Diversification of constructed wetlands to solve major environmental challenges

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Lecture outline

- Introduction to constructed wetlands and the roles of plants
- Constructed wetland bibliometry
- Wetland diversifications
- Site- and application specific CWs
- Cases:
  - Treatment of oil-produced water in Oman
  - Post-tsunami constructed wetland system in Thailand

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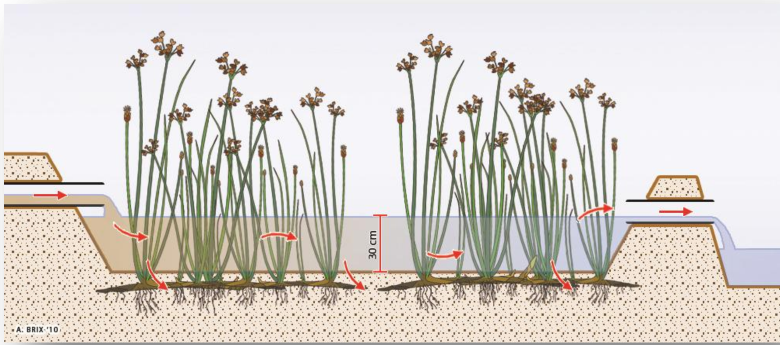
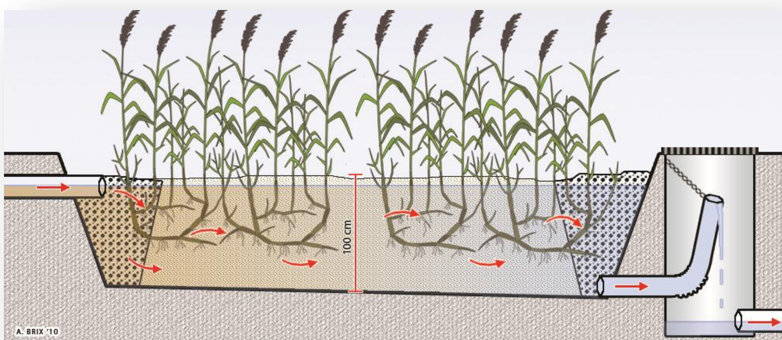
‘Basic’ types of Constructed Wetlands

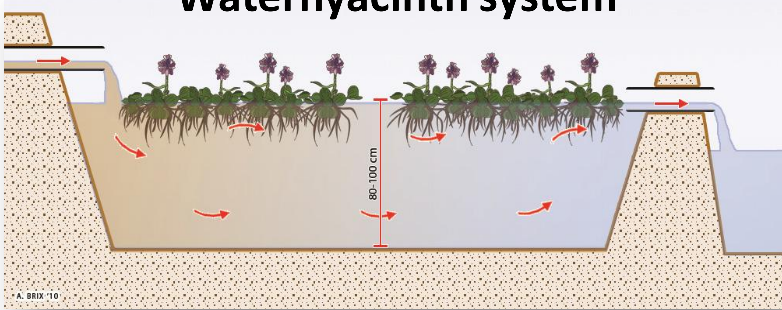
Free-Water Surface Flow (FWS)



Horisontal Subsurface Flow (HSSF)



Waterhyacinth system



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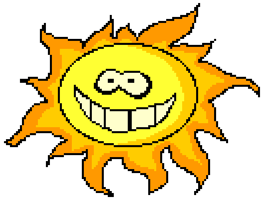
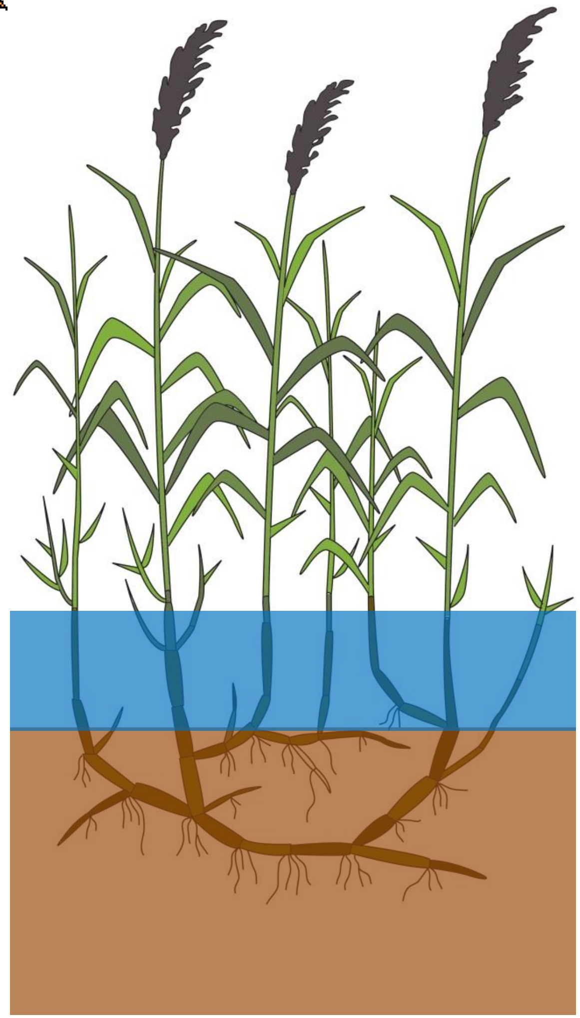
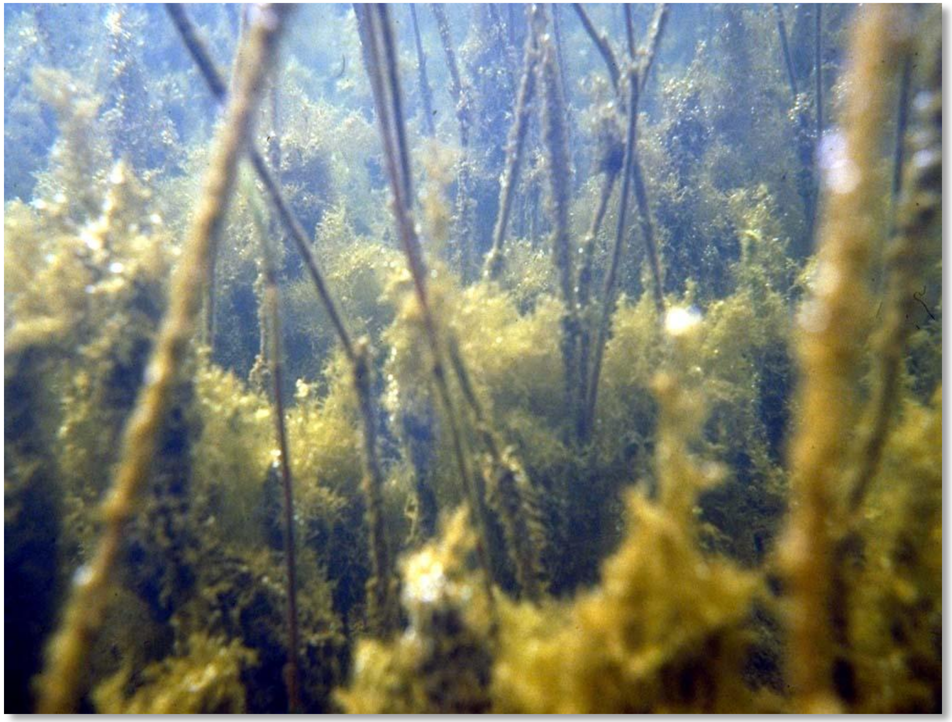
Plants play important functions

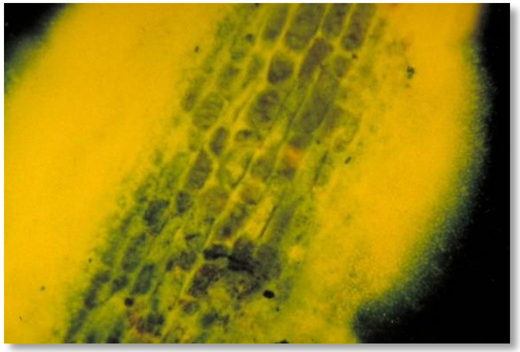


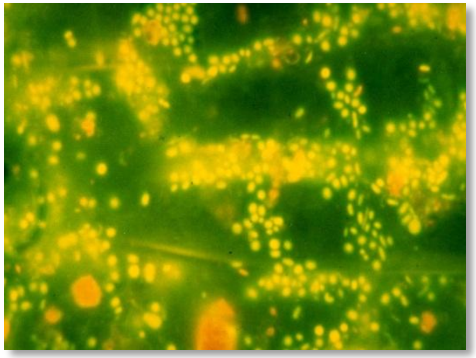


- Growth and biomass production
- Photosynthesis
- Nutrient uptake
- Water uptake
- Oxygen transport
- Metabolism
- Food chain support

Surface area for attached microbial growth







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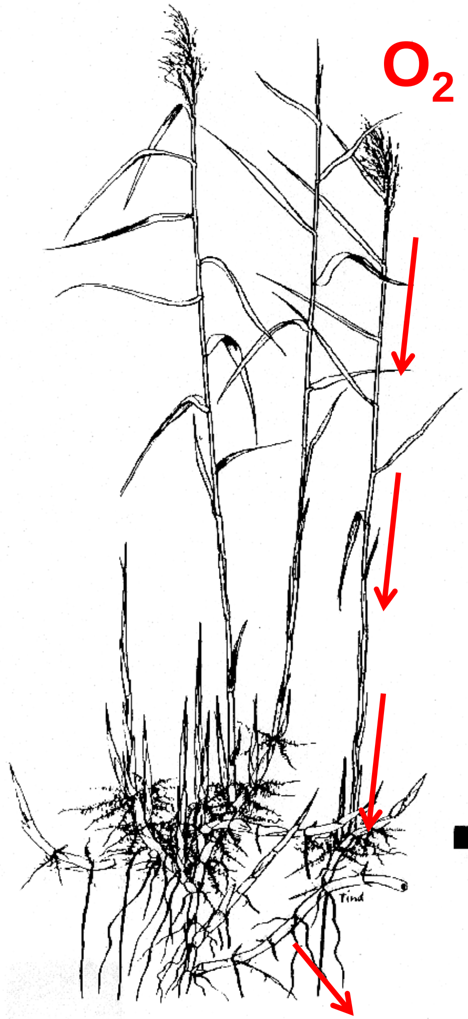
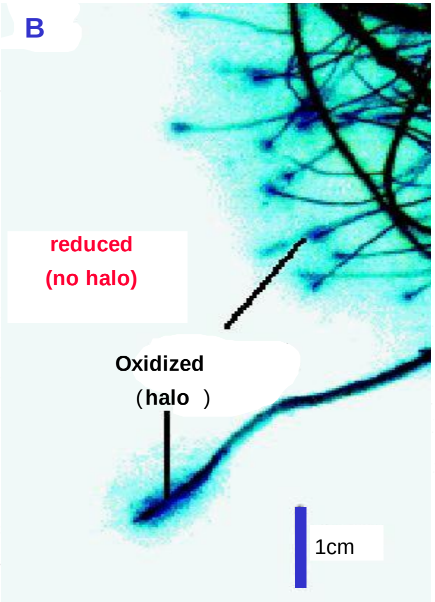
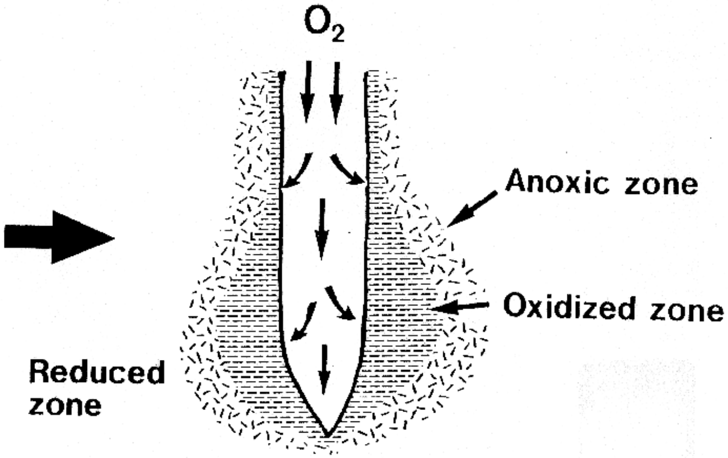
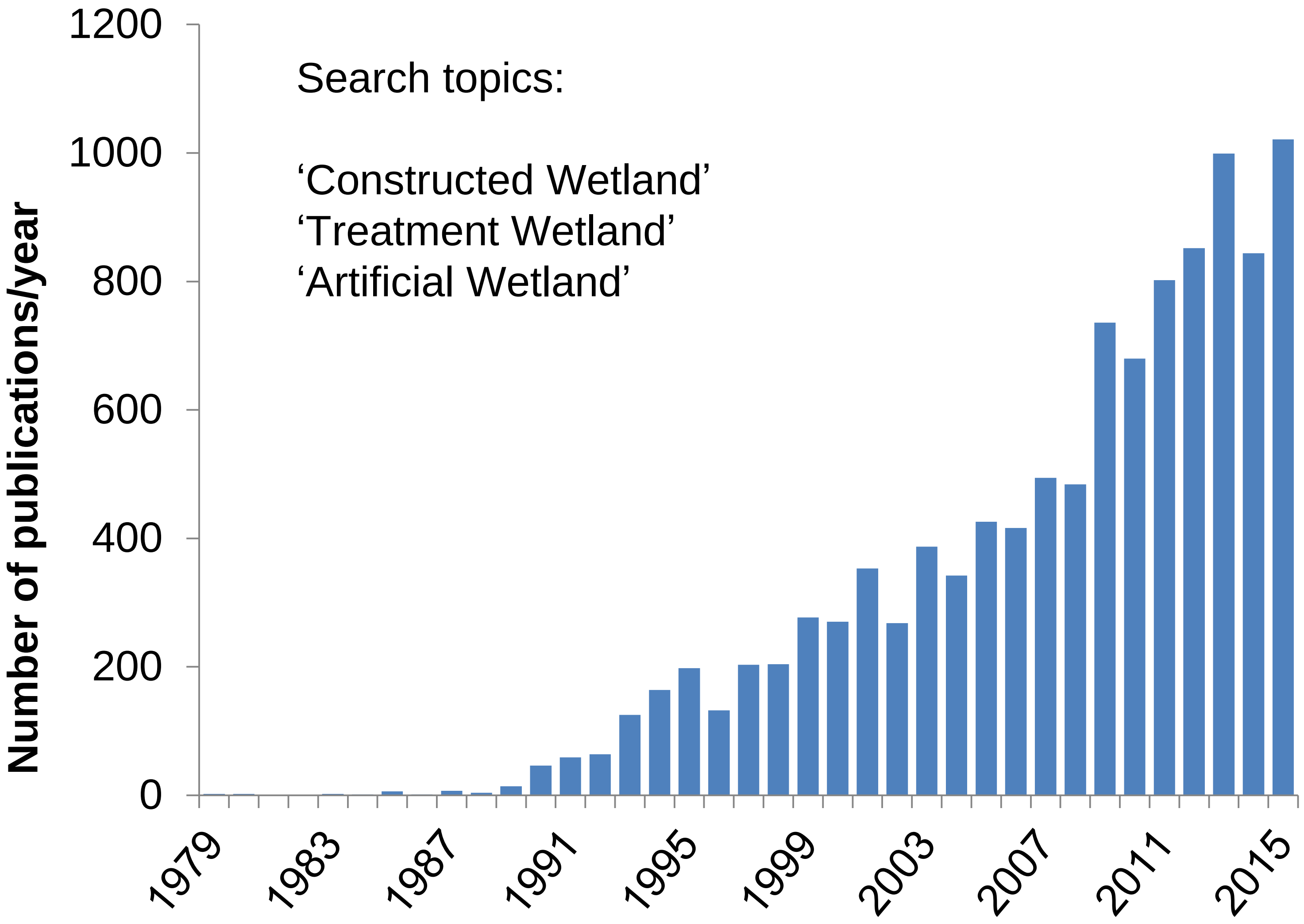
Oxygen release from roots







