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Abstract: A review of the legal requirements for environmental risk assessment indicates that despite the range of international and EU legislation and guidance proposing the need for risk assessment and management a common framework and procedure has yet to be established. This in turn has limited the implementation of environmental risk assessment and management mainly to fields where liability issues can arise such as in cases of contamination hazards etc. In order to enable the formalized and more systematic utilization of risk assessment and management procedures in environmental decision making processes the “Remotely Accessed Decision Support System for Transnational Environmental Risk Management” (STRiM) project has developed a web based Decision Support System (DSS) for transboundary environmental risk assessment and management. This DSS is implemented as a web based application which enables environmental administrators and decision makers to undertake generic risk assessment and management identifying areas where detailed risk assessment is required as well as appropriate risk management options. The web based DSS serves as an integration platform for the other components of the system: map server, Risk Assessment indicator database and document database. The main functionality of the web based DSS includes qualitative risk assessment for the identified environmental hazards, MCA facilitated options appraisal for the selection of applicable risk management options and automated report generation. The map server is used to handle GIS maps that illustrate various steps of the risk assessment procedure. The web based DSS is implemented using a three-tier architecture, Java EE 5 platform, Java Server Faces and Java Enterprise Beans technologies, and Open Source products for the application server, database and integrated development environment. Within the context of the STRiM project the web application has been trailed successfully in four pilot trials addressing a range of risks, such as forest damage from storms, water pollution from olive mill waste, wetland loss from water abstraction, and damage from flooding.

Keywords: Trans-boundary Risk; Decision Support Systems; Risk Assessment; Risk Management

1. INTRODUCTION

Awareness of the need to face the risks and challenges for balanced and sustainable development in Europe posed by natural and technological hazards in Europe is increasing. There are several elements in EU legislation, policies and programmes encouraging the
introduction of risk management into planning and decision making, (underpinned by the precautionary principle) yet this inclusion is far from complete and proving problematic [Peltonen, 2006; Kriebel et al 2001]. Currently, hazards are being addressed in heterogeneous, fragmented ways and at different levels by existing community instruments. Although the Seveso II Directive is the legislative basis for risk management of major accidents there is no uniform approach within the EU to deal with environmental risk in general, and subsequently no standardised risk assessment framework and decision support tool to enable its implementation, something the STRiM project attempts to address. In the EC adopted legislative proposals for cohesion policy reform (COM(2004) 492-496) risk prevention is mentioned as a priority under all the three objectives of convergence, regional competitiveness and employment and European territorial cooperation. In fact, the third priority territorial cooperation acknowledges the need for risk management at transnational and interregional level. In addition key measures, such as the Directives on Environmental Impact Assessment (EIA), on Strategic Environmental Assessment (SEA) including the Water Framework Directive (WFD) point out the need for the inclusion of risk assessment and management as well as the consideration of transboundary impacts, yet the process of doing this is not specified, subsequently limiting its implementation.

The STRiM project (Remotely Accessed Decision Support System for Transnational Environmental Risk Management) aims to address these issues by developing a planning relevant framework to enable generic, transboundary environmental risk assessment. Transboundary risks are defined as “risks that are generated under one regulatory jurisdiction and have significant actual or anticipated impacts in another, regionally or globally, are a source of concern for regulators, politicians and public” [Tait and Bruce, 2000, pp1]. The challenge is great, considering the acknowledged difficulties of transboundary or cross border assessment in general, such as technical limitations eg data incompatibility, social and political limitations such as sovereignty differing languages, cultures, levels of economic growth, varying regulatory structures, political systems etc [Craik, 2007].

