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.
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)
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

Primary Treatment
Influent
Vertical Flow (I)
Vertical Flow (II)
Horizontal Flow (III)
Effluent

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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
- 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

- 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.)
... Examples in Europe

PORTUGAL - Beja-Sado: Stabilization ponds (aerated, facultative, maturation), HSF CW, filters (23435 p.e.)
Laboratory of Ecological Engineering & Technology

- 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


- 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

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... Horizontal subsurface flow (HSF) CWs

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

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Removal Performance

COD

BOD

TN

LabN

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Department of Environmental Engineering, Democritus University of Thrace

---

Horizontal subsurface flow (HSF) CWs

…Removal Performance

---

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---

…Pilot-scale Constructed Wetland Experiments

Free-water surface (FWS) CWs


- 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

---

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

![Chart Removal BOD]

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

![Bar chart removal performance]

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Pilot-scale VFCW description:

- **10 VFCW units: W1 – W10**
- **Plastic cylindrical tanks:**
  - **d = 0.8 m**
  - **h = 1.5 m**
  - **A = 0.57 m²**
- **a) Drainage media:** Cobbles layer (15 cm thick)
- **b) Layers of other porous media:** Medium to 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**

**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
- Cobble: $d_{50} = 90$ mm

**AMERICAN TYPE W10**

- Sand: $d_{50}=0.5$ mm
- Fine gravel: $d_{50} = 6$ mm
- Medium gravel: $d_{50} = 24.4$ mm
- Cobble: $d_{50} = 90$ mm
Vertical flow (VF) CWs: Description

<table>
<thead>
<tr>
<th>Pilot unit #</th>
<th>Medium gravel</th>
<th>Fine gravel</th>
<th>Plant</th>
<th>Ventilation tubes</th>
<th>CW type</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>Carbonate</td>
<td></td>
<td>Reed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2</td>
<td>Carbonate</td>
<td></td>
<td>Cattail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W3</td>
<td>Carbonate</td>
<td></td>
<td>Unplanted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W4</td>
<td>Zeolite</td>
<td>Carbonate</td>
<td>Reed</td>
<td>Yes</td>
<td>European</td>
</tr>
<tr>
<td>W5</td>
<td>50% Carbonate</td>
<td>Carbonate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W6</td>
<td>50% Carbonate</td>
<td>Carbonate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W7</td>
<td>River bed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W8</td>
<td>Carbonate</td>
<td></td>
<td></td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>W9</td>
<td>Carbonate</td>
<td></td>
<td></td>
<td>Yes</td>
<td>French</td>
</tr>
<tr>
<td>W10</td>
<td>Carbonate</td>
<td></td>
<td></td>
<td></td>
<td>American</td>
</tr>
</tbody>
</table>

Vertical flow (VF) CWs: Removal time-series

[Graphs showing removal time-series for each CW type]
**Vertical flow (VF) CWs:**

% Removal

![Graph showing removal of BOD, COD, TKN, NH4+-N, TP, PO4-3-P for W1 to W10 and the mean (W1-W10).]

---

**Pilot-scale Constructed Wetland Experiments**

**Pilot-scale sludge drying reed bed units (SDRB)**


- **Pilot-scale SDRB description:**
  - 11 SDRB (VFCW) units: S1 – S11
  - Plastic cylindrical tanks: \( d = 0.8 \text{ m} \)
    - \( h = 1.5 \text{ m} \)  \( A = 0.57 \text{ m}^2 \)
  - 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

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Pilot-scale SDRB: Description

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

Mean Value: TS 17.5%, VS 66%

Pilot-scale SDRB: Results...
Pilot-scale SDRB: … Results

Decrease TKN concentration in accumulated sludge: 21%

Decrease TP concentration in accumulated sludge: 50%
Pilot-scale Constructed Wetland Experiments

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


- 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, $\epsilon = 34\%$)
- MG-R: coarse (Z-C) ($d_{50} = 2.78$ mm, $\epsilon = 39\%$)

![Diagram of Pilot-scale Constructed Wetland Experiments](image)

Pilot-scale gravity-filters of zeolite: Results

![Graphs showing results](image)
Pilot-scale gravity-filters of zeolite: ... Results

<table>
<thead>
<tr>
<th>Pollutant Removal (%)</th>
<th>Filter Z-C</th>
<th>Filter Z-F</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>60.6</td>
<td>63.2</td>
</tr>
<tr>
<td>COD</td>
<td>52.5</td>
<td>62.0</td>
</tr>
<tr>
<td>TKN</td>
<td>75.1</td>
<td>83.2</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>78.3</td>
<td>85.8</td>
</tr>
<tr>
<td>TP</td>
<td>56.8</td>
<td>40.5</td>
</tr>
<tr>
<td>OP</td>
<td>56.4</td>
<td>39.2</td>
</tr>
</tbody>
</table>
Pilot-scale Constructed Wetland Experiments

