Sustainable Water Integrated Management - Support Mechanism (SWIM- SM)

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

Project funded by the European Union

STUDY TOUR ON WASTEWATER MANAGEMENT
USING NATURAL TREATMENT SYSTEMS (NTS) IN RURAL AREAS

Introduction to different types of NTSs with some comparative analysis

Salvatore Barbagallo, Giuseppe L. Cirelli ,
Alessia Marzo, Mirco Milani, Attilio Toscano

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

Catania, (Italy) 27 July 2015

Introduction

Different types of NTSs

- Constructed Wetland
    - Surface flow (SF) or free water surface (FW)
    - Subsurface horizontal flow (HSSF, HF)
    - Vertical flow (VF)
- Waste Stabilization Ponds
    - Anaerobic ponds
    - Facultative ponds
    - maturation ponds
- Wastewater storage reservoir
    - Continuous-flow single reservoirs
    - A single batch reservoir
    - Sequential batch reservoir

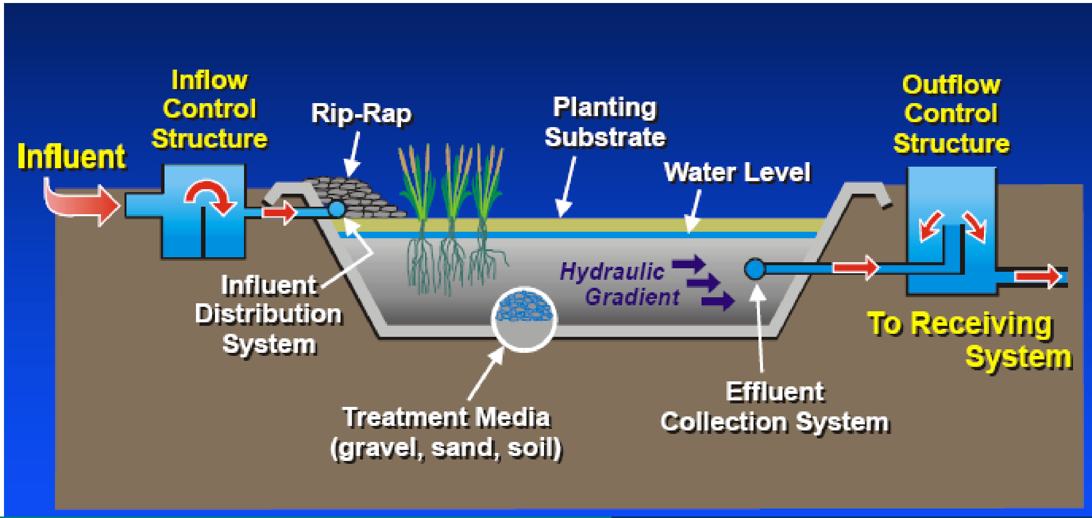
Constructed Wetland

National experience and capacity needs for the construction and operation of NTSs

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

Constructed Wetland

- Constructed wetlands are designed to emphasize specific characteristics of the natural wetland environment, aiming to improve the overall treatment capacity of the system
- Treatment is the result of complex interactions between
  - Sediment / gravel bed
  - Root zone / pore water
  - Litter / detritus
  - Water
  - Air
  - Plants
  - Roots
  - Bacteria growing in biofilms



Wastewater treatment mechanisms (slide 1 of 2)

- **BOD removal**
  - particulate BOD by settling and filtration, then converted to soluble BOD by hydrolysis
  - soluble BOD due to degradation by attached microbial growth (biofilms on stems, roots, gravel particles etc)

- **Suspended solids removal**
  - removal occurs within few meters near inlet by settling and filtration

- **Nitrogen removal**
  - nitrification/denitrification in biofilms
  - plant uptake
  - volatilization as ammonia (at pH > 8.5)

Wastewater treatment mechanisms (slide 2 of 2)

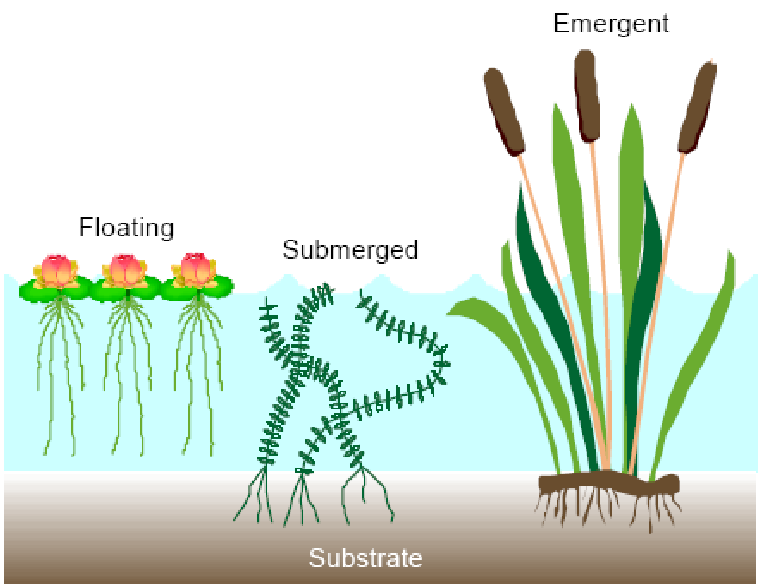
- **Phosphorus removal**
  - plant uptake
  - retention in the soil (adsorption)
  - precipitation with Ca, Al and Fe
- **Pathogen removal**
  - predation by protozoa
  - sedimentation and/or filtration
  - die-off from unfavorable environmental conditions (UV light, pH and temperatures)
- **Heavy metal removal**
  - precipitation and adsorption
  - plant uptake

Constructed Wetlands

- Three types of wetlands are in widespread use:
  - **Surface flow (SF) or free water surface (FW)** wetland have areas of open water and are similar in appearance to natural marshes. they contain areas of open water, floating vegetation, and emergent vegetation. They offer habitat benefits similar to natural wetlands, and invariably attract a variety of wildlife. These wetlands typically are used to polish effluent from secondary treatment processes such as lagoons, trickling filters, or activated sludge systems
  - **Subsurface horizontal flow (HSSF, HF)** wetland, also known as Vegetated submerged Bed (VSB), employ a gravel bed planted with wetland vegetation. The water is kept below the surface of the gravel, and flows horizontally from the inlet to the outlet. The wastewater is treated as it flows through the gravel media and around the roots and rhizomes of the plants. minimized. HSSF wetlands are typically used to treat primary effluent to secondary treatment standards.
  - **Vertical flow (VF)** constructed wetland distribute water across the surface of a sand or gravel bed planted with wetland vegetation. The water percolates down through the plant root zone.

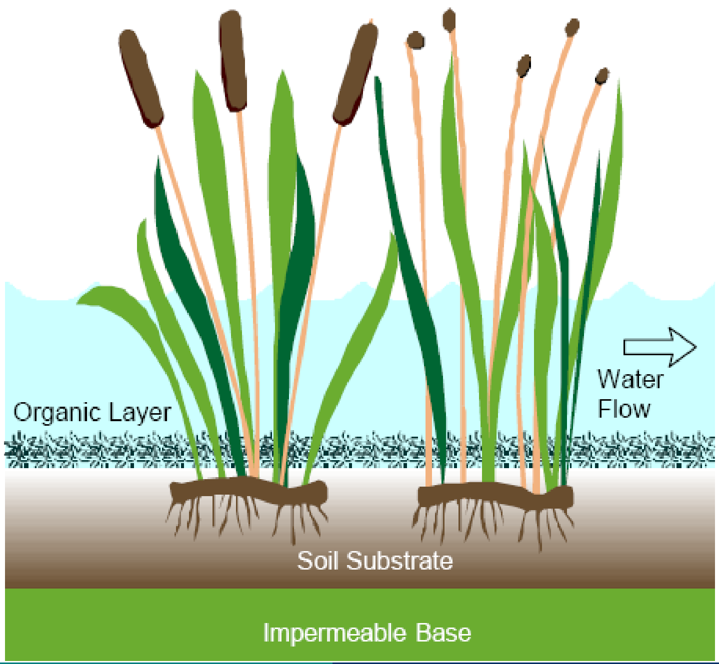
Surface flow (SF) or free water surface (FW)

- The "technology" arose in the 1970s in North America with the ecological engineering of natural wetlands for wastewater treatment
- Free water surface (FWS) constructed wetlands closely resemble natural wetlands in appearance and function, with a combination of open-water areas (water surface is exposed to the atmosphere), emergent, sub emergent and/or floating vegetation, varying water depths, and other typical wetland features
- They offer habitat benefits similar to natural wetlands, and invariably attract a variety of wildlife



Free water surface (FWS)

