INTERNATIONAL WORKSHOP

CURRENT DEVELOPMENTS IN REMEDIATION OF CONTAMINATED LANDS

Institute of Soil Science and Plant Cultivation (IUNG) Puławy, Poland

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ENHANCED NATURAL ATTENUATION FOR RISK- REDUCTION AT OIL HYDROCARBONS CONTAMINATED LAND

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OUTLINE

- INTRO: approach, definitions
- METHODS OF ENHANCING NATURAL ATTENUATION
  - ✓ biostimulation
  - ✓ bioaugumentation
- ENA LAB STUDIES
  - ✓ preliminary results
- CONCLUSIONS

LAND REMEDIATION APPROACH - HISTORY

- CONTAMINATED SITES

- SOIL & GW REMEDIATION

-remediation targets (e.g. Dutch A,B,C list)

-costs

-intensive vs extensive techniques, in situ vs. ex-situ techniques

-residual concentrations after treatment

- HOW CLEAN IS CLEAN?

- NA

-Natural Attenuation, or

-No Action

GOALS OF CONTAMINATED LAND REMEDIATION

Multi-functionality vs. risk-reduction approach

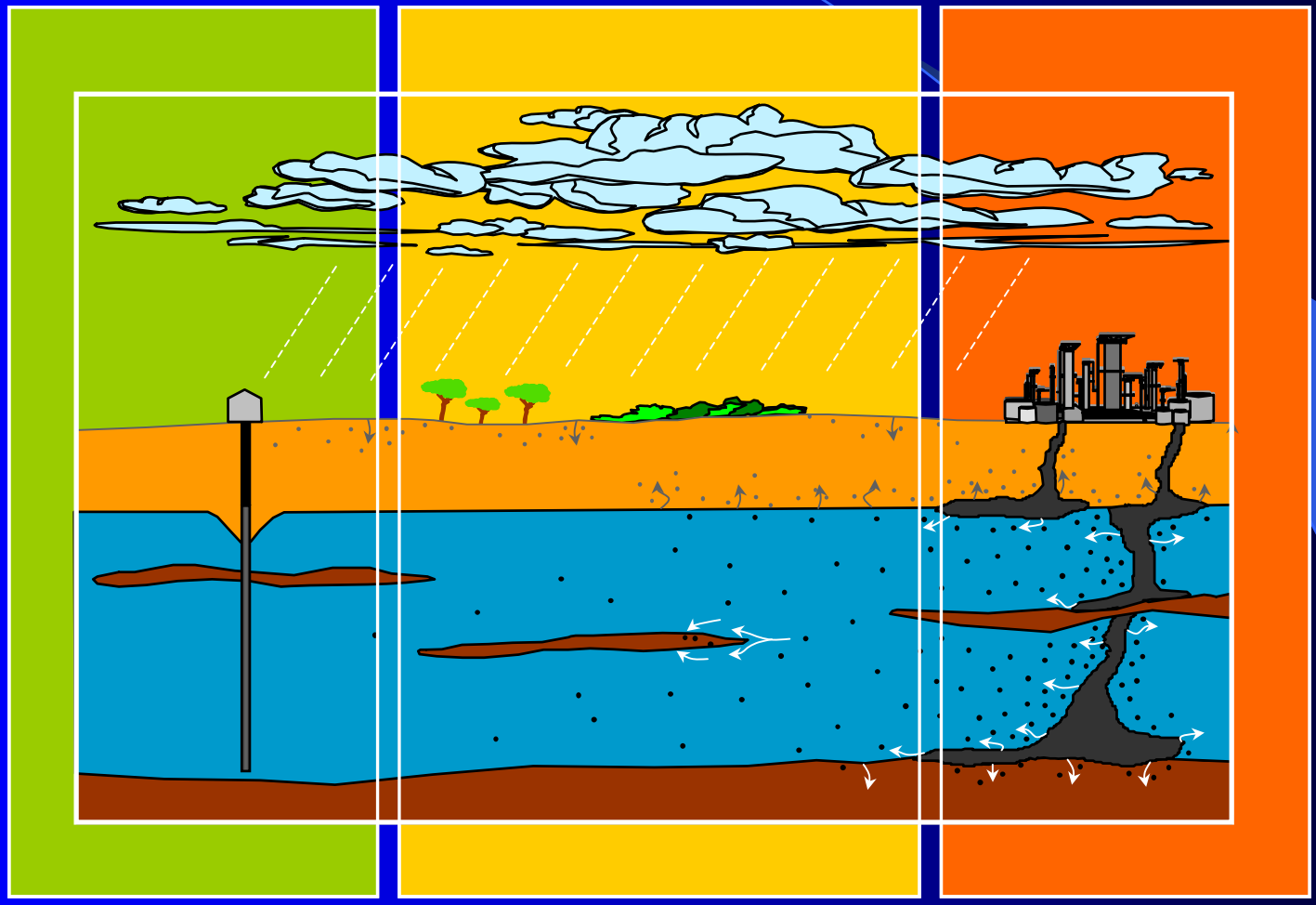
- Remediation approach and goals changed into risk-reduction for humans and ecosystems to acceptable levels, as restoration of multi-functionality and complete contaminants removal not feasible technically and economically
- Currently, the management approaches for brownfields, abandoned post-industrial areas, etc. deal with risk-reduction and beneficial use of contaminated land, by integrating remediation with industrial or infra-structural activities (re-development, revitalisation)
- Source remediation in such cases often less favourable than plume management/control $\rightarrow$ remediation goals changed from target-oriented into risk-oriented
- Currently applied risk evaluation procedures commonly based on the source-pathway-receptor sequence

SOURCE – PATHWAY - RECEPTOR SEQUENCE

receptor

pathway – contamination plume

source



DEFINITIONS: NA

- Natural Attenuation (NA) refers to fate of contaminants during their transport within groundwater from a source towards a receptor

- NA may include a set of natural (geogenic) processes reducing contaminants concentrations or mass fluxes without additional stimulation

✓destructive processes: biodegradation, chemical/photo degradation, (bio)transformation, humification, etc.

✓non-destructive processes: dilution, filtration, immobilisation ((bio)sorption/ion-exchange/(bio)precipitation), evaporation, diffusion, dispersion, etc.

DEFINITIONS: MNA

- Monitored Natural Attenuation (MNA) or Barrier-Controlled MNA: controlling/monitoring geogenic processes to predict/ prevent contaminants spreading and associated risks to groundwater

DEFINITIONS: ENA

- Enhanced Natural Attenuation (ENA) - designed for limited use of plume control and/or active/passive remedial techniques to stimulate self-purification processes

- Enhancement achieved mainly by 4 general passive/active intensive/extensive approaches

