Water Treatment: Where have we been and where are we going?

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Outline of Talk

- The historical development of water treatment technology
  - potable water
  - municipal wastewater
- The impact of recent developments in membrane technology
- The problem of water quality and water distribution

Where have we been in the treatment of drinking water?

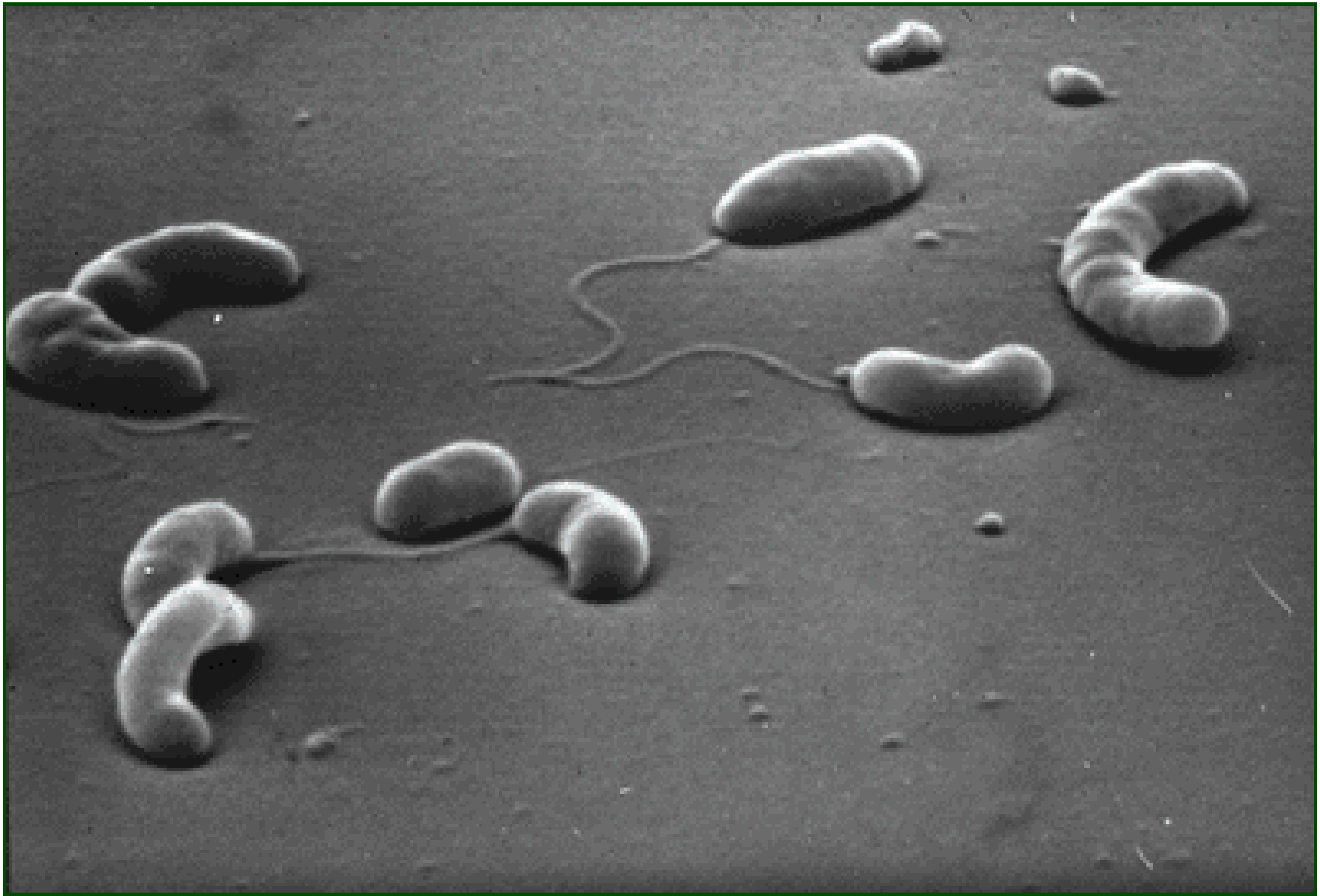
The History of Water Treatment

- Early 19th century
  - The development of the world's cities had reached the point where epidemics of classic water-borne disease become the biggest risk to citizens living in those cities
  - Why do I say the development of the world's cities "had reached the point"?

