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DEVELOPING NEW APPROACHES TO SPATIAL DECISION SUPPORT: PUTTING GIS ON THE WEB

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Abstract

This working paper outlines some new ideas regarding the potential of the World Wide Web as a medium for mass public participation in spatial decision-making. The paper describes a recently published series of web pages dedicated to publicising important spatial decisions regarding the disposal of radioactive waste in Britain and making relevant spatial datasets and analytical tools available to the internet using public.

1. Introduction

In a little over two years, the World Wide Web (WWW) has developed into a mass access, multi-media technology capable of two way server-client interaction. It is this ability to process bi-directional flows of information, that gives the WWW the potential to radically alter the way in which important policy decisions are made. Equipped with appropriate datasets, spatial models and a GIS engine, the WWW and associated web browsers, such as Mosaic and Netscape, could become a vehicle for effective Open Spatial Decision Support Systems (OSDSS).

At present the WWW is commonly used for providing open and wide-spread access to specific information. In this mode the information flow is uni-directional from server (i.e. information provider) to client (i.e. information user). Increasingly, however, the information flow is becoming bi-directional allowing clients to submit requests to servers, execute simple tasks, receive results and in return, give free or fixed format feedback. Several web sites now give users access to powerful GIS packages (e.g. GRASS and Arc/Info) running on example datasets. By providing access to appropriate data, spatial models and GIS via user-friendly web browsers it is suggested that the WWW has the potential to develop into a flexible medium for OSDSS. This paper examines this potential, evaluates associated problems and gives an example of a prototype web-based OSDSS.

2. Old ideas and current thinking

Much research has focused in recent years on the role of GIS in spatial decision-making and support (e.g. Clarke, 1990; Kyem, 1994; Carver et al. 1996). Some research has focused more specifically on developing GIS-based SDSS for improving public involvement in important decision problems. In developing integrated GIS and multi-criteria techniques for site search and evaluation problems Carver (1991a) describes the potential for such systems as follows:

"...a PC or workstation based GIS-MCE system and an experienced operator in a committee room could create significant improvements in the way decisions for siting are made. In addition... SDSS may also have an important role to play in providing more efficient means of public participation and consultation throughout the site-search process by allowing... feedback to decision-makers regarding public sentiment." (p.337-8)

It is interesting to note that such ideas, although not unique, were being developed long before the advent of the WWW. As such these systems were by necessity bound to stand-alone or locally networked systems, thereby severely restricting their outreach to small groups of interested individuals.

Current thinking involves a move away from stand-alone systems towards developing open access SDSS on the WWW. By creating such web-based systems it is possible to greatly widen the potential audience at the same time as exploiting the open nature of the WWW to develop independence from traditional decision-making groups.

3. The potential of the WWW

"Information is power"

The WWW holds great potential for GIS and other spatial information technologies. GIS have been severely criticised, not without some justification, as being elitist (e.g. Pickles, 1995). The hardware, software and data required can be prohibitively expensive for most individuals. Similarly, the training required to successfully use most GIS packages extends to only a very small proportion of the population. Conversely, not everyone needs nor wants to use GIS in their everyday lives, but for those situations where it may be useful the WWW may prove an invaluable medium for popularising the use of GIS and related technologies.

At present GIS on the WWW is generally restricted to uni-directional flows of information from server to client. Typical GIS web-sites provide the client with textual information on GIS products, answers to frequently asked questions (FAQs), metadata and descriptions of GIS applications together with associated graphics of GIS data and outputs. Some sites provide downloadable data sets, software updates and bug-fixes. A recent advance has been the development of interactive GIS web-sites which allow the client to submit requests for information, execute simple tasks and even use GIS software on remote servers. In the latter case, the client can browse example data sets, perform simple spatial queries, select, control and run GIS tasks, and then view the results. Here, the information flow has become truly bi-directional.

This capability for bi-directional flows of information across the Internet using the WWW effectively paves the way for OSDSS. The WWW already provides anyone with a PC and modem with access to GIS software running on powerful servers. By adding appropriate analytical and predictive models, problem specific information and relevant spatial and aspatial data sets, the WWW provides the client with all the essential ingredients of a SDSS as defined by Fedra and Reitsma (1990). These are summarised in table 1.