✓biostimulation

✓bioaugumentation

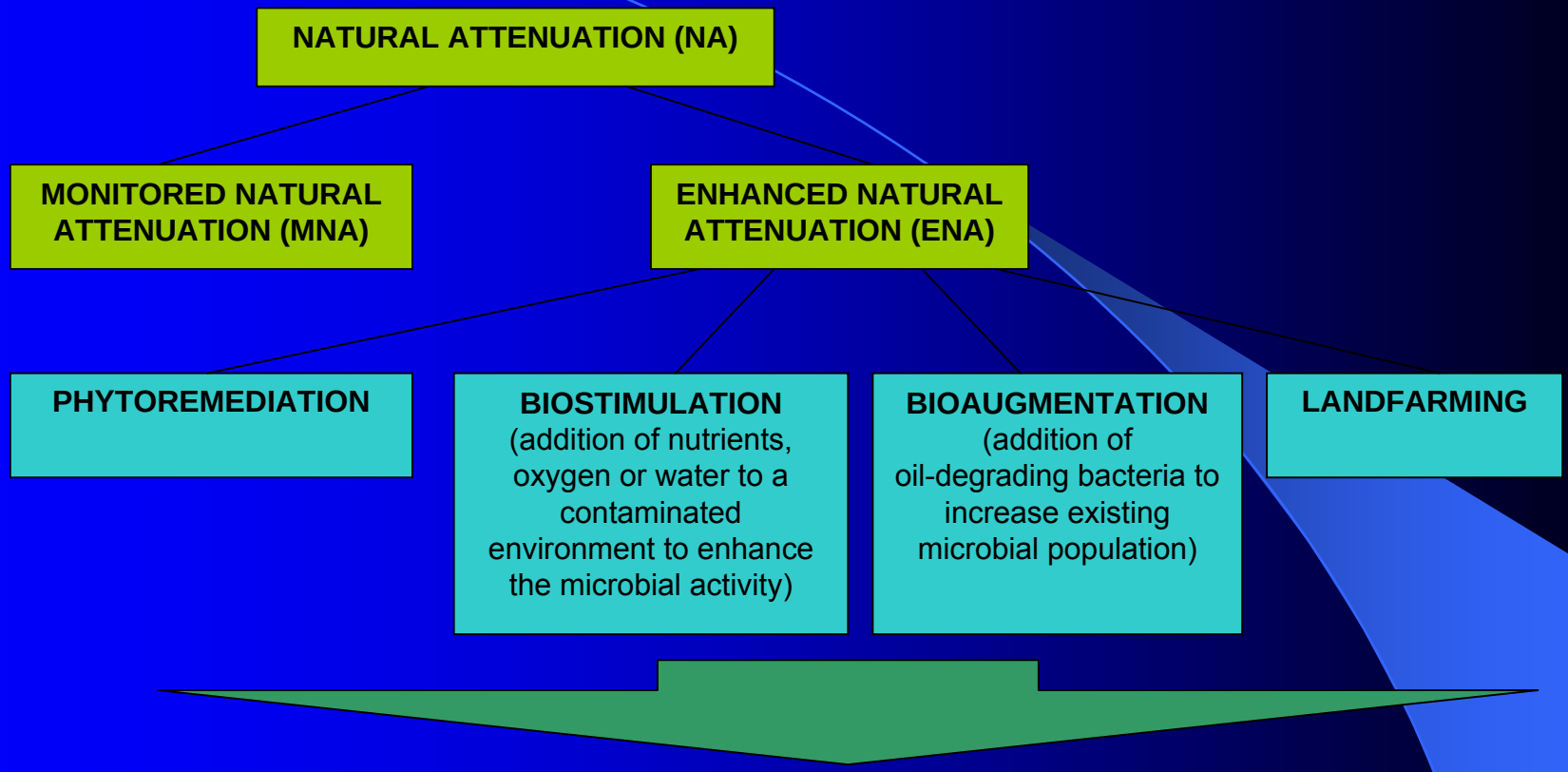
✓phytoremediation

✓landfarming

DEFINITIONS: ENA

- ENA - related cost effective measures
  - ✓bioventing, biosparging, bioslurping, ORC …)
  - ✓pump-and-treat (P&T)
  - ✓biobarriers, bioscreens
  - ✓permeable reactive barriers (PRB)
  - ✓Combinations
  - ✓ …..

