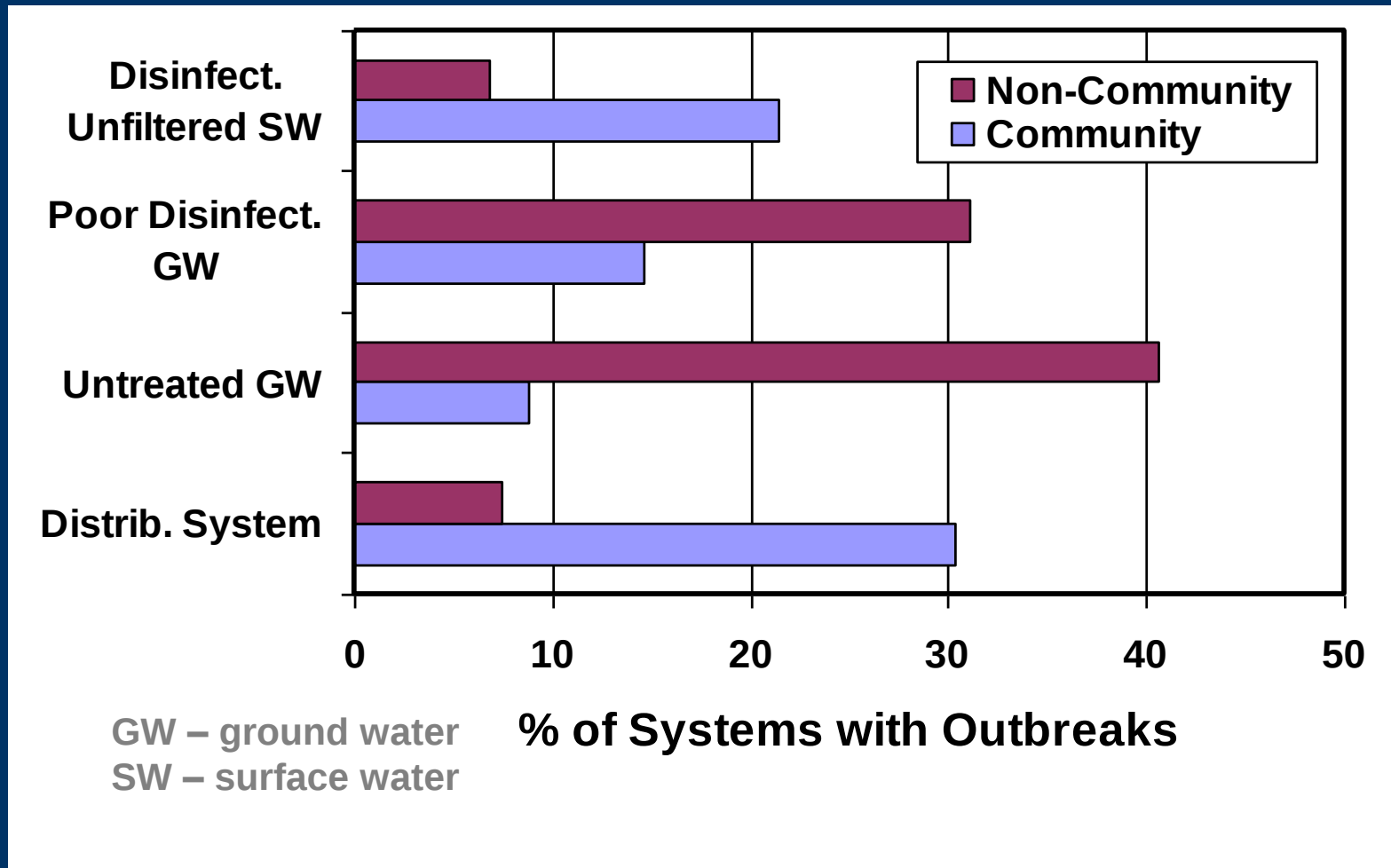


Distribution Systems

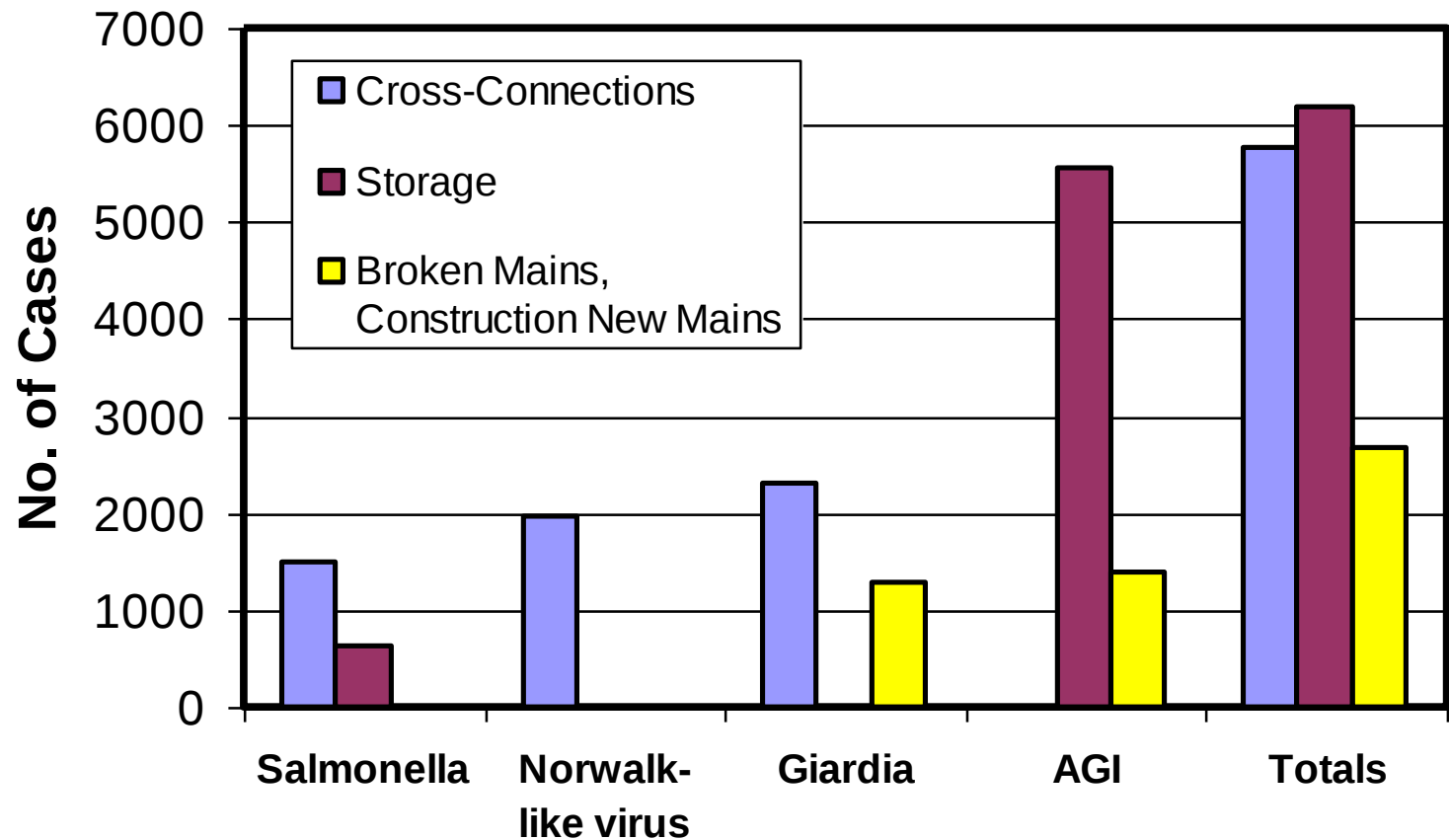
ENV H 440/545

Major deficiencies resulting in outbreaks can be determined from CDC surveillance data or literature

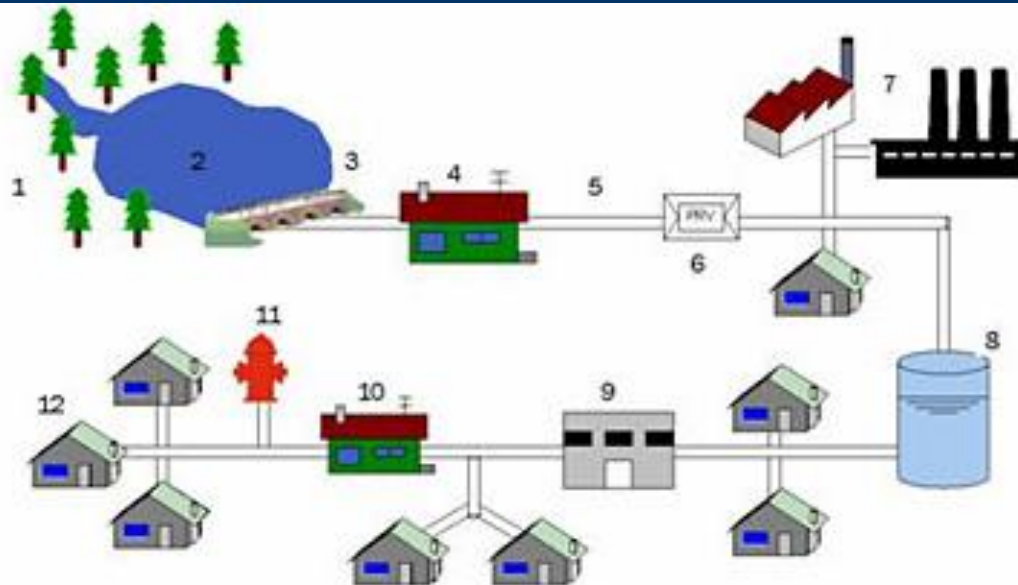


Craun, G.F. & Calderon, R.L. (2001) JAWWA, 93(9):64-75.

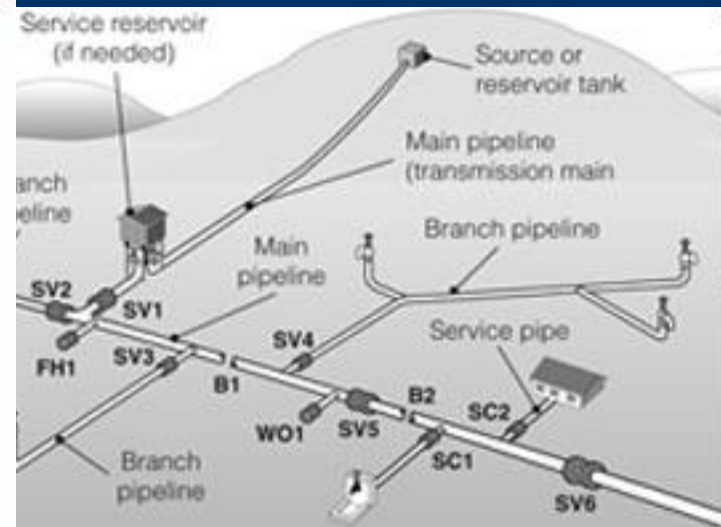
Distribution system deficiencies account for largest outbreaks (1971-98)



Craun, G.F. & Calderon, R.L. (2001) JAWWA, 93(9):64-75.