The potential provided by the WWW for giving widespread public access to advanced SDSS is enormous. This is not just a technical problem of providing general access to GIS software and data across the Internet, but an emergent technology that may have far-reaching impacts on contemporary

political systems. It is suggested here that web-based SDSS could fundamentally alter the role of the general public in the making of important decisions. By providing detailed and accurate information regarding particular decisions, it is possible, where public involvement is appropriate, to go some way towards empowerment of the majority, thereby significantly enhancing the representativeness of decisions made by the empowered minority. This is illustrated in the following description of a prototype web-site dedicated to the problem of finding a suitable site for a radioactive waste disposal facility in Britain.

4. Example: an OSDSS for radioactive waste disposal

By way of example, this paper reviews some of the work already done in setting up simple web-based SDSS using GIS and multi-criteria evaluation (MCE) techniques to address the problem of siting a radioactive waste disposal facility in Britain. (Carver & Openshaw, 1995). Clearly, radioactive waste disposal is an important and controversial problem, and as such attracts a high level of interest. This makes it ideal for investigating public response to web-based SDSS. Radioactive waste disposal is also an extremely difficult problem; it is political, it is spatial, it involves multiple criteria and it involves multiple stakeholders.

The political risks in developing a new radioactive waste disposal facility are high since no government is likely to win votes on the strength of it. Previous attempts to find a site for the nations growing stock pile of radioactive waste has shown local people to be strongly opposed to any plans for a disposal facility in their area. This often referred to as the NIMBY (Not In My BackYard) syndrome and has led to vociferous and highly politicised anti-dump campaigns. The geographical problem of finding a suitable disposal site is accentuated by the small and densely populated nature of the country. IAEA siting guidelines (1983) state that any disposal facility should be within an area of suitable geology, remote from areas of high population, easily accessible and outside of designated conservation areas. The geography of Britain makes this a particularly difficult problem since their are few suitable geological environments and the areas remote from population are generally remote from access and more often than not designated as conservation areas. Thus, the relevant siting criteria are conflicting and therefore require careful analysis. A further complicating factor is the multiple stakeholder nature of the problem since it involves not just the nuclear industry, but also national government, local government, the general public and various political and environmental pressure groups. As a result of the complex political, geographical, multi-criteria and multi-stakeholder nature of the problem the adoption of a GIS-based SDSS approach would seem appropriate.

A simple GIS-based SDSS has been developed to address this problem already (Carver, 1991b). This system was developed within the PC Arc/Info package using standard GIS functions (mainly map

overlay and display) and custom MCE routines programmed in FORTRAN, linked within a GUI written in SML (Simple Macro Language). This suffers from the fact that it runs only on a stand-alone PC and so is isolated from potential users and interest groups. The system developed here applies the same principles of GIS map overlay and MCE routines but within the WWW environment. This immediately makes it accessible to a global audience.

The web-based SDSS described here is based on the simple manipulation of Arc/Info ASCII grid images. It is possible to run Arc/Info itself across the WWW as illustrated by web-sites at ESRI (Environmental Systems Research Institute) and Edinburgh Department of Geography for example. The URLs (Universal Resource Locators) for these and other web-sites mentioned in this paper are listed in appendix 1. However, it is far easier and more practical for the purposes of this web-site to use a simple custom program to emulate the required Arc/Info functions. The reasons for this are three fold and rather pragmatic:

1. it does not require an Arc/Info licence for each client access;
2. it is much quicker; and
3. it is easier to implement.

The custom code used here performs two tasks; a series of binary map overlays using constraint map chosen by the client, and a simple MCE routine based on factor maps and weights again specified by the client. This operates on a series of pre-loaded ASCII grid images in a single operation. These grid images and their descriptions are listed in table 2.

All the images listed in table 2 are at $4km^2$ resolution. The constraint maps are stored as 0/1 binary images. The factor maps are stored as 0-255 normalised images required by the MCE routine.