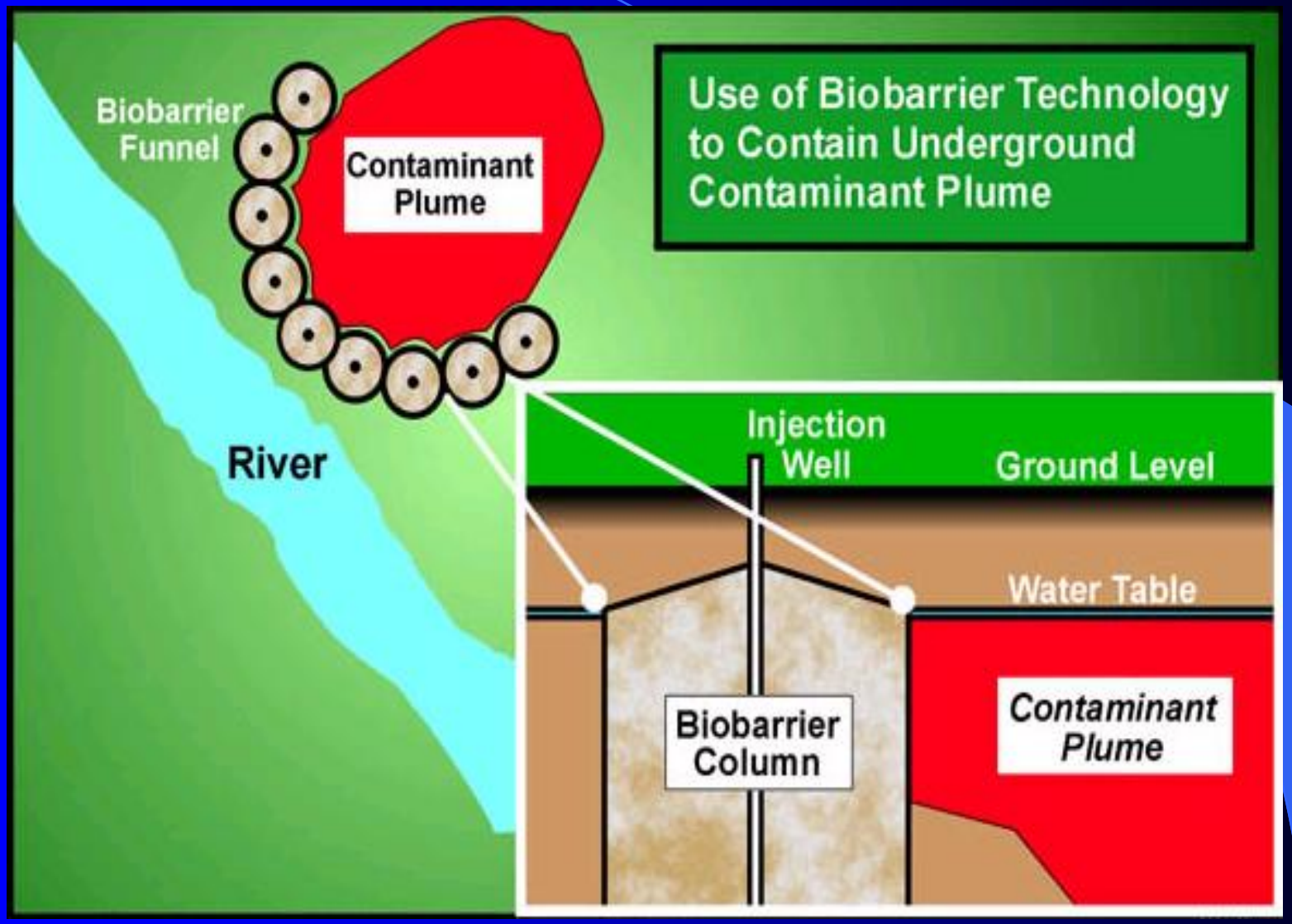
PROCESSES RELATED TO ENA



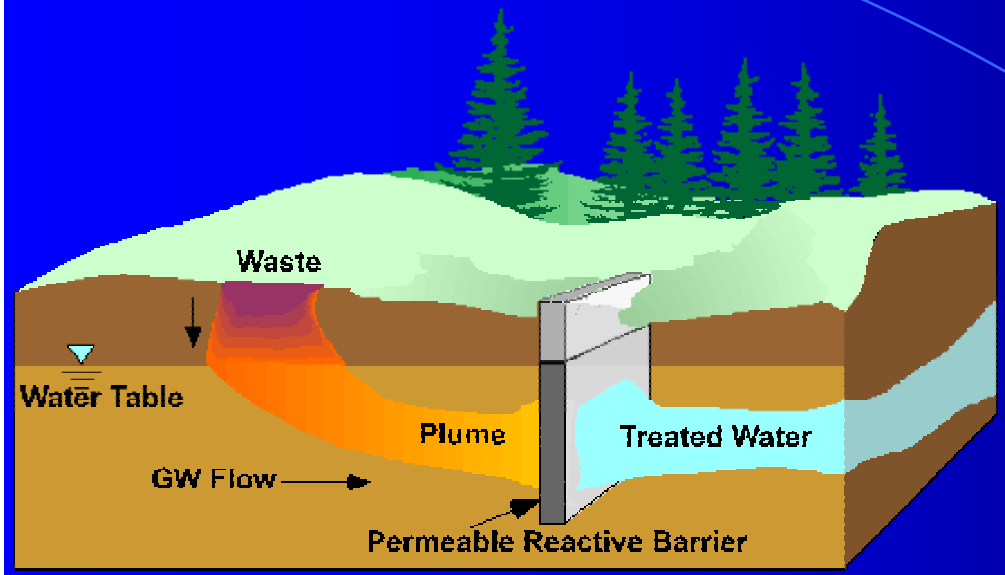
THE WAYS OF ENHANCEMENT OF NATURAL ATTENUATION

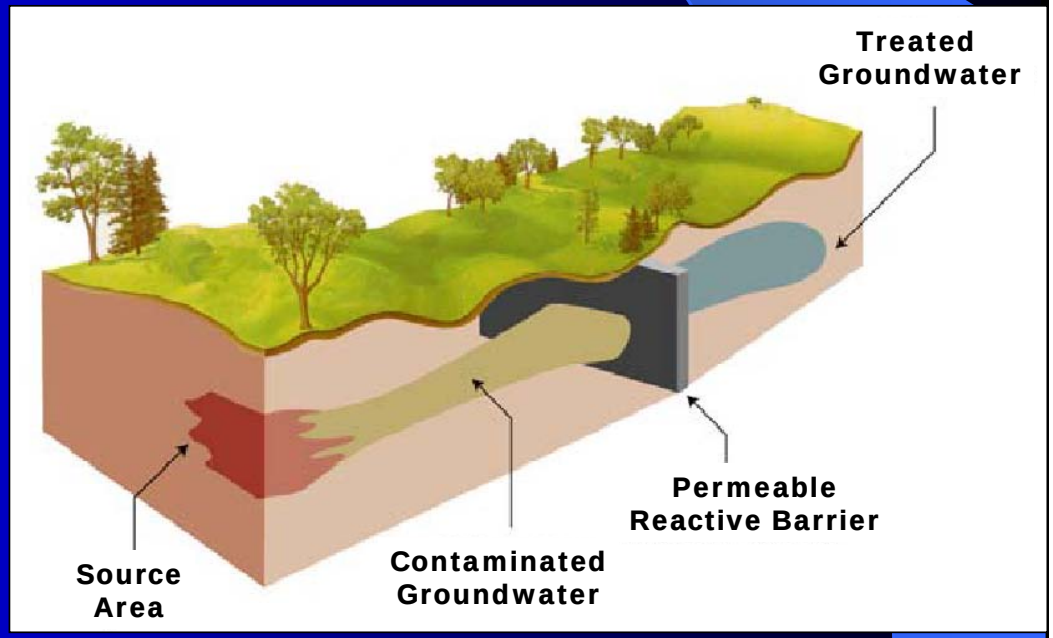
BIOVENTING	COMPRESSED AIR AERATION
BIOSLURPING	AERATION BY TILLING THE SOIL
BIOSPARGING	THE ADDITION OF OXYGEN RELEASING COMPOUNDS
IRRIGATION	AND AGENTS
SPRAYING	DIRECTLY INJECTION OF BACTERIAL SUSPENTION
FERTILIZATION	INTO SOIL

