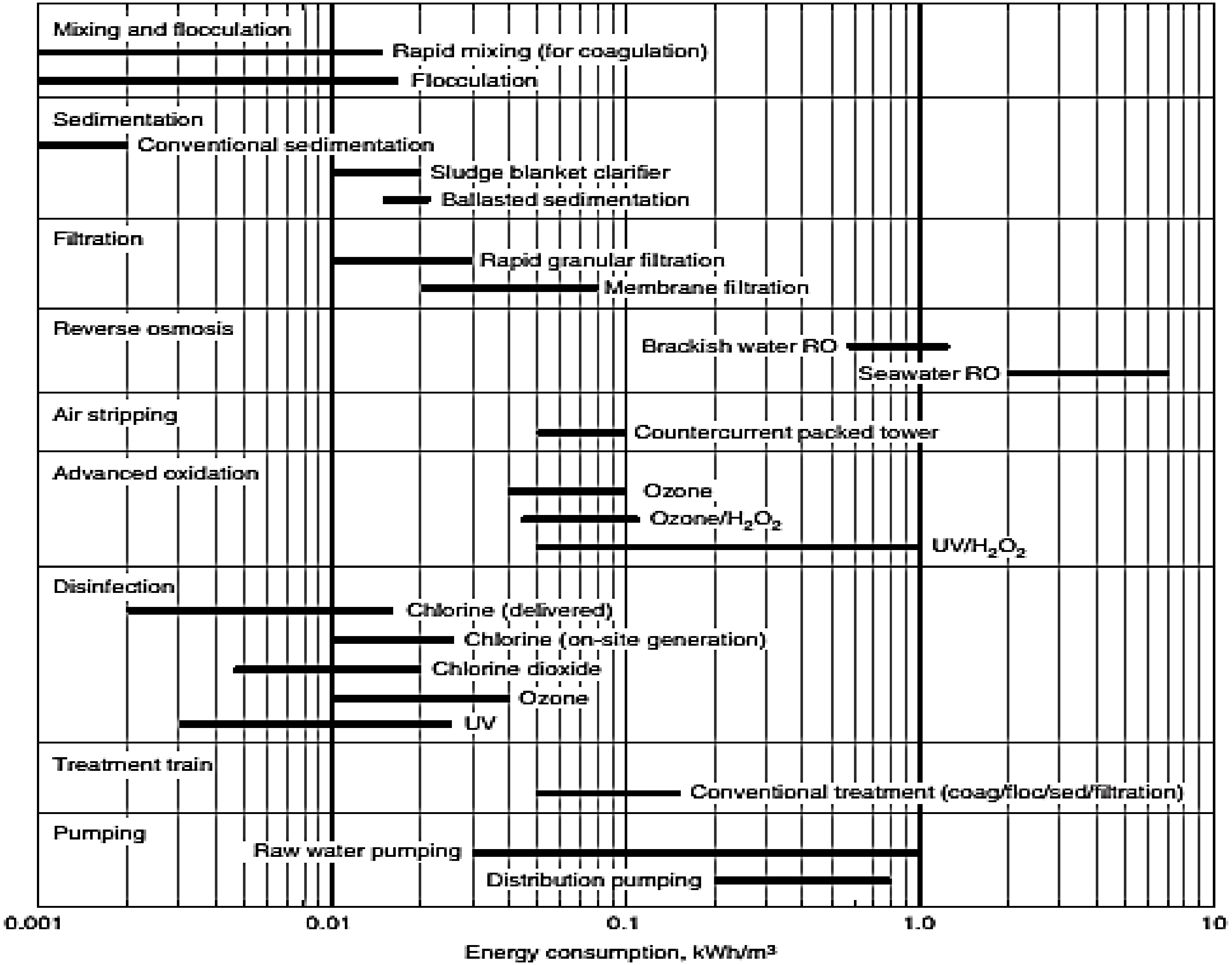
Specific energy consumption is the energy consumed per unit volume of water produced and can be calculated from

$$E = \frac{P_W}{Q_P}$$

where E = specific energy consumption, kWh/m^3
Q_P = product water flow rate, m^3/d or ML/d

$$r = \frac{Q_P}{Q_F}$$

where r = is the recovery.



Electricity consumption by common water treatment processes (data obtained from Elliott et al., 2003; Vince et al., 2008; EPRI, 2009; Veerapani et al., 2011; and authors' experience).

Design and Selection of Process Trains

(1) the source water quality

(2) the desired finished-water quality,

(3) the quantity of water needed (the capacity of the facility).

- the source water quality

historical data- from the existing facility
withdraw water upstream or down stream
state and federal agencies

- the desired finished-water quality

Depends on the intended use of the water and the regulatory parameters governing that use.

Unregulated parameters may also be part of the finished-water quality goals.

National and international guidelines for drinking water quality

Country or Region	Guidance or Regulatory Document	Reference
United States	Safe Drinking Water Act	EPA (2011)
Canada	Guidelines for Drinking Water Quality	Health Canada (2011)
European Union	Drinking Water Directive	Europa (2011)
International	Guidelines for Drinking Water Quality	WHO (2011)

# of information that are useful during process selection

- **Textbooks, design guides, and reference materials:**
  Examples
  MWH's Water Treatment: Principles and Design (Crittenden et al., 2012),

  Integrated Design and Operatic of Water Treatment Facilities (Kawamura, 2000).

  Ten State Standards (Great Lakes–Upper Mississippi River Board, 2007).

  The U.S. EPA and

  The American Water Works Association (AWWA)

Regulatory guidance

- For contaminants regulated in the Safe Drinking Water Act, the U.S. EPA has designated certain processes as *best available technology* (BAT), which are processes that EPA certifies as being the most effective for removing a contaminant.
- For some contaminants, the U.S. EPA identifies *treatment techniques*, which are specific processes and associated requirements that are required in order to meet the regulations.

- **Engineering experience** from the utility, or other utilities in the region.
- **Recent research:** such as journals and conference proceedings
- **Laboratory (bench) testing:** to determine chemical doses needed to achieve treatment or to verify that specific chemical reactions will take place as expected.
- **Pilot testing:** small-scale versions of actual treatment processes

They are necessary when the hydraulics of a process is as important as the chemistry in achieving effective treatment;

They can be used to establish the suitability of the process in the treatment of specific water under specific environmental conditions, verify performance claims by manufacturers, optimize or document process performance, satisfy regulatory agency requirements, and generate the necessary data on which to base a full-scale design.

THE END
THANK YOU FOR ATTENTION

ANY QUESTION?