GIS Based Decision Support Tool for Remediation Technology Selection

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Abstract: - Development and use of remediation technologies for contaminated soils and water progresses at a very fast pace and thus a large number of cleanup alternatives emerge. The selection of the most appropriate Remediation technology for the given site must be based on many, usually conflicting, criteria. To successfully apply all these criteria a multicriteria decision support system (DSS) is needed. Such a system must have access to data from evaluation of remediation technology performances according to all given criteria. As the managing of all environmental data is usually accomplished with a Geographical Information Systems (GIS) it is the most suitable environment for an environmental multicriteria DSS. We will present one multicriteria DSS which is integrated into the GIS platform in order to make the appropriate decision making possible directly from GIS environment.

Key-Words: - Decision support Systems, Geographic Information System, Remediation technologies, Multicriteria Decision Making

1 Introduction

Numerous accidents, spills, leaks, and past improper disposal and handling of hazardous materials and wastes have resulted in a vast number of sites worldwide which have contaminated land and water (groundwater and surface water). Some of the more common categories of contaminants include: industrial solvents, petroleum products, metals, pesticides, bacteria, and radiological materials. These contaminated sites can threaten human health as well as the environment, in addition to hampering economic growth and the vitality of local communities. A variety of cleanup programs to assess and clean up these contaminated sites have been developed. [1]

The selection and use of more cost-effective remedies requires better access to data on the performance and cost of technologies used in the field. Various data on the existing remediation technologies, like cost, performance or required clean-up time needs to be assembled and made available for the decision maker.

Even with all the appropriate data on the remediation technologies, the selection of the most suitable remediation technology has become a very challenging task as their number has grown to an extent which is hardly manageable for decision makers. When selecting the most appropriate technology they confront the challenge of making decisions considering a variety of problems and satisfying a number of conflicting criteria. They are required to balance information about technology performance and risk with fixed or limited budgetary resources and regulatory constraints. To facilitate the simultaneous consideration of many criteria for a very large number of alternative remediation technologies a Decision Support System (DSS) with support for multicriteria decision making is needed [2].

Managing of all environmental data is usually accomplished with Geographical Information Systems (GIS). They combine layers of information about a place to give a better understanding of that location. One of the main benefits of GIS is better resource management both within and outside an organization. A GIS can link data sets together by common location data, such as addresses or latitude and longitude, which helps members of the public, private environmental companies, and governmental departments share their data. By creating a shared database, information can be collected once and used many times.

Some sites may encompass a large area, include several types of contaminated media, or include areas in which the types of contamination differ. To facilitate the establishment of remedies at a complex site, the site may be divided into operable units, with separate remedies for each. Such operations can be most efficiently performed within the GIS. Often the selection of treatment technologies depends on site-specific factors, such as hydrology or geology which are also available from GIS. [3]

Although GIS have a central role in integrating environmental data which comes from various sources, including the environmental data monitoring, and also facilitates the clear understanding of the status and trends of the ecological health it usually lacks decision

support capabilities. Therefore it is very important to integrate multicriteria DSS with GIS.

One such integration effort is described in this paper. The result is a remediation technology selection plug-in for the ArcGIS, the industry standard GIS software from ESRI, which implements decision making features of traditional DSS for remediation technology selection based on multicriteria analysis and uses its remediation technology database.

The rest of this paper is organized as follows. Chapter II describes the integration of Multicriteria decision making system for remediation technology selection into the GIS platform. In Chapter III we present an illustrative example of how the software can be used in a scenario of remedial technology selection. Finally, the conclusion of the paper is given in the chapter IV.

2   GIS Based Multicriteria Decision Making Tool

In order to select the most efficient remediation technology it is necessary to simultaneously analyze all aspects of available remedial techniques. The selection of the preferred remedial options is based on technical, financial, environmental and social criteria. These criteria are ranked by all involved parties to determine their relative importance for a particular project.

