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Alum sludge: From "waste" to valuable raw material

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How Bad is the Water Problem?

- 1/3 of the world's population lives in water-stressed countries (UNEP)

- By 2025, it is expected to increase to 5 billion (UNEP)

- Nearly 1/3 of the world's land surface may be risk of extreme drought by 2100 (Burke et al. 2006)

REUSE
REDUCE
RECYCLE

Engineered Wetland substrate/media

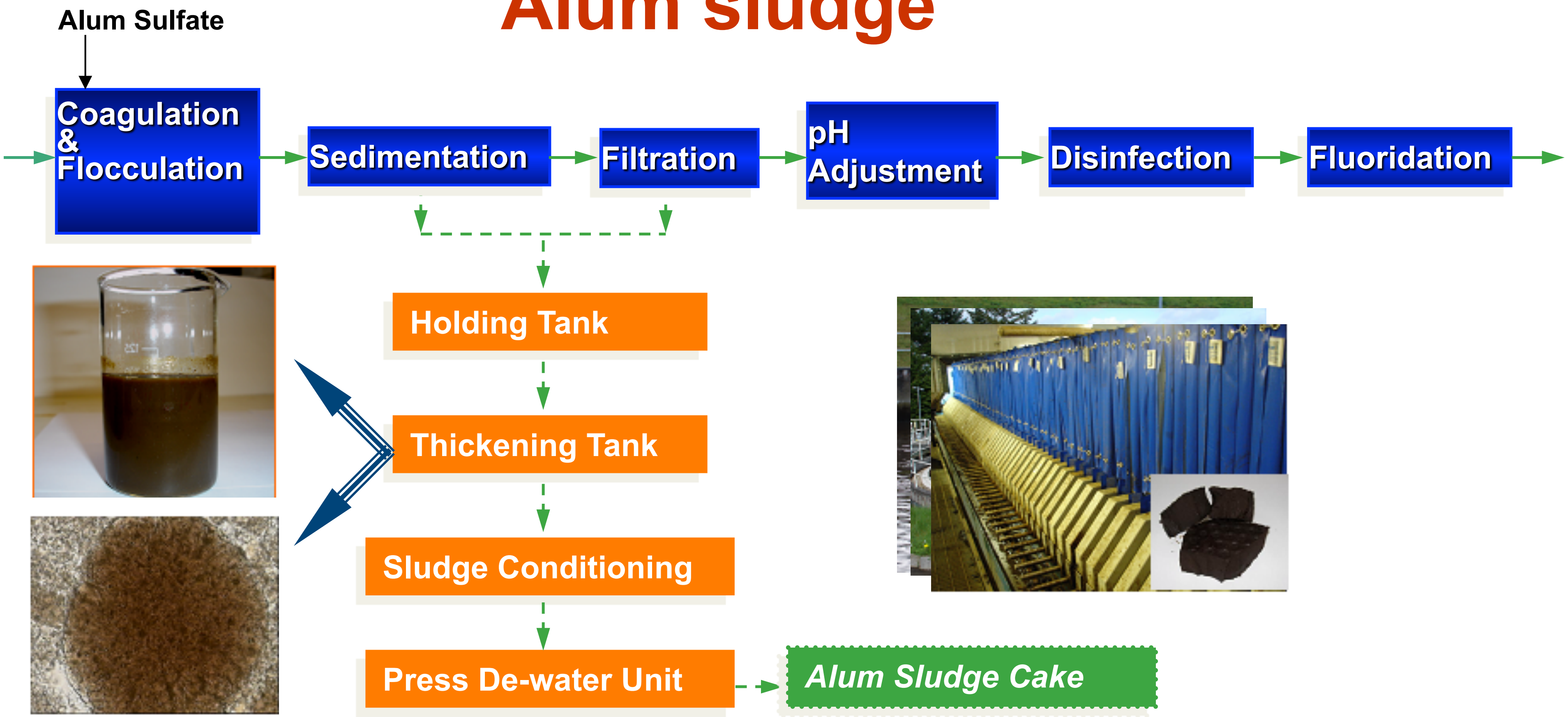
Shale

LECA

Laterite

Dewatered alum sludge cakes

Alum sludge



Water and sludge treatment process (Ballymore Eustace, Ireland)

Alum Sludge

Excellent P adsorption ability

Capacity:0.975-6.050 mg-P/g-sludge at pH 7, depending on the particle size and P species(*Y. Zhao et al,* 2007)

Mechanism: Ligand Exchange(*Y. Yang et al*, 2006)

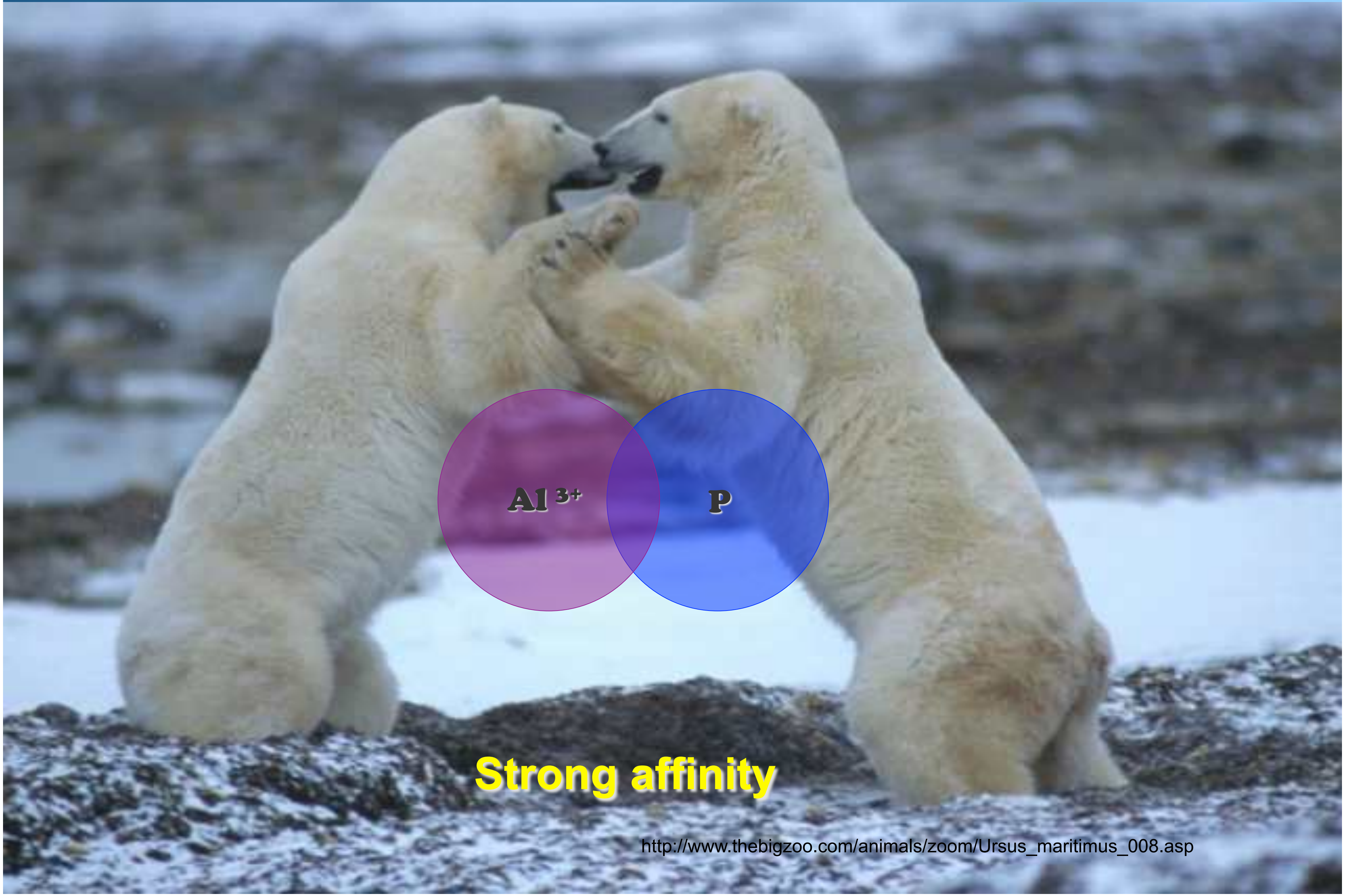
Alum-Sludge

Reuse!

