Constructed wetlands – Introduction and principles

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Workshop on "Constructed Wetlands"
Ramallah, Palestine
22 January 2006

Overview

Introduction
  - The global situation
  - WWT in rural areas

Constructed wetlands for WWT
  - Natural vs. constructed wetlands
  - Removal mechanisms, processes
  - The role of the plants
  - Classification of CWs
  - History of CWs
  - Principles of design

Introduction

Global situation

- Facts
    - 1.2 billions of people on earth without access to safe drinking water
    - 2.7 billion of people without sanitation
    - less than 10% of the worlds population served by wastewater treatment technology
- Situation at the local scale
    - ongoing population growth (particularly in water scarce areas)
    - migration
    - rapid growth of big cities (particularly of peri-urban areas, incl. slums)

Wilderer, 2004

Introduction

UN Millennium Development Goals

Response of the UN (General Assembly, 8 Sept. 2000)

- until 2015 halving the number of people
  - suffering from extreme hunger
  - lacking of basic education
  - not having access to safe drinking water
    (+ sanitation and wastewater treatment)
  - … child mortality, HIV, gender equality …

Introduction

Rough calculations

- Water supply
  - 50% of 1.2 billion people to be served until 2015 with safe drinking water
    => 60 Mio people / a
  - considering 300 working days per year
    => 200’000 people to be served every day with adequate water supply

- Sanitation
  - 50% of 90% of the 6 billion people on earth to be connected to WWTPs until 2015
    => 540 Mio people / a
  - considering 300 working days per year
    => *every day WWTPs are to be built serving 1’800’000 p.e.*

Wilderer, 2004

Introduction

Global situation

Conclusion

➔***mission impossible***

except

we replace traditional concepts of

- designing treatment processes
- manufacturing
- operating and maintaining plants

by any novel methods

Introduction

Wastewater treatment alternatives

- *Natural systems* utilise soil as a treatment and/or disposal medium (such as constructed wetlands or waste stabilisation ponds).
- *Conventional treatment systems* utilise a combination of biological, physical and chemical processes, employ tanks, pumps, blowers, rotating mechanisms and/or mechanical components as a part of the overall system.
- *Alternative treatment systems* use source control and separating systems and are reuse oriented.

Introduction

Sanitation systems

- *Decentralized* or ‘*on-plot*’ systems in which safe disposal of excreta takes place on or near a single household or a small settlement
- *Centralized* or ‘*off-plot*’ systems in which excreta are collected from individual houses and carried away from the plot to be treated off-site

The selection of the most appropriate sanitation system is influenced by

- ecological,
- technical,
- social,
- cultural,
- financial, and
- institutional factors.

Introduction

Need and requirements for wastewater treatment in rural areas

- small communities, groups of houses, and also single houses with sometimes large distances between them,
- low population density, and
- primary agricultural use and only little industry

➔ highly fluctuating wastewater flows, and high concentrations of the wastewater constituents with high fluctuations.

➔ additionally only few trained personal is available to operate wastewater treatment plants

Introduction

Requirements for WWT in rural areas

- simplicity of the technology,
- simple operation and maintenance,
- high robustness,
- large volume, to puffer the high fluctuations of flow and concentrations,
- high stability, and
- low surplus sludge production

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Structural components of wetlands

- Vegetation. The prevalent vegetation consists of macrophytes that are typically adapted to areas heaving hydrologic and soil conditions described in the definition.
- Soil. Soils are present and have been classified as hydric, or they posses characteristics that are associated with reducing soil conditions.
- Hydrology. The area is inundated either permanently or periodically at mean water depth of $\leq$ 2 m, or the soil is saturated to the surface at some time during the growing season of the prevalent vegetation.

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Natural vs. constructed wetlands

Natural wetlands

- used for wastewater discharge (and treatment) for centuries
- uncontrolled discharge → irreversible degradation

Constructed wetlands

- artificial wetlands designed to improve water quality
- utilize natural processes in controlled environment
- micro-organisms, substrate, vegetation
- getting more popular since > 25 years around the world

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CWs are feasible for several reasons

- simple in construction and operation
- often less expensive to build and to operate than other treatments
- O/M – only periodic on-site labour
- high process stability (buffering capacity)
- treat water with very different qualities
- high treatment efficiency
- facilitate water reuse and recycling

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CWs – additional benefits

- habitat for many wetland organisms
- fit harmoniously into the landscape
- wildlife habitat and aesthetic enhancement of open spaces
- environmentally sensitive approach favoured by the public

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Removal mechanisms (1)

The removal mechanisms principally depend on:

- hydraulic conductivity of the substrate,
- types and number of microorganisms,
- oxygen supply for the microorganisms, and
- chemical conditions of the substrate.

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Removal mechanisms (2)

The removal mechanisms principally depend on:

- settling of suspended particulate matter,
- filtration and chemical precipitation,
- chemical transformation,
- adsorption and ion exchange on surfaces of plants, substrate, and litter,
- breakdown, and transformation and uptake of pollutants and nutrients by micro-organisms and plants, and
- predation and natural die-off of pathogens.

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Removal mechanisms (3)

CWs remove:

- *Suspended Solids*
- *Organic matter* (BOD, COD, TOC),
- *Nutrients* (N, P)
- *Organic contaminants* (e.g. LAS, BTEX, MTBE, oil derived hydrocarbons, Explosives, Glycol, ...)
- *Anorganics* (e.g. heavy metals)
- *Pathogens*

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Suspended matter

Processes:

- all settleable and flotable solids of wastewater origins are removed
- sedimentation and filtration
- a major threat for good performance can be clogging of the pores

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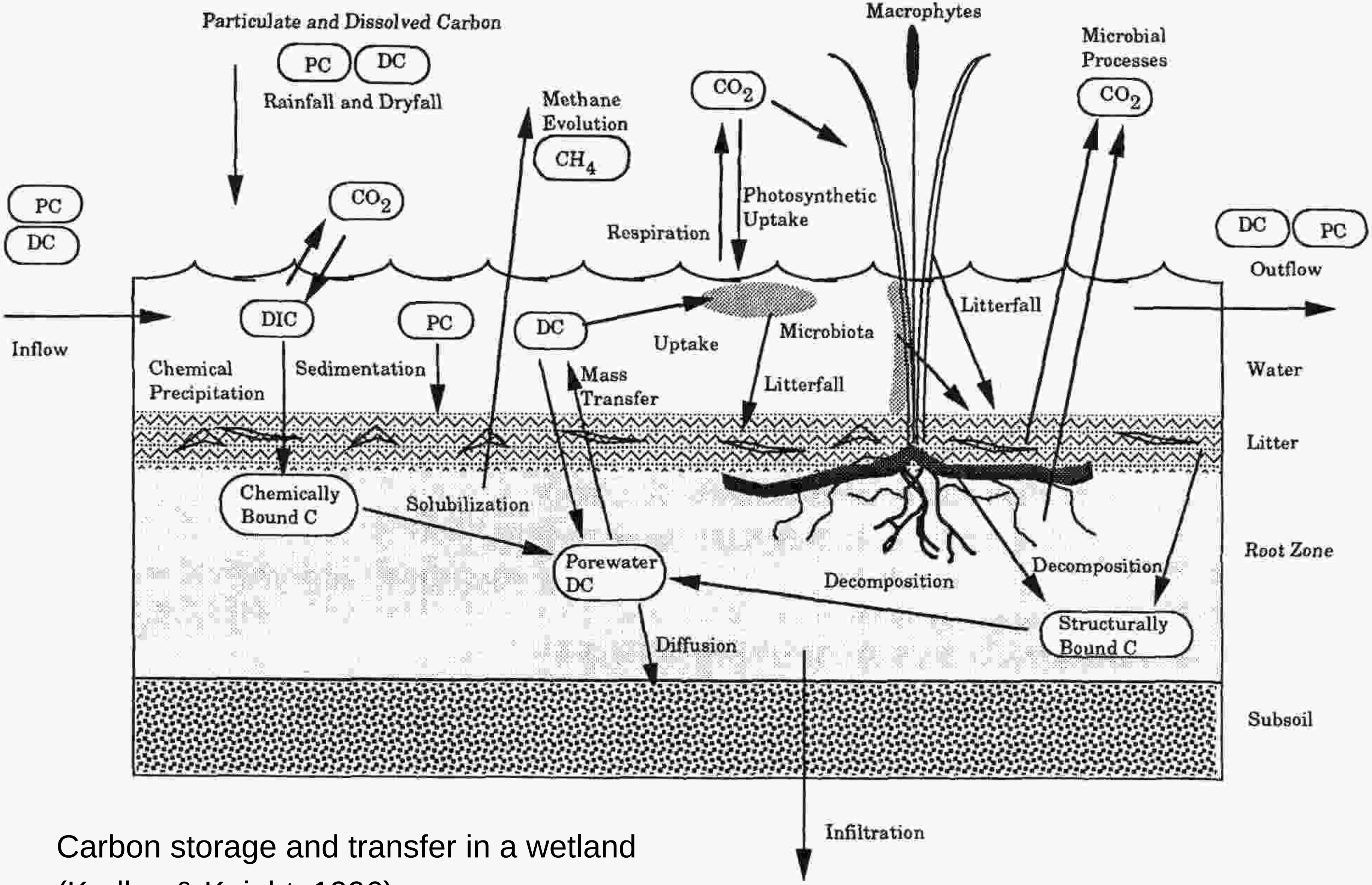
Organic matter removal

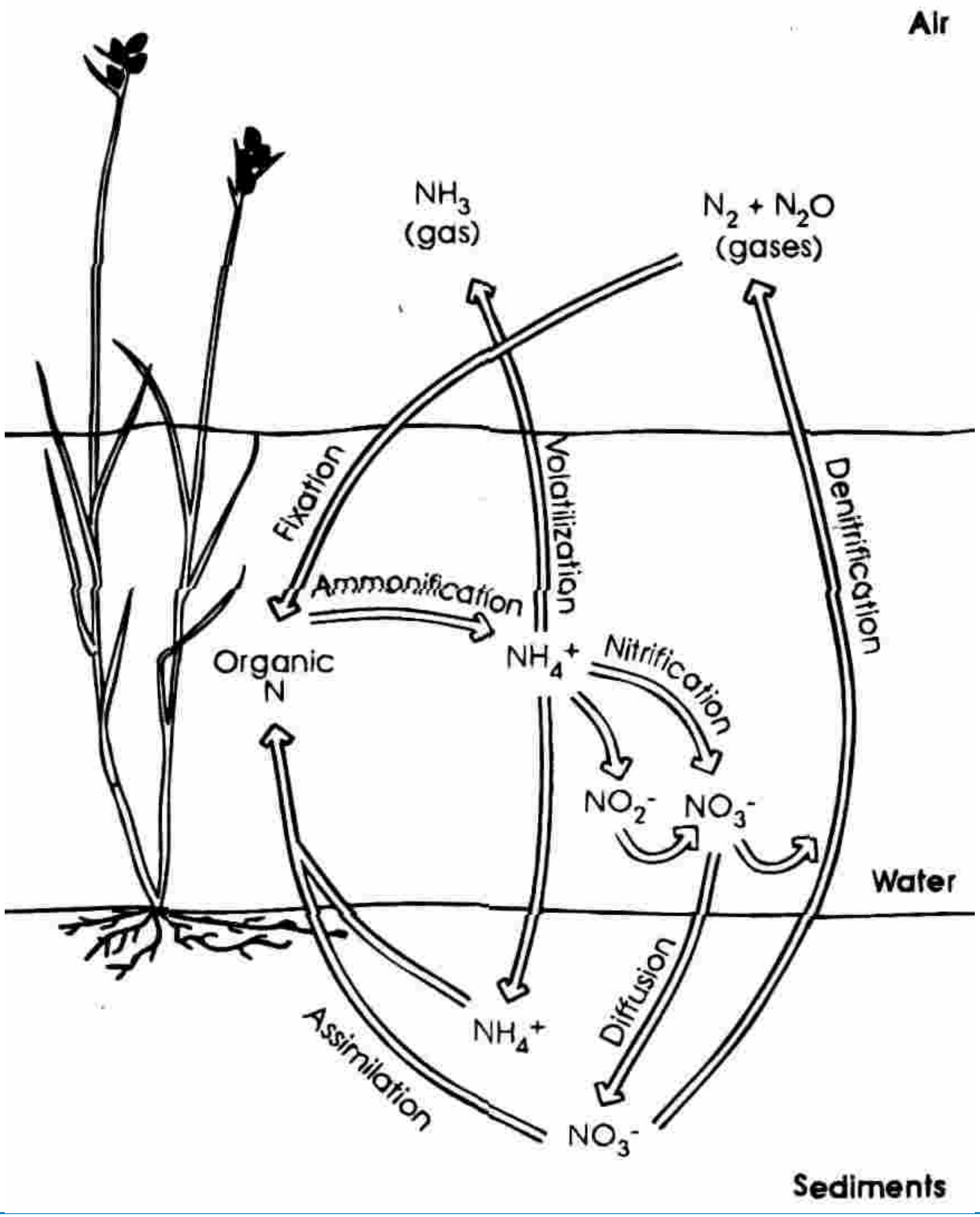
Processes:

- Attached and suspended microbial growth
- Aerobic and anaerobic degradation
- oxygen supply
- Uptake by the macrophytes is negligible compared to biological degradation



Carbon storage and transfer in a wetland

(Kadlec & Knight, 1996)



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Simplified wetland nitrogen cycle (Kadlec & Knight, 1996)

Processes

- fixation
- volatilisation,
- ammonification,
- nitrification/dentrification,
- plant uptake and
- matrix adsorption

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Nitrogen

Nitrification

- biological oxidation of ammonium to nitrate with nitrite as an intermediate
- Nitrification is a chemoautotrophic process
- energy from the oxidation of ammonia and/or nitrite
- carbon dioxide is used as a carbon source for synthesis of new cells

$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + 2\ H^+ + H_2O$

$NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$

$\mathbf{NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O}$

Influencing factors: temperature, pH value, alkalinity of the water, inorganic C source, microbial population, and concentrations of ammonium-N and dissolved oxygen.

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Nitrogen

Denitrification

- reduction of nitrate to molecular nitrogen or nitrogen gases
- nitrogen oxides serve as terminal electron acceptors
- Most denitrifying bacteria are chemoheterotrophs

$\mathbf{NO_3^- + (OM)} \rightarrow N_2$

Influencing factors: organic carbon source available + absence of molecular oxygen

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Nitrogen

Ammonia volatilisation

$NH_3(aq) + H_2O = NH_4^+ + OH^-$

- at pH of 9.3 the ratio between ammonia and ammonium ion is 1:1 and the losses via volatilisation are significant
- photosynthesis often creates high pH values

Plant uptake

- uptake by plant is limited by its net productivity and the concentration of nutrients in the plant tissue
- If plants are not harvested ➔ no removal
- Emergent macrophytes: range 1000-2500 kg N ha^{-1} yr^{-1}
- Water Hyacinth (*Eichhornia crassipes*) up to 6000 kg N ha^{-1} yr^{-1}
- submerged macrophytes 700 kg N ha^{-1} yr^{-1}

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Phosphorus

Phosphorus is typically present in wastewater as orthophosphate, dehydrated orthophosphate (polyphosphate) and organic phosphorus.

P-removal: adsorption, plant uptake, complexation and precipitation

Adsorption and retention: interaction of redox potential, pH, Fe, Al, Ca
Adsorption of P is greater in mineral vs. organic soils

Precipitation
acid soils: precipitation as insoluble Fe-P and Al-P
alkalic soils: precipitation as insoluble Ca-P

Plant uptake capacity of macrophytes is lower for P as for N

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Heavy metals

The processes of metal removal: sedimentation, filtration, adsorption, complexation, precipitation, cation exchange, plant uptake, and microbially-mediated reactions, especially oxidation.

Plant uptake

- metals dissolved in waters are available to living plants
- highest concentrations of metals are found in plant roots
- lower concentrations are found in rhizomes
- the lowest concentrations are found in stems and leaves

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Pathogens

Factors for Pathogen removal

- **Physical factors**: mechanical filtration and sedimentation
- **Chemical factors**: oxidation., UV radiation, exposure to biocides excreted by plants and adsorption to organic matter
- **Biological factors**: antibiosis, predation by nematodes, protists and zooplankton, attack by lytic bacteria and viruses and natural die-off.