Increasingly, literature attributes the lack of practical implementation of risk management procedures to the lack of science policy integration within existing decision making processes and the policy/decision maker and scientist conflict [Quevauviller et al 2005; Willems and de Lange, 2007] It is argued that policy makers and implementing authorities are in need of Decision Support Systems (DSS) in the field of environmental management which can enable science knowledge transfer simultaneously paying greater attention to potential user needs and to the identification of concrete application contexts [Giuponi, 2007]. Therefore, STRiM, as an INTERREG project whose primary aim is the building of bridges between scientific research and the praxis of planners and multiple other stakeholders [Peltonen, 2006] has focused on the development of a common framework and DSS to enable the integration and implementation of transboundary environmental risk management.

Prior to developing the DSS, the STRiM consortium conducted a literature review and end user interview survey to establish what existing environmental risk assessment DSS tools where available, their use, and limitations. It was established that there is no commonly adopted environmental risk assessment procedure within the EU, like there is for EIA and SEA and subsequently no common decision support tool. However, a web based review of existing risk assessment tools, indicated that there is a plethora of national, both commercial and public, domain specific risk assessment DSS tools. For example, only in Great Britain, regarding contaminated land, there are many used tools (eg CLEA, SNIFFER, RBCA, Risk Assistant, Risc-Human health). Additionally, from the interviews it was established that risk assessment as a procedure and concept is much less understood, and often confused with impact assessment. Recommendations to develop a generic/qualitative environmental risk assessment framework and supporting DSS in order to enable implementation were made.

2. THE STRiM FRAMEWORK AND DECISION SUPPORT TOOL

The STRiM project was developed based on the findings of its predecessor ISOTEIA project (INTERREG IIIB CADSES, 3B093). ISOTEIA concluded that risk management
decision makers and users are in need of a common framework to carry out environmental risk assessment and management at a transnational level as well as user focused decision support tools and guidance (Karydas et al., 2006). In particular end user confusion regarding the implementation of the concept of risk and utilisation of probability components in decision making proved to be an issue in its formalised uptake in environmental management. Based on the above, the STRiM DSS has been developed providing a common framework to carry out generic risk assessment and management, for any environmental risk, regardless of temporal and spatial boundaries.

The STRiM DSS was designed to adhere to the following specifications, which in turn influenced its nature.

1. User focused (simple, cost and time efficient)
2. Participatory (enabling multi-stakeholder collaboration and risk communication)
3. Generic (applicable to any environmental risk)
4. Transboundary (provides the opportunity for the assessment and management of risks regardless of administrative, geographical and political boundaries)

The generic/ qualitative nature and wide scope of this framework is recognised. Indicatively it can be used to inform a decision regarding whether to give planning permission to a small scale olive mill processing unit and similarly to a decision regarding the diversion of a transnational river. The target audience is wide focusing on practitioners, technicians and decision makers, not the scientific community. Typical applications foresee the involvement of a team of decision makers and technicians, including interested stakeholders (which can represent the perspectives of different countries and interests) assisted by the remotely accessed STRiM DSS to arrive at an informed decision regarding identification of hazards requiring detailed risk assessment as well as a prioritised list of the best risk management option to address a given environmental risk. Due to the generic nature of this tool, its quantitative component is undoubtedly limited, enabling users to inherently make subjective decisions using qualitative data. However, this does not undermine the value of this tool, as its primary aim is to introduce the concept and procedure of risk assessment in environmental decision making, providing indications regarding the need for more detailed quantitative risk assessments as well as risk management actions.

2.2 The STRiM software

Technically, STRiM DSS is implemented as a Web-based application enabling its users to create risk assessment and management case studies by carrying out the following five steps, on an anytime-anywhere basis.

