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**ECOLOGICAL INDEX OF CONCERN (EIoC)**
**Management tool for identifying polluted soil that qualifies for ecological upgrade**

# Abstract

In response to the target of “zero net land take” set by the French government in its Biodiversity Plan, technical and research institutions, municipalities and consultancy firms are stepping up initiatives to identify industrial or urban brownfields that are suitable for ecological restoration, with the goal of incorporating more green spaces into our cities.

Some of these polluted and abandoned sites are home to evolving ecosystems of ecological interest (e.g. heritage species). This raises the question of whether to leave the pollution in place to preserve the ecosystems there or whether to undertake decontamination operations and risk sacrificing them. Since pollutant concentration levels that are higher than background and other management values do not necessarily impact an ecosystem, it is possible to upgrade this category of brownfield to one which has a potential for ecological use - providing that an absence of risk can be demonstrated. The ecosystem risk assessment (ERA) process as described, for example, in the Ineris document referenced in the footnote[1], can be used to help make such decisions. However, the ERA methodologies prescribed are rarely implemented because they are often regarded as technically and financially too costly.

An “Ecological Index of Concern” (EIoC) has therefore been developed to investigate the potential risk associated with soil pollution based on the principles of the TRIAD method (NF ISO 19240) and, in particular, on the combination of the three-pronged (ecological, chemical and eco-toxicological) approach for assessing risk to ecosystems. The EIoC defines three categories of polluted sites: (1) those whose state raises “no concern”, meaning that the site might be readily upgraded to a site for ecological use, (2) those whose state raises “moderate concern”, meaning that the site can be reclassified as either of the other two states once the bioavailable character of the pollution has been established and (3) those whose state gives “cause for concern” and require more extensive investigation, such as an ERA.

The Ecological of Concern Index (EIoC) is a promising tool for guiding the management or remediation methods of polluted sites. In case studies developed as part of Ademe’s Tipomo project, the EIoC has demonstrated its workability and utility for brownfields with higher pollutant levels that the background values but where the soil had potential environmental benefit for the ecosystems already present (carbon storage, recreational zones, reducing heat islands and flooding, etc.).

[1] INERIS (2022). *Document d’orientation pour l’évaluation du risque chimique pour les écosystèmes - Impact local des activités humaines sur les milieux naturels et la biodiversité* (document in French) (“Guidance document on the assessment of chemical risk for ecosystems - Local impact of human activity on natural habitats and biodiversity”)

# 1. Context and issues at stake: urban and peri-urban soil pollution

A large number of environmental, social and economic debates are focusing on the future of urban or peri-urban brownfields, and all the more keenly, given the goals to reduce urban sprawl and requalify abandoned sites. Such sites play an essential role in the “zero net land take” target set out in France’s Biodiversity Plan and, indeed, some of these sites lend themselves to a change of land use, to one of ecological use (see box below). When degraded sites are offered a new lease of life, the rewards are many: people gain a pleasant environment, a heat sink is created for a local community and a certain biodiversity within an urban enclave can be maintained.

When requalification projects concern polluted sites with identified health or ecological issues, the national methodology for managing polluted sites and soils is to prescribe a health and environmental risk assessment. The “risk”-type approach enables the ecological quality of the environment to be examined. An ERA (ecosystem risk assessment) (INERIS, 2022) is based, for example, on the calculation of a risk characterisation ratio that is essentially the same as the risk quotient used to estimate the health risk. It corresponds to the ratio between the exposure concentration (predicted from measured or modelled concentration levels) (the PEC) and the predicted no-effect concentration (PNEC). The ERA can also be conducted by applying the standardised TRIAD[2] approach which uses the tools from various fields of risk assessment science to reduce the uncertainties of the assessment and to obtain the most relevant result possible. However, such studies are long and expensive and are not systematically carried out on all polluted sites. Even when they are used, uncertainties may remain about the need to remediate the brownfield if the process results in the destruction of an ecosystem evolving on the site.

