CL:AIRE

EiCLaR 06
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EiCLaR bulletin

CL:AIRE's EiCLaR bulletins describe *in situ* bioremediation technology developments and tools created within the EiCLaR project. This bulletin describes the development of a decision support tool for screening potentially suitable remediation technologies.

Decision support tool for remediation options assessment

1. INTRODUCTION

In the past, there have been multiple attempts to popularise decision support tool (DST) software to assist options assessment for remediation technologies. However, these often have little market penetration, as service providers tend to maintain in-house systems that are customised to their own specific business interests. EiCLaR will take a nuanced approach by providing a technical diagnosis of the suitability of different remediation options. It benchmarks a range of techniques including the four developed within EiCLaR to provide an initial remediation options appraisal that can be used within standard consultancy and contracting services.

Decision support information will be collated and formatted using the concept of "operating windows", an engineering concept used to collate key operating parameters and limits of applicability. Operating window methods are primarily used in engineering to improve reliability. Operating windows define limits for a critical factor, above or below which failure of a machine or process occurs. Operating windows have great potential value in providing a unifying concept in decision-making by helping stakeholders understand the optimum usage of a particular remediation technique. The approach includes the development of a web-based DST which provides site-specific rankings and outputs based on the provided input parameters, thus providing guidance to remediation companies, administrative actors, or site owners. The DST employs a fuzzy-logic algorithm to interpret the data stored in the operating window. A user-friendly graphical interface has been developed which allows users to manipulate site-specific input data, generate outputs to use in their reports, access further information from the knowledge base, and contact supporting services for more in-depth consultancy (https://contaminatedland.info).

2. DEVELOPMENT OF THE DST

Based on the operating windows approach, a DST has been developed. This DST can be used to help identify whether a specific technique is a potentially suitable method to remediate a given contaminated site. The tool is aimed at the initial screening stage and is therefore set up in a comprehensible and user-friendly way to provide low-barrier access to applying the operating windows in real-world applications. The interplay between some factors is complex and therefore cannot be reflected in a simple DST. Thus, the use of the DST cannot replace the consultation of experts when deciding about the application of technologies at a given site. The tool will therefore also provide the user with all relevant contact information of the appropriate EiCLaR partner(s).

Figure 1. Front-end workflow of the DST.

3. DESCRIPTION OF THE DST

The DST is structured in the following way: users create an account by registering on the DST website. They are then asked to fill in values of several input parameters summarizing conditions at the site of investigation. By comparing these parameter values with operating window data, the technologies are ranked according to suitability (i.e. they are given a suitability score). These scores are then used to (a) provide a first estimate about whether the application of technologies is promising for the given site and (b) rank the technologies by their estimated degree of suitability (short list). Finally, the tool provides a detailed PDF report to the user. This report summarizes the suitability for the specific site in combination with information about the different technologies. The report is amended by multiple technical annexes. Users are also provided with an option to contact a technical support service from an accredited enquiry panel. Table 1 overleaf gives an overview of the remediation technologies considered in the DST. Figure 1 summarizes the front-end workflow of the DST.

Enhanced and Innovative *In Situ* Biotechnologies for Contaminated Land Remediation

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Table 1: Overview of remediation technologies considered in the DST.

Group	Remediation Technology
EiCLaR	Electro-Nano-Bioremediation Bioaugmentation Bioelectrochemical Remediation Enhanced Phytoremediation
In situ treatment technologies	Monitored Natural Attenuation (MNA) In situ flushing to change contaminant mobility In situ bioremediation Soil vapour extraction / venting and bioventing Air sparging and biosparging In situ chemical oxidation / reduction (ISCO/R) Electro-remediation Phytoremediation In situ stabilisation In situ thermal Fracturing techniques for enabling in situ remediation Permeable reactive barriers
Ex situ treatment technologies	Ex situ bioremediation Soil washing and related ex situ treatments Solidification/stabilisation Ex situ thermal treatments Vitrification
Passive and hydraulic containment	Capping and cover systems Impermeable barriers Pump and treat
Excavation	Excavation