Number of publications in Web of Science



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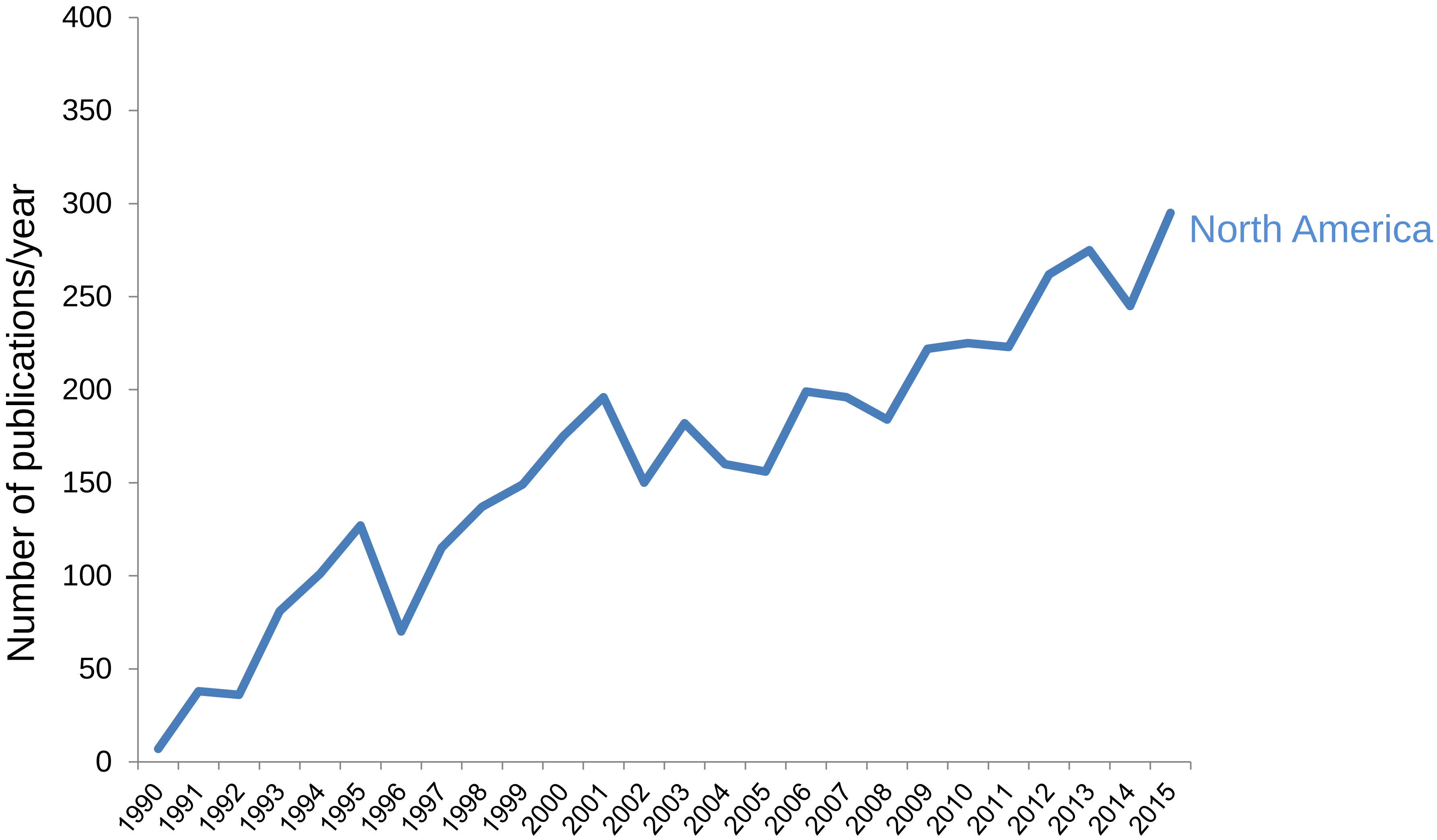
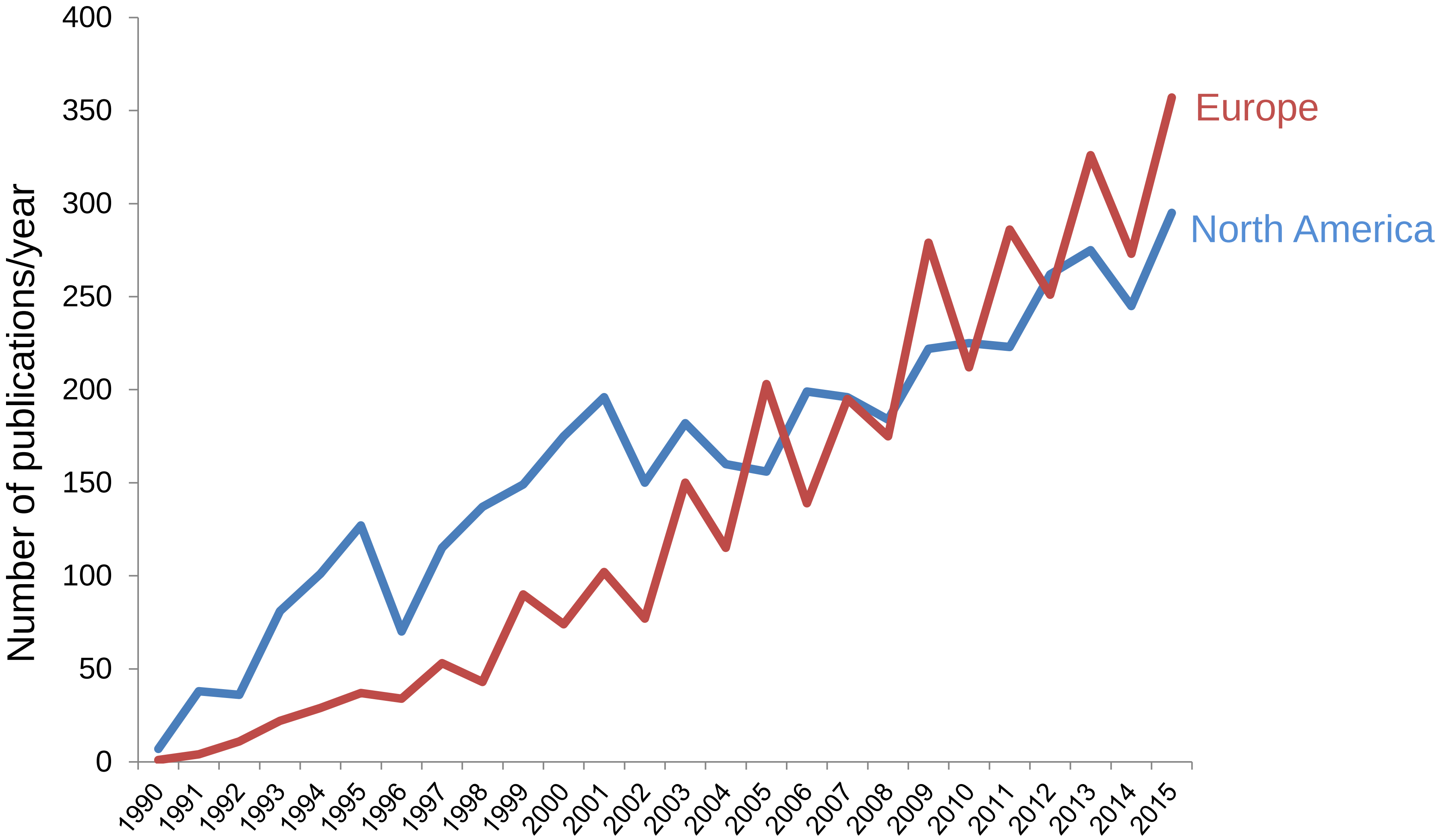


Number of publications in Web of Science



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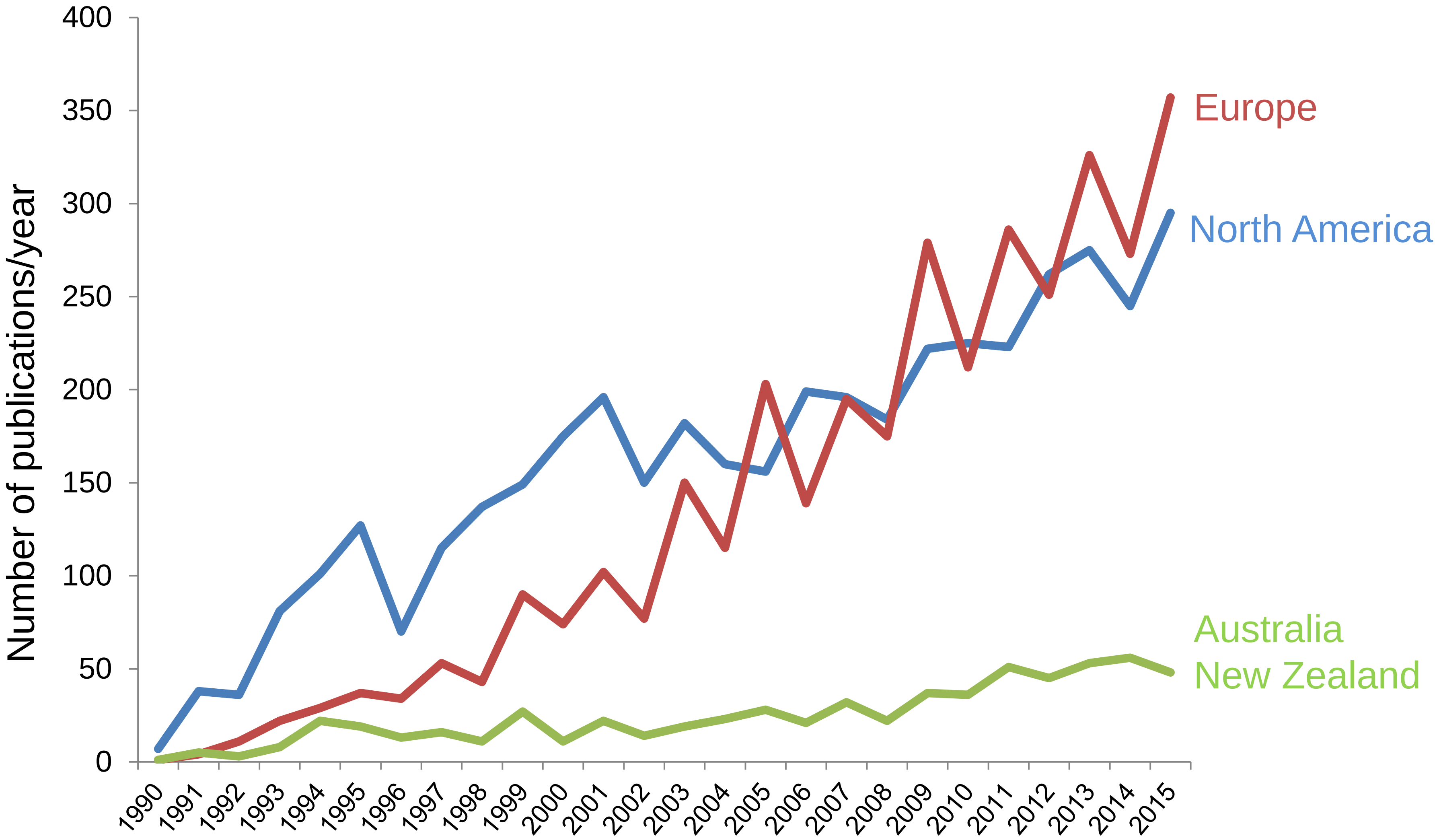
Number of publications in Web of Science