**Ecological use**

The “Climate and resilience” act is the driving force behind Article L.556-1 A which was added to the Environment Code in 2021 to simplify rehabilitation operations of polluted sites and soils. The Code defines “use” as “the function or activity or activities being carried out or contemplated on a defined piece or pieces of land, the soil covering that land or the buildings and facilities on it.” It defines rehabilitation, such as of polluted sites, as “measures that ensure the compatibility of the state of the soil with, on the one hand, the provisions of the Environment Code (Article L. 511-1 and, if relevant, Article 211) and, on the other hand, with the intended use of the land.” Decree No. 2022-1588 of 19 December 2022 lists and defines the eight different types of soil use in the management of polluted sites and soils. The decree came into effect on the first of January 2023. Ecological use implies the operations to preserve, restore or improve the functionality of the soil, mainly by means of reversing soil sealing, in order to develop habitats for the ecosystems.

# 2. Goals

A new methodological approach to characterising the quality of the soils has been developed called the Ecological Index of Concern (EIoC). Its aim is to simplify the management and, ultimately, the upgrading of polluted sites and, in particular, the management of abandoned sites where evolving ecosystems of ecological value are present (e.g. where protected or heritage species are found).

The method can be employed prior to risk assessment procedures, in order to screen for situations where polluted soil is liable to have an adverse effect on terrestrial ecosystems. The results of the Ecological Index of Concern should therefore enable us to identify polluted sites with evolving ecosystems that qualify for simplified upgrading to ecological use (as part of a green belt or a biodiversity reserve, etc.) and those where an ERA, using the methods described above, is required before upgrading can go ahead.

[2] Standard NF ISO 19 204: Procedure for assessing specific ecological risks at the contamination site (Triad approach).

**The Tipomo project**

The Ecological Index of Concern (EIoC) was developed as part of an ADEME study, the "*Étude du Transfert, Indice de Préoccupation : Outil pour la valorisation des friches MOyennement contaminées*" (report in French) ("Study of Transfer, Ecological Index of Concern: Tool for upgrading moderately contaminated sites"), otherwise known as the "Tipomo project". The project partners — the French national institute for industrial environment and risks (INERIS), the Saint-Étienne engineering school (École des mines) and the EODD engineering consultancy — worked together to test the new management tool during a case study performed on eight urban brownfields selected from the database of ADEME's "RESOLU" programme.

Details of the Tipomo project are presented in the research report (in French), available in Ademe's online library. The report contains, for example, the detailed method used to calculate the Index and the correlation between the interpretation of the Index and the results of a battery of bioassays carried out on soil organisms.

# 3. The Ecological Index of Concern

## 3.1. Context of use

The Ecological Index of Concern (EIoC) is a management tool that can be used before performing an ecosystem risk assessment. Its purpose is to classify polluted sites intended for ecological use based on the level of concern it presents for the health of terrestrial ecosystems.

The Ecological Index of Concern applies to urban or peri-urban industrial brownfields that are polluted with 5 PTEs (potentially toxic elements), in this case, arsenic, cadmium, copper, lead and zinc, and with the PAHs listed in the US Environmental Protection Agency's list of priority PAHs. A prerequisite for carrying out an Ecological Index of Concern procedure is that the polluted sites in question must sustain an evolving ecosystem (significant ground cover and one or several soil functions[4]).

The Ecological Index of Concern provides managers with sufficient information to allow them to upgrade the use of a polluted site to one that supports a functional biodiversity, while dispensing with the need for an ERA whose cost/benefit ratio is not justified.

## 3.2. Method principles

The iterative method is based, firstly, on the total pollutant concentrations measured in the soil. To start with, the total PTE and PAH concentrations are combined to form an Index comparable to a calculation of toxic pressure: one Index for the PTEs ($EIoC_{metals}$) and one Index for the PAHs ($EIoC_{PAH}$). The indices are compared with a lower threshold value of 5 and an upper threshold value of 15 (Figure 1). If the indices $EIoC_{metals}$ and $EIoC_{PAH}$ are below the lower threshold value, the polluted site is classified as raising "no concern" and can be upgraded to being of ecological use without the need to carry out an ecosystem risk assessment. If either the $EIoC_{metals}$ or the $EIoC_{PAH}$ index is greater than the upper threshold value, the state of the polluted site gives "cause for concern" and an ecosystem risk assessment must be done to confirm the compatibility between the pollution in situ and the ecological use intended for the site (ecological continuity, green space, natural area, etc.). The data obtained from the Ecological Index of Concern calculation provide a good starting point from which to conduct the risk assessment. In other cases (where one or both indices are between the lower and the upper threshold value and neither is greater than the upper threshold value), a bioavailability characterisation of the substances can be performed to determine the state of the brownfield site more accurately.

