Implementation of Sustainable Geoengineering Practices

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Concordia Institute for Water, Energy and Sustainable Systems (CIWESS)

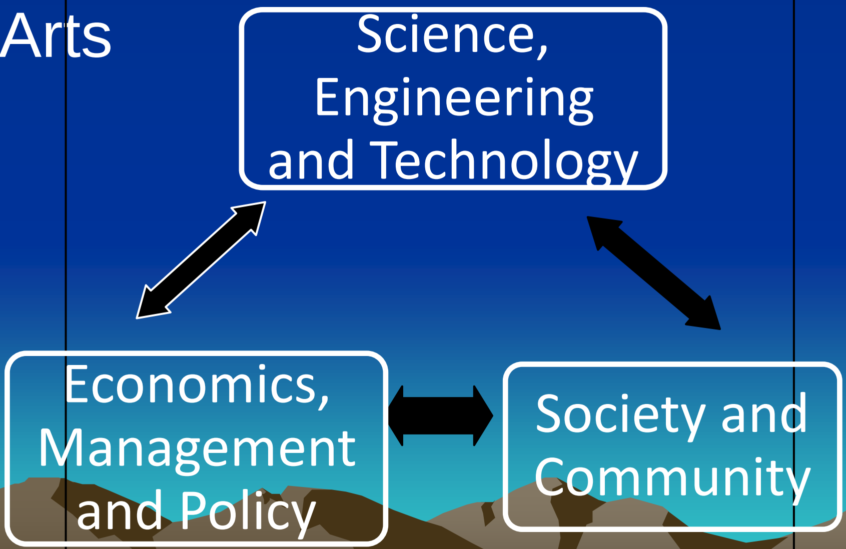
Multi-faculty approach:

- Engineering & Computer Science
- Arts & Science
- John Molson School of Business
- Fine Arts

Inter-university initiative:

- Concordia University
- McGill University
- Ecole Polytechnique
- Ecole de Technologie Supérieure
- York University
- UQAT

International collaborators



http://www.concordia.ca/ciwess

The Environment-Related Challenges

To propose long-term environmental strategies for achieving **sustainable development** by the year 2000 and beyond

The concept of sustainability as applied to the city is the ability of the urban area and its region to function at levels of quality of life desired by the community, without restricting the option available to the present and future generations and without causing adverse impacts inside and outside the urban boundary

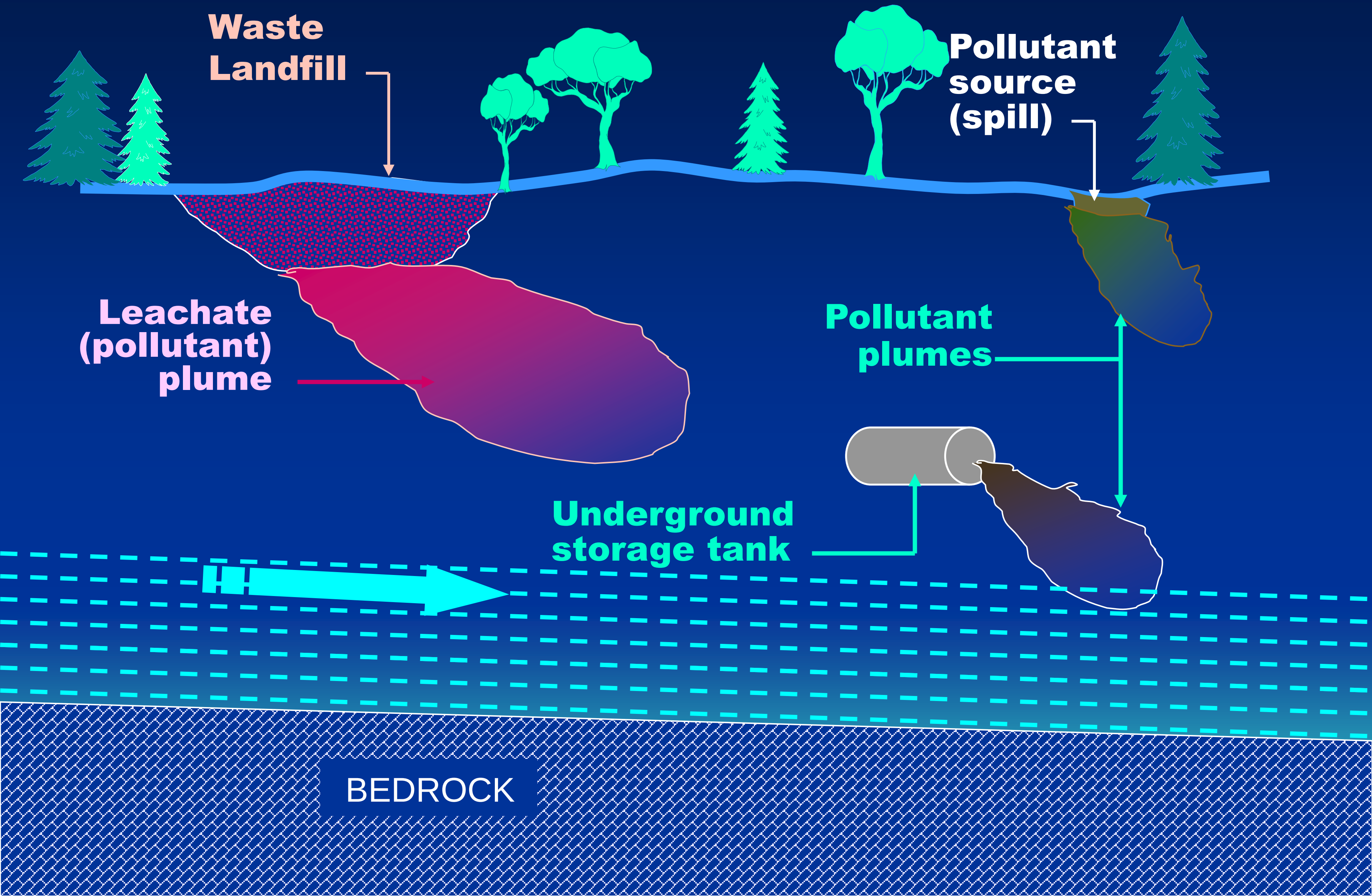
The geoenvironment is the principal resource base for almost all of the elements required for human sustenance

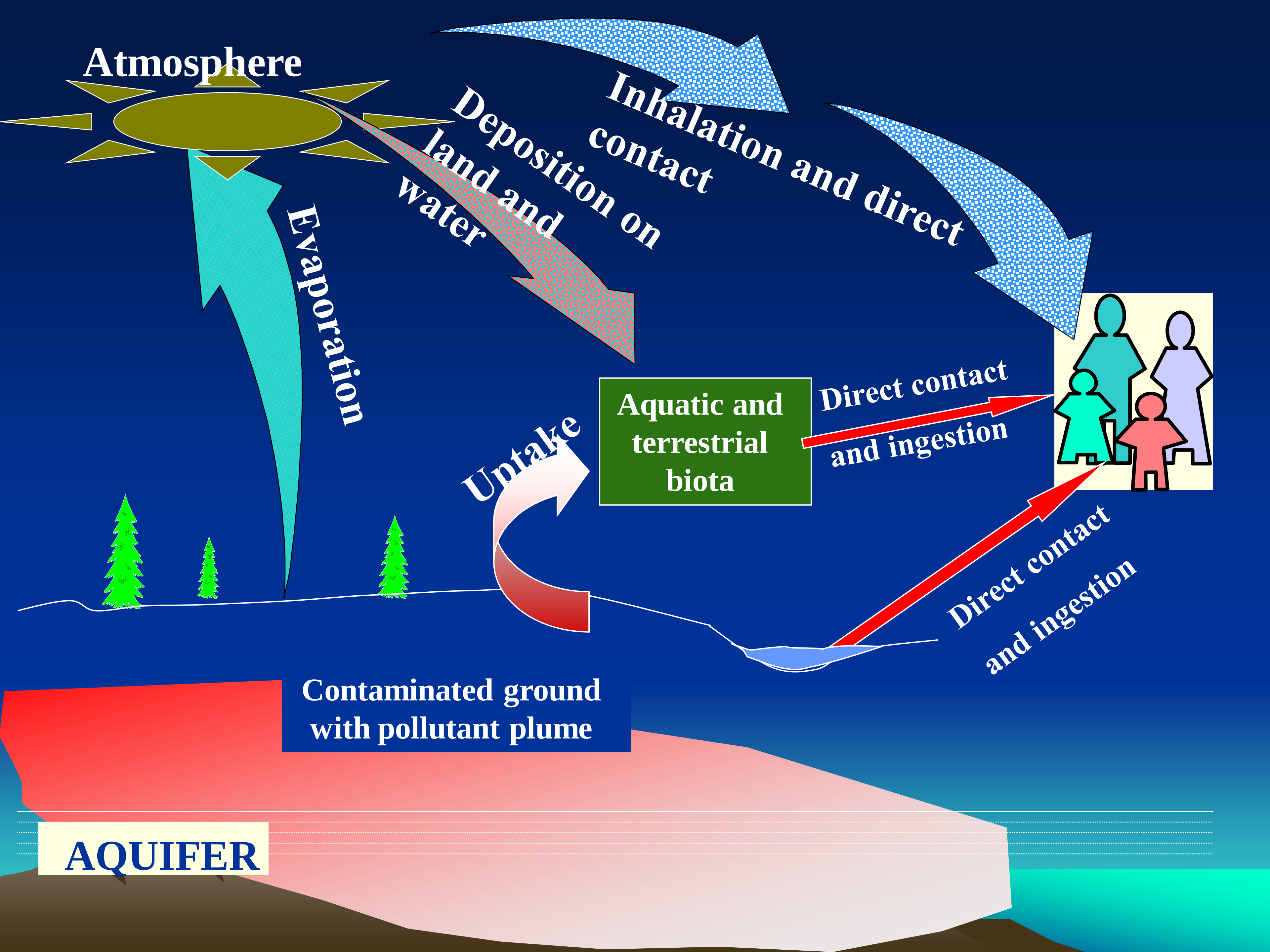
to meet the goals of sustainable development, one is required to practise:

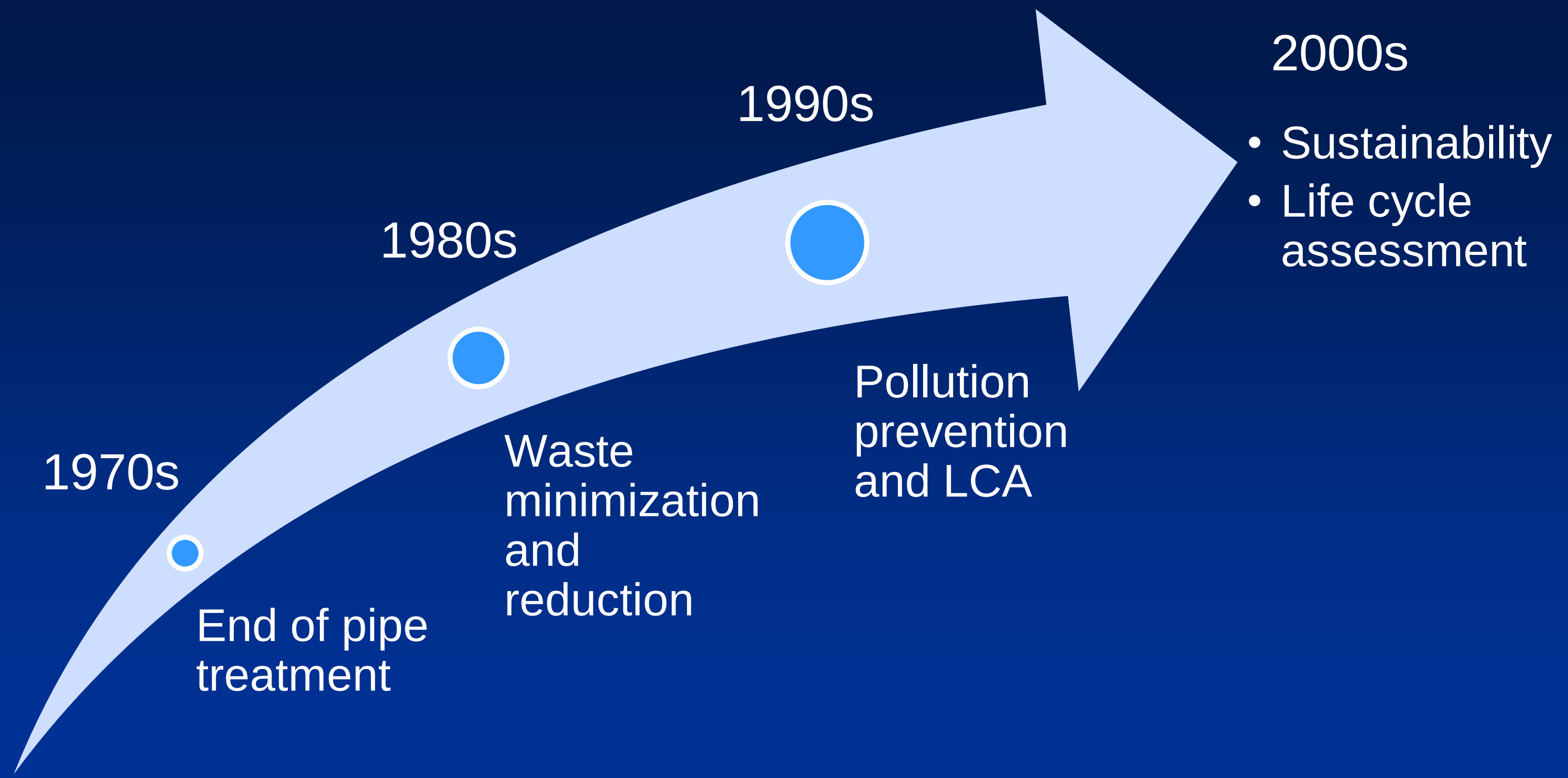
[a] geoenvironment resource conservation and

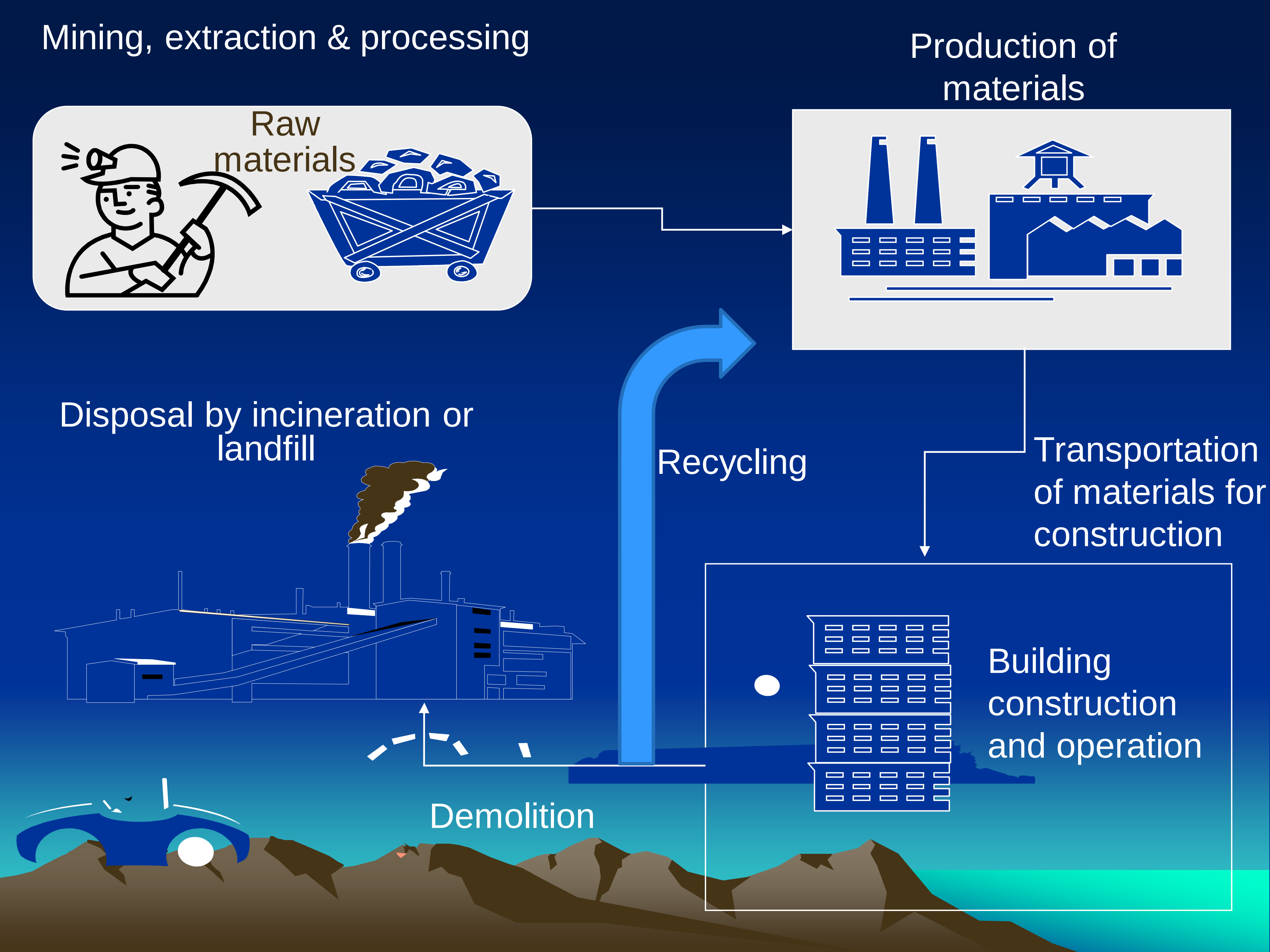
[b] geoenvironmental impact mitigation and management

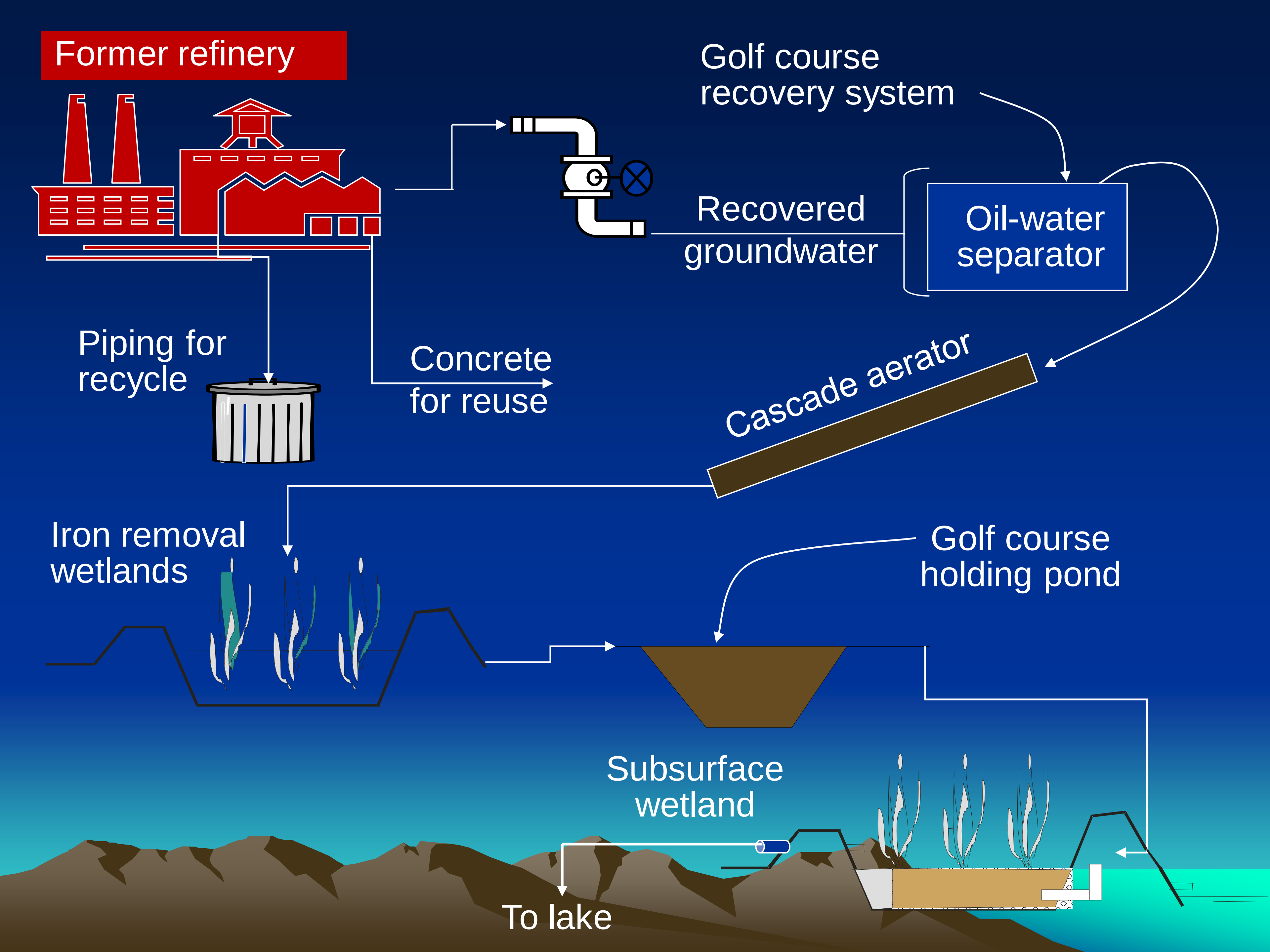
Some common sources of pollutants in the ground



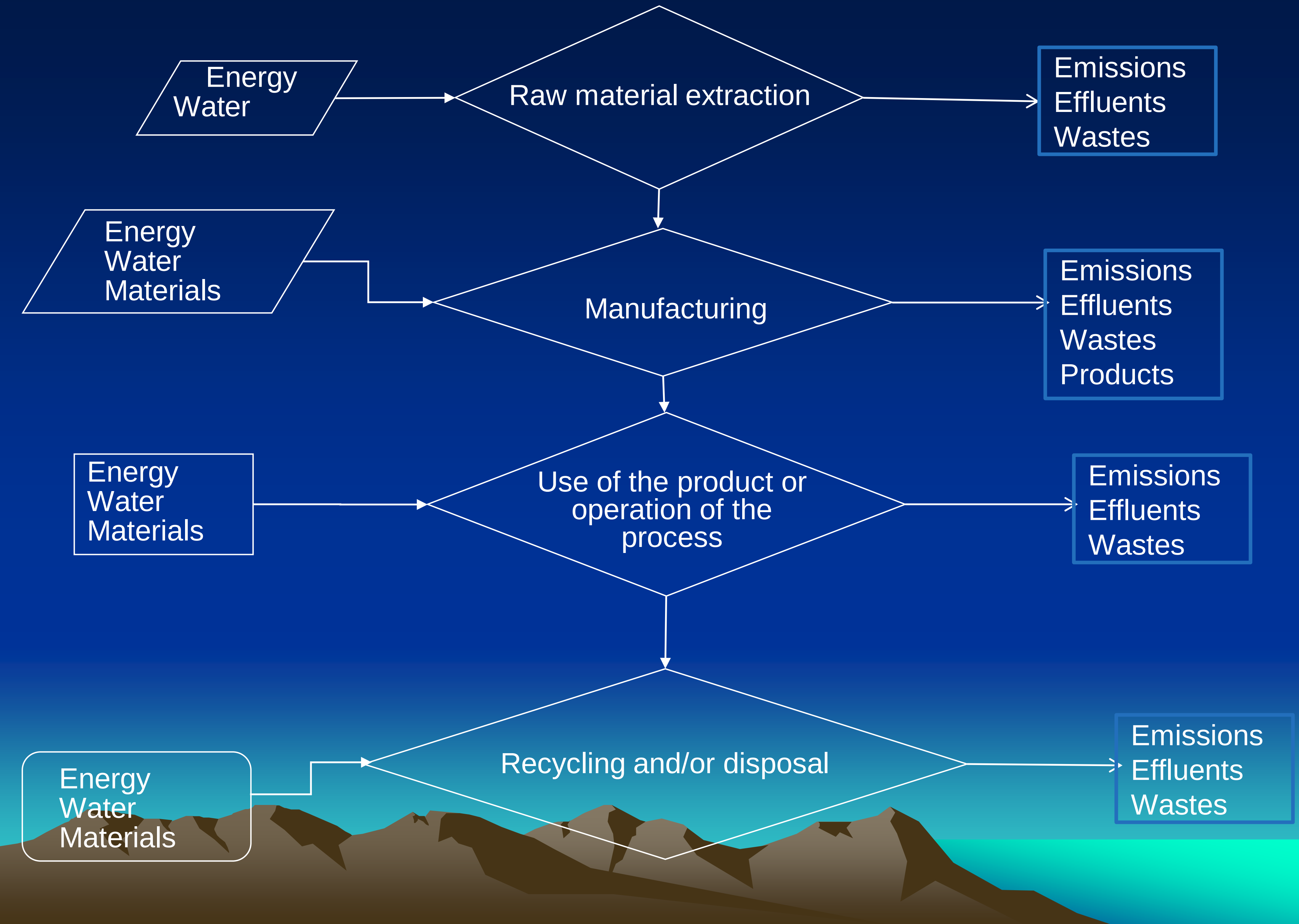

Atmosphere
Inhalation and direct contact
Deposition on land and water
Evaporation
Uptake
Aquatic and terrestrial biota
Direct contact and ingestion
Direct contact and ingestion
Contaminated ground with pollutant plume
AQUIFER


1970s
End of pipe treatment
1980s
Waste minimization and reduction
1990s
Pollution prevention and LCA
2000s
• Sustainability
• Life cycle assessment


Mining, extraction & processing
Raw materials
Production of materials
Transportation of materials for construction
Building construction and operation
Recycling
Disposal by incineration or landfill
Demolition



Former refinery
Golf course recovery system
Recovered groundwater
Oil-water separator
Piping for recycle
Concrete for reuse
Cascade aerator
Iron removal wetlands
Golf course holding pond
Subsurface wetland
To lake


Energy
Water
Raw material extraction
Emissions
Effluents
Wastes
Energy
Water
Materials
Manufacturing
Emissions
Effluents
Wastes
Products
Energy
Water
Materials
Use of the product or operation of the process
Emissions
Effluents
Wastes
Energy
Water
Materials
Recycling and/or disposal
Emissions
Effluents
Wastes

Sustainability Indicators

Energy
- Energy cost and consumption
- Ratio of renewable to nonrenewable energy use

Air quality
- Toxic emissions
- Climate change
- Emissions during transport

Biodiversity
- Aquatic plant growth
- Types of birds
- Monitoring and managing efforts for biodiversity
- Habitat and Biodiversity

Food
- Fish/shellfish consumption and fishing practices
- Food safety
- Residue recycling
- Sustainable aquaculture

Water
- Water consumption
- Mass of pollutants in water
- Recycled water use
- Acres of habitat restored
- Recreational use

Waste
- Tons of solid waste
- Recycling or reuse rate
- Conservation and waste reduction (energy or waste)
- Hazardous waste exposure
- Contaminated sites within city limits

US Army Corps of Engineers (USACE) sustainability checklist

- Integrated design principles
- Optimization of energy performance
- Protection and conservation of water
- Indoor environmental quality
- Minimization of material impact through green purchasing, waste diversion, etc.
- Siting and orientation of facilities, layout and size of the building
- Stormwater runoff management during and after construction
- Durability and sourcing and transportation
- Facility performance certification for sustainability.