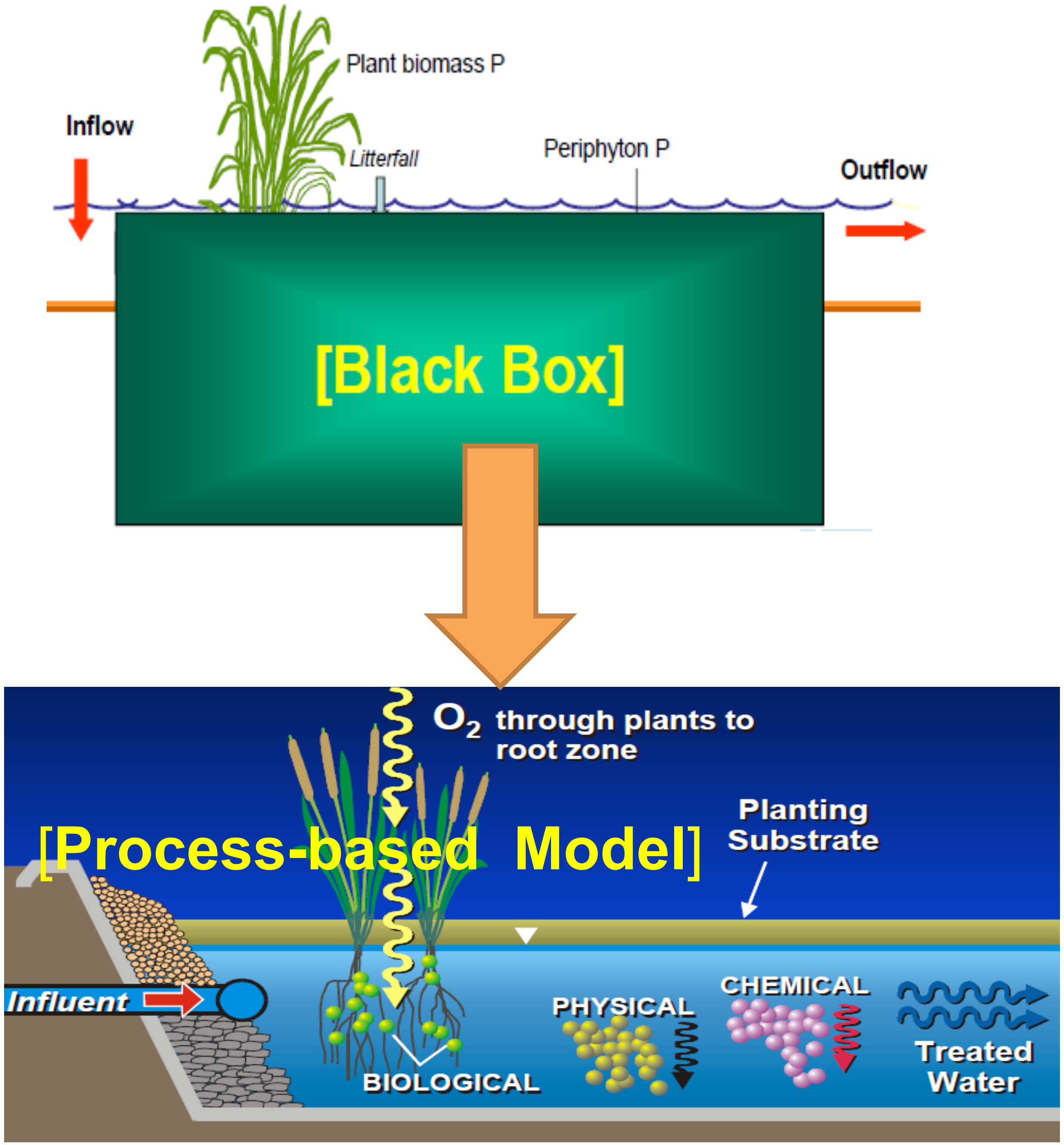
Characteristics of Alum Sludge: Chemical Composition

	Unit	Average	±SD, n=3
pH	–	6.14	0.01
Water content	% (at 103±2 °C)	95.21	0.09
Aluminum: 170 mg-Al/g-sludge			
Iron	mg-Fe/g-sludge	5.2	0.13
Calcium	mg-Ca/g-sludge	5.18	0.18
Magnesium	mg-Mg/g-sludge	1.59	0.05
Humic acid	mg-C/g-sludge	118.4	3.47
Silicon	mg-Si/g-sludge	6.79	0.48

Alum sludge & Phosphorus



Engineered wetland system



Kathe Seidal

Dr. Seidel was not only the pioneer of Reed Bed technology, but one of the principal pioneers of all other systems that use aquatic vegetation.

R.Kadlec

"………We have a solid foundation of empirical understanding, but to advance our knowledge, we need to understand the internal processes that lead to the observed performance"

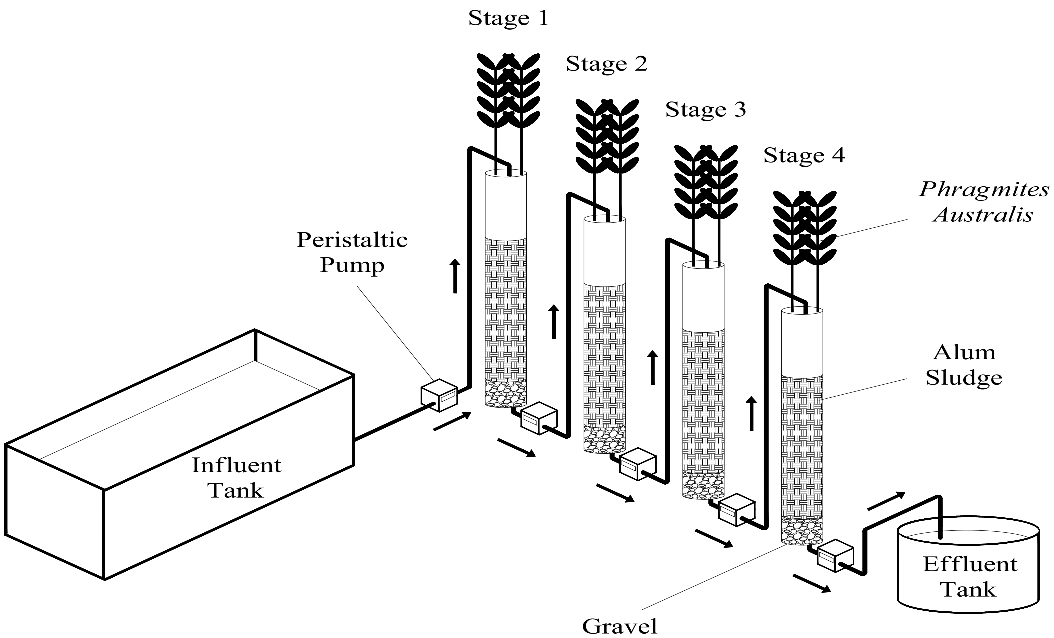
Sven Erick Jorgenson

" The application of models in ecology is almost compulsory, if you want to understand the function of such a complex system as an ecosystem……"

Objectives & Experimental Set-up

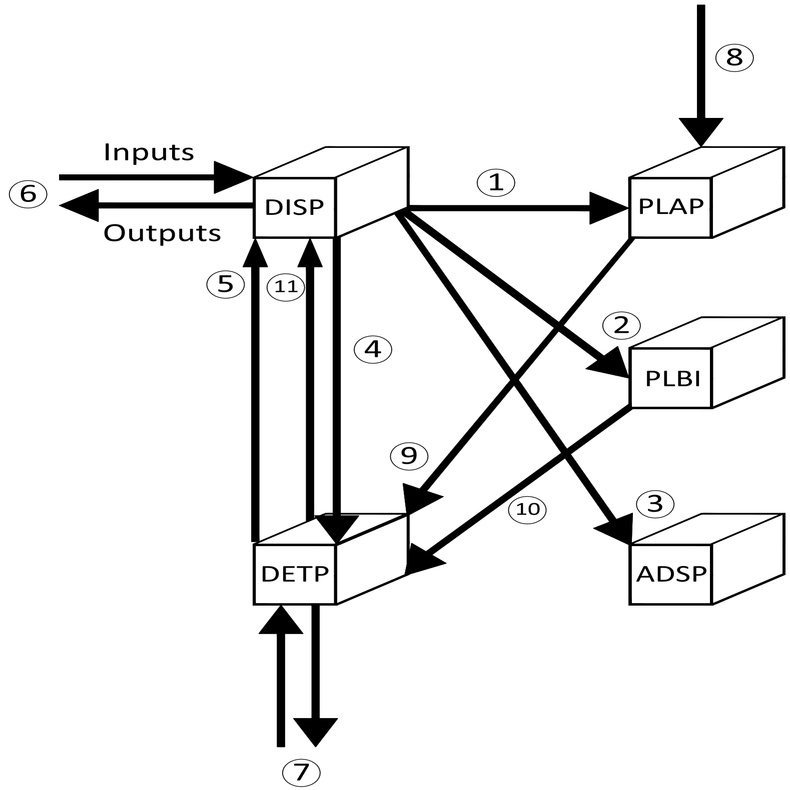
- ❖ Develop a dynamic simulation model for P and N removal from a newly developed VFCW, which uses dewatered alum sludge as main substrate

- ❖ To determine the major pathway for P and N removal



Schematic view of the laboratory scale 4-stage DASC-based CWs system

Methodology

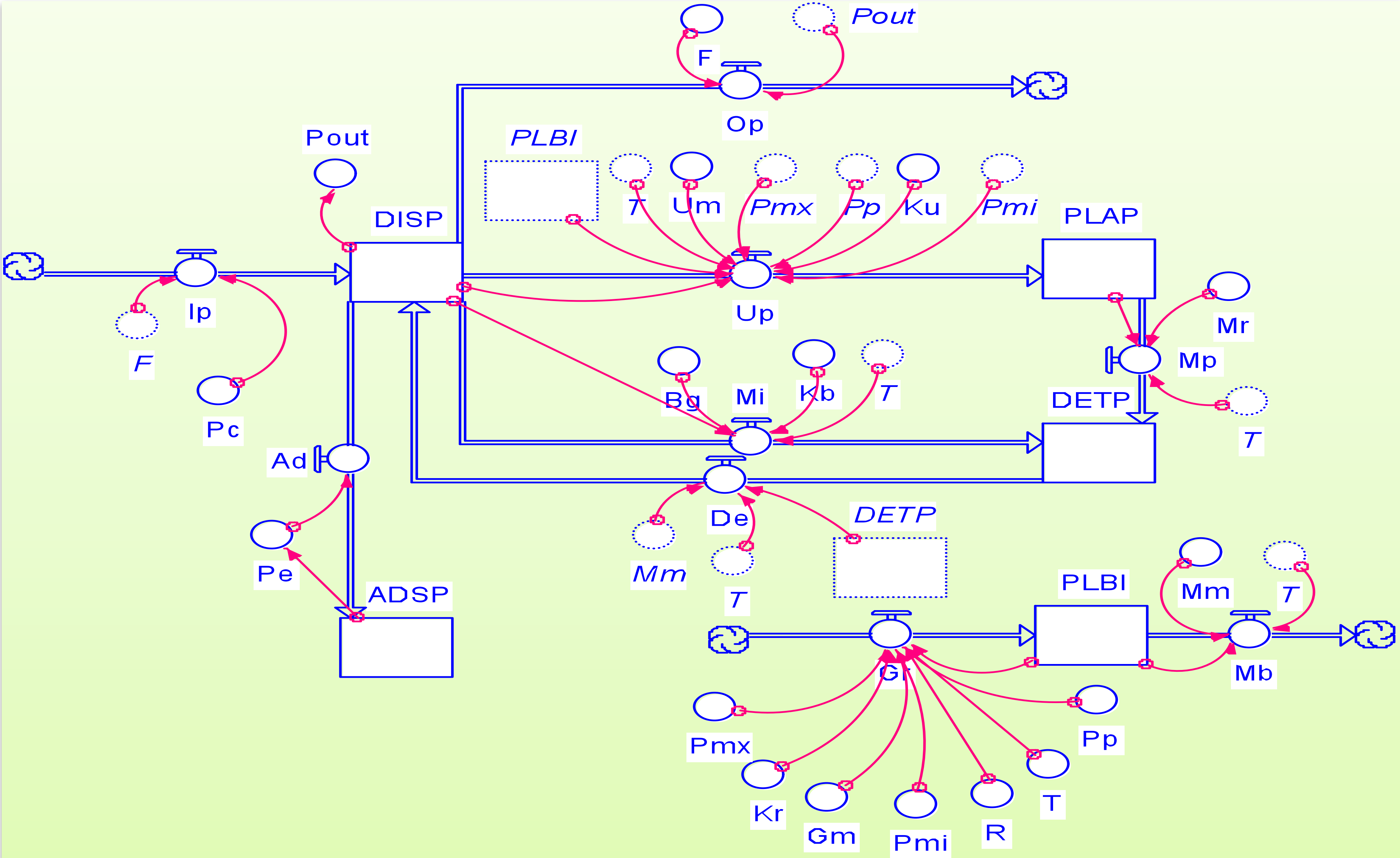


1.Growth of plant biomass
2. Adsorption of P in DASC
3. Microbial 4.Uptake/ consumption
5. Mineralization
6,7.Input P/Output P
8 Solar Radiation
9,10 Mortalities
11 Settling of Detritus

