Common Biological Problems with Wastewater Treatment: From Lagoons to Activated Sludge

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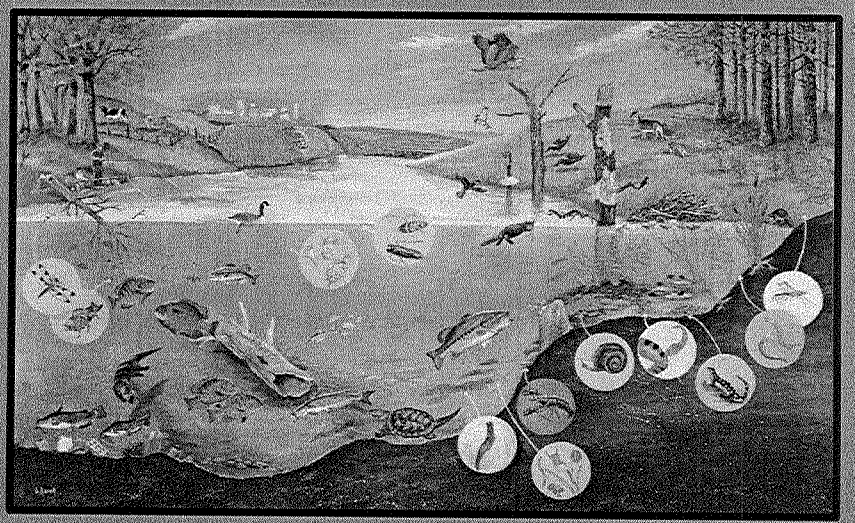
Presentation Outline

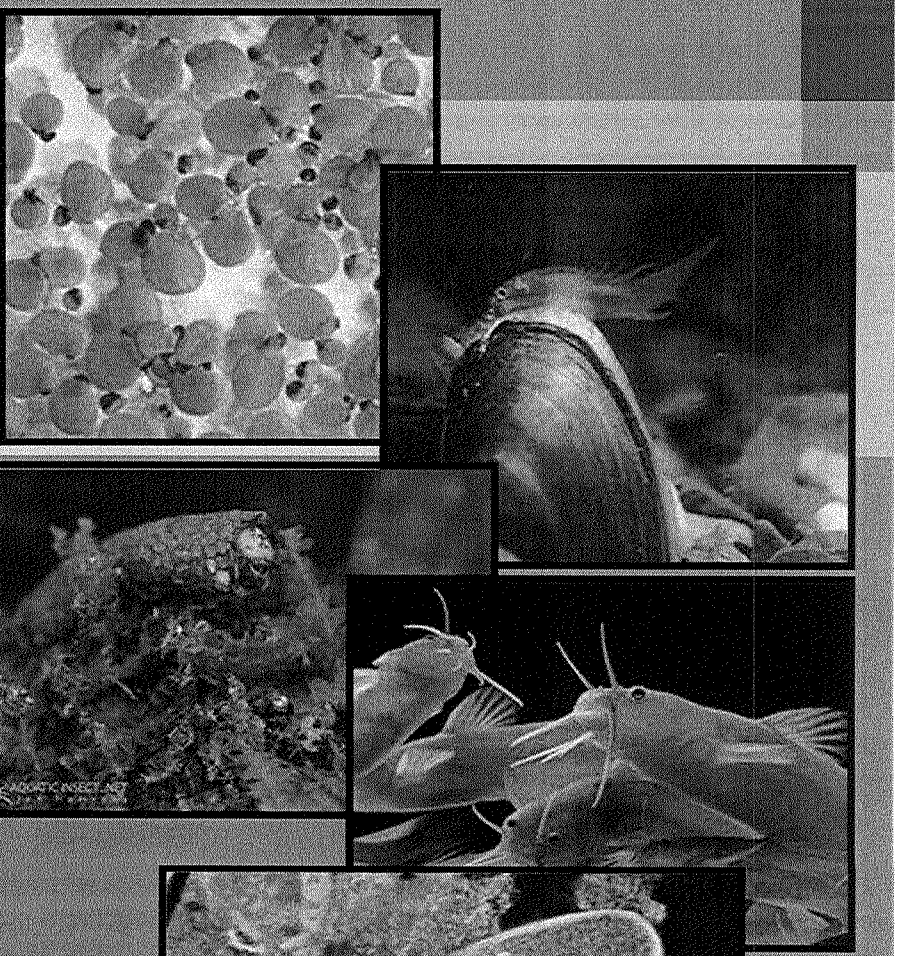
- Part I – What is Biology & its role in wastewater treatment
- Part II – Types of biological WWTPs
- Part III – The biological "players" involved in wastewater treatment
- Part IV – Common biological problems with wastewater treatment



Part I

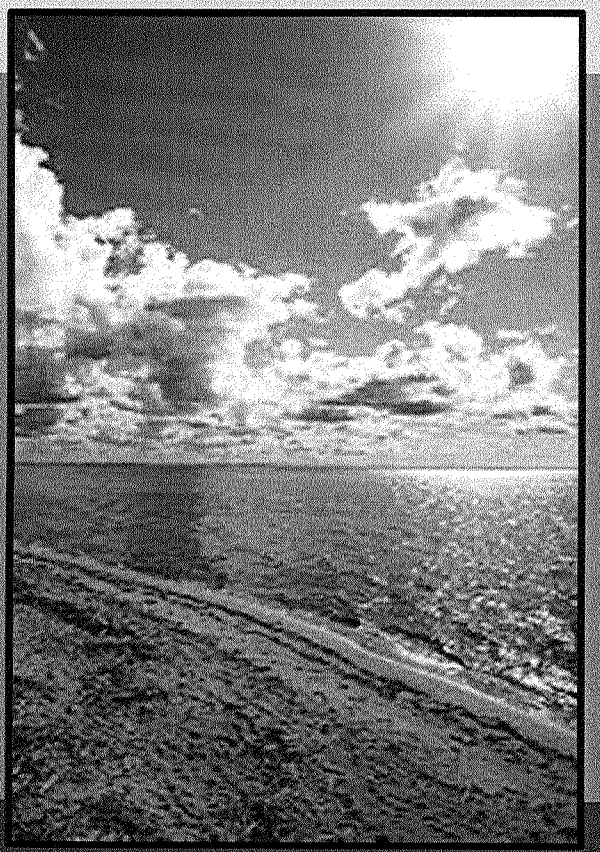
WHAT IS BIOLOGY AND WHAT IS ITS ROLE IN WASTEWATER TREATMENT?

What is Biology?



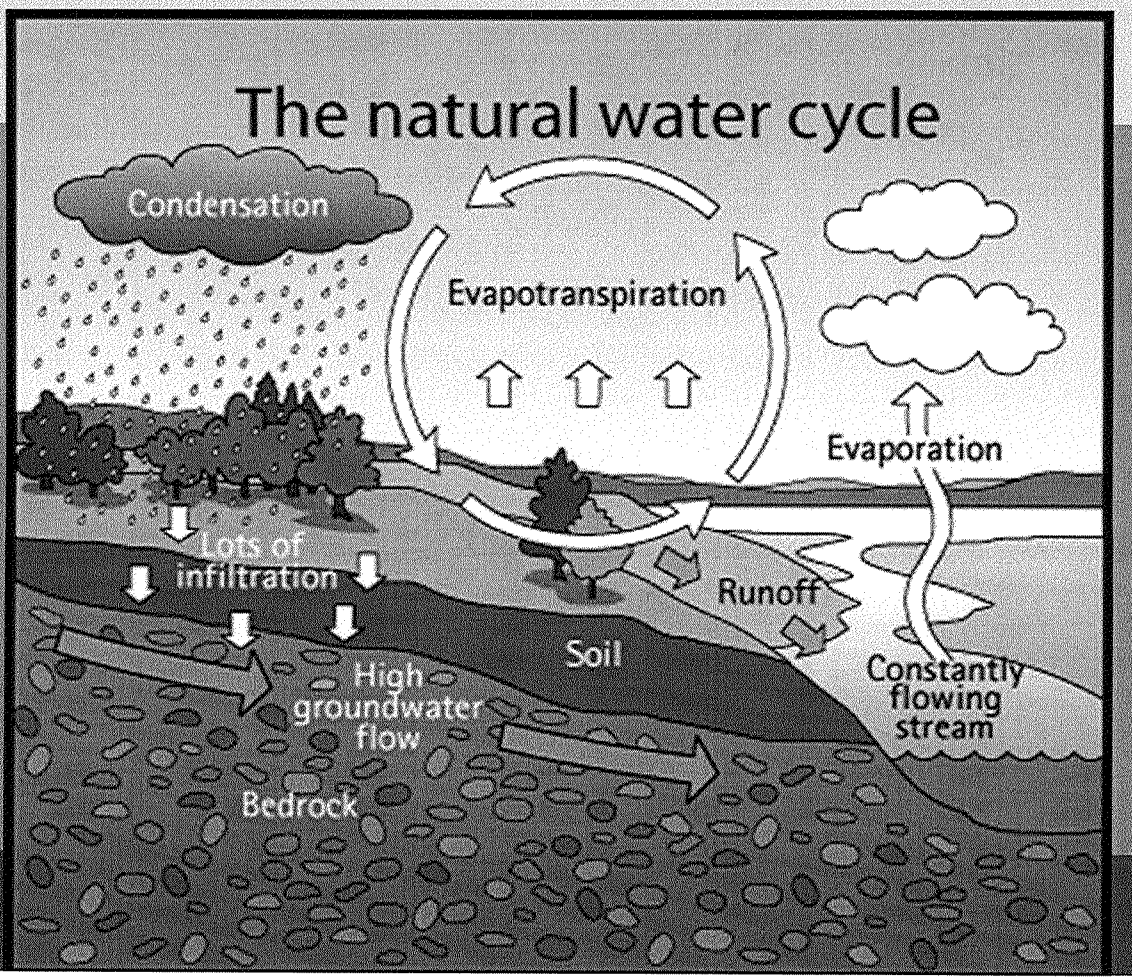
- Biology is the study of living organisms, divided into many specialized fields that cover their morphology, physiology, anatomy, behavior, origin, and distribution.
- Biology is built upon mathematics, physics, and chemistry; and it is the most complex science.
- Biology is life.

Life Depends on the Water Cycle



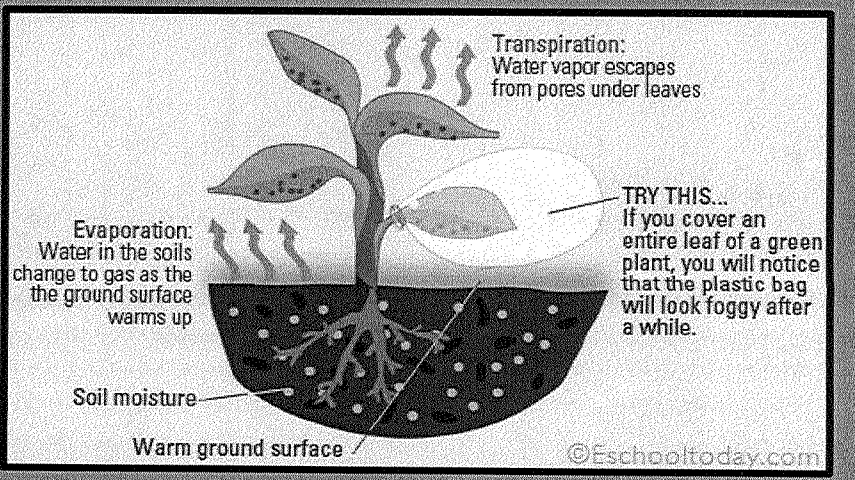
- Water is necessary to sustaining life on Earth.
- It helps tie together the Earth's lands, oceans, and atmosphere into an integrated system.

The Natural Water Cycle

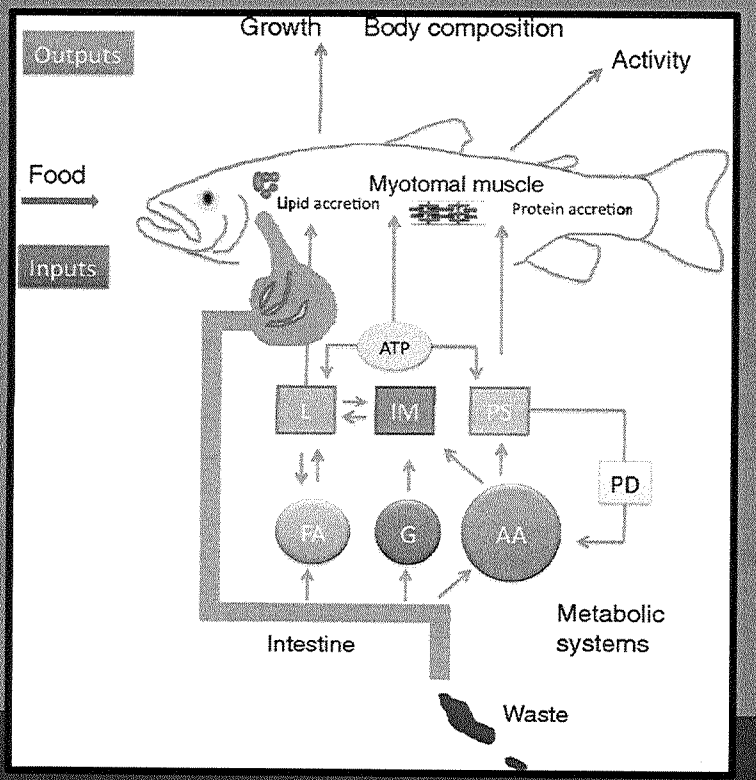


The Natural Water Cycle

- The water cycle describes the continuous movement of water on, above, and below the surface of the Earth.
- The water moves by the physical processes of evaporation, condensation, precipitation, infiltration, runoff, and subsurface flow.



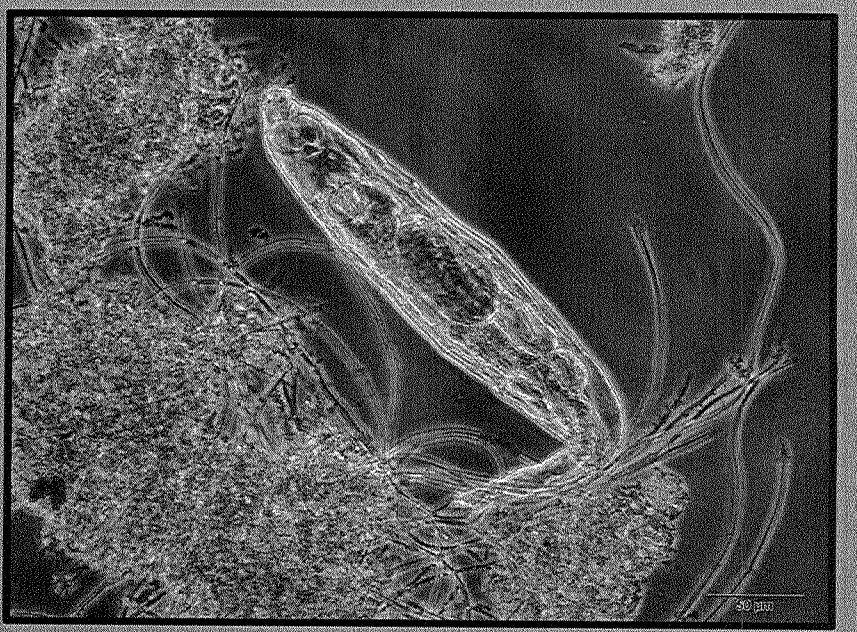
Life Converts Matter into Energy and Waste



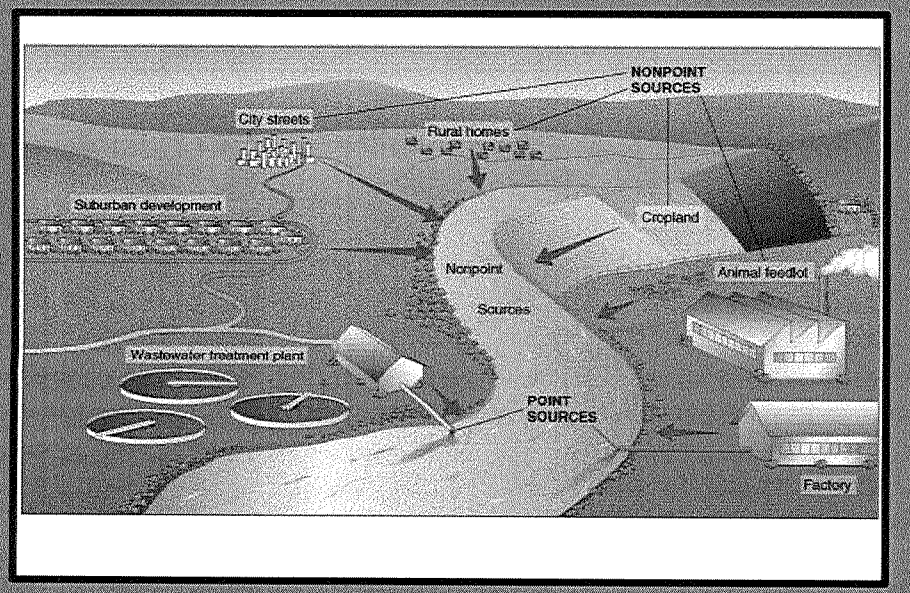
- Two types of waste:
- Solid waste from digestion.
- Metabolic wastes produced by chemical reactions such as respiration, hydrolysis, synthesis, and neutralization.
- Wastes contaminate the water cycle.

