CONSTRUCTED WETLANDS

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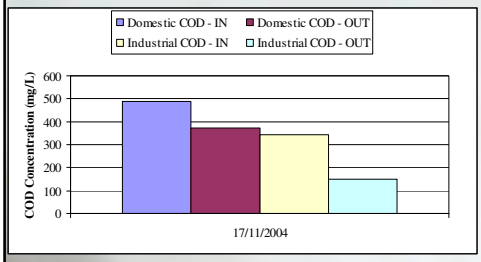
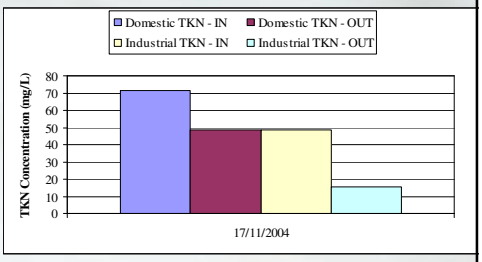
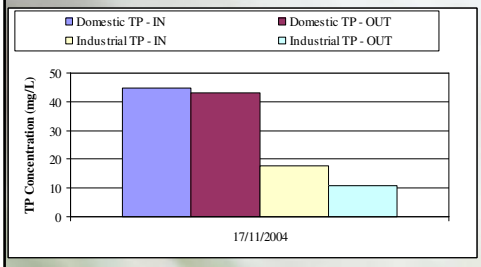
Introduction

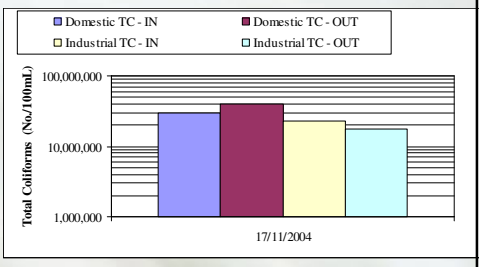
- Based on the 1991/271/EEC Directive, all EU countries must provide suitable treatment facilities for domestic wastewater
- In Greece, 50-60% of the population, mostly people residing in the large urban centers, is currently served with treatment plants
- Conventional wastewater treatment facilities are used, which suffer from various problems:
  - operational problems and treatment deficiencies
  - high operational costs
  - lack of personnel
- In rural areas, the population is mostly served with septic tanks
  - Natural treatment systems, particularly constructed wetlands, are ideal for wastewater treatment in rural areas

Conventional System - Monitoring









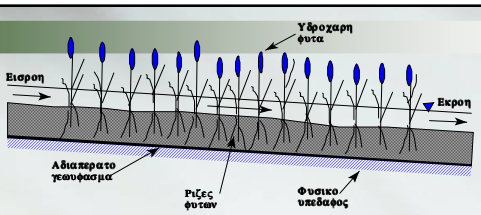
Natural Systems for Wastewater Treatment

- **Natural systems use the physical, chemical and biological processes, which also take place in the natural environment when wastewater, soil, plants, microorganisms and the atmosphere interact.**
  - **Aquatic natural systems**
  - **Terrestrial natural systems**

Aquatic Natural Systems

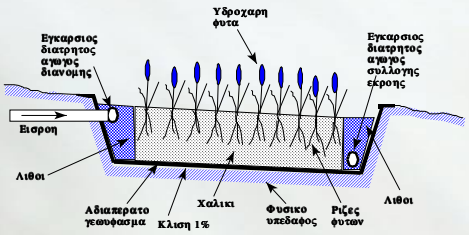
- Stabilization or Oxidation Ponds
- Constructed Wetlands
  - Free-water surface flow (FWS)
  - Subsurface flow
    - Horizontal Subsurface flow (HSF)
    - Vertical Subsurface flow (VF)

Free-water surface flow CW



(α) Τεχνητος Υγροβιοτοπος Επιφανειακης Ροης

Horizontal subsurface flow CW



(β) Τεχνητος Υγροβιοτοπος Υποεπιφανειακης Ροης

Σχημα 6.12. Ειδη Τεχνητων Υγροβιοτοπων

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Vertical Flow Constructed Wetland

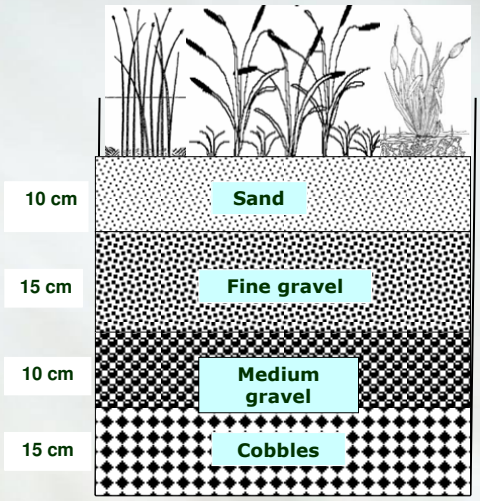
EUROPEAN TYPE

Sand: d_{50} = 0.5 mm

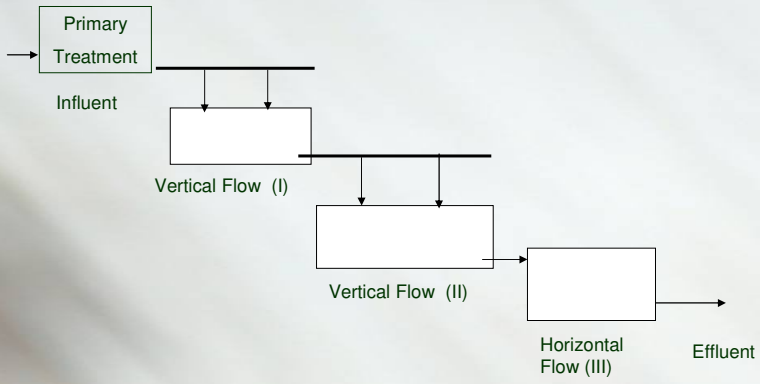
Fine gravel: d_{50} = 6 mm

Medium gravel: d_{50} = 24.4 mm

Cobbles: d_{50} = 90 mm



Vertical Flow Constructed Wetland



Comparison of Conventional Treatment Systems and Constructed Wetlands

CONVENTIONAL SYSTEMS

- Use of non-renewable energy sources (concrete, steel, electricity, chemicals etc.)
- Production of large quantities of by-products (activated sludge)
- Mechanical parts
- Requirement of specialized personnel
- High construction and operation cost
- Low area demand

CONSTRUCTED WETLANDS

- Use of renewable energy sources (solar, wind etc.)
- Production of small quantities of by-products
- No mechanical parts
- No requirement of specialized personnel
- Low construction and operation cost
- Large area demand

Examples in Greece

- Conventional system – Wastewater treatment plant in Parikia, Paros Island

… Examples in Greece

- Stabilization ponds and constructed wetlands – Pilot-scale units in NAGREF facilities near Gallikos river, Thessaloniki

… Examples in Greece

- Irrigation with wastewater – Pilot-scale systems in NAGREF facilities in Heraklion, Crete

... Examples in Greece

- Olive mill wastewater treatment – Pilot-scale units in NAGREF facilities in Heraklion, Crete

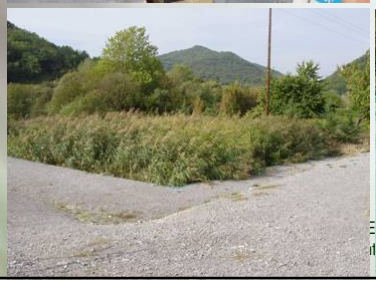
Examples in Europe

… Examples in Europe

- FRANCE - Alba la Romaine: Sludge treatment in a CW

… Examples in Europe

- FRANCE - Saint Thomé: Vertical flow CW (400 capita)



… Examples in Europe

- **FRANCE – Roussillon: Vertical flow CW (1250 capita)**

… Examples in Europe

PORTUGAL – Alcochete: HSF CW (500 p.e.)

Sludge treatment

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Department of Env

… Examples in Europe

PORTUGAL - Beja-Sado: Stabilization ponds (aerated, facultative, maturation), HSF CW, filters (23435 p.e.)

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- Research in constructed wetland systems:
  - Pilot-scale experiments for the optimization of CW design parameters
  - Monitoring of full-scale CW facilities
  - Design, construction supervision, and monitoring of new CW facilities, and
  - Development of models and decision support systems (DSS)

1. Pilot-scale Constructed Wetland Experiments

…Pilot-scale Constructed Wetland Experiments

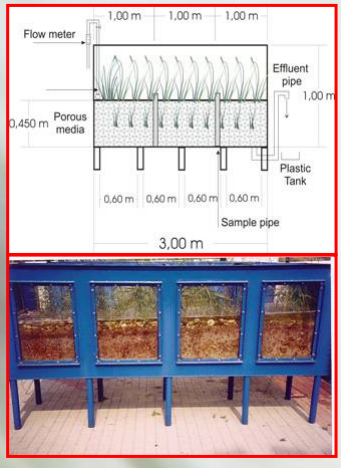
Horizontal subsurface flow (HSF) CWs

Akratos C.S. and Tsihrintzis V.A. (2007). Effect of Temperature, HRT, Vegetation and Porous Media on Removal Efficiency of Pilot-Scale Horizontal Subsurface Flow Constructed Wetlands, *Ecological Engineering*, Vol. 29, No. 2, pp. 173-191.

- **Five rectangular CW tanks made of steel, with dimensions 3m long, 0.75 m wide and 1 m deep**
  - **3 units were filled with medium gravel from a quarry (MG, D_{50}=15.0 mm):**
    - **1 unit was unplanted (control unit)**
    - **The other two units were planted, one with *Typha* and the other with *Phragmites***
  - **One unit was filled with fine gravel (FG, D_{50}=6.0 mm) and another one with cobbles (CO, D_{50}=90.0 mm) from a riverbed. Both of them were planted with *Phragmites***
  - **The setup allowed for the testing of the effect of various parameters such as:**
    - **vegetation, porous media (size, origin)**
    - **flow, organic loading, hydraulic residence time**
    - **Temperature, season**

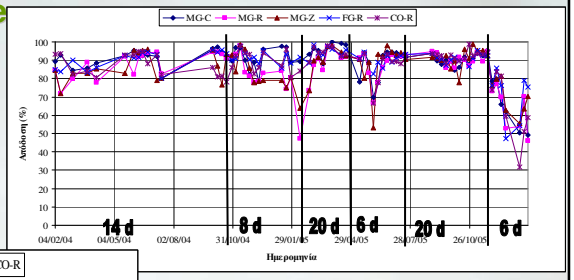
    on the removal efficiency of the CWs