The History of Drinking Water Treatment
[and what we have accomplished]

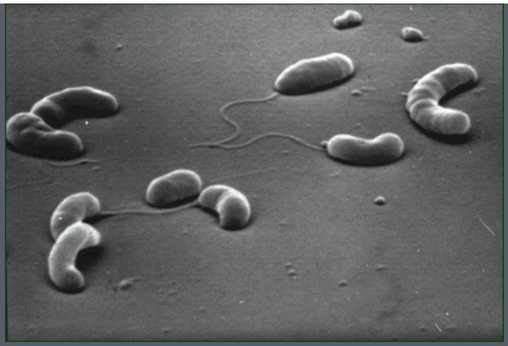
- Early 19th century (continued)
  - Because the development of our cities had become so dense that drinking water was often exposed to significant contamination from human feces
  - Because we had begun to address sanitation problems by using water to transport our personal wastes to the nearest watercourse (the first flush toilets were invented in 1775)
  - The principal epidemic diseases at issue were:
    - Cholera
    - Typhoid fever
    - Dysentery

Classic Cholera was particularly notable



***Vibrio cholerae* (comma bacillus)**

taken from historique.net



Vibrio cholerae (comma bacillus)

taken from historique.net

Characteristics of the Disease:

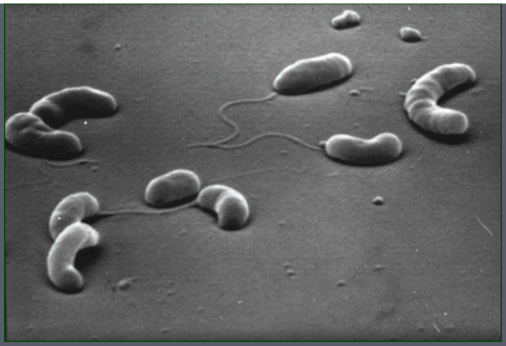
- Illness begins 2 to 3 days after exposure
- The bug colonizes the small intestine. Once there, it releases an enterotoxin which causes intestinal cells to transport water and electrolytes from blood and tissue into the intestine
- Symptoms: No Fever, Explosive vomiting and diarrhea, abnormally low blood pressure, abnormally low body temperature, muscle cramps - often shock; coma and death by dehydration
- If the victim is not treated, the whole process can reach completion in less than 24 hrs and the death rate is ~ 50%

Vibrio cholerae (comma bacillus)

taken from historique.net

More:

- First pandemic is thought to have started in India in 1813
- During the next 110 years cholera rampaged around the world in six pandemics, killing hundreds of thousands each time
- It is important to understand that the very survival of this classic form of cholera depends on a cross-connection between drinking water and sewage; why?
  - The victim is rapidly immobilized (i.e. He can't expose his friends by visiting them or preparing their food)
  - There were few asymptomatic carriers (i.e. those who survive no longer shed the pathogen in their feces)
  - The infectious dose is huge (> 10^6 organisms)



Vibrio cholerae (comma bacillus)

taken from historique.net

More:

- This is the organism that Dr. John Snow studied when he first showed the connection between drinking water and enteric disease in London (1854)

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water:

  Action 1. Apply the sanitary principle, i.e. find a source of water that has never been exposed to human waste

  - This is a “go back to nature” principle
  - It is easily grasped and it has broad appeal
  - We still find statements about using a “protected source” throughout our literature today
  - And it works. There are many dramatic examples in our history where we built aqueducts to protected supplies and the action dramatically improved public health (NYC is such an example)

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):
  - Action 2. Use continuously pressurized water systems
    - First advanced by Thomas Hawksley, Britian's leading water engineer in the time immediately following Snow's discovery:
    - Previously water systems were often pressurized intermittently
    - Hawksley advocated that systems be continuously pressurized so that, in case of a leak:
      - Clean water can go out
      - Contaminants can't go in

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):
  - *Simultaneous compliance with these two principles, alone, is sufficient to end classical waterborne disease*
  - Many cities gained protection by these methods. In the U.S., some examples are: Los Angeles, New York City; Boston; San Francisco; Oakland, CA; Seattle, and Portland, OR.
  - But, from the beginning, many other cities were not able to gain protection in this way because they did not have access to a protected water supply

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):

Action 3. This lead to the use of water treatment technology as a way to "repurify" water that has been contaminated