ENA: biobarrier technology

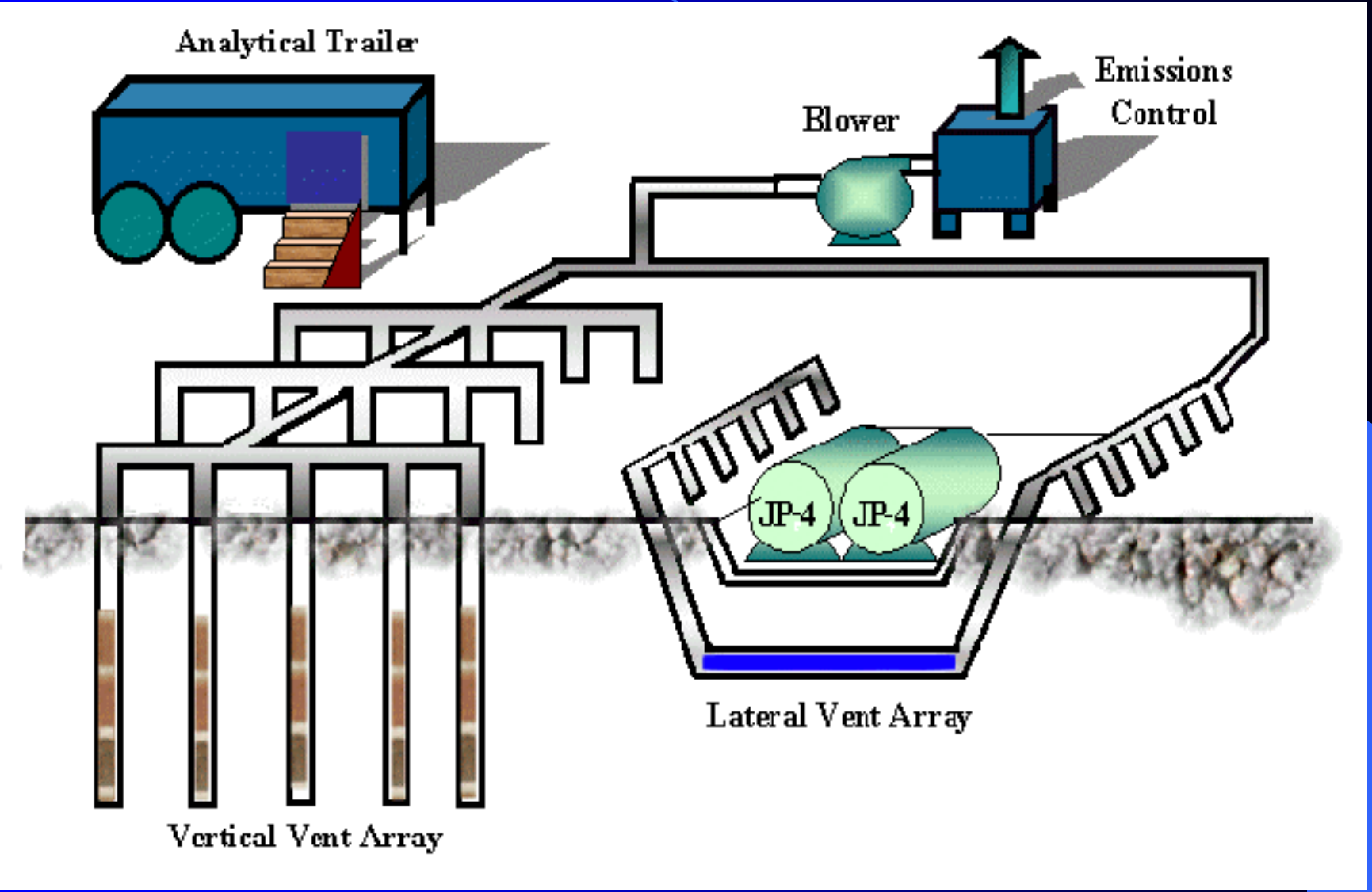


ENA: biobarrier technology

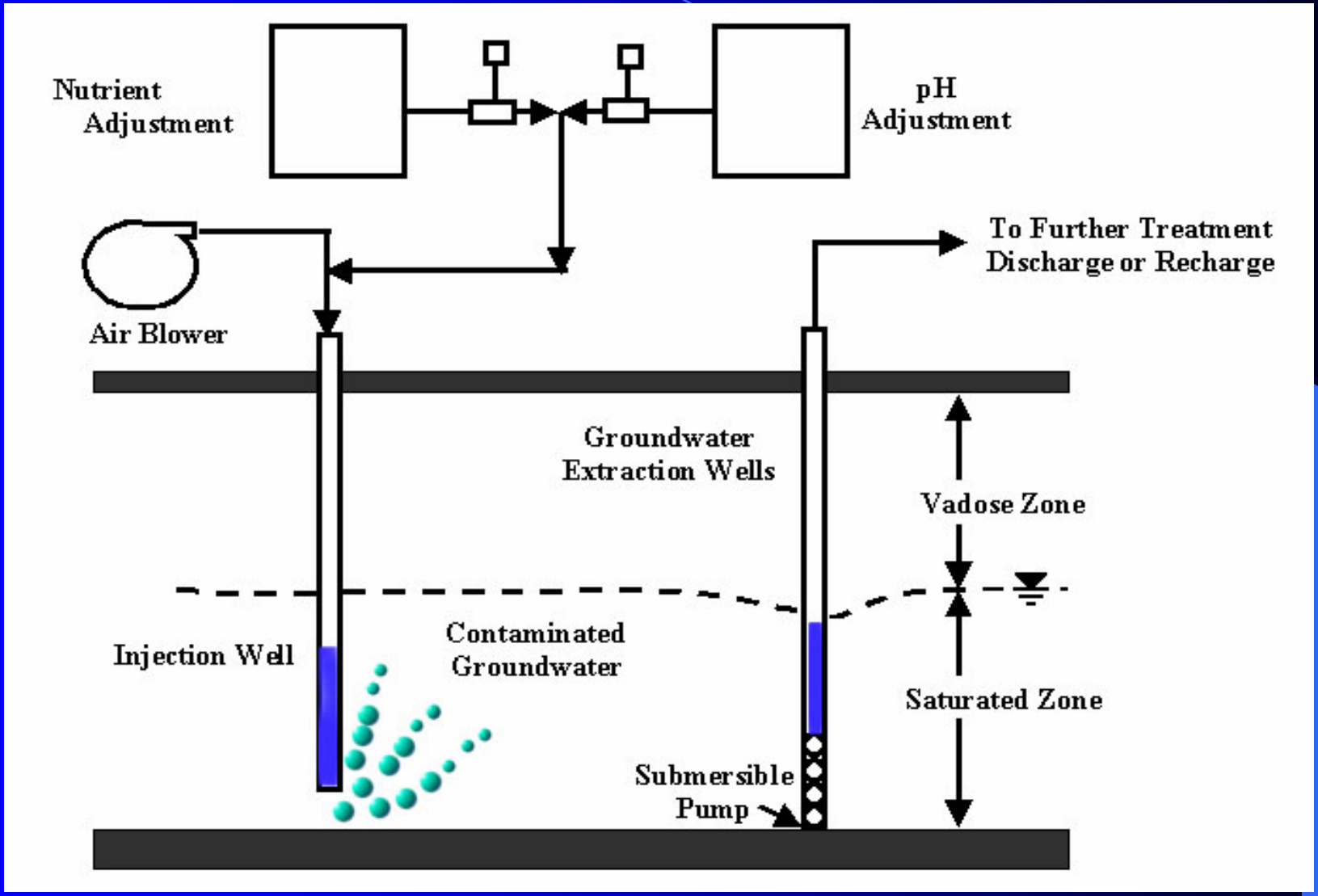




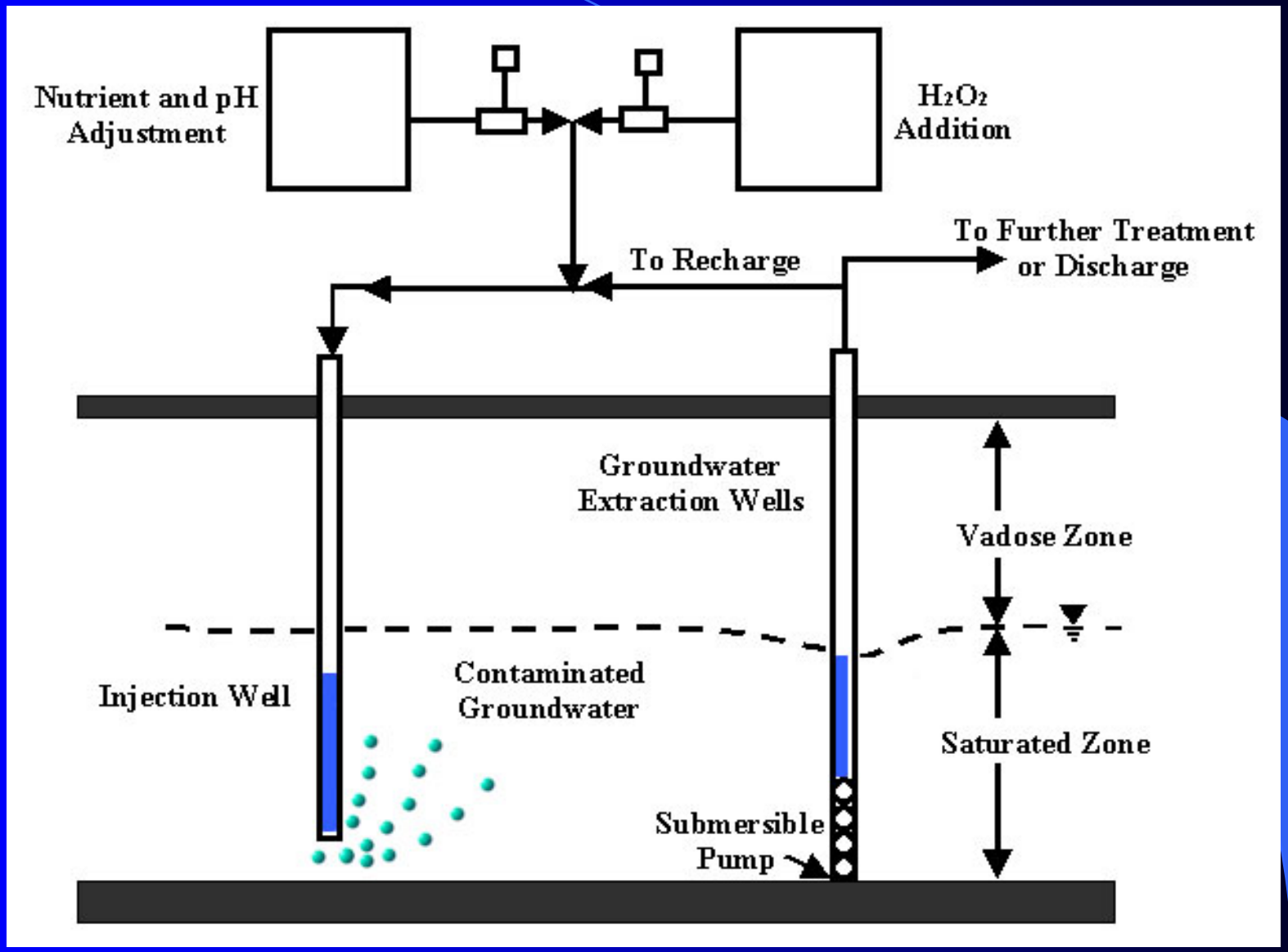
ENA: bioventing