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The role of the plants

Aerial plant tissue	-Light attenuation → reduced growth of phytoplankton -Influence on microclimate → insulation during winter (litter layer) -Reduced wind velocity → reduced risk of resuspension -Aesthetic pleasing appearance of system -Storage of nutrients
Plant tissue in water	-Filtering effect → filter out large debris -Reduce current velocity → increase rate of sedimentation, reduces risk of resuspension -Provide surface area for attached biofilms -Excretion of photosynthetic oxygen → increases aerobic degradation -Uptake of nutrients
Roots and rhizomes in the sediment	-Stabilising the sediment surface → less erosion -Prevents the medium from clogging in vertical flow systems -Release of oxygen increase degradation (and nitrification) -Uptake of nutrients -Release of antibiotics

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The role of the plants

Oxygenation

Macrophytes have an *aerenchym* (air space tissue), through which air-oxygen is transported to the roots.

but unfortunately much less than needed for degradation of BOD5 and for nitrification.

oxygen release rates vary from less than 10 to 160 ng oxygen cm-2 root surface min-1

Phragmites: o,1-4.3 g m-2 day-1
free-floating plants: 0.25-9.6 g m-2 day-1

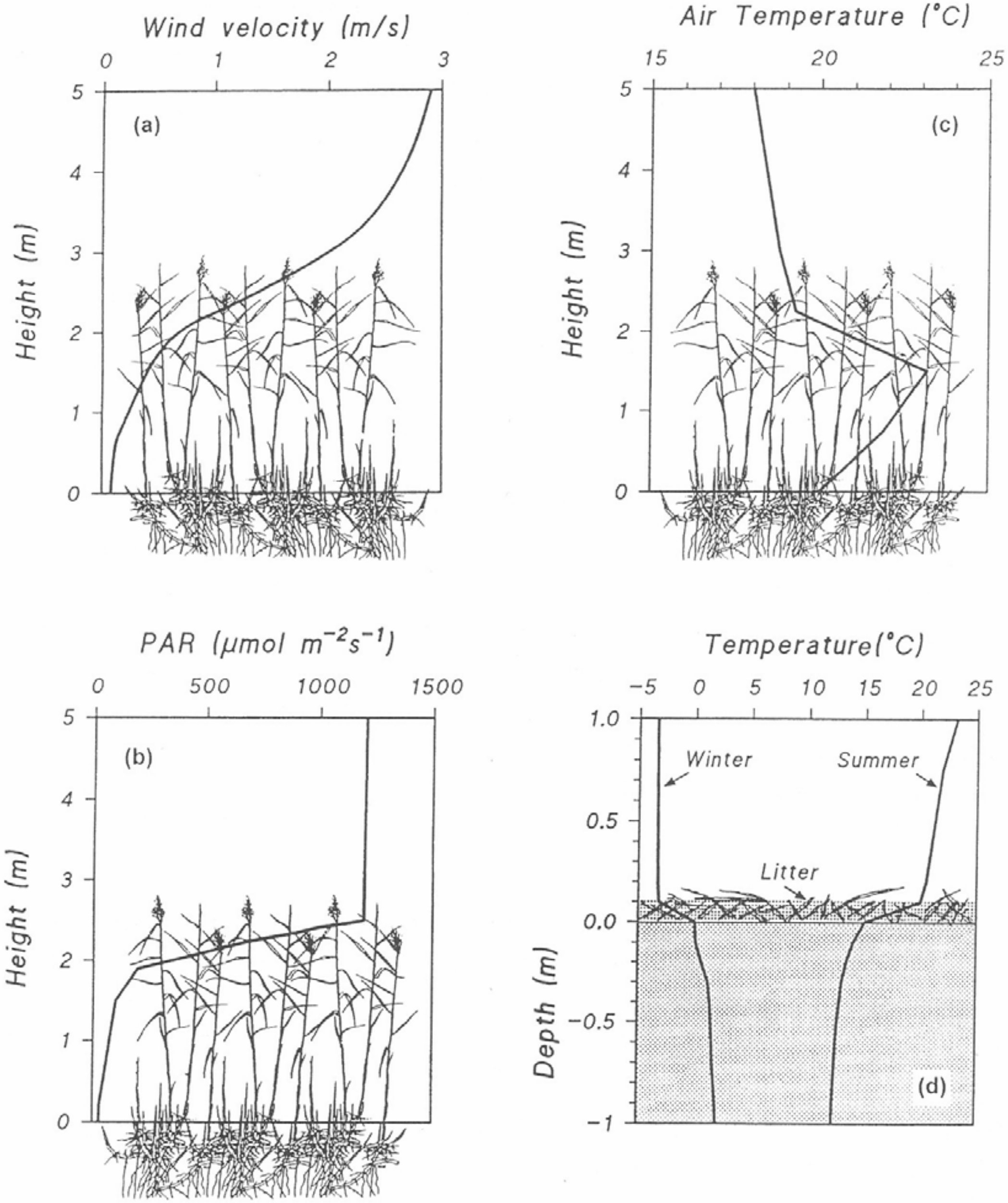

Figure 7.2. *Effects of a dense canopy of Phragmites australis on (a) the wind velocity, (b) the incident light intensity and (c) air temperature during summer, and (d) effects of the litter layer on the soil temperature during winter and summer, respectively. (Modified from Brix (1994).)*

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Classification of CWs

1. according to the life form of plants:
    - **rooted emergent macrophyte-based**
    - free floating macrophyte-based
    - submerged macrophyte-based

2. according to the water flow (for rooted emergent systems):
    - surface flow (SF)
    - **subsurface flow (SSF) – horizontal / vertical flow**

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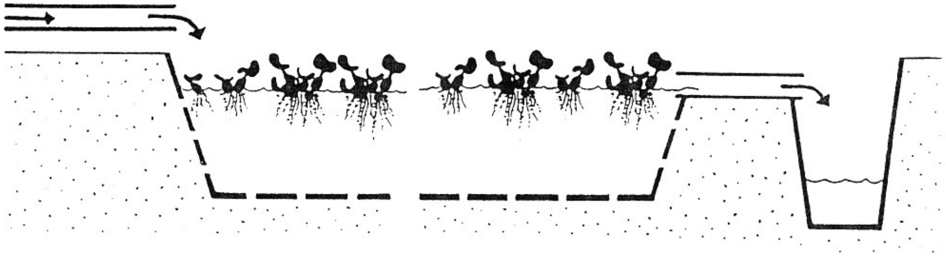
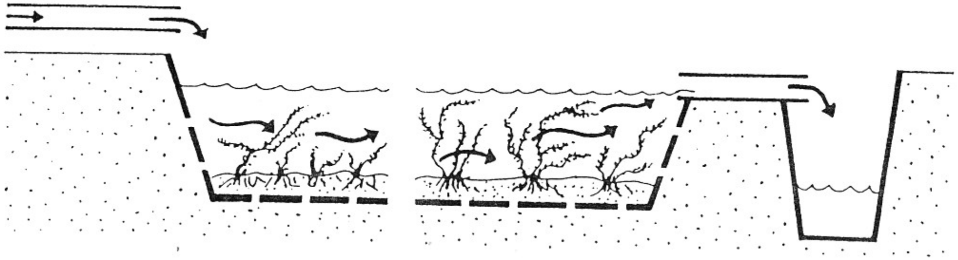
Surface Flow Constructed Wetlands - floating and submerged vegetation



Free-Floating Macrophyte Treatment System



Submerged Macrophyte Treatment System

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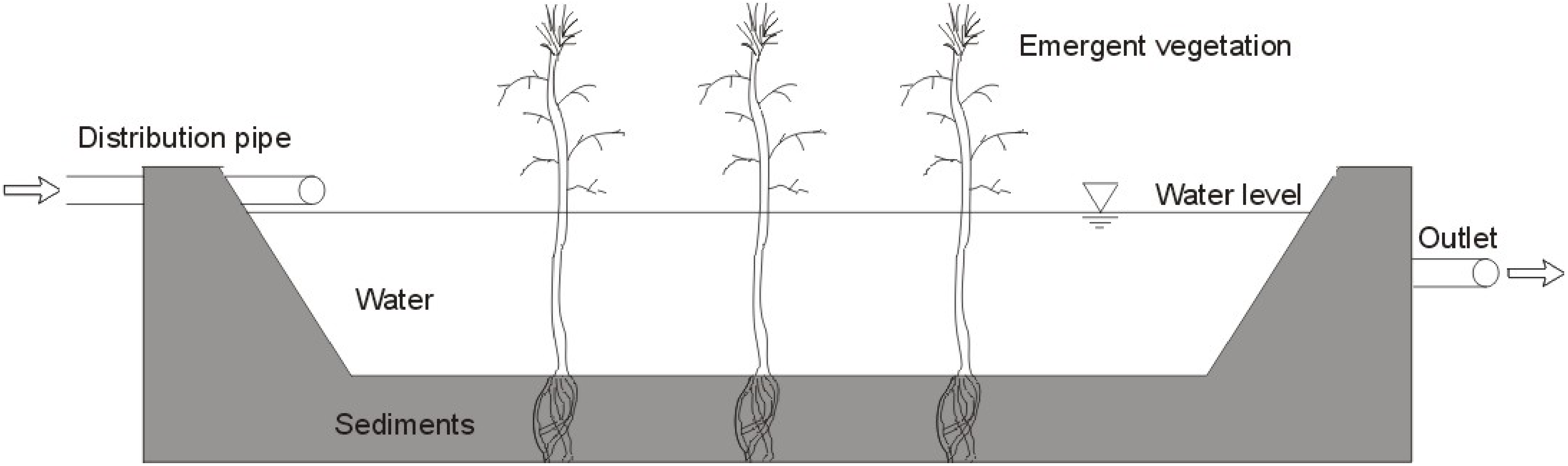
Surface Flow Constructed Wetlands - emergent vegetation



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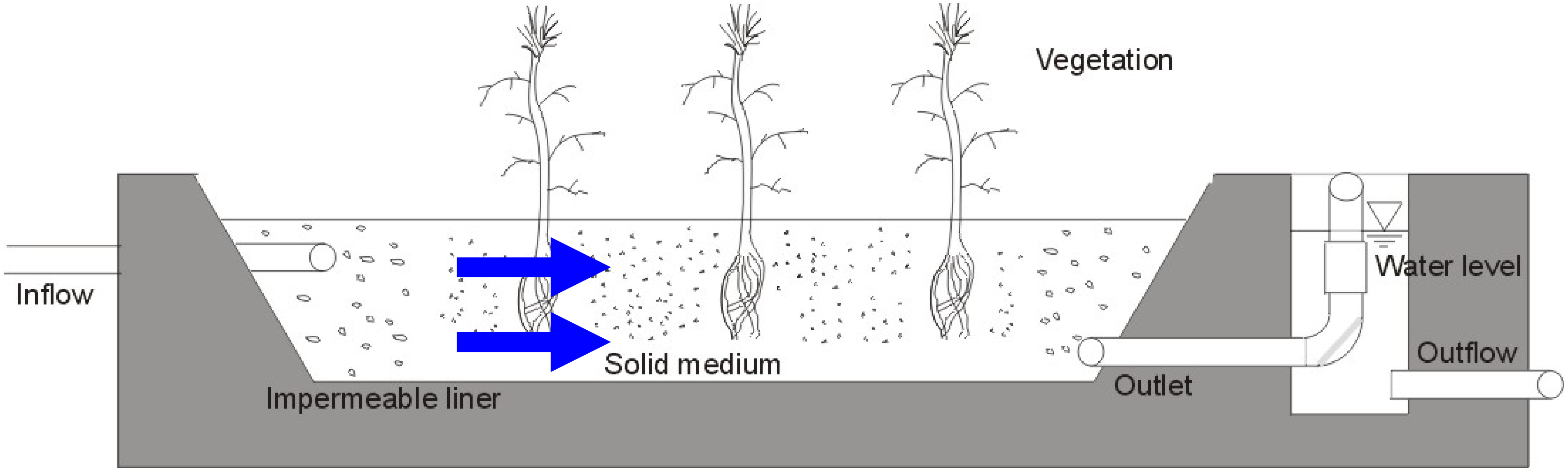
Subsurface Flow Constructed Wetlands – Horizontal flow



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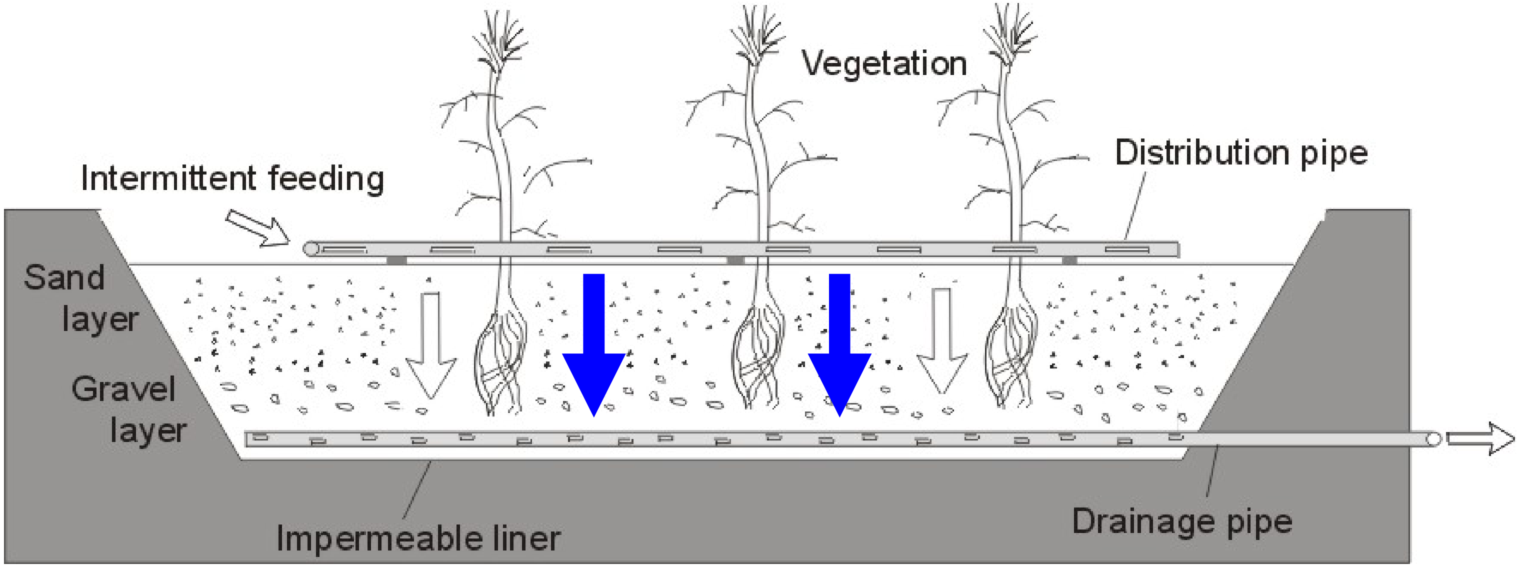
Subsurface Flow Constructed Wetlands – Vertical flow



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Subsurface horizontal vs. vertical flow CWs

Horizontal flow

- under the surface more or less horizontal flow
- level control arrangement at the outlet
- treatment during the passage through the rhizosphere
- oxygen transport capacity of the reeds is insufficient

Vertical flow

- VF systems have a distribution system covering surface area
- VSF are usually fed intermittently
- liquid percolates vertically down through the medium
- collection of water by drainage system at the bottom
- during drainage of the bed air fills the pores of the medium
- oxygen transfer sufficient for nitrification

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History of CWs

Surface flow systems

- Started in Noth America in the 1970s, with the ecological engineering of natural wetlands for watewater treatment
- 1973: first engineered CW treatment pilot system in Brookhaven
- 1973: Mt View Sanitary District in California wetland for wildlife habitat
- 1975: Industrial stormwaters and process waters, Amoco Oil Company
- Currently, Florida has several of the largest CW treatment areas in the world (Lakeland and Orlando, both started in 1987)

Surface flow wetland, Iron Bridge, Orlando

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History of CWs

Surface flow systems

- Largest CW: 1800 ha Kis-Balaton project in Hungary, operated since 1985
- FWS in operation in Australia
- FWS preferably in warmer climates
- Ekeby Wetland in Sweden polishing secondary effluent with respect to nutrients since 1999
- Tests with waterhyazinth systems in Czech Republic in the eighties and nineties

Kis Balaton, Hungary

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History of CWs

Subsurface flow systems - First steps

- 1952: first experiments in Germany at the Max Planck Institute
- 1957: Seidel: capability of macrophytes in treating water
- 1966/1967: Seidel proved Juncus to eliminate phenol
- Seidel and Kickuth worked together at the Max Planck Institute, later they both worked seperately.
- Seidel: Max Planck Institute Process (MPIP), Krefeld - or Seidel System
- Kickuth: RZM (Root Zone Method)
- 1967: Zuyder Zee-Project in NL

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History of CWs

Subsurface flow systems - Full-scale application

- 20 years of research before the first operational full-scale CW
- Since (mid-seventies) the technology has grown remarkably
- European countries: low-cost and low-maintenance system for small village communities
- Countries which mainly have contributed to the introduction and development of SSF CW are Austria, Denmark, France, Germany and UK

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History of CWs

Subsurface flow systems - Austria

- Centralization was preferred in rural areas
- High costs, technical and ecological disadvantages caused a change in preference
- On-site technologies, such as CW, taken into consideration
- Authorities did not approve CW-technology, Reasons: lack of long term experience, operation during winter, hygienic problems, clogging of substrate,...
- Advantages not taken into consideration

- 1982: 1st experimental CW Mannersdorf (RZM … root zone method)

CW Mannersdorf – Lowe Austria - Subsurface flow

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History of CWs

First 10 to 15 years the main interest was in **HSF systems:**

+ high elimination of COD and BOD_5, even in cold seasons.
- nutrient removal only 40-60%
- high hydraulic conductivity - reduced contact time
- oxygenation deficiency

Legislation in many countries demanded **fully nitrified effluents**:

development of sand and gravel - based systems with
vertical - flow systems and
intermittent loading

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History of CWs

Recent developments (last 5-10 years)

- Broadening the area of application
- Increasing the loading rates
- Application of Hybrid Systems
- Increasing the knowledge on the detailed processes in the black-box CW including development of numerical modelling tools

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Principles of design

Specific area demand: e.g. 4 m²/p.e. for vertical flow constructed wetlands in Austria (OENORM B 2505, 2005).

Regression models: correlate the mean values of the influent and effluent concentrations.

First-order models with background concentration: Calculating the mass balance, assuming plug-flow conditions and introducing a background concentration c* one gets the following equation to calculate the concentration c at a standardised flow distance y (inflow: y = 0; outflow: y = 1):

$$\ln\left(\frac{c - c^*}{c_{in} - c^*}\right) = -\frac{k}{q} \cdot y$$

where k = first-order areal rate constant [m/d]; and q = flow [m/d].

Irreversible Models. If c* = 0 the first-order models are called irreversible models.

Contact

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Application of CWs:
Case studies - 1

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Overview

Introduction

Case studies

- Industrialized countries
    - CW for treatment of mechanically pre-treated wastewater (Austria)
    - CW for treatment of raw wastewater (France)
    - Integrated natural system for landfill leachate treatment (USA)
    - CW for treatment of greywater (Germany)
- Developing countries
    - CW for treatment of hospital wastewater (Nepal)
    - CW for treatment of hospital wastewater (Uganda)

Summary

Introduction

- CWs are artificial wetlands designed to improve water quality.
- They are effective in treating organic matter, nutrients and pathogens and are worldwide used to treat different qualities of water.
- Compared to conventional technical solutions for water treatment CWs are relatively easy to maintain and operate resulting in low operating costs.
- CW technology fulfils the basic criteria for EcoSan concepts (prevention of diseases, affordability, protection of the environment, acceptability, and simplicity).
- CWs are also very suitable for the application in developing countries where most of the problems with inadequate sanitation occur. A crucial step for the implementation of CWs in developing countries is proper technology transfer.