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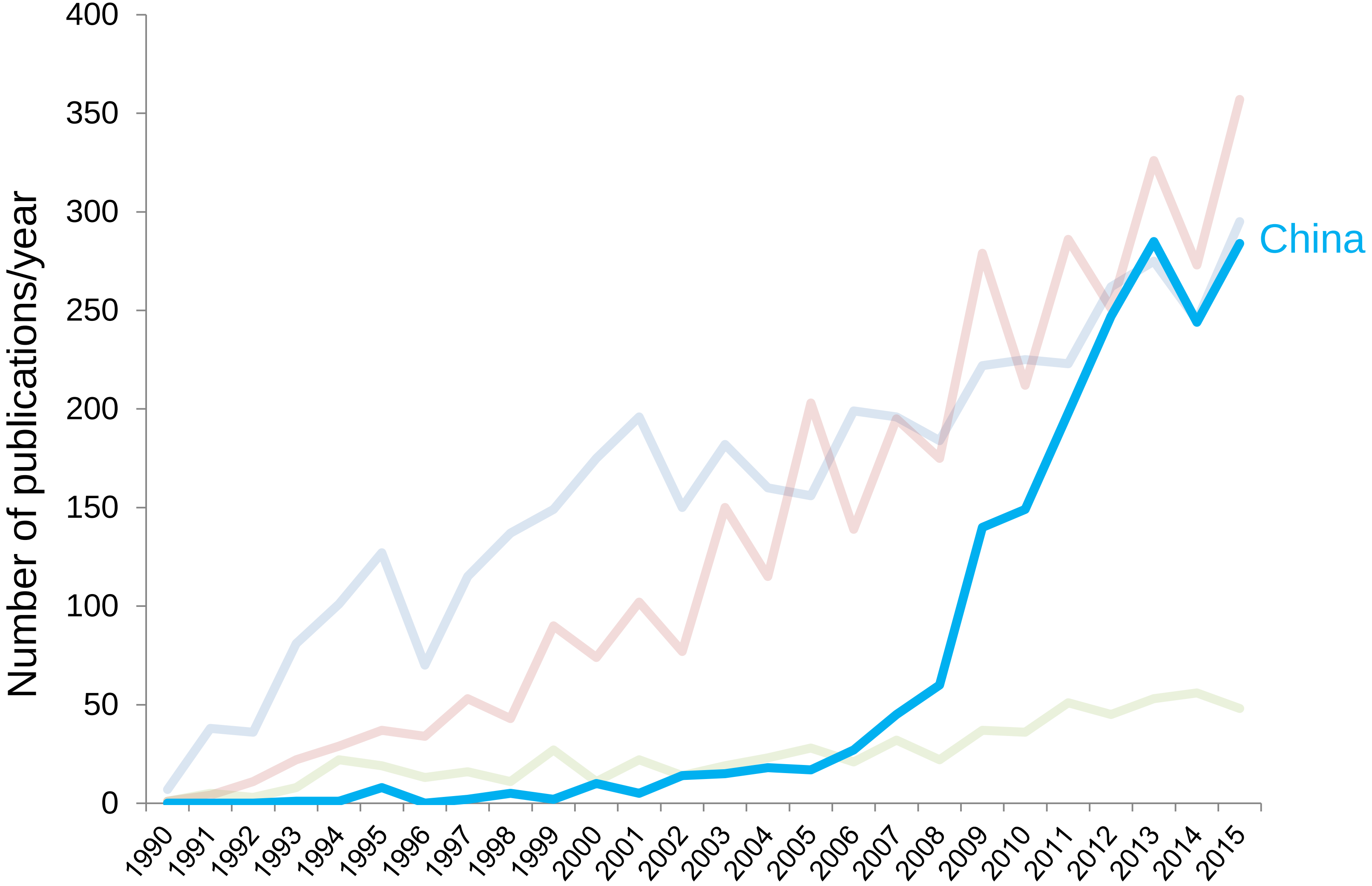

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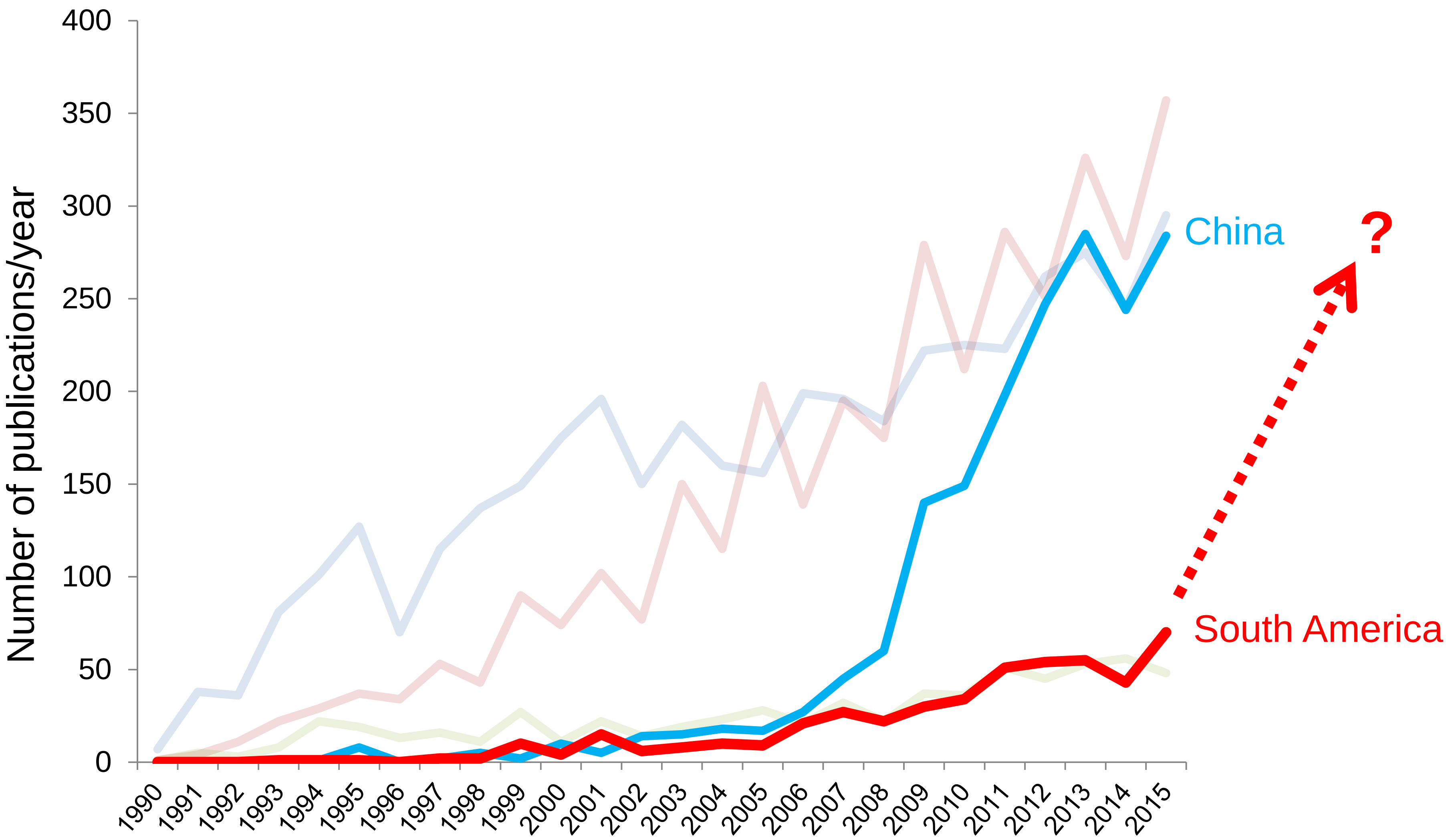

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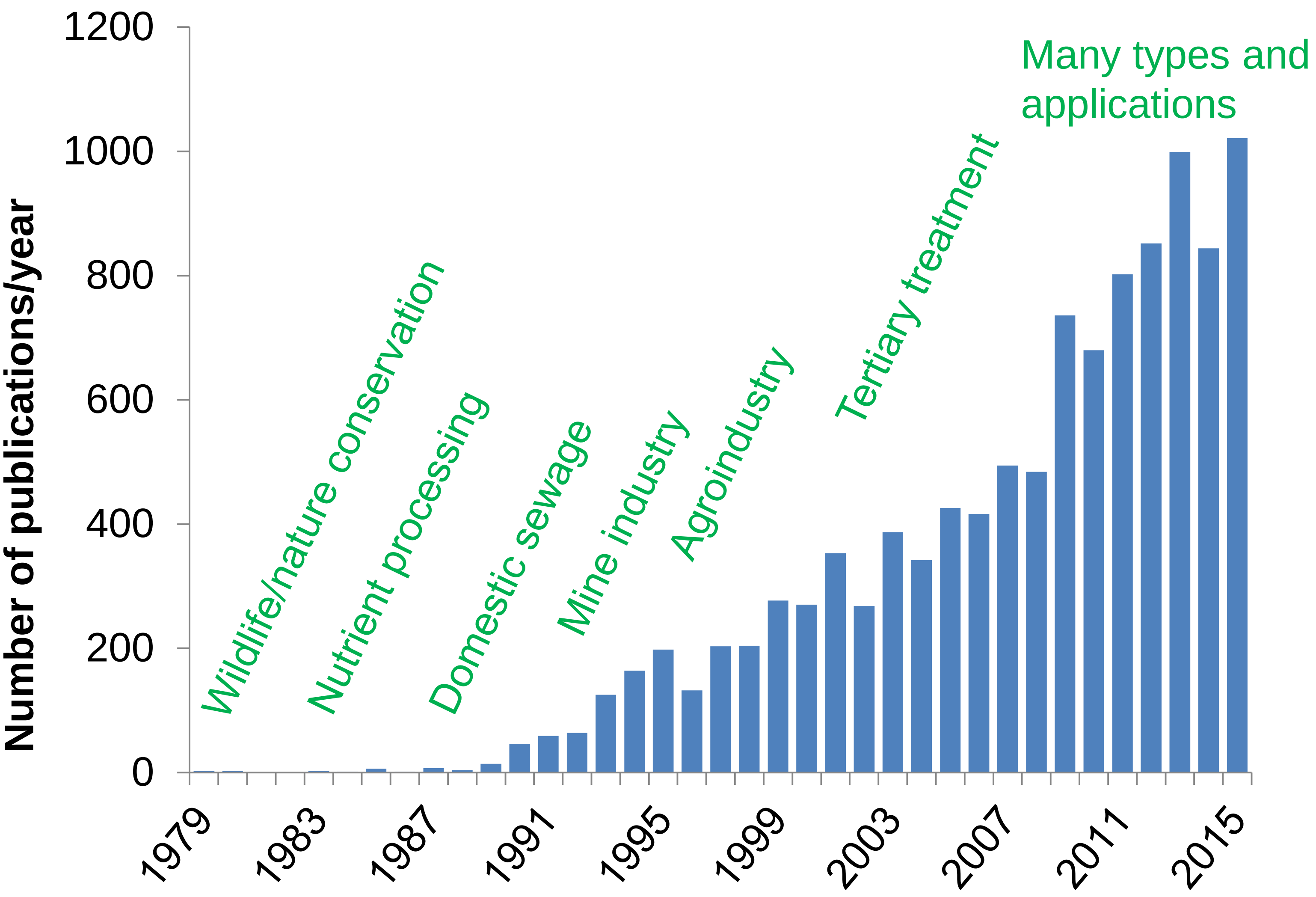

Early CW developments in North America

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Early CW developments in Europe

Early CW developments in Australia

Bron Bay; P removal from WWTP effluent

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Experiences from ‘passive’ natural systems:

- Good removal of TSS, BOD and COD (>90%)
- Fair, but varying removal of N and P (30-50%)

NO nitrification !!!