Sustainability indicators used in rating or reporting tools (adapted from MacAskill, 2011)

Aspects	BREEAM	CEEQUAL	LEED	GRI	Envision
Environmental					
Atmosphere	X	X	X	X	X
Biodiversity/ecology	X	X	X	X	X
Climate change	X	X	X	X	X
Energy	X	X	X	X	X
GHG management	X	X	X	X	X
Land management	X	X	X	X	X
Minimization of waste	X	X	X	X	X
Noise/dust	X	X	X	X	X
Resource/material efficiency	X	X	X		X
Soil		X			X
Water		X			X

Sustainability Indicators

Aspect	BREEAM	CEEQUAL	LEED	GRI	ENVISION
<u>Social</u>					
Accessibility	X	X	X	X	X
Culture/communities	X	X	X	X	X
Equity	X	X		X	X
Health and safety/security		X		X	X
Heritage		X		X	X
Human rights		X			
Landscape/visual impact		X			

Which tool?

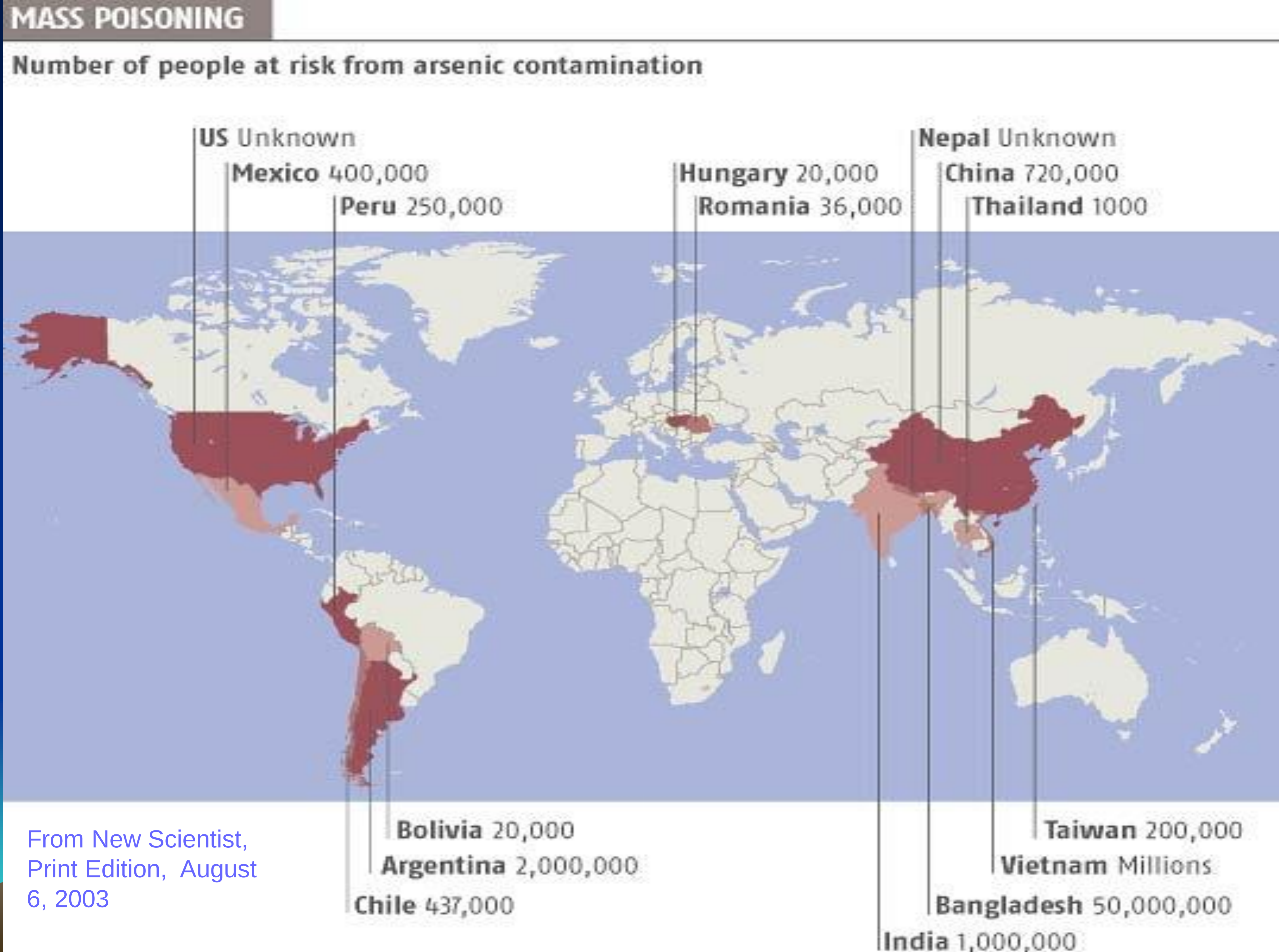
- Are all sustainable engineering issues covered?
- Are the state of the art processes supported?
- Are goals set?
- Is performance measured against the goal?
- Does the weighting system vary according to region or situation?
- Are the results consistent?

The problem of contaminants

Naturally occurring

Non point source

Point source



From New Scientist, Print Edition, August 6, 2003

Industrialization, Urbanization

Agricultural Activities

Farm wastes, Soil erosion, Fertilizers, Insecticides, Pesticides, Fungicides, Etc.

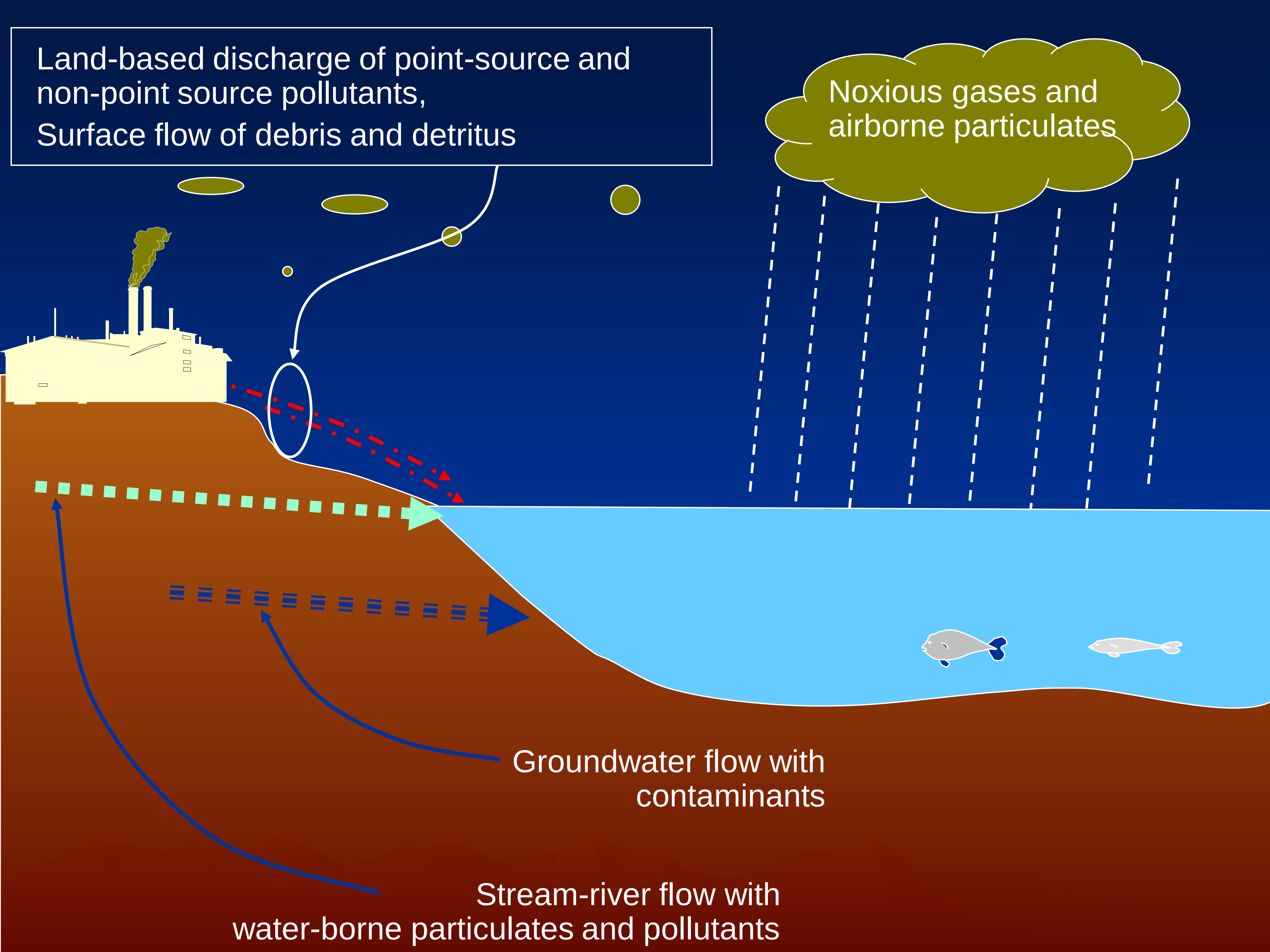
Surface Flows

source

point

Non poin
(rivers, la
conside

waters
water is
f water


Land-based discharge of point-source and
non-point source pollutants,
Surface flow of debris and detritus
Noxious gases and
airborne particulates
Groundwater flow with
contaminants
Stream-river flow with
water-borne particulates and pollutants

The “cleaned-up” state of remediated sites depends on:

A. Site and situation specificities

B. The aims or objectives of the remediation scheme

C. The type of remediation technology used

D. Economics ($$$ available or allocated)

Sustainability requirements for remediation

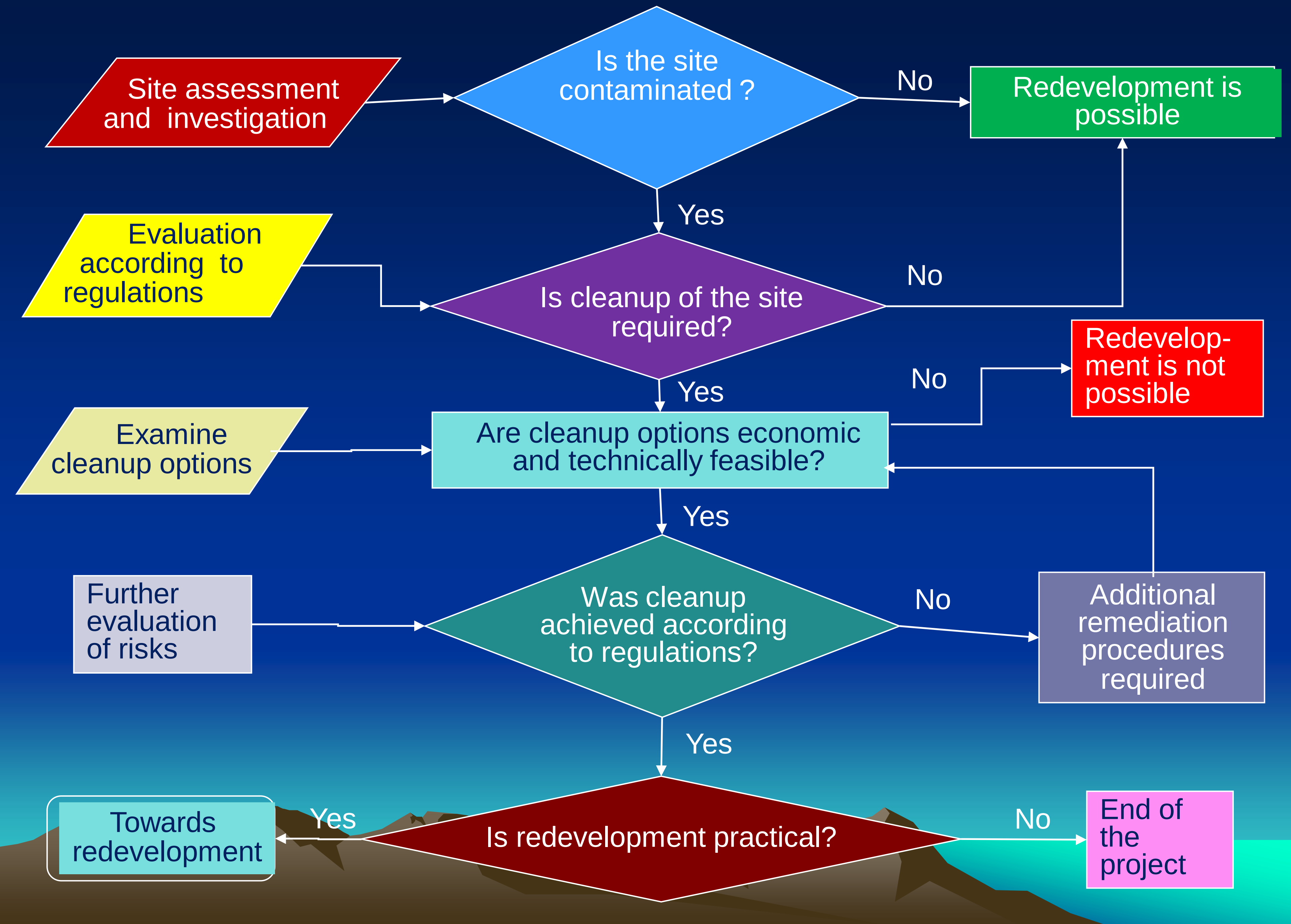
For remediated soils to remain remediated, the input rate of contaminants $\leq$ remediation rate determined:

(a) by natural remediation or recovery processes in the remediated sediment, or

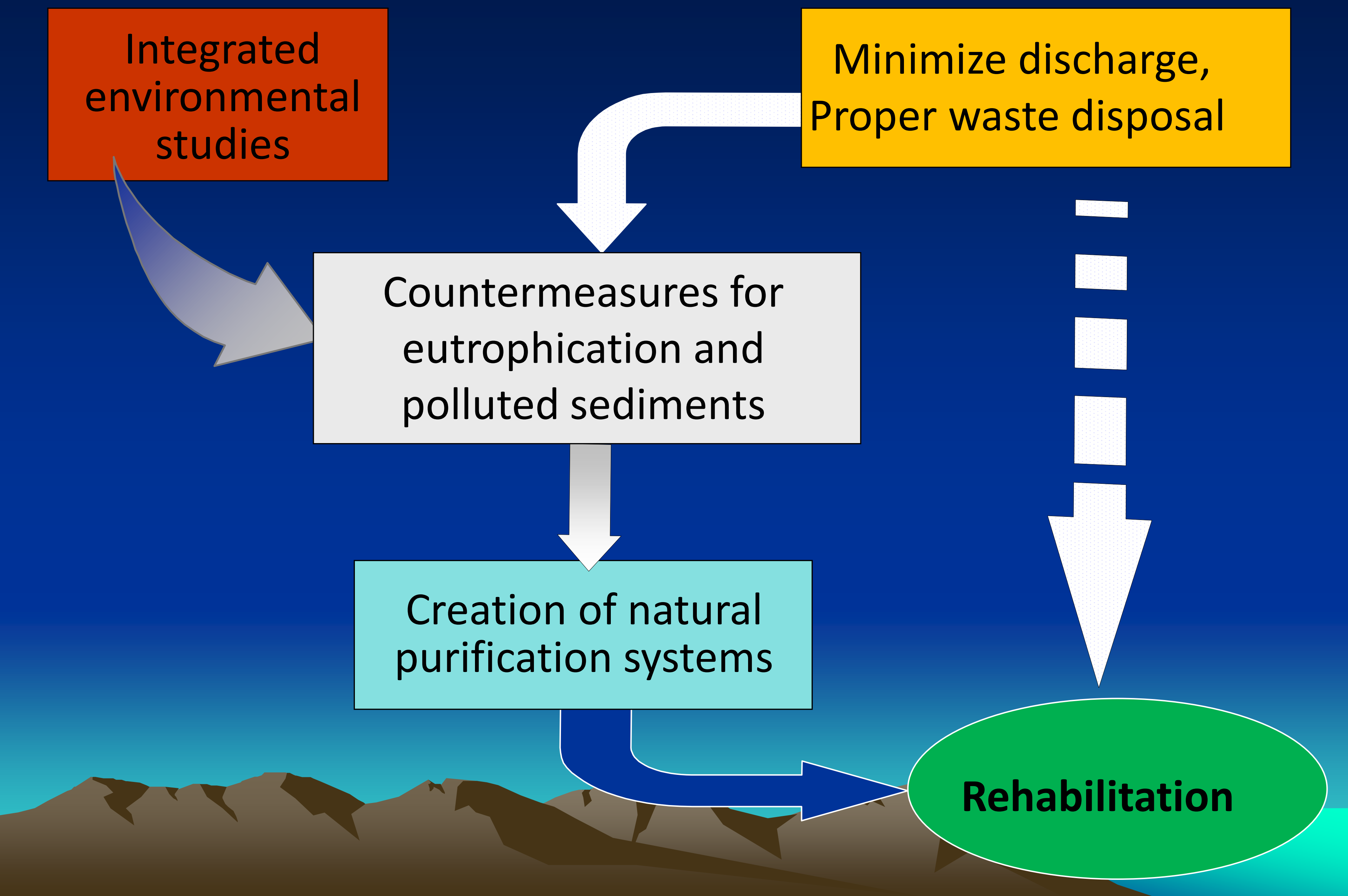
(b) by human intervention

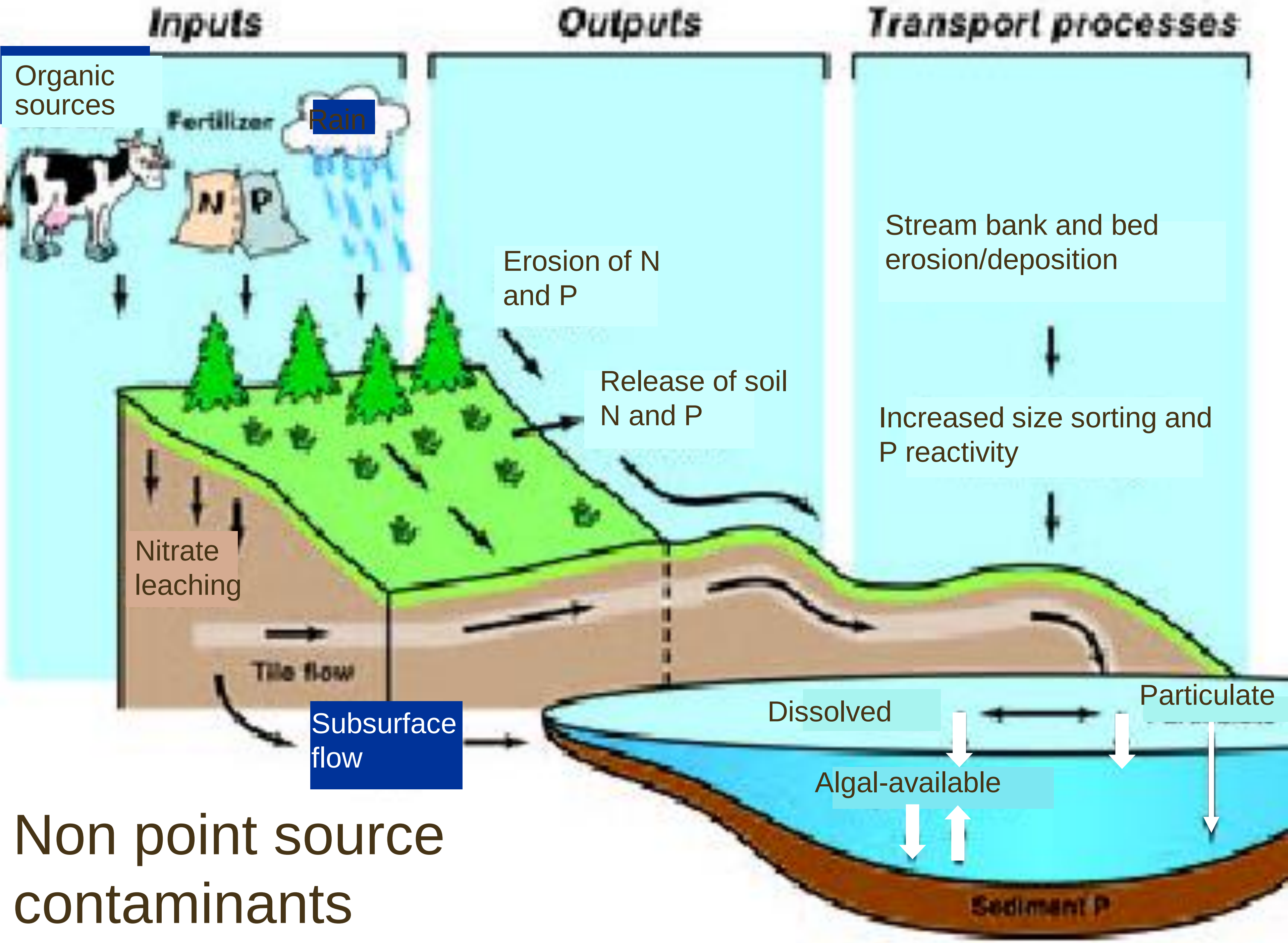
The requirements for this to happen include:

1. Elimination or reduction of rate and-or quantity of input contaminants
2. Natural and-or technological remediation processes capable of decontaminating and-or detoxifying the incoming contaminant load
3. Restoration of habitat, breeding grounds and natural species


Site assessment and investigation
Is the site contaminated ?
No
Redevelopment is possible
Yes
Evaluation according to regulations
Is cleanup of the site required?
No
Yes
No
Redevelop-ment is not possible
Examine cleanup options
Are cleanup options economic and technically feasible?
Yes
Further evaluation of risks
Was cleanup achieved according to regulations?
No
Additional remediation procedures required
Yes
Towards redevelopment
Yes
Is redevelopment practical?
No
End of the project