Case studies

Case studies

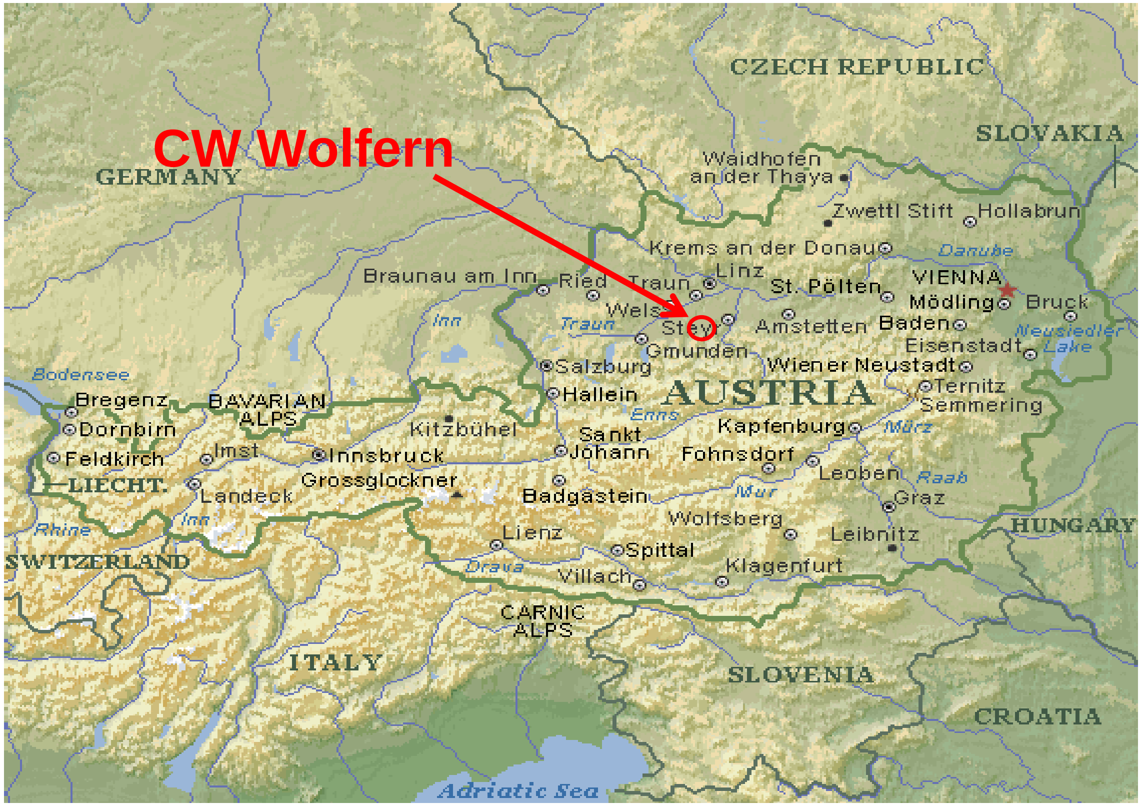
- Industrialized countries
    - CW for treatment of mechanically pre-treated wastewater (Austria)
    - CW for treatment of raw wastewater (France)
    - Integrated natural system for landfill leachate treatment (USA)
    - CW for treatment of greywater (Germany)

Location of Austria in World Map

Map not to Scale

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater


CW Wolfern

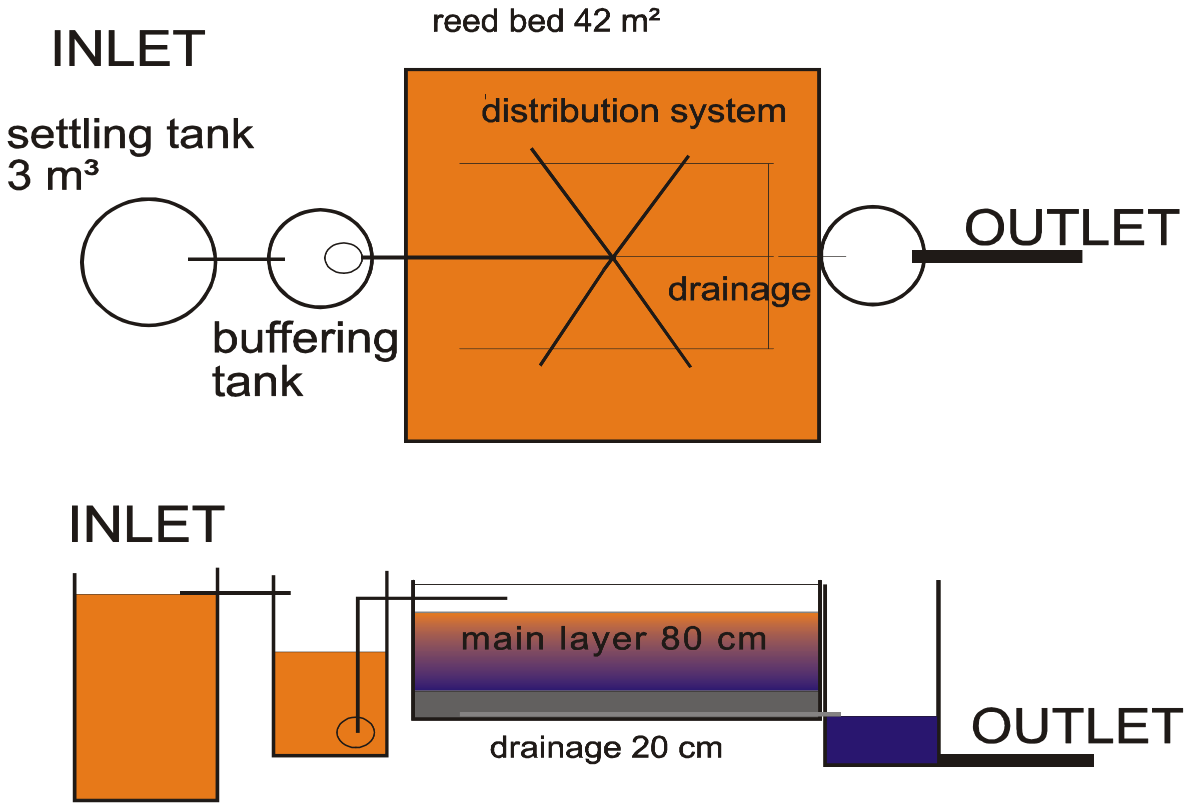
Austria:
~ 83’000 km²
~ 8 Mio. people
2001:
85 % connected to sewer lines
remaining: mainly rural areas

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater



INLET

reed bed 42 m²

settling tank
3 m³

distribution system

drainage

buffering
tank

OUTLET

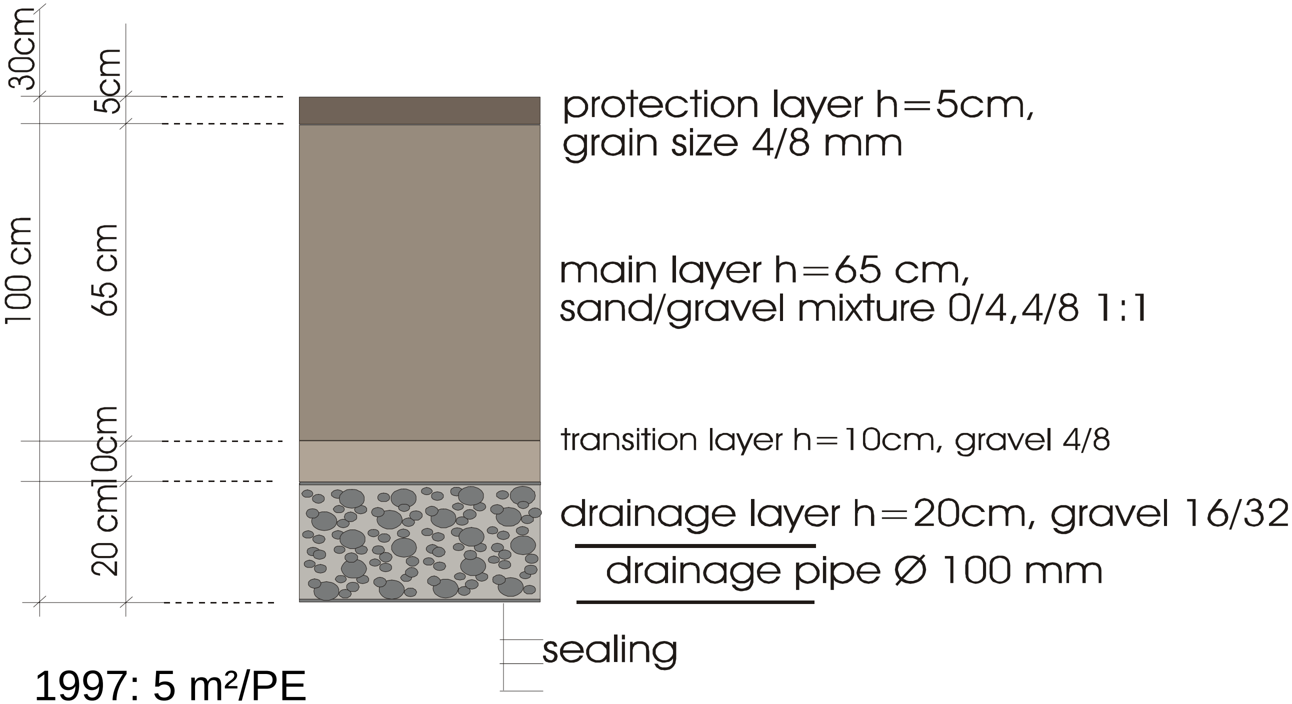
INLET

main layer 80 cm

drainage 20 cm

OUTLET

Austrian design standard for vertical flow CWs (ÖNORM B 2505)



protection layer h=5cm,
grain size 4/8 mm

main layer h=65 cm,
sand/gravel mixture 0/4,4/8 1:1

transition layer h=10cm, gravel 4/8

drainage layer h=20cm, gravel 16/32

drainage pipe Ø 100 mm

sealing

- 1997: 5 m²/PE
- 2005: 4 m²/PE for subsurface vertical flow CWs for domestic wastewater

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater

Plants: common reed (*Phragmites australis*)

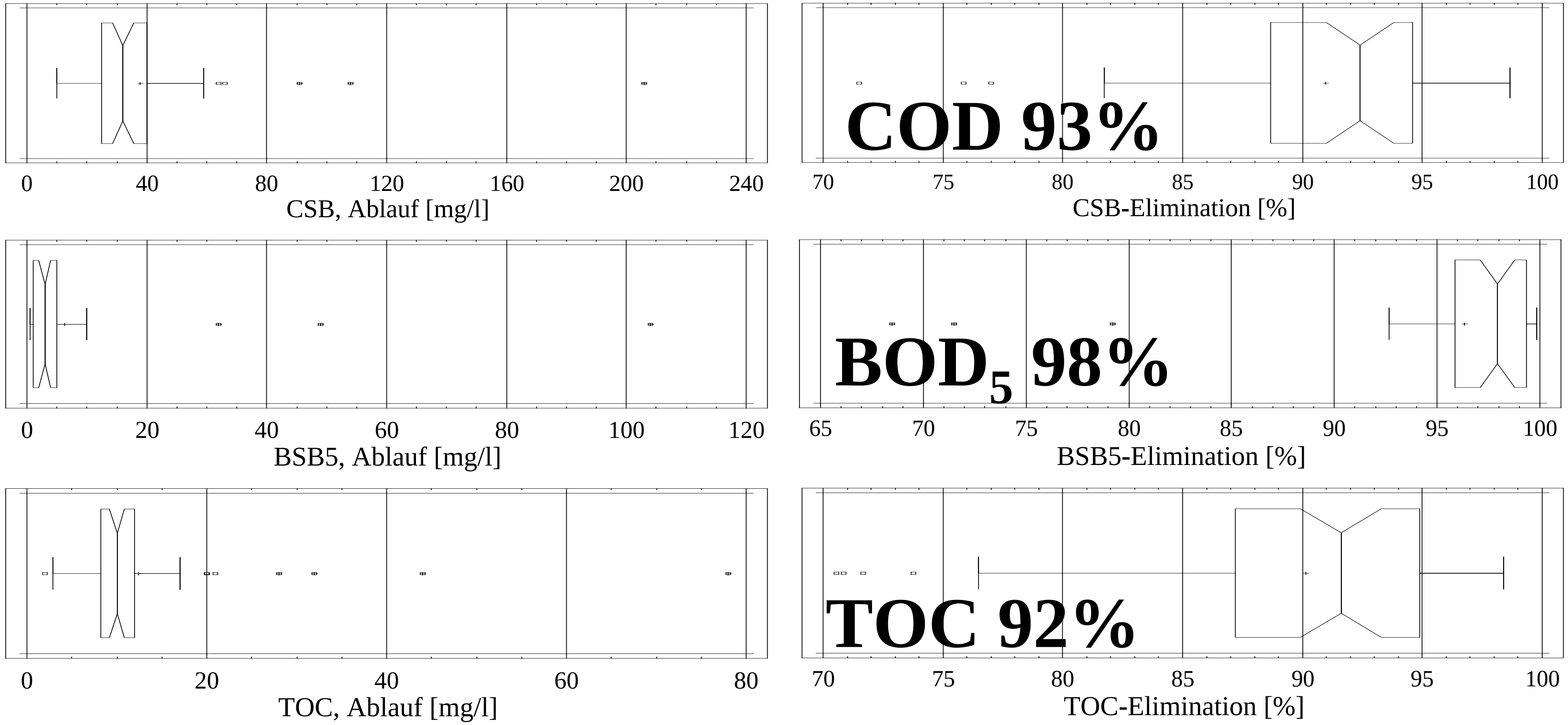
CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater

- hydraulic loading (November 1991 to June 1999):
  - 26 mm/d ➔ 87 % of design load (30 mm/d)
- Influent concentrations (Mean values):
  - COD: 485 mg/l
  - BOD5: 173 mg/l
  - TOC: 149 mg/l
  - NH4-N: 60 mg/l
  - TN: 75 mg/l
  - TP: 11 mg/l

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater



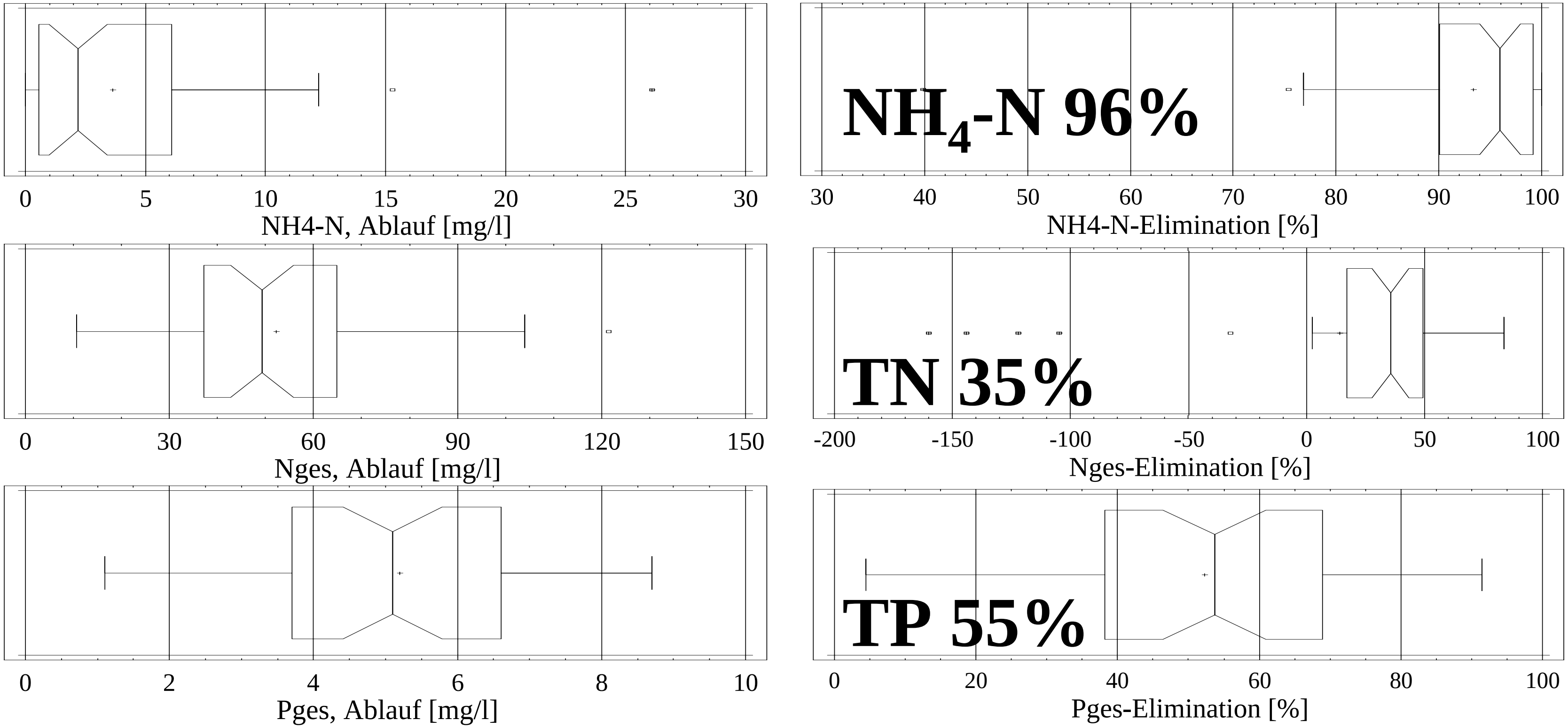
COD 93%

BOD_5 98%

TOC 92%

CW Wolfern, 8 p.e., Austria

Treatment of mechanically pre-treated wastewater



NH_4-N 96%

TN 35%

TP 55%

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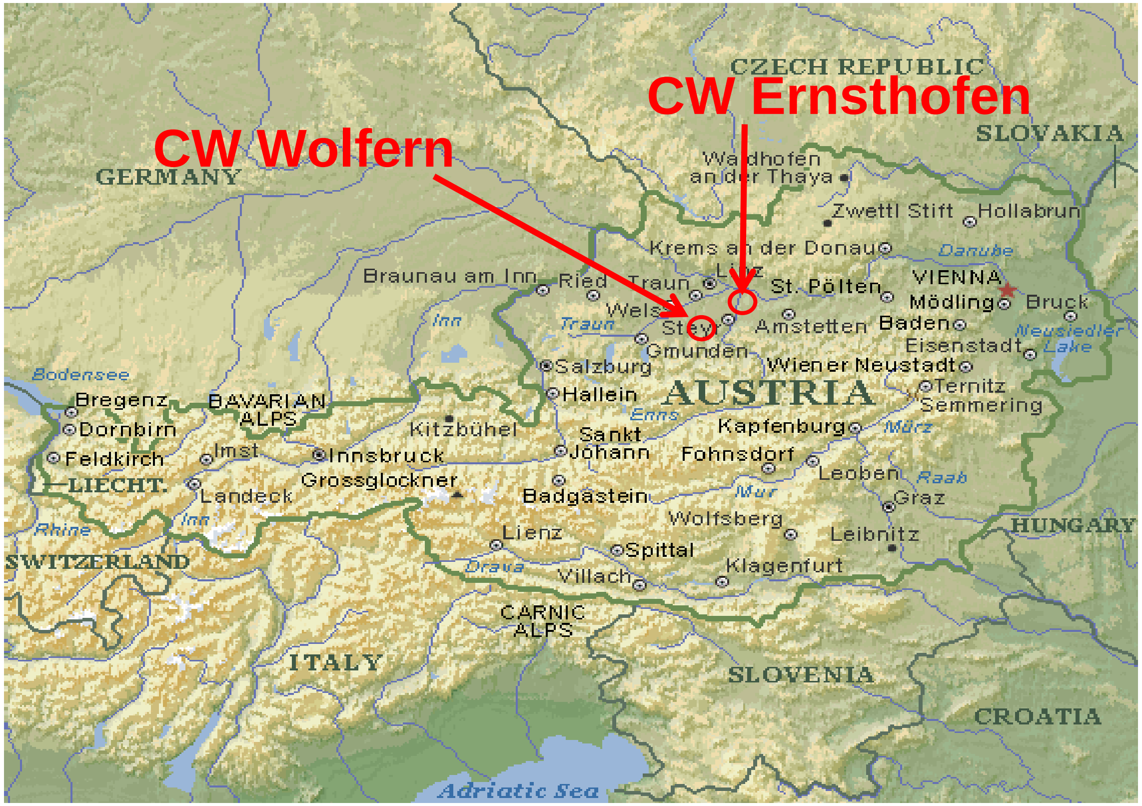
CW Ernsthofen, experimental, Austria