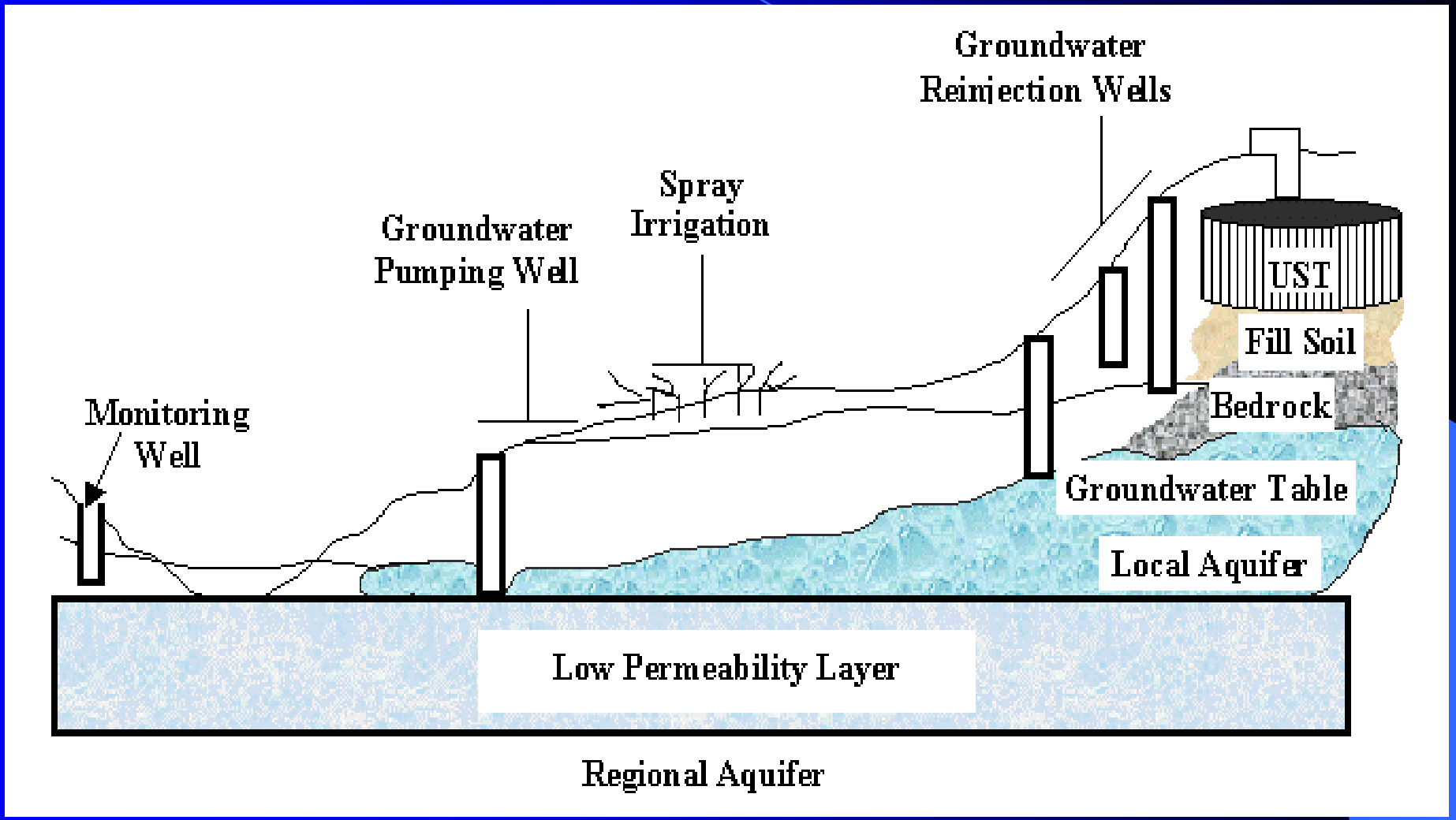
ENA: typical O_2 – enhanced bioremediation system with air sparging



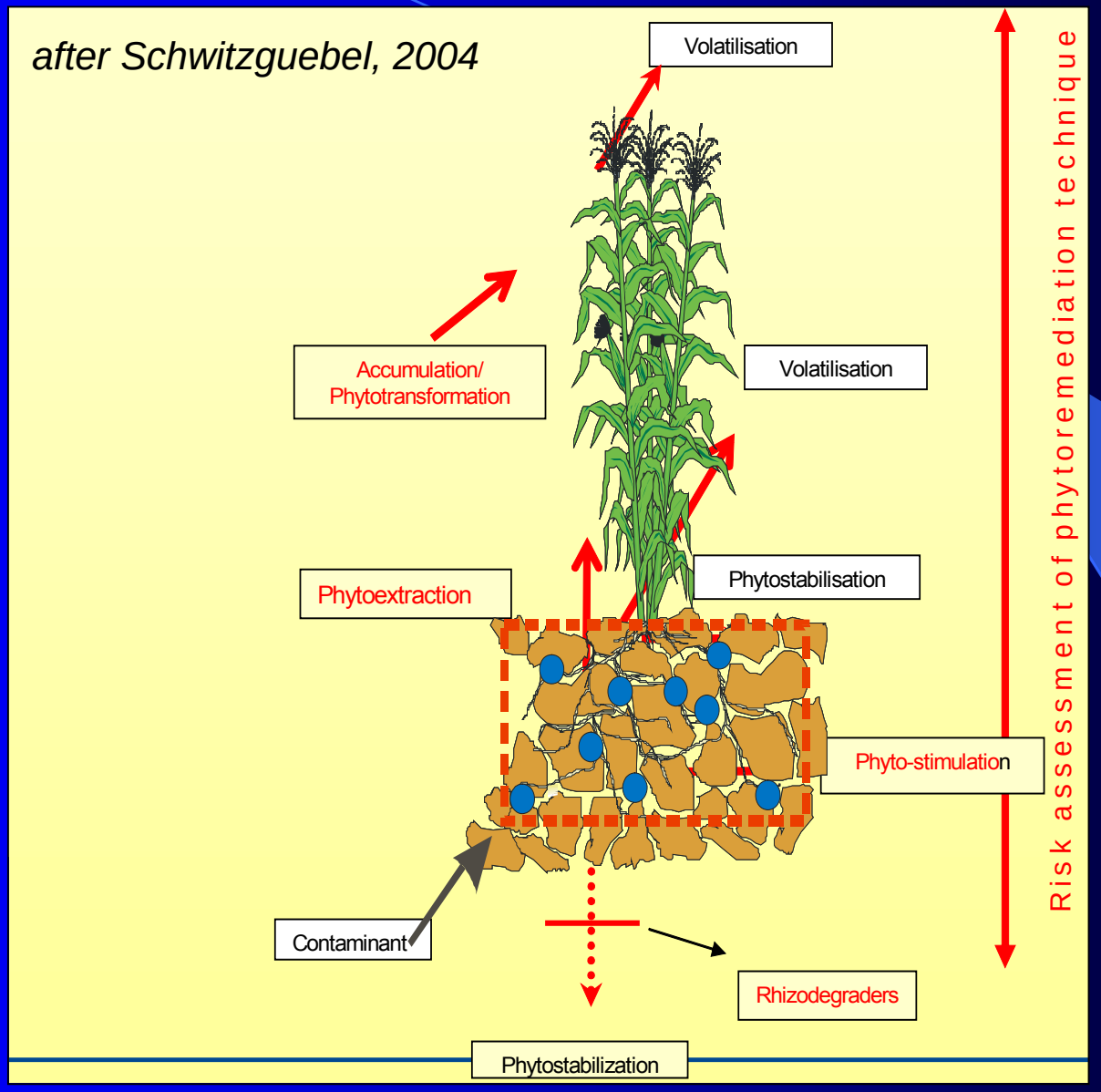
ENA: O_2 - enhanced H_2O_2 bioremediation system