Conceptual model for the P removal in DASC-based CWs

STELLA is a flexible computer modelling package with an easy, intuitive interface that allows users to construct dynamic models that realistically simulate biological systems

Methodology

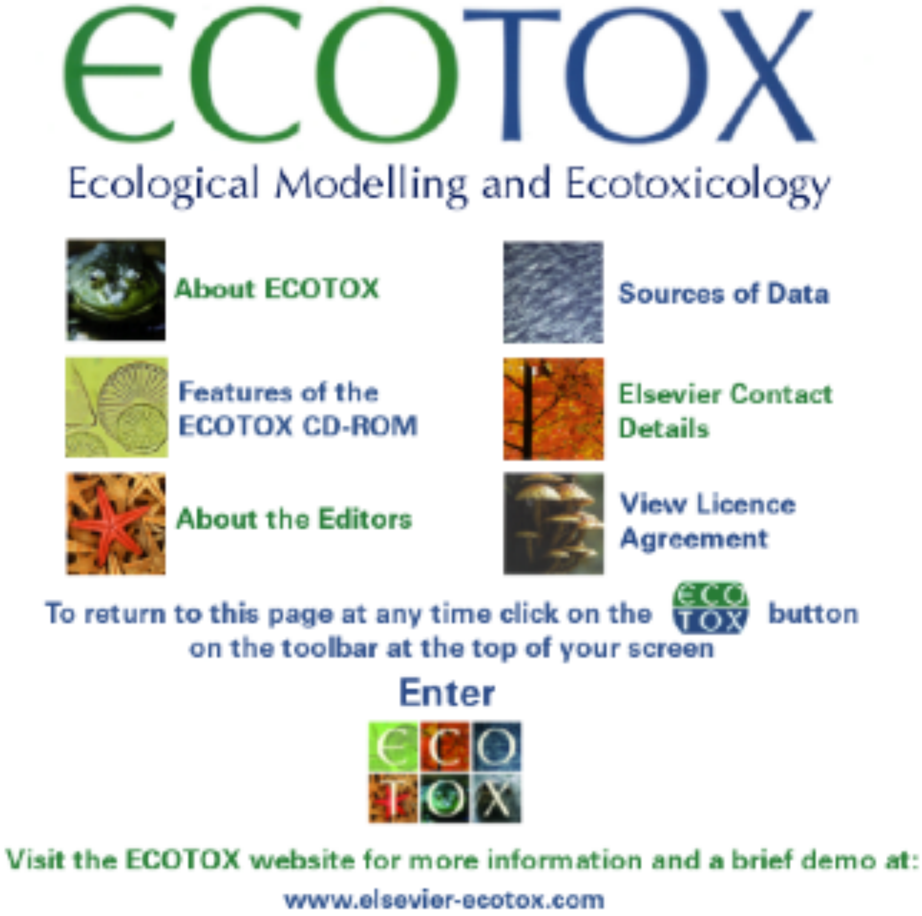


A STELLA diagram of the Phosphorus model

Methodology

Processes	Mathematical Equations
Adsorption (Ad) :	$Ad = F_a\,(DISP - P_e \times V)\,;\,P_e = \left(\dfrac{ADSP}{T_A \times K_F}\right)^n$
Growth (Gr) :	$Gr = \dfrac{G_m \times PLBI \times R_a \times (P_p - P_{\min}) \times 1.05^{(T-20)}}{(R_a + K_r) \times (P_{\max} - P_{\min})}$
Uptake (Up):	$Up = \dfrac{U_{\max} \times PLBI \times (P_{\max} - P_p) \times DISP \times 1.05^{(T-20)}}{(DISP + K_u) \times (P_{\max} - P_{\min})}$
Microbes (Mi)	$Mi = \dfrac{Bg \times DISP \times 1.05^{(T-20)}}{DISP + K_b}$
Plant Mortality (Mp)	$Mp = PLAP \times M_r \times 1.07^{(T-20)}$
Biomass Mortality (Mb)	$Mb = PLBI \times M_r \times 1.07^{(T-20)}$
Detritus (De)	$De = DETP \times M_{\max} \times 1.07^{(T-20)}$

Methodology

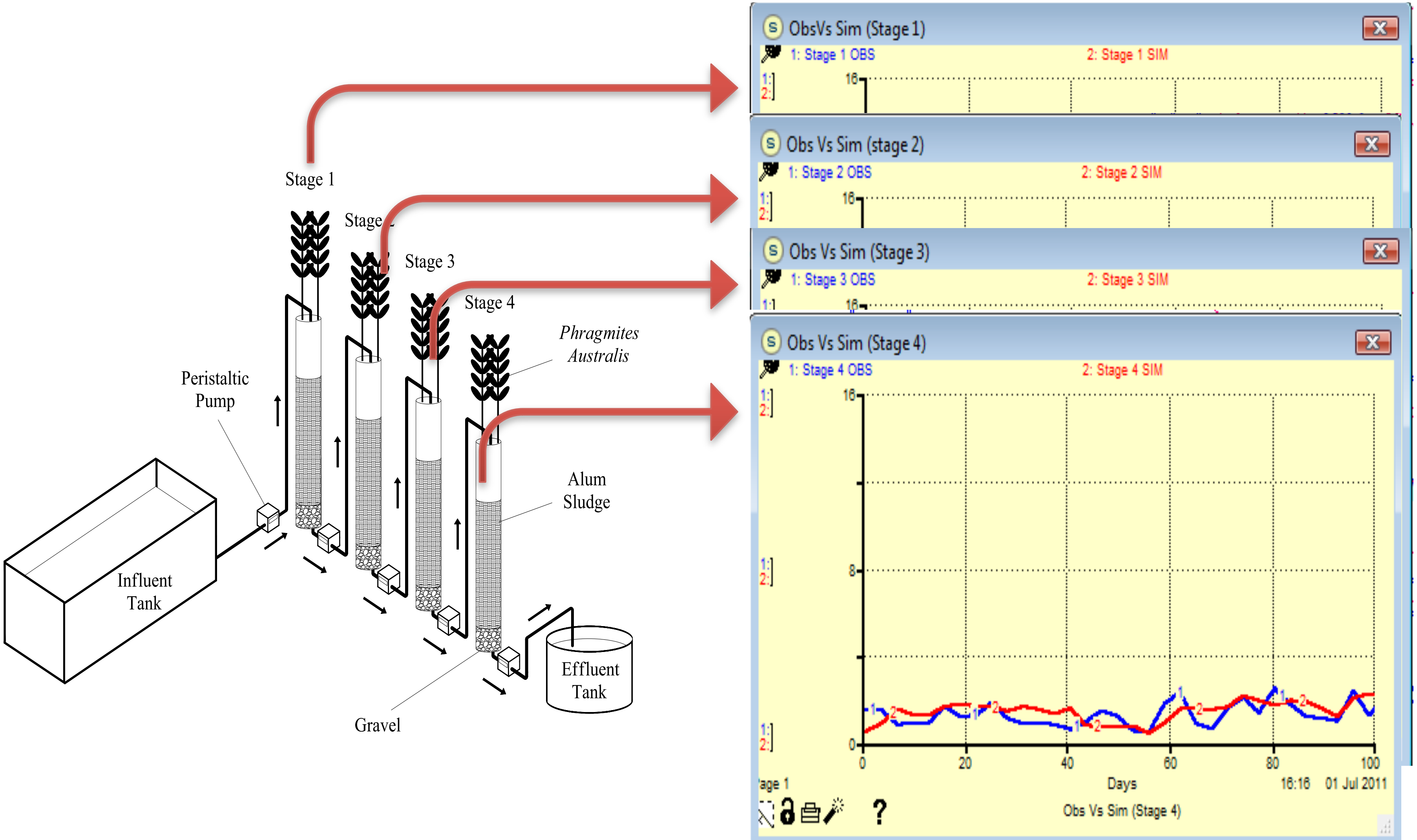


Results

Observed and Simulated P concentration (mg/l) for the DASC based CWs

CW stages	Mean and Standard Deviation (Observed)	Mean and Standard Deviation (simulated)
Stage 1	5.754±1.07	6.528±2.28
Stage 2	3.441±0.65	3.808±1.22
Stage 3	2.130±0.56	2.320±0.78
Stage 4	1.314±0.46	1.454±0.46

Results



Comparison of Observed P conc.(mg/l) and Simulated P conc. (mg/l)

Results

Mass balance analysis of P processes in all stages of DASC-CWs

CW Stages	P Adsorption (%)	Plant uptake (%)	Microbial uptake (%)
1	62-71	6-11	3-7
2	55-69	8-14	3-6
3	57-63	14-19	9-12
4	47-61	9-19	7-11