Strategy for rehabilitation of marine environment



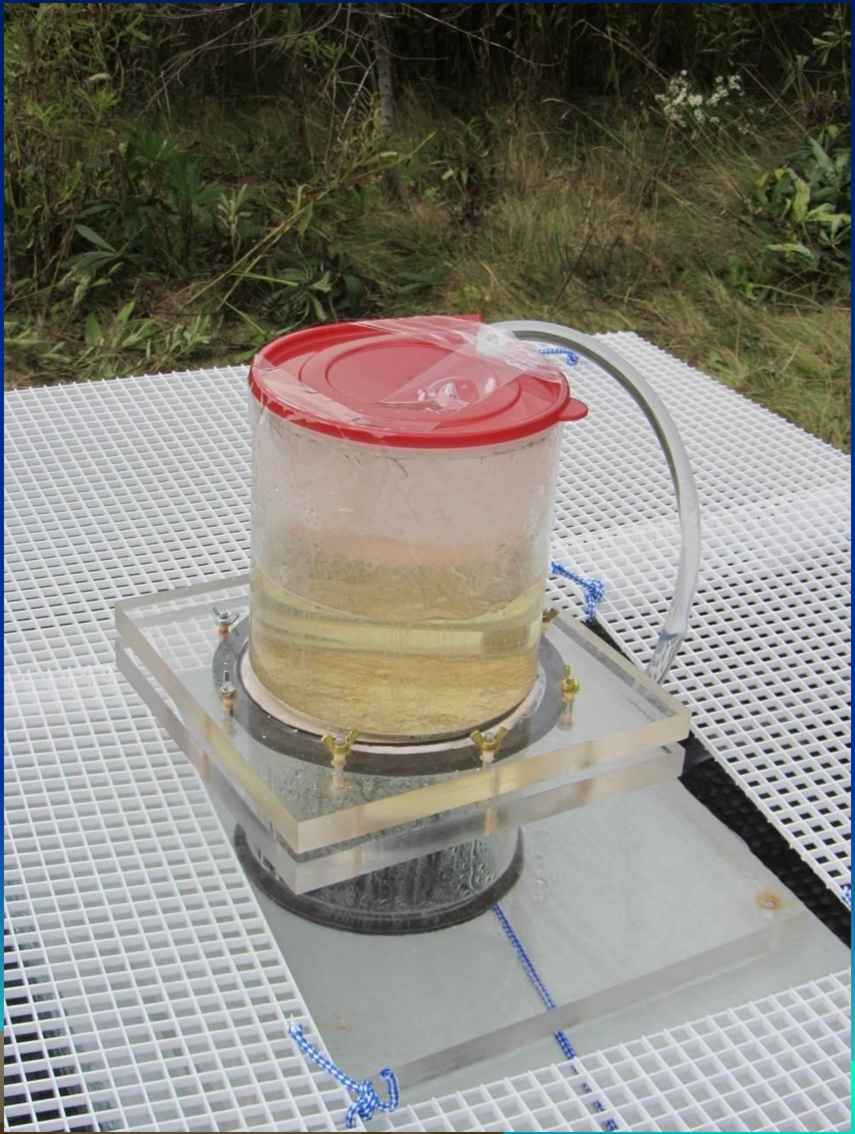


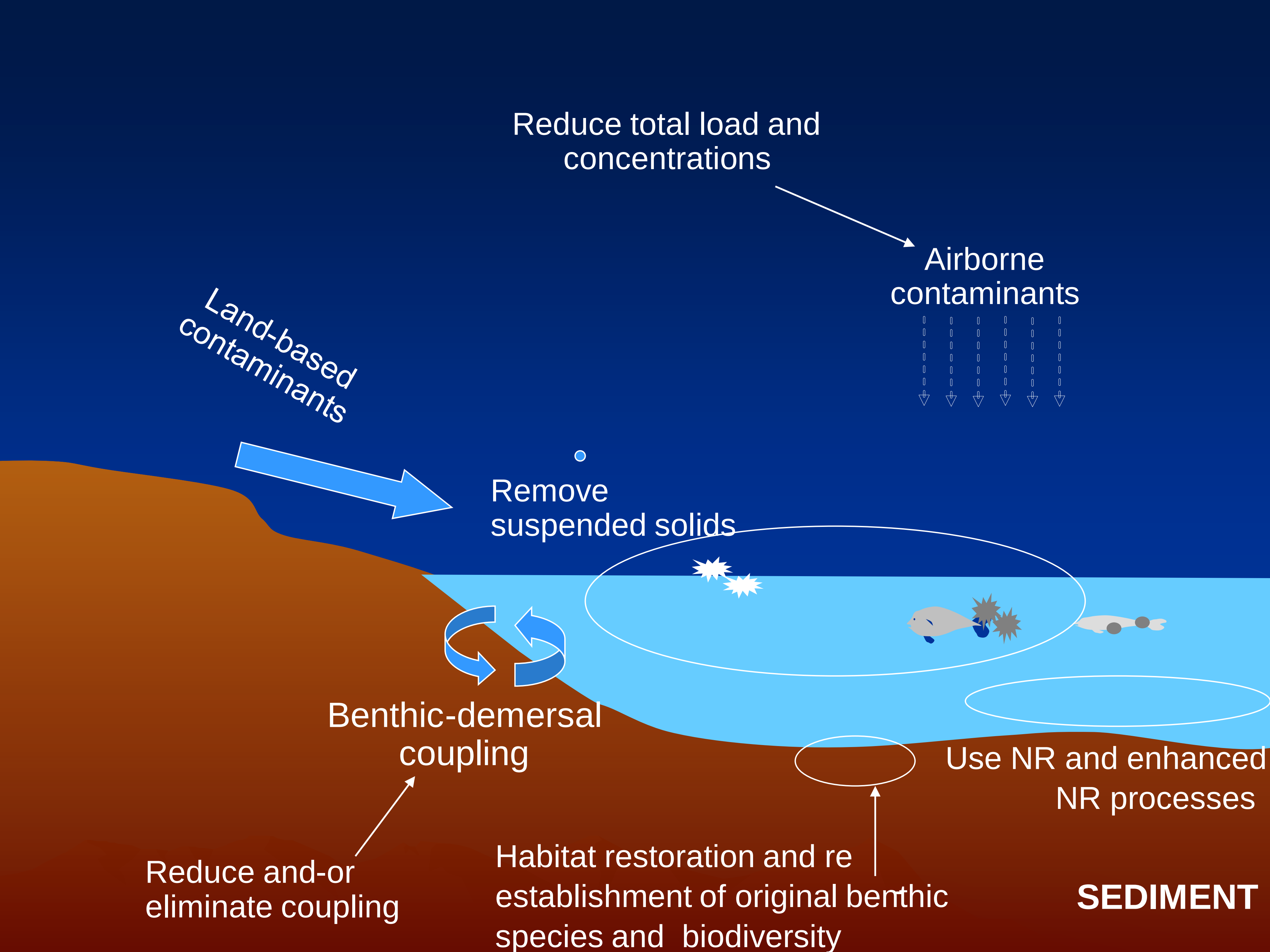
Non point source contaminants

Des Hurons River, Quebec

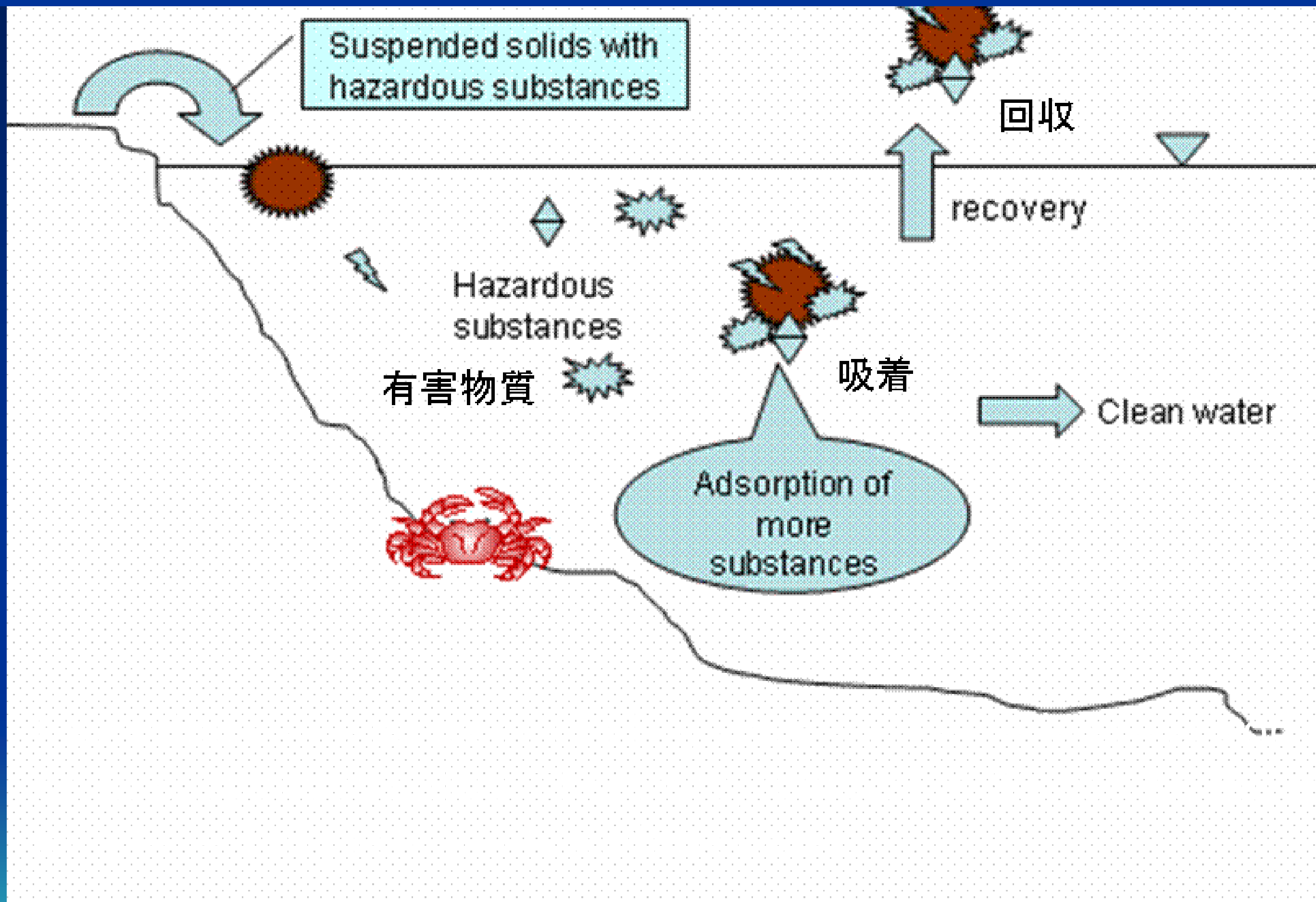
Cyanobacteria floating on the water surface in Lac Saint-Amour, Saint Anne des Lacs

Lac Caron




Reduce total load and concentrations
Airborne contaminants
Land-based contaminants
Remove suspended solids
Benthic-demersal coupling
Use NR and enhanced NR processes
Reduce and-or eliminate coupling
Habitat restoration and re establishment of original benthic species and biodiversity
SEDIMENT

Principle of water purification by filtration



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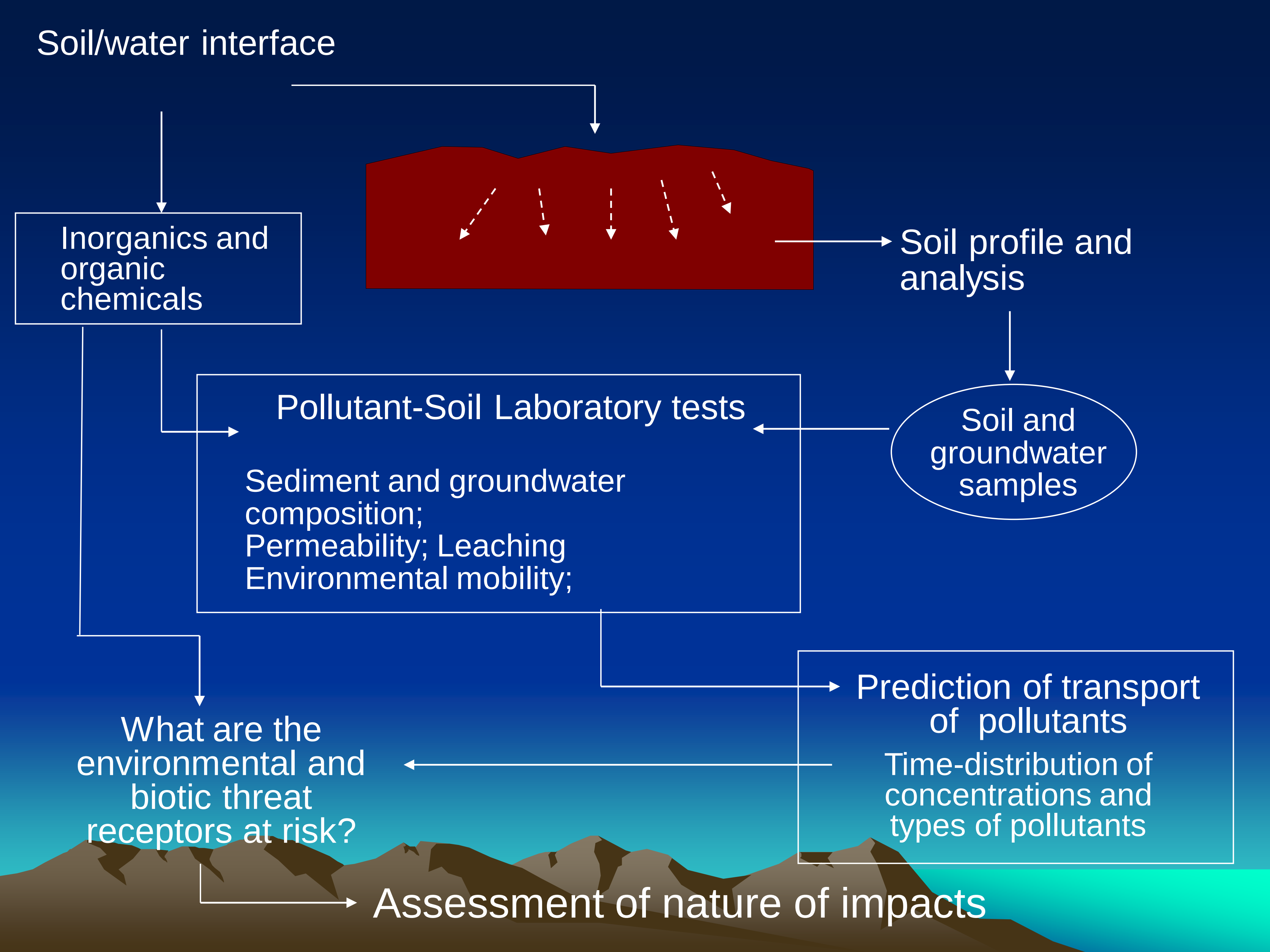
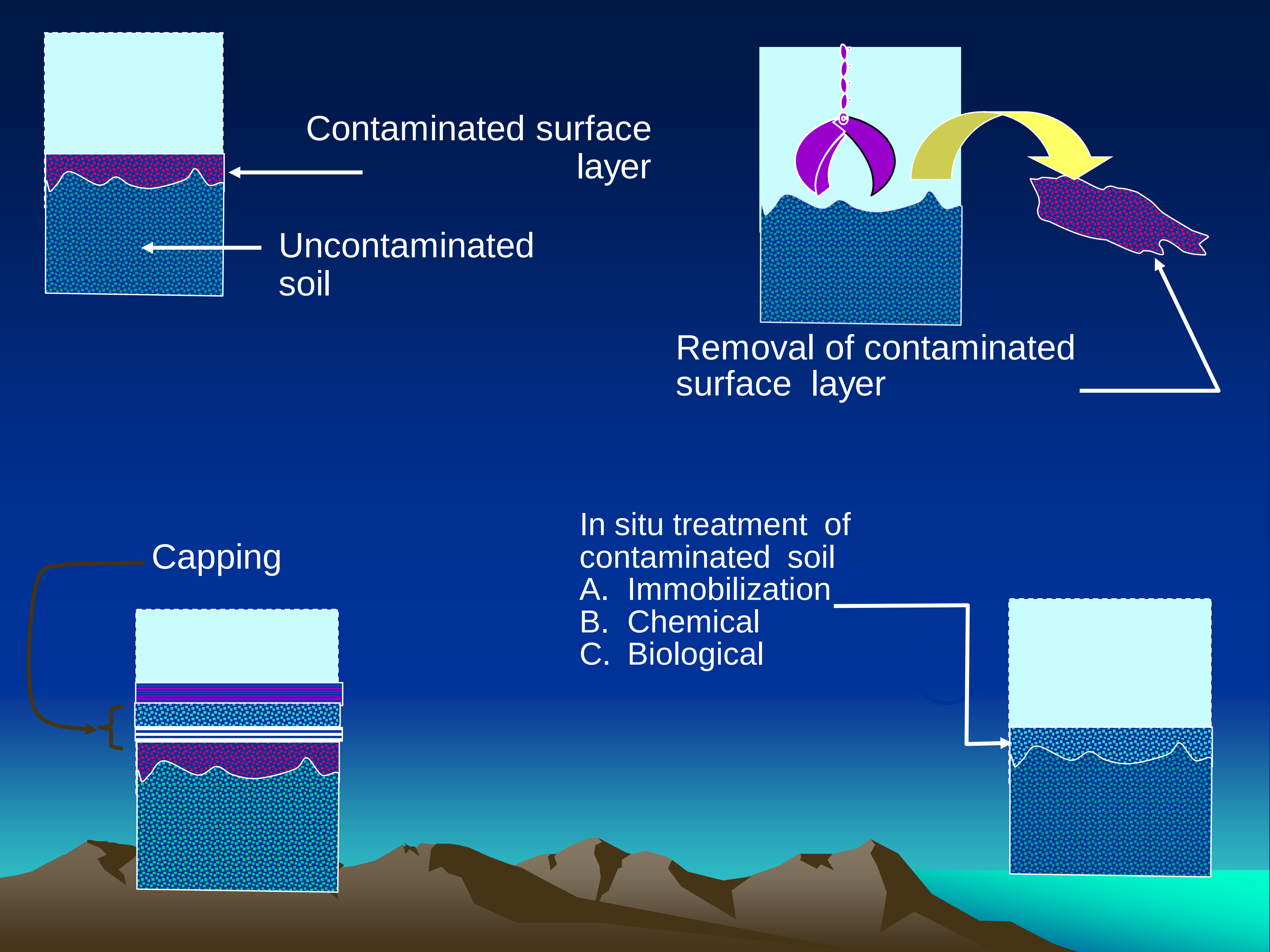
Source Yong et al., 2006 Geoenvironmental Sustainability, CRC Press, Boca Raton


Soil/water interface
Inorganics and organic chemicals
Soil profile and analysis
Pollutant-Soil Laboratory tests
Sediment and groundwater composition;
Permeability; Leaching
Environmental mobility;
Soil and groundwater samples
Prediction of transport of pollutants
Time-distribution of concentrations and types of pollutants
What are the environmental and biotic threat receptors at risk?
Assessment of nature of impacts



Contaminated surface layer
Uncontaminated soil
Removal of contaminated surface layer
Capping
In situ treatment of contaminated soil
A. Immobilization
B. Chemical
C. Biological

Common definition of natural attenuation NA

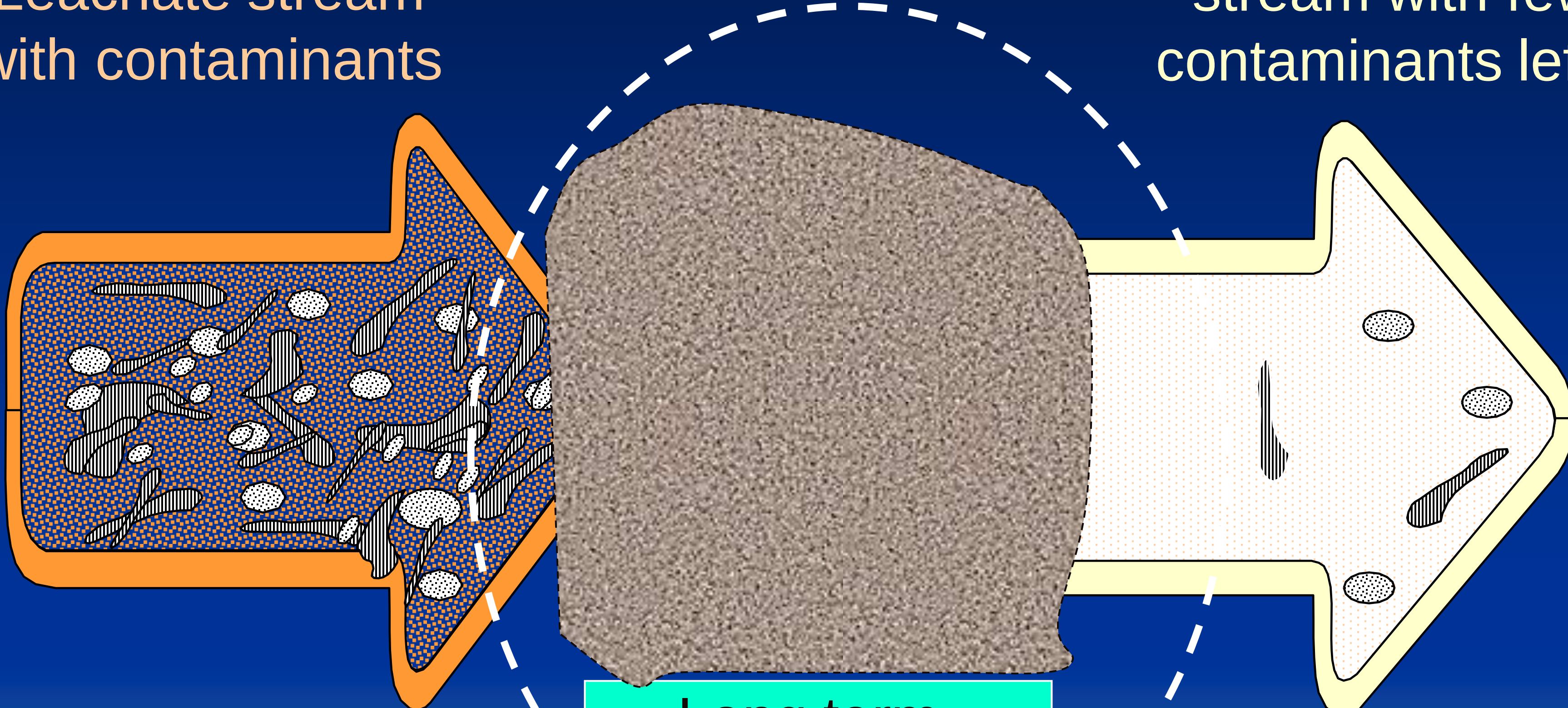
Natural attenuation is a process that involves the biodegradation, dispersion, dilution, sorption, volatilization of contaminants, together with chemical and biochemical reactions and transformations of the contaminants to reduce contaminant toxicity, volume, mass, and concentrations to levels considered as non-threatening to biotic receptors and the environment.

From Yong and Mulligan (2019)

Sustainability of natural attenuation?