- Filtration was the first technology widely applied
  - Perhaps it began with the observation that outbreaks did not occur when water was supplied from deep wells
  - Early technologies: river-bank filtration (Aachen 1850s), dune filtration (Netherlands mid-19th century), slow sand filtration (Dárcy, 1854)
  - Later technology: Coagulation (aluminum or iron salts), sedimentation, rapid sand filtration (George Fuller, 1888)

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):

Action 3. Repurification (continued):

- But filtration wasn't always reliable.
  - Some groundwater supplies were shown to be contaminated
  - Bacteria were also found in some filtered waters
  - Today we know filtration removes between 50% and 99.9% of the bacteria in water
  - Heavily contaminated supplies require more

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):

Action 3. Repurification (continued):

- Disinfection had already found its way into medical practice (1847 - Semmelweis, a Hungarian, stopped pueperal fever in a Vienna hospital by requiring doctors to wash their hands in chlorine solution)
- Around the beginning of the 20th Century, disinfectants, particularly chlorine began to appear as a method of water treatment

The History of Drinking Water Treatment

- The actions taken by engineers and Scientists responsible for safe water(cont'd):

Action 3. Repurification (continued):

  - Disinfection became nearly universal by 1940

Together; filtration and disinfection remain the core of modern water treatment

The History of Drinking Water Treatment

- The Middle of 20th century

  (About the time I was born)

  - Developed world: Classical water-borne disease of the human-to-human fecal-oral route had been eliminated.
  - The Undeveloped World: Classic waterborne disease of the human-to-human fecal-oral route remained the chief cause of death among children
  - In fact: a major distinguishing characteristic between the developed world and the undeveloped world became the general availability of safe drinking water.
  - This basic situation remains unchanged today

The History of Drinking Water Treatment

- More recent developments during the 20th Century have mostly been in understanding contaminants:
  - Measurement of particulates
    - Jackson Candle (~5 turbidity units)
    - Light Scattering (~0.02 turbidity units)
    - Particle size analysis
  - Organics
    - Disinfection byproducts (1974)
    - Volatile organic chemicals: TCE, PCE, etc. (~1980)
    - Some herbicides and pesticides, e.g. atrazine (1980s)
    - Pharmaceuticals and personal care products (~1995)

The History of Drinking Water Treatment

- More recent developments during the 20th Century have mostly been in understanding contaminants:
  - Pathogens
  - Enteric bacteria
    - mid 70s *Campylobacter jejuni* (diarrhea)
    - ~ 1980 *Legionella pneumophila* (pneumonia)
    - mid 80s *Helobacter pylori* (ulcers, stomach cancer)
    - Early 80s to present - pathogenic *E. coli* (traveler's diarrhea to hemolytic uremic syndrome)

The History of Drinking Water Treatment

- More recent developments during the 20th Century have mostly been in understanding contaminants:
  - Enteric viruses
    - late 40s (Polio)
    - 1960s (Hepatitis)
    - 1980s (rotavirus)
    - 1990s ((norovirus, adenovirus?, astrovirus?)

The History of Drinking Water Treatment

- More recent developments during the 20th Century have mostly been in understanding contaminants:
  - Protozoa:
  - *Early 1980s - G. lamblia*
    - Zoonotic (infects both animal and man)
    - More resistant to chlorine
  - *Late 1980s - C. parvum*
    - <u>*Also*</u> zoonotic
    - <u>*MUCH*</u> more resistant to chlorine

Where have we been in the treatment of municipal wastewater?

The History of Wastewater Treatment

- Beside the contamination of drinking water, the original problem identified with municipal wastewater discharge was oxygen depletion in rivers and streams
  - BOD_5 test - Royal Commission 1908
  - Activated Sludge - Fowler, England 1914
  - Oxygen-Sag Curve - Streeter-Phelps 1925
- In the Clean Water Act in the 1970s, the emphasis was still on removal of BOD_5 and suspended solids

The History of Wastewater Treatment

- The impact of nutrients and eutrophication began to become clear in the 1960s
- Cost-effective biological processes for removal of phosphorous and nitrogen began to appear in the 1970s (Bernard), were perfected in the 1980s, and are being widely deployed today.

The History of Wastewater Treatment

- Perhaps one of the biggest dilemmas in developed countries today is the control of endocrine disruptors, pharmaceuticals and personal care products.
- Today the edge in wastewater treatment is our need to address the treatment required for reuse

Now I want to move to a focus on the future

I’d like to do that by looking at two topics: 1) membranes in water treatment and 2) the role of the distribution system

We are in the beginning of a revolutionary change in water treatment technology

Membrane technology is at the heart of that revolution.