From a client perspective the web-site described here performs several tasks. These are as follows:

1. an information system (based on hypertext and embedded images) describing the relevant aspects of the radioactive waste problem;
2. a data viewer (based on hypertext and embedded images) allowing the client to browse through images of the constraint and factor maps included in the system and view text describing their source, meaning and relevance;
3. an *a priori* site selection map (this is a clickable map that allows the client to identify an initial site which they feel would be suitable for a disposal facility, the location of which is stored for later comparison);

4. a data selection and weighting menu which allows users to specify which constraint and factor maps they feel are important to the siting decision and to specify preference weightings for the chosen factor maps;
5. a hidden overlay and MCE routine which runs on the ASCII grid images according to client choices to produce a results map;
6. a results map viewer which allows clients to view the results of their site search using their chosen maps and weights (this uses a continuous greyscale shading to show worst to best sites with the very best sites being highlighted in red) this map is also clickable and allows the user to re-specify their perceived best location based on the map produced; and
7. a client feedback page which allows clients to provide information about themselves and comment on the system and the decision problem.

All of the above is programmed in HTML v2.0 with the exception of the overlay and MCE routine which is programmed in C. All the menus are very easy to use and full instructions and explanations are provided as appropriate. The decision process outlined by the system is prescriptive (i.e. the data sets are provided for the client and only one model can be used), but is flexible in that the client can step backwards through the web pages to any previous stage and review the data or alter selections made. Example pages are shown in figures 1 to 4.

5. Potential merits, potential pitfalls

Several advantages of web-based SDSS have been identified above in reference to the radioactive waste disposal example. These include:

1. lack of physical constraints and ability to reach a far greater audience than traditional stand-alone systems (i.e. the system can be accessed from anywhere in the world by anyone with a PC and a modem);
2. practical and interactive means of opening up of the decision-making process to a much wider selection of the population; and
3. ability to acquire more feedback from the public both in terms of quality and quantity in regard to a particular decision problem.

On a practical level, simple geographical problems of distance will prevent otherwise interested groups and individuals from participating in a public consultation exercise using traditional stand-alone systems. The mere effort of travelling to a meeting is enough to put most people off participating in such exercises. Similarly, the practical problems of giving everyone hands-on use of a SDSS at public meetings are not to be underestimated. With web-based systems both the problems of geographical

distance and physical access to the keyboard/mouse are effectively circumvented. Multiple stakeholder SDSS becomes a practical possibility through the removal of geographical and physical barriers to participation. Public involvement is through virtual 'information space' rather than physical geographical space with commonalty as a key theme (i.e. common working environment, common problem, common data and common models). The interactive, hands-on nature of web-based SDSS not only gives the public direct access to data and models but also allows experimentation through 'What if?' modelling and exploration of feedback mechanisms enabled by browser software. This is close to the model for Idea Generation Systems (IGS) proposed by Heywood and Carver (1994), but is extended to a much greater audience than the 'family' groups suggested in that particular research paper. Given the political will and interest, OSDSS on the WWW have the potential to open up the decision-making process to the wider public, whereas they are at present largely restricted to *post hoc* involvement through public inquiries and other traditional means of involvement such as voting in elections, lobbying members of parliament, forming petitions, etc. This gives rise to ideas relating to 'Digital Democracy' or the true democratisation of decision-making via the WWW. This is surely a utopian dream but for specific decisions of great importance that will ultimately affect the whole population, then such systems may have a valid and useful role to play. In the none to distant future they could become a powerful political medium, giving decision problems massive public coverage. The advantages of OSDSS on the WWW accrue to the decision-makers as well as the public. Feedback in sufficient quality and quantity can inform the decision-maker of grass-roots public feeling about a particular decision problem and so act as a guide in choosing between decision alternatives.