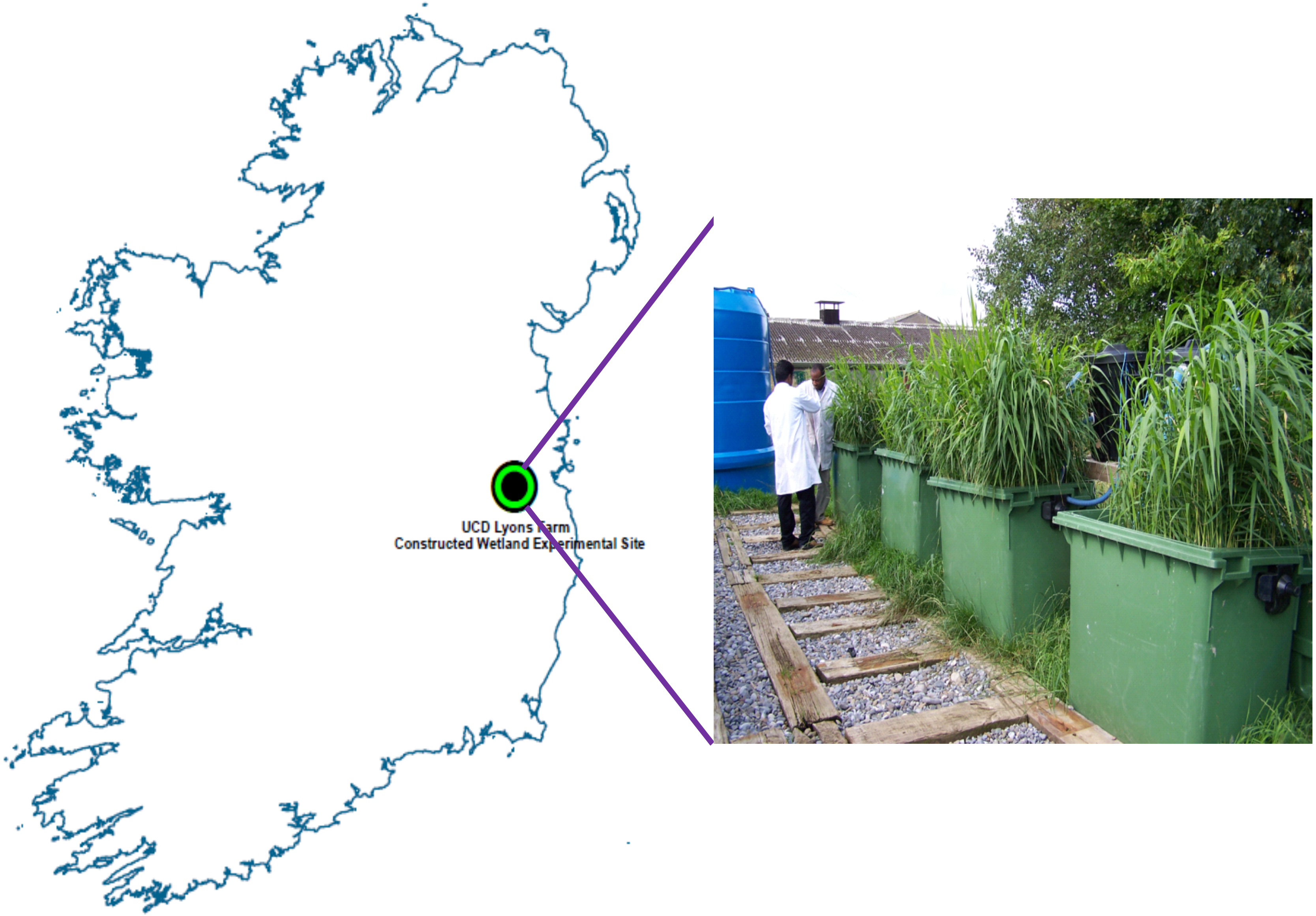
Conclusions (1)

- **The simulated effluent P concentration in all the 4-stages had a considerably good agreement with the observed results**

- **The major P transformation pathways are adsorption, plant uptake and microbial uptake.**

- **The fate of P in all the four stages clearly shows that adsorption played a pivotal role in each stage of the system due to the use of the alum-sludge as a substrate.**

Field-Scale Experimental Set-up



Methodology

A: DASC waste material produced from potable water treatment plant,
B: DASC as a resourceful material for CW substrate used in this study,
C: Installation of well into the system to collect water sample for analysis and for spot the submersible pump,
D: DASC in green bin for water treatment

Methodology

E: Installation phase of the DASC-based CW system,
F: Schematic view of the each stage linked together for operation


System setup
2 months later
4 months later

Engineered Wetlands

...mainly to remove the organics, nutrients such as Nitrogen and Phosphorus from the wastewater

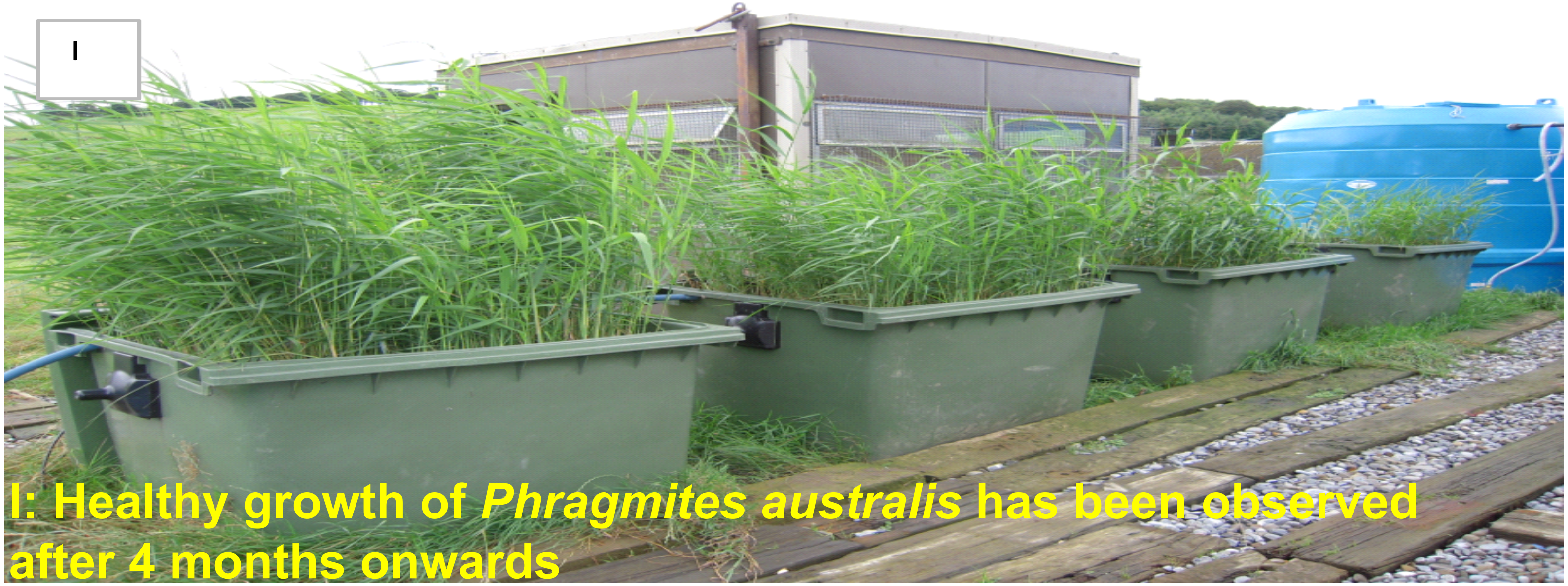
Engineered Wetland Site, UCD's Lyons Farm

Wastewater treatment using Alum-sludge

Engineered Wetland Site, UCD's Lyons Farm

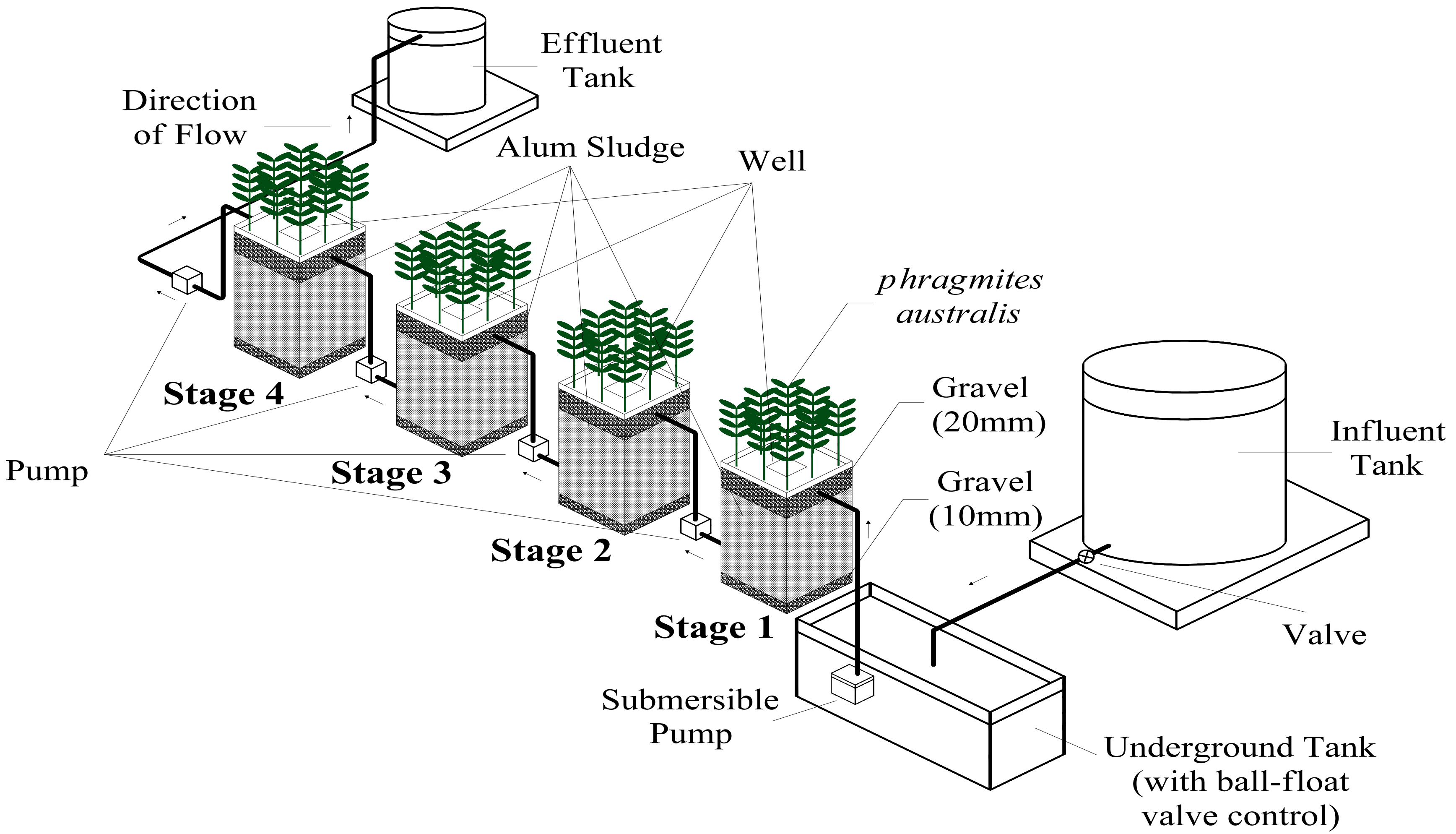
Methodology

H: Growth of *Phragmites australis* in DASC based CW after 2 months of operation period

