15th Specialized Conference on
Small Water & Wastewater Systems
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איגוד ישראלי למים
Israel Water Association

WATER SENSITIVE URBAN DESIGN: Development of a hybrid bio-filter for storm-water harvesting and for groundwater remediation

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קרן קימת לישראל
K K L – J N F

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Water-related urban problems

- Water scarcity (population growth, higher leaving standards, climate change*)
- Excess water (floods due to soil sealing – causing casualties & property damage)

*Global warming & increasing weather extremes

Excess water*

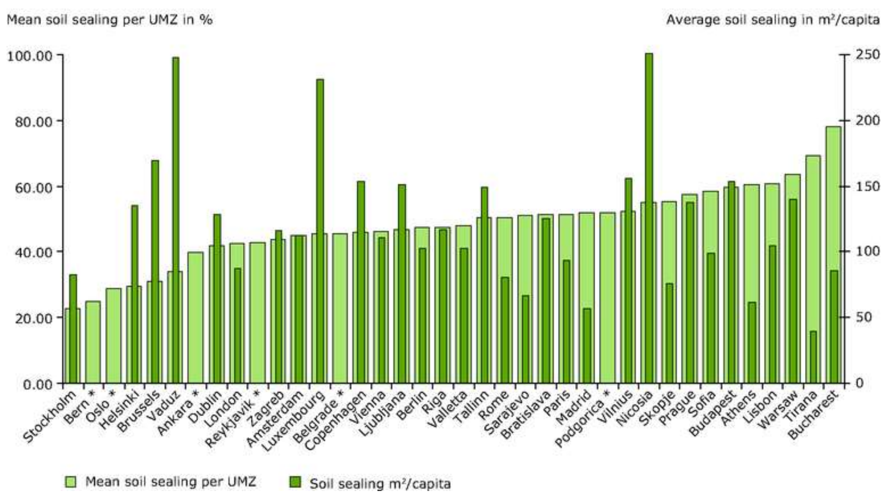
EEA Report | No 2/2012

Urban adaptation to climate change in Europe

Challenges and opportunities for cities together with supportive national and European policies

*
- Property damage
- Casualties
- Water pollution

Urban flooding – impervious surfaces reduce the drainage of rain water and increase the risk for urban flooding



Source: Europe Environmental Agency

Fate of storm-water

	Rural area	Urban area
Evaporation	50-70%	0-30%
Infiltration	25-35%	0-15%
Runoff	5-15%	50-100%

An integrated concept:
Water Sensitive Urban Design (WSUD)

Converting marginal water to precious resources that beautify and green the city and prevent pollution, flood damages, and micro-climate effects.

Water Sensitive Urban Design- Highlights

- Access to secured and clean water supply
- Aesthetic & healthy aquatic ecosystems
- Effective sewerage, drainage, & flood management
- Moderation of urban heat
- Improvement of the quality of public spaces

WSUD flexible approach

- Quality oriented treatment/reuse: garden irrigation, aquifer recharge, toilet flushing, etc.
- Multi-purpose design: mitigate flood damages, beautify urban landscapes, improve micro-climate, and protect receiving waters (groundwater, streams, & beaches).
- Different urban scales ranging from households, street caps, and neighbourhoods(decentralization).
- Integration of new technologies into existing and future infrastructure.

Advantage of in-city wastewater reuse and storm-water harvesting

Large sources of water are generated close to where it is needed

Within the WSUD concept, today's topic:
"Bio-filters"
"Bio-retention systems"
"Rain gardens"

Subsurface engineered systems for controlled harvesting, treatment, and recharge/reuse of storm-water

Unique Application in Israel
(different from “conventional” bio-filters)

- The prolonged hot and dry periods in Israel that last 7-8 months each year require “bio-irrigation” of bio-filters to preserve the biomass (plants and bacteria).
- Israel coastal aquifer is polluted with high levels of nitrate. Thus, the Israeli bio-filter will be a multipurpose tool.

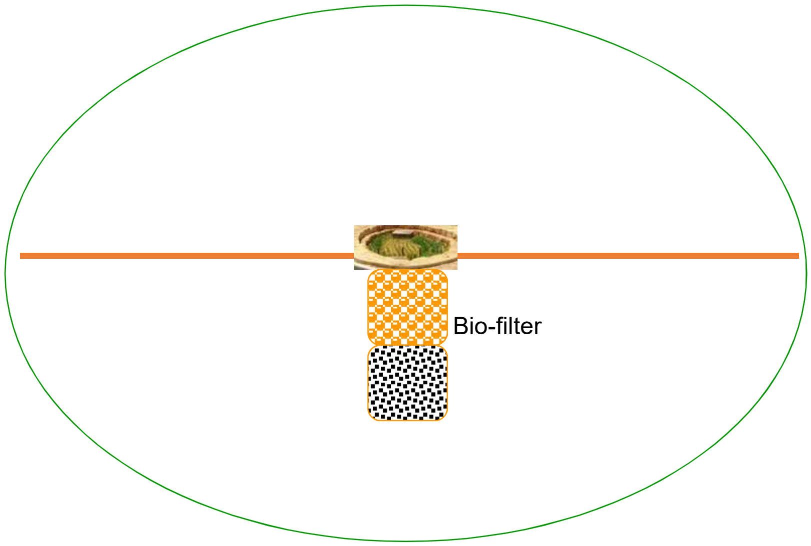
The suggested solution

- A modified version of the bio-filter (**hybrid**):