- | | | |
|---------------------------------|-------------------------------------|----------------------------|
| 1. Watershed Management | 5. Treated Water Quality Monitoring | 9. Pump Stations |
| 2. Raw Water Quality Monitoring | 6. Pressure Reducing Valves | 10. Rechlorination Station |
| 3. BC Hydro Penstocks | 7. Industrial Park | 11. Fire Hydrants |
| 4. Disinfection Station | 8. Reservoirs | 12. Your Home |



KEY

- | | |
|--------------------------|------------------------------|
| SV Stop valve | SC Boundary stop cock |
| B Breakage | FH Fire hydrant |
| WO Wash-out valve | |



Steel water storage tank

Prestressed concrete
water storage reservoir



Distribution System

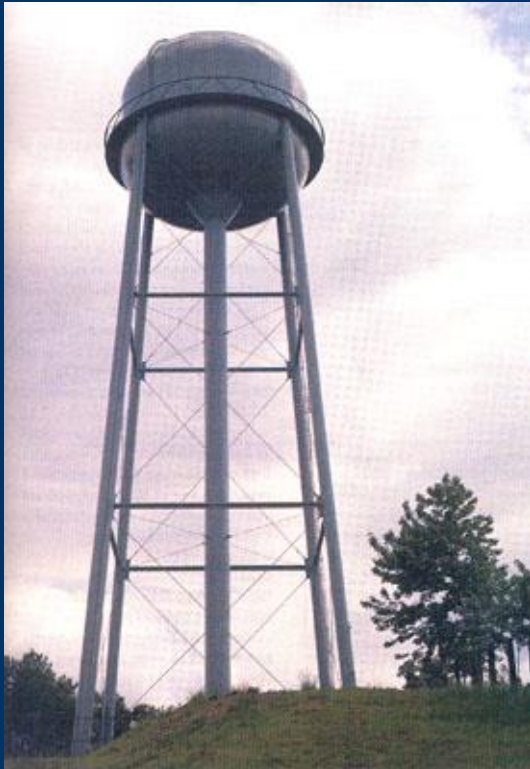


- **Backflow (back-siphonage) and cross-connections**
 - Buildings, residences, medical care facilities, animal processing facilities, irrigation systems, wastewater pumping and treatment facilities

Distribution System

- Pathogen intrusion during main breaks, repairs or new main construction
 - Cabool, MO (1989): *E. coli* O157:H7 outbreak
 - 243 cases, 32 people hospitalized, 4 deaths
 - Possible causes:
 - Water meter replacements
 - 2 recent main breaks
 - Lack of flushing and disinfection practices





Water Storage

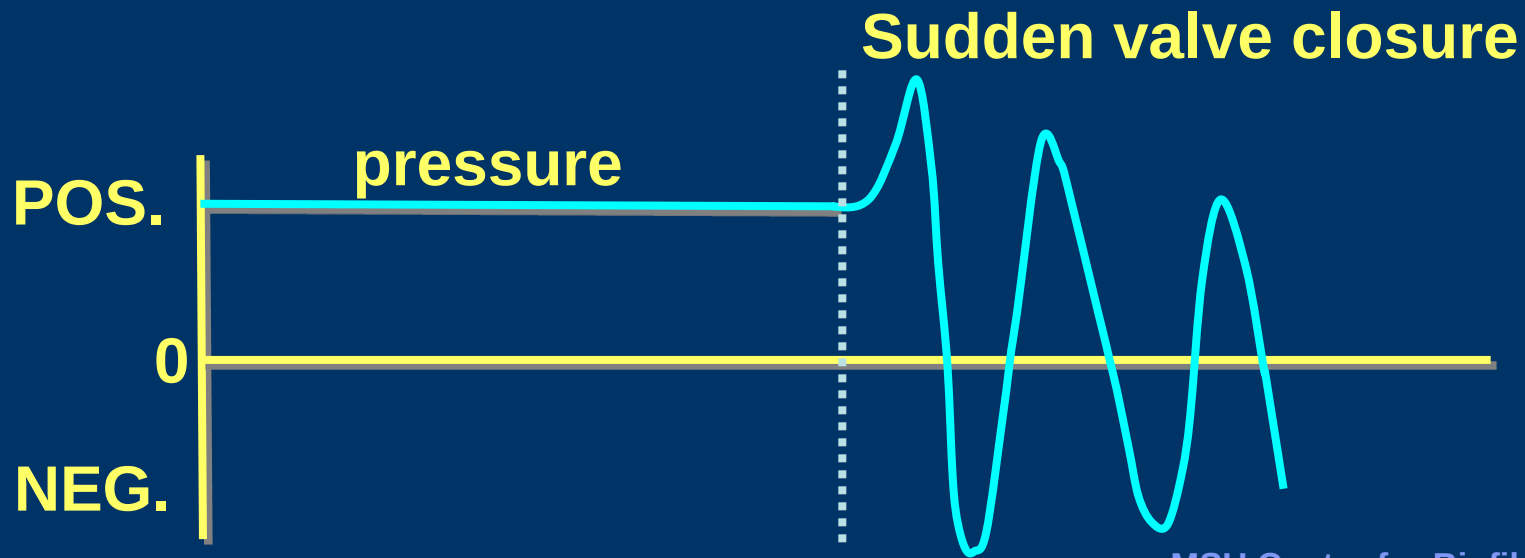
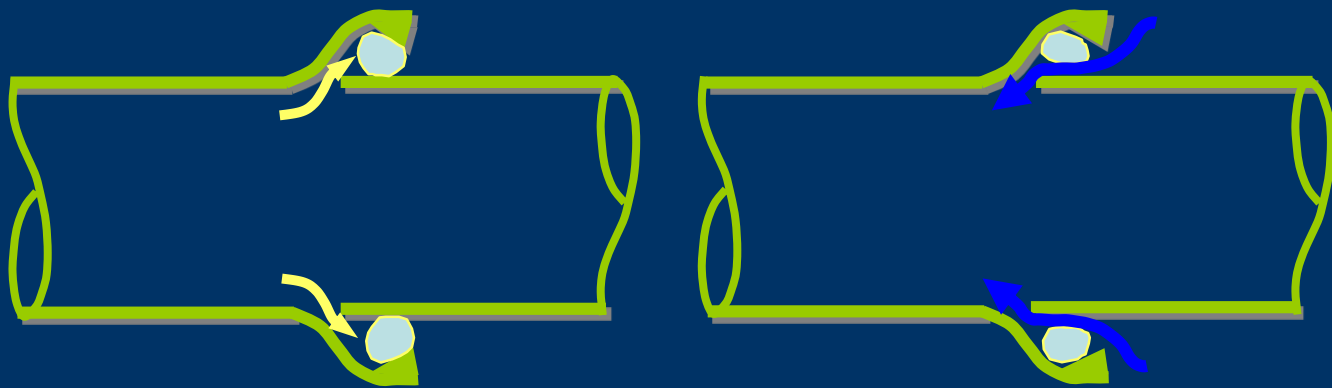
- Unprotected openings in storage tank (air vents, access doors, structural failures)
- Inadequate maintenance: cleaning, repair and disinfection following maintenance
- Excessive or too little storage volume

Pumping

- Backflow and cross-connections
- Poor pump control during start-up and shut-down, resulting in hydraulic surge (intrusion during low or negative pressure)



Intrusion of pathogens into distribution system can occur during low or negative pressure



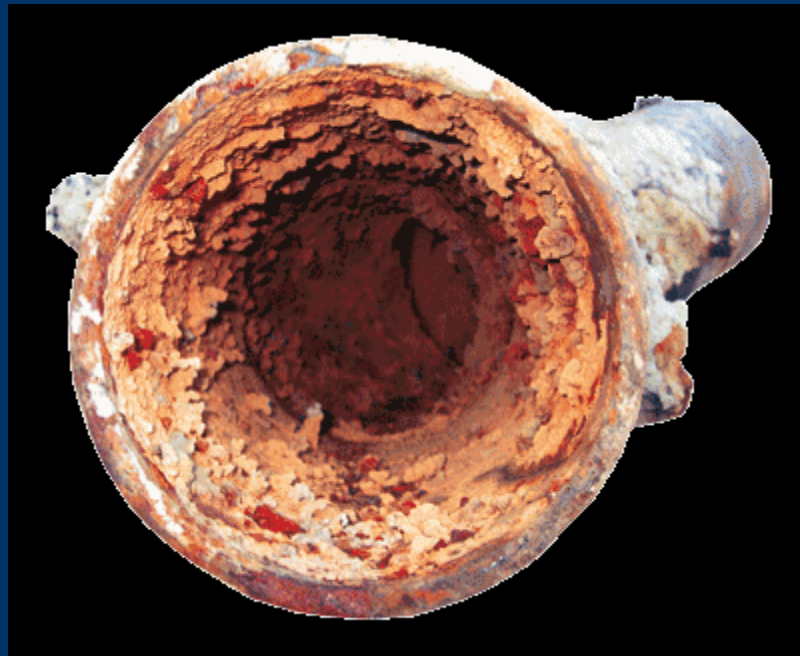
Iron Corrosion and Drinking Water Biofilm

