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

CSEI Catania
Centro Studi di Economia applicata all'Ingegneria

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

NTS theory, principles and standards of operation with comparisons to conventional system

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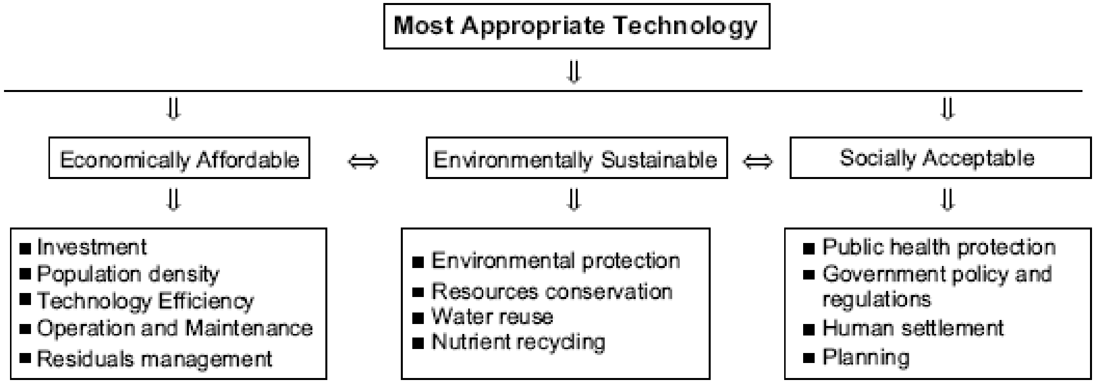
integrated wastewater management approach

- An integrated wastewater management approach ensures that all the perspectives of effective management that include economical, social, technical and environmental dimensions are taken into consideration.
- Choosing the ‘‘**Most Appropriate Technology**’’ is not an easy task but it could reduce the risk of future problems and failures
- the ‘‘**Most Appropriate Technology**’’ is (Ho, 2005):
  - **economically affordable**: An assessment of the cost effectiveness of the selected system should be undertaken taking into consideration the capital cost for planning and construction the costs of operation and maintenance and the value of the land used.
  - **environmentally sustainable**: the technology chosen should ensure the protection of environmental quality, the conservation of resources, and the reuse of water as well as the recycling of nutrients
  - and **socially acceptable**: local factors that can directly affect the operation and maintenance of a certain system. These include, the local community habits and lifestyle, public health protection, government policies and regulations as well as public acceptance



Conventional wastewater system

- Conventional wastewater system, also referred to as Intensive treatment, is the most common approach in the industrialized countries with Activated Sludge as the conventional technology.
  - This conventional treatment is based on intensive biological treatment to remove pollutants, in relatively short time and confined space. They can reach very high treatment efficiencies.