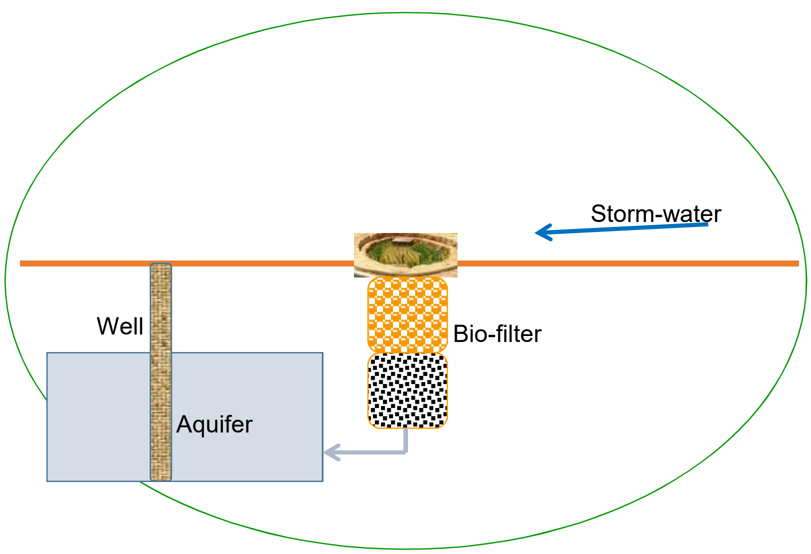
1. The dual-purpose system will harvest-treat-recharge stormwater, during winter.

2. It will remediate nitrate contaminated groundwater during dry summer months.

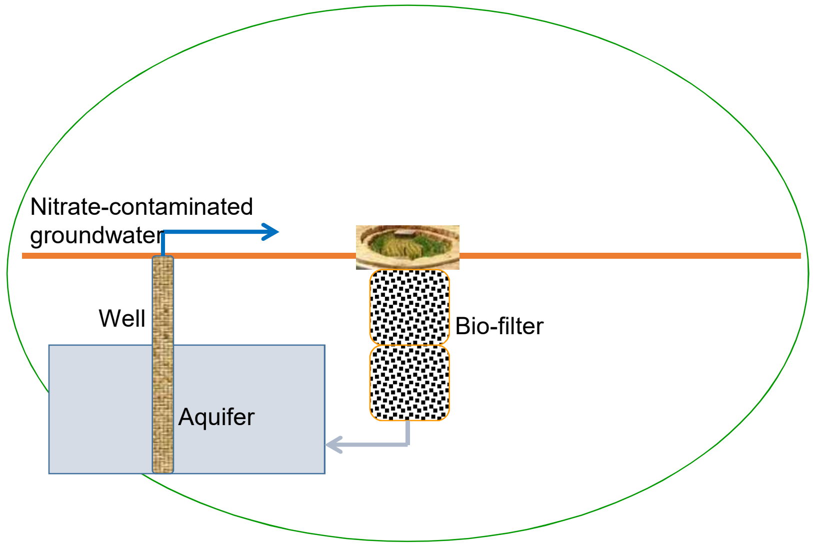
Storm-water bio-filtration system



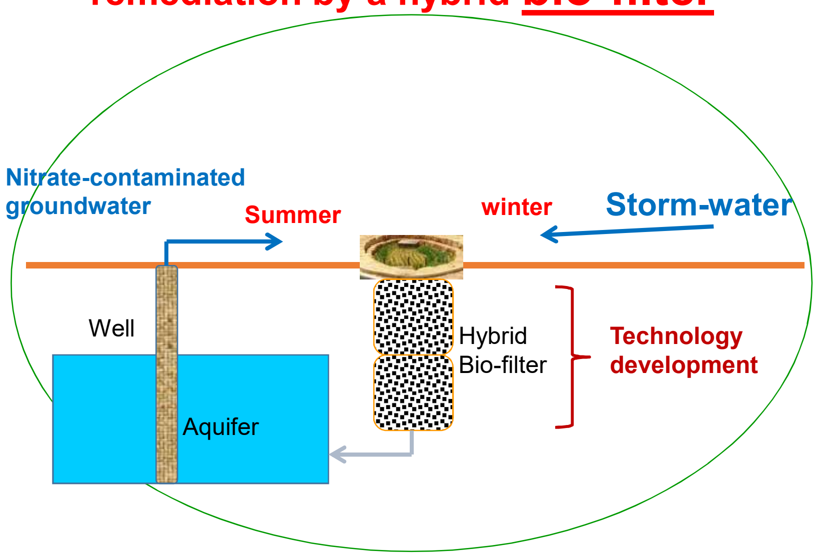
Storm-water bio-filtration system - winter