Treatment of mechanically pre-treated wastewater



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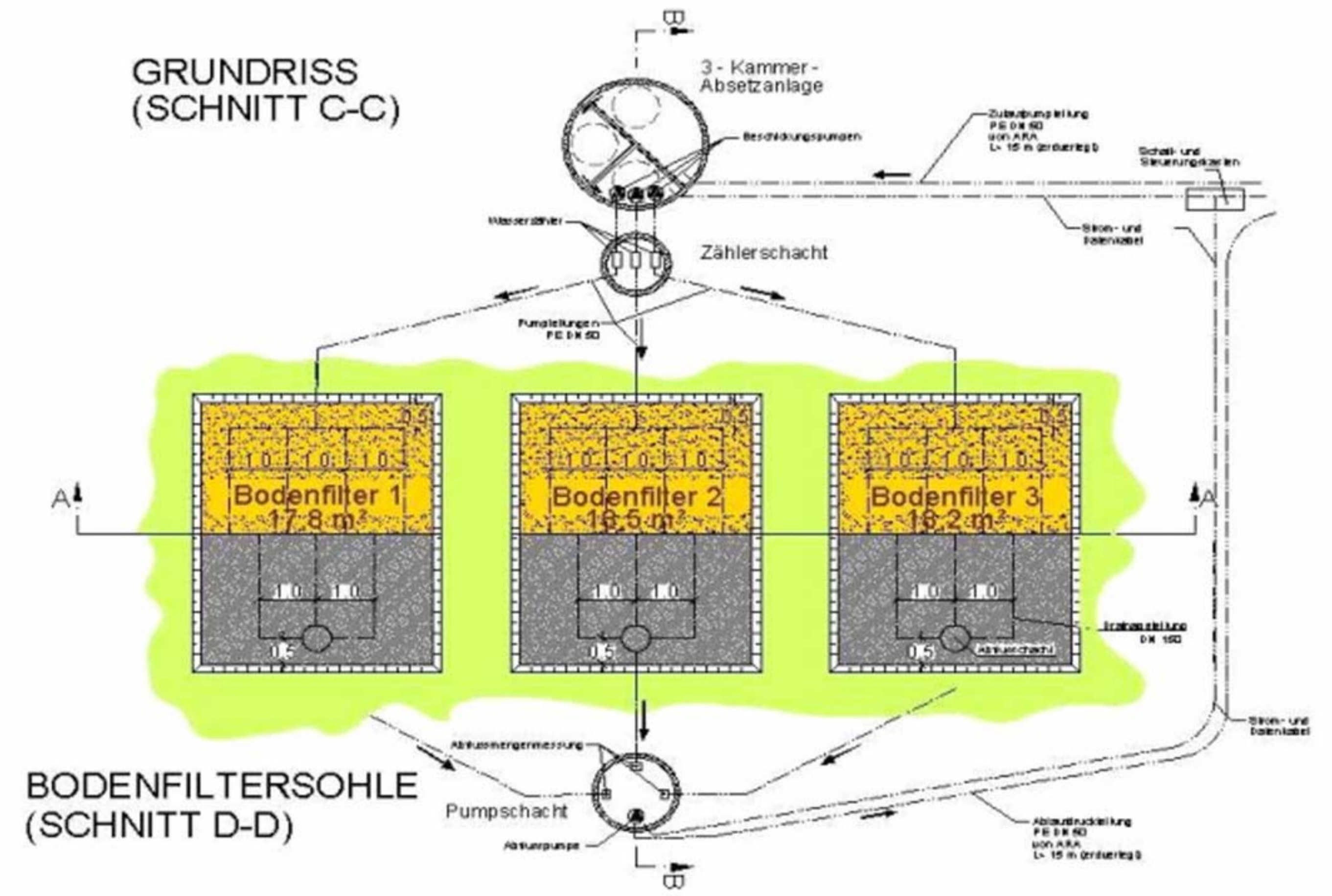
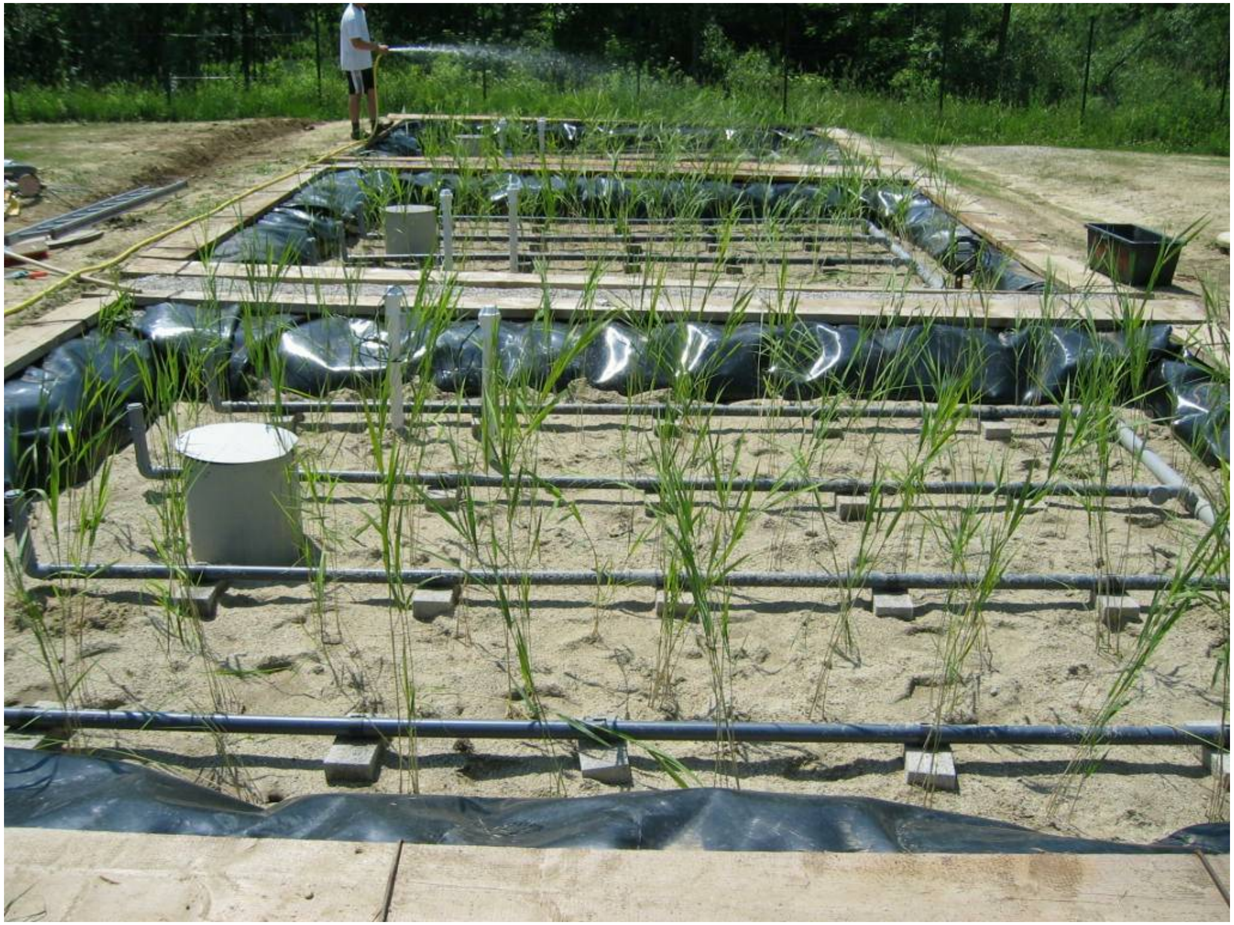


CW Ernsthofen, experimental, Austria

Treatment of mechanically pre-treated wastewater

- 3 parallel beds
  - surface area 20 m² each
  - organic loading of 20, 27, 40 g COD/(m².d)
    ➔ resp. 4, 3, 2 m²/PE
    (➔ resp. 5, 7, 10 PE)
- Austrian effluent standards
  - 90 mg COD/l
  - 25 mg BOD5 /l
  - 10 mg NH4-N/l (wastewater temperature > 12°C)

CW Ernsthofen, experimental, Austria



4 June 2003

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CW Ernsthofen, experimental, Austria

19 October 2003

CW Ernsthofen, experimental, Austria

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10 December 2003

CW Ernsthofen, experimental, Austria

3 March 2004

CW Ernsthofen, experimental, Austria

13 May 2004

CW Ernsthofen, experimental, Austria

Organic matter - COD

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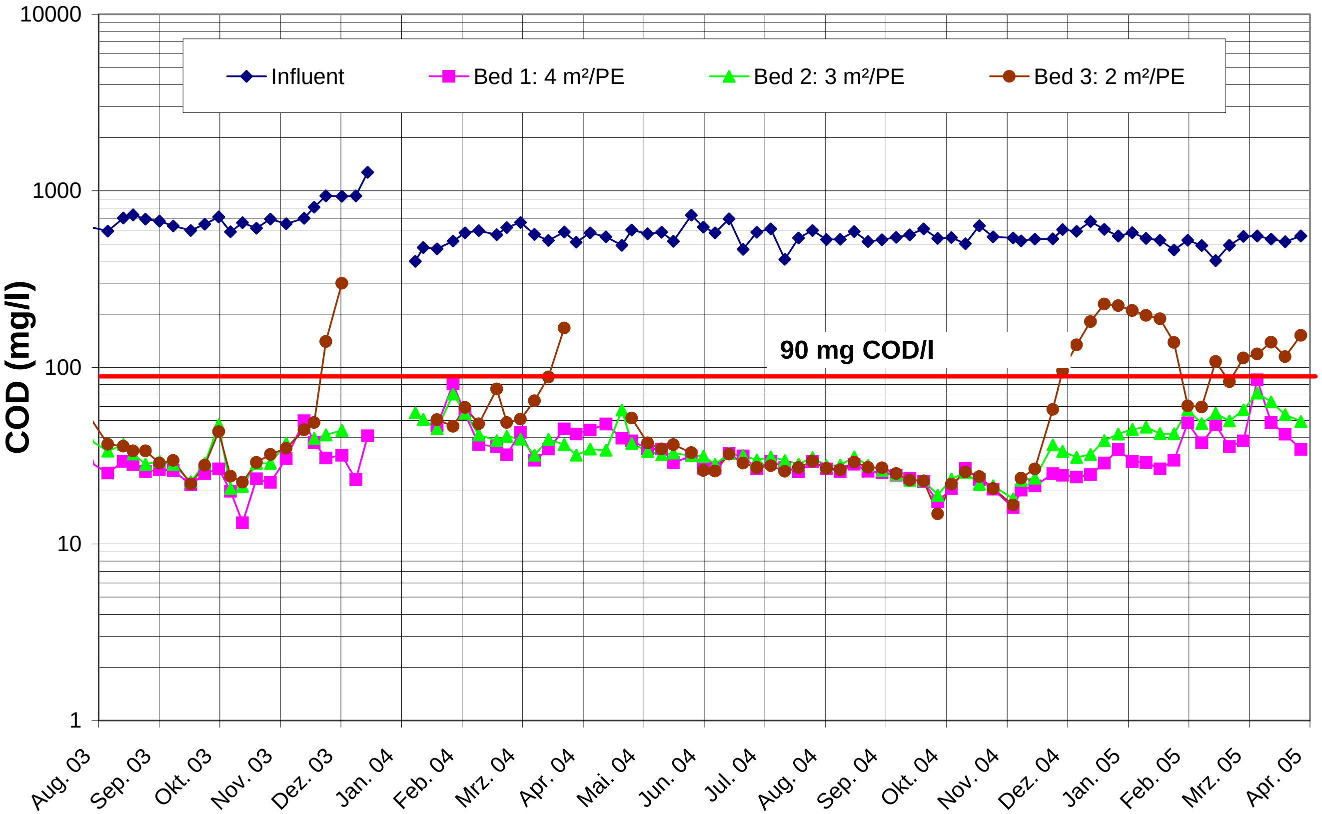

CW Ernsthofen, experimental, Austria

Organic matter - COD

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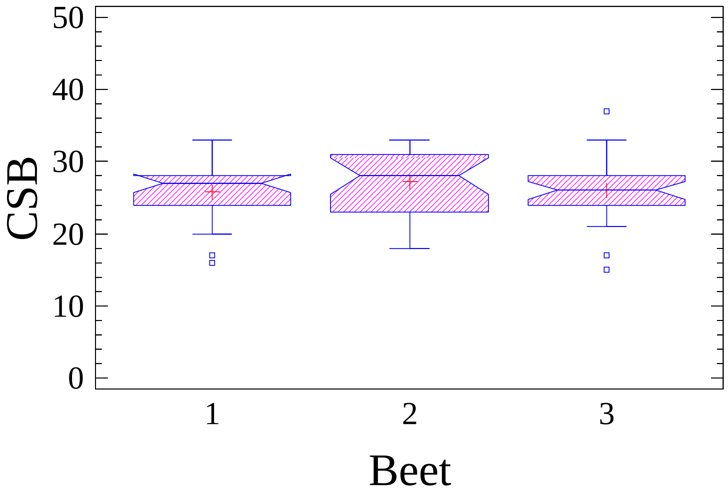
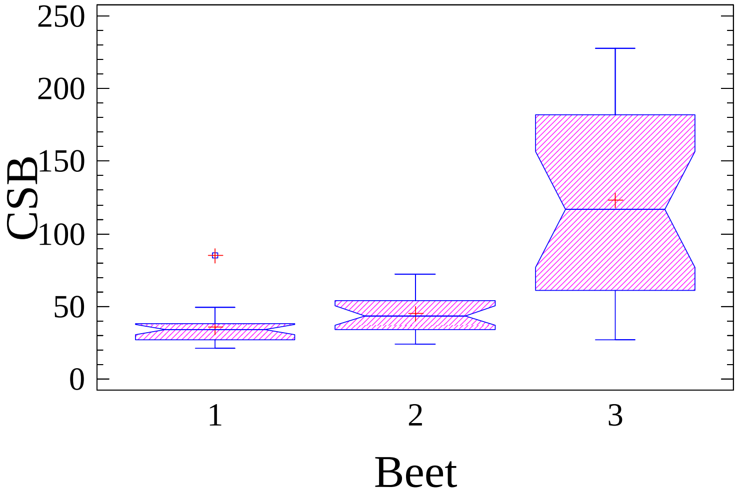
Temperature > 12°C