Membranes in water treatment

- There are three areas in water treatment where membrane technology is causing major change:
  - Membrane filtration
  - Desalination
  - Membrane bioreactors

Membranes in Water Treatment

Membrane Filtration:

- Late 1950s - Applied to laboratory measurements
- Late 1960s - Applied to pasteurization of beverages
- 1990s - Introduced to treatment of drinking water and the recycling of wastewater
- The technology being used now is quite a bit more advance than that used earlier.
  - Not so much in its ability to remove contaminants
  - But in it's ability to cost-effectively deal with very large volumes of water
  - The key developments were in membrane cleaning - prior to the 1990s most membrane filters were disposable

Membranes in Water Treatment

Membrane Filtration:

- During this generation, membrane filtration will revolutionize water treatment practice
- For the first time we have the potential to sterilize the water, to completely eliminate all pathogens
- No commercial membrane filtration system is quite there today, but the technology is developing rapidly and the promise is there.

Membranes in Water Treatment

Membrane Filtration:

- What are the Challenges we face?
  - The resilience of membrane system designs must be improved.
    - most systems use thousands of hollow fibers and it is common for these fibers to fail via fatigue at certain critical points.
  - The design of membrane filtration systems must become more uniform and consistent. Right now an early user faces two important risks:
    - Early obsolescence - every manufacturer is constantly changing its standard design
    - Forced marriage - replacements and upgrades can only be obtained from the original manufacturer.

Membranes in Water Treatment

Membrane Filtration:

- What are the Challenges we face? (continued)
  - Systems for monitoring to verify performance must be improved and standards must be developed
  - We must gain a better understanding of the mechanisms of membrane fouling
    - Right now pilot studies must be done on every water source before a design can be contemplated.

Membranes in Water Treatment

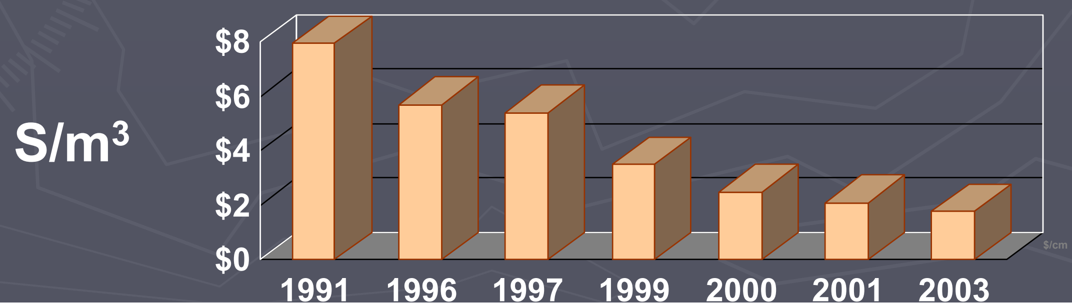
Desalination:

- Important advances have also occurred in another membrane process, reverse osmosis
- Research funded by the U.S. Office of Saline Water in the mid 1970s led to the development of the concept of a thin film composite reverse osmosis membrane
  - The original RO membranes invented by Loeb and Sourirajan at UCLA in 1958 were asymmetrical membranes made entirely of cellulose-acetate
  - The thin film composite membrane consisted of two layers: a very thin rejection surface, designed to reject the target ions and a very porous support layer designed to support the rejection surface while offering a minimum of hydraulic resistance

Membranes in Water Treatment

Desalination:

- By the mid 1990s several manufacturers had perfected commercial products that follow the thin film composite concept.
- They have continued to improve on these products until, today, membranes with a rejection of 99.9% and higher are available; allowing the production of potable water from seawater in a single pass
- Also numerous innovations in energy recovery, etc. have made the overall process more energy efficient
- As a result, during the past decade, reverse osmosis has displaced thermal processes as the process of choice for desalination and a number of new projects are in development



Membranes in Water Treatment

Desalination:

- Challenges remain here as well:
  - Pretreatment - the processes required for the pretreatment of seawater to make it suitable for reverse osmosis are not adequately understood
  - Boron - current membrane technology produces water with a boron level that is rather high (0.5 to 1.5 mg/L). The significance of boron at these levels needs to be better understood and boron removal needs to be further optimized.
  - Corrosion - desalted water is corrosive and conventional method of adjusting $CaCO_3$ saturation is costly and hardens the water
  - Distribution - desalted water is produced on the coast and at sea level and existing water distribution systems are designed to take the water in the opposite direction.
  - Fouling - the forms of fouling in seawater desalting are not adequately understood

