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Considering Uncertainties in the Functional Unit: Development of a More Flexible Strategy to Achieve the Goal of an LCA Study

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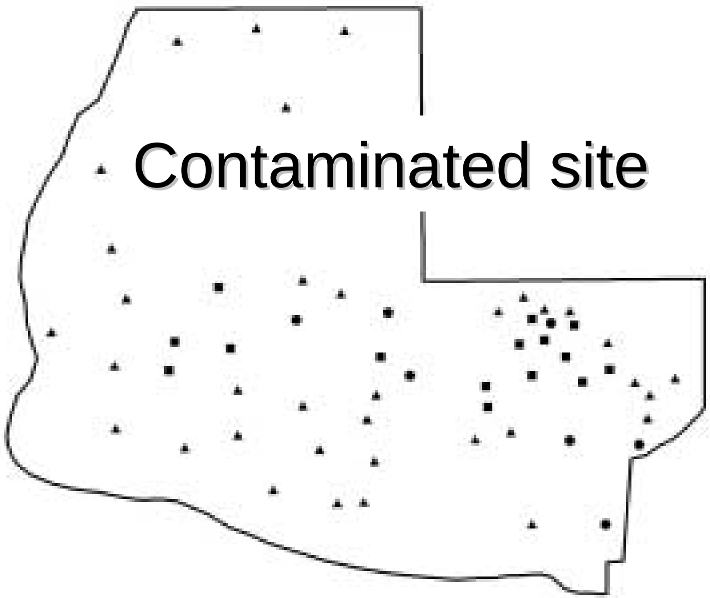
Outline

- Problem: Site remediation, environmental impacts and uncertainties
- Methodology
  - How to do a probabilistic LCA
  - Model development: METEnvORS
- Case study: Remediation of a diesel-contaminated site
- Deterministic approach- Classical LCA
- Probabilistic approach- Use of METEnvORS
- Conclusions

Site remediation, environmental impacts and uncertainties

Problem



Site remediation technology

LCA approach

Primary impacts

Reduction of local contamination (site contamination)

Secondary impacts

Local and global environmental impact generation from the remediation activities

Environmental impact minimization is a must in a sustainable development context

Site remediation, environmental impacts and uncertainties

Problem

Classical LCA- Deterministic approach

- Initial level of contamination: Mean concentration
- Main assumption: The selected technology is fully effective
- Functional unit: Decontaminate a given volume of soil from an initial concentration to a final one using a specific technology

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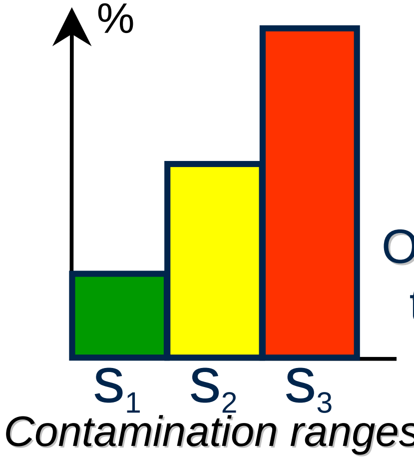
- Mean concentration does not consider spatial variability
- The technology's effectiveness is a function of, in part, the initial and final contamination levels

Site remediation, environmental impacts and uncertainties

Problem

Probabilistic LCA approach

- Initial level of contamination: Discrete or continuous probability distribution of contamination ranges
- Technology's effectiveness is