Leachate stream with contaminants

Attenuated leachate stream with few contaminants left



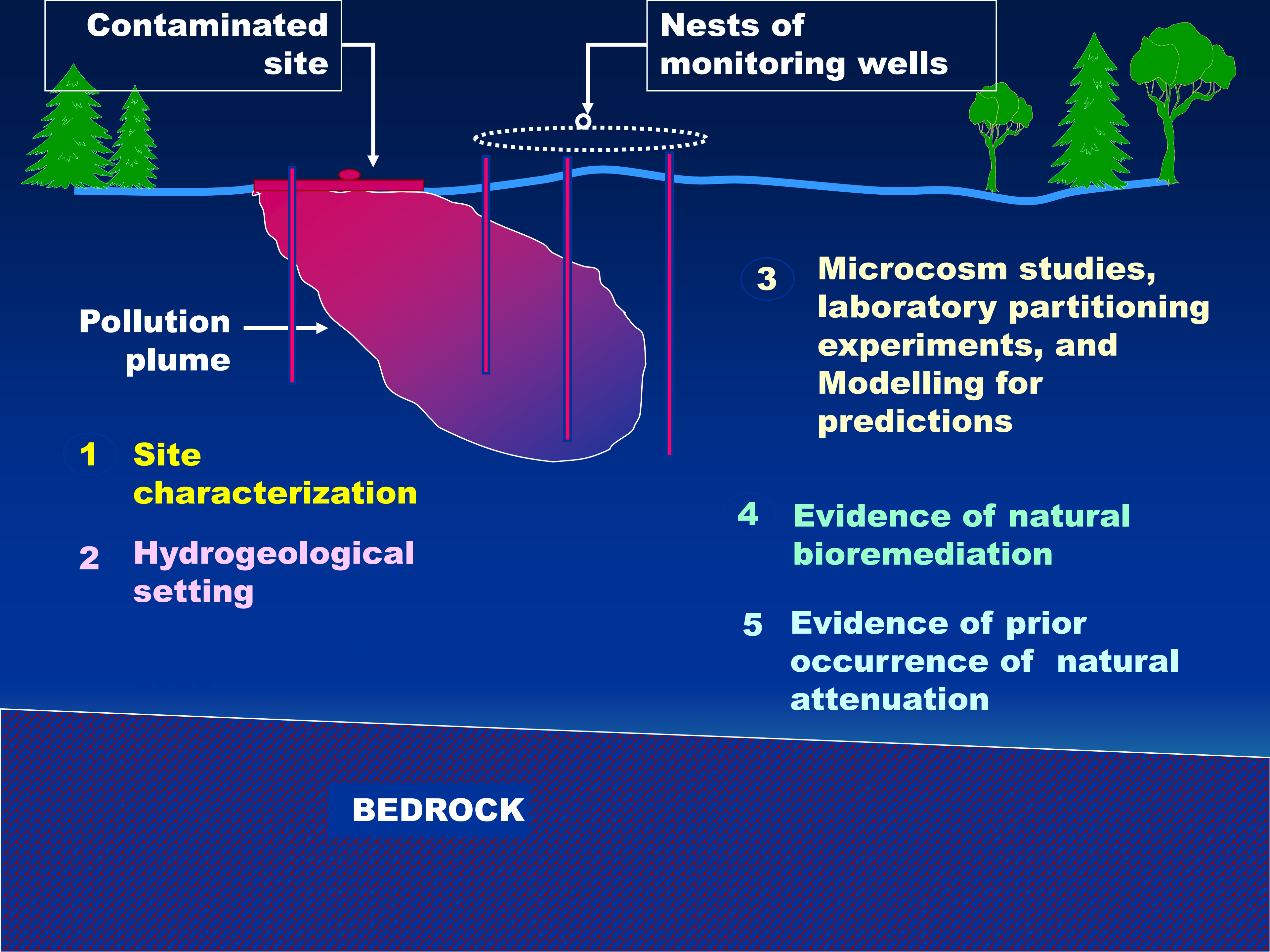
Long term performance of natural attenuation processes

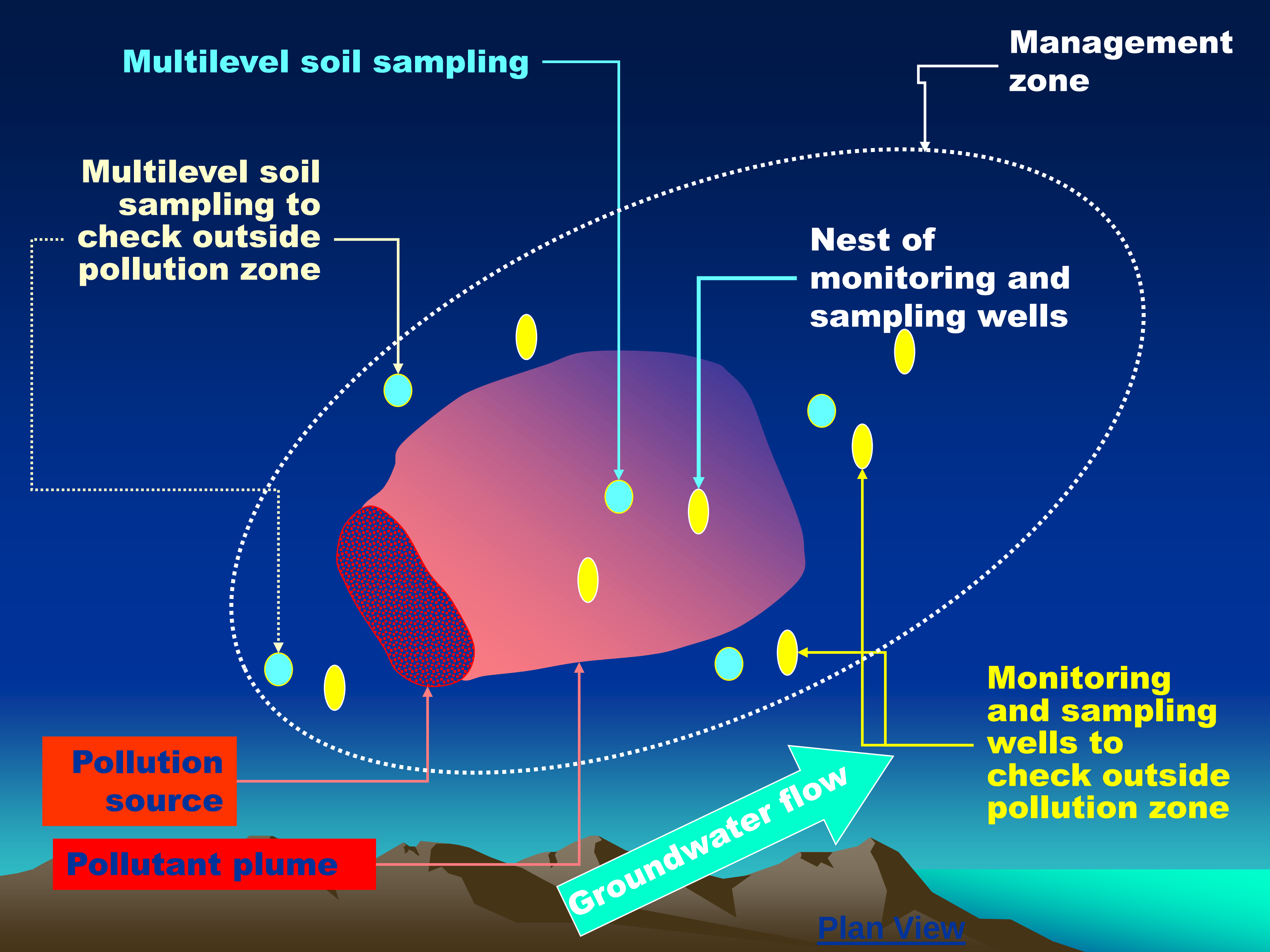
Long term supply of electron acceptors, sorption sites, status of pH, Eh

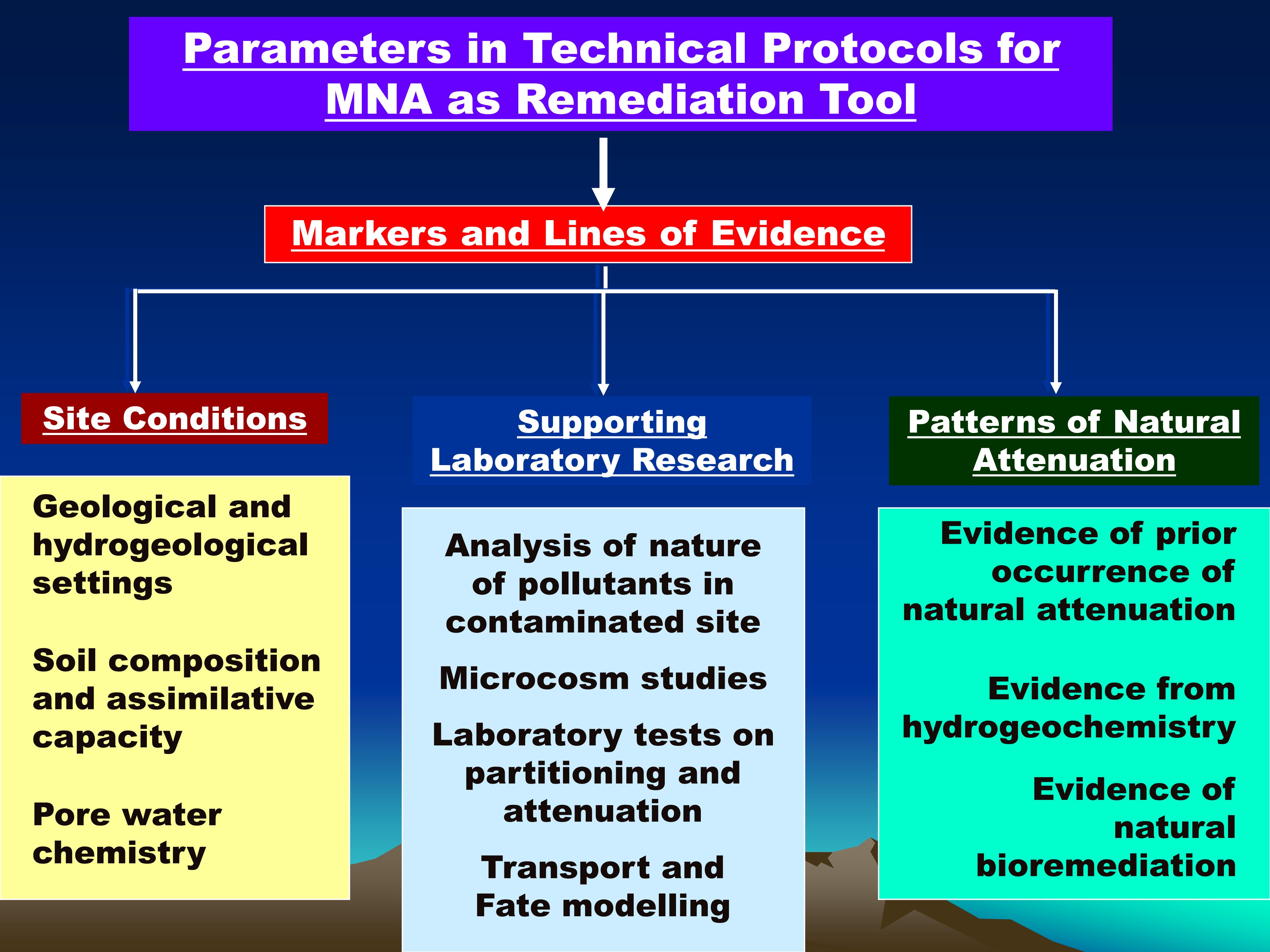
Geochemical and Biogeochemical processes

Evidence of natural attenuation

- National Research Council protocol for groundwater
  - Decrease in contaminant concentration
  - Chemical indicators of microbiological activity
  - Laboratory microcosm studies
- Other protocols similar (ASTM, OSWER, US Air Force, API
- Newer guidance on inorganics, radionuclides from EPA


Contaminated site
Nests of monitoring wells
Pollution plume
1 Site characterization
2 Hydrogeological setting
3 Microcosm studies, laboratory partitioning experiments, and Modelling for predictions
4 Evidence of natural bioremediation
5 Evidence of prior occurrence of natural attenuation
BEDROCK


Multilevel soil sampling
Management zone
Multilevel soil sampling to check outside pollution zone
Nest of monitoring and sampling wells
Monitoring and sampling wells to check outside pollution zone
Pollution source
Pollutant plume
Groundwater flow
Plan View



Parameters in Technical Protocols for MNA as Remediation Tool
Markers and Lines of Evidence
Site Conditions
Supporting Laboratory Research
Patterns of Natural Attenuation
Geological and hydrogeological settings
Soil composition and assimilative capacity
Pore water chemistry
Analysis of nature of pollutants in contaminated site
Microcosm studies
Laboratory tests on partitioning and attenuation
Transport and Fate modelling
Evidence of prior occurrence of natural attenuation
Evidence from hydrogeochemistry
Evidence of natural bioremediation

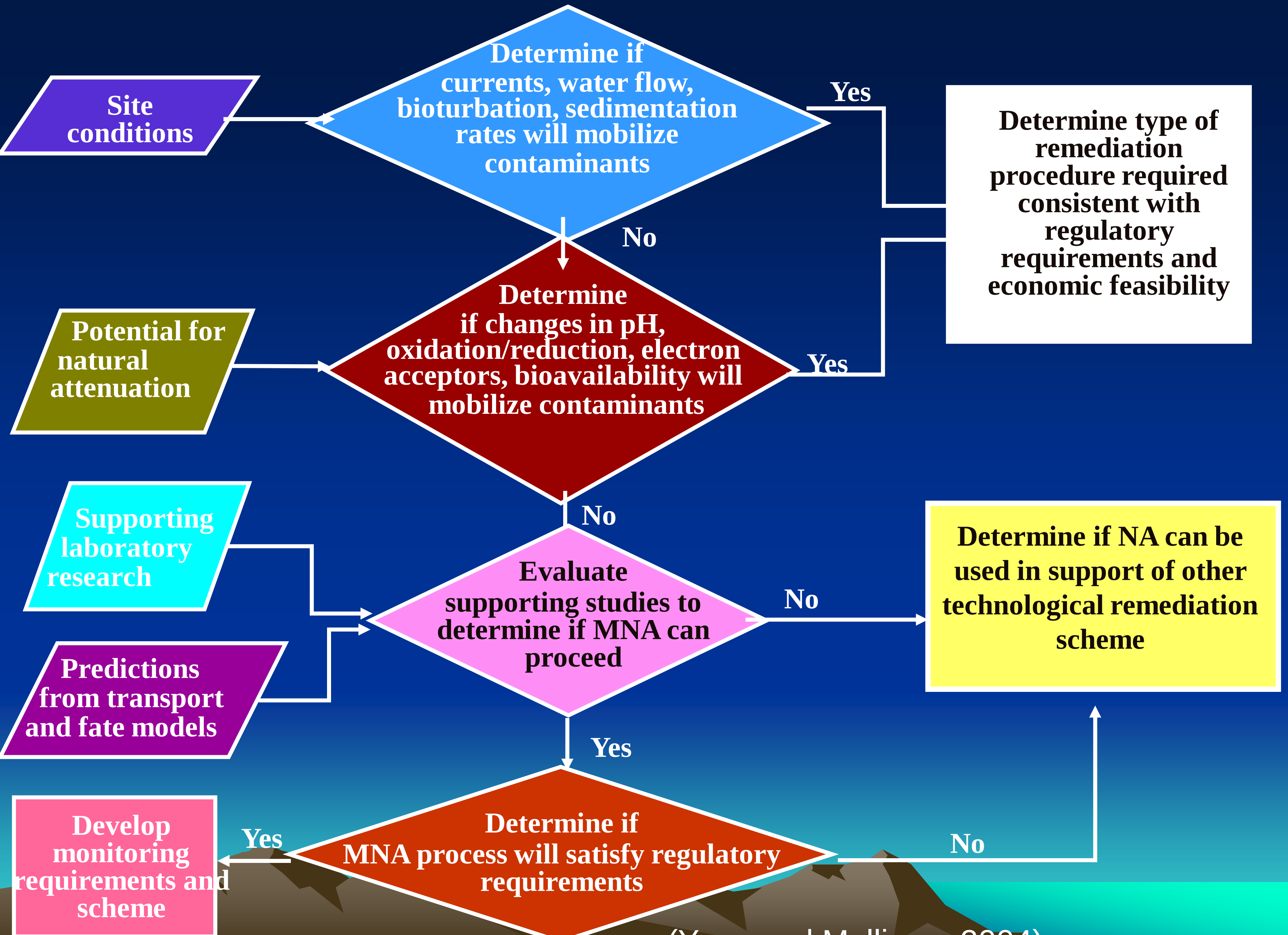
Lines of evidence (groundwater and sediment natural attenuation)

- First -40% loss of PCE and TCE at field scale
- Second line -Presence of biogeochemical indicators –dissolved oxygen, low levels of Fe(II), sulfate and presence of methane etc.
- Third-presence of indigenous bacteria capable of PCE, TCE degradation

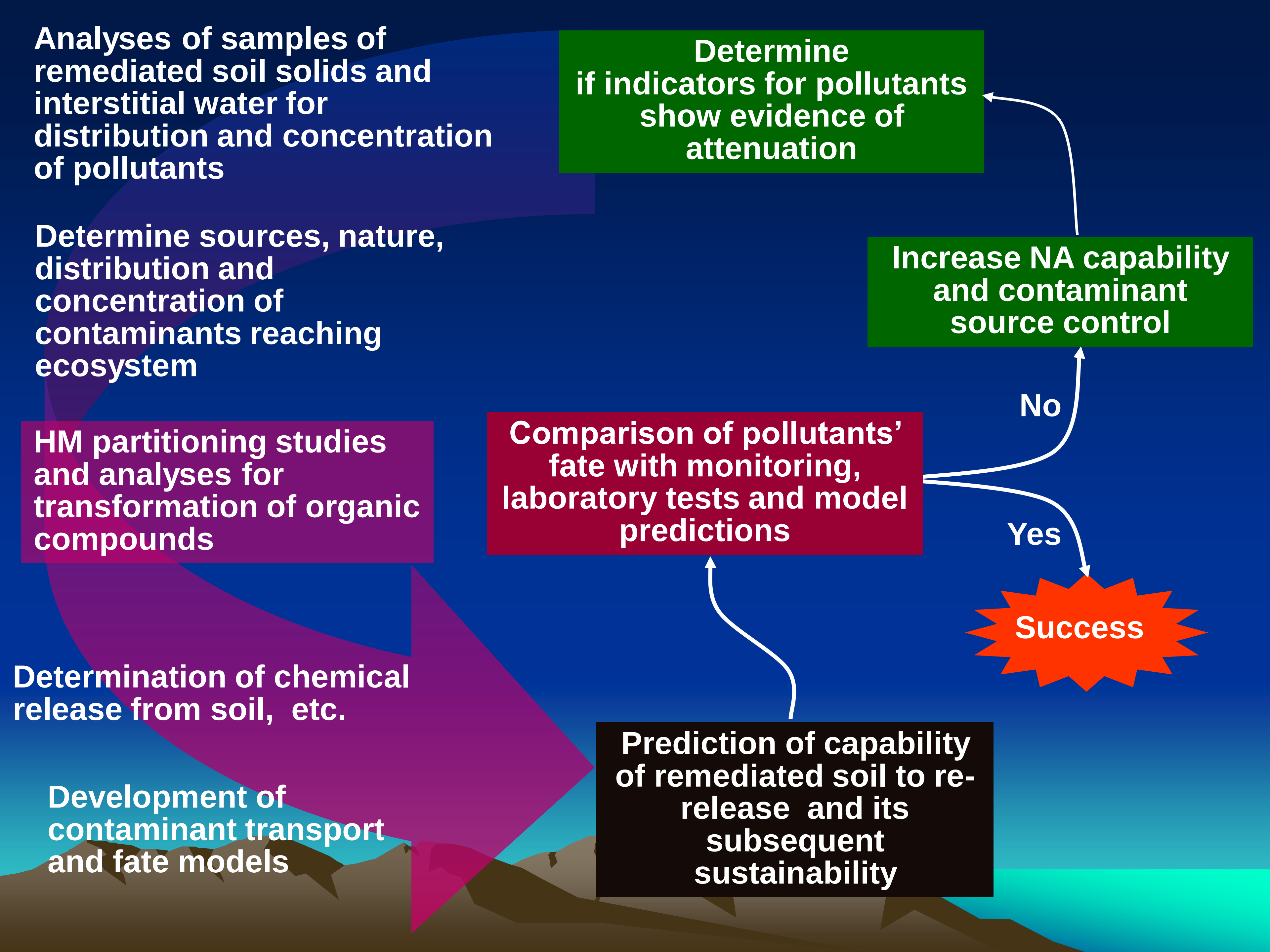
Witt et al. 2002

RTDF Framework

- Source characterization and control
- Identification of fate and transport process
- Identification of historical trends of contaminants
- Biological end-point trend identification depending on site conditions
- Develop predictive tools such as numerical models



(Yong and Mulligan, 2004)


Analyses of samples of remediated soil solids and interstitial water for distribution and concentration of pollutants
Determine sources, nature, distribution and concentration of contaminants reaching ecosystem
HM partitioning studies and analyses for transformation of organic compounds
Determination of chemical release from soil, etc.
Development of contaminant transport and fate models
Determine if indicators for pollutants show evidence of attenuation
Increase NA capability and contaminant source control
Comparison of pollutants' fate with monitoring, laboratory tests and model predictions
No
Yes
Success
Prediction of capability of remediated soil to re-release and its subsequent sustainability

Case studies

- PCB natural attenuation in sediments at Lake Harwell, SC
- Mole percentage of PCB congeners determined, compared to 1987
- Slow in situ dechlorination
- Capping with fresh sediment may be needed to decrease risk to bioaccumulation

Pakdeesusul et al 2005

Weathering in sediments near Seattle, WA

- Three sources determined-creosote, urban runoff and natural background
- Urban runoff-50 to 70 years
- Unweathered and pure creosote below 30 cm
- Surface sediments to 30 cm were creosote and urban runoff
- Low molecular weight lost
- No extensive clean sediment deposits so capped with 1 to 3 m clean sand

Brenner et al., 2002

Heavy metals in Port Philip Bay, Australia

- Concentrations of HM not higher near shore and estuarine area compared to coastal water
- HM in fish and shell fish
- Fe precipitation and Mn oxyhydroxide ppt with HM
- As(III) concentration increased with depth, not anthropogenic
- Oxidation to As(V) near surface

Fabris et al., 1999

Biosurfactants

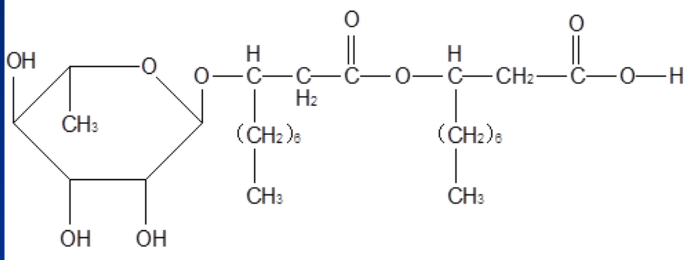
- Produced either on the surfaces of microbial cell or excreted extracellularly by bacteria or yeasts
- Advantages
  - Higher biodegradability and lower toxicity
  - Potentially more economic than the other surfactants
  - Potential to decrease the environmental impacts of soil, sediment, mining residues and wastewater contaminants

Rhamnolipid Biosurfactant

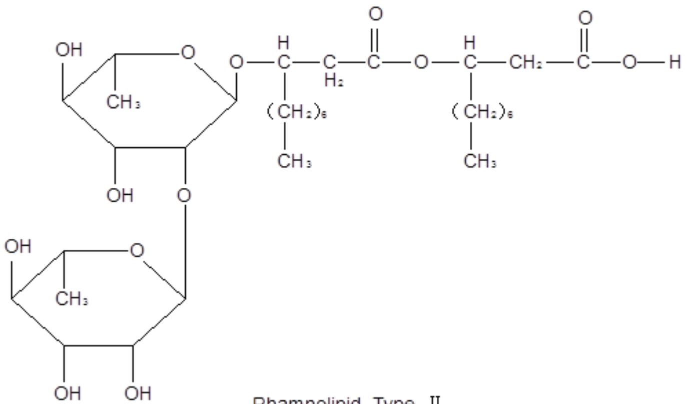
- *Pseudomonas aeruginosa* species has the ability to produce four different rhamnolipids (R1 – R4)
- Anionic and capable of lowering the water surface tension from 72 to 29 mN/m
- Rhamnolipid important environmental applications are:
  - Biodegradation of petroleum hydrocarbons and (PAHs)
  - Removal of heavy metals and organics
  - Dispersing oil in contaminated water

