IMPLEMENTATION OF A NANOSCALE ZERO-VALENT IRON REACTIVE ZONE FOR THE TREATMENT OF TCE IN A DEEP AQUIFER, VALCARTIER, QUEBEC, CANADA

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Presentation Outline

- Context of the pilot test
- Theoretical background
- Description of the pilot test
  - Geology and hydrogeology
  - NZVI injections
  - Groundwater recirculation system and dissolved H_2 system
- Results
  - Geochemical evolution
  - TCE treatment
- Conclusions

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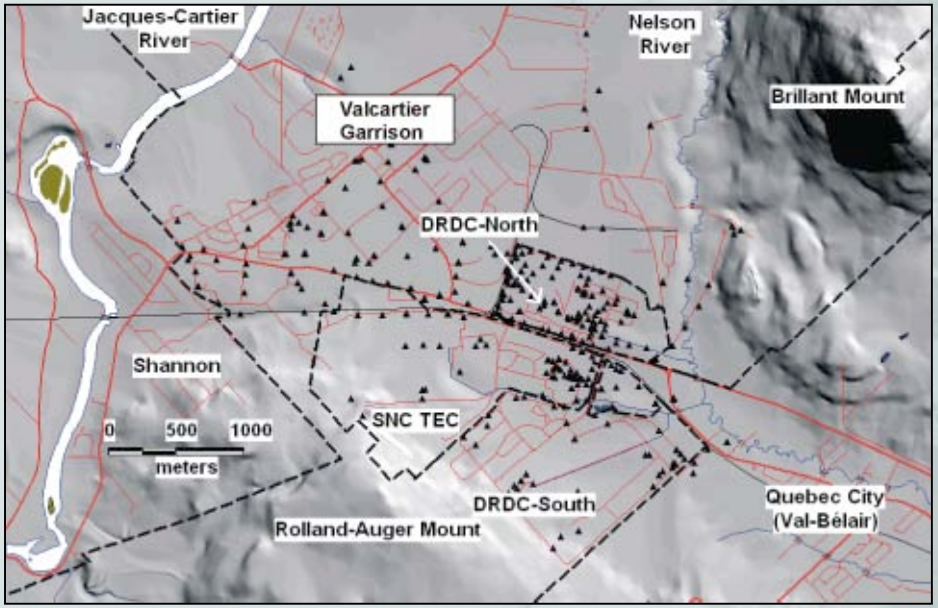
Pilot-Scale Test Location

- Valcartier Garrison is located about 30 km north of downtown Quebec City.
- The Municipality of Shannon is located west of the site and Val-Belair (Quebec City surrounding area) located east of the site.
- West of the site is the Jacques-Cartier River.



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Context of the Pilot-Scale Test

- The Department of National Defence (DND) in responsible for the environmental management of Valcartier Garrison.
- TCE was discovered in groundwater in 1997 in a few monitoring wells and a drinking water well.
- In 2000, DND was informed of the presence of dissolved TCE in private wells in Shannon.
- As a short-term solution, DND allocated funds to build a municipal water supply in Shannon.
- In April 2006, Golder and GAIA were selected to demonstrate the applicability of in situ injection of nanosized iron as a containment solution.

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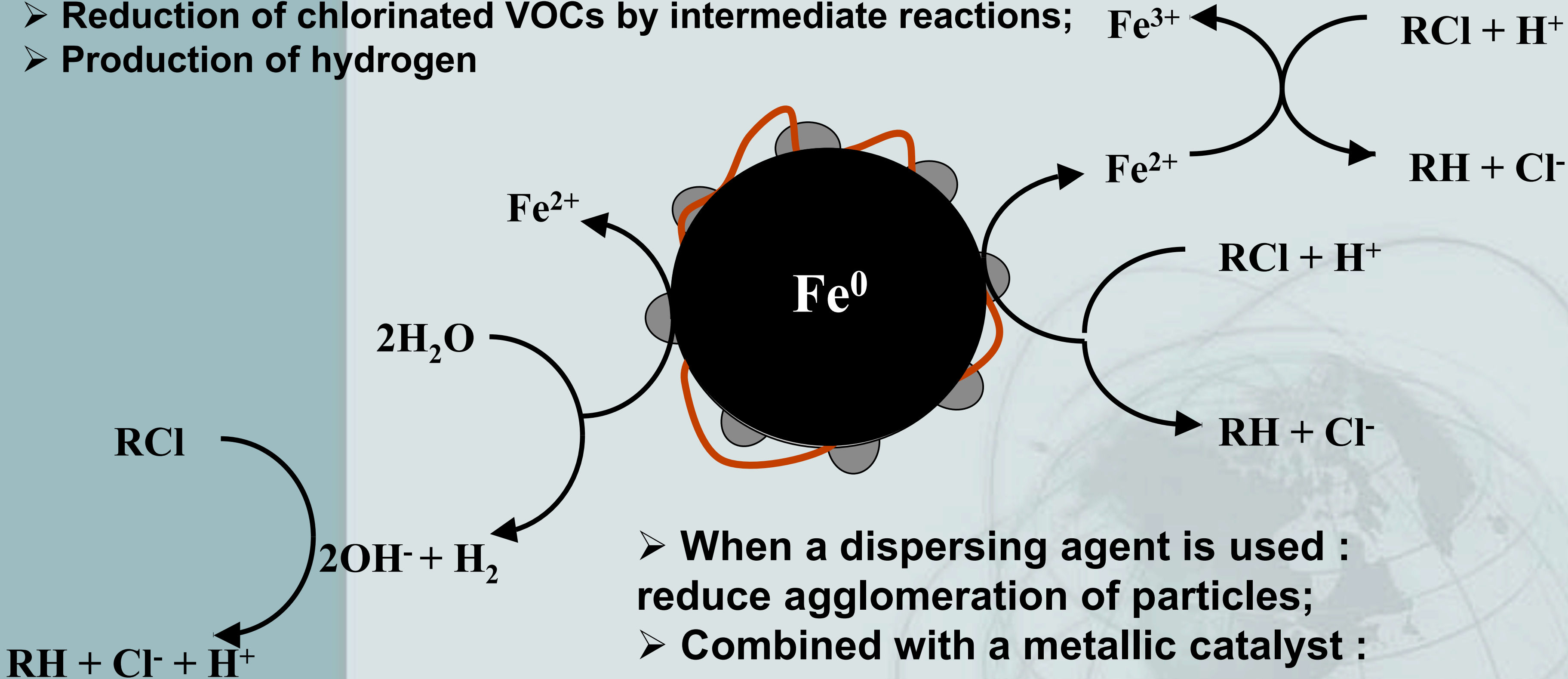
NZVI Technology - Fiction and Reality