One Organism's Waste Is Another Organism's Food

- Most organisms are inefficient at converting matter; and thus, generate wastes.
- Other organisms are efficient at converting these wastes to energy.
- Wastes become more concentrated and contain less useable components as they move through the food web.
- The wastewater cycle takes advantage of these efficient waste-consuming organisms.

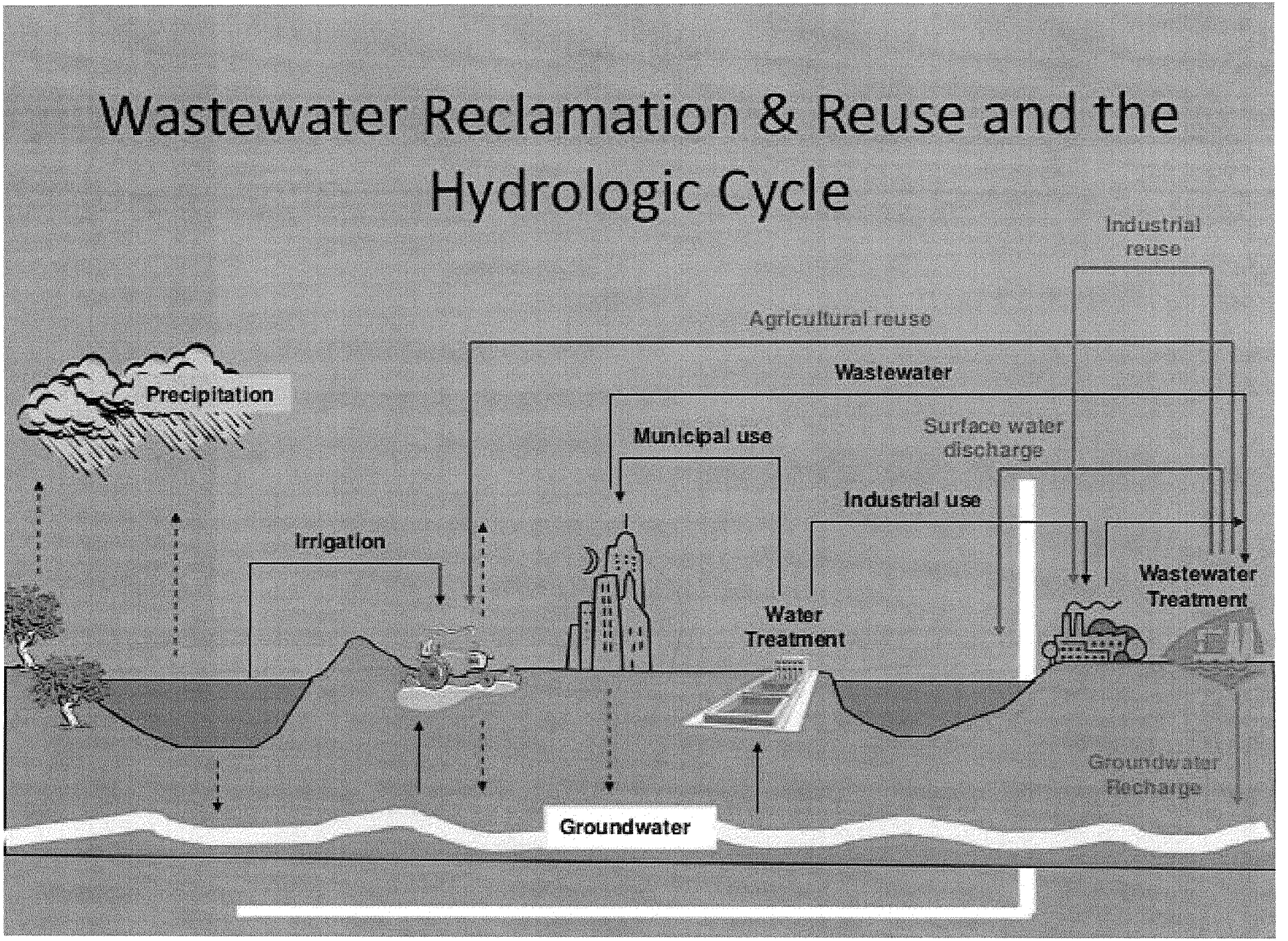


The Wastewater Cycle



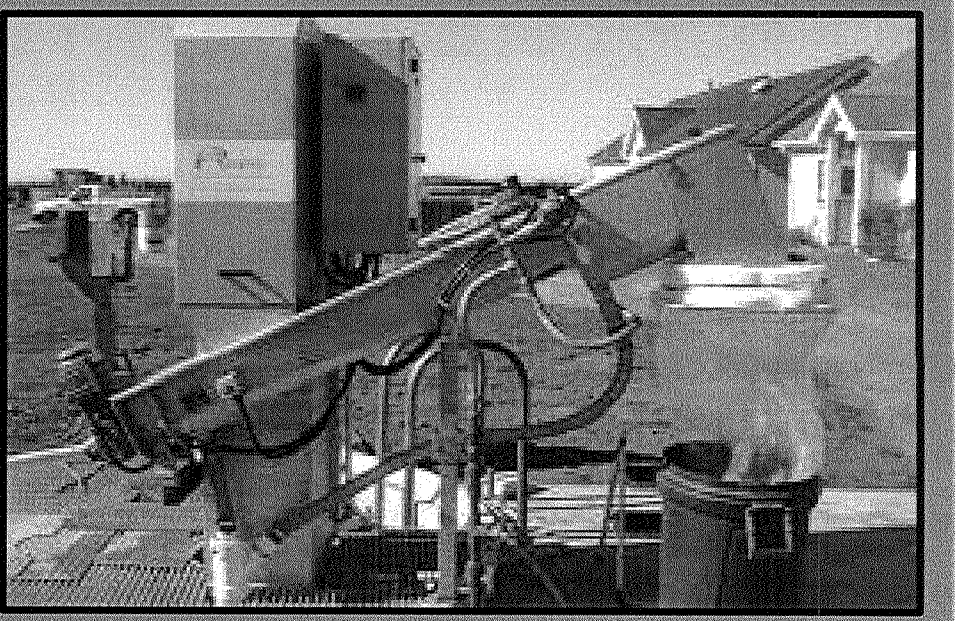
- Human activities require a faster paced water cycle.
- Wastewater treatment systems mimic the water cycle, but at much faster rates.
- Lagoon systems are closest to natural water cycle.
- Activated sludge and biofilm reactors cycle water within weeks, days, and hours.

Wastewater Reclamation & Reuse and the Hydrologic Cycle



Wastewater Treatment

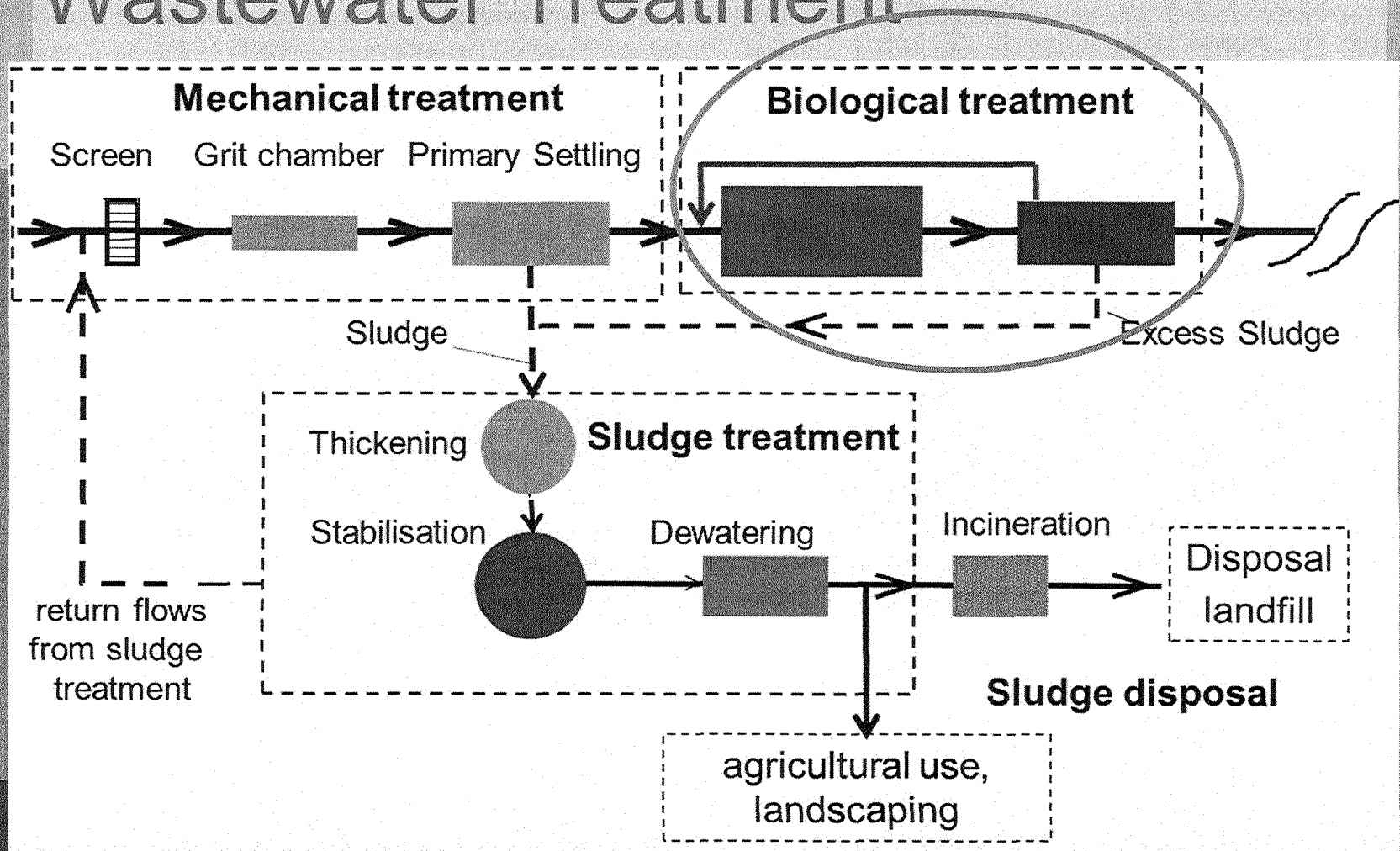
- Wastewater treatment involves primary or mechanical (physical), secondary (biological), and tertiary (advanced) processes.
- Mechanical (physical) – removal of solids (preliminary); settling of larger particles (primary).



Wastewater Treatment

- Secondary (biological) – removal of organics.
- Tertiary (combination of physical, chemical, and biological) – removal of inorganics such as nutrients, minerals, and metals.

Wastewater Treatment



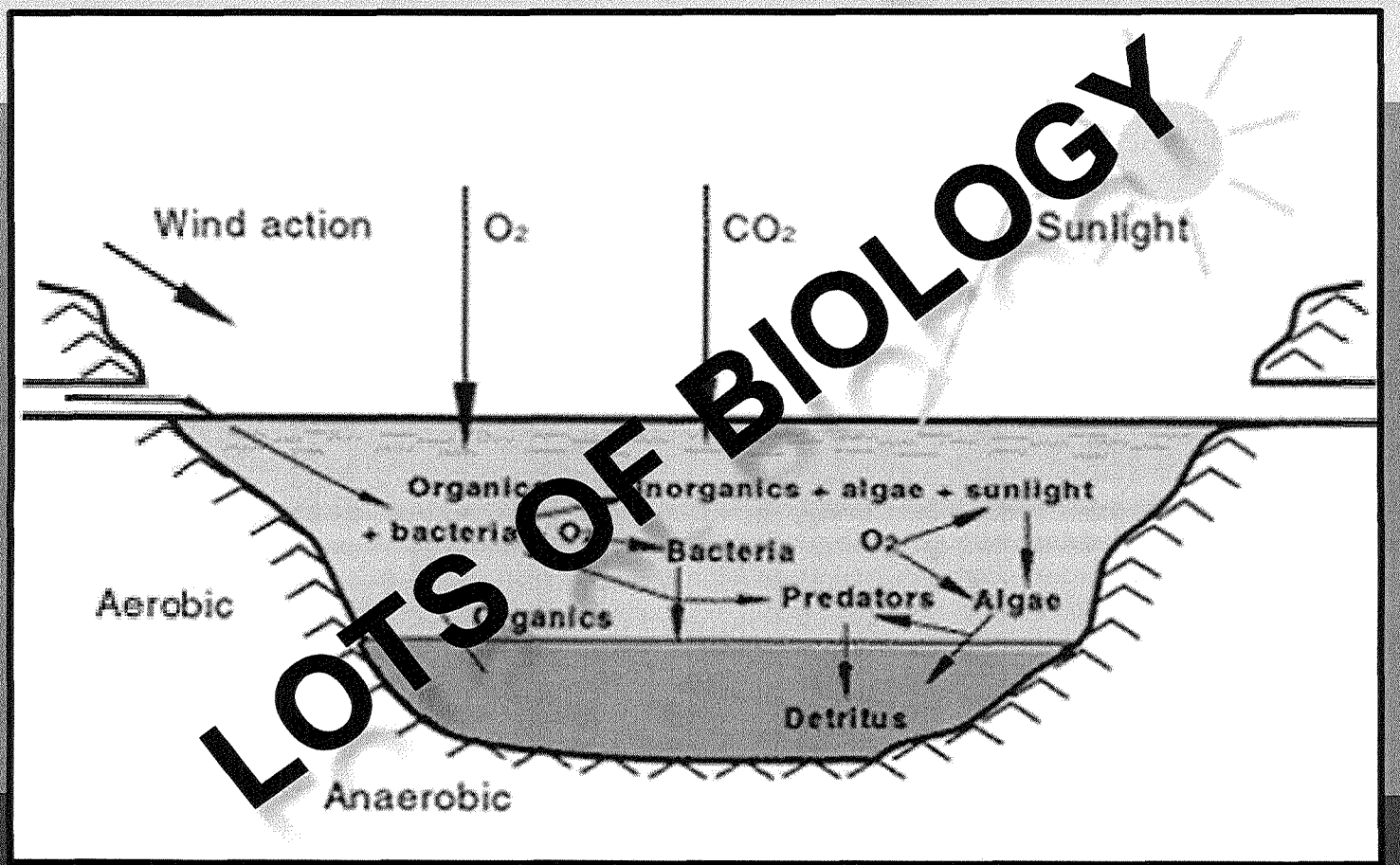
Part II

TYPES OF BIOLOGICAL (SECONDARY) WASTEWATER TREATMENT SYSTEMS

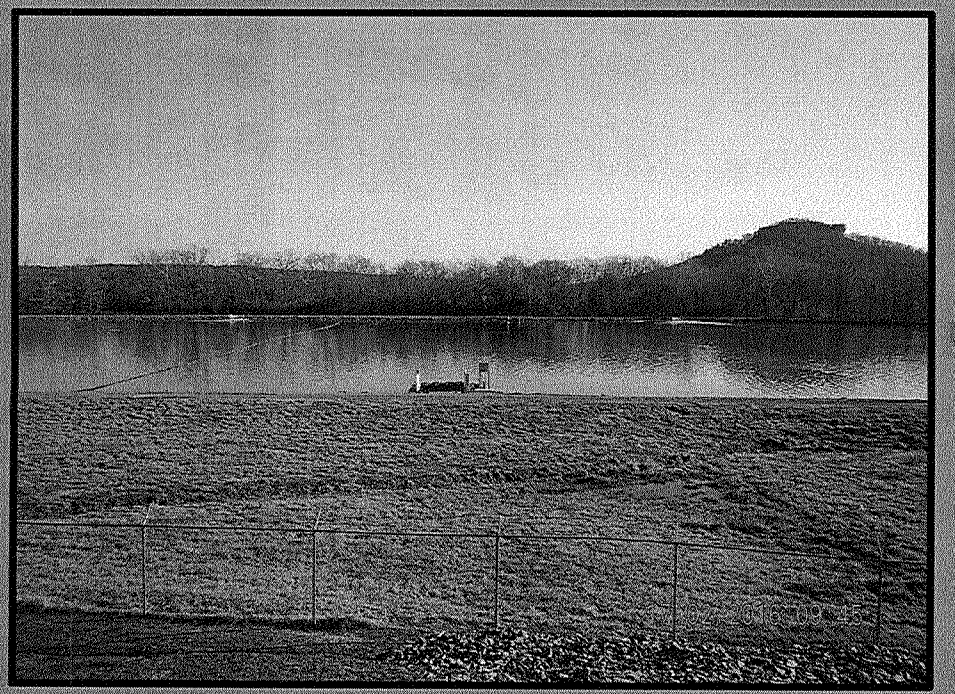
Biological Wastewater Treatment Systems

- Lagoon – most similar to natural water cycle
- Biofilm (fixed) – most solids removed upfront with wastewater provided for zoogleal film.
- Activated sludge (suspended) – complete microorganism ecosystem (F:M).

