In-situ Iron Removal by Ozonation: A Novel Approach to Protect Production Boreholes and Water Supply

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Introduction

- Fe^{2+} and Mn^{2+} threaten sustainability of wellfields due to water Quality Problems
  - Aesthetic issues
  - Potable issues
  - Health issues
  - Supply Problems
    - Borehole clogging

Ultimately limits use of the water
and/or
increases costs to maintain supply
giving groundwater a bad name


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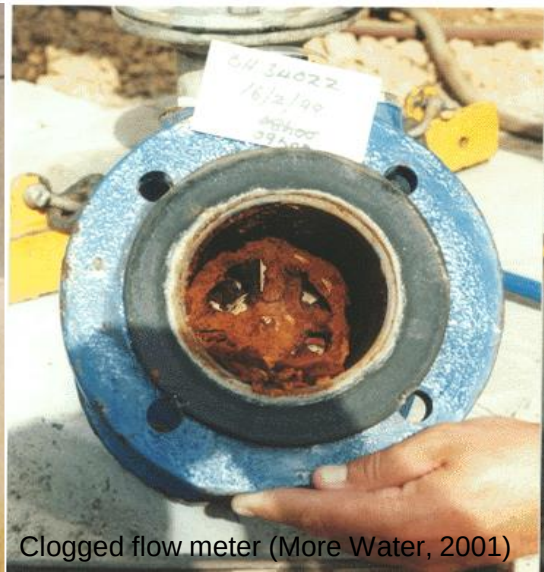

Clogged flow meter (More Water, 2001)

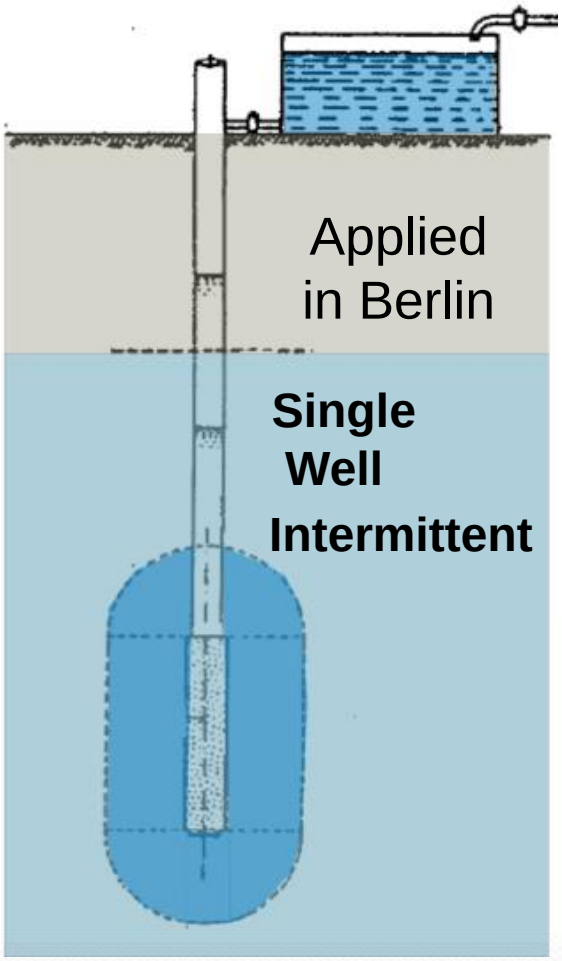
Iron (and Mn) removal principle

- Iron is soluble in reduced form (Fe^{++})
- Iron is insoluble in oxidized form (Fe^{+++})
- Aquifers with reducing conditions yield Fe^{++}
- Iron is removed by oxidation and precipitation as various (hydr)oxides
- Either *ex-situ* or *in-situ*
- *In-situ:* create oxidizing zone in aquifer to retain insoluble iron (Fe^{+++}) in the aquifer

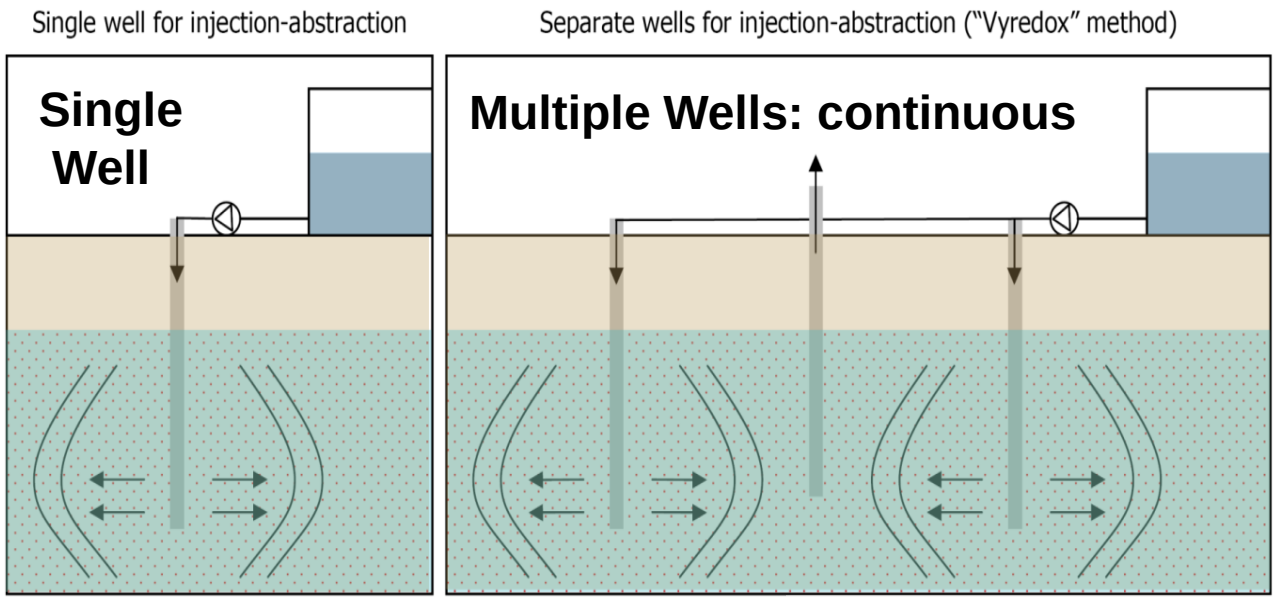
In-situ iron removal methods

Subsurface iron removal patent (1900)

Since the 1970's several different designs implemented with the main two including:



Modified from Olthoff (1986)



Modified from van Halem *et al.* (2008)