The whole idea of providing access to SDSS over the WWW is, however, not without certain conceptual, practical and ethical problems. On a conceptual level questions arise over how to address the inevitable differences in stakeholder's mental models and cognition of the problem in hand. Although there are precedents in the literature for suggesting that multi-level systems can be used to address this particular problem (e.g. Watson & Wadsworth, 1994), a further and more difficult issue arises in how to deal with certain classes of decision problem involving multiple stakeholders, multiple objectives and multiple representations of the decision problem through the application of different decision models (Carver et al. 1996). As regards the practical problems facing the design of usable web-based OSDSS, these focus on those issues relating to system design (structure, user-interface, feedback mechanisms, speed, etc.) and those relating to GIS, spatial models and data access. These are dealt with elsewhere in the GIS literature. A more immediate and difficult set of problems facing web-based SDSS, however, are those ethical issues concerning under-representation, trivialisation of the decision making process, bias in system development and political intransigence. These need to be fully researched and systems developed before the WWW is perceived as a mature enough technology for effective OSDSS to become widespread. These are considered in turn below.

Under-representation is a major problem currently facing any ideas for practical real world use of web-based SDSS. Not everyone at present has access to the WWW and many people lack essential technical knowledge and are not familiar with new developments. The gives rise to the danger of creating an "Information Underclass" for whom there is no access to information and as a consequence lack even a minimum level of understanding of the problem itself. Apathy and antagonism will surely play an important role here. Many people may simply be uninterested or lack the incentive to participate. On the other hand, many people may be actively hostile to any idea of digital methods of involvement. This 'technophobic' minority is however, likely to reduce with time as more and more people (particularly in the younger generation) become familiar with computers and their use across a broad spectrum of activities from the home to the workplace. Similarly, the passage of time is likely to see an increased market penetration of the WWW (or its future equivalent) just as television re-shaped our home social lives in the 1960s and 70s and just as the mobile 'phone is re-shaping personal communications today. In the short-term, there is likely to be a massive rise in the numbers of people with connections to the WWW. Even those who do not own a PC will have easy access to WWW stations at local libraries, council offices and other public places.

Another potential pitfall for web-based SDSS is their potential to trivialise the decision-making process. Decision-making is a complex and difficult task, especially at the level of the decisions being discussed here. Public involvement in these decisions through web-based systems necessitates simplification and therefore increases the danger of missing key points or issues and calls into question the value of the expert knowledge of the trained decision-maker. It is perhaps true to say that the best people to make decisions are not the public at large, but the existing decision-making minority who have the required level of expertise and training to do the job effectively. Web-based SDSS may be seen as undermining this authority and replacing it with a 'plug and play' approach not too dissimilar to such products as SimCity. This criticism of "Nintendo" decision-making gives rise to a real worry over misrepresentation of the real views of the population. Clients more used to computer games than work-place computer applications may not take the problem seriously and be tempted to play around thereby giving false feedback to the decision-makers.

For many people who are genuinely interested in the decision problem, bias in system development may be a real concern. One of the advantages of the WWW is its independent nature, but this gives rise to the problem of potential bias in system authorage and control. Taking the radioactive waste disposal problem as an example, a web site authored by the nuclear industry is likely to paint a somewhat different picture of the problem than say one authored by an environmental pressure group. The potential for (dis)information in the data, models, SDSS structure and associated text is enormous. Essentially the onus is on the client to recognise this and place their (dis)trust accordingly. This is a basic flaw with any information media, be it the press, television, radio or the WWW. Any attempt to

police the information provided on WWW is against its basic principles of freedom of information and so is either doomed to failure or if successful, will ultimately kill-off the WWW.

Perhaps the greatest barrier to the development of successful web-based SDSS is that of political intransigence. Although enlightened political minds have recognised the vast potential of the Internet and WWW as an (dis)information medium, the political machine as a whole is likely to be unenthusiastic. As stated above "information is power" and most politicians will recognise this and hence view the WWW and web-based SDSS in particular as a grave threat to their role as decision-makers and the current political status quo. Politicians and other decision-makers in industry and commerce invariably subscribe to the "we know best" principle and perhaps rightly so. Whereas the advantages of web-based OSDSS from an academic point of view are that they offer an open, flexible and rational approach to public involvement in the decision-making process, the politician is likely to see these qualities as distinct disadvantages that are likely to undermine positions of power in the decision-making hierarchy.