Storm-water bio-filtration system - summer



BGU study: Storm-water harvesting & groundwater remediation by a hybrid bio-filter



Bio-filter processes

Biodegradation
- TOC
- Nitrification
- Denitrification
- Assimilation (N, P)

Retention
- Suspended solids
- Pathogens
- Heavy metals

Sorption
- Heavy metals
- Residual organics
- Phosphorus

Biodegradation (TOC, Nitrification, Denitrification, Assimilation (N, P)): Columns study

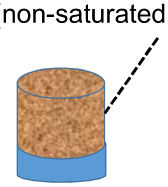
All processes: Pilot plant study

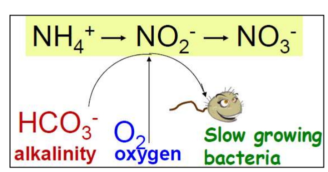
N content in storm-water and in contaminated groundwater

Storm-water	4 mg/L (Ammonia)
Groundwater	120 mg/L (Nitrate)

Removal of ammonia = biological **nitrification**

Requires: **Oxygen** (non-saturated zone)



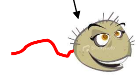


Removal of Nitrate: Denitrification

$NO_3^- \longrightarrow NO_2^- \longrightarrow NO \longrightarrow N_2O \longrightarrow N_2$

COD

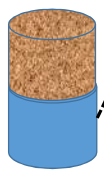
Organic matter



Inhibiting substance:

oxygen

Requires: **saturated zone**



The challenges in groundwater remediation:

- Reduction of nitrate levels to low levels
- Prevention of nitrite formation
- Prevention of organics leaching
- Prevention of anaerobic conditions

Preliminary study: Carbon source selection

4 carbon sources were compared:

Methanol

Glucose

Potato starch

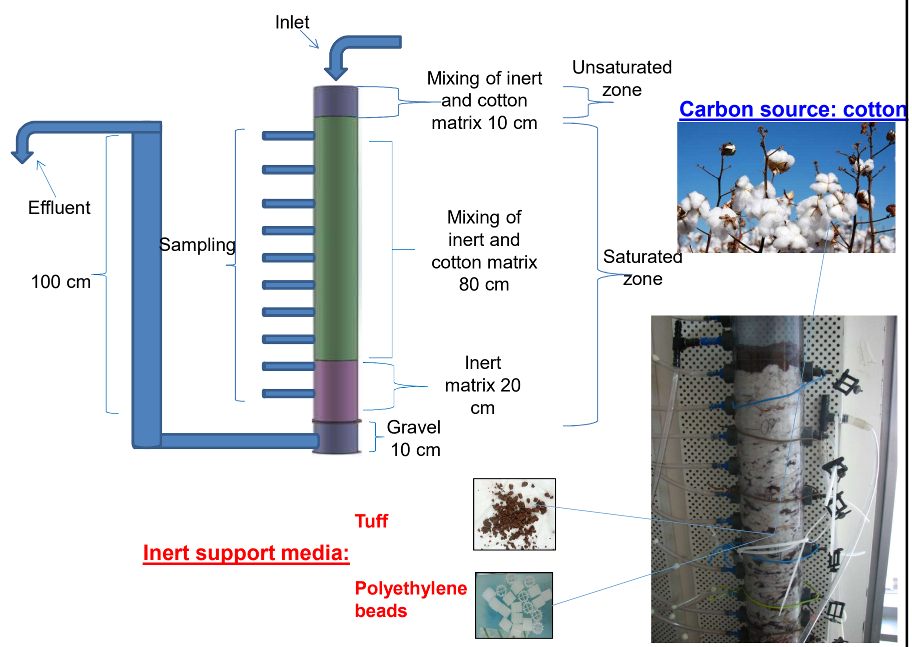
Cotton wool

C_0 (negative control)

Preliminary batch study: carbon source comparison

	Methanol	Glucose	Starch	Cellulose
Nitrate removal rate	26 ppm nitrate/day	50 ppm nitrate/day	46 ppm nitrate/day	27 ppm nitrate/day
Nitrite formation	**No**	Accumulated	Accumulated	**No**
TOC formation	40-50ppm	40-50ppm	40-50ppm	**Low**
Ammonia formation	**No**	Very high	**No**	**No**
Type of source	Liquid	Liquid	**Solid**	**Solid**

