Attenuation of stormwater contaminants during infiltration and storage in a shallow primary aquifer

R. Schneuwly, K. Carden, and C. T. Tanyanyiwa

Theme: Quality and Clogging Issues: Predictions and Management in Basins and Bores

Session: Parallel 5

12th International Symposium on Managed Aquifer Recharge
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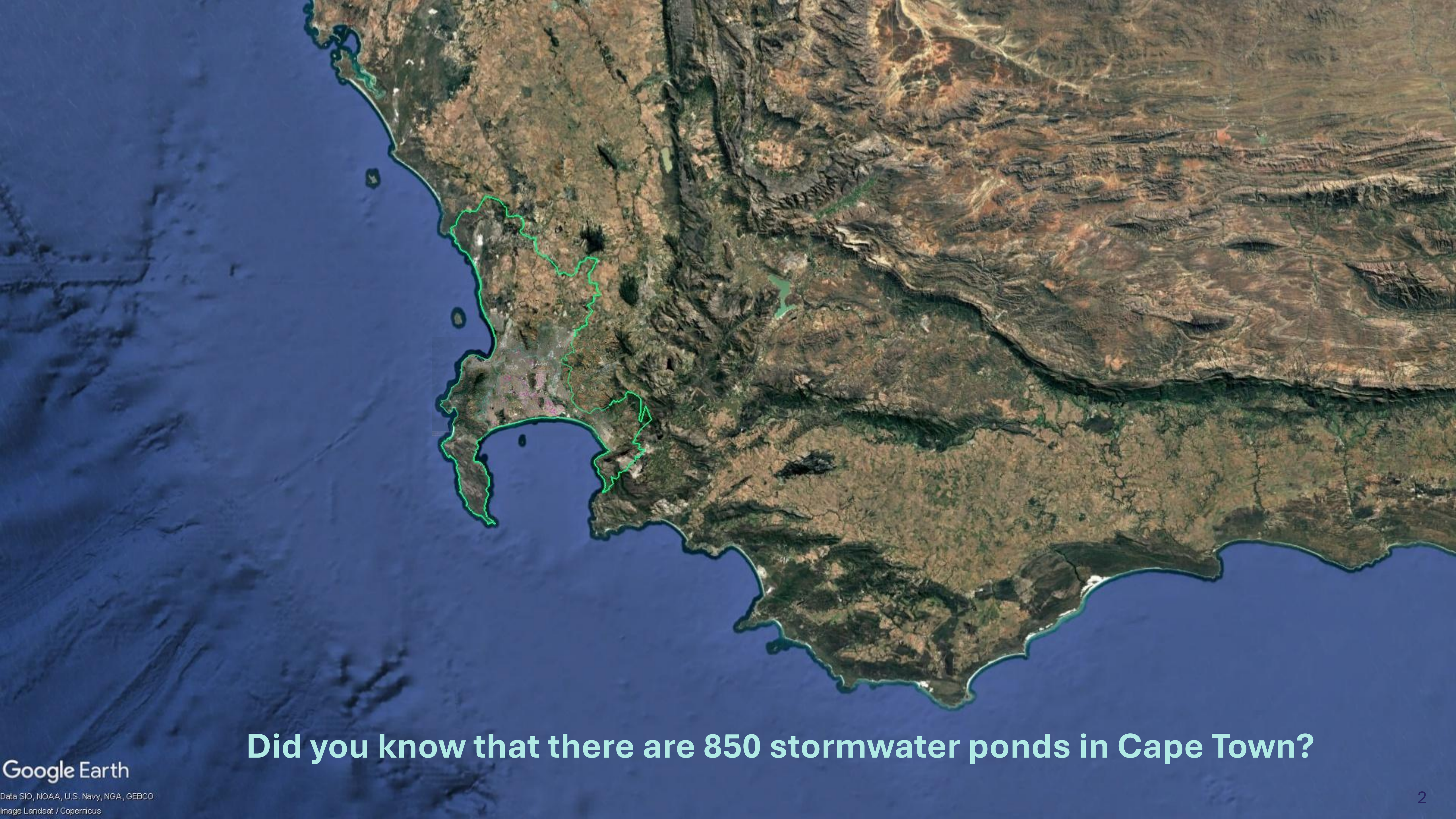

Did you know that there are 850 stormwater ponds in Cape Town?


Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
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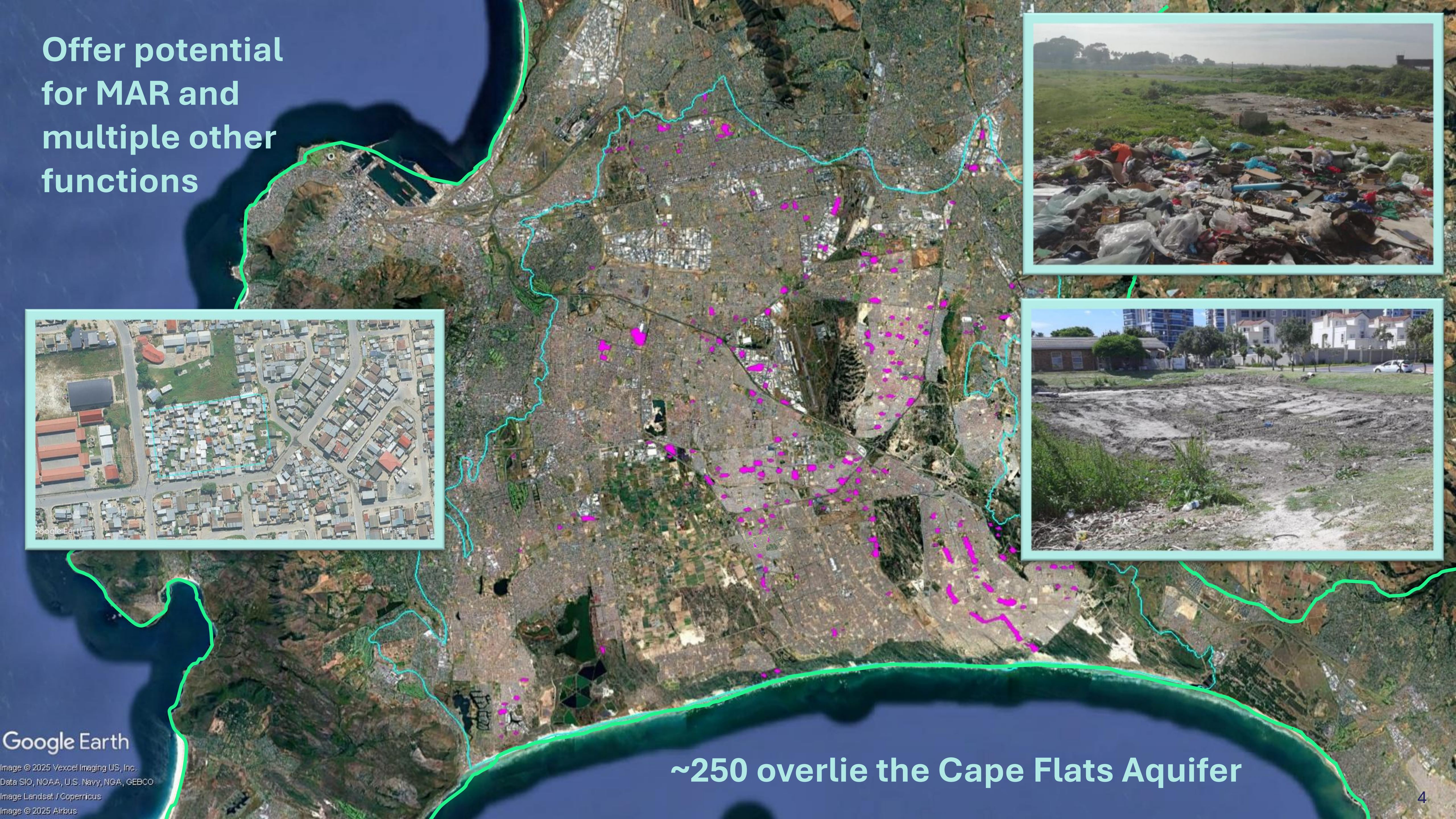
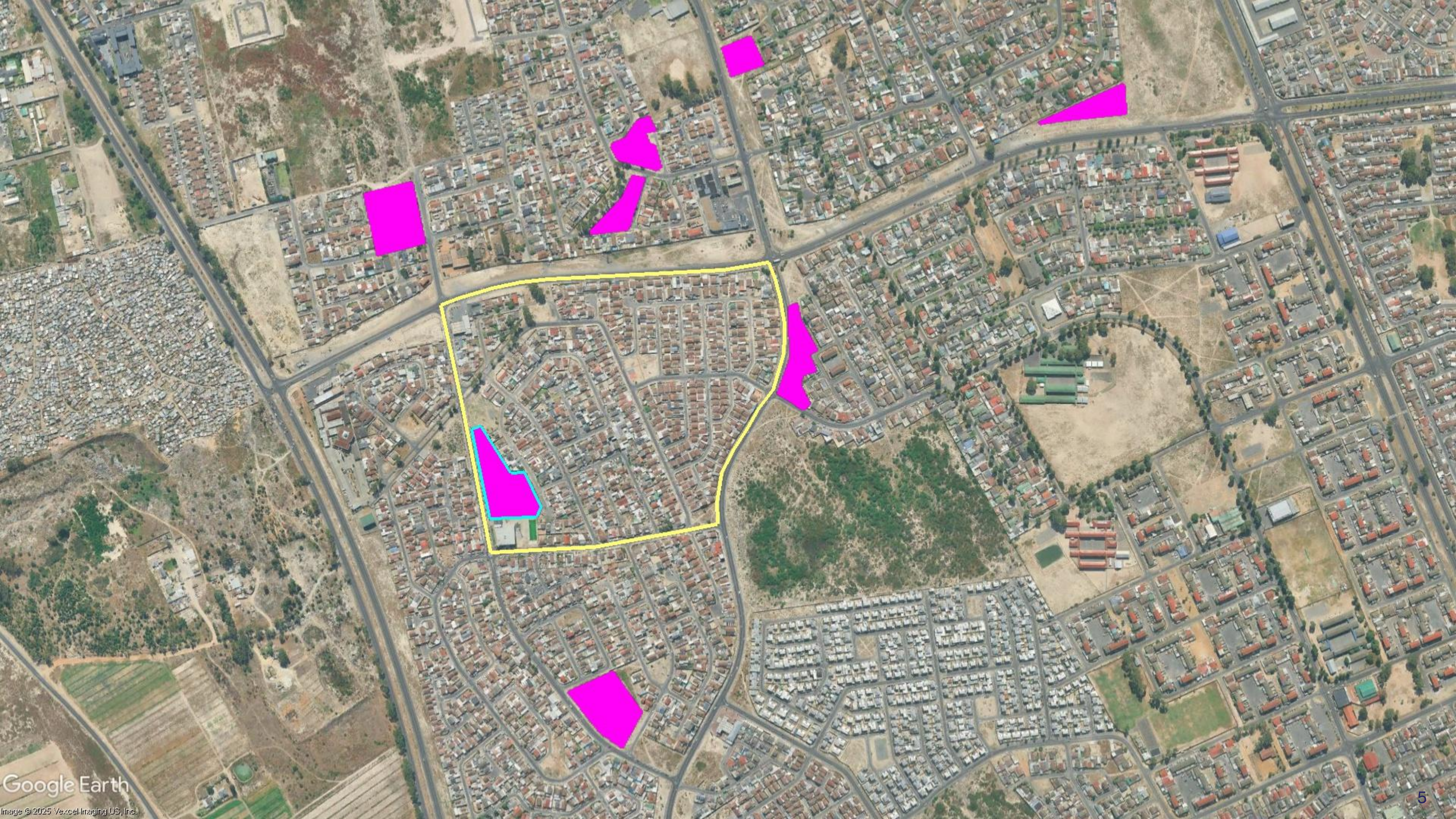
Offer potential for MAR and multiple other functions