- Nano Scale Zero-Valent Iron : NZVI
- Particle size ranging from 40 to 100 nm;
- Enhance mobility and reactivity in comparison with micro sized zero-valent iron (higher specific surface).

Reality	Fiction	Why?
Mass reduction of contaminants: between 60 to 90% in 6 months to 1 year	100% of mass reduction of contaminants in hours	Laboratory results vs field, perfect mix, perfect contact
Limited radius of influence	Migration of NZVI particles on very important distance	Floculation, agglomeration, settling, interaction with other species (ex. iron oxides)
NZVI is nanosized at production stage but greater in diameter when injected	NZVI is nanosized	Rapid agglomeration of the particles in the aquifer right after injection

Theoretical Background

- Surface reactions - corrosion – iron oxide production;
- Reduction of chlorinated VOCs by contact reactions;
- Reduction of chlorinated VOCs by intermediate reactions;
- Production of hydrogen



- When a dispersing agent is used : reduce agglomeration of particles;
- Combined with a metallic catalyst : higher reaction kinetic.

Effects

- Reduction of VOCs, PCBs, pesticides, metals, etc.;
- Fast consumption of electron acceptors;
- Lower Oxydo-Reduction Potential (ORP).

} Stimulate VOC biological reduction

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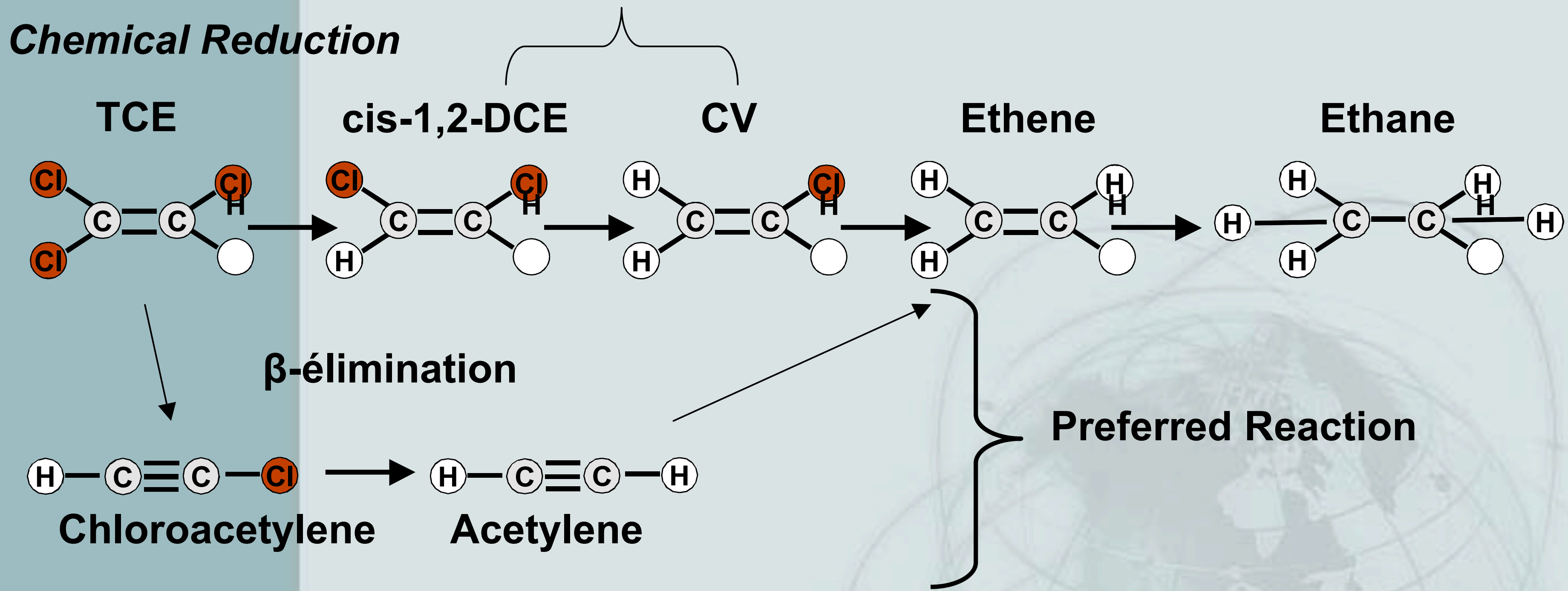
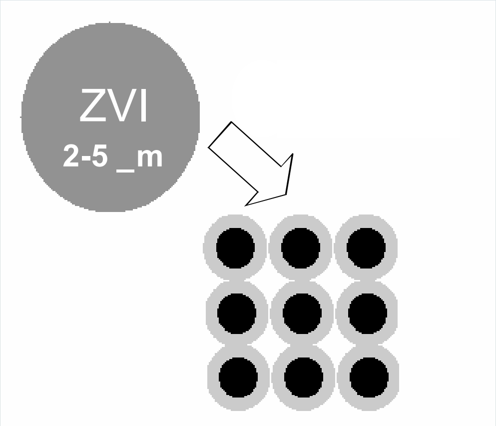
Reactions Leading to Reduction of TCE