Denitrification bio-filter: generation I

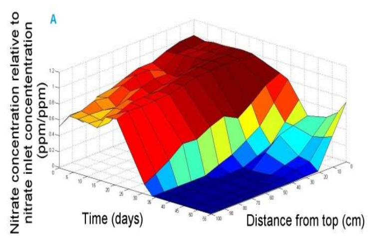


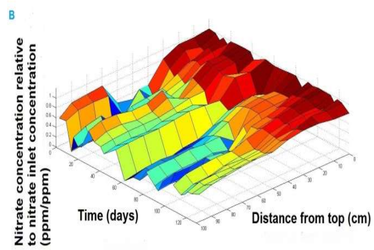
Influent properties* and effluent requirements

	Inlet (mg/L)	Effluent required by regulation (mg/L)
NO_3	120	<50
NO_2	0	<3
TOC	0	-
SO_4	60-70	<250
NH_3	0	-

***Tap water enriched with nitrate**

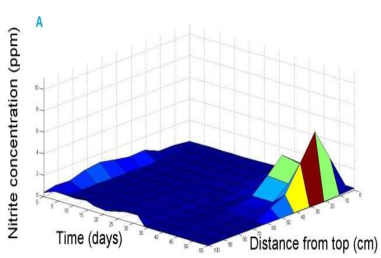
Nitrate concentration relative to inlet concentration as a function of time and distance along the column in Phase I (A) and Phase II (B)

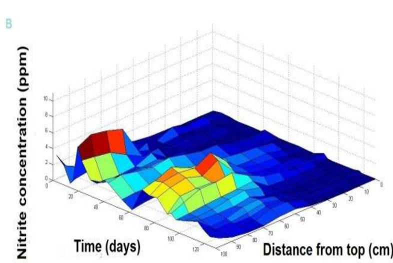




		NO_3^- [mg/L]	NO_2^- [mg/L]	TOC [mg/L]	SO_4^{3-} [mg/L]
Phase I Q/A=30 mm/h	Inlet	137.16 ± 11.68	0	0	54.73 ± 2.19
	Outlet	2.08 ± 5.52	0.17 ± 0.42	24.74 ± 6.43	16.22 ± 13.56
Phase II Q/A=60 mm/h	Inlet	116.02 ± 13.85	0	0	49.67 ± 5.98
	Outlet	38.53 ± 17.03	1.78 ± 0.87	2.32 ± 0.48	51.08 ± 7.58

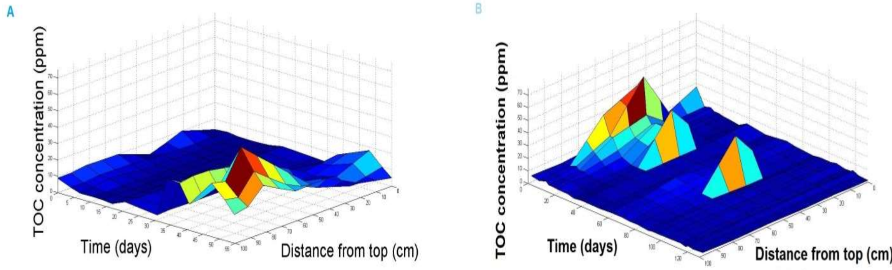
Nitrite concentration as a function of time and distance along the column in Phase I (A) and Phase II (B)





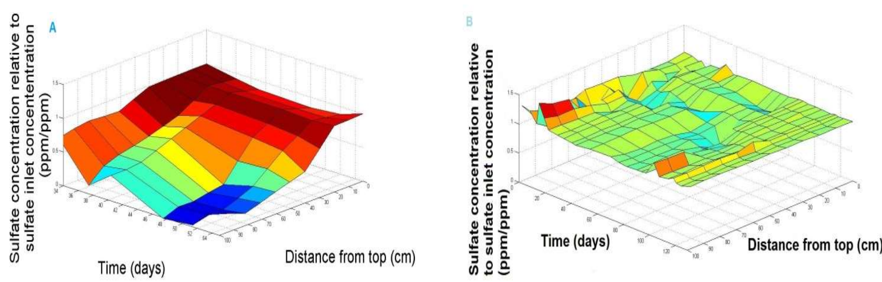
		NO_3^- [mg/L]	NO_2^- [mg/L]	TOC [mg/L]	SO_4^{3-} [mg/L]
Phase I	Inlet	137.16 ± 11.68	0	0	54.73 ± 2.19
	Outlet	2.08 ± 5.52	0.17 ± 0.42	24.74 ± 6.43	16.22 ± 13.56
Phase II	Inlet	116.02 ± 13.85	0	0	49.67 ± 5.98
	Outlet	38.53 ± 17.03	1.78 ± 0.87	2.32 ± 0.48	51.08 ± 7.58