~250 overlie the Cape Flats Aquifer


Google Earth
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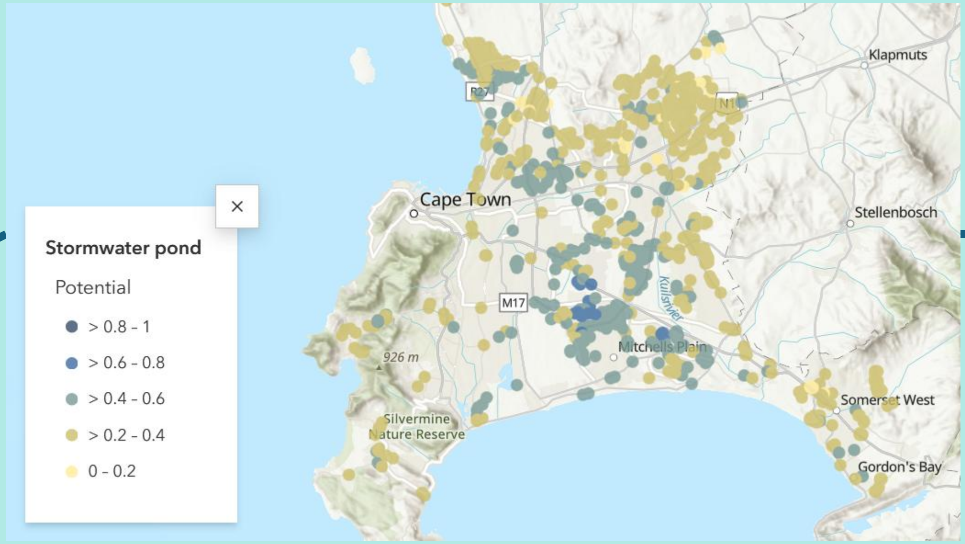
Stormwater harvesting with storage in the CFA offers more storage capacity and better water quality compared to surface water storage. – **John Okedi, PhD**

2019

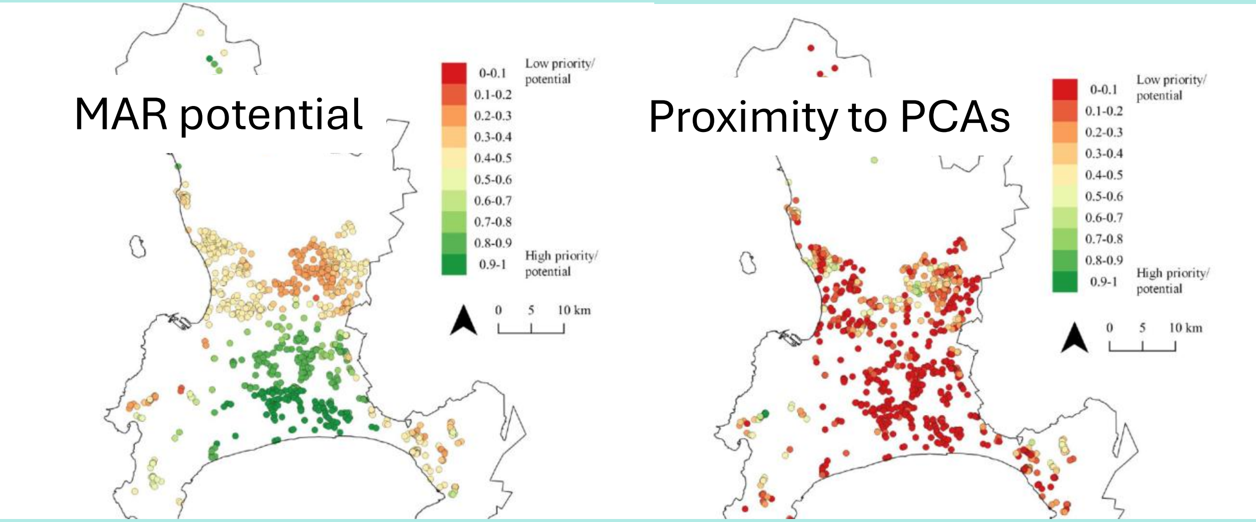
Potential of stormwater ponds as multifunctional blue-green infrastructure. **Jess Fell, PhD**



Pathways to water resilient South African cities

Viability of transforming stormwater ponds into infiltration ponds. **Craig. T. Tanyanyiwa, PhD**

Water quality limitations due to the proximity of potentially contaminating activities



Need to understand the effect of stormwater infiltration on groundwater quality.