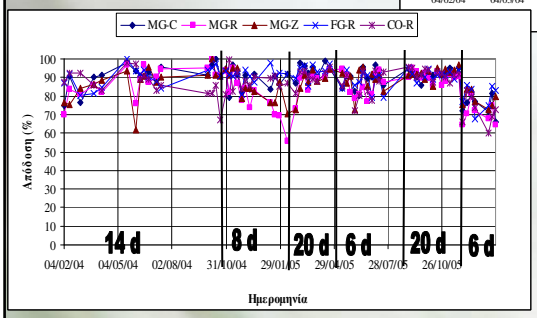
Horizontal subsurface flow (HSF) CWs



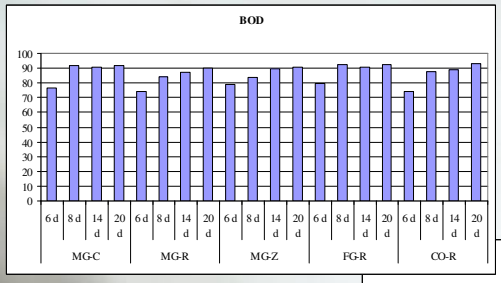
… Horizontal subsurface flow (HSF) CWs

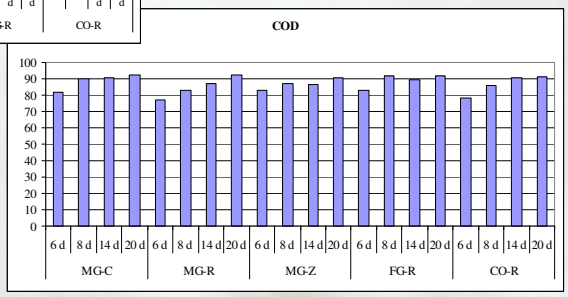
… Horizontal subsurface flow (HSF) CWs:
Removal Performance





Horizontal subsurface flow (HSF) CWs …Removal Performance





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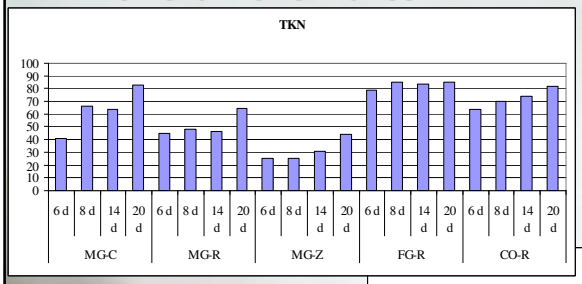
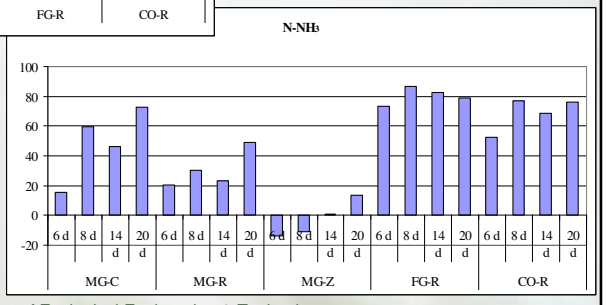
Horizontal subsurface flow (HSF) CWs …Removal Performance





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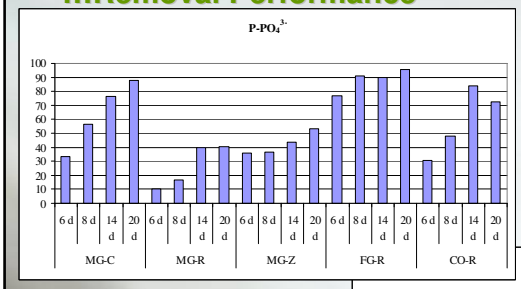
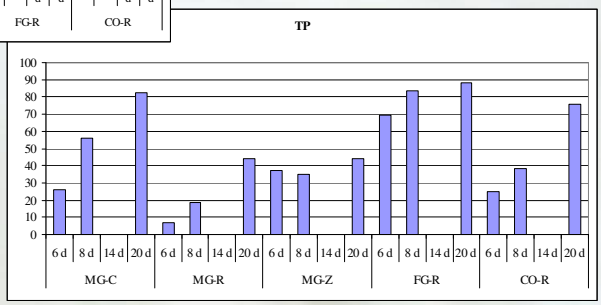
Horizontal subsurface flow (HSF) CWs ...Removal Performance





...Pilot-scale Constructed Wetland Experiments

Free-water surface (FWS) CWs

Kotti I.P. and Tsihrintzis V.A. (2009). Effect of Temperature, HRT, Vegetation, Substrate Material and Plan-view Shape on Removal Efficiency of Pilot-Scale Free-Water Surface Constructed Wetlands (Submitted).
Akratos C.S., Tsihrintzis V.A., Gikas G.D., Kotti E. (2006a). Natural Systems for Wastewater Treatment: Constructed Wetlands in North Greece. In: Proceedings of the Conference "Small scale wastewater treatment facilities", April 6-9, Portaria, Volos , pp. 169-175 (in Greek).

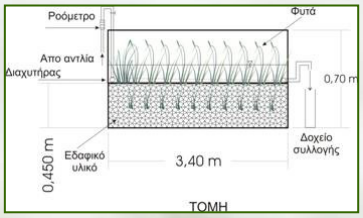
- Five CW tanks made, with dimensions 3.4 m long, 0.85 m wide and 0.75 m deep:
  - **1 rectangular unit, with sand, planted with *Typha***
  - **1 rectangular unit, with clay, planted with *Typha***
  - **1 rectangular unit, with clay, planted with *Arundo donax***
  - **1 rectangular unit, with clay, planted with *Phragmites***
  - **1 trapezoidal unit, with clay, planted with *Typha***
- **The setup allowed for the testing of the effect of various parameters such as:**
  - **vegetation, substrate material**
  - **shape of unit in plan view**
  - **flow, organic loading, hydraulic residence time**
  - **Temperature, season**

  on the removal efficiency of the CWs

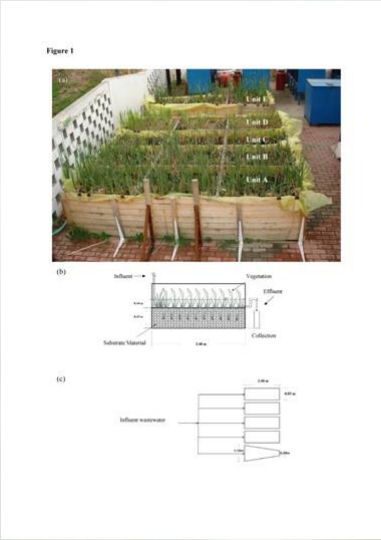
Free-water surface (FWS) CWs



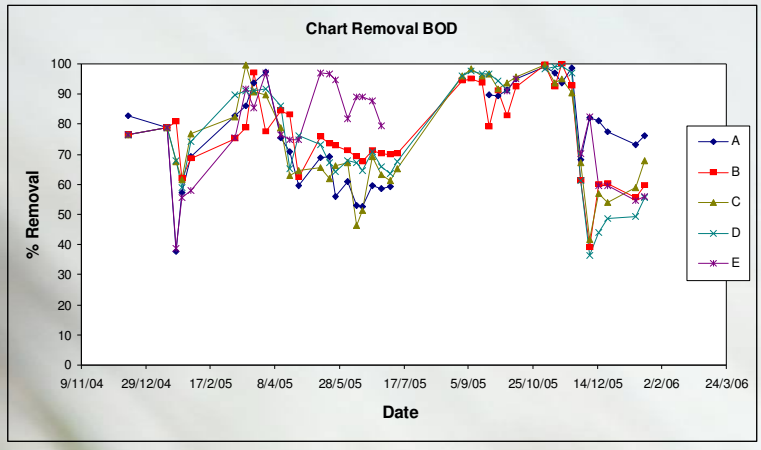




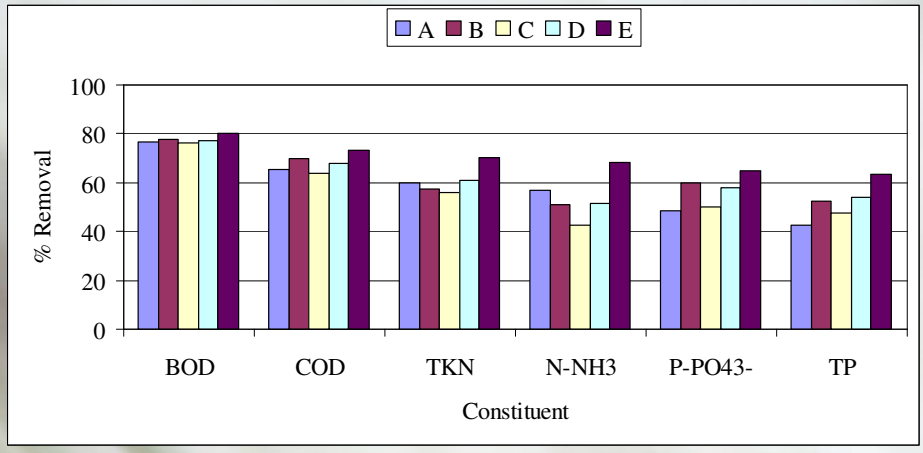
… Free-water surface (FWS) CWs



… Free-water surface (FWS) CWs: Removal Performance



… Free-water surface (FWS) CWs: Removal Performance



…Pilot-scale Constructed Wetland Experiments

Vertical flow (VF) CWs

Stefanakis A.I. and Tsihrintzis V.A.. (2009). Performance of Pilot-Scale Vertical Flow Constructed Wetlands Treating Simulated Municipal Wastewater: Effect of Various Design Parameters, *Desalination*, (in press).

- **Pilot-scale VFCW description:**
  - **10 VFCW units: W1 – W10**
  - **Plastic cylindrical tanks: d = 0,8 m**
    h = 1,5 m A = 0,57 m^2
  - **a) Drainage media: cobbles layer (15 cm thick)**
    b) Layers of others porous media (medium - fine gravel, sand)
  - **Porous media: carbonate (quarry), igneous (riverbed)**
  - **Alternative media: zeolite, bauxite**
  - **Plants: common reed (*Phragmites australis*), cattail (*Typha latifolia*)**
  - **PVC ventilation tubes for aeration**
  - **Type: European, French, American**
  - **Outflow: 10 plastic tanks of 150 L**

Vertical flow (VF) CWs … Description

Vertical Flow Constructed Wetlands

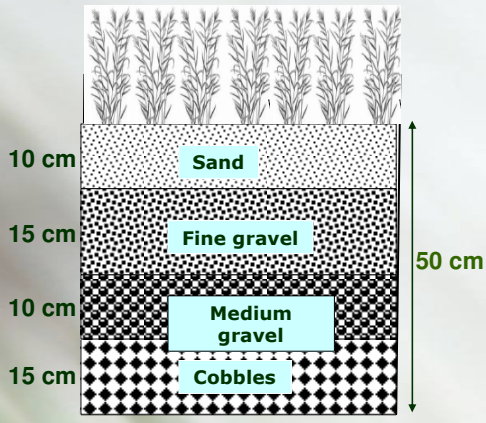
Outflow plastic tanks

Vertical flow (VF) CWs … Description




Vertical flow (VF) CWs: Description

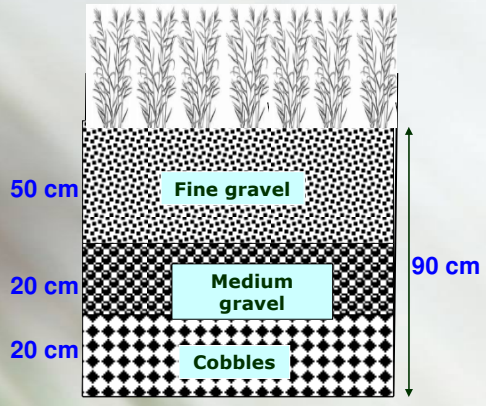
EUROPEAN TYPE: W1 - W8



- Sand: d_{50} = 0,5 mm
- Fine gravel: d_{50} = 6 mm
- Medium gravel: d_{50} = 24,4 mm
- Cobbles: d_{50} = 90 mm