ENA: typical enhanced bioremediation system



ENA: phythoremediation



EVALUATING POTENTIAL FOR NA

$r_m < r_{NA}$ → potential for NA (MNA)

$r_m > r_{NA}$ → need for enhancement

if

$r_{MNA} >> r_{NA}$ → go for ENA

r_m – contaminant migration rate/plume spreading velocity

r_{NA} – rates of NA processes

r_{ENA} – remediation rates when NA is enhanced

ENA LAB STUDIES: BIOSTIMULATION & BIOAUGUMENTATION

- ENA at oil-hydrocarbons contaminated land mainly directed to increase intrinsic biodegradation rates, which can be achieved by

✓adding nutrients, oxygen or water to contaminated environment (biostimulation)

✓inoculating indigenous/extraneous/genetically modified oil-degrading bacteria to supplement existing microbial population (bioaugmentation or seeding)

- ENA as

✓final remediation (polishing) step

✓independent method of remediation

ENA LAB STUDIES: FORMER MILITARY AIRPORT

- Respirometer studies to determine the effect of bioaugumentation and biostimulation (by diverse ways of oxygen supply) on enhancing NA in soils contaminated with oil-hydrocarbons at former military airport in Kluczewo (Poland)

- Bioaugmentation: inoculating indigenous and extraneous bacteria able to degrade hydrocarbons

- Biostimulation: oxygen supplied by: aerated water, aqueous solutions of hydrogen peroxide (H_2O_2) and potassium permanganate ($KMnO_4$)

- Intrinsic and enhanced biodegradation evaluated based on mean O_2 uptake and CO_2 production rates obtained using a linear regression of the cumulative curves

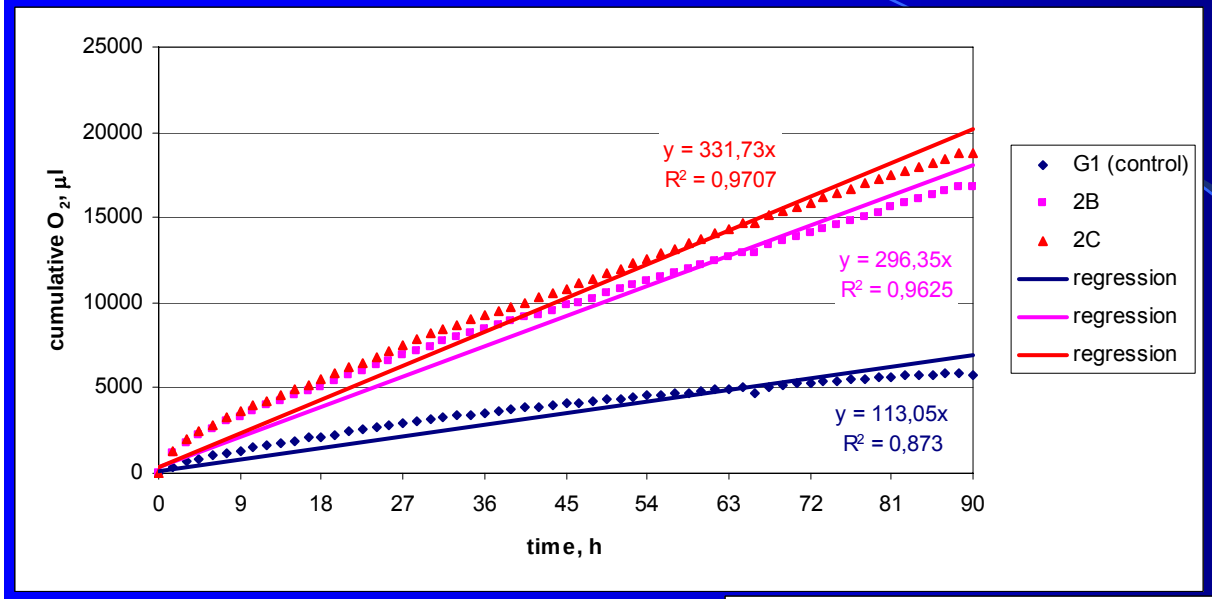
RESPIROMETER TESTS

10-chamber Micro-Oxymax® (Columbus, Ohio) Respirometer

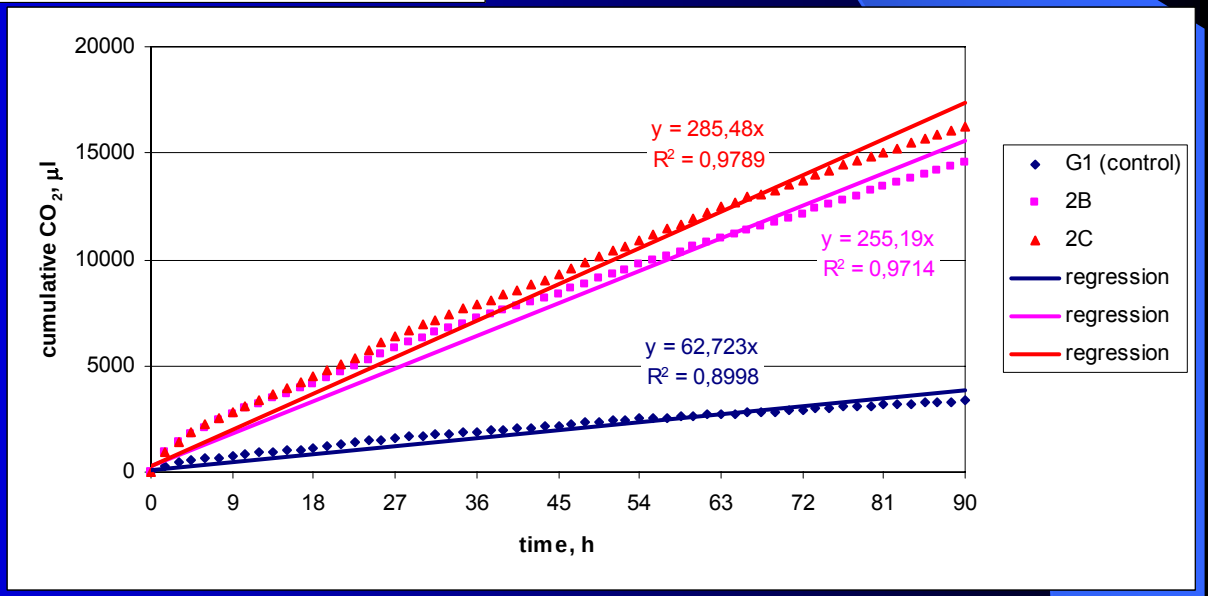
Institute of Environmental Engineering, Czestochowa, PL