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[3] Nicolas PUCHEUX (INERIS), Nicolas MANIER (INERIS), Olivier FAURE (Ecole des Mines de Saint-Etienne, research unit UMR 5600 EVS) - 2021 – "*Identification de friches polluées éligibles à une reconversion écologique - étude TIPOMO, Étude des Transferts, Indices de Préoccupation : Outils pour la valorisation des friches urbaines MOyennement contaminées"* ("Identification of polluted sites that qualify for ecological upgrade - TIPOMO study, Study of Transfer, Indices of Concern: Tools for upgrading moderately contaminated urban brownfields") 103 pages

[4] Ecological functions of soil: Phenomena specific to the ecosystem arising from the combination of the state of the ecosystems and of the ecological structures and processes, and that occur with or without the presence of humans. Essentially, this includes the basic functions and the maintenance of the ecosystems' ability to function (nutrient cycling, soil formation, primary production, etc.)

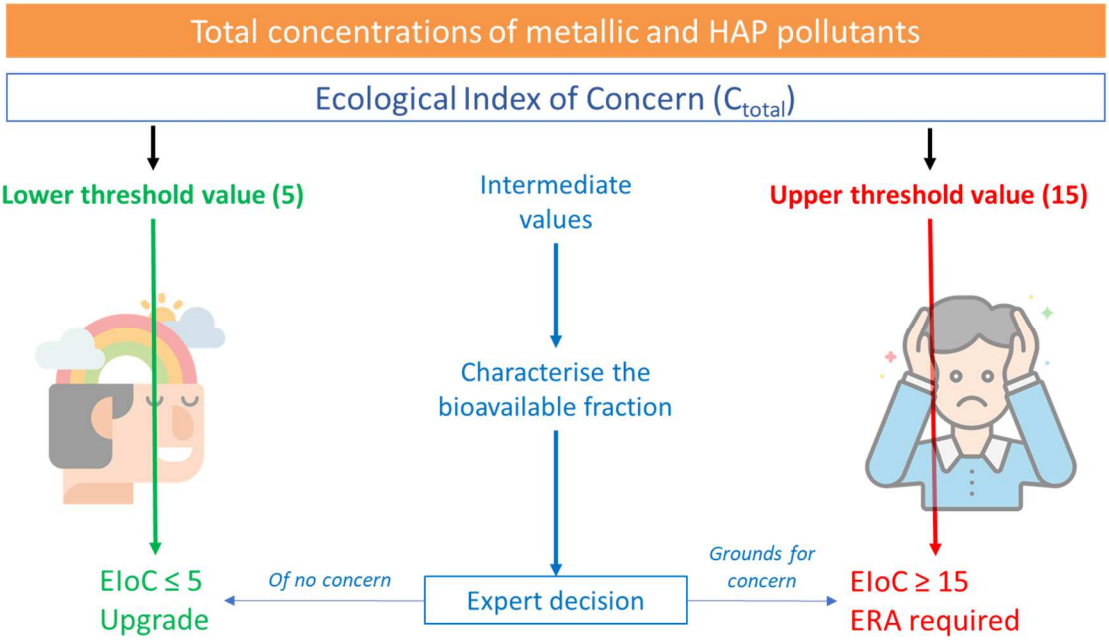


*Figure 1: How the Index of Concern is used*

The Ecological Index of Concern calculation is a management tool used to differentiate three types of contaminated sites that sustain an evolving ecosystem:

- Sites where the residual pollution poses no risk for the ecosystems (no cause for concern);
- Sites where the residual pollution might be a cause of concern for its ecosystems (moderate concern). The **bioavailability** of the pollutants must be measured to provide a more accurate assessment of the state of the soil on the site;
- Sites where the residual pollution is worrying for the in-situ ecosystems (cause for concern). No impact has been demonstrated but an ecosystem risk assessment must be conducted.