2.1   System Architecture

Remediation technology selection decision support system is based on the central Remediation technology database and multiple DSS systems for Multicriteria Decision making which all use the central data repository. The conceptual view of the entire system is shown in Fig. 1. This paper describes the GIS based tool for Remediation Technology Selection (Chapter 2.3) and the underlying Remediation Technology database (Chapter 2.2). Two other parts of the system from the Fig.1 are Remediation technologies DSS Application, which is a three-tiered Java application which contains both features for multicriteria decision making and for the creation and maintenance of the Remediation technology database and storing the evaluation of cleanup alternatives results. The Web Repository of remediation technologies is a web-based application which provides access to the repository data.
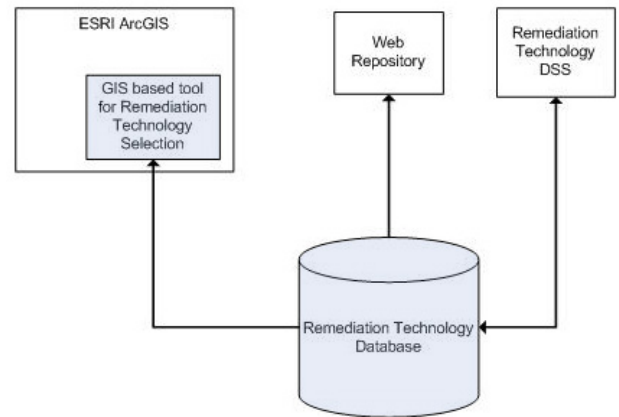

Fig. 1 Remediation Technology DSS Architecture

2.2   Remediation Technology Database

The data in the Remediation technology database is organized in sessions, which represent containers for all data about various remediation technologies, criteria and the performance values of the technologies according to every criterion.

The data in the sessions is arranged as follows. Remediation technologies are organized in technology groups, which form a tree-like hierarchical structure. For example, the root technology group is "*Remediation Technologies*", which contains more specific groups like "*Groundwater Remediation Technologies*" [4] and "*Soil Remediation Technologies*" [5]. They contain other more specific technology groups like "*Biological Technologies*" or "*Physical/Chemical Treatments*" which can further be divided into "*Ex-Situ*" and "*In-Situ*" technologies. There is a name and a short description for each technology group.

Besides being categorized in the appropriate technology group, every remediation technology has a name, a brief description, values regarding the applicability to main groups of contaminants, and finally, values of present social, economic, technical and environmental criteria.

Criteria are also organized in the tree/like hierarchical structure in a similar manner as the remediation technologies organization. Criteria used for multicriteria analysis are divided into two groups, one group is for the contaminant applicability criteria, and the second is for the socio-economical criteria. There is a name and a short description for each criterion group.

Every criterion has a name, a brief description and weight. Besides that it has algorithm specific fields for MCDA algorithm support which is described in chapter 2.3.3 Multicriteria Algorithm. These fields are: a selected preference function, two preference function parameters and an indication of whether the given

criterion should be maximized or minimized in the analysis.

The Remediation technology database has already started to grow and contains 37 groundwater treatments and 37 soil remediation technologies at the moment of writing this paper.

The database management system used for the Remediation Technology database is MaxDB. It is a heavy-duty, open source database for OLTP and OLAP usage which offers high reliability, availability, scalability and a very comprehensive feature set needed for the operation of the system in real world deployments. It also runs on all major operating systems.

Database provides Application Programming Interface (API) for access from applications through Open Database Connectivity (ODBC), an open standard API. In addition to the ODBC software, a separate module or driver must be installed in order to use DBMS through ODBC. The ODBC connection scheme is shown in Fig. 3.
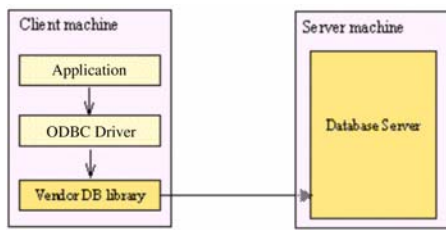

Fig. 2 ODBC connection scheme

ODBC is based on and closely aligned with The Open Group standard Structured Query Language (SQL) Call-Level Interface. It allows programs to use SQL requests that will access databases without having to know the proprietary interfaces to the databases. ODBC handles the SQL request and converts it into a request the individual database system understands. This enables the change of an underlying DBMS without making changes in the application.

2.3 GIS Based Tool Remediation Technology Selection

GIS tool for Remediation Technology selection is developed to provide decision making directly from GIS, where all environmental data is usually integrated and accessible. The decision is taken based on the type and extent of contamination, cleanup time required, physical, and geologic site characteristics, available technologies, resource requirements, social acceptance, and compliance with federal and state laws, etc.