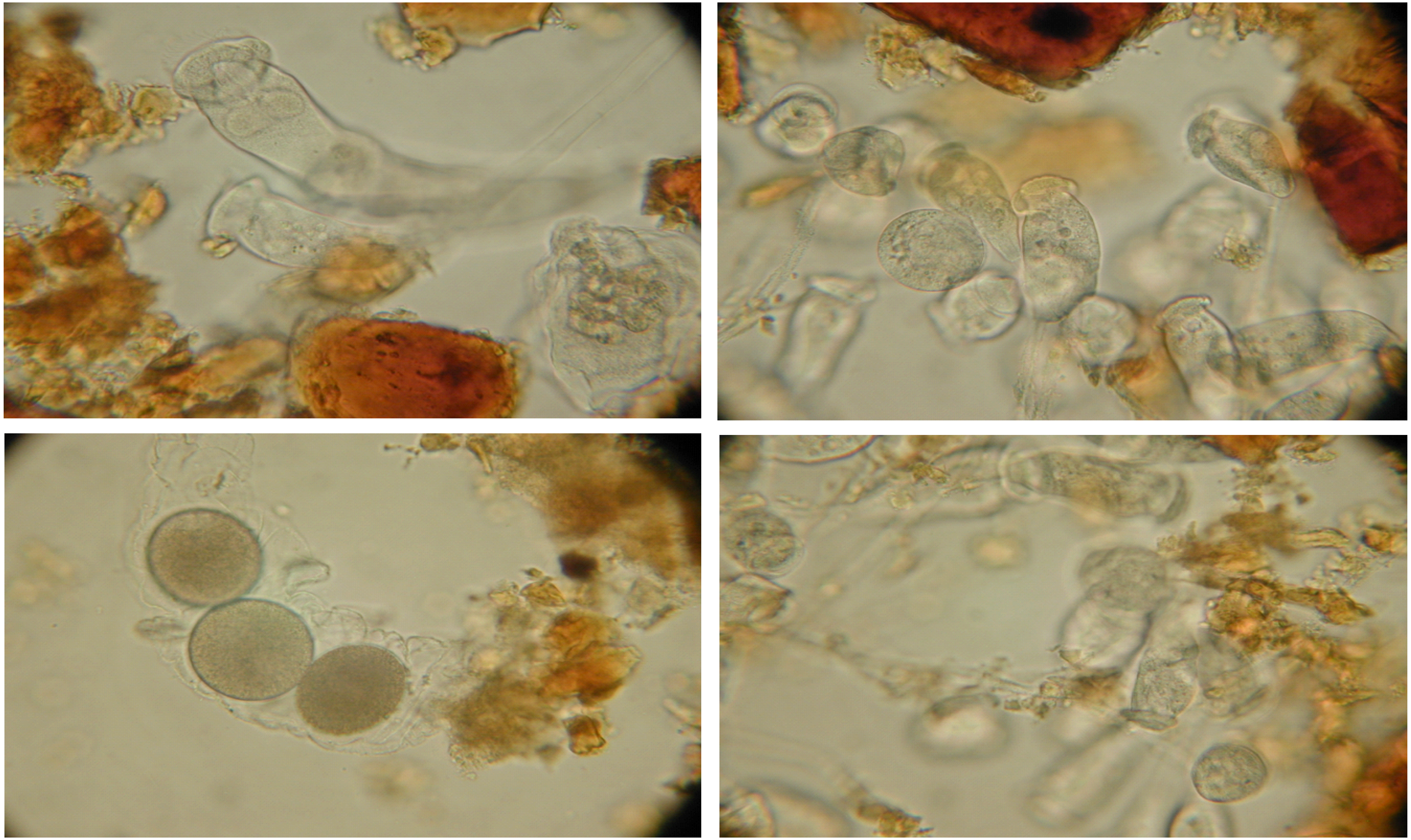


I: Healthy growth of *Phragmites australis* has been observed after 4 months onwards