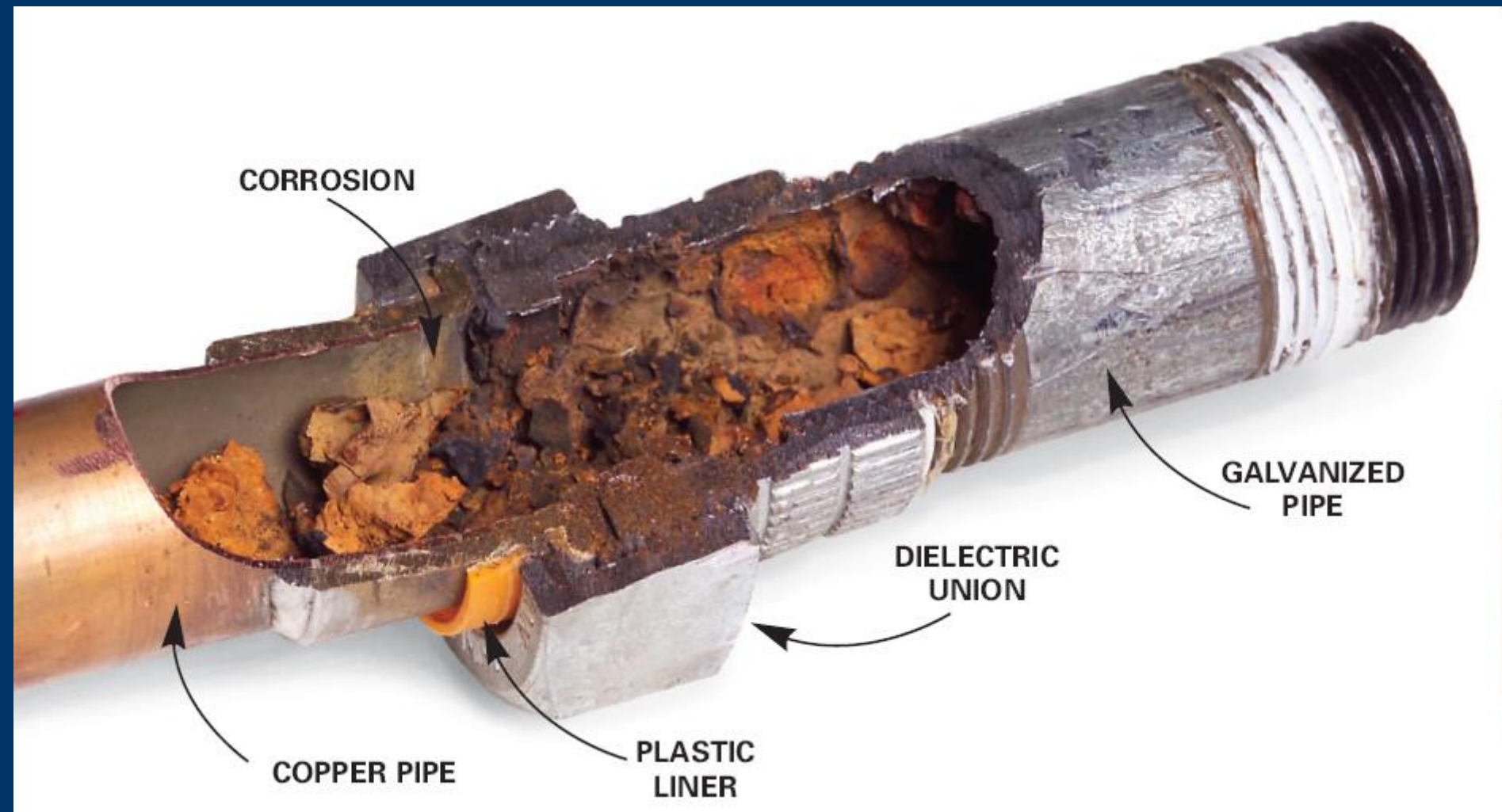


© CENTER FOR BIOFILM ENGINEERING - MONTANA STATE UNIVERSITY - BOZEMAN, MONTANA
C. ABERNATHY















Source: AP

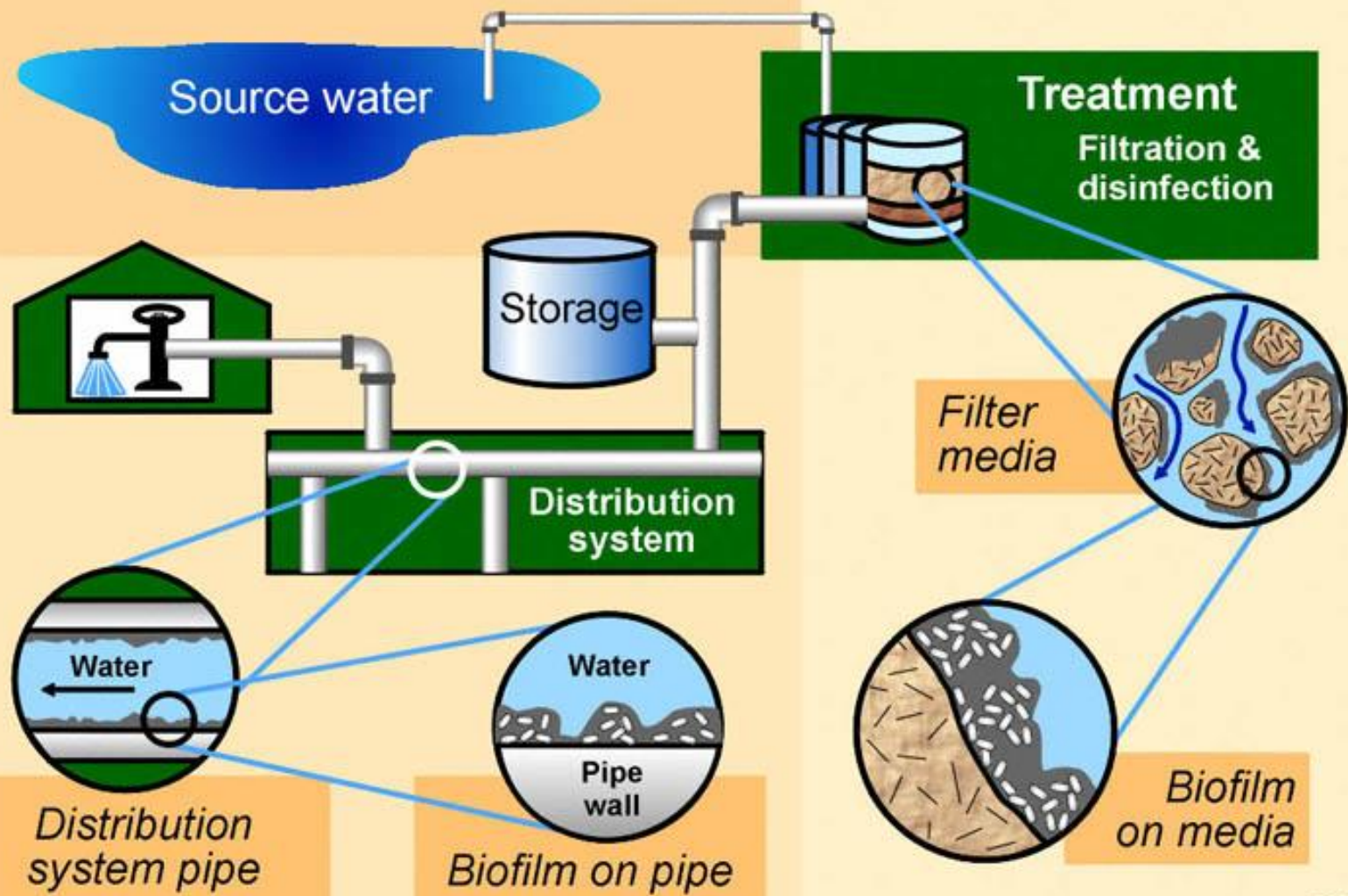


Taste and Odor

- **Dirty or Musty**
 - Geosmin and MIB (2-methylisoborneol)
 - blue-green algae, actinomycetes
- **Fishy, Cod liver Oil**
 - Chrysophyta, Pyrrophyta
- **Septic Odor**
 - Pryrophyta
- **Cucumber Odor**
 - Chrysophyta

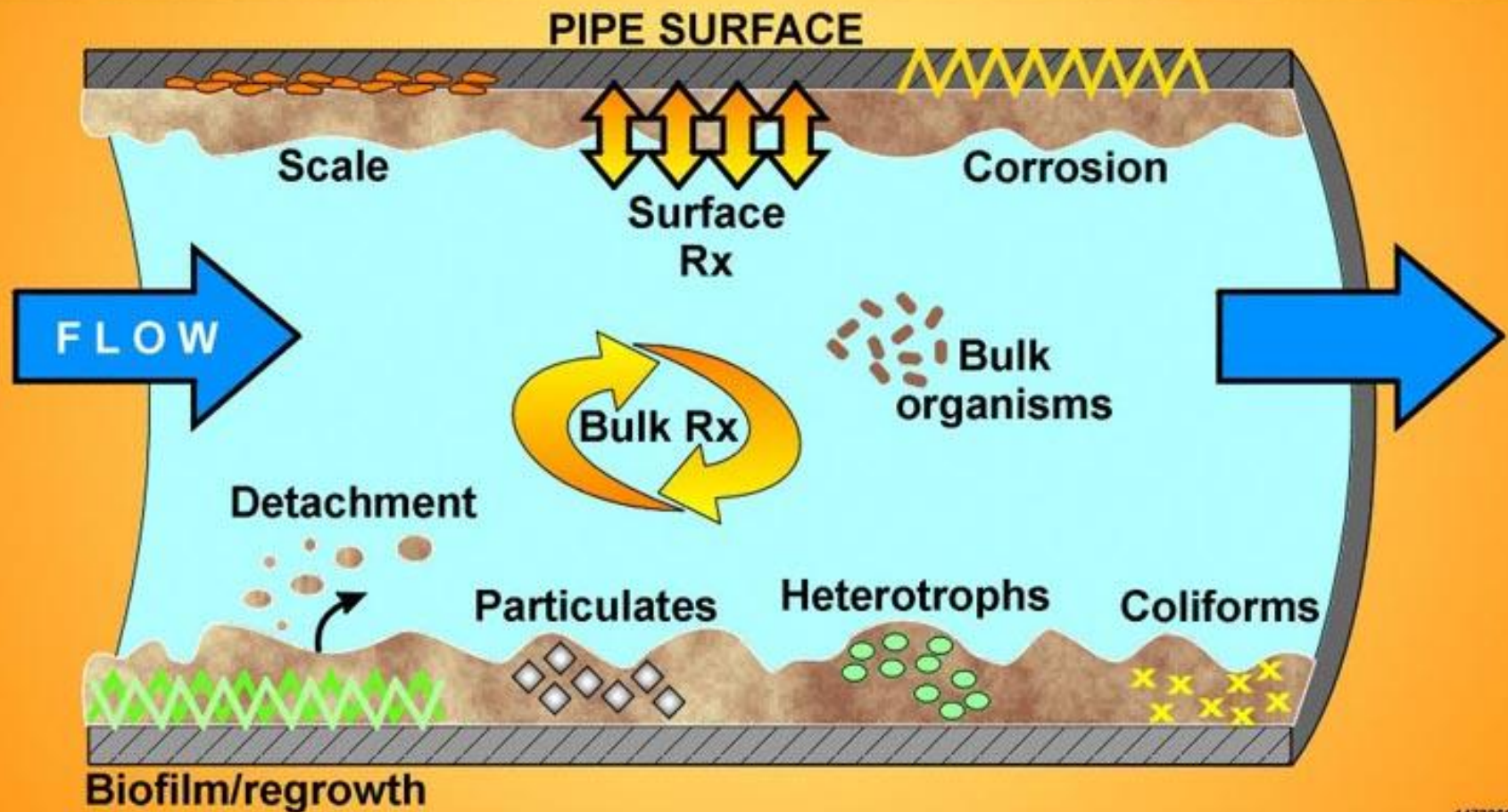
Nuisance Bacteria

- Acintomycetes/Streptomycetes
 - Thin filamentous, gram postive rods
 - Taste and odor
- Iron Bacteria
 - E.g. Leptothrix, Thiobacillus, Clonothrix, Sphaerotilus, Caulobacter, Hyphomicrobium
 - Main corrosion
 - Increase oxidant demand
- Sulfur Bacteria
 - E.g. Desulfovibrio, Thiothrix, Chlorobium, Chromatium, Thiobacillus
 - Formation of tubercles; pipe corrosion; increase oxidant demand
 - Reduce Sulfur compounds to H_2S
- Nitrifying bacteria
 - E.g. Nitrosomonas, Nitrobacter, Nitrospira, Nitrococcus
 - Increased oxygen demand (Nitrite);



BS01499

The Distribution System as Reactor

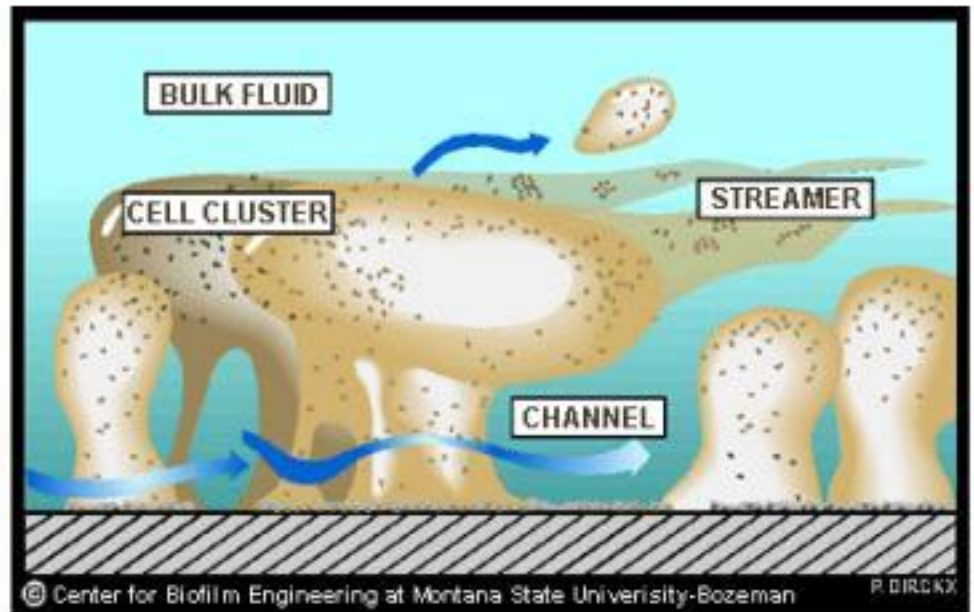


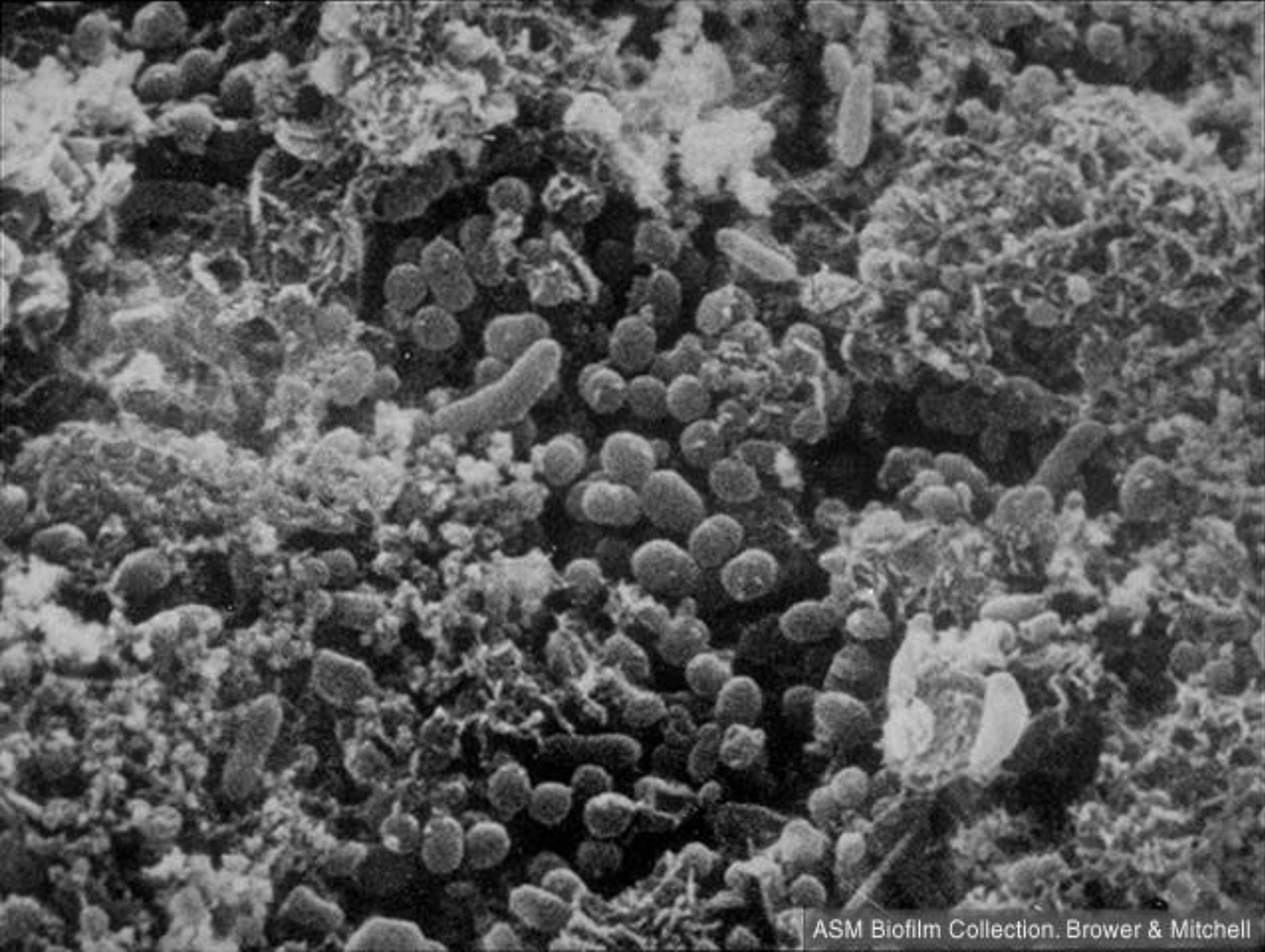
147896CS

Biofilms: the coral reefs of the microbial world

- sessile microorganisms
- multispecies community
- structure influenced by fluid dynamics