Chemical Reduction (*hydrogenolysis*) and/or
Biological Reduction (*reductive dechlorination*)



From: Roberts, A. L., et. al, 1996 Reductive Elimination of Chlorinated Ethylene by ZV Metals. En. Science and Tech.

Production



Golder-NZVI iron is produced by grinding Fe^0 particles

Application of NZVI Technology in the Context of Valcartier

Valcartier NZVI Pilot-Scale Test:

- Dissolved TCE plume to be treated
- Treatment planned to control dissolved TCE plume migration
- Initial duration of the pilot-scale test : 10 months
- TCE treatment performance criteria: 5 µg/l

Objectives :

1) Install and operate an NZVI in situ reactive zone to control plume
2) Demonstrate the efficiency of the technology to reach performance criteria
3) Identify the factors affecting the scale-up of the technology to a full-scale implementation

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Project Schedule

- **Summer 2006**
  - Lab and field experimentation;
  - Installation of monitoring and injection system
- **Fall 2006**
  - NZVI injection
- **Winter 2007 (technology validation period)**
  - Monitoring of the treatment process evolution
- **Summer 2007 (prolongation)**
  - Complemental characterisation work:
    - Completion of CPT profiles to better define the local hydrostratigraphy
    - Supplemental monitoring well installation with direct-push;
    - Microbial study (BART tests, DGGE analyses, PCR analysis, biodegradation test, etc.).
- **Fall 2007 (prolongation)**
  - Design and installation of the dissolved H2 and groundwater recirculation systems

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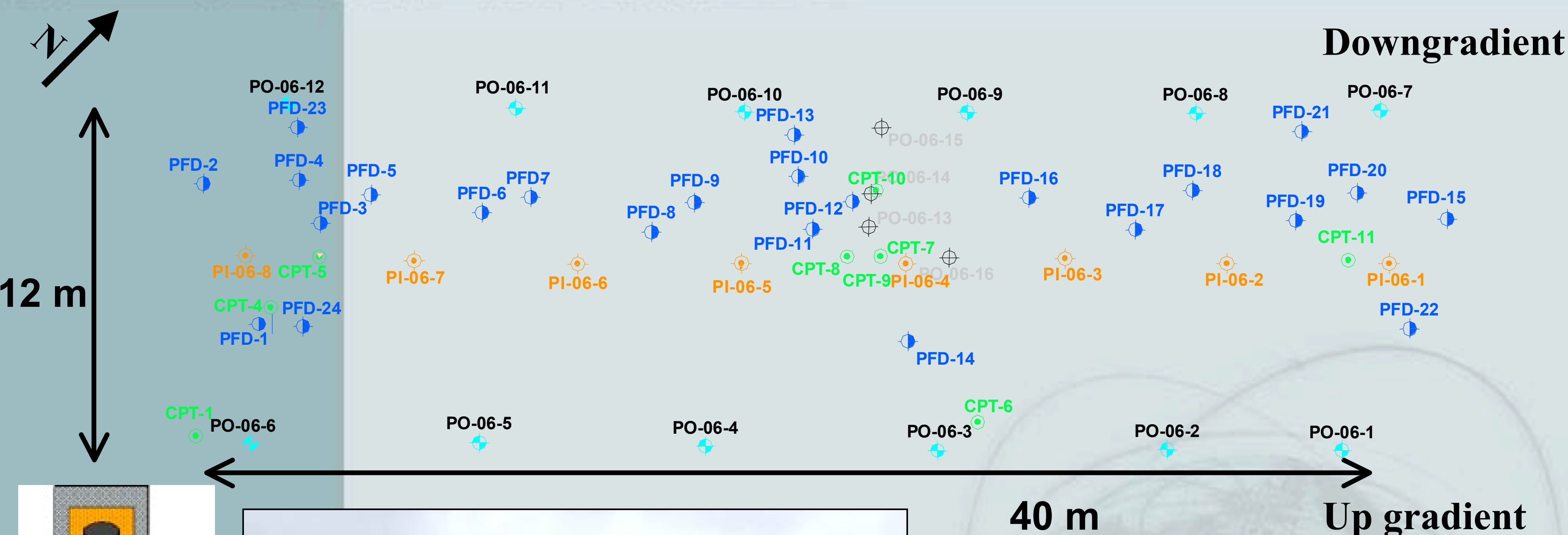
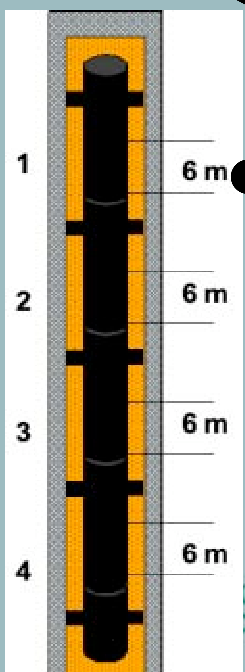
Pilot-scale Test Set-up