TOC concentration as a function of time and distance along the column in Phase I (A) and Phase II (B)



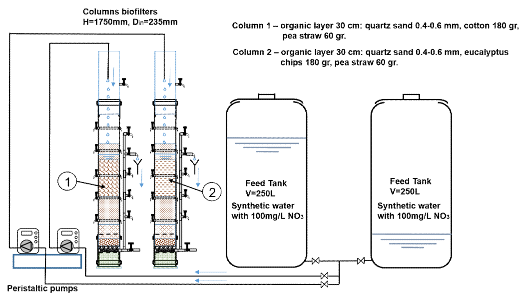
		NO_3^- [mg/L]	NO_2^- [mg/L]	TOC [mg/L]	SO_4^{3-} [mg/L]
Phase I	Inlet	137.16 ± 11.68	0	0	54.73 ± 2.19
	Outlet	2.08 ± 5.52	0.17 ± 0.42	24.74 ± 6.43	16.22 ± 13.56
Phase II	Inlet	116.02 ± 13.85	0	0	49.67 ± 5.98
	Outlet	38.53 ± 17.03	1.78 ± 0.87	2.32 ± 0.48	51.08 ± 7.58

Sulfate concentration relative to its inlet concentration as a function of time and distance along the column in Phase I (A) and Phase II (B)

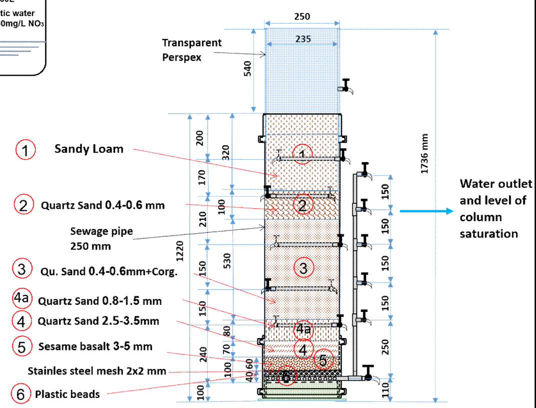


		NO_3^- [mg/L]	NO_2^- [mg/L]	TOC [mg/L]	SO_4^{3-} [mg/L]
Phase I	Inlet	137.16 ± 11.68	0	0	54.73 ± 2.19
	Outlet	2.08 ± 5.52	0.17 ± 0.42	24.74 ± 6.43	16.22 ± 13.56
Phase II	Inlet	116.02 ± 13.85	0	0	49.67 ± 5.98
	Outlet	38.53 ± 17.03	1.78 ± 0.87	2.32 ± 0.48	51.08 ± 7.58

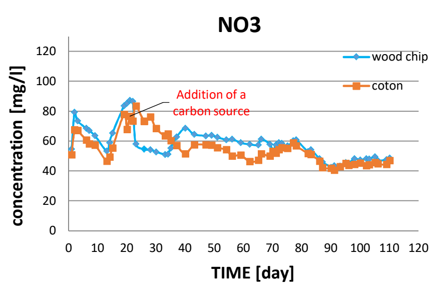
Denitrification bio-filters: generation II

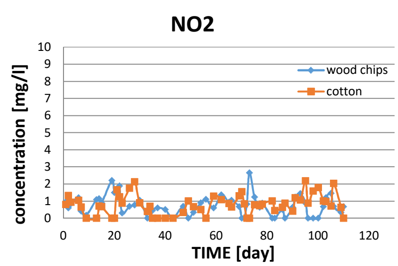


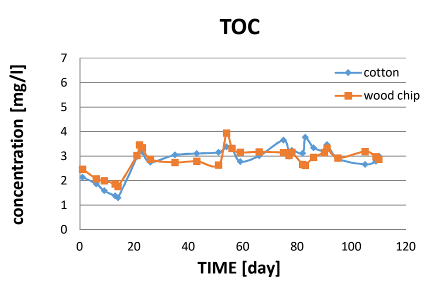
Pilot plant biofilters



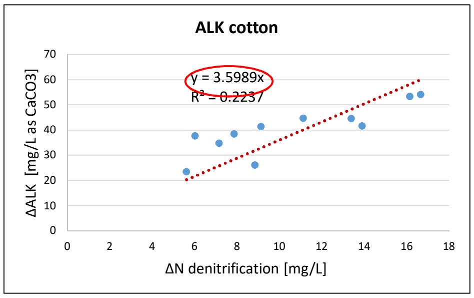
Results – 36 mm/h

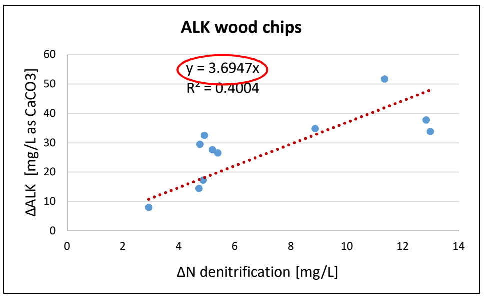






Alkalinity balances





Theoretically, 3.6 mass units of alkalinity as $CaCO_3$ are formed per 1 mass unit of NO_3-N denitrified.