My MSc (Eng) included a field study and **soil-column experiments**

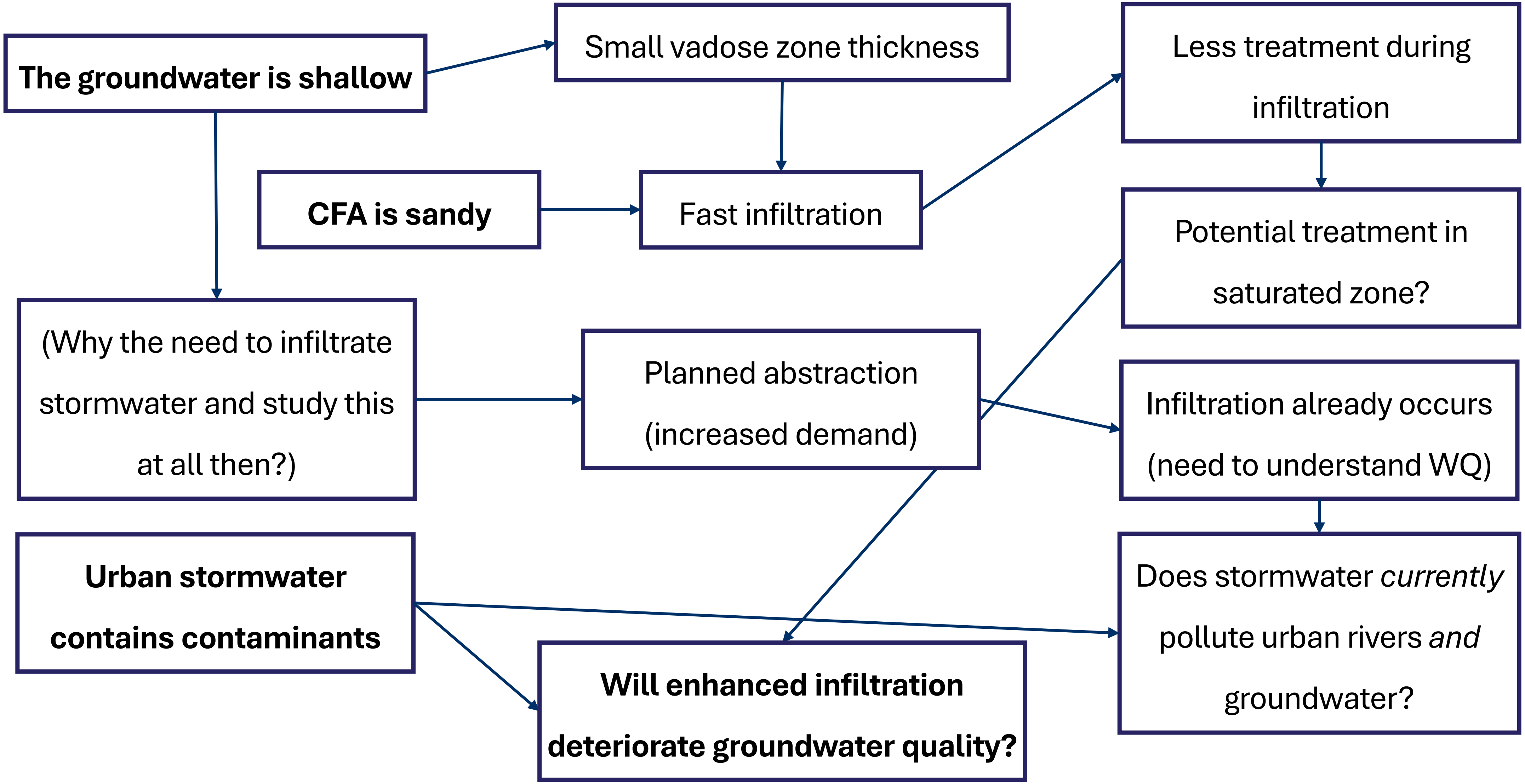
2021-2023

118% increase in infiltration after low-tech detention pond retrofit

Soil-column experiments

1. Problem overview and research question
2. Water quality guidelines for context
3. Mechanisms for contaminant retention and transformation in soil
4. How the experiments were done
5. Synthetic stormwater concentrations
6. Results phosphate, zinc and nitrogen
7. Key findings and future research

1. Problem overview and research question



2. Water quality guidelines and limits

FUTURE WATER

Parameter	Units	Aquatic Ecosystems (CoCT			Discharge of wastewater to a water resource		SANS 241 drinking water standard
		Target	Poor	Unacceptable	General Limit	Special Limit	Acute/ chronic/ aesthetic
Dissolved oxygen	mg/L	>6	4 - 6	<4			
Chemical oxygen demand	mg/L				<75	<30	
Total organic carbon	mg/L						<10
Total inorganic nitrogen	mg/L	**<1.0**	1 - 4	>4			
NO_3^- as N	mg/L				<15	<1.5	<11
$NH_4^+ + NH_3$ as N	mg/L				<6	<2	<1.5
NH_3 as N	mg/L	**<0.015**	0.015 – 0.1	>0.1			
Phosphate as P	µg/L	**<25**	25 – 125	>125	<10 000	<1 000	-
Zinc	µg/L	<2			<100	<40	<5 000

Aquatic ecosystems are sensitive

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3. Contaminant attenuation in soils

- **Physical settling and filtration** of particles
- Phosphate and metals - **sorption** on soil particles
- NH_4^+ slowed down by **cation exchange**
- NH_4^+ → NO_3^- microbial *oxidation* - **nitrification**
- NO_3^- → N_2 microbial *reduction* **denitrification**
- NO_3^- highly mobile in soil
- Organic compounds may be retained (**sorption)**
- Biodegradable organic compounds are transformed by **microbial processes** (including denitrification)

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4.1 How the experiments were done