Biological Wastewater Treatment - Lagoon



Biological Wastewater Treatment - Lagoon

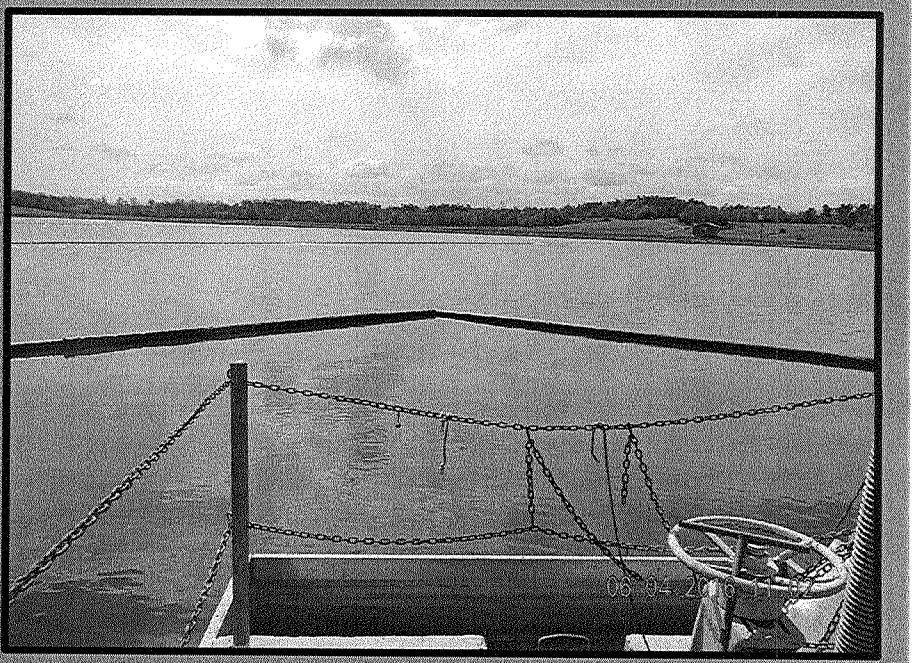


City of Hot Springs

- Lagoon systems are one of the simplest and least expensive.
- They use natural and energy-efficient processes to provide low-cost wastewater treatment.

Biological Wastewater Treatment - Lagoon

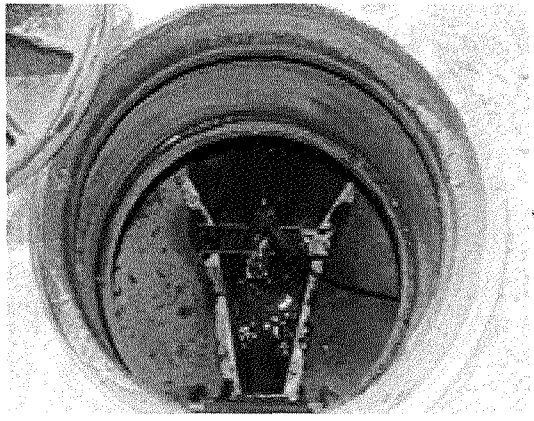
- They can handle intermittent use and shock loadings better than many systems.
- They are very effective at removing disease-causing organisms (pathogens) from wastewater.



City of Mena

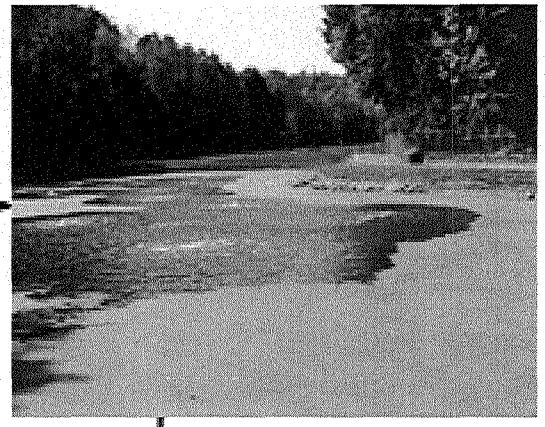
HOW A RURAL LAGOON SYSTEM WORKS

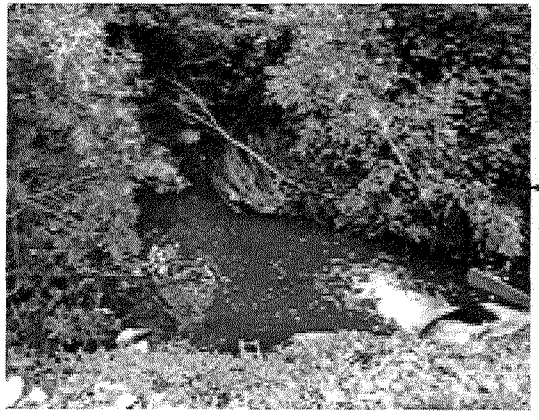
INFLUENT

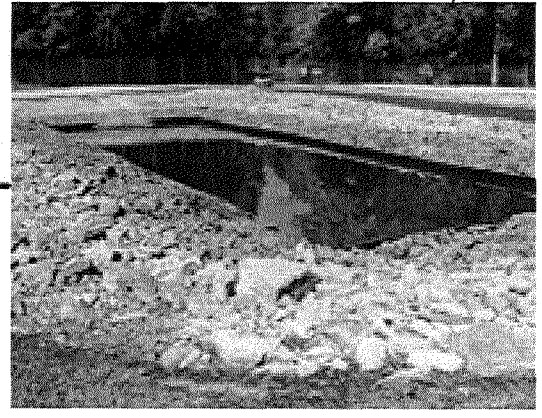


FIRST AERATED LAGOON

SECOND AERATED LAGOON







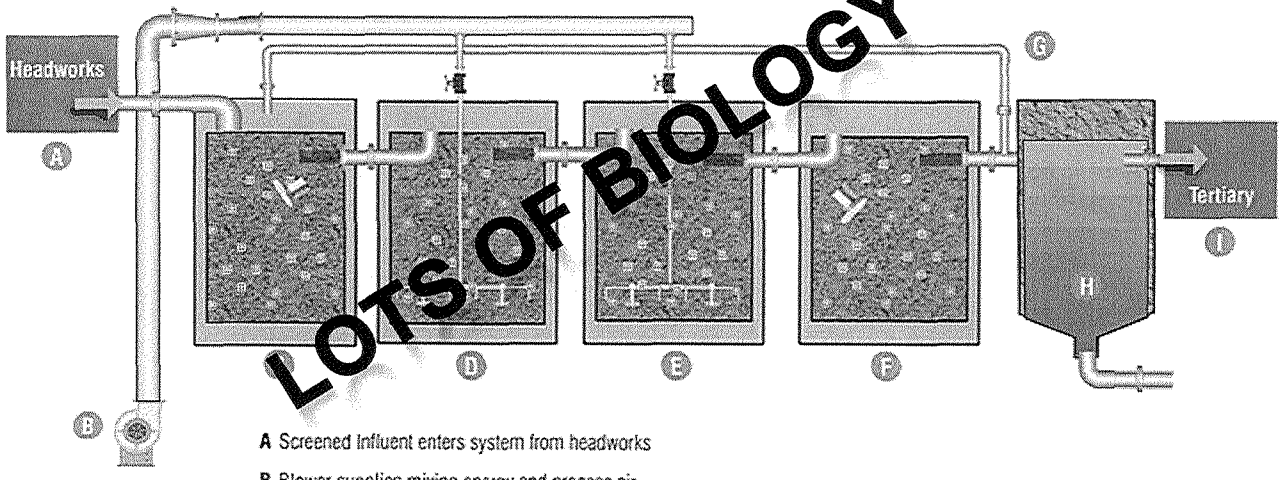
IMAGES COURTESY OF WEI ZHENG

EFFLUENT INTO CREEK

SAND TANK

Wastewater, called the influent, is pumped from homes to the sewage treatment facility. This water is then pumped through a series of lagoons, either aerated or not, that contain microorganisms to degrade contaminants like pharmeceuticals, personal care products (PPCPs) and hormones. The water is pumped into a sand tank for further filtration, then the effluent is finally discharged into a creek or other body of water.

Biological Wastewater Treatment - Biofilm



A Screened Influent enters system from headworks

B Blower supplies mixing energy and process air

C Anoxic reactor for removal of total nitrogen commonly called de-nitrification (DNIT)

D Biochemical oxygen demand (BOD) reduction reactor

E and **F** Nitrification (NIT) to reduce the ammonia limits and prepare the recycle stream

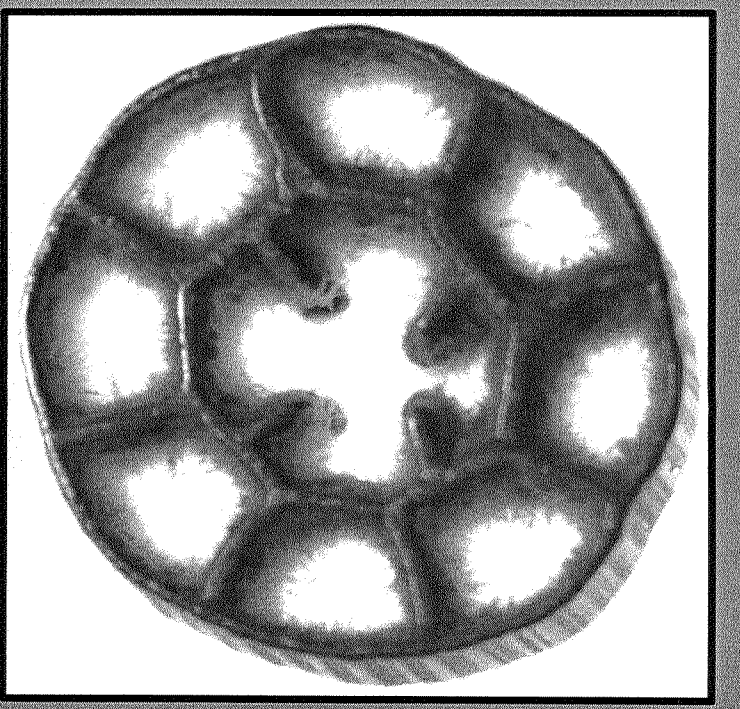
G Return flow back to the anoxic unit **C** for de-nitrification

H Clarification follows the treatment process to remove suspended solids from the treated wastewater (ie: DAF, Lamella, settler, etc.)

I Optional tertiary treatment (ie: UV disinfection, sand filter etc.)

Biological Wastewater Treatment - Biofilm

- The biofilm process is a process which uses a biofilm (fixed) for the purposes of filtration, bioremediation, or barrier formation.
- Biofilms are particularly effective due to the complex matrix structure which protects inner cells, facilitates communication and interactions amongst the cells, and allows for growth through cell division and adhesion.



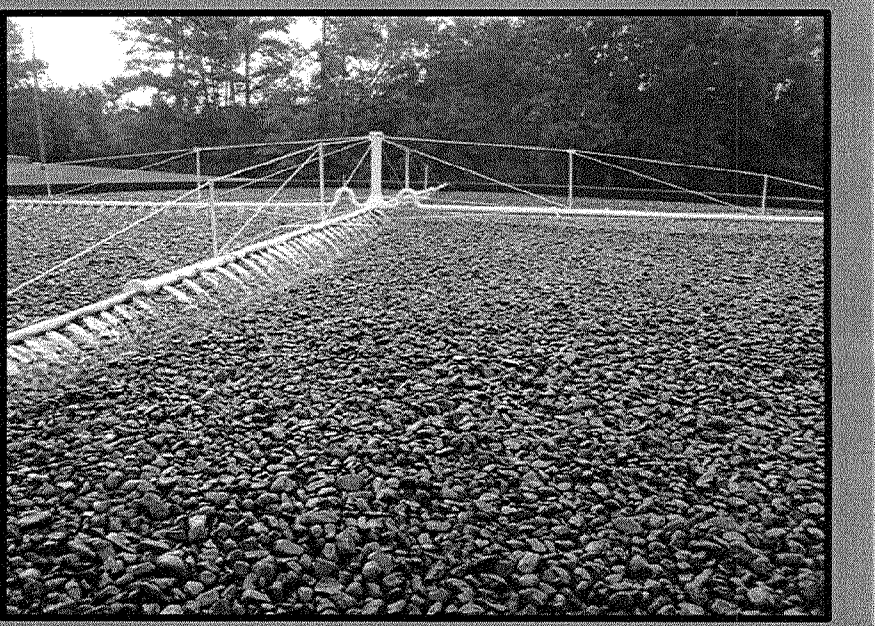
Biological Wastewater Treatment - Biofilm

- For wastewater treatment, biofilms can be grown on filters, which provide protection and close contact with neighboring microbes, to be used in the treatment process.
- By running the wastewater over the filters, the biofilm will be able to break down and extract some undesirable organic compounds.

City of Batesville

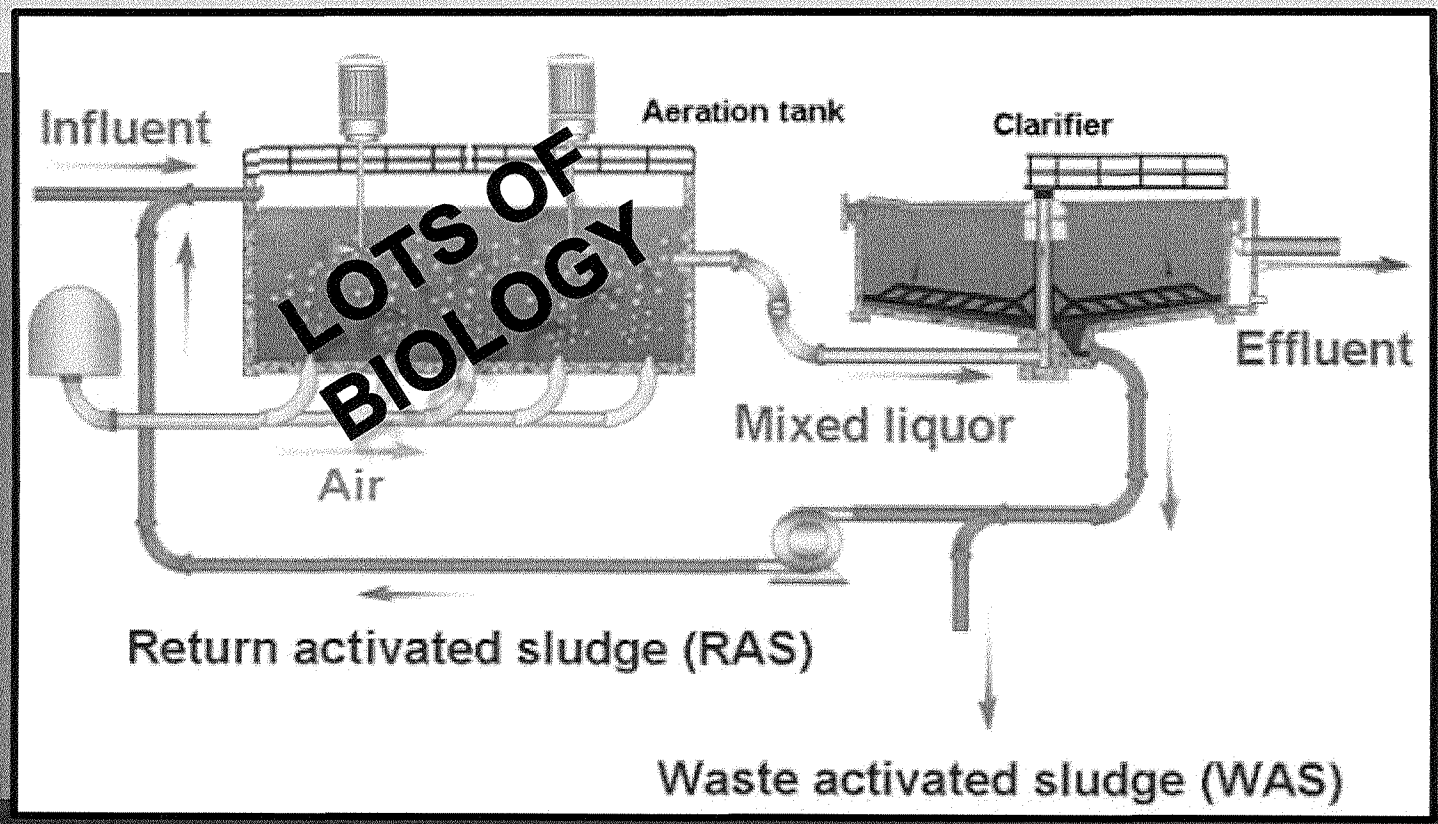
Biological Wastewater Treatment - Biofilm

- Not as susceptible to washout as a suspended growth (standard activated sludge or lagoon) system.
- Fixed film methods need less maintenance and control, are more resilient, and are appropriate where cost and maintenance are major issues.