coral reef

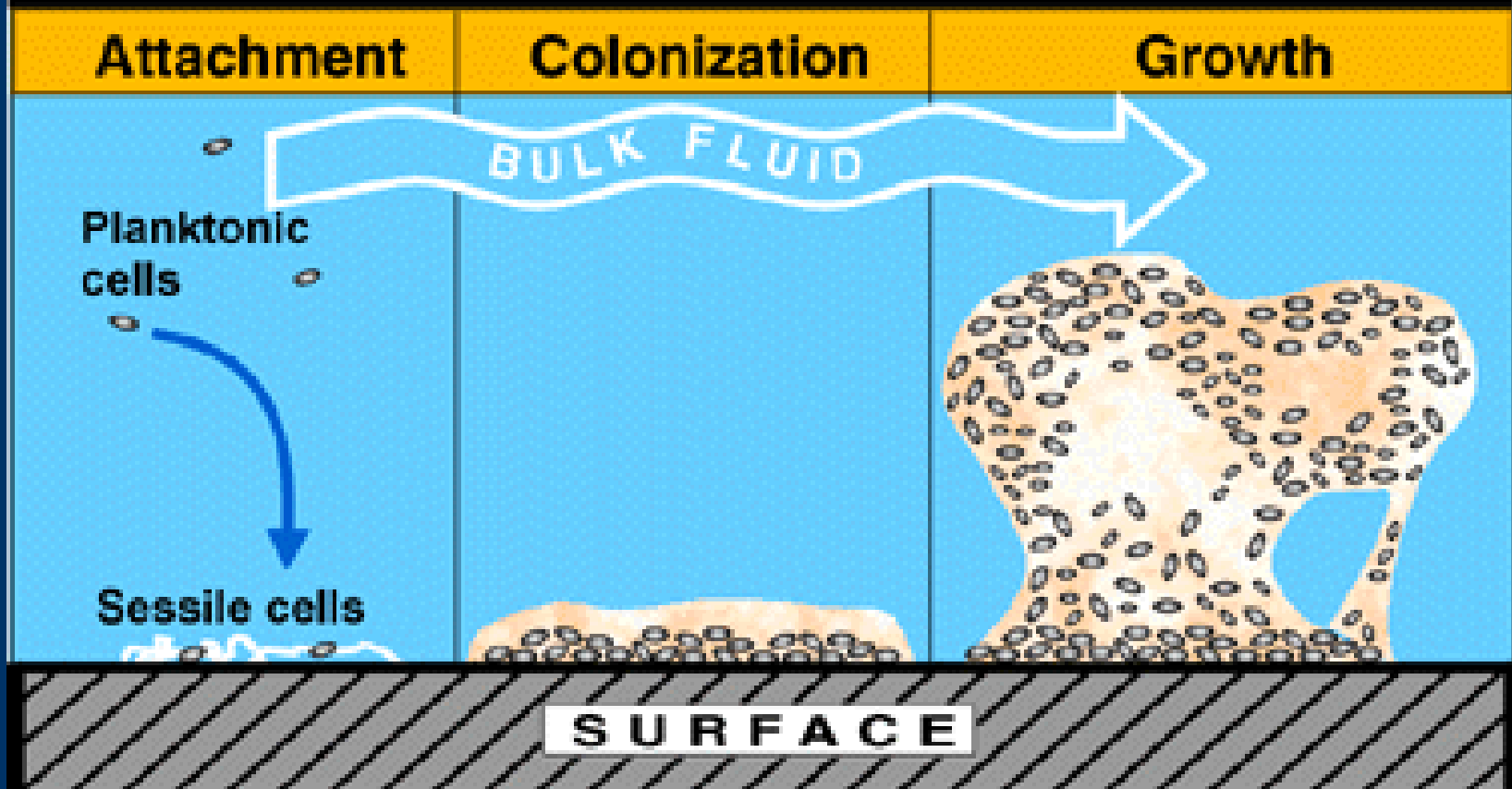




Characteristics of Biofilms

- Form on surfaces in aquatic systems
- Resistant to biocides
- Composed of organic and inorganic constituents
- Use sorbed and soluble substrates
- Monitoring is difficult
- Release organisms into bulk fluid

Biofilm formation:



REVERSIBLE
ADSORPTION
OF BACTERIA
(sec.)

IRREVERSIBLE
ATTACHMENT
OF BACTERIA
(sec.-min.)

GROWTH &
DIVISION
OF
BACTERIA
(hrs.-days)

EXOPOLYMER
PRODUCTION
& BIOFILM
FORMATION
(hrs.-days)

ATTACHMENT
OF OTHER
ORGANISMS TO
BIOFILM
(days-months)



Surface penetration



Molecular fouling
conditioning film

Microfouling
bacteria

microalgae
fungi

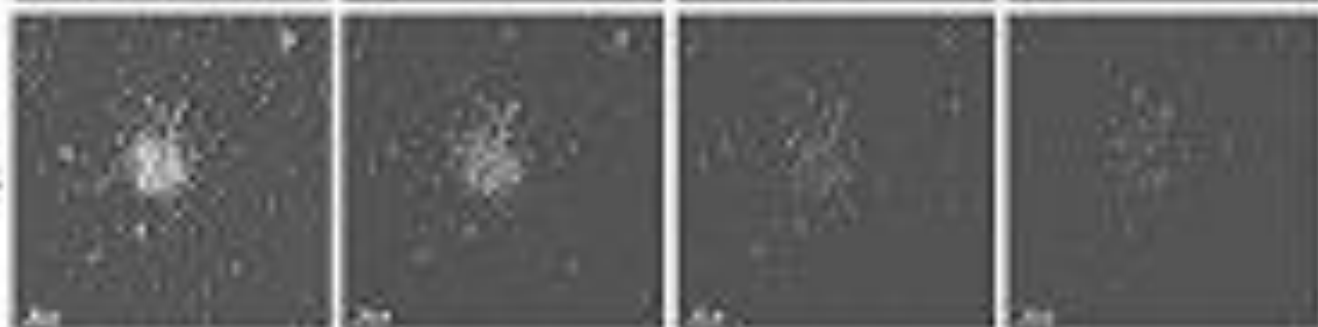
Macrofouling
macroalgae
invertebrates

Natural
anti-fouling

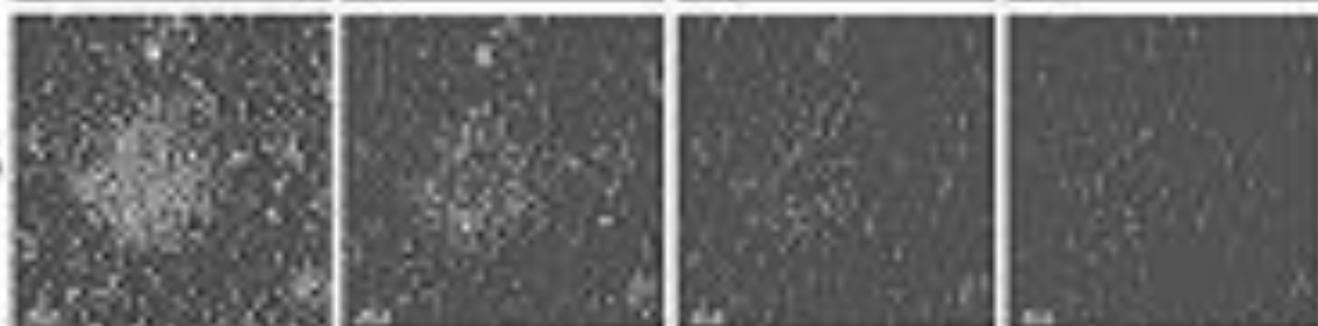
12



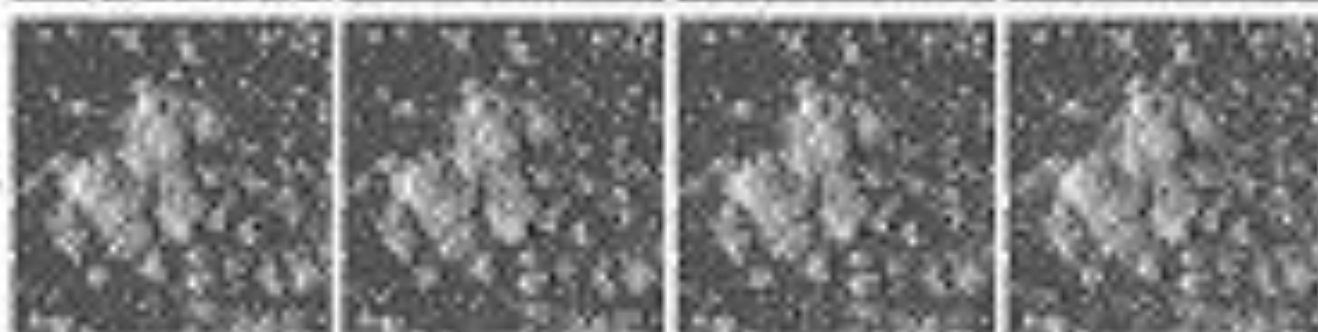
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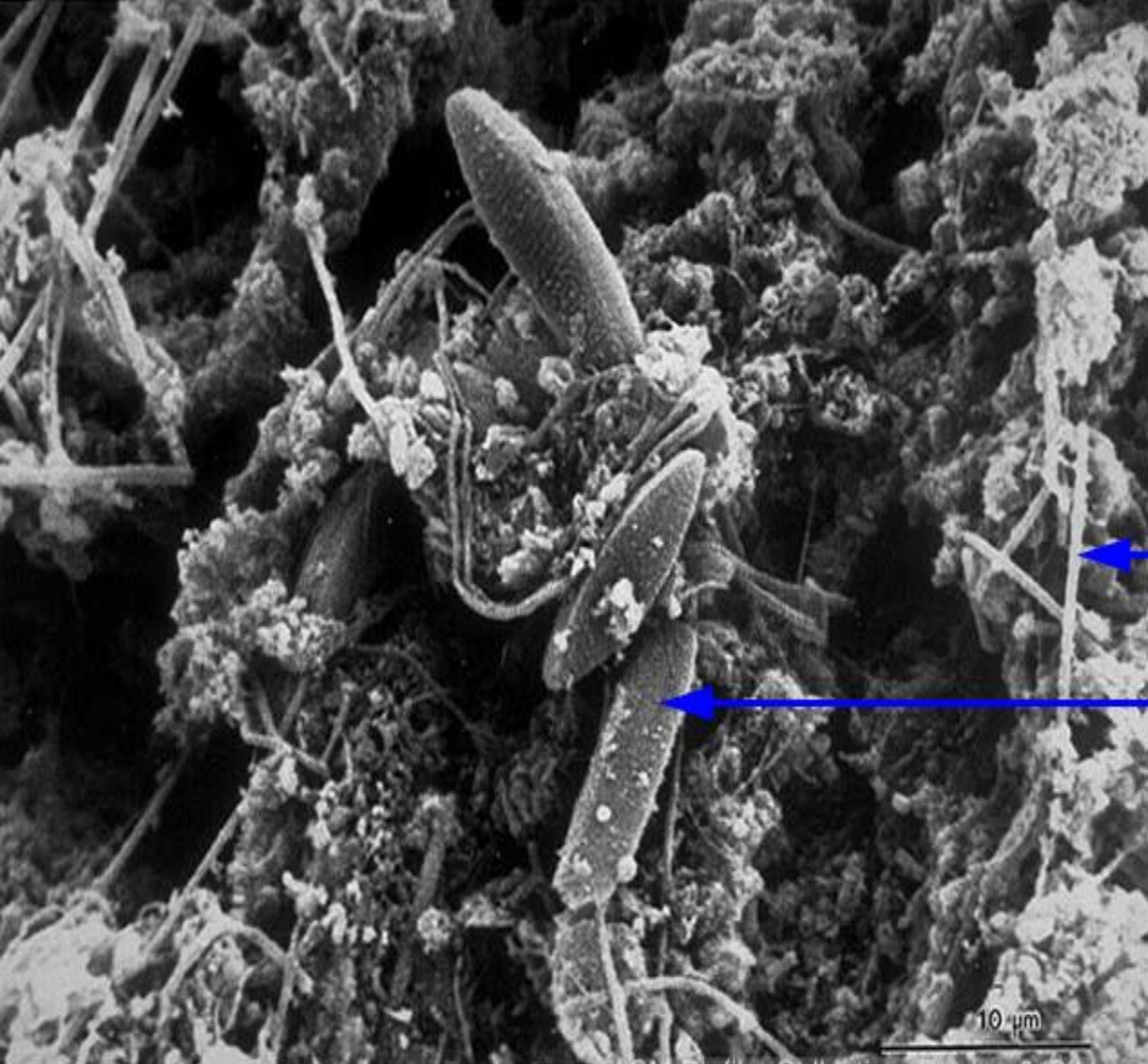