- These systems can be used for secondary treatment of wastewater, but they are most commonly used as tertiary treatment—that is, to remove nutrients to prevent eutrophication (algae growth) in the receiving water body
- The FWS systems are fed continuously and the wastewater entering the basin is in direct contact with the atmosphere. The upper layer of the stream is in an aerobic condition, while the deeper layers are in anaerobic condiction
- The water depth in this type of wetland can range from a few centimetres to ≤ 0.8 m, depending on the use of the wetland. A normal operating depth of 0.3 m is typical.
- Typical hydraulic loading rates are between 0.7 and 5.0 cm d–1
- Aerobic and anaerobic microorganisms destroy organic material, suspended in the stream or settled on its bottom.
- The nitrogen is removed by ammonification, nitrification, denitrification, ammonia volatilization and vegetal adsorption

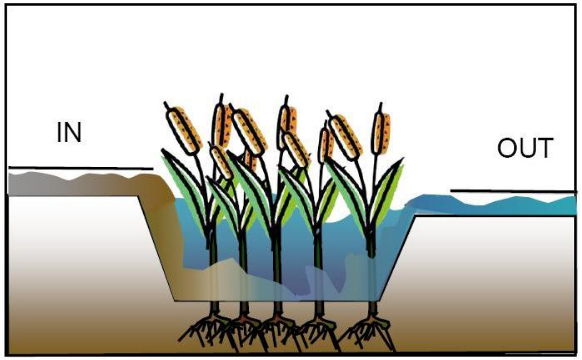


Role of aquatic plants in free water surface (FWS) constructed wetlands

- Nutrient uptake
- Heavy metal accumulation in plant tissue (Note: usually not a problem with domestic wastewater or grey water)
- Habitat for wildlife
- Aesthetics
- Stems = mechanical filter + attachment of biofilm
- Limitation of algal growth by providing shadow
- Reduce water current velocity → increases settling

Free water surface (FWS)

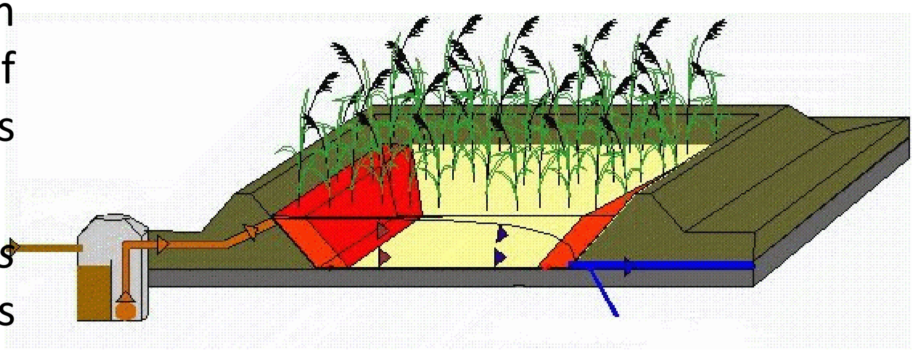
- Perfomances could be affected by the weather conditions
- Environmental impact problems
- Land requirement (> 3-4 m2/PE for a TT)
- Few examples in Italy and Europe, several examples in USA, Australia, India, …….
- Type of plants used:
  - Phragmites, Typha, Juncus, Scirpus, Carex…….)
  - (Lemna, water hyacinth, …..)
  - (Potamogeton, Myriophyllum heterophillum, Elodea)
  - microphytes



Free water surface (FWS)

Subsurface horizontal flow (HSSF, HF)

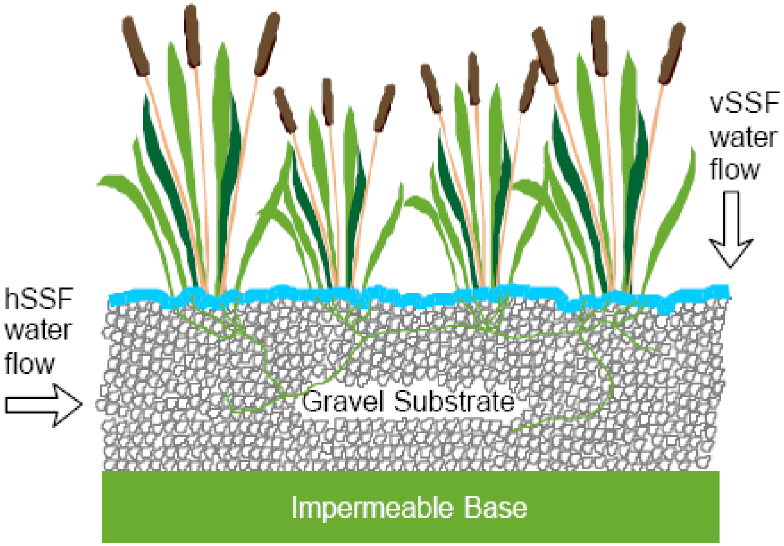
- Horizontal subsurface flow (HSSF) constructed wetlands (also known as Vegetated submerged Bed, VBS) are typically used to treat primary effluent
- The design typically consisted of a rectangular bed, lined with synthetic or clay materials to prevent water percolation, planted with vegetation where water is kept below the surface of the gravel, and flows horizontally from the inlet to the outlet.
- wastewater is uniformly distributed on the whole width of the basin trough a pipe disposed on the ground at the entrance of the basin. Wastewater is fed in a continuous flow and goes through the whole basin going out at its end.
- The filter medium is made of inert material of constant size. This can be anything from soil to light expanded clay aggregate, but 10-14 mm gravel is the most common. An inlet zone of larger media ensures the influent liquid is distributed effectively into the media.
- The most frequently used plant is *P. australis (Cav.) Trin. ex Steud*. (common reed) which is used either singly or in combination with other macrophyte species.



Horizontal subsurface flow (H-SSF)

Subsurface horizontal flow (HSSF, HF)

- Typical arrangement of H-SSF constructed wetland has the depth of filtration bed usually 0.6–0.8 m in order to allow roots of wetland plants to penetrate the whole bed. The H-SSF CW tend to be oxygen-limited since the reeds cannot supply the oxygen at the rate required by the wastewater load
- These systems are applied more often than the FWS ones because they require a smaller surface to provide good results. The purification efficiency is nearly the same during the whole year, because high thermal excursion is avoided by the presence of the medium.
- horizontal subsurface flow usually provide high treatment effect in terms of removal of organics (BOD5, COD) and suspended solids (SS). Lower is nitrogen removal due to the presence of anaerobic conditions, which are not favourable for the nitrification process.



Role of aquatic plants in sub-surface flow (SSF) constructed wetlands

- Nutrient uptake
- Heavy metal accumulation in plant tissue (Note: usually not a problem with domestic wastewater or grey water)
- Habitat for wildlife
- Aesthetics
- Root system = mechanical filter + attachment of biofilm
- Root system maintains hydraulic conductivity
- Oxygen transfer (active and passive) → plants are transporting oxygen to their root zone to allow the roots to survive in anaerobic conditions. Part of this oxygen is available for microbial processes.

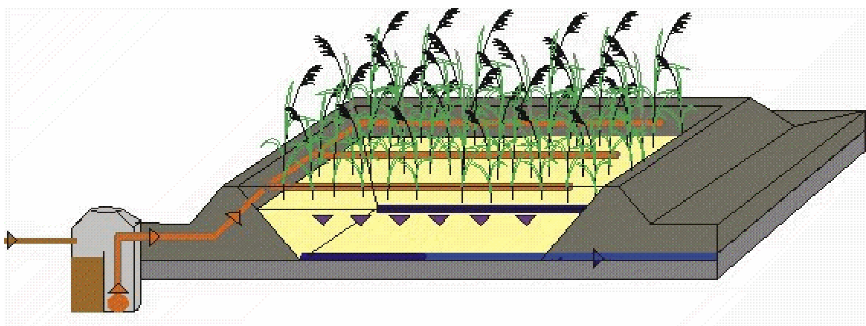
Subsurface horizontal flow (HSSF, HF)

- Earth basin, waterproofed (PEAD, PVC, …liners) and rectangular shaped with a depth of about 0.60 m
- Filled with a sand/gravel media
- Horizontal flow crossing the porous media planted with macrophites (Phragmites sp., Typha, etc.)
- Saturated media, but water level is below surface
- Secondary treatment for small communities and sparsely houses
- Easy in O&M
- Low water hydraulic losses
- No free water (low inseptcs population)
- Land need about 4-5 m2/PE (secondary treatment) and 1-2 m2/AE (tertiary treament)
- High removal of organic matter and TSS, small removal in nutrients
- Average microrganism removal 2 log unit with rarely peak to 3-4 log unit
- Well developed in Europe, several small systems also in Italy