Vertical flow (VF) CWs:
… Description

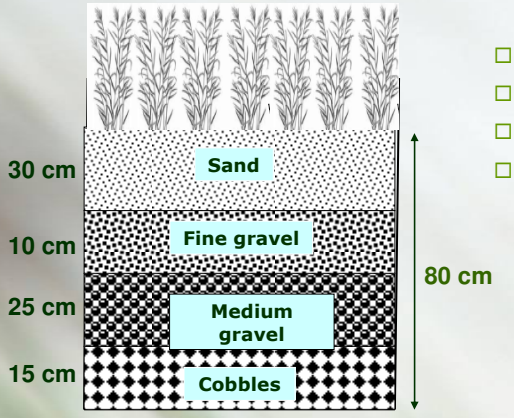
FRENCH TYPE W9



- Fine gravel: d_{50} = 6 mm
- Medium gravel: d_{50} = 24,4 mm
- Cobbles: d_{50} = 90 mm

Vertical flow (VF) CWs:
… Description

AMERICAN TYPE W10

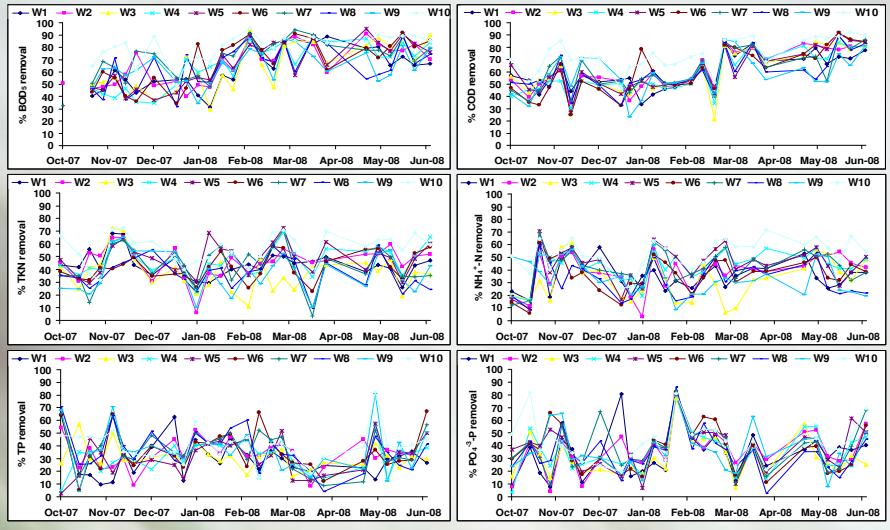


- Sand: d_{50}=0.5 mm
- Fine gravel: d_{50} = 6 mm
- Medium gravel: d_{50} = 24.4 mm
- Cobbles: d_{50} = 90 mm

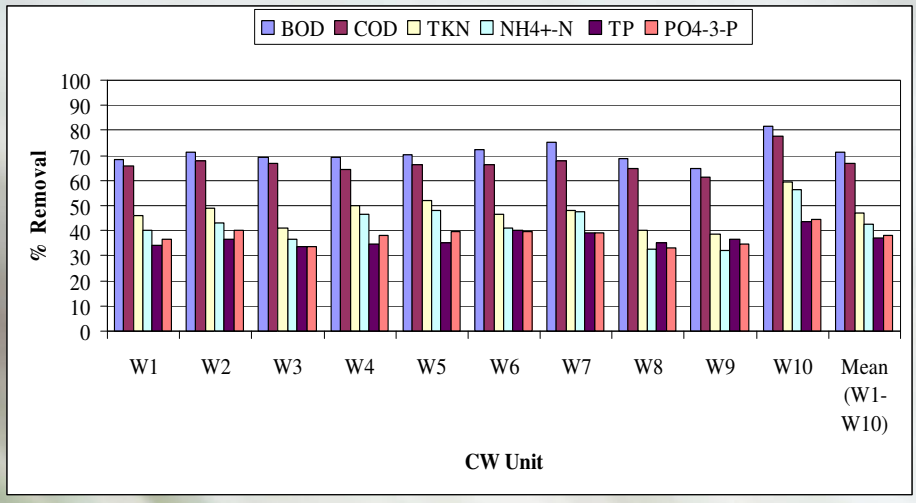
Vertical flow (VF) CWs:
… Description

Pilot unit #	Medium gravel	Fine gravel	Plant	Ventilation tubes	CW type
W1	Carbonate		Reed	Yes	European
W2	Carbonate		Cattail		
W3	Carbonate		Unplanted		
W4	Zeolite	Carbonate	Reed		
W5	50% Carbonate 50% Zeolite	Carbonate			
W6	50% Carbonate 50% Bauxite	Carbonate			
W7	River bed				
W8	Carbonate			No	
W9	Carbonate			Yes	French
W10	Carbonate				American

Vertical flow (VF) CWs:
Removal time-series



Vertical flow (VF) CWs: % Removal



…Pilot-scale Constructed Wetland Experiments

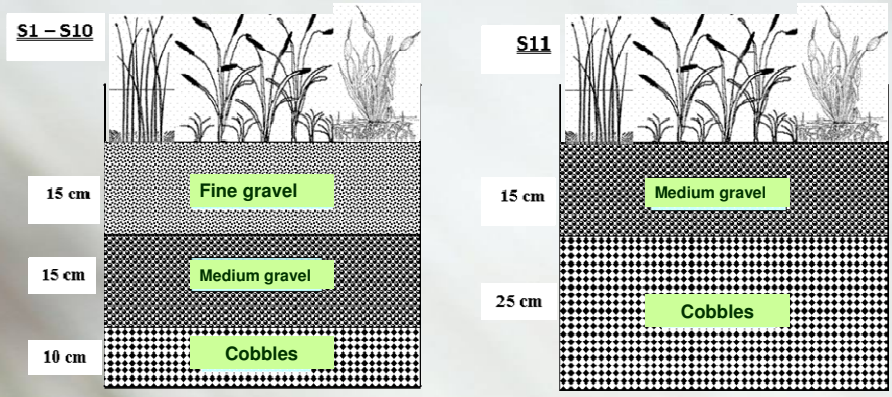
Pilot-scale sludge drying reed bed units (SDRB)

Stefanakis A.I. and Tsihrintzis V.A. (2009b). An experimental study of activated sludge treatment in Sludge Drying Reed Beds, Proceedings of the 3rd International Conference AMIREG2009, Athens, 7-9 September 2009 (http://heliotopos.conferences.gr/?amireg2009) (accepted).

- **Pilot-scale SDRB description:**
  - **11 SDRB (VFCW) units: S1 – S11**
  - **Plastic cylindrical tanks: d = 0,8 m**
    h = 1,5 m A = 0,57 m^2
  - **a) Drainage media: cobbles layer (15 cm thick)**
    b) Layers of others porous media (medium - fine gravel, sand)
  - **Porous media: carbonate (quarry), igneous (river bed)**
  - **Plants: common reed (*Phragmites australis*), cattail (*Typha latifolia*)**
  - **PVC ventilation tubes for aeration**
  - **Sludge loading rate**
  - **Cr**

Pilot-scale SDRB:
… Description

Pilot-scale SDRB
… Description



d=0.4 m

Pilot-scale SDRB:
… Description

Unit	Medium gravel	Fine gravel	Plant	Aeration tubes	Material size	Loading (kg/m²/yr)	Adding Cr
S1	River bed		Reed	YES	Fine	75	No
S2	Carbonate		Reed			75	
S3	River bed		Cattail			75	
S4			Unplanted			75	
S5			Reed			30	
S6						60	
S7						75	Yes
S8						30	
S9						60	
S10				NO		75	No
S11				YES	Medium	75	

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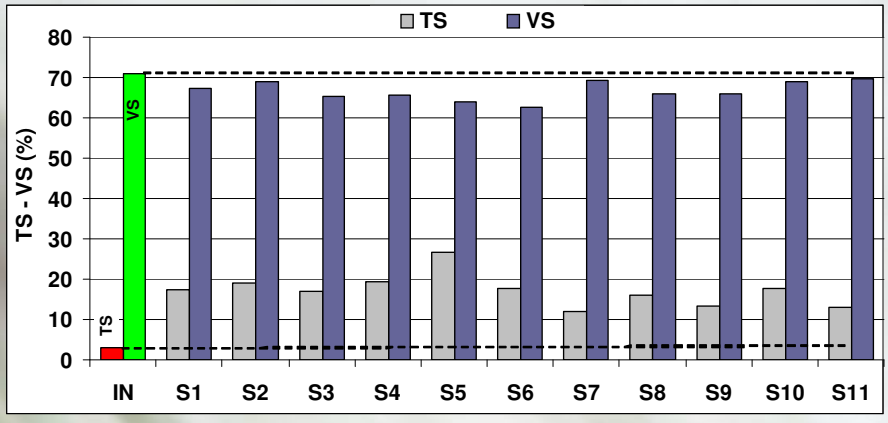
Pilot-scale SDRB:
Results…

Mean Value: TS 17.5% , VS 66%



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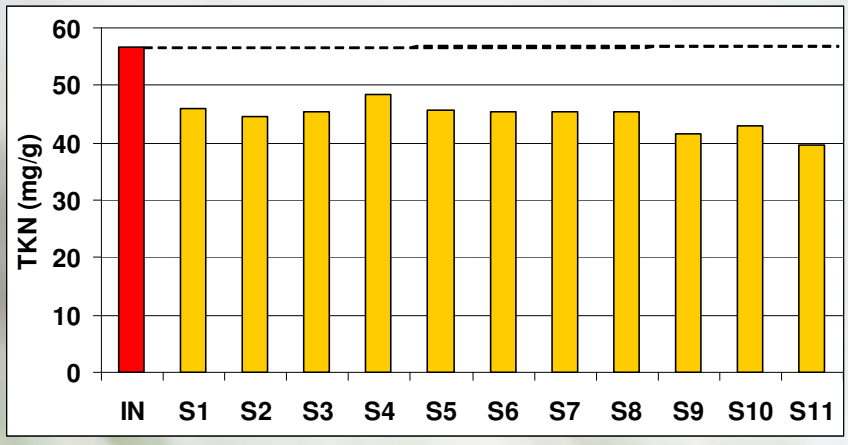
Pilot-scale SDRB:
… Results

Decrease TKN concentration in accumulated sludge: 21%



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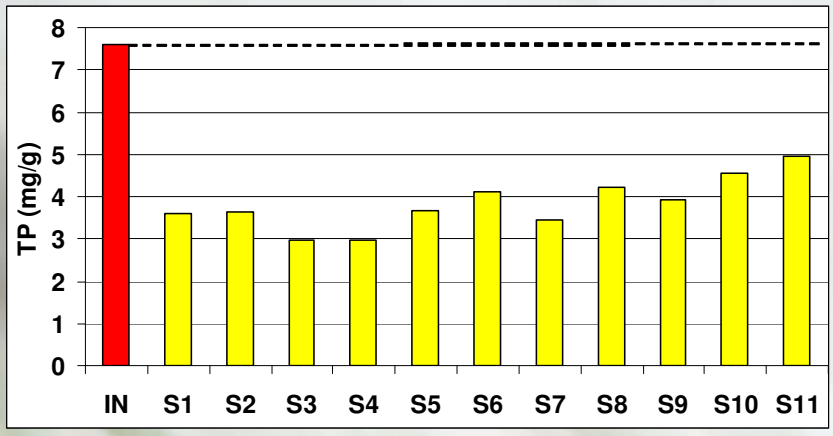
Pilot-scale SDRB:
… Results