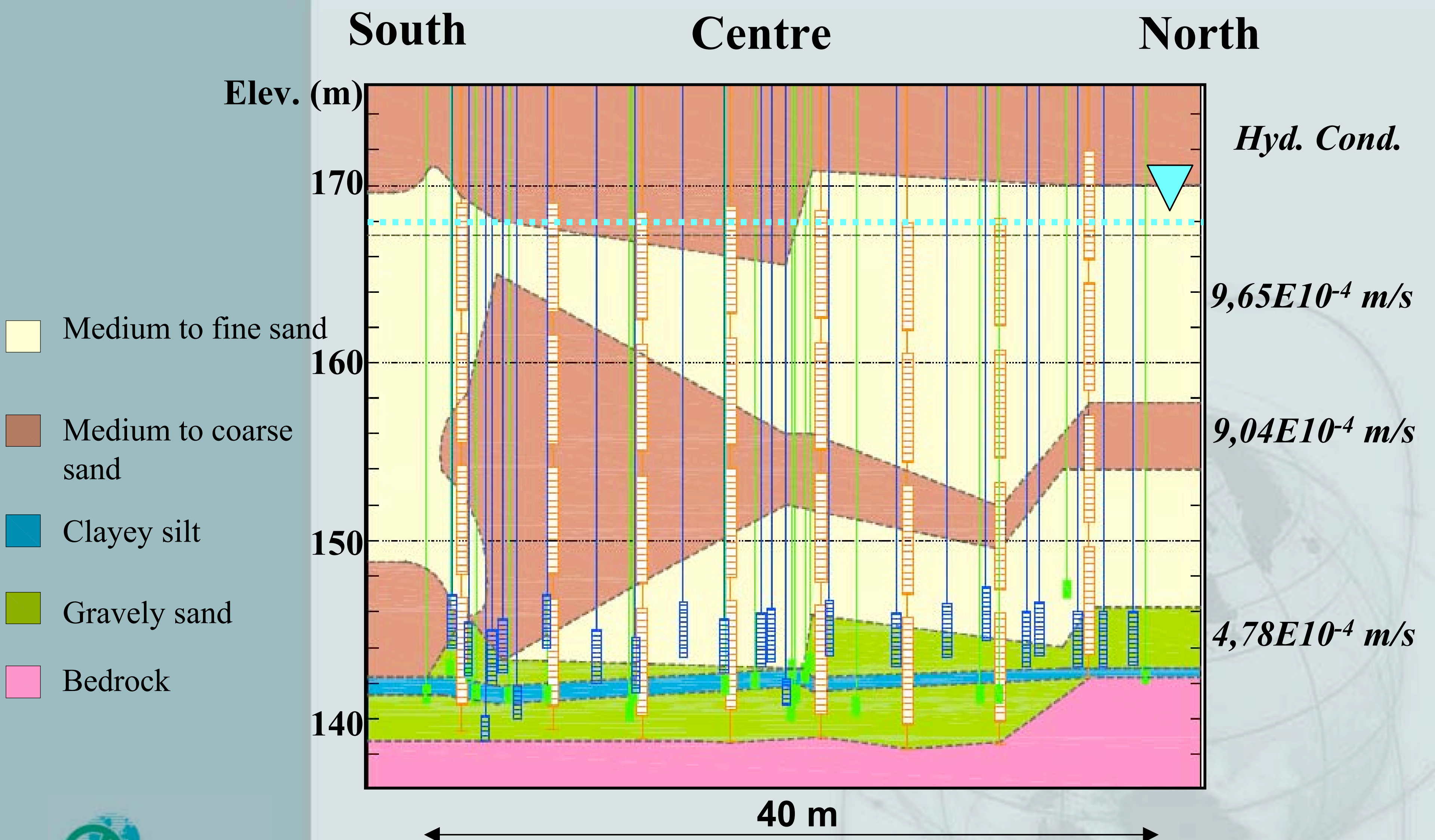
PO-06-1 Upgradient and downgradient monitoring wells (12x2)

PI-06-1 Injection wells (8)