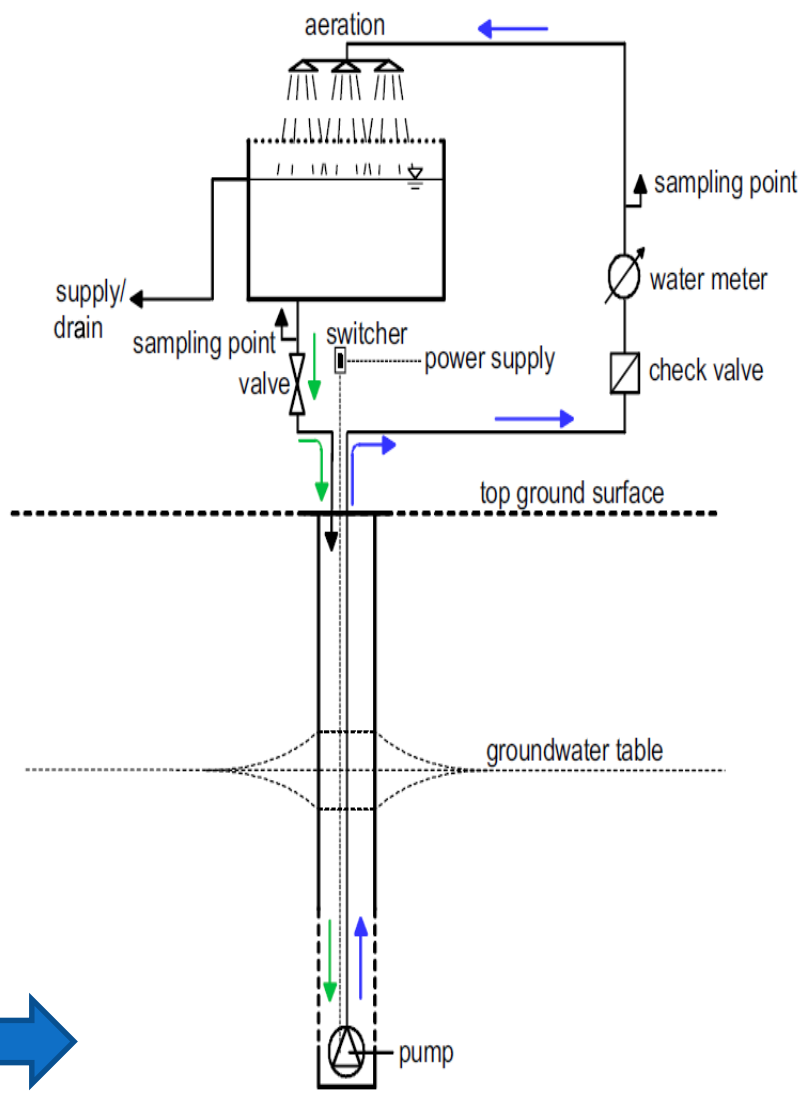
Applied in:

- Bangladesh
- China
- Denmark
- Egypt
- France
- Germany
- India
- Norway
- Sweden
- Switzerland
- The Netherlands
- USA

Benefits of in-situ iron removal

- **Reduce or obviate the need for above-ground removal treatment**

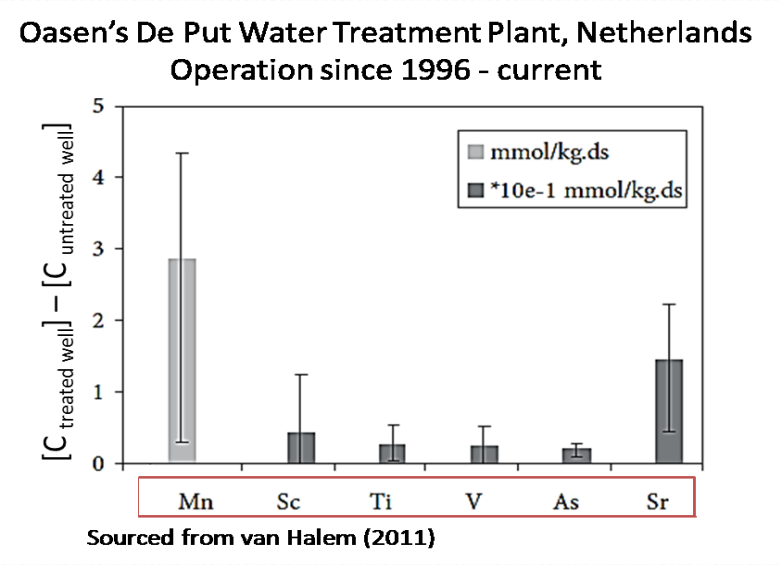
- In addition:
  - Simple and Cost-effective to operate
  - Lower space requirements
  - Lower energy consumption
  - No chemicals necessary
  - No hazardous by-products formed