Decrease TP concentration in accumulated sludge: 50%



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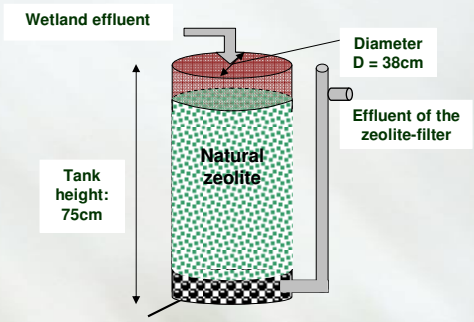
…Pilot-scale Constructed Wetland Experiments

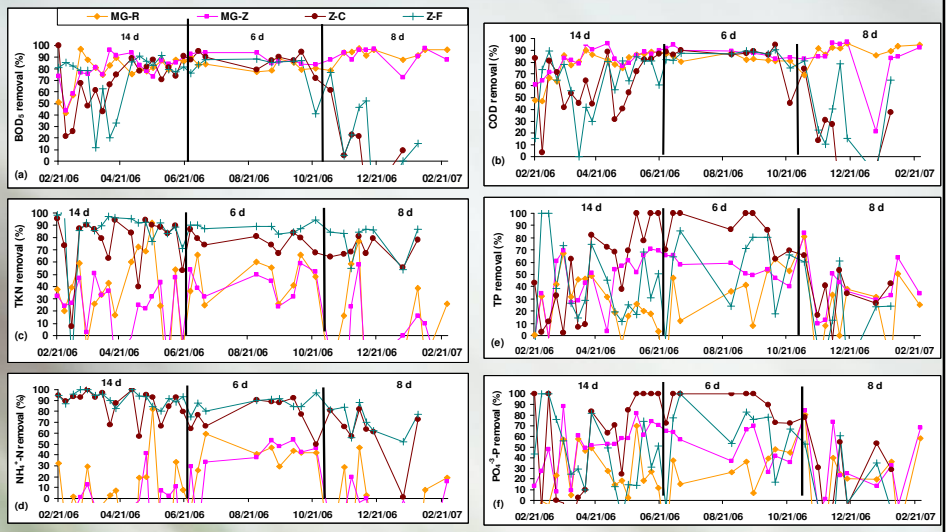
Pilot-scale gravity-filters of zeolite as additional treatment stage of HSF CWs

Stefanakis A.I., Akratos C.S., Gikas G.D. and Tsihrintzis V.A. (2009c). Performance of Natural Zeolite (Clinoptilolite) as Filter Medium, Providing an Additional Treatment Stage of the Effluent of two Pilot-scale, Horizontal Subsurface Flow Constructed Wetlands, *Microporous and Mesoporous Materials*, 124 (1-3), 131–143 (doi:10.1016/j.micromeso.2009.05.005)

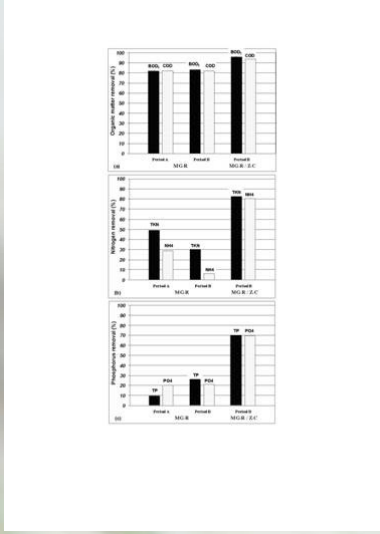
- 2 zeolite filters receive the effluent of the two HSF CWs units (MG-R & MG-Z)
- Plastic tank (85L)
- Influent at the top
- MG-Z: fine grained (**Z-F**) (d_{50} = 1.22 mm, ε = 34%)
- MG-R: coarse (**Z-C**) (d_{50} = 2.78 mm, ε = 39%)

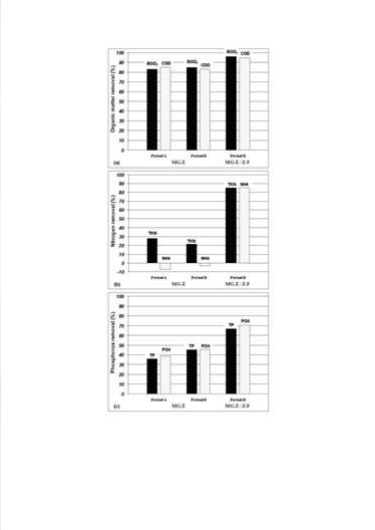


Pilot-scale gravity-filters of zeolite: Results



Pilot-scale gravity-filters of zeolite: … Results





Pilot-scale gravity-filters of zeolite: … Results

Pollutant Removal (%)

	Filter Z-C	Filter Z-F
BOD	60.6	63.2
COD	52.5	62.0
TKN	75.1	83.2
NH_4-N	78.3	85.8
TP	56.8	40.5
OP	56.4	39.2

…Pilot-scale Constructed Wetland Experiments

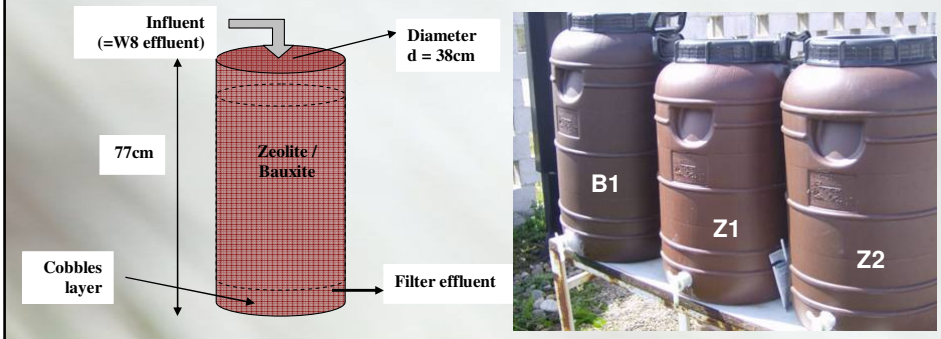
Pilot-scale gravity-filters of various materials as additional treatment stage of VF CWs

Stefanakis A.I. and Tsihrintzis V.A. (2008). Constructed Wetland and Effluent Quality Improvement Using Zeolite and Bauxite as Filter Media. In: Proceedings *AQUA 2008, 3rd International Conference, Water Science and Technology with emphasis on water and climate*, 16-19 October, Athens, Hellas.

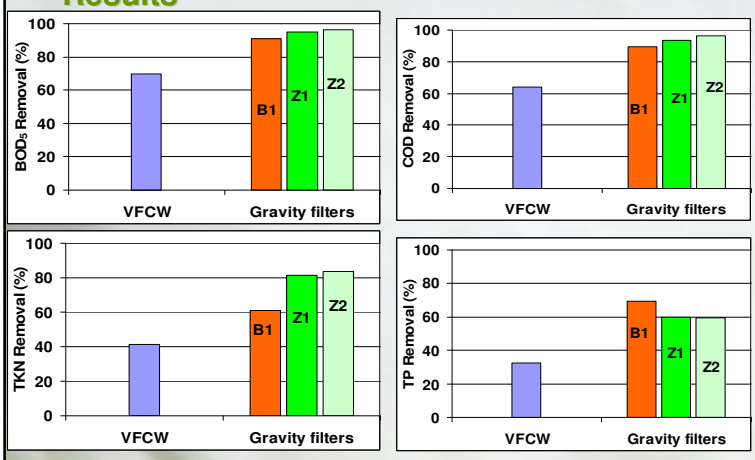
- **Treatment of 10 L from VFCW effluent**

Filter	Porous media	Porosity	Media volume (L)	Media height (cm)	Residence time RT (d)
B1	Bauxite (d_{50}=21 mm)	0.45	32.2	0.30	1
Z1	Zeolite (d_{50}=15 mm)	0.43	33.3	0.30	
Z2			43.3	0.38	2

Pilot-scale gravity-filters of various materials as additional treatment stage of VF CWs: Description



Pilot-scale gravity-filters of various materials as additional treatment stage of VF CWs: Results



Org. matter

VFCW+
Z2>Z1>B1
(95-94-90%)

Nitrogen

VFCW+
Z2>Z1>B1

(85-82-60%)

Phosphorus

VFCW+
B1>Z1≈Z2
(71-61%)

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Lysimeters for ET Estimation in CW

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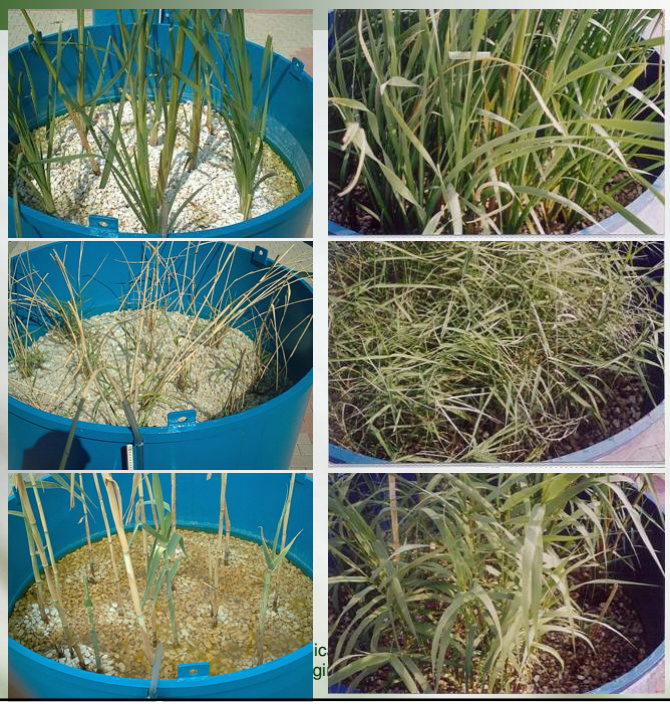
Department of Environmental Engineeri



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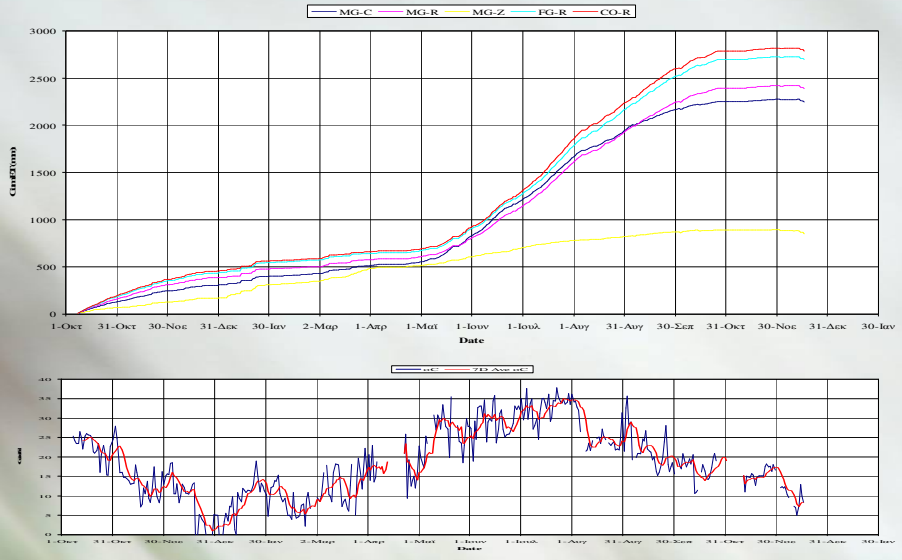
Lysimeters for ET Estimation in CW