Storm-water treatment mode (“winter configuration”)

Seven different columns

1. Australian mode bio-filter (long) with no vegetation;
2. Australian mode bio-filter with no vegetation and with a seed of acclimated bacteria;
3. Short bio-filter with ***Agapanthus***;
4. Short bio-filter with ***Tulbaghia***;
5. Short bio-filter with ***Vetiver***;
6. Short bio-filter with ***Vetiver*** (a second identical one);
7. Short bio-filter with no vegetation.

(**Long**(120cm/**short**(70cm

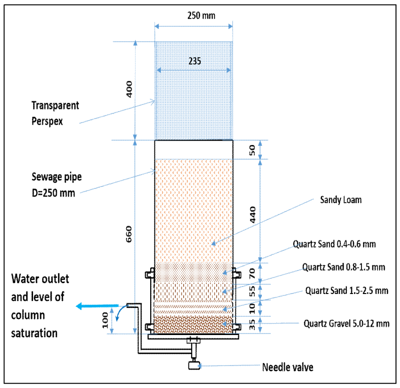
With/without **plants**

Gradual increase of hydraulic load

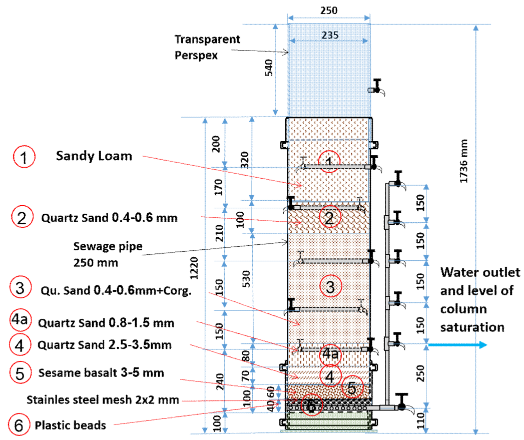
A. Daily feed of 1 liter;
B. 2 liters twice a week;
C. 5 liters once a week.
D. 10 liters once a week.
E. 15 liters once a week.

Two types of bio-filter columns tested

Short – infrastructure fitted



Long – Australian type



Layout of the experimental systems

Types of plants tested (from left):

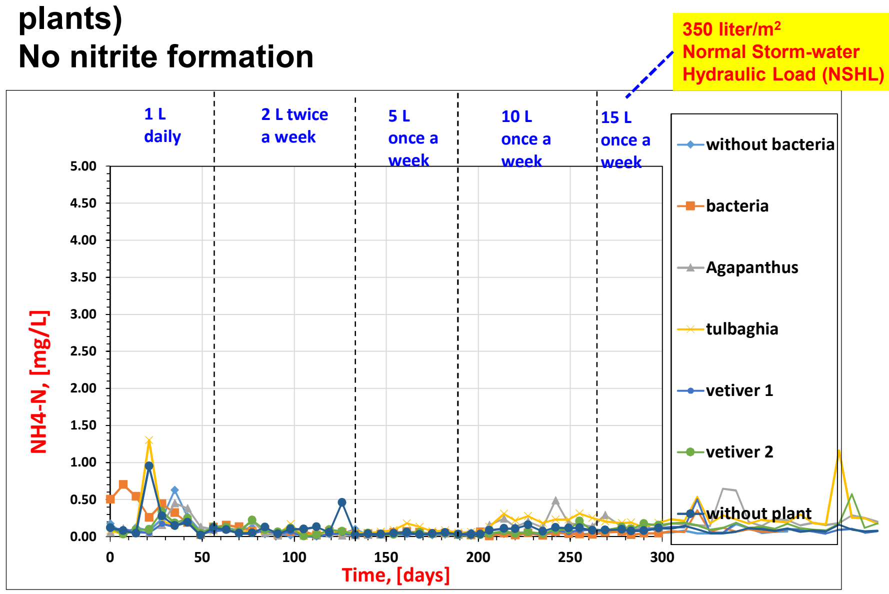
- *Agapanthus*
- *Tolbaghia*
- *Vetiver*