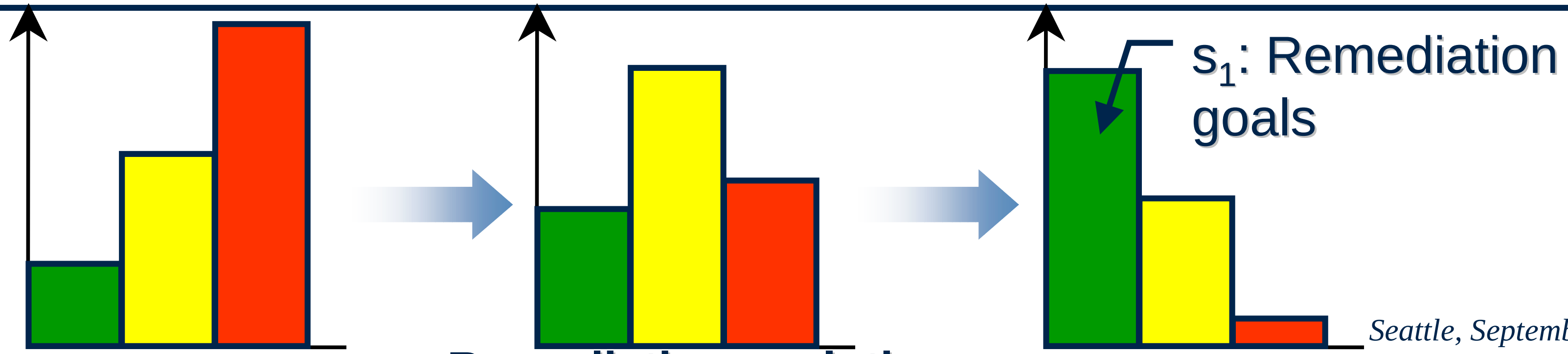


$q(s_1;s_2;s_3)$

Overall definition of the initial level of contamination

Functional unit

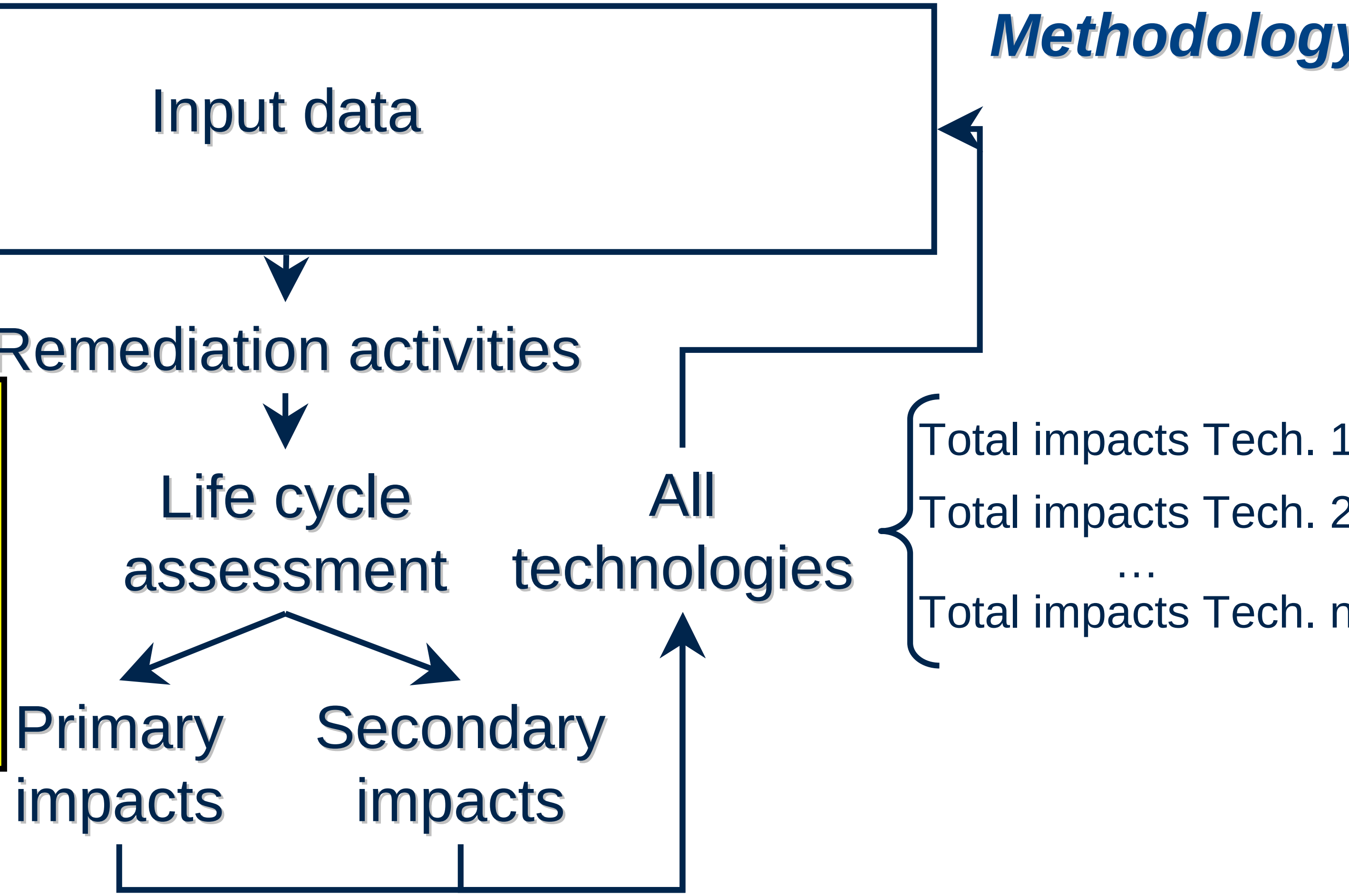
Decontaminate a given volume of soil from an initial q with a given technology until the most probable range in the final q respects the remediation goals