60



84





Bacterial filament

Diatom

10 μm

Factors Affecting Formation

- **Substratum effects**
 - Texture or Roughness
 - Hydrophobicity
 - Conditioning Film
- **Characteristics of Aqueous Medium**
 - Flow Velocity
 - pH
 - Temperature
 - Salts (Cations)
 - Presence of Antimicrobial agents
- **Cell Properties**
 - Hydrophobicity
 - Appendages
 - EPS

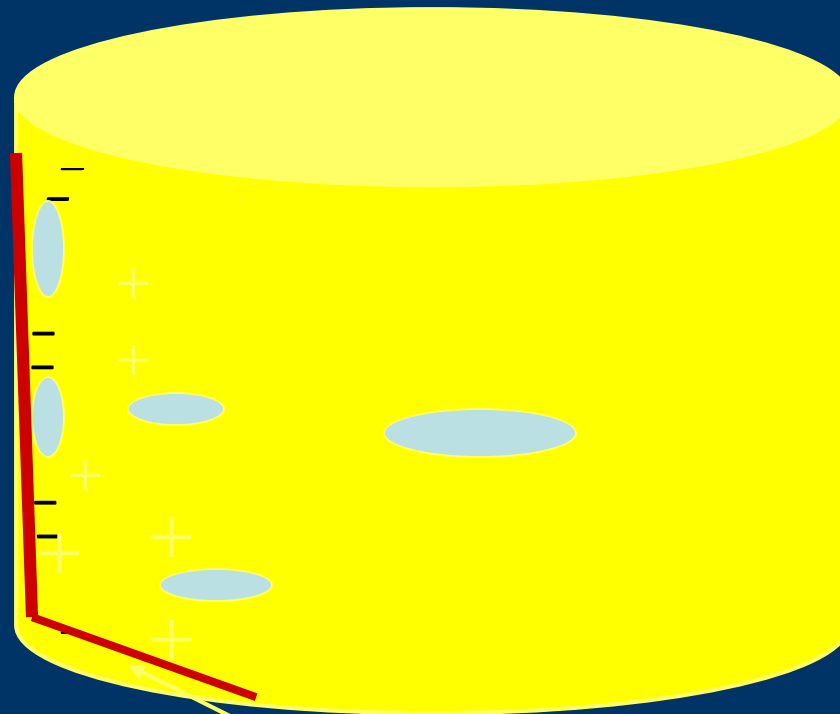
Mechanism of Surface Attachment

- Two phases
 - Reversible- can wash off with 2.5% NaCl
 - Hastened by cations, divalent more than mono-
 - Must last up to 12 hours
 - Doesn't happen in high nutrient concentrations
 - Irreversible – can't wash off with 2.5% NaCl
 - Must have reversible first
 - Fibers attaching to surface
 - A biofilm is forming.

Surface Attachment

Both Cells and Wall have net negative charges

Cations neutralize the charge and allow cells to get close enough to the wall for non-ionic forces to be important