Subsurface horizontal flow (HSSF, HF)

Vertical flow (VF)

- Vertical flow (VF) constructed wetland are typically used as secondary treatment.
- These are similar to the H-SSF, consist of excavated bed lined with synthetic materials, but the wastewater is fed from the top through a web of pipes, which distributes it on the whole basin surface. Wastewater goes down the basin in a horizontal flow and is collected at its bottom.
- At the base of the excavation are drainage pipes which are usually turned up so they reach the surface at their ends. This allows air to move in and out of the wetland.
- The pipes are overlain by media or a number of different layers of media. These range from soil to light expanded clay aggregate, but gravels and coarse sands are most widely used.
- The wastewater is dosed intermittently onto the bed flooding the surface often using a pump. Filling-emptying phases of the basin allow a higher oxygen concentration than in the H-SSF systems, increasing the efficiency of nitrification and organic material degradation.
- To have a continuous purification process a second filter bed is needed or a collecting and regulating pool can be introduced

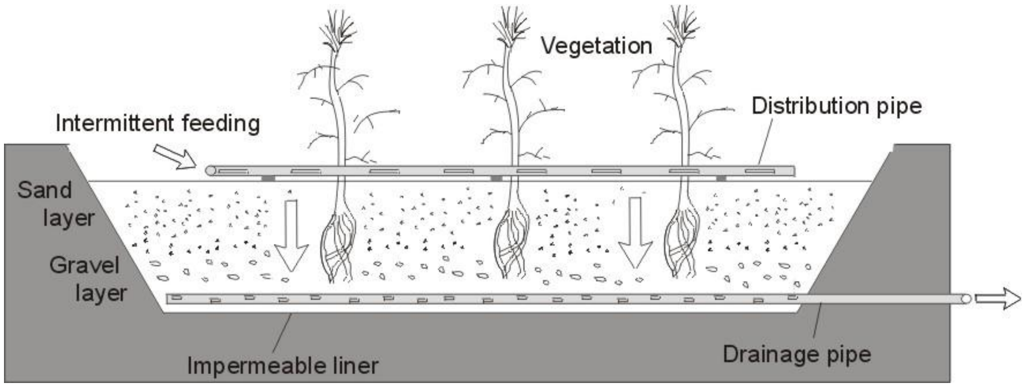


Vertical subsurface flow (V-SSF)

Vertical flow (VF)

- Earth or concrete basin, waterproofed (PEAD, PVC, …liners) with a depth of about 0.80 m
- Saturated/unsaturated media (filling/rest period) to promote oxigen : at least 4-6 times per day
- VF constructed wetlands require less land (1–3 m2/PE) as compared to horizontal flow systems (5–10 m2/PE) but require more operation and maintenance.
- Increase aeration of wastewater with prevailing aerobic conditions
- high organic matter degradation: 92% for BOD5, 87% for COD
- Good removal of nutrients (several application H-SSF+V-SSF CWs). The very efficient aeration of the filter medium and the alternation of aerobic and anaerobic conditions allow ammoniac nitrogen removal of 77%, nitrogen removal of 47% and phosphorous removal of 70%.

- Suspended solids average removal is about 90%, bacteria removal is higher than 99%
- Less developed than H-SSF system because O&M works are a little more complex



Vertical flow (VF)

Design criteria for different types of constructed wetlands

Design parameter	FWS (free water surface)	HSSF (horizontal sub-surface flow)	VSSF (vertical sub-surface flow)
Data is for which wastewater type	Mixed domestic wastewater		greywater
Detention time (days)	5 - 14	2 - 7	N/A
Max. BOD loading rate ($g/m^2/day$)	8	7.5	4-6
Water or substrate depth (m)	0.1 – 0.5	0.1 – 1.0	N/A
Hydraulic loading rate (mm/d)	7 - 60	2 - 30	40 - 80
Area requirement ($ha/m^3/day$)	0.002 – 0.014	0.001 – 0.007	N/A
Aspect ratio – length/width	2:1 to 10:1	0.25:1 to 5:1	N/A
Mosquito control	Required	Not required	Not required
Harvest frequency (years)	3-5	3-5	N/A

Source: Wood (1995) for FWS and SSF; Ridderstolpe (2004) for VSSF

Advantages of the CW system

- Operation and maintenance (O&M) costs are low and relatively simple
- Constructed wetlands are characterized by robustness, performance reliability, and resistance to flow fluctuations.
- The subsurface flow conditions limit insect breeding and proliferation of vectors.
- Certain wetland plant species grown on the constructed wetland can be reused as animal fodder (such as elephant grass) or ornamental flowers (such as Heliconia species) and can generate income.
- Organic pollutants, suspended solids, and pathogen can be removed with great efficiency.
- The reduced levels of pathogens in the effluent and remaining nutrients render the effluent appropriate for crop irrigation, provided that additional health protection measures are taken.
- Constructed wetlands provide indirect benefits such as green space, wildlife habitats and recreational and educational areas.

limitations of the CW system

- The surface requirements are high compared with those of conventional technical treatment technologies (cost and availability of suitable land).
- A relatively large amount of adequate filter material and sealing material is required.
- The deposition of inert solids and biomass can lead to the clogging of certain parts of the filter material.
- The replacement of clogged material is expensive and, in the case of community-managed systems, may not be carried out easily without technical assistance.
- the need for a preliminary treatment before the wastewaters treated by the system (normally they do not used to treat raw wastewaters).
- the need of higher (than a conventional system) retention time

Waste Stabilization Ponds

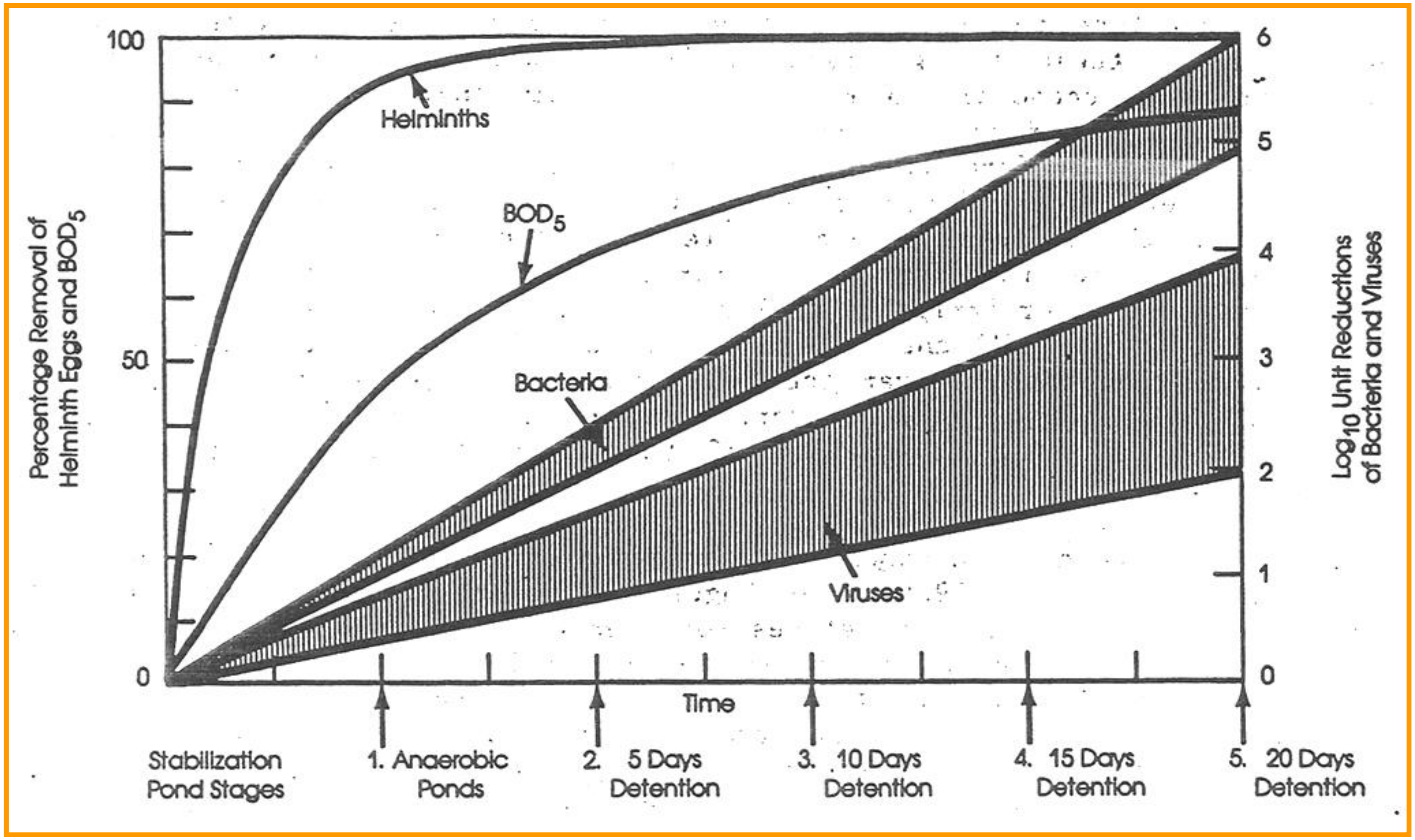
National experience and capacity needs for the construction and operation of NTSs

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

Waste Stabilization Ponds (WSPs)

- Waste Stabilization Ponds (WSPs), also called lagoons, are used to treat municipal and industrial wastewater all over the world.
- They are large shallow basins enclosed by earthen embankments in which wastewater is biologically treated by natural processes involving pond algae and bacteria.