Methodology

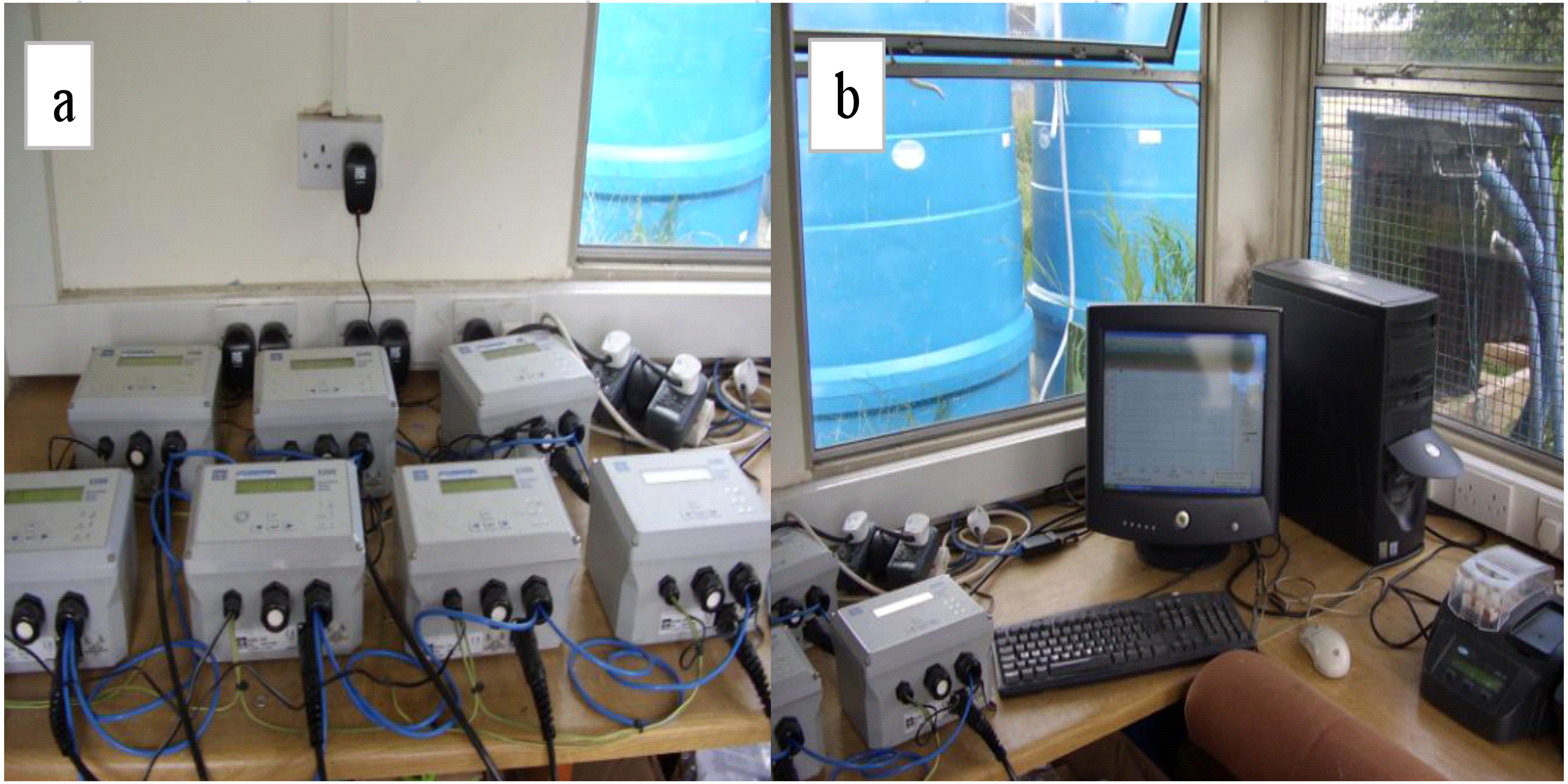


Methodology



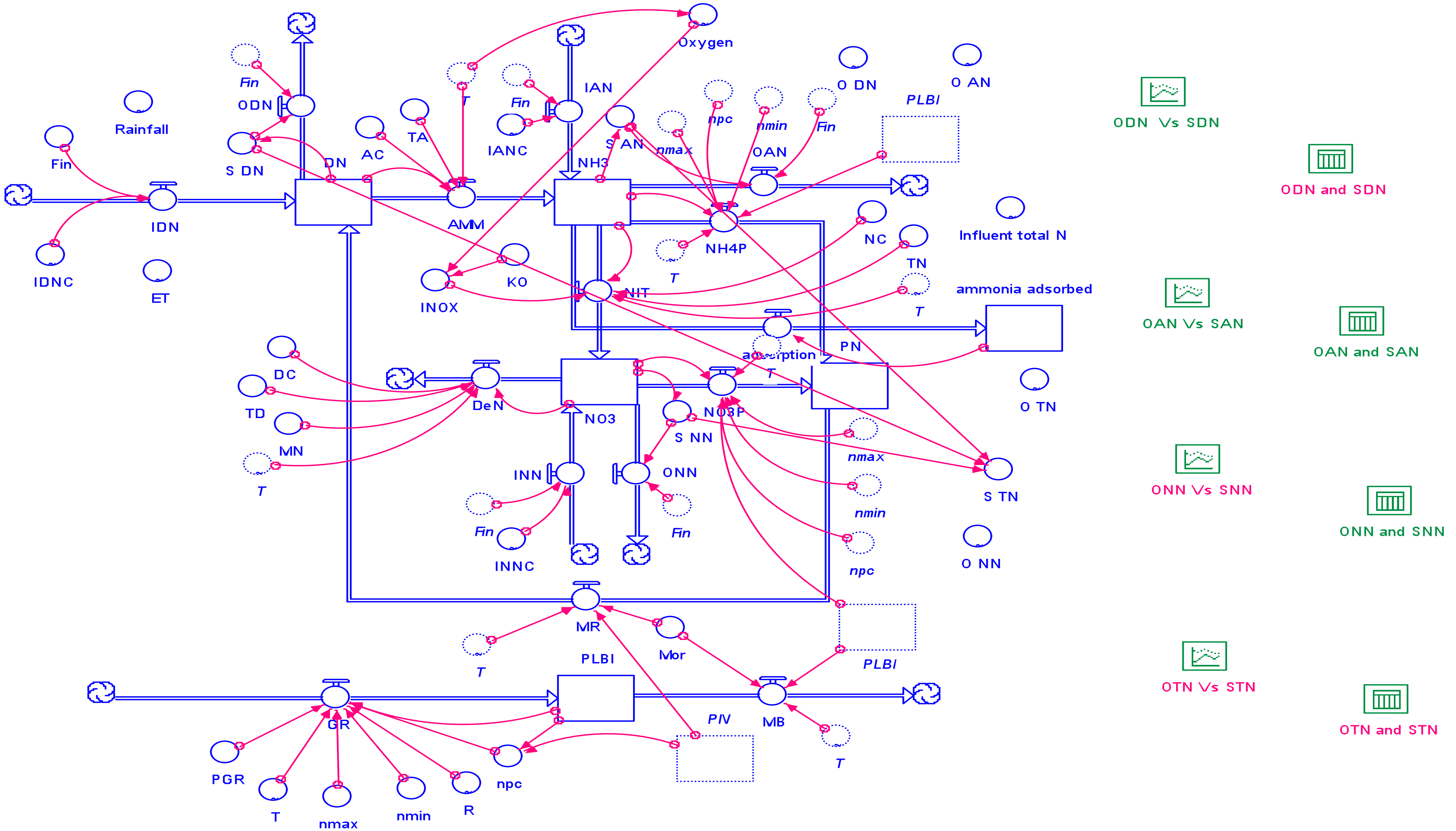
Microscopic images of various kinds of bacteria presence in DASC based CW

Methodology



YSI probe module (a) and the computer system connected the probes to download the data (b) at the pilot field-scale DASC CW system

Methodology



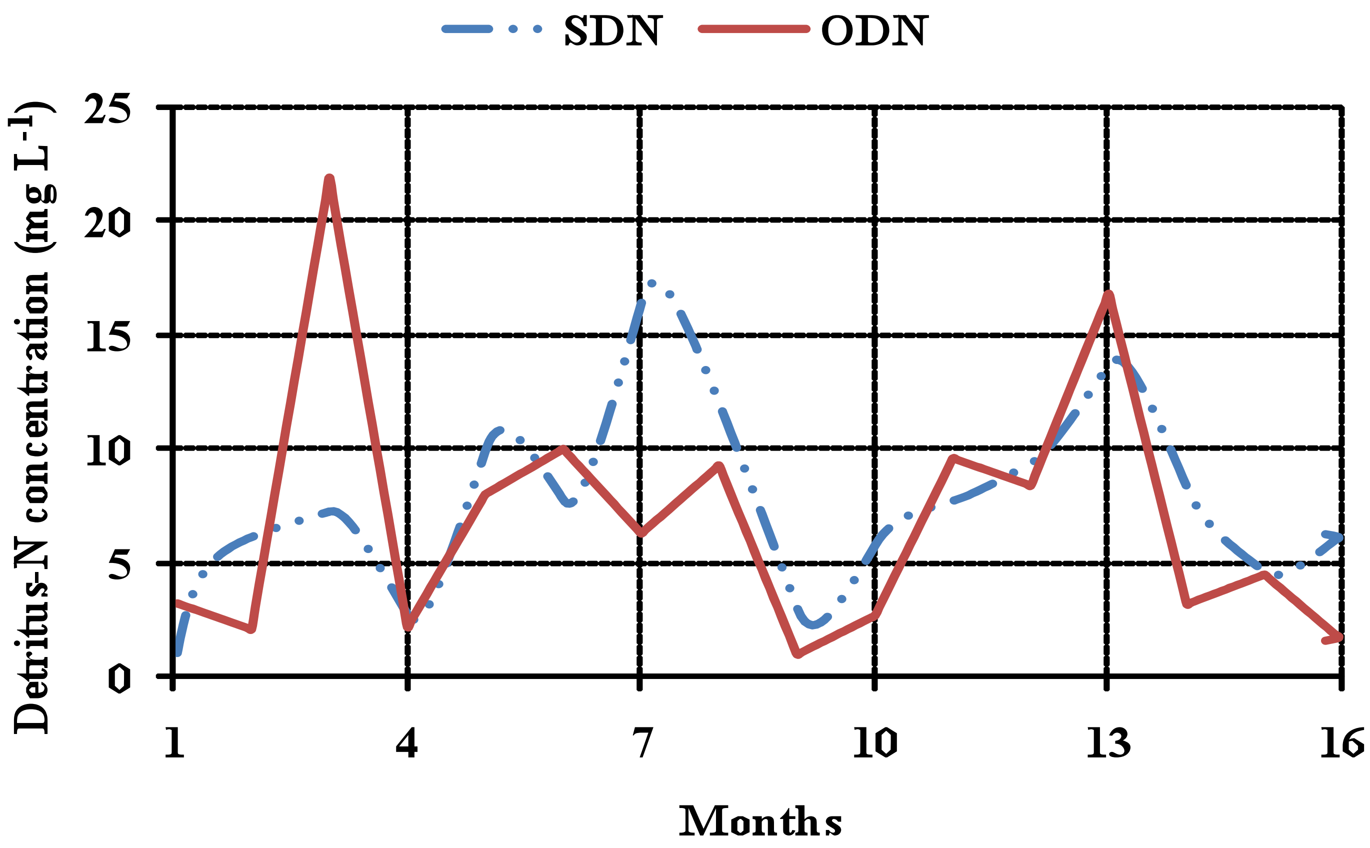
Conceptual model for N removal in pilot field-scale DASC based CW system

Methodology

Summary of N-processes and its mathematical formulations/equations used in novel DASC based CW

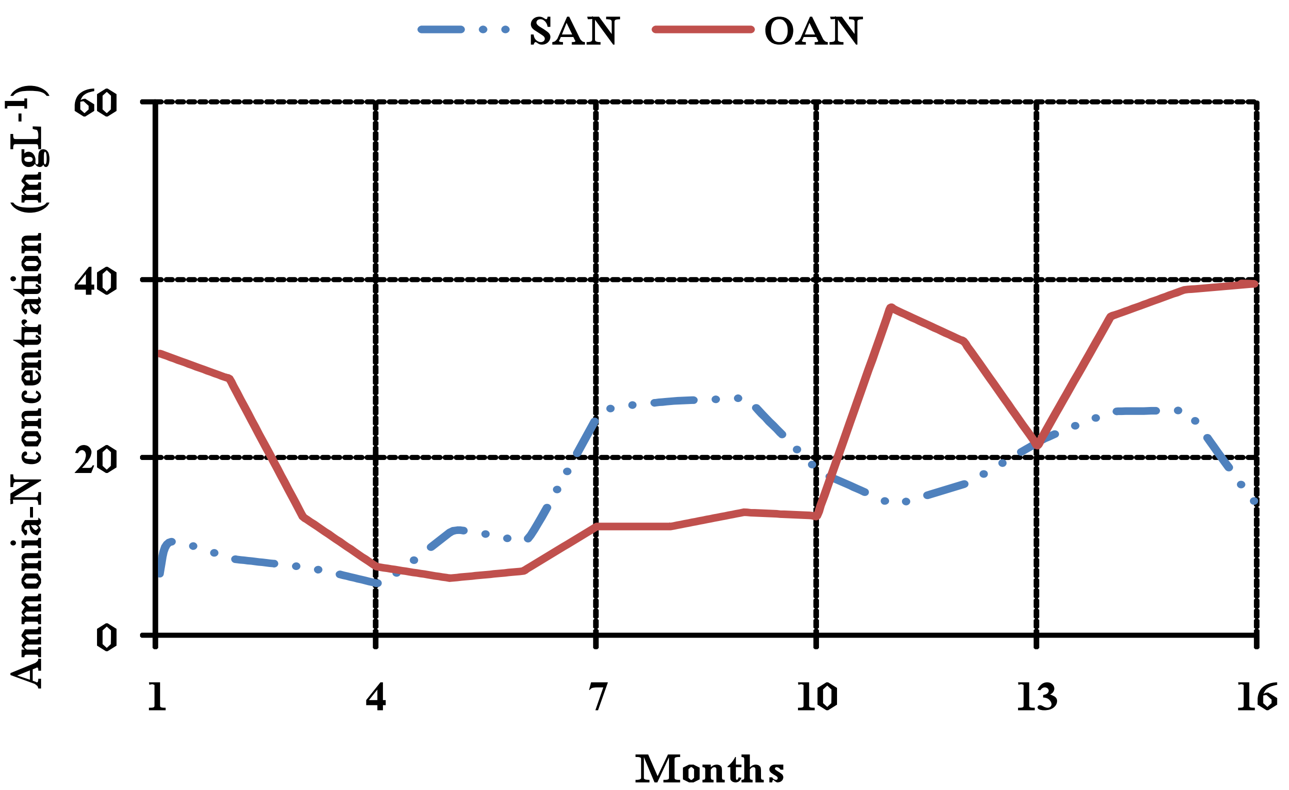
Processes	Mathematical formulations / Equations	References
Hydrology	$\frac{d\,(\text{water in DASCCW})}{dt} = W_{in} + \text{Rainfall in DASCCW area} - ET - W_{out}$	This study
Nitrification	NH_3-N*NC*INOX*TN^(T-20)	Jørgensen, (2009)
Denitrification	$DC \times TD^{(T-20)} \frac{NO_3 - N}{(N0_3 - N + MN)}$	Jørgensen, (2009)
Ammonification	$DN \times AC \times TA^{(T-20)}$	Jørgensen, (2009)
Growth	$PLBI \times PGR \times R \times 1.05^{(T-20)} \times \frac{(npc - n\min)}{(n\max - n\min)}$	This study
Plant NH_4-N Uptake	$0.4 \times PLBI \times 1.05^{(T-20)} \times \frac{(NH_4 - N)}{(NH_4 + 1)} \times \frac{(n\max - npc)}{(n\max - n\min)}$	This study
Plant NO_3-N Uptake	$0.4 \times PLBI \times 1.05^{(T-20)} \times \frac{(N0_3 - N)}{(N0_3 + 1)} \times \frac{(n\max - npc)}{(n\max - n\min)}$	This study
Mortality of plant	$PN \times 1.05^{(T-20)} \times mr$	Zhang et al. (2003)
Mortality of biomass	$PLBI \times 1.05^{(T-20)} \times mr$	Jørgensen, (2009)
Adsorption	IF NH_4-N ad < 1698840 THEN 1.2* (1698840- NH_4-N ad) ELSE 0	This study
Oxygen transfer	$\frac{Oxygen}{(Oxygen + KO)}$	Jørgensen, (2009)