Remediation evolution

How to do a probabilistic LCA

Methodology



Quantify all impacts associated with the remediation activities

Deterministic LCA →
Probabilistic LCA →

How to do a probabilistic LCA

Methodology

Possible contamination levels | Input data | Technologies' effectiveness

↓

Remediation activities

↓

Life cycle assessment

↙ ↘

Primary impacts | Secondary impacts

↓

All technologies (annually) → METEnvORS

↑

One additional year of treatment if remediation goals are not achieved

Quantify all impacts associated with the remediation activities

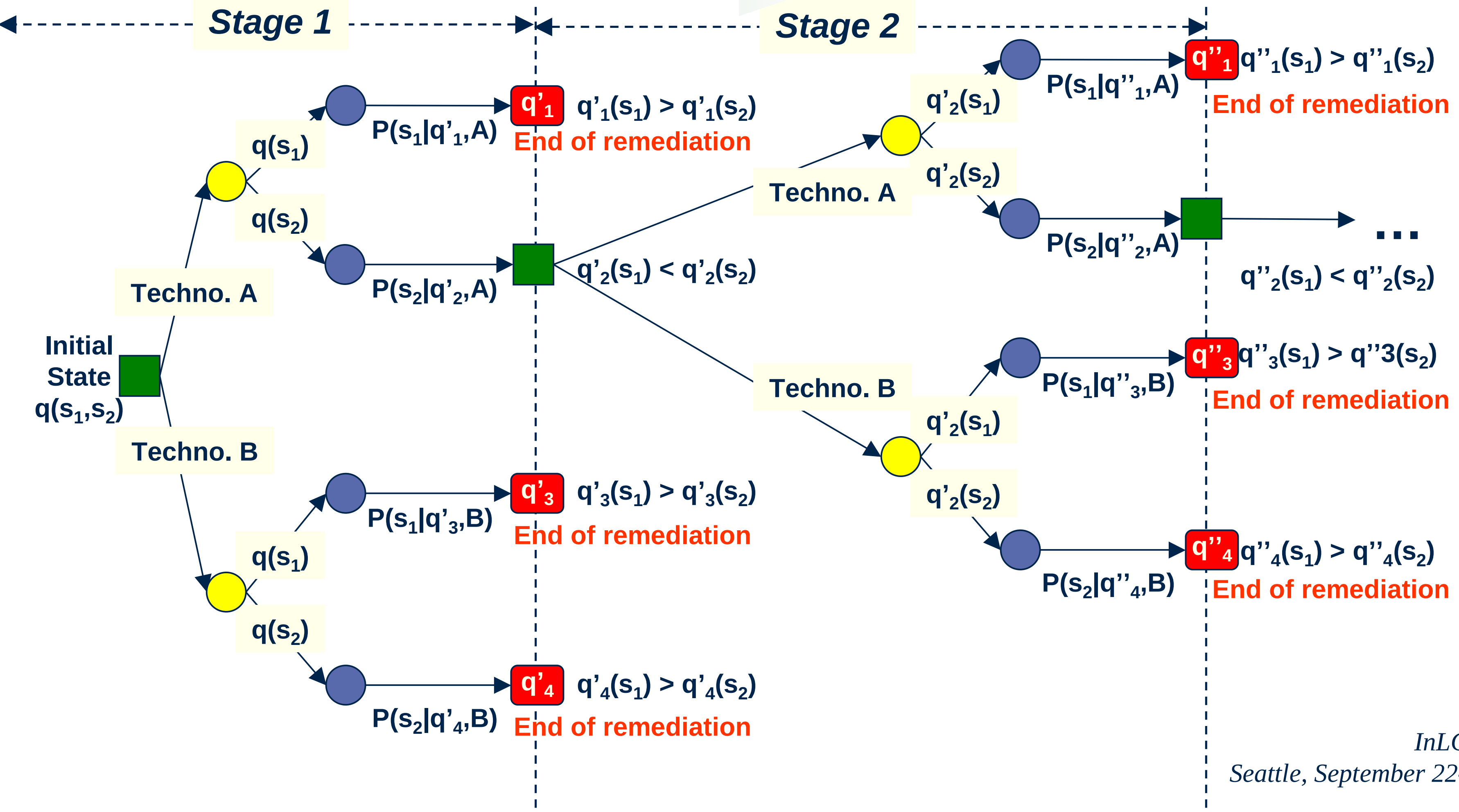
Deterministic LCA →
Probabilistic LCA →

Minimizing the expected environmental impacts

Model development: METEnvORS

Model for the Evaluation of the Technically and Environmentally Optimal Remediation Strategy