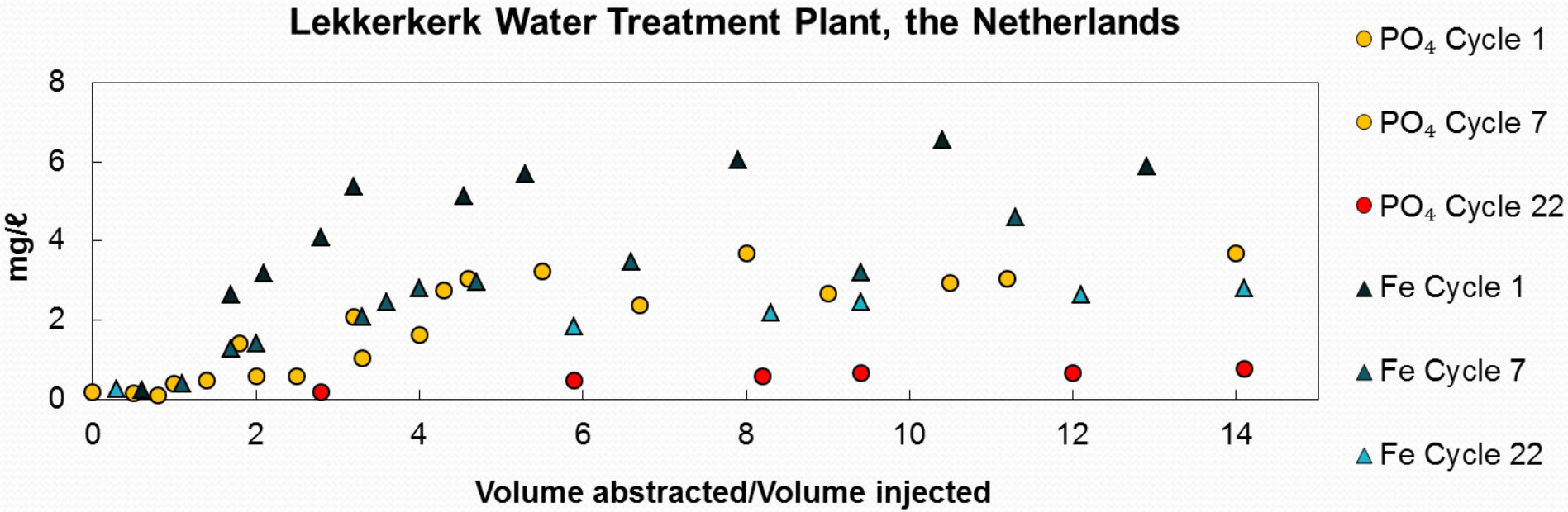


For example:
An in-situ iron removal set-up in India which produces 2 m^3 of drinking water per day at US$ 1
(Sen Gupta *et al.*, 2009)

Benefits of in-situ iron removal

- **Co-removal of other ions**
  - Arsenic (As^{3+})
  - Phosphate (PO_4^{3-})

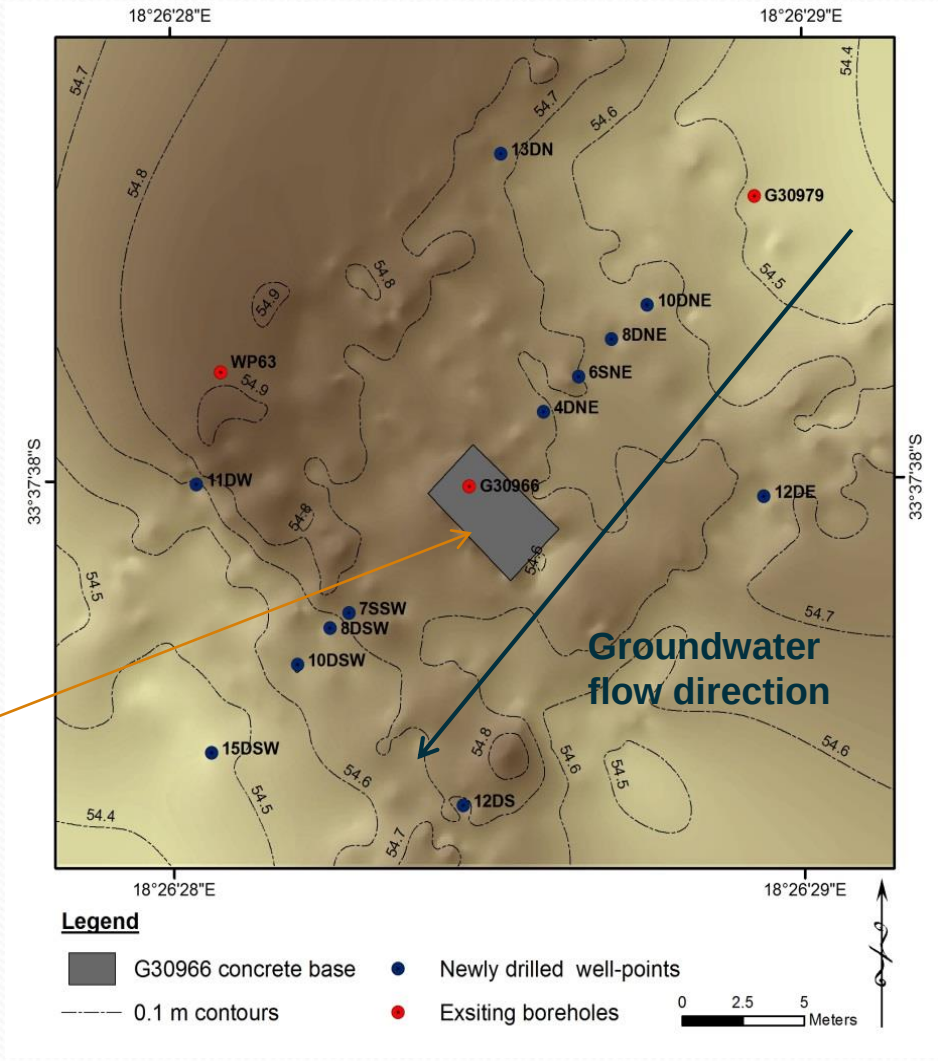




Atlantis Aquifer pilot study

- Reduce Fe and Mn in abstracted water below WHO (2008) guidelines
  - Fe < 0.3 mg/ℓ
  - Mn < 0.1 mg/ℓ
- Vyredox-approach
- Ozone as the oxidant