General removal curves in Wastewater stabilization pond



Waste Stabilization Ponds

- Wastewater stabilization pond systems can be classified in respect to the type(s) of biological activity occurring in a pond. Three types, usually arranged in series to improve the efficiency of their performance, are distinguished:
  - Anaerobic ponds
  - Facultative ponds
  - Maturation ponds

Table 1.1. Basic Wastewater Pond Specifications (adapted from Curi and Eckenfelder 1980).

Pond	Application	Typical Loading (BOD_5)*	Typical Detention Time (d)	Typical Depth (m)	Comments
Anaerobic	Industrial wastewater	280-4500 kg / 1000 m^2/d	5-50	2.5-4.5	Subsequent treatment normally required.
Facultative	Raw municipal wastewater. Effluent from primary treatment, trickling filters, aerated ponds, or anaerobic ponds.	22-56 kg/ 1000m^2/d	7-50	0.9-2.4	Most commonly used wastewater treatment pond. May be aerobic through entire depth if lightly loaded.
Aerobic	Generally used to treat effluent from other processes. Produces effluent low in soluble BOD_5 and high in algal solids.	112-225 kg/ 1000 m^2 /d	2-6	0.18-0.3	Maximizes algae production and, if algae are harvested, nutrient removal.

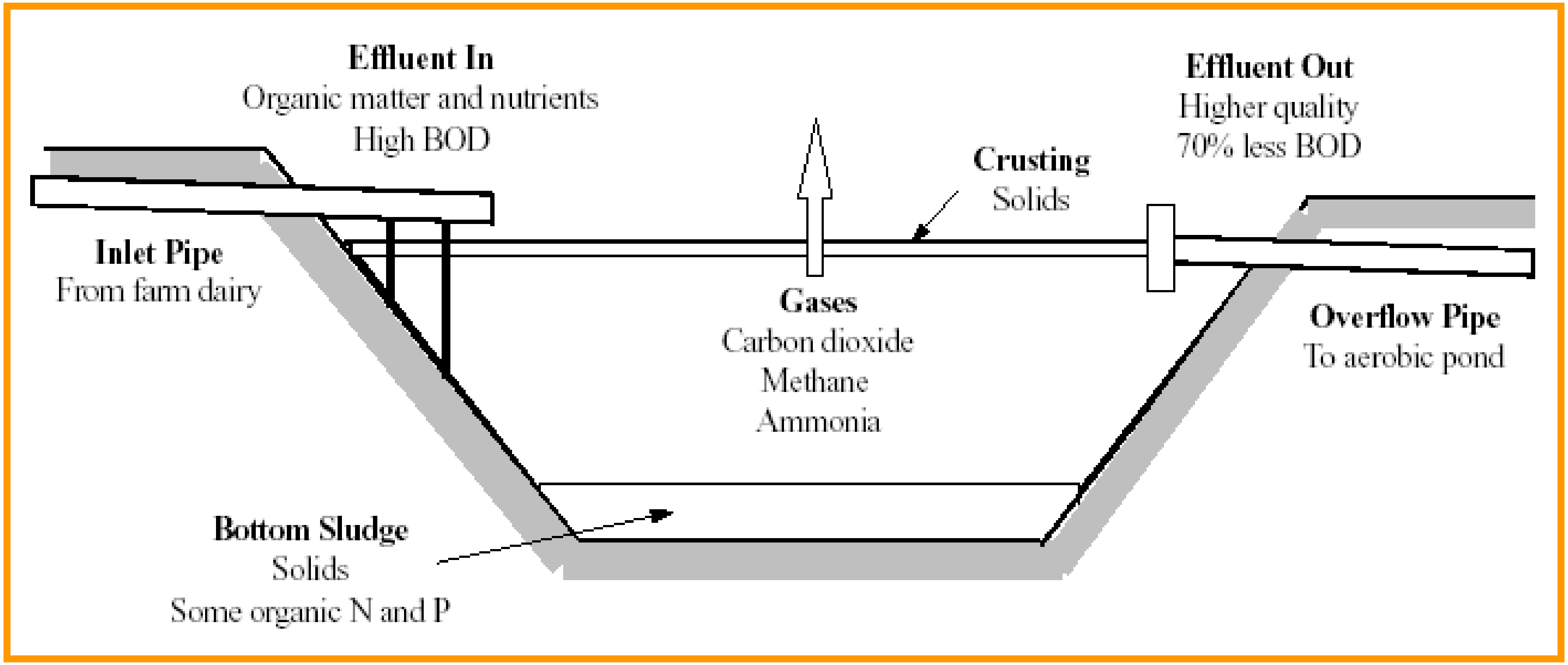
*BOD_5 = Biochemical Oxygen Demand measured over 5 days

C
Ce
ap

Anaerobic ponds

- Anaerobic ponds are typically used as primary treatment or as a pretreatment step in municipal systems.
- They are commonly 4-5 m deep and receive such a high organic loading (usually > 100 g BOD/m^3 d equivalent to > 3000 kg/ha/d for a depth of 3 m). They contain an organic loading that is very high relative to the amount of oxygen entering the pond, which maintains anaerobic conditions to the pond surface.
- Anaerobic bacteria break down the organic matter in the effluent, releasing methane and carbon dioxide. Sludge is deposited on the bottom and a crust forms on the surface. The predominant biological treatment reactions are bacterial acid formation and methane fermentation.
- In anaerobic ponds BOD removal is achieved (as in septic tanks) by sedimentation of settleable solids and subsequent anaerobic digestion in the resulting sludge layer
- Anaerobic ponds don't contain algae, although occasionally a thin film of mainly *Chlamydomonas* can be seen at the surface. They work extremely well in warm climate (can obtain 60-85% BOD removal) and have relatively short retention time (for BOD of up to 300 mg/l, one day is sufficient at temperature > 20°C).
- Detention time times of 1 - 5 days for urban wastewater, 5 - 50 day for industrial wastewater
- The effluent from anaerobic ponds usually requires further treatment prior to discharge

Operation of the Anaerobic Pond



Anaerobic Pond

- Anaerobic ponds reduce N, P, K and pathogenic microorganisms by sludge formation and the release of ammonia into the air. As a complete process, the anaerobic pond serves to:
  - Separate out solid from dissolved material as solids settle as bottom sludge.
  - Dissolve further organic material.
  - Break down biodegradable organic material.
  - Store undigested material and non-degradable solids as bottom sludge.
  - Allow partially treated effluent to pass out
- The system must operate at conditions favorable for the performance of methanogenic bacteria. Ideally, temperatures should be maintained within the range of 25 to 40° C. Anaerobic activity decreases rapidly at temperatures below

Table 3-4. BOD_5 Reduction as a Function of Detention Time and Temperature (World Health Organization, 1987)

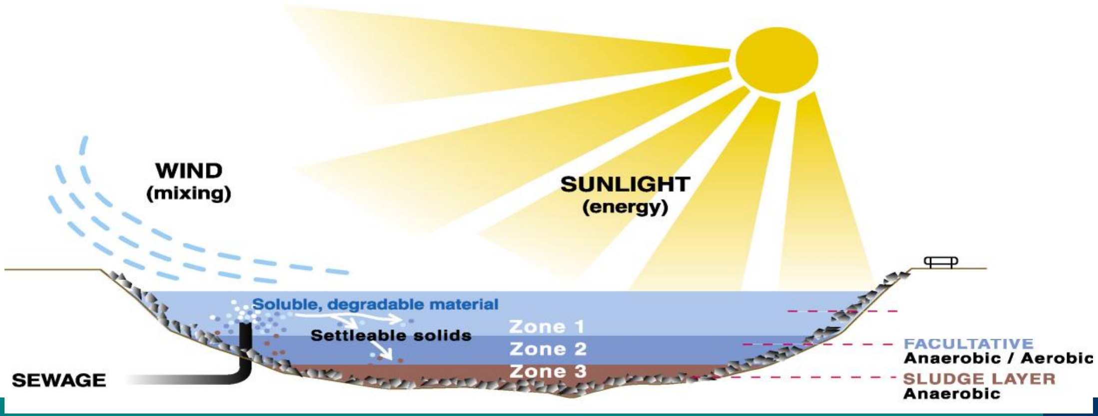
Temperature (°Celsius)	Detention Time (Days)	BOD_5 Reduction (Percent)
10	5	0-10
10-15	4-5	30-40
15-20	2-3	40-50
20-25	1-2	40-60
25-30	1-2	60-80

Advantages and Disadvantages of anaerobic ponds

- The advantages of anaerobic ponds are several:
  - sludge removal is infrequently needed;
  - 80-90 percent BOD5 removal can be expected;
  - the energy requirements to run the plant are low or none; a
  - no operation and maintenance (O&M) is relatively uncomplicated.
- On the other hand, the Disadvantages of anaerobic ponds are:
  - they are not designed to produce effluent that can be discharged;
  - the ponds can emit unpleasant odors (aeration should be provided at the surface of the pond to oxidize the escaping gases or locate the pond in a remote area)
  - the rate of treatment is dependent on climate and season.
  - A relatively long detention time is required for organic stabilization due to the slow growth rate of the *CH4* formers and sludge digestion.