Results



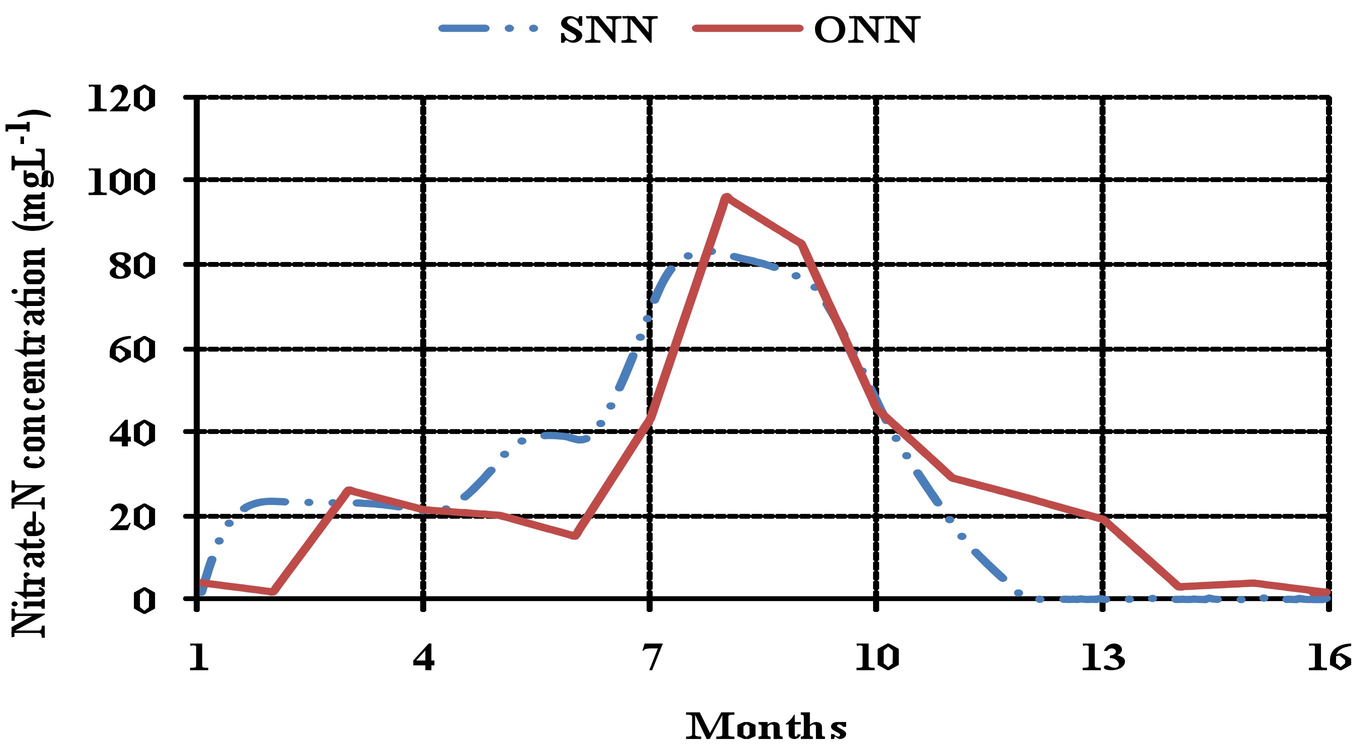
Comparison of observed DN (ODN) and simulated DN (SDN) values of effluent concentration in DASC based CWs

Results



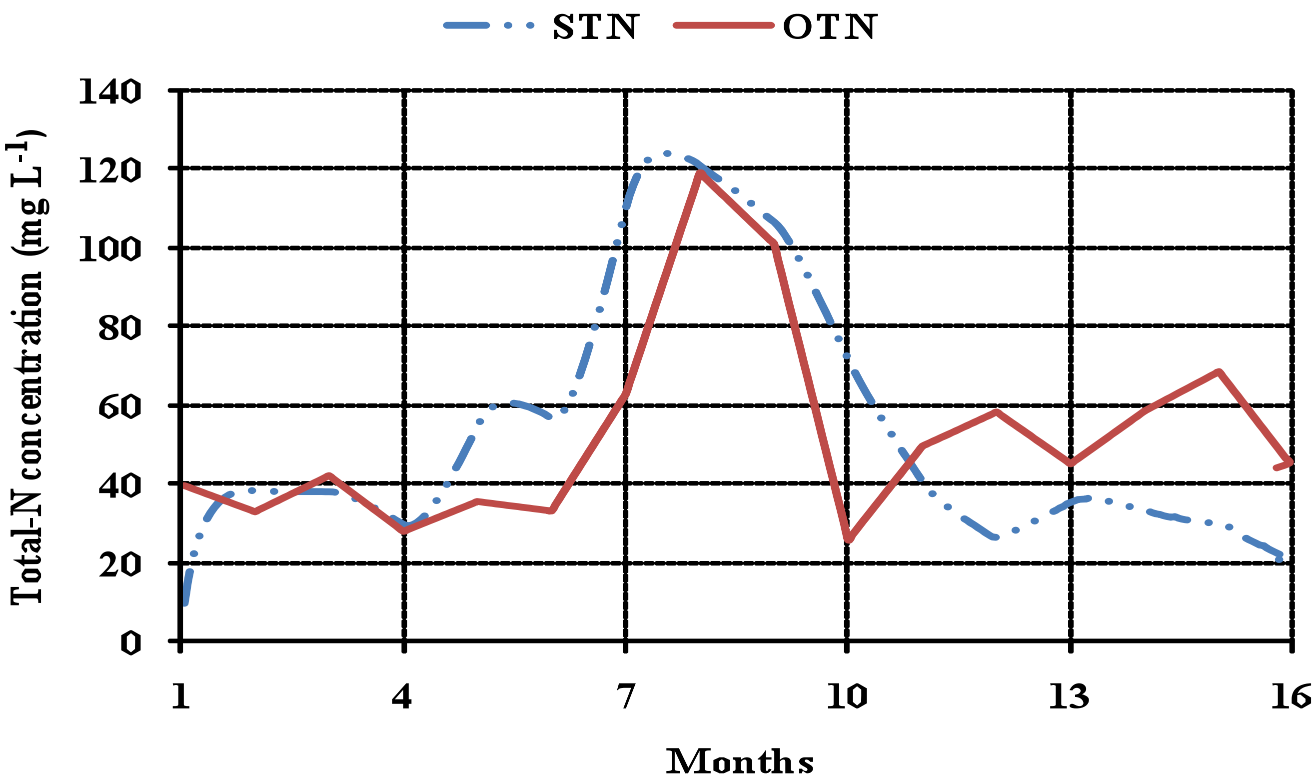
Comparison of observed NH_4-N (OAN) and simulated NH_4-N (SAN) values of effluent concentration in DASC based CWs

Results



Comparison of observed NO_3-N (ONN) and simulated NO_3-N (SNN) values of effluent concentration in DASC based CWs

Results



Comparison of observed TN (OTN) and simulated TN (STN) values of effluent concentration in DASC based CWs

Results

Effluent concentration of different forms of N in DASC based CW

Forms of N	Observed (mgL^{-1})	Simulated (mgL^{-1})
DN	1.89 - 21.90	2.34 - 17.35
NH_4-N	6.60 - 39.90	0.41 - 26.67
NO_3-N	1.70 - 96.20	1.20 - 97.96
TN	25.80 - 119.3	41.00 - 138.36

Conclusion (2)

- The simulated effluent DN, NH_4-N, NO_3-N and TN had a considerably good agreement with the observed results.

- NIT accounts for 65.60% followed by ad (11.90%) and then AMM accounts for (8.90%) followed by NH_4-N(P) (5.90%) and NO_3-N(P) (4.40%). DeN did not show up any significance in DASC based CW and the model result shows only 2.90%.

- The TN removal was found 52% of the total influent TN in the DASC based CW.

Overall Conclusion

1. Engineered wetlands offer possibilities to meet EU-WFD goals
2. Alum-sludge based EWs can be able to remove phosphorus up to 97%
3. Alum-sludge is novel reuse alternative to treat the polluted water
4. This technology holds great promise as a low-cost wastewater treatment system.
5. Process based modelling of N and P helps for design optimization
6. Genetically modified bacteria may help to improve the rate of removal.

> **The beneficial reuse of dewatered alum sludge as a substrate in EWs system can be a promising solution to transfer alum sludge as a "waste" to a useful raw material, thus developing a <u>cost-effective new generation</u> of treatment wetland system.**


Fig. 1. Dewatered alum sludge cakes.

UCD RESEARCH UNCOVERS POTENTIAL NEW WATER TREATMENT RESOURCE

A. O. Babatunde and Y. Q. Zhao of the Centre for Water Resources Research, School of Architecture, Landscape and Civil Engineering, UCD provide an overview of an innovative binary approach to the issue of sustainable development whereby alum sludge, a residual produced by water treatment plants and hitherto consigned to landfill in Ireland has been tested and is being reused as a new alternative media in constructed wetlands for wastewater treatment.