Forming Biofilm

Attachment

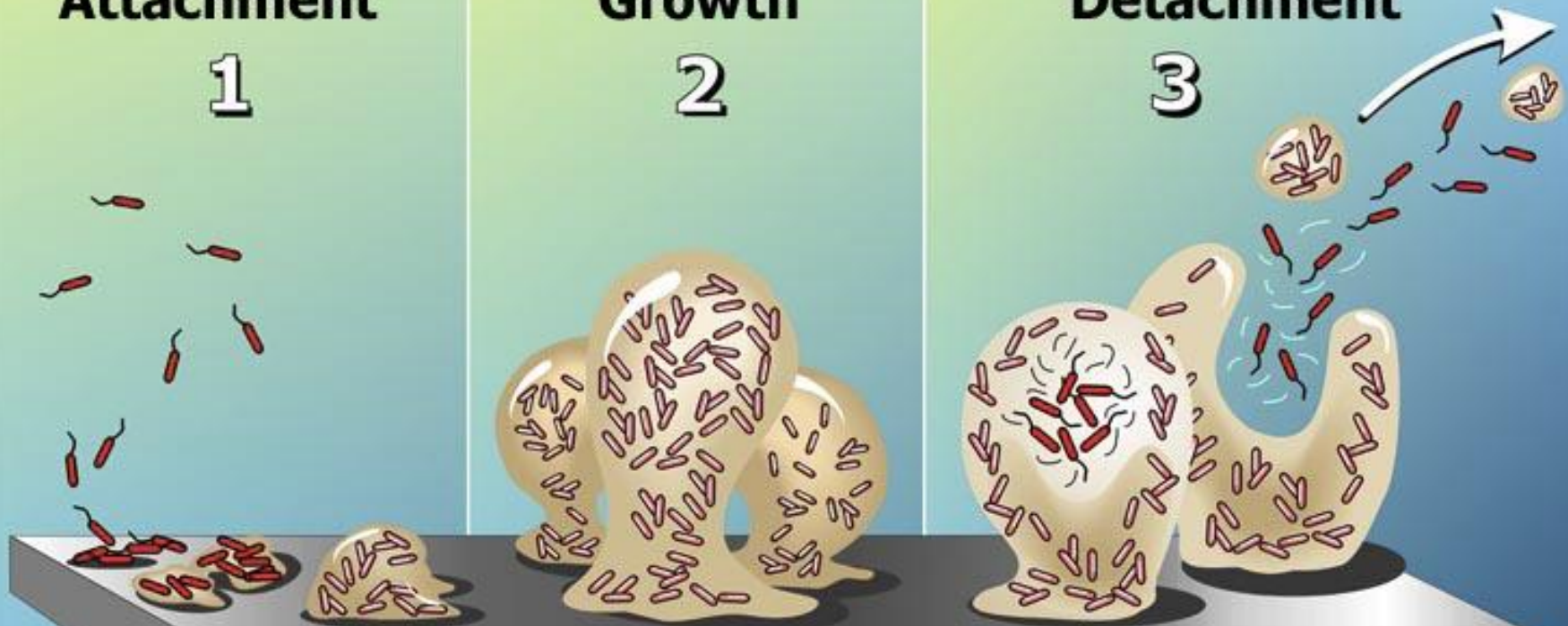
1

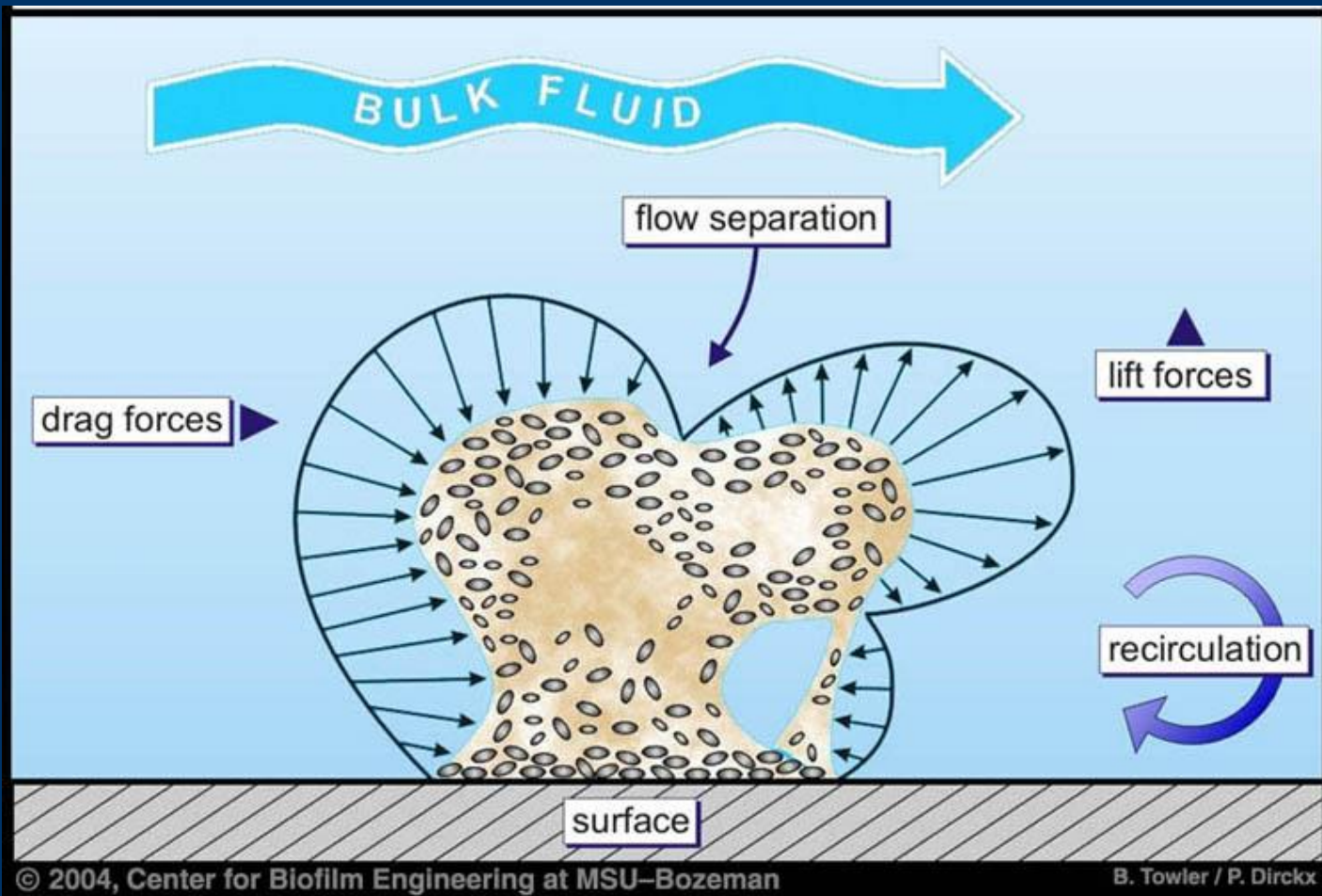
Growth

2

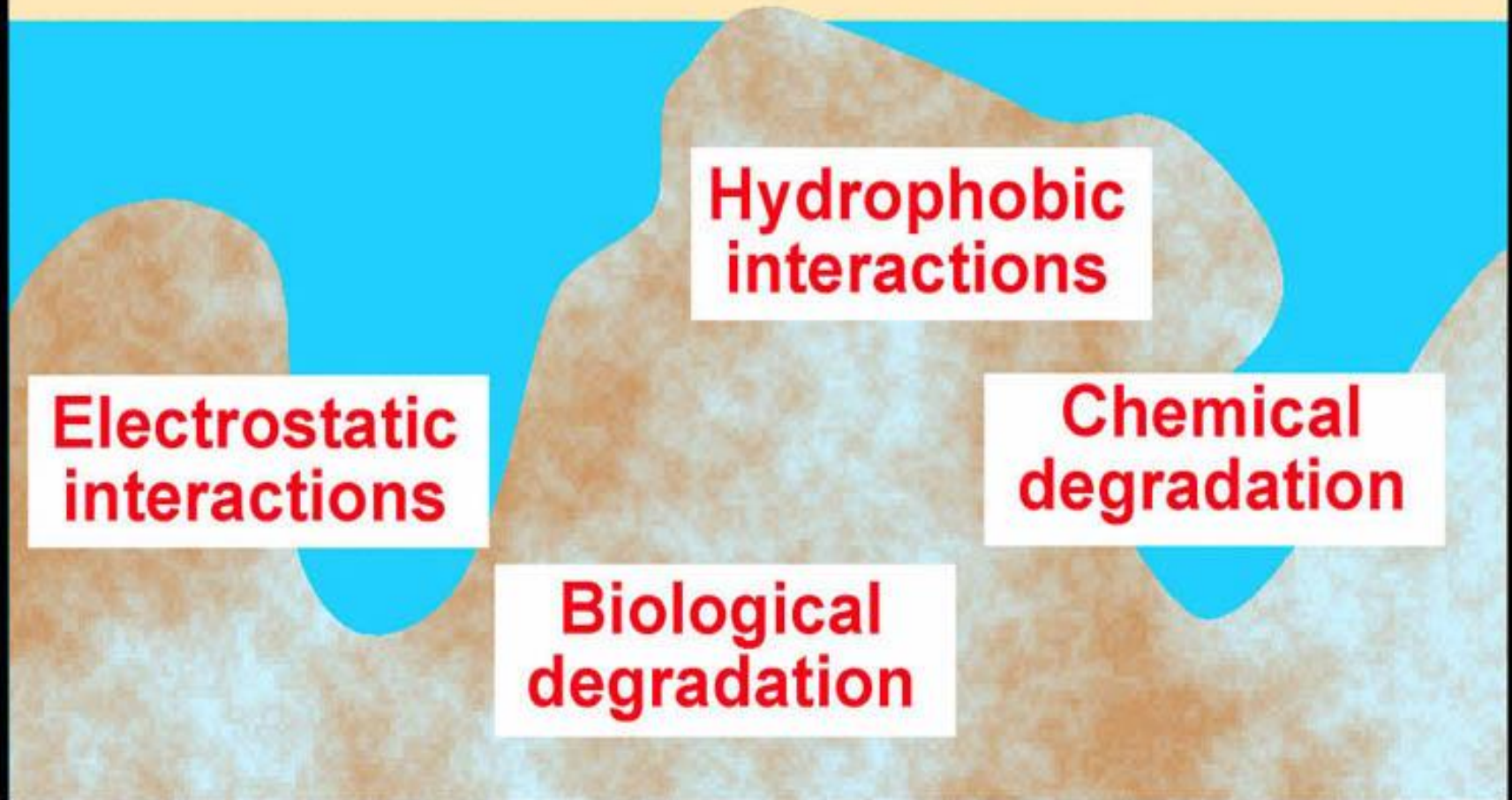
Detachment

3

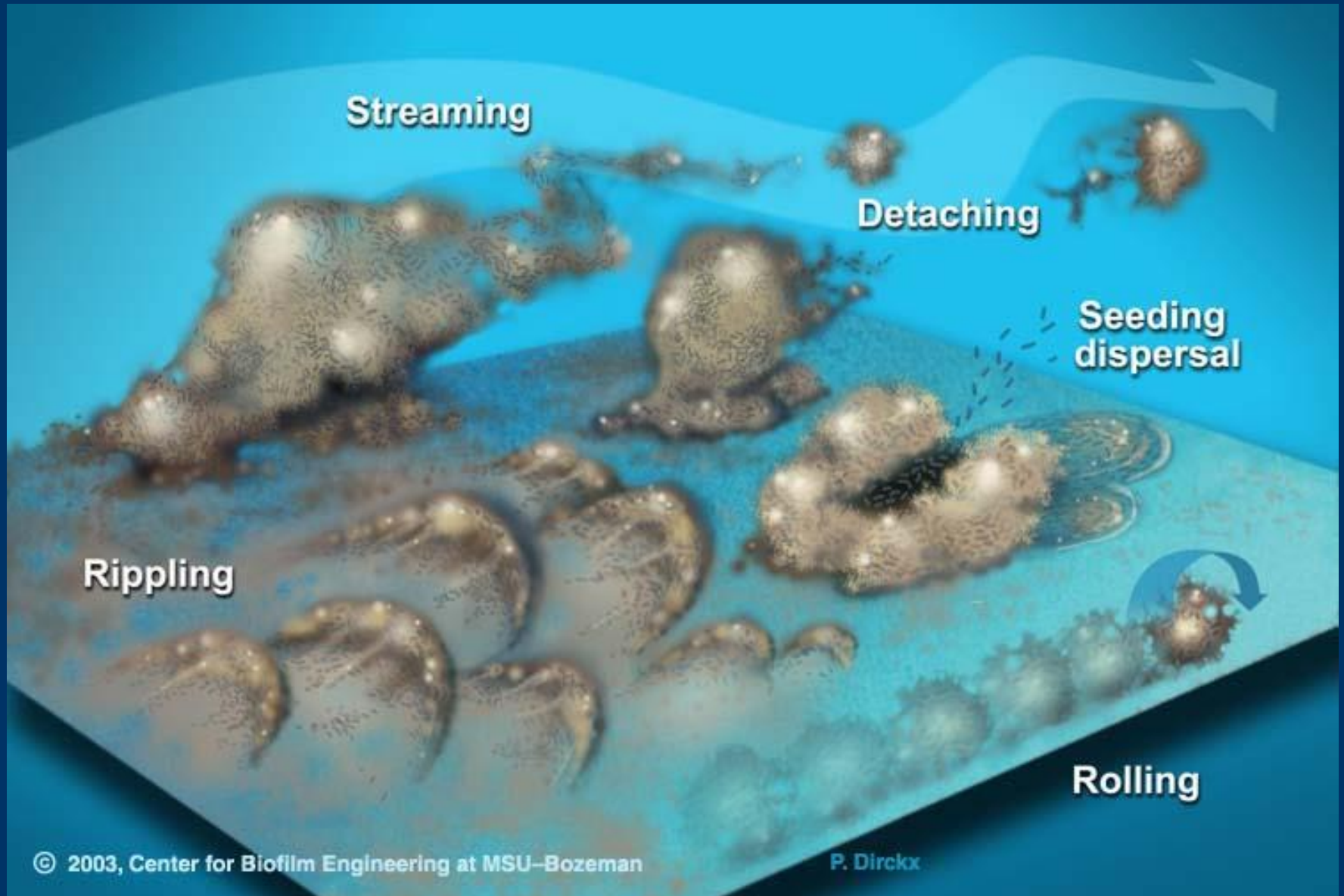


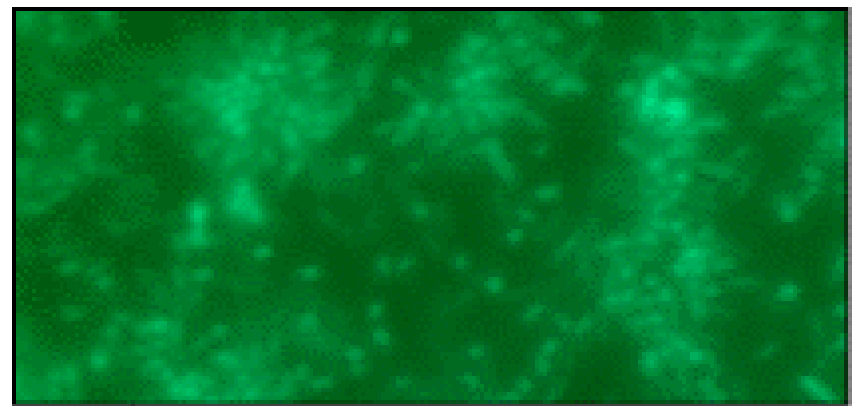
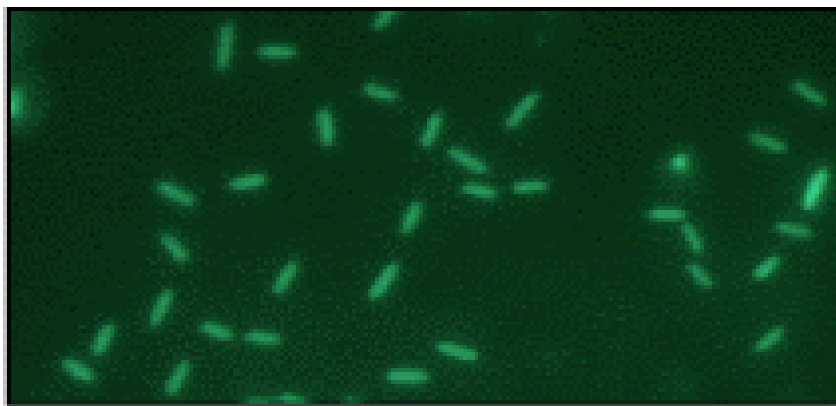
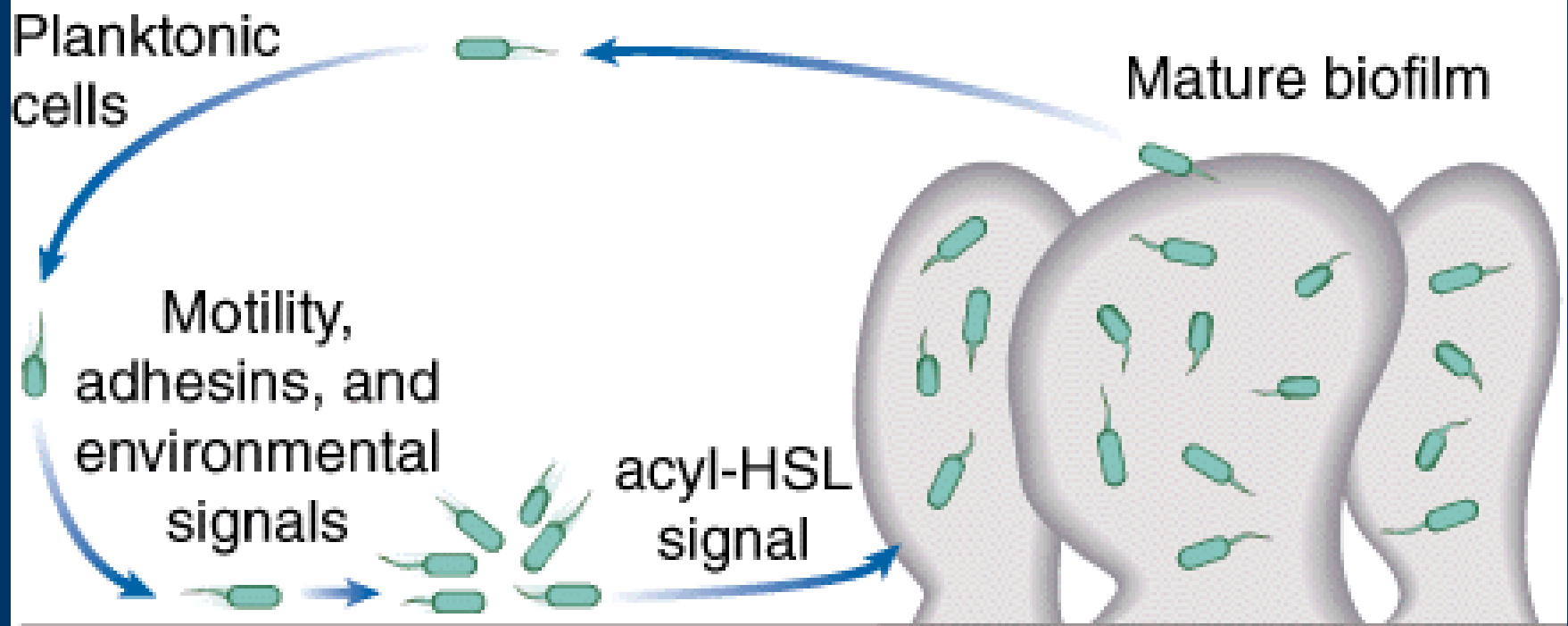