PFD-22 Small diameter monitoring wells

CPT-6 CPT-Resistivity Profiles

Hydrostratigraphic Context



Groundwater migration velocities ranging between 13 to 68 m/yr

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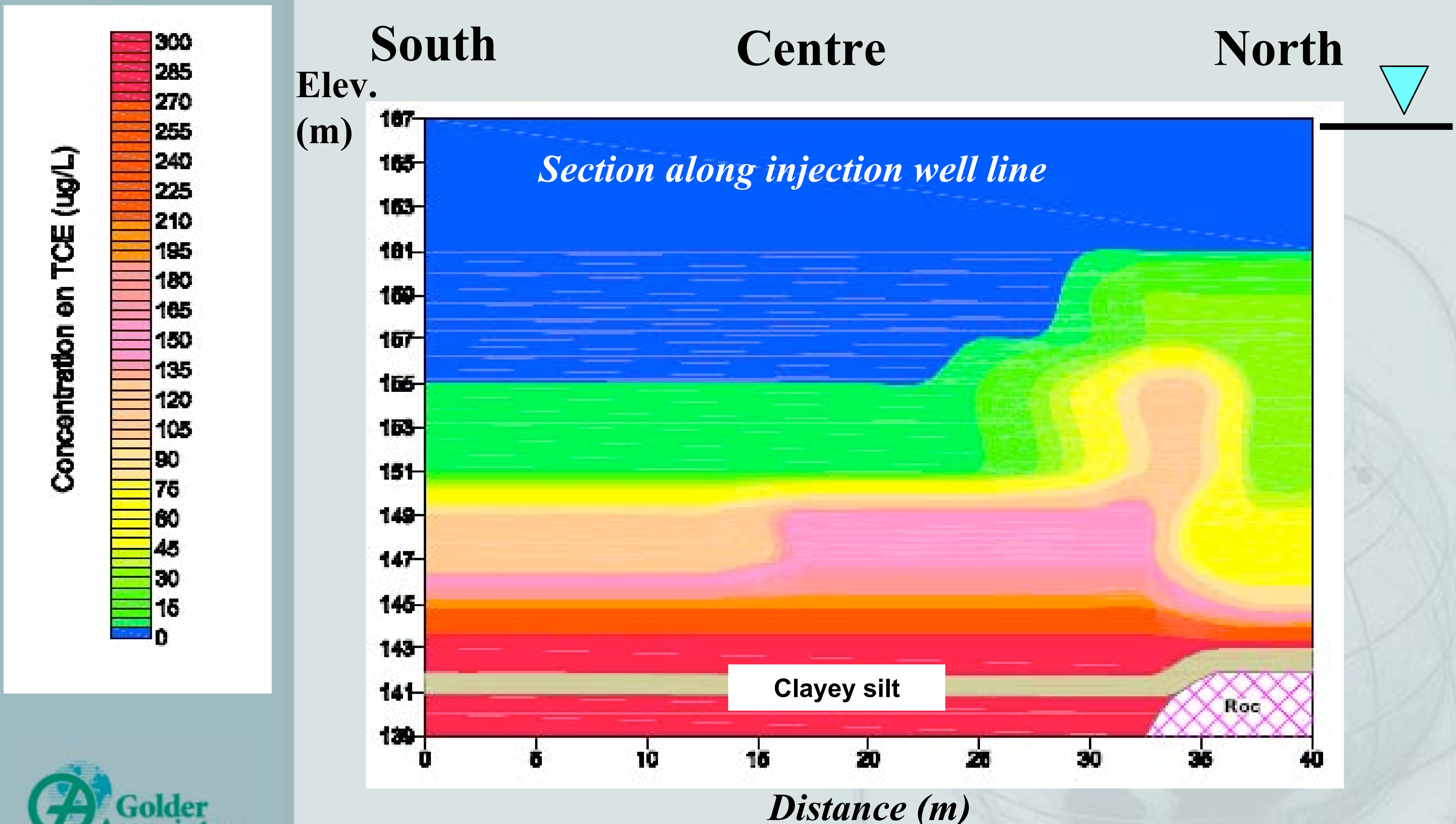
Initial Contaminant Mass Distribution

Interpreted Initial TCE Concentration Distribution



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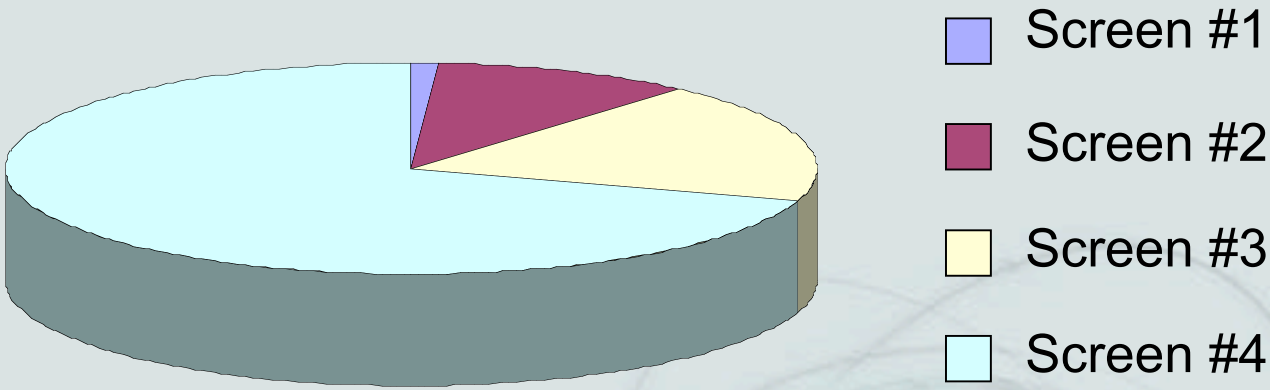
Summary of NZVI Injections

Total Injected NZVI Mass



- Mass of NZVI injected based on TCE concentration distribution with depth in the aquifer;

- A metallic catalyst added to NZVI particles prior to injection to speed up degradation rate;

- A food-grade dispersing agent used to enhance particle migration distance and used to reduce settling;

- Very small mass of NZVI injected under the silt layer.