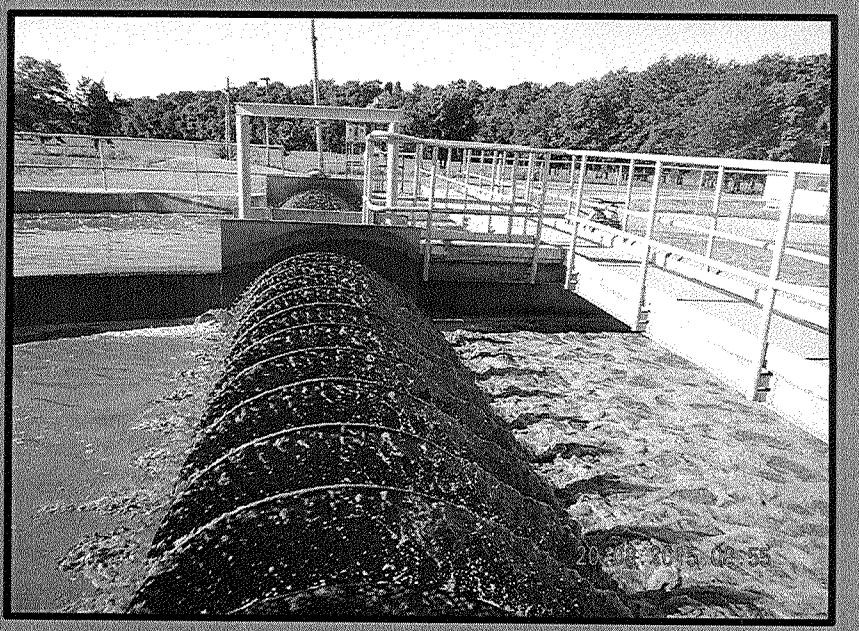
Shumaker Public Service Corp

Biological Wastewater Treatment - Activated Sludge



Biological Wastewater Treatment - Activated Sludge

- Activated sludge is a multi-chamber reactor unit that makes use of (mostly) aerobic microorganisms to degrade organics in wastewater and to produce a high-quality effluent.
- The microorganisms oxidize the organic carbon in the wastewater to produce new cells, carbon dioxide, and water.



City of Van Buren – North Plant

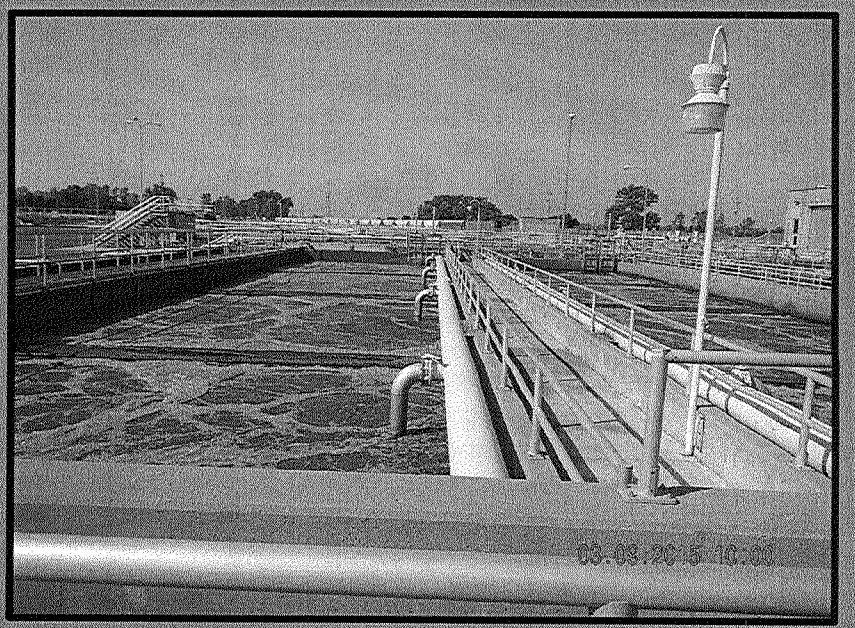
Biological Wastewater Treatment - Activated Sludge

- Activated sludge processes are one part of a complex treatment system.
- This technology is effective for the treatment of large volumes of flows.

City of Green Forest

Biological Wastewater Treatment - Activated Sludge

- Highly trained staff is required for maintenance and trouble-shooting.
- The activated sludge process is appropriate for almost every climate.



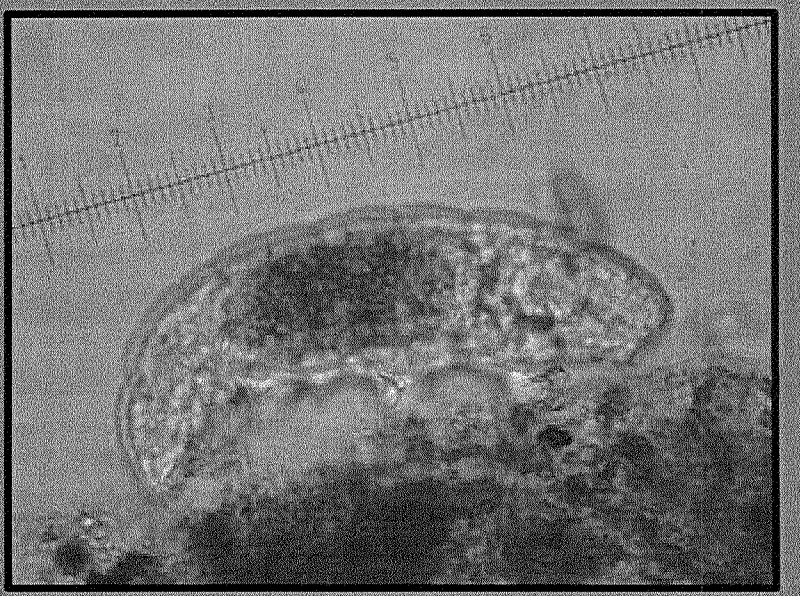
City of Fort Smith – "P" Street

Part III

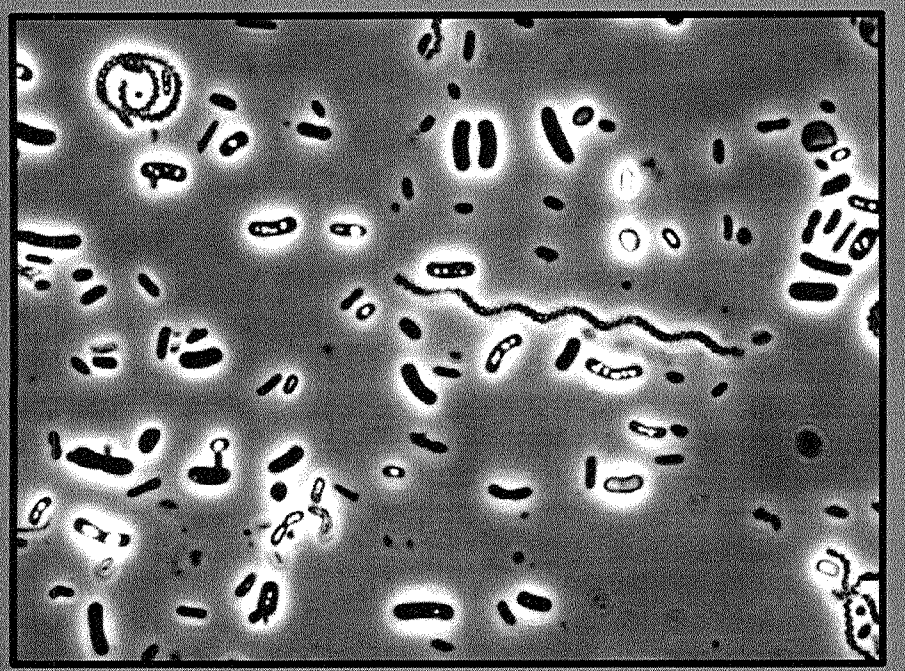
THE BIOLOGICAL "PLAYERS" INVOLVED WITH WASTEWATER TREATMENT

Major Biological Players in Wastewater Treatment

- Bacteria (unicellular; aerobic and anaerobic); includes cyanobacteria (blue-green algae).
- Protists (unicellular); includes molds and algae.
- Higher (multicellular) organisms of the Fungi, Animal, and Plant Kingdoms.



Bacteria



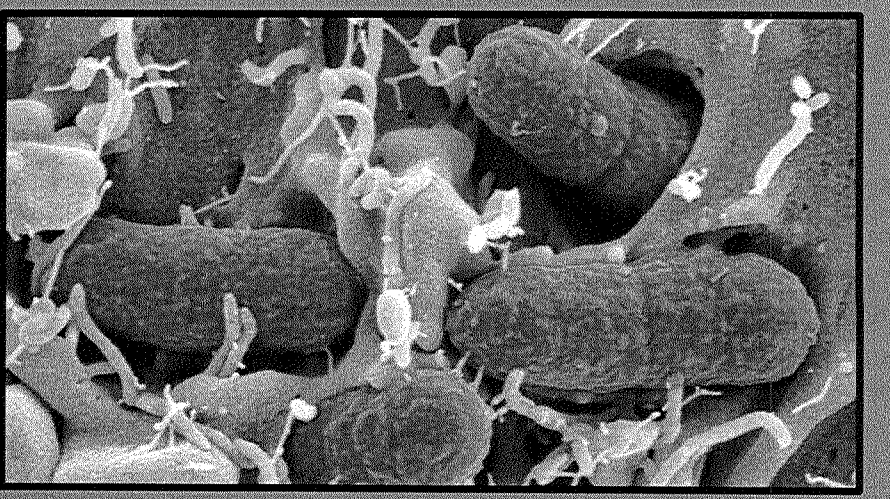
Bacteria are unicellular, prokaryotic (without a nucleus; DNA is free within the cell) organisms.

Three basic shapes: spheres, spirals, and rods.

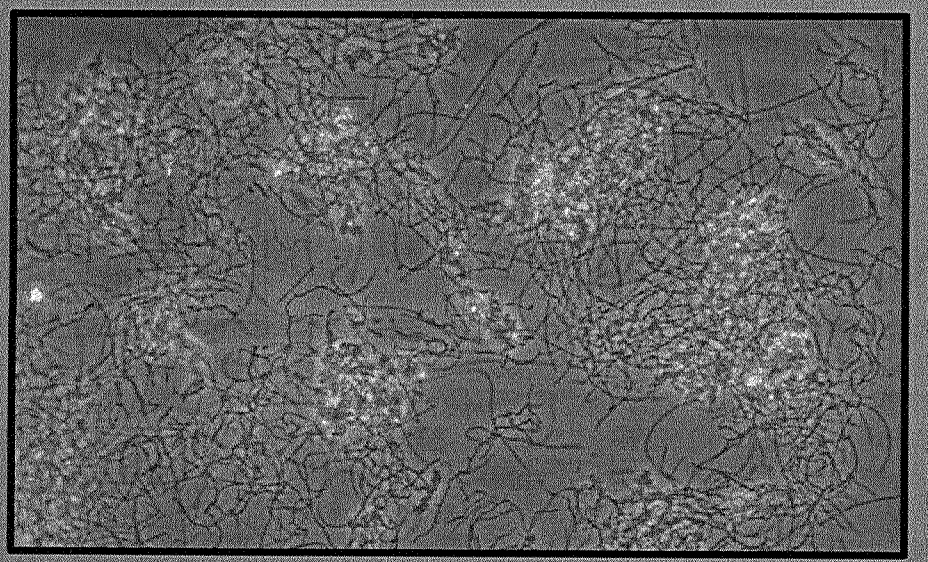
"Bugs"

Bacteria

- Bacteria were among the first life forms to appear on Earth and are present in most of its habitats – they are everywhere.
- Bacteria also live in symbiotic (beneficial) and parasitic (harmful) relationships with plants and animals.



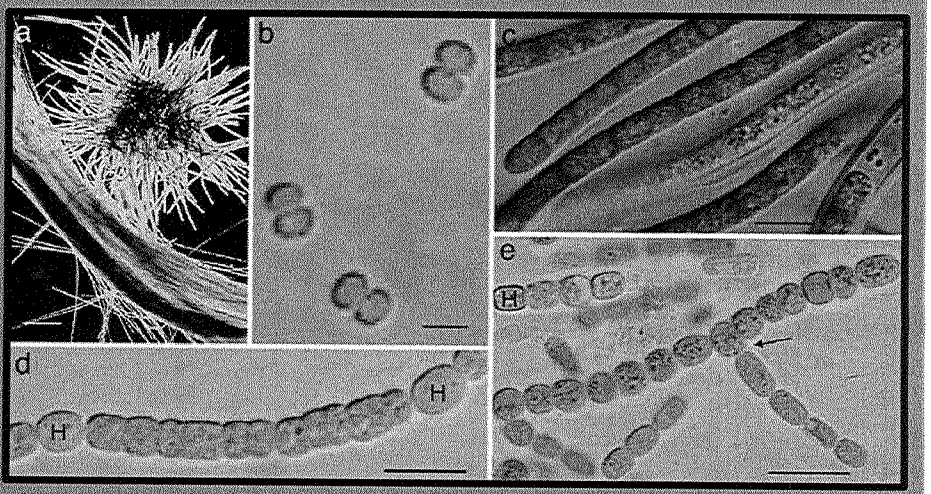
Bacteria



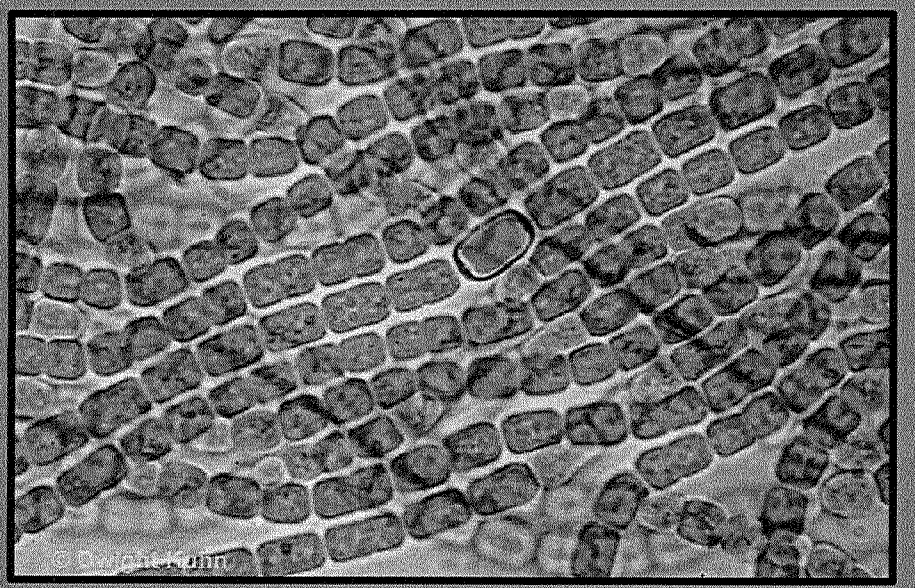
- Bacteria are vital in recycling nutrients, with many of the stages in nutrient cycles dependent on these organisms, such as the fixation of nitrogen from the atmosphere and putrefaction.