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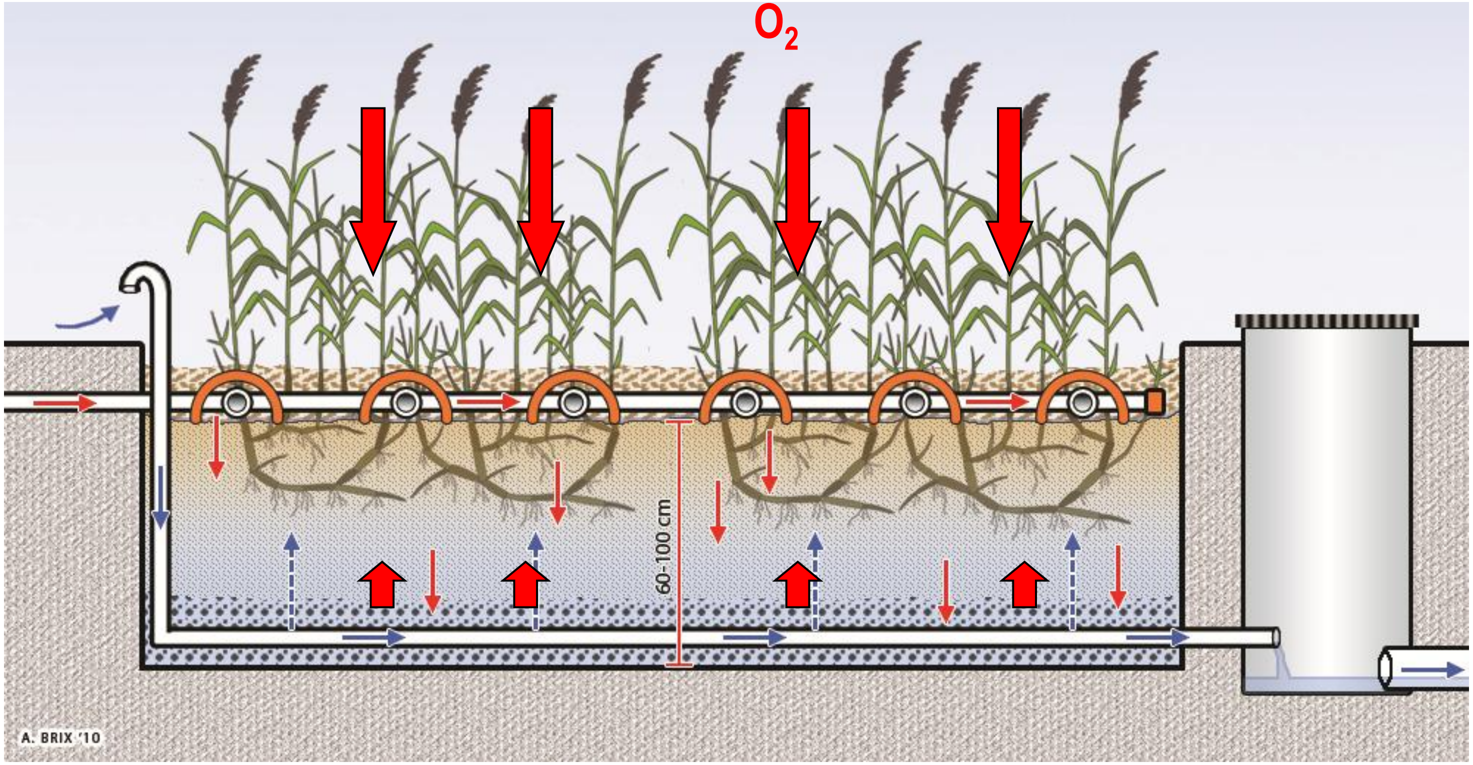
Vertical Flow systems



- Good oxygen conditions:
  - Un-saturated flow
  - Pulse-loading
  - Passive aeration from drainage pipes

Nitrification > 90%

$NH_4 \rightarrow NO_3$

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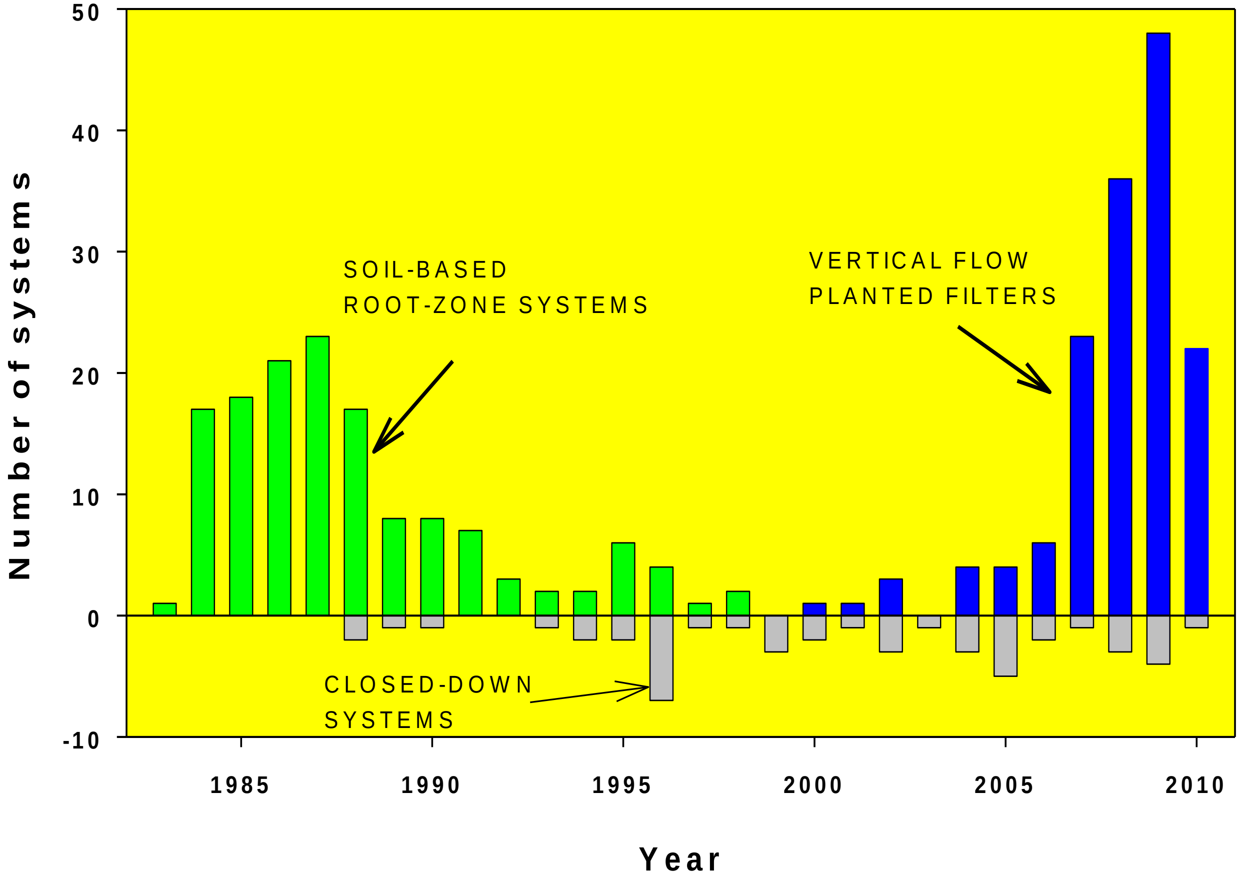
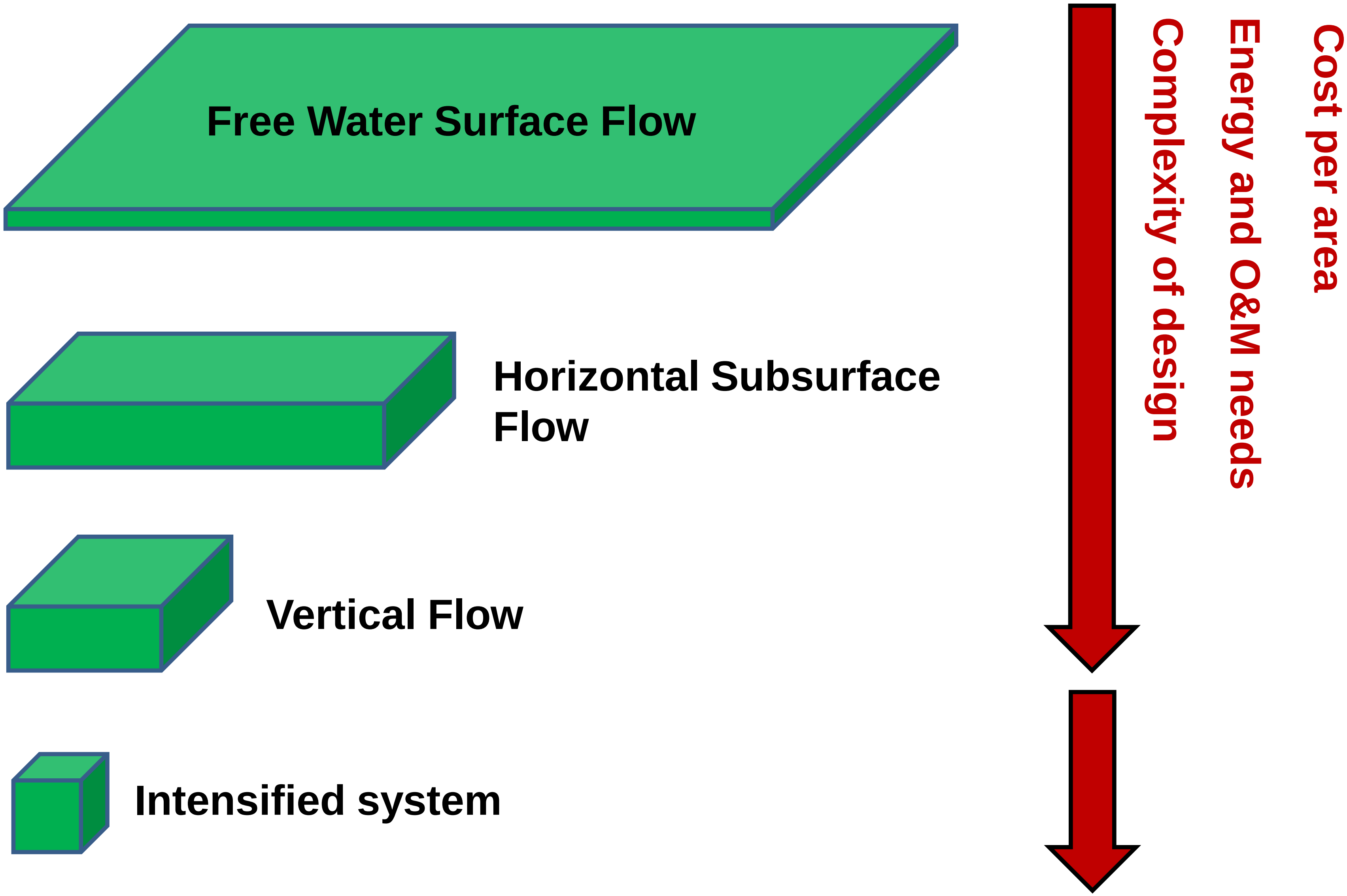
CW systems in Denmark