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


- Treatment of 10 L from VFCW effluent

<table>
<thead>
<tr>
<th>Filter</th>
<th>Porous media</th>
<th>Porosity</th>
<th>Media volume (L)</th>
<th>Media height (cm)</th>
<th>Residence time RT (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Bauxite ((d_{50}=21 \text{ mm}))</td>
<td>0.45</td>
<td>32.2</td>
<td>0.30</td>
<td>1</td>
</tr>
<tr>
<td>Z1</td>
<td>Zeolite ((d_{50}=15 \text{ mm}))</td>
<td>0.43</td>
<td>33.3</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Z2</td>
<td>Zeolite ((d_{50}=15 \text{ mm}))</td>
<td>0.43</td>
<td>43.3</td>
<td>0.38</td>
<td>2</td>
</tr>
</tbody>
</table>

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

Influent (=W8 effluent)

Diameter \(d = 38 \text{ cm}\)

Z7 cm

Cobbles layer

Filter effluent

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

Results

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

Nitrogen
VFCW+
Z2>Z1>B1
(85-82-60%)

Phosphorus
VFCW+
B1>Z1≈Z2
(71-61%)

Lysimeters for ET Estimation in CW
Lysimeters for ET Estimation in CW

Date
Cum ET (mm)

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2. Monitoring of Full-scale Facilities

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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

- 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: Monitoring

Inflow

20-2-2004

20-5-2004

Vassova lagoon CW: ...Description

20-2-2004

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... Monitoring of Full-scale Facilities

**Nea Madytos CW**


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

---

**Nea Madytos CW: Plan view**

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Nea Madytos CW: Description

Inflow-screen

Imhoff tanks

VF CWs for sludge treatment

1st stage VF CWs
Nea Madytos CW:
... Description

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26-3-2004

1-4-2004
Nea Madytos CW: Pollutant concentrations

Pollutant concentrations

BOD (mg/L)

Inflow
Outlet Imhoff
Outlet 1st stage CW
Outlet 2nd stage CW
Outlet 3rd stage CW
Outlet 1st tank
Outlet 2nd tank

COD (mg/L)

Inflow
Outlet Imhoff
Outlet 1st stage CW
Outlet 2nd stage CW
Outlet 3rd stage CW
Outlet 1st tank
Outlet 2nd tank

Graph showing pollutant concentrations over time for Nea Madytos CW with data points for BOD and COD.
Nea Madytos CW: Pollutant removal

![Graphs showing pollutant removal percentages for various stages and pollutants: BOD, COD, TKN, NH3, PO4, TP, TC, TSS.](image)

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Nea Madytos CW: ... Pollutant removal

![Graph showing pollutant removal percentages for various stages and pollutants: BOD, COD, TKN, NH3, PO4, TP, TC, TSS.](image)

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Nea Madytos CW:
Cost

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

Gomati CW

- 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 stage HSF CW
    - VF CWs for sludge treatment
Gomati CW: ...
Description

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Gomati CW: Pollutant concentrations

Pollutant concentrations over time, showing BOD and TKN removal for different treatment stages.

Gomati CW: ... Pollutant removal

Pollutant removal efficiencies for BOD, COD, TKN, NH3, TP, PO4, TSS, and TC across different stages of treatment.
**Gomati CW: Pollutant removal**

![Bar chart showing pollutant removal percentages](chart.png)

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>HSF</th>
<th>VSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population equivalent</td>
<td>p.e.</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Inflow</td>
<td>L/p.e./d</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>BOD₃</td>
<td>g/p.e./d</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Suspended Solids, SS</td>
<td>g/p.e./d</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>TKN</td>
<td>g/p.e./d</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total phosphorus, TP</td>
<td>g/p.e./d</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Length</td>
<td>m</td>
<td>10</td>
<td>7.0</td>
</tr>
<tr>
<td>Width</td>
<td>m</td>
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<tr>
<td>Bed depth</td>
<td>m</td>
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<td>0.9</td>
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<td>Bed surface</td>
<td>m²</td>
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<td>24.5</td>
</tr>
<tr>
<td>Number of plants</td>
<td>Plant/m²</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Vegetation type</td>
<td></td>
<td>Reed</td>
<td>Cell A: Reed; Cell B: no plant</td>
</tr>
</tbody>
</table>

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Horizontal subsurface flow CW


Site 1: Kosmio

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Horizontal subsurface flow CW: Description

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Horizontal subsurface flow CW: Description

Pollutant removal

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>BOD Concentration (mg/L)</th>
<th>Removal (%)</th>
<th>Mean C (mg/L)</th>
<th>Mean R (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>80</td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>80</td>
<td>100</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>TKN Concentration (mg/L)</th>
<th>Removal (%)</th>
<th>Mean C (mg/L)</th>
<th>Mean R (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>2</td>
<td>2</td>
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<tr>
<td>3</td>
<td>4</td>
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<tr>
<td>4</td>
<td>6</td>
<td>45</td>
<td></td>
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<tr>
<td>5</td>
<td>8</td>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>TP Concentration (µg/L)</th>
<th>Removal (%)</th>
<th>Mean C (mg/L)</th>
<th>Mean R (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>80</td>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Vertical flow CW