None of the above problems need be seen as insoluble, rather they are challenges to the development of true OSDSS. It may just be a matter of time before all these problems are resolved, although it is perhaps true to say that political intransigence is still likely to remain a major obstacle.

6. Conclusions

This working paper has outlined the potential for web-based SDSS in addressing specific and important spatial decision problems where a high level of public input is required or appropriate. It is the view of the authors that despite the potential difficulties such systems have an important role to play in improving public involvement in the decision-making process at a variety of scales from local to global and for a variety of problems with a significant spatial component. The benefits of adopting a web-based approach to spatial decision-making and support focus on the lack of geographical and physical constraints to involvement, the widening of potential audiences and the opportunities for public feedback into the decision-making process. The problems focus on issues of under representation, trivialisation of the decision-making process, the potential for bias in system development and political intransigence. Although the problems are not insoluble, much research, technical development and even political reform are required before such systems become commonplace.

Future developments are likely to see further experimental web-based SDSS coming on-line in the next few years whilst the wider development of the WWW as an accepted information medium will see improved public and political awareness of what is possible in this growing field.

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Table 1. Requirements of SDSS provided by web-based OSDSS

Requirements of SDSS:	*Requirements provided by web-based OSDSS:*
Spatial and aspatial data specific to problem	Pre-loaded on web-pages
Analysis and modelling	GIS functions and external models linked using HTML
Expert knowledge	Server-based information systems and client-based knowledge
Tabular and graphical reporting	Programmed in HTML and viewed using client's browser software
Easy-to-use graphic user interface (GUI)	Programmed in HTML and run on client's own browser software
Problem	The decision problem being addressed
User	The client

Table 2. Arc/Info ASCII grid images

Constraint maps (binary images):	*Description:*
Deep geology	Geological environments considered suitable for the deep disposal of low and intermediate level radioactive wastes
Surface clay geology	Geological environments considered suitable for the near surface disposal of low and short-lived intermediate radioactive wastes
Population	Areas with population density less than 490 persons per square kilometre; this threshold is derived from NII relaxed nuclear power station siting guidelines by Beale (1987)
Conservation	Areas outside of existing conservation areas including national parks, areas of outstanding natural beauty, heritage coasts, national scenic areas, environmentally sensitive areas and regional parks
Coastal location	Areas within 10km buffer of the coastline
Factor maps (normalised images):	
Population density	Population density calculated from 1991 Census returns
Population accessibility	Population accessibility function based on distance weighted sum of population within 25km radius filter
Strategic accessibility	Accessibility to waste producer sites based on distance weighted sum of actual and predicted waste arisings
Rail access	Linear distance from nearest railway line
Road access	Linear distance from nearest road weighted by road class
Conservation area access	Linear distance from nearest conservation area

Appendix 1. Useful WWW URLs

Places to run GIS:	
http://www.esri.com/	Arc/Info home pages
http://www.geo.ed.ac.uk/home/research/massam.html	Arc/Info interface
http://ellesmere.csm.emr.ca/wnaismap/naismap.html	Canada mapping project
http://www.wsdot.wa.gov/regions/northwest/NWFLOW/	Real-time traffic maps
http://www.idrisi.clarku.edu/	Idrisi Project home page
GIS information sources:	
http://www.geo.ed.ac.uk/home/giswww.html	GIS WWW resource list
http://triton.cms.udel.edu/~oliver/gis_gip/gis_gip_list.html	GIS and GIP software listing
http://www.census.gov/geo/gis/faq-index.html	GIS FAQ and information
Radioactive waste disposal:	
http://www.nrc.gov/radwaste.html	US Govt. radwaste pages
http://www.nirex.co.uk/	Nirex home page
Radioactive waste disposal web-based SDSS:	
http://karl.leeds.ac.uk/mce/mce-home.htm	
Other web-based SDSS:	
http://www.pisa.intecs.it/projects/GeoMed/	GeoMed Project
http://ncgia.ucsb.edu/research/i17/I-17_home.html	NCGIA I-17 home page
http://weber.u.washington.edu/~tjmoore/csdm.html	The UW/UI Collaborative Spatial Decision Making (CSDM) home page
http://www.edvz.sbg.ac.at/geo/idrisi/wbdecisi.htm	IDRISI Resource Center -- GIS and Decision Making Workbook