Step 1- Developing all the possibilities

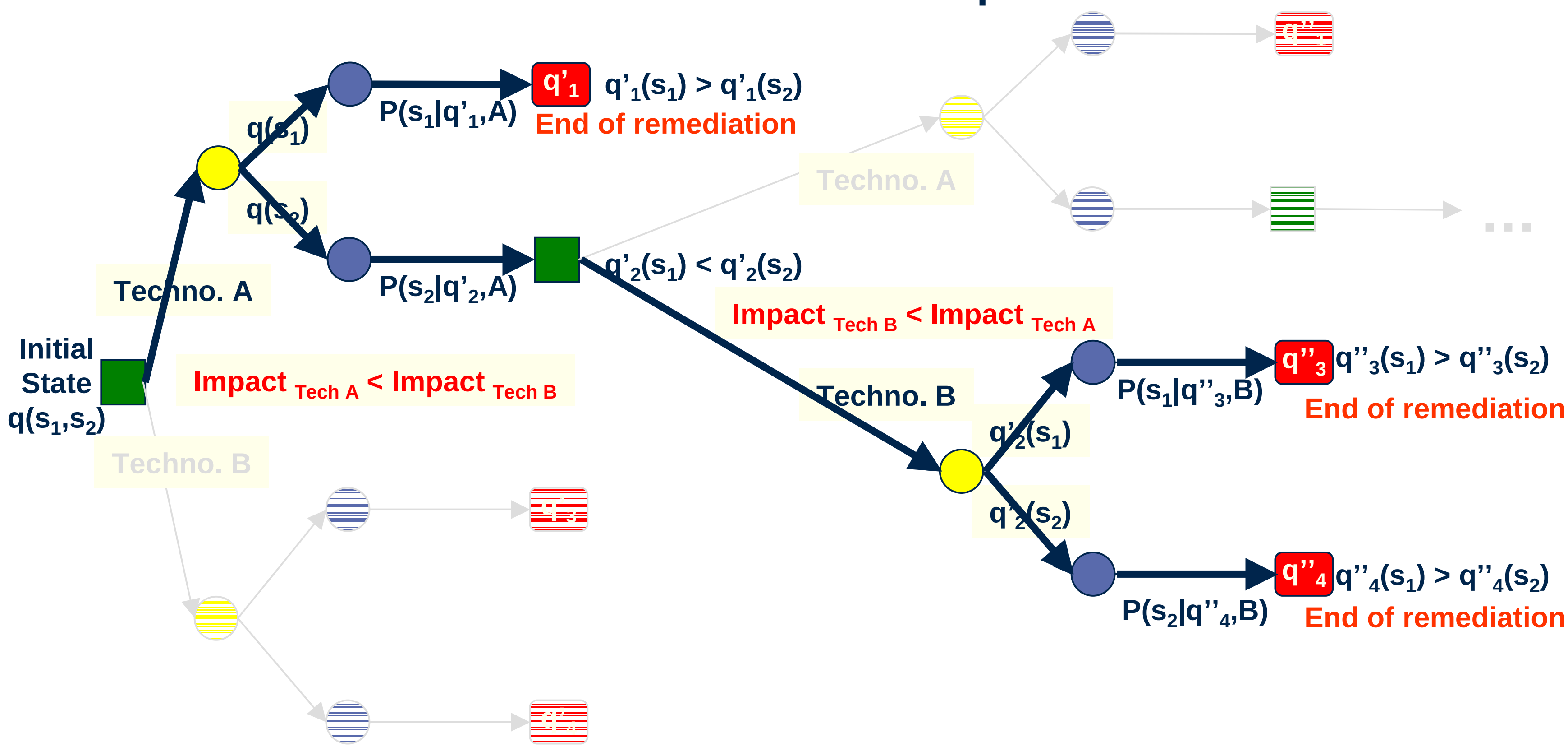


Model development: METEnvORS

Methodology

Step 2- Backwards resolution

Decision criterion: Environmental impact minimization at each stage

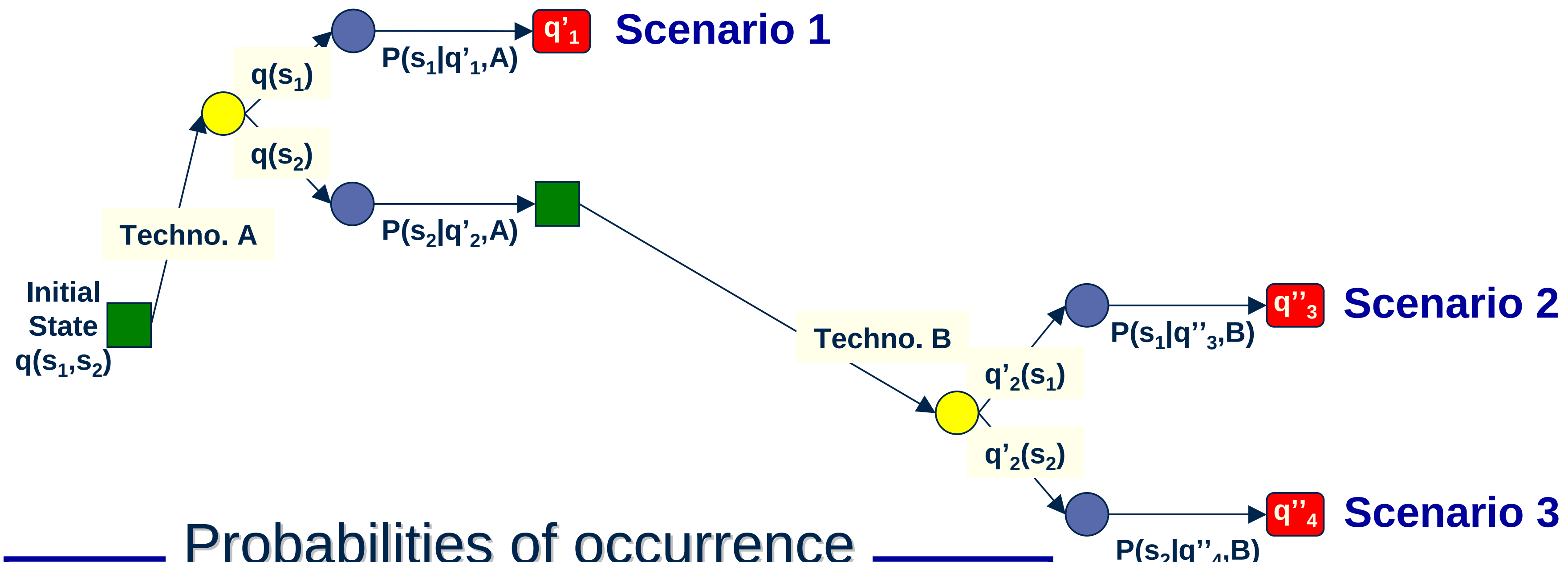


Model development: METEnvORS

Methodology

Total impact

Scenario 1: Impact(q'$_1$) + Impact(Tech.A)$_{\text{Stage 1}}$
Scenario 2: Impact(q''$_3$) + Impact(Tech.A)$_{\text{Stage 1}}$ + Impact(Tech.B)$_{\text{Stage 2}}$
Scenario 3: Impact(q''$_4$) + Impact(Tech.A)$_{\text{Stage 1}}$ + Impact(Tech.B)$_{\text{Stage 2}}$