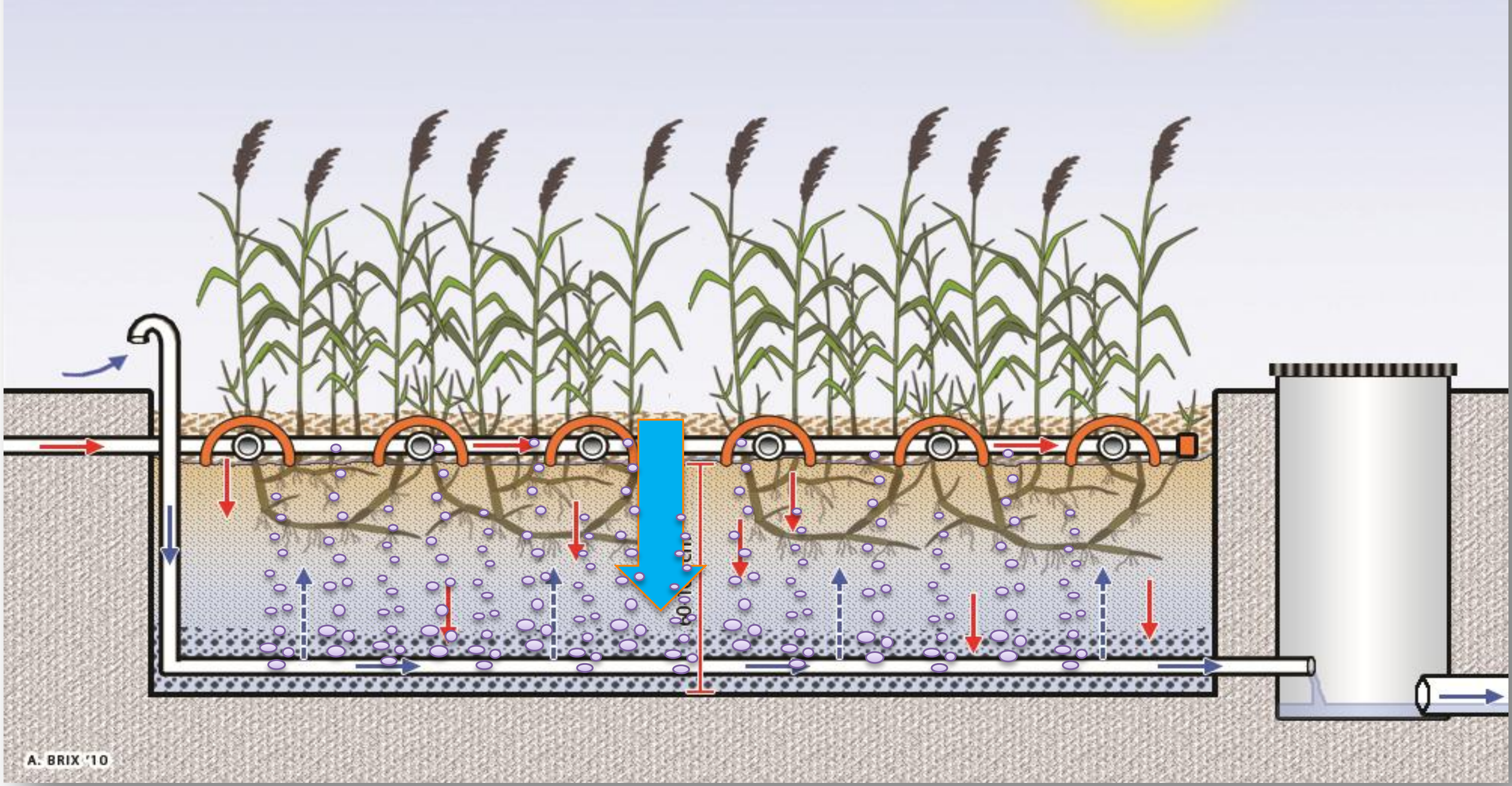


>90% removal of P
>50% removal of total-N
>90% removal of NH_4

Wetland area needed depends on the type of system:



Intensified system with forced aeration



Oxygen transfer rate up to 250 g/m^2/day
(HSSF ~5 g/m^2/day; VF ~25 g/m^2/day)

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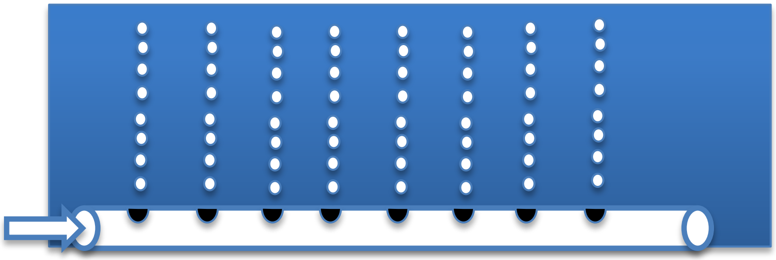
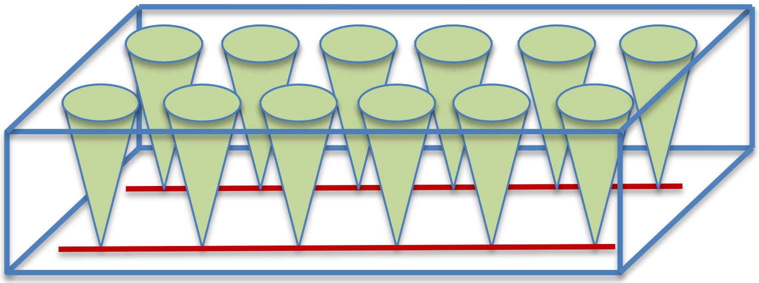
Aeration Network





- Orifice back pressure matches water depth
- Air distribution is uniform
- Blower operates at water depth pressure
- Lowest energy design

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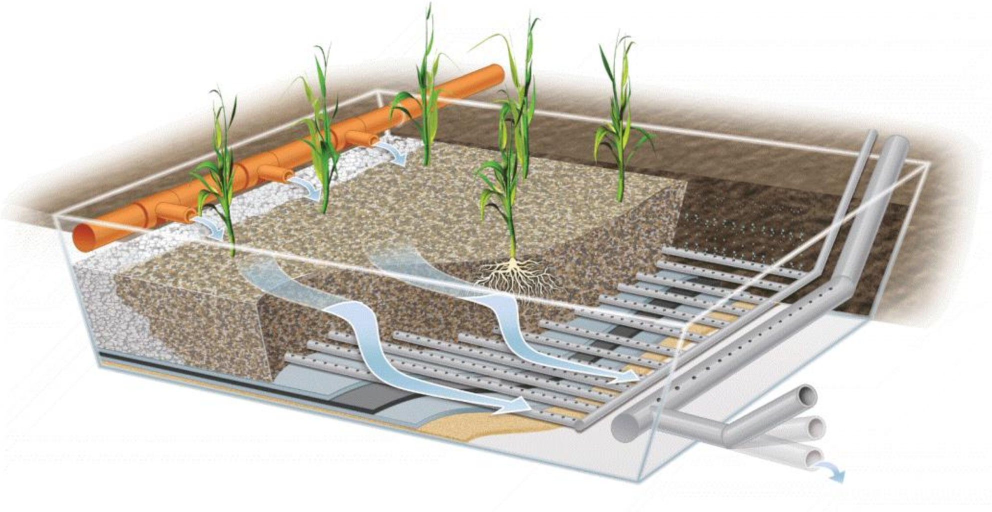
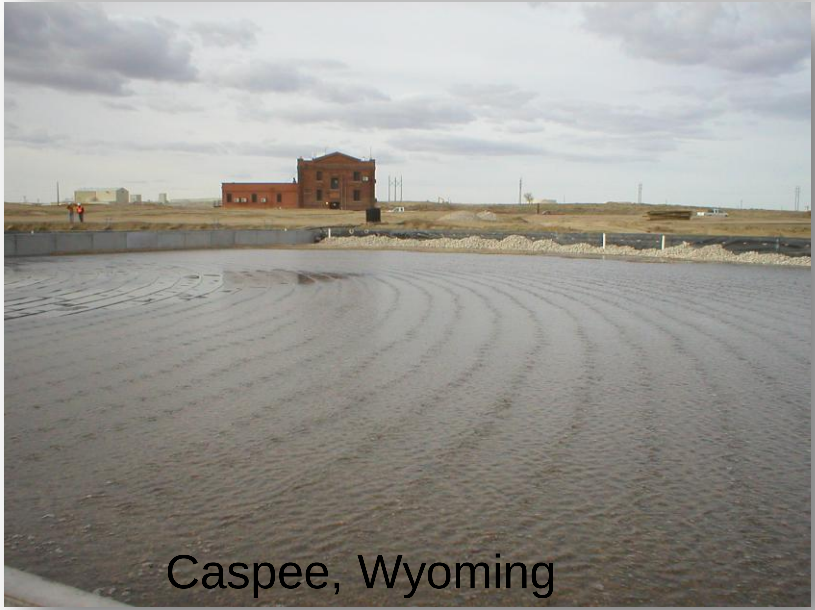
Forced Bed Aeration™



Source: Naturally Wallace (http://naturallywallace.com)

Buffalo Airport, New York



Caspee, Wyoming

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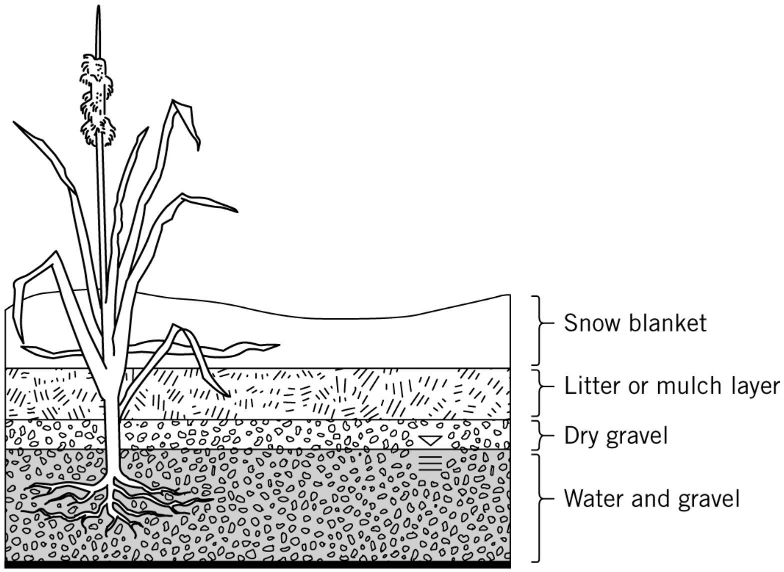
Why using systems with forced aeration?

- Limited land area; need more treatment per m^2 than passive wetland systems
- Existing system is overloaded; need to increase treatment capacity (refurbishing?)
- Change in regulatory standards (nitrification)
- High seasonal loadings
- Minimize bed clogging
- Minimize water loss through evapotranspiration (ET)

Site- and application specific CWs

Cold-Climate Wetlands



Plants, litter, snow and ice provide an insulating layer.

Mulch or compost can be designed into the system as an additional insulating layer

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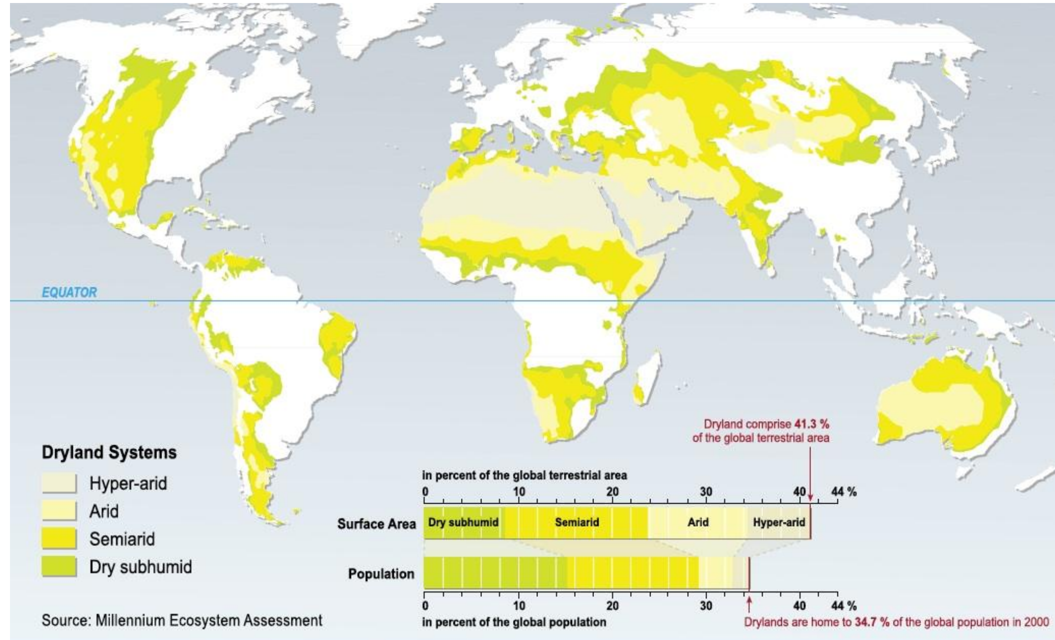
Site- and application specific CWs

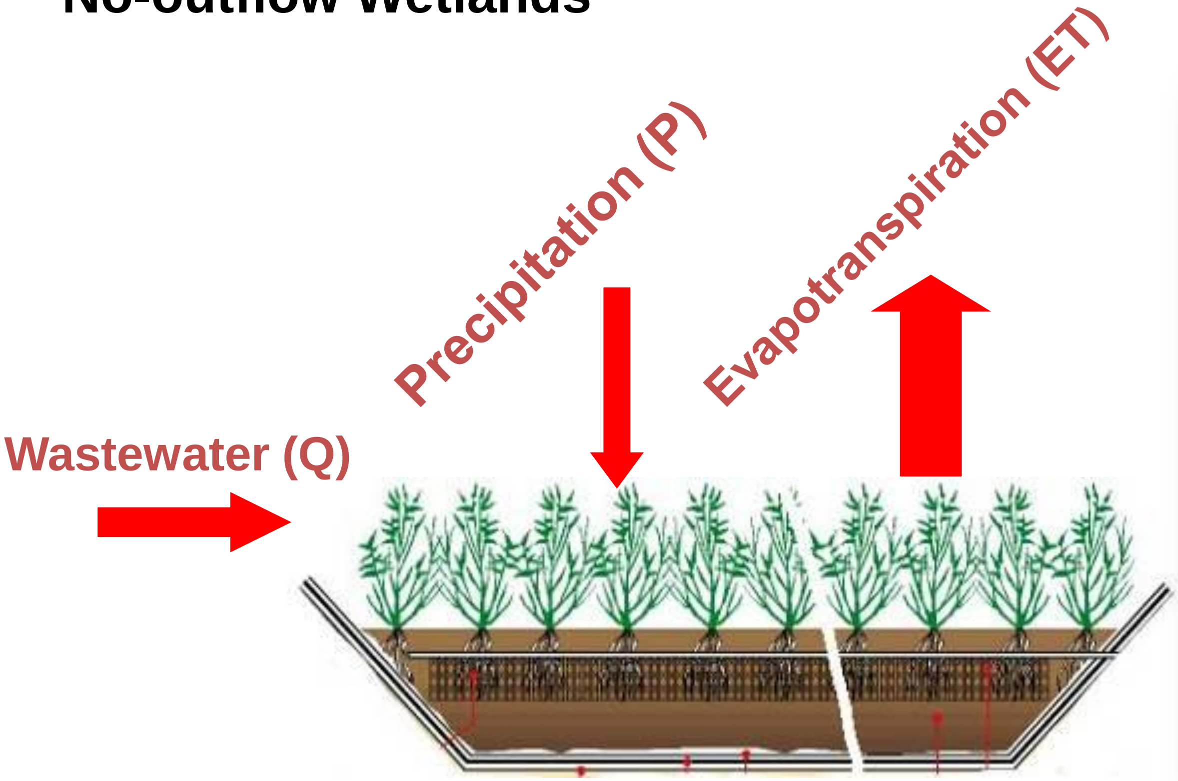
Arid-Climate Wetlands



Minimize water loss due to evapotranspiration so treated water can be used for agriculture