Rhamnolipid

An anionic biosurfactant produced by *Pseudomonas aeruginosa* species



Rhamnolipid Type I



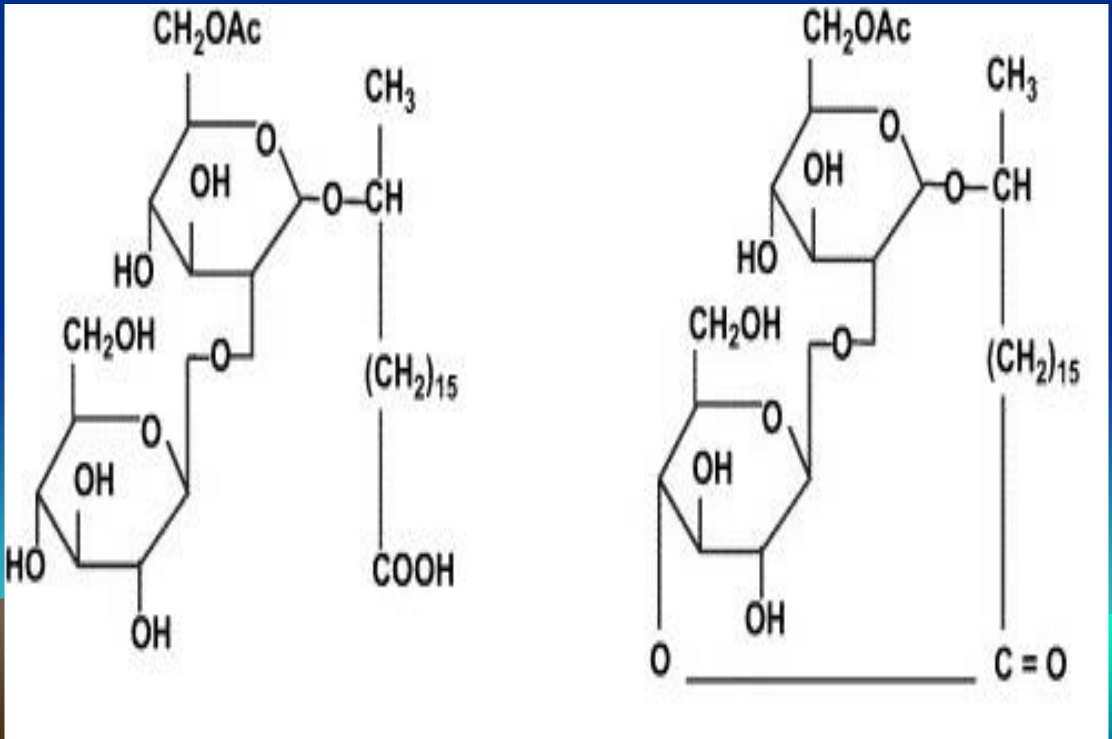
Rhamnolipid Type II

Rhamnolipids type I or mono-rhamnolipids contain one rhamnose group while rhamnolipids type II or di-rhamnolipids; contain two rhamnose groups

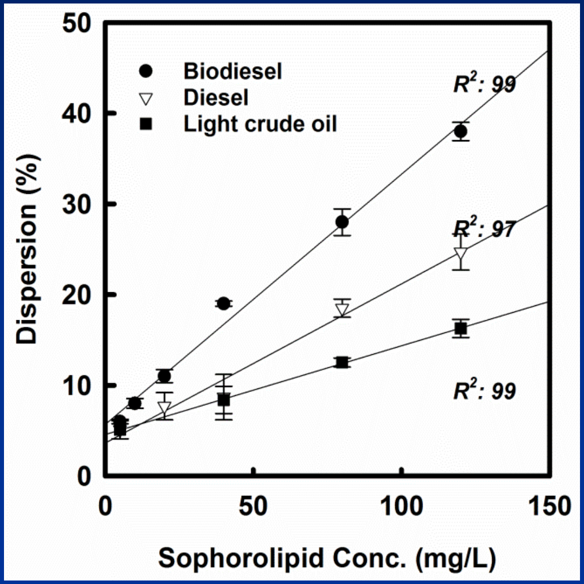
Sophorolipids

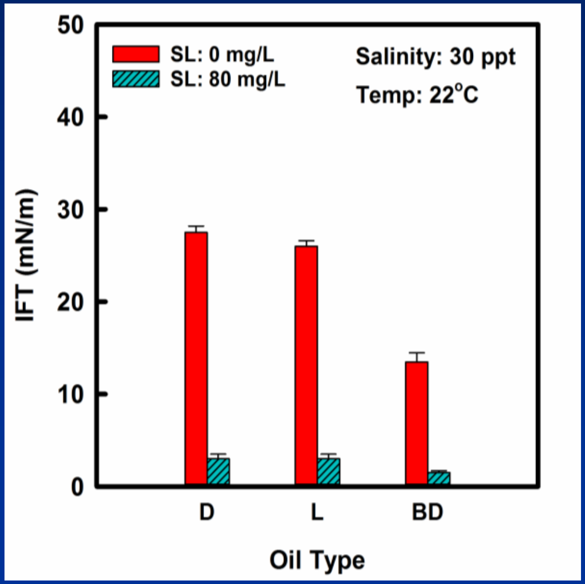
- Glycolipid
  - Main producers: yeasts of *Candida* sp.
    - Primary producer: *Candida bombicola*

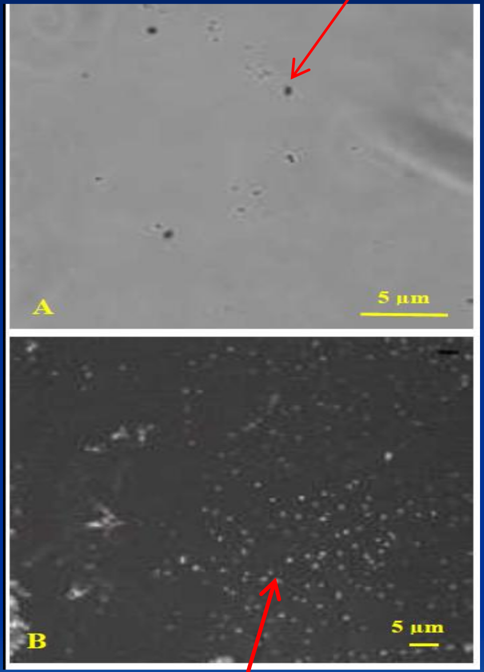
Structure of sophorolipid produced by *C. bombicola*



Effect of sophorolipid (SL) concentration on oil dispersion





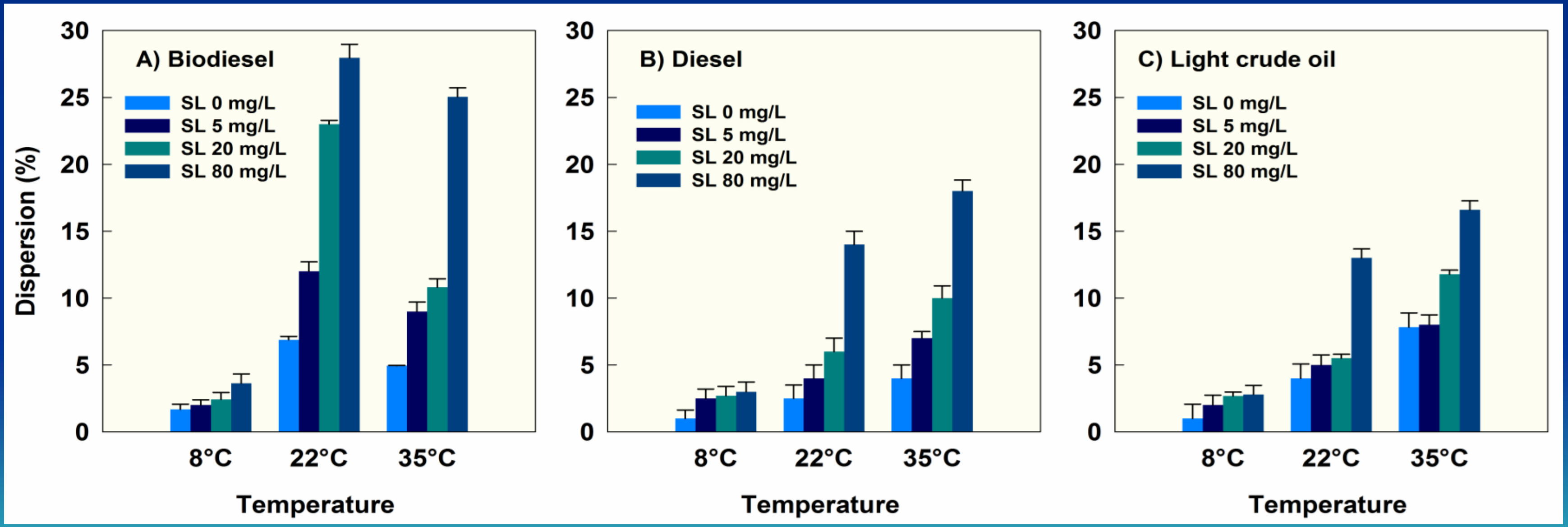


Symbols, experimental data
—, best fit linear functions
Scale bars: 5 µm
IFT: Interfacial tension

$$\text{Dispersion Effectiveness}\,(\%) = \frac{\text{Dispersed-oil concentration}}{\text{Initial oil concentration}} \times 100$$

Effect of Temperature

- The dispersion of diesel, biodiesel and light crude oil increased as the temperature increased from 8ºC to 22°C
- The dispersion of biodiesel reduced slightly at 35ºC
- The dispersion of diesel and light crude oil increased at 35ºC



Biodegradation test

Biodegradation Treatments

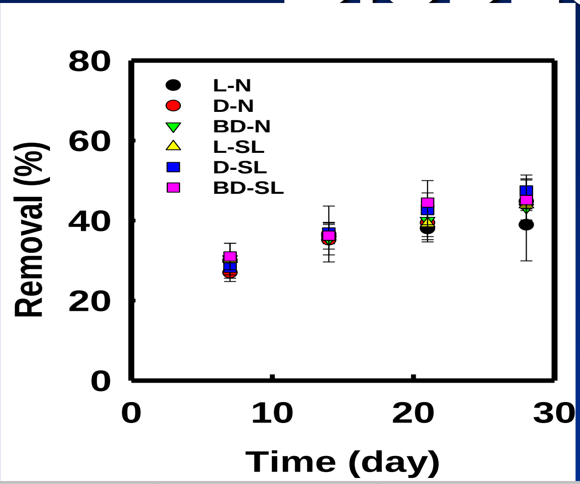
- Control or natural treatment (seawater; 20 mL and sterilized weathered oil;100 µL)

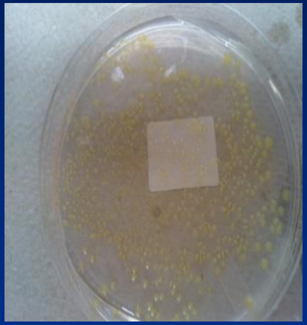
- Sophorolipid treatment (seawater; 20 mL, weathered oil and SL ;100 µL)

Incubation and Sampling

- Room temperature, 100 ± 1 rpm, 28 days
- Sampling days; 0, 7, 14, 21 and 28

Presence of Indigenous Biodegrading Bacteria





Classifications	Biodiesel	Diesel		Light crude oil	
Phylum	*Firmicutes*	*Actinobacteria*	*Firmicutes*	*Proteobacteria*	*Actinobacteria*
Class	*Bacilli*	*Actinobacteria*	*Bacilli*	*Alphaproteobacteria*	*Actinobacteria*
Order	*Bacillales*	*Actinomycetales*	*Bacillales*	*Sphingomonadales*	*Actinomycetales*
Family	*Bacillaceae*	*Dietziaceae*	*Paenibacillaceae*	*Sphingomonadaceae*	*Mycobacteriaceae*
Genus	*Bacillus*	*Dietzia*	*Paenibacillus*	*Sphingomonas*	*Mycobacterium*
Dominancy (%)	100	47	53	97	3

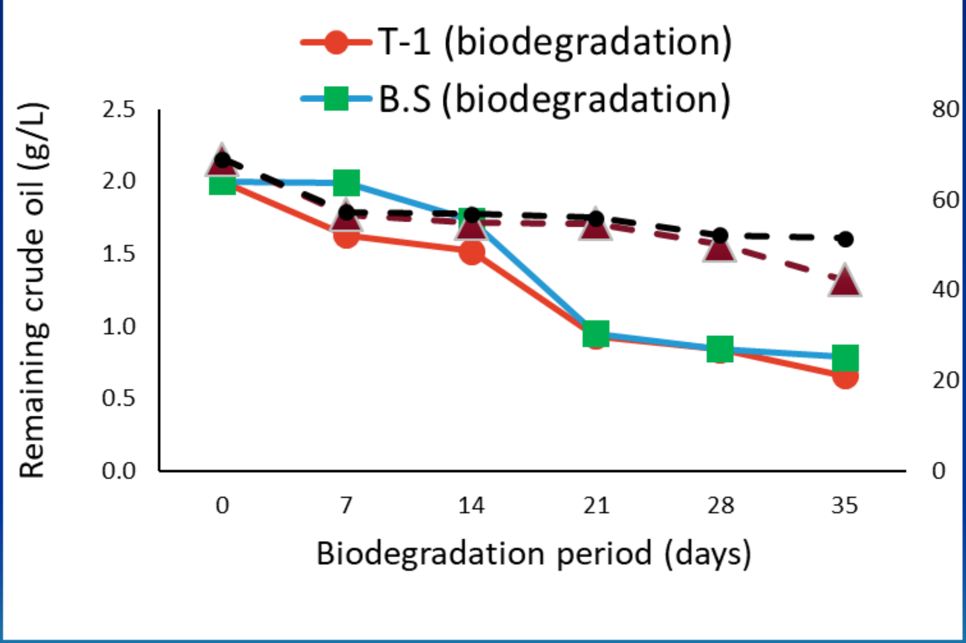
Screening and characterization of biosurfactant-producing bacteria from oil sands tailings ponds

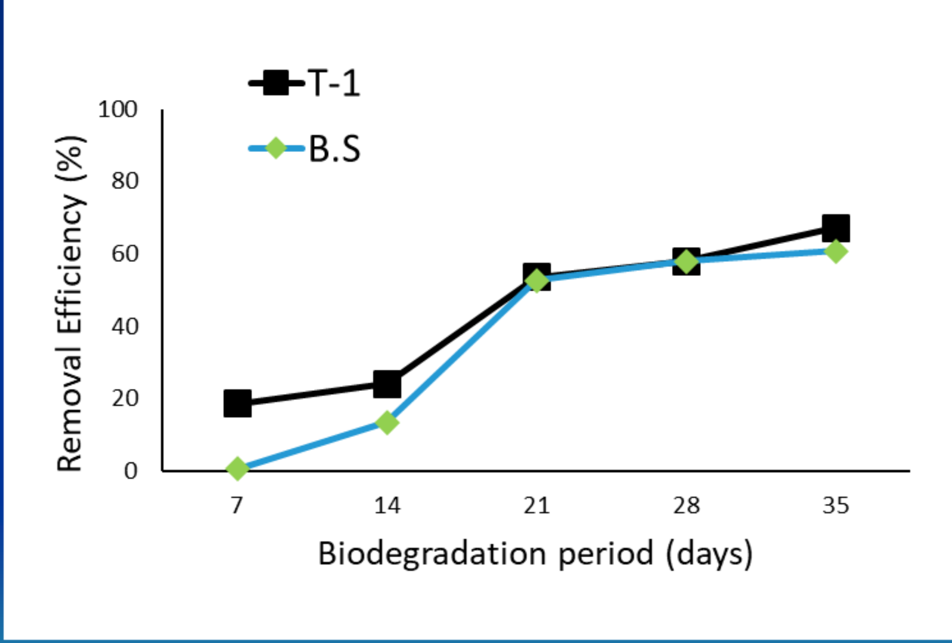
Oil displacement test → Emulsification capacity assay → Surface tension measurement → Blood agar assay → CTAB agar plate

- Culture broth transferred to the LB agar plates
- Sterile sheep blood added to the LB media
- Clear zones around the colony observed

Isolated strain and *B.subtilis* biodegradation study

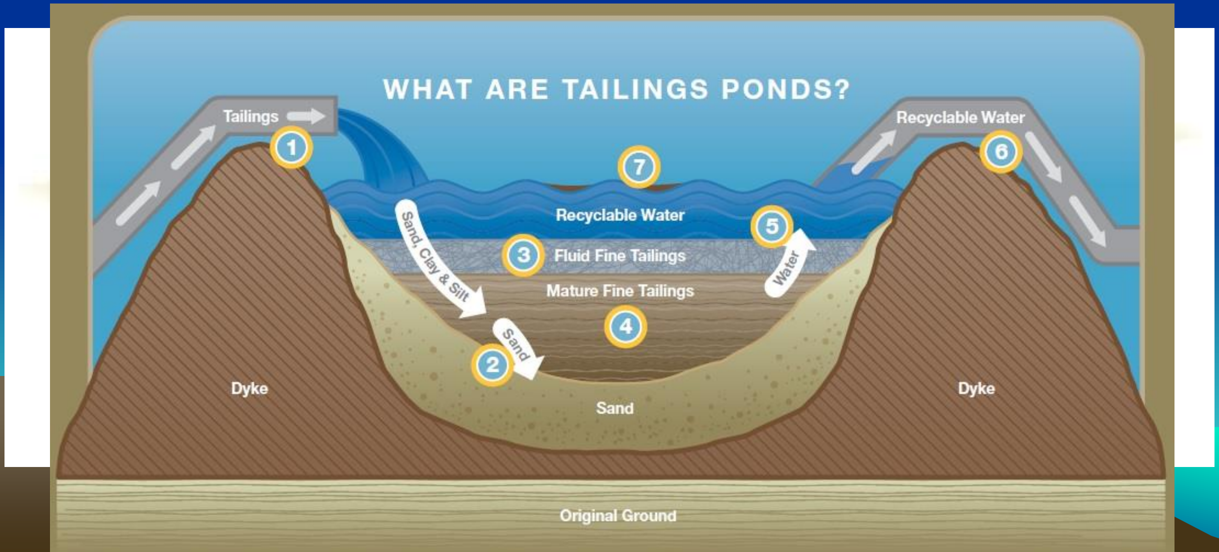
Biodegradation experiment





Oil sands tailings

- By-product from the extraction of bitumen
  - Sand, clays, water and residual bitumen and hydrocarbon
  - About 130 km^2 (22 % of the 602 km^2 disturbed land)
- Coarse grained tailings settle rapidly at the edge
- Fine grained tailings concentrated at the center (mature fine tailings MFT)
  - Very slow sedimentation rate (many years)



Oil sand tailings problems

- Recovering water from tailings for re-use
  - Reduce the need for fresh water
- Consolidating the tailings solids
  - Decrease the volume of stored tailings for subsequent reclamation
- Decrease the toxic impacts of tailing ponds (which affect ecosystem and human health)

Management and increase in tailings settlement rate is an important environmental and economical issue

Statement of the Problem

- Limitations of existing effective method for oil sand tailings sedimentation
  - Polymeric flocculation methods
    - Selection and performance of the flocculants
    - The recycle water quality, startup and operational costs
    - Experienced operators and careful operational control
  - Microbial activity and methanogenesis densification methods
    - Controlling the CH_4 and CO_2 emissions from tailing ponds (as greenhouse gases)

It has been reported that synthetic surfactants can change surface wetting characterization of particles and increase sedimentation and dewatering

Rhamnolipid as flocculating agent and microorganisms together with rhamnolipid?

Sedimentation will increase without producing large amounts of CH_4 while taking advantage of the biosurfactants for the remaining water and sediment bioremediation

Principles

Sedimentation experiments

Downward movement of the boundary between clear liquid and suspended tailings

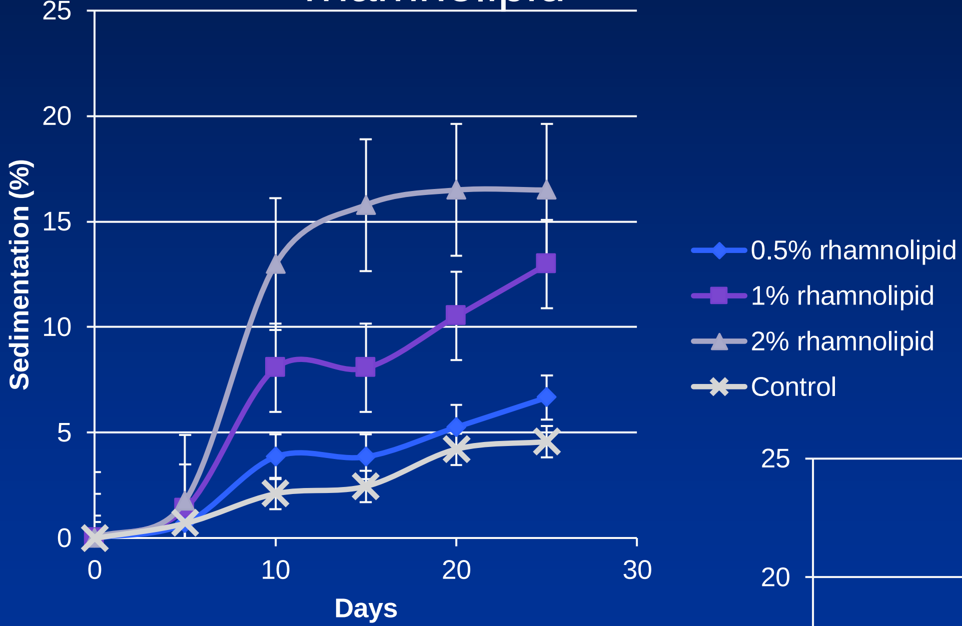
Position of the boundary

$S(\%)=1-h/H$ *(Bordenave et al., 2010)*

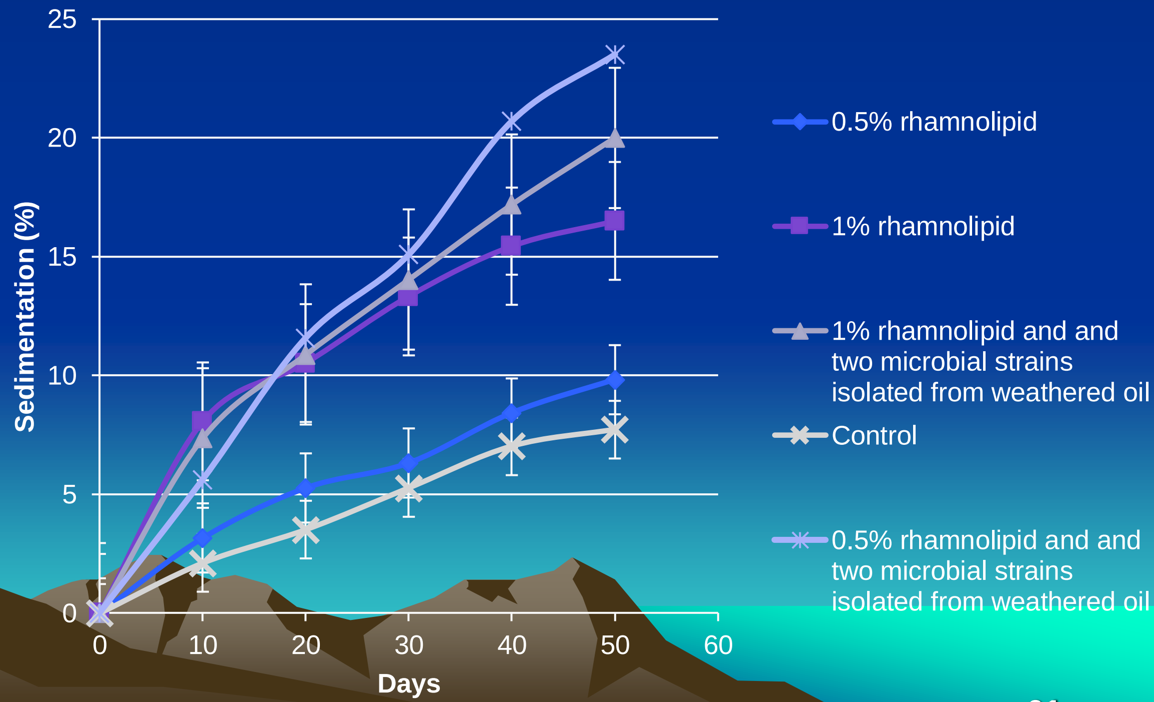
Sedimentation

Total height of the liquid column

Sedimentation of tailing using rhamnolipid



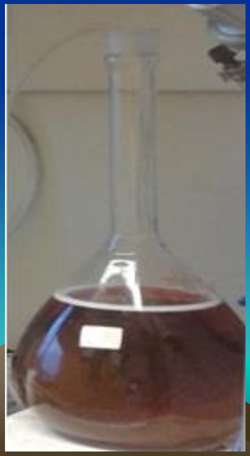
Sedimentation of tailing using rhamnolipid and microbial culture