The user input parameters comprise both site characteristics and contaminant properties. The site characteristics summarize the physical, hydrogeological, and hydro-chemical properties of the site (e.g., hydraulic conductivity). The contaminant properties allow the user to specify the type (e.g., aliphatic, PFAS, PCB, …), phase (plume, NAPL pool, sorbed phase or residual NAPL) and location of the contamination (saturated zone, unsaturated zone or capillary fringe). All parameter values for a specific site are either entered by choosing an entry from a dropdown list (for categorical variables on a nominal scale, e.g., contaminant type) or by selecting a number from a predefined range with a slider (for parameters that are defined on a continuous scale, e.g., temperature).

The user input values are compared to a database of decision rules derived from the operating windows with the help of fuzzy logic. Fuzzy logic in principle is based on the definition of separate rules that are all evaluated simultaneously (a process called "fuzzification"), to construct a scalar output (by a process called "defuzzification"). This avoids arbitrary cut-off intervals (e.g., a certain temperature threshold for a technology) and achieves a continuous input/output relationship, while keeping the formulation of the underlying rules comparably simple (explained in the following). In the context of the EiCLaR DST, the team has come up with a simplified fuzzy logic algorithm to evaluate a remediation technology's overall suitability score according to the user input values. The linkage between input and output is provided by the database of decision rules, which describes the limits for each parameter individually. The evaluation makes use of several terms defined as follows:

Overall suitability: The overall suitability of a remediation technology depends deterministically on the input parameter values and is determined through a list or table of rules. A derived score for each technology ranges from ≤ 0 ("completely unsuitable conditions") to 100 ("perfectly suitable conditions").

Fuzzy input parameter state: For the fuzzy rule formulation, different states are defined for each input parameter. An example for such a state would be "cold" for temperature. A state can be partially fulfilled (e.g., "cold" ranges from 5°C to 6°C, with a partial fulfilment between 3°C and 8°C). The degree of fulfilment is defined by a trapezoidal function with respect to the input parameter. For continuous input parameters, the states can be overlapping (e.g., allowing a gradual change from state "cold" to state "mild" on the temperature scale). For categorical input parameters, each category is assigned an arbitrary interval on a virtual scale. The trapezoidal functions collapse to non-overlapping step functions in this case.

Rule: A rule describes the suitability of a remediation technology for a given qualitative value and fuzzy input parameter state. All rules are based on the operating windows and are formulated in a human-readable language. An example for a rule would be "Technology XYZ is 'suitable' when the temperature is 'cold', where 'cold' is the qualitative value, 'temperature' is the parameter and the value entered by the user falls within the operating window". All rules are collected in a database.

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Suitability statement: Five different suitability statements can be used in the rules ("not suitable", "poor", "potentially suitable", "suitable" and "unknown"). Each one can be translated to a numeric base score ranging from minus infinity ("not suitable[1]") to 100 ("suitable").

To determine the overall suitability for a specific remediation technology under a given set of user input parameters, the fuzzy logic algorithm iterates through all rules, reads the suitability statements in their numeric form, weights them according to the fulfilment of the fuzzy input parameter state and determines the overall average. The remediation technology is then either deemed "suitable", "potentially suitable", or "not suitable". If some parameters are not available for a specific site, the user can deselect them through a checkbox to ignore the corresponding rules in the evaluation.

Figure 2 shows a screenshot of the DST parameter input form.

Each suitability statement in the rules table has been peer reviewed and validated by industry experts.