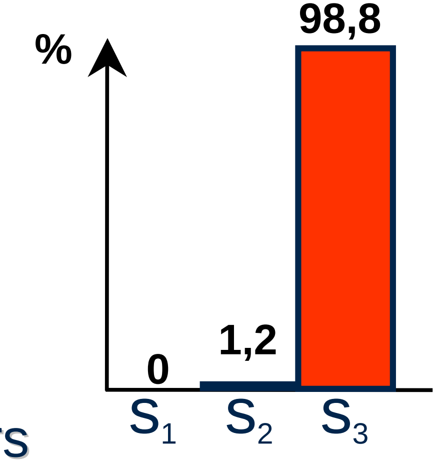
Probabilities of occurrence

Scenario 1: $q(s_1) * P(s_1|q'_1,A)$
Scenario 2: $q(s_2) * P(s_2|q'_2,A) + q'_2(s_1) * P(s_1|q''_3,B)$
Scenario 3: $q(s_2) * P(s_2|q'_2,A) + q'_2(s_2) * P(s_2|q''_4,B)$

Remediation of a diesel-contaminated site

Case study

- Contaminated volume: 8 000 m^3 of soil
- Mean concentration: 6 145 mg diesel/kg soil
- Initial state of the site (q):
  - Range < 700 mg/kg (s_1)
  - Range 700 – 3 500 mg/kg (s_2)
  - Range > 3 500 mg/kg (s_3)
- Remediation goals: Reaching the s_1 range
- Maximum remediation duration of three years
- Available technologies:



Bioventing

- Does not require soil excavation
- Not fully effective for this remediation

Biopile

- Requires soil excavation
- Fully effective for this remediation

Remediation of a diesel-contaminated site

Case study

Functional unit

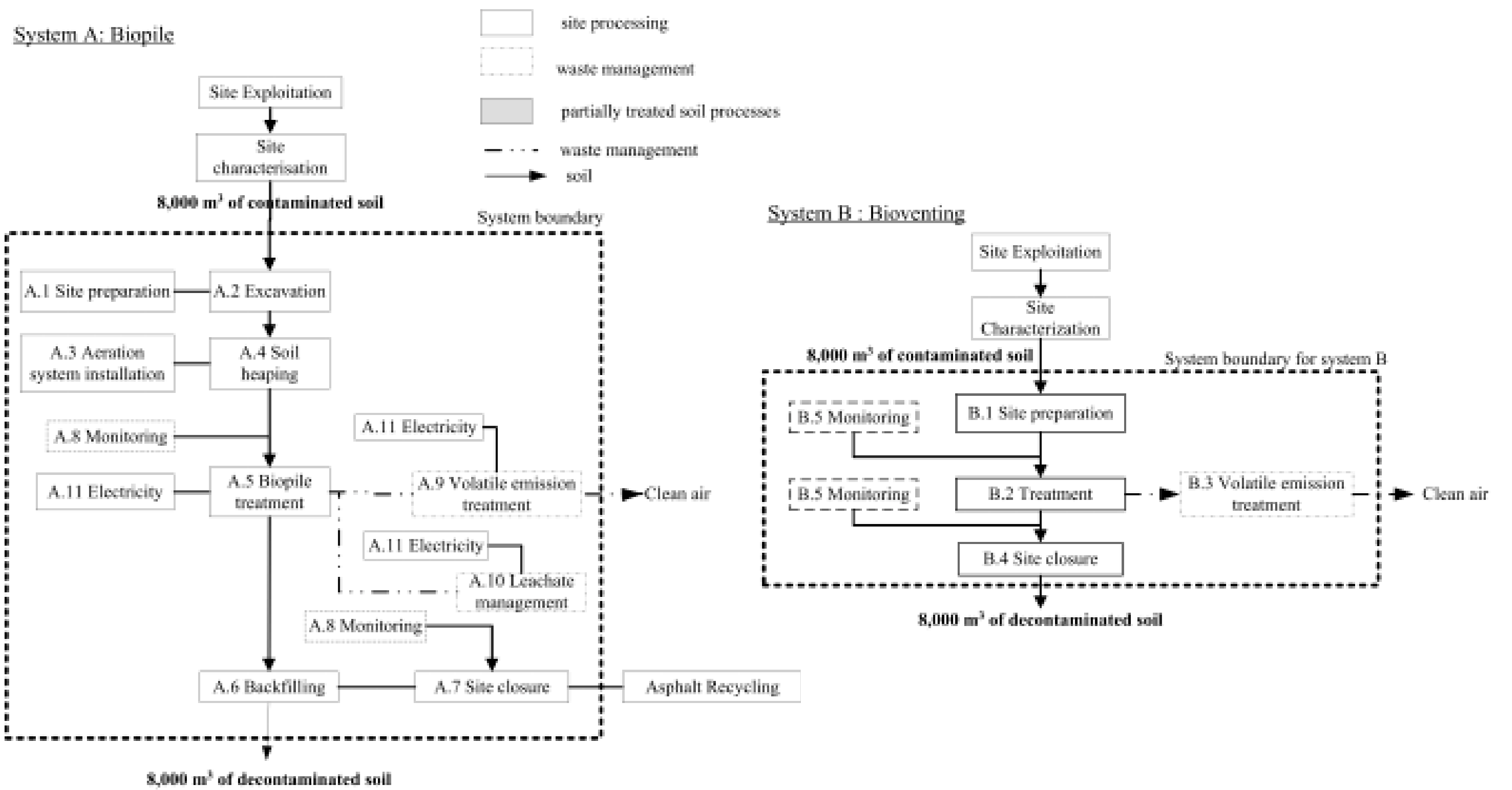
Decontaminate 8 000 m^3 of diesel-contaminated soil from an initial contamination probability distribution q(0%; 1,2%; 98,8%) using a combination of bioventing and biopile to reach either a new state of the site for which the s_1 range has the highest probability of occurrence or a maximum of three years of treatment.