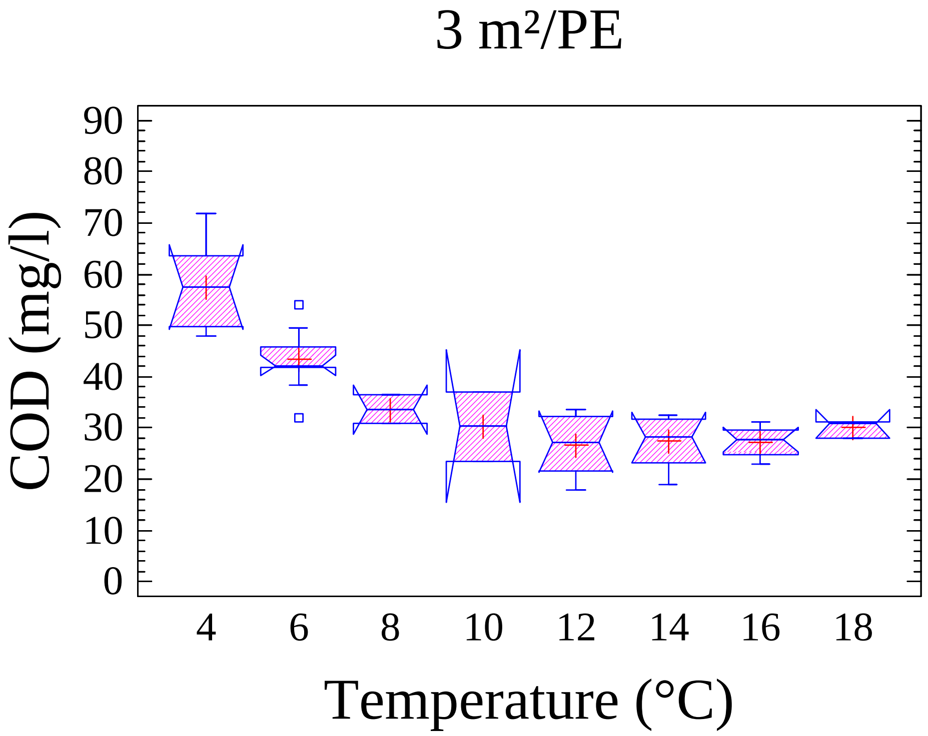


Temperature < 12°C



CW Ernsthofen, experimental, Austria

Organic matter - COD



CW Ernsthofen, experimental, Austria

Ammonium nitrogen NH_4-N

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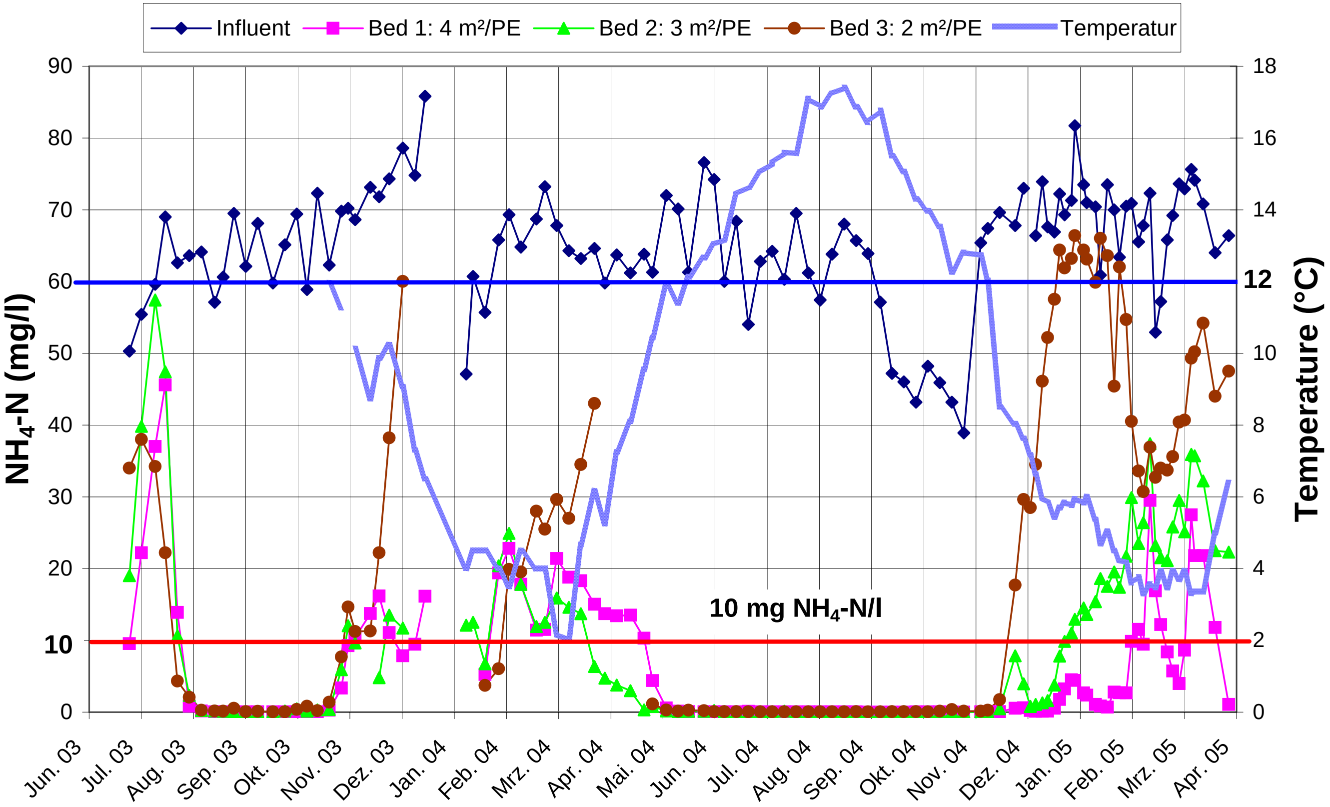
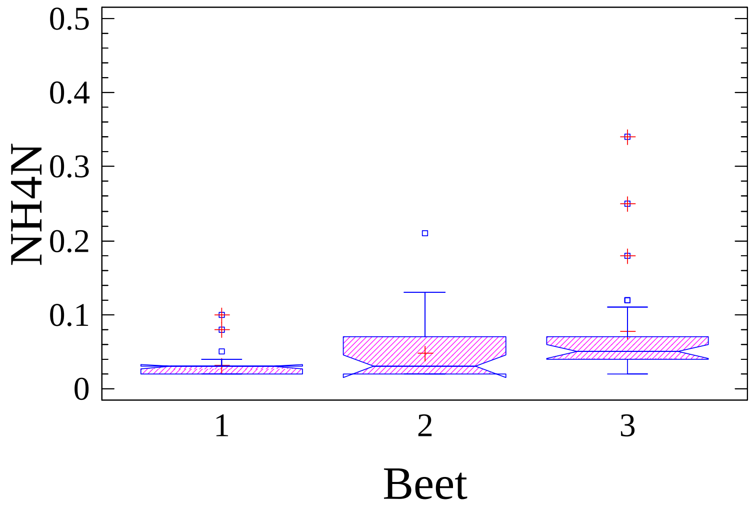


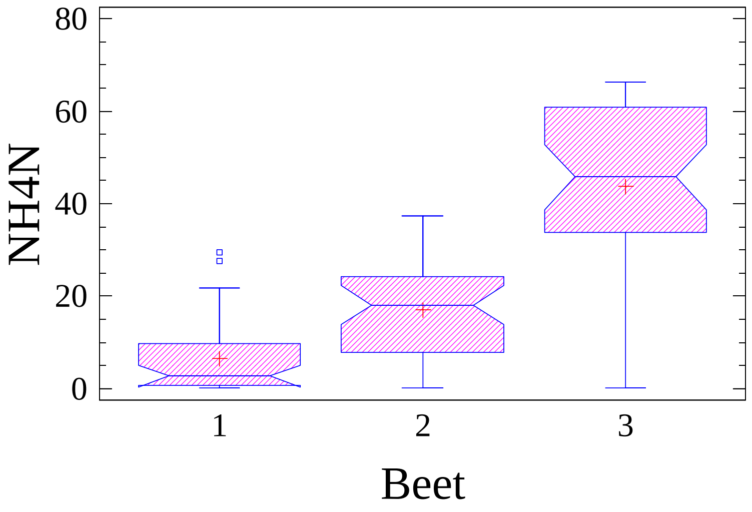
CW Ernsthofen, experimental, Austria

Ammonium nitrogen NH_4-N

Temperature > 12°C

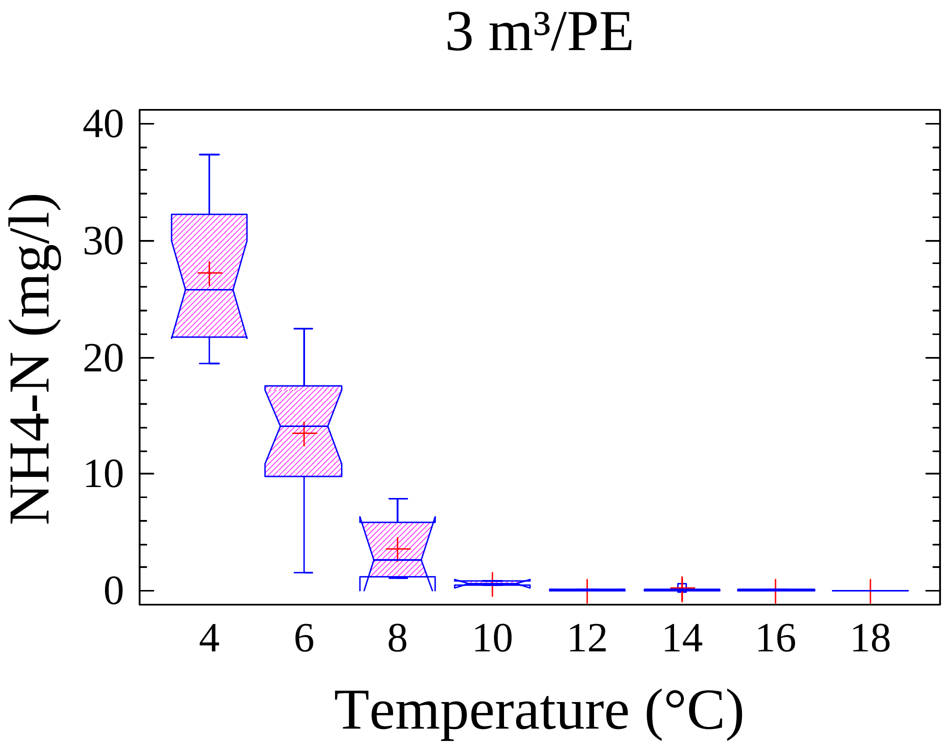


Temperature < 12°C



CW Ernsthofen, experimental, Austria

Ammonium nitrogen NH4-N

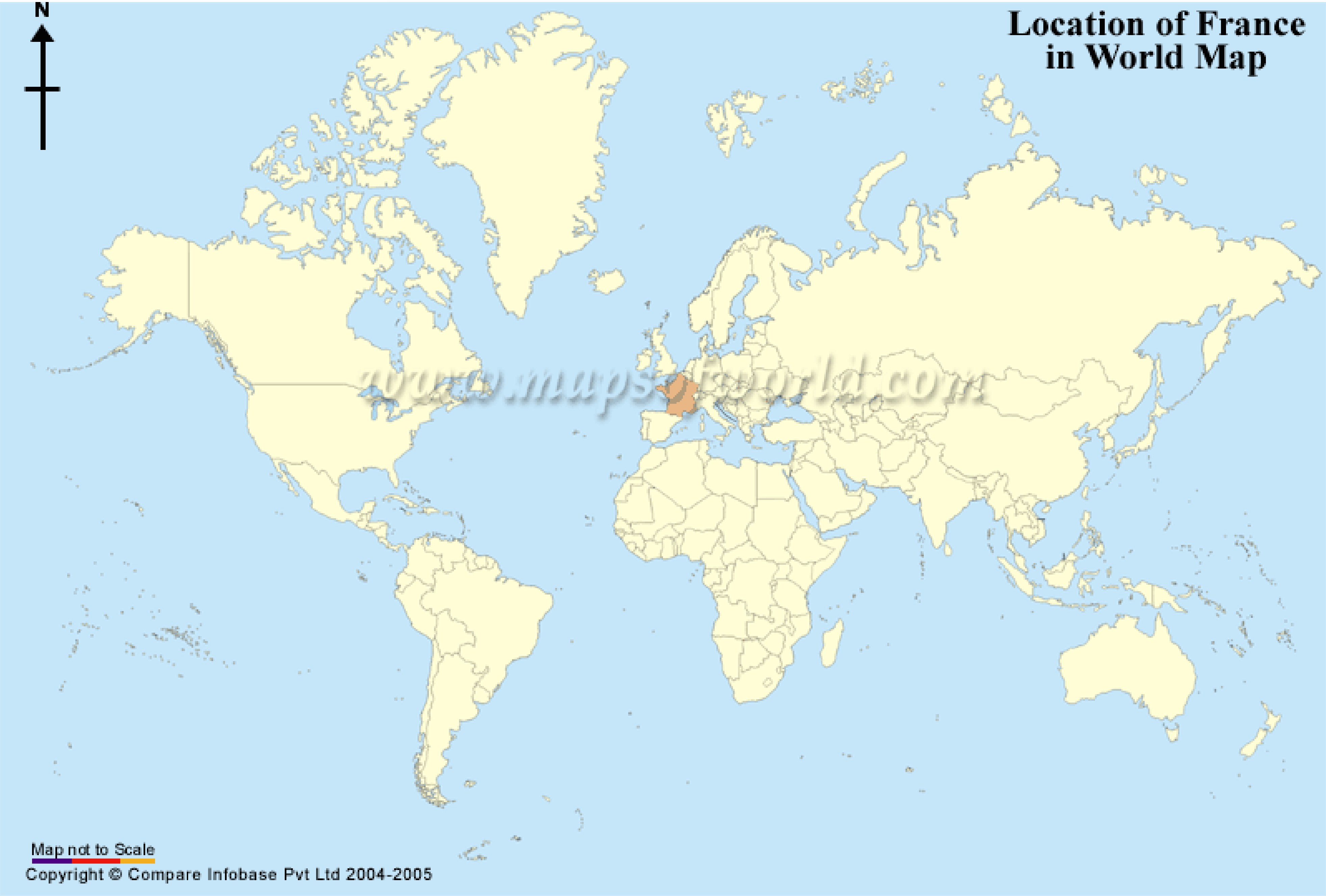


CW Ernsthofen, experimental, Austria

Summary

- General
    - For water temperatures higher than 12°C the effluent concentrations were far below the required values for all three beds (no statistically significant differences between the beds)
    - Beds with higher organic loading respond more sensitive to fluctuations of the influent concentrations.
- 20 mg COD.m^{-2}.d^{-1} (4 m^2 per person)
    - required effluent standards and removal efficiencies the whole year around.
- 27 mg COD.m^{-2}.d^{-1} (3 m^2 per person)
    - required effluent concentrations for COD and BOD_5 could not be met during the whole winter period.
- 40 mg COD.m^{-2}.d^{-1} (2 m^2 per person)
    - failed during operation in winter.
    - High organic loading is applicable for CWs that are only operated during the warm season when wastewater temperatures are above 12°C.

Location of France in World Map



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CW Roussillon, 1250 p.e., France

Treatment of raw wastewater (French system)

Roussillon en Provence

By courtesy of Dirk Esser

CW Roussillon, 1250 p.e., France

Treatment of raw wastewater (French system)

- The French system
  - 2-stage system
  - Stage 1: course gravel, 1.2 $m^2.PE^{-1}$
  - Stage 2: fine gravel, 0.8 $m^2.PE^{-1}$
  - High hydraulic loading
  - Parallel beds with alternative loading/resting periods (e.g. 3 beds: 1 week loading, 2 weeks resting)
- Intermittent loading by siphons
  - no energy required
- Sludge accumulation on stage 1, removal every 10-15 years, no negative impact in plant re-growth

By courtesy of Dirk Esser

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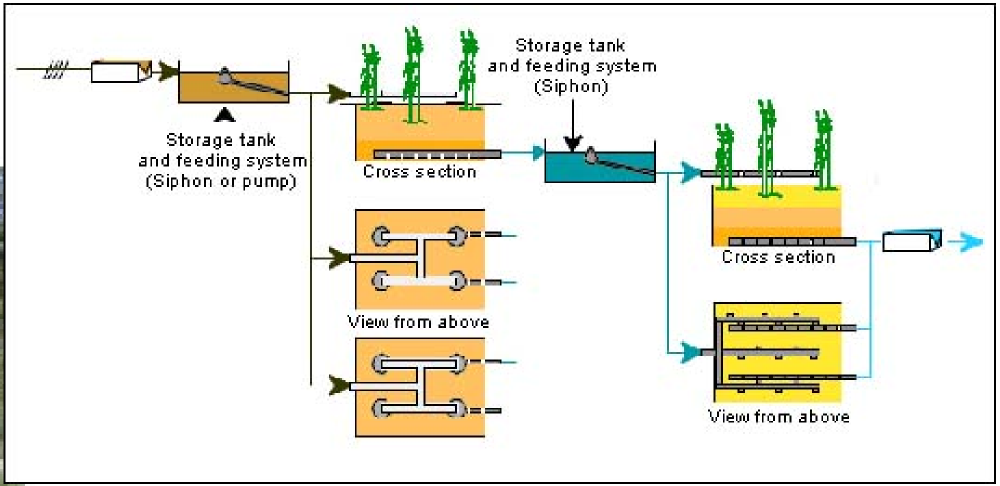
CW Roussillon, 1250 p.e., France

Treatment of raw wastewater (French system)



Reed bed filter

	Stage 1	Stage 2
Percolation	Vertical	Vertical
Feeding	Siphon	Siphon
Sizing	3 beds of 350 m^2	2 beds of 250 m^2

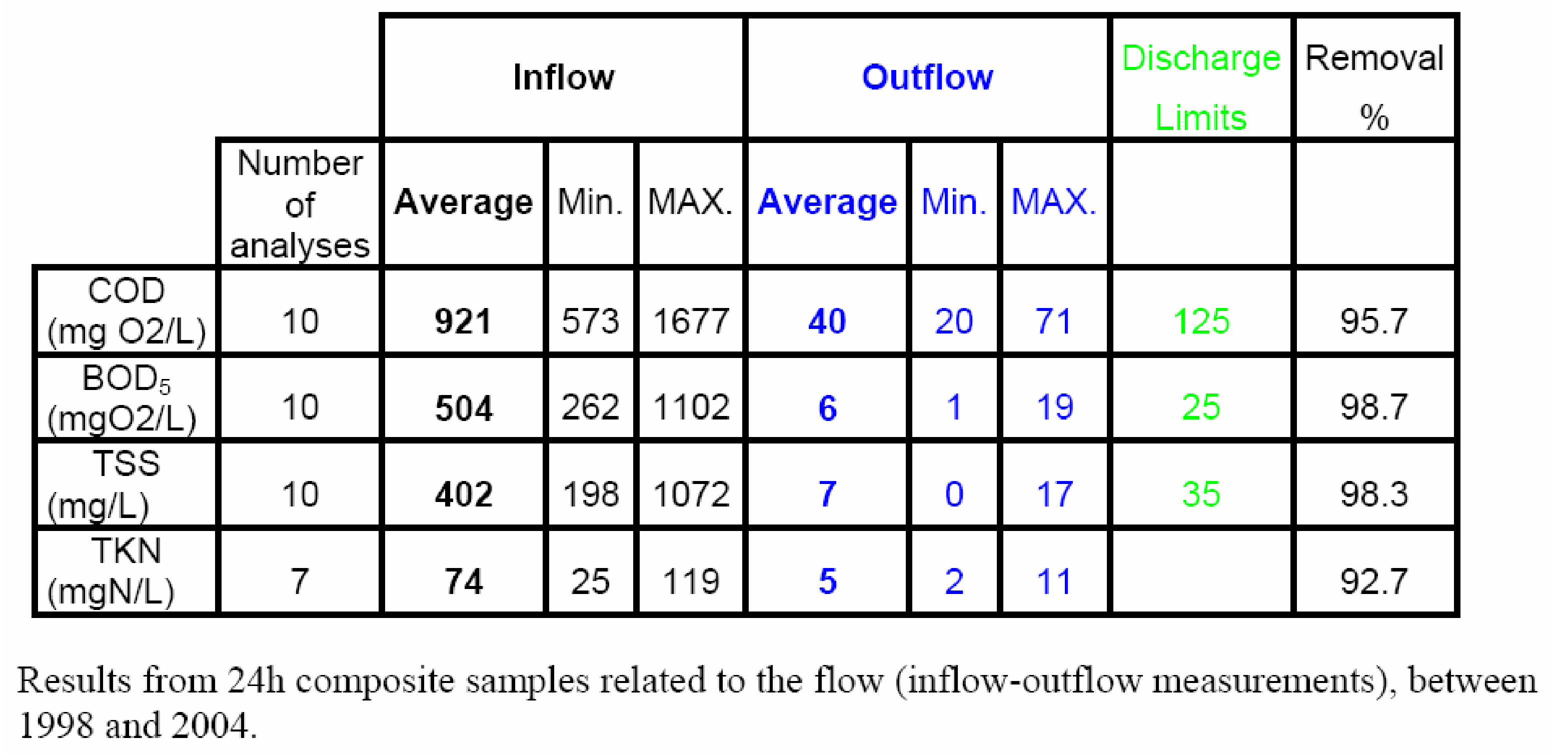
By courtesy of Dirk Esser

CW Roussillon, 1250 p.e., France

Treatment of raw wastewater (French system)

CW Roussillon, 1250 p.e., France

Treatment of raw wastewater (French system)



		Inflow			Outflow			Discharge Limits	Removal %
	Number of analyses	**Average**	Min.	MAX.	**Average**	Min.	MAX.		
COD (mg O2/L)	10	**921**	573	1677	**40**	20	71	125	95.7
BOD$_5$ (mgO2/L)	10	**504**	262	1102	**6**	1	19	25	98.7
TSS (mg/L)	10	**402**	198	1072	**7**	0	17	35	98.3
TKN (mgN/L)	7	**74**	25	119	**5**	2	11		92.7

Results from 24h composite samples related to the flow (inflow-outflow measurements), between 1998 and 2004.