## 3.3. Calculating the EIoC

First, the total PTE and PAH concentrations are aggregated in the form of two indices: one index for the PTEs ($EIoC_{metals}$) and one for the PAHs ($EIoC_{PAH}$). The Ecological Indices of Concern are calculated by taking into account, on the one hand, the concentrations of the substances and, on the other hand, their toxicity in the form of the ecotoxicity potential (EcotoxPot) of each substance. The EcotoxPots are relative values based on the concentrations that have no effect on the environment (PNEC) of the substances. The equation proposed is derived from the METOX index calculation method: a management tool used by water agencies to measure aquatic pollution and to calculate any tax that certain polluters must pay the area water boards.

[5] Bioavailability and Bioaccessibility of Pollutants in Contaminated Soils: State of Present Knowledge and Research Avenues, RECORD, 2012, 259 pages.

As with the METOX calculation method, the total concentration of the substance measured is multiplied by a factor indexed to its degree of toxicity, where it is the toxicity for terrestrial rather than aquatic organisms that is of interest in this case. It is then divided by 100 to express it on a more practical scale.

$$EIoC_{\ substance} = \frac{Total\ concentration\ substance \times E\text{cotoxPot}\ substance}{100}$$

The EcotoxPots established when this document was written are shown in appendices 1 and 2. The $EIoC_{metals}$ and the $EIoC_{PAH}$ are then differentiated by calculating them as follows:

$$\text{EIoC}_{\text{metals}} = 5 \times \sum \frac{\text{EIoC}_{\ substance\ ETP}}{n_{MTE}}$$

(where $n_{ETP}$ represents the number of metals considered)

$$\text{EIoC}_{\ \text{PAH}} = 5 \times \sum \frac{\text{EIoC}_{substance\ \text{PAH}}}{n_{PAH}}$$

(where $n_{PAH}$ represents the number of PAHs considered).

Appendix 3 gives an example of an EIoC calculation.

## 3.4. Interpreting the Ecological Index of Concern

The calculated Ecological Indices of Concern are interpreted with reference to a lower and an upper threshold value (Figure 1). They allow the user to distinguish sites that are of no concern and which can be upgraded to ecological use from those where the level of pollution is too great for immediate upgrading without more extensive analysis in the form of an Ecosystem Risk Assessment (ERA).

- The lower threshold value (5)

The EIoC value (PTEs and PAHs) below which the state of a site is considered to cause no concern is 5. The is the value that would be obtained for a site where total concentration levels are below the background values. The limit enables us to readily identify sites that are of no concern for the environment.

- The upper threshold value (15)

The EIoC value (PTEs and PAHs) above which the state of a site is considered to cause concern is 15. This is the value that would be obtained for a site whose total concentrations are too high to allow a decision to be taken about its future use without performing an Ecosystem Risk Assessment (ERA).

The interpretation of the index according to the threshold values is shown in Figure 1. There are three types of industrial brownfields on which evolving ecosystems exist:

- **$EIoC_{metals}$ and $EIoC_{PAH}$ ≤ 5: (no concern)** the state of the soil causes no concern for the ecosystems and is suitable for ecological restoration or ecological upgrading.
- **5 ≤ $EIoC_{metals}$ and $EIoC_{PAH}$ ≤ 15: (moderate concern)** the state of the soil is likely to cause concern for the **ecosystems** there. The pollutant **bioavailability** must be measured to provide a more precise assessment of the state of the site. The range (5-15) enables us to distinguish polluted sites where an ERA is required from those whose bioavailability measurement suggests they could be upgraded.

- **$EIoC_{metals}$ and $EIoC_{PAH}$ >15: (cause for concern)** the state of the soil gives cause for concern and an Ecosystem Risk Assessment (ERA) must be done to evaluate compatibility between the soil pollution and the ecological use intended. The document referred to in the footnote provides guidance on assessing the chemical risk for ecosystems (in French)[6].

The results of bioavailability testing can allow a site "of moderate concern" to be upgraded to one of "no concern". Neither the guidance document nor the Tipomo[7] project report, which describes how the index is constructed, determines the tools to be used for measuring the bioavailability of pollutants in the soil. However, the Tipomo project report offers a number of potential approaches; four of the techniques, from chemical extraction (CaCl2-extractable trace elements and non-exhaustive extraction techniques - Tenax extraction) to measuring the fraction accumulated in the tissues of exposed organisms (TML index - plants and measuring bioaccumulation in earthworms) have already been used, as well as observing the effects of the bioavailable fraction on living models (battery of laboratory bioassays). The cases studies in the report also provide examples of interpretations of anticipated results for "moderate concern" sites. Appendix 4 provides a non-exhaustive list of standardised bioavailability measurement.