The DST is available at https://contaminatedland.info

4. CONCLUSIONS

The EiCLaR DST provides a remediation technology selection process linked to an operating window assessment of the techniques that are included in the tool. It is based on a fuzzy logic algorithm that allows for a broader range of endpoints than "pass/fail". The DST is designed to provide outputs on the applicability of remediation technologies for a given site that can be directly transcribed into user practice and automate some aspects of report production. The tool considers 20 established technologies, as well as the four emerging EiCLaR technologies. Detailed technical information about these four technologies is linked/provided within the DST. The tool is part of broader guidance on achieving sustainable and risk-based land management (Bardos, 2024). It will be linked to practical illustrative case studies. It is also framed in a broader support package providing access to wide ranging expertise available on a fixed price tariff.

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References
Bardos, R.P. 2024. Sustainable risk based land management. In Publication.

[1] A value of minus infinity enforces that the result of all calculations will be minus infinity, too. The corresponding rule therefore ensures that a technology is always ranked as "not suitable" if this condition is active.

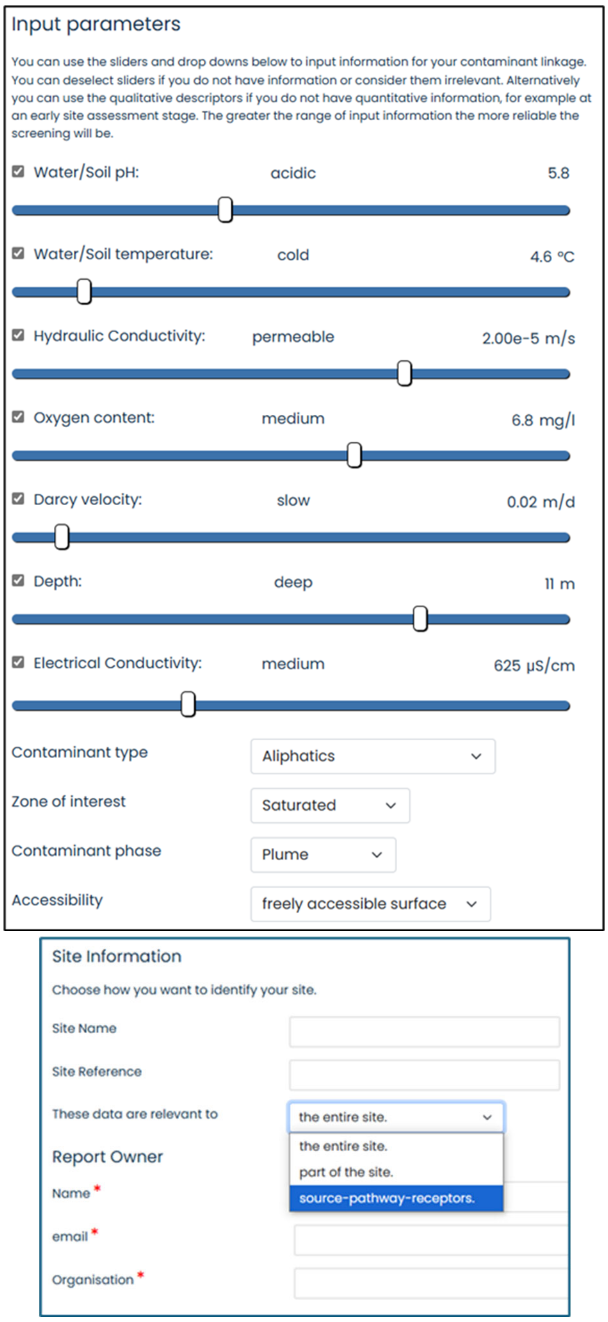

Figure 2. Screenshots of the DST parameter input form.

For further information please contact the authors:
Paul Bardos, r3 Environmental Technology Ltd, Reading, UK, paul@r3environmental.co.uk
Matthias Loschko, BoSS Consult GmbH, Stuttgart, Germany, matthias.loschko@bosscon.de
Jonas Allgeier, BoSS Consult GmbH, Stuttgart, Germany, jonas.allgeier@bosscon.de
Helen McLennan, Chateau9, Limoges, France, helen.mclennan@chateau9.com