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2. Monitoring of Full-scale Facilities

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… Monitoring of Full-scale Facilities

… Monitoring of Full-scale Facilities

- Three full-scale CW facilities were monitored for relatively long periods, and useful data on their performance have been collected.
- These include:
  - Vassova lagoon CW, Kavala Prefecture
  - Nea Madytos CW, Thessaloniki Prefecture
  - Gomati CW, Chalkidiki Prefecture

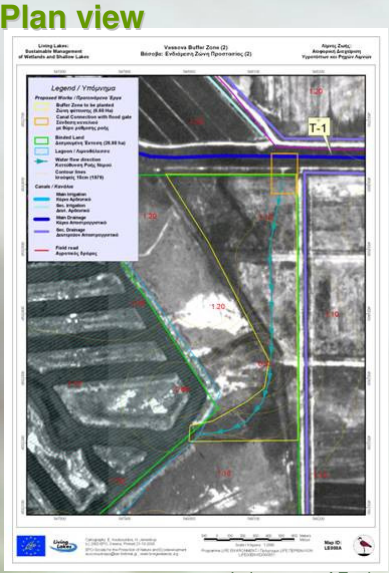
… Monitoring of Full-scale Facilities

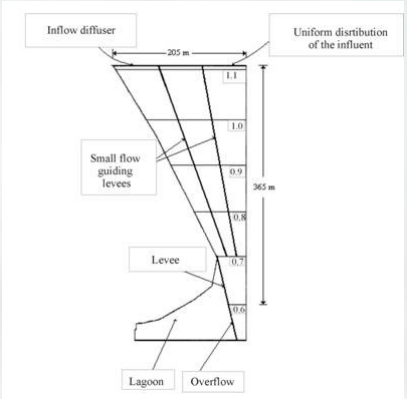
Vassova lagoon CW

Akratos C.S., Tsihrintzis V.A., Pechlivanidis I., Sylaios G.K. and Jerrentrup H. (2006b). A Free Water Surface Constructed Wetland for the Treatment of Agricultural Drainage Entering Vassova Lagoon, Kavala, Greece, Fresenius Environmental Bulletin, Vol. 15, No 12.

- **Vassova lagoon is a small and shallow lagoon in the area of Nestos River Delta used for fisheries**
- **The problem: Increase of the lagoon salinity because lack of freshwater input, shallow depth, evaporation and low precipitation**
- **Free-water surface constructed wetland**
  - **Treatment agricultural drainage from a nearby drainage canal (phosphorus and other pollutant removal)**
  - **Freshwater input into the Vassova lagoon**

Vassova Lagoon CW: Plan view





Vassova lagoon CW: Monitoring

Vassova lagoon CW: …Description

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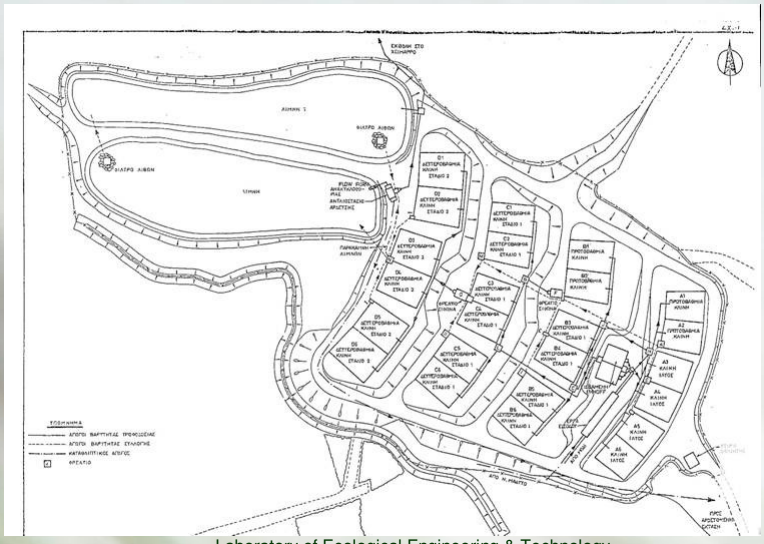
… Monitoring of Full-scale Facilities

Nea Madytos CW

Akratos C.S., Gikas G.D., Tsihrintzis V.A. (2006c). Monitoring of a Vertical Flow Constructed Wetland of Nea Madytos. In: Proceedings of the Conference "Small scale wastewater treatment facilities", April 6-9, Portaria, Volos , pp. 193-199 (in Greek).

- **Vertical Flow CW**
- **Wastewater treatment of Nea Madytos and Modi villages, Thessaloniki Prefecture, North Greece**
  - **Population:**
    - **1992: 2060 p.e.**
    - **2012: 3300 p.e.**

Nea Madytos CW: Plan view



Nea Madytos CW: Description

Inflow-screen

Imhoff tanks

Nea Madytos CW: … Description

VF CWs for sludge treatment

1st stage VF CWs

Nea Madytos CW:
… Description

Nea Madytos CW:
… Description

26-3-2004

1-4-2004

Nea Madytos CW:
… Description

22-4-2004

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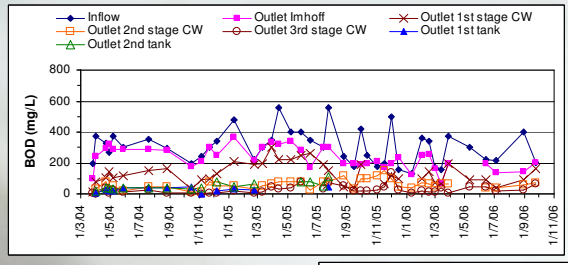
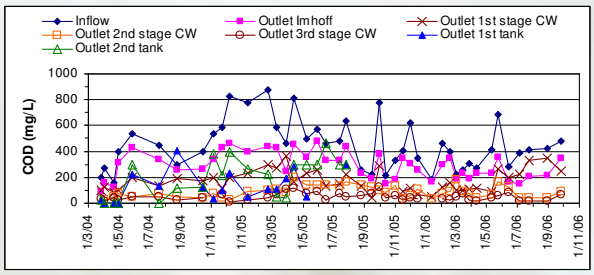
Nea Madytos CW:
Pollutant concentrations





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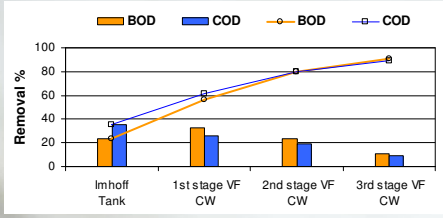
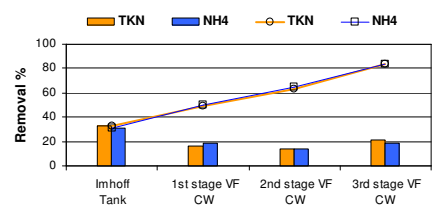
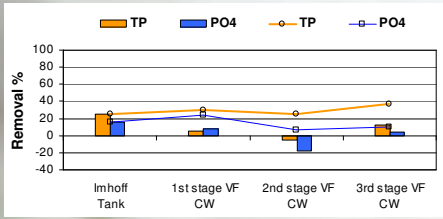
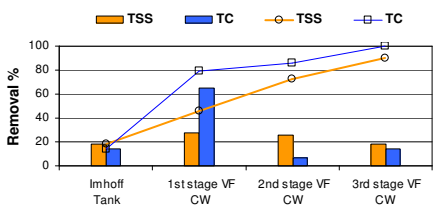
Nea Madytos CW: Pollutant removal

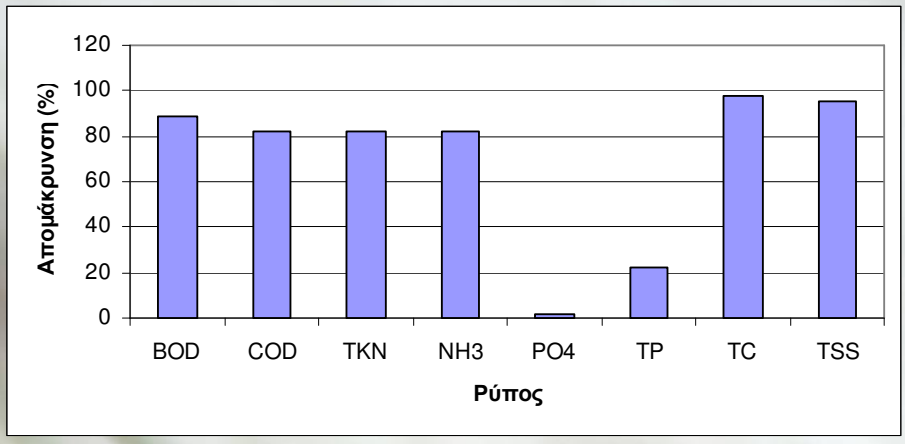








Nea Madytos CW: ... Pollutant removal



Nea Madytos CW: Cost

- **Construction cost:**
  - **Total: 580,000 €**
  - **Per capita: 193 €/capita**

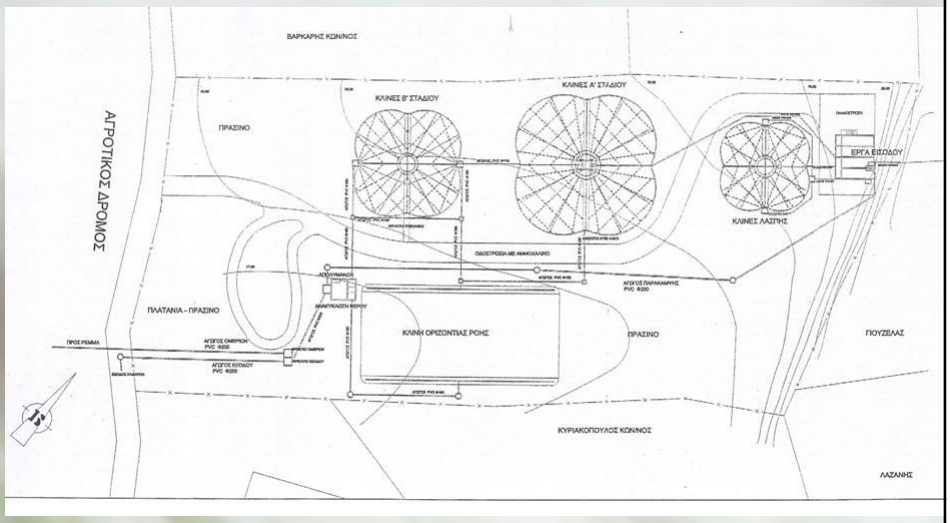
… Monitoring of Full-scale Facilities

Gomati CW

Gikas G.D., Akratos C.S. and Tsihrintzis V.A. (2007a). Performance Monitoring of a Vertical Flow Constructed Wetland Treating Municipal Wastewater. Global NEST Journal, Vol. 9, No. 3, pp. 277-285.