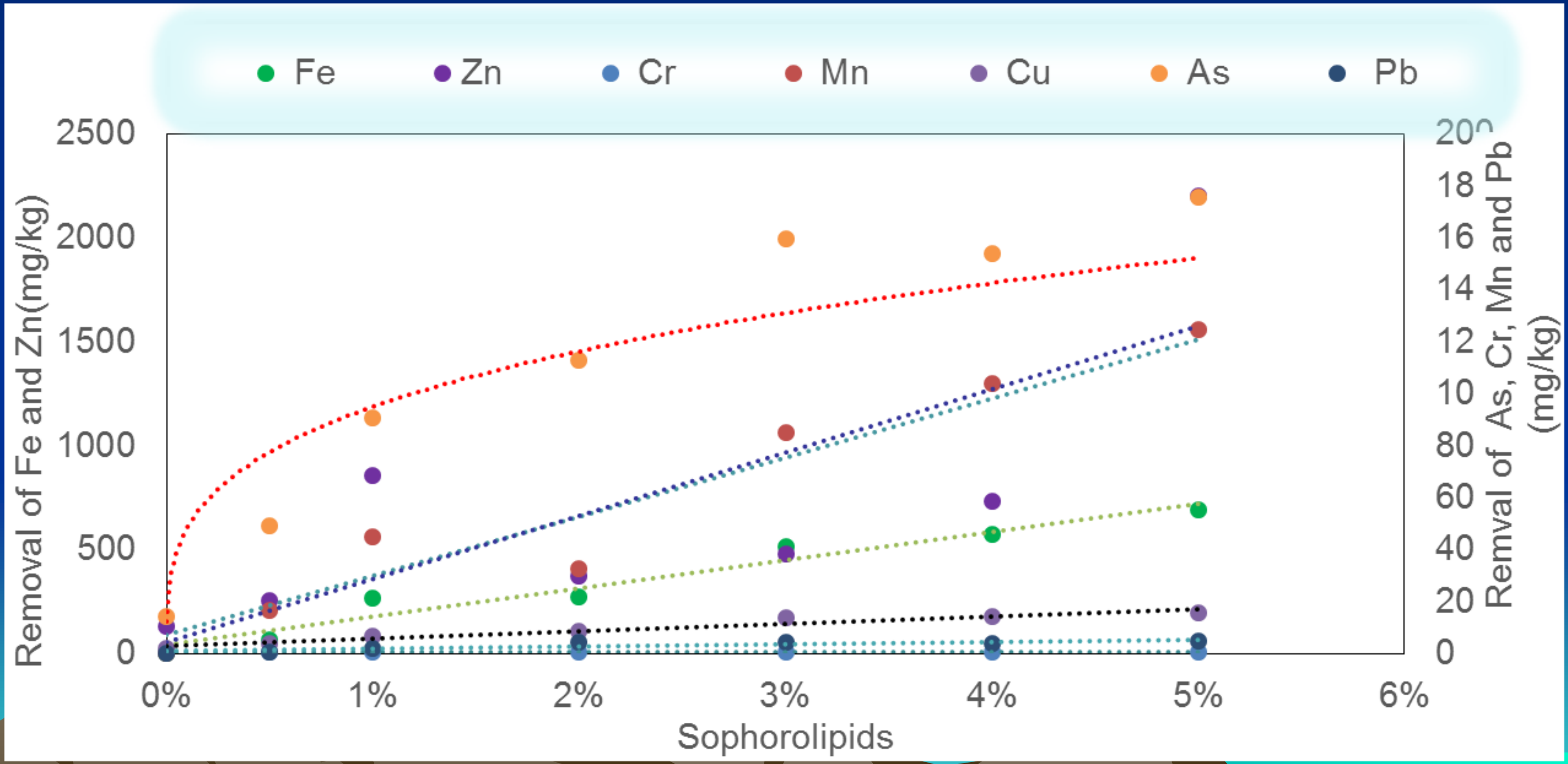
Metal removal from mining tailings

- Mine tailings sample from Giant Mine, Yellowknife, Northwest Territories, Canada

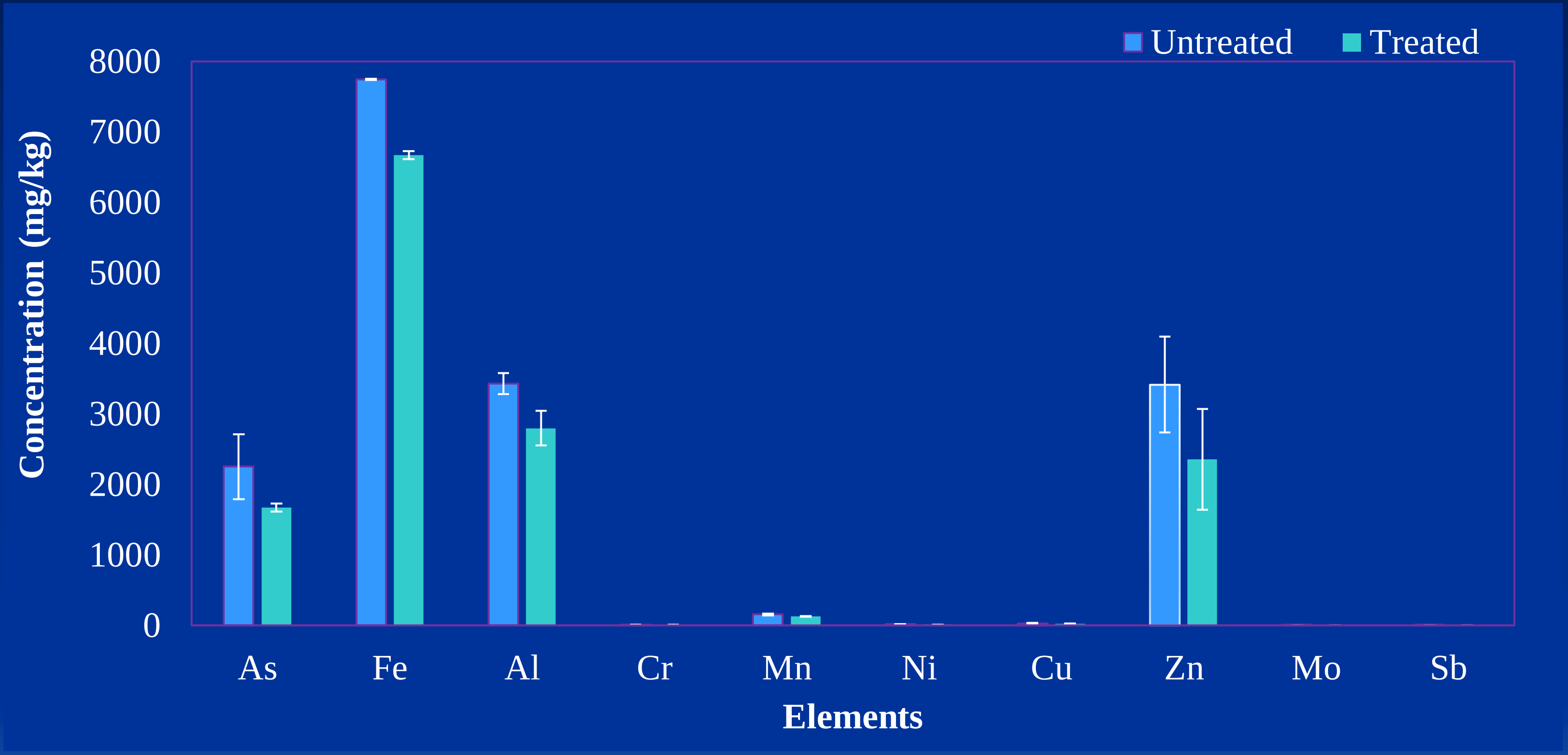
- sophorolipids used in this experiment provided by *Ecover Co., Belgium*



Removal of Mn, Fe, As, Cr, Ni, Cu & Pb with different concentrations of SL from mining residues

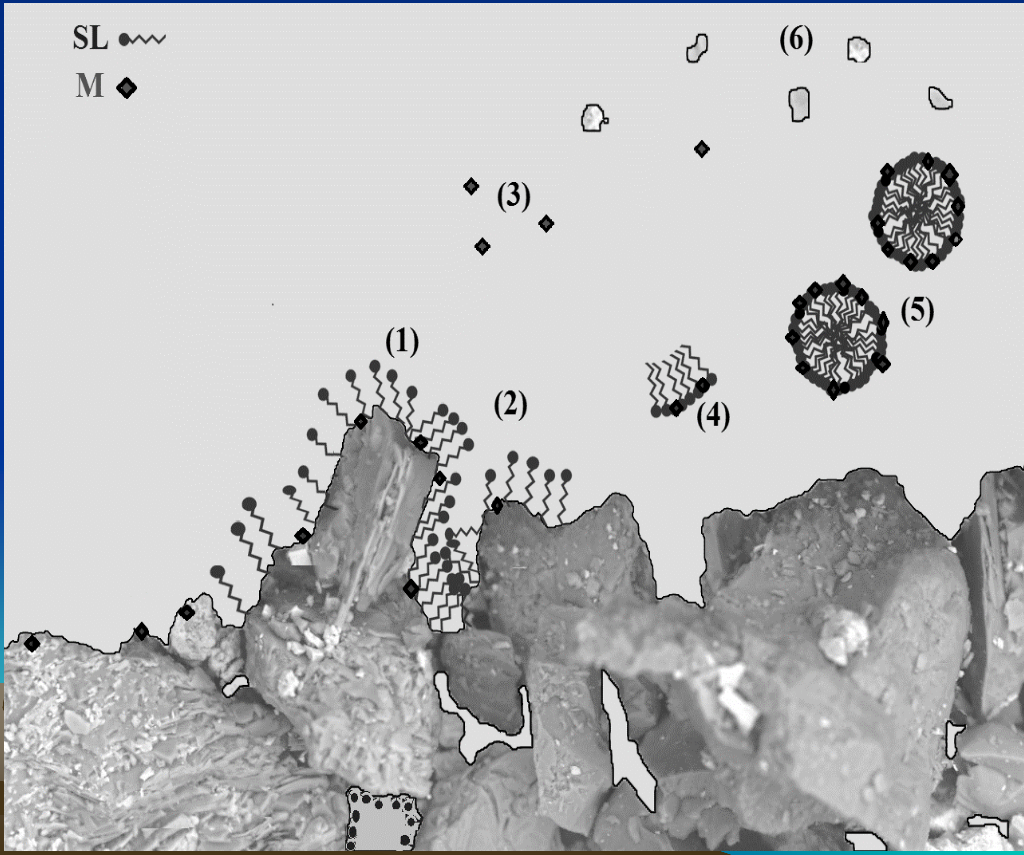


Comparison between the total elements extracted from the untreated sample and the sample washed with 1% sophorolipids at pH 5 (continuous experiments)



Schematic of the mechanisms of the mobilization of heavy metals/ metalloids (M) by sophorolipids

- (1) Lowering interfacial tension
- (2) Solubilization
- (3) Diffusion, electrostatic interaction and competition
- (4) Complexation
- (5) Complexation with free ions



Sustainability & Remediation

- There are multiple forums, groups and agencies working on the application of sustainability principles in remediation – such as :
  - Europe
    - CLAIRIET (« Contaminated Land Rehabilitation Network for Environmental Technologies »)
    - NICOLE (« Network for Contaminated Land in Europe »)
    - EuroDemo (« European Platform for Demonstration of Efficient Soil and Groundwater Remediation »)
    - SURF (« Sustainable Remediation Forum ») – USA & UK
  - USA
    - Cal/EPA Green Remediation Symposium (Sacramento, CA – February, 2009)
    - U.S. EPA – Green Remediation
  - Canada
    - PWGSC and Environment Canada

GoldSET : Sustainability Evaluation Tool

Site Description

- Site Specific
- Conceptualization of Site Conditions
- Objective(s) Definition

Options Description

- Fatal Flaw Analysis:
  - Objectives
  - Cost
  - Duration
  - Technical
  - Legal

Indicators

Strategic Issues:
- Environmental
- Social
- Economics

Rigorous Selection process:
e.g. GEMI *Metrics Navigator* ™

Linking to Stakeholders through:
- International Standards & Best Practices
- Corporate Objectives
- Legal Requirements

Scoring

Quantification of Indicators:
- Specific to Client Requirements

Evaluation of Options based on "Triple Bottom Line":
- Eco-efficiency
- Cost Benefit Analysis
- Stakeholder Concerns

Structured System for Ranking Options:
- Tailored Scoring & Weighting
- Ternary Diagrams

Interpretation & Reporting

OPTION A
OPTION B
OPTION C
OPTION D

Recommendations to support decision making:
- Tangible
- Transparent
- Optimized

Automated Reporting

UNIVERSITÉ Concordia UNIVERSITY

Case study

- A benzene spill occurred along the highway near a small town of 1600 residents following a train derailment.
- Concentration of benzene in ground water was 55 µg/L must be reduced to its maximum contaminant level (MCL) of 5 µg/L for drinking water
- Affected site was 6 hectares

Options

- Pump and treat and activated carbon
- Pump and treat and air stripping
- Biosparging and soil vapour extraction (SVE)
- Natural attenuation.

Quantitative indicators

Step 5 - Quantitative Indicators

Environmental Aspect						
Code	**Indicator**	**Units**	**Biosparging**	**Natural Attenuation**	**pump and treat and air striping**	**pump and treat and activated carbon**
ENV-8	Water Usage	Litres	0	0	0	300000000
ENV-12	Greenhouse Gas Emissions	Tonnes CO2 e	8.9	0.34	30.49	209.99
ENV-13	Energy Consumption	GJ PFE	4719.04	4.9	15819.27	4719.69
ENV-14	Quantity of Wastes	Tonnes	1.36	0.02	5.9	5.9
ENV-15	Hazardous Wastes	Tonnes	0	0	0	0

Social Aspect						
Code	**Indicator**	**Units**	**Biosparging**	**Natural Attenuation**	**pump and treat and air striping**	**pump and treat and activated carbon**
SOC-6	Public Disruption (Duration of Work)	Years	2	20	5	2

Economic Aspect						
Code	**Indicator**	**Units**	**Biosparging**	**Natural Attenuation**	**pump and treat and air striping**	**pump and treat and activated carbon**
ECONO-1	Net Present Value of Options' Costs	$	4513000	3234000	3338965	4504131

Economic aspects

Economic Aspect						
Code	**Indicator**	**Biosparging**	**Natural Attenuation**	**pump and treat and air striping**	**pump and treat and activated carbon**	**Weight**
ECONO-1	Net Present Value of Options' Costs	0	100	91	1	3
ECONO-2	Potential Litigation	50	50	50	50	2
ECONO-3	Financial Recoveries	25	25	25	50	2
ECONO-4	Environmental Reserve	0	0	0	0	1
ECONO-5	Standards, Laws and Regulations	100	90	90	90	2
ECONO-6	Service Reliability and Performance	66	66	66	100	2
ECONO-7	Reuse of the Property by the Corportation	100	100	100	100	2
ECONO-8	Corporate Image	90	100	90	90	1
ECONO-9	Reliability (Maintenance and Repair)	90	90	90	90	3
ECONO-10	Technological Uncertainty	90	90	90	100	2
ECONO-11	Logistics	100	90	90	90	1

Environmental aspects

Environmental Aspect						
Code	**Indicator**	**Biosparging**	**Natural Attenuation**	**pump and treat and air striping**	**pump and treat and activated carbon**	**Weight**
ENV-1	Soil Quality	90	100	0	100	1
ENV-2	Sediment Quality	0	0	0	0	1
ENV-3	Contaminated Soil Erosion and Transport	100	0	0	0	1
ENV-4	Groundwater Quality	100	100	100	100	3
ENV-5	Free Product	0	90	90	100	1
ENV-6	Surface Water Quality	0	100	0	100	1
ENV-7	Waterborne Contaminant Migration	100	90	90	90	3
ENV-8	Water Usage	50	50	50	50	1
ENV-9	Impacts on Fauna and Flora Resulting from the Proj	90	100	45	0	2
ENV-10	Impacts on Fauna and Flora During the Project	66	100	66	0	2
ENV-11	Soil Vapour Intrusion	90	100	0	0	2
ENV-12	Greenhouse Gas Emissions	92	100	75	0	1
ENV-13	Energy Consumption	54	100	0	54	3
ENV-14	Quantity of Wastes	63	100	52	0	1
ENV-15	Hazardous Wastes	50	50	50	50	1
ENV-16	Residual Impact of Technology	100	100	66	100	3

Social aspects

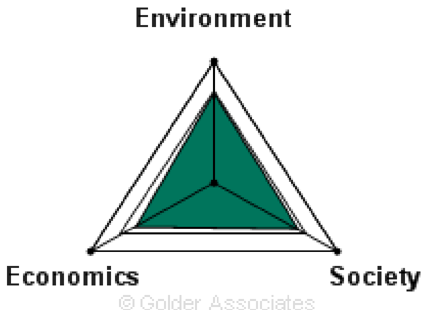
Social Aspect

Code		Indicator	Biosparging	Natural Attenuation	pump and treat and air striping	pump and treat and activated carbon	Weight
SOC-1		Community Health and Safety	100	100	100	100	3
SOC-2		Worker's Health and Safety	66	100	66	66	2
SOC-3		Drinking Water Supply	50	50	50	50	3
SOC-4		Direct Local Employment	66	33	66	66	1
SOC-5		Opportunities for Local Business Generation	45	90	45	100	1
SOC-6		Public Disruption (Duration of Work)	100	0	73	100	2
SOC-7		Quality of Life (During the Project)	66	66	66	66	2
SOC-8		Public Use	0	0	0	0	1
SOC-9		Cultural Heritage	100	100	100	100	1
SOC-10		Impact on the Landscape	66	100	66	66	1
SOC-11		Management Practices	50	75	50	75	3

Comparison of options

Biosparging

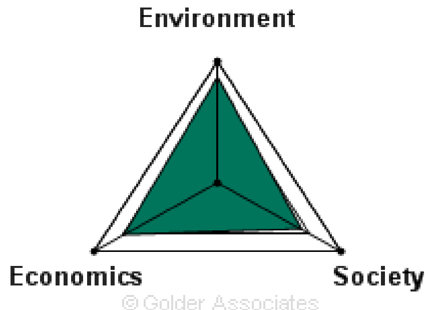
ENVIRONMENT	74%
SOCIETY	67%
ECONOMICS	63%



Public Disruption (Duration of Work) :
2 Years
Net Present Value of Options' Costs :
4513000 $

Natural Attenuation

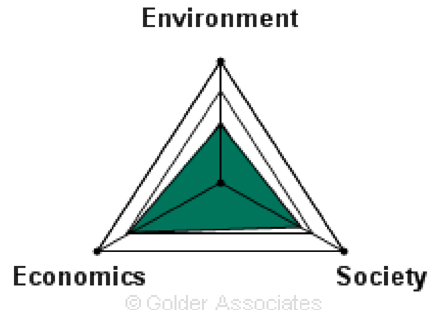
ENVIRONMENT	87%
SOCIETY	67%
ECONOMICS	76%



Public Disruption (Duration of Work) :
20 Years
Net Present Value of Options' Costs :
3234000 $

pump and treat and air striping

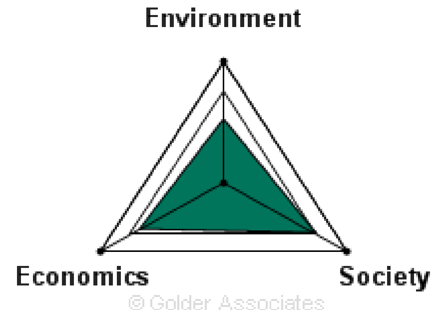
ENVIRONMENT	48%
SOCIETY	64%
ECONOMICS	74%



Public Disruption (Duration of Work) :
5 Years
Net Present Value of Options' Costs :
3338965 $

pump and treat and activated carbon

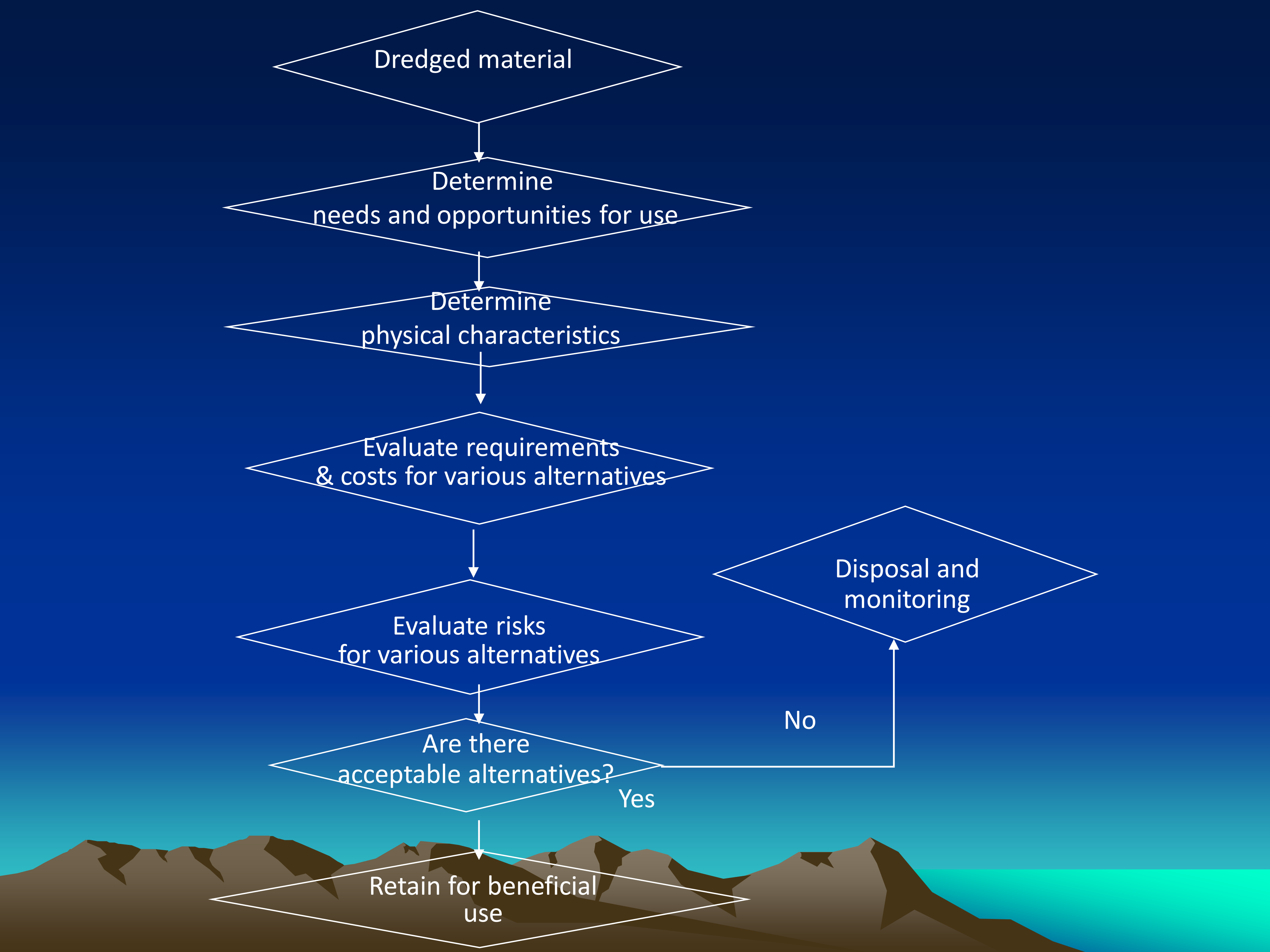
ENVIRONMENT	53%
SOCIETY	74%
ECONOMICS	68%



Public Disruption (Duration of Work) :
2 Years
Net Present Value of Options' Costs :
4504131 $

Sediment management

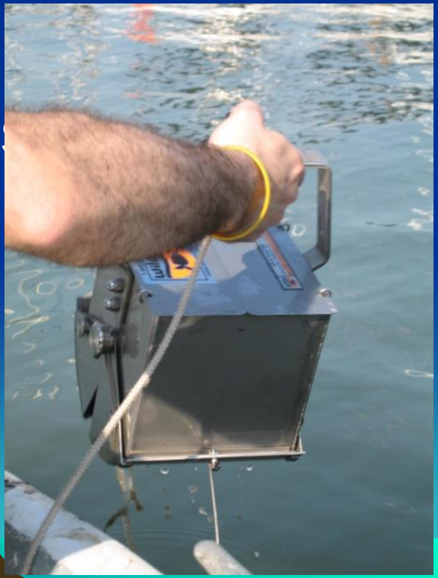
- Dredging used for maintenance of rivers, harbors and canals for boat navigation
- Dredging increases suspended matter and sediment transport
- Contaminated sediment to be landfilled or ocean disposed



Dredged material
Determine
needs and opportunities for use
Determine
physical characteristics
Evaluate requirements
& costs for various alternatives
Evaluate risks
for various alternatives
Are there
acceptable alternatives?
No
Disposal and
monitoring
Yes
Retain for beneficial
use

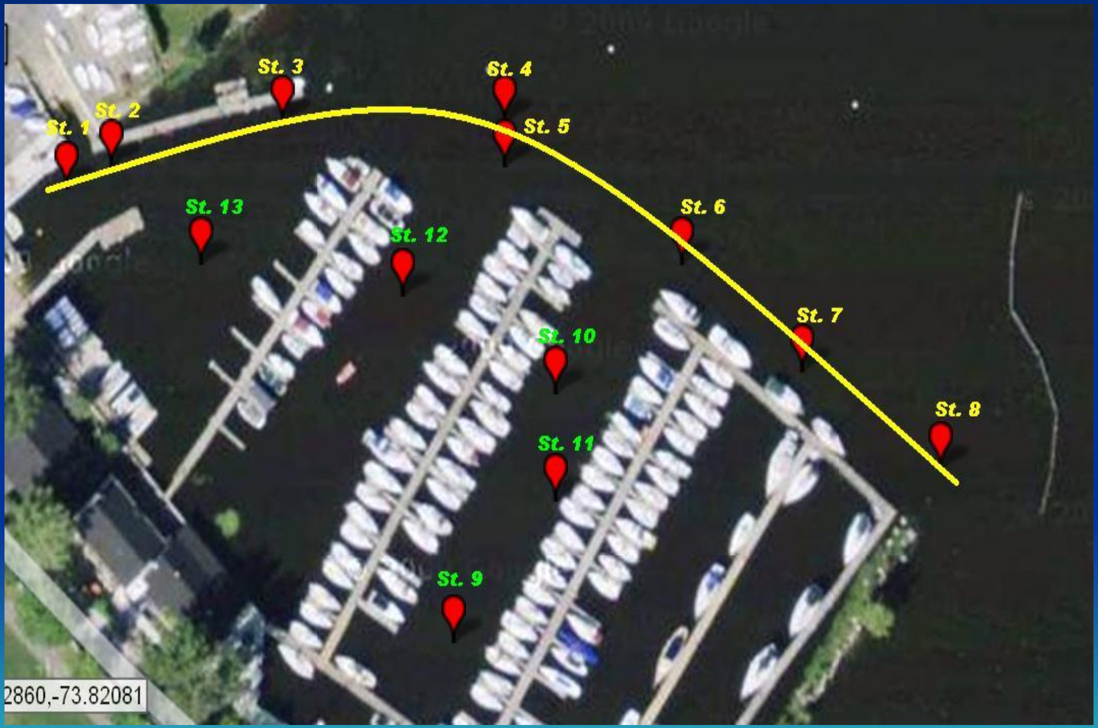
Methodology

- Surface samples with a Birge Ekman sample and core samples with a core tube sampler to 0.5 m in depth
- Analysis included
  - Arsenic, chromium, copper, mercury, nickel, lead and zinc
  - Polycyclic biphenyls (PCBs)
  - Polycyclic aromatic hydrocarbons (PAHs
  - Grain size distribution
  - LOI to represent total organic carbon
  - Petroleum hydrocarbons (C10-C50) .