Site- and application specific CWs

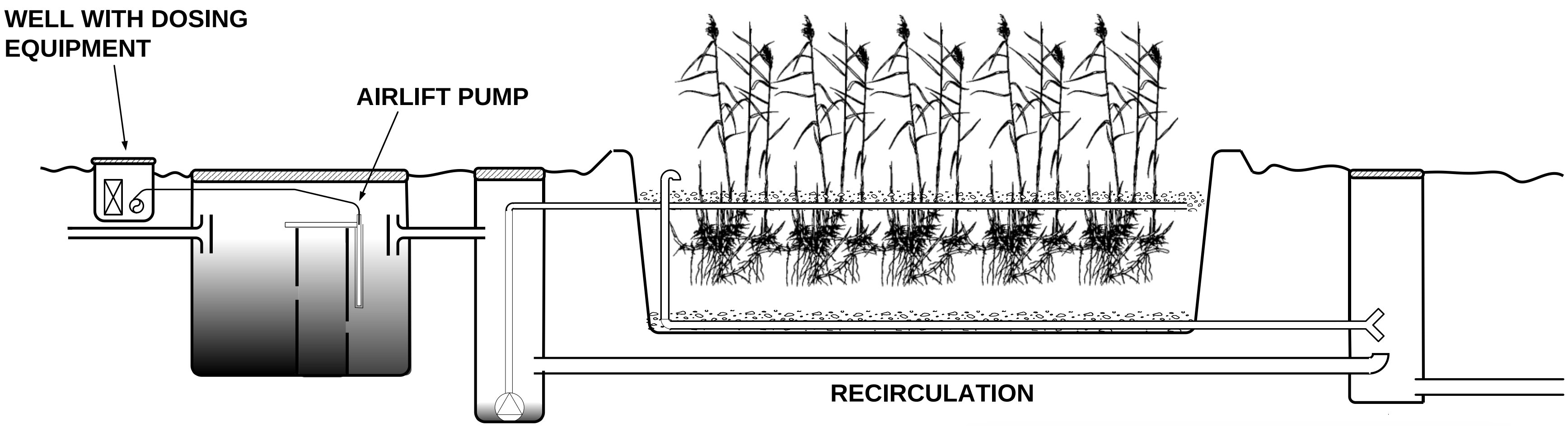
No-outflow Wetlands



All wastewater is evaporated to the atmosphere on an annual basis, i.e. there is no outflow

Site- and application specific CWs

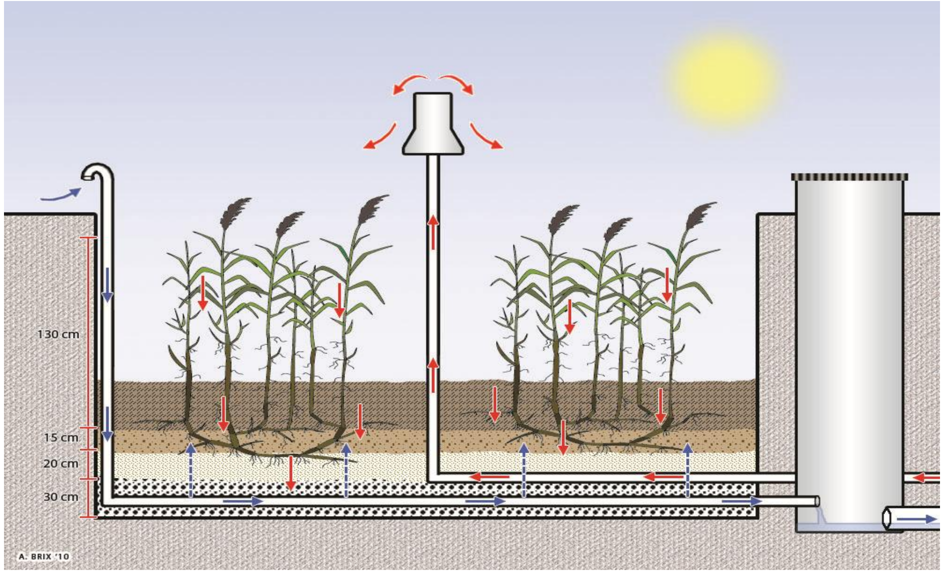
P-removal Wetlands



- **Chemical precipitation of P in the sedimentation tank**
- **Incorporation of P-binding media**

Site- and application specific CWs

Sludge Treatment Wetlands



(Photo: Steen Nielsen)

- **Effective drainage layer**
- **Ventilated drain system**
- **Graded filter and growth layer**
- **Reeds (*Phragmites australis*)**

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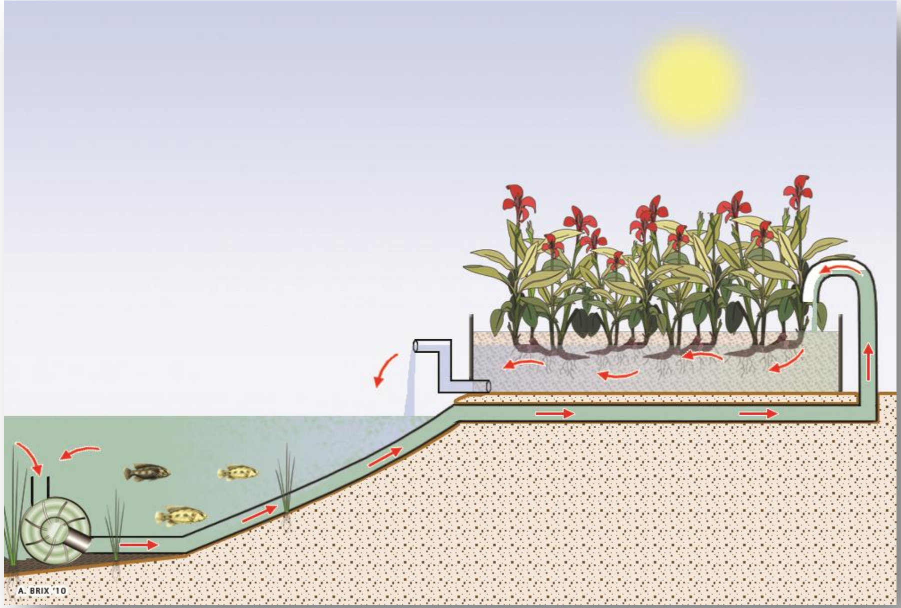
Site- and application specific CWs

Aquaculture Wetlands



Site- and application specific CWs

Aesthetic Wetlands

Use nice-looking plants; integrate into parklike environment

Site- and application specific CWs

Wildlife and Recreation Wetlands

Factors affecting choice of CW system:

- Land (availability, topography)
- Type and strength of wastewater
- Hydraulic loading (rate and fluctuation)
- Target pollutant(s)
- Effluent standards

- Site specific parameters:
  - Secondary goals
    - e.g. wildlife, aesthetics, water re-use, etc.
  - Climate
  - Seasonality
  - Economy

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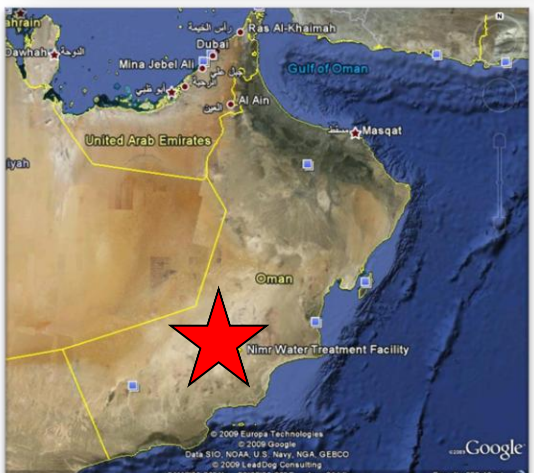
Case 1: Oil-field produced water



Water to oil ratio typically 10:1

Major concerns include:
- Salt content
- Residual oil and hydrocarbons
- Naturally occurring radio active material

Produced water historically pumped into aquifers
- Energy and cost intensive
- Groundwater contamination issues

شركة تنمية نفط عمان
Petroleum Development Oman

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Nimr Water Treatment Plant (Oman)

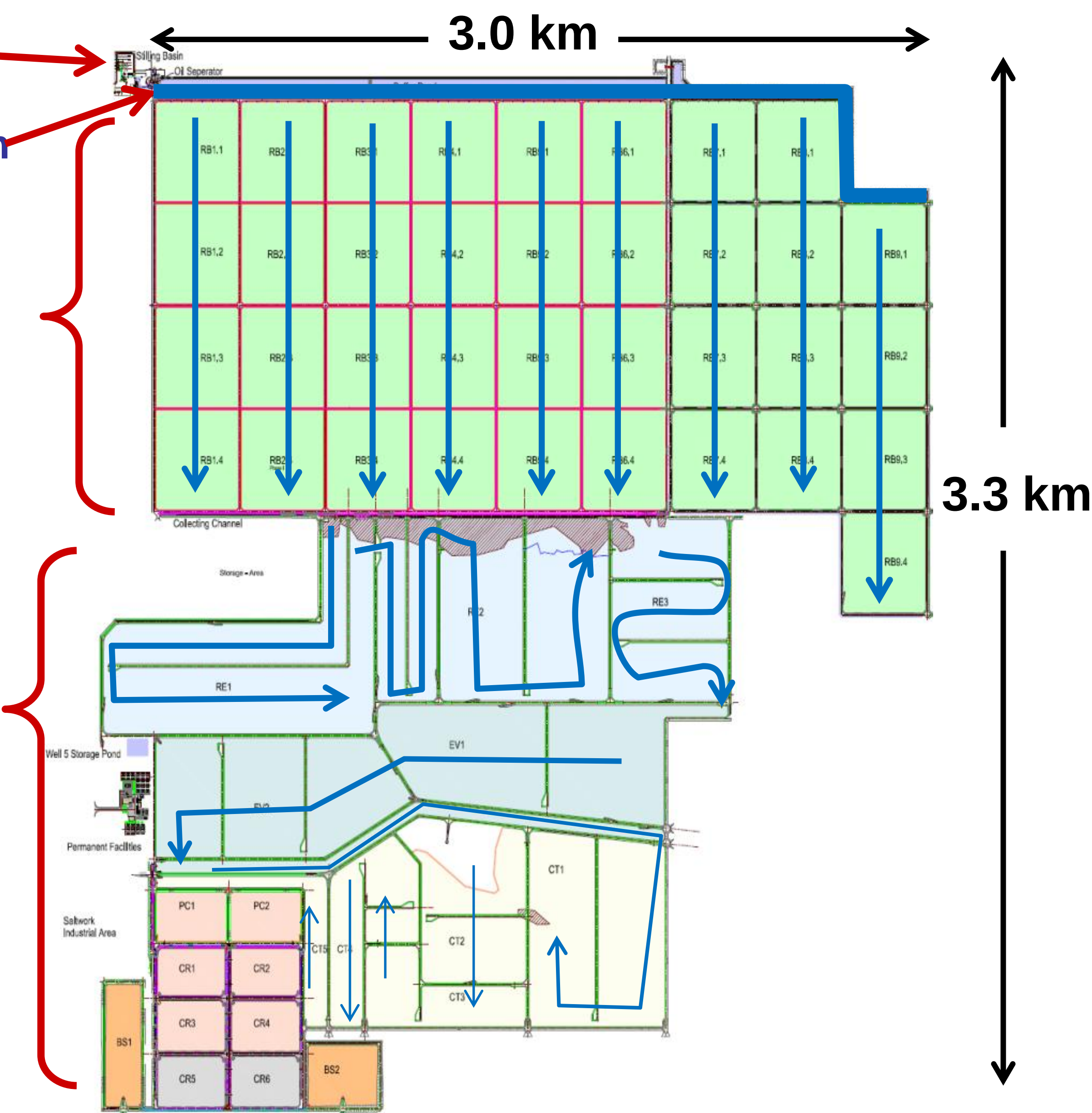
Schematic Overview of Wetland System for Produced Water