Before a treatment technology can be selected for a contaminated site, detailed information about the site conditions and contaminants must be collected. GIS tool uses this information to determine which of the possible remedies will be capable of meeting the clean-up

standards set by its users, respecting above mentioned financial and other constraints. The following section (Chapter 3) will illustrate and further clarify the role of GIS tool in supporting remedial actions with usage example.

The tool is developed as a plug-in for the ESRI's ArcGIS, the industry standard GIS software using the ArcObjects technology and C# programming language for the user interface.

2.3.1 ArcObjects
ESRI ArcObjects is the development platform for its ArcGIS family of applications. The ArcObjects software components expose the full range of functionality available in ArcGIS to software developers. It is a framework that enables creation of domain-specific components from already available GIS components. ArcObjects provides an infrastructure for application customization which builds on top of the existing ArcGIS functionality and provides application developers an ability to concentrate on serving the specific needs.

ArcObjects technology was developed as a set of platform-independent software components, written in C++ and Microsoft Component Object Model (COM). ESRI offers developers flexibility in selecting a development environment for ArcGIS, as they can chose either Java, .NET, C++ or COM for working with ArcObjects (Fig. 4). [6]
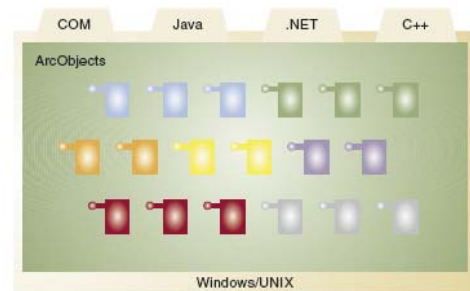

Fig. 3 ArcObjects Development environments

The selected environment for the work presented in this paper is .NET, and the chosen language is C#. By choosing Microsoft Visual Studio .NET as the development tool we were able to use the ArcObjects support for Visual Studio .NET for a more efficient development process.

2.3.2 Extending ArcGIS Desktop
ArcGIS Desktop applications can be customized with a powerful mechanism called Extensions (Fig. 5). An extension can provide a toolbar with new tools, listen for and respond to events, perform feature validation, and so on. Extensions act as a central point of reference for

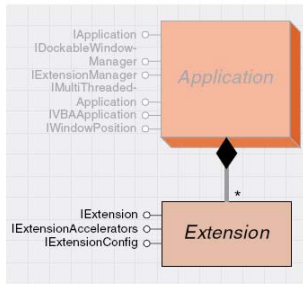developers when they are creating commands and tools for use within the applications.

Fig. 4 ArcGIS Desktop Extension

Any extension that is registered with an application is automatically loaded and unloaded by the application, the end user does nothing to load or unload. So, after installation, the Remediation technology selection DSS tool extension will be started when ArcMap is started and shutdown when ArcMap is shutdown.

The Remediation technology selection is implemented as a dynamic link library (DLL), and can be installed easily from an ArcMap's tool menu.

2.3.3 Multicriteria Algorithm

A multicriteria analysis performed by presented Remediation technology DSS is the process during which the relative merits of the remediation alternatives are compared to each other and the most appropriate is selected from among them for site cleanup implementation.

The explicit consideration of multiple, even conflicting objectives in a decision model has made the area of multiple criteria decision-making (MCDM) very popular among researchers during the last two decades resulting in lots of methods [7]. In order to support the decision-maker who must solve multicriteria problems we have adopted the outranking method called PROMETHEE II [8] which provides a total preorder on the set of possible decisions. The method is based on the notion of the extended criteria that can be easily defined by the decision-maker. They represent the natural notion of intensity of preference of the criterion, and the maximum of two parameters to be defined which have a real world meaning. The extension is based on the introduction of a preference function, giving the preference of the decision-maker for an action a with regard to b. This function is defined separately for each criterion, where its value is between 0 and 1. The smaller the function, the greater the indifference of the decision-maker; the closer to one, the greater his preference is. In case of strict preference, the preference function is 1. Numerous practical applications of the PROMETHEE method have shown that it is very easily accepted and understood by the practitioners, being the easiest approach for solving a multicriteria problem by considering simultaneously extended criteria and outranking relations.

The technologies that are subject to multicriteria analysis are ranked according to so called outgoing and incoming flows. The outgoing flow describes the degree to which a technology dominates the other ones, while the incoming flow represents the degree to which it is dominated by others. Using the outgoing and incoming flows the net-flow of each technology is computed as their difference and the selection of the best available technology (with the highest net flow) is recommended, together with the list of ranked technologies.