- **Description:**
  - **Population: 1000 p.e.**
  - **Vertical flow, comprises the following stages:**
    - **Screen**
    - **Primary settling tank**
    - **Sludge tank**
    - **Siphon tank**
    - **1st stage VF CWs**
    - **2nd stage VF CWs**
    - **3rd srage HSF CW**
    - **VF CWs for sludge treatment**

Gomati CW: Plan view



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Gomati CW: Description

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Gomati CW:
… Description

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Gomati CW:
…Description

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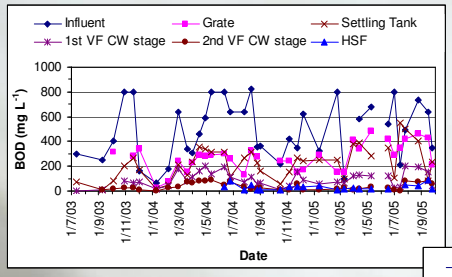
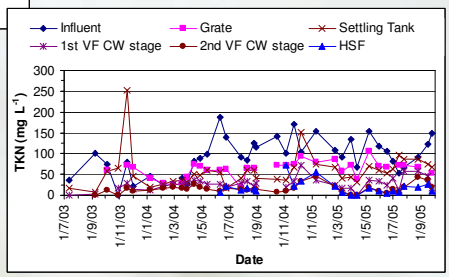
Gomati CW: Pollutant concentrations





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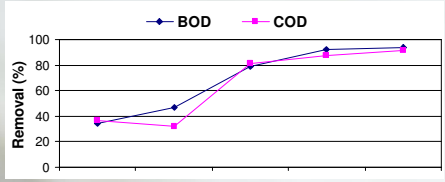
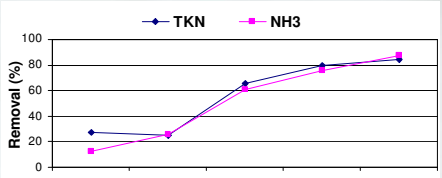
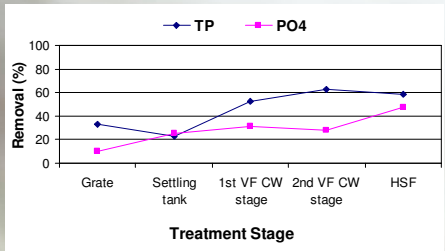
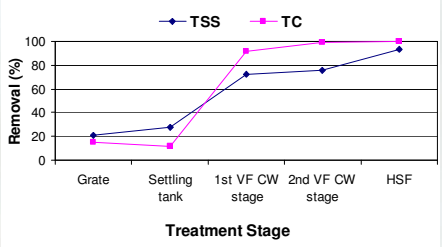
Gomati CW: … Pollutant removal









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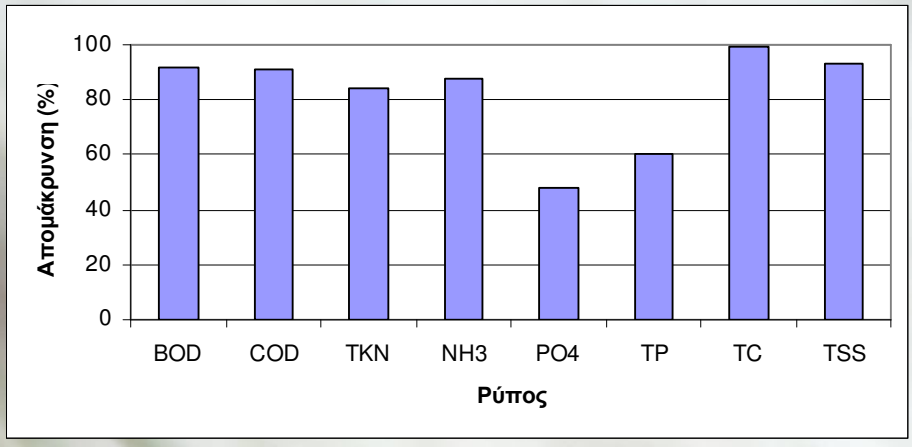
Gomati CW:
… Pollutant removal



Gomati CW:
Cost

- **Construction:**
  - Total: 345.300 € + tax
  - Per capita: 345 €/capita
  - Includes: access road, plant, fence
- **Operation/Maintenance:**
  - Electric energy: 810 €/yr
  - Work-salaries : 6000 €/yr
  - Miscellaneous : 150 €/yr
  - TOTAL : 6969 €/yr or 6.96/p.e./yr

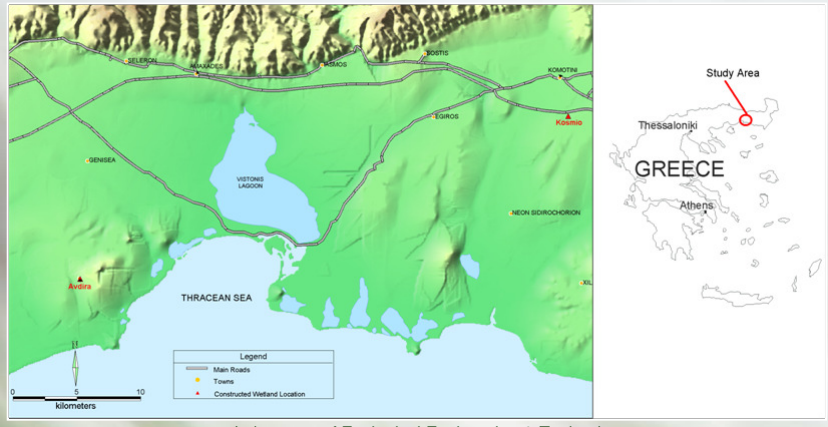
3. Design, Construction and Monitoring of New Facilities

- Small-scale CWs for onsite treatment of household wastewater
  - Horizontal subsurface flow CW
  - Vertical flow CW
- Full-scale system in N. Oikismos, Kastoria Prefecture
- Full-scale system in Rhoditis, Rhodope Prefecture

… Design, Construction and Monitoring of New Facilities

Small-scale CWs for onsite treatment of household wastewater

Gikas G.D., Tsihrintzis V.A., Kotti E. (2007b). Small-Scale Constructed Wetland for on-site Treatment Domestic Wastewater. In: Proceedings of the 6th National Conference, "Water Recourses Management Based on Watershed", EEDYP, June 14-16, Chania, Crete, Greece, pp. 199-207 (in Greek).



Small-scale CWs for onsite treatment of household wastewater

Design Parameters and technical specifications of the two on-site CWs

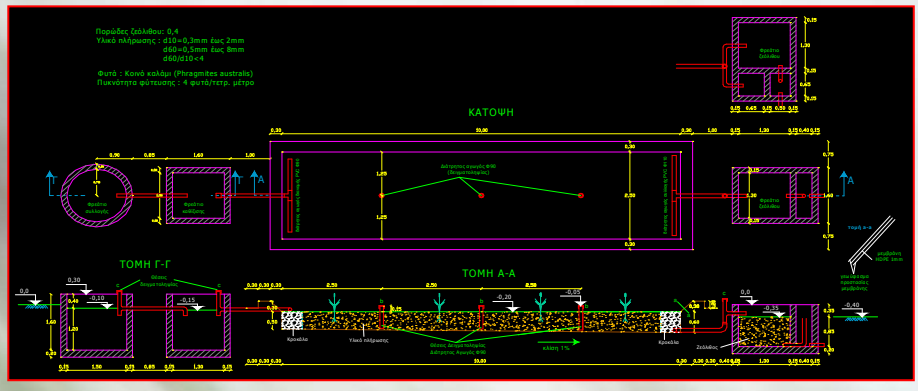
Parameters	Units	System type	
		HSF	VSF
Population equivalent	p.e.	4	8
Inflow	L/p.e./d	150	150
BOD_5	g/p.e./d	50	50
Suspended Solids, SS	g/p.e./d	52	52
TKN	g/p.e./d	10	10
Total phosphorus, TP	g/p.e./d	1.2	1.2
Length	m	10	7.0
Width	m	2.5	3.5
Bed depth	m	0.6	0.9
Bed surface	m^2	25.0	24.5
Number of plants	Plant/m^2	16	16
Vegetation type		Reed	Cell A:Reed; Cell B:no plant

… Design, Construction and Monitoring of New Facilities

Horizontal subsurface flow CW

Gikas G.D., Tsihrintzis V.A. (2009a). On-Site Treatment of Domestic Wastewater Using Small-Scale Constructed Wetland. Proceedings International Conference "Asset Management of Medium, and Small Wastewater Utilities", IWA, Alexandroupolis, Thrace, Greece, 3 - 4 July 2009 (http://iwasam.env.duth.gr) (accepted).

Site 1: Kosmio



Horizontal subsurface flow CW: Description

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Horizontal subsurface flow CW: …Description

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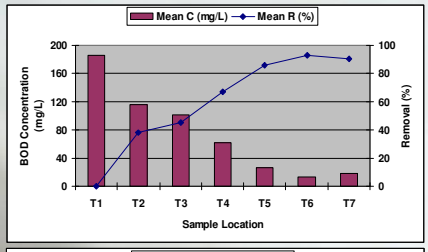
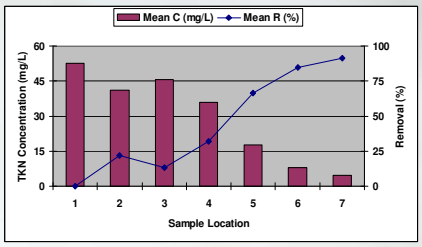
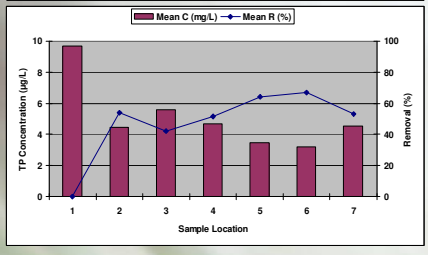
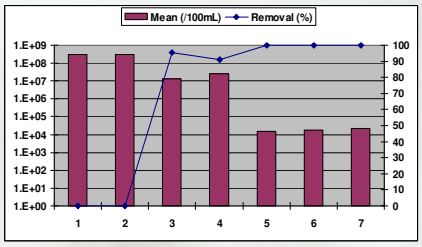
Horizontal subsurface flow CW: …Description

Horizontal subsurface flow CW: Pollutant removal









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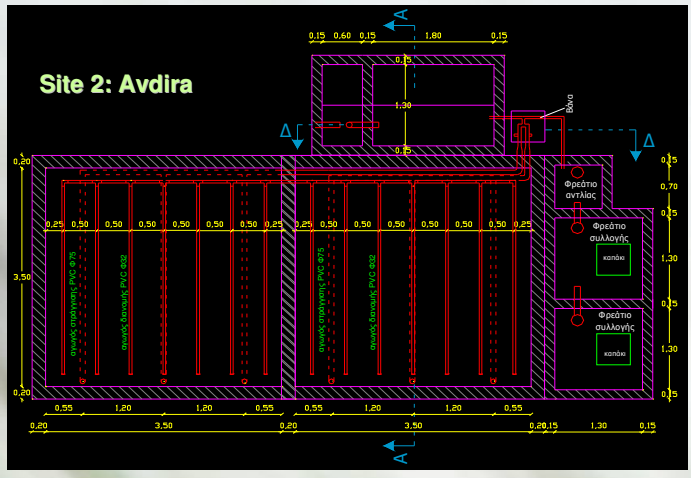
… Design, Construction and Monitoring of New Facilities

Vertical flow CW

Gikas G.D., Tsihrintzis V.A. (2009b). A Small-Size Constructed Wetland for on –site Treatment of Household Wastewater. Proceedings of 11th International Conference on Environmental Science and Technology (CEST2009), September 3-5, Chania, Crete, Greece.