Chemical coagulants (commonly aluminium and iron salts) are used in potable water treatment processes to remove impurities from raw waters. These salts hydrolyse to form amorphous oxides that adsorb organic matter and other impurities present in the raw water and aggregate into a flocculated mass.

They are separated from the treated water and mechanically dewatered, thus becoming a residual cake (referred to as dewatered waterworks sludge) which requires final disposal mostly in landfills.

The amount and disposal cost of such residues generated at various waterworks have been increasing rapidly in recent years but options available for their final disposal have become increasingly limited amidst tighter environmental regulations.

In Ireland, an estimated 15,000 to 18,000t-DS(Dry Solid)/pa of alum sludge is currently being generated and this could double by the end of the next decade.

In contrast to the current global repositioning of waterworks sludge for sustainable reuse (Babatunde and Zhao, 2007), waterworks sludge in Ireland (mainly alum sludge since aluminium sulphate is used as the primary coagulant) is still mainly regarded as waste of no value and is consigned to landfills at huge expense.

This has been the practice for three main reasons: (1) The perceived aluminium toxicity of the sludge, (2) lack of well developed and economical options for recycling the sludge (RPS-MCOS web news) and (3) marginal agricultural benefit of the sludge. Presently, it costs about 3million/pa to landfill sludge produced from the biggest water treatment plant in Ireland. Fig.2 (page 232) indicates that Ireland has the highest proportion of waterworks sludge being disposed through landfill in relation to the quantity produced.

Concept

In a bid to develop a sustainable alternative disposal method for waterworks sludge in Ireland, a binary approach was adopted aimed at transforming the residual sludge into a resource. Under a 3-year research grant (grant No. 2005-ET-MS-38-M3) by the Irish Environmental Protection Agency to the University College Dublin, a novel constructed wetland system using the Irish dewatered alum sludge as the main substrate to enhance wastewater treatment is being pioneered and developed. Although the concept of constructed wetlands system for wastewater treatment is not entirely new, its use in the treatment of various wastewaters has gained increased acceptance with several recent innovations developed to address its perceived limitations.

These include hybrid systems, tidal vertical flow wetlands with recirculation and anti-sized reed beds. In addition,

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CASE STUDY: UCD wastewater project

Green technology helps in the battle against water pollution

Another project that's going to be highlighted in the Innovation Lounge comes from the School of Architecture, Landscape and Civil Engineering at UCD. It's designed to find novel approaches for enhancing high strength wastewater treatment in cnstructed wetland systems.

Constructed wetlands are artificial marshes or swamps used for waste water treatment; the vegetation in these wetlands provides a sub-strate upon which micro-organisms can grow as they break down organic materials. These artificially created wetlands are an increasing popular means of disposing of waste water, storm water and sewage, a truly "green" technology.

Extensive studies have been carried out at UCD to develop novel approaches to enhance pollution removal using these wetlands,

These include a "tidal flow" operational strategy, an "anti size" arrangement of the wetland medium and alum sludge-based constructed wetland systems. These innovative approaches have shown the ability of constructed wetlands to enhance oxygen transfer and speed up phosphorus removal.

Dr Yaqian Zhao is a permanent lecturer in the centre for water resources at the UCD School of Architecture; a graduate of Lanzhou Jiaotong university in China, he obtained his PhD at Strathclyde University in Scotland. He has extensive research experience in the waste water field, and in the past few years has been working to develop the alum-based constructed wetland system to re-use waste and enhance the efficiency of waste water treatment. He is the principal investigator for these group projects at UCD.

The project that will be displayed in the Innovation Lounge is his braincild, and he explains that research started in November 2004.

The project has several aims, as Dr Zhao details. "We want to prolong the clogging and therefore the lifetime of the constructed wetland. This is the most commonly faced problem in practice. We are working to enhance oxygen diffusion and we also want to reuse alum [illegible] which is a [illegible] water [illegible] plants in Ireland and turn it from a residual product into a resource, in line with the principle of sustainability."

He goes on to say that the whole purpose of developing this novel approach to constructed wetland systems is to produce a system that is cheap, greenand capable of significantly reducing high levels of nutrients and organic matter in high strength wastewaters.

The project has been financed from a number of sources, including the Environmental Protection Agency, the Department of Agriculture and Food, Enterprise Ireland, the UCD Urban Institute, the UCD seed [illegible] programme and the UCD [illegible] scholarship programme. Dublin City Council's Ballymore water treatment works has helped by supplying the alum sludge.

Dr Zhao explains that one of the key purposes of the project is to enhance the removal of phosphorus and organic material from high grade wastewaters. Other aims include the conversion of residual material [illegible] prevention of pollution and developing a low cost wastewater treatment system for rural areas, including farms and single houses.

At this stage, the new approaches have been fully tested in the laboratory and the "anti size" and "tidal flow" approaches have been the subject of field trials. Alum sludge-based wetland is now at the design stage, for field testing.

Globally, Dr Zhao says that research into developing constructed wetlands is well advanced. "However, to the best of my knowledge, there is no report of using alum sludge cake as the main substrate for wastewater treatment [illegible] constructed wetlands. Here in Ireland, the research is still in its early stages [illegible] significant [illegible] being made, with UCD playing a leading role." The field demonstration of the project has now started.

Ultimately, the findings of this research can be applied to the treatment of a wide variety of wastewaters, both domestic and industrial. It' s particularly relevant to high strength wastewaters, where the removal of nutrients, especially phosphorus and organic matter, are of primary interest.

Others working on the project UCD include Dr Akintunde Babatunde; Ms Xiahong Zhao and Weicheng Li. In addition to this waste water project, Dr Zhao is also working on developing non-polymer conditioning processes for waterworks sludge.

The technology behind the wastewater project will be highlighted in the Innovation Lounge and copies of documentation relating to the project will be available. Personnel will be on hand to answer any queries and subsequent contacts can be made by email.

The whole project represents a revolutionary approach to waste water treatment and Dr Zhao expects that at the Innovation Lounge, it will be of great interest to most visitors to the show. "Academic people, research institutes, local authorities, industries treating wastewater, environmental agencies, people involved with phosphorus control and recycling and NGOs should all find our research of much interest," he concludes.

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Milestones...............

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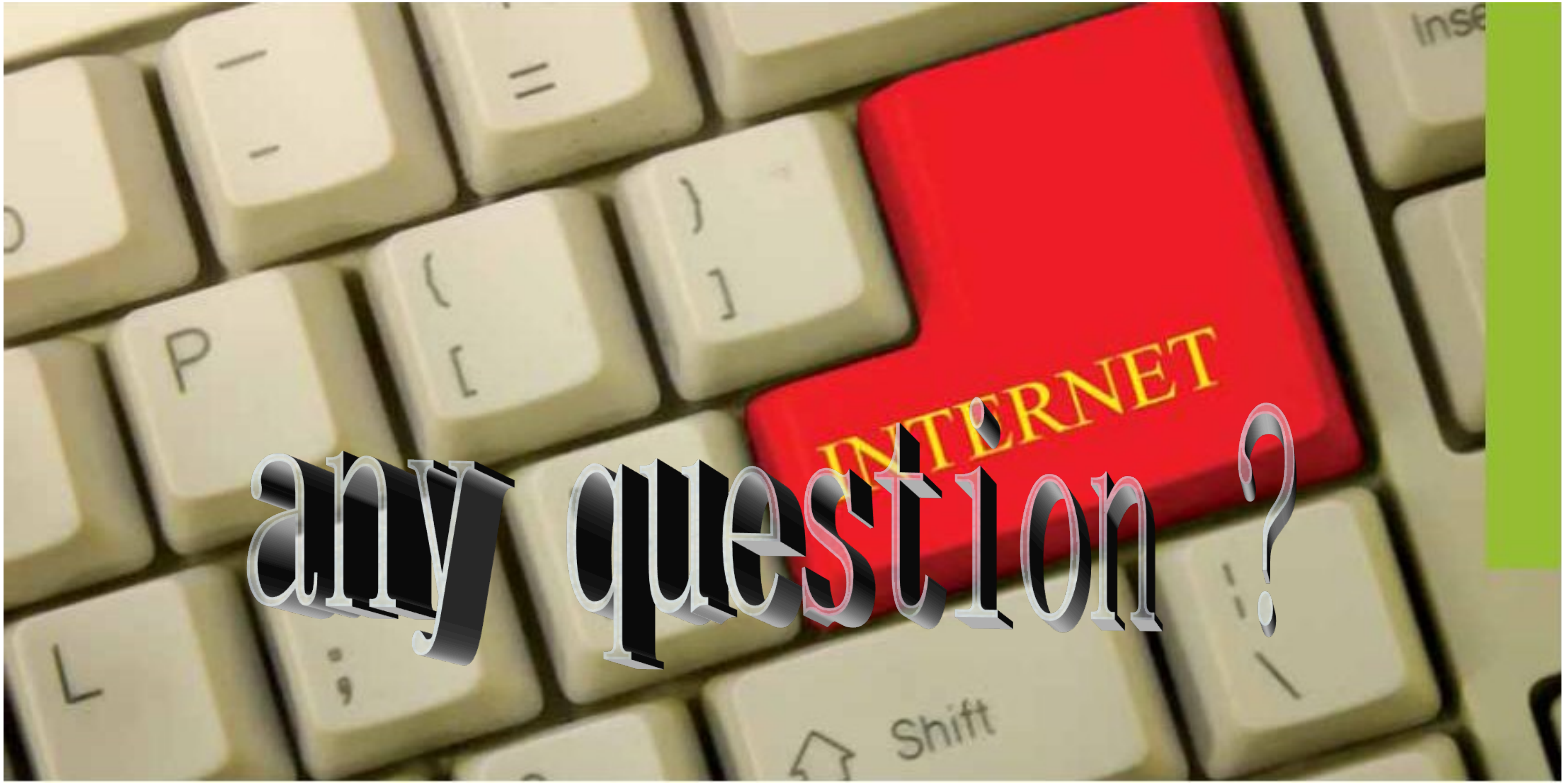

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