Field study

Collected the soil

Lab experiments

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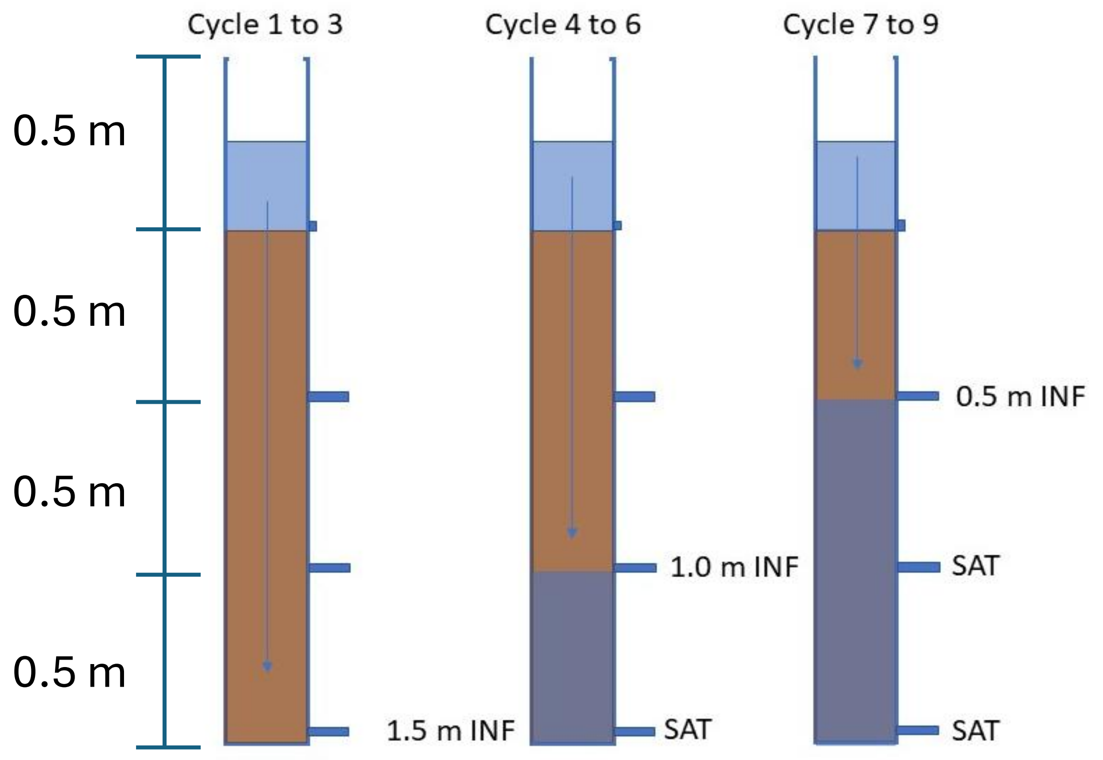
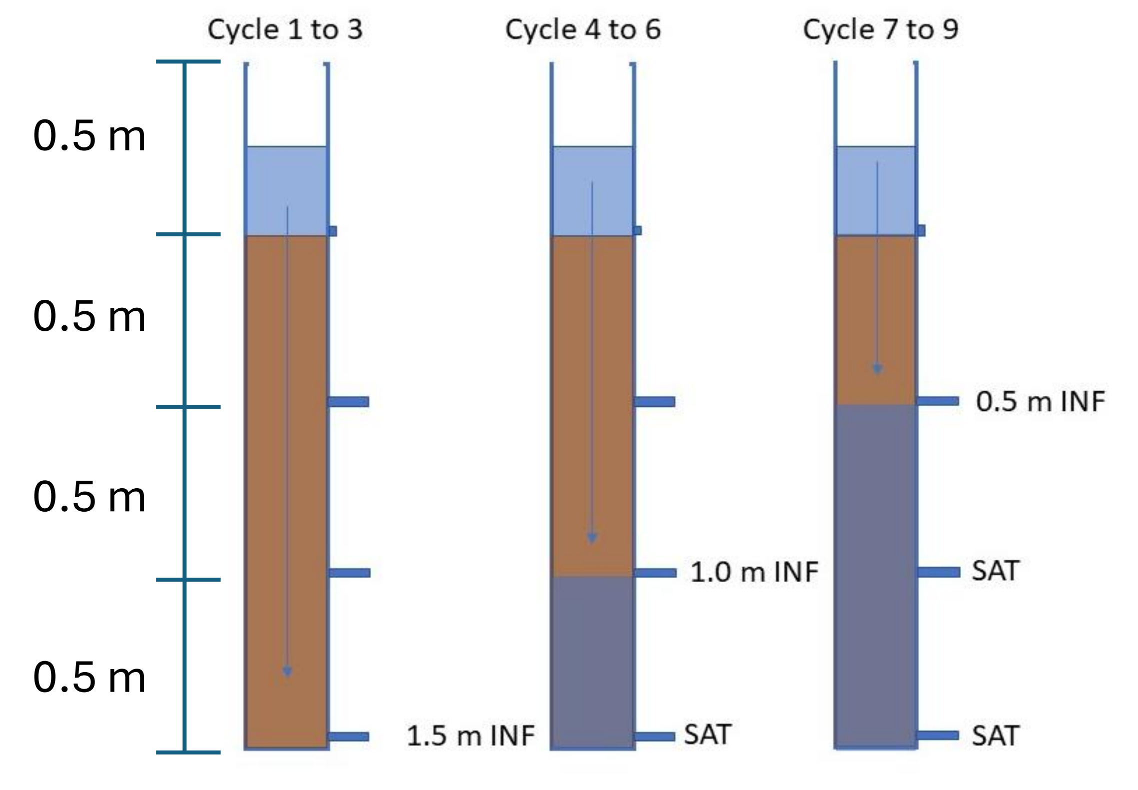
4.2 How the experiments were done



- Columns were 2 m tall and 110 mm diameter
- 4 experimental conditions each in duplicate
- Soil or sand was packed to 1.5 m depth
- Sample ports were 0.5, 1.0 and 1.5 m below soil surface.
- Raising the "water table" allowed sample collection from the 1.0 and 0.5 m sample ports
- Samples post infiltration (INF) and from saturated zone (SAT)

Experiment	A	B	C	D
Media	soil	soil	soil	Course sand
	5% clay, 2% silt, 40% fine sand, 33% medium sand, 20% coarse sand			<1% clay, 90% coarse sand
SSW	low	high	high no OC	high

4.3 How the experiments were done



- 9 x 14-day cycles:
  - Load columns on day 1 and 2
  - Sample on day 2, 3 and 4 - INF
  - Sample on day 4 - SAT
  - 11 day drying period
- Water samples were tested for contaminants
- Soil and sand was tested before and after the experiment.