2.3.4 Remediation Technology Selection Toolbar

The GIS based Remediation Technology Selection toolbar is implemented as an Extension to ArcGIS Desktop ArcMap application (Chapter 2.3.2). It contains a toolbar with two commands: Database Settings and Remediation Technology Selection tool.

The Database settings command (Fig 6.) is used to set-up the connection with Remediation technology database. Connection parameters are IP address of the Server, IP Port, Database name, User name and password as shown in Fig 6.
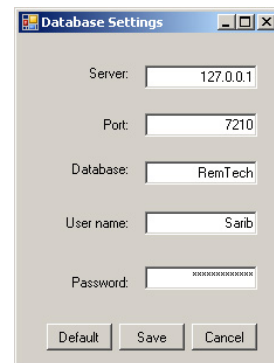

Fig. 5 Database settings command

It is implemented as an ArcObjects Button Command (Fig. 7). As every ArcObjects COM-based command it implemented the *ICommand* interface. This interface determines the behavior and properties of simple commands, such as buttons and menu items.
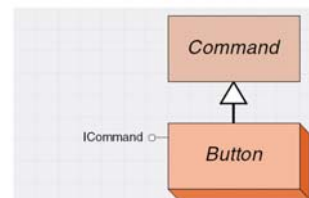

Fig. 6 Button class

The second command is a Remediation Technology Selection tool. It is implemented as an ArcObjects Tool (Fig. 8).
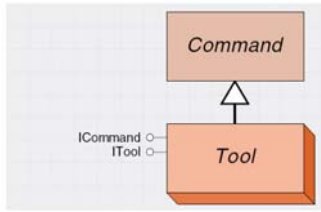
Fig. 7 ArcObjects Tool class

Remediation Technology Selection tool is shown in Fig. 10 in the next chapter where one example of its usage is described.

In Fig. 9 an algorithm for using the Remediation technology selection tool is presented. When selecting the most appropriate technology the decision maker uses the algorithm in several steps.
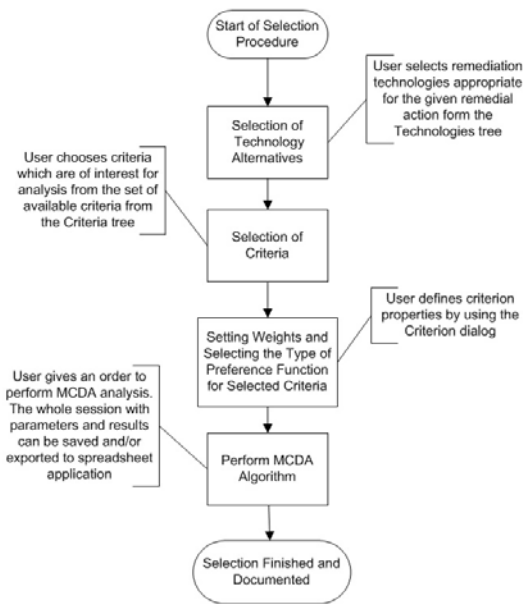

Fig. 8 Remediation technology selection procedure

A user first selects a subset of technologies he/she is interested in (or uses a full set of technologies), then selects his/her own criteria and their preference functions (or uses default functions) and corresponding weighting factors. After that he selects the contaminant (or a group of contaminants) present in the polluted site, and finally gives an order to the DSS to perform a multicriteria analysis. The DSS calculates results and displays the list of ranked technologies.

3   Illustrative example

We will present an example of selecting the most appropriate remediation technology for the HE MOSTE site which is polluted with heavy metals.

The opening screen of the GIS plug-in for the Remediation technology selection is presented in Fig.10
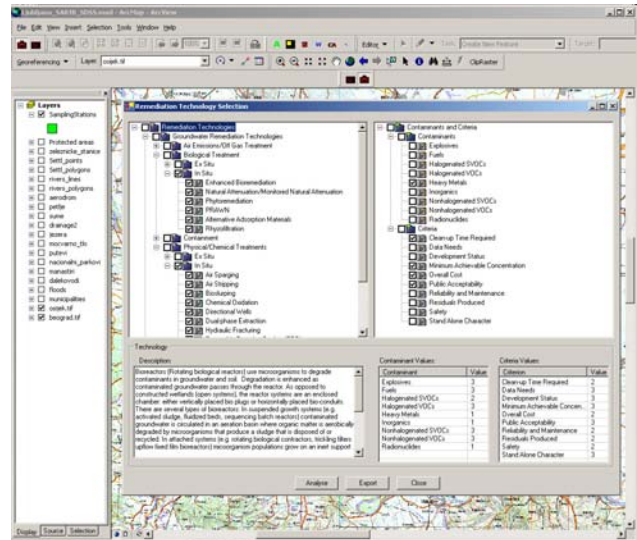