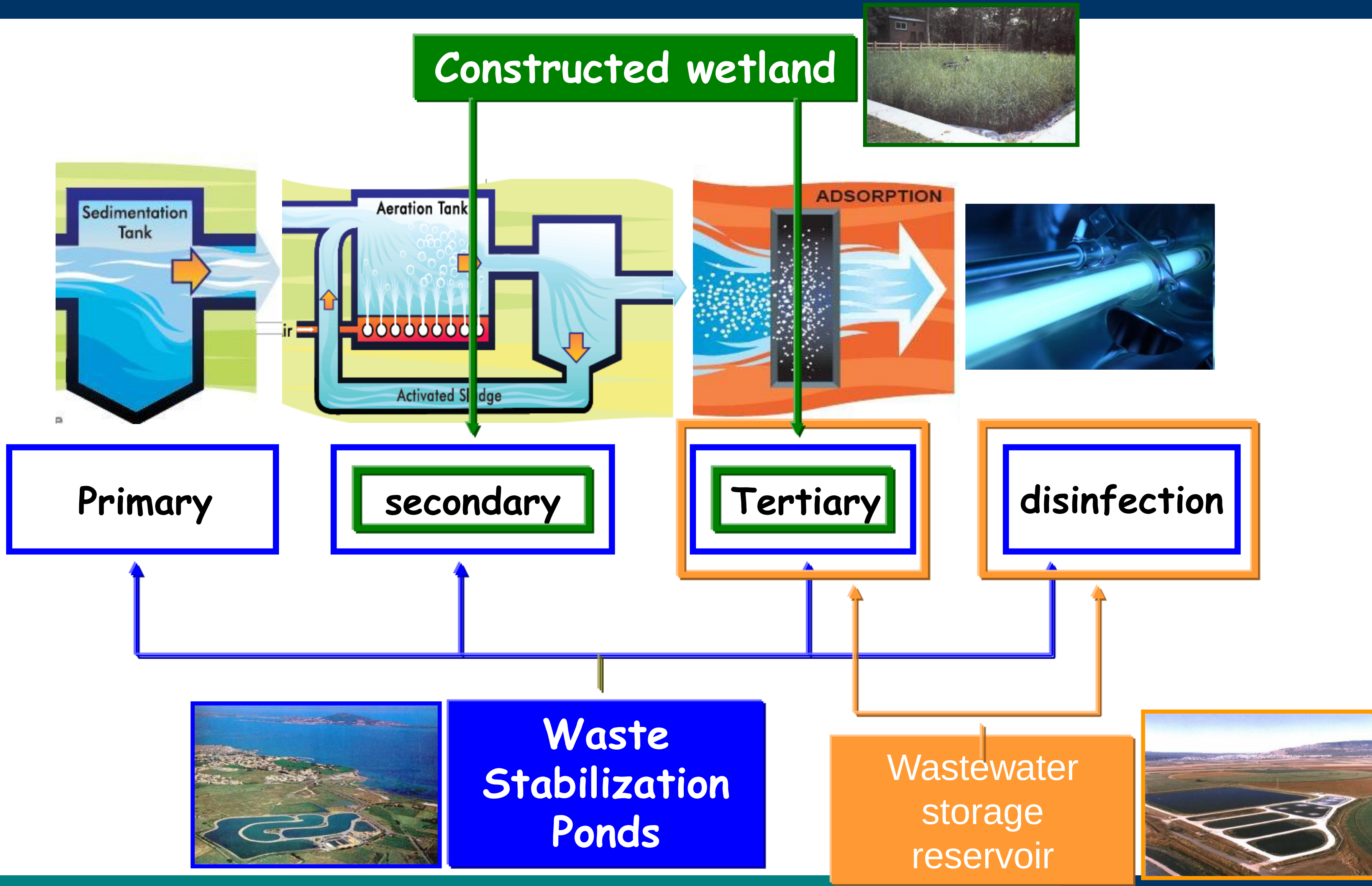
- Additional advanced treatment can be added such as disinfection unit (chlorination, ozonation, UV) and removal of nutrients (N and P), depends on the disposal/reuse requirements.

- These intensive technologies require small space area and thus have financial benefits especially in densely populated urban areas where land value is high.

- Conventional treatment also shortens the period that the wastewater effluent remains in treatment units and so can treat more effluent over a period of time

- However, they are energy intensive, require highly skilled manpower (for design, construction, operation and maintenance), and require large amount of capital for both construction and operation