Experiment	A	B	C	D
Media	soil	soil	soil	Course sand
	5% clay, 2% silt, 40% fine sand, 33% medium sand, 20% coarse sand			<1% clay, 90% coarse sand
SSW	low	high	high no OC	high

5.1 Synthetic stormwater (SSW) concentrations

FUTURE WATER

Contaminant	Low – typical residential stormwater	High – 5 x higher	High with no organic carbon
DOC (mg/L)	13.5	67.7	0
NO3-N (mg/L)	1.2	6.0	6.0
NO2-N (mg/L)	0.2	1.0	1.0
NH4-N (mg/L)	0.5	2.5	12.5
Organic N (mg/L)	2.0	10.0	0
Total N	3.9	19.5	19.5
PO4-P (µg/L)	200	1100	1100
Cr (µg/L)	2	10	10
Cu (µg/L)	14	70	70
Pb (µg/L)	2	10	10
Ni (µg/L)	2	10	10
Zn (µg/L)	84	420	420
Total metals (µg/L)	104	520	520
Relevant Experiment	**A**	**B & D**	**C**

5.2 Synthetic stormwater (SSW) concentrations

FUTURE WATER

Screened against South African Water Quality Guidelines for Freshwater Ecosystems (1996)

Contaminant	**Low – typical residential stormwater**	**High – 5 x higher**	**High with no organic carbon**
DOC (mg/L)	13.5	67.7	0
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Total metals (µg/L)	104	520	520
Relevant Experiment	**A**	**B & D**	**C**

Poor

Unacceptable

5.3 Synthetic stormwater (SSW) concentrations

FUTURE WATER

Screened against South African Drinking Water Standard (SANS 241:2015)

Contaminant	Low – typical residential stormwater	High – 5 x higher	High with no organic carbon
DOC (mg/L)	13.5	67.7	0
NO3-N (mg/L)	1.2	6.0	6.0
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Zn (µg/L)	84	420	420
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Relevant Experiment	**A**	**B & D**	**C**

Does no exceeds SANS 241

Exceeds SANS 241

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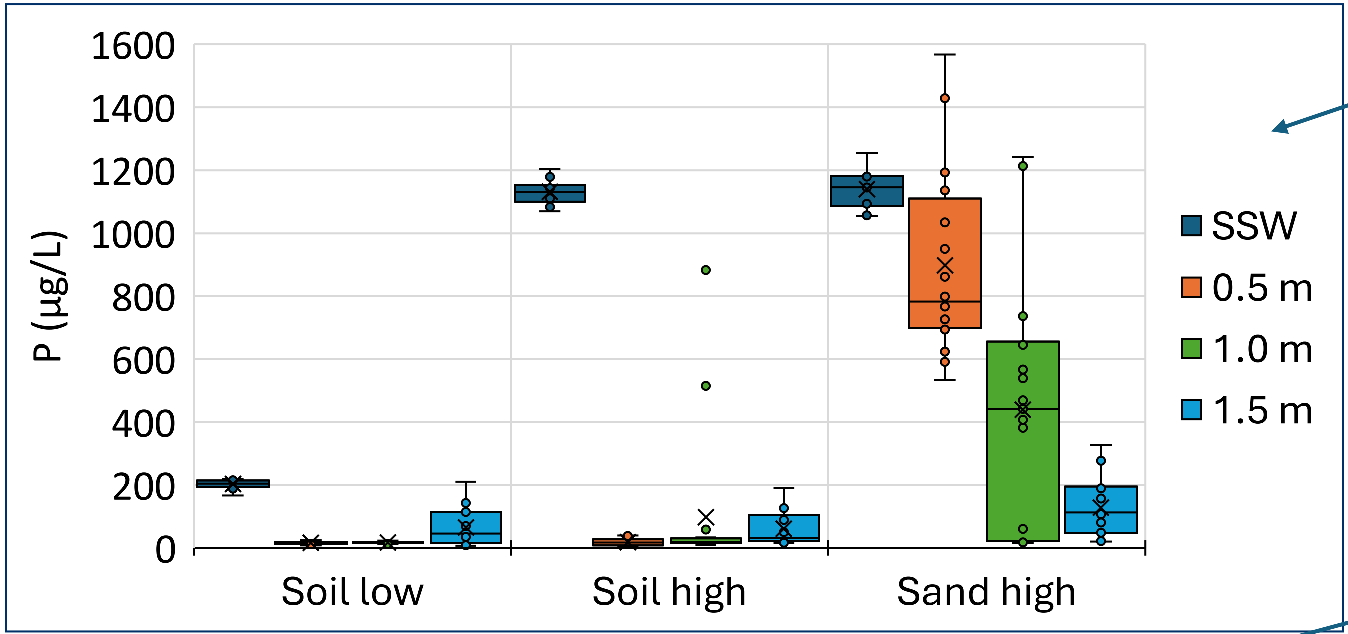
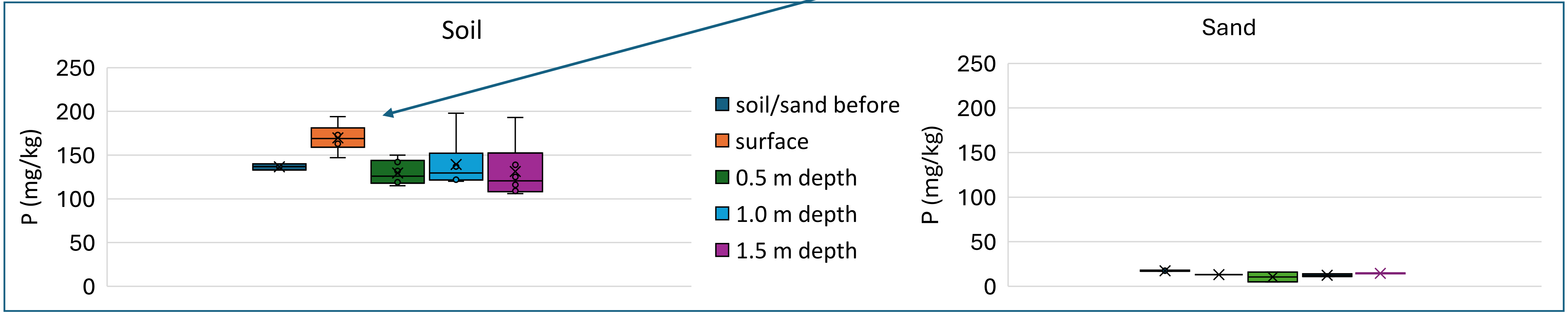
6.1 Results - phosphate