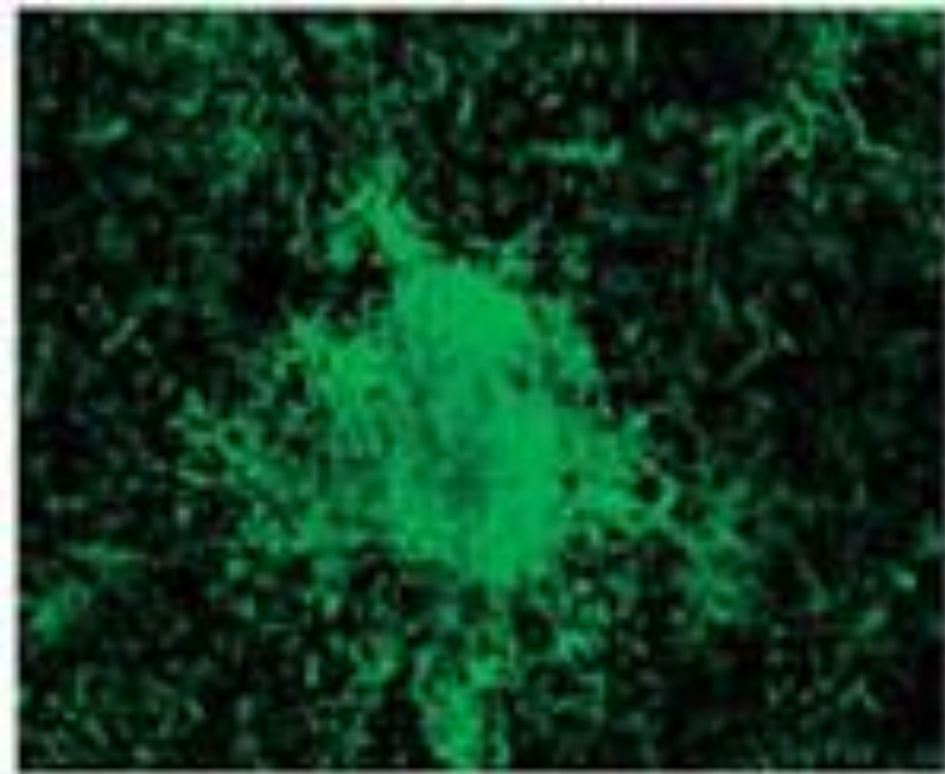
Biofilm: Cohesive forces/detachment modes