Bacteria

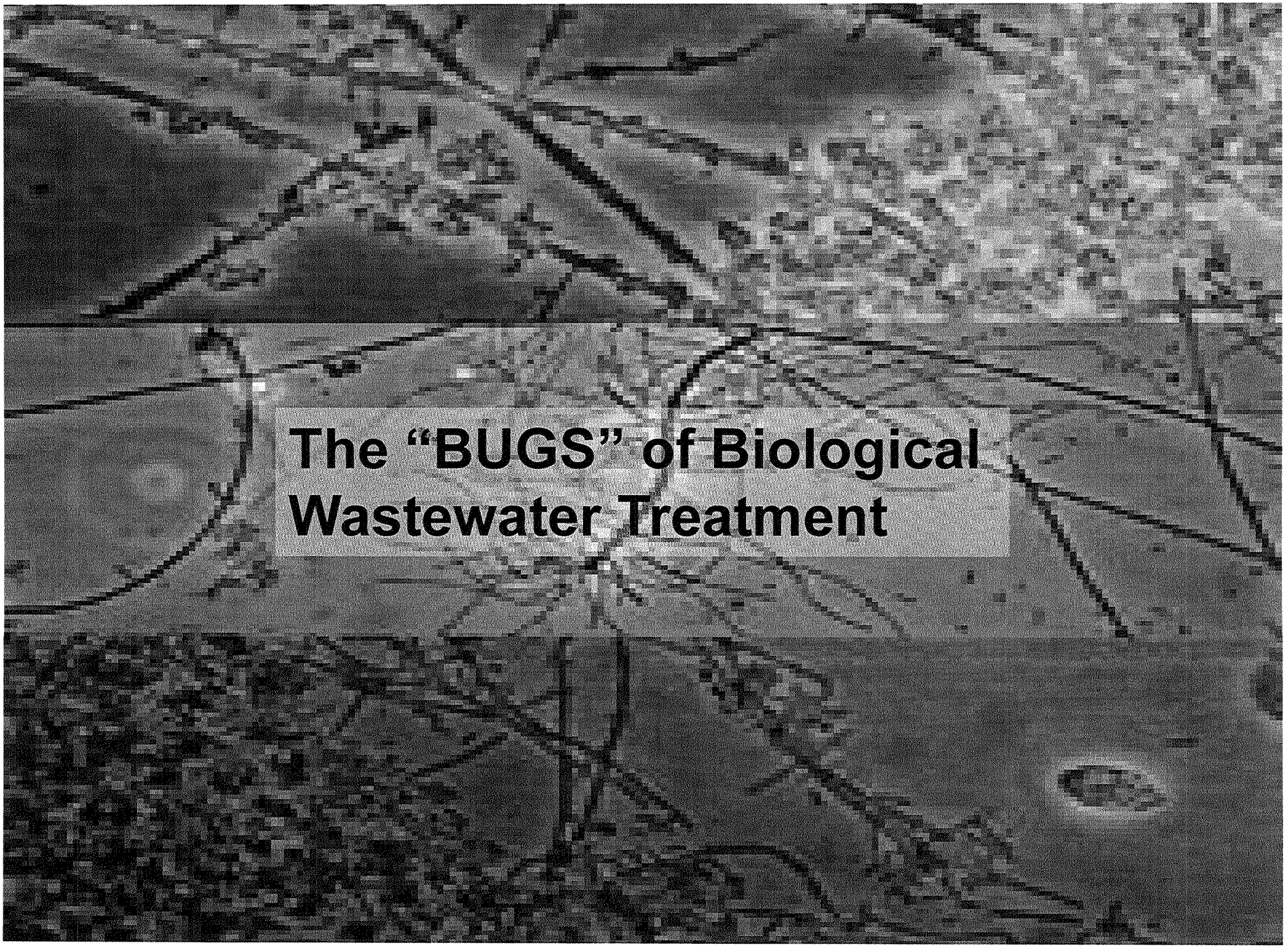
- Cyanobacteria are a group of photosynthetic, nitrogen fixing bacteria that live in a wide variety of habitats such as moist soils and in water.
- They range from unicellular to filamentous and include colonial species.



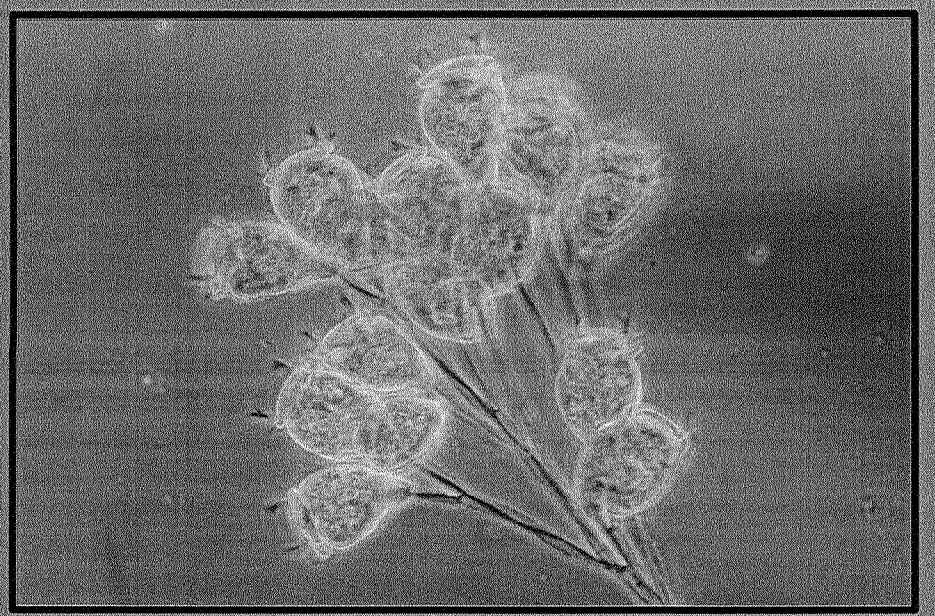
Bacteria



- Cyanobacteria can fix atmospheric nitrogen in anaerobic conditions by means of specialized cells called heterocysts.
- They fix nitrogen gas into ammonia (NH_3), nitrites (NO_2), or nitrates (NO_3).
- Some cyanobacteria can be toxic; Harmful Algal Blooms.


The "BUGS" of Biological
Wastewater Treatment

Protists

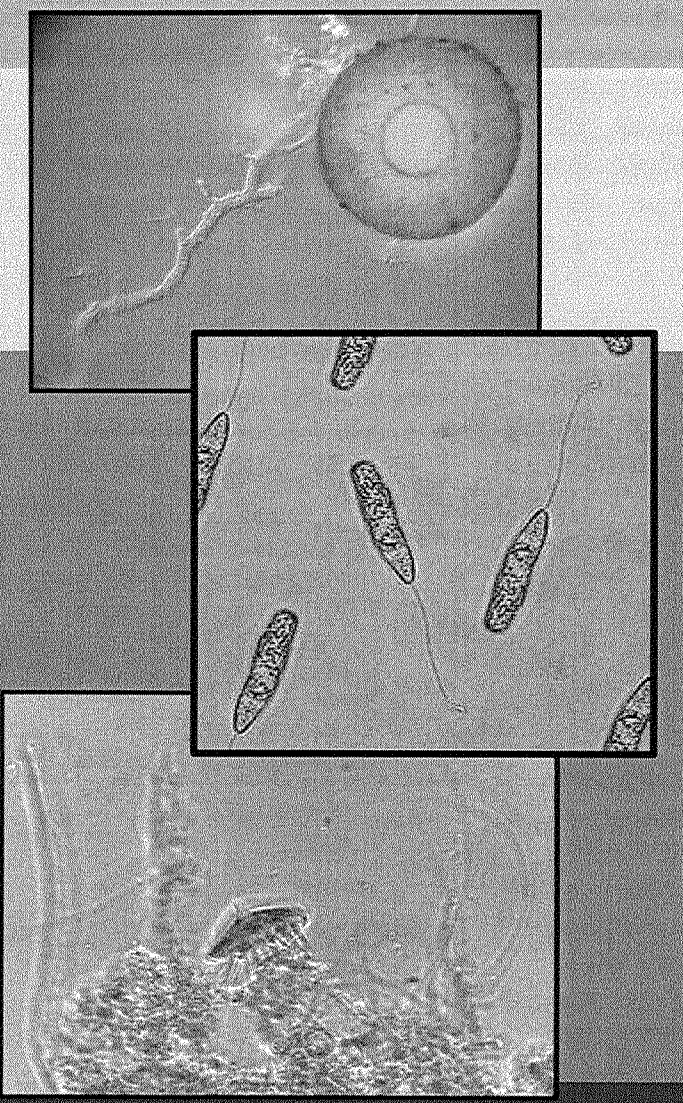


Protists are a diverse group of unicellular, eukaryotic (DNA contained in a nucleus) organisms.

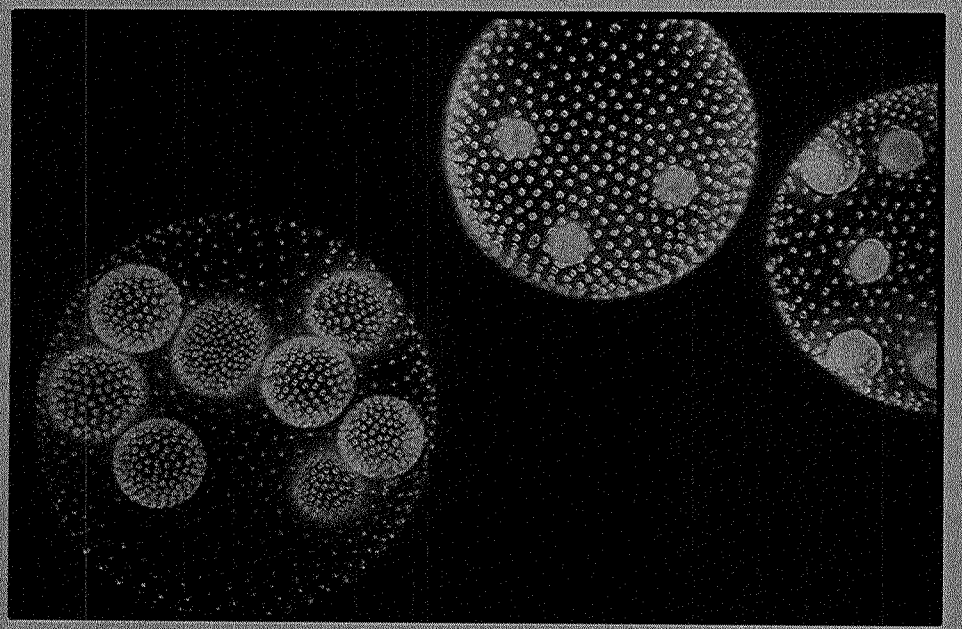
Protists live in almost any environment that contains liquid water.

Protists

- They can be heterotrophic (eat other living things), autotrophic (make food), or saprophytic (eat dead things).
- Protozoa are animal-like: flagellated, ciliated, and amoeboid.
- Protophyta are plant-like (contain chlorophyll): algae.
- Molds are fungus-like.



Protists

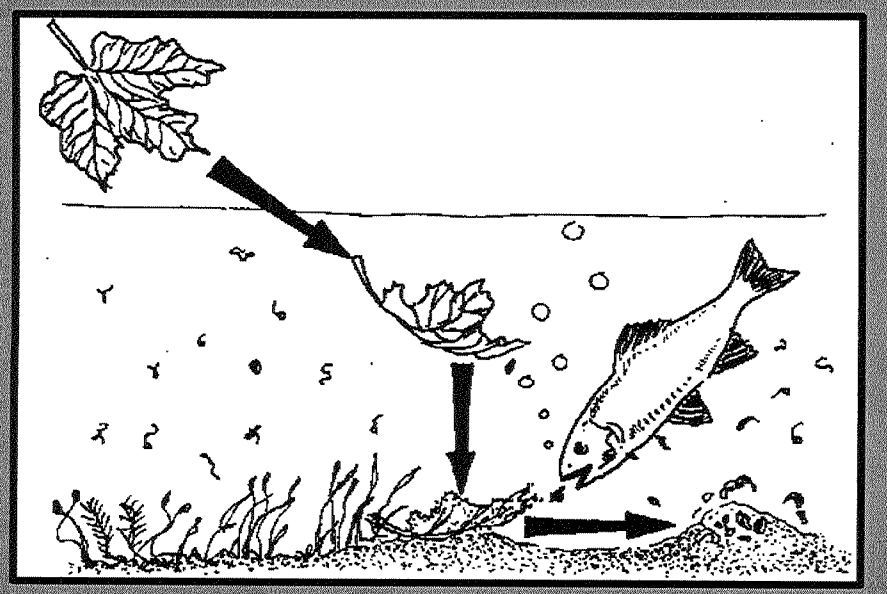


- Autotrophic protists (algae) are primary producers in aquatic ecosystems.
- These protists can also be responsible for algal blooms.

Protists

- Some protists are pathogenic/parasitic.
- The following protists cause waterborne diseases: *Amoebiasis*, *Cryptosporidiosis*, *Cyclosporiasis*, *Giardiasis*, and *Microsporidiosis*.

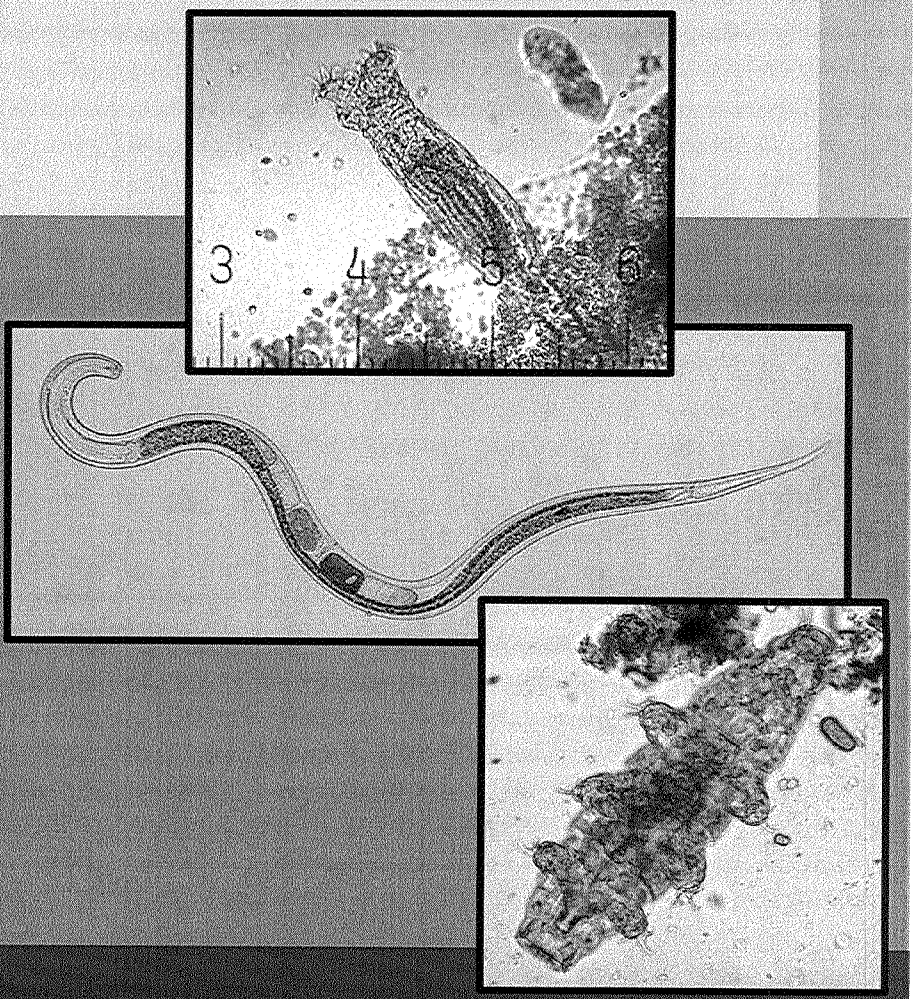
Fungi



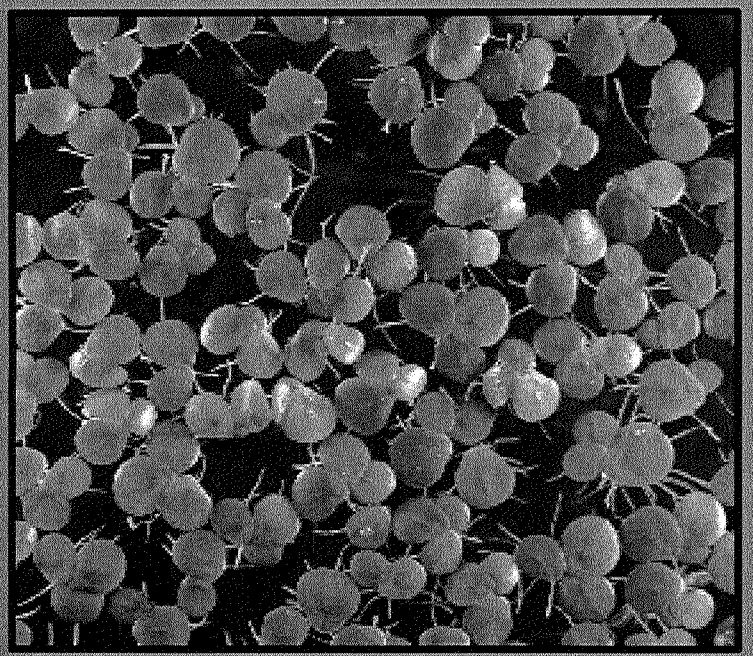
- Fungi are multicellular, eukaryotic organisms.
- They are unique in that their cell walls contain chitin.
- They are heterotrophic and are mainly decomposers.