Membranes in Water Treatment

Membrane Bioreactors

- Membrane filtration technologies have also been successfully applied to the solids separation step in the activated sludge process
- This innovation results in several important improvements:
  - The quality of the effluent is vastly improved for example:

	Conventional Activated Sludge	Membrane Bioreactor
SS	5 to 10	< 0.1
Turbidity	2 to 5	< 0.1
coliform	10,000 to 100,000	ND to 100

Membranes in Water Treatment

Membrane Bioreactors

- Membrane filtration technologies have also been successfully applied to the solids separation step in the activated sludge process
- This innovation results in several important improvements:
  - The quality of the effluent is vastly improved for example:
  - The process biology does not have to be operated to produce a settleable sludge
  - The process can operate at a much higher organic loading (requires less space)
  - Produces an effluent that can go directly to RO

Membranes in Water Treatment

Membrane Bioreactors

- Membrane bioreactors also have their challenges:
- When conventional biological processes fail the water continues to pass through the plant but the quality is unacceptable
- When a membrane bioreactor fails the quality remains high but the water fails to pass through the plant (fouling)
- As unacceptable as conventional failure is, this new type of failure is even worse

Membranes in Water Treatment

Membrane Bioreactors

- Other challenges
  - Gaining a better understanding of the causes of membrane fouling and how they can be controlled
  - Developing the basic operation rules for the process
  - Understanding how to design the process so that an easily dewatered sludge is produced
  - Designing better oxygen transfer in these high solids systems
  - Exploring the ability of MBR to remove xenobiotics

Now a look forward

The future in the developed world

- Increasingly the issues will be the same with all drinking water sources, protected or not
  - As population increases the impact of human activity will become evident in even the most protected drinking water sources
  - Likewise the pressure of population growth will force us to use (and reuse) increasingly compromised water sources
  - As detection limits go lower we will find that there are anthropogenic chemicals in every water source
  - Regulation of municipal waste discharge and non-point pollution will become intimately and formally connected with regulation of drinking water quality

The future in the developed world

The way we distribute water will become a strategic issue:

- We are using a distribution network sized to handle irrigation and fire-flows to transport high quality drinking water
- We are also using the same high quality water for all these purposes.
- We are irrigating our lawns with highly treated water that is designed to be pathogen free, odor free - even free of low level, long-term chronic risk

The future in the developed world

The way we distribute water will become a strategic issue:

- When we want to consider the use of recycled wastewater we build a separate infrastructure of similar capacity that is used only for irrigation
- In Southern California today, we are surrounded by that kind of infrastructure
- Providing such infrastructure is expensive in new developments, but it is much more expensive and much more intrusive when it must be built in older, existing neighborhoods
- Is this approach economical and sustainable?

The future in the developed world

Water distribution, a strategic issue: (continued)

- In developed countries, we have reached the point where our strategy for distribution of water in municipalities is one of the principle limits on our ability to provide the consumer with better water
- We have reached the point where we can make drinking water of extremely high quality at the treatment plant
- Increasingly, the challenge we face is finding ways to deliver that water to the consumer without compromising its high quality
- Hawksley's idea of continuously pressurized systems, while still essential, is not enough if we are using a large, old distribution system with long detention times

The future in the developed world

Water distribution, a strategic issue: (continued)

- Perhaps we should consider another kind of dual system?
  - The existing distribution system for "semi-potable" water
    - All short-term risks removed (i.e., pathogens)
    - Source not necessarily protected
    - Long-term chronic risks and aesthetic concerns not fully addressed

The future in the developed world

Water distribution, a strategic issue: (continued)

- If we do that, what will we do for potable water?
- Perhaps we build a tiny parallel system for drinking water made of special materials
  - Low flow, but protected source and/or Super-Treated
  - Long-term chronic risks and aesthetic concerns fully addressed
  - One or two taps in each home - clearly identified as *potable*

The future in the developed world

Water distribution, a strategic issue: (continued)

- Perhaps we will provide “drinking water stations”
  - Special stations or kiosks could be built which take water from the legacy system and give it “super treatment”
  - Citizens drive by for a free fill-up and take the water home
  - Both the private sector and the public sector might compete to offer these services
- Publicly provided bottled water is another possibility

I think we can be assured of one thing

The next generation will would be wise to go beyond models we use today *fiinis*