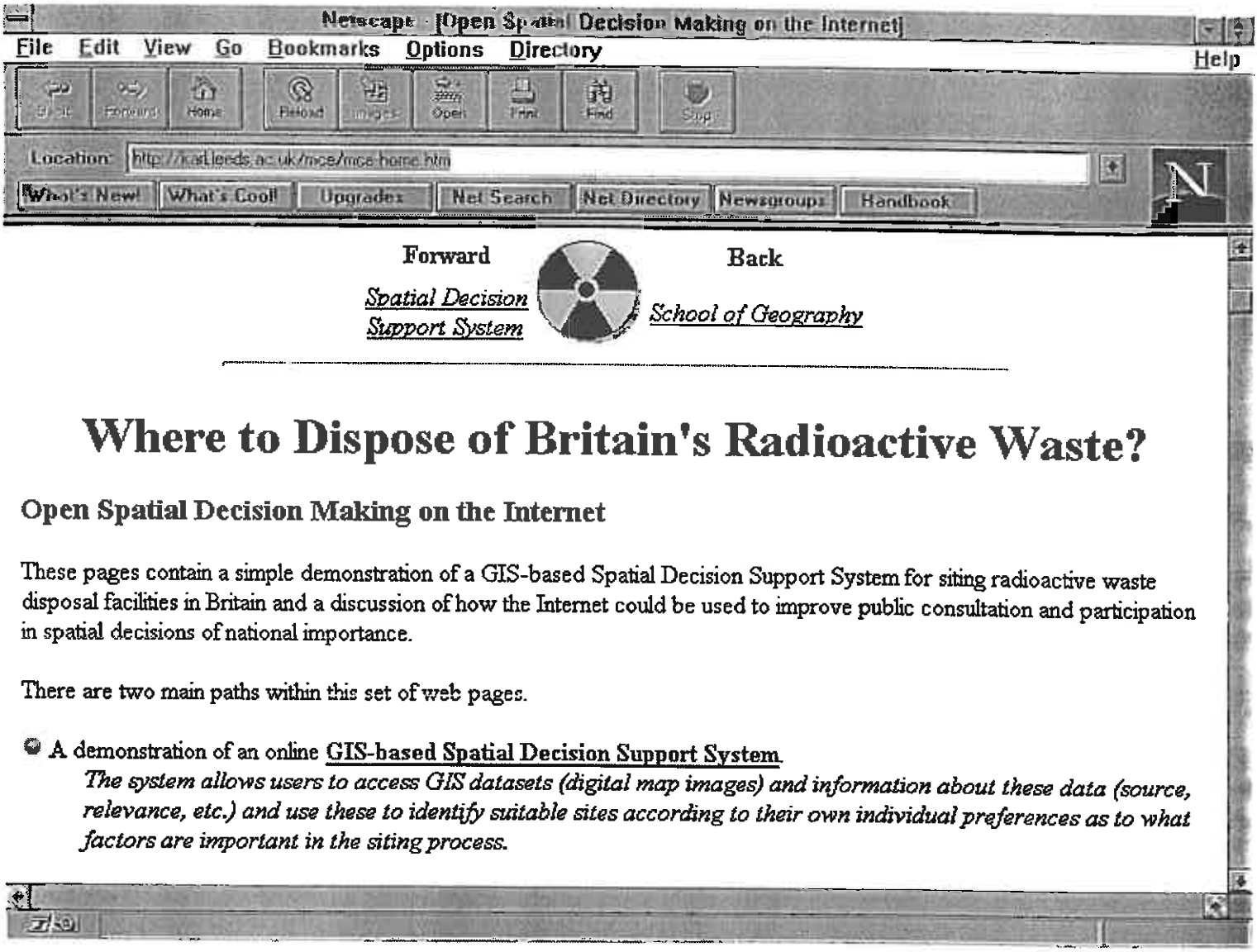

Figure 1. OSDSS home page "Where to dispose of Britain's nuclear waste?"