2.1 The STRiM Risk Assessment and Management Framework

A review of risk literature indicates a plethora of definitions of risk [Pediaditi et al., 2005] including of a range of risk assessment and risk management frameworks [Power and McCarty, 1998] none of which are commonly adopted, thus limiting their use in decision making. This issue is also valid for the CADSES region which this project focuses on. The STRiM RA & M framework consists of 5 iterative steps (Figure 1) and is predominantly based on the DEFRA [2002] guidelines due to their focus on risk management and applicability to any type of environmental risk. It needs to be emphasised that although the DEFRA [2002] guidelines theoretically elaborate on detailed risk assessment, the STRiM DSS application focuses on generic risk assessment and is qualitative in nature. Due to the user focused nature of this framework and the intention for its implementation in everyday environmental management decision making which is constrained by limited resources and time emphasis is placed in a) correctly defining the problem and prioritising risks before moving on to data collection, (commonly applied in EIA as scoping) b) considering risks taking into account potential management solutions from the onset c) enabling multi-stakeholder engagement and transparency in determining risk significance. The STRiM DSS as described below provides users with additional tools such as an indicator database for consultation during Step 3 (Figure 1), guidance on participation and risk communication for each step of the process as well as a compendium of potentially relevant environmental legislation (Initiation and Step 1, Figure 1). Users of the DSS having completed the STRiM RA and M process are provided with an automated report, of the procedure followed and results generated, i.e. a prioritised list of the most appropriate risk management options and significant hazards requiring further detailed risk assessment.
• Step 0. **Initiation** consists of the starting point of any RA or RM, which entails the consideration of the need to conduct the assessment.

• Step 1. **Problem Formulation** is composed of four components: baseline description, potential risk identification and components description, identification of risk generating processes and definition of boundaries and controlling factors.

• Step 2. **Generic (Qualitative) Risk Assessment and Management Process** includes qualitative risk assessment of selected hazards and options appraisal of applicable management options.

• Step 3. **Risk Management** evaluates and discusses the preferred risk management options and monitoring strategy.

• Step 4. **Risk Communication** describes the risk communication procedure followed in the case study.

• Step 5. **Risk Monitoring** consists of the implementation of risk management options and monitoring of their effectiveness.

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**Figure 1. STRiM Risk Assessment and Management Framework**

STRiM DSS facilitates an automatic Qualitative Risk Assessment based on the user’s estimation of risk-specific magnitude of impacts and three probabilities contributing to risk: a) probability of hazard occurring, b) probability of receptor being exposed and c) probability of harm occurring. It also supports Options Appraisal of different risk management options and enables the selection of the best option using Multi-Criteria...
Analysis (MCA) and according to the stakeholders’ preferences. Although the current version of STRiM DSS does not support Quantitative Risk Assessment, this feature can be also implemented. The Risk Assessment and Management (RA&M) DSS serves as an integration platform (Figure. 2) for the other components of STRiM DSS: DSS map server (IMS), DSS indicator database and DSS document database.

The RA&M DSS Client Application offers an intuitive, user-friendly interface to facilitate an easy utilization of the application functionality (Figure 3). DSS map server (MS) Client Application is also implemented as a Web application and offers a capability of handling, combining and viewing GIS files in order to create maps needed in STRiM DSS. The business tier contains:

- Working Session, which performs retrieval and storage operations for the Initiation, Problem Formulation, Generic Risk Assessment and Management Process, Risk Management and Risk Communication steps of the STRiM Risk Assessment and Management Framework.
- DSS MS Server Components used to communicate with the underlying UMN MapServer to handle GIS files and fetch data from STRiM GIS.

RA&M DSS Database is a relational database used to store information about the objects in RA&M DSS Application: users, case studies, baselines, hazards, risk generating processes, boundaries, controlling factors, magnitude of impacts, probabilities, risk prioritization, management options, options appraisal, risk management, risk monitoring. DSS Indicator Database contains a set of environmental indicators for risk assessment for different environmental domains collected from a number of existing and commonly used environmental databases. STRiM GIS acts as a spatial database which contains the thematic maps needed for risk assessment. These thematic maps are attached to case studies developed using STRiM DSS. In order to visualize spatial data, STRiM GIS employs MapServer from the University of Minnesota. MapServer is one of the leading packages for web mapping applications, providing feature-rich cartographic output, such as scale bars, legends, reference maps, and labelling. MapServer has the ability to generate thematic maps based on classes and regular expressions. Moreover MapServer implements the open geospatial consortium implementation specifications for open web services (OWS), namely Web Mapping Service (WMS), Web Feature Services (WFS) and Web Coverage Service (WCS). It also supports GML and provides on-the-fly projection capability.