Wastewater treatments



Unit	Main advantages	Main disadvantages
	Media filters: Intermittent Sand Filter (ISF) and Recirculating Sand Filter (RSF)	
	• Minimum and easy operation and maintenance • High quality effluent especially for BOD and TSS[a] • Nitrogen can be completely transformed to nitrate if aerobic conditions are present • No chemicals required	• Cost may increase if the media is not available locally • Regular maintenance required • Clogging is possible • Electric power is needed • The land area required may be a limiting factor
	Lagoons	
Facultative Lagoons (FL) and Aerated Lagoons (AL)	• Effective in removal of settleable solids, BOD, pathogens, and ammonia • Effective at removing disease causing organisms • High-nutrient and low pathogen content effluent • Cost-effective in areas where land is inexpensive • Require less energy than most other wastewater treatment systems • Can handle periods of heavy and light usage • The effluent can be used for irrigation because of its high nutrient and low pathogen content	• Not very effective in removing heavy metals • Do not meet effluent criteria consistently throughout the year • Often require additional treatment or disinfection to meet state and local discharge standards • Sludge accumulation is higher in cold climates • Mosquitoes and insects can be a problem if vegetation is not controlled • Odor may be a problem • Require more land area than other wastewater treatment systems
Anaerobic Lagoons (AnL)	• Easy to operate and maintain • Effective at removing disease causing organisms • More effective for strong organic waste • Produce methane and less biomass per unit of organic loading • Cost effective (not aerated or heated) • Effluent can be used for irrigation because of the high nutrient content • Generally low sludge production • Simple to operate and maintain	• Less efficient in cold areas and thus may require longer retention time • Not very effective in removing heavy metals • Often require additional treatment or disinfection to meet discharge standards • Require a relatively large area of land • Odor production • Not suitable for domestic wastewater with low BOD levels
Aerobic Lagoons (AoL)	• Effective at removing disease causing organisms (5e) • Simple to operate and maintain • Effluent can be used for irrigation because of the high nutrient and low pathogen content	• Not very effective in removing heavy metals from the wastewater • Often require additional treatment or disinfection to meet discharge standards • Require large land areas
	Aerobic treatment	
Suspended Growth (SG)	• Extended aeration plants produce a high degree of nitrification since hydraulic and solid retention times are high • Extended aeration package plants are available on the market	• Some odor and noise may be issued • Require electricity • Require regular operation and maintenance
Sequencing Batch Reactor (SBR)	• Suitable for site conditions for which enhanced treatment, including nitrogen removal, is necessary for protecting local ground and/or surface water • The lower organic and suspended solids content of the effluent may allow a reduction of land area requirements for subsurface disposal systems	• Relatively high initial capital costs • Operational control and routine periodic maintenance is necessary to ensure the proper functioning of this type of treatment system • May be most applicable to cluster systems
Attached Growth (AG)	• Better capturing of suspended solids than the suspended growth • Less complex than extended aeration systems • Very minimal operation is needed	• Nitrification can occur at low loading rates in warm climates • Very few commercially produced fixed films systems are currently available for on site application • Require electricity
Constructed Wetlands (CW)	• The lower organic and suspen0wded solids content of the effluent may allow a reduction of land area requirements for subsurface disposal systems • Inexpensive to operate and construct • Reduced odors • Able to handle variable wastewater loadings • Reduces land area needed for wastewater treatment • Provide wildlife habitat	• Some maintenance of wetland units will be required periodically • The area of a site occupied by the wetland would have very limited use • Require a continuous supply of water • Affected by seasonal variations in weather conditions • Can be destroyed by overloads of ammonia and solids levels • Remove nutrients for use of crops

- **Advantages and disadvantages of the most common secondary treatment methods** (Brix, 1994; Crites and Tchobanoglous, 1998; Reed et al., 1995; Tchobanoglous and Crites, 2003)

Perfomance of treatment systems

- Removal rates (%) and level achieved [into brackets) of main parameters

Removal rates of various decentralized wastewater treatment technologies (Bitton, 1994; Brix, 1994; USEPA, 2002)