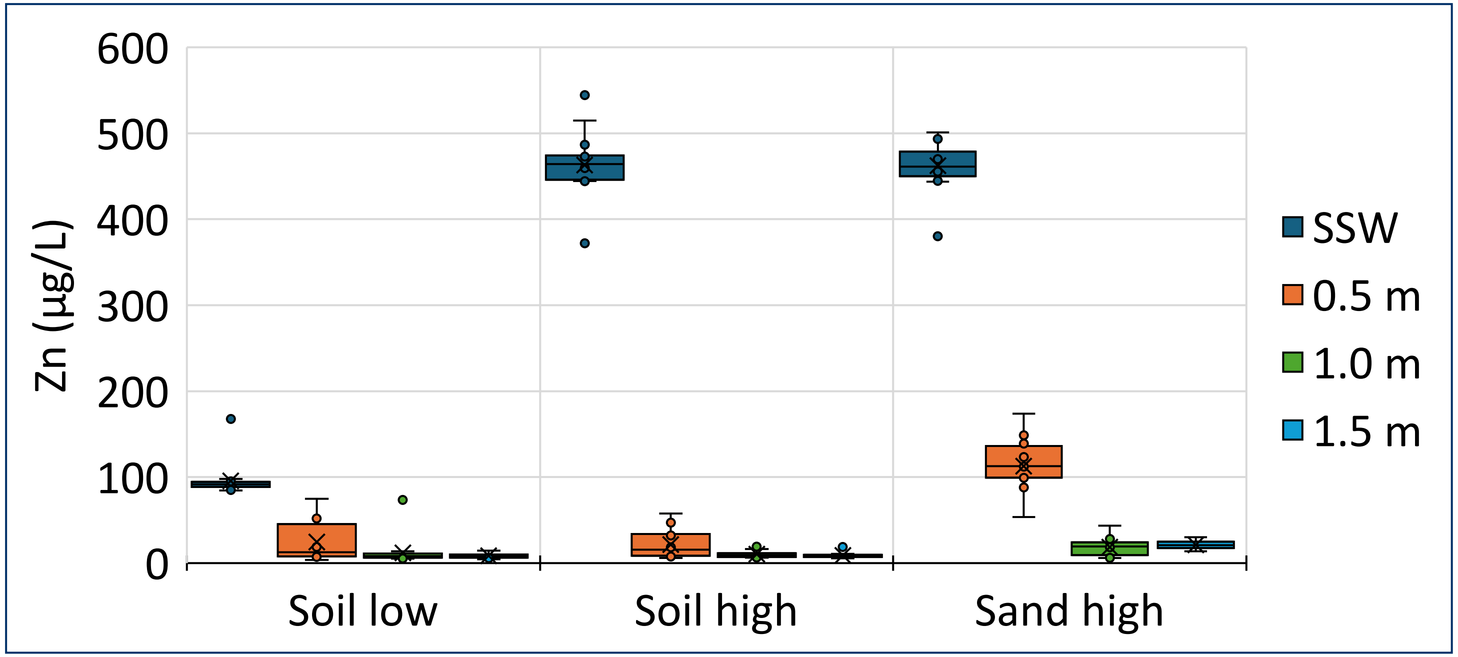
Concentrations in water after infiltration through the soil/sand