2.3 Geospatial data services and data sharing
The effortless sharing of geospatial data is a major requirement of STRiM GIS. In order to support collaborative decision making among its stakeholders, STRiM GIS data services were developed to overcome most technical impediments to the accessibility of shared data. In Internet Mapping applications, spatial data is expected to be massive, collected by a variety of sources and represented in a multitude of formats. In order to allow effective sharing, STRiM GIS provides users with a number of data services. STRiM GIS data storage is either file-based, or utilizes spatial relational databases. For file-based data, there
are the following basic services: the file management service, the data translation service and the data composition service.

Figure 3. STRiM Risk Assessment and Management DSS user interface

The file management service allows STRiM GIS users to upload, download, delete and inspect spatial data files in a variety of formats. File transfer to and from the server uses standard web mechanisms. Inspection applies to raster images and presents the user with file related metadata, without accessing the bulk of the file. The file translation service is essentially a front-end to the Geospatial Data Abstraction Library (GDAL) for raster data translation and the OGR Simple Features Library for vector data translation (Warmerdam), and support translation between over 40, as of this publication, different geospatial data formats. Typically a user would translate a given raster file into an HDF4 [HDF Group] dataset that is then used for raster analysis and map algebra via the NAP module described below. The base options of the translation facility are quite strict regarding format conversions, and are used as default in this implementation, otherwise errors would occur upon translation. Although not currently implemented, a user should be able to “relax” these default, options by using, among others, the “-not_strict” flag which is more “forgiving of mismatches and lost data when translating to the output format” (GDAL translate). A number of spatial database servers can also be supported for storing spatial data. Currently, only simple feature vector data can be stored in spatial databases. The STRiM GIS implementation is based on the PostGIS RDBMS, but using different RDBMS products is straightforward. The data composition service is used to combine together spatial data files or database-stored records. Data from the selected files or database tables is used to define a number of layers, as well as queriable data attributes, via a form-based interface. The final product of this process is a new map, which can then be loaded into the visualization service, to be explored and/or processed by the spatial analysis tools.

Spatial processing in STRiM GIS is currently heavily geared towards processing raster data via map algebra service, providing a plethora of unary and binary arithmetic, logical and fuzzy-logic related operators, as well as several map classification methods. All map algebra functionality on raster data is currently implemented by the Numerical Array Processor library (NAP), a language similar to APL, J, IDL and Matlab (Davis, 2002). In a setting where map algebra operations are computed on the same machine as the web server, it could be impossible to support more than a few concurrent users without severe drop in system responsiveness (Hawick, 2003). To alleviate this, our data analysis services are architected on a client/server model: processing is performed on a number of dedicated compute servers, (possibly) separate from the web server machine. Dispatch is via Simple Object Access Protocol (SOAP), which is also similar to widely adopted standards for Grid computing (Globus and the Open Grid Software Architecture standard). All the aforementioned modules are integrated into and run as threads under the TclHttpd Web Server, a robust, multi-threaded application server, (Welch, 2000).
3. STRiM DSS IMPLEMENTATION & EVALUATION

In order to test the functionality and applicability of the STRiM RA & M framework as well as DSS a number of pilot trials have been carried out (Table 1). An international training seminar to over 60 practitioners is organised for June 2008 where a user focused evaluation of the DSS will be carried out. In this paper preliminary results from the pilot trials which involved end user and stakeholder consultations during the process are presented.