		BOD % [levels achieved][a] (mg/l)	TSS % [levels achieved] (mg/l)	Nitrogen % [levels achieved] (mg/l)	Phosphorous % [levels achieved] (mg/l)	FC % [levels achieved] (counts/100 ml)
Media filters	ISF	[3–30]	[5–40]	18–50	Limited	99–99.99
	RSF	85–95 [10 or more]	85–95 [10 or more]	50–80	NA	NA
Lagoons	FL	75–95	90	Up to 60	Up to 50	[2–3]
	AoL	NA	NA	NA	NA	Effective
	AL	75–95 [35]	90 [20–60]	10–20 [30]	15–20	[1–2]
	AnL	50–80	NA	NA	NA	Effective
Aerobic treatment	SG	70–90 [20–50]	70–90 [7–22]	NA	< 25	Highly variable
	AG	[5–40]	[5–40]	0–35	10–15	[1–2]
Constructed wetlands	Up to 98 [5–10]	Up to 98 [10–20]	Up to 98	Up to 98	NA	

[a] Levels achieved = the concentration of the contaminant in wastewater after treatment.

Media filters: Intermittent Sand Filter (**ISF**) and Recirculating Sand Filter (**RSF**)
Lagoons: Facultative Lagoons (**FL**) and Aerated Lagoons (**AL**) Anaerobic Lagoons (**AnL**) Aerobic Lagoons (**AoL**)
Aerobic treatment: Suspended Growth (**SG**), Attached Growth (**AG**)

Performance of WPS

Table 6: Mean annual performance of five waste stabilization ponds in series in northeast Brazil

Source (at 24-27°C)	Retention (days)	BOD_5 (mg/l)	Suspended solids (SS) (mg/l)	Faecal Coliforms (per 100 ml)	Human intestinal nematode eggs (per litre)
Raw wastewater	-	240	305	4.6×10^7	804
Effluent from:					
Anaerobic pond	6.8[a]	63	56	2.9×10^6	29
Facultative pond	5.5	45	74	3.2×10^5	1
First maturation pond	5.5	25	61	2.4×10^4	0
Second maturation pond	5.5	19	43	450	0
Third maturation pond	5.8	17	45	30	0

Source: Mara and Silva (1986)

[a] Later work showed the same performance for BOD and SS removals at retention times of ~ 1 day (Silva, 1982)

Performance of WPS and conventional system

Table 1.2 Removals of excreted pathogens achieved by waste stabilization ponds and conventional treatment processes

Excreted pathogen	Removal in WSP	Removal in conventional treatment
Bacteria	up to 6 log units[a]	1 – 2 log units
Viruses	up to 4 log units	1 – 2 log units
Protozoan cysts	100%	90-99%
Helminth eggs	100%	90-99%

[a] 1 log unit = 90 percent removal; 2 = 99 percent; 3 = 99.9 percent, and so on.

Performance of Wastewater Storage Reservoir

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) Nitrogen	50 %	90 % 70 % – 80 % (1) 60 % – 85 % (1)	Juanico&Shelef (1991) Juanico&Shelef (1994) 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.

Performance of CWs

- Comparison of actual performance for 107 constructed wetlands in Flanders, Belgium (based on measured average concentrations)

Parameter	FWS	VSSF	HSSF	Combined	VSSF greywater
COD removal (%)	61	94	72	91	90 – 99 (BOD)
SS removal (%)	75	98	86	94	90-99
TN removal (%)	31	52	33	65	30
TP removal (%)	26	70	48	52	30 – 95

Source: Rousseau *et al*. (2004)
Note: all these wetlands in Flanders treat mixed domestic wastewater

The column on the right in green is for greywater treatment in vertical sub-surface flow wetlands (Ridderstolpe, 2004)