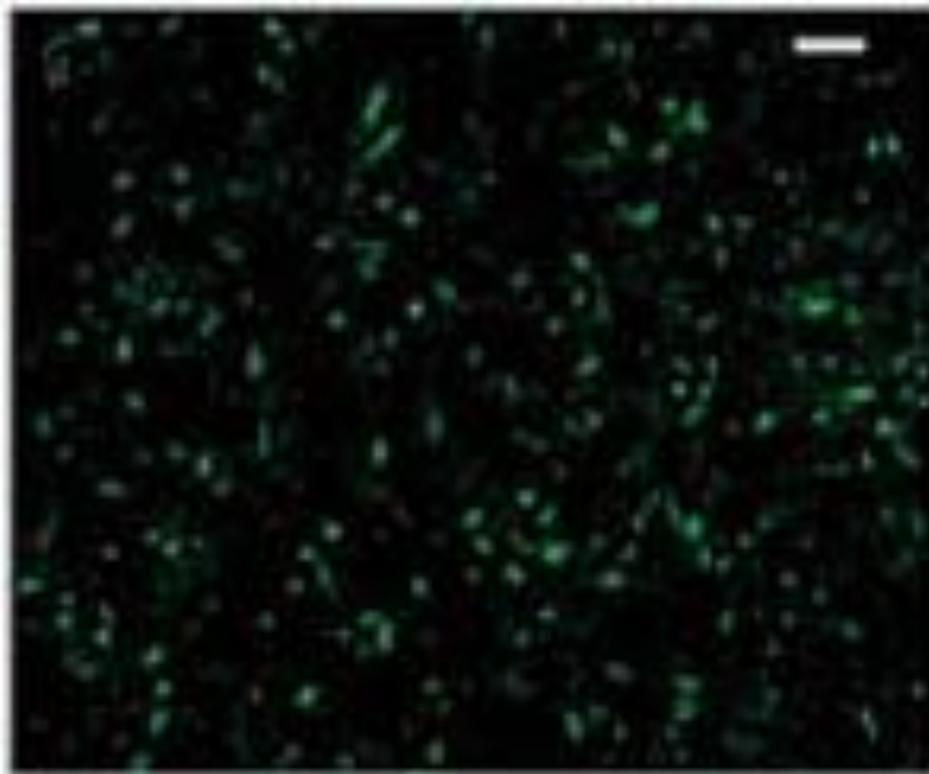
196497cs





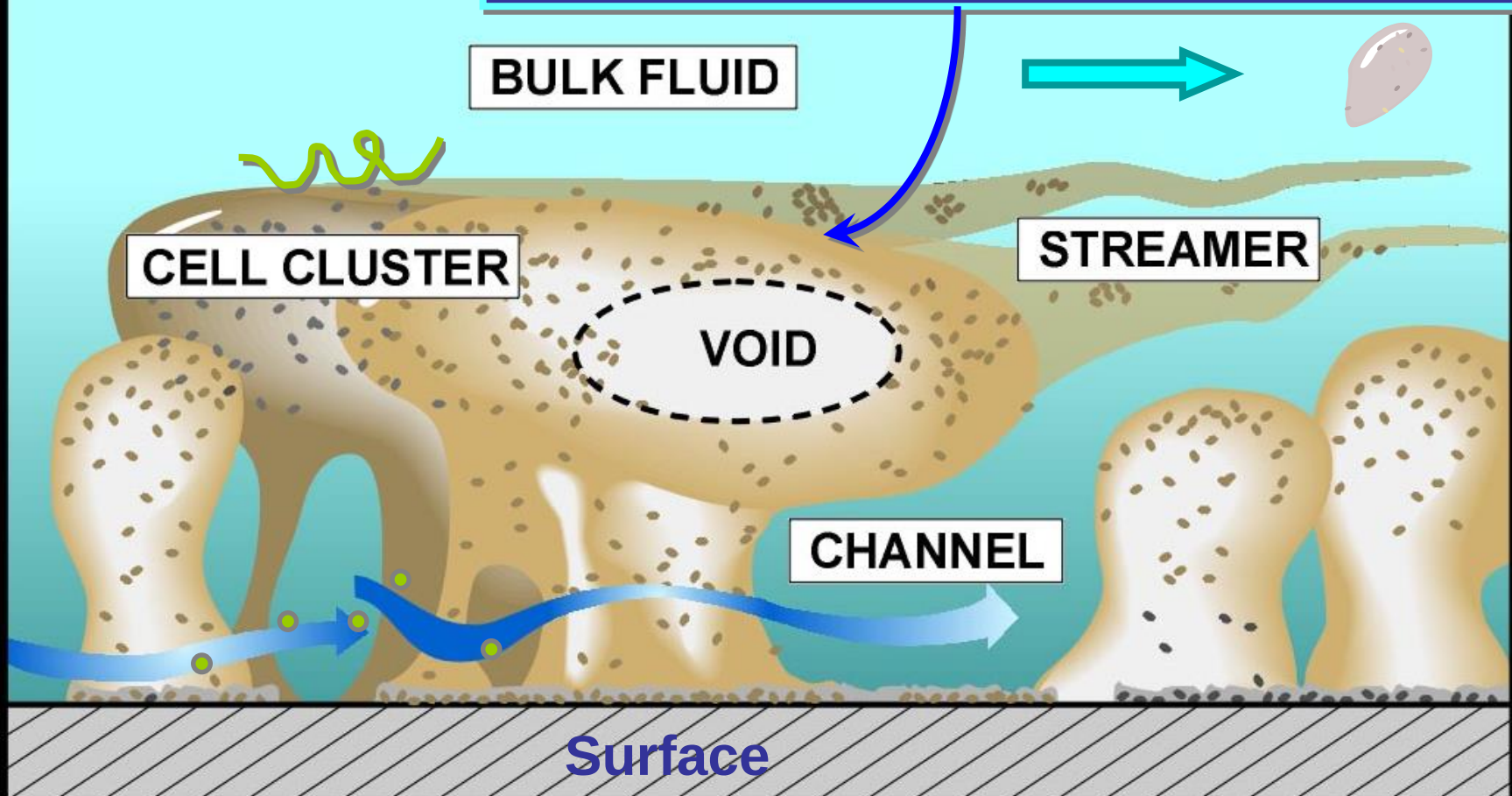


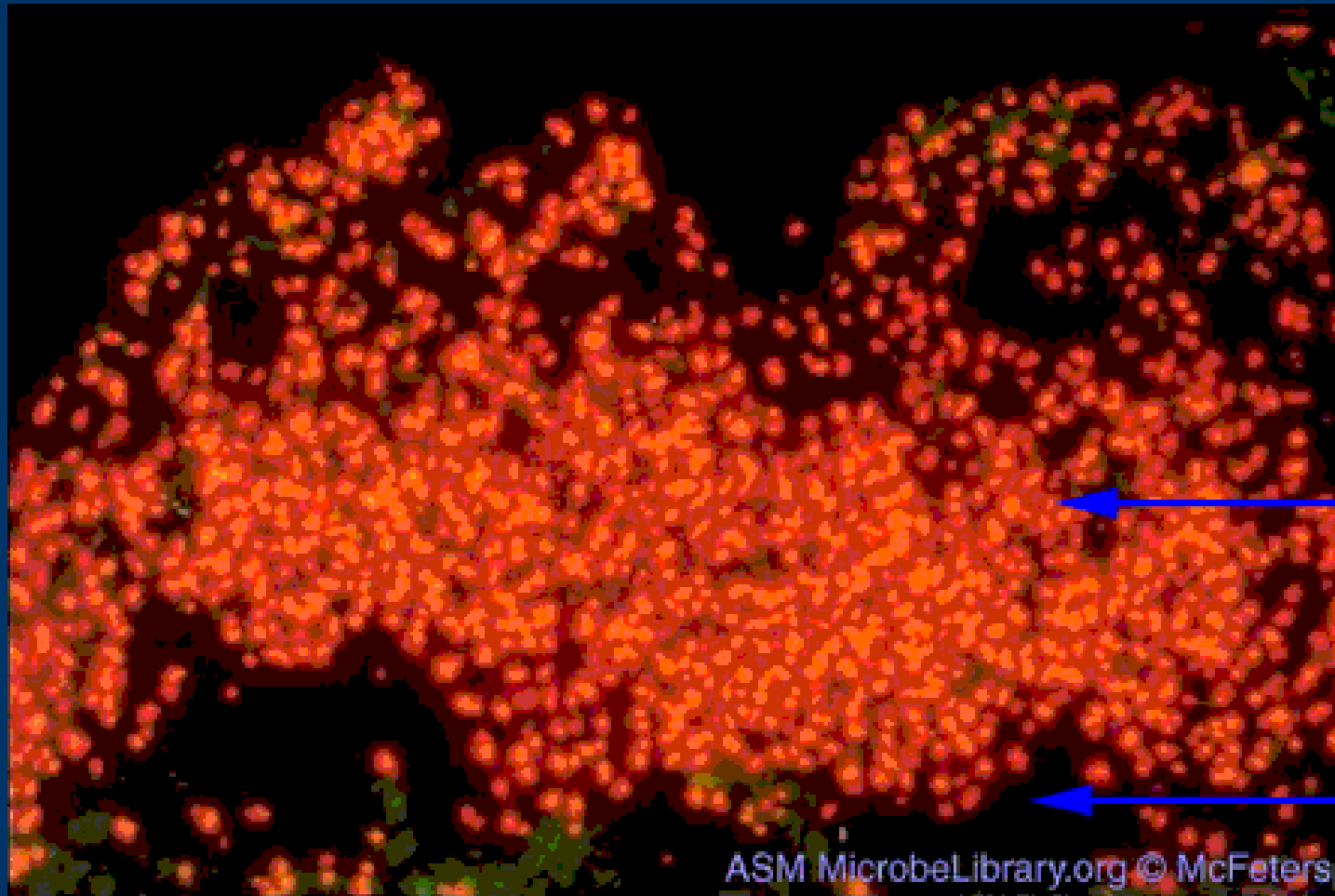
With Lactoferrin



Without Lactoferrin

Extracellular Polymeric Substances

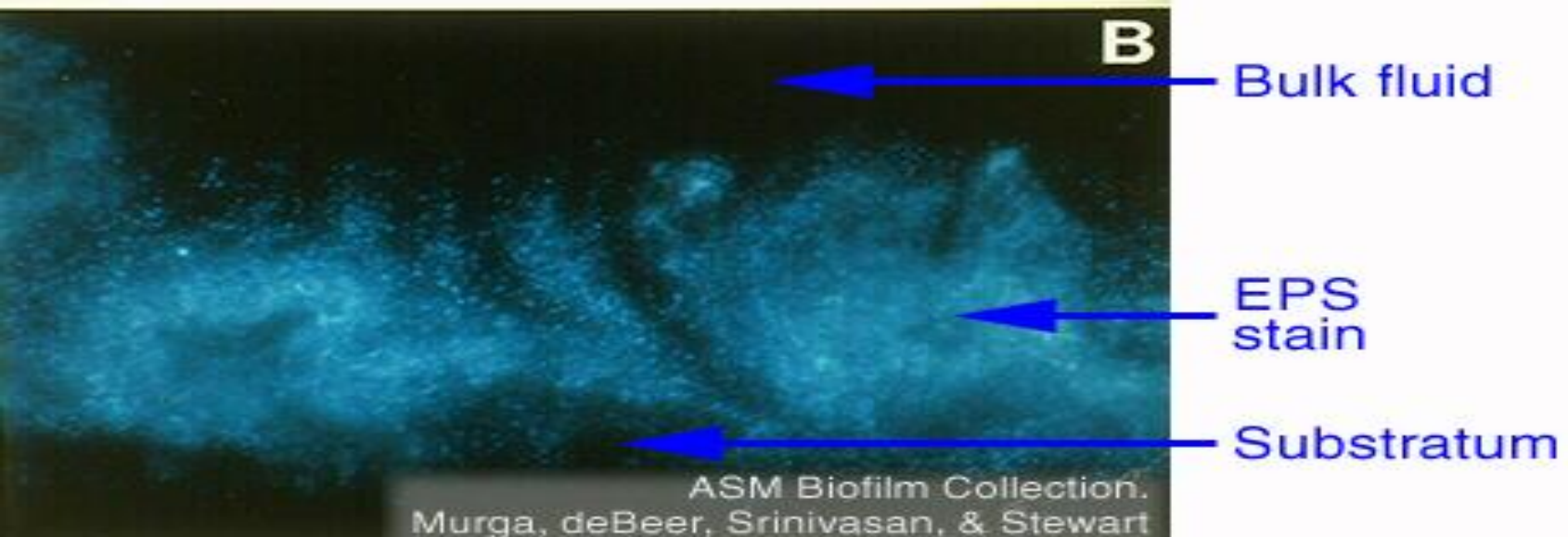
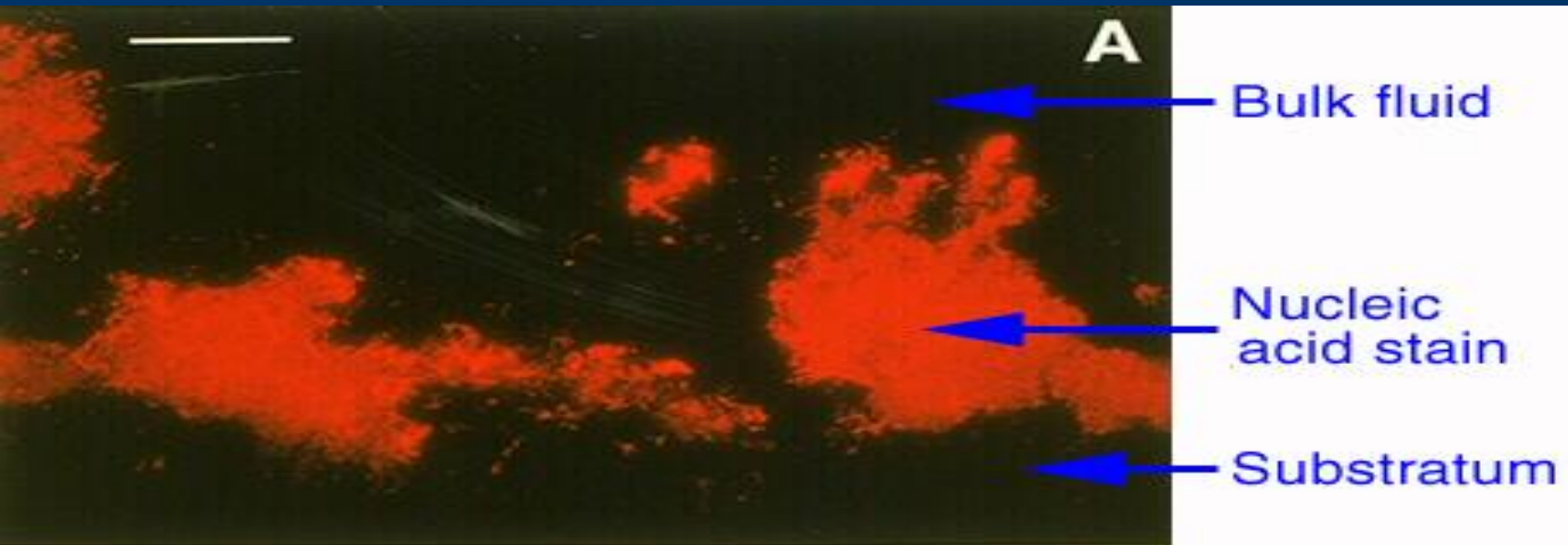




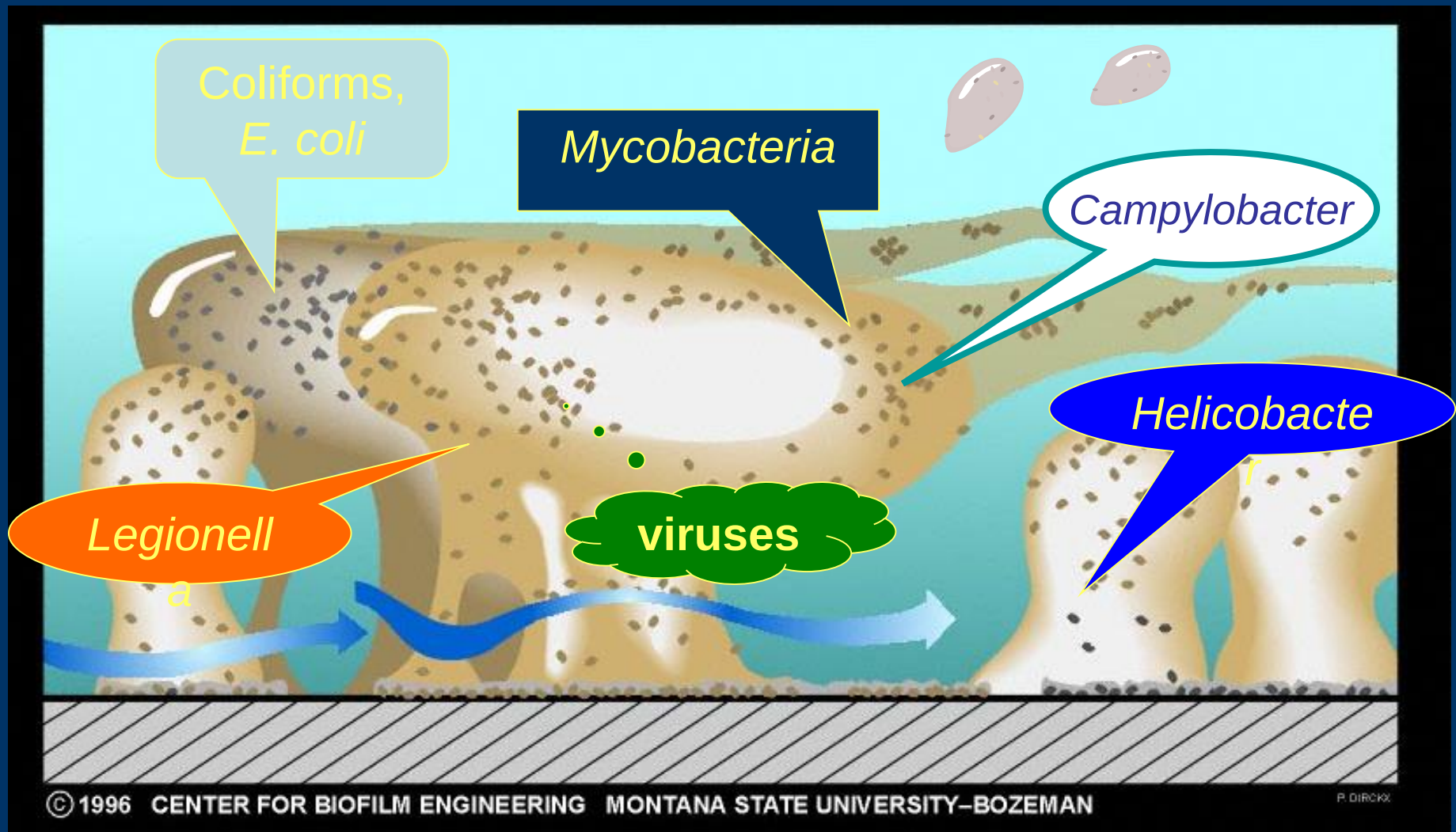
Respiring
bacteria
(red)

Substratum

Biofilms



Pathogens can reside within drinking water system biofilms

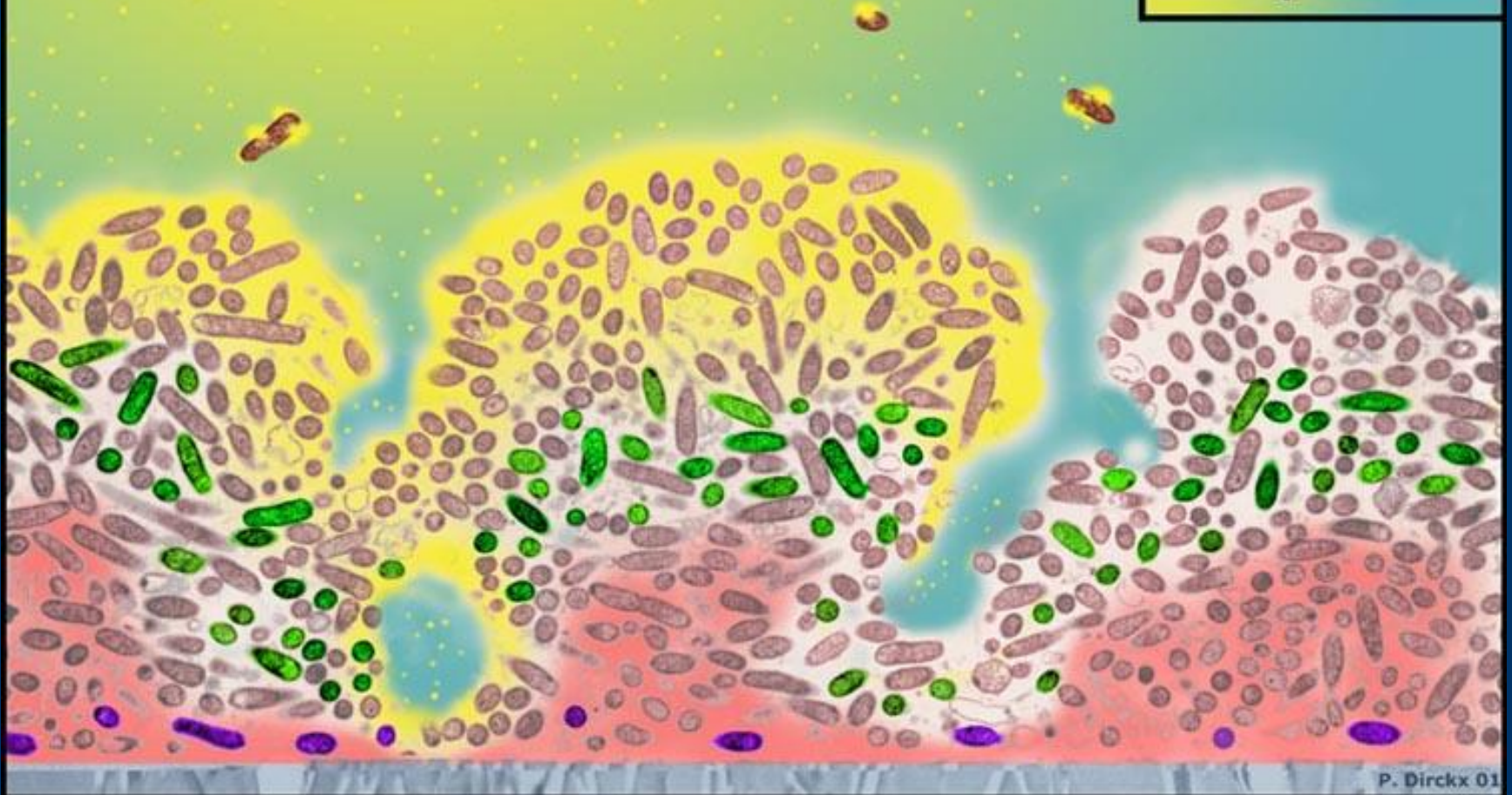


Pathogens in Biofilms

- Klebsiella spp.
- E.coli spp.
- Pseudomonas spp.
- Legionella spp.
- Mycobacteria spp.
(MAC)
- S.aureus
- V.cholerae
- L.monocytogenes
- Salmonella spp.
- Helicobacter spp.
- Amoeba,
- Cryptosporidium
parvum
- Giardia lamblia
- Enteroviruses (Other
viruses?)

Mechanisms of Biofilm Tolerance

Antimicrobial
Depletion



P. Dirckx 01

**Slow
Penetration**

**Stress
Response**

**Altered
Microenvironment**

Persisters