By courtesy of Dirk Esser

Case studies

Case studies

- Industrialized countries
    - ✓ CW for treatment of mechanically pre-treated wastewater (Austria)
    - ✓ CW for treatment of raw wastewater (France)
    - Integrated natural system for landfill leachate treatment (USA)
    - CW for treatment of greywater (Germany)
- Developing countries
    - CW for treatment of hospital wastewater (Nepal)
    - CW for treatment of hospital wastewater (Uganda)

Contact

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Application of CWs:
Case studies - 2

Dr. Guenter Langergraber

Institute of Sanitary Engineering and Water Pollution Control

Workshop on "Constructed Wetlands"
Ramallah, Palestine
22 January 2006

Case studies

Case studies

- Industrialized countries
    - ✓ CW for treatment of mechanically pre-treated wastewater (Austria)
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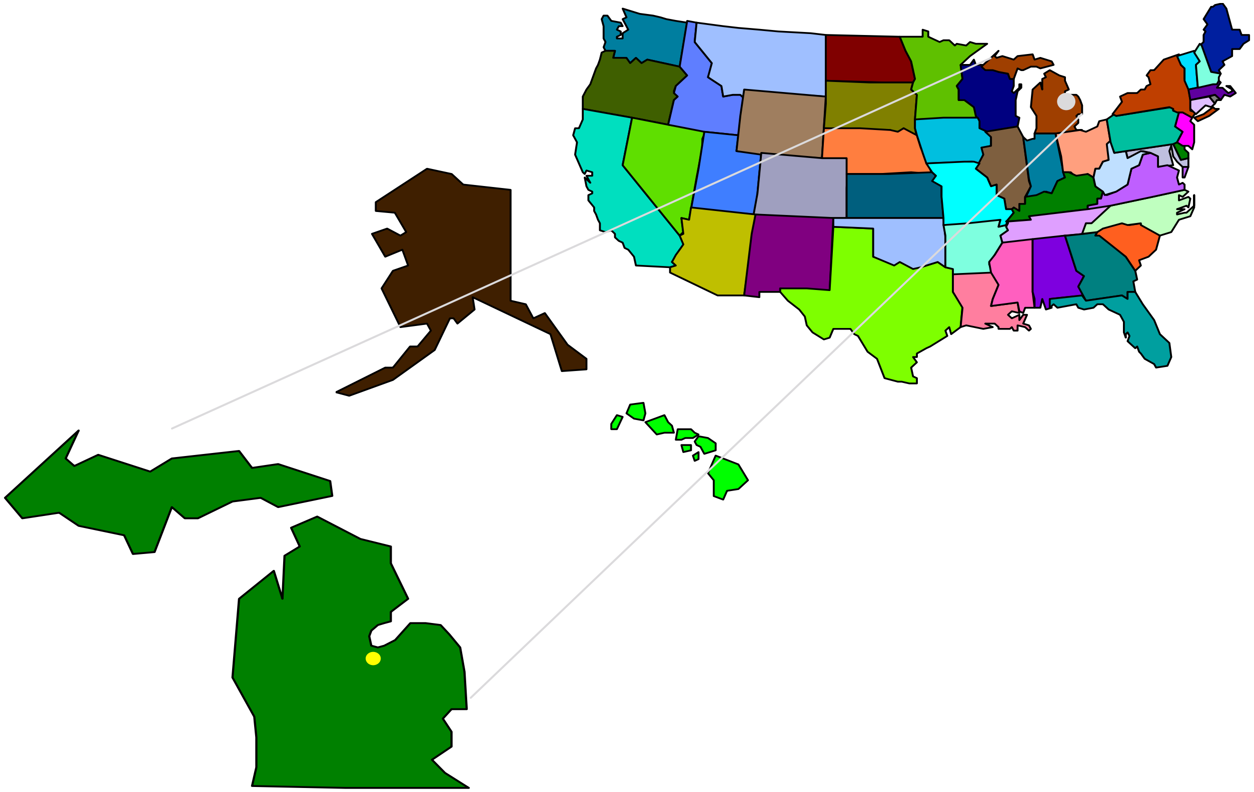
Saginew, Michigan, USA

Integrated Natural System for Landfill Leachate Treatment

By courtesy of Bob Kadlec

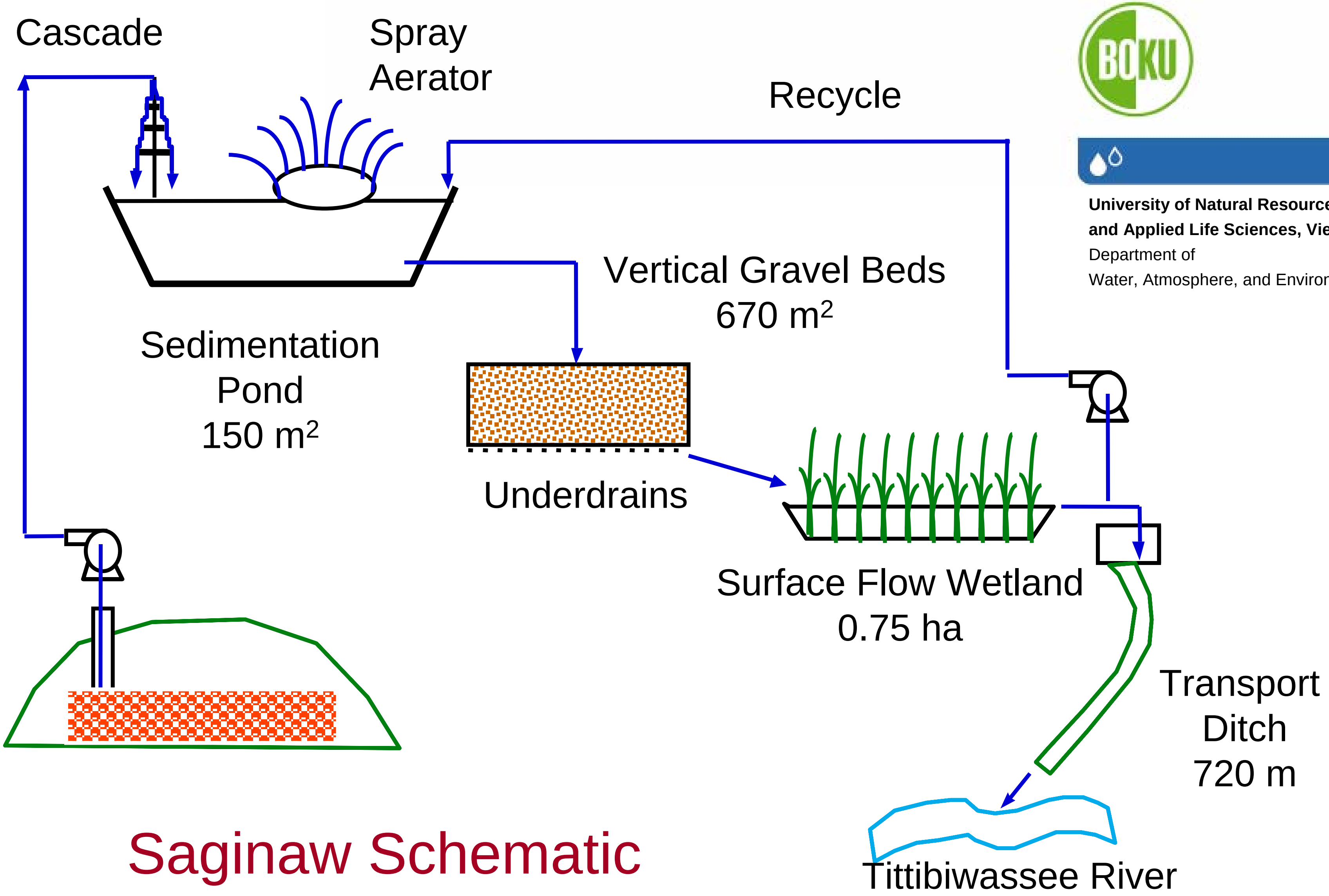
Saginew, Michigan, USA

Integrated Natural System for Landfill Leachate Treatment



By courtesy of Bob Kadlec

Saginaw Schematic



Cascade

Spray Aerator

Recycle

Vertical Gravel Beds
670 m^2

Sedimentation
Pond
150 m^2

Underdrains

Surface Flow Wetland
0.75 ha

Transport
Ditch
720 m

Tittibiwassee River

By courtesy of Bob Kadlec

Saginew, Michigan, USA

Integrated Natural System for Landfill Leachate Treatment

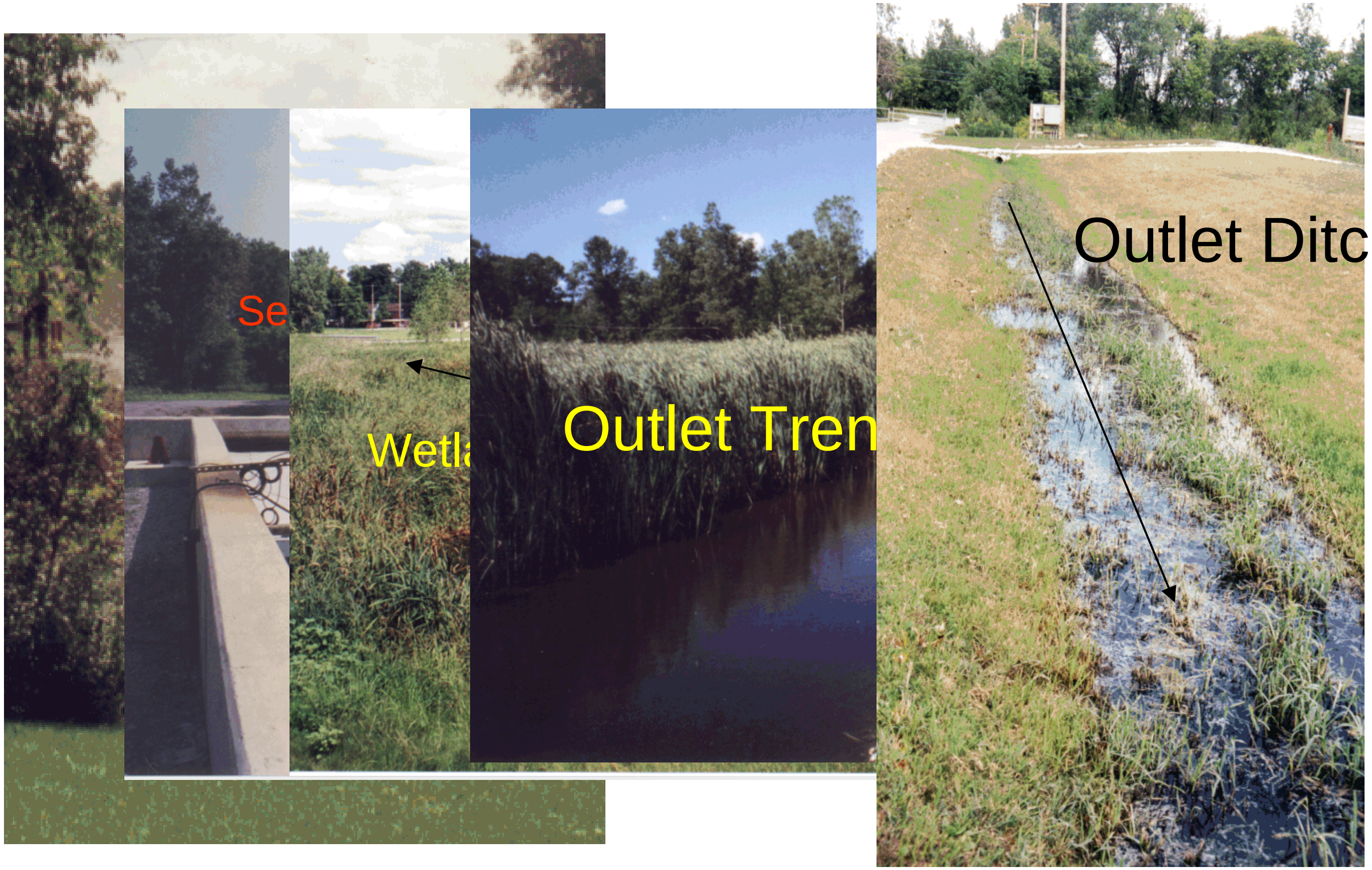
System Characteristics

- Extraction: 90 m^3/d design, level controlled
- Cascade: 2 m high, concentric plate drop
- Sedimentation Basin:
  - 330 m^3, 90 m^3 working, 0.5 day detention @ 180 m^3/d combined feed
- Sand Filters
  - 670 m^2 in two underdrained beds, dump feed, alternate beds
- Wetlands
  - 0.75 ha in two parallel paths
  - 30 cm deep, cattails
  - 30 days detention @ 90 m^3/d
  - deep zones for redistribution

By courtesy of Bob Kadlec

Saginew, Michigan, USA

Integrated Natural System for Landfill Leachate Treatment

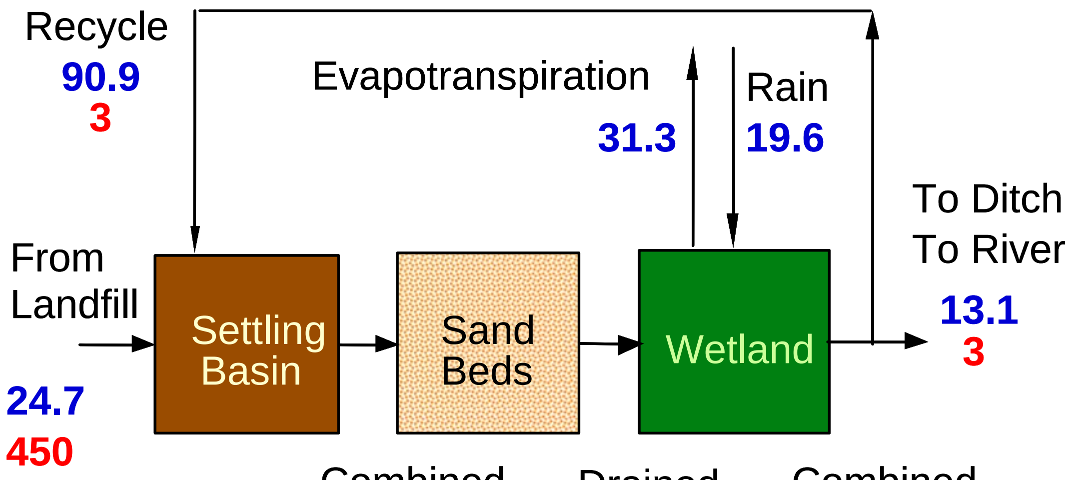


By courtesy of Bob Kadlec

Saginew, Michigan, USA

Integrated Natural System for Landfill Leachate Treatment

Saginaw Water and Ammonia



Recycle
90.9
3

Evapotranspiration
31.3

Rain
19.6

To Ditch
To River
13.1
3

From
Landfill
24.7
450

Settling Basin

Sand Beds

Wetland

	Combined	Drained	Combined
Water Flow, m3/d =	115.6	115.6	104.0
Median NH4-N, mg/L =	87	32	3

By courtesy of Bob Kadlec

Saginew, Michigan, USA

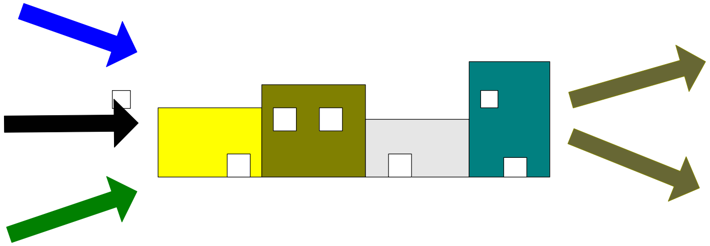
Integrated Natural System for Landfill Leachate Treatment

Saginaw Volatile Organics

	Design Inflow mg/m3	Observed Inflow mg/m3	Inflow Hits/Sample	Outflow Hits/Sample
Benzene	9.8	9.6	1/37	0/27
Toluene	14.6	9.7	8/37	0/27
Ethylbenzene	55.5	14.7	19/37	0/27
Xylenes	130.9	39	29/37	0/27
Total BTEX	210.7	73		
Chloroethane	36	9.4	10/37	0/27