Composition of inflow solution

	Components				Design, mg/L
	NH4Cl (ppm)	K2HPO4 (ppm)	NaHCO3 (ppm)	Humic acid (ppm)	Solute: 0.8DDW+0.2TW
Concentration	20	10	50	10	
TOC	-	-	-	5	5
N	5.24	-	-	-	5
K	-	4.49	-	-	5
P	-	1.77	-	-	2
Cl	13.26	-	-	-	20
Na	-	-	13.70	5	20
pH	5.23		6.81		7
EC [µS/cm]	155.0				150
Alkalinity	-	-	30 mg/L as CaCO3	-	30

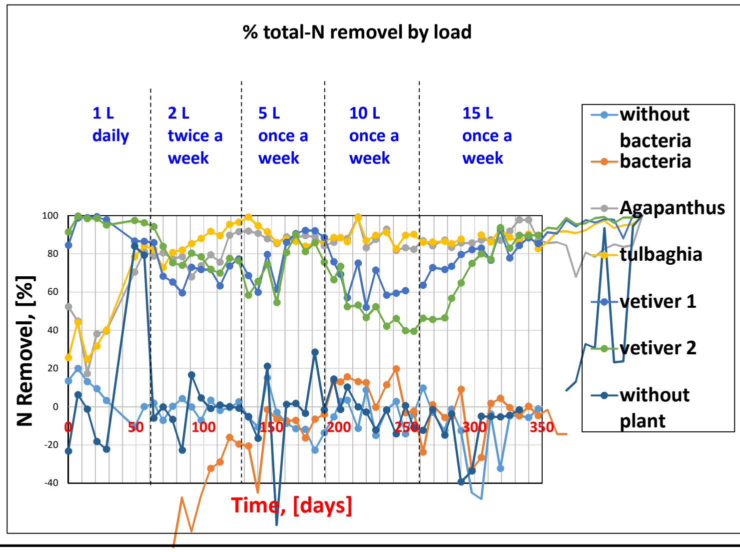
Nitrification Efficiency

- **Complete for all columns (short & long, with/without plants)**
- **No nitrite formation**



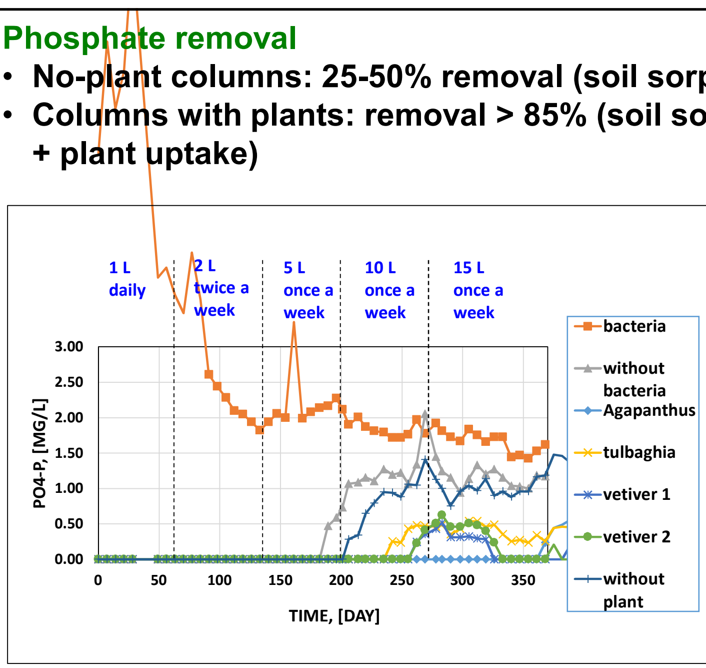
Denitrification/Total-N removal

- No-plant columns: 0% removal (5 mg Ammonia-N converted to 5 mg Nitrate-N)
- Columns with plants: total-N removal > 80%



Phosphate removal

- No-plant columns: 25-50% removal (soil sorption)
- Columns with plants: removal > 85% (soil sorption + plant uptake)



Evaluation of process efficiency

Since 10-15% of the inflow water were lost by evaporation (EV), the removal rate is actually higher. It should be therefore evaluated on the basis of load or on the basis of "corrected outlet concentration".