Animals

- Animals are multicellular, eukaryotic organisms.
- All heterotrophic.
- Separated into two main groups: invertebrates (soft-bodied) and vertebrates (internal skeletal support).
- Top of the wastewater food web and can indicate an old sludge age.



Plants



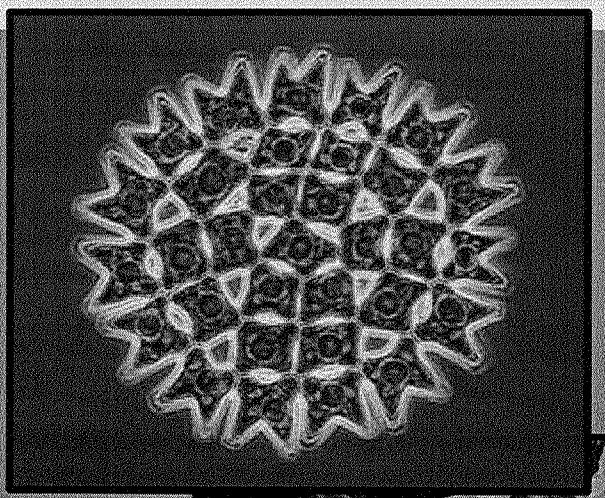
- Plants are multicellular, eukaryotic organisms.
- All autotrophic.
- Separated into two main groups: cone-bearing and flowering.
- Excellent at removing nutrients such as P, K, and N.

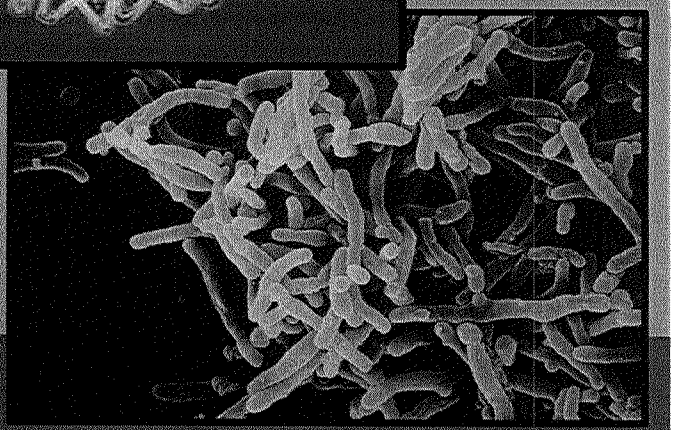
Part IV

COMMON BIOLOGICAL PROBLEMS WITH WASTEWATER TREATMENT

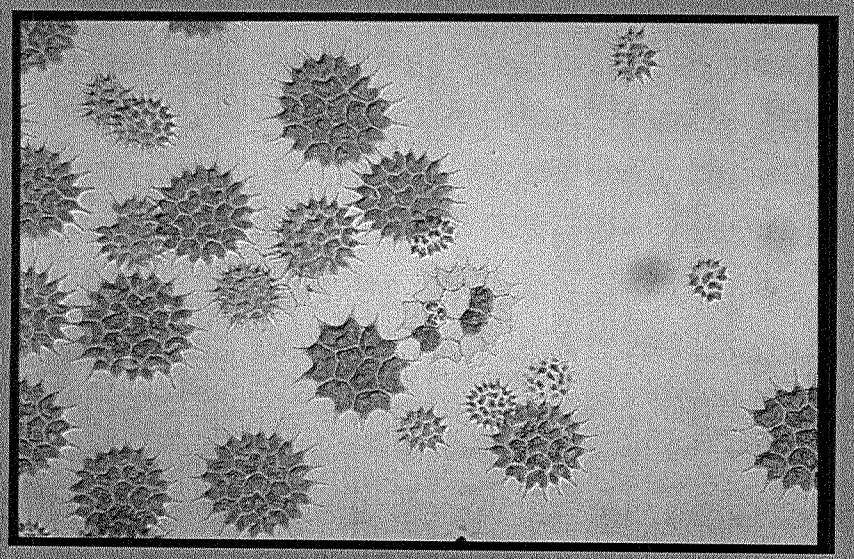
Common Biological Problems with Wastewater Treatment

- It comes down to two main players: bacteria and algae, which can be beneficial and problematic.
- Algae can be problematic in lagoon systems.
- Bacteria can be problematic in (fixed) biofilm and (suspended) activated sludge systems.
- It's about the perfect balance – these two can get out of hand very quickly.

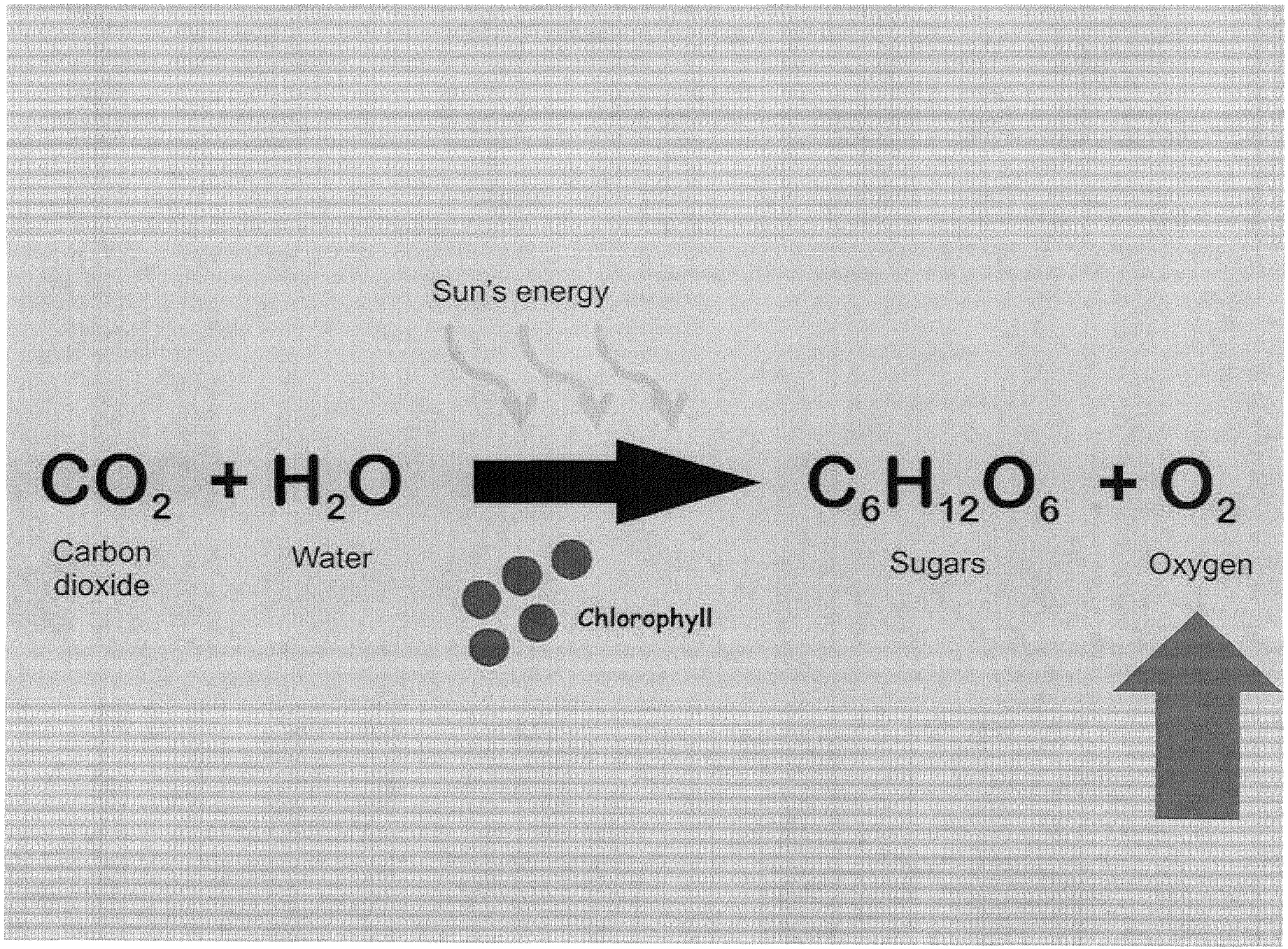




Algal Problems in Lagoon Systems

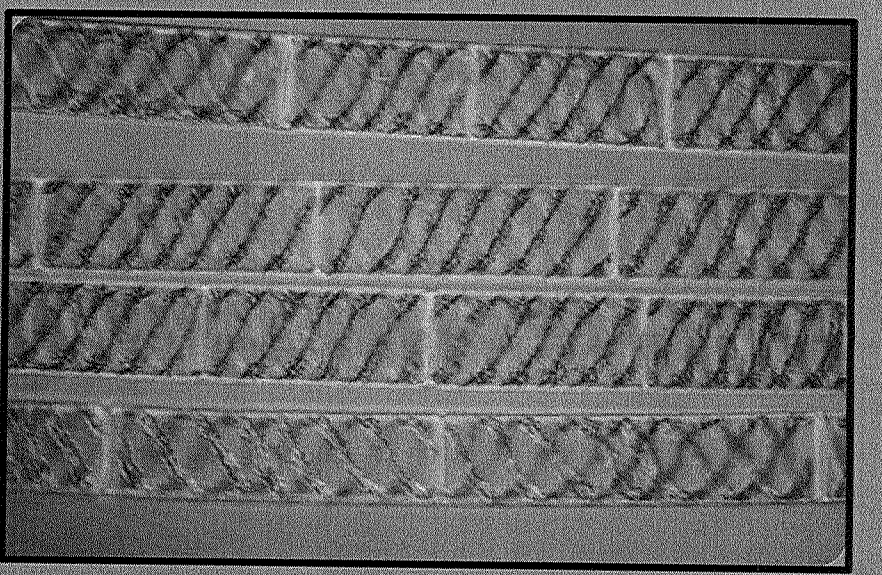


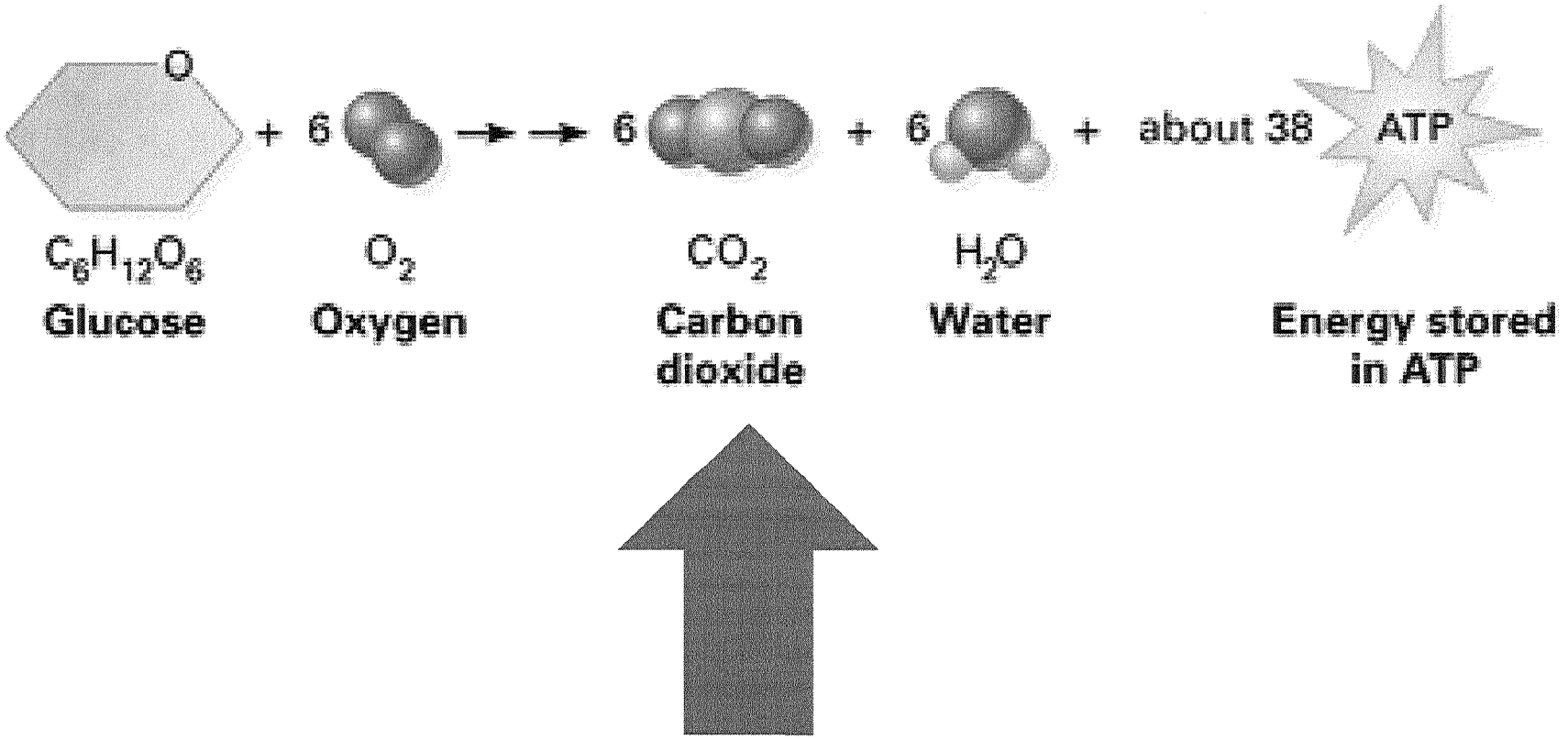
- Due to the openness and depths of lagoon systems, this inhibits the growth of pathogenic bacteria (sun's UV naturally disinfects); however, it facilitates the growth of algae.
- Algae are producers and make their own food (glucose) during the day through photosynthesis.
- This process of photosynthesis also generates oxygen (O_2).