By courtesy of Bob Kadlec

Conventional sanitation concepts

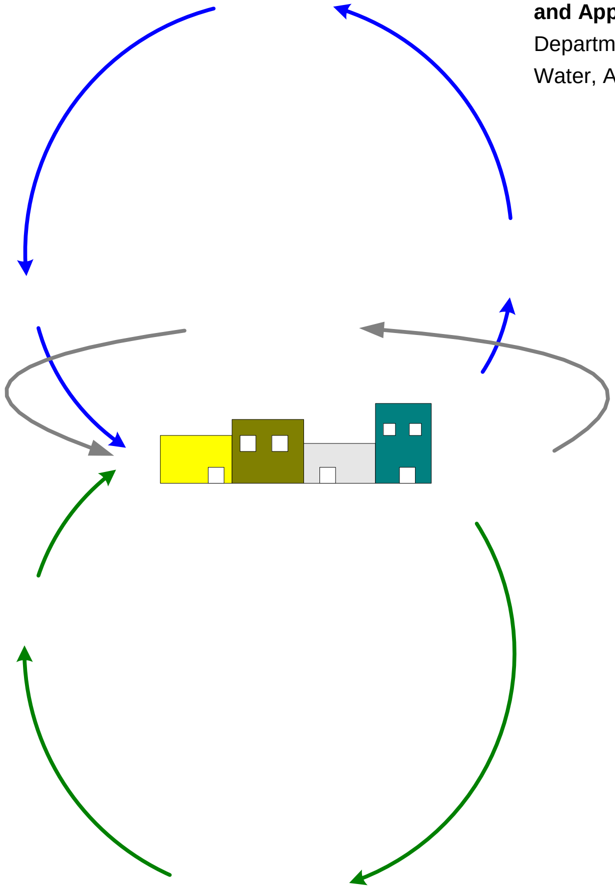


- human excreta are mixed with water and flushed away.
- high water demand
- spreading of pathogens and micro-pollutants (hormons and medical residues)
- loss of economic option for reuse
- disinfection has to be done as an additional expensive treatment step

Ecological sanitation (EcoSan) systems

Fundamentals

- closing water, nutrient, material, energy cycles
- reuse oriented
- holistic approach towards ecologically and economically sound sanitation
- systemic approach
- single technologies are only means to an end
- technologies are not ecological per se



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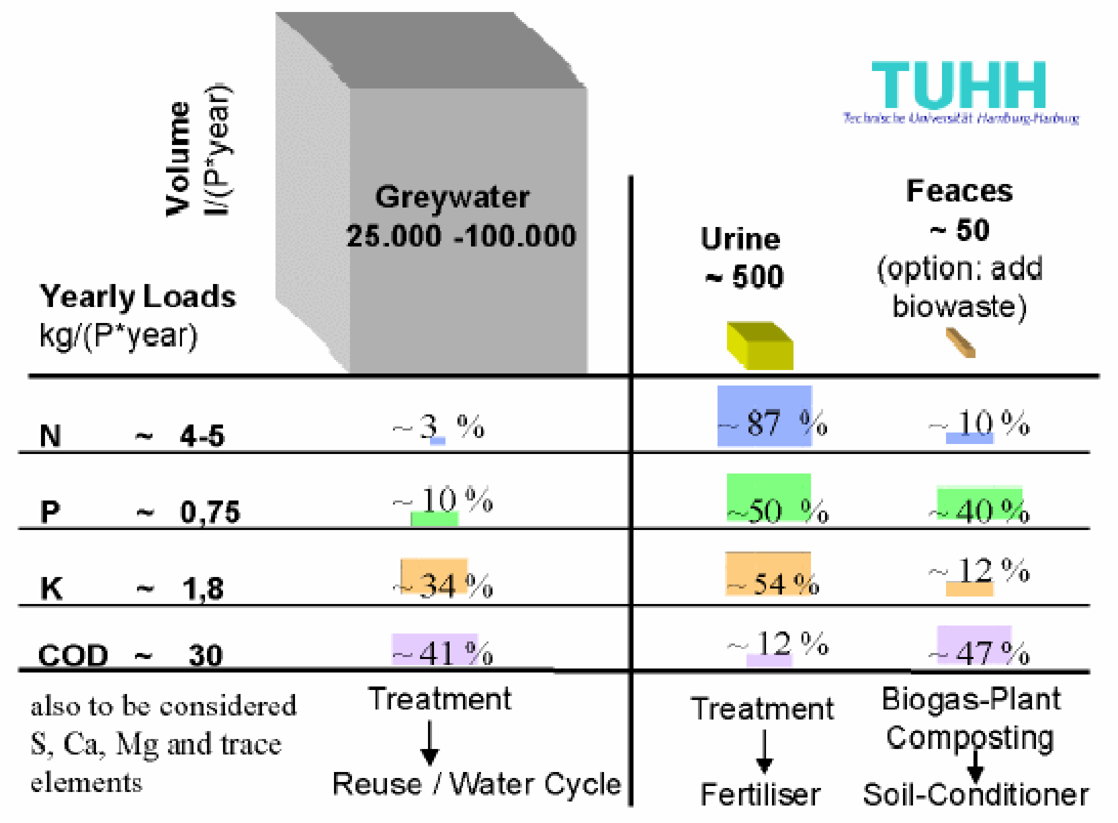
Ecological sanitation (EcoSan) systems

Characteristics of domestic wastewater flows



Volume l/(P*year) Yearly Loads kg/(P*year)	Greywater 25.000 -100.000	Urine ~ 500	Feaces ~ 50 (option: add biowaste)
N ~ 4-5	~3 %	~87 %	~10 %
P ~ 0,75	~10 %	~50 %	~40 %
K ~ 1,8	~34 %	~54 %	~12 %
COD ~ 30	~41 %	~12 %	~47 %
also to be considered S, Ca, Mg and trace elements	Treatment ↓ Reuse / Water Cycle	Treatment ↓ Fertiliser	Biogas-Plant Composting ↓ Soil-Conditioner

- no dilution for urine and faeces
- wet weight
- about 50'000 litre/(P.yr) for flush toilet

Ecological sanitation (EcoSan) systems

Sources of hygienic hazards

- ***Human faecal excreta*** may be harmless but it can contain large amounts of pathogenic organisms.
- ***Human urine*** does not normally contain pathogenic organisms that will transmit enteric disease to other individuals. Only in special cases, e.g. a systemic infection with fever, pathogenic organisms will be present in urine. (Medical residues)
- ***Greywater*** normally contains low amounts of pathogenic organisms.
- ***Stormwater*** may have a high loads of faecal contamination (animals).
- In ***Wastewater*** all microorganisms originating from human excreta will occur in amounts reflecting their occurrence in infected persons or carriers connected to the system. Untreated wastewater should always be regarded as potentially containing pathogenic organisms.

Ecological sanitation (EcoSan) systems

Treatment and reuse

- Recommendations how to sanitise human excreta before use (e.g. Schönning, 2004; Jönsson et al., 2004).
- Treatment
  - Urine: die-off of pathogens during to storage (6 months); removal of other substances found in urine, like micro-pollutants (e.g. medical residues and endocrine disruptors) is still a matter of discussion
  - Faeces: destruction of pathogens due to e.g. drying, storage, composting, digestion, chemical treatment and incineration
- Reuse
  - Urine: diluted urine as N + P fertilizer
  - Faeces: fertilizer + increased humus content and thus water holding capacity of the soil ➔ prevention of the degradation of soil fertility

Ecological sanitation (EcoSan) systems

Wastewater as a resource?

- Most of the soluble nutrients are found in urine. If urine is separated and converted to agricultural usage, the biggest step towards nutrient reuse and highly efficient water protection will be taken.
- The hygienic hazards of wastewater are originated mainly from faecal matter. Separation opens the way to hygienisation and finally to an excellent end-product.
- Greywater, i.e. wastewater that is not mixed with faeces and urine, is a great resource for high quality reuse of water.
- Source control should include evaluating all products that end up in the water. High quality reuse will be far easier when household chemicals are not only degradable but can be mineralised with the available technology.

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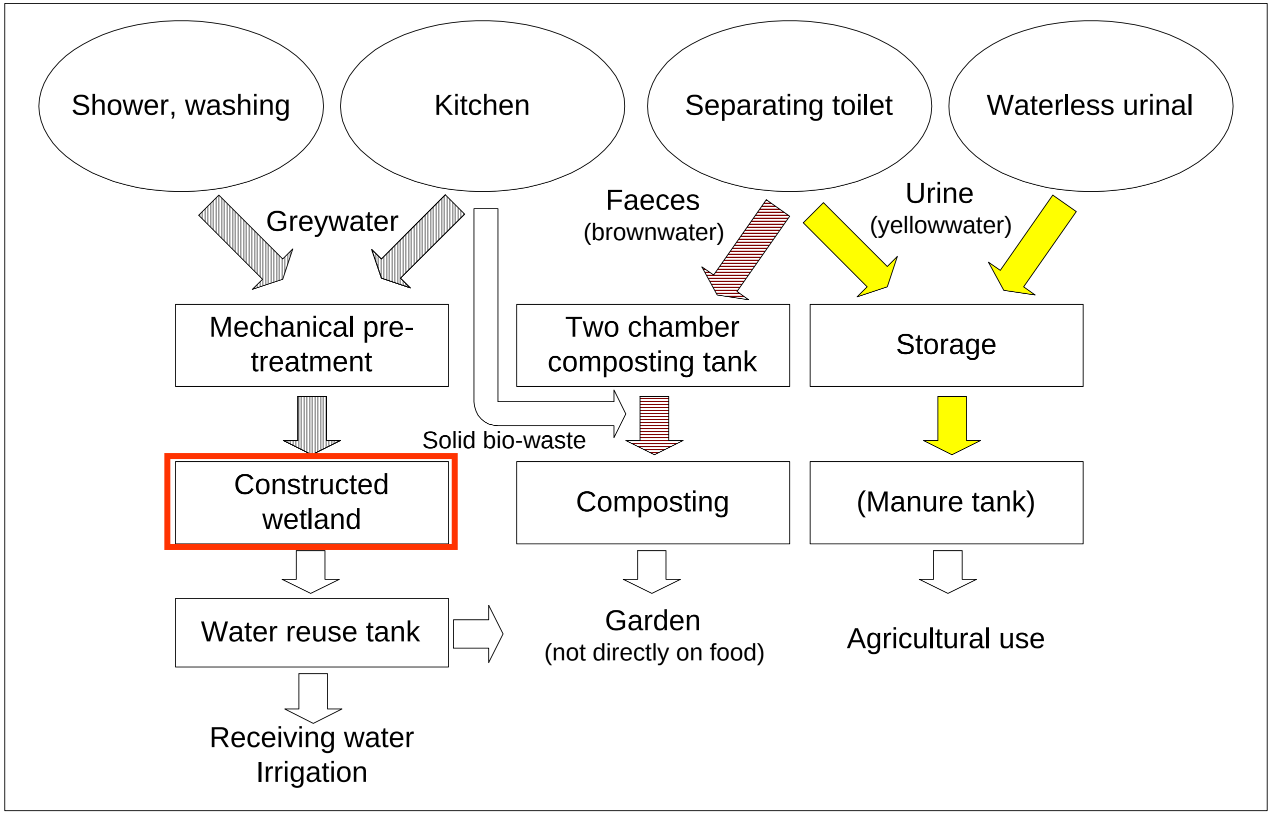
Ecological sanitation (EcoSan) systems

Possible concept for handling of wastewater streams



The Use of CWs in EcoSan Systems

- CW systems are widely applied in EcoSan systems for greywater treatment.
- Compared to technical solutions or greywater treatment (e.g. rotating biological contactor) CWs are relatively easy to maintain and operate resulting in low operating costs.
- Other applications of CW technology in EcoSan concepts like stormwater treatment and treatment of the total wastewater can be hardly found in literature under the terminus "EcoSan".

The Use of CWs in EcoSan Systems

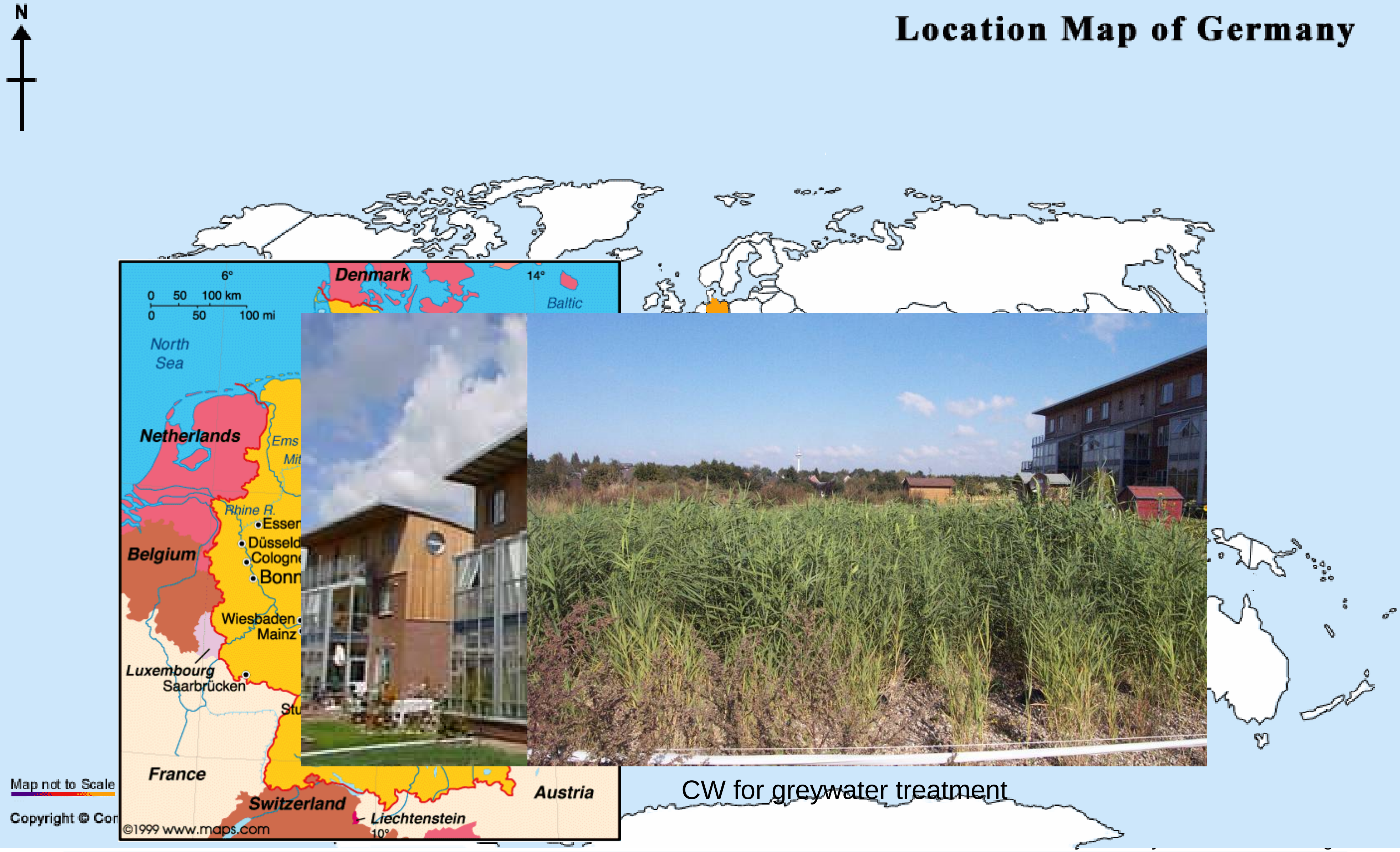
CW technology and basic EcoSan Criteria

According to Esrey et al. (1998) a sanitation system that contributes toward the goals of EcoSan must meet or at least be on the way towards meeting the following criteria:

1. **Prevention of diseases** (by destroying or isolating pathogens),
2. **Affordability** (especially O/M-costs are lower for CWs compared to conventional systems),
3. **Protection of the environment** (reduction of pollution, very low energy requirement, biodiversity, habitat for wetland organisms, climatic functions)
4. **Acceptability** (aesthetically inoffensive and consistent with cultural and social values), and
5. **Simplicity** (to allow maintenance with the local technical capacity, institutional framework and economic resources).

➔ CW technology fulfils the basic criteria for EcoSan concepts

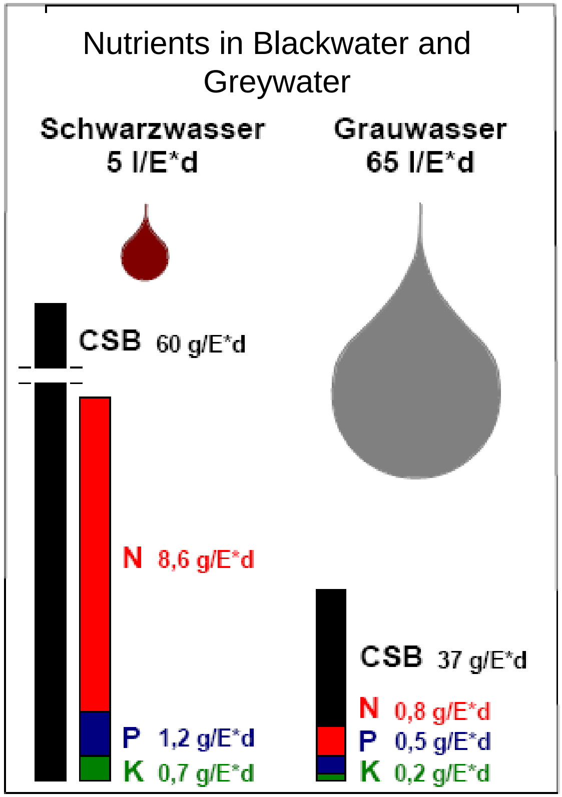
Location Map of Germany



CW for greywater treatment

The Use of CWs in EcoSan Systems

CW Flintenbreite, Lübeck, Germany



Dimensioning: 2 m²/person
Actual load: 3.5-4 m²/person

Parameter	Influent (mg/l)	Effluent (mg/l)	Effluent limit (mg/l)
COD	421	41	150
BOD5	144	9	25
Total N	10.1	4.0	-
NH4-N	-	< 0.5	-
NO3-N	-	1.4	-
Total P	5.3	4.3	-
PO4-P	4.7	3.9	-

By courtesy of Martin Oldenburg

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The Use of CWs in EcoSan Systems

Summary

- CW technology fulfils the basic criteria for EcoSan concepts - prevention of diseases, affordability, protection of the environment, acceptability, and simplicity.
- This makes CWs suitable for EcoSan concepts where they can be applied for treatment of greywater, stormwater and/or the total wastewater flow.
- Being a simple, affordable, and sustainable technology CWs are also suitable for the application in developing countries (e.g. Denny, 1997; Haberl, 1999; Shrestha et al., 2001). where most of the problems with inadequate sanitation occur. A crucial step for the implementation of CWs in developing countries is proper technology transfer.