Inflow (oil separator)

Buffer pond & inlet distribution

360ha Surface flow wetlands
(hydrocarbon degradation, evapotranspiration)

350 ha Evaporation ponds & salt-works



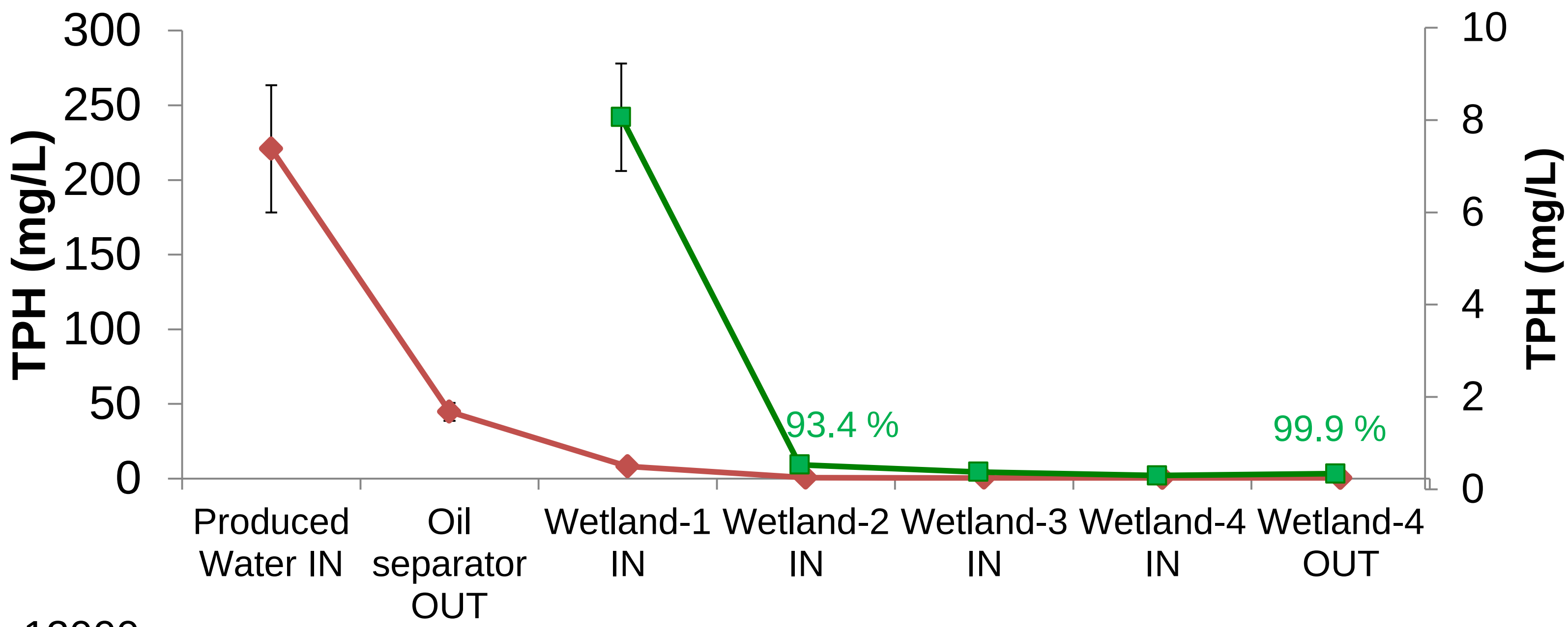
From Tom Headley

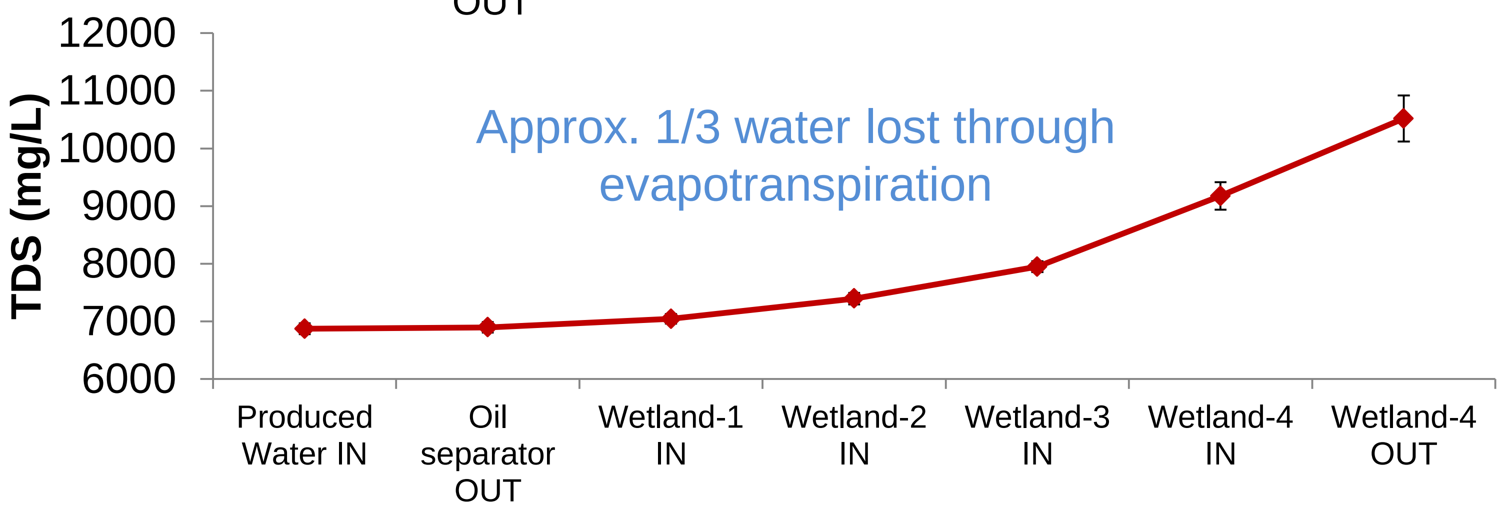
Nimr Water Treatment Plant

Photo: Tom Headley


Nimr Produced Water Treatment Plant
Inlet works to one of the 36 reed bed cells
Photo: Tom Headley

Hydrocarbon Removal (2012)





From Tom Headley

Nimr Produced Water Treatment Plant

Increased Biodiversity and Habitat – > 100 Bird Species Observed

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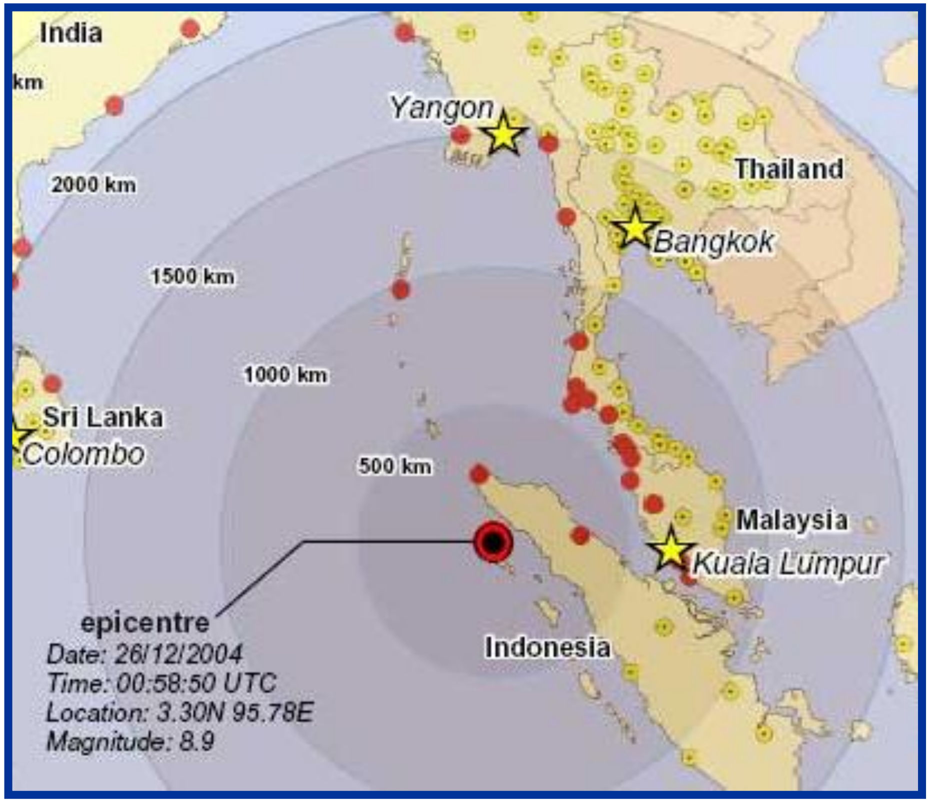
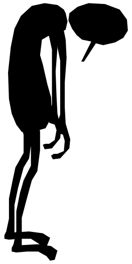
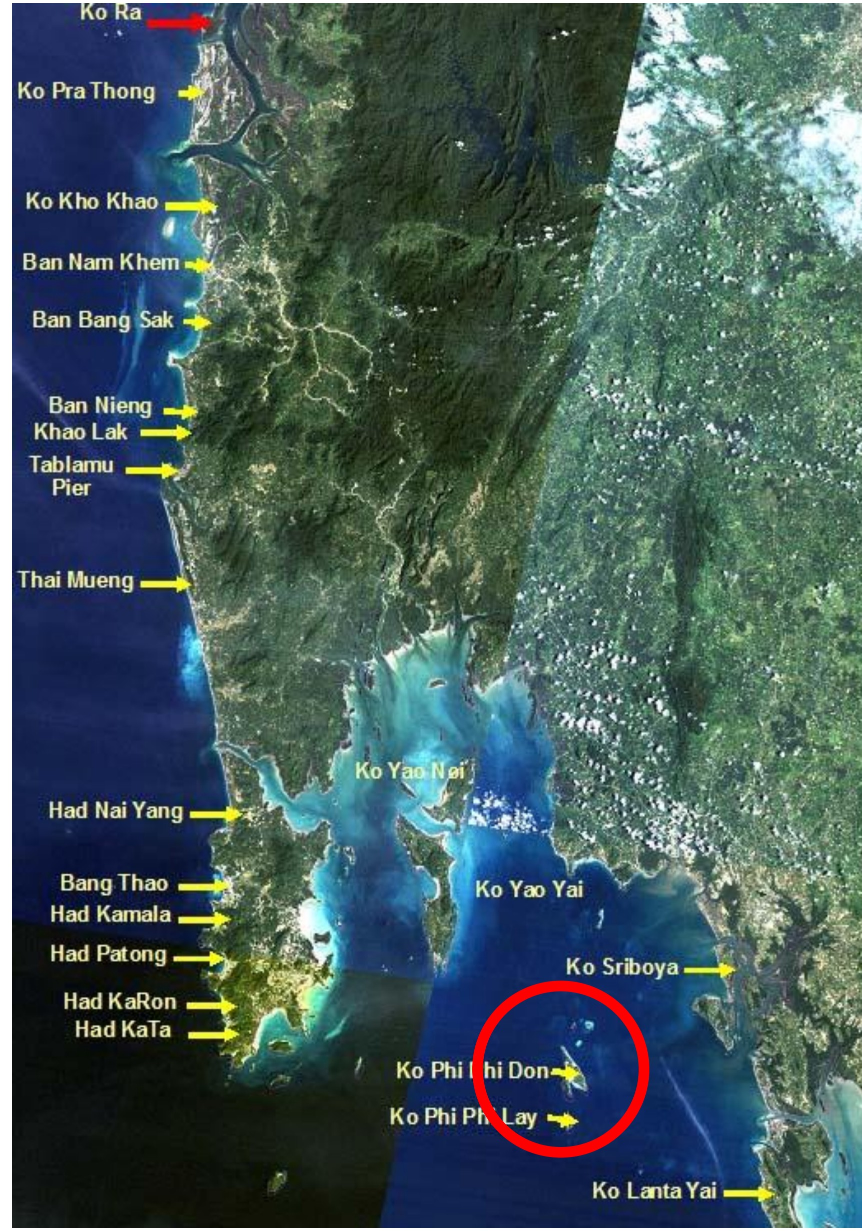
Case 2: Tsunami in South-East Asia

26th December 2004





Koh Phi Phi


Ko Ra
Ko Pra Thong
Ko Kho Khao
Ban Nam Khem
Ban Bang Sak
Ban Nieng
Khao Lak
Tablamu Pier
Thai Mueng
Ko Yao Noi
Had Nai Yang
Ko Yao Yai
Bang Thao
Had Kamala
Had Patong
Ko Sriboya
Had KaRon
Had KaTa
Ko Phi hi Don
Ko Phi Ph Lay
Ko Lanta Yai



2005.04.17

Boundary conditions

Available land: 6000 m^2

Urban integration

Island with no power line

Limited freshwater resource

- No smell
- Aesthetics
- Low-technology
- Low energy requirements
- Re-use of water