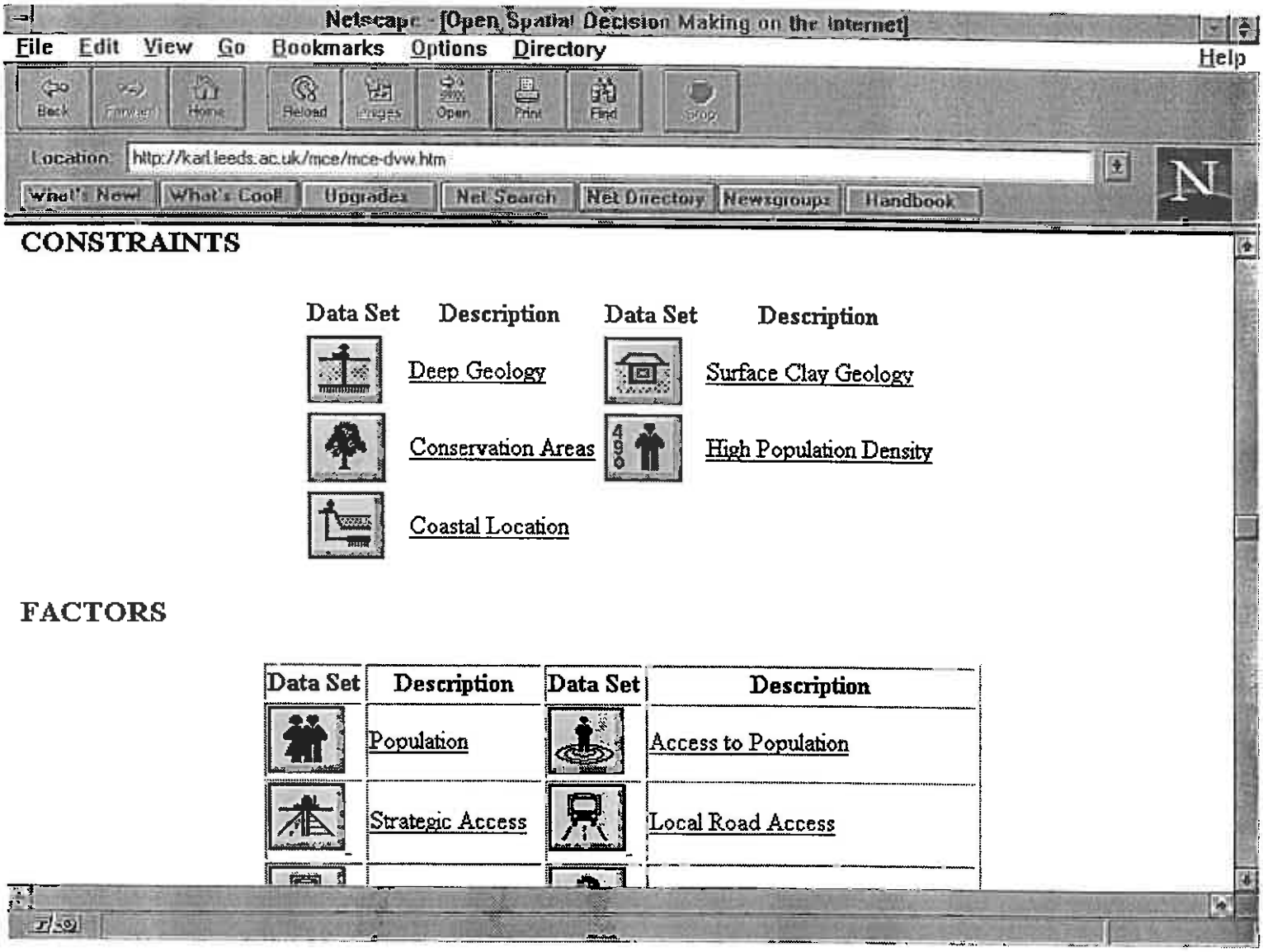

Figure 2. Data viewer page