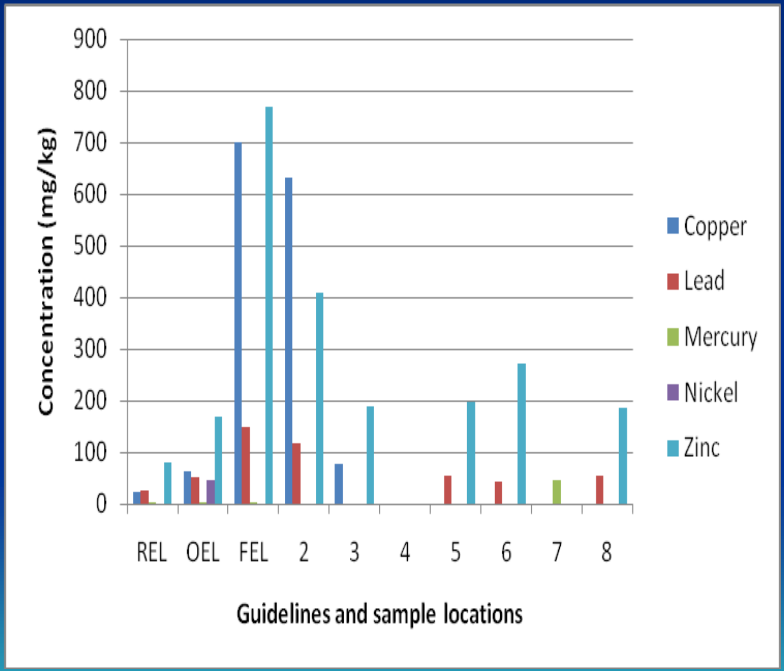


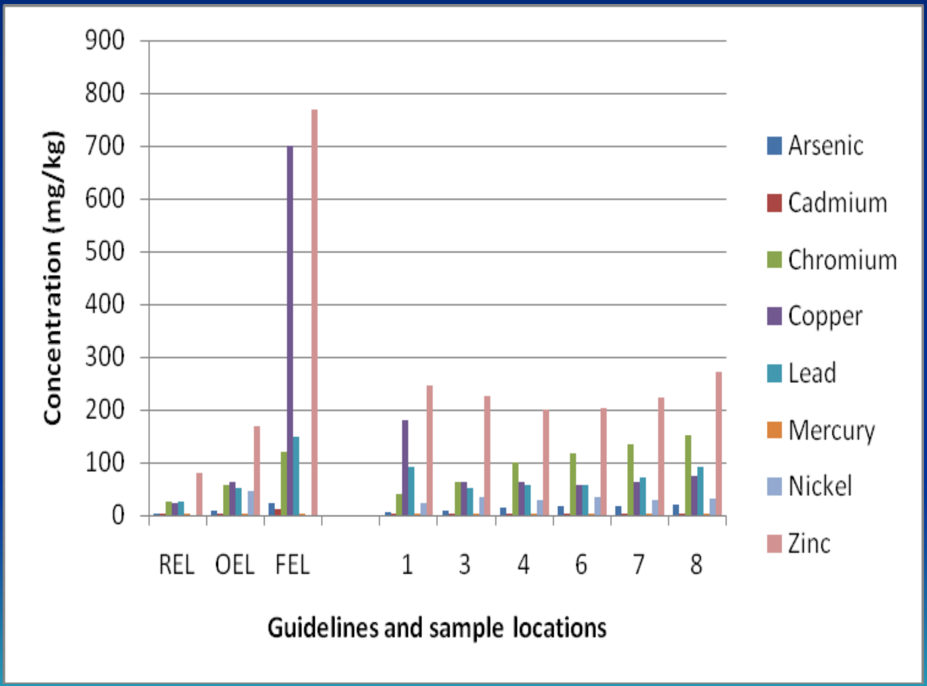
Sampling

Core sampling points for core sediment samples



Heavy metal content of surface and core sediments

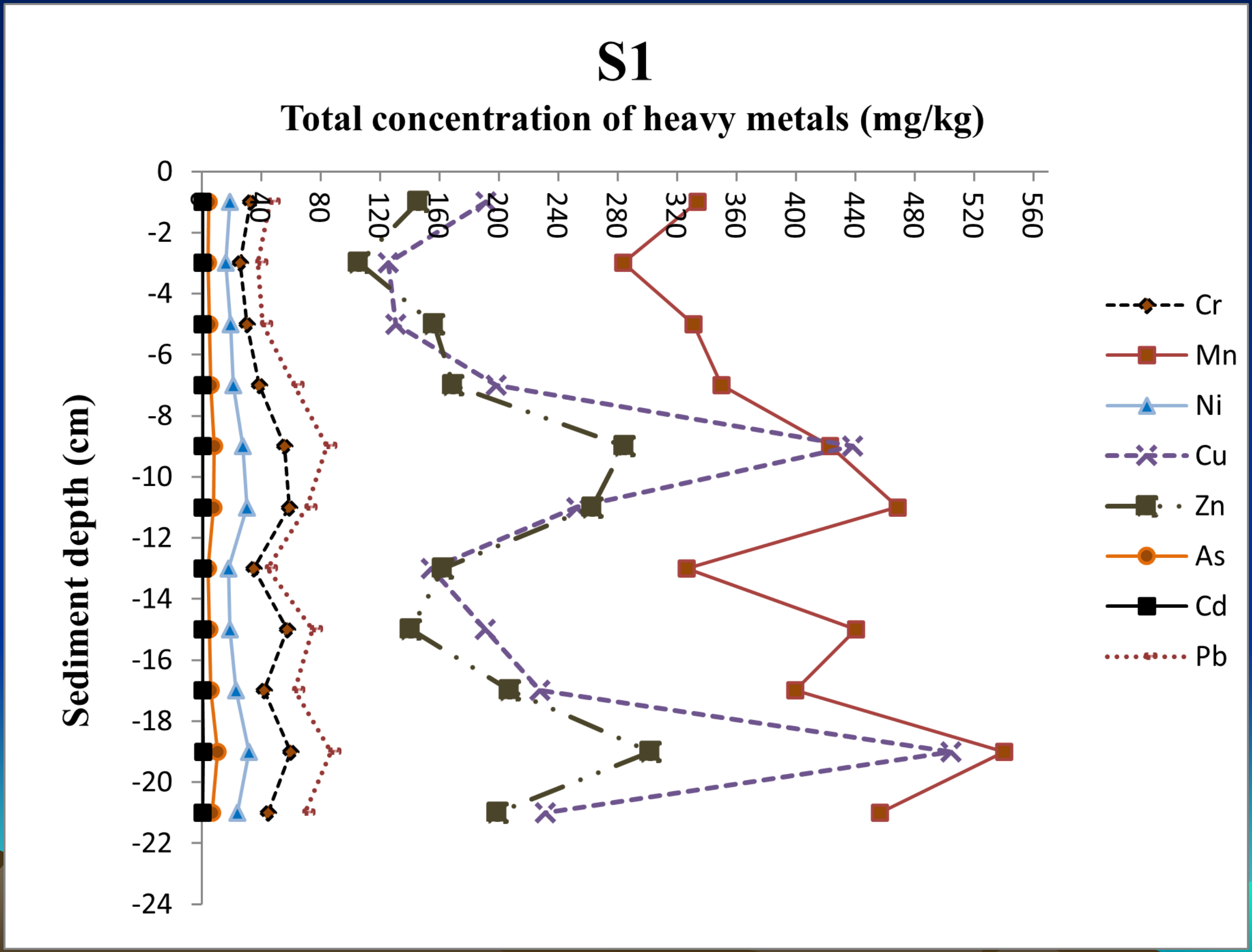




Total concentration of heavy metals in sediment samples in 2019 (mg/kg)

St. No	Cr	Ni	Cu	Zn	As	Cd	Pb
1	54.5	28.3	450.3	230.1	7.0	0.72	57.0
3	61.1	32.6	165.9	244.1	8.12	0.74	55.3
4	62.9	32.0	136.6	297.0	7.0	0.92	46.9
6	31.09	19.4	24.6	97.6	4.0	0.35	18.3
8	61.1	35.4	50.3	241.4	6.9	0.74	28.8
9	68.9	36.4	49.0	212.4	7.7	0.82	32.7
11	64.2	34.9	51.10	205.8	6.5	0.74	28.9
14	74.7	41.8	109.5	212.8	9.9	0.77	32.8

Variations in total concentration of heavy metals with different sediment depths in stations S1



Mean concentration of heavy metals in sediment samples in 2015, 2017 and 2019 (mg/kg).

Year	Cr	Ni	Cu	Zn	As	Cd	Pb
2015*	66.1	40.2	95.2	251.4	7.8	0.82	50.2
2017	65.4	40.7	67.5	160.8	5.6	0.73	32.8
2019	59.8	32.6	129.7	217.7	7.1	0.73	37.6

Recommendations:

- Further samples be taken from Stations #1, #3, #4, #6,#7 and #8 with those from #1 and #8 being tested for leachability and the remainder being sent to MDDEP for toxicity testing.
- Application for a permit to be prepared and submitted to MDDEP.
- Negotiations with construction, dredging, transportation and disposal companies
- Temporary retention pen to be constructed and the site prepared for dredging
- Dredging to performed, site clean up and removal of temporary retention pen

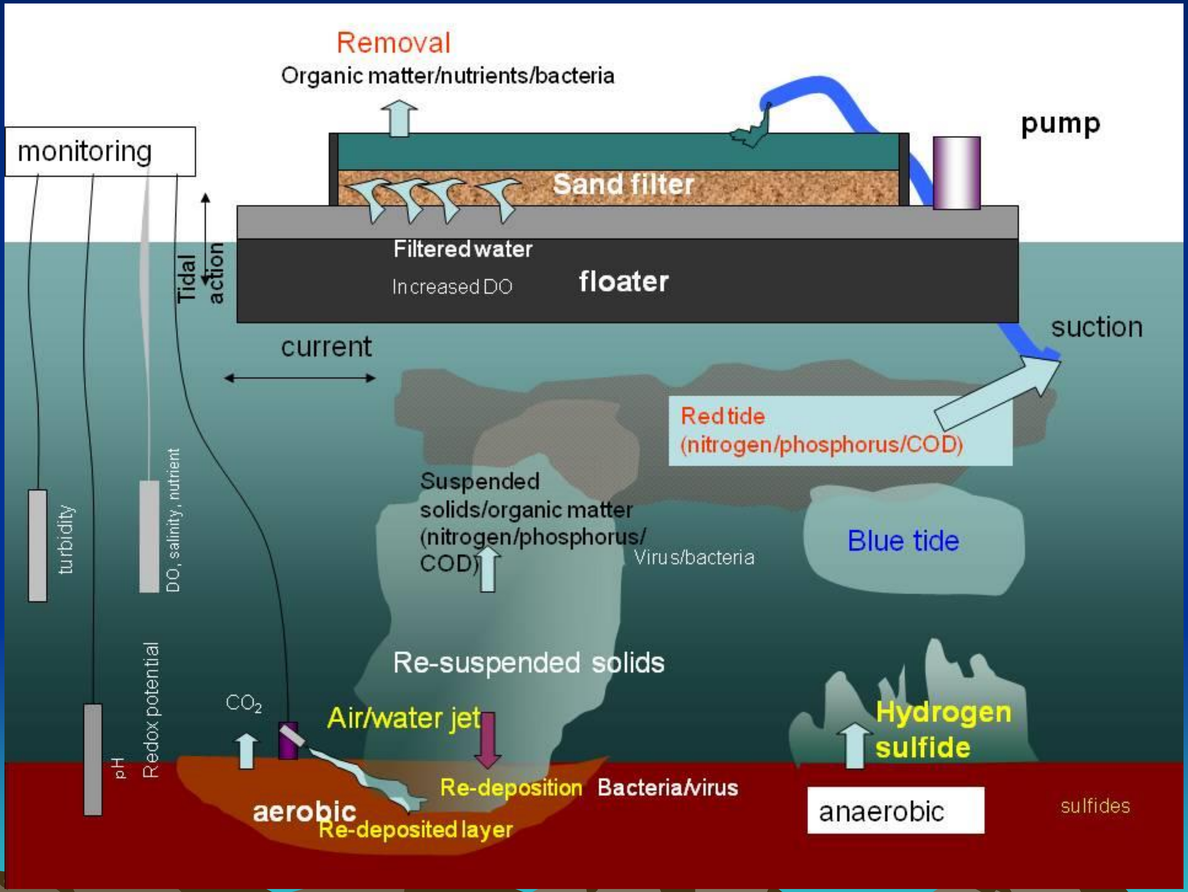
Aeration section with Plexiglas cylinder (A) and filter system (B)

A B

Metal content of the sediments before and after the aeration tests for station 2

Metal	Heavy metal concentration (mg/kg)		
	Before aeration	**After aeration**	**Removal (%)**
Cr	71.14	39.90	43.9
Ni	34.17	19.80	42.1
Cu	64.44	71.34	-10.7
Zn	148.15	125.16	15.5
Pb	10.77	7.99	25.9
As	6.26	4.75	24.2
Cd	0.65	0.43	34.4

Resuspension apparatus



Sustainable ground improvement

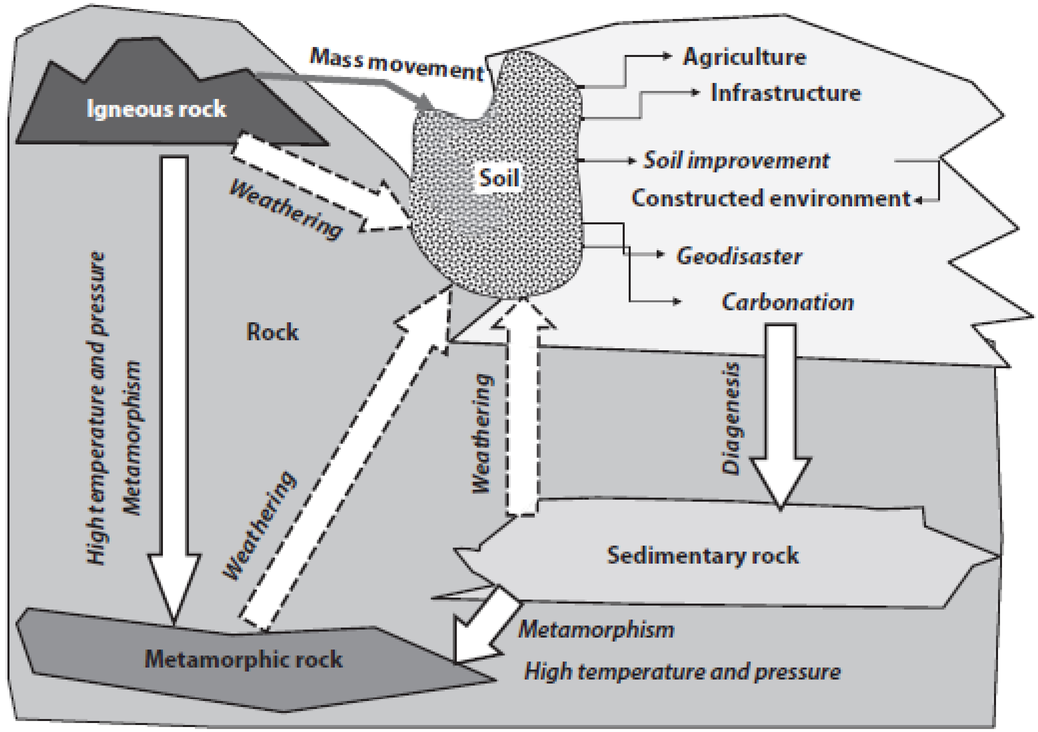


FIGURE 12.1
Weathering of rock, formation of soil, diagenesis, and metamorphism.

Conventional techniques

- Cementing mixing, use of lime, fly ash
- Other binding agents
- Pile foundation
- Drainage

- To improve ground functionality

12.3.2.3 Microbially Induced Carbonates

There are microbial processes that can produce carbonates. In chemical reactions with nitrogen (organic matter), carbonate can be produced as follows (Castanier et al., 1999):

$$\text{Organic matter} + Ca^{2+} \rightarrow CaCO_3\downarrow \text{ (aerobic)} \tag{12.2}$$

$$\text{Organic matter} + Ca^{2+} + NO_3 \rightarrow CaCO_3\downarrow \text{ (anaerobic)} \tag{12.3}$$

$$\text{Organic matter} + Ca^{2+} + \text{urease or uric acid} \rightarrow CaCO_3\downarrow \text{ (aerobic),} \tag{12.4}$$

where the organic matter can be degraded by the proper (aerobic or anaerobic) microbes.

In a sulfur cycle, carbonate will be produced as follows:

In the case of reduction of SO_4^{2-}

$$\text{Organic matter} + Ca^{2+} + SO_4^{2+} \rightarrow CO_3^{2-} + HCO_3^{-} + H_2S\uparrow \rightarrow CaCO_3\downarrow, \tag{12.5}$$

where the organic matter can be degraded by anaerobic microbes. If hydrogen sulfide (H_2S) exists under aerobic conditions, the following reaction occurs.

$$H_2S + 2O_2 \rightarrow 2H^{+} + SO_4^{2-} \tag{12.6}$$

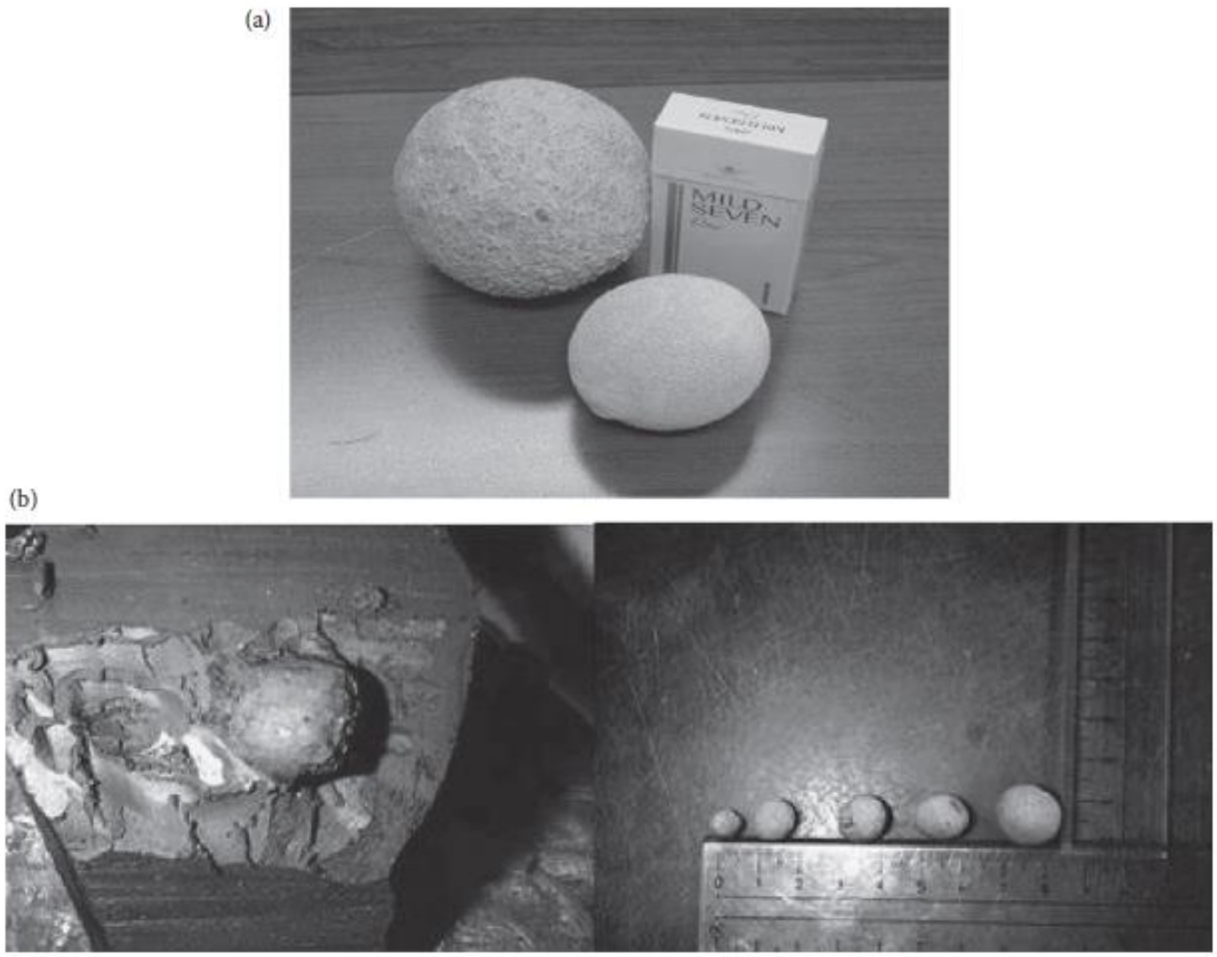


FIGURE 12.5
(a) Carbonate nodules found in bentonite mine. (b) Carbonate nodules found in alluvial sediments near a river mouth.

FIGURE 12.7
(See color insert.) Calcirudite cemented with calcite as a result of the precipitation of carbonate.