Facultative ponds

- Facultative ponds, most common type of pond, are of two types:
  - primary facultative ponds, which receive raw wastewater,
  - secondary facultative ponds, which receive settled wastewater (usually the effluent from anaerobic ponds).
- Like most natural environments, conditions inside facultative lagoons are always changing. Lagoons experience cycles due to variations in the weather, the composition of the wastewater, and other factors. In general, the wastewater in facultative lagoons naturally settles into three fairly distinct layers or zones. Different conditions exist in each zone, and wastewater treatment takes place in all three:
  - ***aerobic layer, at the top***
  - ***aerobic-anaerobic layer, in the middle***
  - ***anaerobic layer, at the bottom***



Facultative ponds

- Facultative ponds normally follow anaerobic ponds in a WSP system. They are usually 1-2 m deep and are geometrically designed to have a high length-to-width ratio (up to 10:1) to simulate a hydraulic plug flow regime.
- They rely on the interaction of
  - Sunlight
  - Algae
  - Microorganisms
  - Oxygen
  - also the wind has an important effect on the behaviour of facultative ponds, as it induces vertical mixing of the pond liquid.
- The term facultative is used because both aerobic and anaerobic conditions are found in the pond. Aerobic conditions are maintained in the upper layers while anaerobic conditions exist towards the bottom of the pond.
- Facultative ponds are designed for BOD removal based on a surface loading of 100-350 kg BOD/ha day to permit the development and stability of a healthy algae population. BOD5 removal can range up to 95%. However, the TSS range may exceed 150 mg/L. Removal of ammonia nitrogen can be significant (up to 80 percent), depending on temperature, pH, and detention time in the system. However, the removal cannot be sustained over the winter season. Removal of pathogens and coliforms can be effective, depending on temperature and detention time

Facultative Lagoons

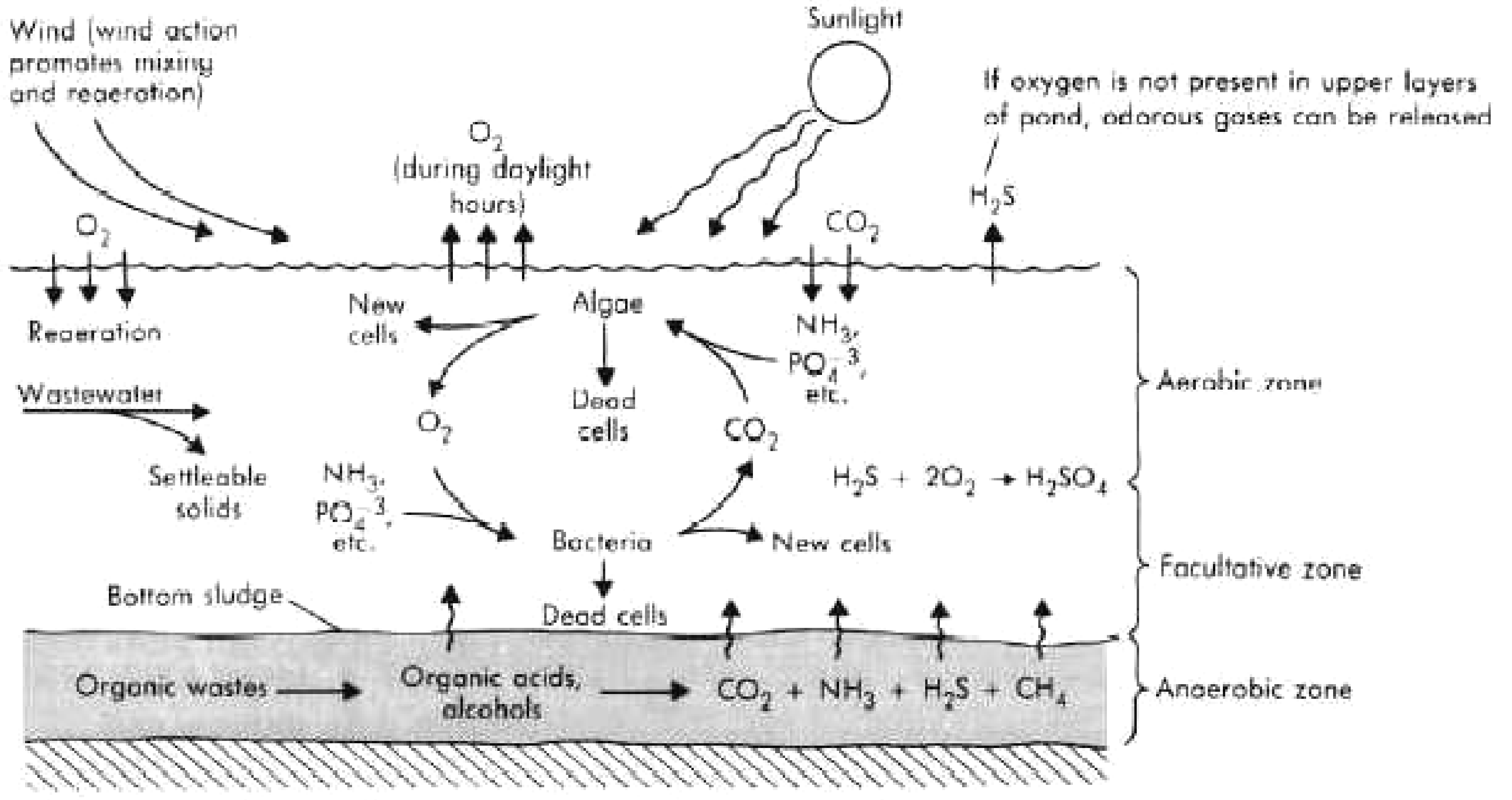
- The ***top layer*** in a facultative lagoon is called the ***aerobic zone***, because the majority of oxygen is present there. How deep the aerobic zone is depends on loading, climate, amount of sunlight and wind, and how much algae is in the water. The wastewater in this part of the lagoon receives oxygen from air, from algae, and from the agitation of the water surface (from wind and rain, for example). This zone also serves as a barrier for the odors from gases produced by the treatment processes occurring in the lower layers.
- Names for the ***middle layer*** include the facultative, intermediate, or ***aerobic-anaerobic zone***. Both aerobic and anaerobic conditions exist in this layer in varying degrees. Depending on the specific conditions in any given part of this zone, different types of bacteria and other organisms are present that contribute to wastewater treatment
- The ***anaerobic zone*** is the layer at the very ***bottom of the lagoon*** where no oxygen is present. This area includes a layer of sludge, which forms from the solids that settle out of the wastewater. Here, wastewater is treated by anaerobic bacteria, microscopic organisms, such as certain protozoa, and sludge worms, all of which thrive in anaerobic conditions.

Facultative Lagoons

- ***Sunlight*** is also extremely important to facultative lagoons because it contributes to the growth of green algae on the water surface. Because algae are plants, they require sunlight for photosynthesis. Oxygen is a byproduct of photosynthesis, and the presence of green algae contributes significantly to the amount of oxygen in the aerobic zone. The more warmth and light the sun provides, the more green algae and oxygen there is likely to be in the lagoon.
- The ***oxygen*** in the aerobic zone makes conditions favourable for aerobic bacteria. Both aerobic and anaerobic bacteria are very important to the wastewater treatment process and to each other. Bacteria treat wastewater by converting it into other substances.
  - ***Aerobic bacteria*** convert wastes into carbon dioxide, ammonia, and phosphates, which, in turn, are used by the algae as food.
  - ***Anaerobic bacteria*** convert substances in wastewater to gases, such as hydrogen sulphide, ammonia, and methane. Many of these products are then used as food by both the aerobic bacteria and algae in the layers above.