Removal rate by load

$$\text{RRload} = \frac{Qin * Cin - Qout * Cout}{Qin * Cin}$$

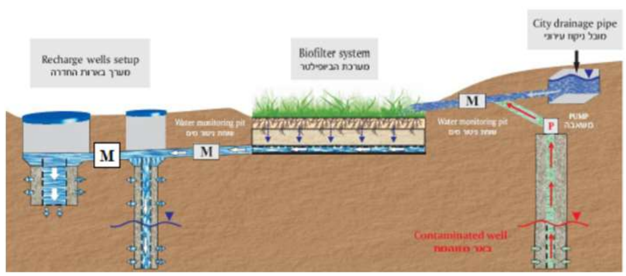
Removal rate by concentration

$$RRconc = \frac{Cin - Cout}{Cin}$$

Removal rate by "corrected outlet concentration"

$$\text{RRconc} *= \frac{Cin - (1 - EV) * Cout}{Cin}$$

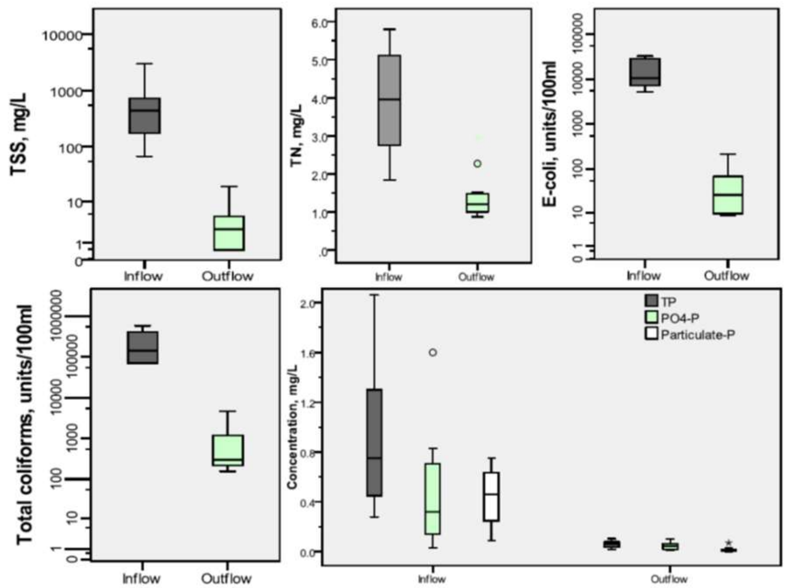
Pilot-plant study – one season, 16 storm events*



*

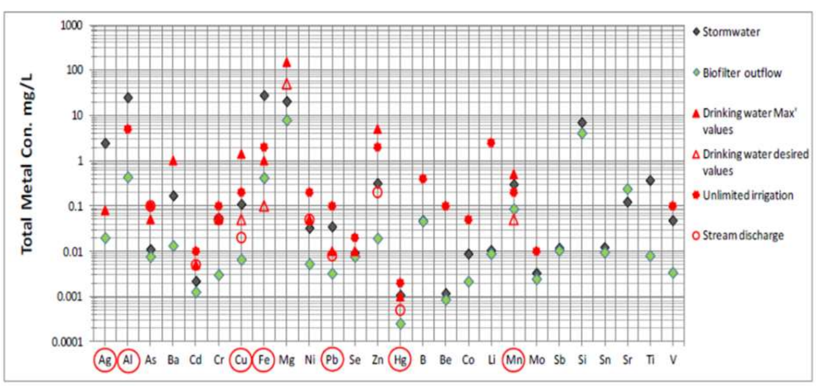
- 35 rainy days
- 5 – 85 mm
- total 472 mm
- 1,200 m^3 treated

Pilot-plant Results – TSS, N, P, pathogens



Standards box plots of Event Mean Concentrations of major pollutants in the biofilter inflow (raw stormwater) and outflow (treated stormwater).

Pilot-plant results - metals



Mean Event Mean Concentrations of heavy metals in untreated stormwater (grey) and treated stormwater biofilter outflow (in green) compared against a number of water quality guidelines.

Conclusions

- In-city solutions (WSUD concept) based on wastewater recycling and storm-water harvesting, are simple means that can be applied easily in various scales.
- They offer many benefits:
  - Saving of water
  - Pollution prevention
  - Reducing the risk and damages of flooding
  - Sustaining evaporative cooling by green areas
  - Beautifying & greening the city

Conclusions - II

- A hybrid bio-filter can serve for both storm-water treatment and bioremediation of nitrate contaminated groundwater.
- The bio-filter incorporating cotton as a carbon source could remove nitrate to the desired concentration value of <50 mg/L, while at the same time very low concentrations of TOC and nitrite are emitted.
- Judicious design is required in order to prevent potential formation of nitrite and sulfide. The nitrite might be formed since it is an intermediate of the denitrification process.
- Complete removal of NOx might lead to two problems: a. leaching of organic matter; b. sulfide formation due to the transformation from anoxic to anaerobic conditions.

Conclusions - III

- In the mode of storm-water treatment, large unsaturated layer on top of the bio-filter enables to achieve complete nitrification.
- Plants on top of the bio-filter improve the removal of N and P compounds, and prevent clogging.
- Pilot-plant study showed that metals and pathogens are removed effectively in spite of the fluctuating storm events.
- It is more accurate to evaluate process efficiency on basis of contaminant load change, due to water loss by evaporation.

Thank you!