Constructed Wetland
Reclaimed water
Pumping Station
Wastewater Collection System

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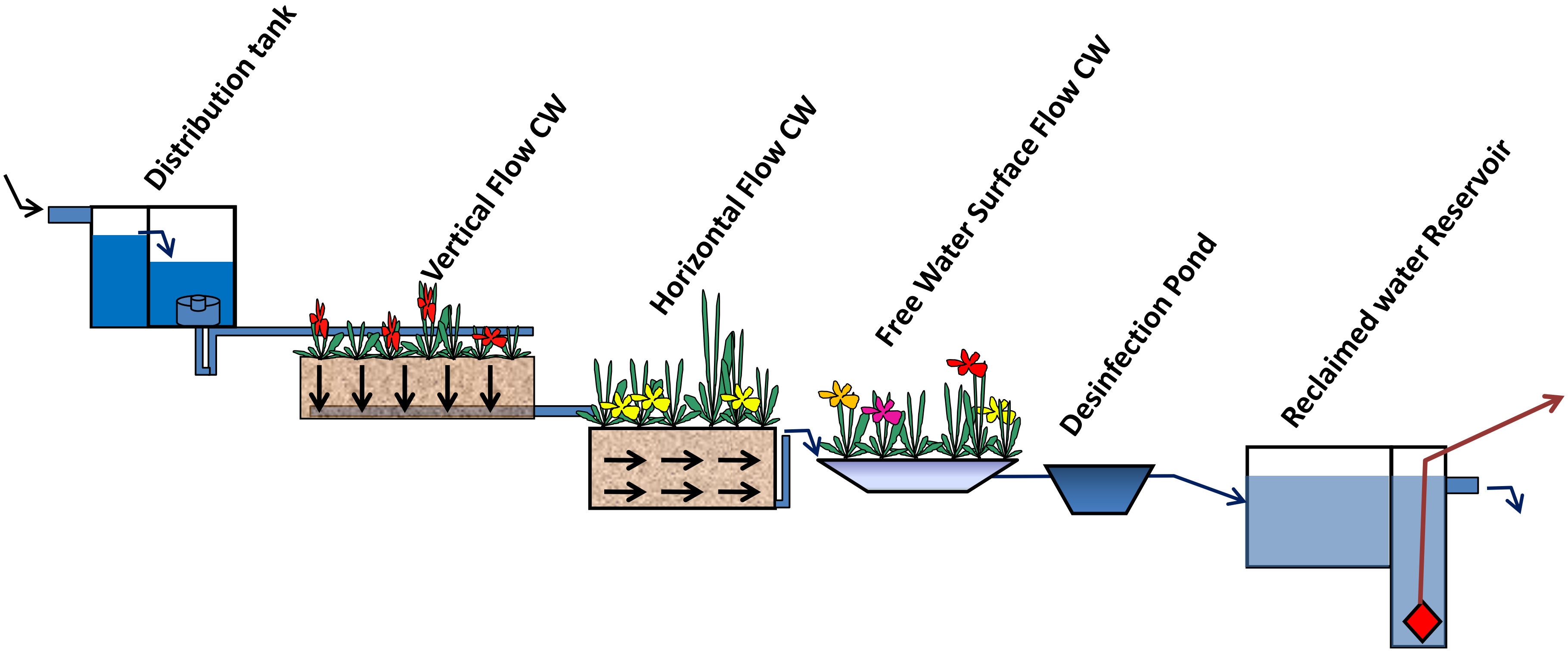
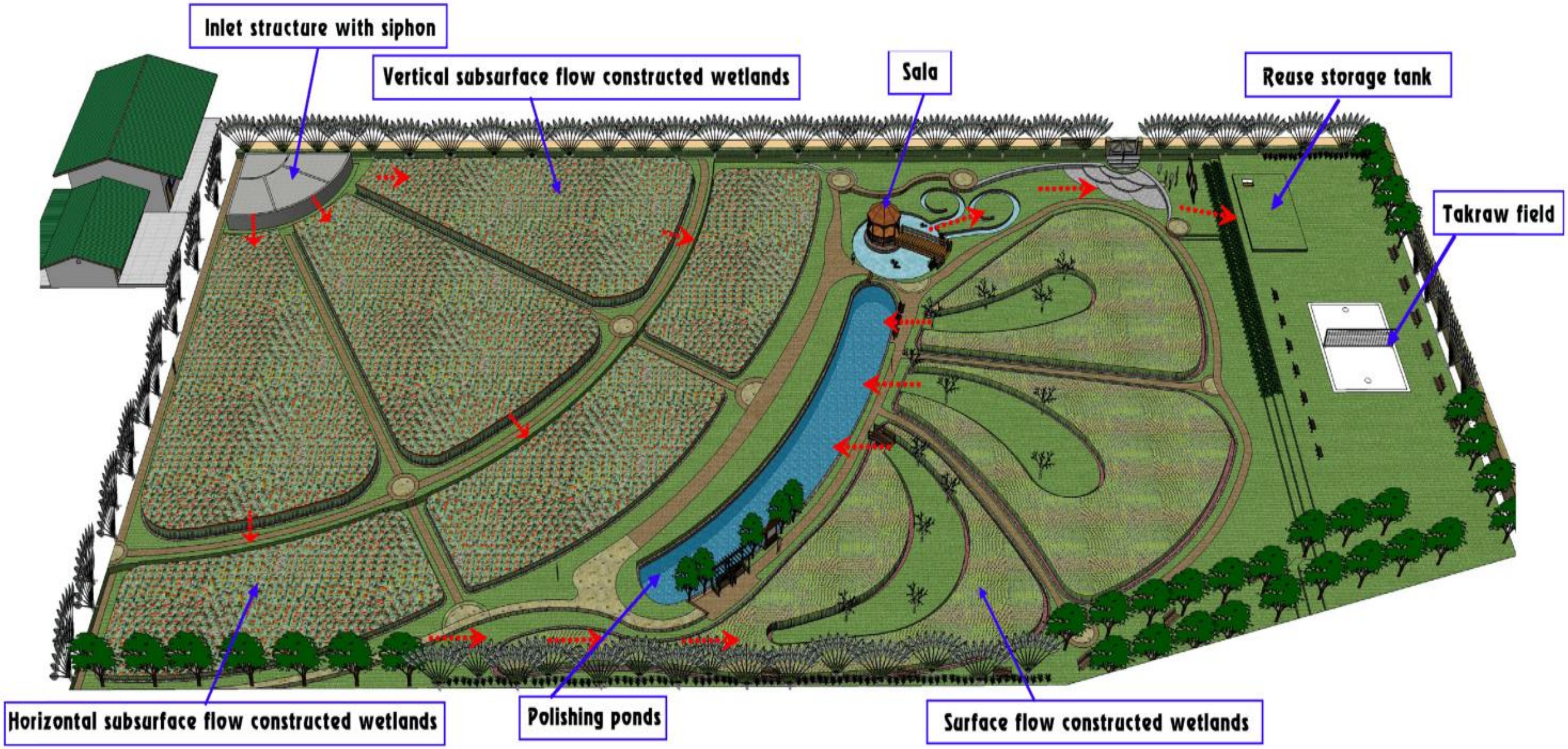
Design: 3 parallel lines



Final design: The Flower and the Butterfly

Capacity: 400 m^3/day; mixed black and grey water

Total Area: 6000 m^2; VF Area: 2300 m^2; HF/SF Area 1500 m^2; Pond Area 200 m^2




Final design:
The Flower and the Butterfly

Pumpstation powered by solar panels

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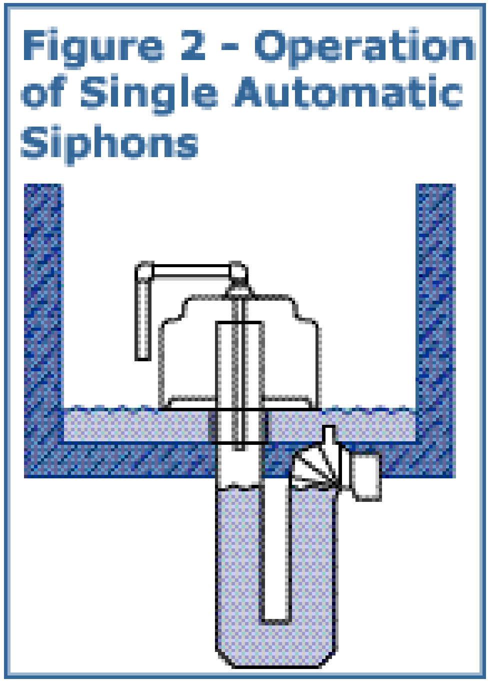
Dosing of VF beds by Siphons

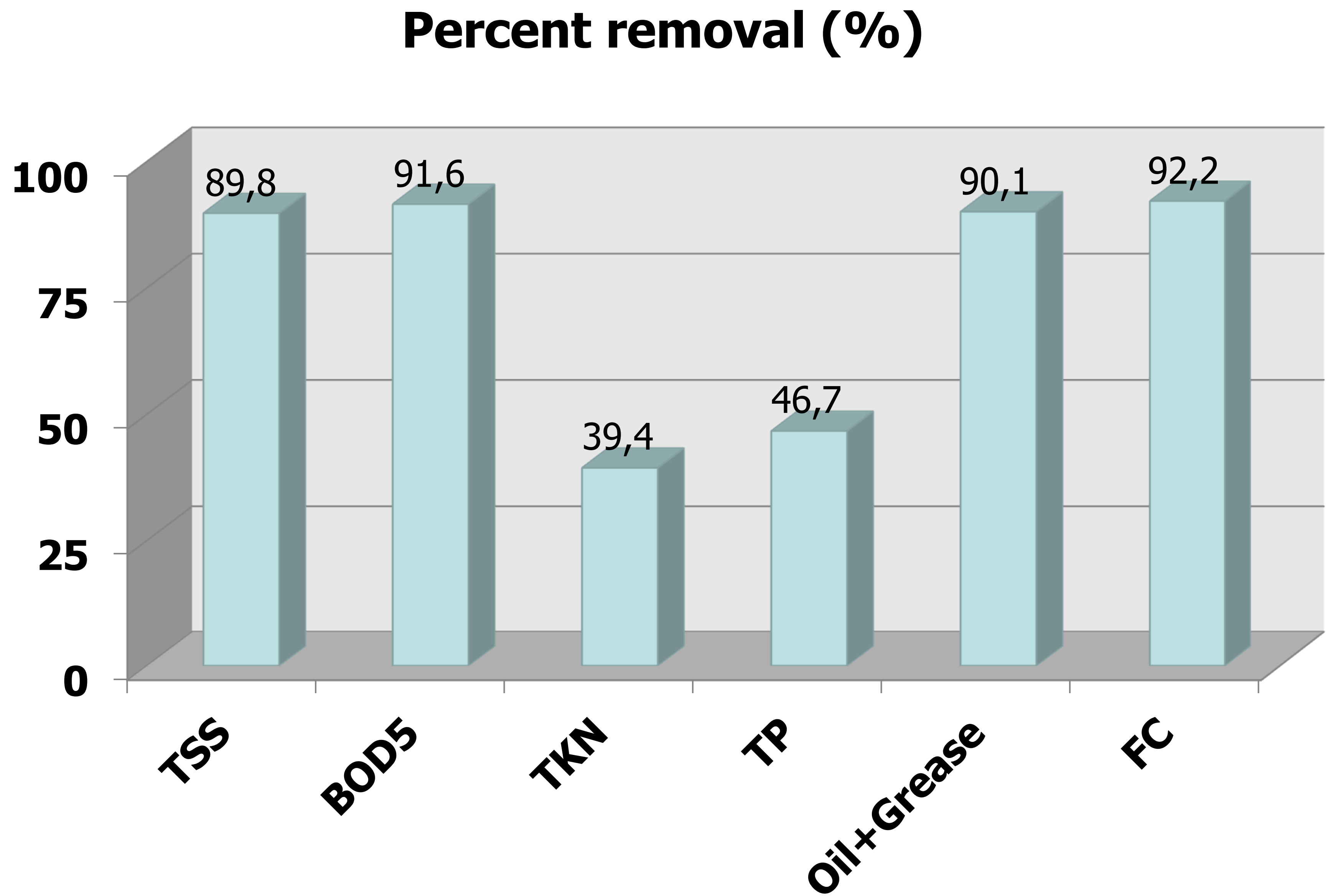



2006. 10. 13


2006. 10. 13


2006. 10. 15


2006. 10. 14

Percent removal (%)
100
75
50
25
0
89,8
91,6
39,4
46,7
90,1
92,2
TSS
BOD5
TKN
TP
Oil+Grease
FC

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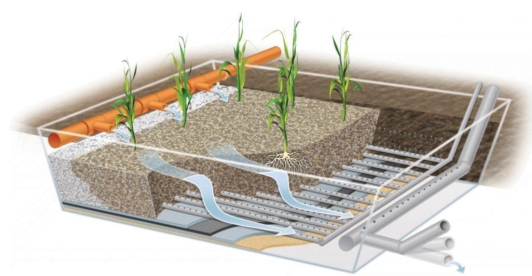
Passive versus intensified systems

LEAST — Energy and O&M Needs → MOST

FWS HSSF	French systems	VF	HF + aeration	VF + aeration	Fill & Drain

MOST ← Area Requirements — LEAST



Thank you for your attention!