BIOSTIMULATION RESULTS: CUMMULATIVE CURVES

Cumulative O_2 uptake

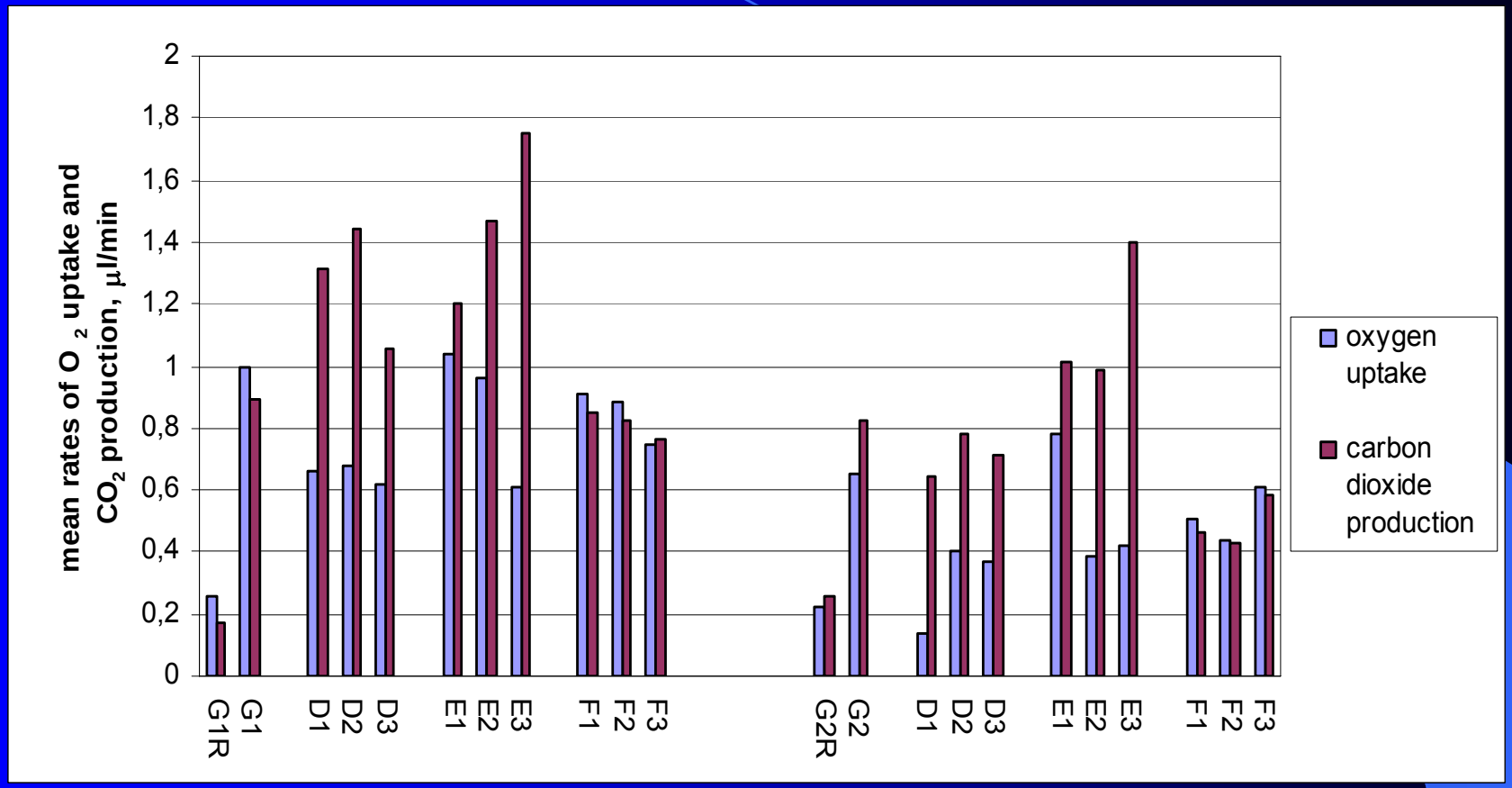


Cumulative CO_2 production



RESULTS: BIOSTIMULATION

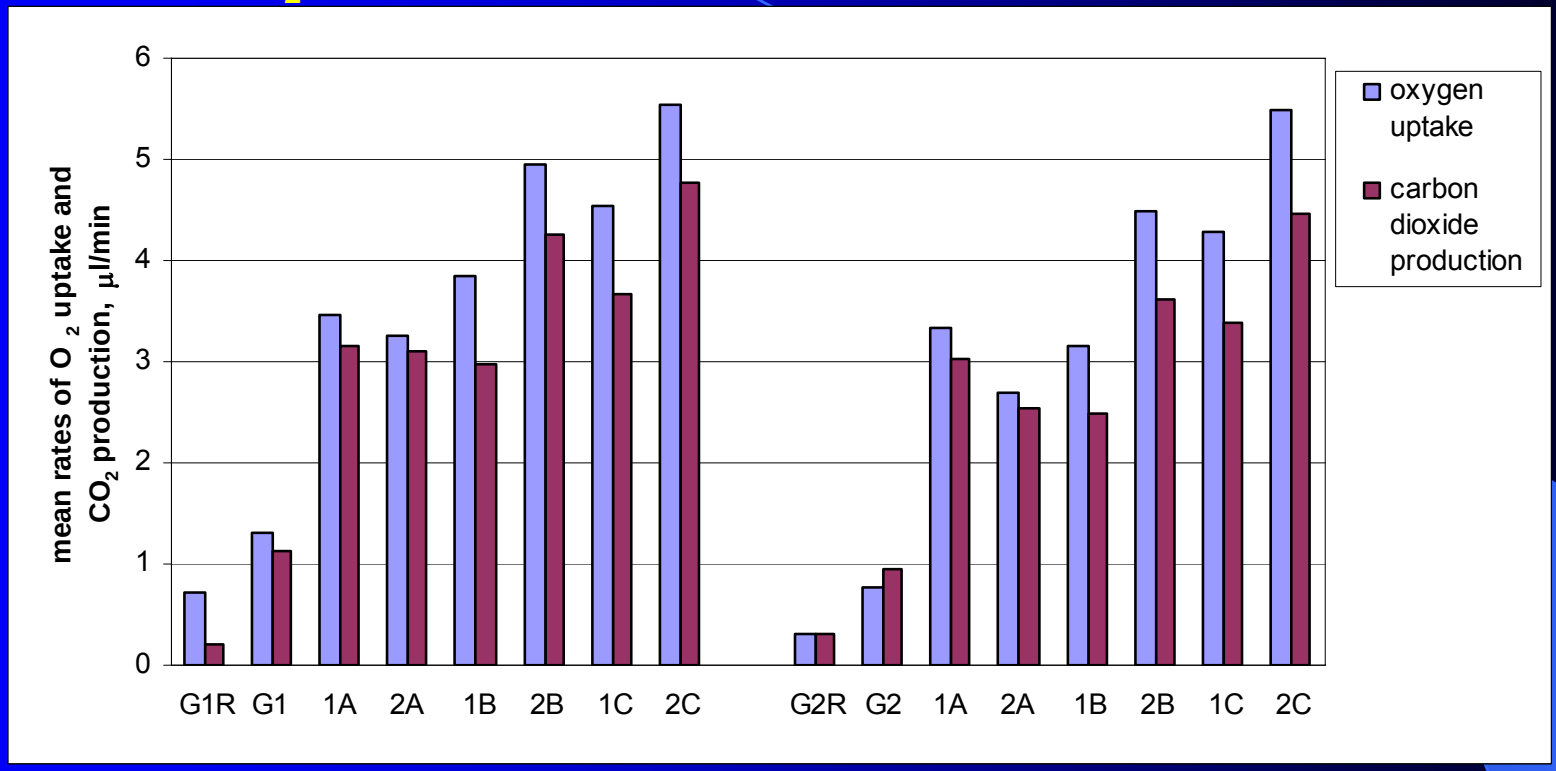
O_2 uptake and CO_2 production rates during intrinsic and enhanced biodegradation