<table>
<thead>
<tr>
<th>No</th>
<th>Pilot Trial Name</th>
<th>Scale</th>
<th>Transboundary</th>
<th>Participatory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Keritis watershed risk assessment and management of water pollution (Crete, Greece)</td>
<td>Localised (watershed)</td>
<td>No-Chania Prefecture</td>
<td>Yes (water and regional authorities, geologists)</td>
</tr>
<tr>
<td>2</td>
<td>Axios Delta: Risk assessment and management of wetland loss resulting from water management processes</td>
<td>Large scale Axios river basin</td>
<td>Yes-Greece &amp; FYROM</td>
<td>Yes (with water authorities)</td>
</tr>
<tr>
<td>3</td>
<td>Assessment and management of flooding risks in the Sava river basin</td>
<td>Large scale Transboundary flood plain</td>
<td>Yes, Bosnia and Herzegovina, Serbia and Montenegro</td>
<td>Yes (consultation with planning authorities)</td>
</tr>
<tr>
<td>4</td>
<td>Generic Risk Assessment and Management for storm break in the national parks of Sumava</td>
<td>Large scale</td>
<td>Yes, Bavaria and Czech Republic</td>
<td>Yes (Administration of National Parks, Forest Owners)</td>
</tr>
</tbody>
</table>

The tangible outputs of the DSS application consist of automated reports which describe the results of each step of the process including a list of risks requiring further detailed study and a prioritised list of risk management options. Within the report a description of risk communication activities is also disclosed. The preliminary evaluation of the framework and DSS against the original specifications (see Section 2) is positive indicating that the STRiM RA & M DSS is in fact a one stop shop to transboundary RA & M in the CADSES region. The pilots illustrated that for the generic assessment a user, without undergoing recommended consultation exercises can effectively carry out and have the automated report within a few hours! In addition, any assessment can be revisited and different risk management options evaluated, illustrating the dynamic nature of this tool.

The flexible qualitative nature of the framework which allows the user to select data sets when estimating risk significance overcomes a commonly acknowledged issue of transboundary assessments in general, that of data incompatibility and unavailability. The applicability of this application at different scales was also concluded as feasible, as the DSS structured yet flexible approach to problem formulation enables the assessments to be undertaken at any scale, relevant to environmental planning decision making such as SEA, EIA or River Basin Management Plans (WFD). However, it was noted that at larger scales, the number of hazards (primary and secondary) requiring further detailed quantitative risk assessment was greater than for the targeted smaller scale pilot trails, underlining the value of having designed the framework to be an iterative process (Figure 1). The capacity of the DSS to assign weightings to management criteria prior to undertaking an options appraisal, illustrates the frameworks recognition of the context specific nature of decision making, yet on the other hand the promotion of multi-stakeholder involvement during the assessment, which can take place remotely (something often an issue in transboundary assessment) the value of this application as a participation media is underlined. Transparency, through the automated report structure enables the clear illustration of the uncertainty and subjectivity involved in all such type of generic procedures.

4. CONCLUSIONS

Despite the preliminary implementation results of the STRiM RA & M DSS indicating the fulfilment of original specifications, there are a number of barriers and inherent limitations to the process. Fundamental is the lack of formalised legislative and institutional adoption of this process by CADSES region governments, which may limit its utilisation in the long term. Similar to any generic procedure, the advantage of its wide applicability to any environmental risk at any given planning relevant scale, limits the detail and increases the
level of uncertainty of the results obtained. Nevertheless, the capacities of this application are formidable as they allow any user (which does not have to have a scientific background) to proceed step by step in formulating the problem he or she wishes to address, conduct a preliminary risk assessment and identify areas which require further investigation as well as most appropriate (to the specific context) management options for further consideration. All this can be carried out jointly, yet remotely, in collaboration with stakeholders and decision makers in bordering countries, or regions. Finally, the capacity of the DSS to automatically produce reports which illustrate the assumptions and decisions made throughout the process apart from reducing the bureaucracy and tediousness of the procedure also increases the transparency required for any effective risk communication process.

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