# 4. Possible developments

The Ecological Index of Concern calculation is relatively easy to apply and is based on the scientific principles used in the field of ERA. The two-step procedure can be used to differentiate sites where the pollution gives cause for concern (EIoC greater than 15) from those that cause no concern (EIoC less than 5). A third group, sites whose EIoC values cause moderate concern, can be classified by pollutant bioavailability testing.

Firstly, it is essential to refer cases where the Ecological Index of Concern shows "moderate concern" and when bioavailability data have been generated for expert opinion. The method has not yet been sufficiently tested to propose threshold values for bioavailable concentrations. An ERA expert's report has been requested in order to select the most appropriate tools for the context and for interpreting the results. For now, this is viewed as possibly hampering the effectiveness of the method.

Another improvement would be to increase the number of substances covered (only 5 PTEs and 16 PAHs are currently considered). A first step might be to identify the groups of substances that are most relevant in the context of polluted soils where local ecosystems are evolving, or to construct a way of adapting the Ecological Index of Concern to other pollution contexts (such as phytomanagement).

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6 INERIS (2022). "*Document d'orientation pour l'évaluation du risque chimique pour les écosystèmes - Impact local des activités humaines sur les milieux naturels et la biodiversité, Ineris*" (in French) ("Guidance document on the assessment of chemical risks for ecosystems - Local impact of human activity on natural habitats and biodiversity").

7 Nicolas PUCHEUX (INERIS), Nicolas MANIER (INERIS), Olivier FAURE (Ecole des Mines de Saint-Etienne, research unit UMR 5600 EVS) - 2021 – "*Identification de friches polluées éligibles à une reconversion écologique - étude TIPOMO, Étude des Transferts, Indices de Préoccupation: Outils pour la valorisation des friches urbaines MOyennement contaminées"* (in French) ("Identification of polluted sites that qualify for ecological upgrade - TIPOMO study, Study of Transfer, Indices of Concern: Tools for upgrading moderately contaminated brownfields "). 103 pages

# 5. Appendices

## 5.1. Appendix 1: Ecotoxic potential of metallic pollutants

*Table 1: Ecotoxicological potential of the metallic pollutants considered*

| Substance | Ecotoxicological potential |
|---|---|
| Arsenic | 10 |
| Cadmium | 150 |
| Copper | 2 |
| Lead | 1 |
| Zinc | 1 |

## 5.2. Appendix 2: Ecotoxic potential of PAHs

*Table 2: Ecotoxicological potential of the PAHs considered*

| Substance | Ecotoxicological potential |
|---|---|
| Acenaphthene | 200 |
| Acenaphthylene | 1000 |
| Anthracene | 500 |
| Benzo[a]anthracene | 900 |
| Benzo[a]pyrene | 1000 |
| Benzo[b]fluoranthene | 200 |
| Benzo[k]fluoranthene | 200 |
| Benzo[ghi]perylene | 300 |
| Chrysene | 100 |
| Dibenzo[ah]anthracene | 900 |
| Fluoranthene | 30 |
| Fluorene | 100 |
| Indeno[1,2,3-cd]pyrene | 400 |
| Naphthalene | 200 |
| Phenanthrene | 50 |
| Pyrene | 100 |

## 5.3. Appendix 3: Calculating and interpretating the Ecological Index of Concern

The following table shows an example of the total concentrations that can be measured in a polluted site with significant ground cover as well as the Ecological Indices of Concern that can be calculated.