Langergraber, G., Haberl, R. (2004): Application of Constructed Wetland Technology in EcoSan Systems. In: IWA (Eds.): *Proceedings of the 4th IWA World Water Congress*, 19–24 September 2004, Marrakech, Morocco, (CD-ROM, paper no. 116541).

Case studies

Summary - Industrialized countries

- In general the use of CWs provides a relatively simple, inexpensive, and robust solution (tolerance against fluctuations of flow and pollution load) for the treatment of water.
- CWs usually need only low operation and maintenance.
- CWs are used for treatment of various types of water in different climatic conditions
- CWs are effective in treating organic matter, nitrogen, phosphorus, and additionally for decreasing the concentrations of heavy metals, organic chemicals, and pathogens.
- If a CW provides different environmental conditions and uses different plant species the treatment efficiency can be improved
- Additional benefits:
    - the facility of water reuse and recycling,
    - the provision of habitat for many wetland organisms,
    - a more aesthetic appearance compared to technical treatment options.

Case studies

- Industrialized countries
    - CW for treatment of mechanically pre-treated wastewater (Austria)
    - CW for treatment of raw wastewater (France)
    - Integrated natural system for landfill leachate treatment (USA)
    - CW for treatment of greywater (Germany)

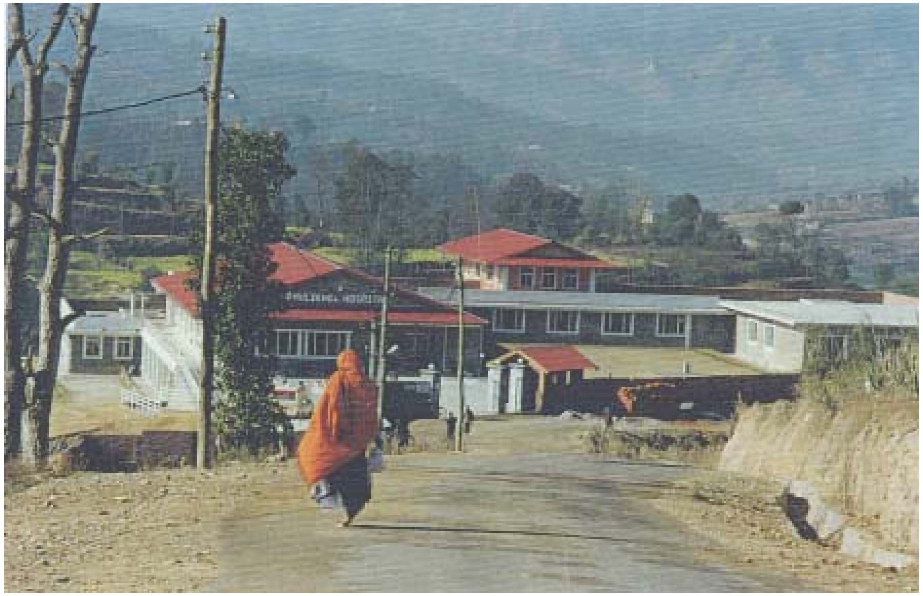
- Developing countries
    - CW for treatment of hospital wastewater (Nepal)
    - CW for treatment of hospital wastewater (Uganda)

CW Dhulikhel / Nepal

CW Dhulikhel / Nepal

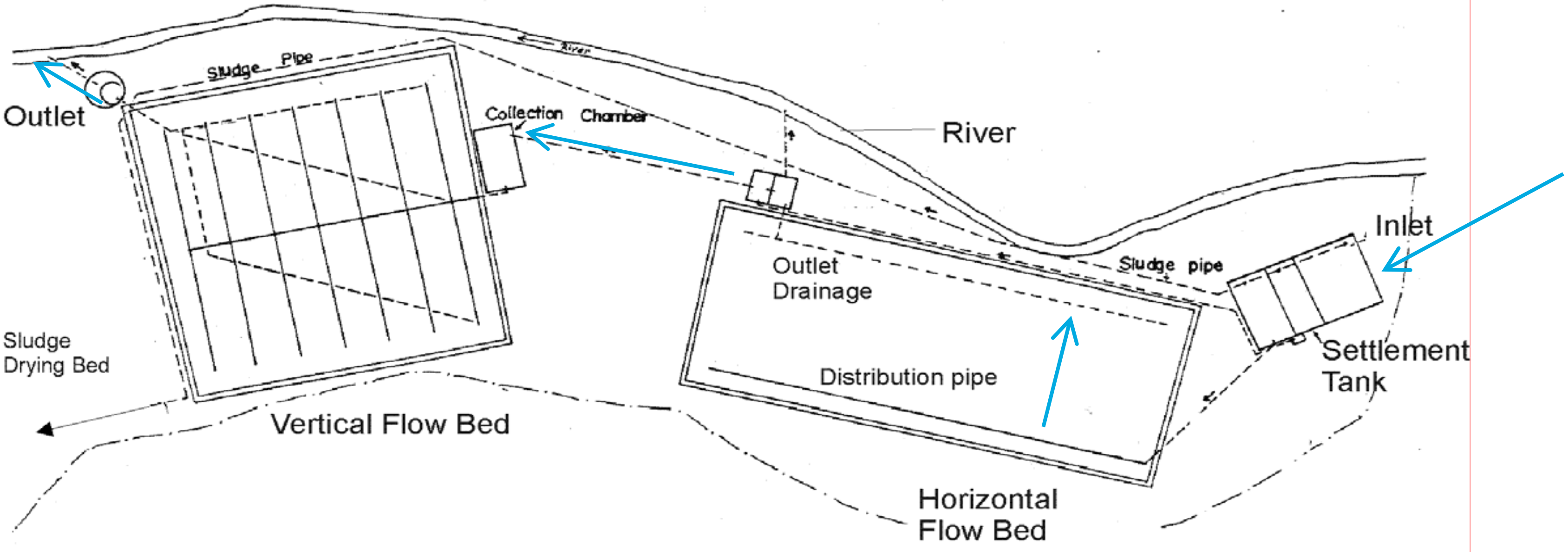
CW Dhulikhel / Nepal

- Dhulikhel hospital



  - 60 beds
  - located 30 km far from Kathmandu city
  - Climate: sub-tropical, annual rainfall 1456 mm

CW Dhulikhel / Nepal

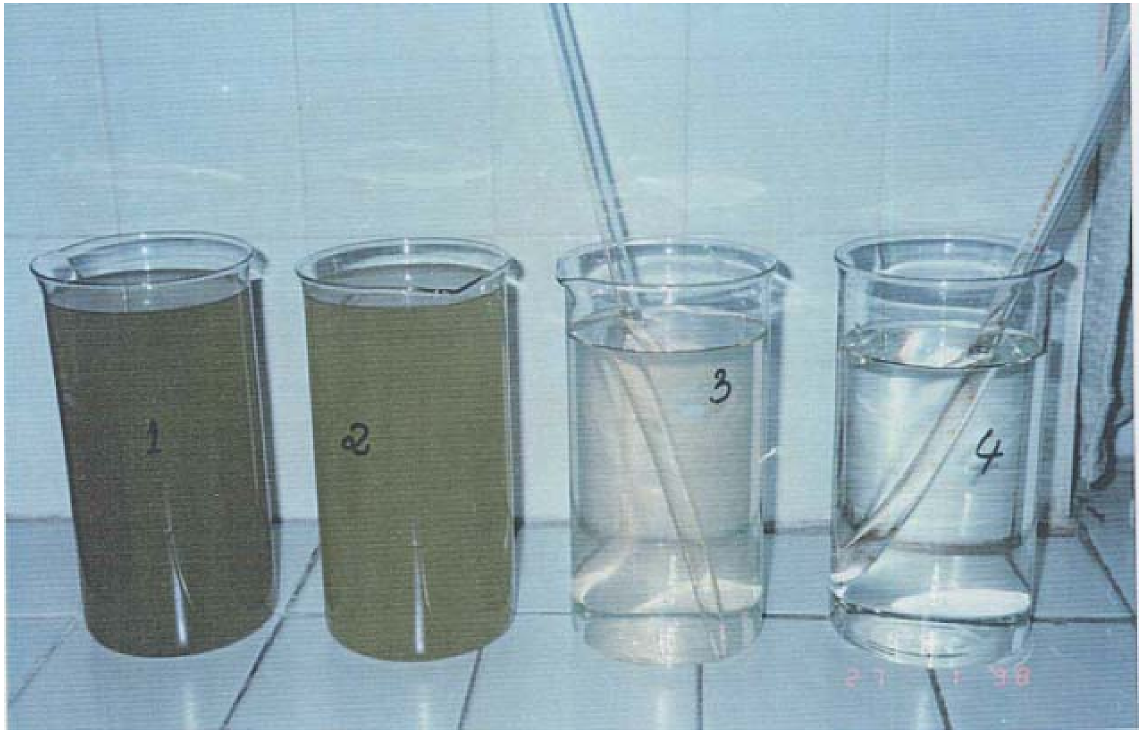


CW Dhulikhel / Nepal

- Design flow rate
  - 20 m^3/day
- Settlement tank
  - 18 m^3 (3 chambers)
- HF bed
  - 140 m^2 (7x20m^2), filled with 60 cm of crushed broken gravel (pore volume 39 %)
- VF bed
  - 121 m^2 (11x11m^2), filled with 90 cm of clean sand (Kf = 10-3 m/s)
- Vegetation
  - beds planted with *Phragmites karka* (local reeds)

CW Dhulikhel / Nepal

CW Dhulikhel / Nepal



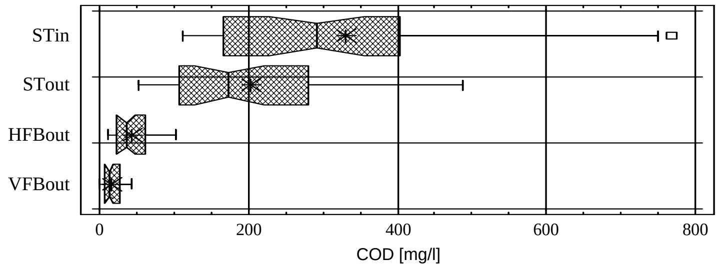
1 … inflow

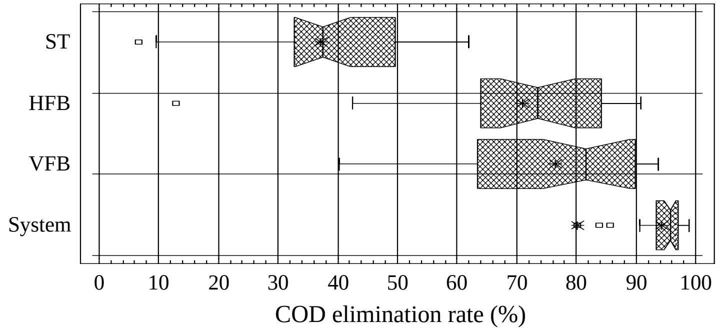
2 … mechanically pre-treated

3 … effluent stage 1

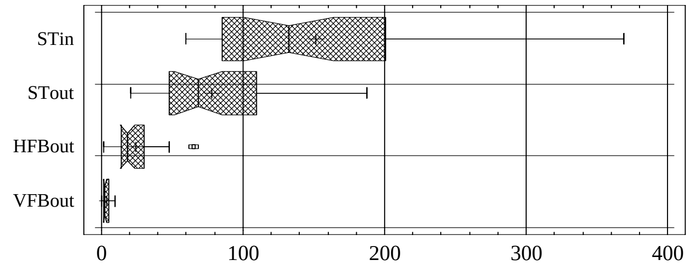
4 … final effluent

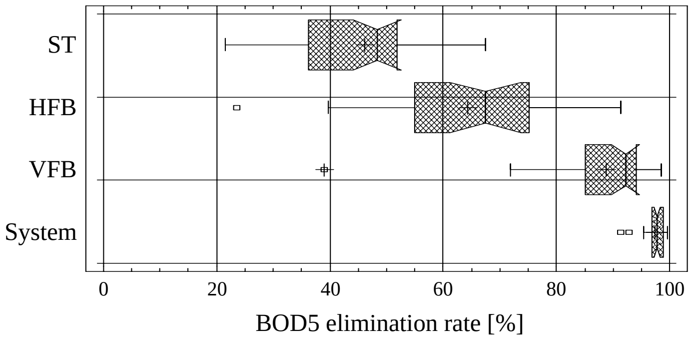
CW Dhulikhel / Nepal





COD





BOD$_5$

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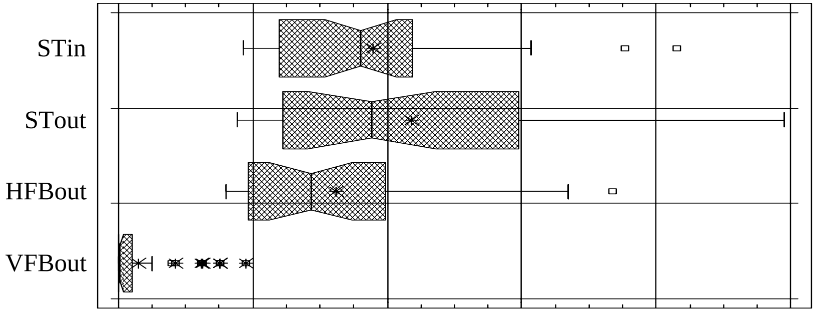
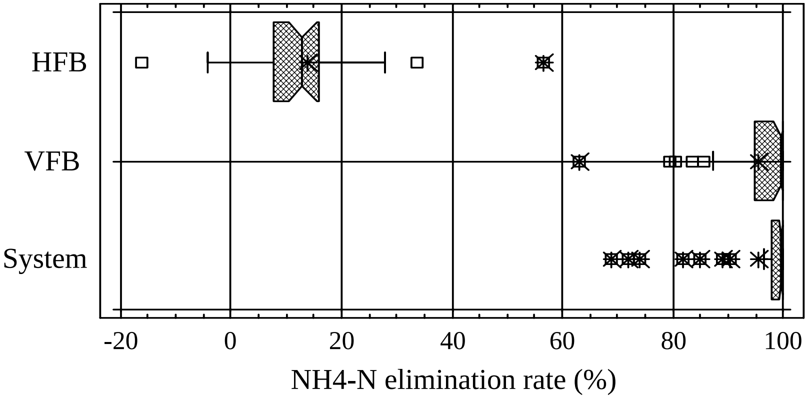
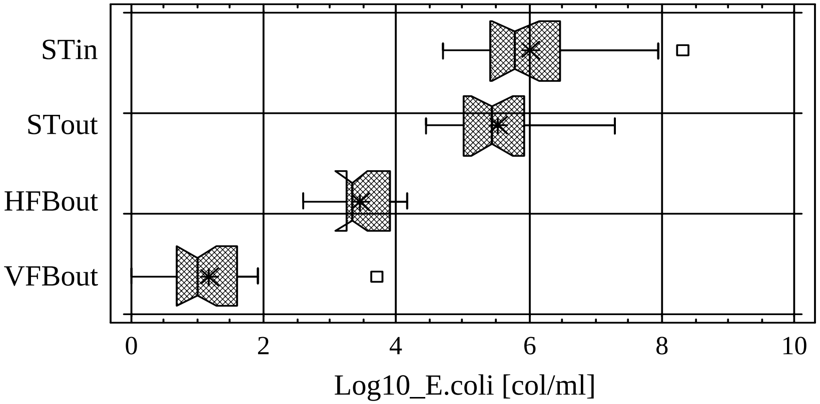
CW Dhulikhel / Nepal



NH$_4$-N





Indicator parameters / pathoges

CW Matany/Uganda

CW Matany/Uganda

CW Matany/Uganda

- Matany Hospital, Bokora County, Moroto, Uganda
- about 1150 p.e.
- 4 VF beds in parallel (1480 m², 4 x 370 m²)

	COD in	COD out	BOD5-in	BOD5-out	NH4-N in	NH4-N out
Median	**255**	**30**	**84**	**5**	**30.0**	**0.2**
Mean	288	30	80	5	27.7	0.4
Maximum	620	45	100	7	45.0	1.1
Minimum	194	15	46	2	9.4	0.1
Dev.	104	8	15	1	13.6	0.4

CW Matany/Uganda

Case studies

Summary - Developing countries

- CW technology fulfils the basic criteria for EcoSan concepts (prevention of diseases, affordability, protection of the environment, acceptability, and simplicity) and are therefore a suitable technology for developing countries (Langergraber and Haberl, 2004).
- Being a simple, affordable, and sustainable technology CWs are also suitable for the application in developing countries (e.g. Denny, 1997; Haberl, 1999; Shrestha et al., 2001).
- The number of examples includes treatment of domestic (Luyiga and Kiwanuka, 2003; Haberl, 1999), hospital (Laber et al., 1999), agricultural (Kantawanichkul et al., 2003), and industrial wastewaters (Abira et al., 2003).
- However, a crucial step for the implementation of CWs in developing countries is proper technology transfer (Denny, 1997; Haberl, 1999)

Summary and Conclusions

- CWs are artificial wetlands designed to improve water quality.
- They are effective in treating organic matter, nutrients and pathogens and are worldwide used to treat different qualities of water.
- Compared to conventional technical solutions for water treatment CWs are relatively easy to maintain and operate resulting in low operating costs.
- CW technology fulfils the basic criteria for EcoSan concepts (prevention of diseases, affordability, protection of the environment, acceptability, and simplicity).
- CWs are also very suitable for the application in developing countries where most of the problems with inadequate sanitation occur. A crucial step for the implementation of CWs in developing countries is proper technology transfer.

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