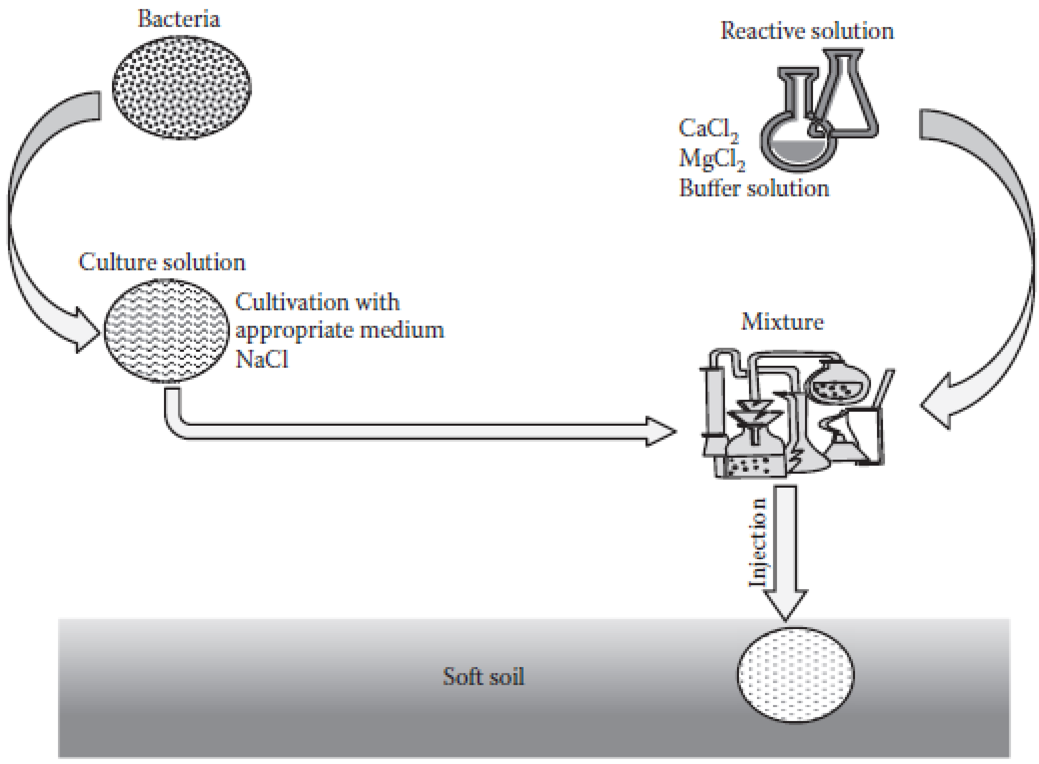


FIGURE 12.8
Procedure for application of artificial diagenesis in soil mantle.

$$(NH_2)_2CO + 2H_2O \rightarrow CO_3^{2-} + 2NH_4^+ \quad (12.8)$$

The reaction is followed by the production of carbonate.

$$1/2Ca^{2+} + 1/2Mg^{2+} + CO_3^{2-} \rightarrow 1/2CaMg(CO_3)_2\downarrow \quad (12.9)$$

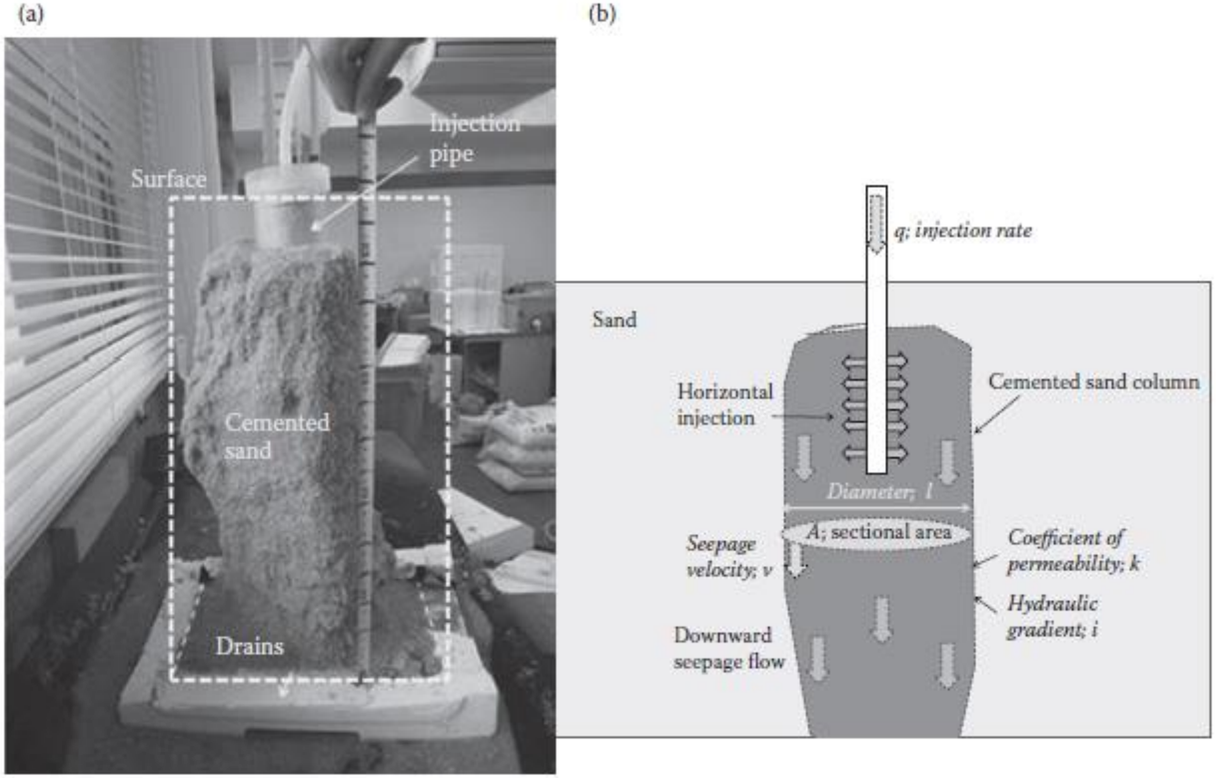


FIGURE 12.10
(a) Sand column formed in relatively deep sand layer. (b) Horizontal and downward flow of the mixture of bacteria and reactive solution in sand.

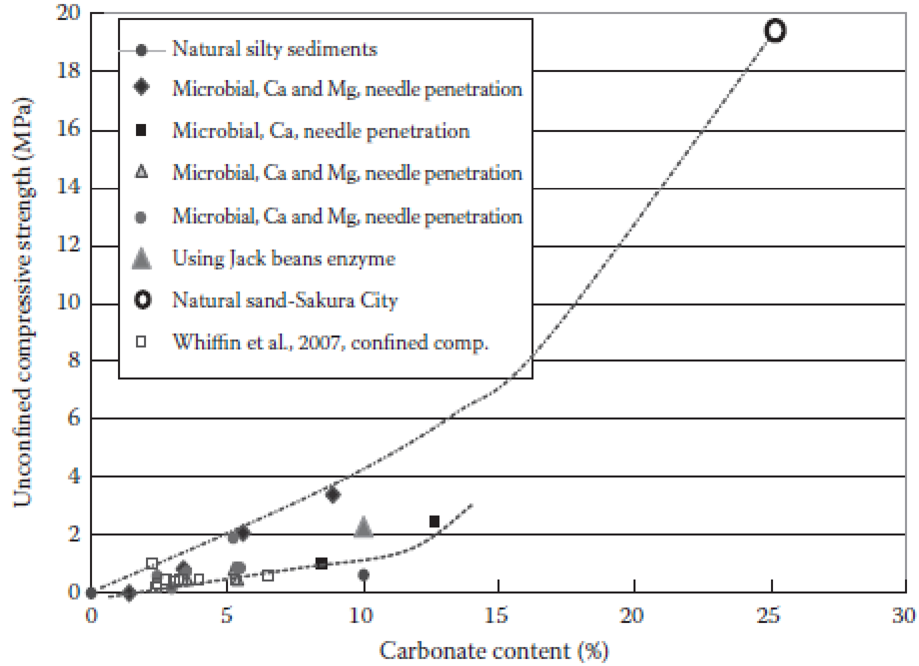


FIGURE 12.11
Correlations between unconfined compressive strengthened carbonate content for both the natural and microbially cemented soils.

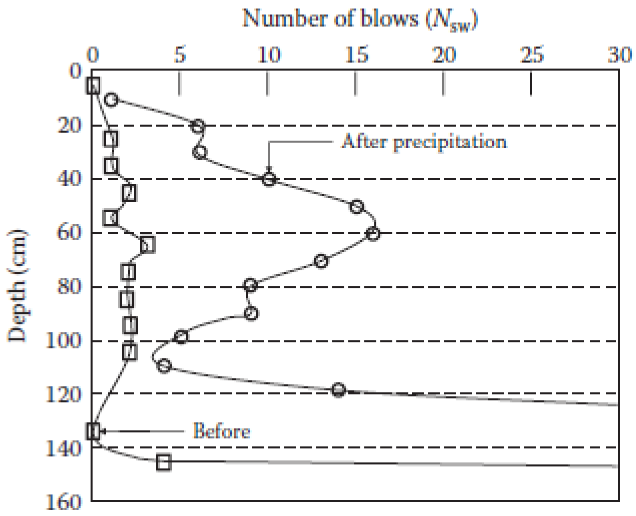


FIGURE 12.14
Results of the dynamic cone penetration test for sand with and without microbial cementation.

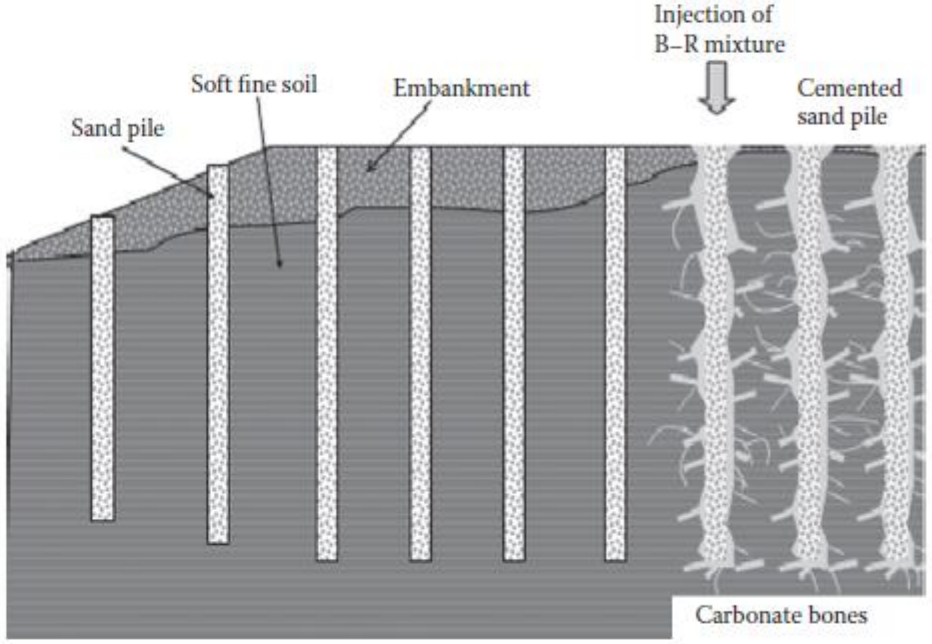


FIGURE 12.15
Application of artificial diagenesis into soft fine soil using sand piles.

Concluding remarks

Sustainable management of soils and sediments includes :

(a) Source control-remove, isolate or immobilize the contaminants,

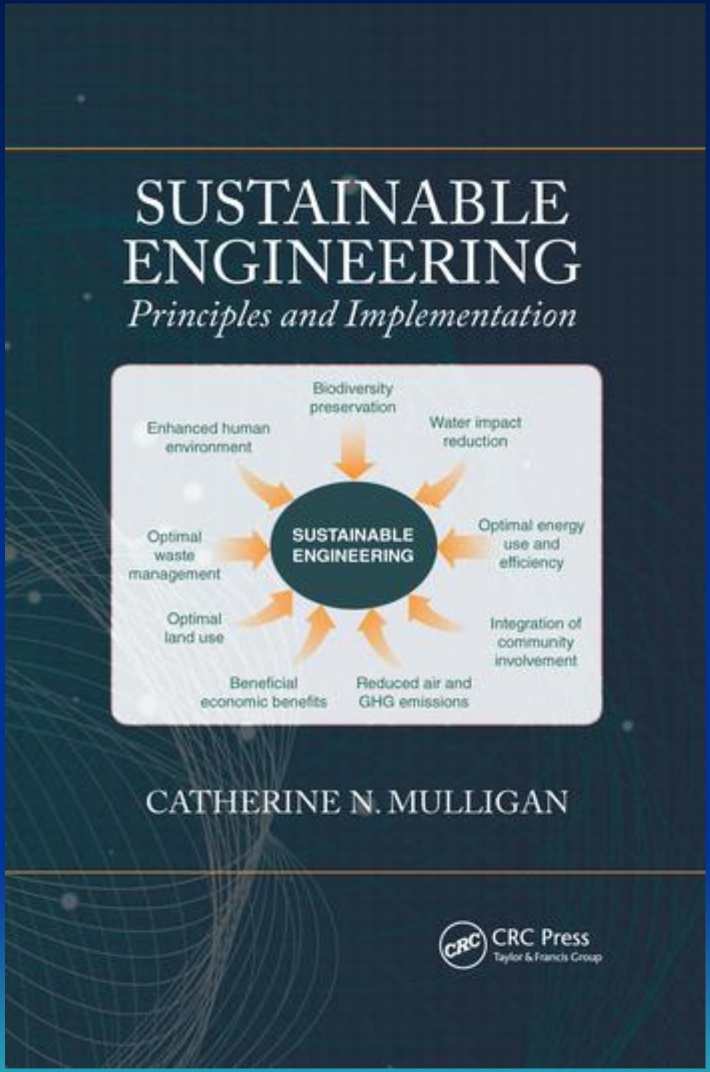
(b) use chemical and/or biological treatments including biosurfactants to reduce contaminant concentrations and toxicity,

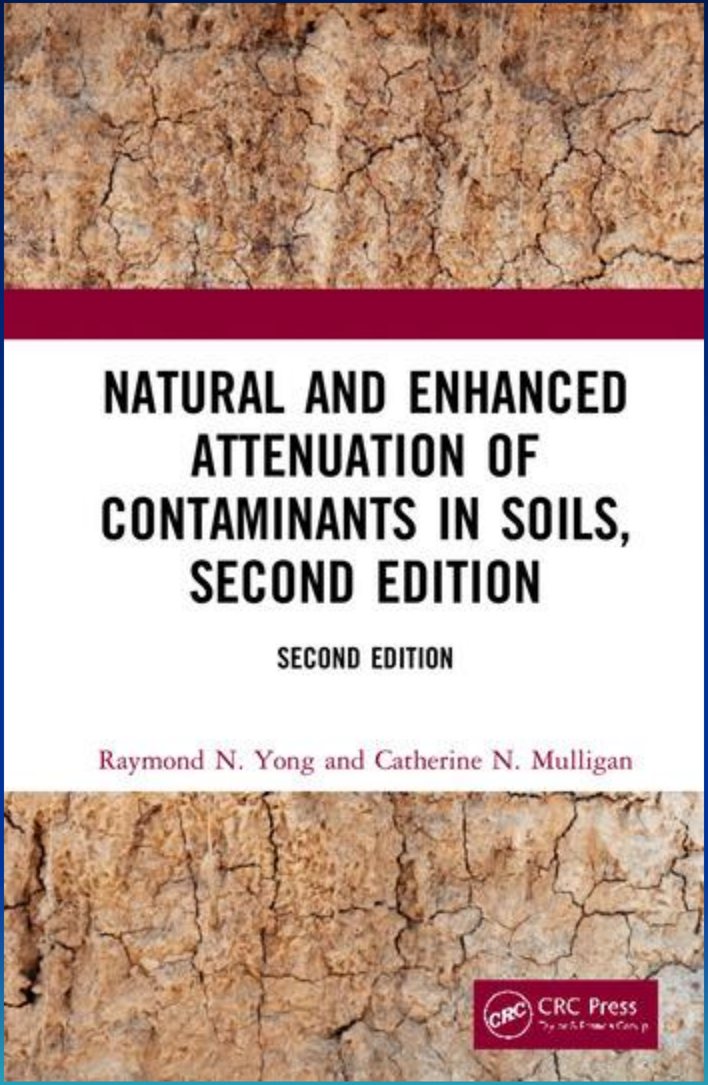
(c) use natural recovery processes inherent in the properties of the soil

(d) Use of sustainable technologies to reduce emissions, water, energy, and material requirements

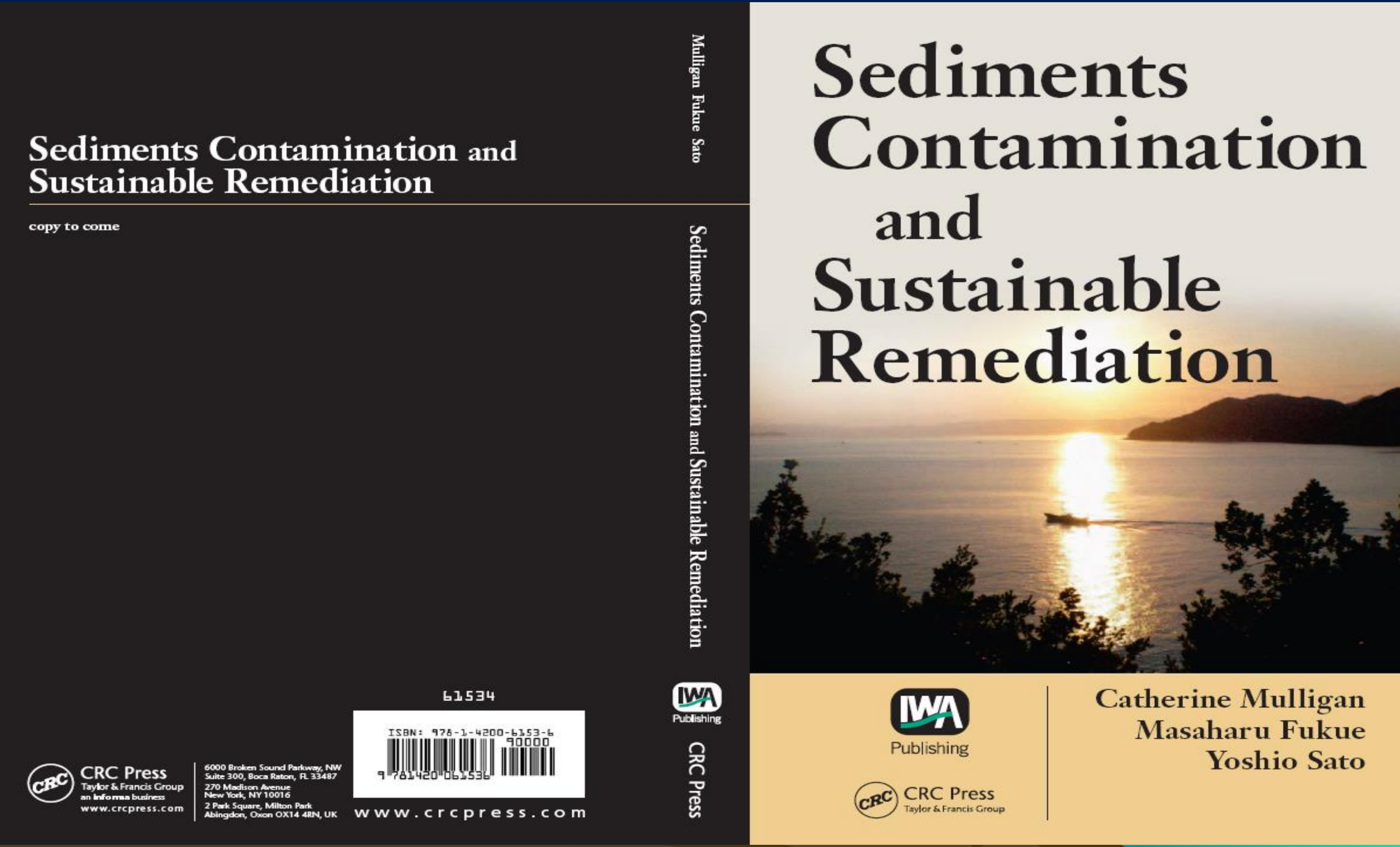
(e) Restoration of habitat and biodiversity

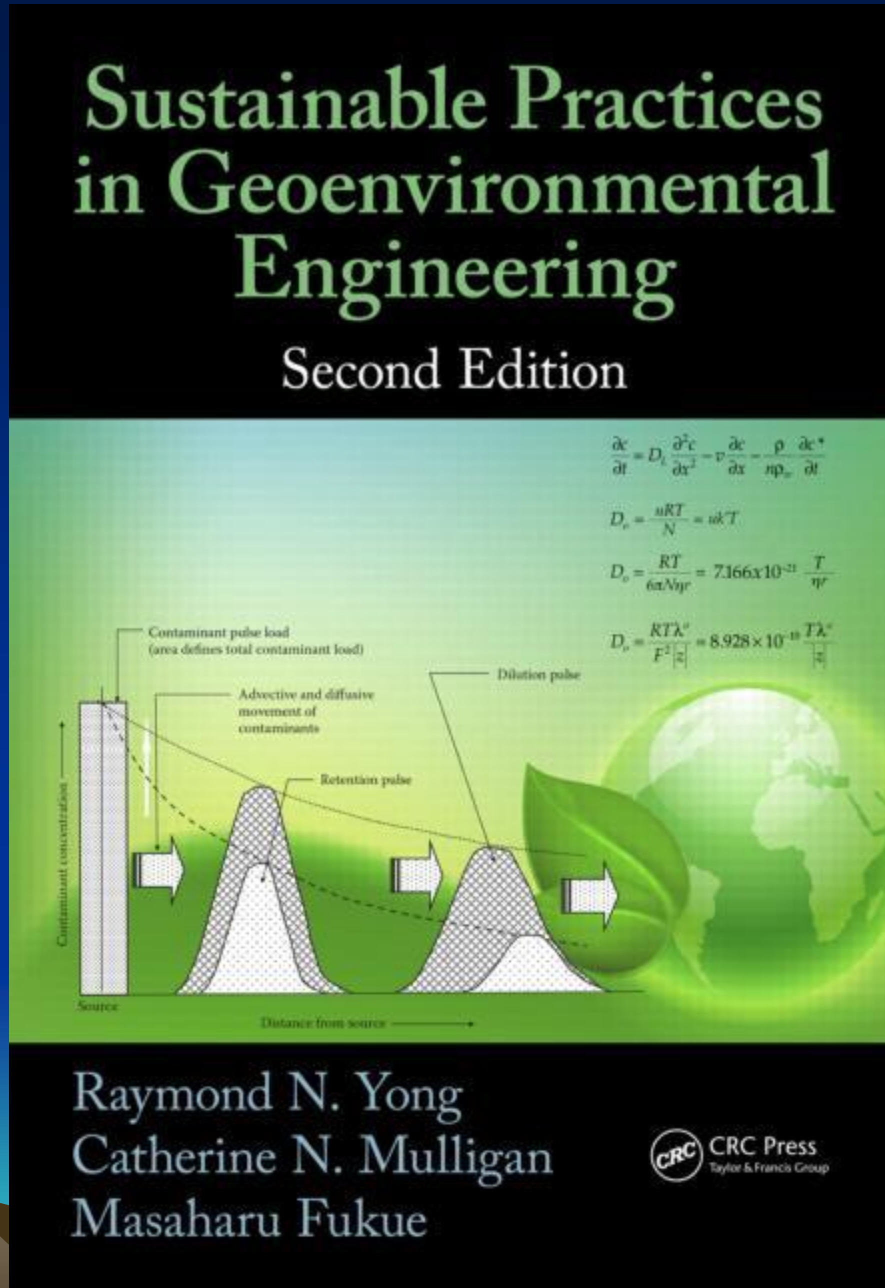
Thank You!!


SUSTAINABLE ENGINEERING
Principles and Implementation
Biodiversity preservation
Enhanced human environment
Water impact reduction
Optimal waste management
SUSTAINABLE ENGINEERING
Optimal energy use and efficiency
Optimal land use
Integration of community involvement
Beneficial economic benefits
Reduced air and GHG emissions
CATHERINE N. MULLIGAN
CRC Press
Taylor & Francis Group


NATURAL AND ENHANCED ATTENUATION OF CONTAMINANTS IN SOILS, SECOND EDITION
SECOND EDITION
Raymond N. Yong and Catherine N. Mulligan
CRC Press

Thank you very much，有難うございました。Merci beaucoup





Sustainable Practices in Geoenvironmental Engineering
Second Edition
Contaminant pulse load (area defines total contaminant load)
Advective and diffusive movement of contaminants
Retention pulse
Dilution pulse
Contaminant concentration
Source
Distance from source
Raymond N. Yong
Catherine N. Mulligan
Masaharu Fukue
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