G30966
Mean Fe = 0.5 mg/l
Mean Mn = 0.2 mg/l



Experimental Layout

- Prototype Design

Testing Ozone/Oxygen Injection

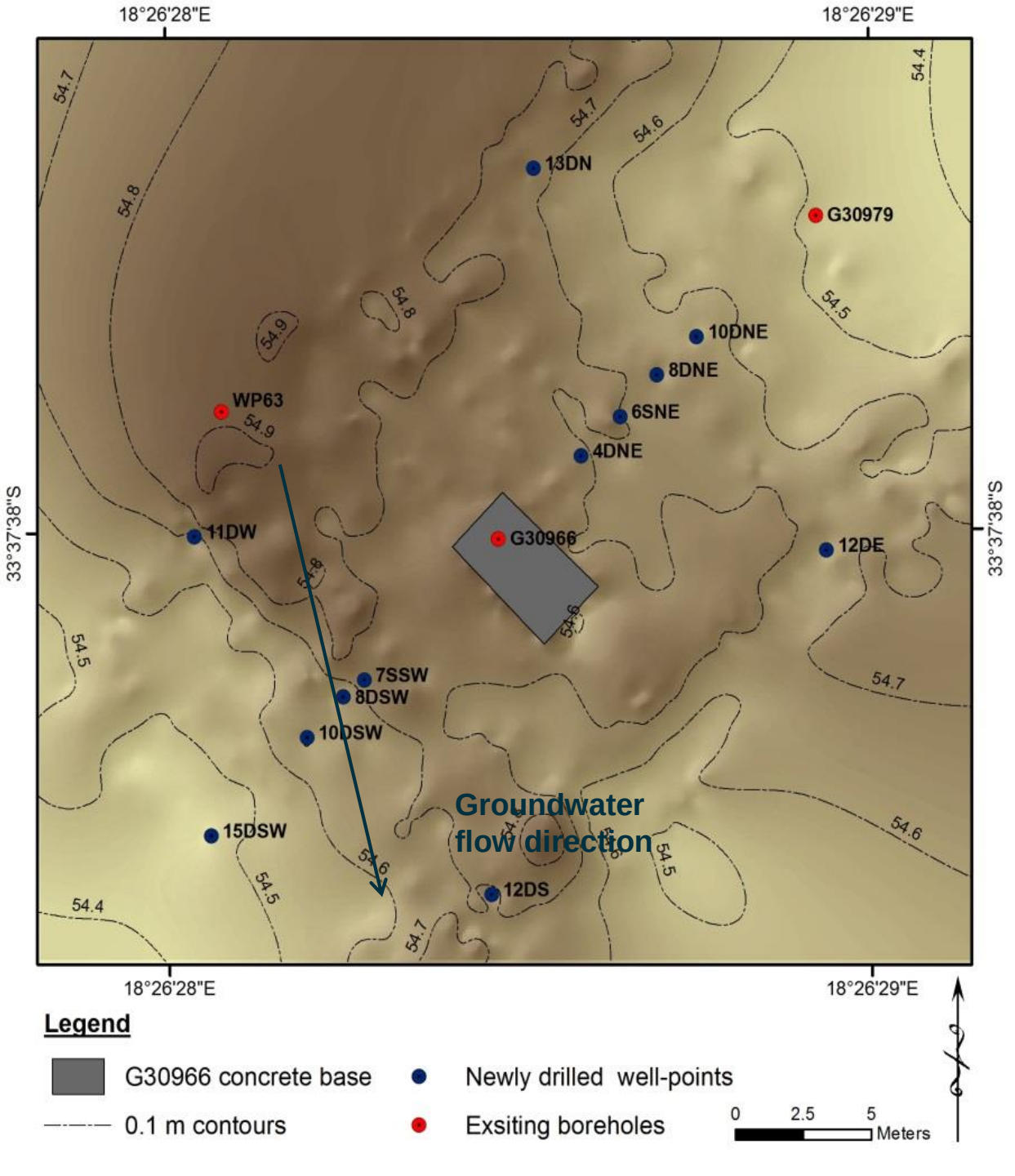
- Four different injection configurations applied
- With/without abstraction

High water table

DWS Assistance . . . &

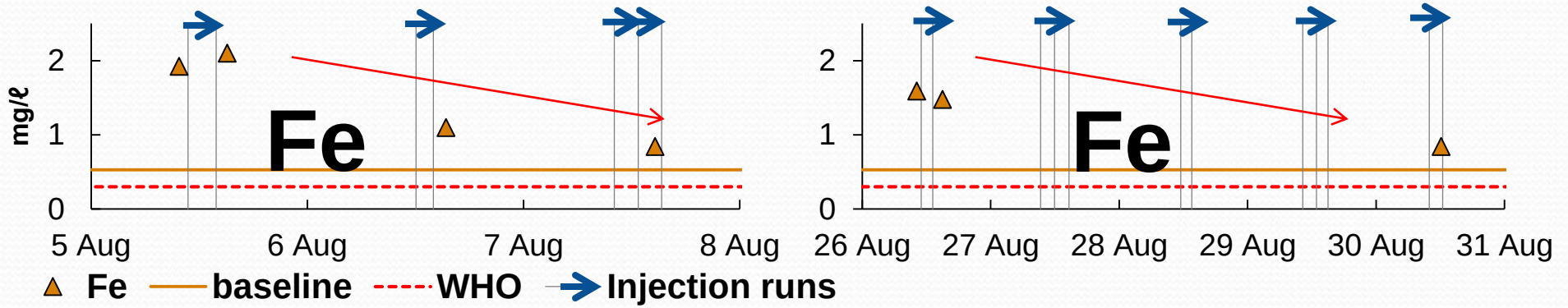
. . . Capacity Building

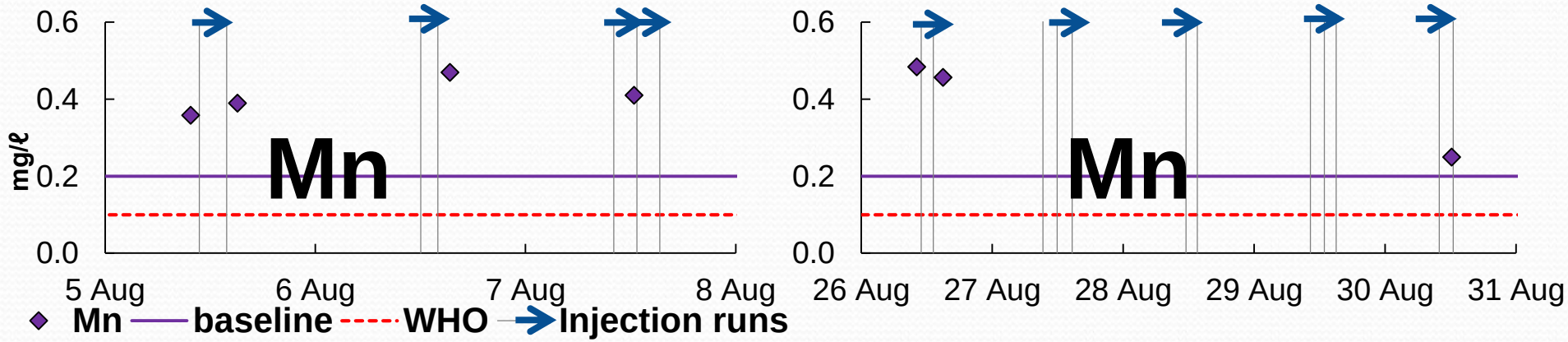
Site Layout


18°26'28"E
18°26'29"E
33°37'38"S
13DN
G30979
10DNE
8DNE
6SNE
4DNE
WP63
11DW
G30966
12DE
7SSW
8DSW
10DSW
15DSW
12DS
Groundwater flow direction
54.7
54.8
54.9
54.6
54.5
54.4
Legend
G30966 concrete base
0.1 m contours
Newly drilled well-points
Exsiting boreholes
0
2.5
5
Meters

Findings

- **Injection at 4DNE no abstraction**
  - **Injection 4 m from production borehole**
  - **Injection rate 1.8 m^3/h**
  - **Injected DO_3 ranged 0.3-0.5 mg/ℓ; DO ranged 15-19 mg/ℓ**