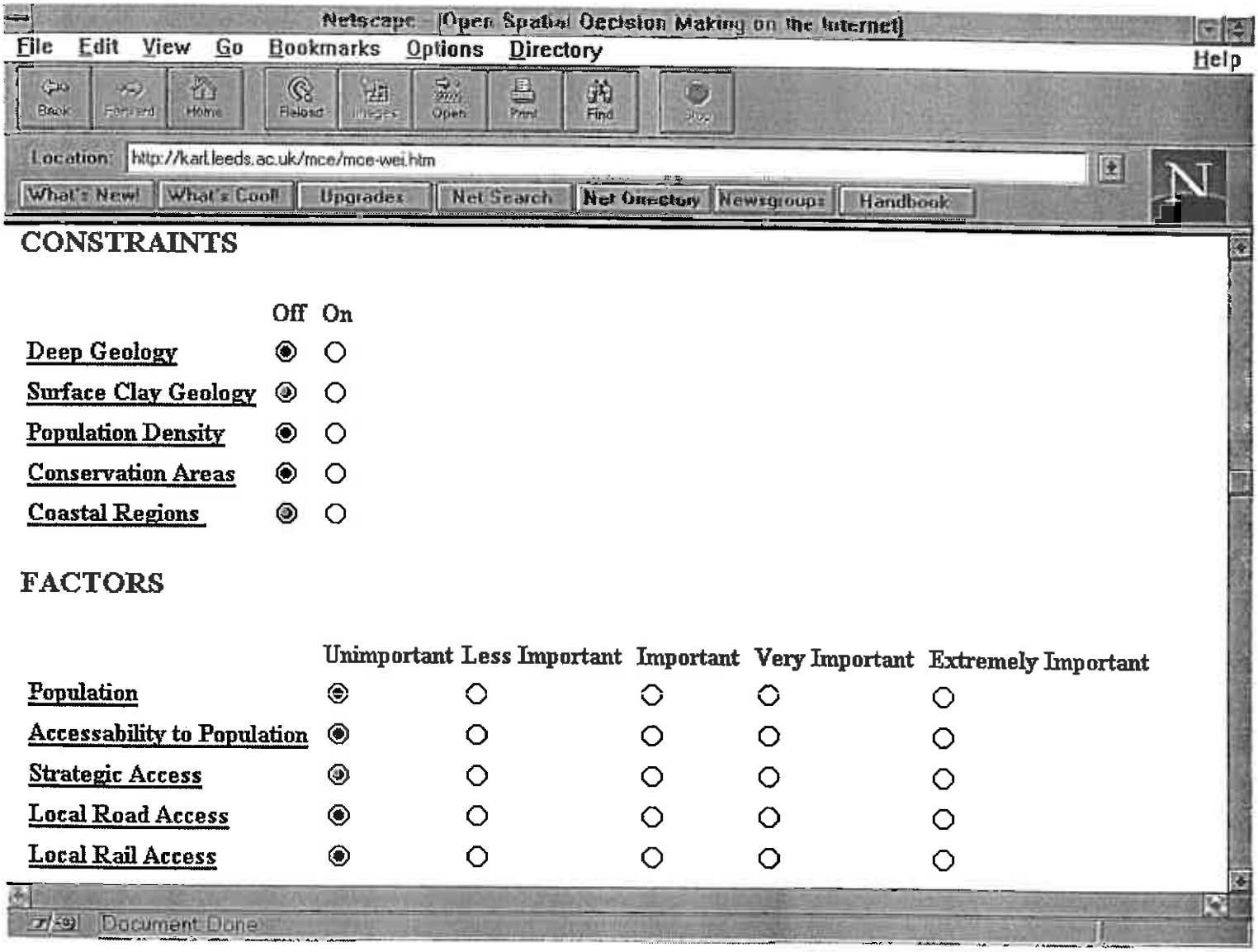

Figure 3. Data selection and weighting page

Figure 4. Example output