*Table 3: Demonstration of Ecological Index of Concern calculations*

| Substance | PTE or PAH | Total concentration in mg/kg (DW) | Index of Concern |
|---|---|---|---|
| Arsenic | PTE | 130 | 13.00 |
| Cadmium | PTE | 1.4 | 2.10 |
| Copper | PTE | 130 | 2.60 |
| Lead | PTE | 230 | 2.30 |
| Zinc | PTE | 620 | 6.20 |
| **Index of Concern — PTEs** | | | **26.20** |
| Acenaphthene | PAH | 0.05 | 0.10 |
| Acenaphthylene | PAH | 0.05 | 0.50 |
| Anthracene | PAH | 0.05 | 0.25 |
| Benzo[*a*]anthracene | PAH | 0.05 | 0.48 |
| Benzo[a]pyrene | PAH | 0.05 | 0.50 |
| Benzo[b]fluoranthene | PAH | 0.06 | 0.12 |
| Benzo[k]fluoranthene | PAH | 0.05 | 0.10 |
| Benzo[ghi]perylene | PAH | 0.05 | 0.15 |
| Chrysene | PAH | 0.06 | 0.06 |
| Dibenzo[ah]anthracene | PAH | 0.05 | 0.45 |
| Fluoranthene | PAH | 0.08 | 0.02 |
| Fluorene | PAH | 0.05 | 0.05 |
| Indeno[1,2,3-cd]pyrene | PAH | 0.05 | 0.20 |
| Naphthalene | PAH | 0.05 | 0.10 |
| Phenanthrene | PAH | 0.06 | 0.03 |
| Pyrene | PAH | 0.07 | 0.07 |
| **Index of Concern — PAHs** | | | **0.99** |

The Ecological Index of Concern for the five metals is 26.2, a value substantially higher than the upper threshold value (15). The soil on this brownfield has a worrying level of metal pollution. Given the index results, the evaluator will not therefore be recommending the site for simplified upgrading, such as to ecological use. A classic ecosystem risk assessment is required to address the situation appropriately. At 0.99, the index of concern for PAHs is well below the lower threshold value of 5. Based on the PAH criterion, it would have been possible to recommend that the brownfield be upgraded for use that is consistent with managing the biodiversity of the site. The interpretation of both scores shows us that the pollution on the brownfield in question is worrying and that it is not possible to pronounce on the risk the site represents for ecosystems without an ecosystem risk assessment. The tool also highlights the fact that if pollution management solutions are to be implemented, particular attention must be paid to the pollution by arsenic and zinc, as these were the highest contributors to the Ecological Index of Concern score.

## 5.4. Tools for characterising the bioavailable fraction of pollution in soil

| Tool category | Tool type or name | Standard |
|---|---|---|
| **Extraction by solvents (PTEs and organometallics)** | Extraction of trace elements (DTPA) | NF ISO 14870 |
| | Extraction of trace elements (EDTA) | NF X31-120 |
| | Extraction of trace elements (HNO3) | NF ISO 17586 |
| | **Extraction of trace elements (CaCl2)** | NEN 5704 (Dutch standard) |
| | Extraction of trace elements (NaNO3) | VSBo (Swiss standard) |
| | Extraction of trace elements (NH4NO3) | NF ISO 19730 |
| **Extraction by adsorbent agent (organic pollutants)** | **Non-exhaustive extraction techniques (Tenax extraction)** | XP ISO/TS 16751 |
| | Non-exhaustive extraction techniques (cyclodextrin) | XP ISO/TS 16751 |
| **Leaching** | Liquid/solid leaching ratio 2L/kg | NF EN ISO 21268-1 |
| | Liquid/solid leaching ratio 10L/kg | NF EN ISO 21268-2 |
| | Leaching by percolation | NF EN ISO 21268-3 |
| **Passive samplers** | DMT (Donnan Membrane Technique) | - |
| | DGT (Diffusive Gradient in Thin film) | - |
| | SPMD (Semi Permeable Membrane Device) | - |
| **Bioindicators of accumulation** | SET Index - Snails (Sum of Excess Transfers) | ISO/DIS 24032. |
| | **TML Index - plants (Total Metal Load)** | - |
| | **Bioaccumulation in earthworms** | Test No. 317 OECD Guideline 207 |

The techniques in bold were used in the Tipomo[8] project.

[8] Nicolas PUCHEUX (INERIS), Nicolas MANIER (INERIS), Olivier FAURE (Ecole des Mines de Saint-Etienne, research unit UMR 5600 EVS) - 2021 – "*Identification de friches polluées éligibles à une reconversion écologique - étude TIPOMO, Étude des Transferts, Indices de Préoccupation : Outils pour la valorisation des friches urbaines MOyennement contaminées"* (Report in French): ("Identification of polluted sites that qualify for ecological upgrade - TIPOMO study, Study of Transfer, Indices of Concern: Tools for upgrading moderately contaminated brownfields ") . 103 pages