Objective

Identify the remediation strategy minimizing both primary and secondary impacts meanwhile reaching the < 700 mg diesel/kg range.

Remediation of a diesel-contaminated site

Case study



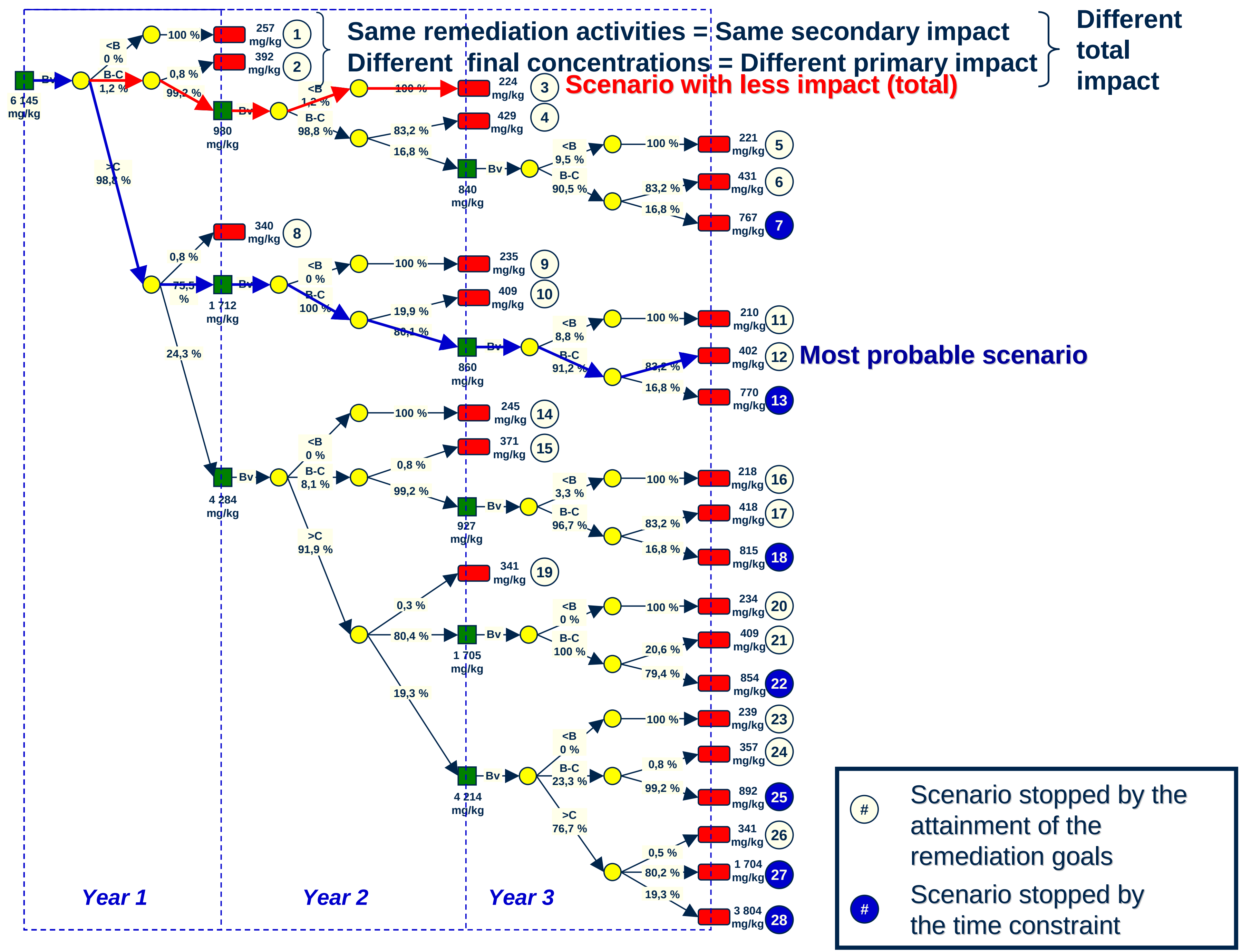
Deterministic approach- Classical LCA

Classical LCA for each technology for the remediation of the site from the initial mean concentration to a concentration under 700 mg/kg gives the following results:

	Biopile	Bioventing
Primary impact	2 215.0 Pt	2 215.0 Pt
Secondary impact	1164.5 Pt	241.9 Pt
Total impact	3279.5 Pt	2356.9 Pt
Treatment duration	2 years	3 years

Impact have been assessed using SimaPro 5 and the EDIP97 methodology

Following a deterministic approach, a three-year bioventing treatment is environmentally preferred to the biopile.



Same remediation activities = Same secondary impact
Different final concentrations = Different primary impact
Different total impact
Scenario with less impact (total)
Most probable scenario
6 145 mg/kg
980 mg/kg
1 712 mg/kg
4 284 mg/kg
840 mg/kg
860 mg/kg
927 mg/kg
1 705 mg/kg
4 214 mg/kg
Year 1
Year 2
Year 3
Scenario stopped by the attainment of the remediation goals
Scenario stopped by the time constraint

Probabilistic approach- Results

- The Optimal Remediation Strategy (ORS) is established considering the uncertainties surrounding the real level of contamination and the ease at achieving the remediation goals
- Both deterministic and probabilistic approaches lead to the selection of the same technology, but
  - ORS is made of 28 scenarios
  - $\sum$ Probability of occurrence of scenarios with total impact < deterministic approach = 72%

Probabilistic approach- Results

	Deterministic approach	Probabilistic approach	
		ORS	Most probable scenario
Duration	3 years	2.8 years (expected value)	3 years
Total environmental impact	2 356 Pt	1 911 Pt (expected value)	1 460.5 Pt
Probability of occurrence	N/A	N/A	45.3%
Final expected concentration	In s_1 range (< 700mg/kg)	N/A	In s_1 range (< 700mg/kg)

Conclusions

- Using METEnvORS highlights on all the occurrences (scenarios) that a remediation may follow
  - These occurrences are results of uncertainties on the level of contamination and the technology’s effectiveness
- Since the model is multistage, the decision-maker can, with the information he has collected during a stage, review his technology choice at the beginning of the next stage
- Knowing the ORS, gives the decision-maker a better picture of the reality
- Including these uncertainties into a site remediation LCA provides a better applicability of LCA in environmental management

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