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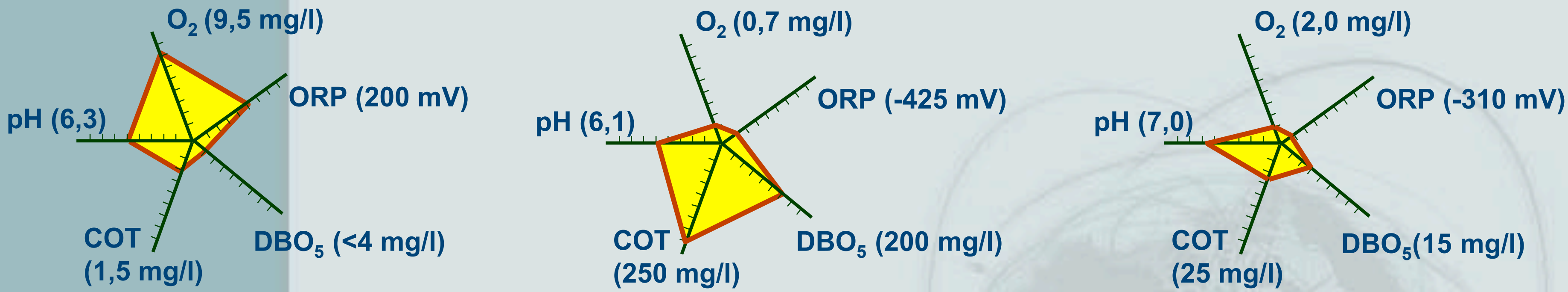
Geochemistry

Evolution of Selected Geochemical Parameters within the Treatment Zone



Before injection | **After injection** | **11 months following injection**

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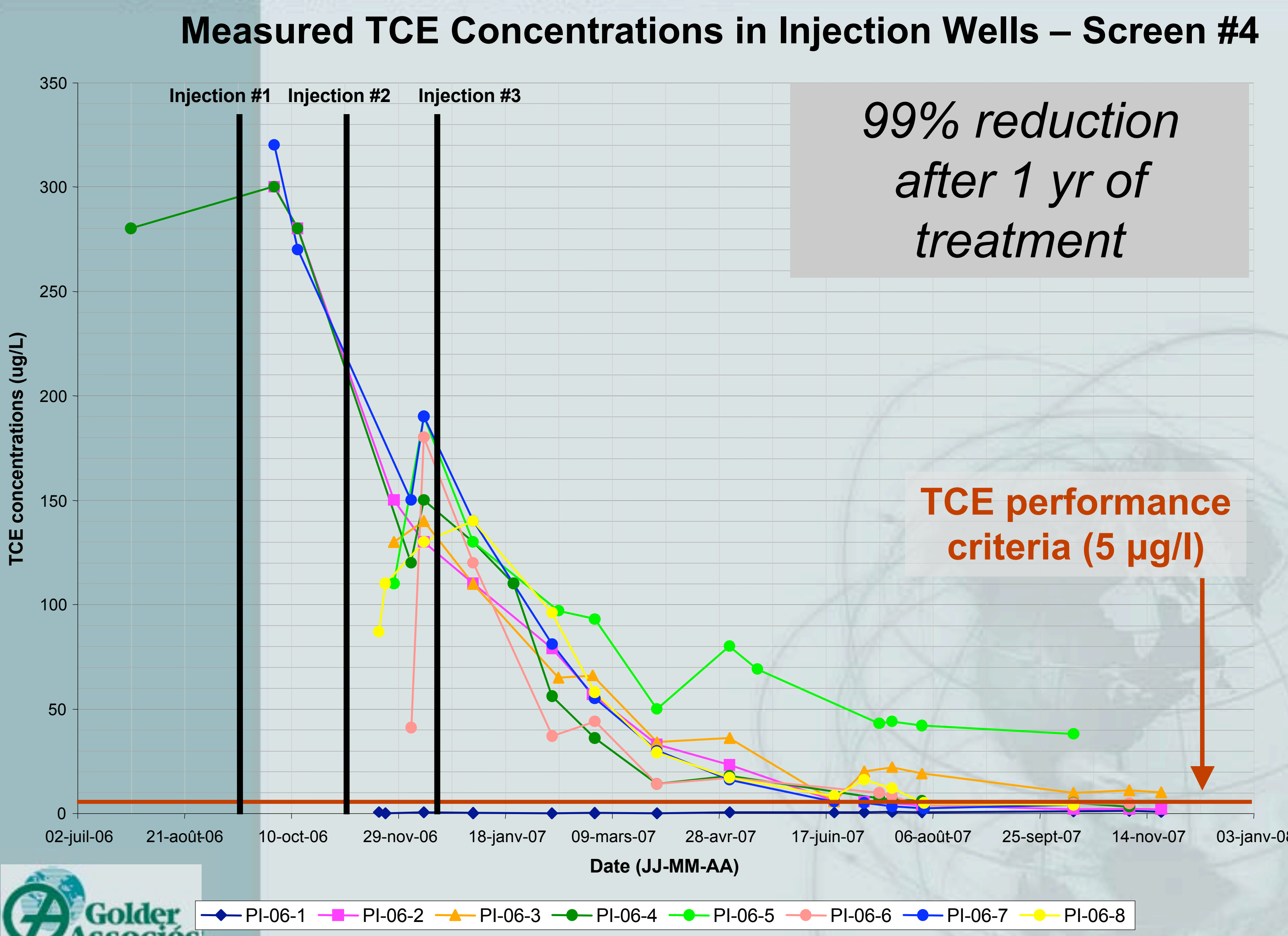
Measured values in injection wells located in the treatment zone