Sun's energy
CO_2 + H_2O
Carbon dioxide
Water
Chlorophyll
$C_6H_{12}O_6$ + O_2
Sugars
Oxygen

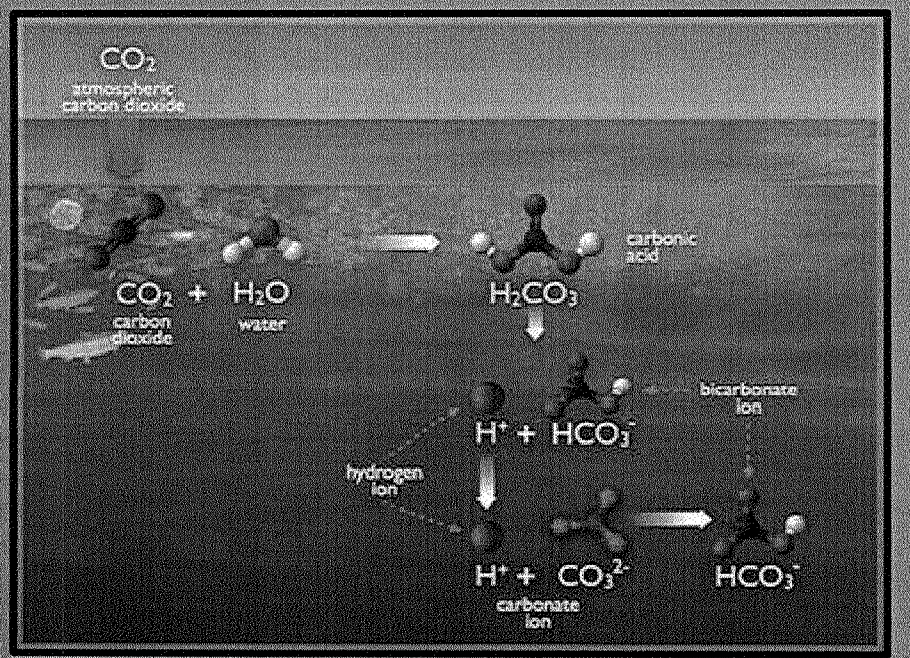
Algal Problems in Lagoon Systems

- However, during the night when the sun is down, algae go through respiration, which consumes O2 and generates carbon dioxide (CO2).
- Oxygen levels in the lagoon can drop considerably during the night.

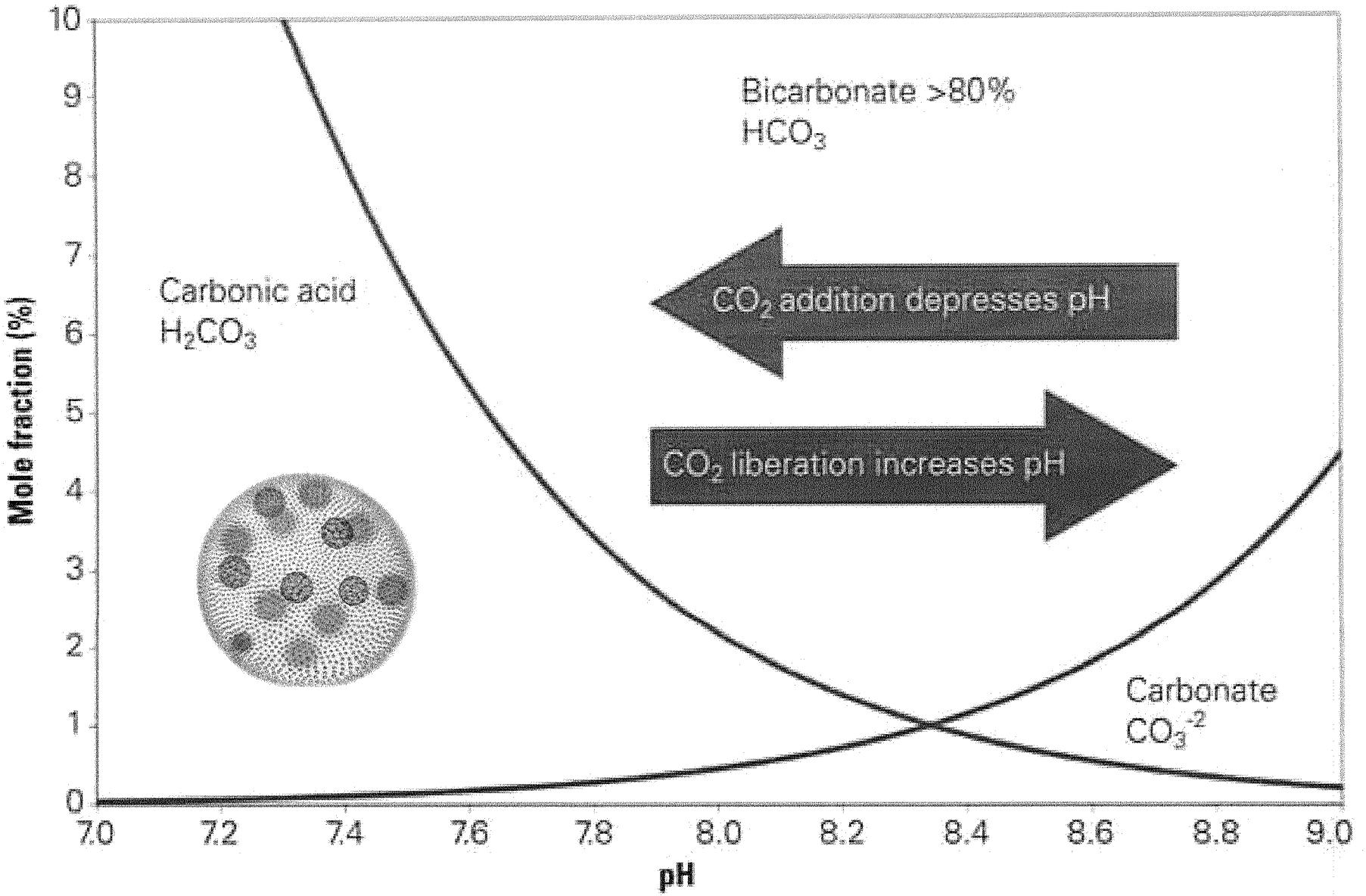



O
+ 6
6
+ 6
+ about 38
ATP
$C_6H_{12}O_6$
Glucose
O_2
Oxygen
CO_2
Carbon dioxide
H_2O
Water
Energy stored in ATP

Algal Problems in Lagoon Systems

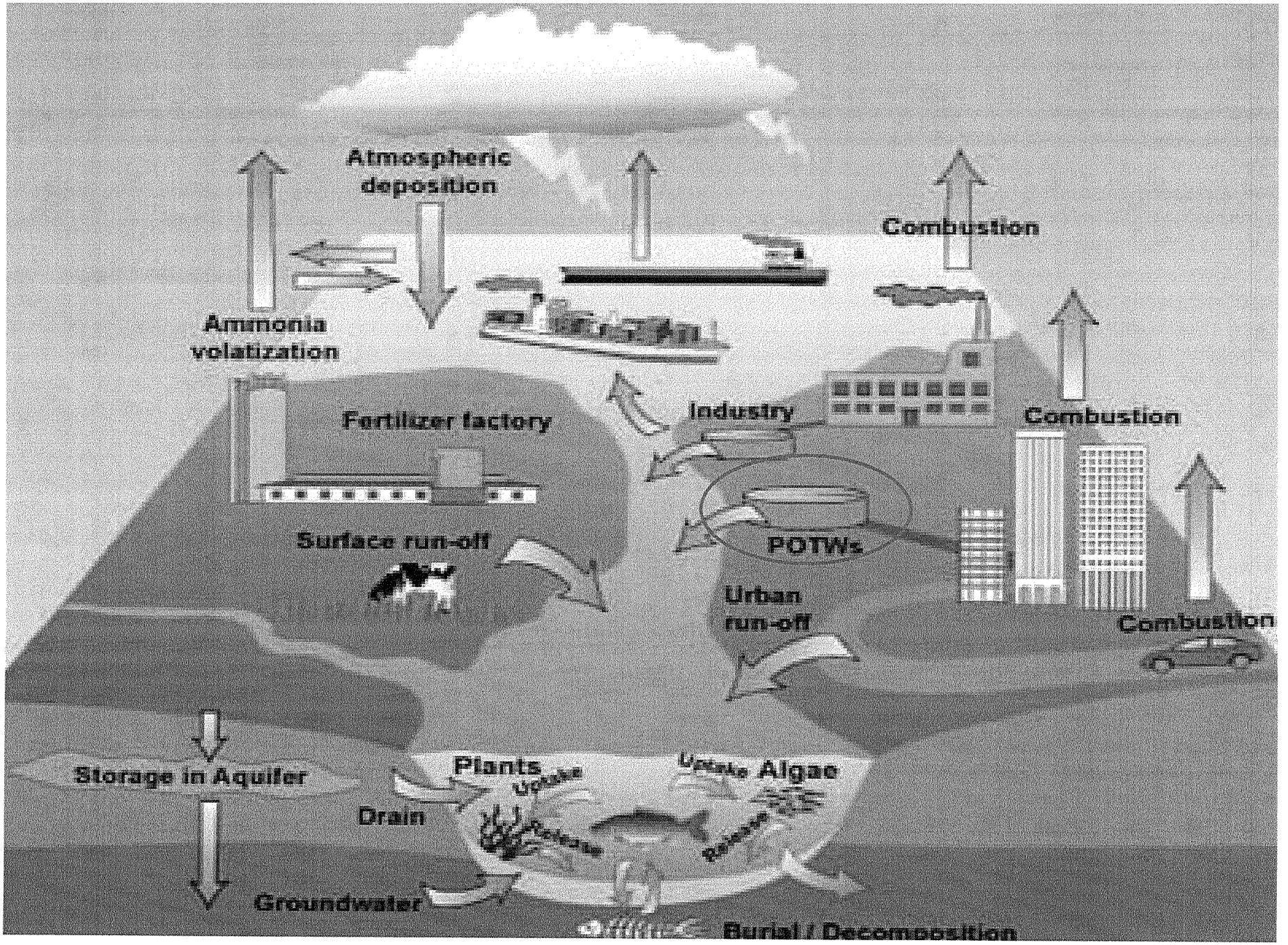


- CO2 affects pH and alkalinity.
- An increase in CO2 decreases pH (becomes more acidic).
- In turn, this affects alkalinity (water's buffering ability).


Mole fraction (%)
10
9
8
7
6
5
4
3
2
1
0
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
8.6
8.8
9.0
pH
Bicarbonate >80%
HCO_3
Carbonic acid
H_2CO_3
CO_2 addition depresses pH
CO_2 liberation increases pH
Carbonate
CO_3^{-2}

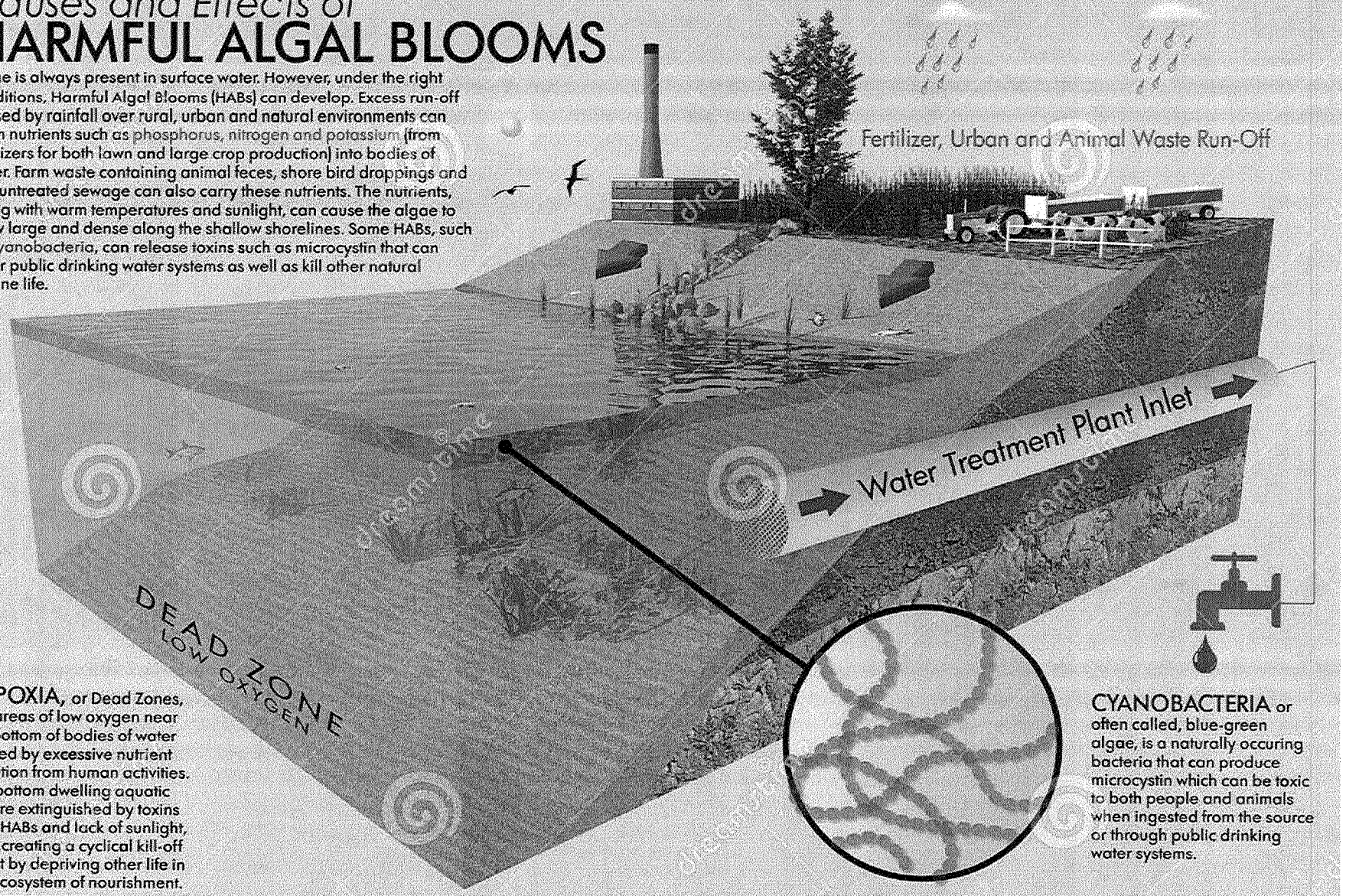
Algal Problems in Lagoon Systems

- Algae, like other autotrophic organisms, require essential nutrients: Phosphorus (P), Potassium (K), and Nitrogen (N).
- These nutrients are used in internal processes and to generate new cells.
- Excessive nutrients can cause a "bloom" or massive growth of algal cells.
- Cyanobacteria (blue-green algae) produce a toxin (microcystin) under certain conditions and are responsible for HABs.


Atmospheric deposition
Combustion
Ammonia volatization
Fertilizer factory
Industry
Combustion
Surface run-off
POTWs
Urban run-off
Combustion
Storage in Aquifer
Plants
Algae
Drain
Groundwater
Burial / Decomposition

Causes and Effects of
HARMFUL ALGAL BLOOMS

Algae is always present in surface water. However, under the right conditions, Harmful Algal Blooms (HABs) can develop. Excess run-off caused by rainfall over rural, urban and natural environments can wash nutrients such as phosphorus, nitrogen and potassium (from fertilizers for both lawn and large crop production) into bodies of water. Farm waste containing animal feces, shore bird droppings and raw untreated sewage can also carry these nutrients. The nutrients, along with warm temperatures and sunlight, can cause the algae to grow large and dense along the shallow shorelines. Some HABs, such as cyanobacteria, can release toxins such as microcystin that can enter public drinking water systems as well as kill other natural marine life.



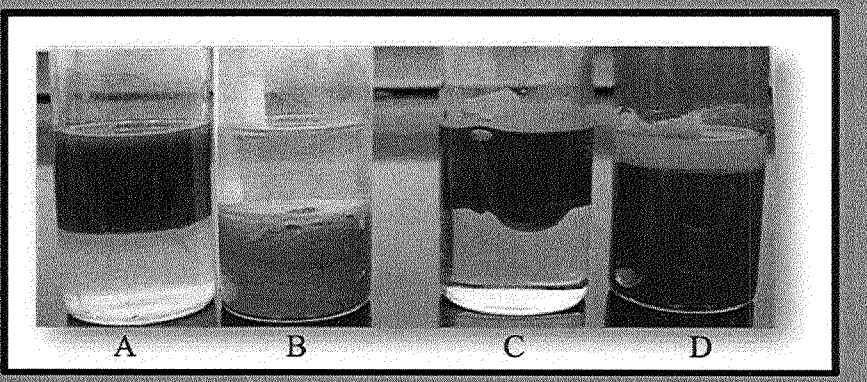
HYPOXIA, or Dead Zones, are areas of low oxygen near the bottom of bodies of water caused by excessive nutrient pollution from human activities. The bottom dwelling aquatic life are extinguished by toxins from HABs and lack of sunlight, thus, creating a cyclical kill-off effect by depriving other life in the ecosystem of nourishment.