Cost

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

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Economic considerations

Technology	Land requirements (square meters per person)	Consumed power (watts per person)	Liquid sludge to be treated (liters per person per year)	Dewatered sludge to be disposed of (liters per person per year)	Construction costs (US$ per person)	O&M costs (US$ per person per year)
Primary treatment (septic tanks)	0.03–0.05	0	110–360	15–35	$12–20	0.5–1.0
Constructed wetlands	*3.0–5.0*[a]	*0*	-	-	*20–30*	*1.0–1.5*
Overland flow	2.0–3.5	0	-	-	15–30	0.8–1.5
Anaerobic pond + facultative pond	1.2–3.0	0	55–160	20–60	12–30	0.8–1.5
Anaerobic, facultative, and maturation pond	3.0–5.0	0	55–160	20–60	20–40	1.0–2.0
Septic tank + anaerobic filter	0.2–0.35	0	180–1,000	25–50	30–50	2.5–4.0
UASB reactor +maturation ponds	1.5–2.5	0	150–250	10–35	15–30	1.8–3.0
Conventional activated sludge	0.12–0.25	18–26	1,100–3,000	35–90	40–65	4.0–8.0
Low-rate trickling filter	0.15–0.3	0	360–1,100	35–80	50–60	4.0–6.0
Rotating biological contactor	0.1–0.2	0	330–1,500	20–75	50–60	4.0–6.0

Costs and land area requirements

Table 1.1 Costs and land area requirements for various methods of wastewater treatment for a rural community of 500 population in Germany

Treatment process	Capital costs[a] (DM/person)	O & M costs[b] (DM/m^3)	Land area (m^2/person)
Activated sludge	2,000	2.00	0.3 - 1 plus 500%[c]
Trickling filter	1,500	1.70	0.4 - 1 plus 500%
Aerated lagoon	1,200	1.70	4 - 10 plus 100%
Vertical-flow reedbed	1,200	1.50	1.5 - 4 plus 100%
Horizontal-flow reedbed	1,500	1.30	6 - 8 plus 100%
WSP	700	1.20	10 - 15 plus 50%

[a] 1996 exchange rate: DM1 = 0.52 ecu.
[b] DM per m^3 of wastewater treated.
[c] Additional working area.

Source: Burka (1996).

costs of natural treatments

- the unit costs are essentially the same for the natual systems.
- The major items included in capital costs of natural treatment unit are
  - Land costs
  - Site investigation
  - Excavation and earthwork
  - Liner
  - Media
  - Plants
  - Inlet structures
  - Outlet structures
  - Miscellaneous piping, pumps, etc.
  - Engineering, legal, and contingencies
- Most of these costs are directly dependent on the design treatment area of the system

CW cost

- Comparison of actual design parameters and costs for 107 constructed wetlands in Flanders, Belgium

Parameter	FWS	VSSF	HSSF	Combined
Design size (PE)	1 – 2000	4 – 2000	152 and 350	5 - 750
Area (m^2/per PE)	7	3.8	5.9 and 3.7	5
Investment cost (€/PE)	392	507	1636 and 879	919

Source: Rousseau *et al*. (2004)
Note: all these wetlands treat mixed domestic wastewater
The flowrates are in most cases not measured, so there is no information on the hydraulic or BOD load to these wetlands.

CW cost

H-SSF CW 196 m^2	Costs €/m²	percentage
Excavation and earthwork	13,26	10,7%
Liner	40,81	33,1%
gravel	19,38	15,7%
Phragmites	6,63	5,4%
Outlet/Inlet structures	15,30	12,4%
Other works	28,06	22,7%

Total cost ______________________________ ***123,47*** €/m²

CW cost

- **Year 2003** **H-SSF CW 1800 m²**

	Costs (€/m²)	Percentage
Excavation and earthwork	8,77	15,0%
Liner	25,55	43,6%
Gravel	15,55	26,6%
Gabions	2,22	3,8%
Phragmites	2,55	4,3%
Outlet/Inlet structures	1,94	3,3%
Other works	2,00	3,4%

Total cost ________________________ ***58,56*** €/m²

WWSR cost

- WWSRs (sequential batch in parallel) require high land extension availability. However, in inland areas low land prices favour this option (5,000-10,000 euro for 10,000 m2)

- Cost analysis in inland area of South-east Sicily have shown that total costs of Tertiary Treatment by WWSRs is comparable and even it smaller than the costs of using conventional water for irrigation:
  - Tertiary treatment by WWSRs 0.15 euro/m^3
  - Conventional water 0.10-0.20 euro/m^3