Site 2: Avdira

Vertical flow CW:
Description
Vertical flow CW: ... Description
Vertical flow CW:

... Description
Vertical flow CW: Pollutant concentrations

Legend:
- ST1
- ST2
- ST3
- effluent CW1
- effluent CW2
- influent ZT
- final effluent

COD (mg/L)

BOD (mg/L)

NH₄⁻N (mg/L)

TKN (mg/L)

TP (mg/L)

Pollutant removal

Septic Tank  CW  Zeolite Tank

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
Study Area

Municipality: N. Oikismos, Korestia
Population: 500 p.e.
Sewage system: separate

Full-scale system in N. Oikismos, Kastoria

Full-scale system in N. Oikismos: Study area

- 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

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>CONCENTRATION (mg/L)</th>
<th>REMOVAL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅</td>
<td>&lt;=15</td>
<td>96 %</td>
</tr>
<tr>
<td>COD</td>
<td>&lt;=40</td>
<td>93 %</td>
</tr>
<tr>
<td>SS</td>
<td>&lt;=15</td>
<td>96 %</td>
</tr>
<tr>
<td>TKN</td>
<td>&lt;=6</td>
<td>91 %</td>
</tr>
<tr>
<td>TP</td>
<td>&lt;=4</td>
<td>50 %</td>
</tr>
</tbody>
</table>

### Full-scale system in N. Oikismos: Cost

<table>
<thead>
<tr>
<th>Construction</th>
<th>Expenditure (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil excavation</td>
<td>74,457</td>
</tr>
<tr>
<td>Plant</td>
<td>20,346</td>
</tr>
<tr>
<td>Structure using concrete, Plumbing</td>
<td>62,801</td>
</tr>
<tr>
<td>Electromechanical</td>
<td>50,004</td>
</tr>
<tr>
<td>Oncost</td>
<td>87,350</td>
</tr>
<tr>
<td>Value-added tax</td>
<td>56,042</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>351,000</strong></td>
</tr>
</tbody>
</table>

**Operating cost**

- Electric energy: 12.25 €/day
  - € 7.35/p.e./yr
  - € 0.13/m³ wastewater
Full-scale system in N. Oikismos: … Construction

Full-scale system in N. Oikismos: … Operation
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

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## COST

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Neon Okiosis</th>
<th>Rhoditis</th>
<th>Gomati</th>
<th>Kyprinos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population served (capita)</td>
<td>600</td>
<td>800</td>
<td>1000</td>
<td>1200</td>
</tr>
<tr>
<td>Flow (m³/d)</td>
<td>90</td>
<td>120</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>Total area (ha) / Unit area (m²/p.e.)</td>
<td>0.73/12.2</td>
<td>0.84/10.5</td>
<td>0.80/8.0</td>
<td>0.93/7.9</td>
</tr>
</tbody>
</table>

### Construction cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Neon Okiosis</th>
<th>Rhoditis</th>
<th>Gomati</th>
<th>Kyprinos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation/fill (€)</td>
<td>133,245</td>
<td>105,672</td>
<td>93,247</td>
<td>136,760</td>
</tr>
<tr>
<td>Planting (€)</td>
<td>36,381</td>
<td>32,080</td>
<td>24,585</td>
<td>45,543</td>
</tr>
<tr>
<td>Reinforced concrete structures (€)</td>
<td>53,211</td>
<td>108,390</td>
<td>210,870</td>
<td>167,242</td>
</tr>
<tr>
<td>Piping (€)</td>
<td>33,985</td>
<td>22,150</td>
<td>37,987</td>
<td>33,644</td>
</tr>
<tr>
<td>Hydraulic structures (€)</td>
<td>24,849</td>
<td>17,468</td>
<td>43,176</td>
<td>28,644</td>
</tr>
<tr>
<td>Electrical/mechanical (€)</td>
<td>64,563</td>
<td>63,240</td>
<td>21,708</td>
<td>90,513</td>
</tr>
<tr>
<td>Total construction cost (€)</td>
<td>346,234</td>
<td>349,000</td>
<td>431,373</td>
<td>502,346</td>
</tr>
</tbody>
</table>

### Operation cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Neon Okiosis</th>
<th>Rhoditis</th>
<th>Gomati</th>
<th>Kyprinos</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual (€/y)</td>
<td>4,410</td>
<td>6,296</td>
<td>6,960</td>
<td>6,955</td>
</tr>
<tr>
<td>Annual per p.e. (€/p.e./y)</td>
<td>7.35</td>
<td>7.87</td>
<td>6.96</td>
<td>5.78</td>
</tr>
</tbody>
</table>

---

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![Graph showing total construction cost and annual operation cost against population served (capita)]
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

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).

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:

\[ K = \left( \frac{22.8}{T} \right) 1.7 \left( \frac{1}{s} \right)^{1.2} \]

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.
Modeling hydrodynamics and constituent transport in HSF-CW systems


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
Use of GIS in siting areas for construction of natural systems

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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www.env.duth.gr/eet

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