TCE concentrations evolution with time – Injection Wells



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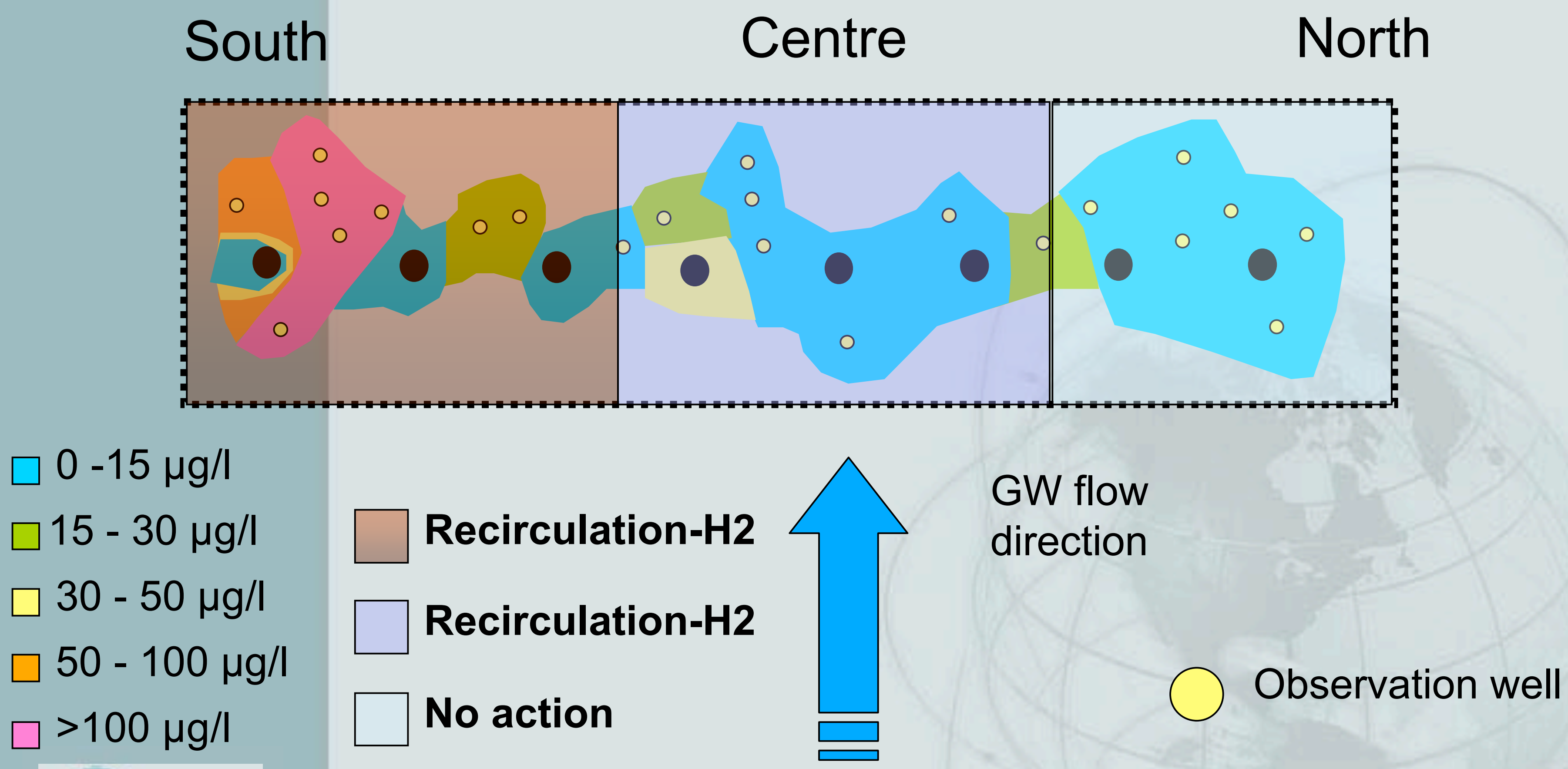
Interpretation of TCE Concentration Distribution – Deep Aquifer

8 Months after Last NZVI Injection



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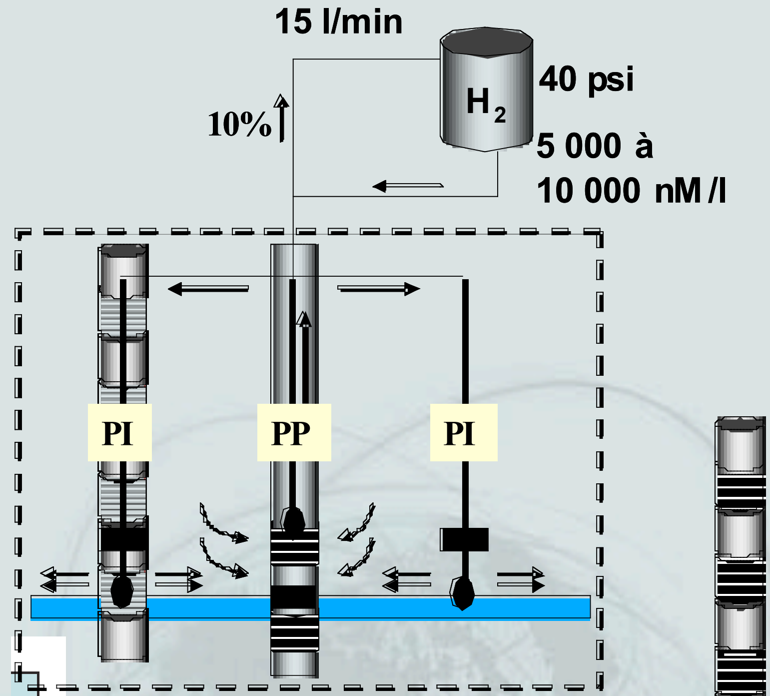
GW Recirculation System – South