Operation of the facultative pond

- Recommended detention times vary from 5 - 50 days in warm climates and 90 - 180 days in colder climates
- depth 1 - 3 m



Facultative Lagoons

- Due to the algae facultative ponds are colored dark green, although they may occasionally appear red or pink (especially when slightly overloaded) due to the presence of anaerobic purple sulphide-oxidizing photosynthetic bacteria.
- The algae that tend to predominate in the turbid waters of facultative ponds are the motile genera (such as *Chlamydomonas, Pyrobotrys* and *Euglena*) as these can optimize their vertical position in the pond water column in relation to incident light intensity and temperature.
- The concentration of algae in a healthy facultative pond depends on loading and temperature, but is usually in the range 500-2000 µg chlorophyll *a* per litre.

Advantages and Disadvantages of facultative ponds

- The advantages of facultative ponds include:
  - infrequent need for sludge removal;
  - Effective removal of settleable solids, BOD5, pathogens, fecal coliform, and, to a limited extent, *NH3*.
  - They are easy to operate and require little energy, particularly if designed to operate with gravityflow.
- The disadvantages include:
  - higher sludge accumulation in shallow ponds or in cold climates a
  - variable seasonal *NH3* levels in the effluent.
  - Emergent vegetation must be controlled to avoid creating breeding areas for mosquitoes and other vectors.
  - Shallow ponds require relatively large areas.
  - during spring and fall turnover, odors can be an intermittent problem.
  - algae in the effluent may increase TSS above the 30 mg/L limit for TSS;
  - low temperatures and ice formation will limit process efficiency;

Maturation ponds

- The maturation ponds, also called aerobic ponds or oxidation ponds, maintain dissolved oxygen (DO) throughout their entire depth.
- They are usually 1-1.5 m deep, which allows light to penetrate throughout the pond
- The maturation ponds are normally used in series with facultative ponds. The size and number of maturation ponds depends on the required quality of the final effluent
- designed to remove excreted pathogens, their contribution to nutrient removal also can be significant.
- Detention time is typically two to six days.
- Curtis and Mara (1994) and Curtis et al. (1992) list the principal mechanisms for faecal bacterial removal in facultative and maturation ponds as:
  - • Time and temperature,
  - • High pond pH, mainly above 9.4, and
  - • High light intensity together with a high dissolved oxygen concentration.
- These ponds are appropriate for treatment in warm, sunny climates.

Wastewater storage reservoir

National experience and capacity needs for the construction and operation of NTSs

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

Wastewater Storage Reservoirs

- Wastewater Storage Reservoirs (WSRs) have been operated for more than 30 years for the storage and treatment of wastewater effluents during the wet winter months.
- Similar to ponds, WSRs however several differences occur:
  - Increased depth (6-8 m, up to 20 m)
  - Greater capacity (up to several millions of m^3)
  - No steady-state hydraulic regime
  - Detention time 50-180 days
- Two main purposes are reached:
  - *REGULATION*
  - *STABILIZATION*
- Basically wastewaters coming from municipalities or food industries are accumulated in WSR after a primary and/or secondary treatment.
- They utilize solar energy (mechanical plants use electricity). Algae within the reservoirs produce most of the oxygen required by the processes (mechanical plants take oxygen from the atmosphere, with high energy consumption).
- Aquatic birds find the reservoirs a good refuge. This is important in areas where the natural habitat of the birds have been invaded by urban, tourism or agriculture development.

Wastewater Storage Reservoirs : Regulation

- to store wastewater produced when water availability exceeds demand
- to meet peak (daily or seasonal) irrigation demand in excess of the average wastewater flow
- to equalise hourly variations in outflow from the treatment plant
- to avoid the introduction of wastewater of unsuitable quality into the distribution network system
- to solve temporary problems concerning treatment plant effluent quality

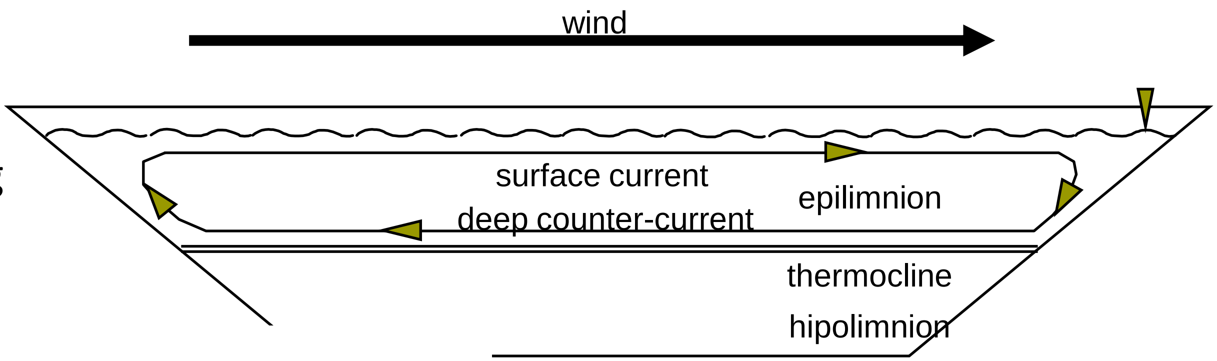
Wastewater Storage Reservoirs : stabilization

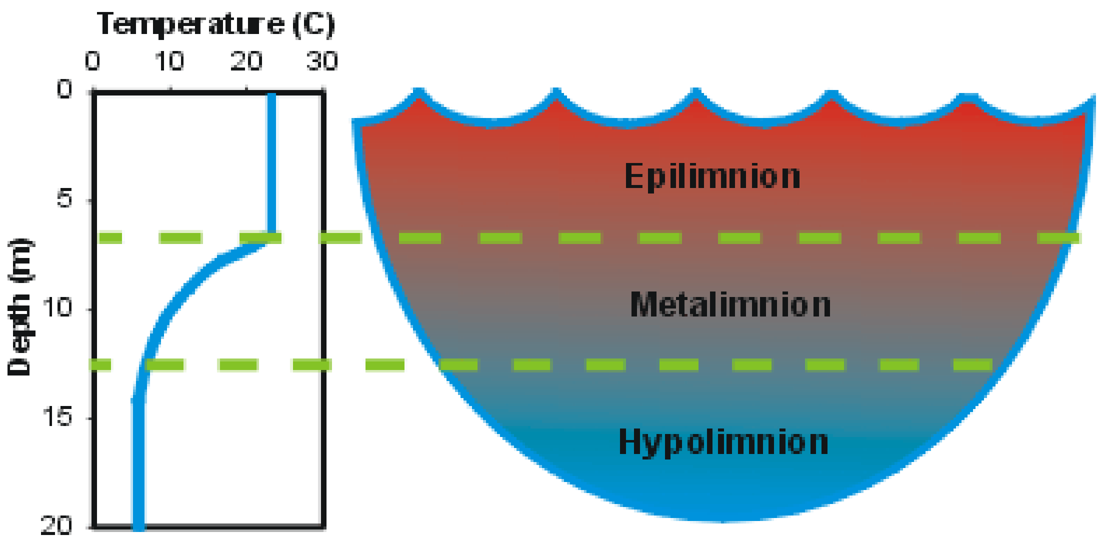
- Stabilization processes occur during detention and lead to significant changes in quality of stored water:
  - Efficient removal of pathogens and parasites
  - Removal of organic matter and SS

Wastewater Storage Reservoirs

- As a consequence of their large size, reservoirs behave not only as chemical reactors but also as limnological units (such as lakes, water supply reservoirs and other large water bodies).
- Some of the limnological elements which affect the behaviour of the reservoirs are evaporation, solar radiation, stratification (Juanico 1994), winds, waves, currents, tides, settling of particles and living organisms

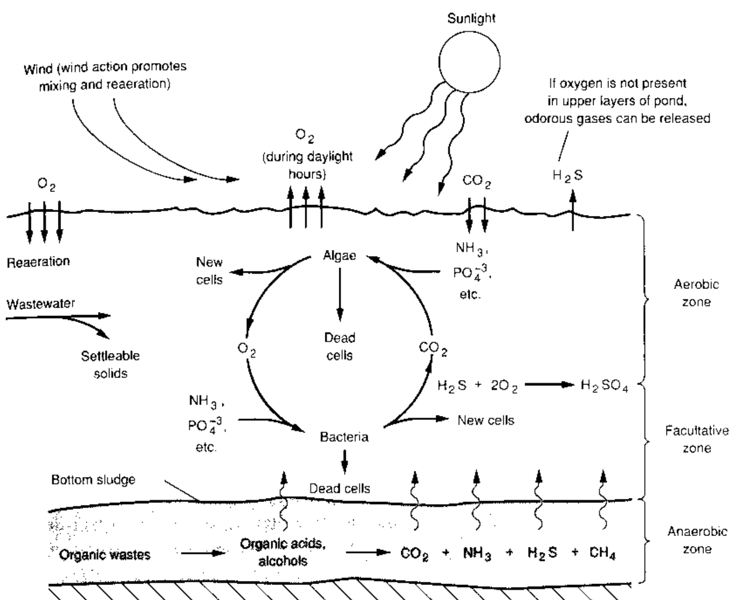
- Effect of the wind on water circulation and mixing