Fig.9 GIS based remediation selection tool

On the left side tree is populated with technologies categorized in the technology groups. It can be used to browse through remediation technologies from the database, as all data about the selected technology are displayed in the bottom section of the screen. This tree is used to select the remediation technologies which will be ranked in the multicriteria decision making analysis. In this example we have selected the In-Situ Biological and In-Situ Physical/Chemical treatments as shown in Fig.10.

On the right side tree in Fig.10 there are two groups of criteria. The first one contains contaminant types, and in our example we have selected "*Heavy metals*". The second group contains socio-economical criteria, of which we have chosen the "*Clean-up time required*", "*Minimum Achievable concentration*", "*Overall Cost*" and "*Public Acceptability*" and given weight values for them. The criteria selection can be seen in the right tree of Fig.10.

After all the Technologies have been selected and all Criteria selected and their weights adjusted, we perform the multicriteria analysis by clicking the analyze button. The results are shown in Fig.11 with the Solar Detoxification being the most appropriate technology for remediation of the selected site according to selected criteria. Other technologies and their corresponding ranks are also present in the table.

Rank	Technology group	Technology	In flow	Out flow	Net flow
1	Soil Remediation Technologies / Physical/Che...	Solar Detoxification	0.94186	7.27907	6.33721
2	Soil Remediation Technologies / Physical/Che...	Soil Washing	1.5	6.44186	4.94186
3	Soil Remediation Technologies / Physical/Che...	Treatment With Fly Ash Zeolit	2.82558	6.37209	3.54651
4	Soil Remediation Technologies / Physical/Che...	Chemical Reduction/Oxidation	1.65116	5.19767	3.54651
5	Soil Remediation Technologies / Physical/Che...	Separation	1.82558	5.13953	3.31395
6	Soil Remediation Technologies / Physical/Che...	Chemical Extraction	2.31395	4.69767	2.38372
7	Soil Remediation Technologies / Physical/Che...	Soil Vapour Extraction	3.0814	5.23256	2.15116
8	Soil Remediation Technologies / Thermal Trea...	Thermal Desorption	2.38372	3.83721	1.45349
9	Soil Remediation Technologies / Thermal Trea...	Vitrification	4.44186	4.5	0.05814
10	Soil Remediation Technologies / Physical/Che...	Solidification/Stabilisation	3.84884	3.2093	-0.63953
11	Soil Remediation Technologies / Thermal Trea...	Incineration	3.86047	2.75581	-1.10465
12	Soil Remediation Technologies / Physical/Che...	Dehalogenation	3.86047	2.75581	-1.10465
13	Soil Remediation Technologies / Biological Tre...	Bioreactors	4.03488	2.23256	-1.80233
14	Soil Remediation Technologies / Biological Tre...	Composting	4.94186	2.90698	-2.03488
15	Soil Remediation Technologies / Biological Tre...	Landfarming	5.2907	2.7907	-2.5
16	Soil Remediation Technologies / Biological Tre...	Biopiles	5.2907	2.7907	-2.5
17	Soil Remediation Technologies / Thermal Trea...	Plasma Arc	6.09302	2.89535	-3.19767
18	Soil Remediation Technologies / Thermal Trea...	Hot Gas Decontamination	5.73256	2.06977	-3.66279
19	Soil Remediation Technologies / Thermal Trea...	Pyrolysis	6.65116	2.05814	-4.59302
20	Soil Remediation Technologies / Thermal Trea...	Open Burning	6.65116	2.05814	-4.59302

**Fig.10 Results of the remediation
technology selection**

4 Conclusion

The choice of the appropriate remediation technology requires a holistic assessment. Different performances of different technologies in technical, financial as well as the environmental aspects need to be considered. Our DSS helps integrate all these aspects by using multicriteria analysis. This is enabled from the GIS software that usually integrates data relevant for making the decisions. ESRI's ArcGIS was a chosen GIS platform as it is an industry standard GIS solution which also provides a powerful ArcObjects technology for extending its GIS software solutions.

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