G1R, G2R – control 1 (uncontaminated soil - depths of 1.5 and 2.0 m)
G1,G2 – control 2 (contaminated soil without enhancement – depths: 1.5 and 2.0 m)
D1, D2, D3 – aqueous solution of H_2O_2 (dilutions of 1:2, 1:5, 1:10)
E1, E2, E3 – aqueous solution of $KMnO_4$ (concentrations: 5, 10, 20 g/l
F1, F2, F3 – distilled water aerated during 24, 48 and 72 hrs

RESULTS: BIOAUGUMENTATION

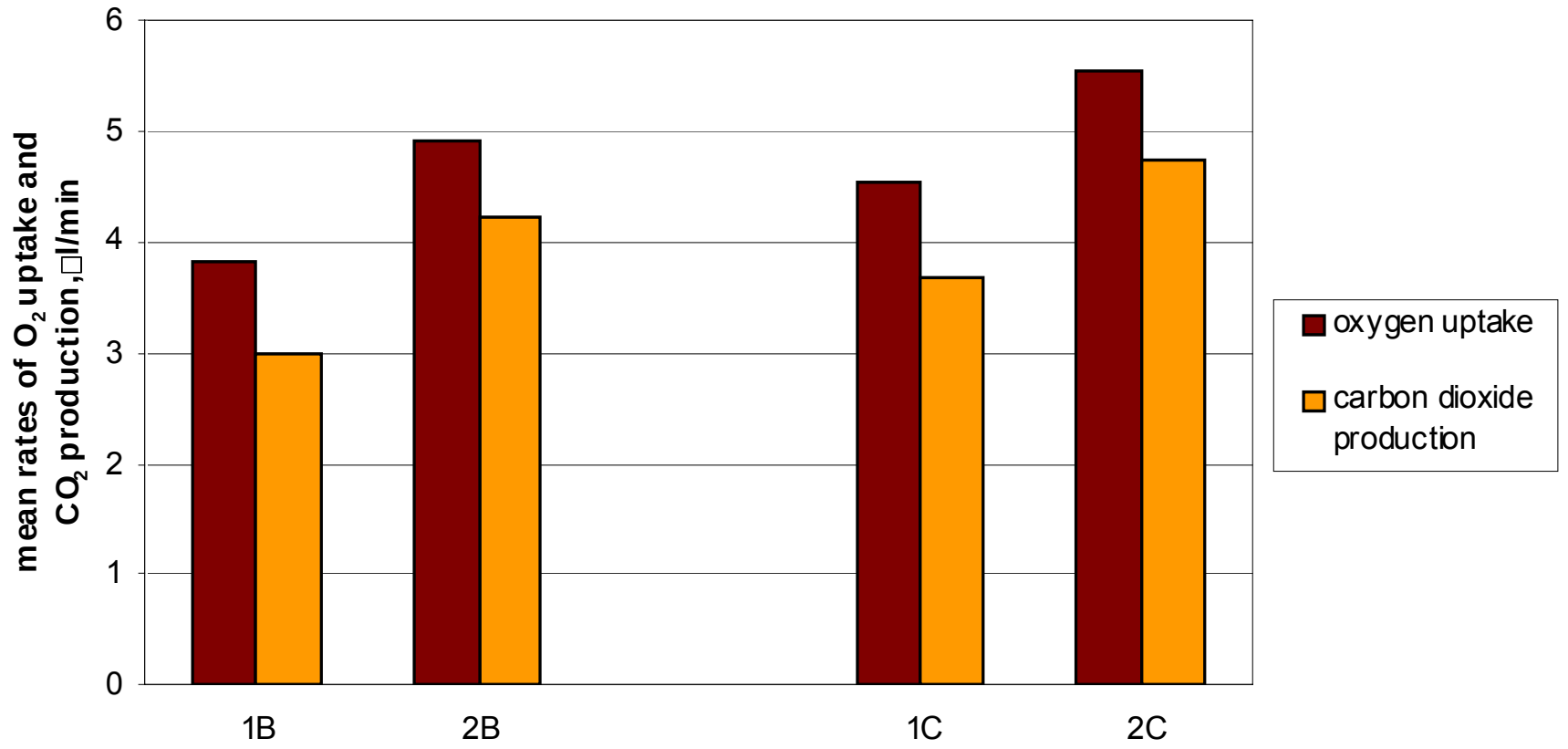
O_2 uptake and CO_2 production rates during intrinsic and enhanced biodegradation



G1R – control (uncontaminated soil: depth - 1.5 m)
G2R – control (uncontaminated soil: depth - 2.0 m)
G1 – contaminated soil without enhancement (depth - 1.5 m)
G2 – contaminated soil without enhancement (depth - 2.0 m)
A – with liquid medium used to cultivate extraneous/indigenous bacteria
B – with biopreparation (extraneous/indigenous bacteria – 2.4×10^{15} CFU/ml)
C – with biopreparation (extraneous/indigenous bacteria – 4.8×10^{15} CFU/ml)

RESULTS: BIOAUGUMENTATION

Extraneous vs. indigenous bacteria application - soil G1



B – addition of biopreparation (extraneous/indigenous bacteria – 2.4×10^{15}CFU/ml)

C – addition of biopreparation (extraneous/indigenous bacteria – 4.8×10^{15}CFU/ml)

CONCLUSIONS (I)

- Remediation goals change: from target-oriented into risk-oriented

- Most accessible and effective *in situ* extensive remediation technologies based on Natural Attenuation (NA)

- Recommended by US EPA and realized as Monitored Natural Attenuation (MNA) or, in the essential cases, as Enhanced Natural Attenuation (ENA)

CONCLUSIONS (II)

- Generally, in all cases enhanced biodegradation rates due to bioaugumentation were 2-4 times higher than the rates of intrinsic biodegradation

- Application of indigenous bacteria was more efficient in comparison to the extraneous consortia

- The highest CO_2 production rates were achieved when aqueous solution of $KMnO_4$ was applied, as the increase of CO_2 production rates were about 71-97% higher compared to a control

- H_2O_2 did not cause any significant improvement of biodegradation rates; hydrogen peroxide can be toxic for microorganisms, which may be the reason of a decrease of CO_2 production rates in some soil samples

- Addition of aerated water resulted in a decrease of CO_2 production rates, as compared to the use of $KMnO_4$; most probably concentrations of dissolved oxygen in water were insufficient for aerobic biodegradation, and the excessive soil moisture reduced air-filled porosity and, consequently oxygen contents in soil