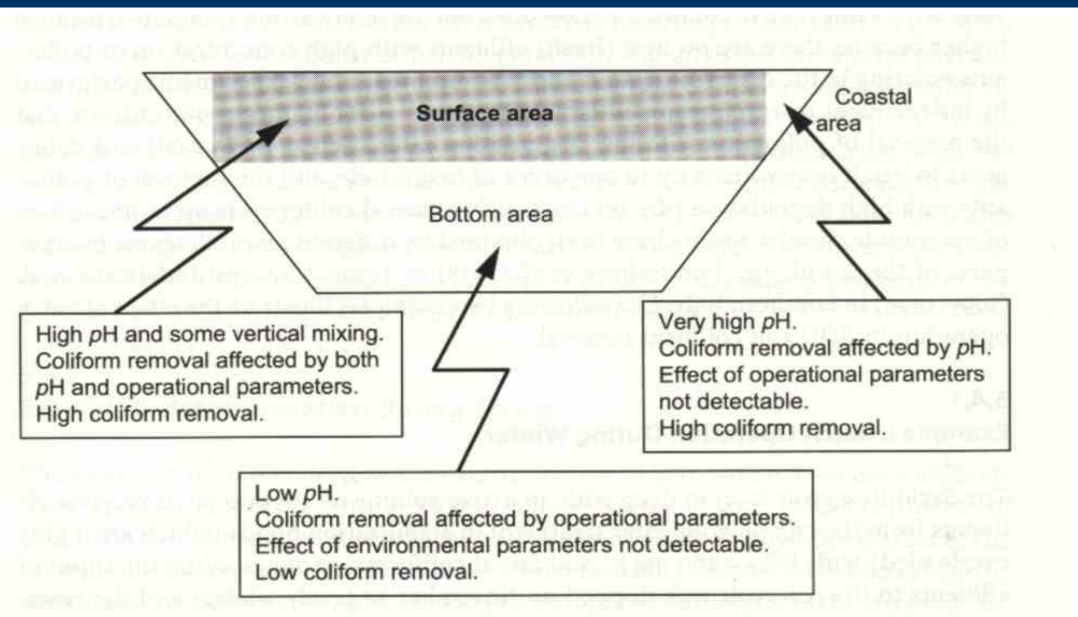


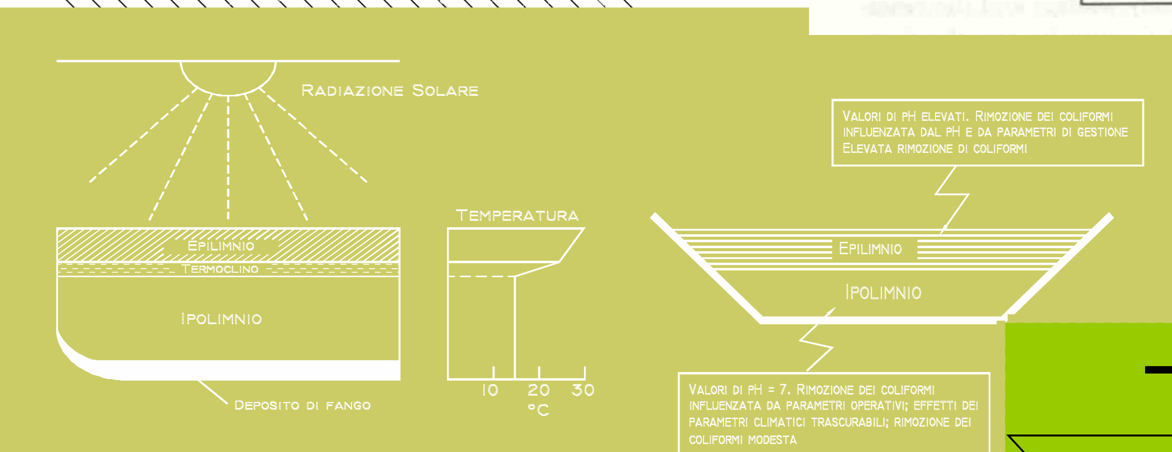


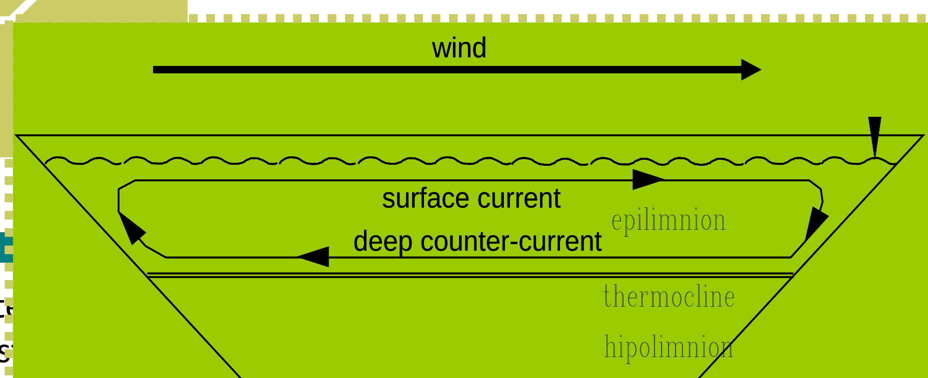
- Thermal stratification

Main Natural Processes Within Reservoirs



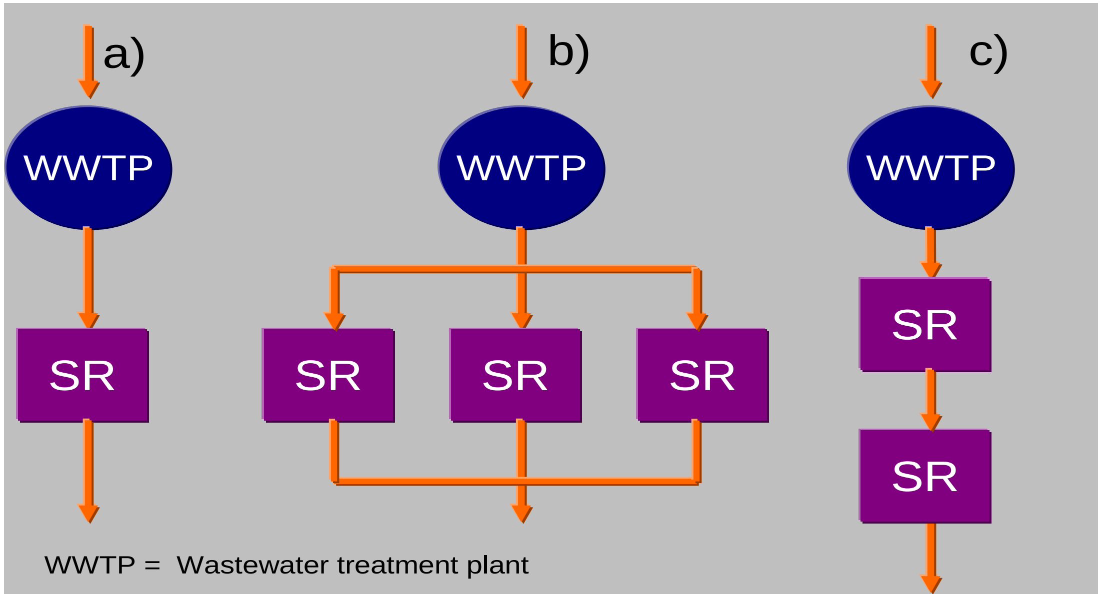






Wastewater storage Reservoirs

- Different operation schemes could be adopted
  - a single reservoir with **continuous inflow** (a) is the simplest one, but water quality problems could occur when irrigation starts, since the retention time drastically decreases.
  - A significant improvement in water quality can be reached with 3 or more **reservoirs in parallel** (b) each of them with batch inflow and a minimal retention time.
  - Another solution considers two **reservoirs in series** (c) using the fresher water coming from the first one only for restricted reuse.
- The operational regime determines the performance of the reservoir in terms of treatment capacity.