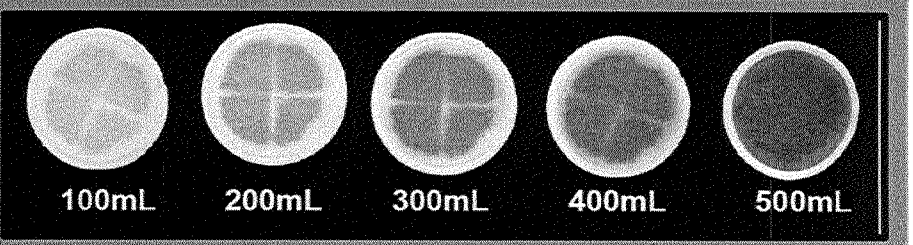
CYANOBACTERIA or often called, blue-green algae, is a naturally occuring bacteria that can produce microcystin which can be toxic to both people and animals when ingested from the source or through public drinking water systems.

AWRC Water Conference – Annual Conference 2016 agenda concerning HABs and Water Quality
July 26- 27, 2016
http://arkansas-water-center.uark.edu/annualconferences.php

Algal Problems in Lagoon Systems

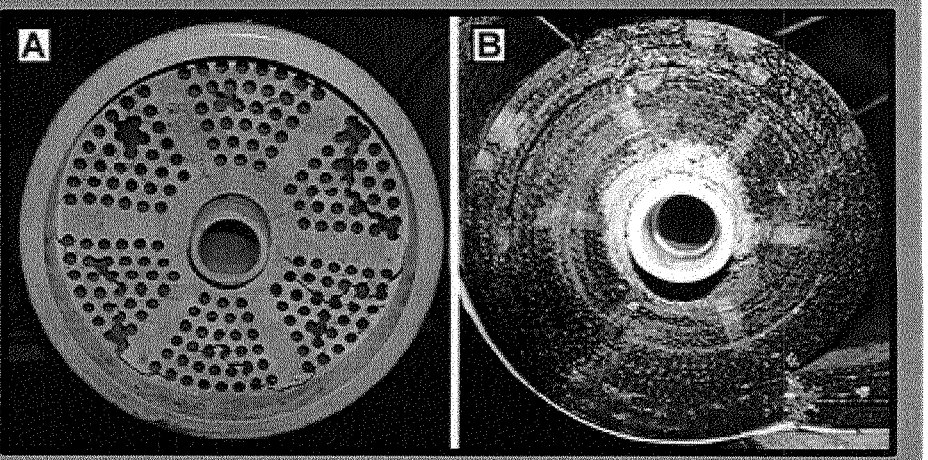
- Algae can contribute to Total Suspended Solids (TSS) at the final effluent.
- This can be problematic based on the effluent limits.



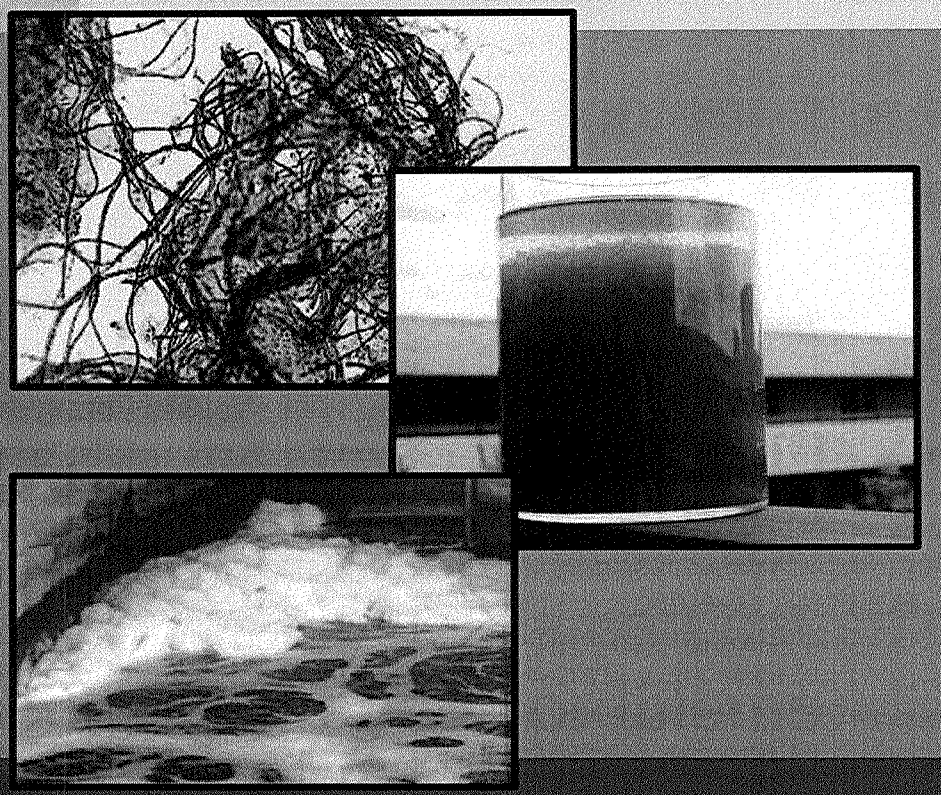


Biofouling in Biofilm Reactor Systems

- Biofouling is the accumulation of micro and macro-organisms on reactor media.
- Biofouling leads to clogging, short-circuiting, and poor effluent quality.



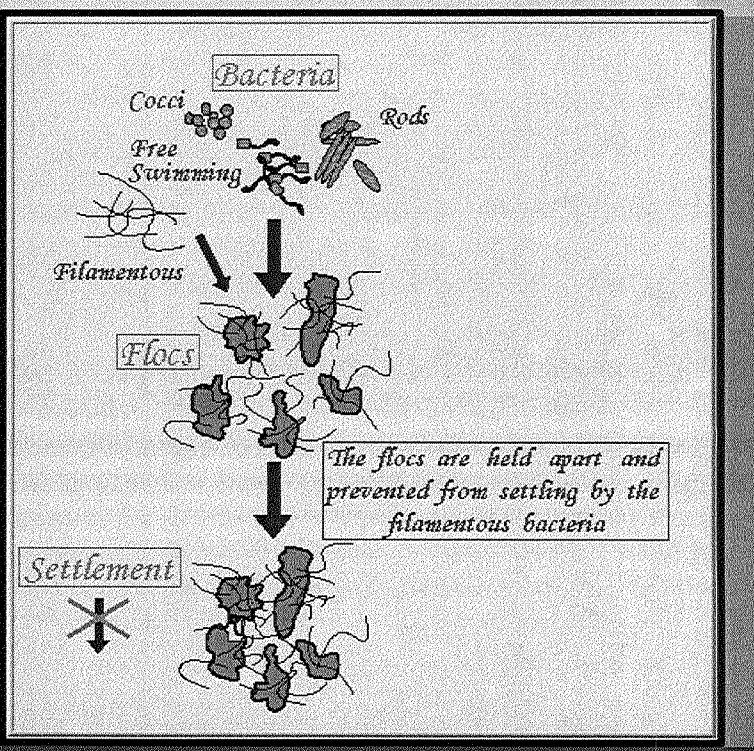
Bacterial Problems in Activated Sludge Systems



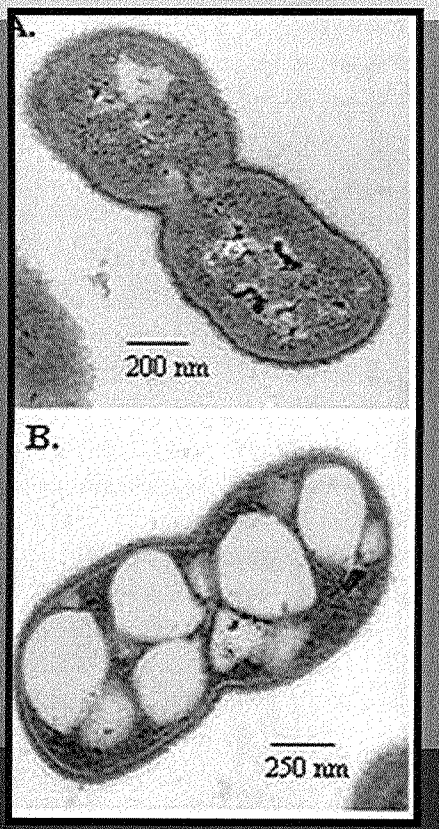
- The majority of bacteria involved with activated sludge is beneficial.
- However, filamentous bacteria such as *Nocardia* can cause serious problems.

Bacterial Problems in Activated Sludge Systems

- Filamentous bacteria are opportunistic and can take hold of a plant if there has been a disturbance (upset).
- These bacteria do not allow for proper flocculation and settling.
- They cause foaming and bulking.

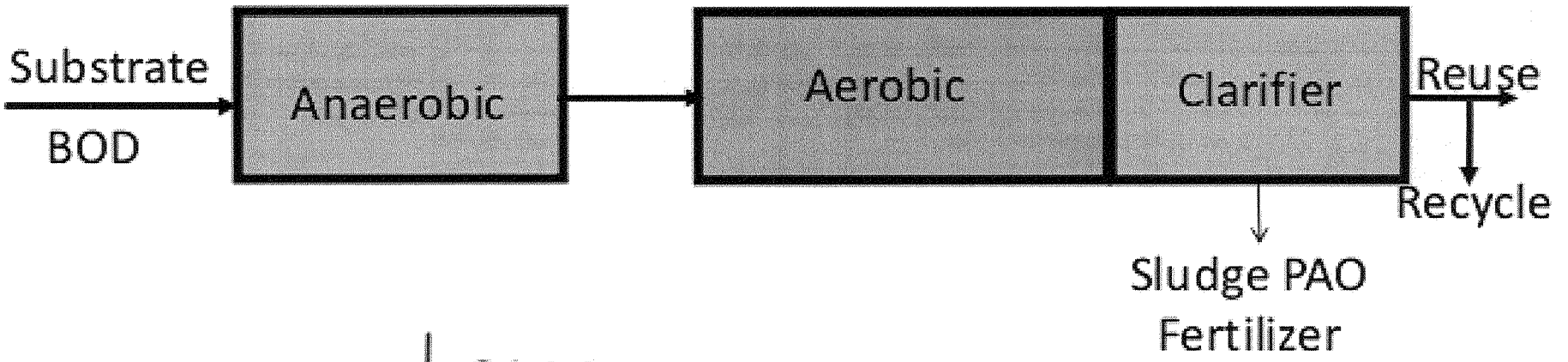


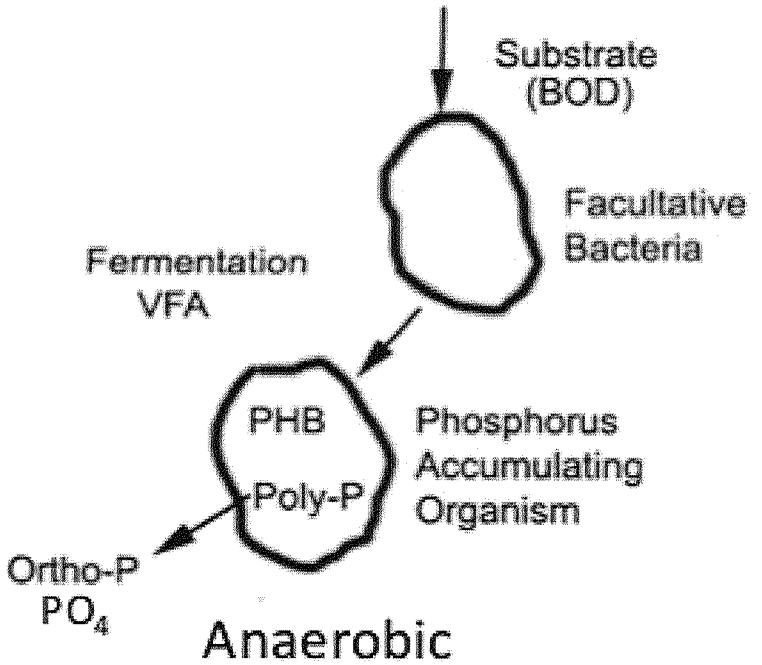
Bacterial Problems in Activated Sludge Systems

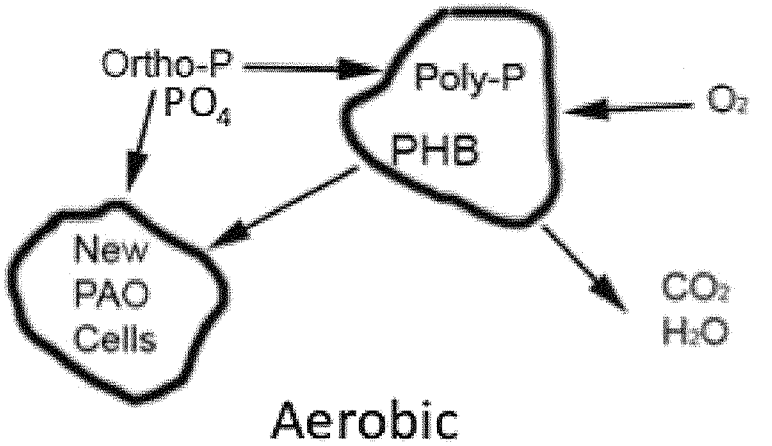


- If provided the proper conditions, certain types of bacteria can provide biological removal of nutrients such as Phosphorus and Nitrogen.
- It is difficult for these species to thrive if there are too many of a dominate species.

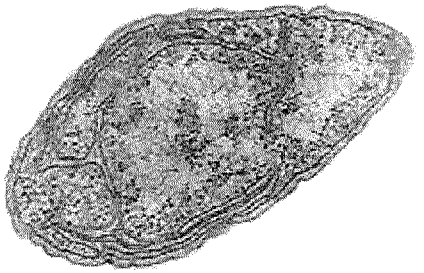
Biological Phosphorus Removal

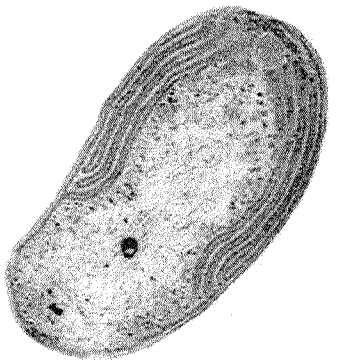






Nitrification





Nitrification of Ammonia Occurs in Two Steps

NH_3-N
Ammonia N

→

NO_2-N
Nitrite N

Nitrosomonas

NO_2-N
Nitrite N

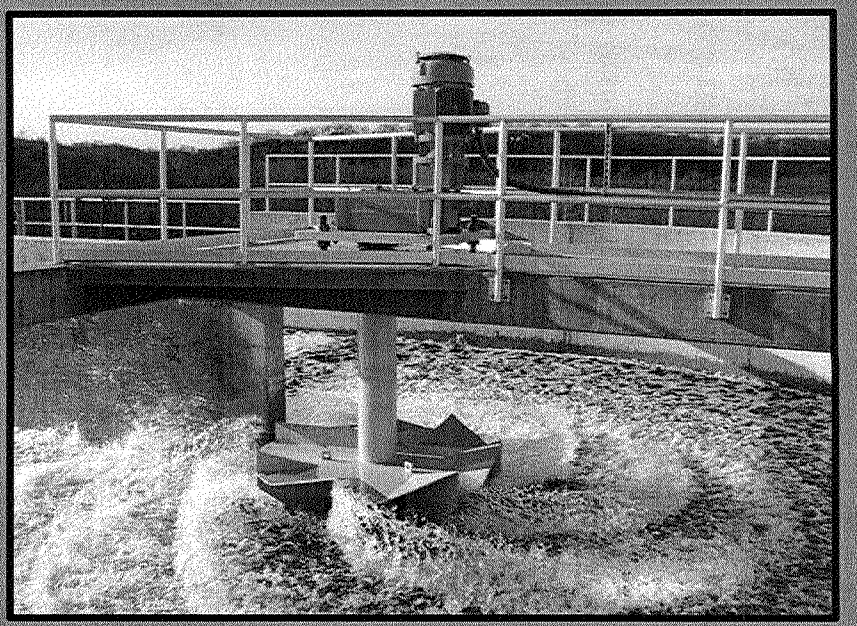
→

NO_3-N
Nitrate N

Nitrobacter

Controlling Biological Problems

- There are many ways to control biological problems associated with wastewater treatment:
- Proper operation and maintenance (O&M)
- Hire a consultant
- Mechanical removal
- Aeration (provide O2 & remove CO2)



Controlling Biological Problems

- Commercial products
- Chemical additions
- Bio-selection (provide conditions that favor one organism over another)
- Bio-control (uses another organism to control problem organism's population)

At this time, I'll take questions/comments related to the topic.