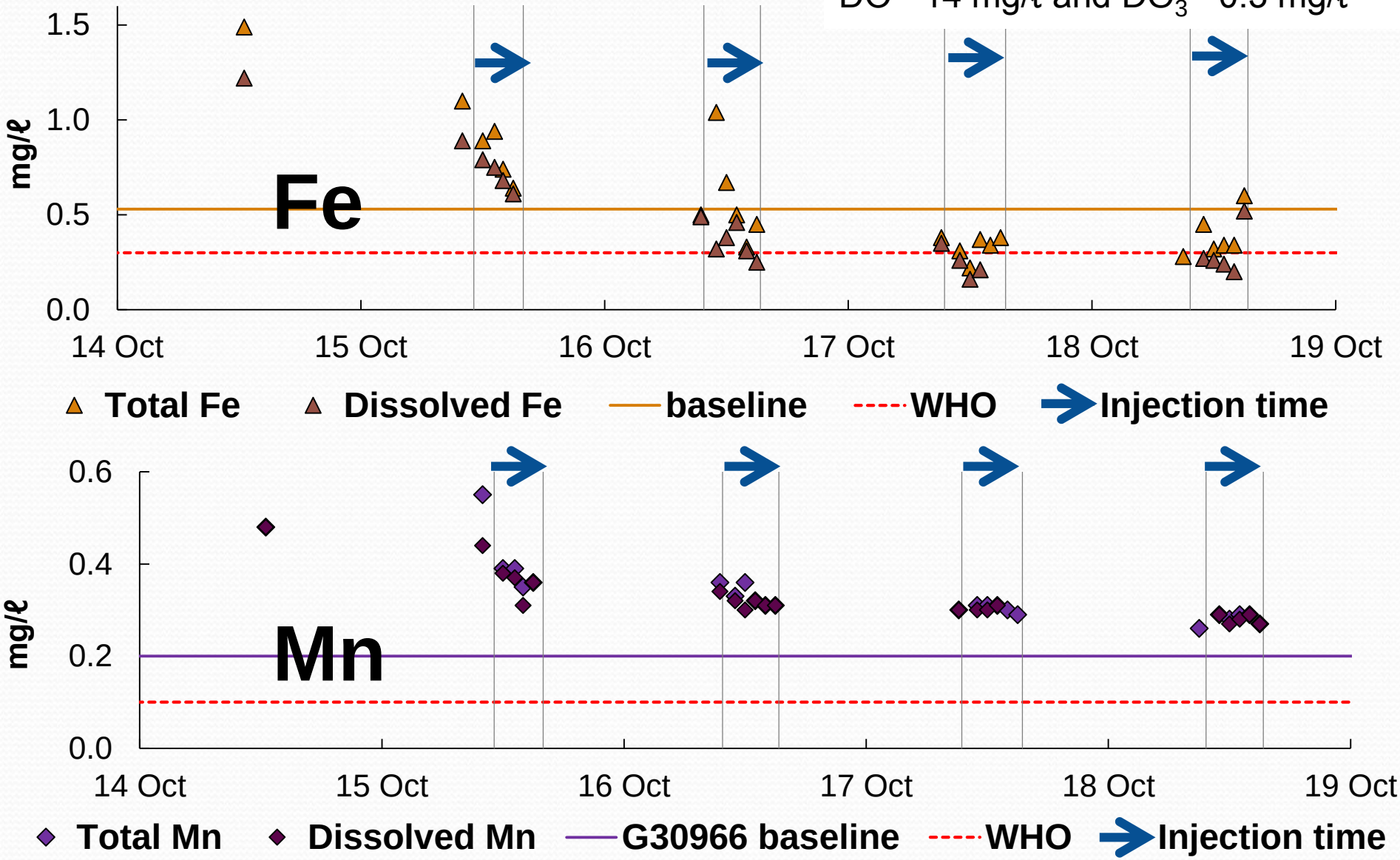




Findings – Production Borehole

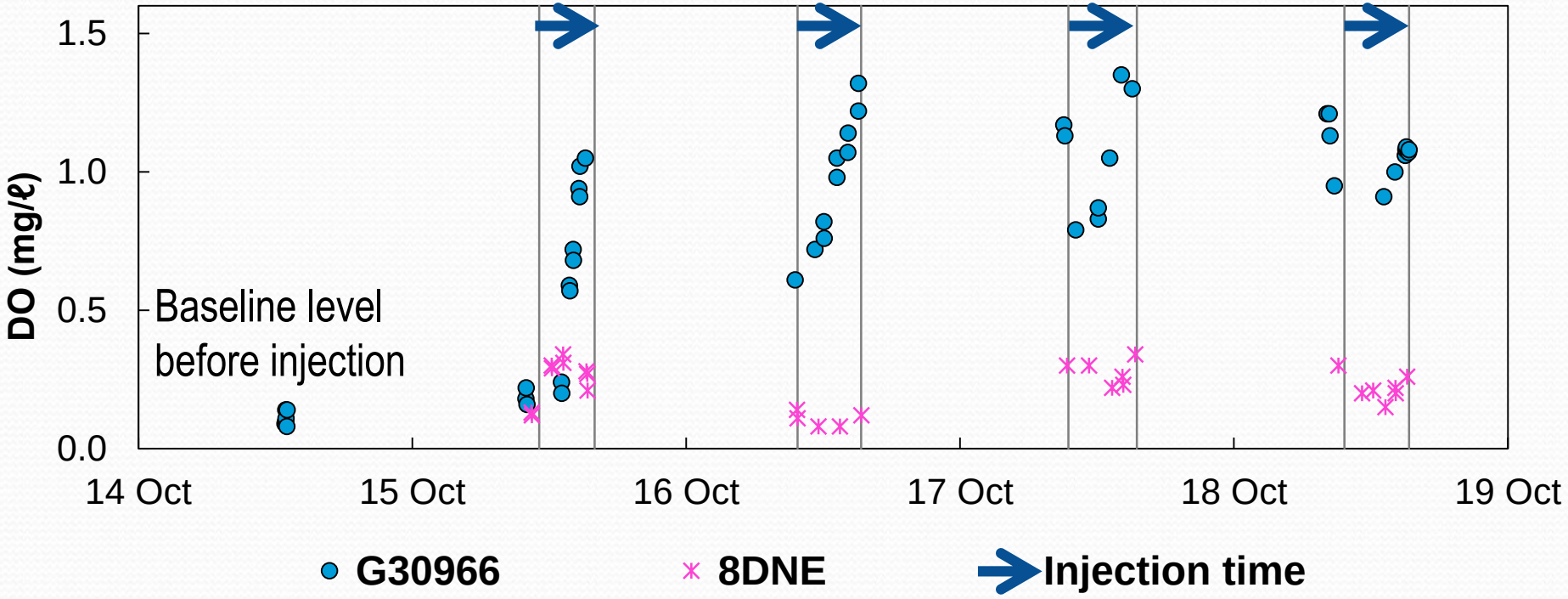
- **Injection at 4 m with abstraction**

Injected 10 m^3 per day at 4DNE at DO ~14 mg/ℓ and DO_3 ~0.3 mg/ℓ



Findings – Production Borehole DO

- **Injection into 4DNE (4 m)**
- **Concurrent abstraction**
- **DO at Prod Bh G30966 and 8DNE (8 m)**