Gas mix: H_2 + N_2



Qpumping = 150 L/min

Groundwater Recirculation System

- Allows hydraulic control in heterogeneous aquifer zone
- Forces GW flow to important NZVI mass zones in the aquifer
- Allows standardization of geochemical conditions and reactive distribution
- GW recirculation system is designed to operate specifically in the deep aquifer

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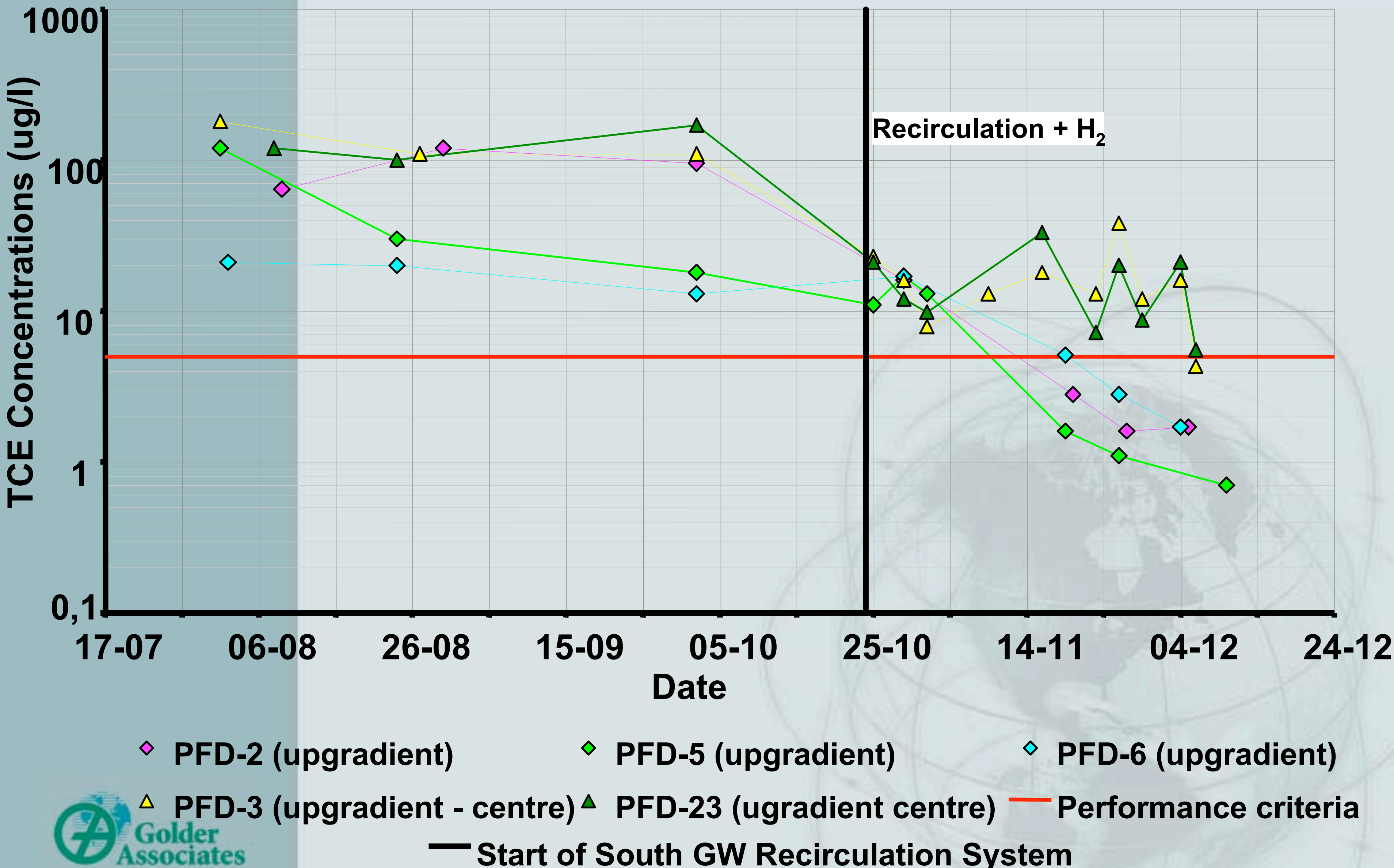
TCE Concentrations – Monitoring Wells Installed in South Treatment Zone



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Conclusions

- NZVI technology is flexible and effective in the particular geological context:
  - The average TCE concentration in the deep impacted aquifer was decreased to <5 µg/l;

- The complete treatment (including biological contribution) needed about 6 months to be effective to reach the performance criteria ;

- The treatment process allowed to stimulate secondary reduction reactions (biological and chemical);

- The efficiency of the treatment process to reduce TCE concentrations significantly has been enhanced by adding reactives (dissolved hydrogen) and by uniformizing geochemical conditions with groundwater recirculation.

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Thank you!

Merci!

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