WWTP = Wastewater treatment plant

SR= Stabilization Reservoir

a) Single SR

b) SR in parallel

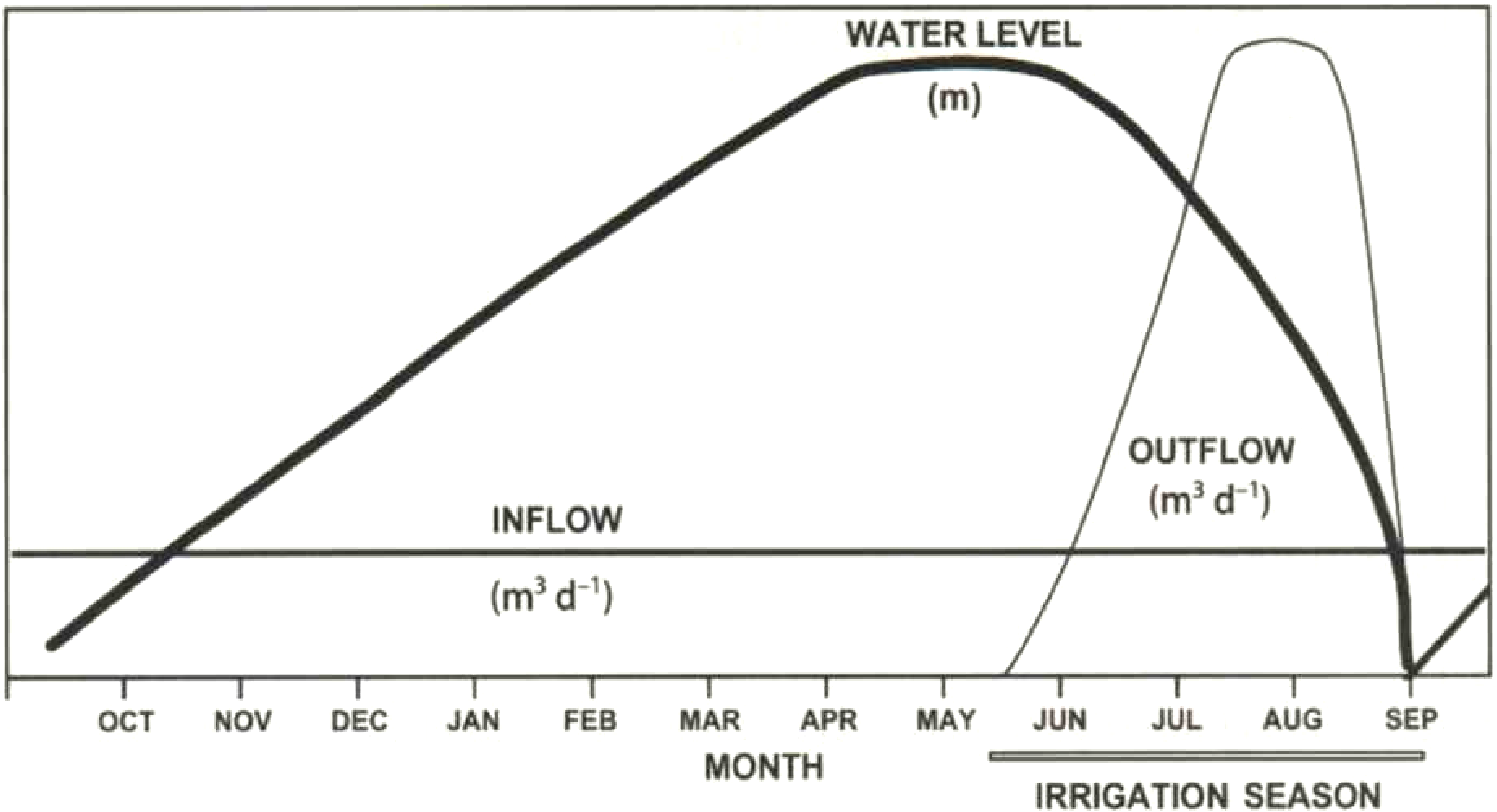
c) SR in series

Continuous-flow reservoirs

- **Continuous-flow** single reservoirs, denominates as ' semi-batch reactors'
- operational regime: a single reservoir, wastewater enters the reservoir all the year round, and wastewater is released from the reservoir only during the cotton irrigation season (generally May to September).
- Inflow is almost constant throughout the year while outflow is zero during the winter and very high during the irrigation season.
- The active volume of the reservoir is computed by making a balance between the gains (inflow and rain) and the losses (evaporation and seepage) during the non-irrigation season.
- The main limitation of continuous-flow reservoirs is the degradation of effluent quality during the irrigation season.
- Maximum removal percentages are obtained at the beginning of the irrigation season, reaching one order of magnitude for BOD, COD, TSS and detergents, and 3-4 orders of magnitude for total coliforms.

Continuous-flow reservoirs

- Typical annual cycle of a continuous-flow wastewater reservoir in Israel



A single batch reservoir

- The batch-operated reservoirs are an answer to the request for better quality effluents that could not be provided by the limited continuous-flow reservoirs.
- In the batch operational mode, the inflow to the reservoir is stopped before the reservoir starts to release effluents. The extent of the filling and batch periods determine the final quality of the effluents. Batch periods between 30 and 50 days are generally used.
- The rate of BOD degradation or Faecal coliforms die-off in the ‘closed’ batch reservoirs is the same than in continuous-flow ones, but the removal finally obtained is much higher because there are no new (fresh) effluents with high concentration of pollutants entering to the reservoir

Sequential batch reservoir

- When the input to the reservoir is closed, effluents must be stored in another reservoir. This requires more than one reservoir in each treatment
- Optimal number of SBR (sequential batch reservoirs) is 3-4, but 5-6 may be used in some cases.
- The fill-batch-emptying-idle cycles of the reservoirs are shorter during the high water demand periods and some of the reservoirs may be emptied twice during the irrigation season.
- SBR reservoirs require more storage capacity than continuous-flow reservoirs due to the period of no inflow of effluents to the reservoir which must be compensated by supplementary storage capacity in another reservoir.
- SBR render effluents of very good quality, but are relatively larger and their operation is more complicated

Wastewater storage Reservoirs

Removal efficiencies

in

wastewater reservoirs

continuous flow

versus

batch

Parameter	Continuous-flow	Batch 30-50 days	Sources
BOD	70 %	90 %	Juanico&Shelef (1991) Soler *et al.* (1991) Juanico&Shelef (1994)
COD	50 %	80 - 90 %	
MBAS (detergents)	50 %	90 %	Juanico&Shelef (1991) Juanico&Shelef (1994)
Nitrogen		70 % – 80 % (1) 60 % – 85 % (1)	Juanico (1999) Avnimelech (1999) Bahri *et al.* (2000)
Phosphorus	< 30 %	10 - 30 %	Sala *et al.* (1994) Araujo *et al.* (2000) (experimental)
Faecal coliforms	90 - 99 %	99.99 % - total	Kott *et al.* (1978) Felgner & Sandring (1983)(experimental) Juanico&Shelef (1991) Juanico&Shelef (1994) Liran *et al.* (1994) Indelicato *et al.* (1996) Athayde *et al.* (2000) (experimental)
Streptococcus and Clostridium		total	Berná *et al.* (1986)
Giardia and Cryptosporidium		99.99 %	Nasser *et al.* (2000)
Polivirus I - Chat		total	Funderburg *et al.* (1978) (experimental)
Nematode eggs		total	Kouraa *et al.* (2002) Barbagallo *et al.* (2002)
Heavy metals	down to background concentration in unpolluted waters (1)	down to background concentration in unpolluted waters (1)	Juanico *et al.* (1995)
Organic micropollutants : -- phthalates -- alkyl phenols -- alkyl benzenes -- hydrocarbons	60 – 75 % (2)		Muszkat (1999)

(1): Data from Juanico and Avnimelech are from two deep reservoirs in series, operated as continuous-flow reactors but with short periods of batch operation. Data by Bahri are from shallow reservoirs.
(2): Soils irrigated with effluents from reservoirs did no present accumulation of studied organic micro pollutants. Those irrigated with effluents from activated sludge plants presented build-up of some organic micro pollutants.

Drawbacks Of Wastewater Storage

- Land consuming (land is not a limiting factor in inland areas)
- Algal growth (clogging risk of emitters)
- Unpleasant odours (siting problem)
- Water losses (evaporation, infiltration)

Wastewater storage Reservoirs

- Storage reservoir for wastewater (WWSRs) treatment can be a valid option to improve quality and to increase availability of wastewater for irrigation purposes

- Experiences carried using WWSRs as secondary or tertiary treatment have shown that in continuous modality the efficiency even if is high, it does not comply with the Italian regulation