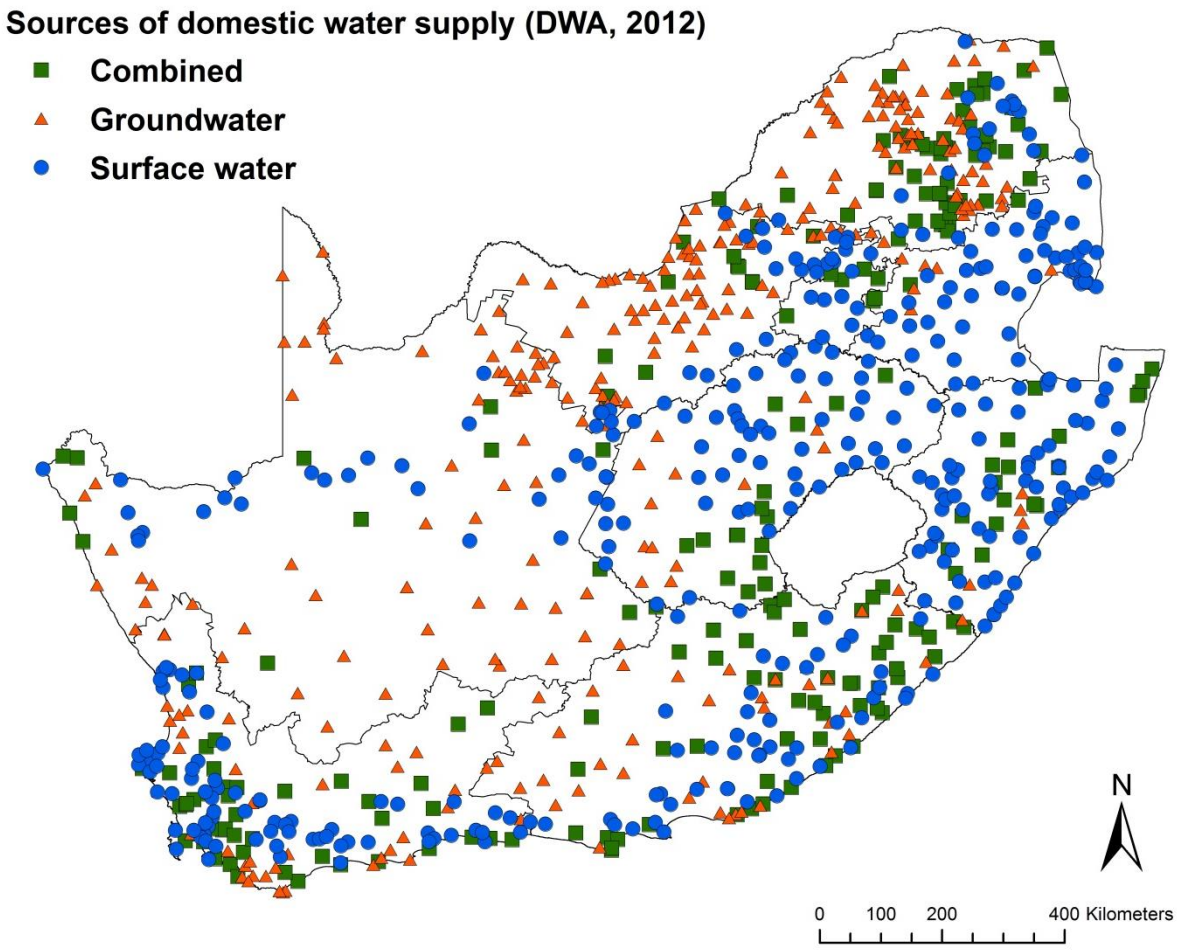


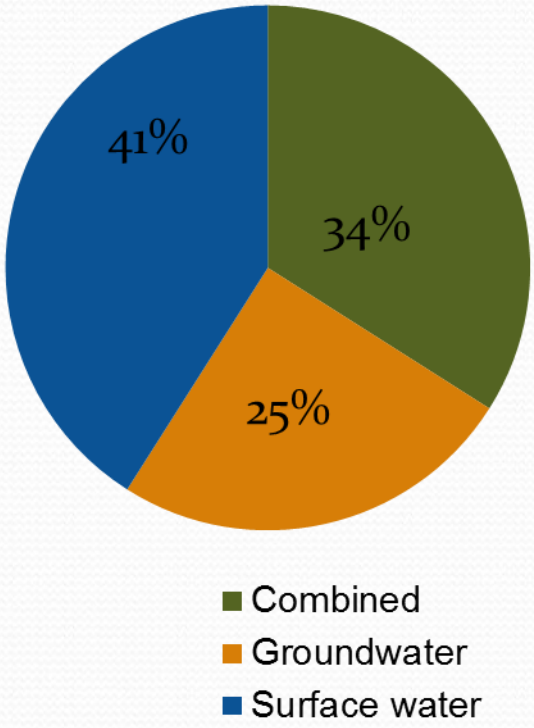
Research Conclusions

- The results confirmed that *in-situ* iron removal in the Atlantis Aquifer was feasible even at a low injection rate and volume (compared to international case studies)
- Using ozone was innovative and may increase the efficiency of *in-situ* Fe and Mn removal from DOC-rich groundwater
- Ozone generation was also very effective in providing a high DO in the subsurface comparable to using oxygen gas
- Higher pH conditions and longer term applications are needed for the desired Mn removal
- Promising technique for South African primary aquifers (and potentially secondary aquifers) as it treats the cause of the problems maintaining good quality groundwater, even at a small-scale application