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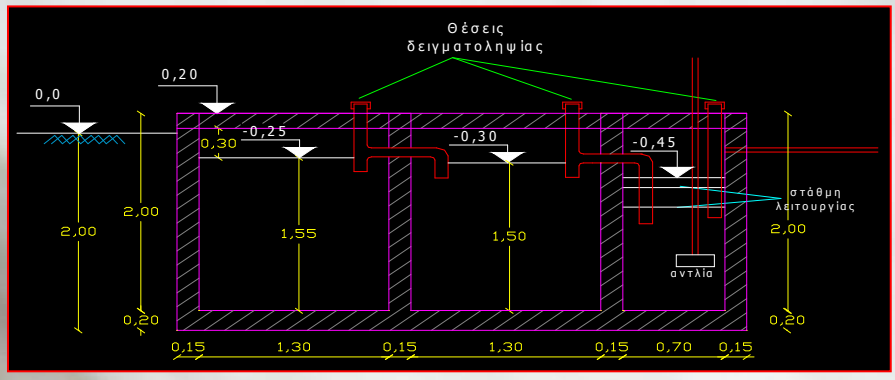
Vertical flow CW: Description



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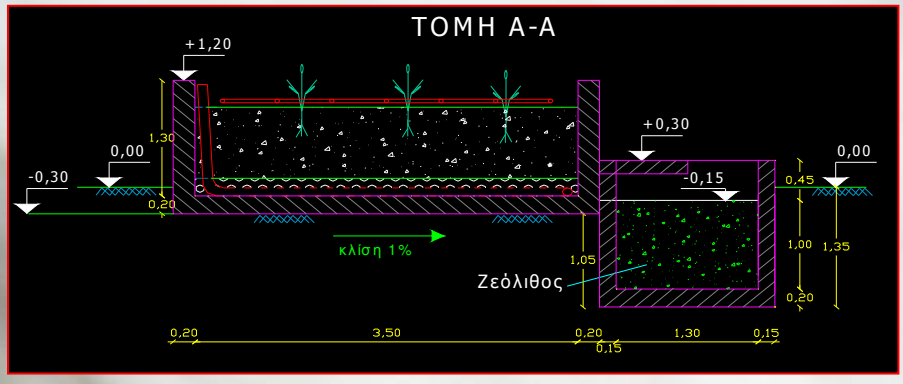
Vertical flow CW:
… Description

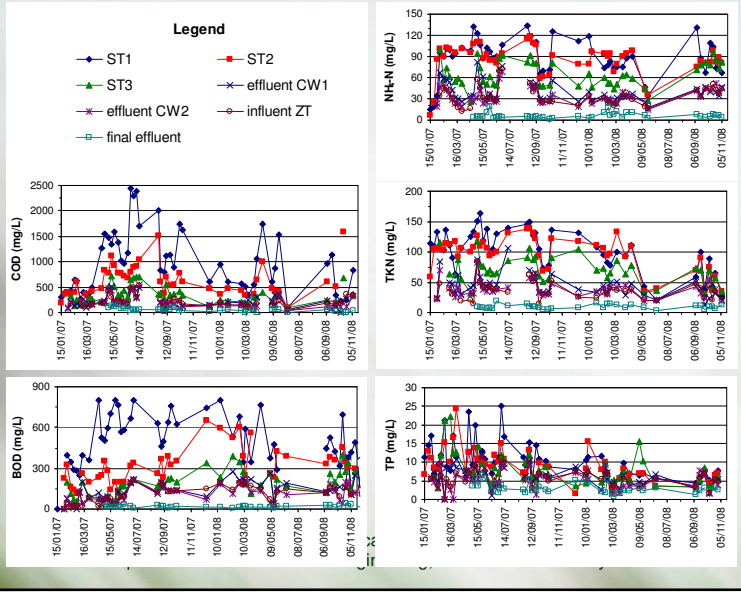


Vertical flow CW:
… Description

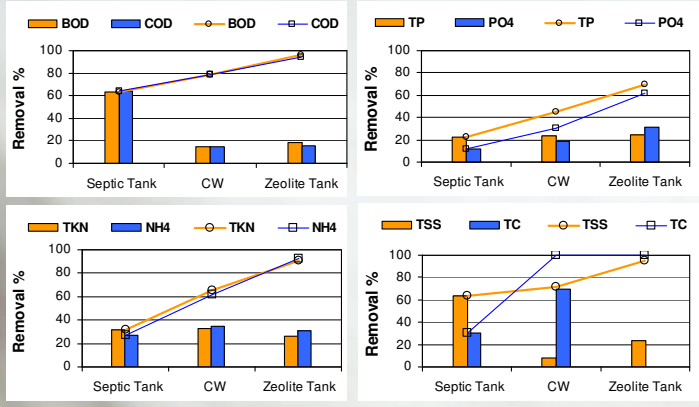
Vertical flow CW:
… Description

Vertical flow CW:
… Description

Vertical flow CW: Pollutant concentrations



Vertical flow CW: … Pollutant removal



Parameter	Removal %
BOD	96,4
COD	94,4
TKN	90,8
NH4	92,8
TP	69,8
PO4	61,6
TSS	95,3
TC	99,96

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… Design, Construction and Monitoring of New Facilities

Full-scale system in N. Oikismos, Kastoria

Gikas G.D., Tsihrintzis V.A., Petalas C., Skias S. (2006). Constructed Wetlands for Wastewater Treatment of N. Korestia, Kastoria District. In: Proceedings of the Conference "Small scale wastewater treatment facilities", April 8-9, Portaria, Volos, pp. 201-208 (in Greek)

Study Area

Municipality: N. Oikismos, Korestia

Population: 500 p.e.

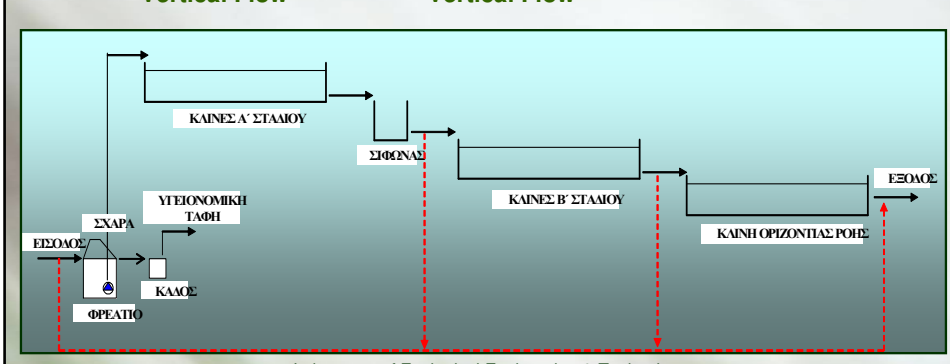
Sewage system: separate

Full-scale system in N. Oikismos: Study area

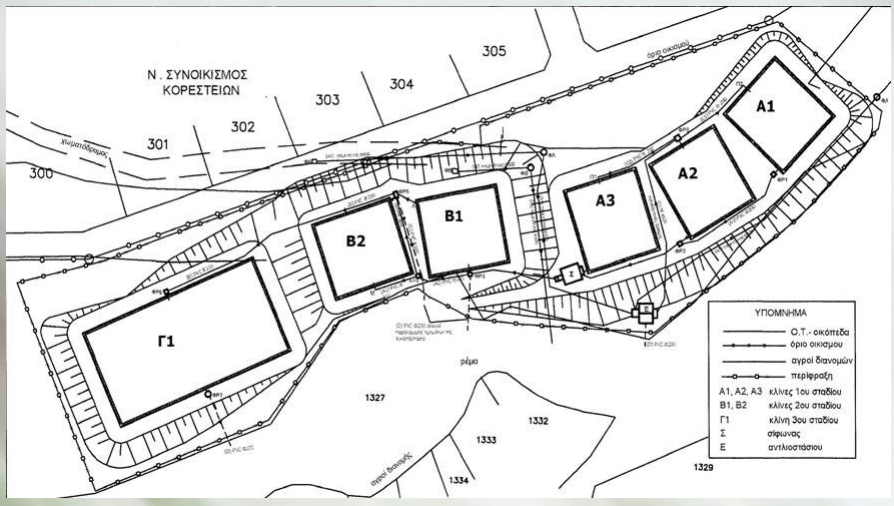
Full-scale system in N. Oikismos: … Study area

Full-scale system in N. Oikismos: Description

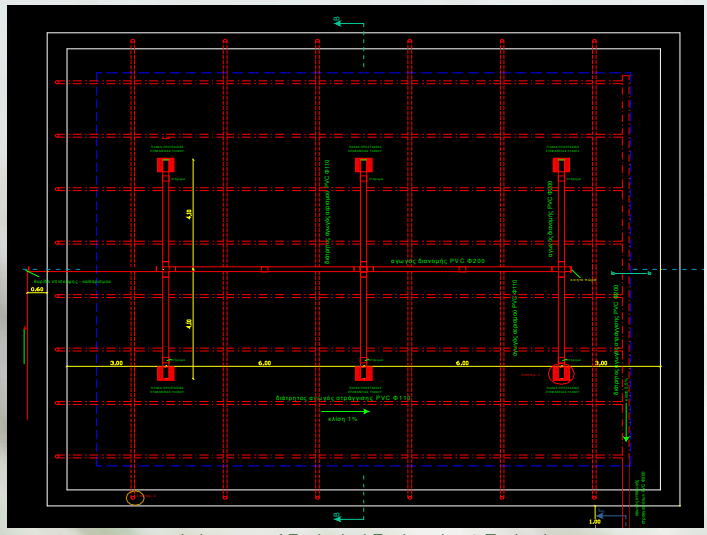
- 1st stage
  - 1,5 m²/p.e.
  - 3 CW beds Vertical Flow
- 2nd stage
  - 1,0 m²/p.e.
  - 2 CW beds Vertical Flow
- 3rd stage
  - 1,5 m²/p.e.
  - 1 HSF CW bed



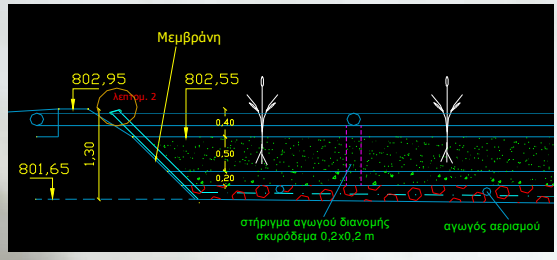
Full-scale system in N. Oikismos: Plan view

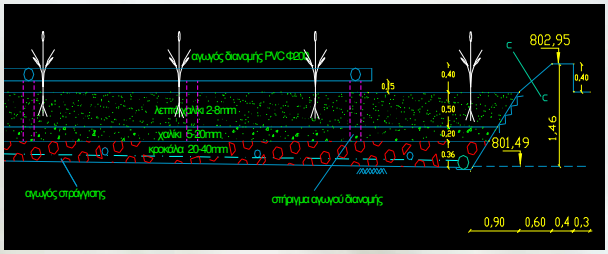


Full-scale system in N. Oikismos: 1st stage CW bed, plan view



Full-scale system in N. Oikismos: 1st stage CW bed, side section





Full-scale system in N. Oikismos: Siphon

Full-scale system in N. Oikismos: Expected effluent quality and removals

PARAMETER	CONCENTRATION (mg/L)	REMOVAL (%)
BOD_5	<=15	96 %
COD	<=40	93 %
SS	<=15	96 %
TKN	<=6	91 %
TP	<=4	50 %

Full-scale system in N. Oikismos: Cost

Construction	Expenditure (€)
Soil excavation	74,457
Plant	20,346
Structure using concrete, Plumbing	62,801
Electromechanical	50,004
Oncost	87,350
Value-added tax	56,042
Total	**351,000**

Operating cost	
Electric energy	12.25 €/day ή 7.35 €/p.e./yr ή 0.13 €/m^3 wastewater

Full-scale system in N. Oikismos: Construction

Full-scale system in N. Oikismos: … Construction

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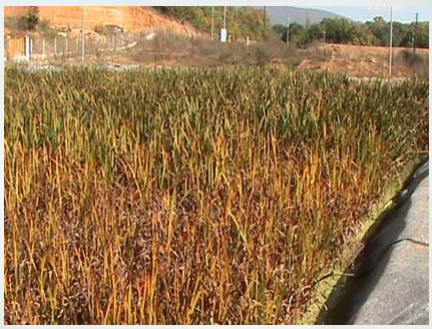
Full-scale system in N. Oikismos: … Construction

Full-scale system in N. Oikismos: … Operation



… Design, Construction and Monitoring of New Facilities

Full-scale system in Rhoditis, Rhodope Prefecture

Study Area

Municipality: Rhoditis, Komotini

Population: 800 p.e.