- Soil retained phosphate better than sand
- SSW concentration less important

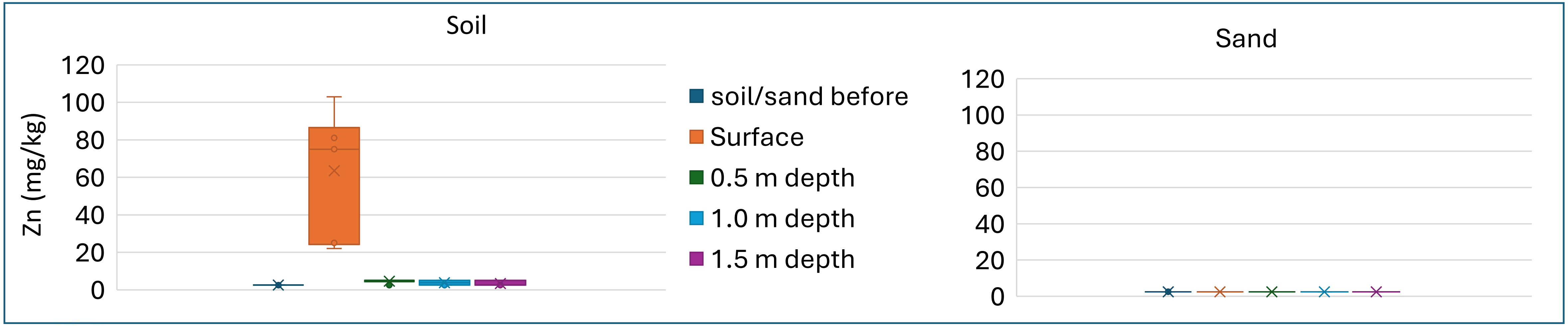
Build up of P in soil at surface



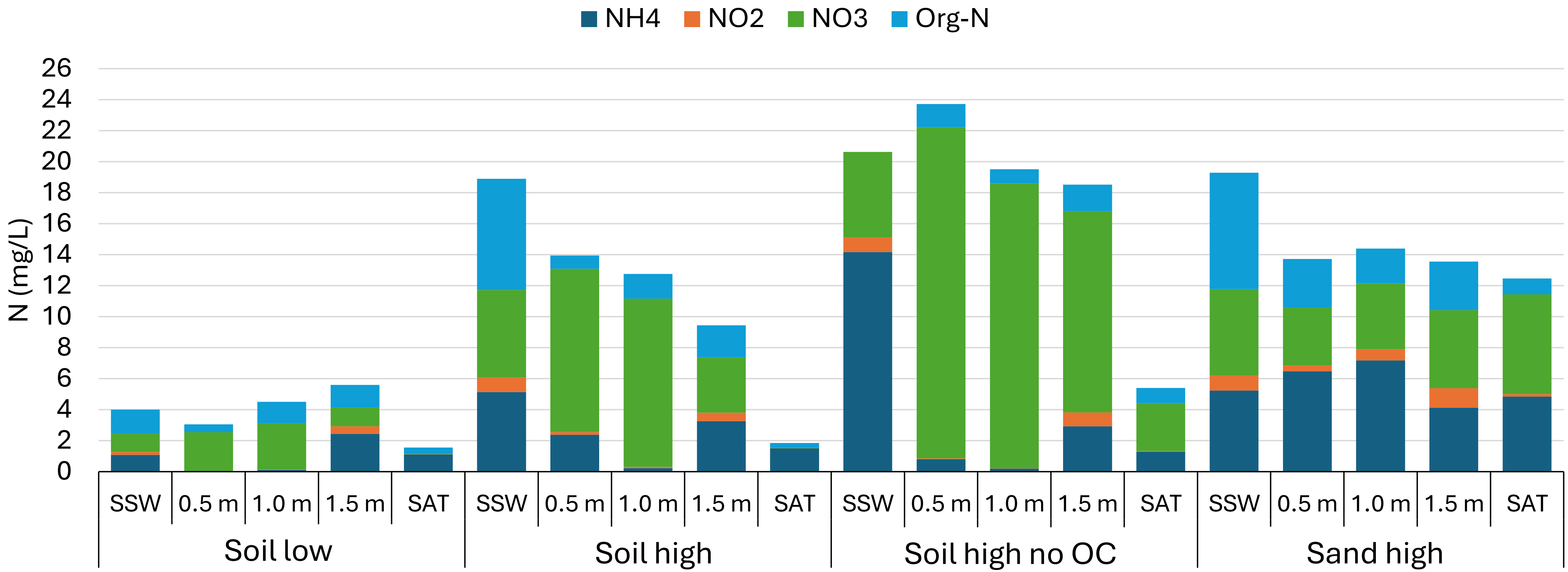
6.2 Results - zinc



- Soil retained zinc better than sand
- No significant difference in effluent concentration for high vs low
- Build up in surface soil



6.3 Results - nitrogen



Mean concentrations of nitrogen species after infiltration and in saturated zone for all experiments

7. Key findings and future research

FUTURE WATER

- Phosphate and metals (Zn, Cr, Cu, Ni, Pb) retention in soils was achieved at low and high concentrations. *What is the total capacity of the soils? How is this influenced by redox conditions?*
- Organic carbon in stormwater may play important role in for nitrogen removal via denitrification in the saturated zone. *How is this influenced by organic matter composition?*
- Concentrations of stormwater contaminants are less important than soil properties (at least in the short term). *How do the soils at this pond compare to soils at other ponds?*
- *Can these results be used to inform an integrated approach to water quality management?*

ISMAR 12 PANEL SESSION

AQUIFER MANAGEMENT, THE MICROBIOME AND BIOSURVEILLANCE – FROM SCIENCE TO OPERATIONS

Wednesday 30th April
Parallel 4
14h00 – 16h00

DR. CHRISTOPHER BRYAN (FACILITATOR)
Geomicrobiologist - BRGM: French Geological Survey, Orleans, France

DR. JENNIFER HARRIS
Geomicrobiologist - BRGM: French Geological Survey, Orleans, France

MR. KOBUS PRINSLOO
Senior Hydrogeologist - Umvoto Africa, Cape Town, South Africa

DR. BRIDGET MAKHAHLELA
Microbiologist - Future Water Institute, University of Cape Town, South Africa

Panel Discussion & Workshop:

- The ecosystem services provided by the groundwater microbiome.
- Where the science is at and what DNA analysis of the microbiome can tell us.
- How microbial biodiversity can be used in the biosurveillance of aquifer health.
- The integration of bioindicator tools into aquifer management – especially during MAR.
- Raising public awareness of aquifer health, and the “invisible microbiome”.

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Acknowledgements

Co-authors: K. Carden, and C. T. Tanyanyiwa

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SPES BONA

FUTURE WATER

UNIVERSITY OF COPENHAGEN

MINISTRY OF FOREIGN AFFAIRS OF DENMARK

DANIDA | INTERNATIONAL DEVELOPMENT COOPERATION

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