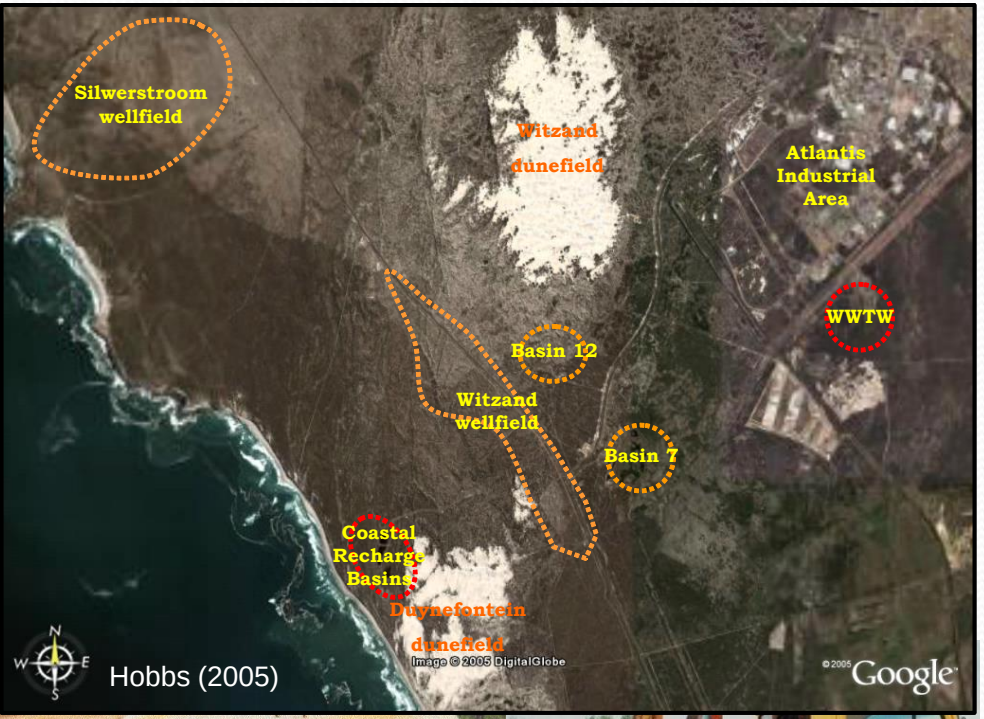
Groundwater in South Africa

- Maintaining water security is a global challenge
- South Africa ranked the 30th driest country
- Groundwater plays a significant role in domestic water supply

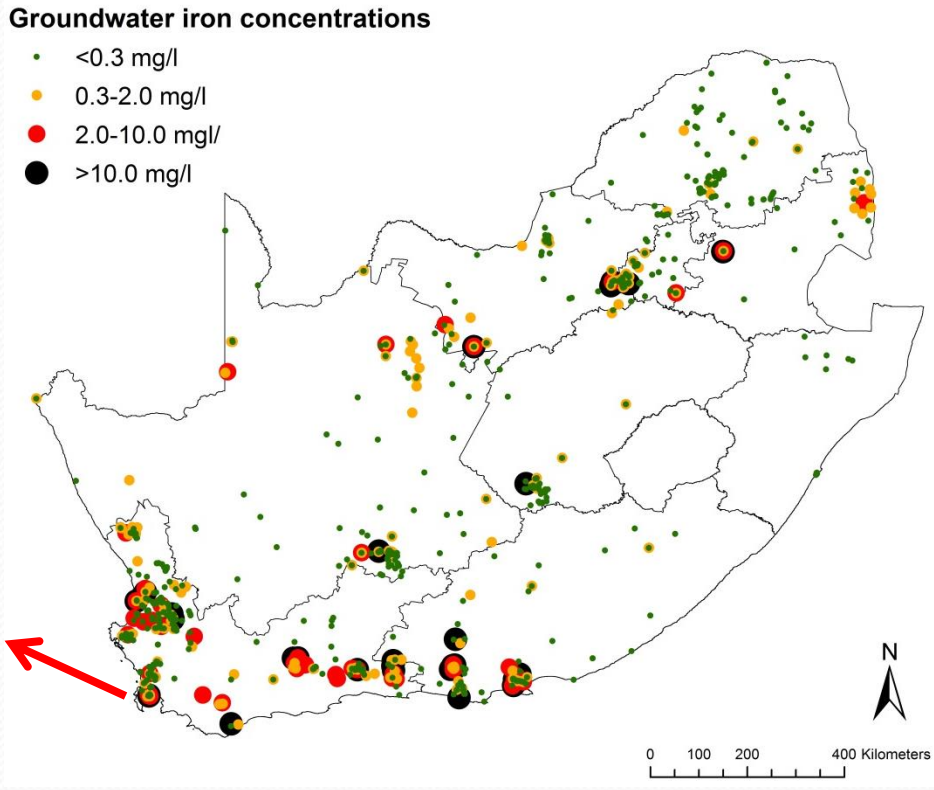


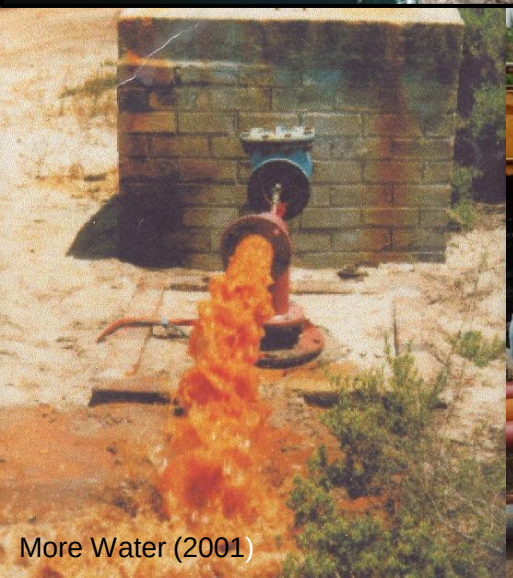


South Africa's experience

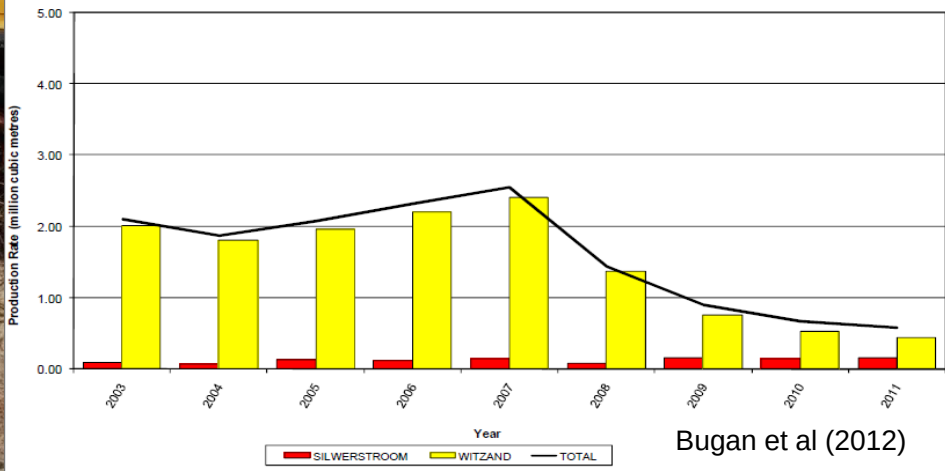


Hobbs (2005)