Construction cost: 349,000 €

System description

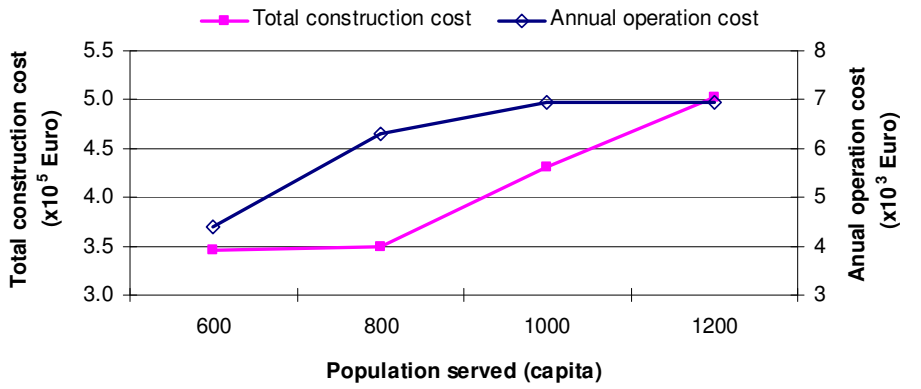
- Septic tank
- 1st stage
  - 1.2 m²/p.e.
  - 3 CW beds Vertical Flow
- 2nd stage
  - 0.8 m²/p.e.
  - 2 CW beds Vertical Flow
- 3rd stage
  - 1.0 m²/p.e.
  - 1 HSF CW bed

Full-scale system in Rhoditis, Rhodope

COST

Parameter	CW Treatment System			
	Neos Oikismos	Rhoditis	Gomati	Kyprinos
Population served (capita)	600	800	1000	1200
Flow (m^3/d)	90	120	150	180
Total area (ha) / Unit area (m^2/p.e.)	0.73/ 12.2	0.84/ 10.5	0.80/ 8.0	0.95/ 7.9
Construction cost				
Excavation/fill (€)	133,245	105,672	93,247	136,760
Planting (€)	36,381	32,080	24,385	45,543
Reinforced concrete structures(€)	53,211	108,390	210,870	167,242
Piping (€)	33,985	22,150	37,987	33,644
Hydraulic structures (€)	24,849	17,468	43,176	28,644
Electrical/mechanical (€)	64,563	63,240	21,708	90,513
Total construction cost (€)	346,234	349,000	431,373	502,346
Operation cost				
Annual (€/y)	4,410	6,296	6,960	6,935
Annual per p.e. (€/p.e./y)	7.35	7.87	6.96	5.78

... COST



4. Development of CW Models and DSS

- Use of Artificial Neural Networks
- Modeling hydrodynamics and constituent transport in HSF-CW systems
- Use of GIS in siting areas for construction of natural systems

… Development of CW Models and DSS

Use of Artificial Neural Networks

Akratos C.S., Papaspyros J.N.E., Gikas G.D., Tsihrintzis V.A., (2006d). Performance and Modeling of Vertical Flow Constructed Wetlands Treating Municipal Wastewater in North Greece, *Proceedings of the 10th International Conference for Wetland Systems for Pollution Control*, September 24-29, 2006, Lisbon, Portugal, Vol. I.

Akratos C.S., Papaspyros J.N.E., Tsihrintzis V.A. (2008). An Artificial Neural Network Model and Design Equations for BOD and COD Removal Prediction in Horizontal Subsurface Flow Constructed Wetlands, *Chemical Engineering Journal*, Vol. 143, No. 1-3, pp. 96-110.

Akratos C.S., Papaspyros J.N.E., Tsihrintzis V.A. (2009a). Total Nitrogen and Ammonia Removal Prediction in Horizontal Subsurface Flow Constructed Wetlands: Use of Artificial Neural Networks and Development of a Design Equation, *Bioresource Technology*, Vol. 100, No. 2, pp. 586-596.

Akratos C.S., Papaspyros J.N.E., Tsihrintzis V.A. (2009b). Artificial Neural Network Use in Ortho-phosphate and Total Phosphorus Removal Prediction in Horizontal Subsurface Flow Constructed Wetlands, *Biosystems Engineering*, Vol. 102, No. 2, pp. 190-201.

Use of Artificial Neural Networks

- Artificial Neural Networks (ANNs) were used to model HSF CWs based on two-year experimental data from five pilot-scale units
- Hyperbolic design equations, combining zero and first order kinetics, were produced to predict BOD, COD, nitrogen and phosphorus removal. These equations showed better predictions than the commonly used first order model.
- The common form of these equations is:

$$R = \frac{HRT}{K + HRT}$$ where HRT and K are in days

For BOD removal: $K = \left(\frac{22.8}{T}\right)$

For COD removal: $K = \left(\frac{15}{T}\right)$

where T is the wastewater temperature (°C).

… Use of Artificial Neural Networks

For TN removal: $K = \left(\frac{22.8}{T}\right) 45.5 \left(\frac{n}{1-n}\right)^3$

where *n* is the porosity and (n/(1-n))3 is an expression entering many formulas predicting hydraulic conductivities in porous media.

For ortho-phosphate removal: $K = \left(\frac{22.8}{T}\right) 1.7 \left(\frac{1}{s}\right)^2$

where 1/s is a parameter named inverse specific area ($1/s=(D_{50}/(D_{max}-D_{min}))/(1-n)$) and 1.7 is the constant of the inverse specific area.

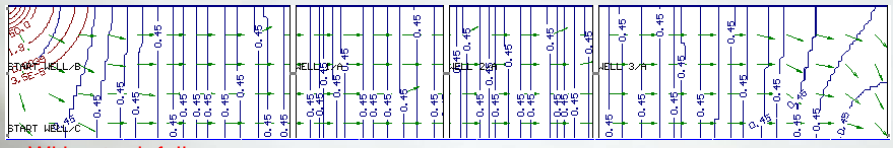
… Development of CW Models and DSS

Modeling hydrodynamics and constituent transport in HSF-CW systems

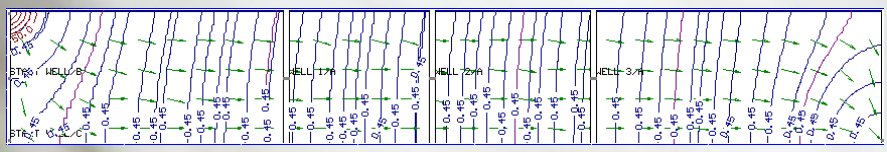
Liolios K.A., Moutsopoulos K.N., Tsihrintzis V.A., Akratos C.S. (2009). Modeling of Flow and Effects of Climatic Parameters in Horizontal Subsurface Flow Constructed Wetlands, In: *Proceedings of the Common Conference, 11th Conference of the Hellenic Hydrotechnical Society and 7th Conference of the Hellenic Committee of Water Resources Management under the theme "Integrated Water Resources Management under Climatic Change Conditions"*, pp.611-618 (in Greek).

The Visual MODFLOW was used to simulate pilot-scale HSF CWs. The model was calibrated using measured values and was used satisfactorily to test the effect of precipitation on removal efficiency of CWs

Model flow domain prediction

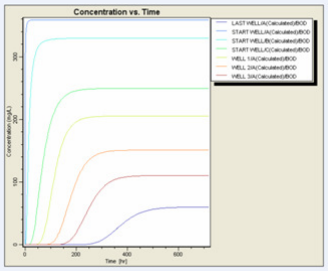


Without rainfall

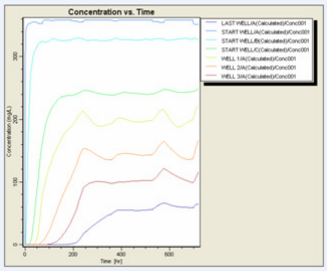


With rainfall

Model concentration predictions



Without rainfall



With rainfall

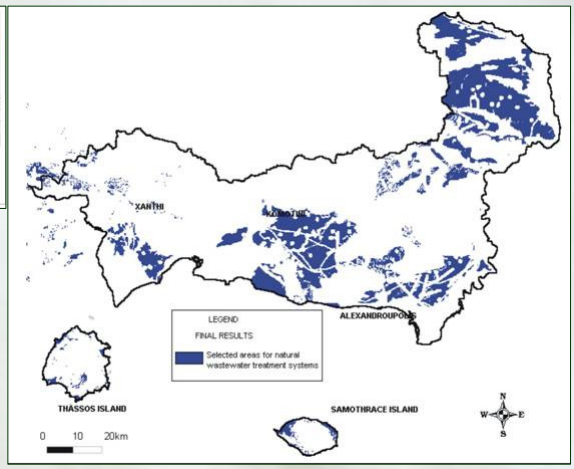
… Development of CW Models and DSS

Use of GIS in siting areas for construction of natural systems

Gemitzi A., Tsihrintzis V.A., Christou O., Petalas C. (2007). Use of GIS in Siting Stabilization Pond Facilities for Domestic Wastewater Treatment, *Journal of Environmental Management* Vol. 82, pp. 155–166

- Geographic information systems (GIS) were used for the problem of siting areas for construction of natural systems, such as stabilization ponds (SPs) for domestic wastewater treatment.
- Based on the GIS analysis, suitable locations were identified in each municipality first, and then the total required surface area of these systems was compared to the available surface area of each municipality, in order to decide whether SP systems could be a viable solution to the wastewater management problem in the particular region.

Use of GIS in siting areas for construction of natural systems: Results



Conclusions

- Experiments in pilot-scale CW units and monitoring of full-scale facilities have demonstrated the effectiveness of CWs in treating municipal wastewater in Greece
- Special materials, such as zeolite and bauxite, can be used to provide additional polishing of CW effluent when this is needed
- Constructed wetlands are also efficient systems for dewatering and mineralization of activated sludge
- CW systems are an economic and reliable solution for the treatment of wastewater from small communities in rural areas

Thank you!

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