More Water (2001)


Tredoux & Cavé (2002)



Bugan et al (2012)

Research Impact

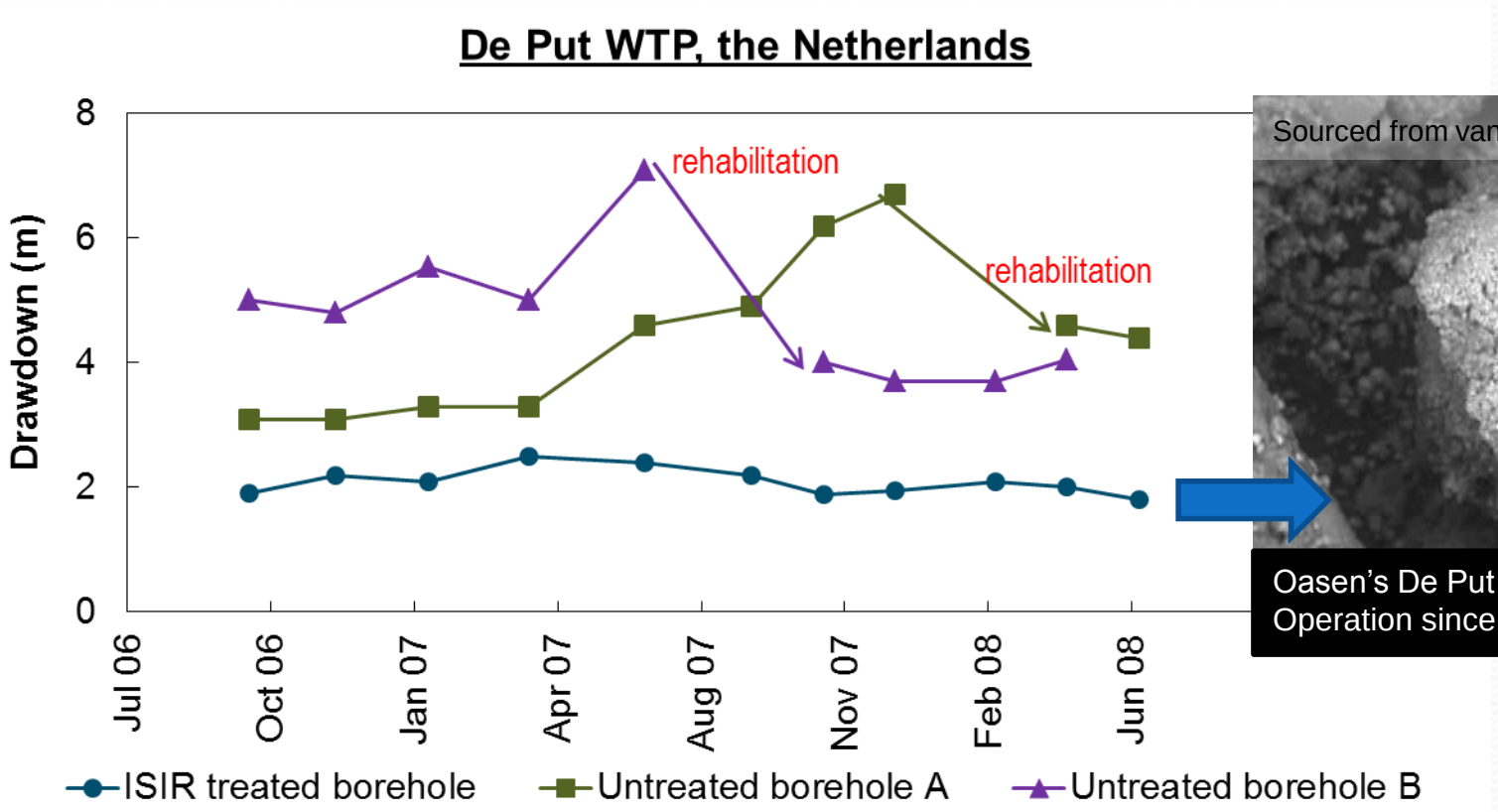
- Pilot scale testing completed successfully
- Next step full scale application at operational water supply

Key advantage:

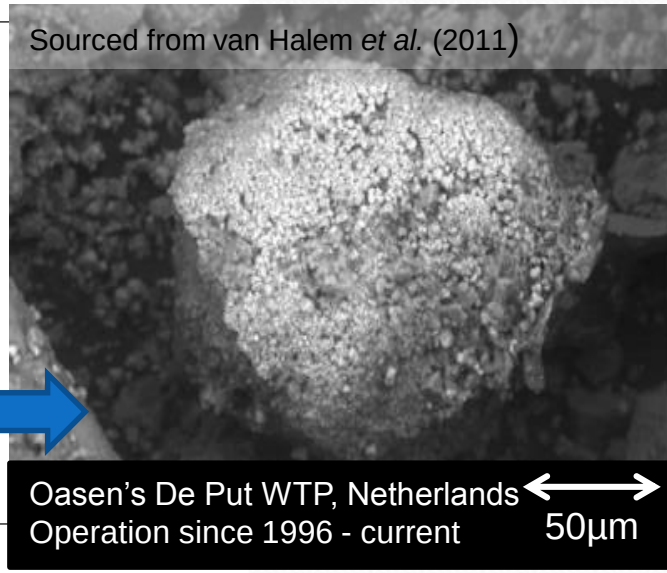
- In situ treatment permanently addresses the *cause* of the problem
- Only alternative is rehabilitation which only addresses the *symptoms* and only provides temporary relief at a very high cost

Benefits of in-situ iron removal

- **Improving production borehole longevity**
  - Reduction in iron-related clogging processes at the borehole
  - Fe(III)-oxides reduce potential for further mobilisation



Data taken from Appelo *et al.* (1999)



Thank you for your attention

Further reading:

To order the report, *Preventing production borehole clogging by in situ iron removal in South African aquifer systems* (**Report No. 2070/1/14**) contact Publications at Tel: (012) 330-0340, Email: orders@wrc.org.za or Visit: www.wrc.org.za to download a free copy.

Acknowledgements

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