IPDS: INTEGRATED PLANNING DECISION SUPPORT SYSTEM

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KEYWORDS: **IPDS, Decision Support Systems, Planning, Hazards, Vulnerability, Risk**

ABSTRACT

The Integrated Planning Decision Support System (IPDS) is designed as a decision support system (DSS) to assist governments and communities in evaluation of geological hazards, vulnerability, and risk. It is at the same way designed to assist an urban planner in organizing, analyzing, modifying, and reevaluating existing or needed spatial information within land-use planning activities improving life stability through risk mitigation. The IPDS system incorporates the Geographic Information Systems (GIS) Geographic Resource Analysis Support System (GRASS) and engineering numerical models within a Graphic User Interface (GUI), to provide the user with comprehensive modelling capabilities for geological hazards, vulnerability, and risk assessment. The methodology that IPDS follows for the evaluation of hazards takes into account the weight of each influencing factor within hazardous geologic processes. IPDS interactive algorithms compute the following parameters for each cell (based on the maximum resolution of the data): the related hazard, the vulnerability to geological hazards, and the risk. One purpose of this DSS is the definition of land-use suitability categories for urban planning. The interdisciplinary formulation of optimum plans for land-use is one of the goals of IPDS, this goal is obtained by providing the user a dynamic user-friendly environment for modeling.

This DSS incorporates the following information: topography, aspect, bedrock and surficial geology, structural geology, geomorphology, soils (geotechnical data), land cover, land-use, hydrology, precipitation (annual average and probable maximum), Federal Emergency Management Agency floodway maps (1986), and historic data to assess hazards. IPDS is designed to assess any "generic" hazard, such as debris flows, subsidence, and floods, with probable maximum precipitation and seismicity as triggering factors for susceptibility scenarios. The regular items considered in vulnerability analysis are (1) ecosystem sensitivity, (2) economic vulnerability, and (3) social infrastructure vulnerability. The risk is assessed as a function of hazard and vulnerability.

INTRODUCTION

Since humans have started to modify nature for development without consideration of environmental processes, the incidence of such dangerous events as landslides, debris flows, rock fall, floods, and wildfires has increased. The magnitude of these hazards and the associated risk intensity posed by such events grows proportionally with population density. Because of the continuing reduction of available stable lands for urban population growth and the high pressure for new subdivisions on unstable lands surrounding urban areas, the need for risk and vulnerability reduction programs, and for restoration, maintenance, and management decisions in settled areas has become a major component of the overall management effort of urban planners around the world.

Natural disasters are considered as very complex phenomena that demand interrelations among geologists, civil engineers, geographers, planners, sociologists, and many others. Because of the complex nature of the interrelations among all the different components of these type of problems, a Decision Support System (DSS) called Integrated Planning Decision Support System (IPDS) is proposed as a framework for the development of an overall plan. This interactive computer system has been developed to create, run, save, and analyze the results of modeled environmental scenarios. The study assesses geological hazards, vulnerability, and risks, to configure a land use suitability zoning model for urban planning based on weighted average of many different factors. To obtain this, the purpose and scope of the study had to include sufficient information to prepare comprehensive maps and descriptive analyses through computer-based modelling concerning the environmental and engineering characteristics of projected urban areas.

Goals A common goal of professionals working with urban development is to achieve specified acceptable levels of stability for humans and social infrastructure in connection with the ecosystem. The size of urban development is determined by the ability of the environment to satisfy the requirements of low hazards, and by the stability of services such as transportation, electricity, water, etc. Therefore, the main goal of IPDS, as an environmental tool is ***to optimize social habitat, thereby improving life stability.*** To reach this, our main objective is the development of a DSS oriented to land use management, with the incorporation of information on geology, geotechnics, geographic information systems, sociology, hydrology, and computer science.

An effective human habitat development plan must prescribe the actions to be taken in terms of social development interest, specific location characteristics (Nevo and García, 1993), and improvement of this scenario. In this project, the objective of such a plan is defined as minimizing the risk to any development. This can be accomplished by improving the knowledge of existing hazard conditions and distribution, and through social zoning, evaluating the existing vulnerability of human settlements, critical facilities and public assembly sites. Finally, as a projected goal in this research, the future objectives of IPDS are to define the optimization of the land use supported with the minimization of the natural risks and the minimization of the cost of landscape modifications that are necessary to satisfy, as closely as possible, the stated Land Use Suitability Index (LUSI) or social needs within its development.

Previous Work Recent advances in computer technology, and in the understanding of how computers can aid organizational decision-making in uncertain environments, have lead to an increasing interest in automated models to handle GIS. Yet relatively limited work has addressed general geological hazard and vulnerability assessment and mitigation planning. Working with a PC-GIS software, Mora and Vahrson (1992) delineated a

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methodology for landslide determination; DeBalogh et al. (1983), and Dong et al. (1988) worked on vulnerability mitigation with emphasis on earthquakes; and Emmi and Horton (1993) developed a model of seismic risk assessment using GIS. Very few researchers (Hazards Management Group, 1988 and Hobeika, 1988, are among the exceptions) have emphasized the emergency preparedness planning process. Stimulated by Hurricane Andrew, Berke and Stubbs (1989) designed a DSS for hurricane mitigation planning. The work presented here differs in that: (a) this research provides a new approach for the optimal planning of human habitat using a DSS interface; (b) it evaluates multiple controlling variables through the use of GIS-based weighted algorithms; (c) it places more emphasis than has been common in previous studies on land use, geotechnical data, and both bedrock and surficial geology; and (d) it presents a new way to skip over the existing difficulties of combining so many parameters involved in planning decisions, in recognition of the need for an easy way to do this work by professionals without extensive computer experience.

IPDS: INTEGRATED PLANNING DECISION SUPPORT SYSTEM

IPDS has been developed with support from The Integrated Decision Support Group (IDS) at Colorado State University. IDS is intensively working on GIS integrated within mathematical and graphical models.

IPDS: A Decision Support System Oriented to Urban Planning In order to create a planning-purpose spatial decision support system, integration of factual modeling, reasoning and decision making had to be accomplished. IPDS is a computer environmental system that provides functionality to develop specific spatial decision support without the need to write special code to perform some necessary operations. IPDS interface combines individual technologies in a single user-friendly computer environment, where each technology can share the data and control the execution of the overall solution process (Djokic, 1993). Geological hazard zoning and urban planning are examples of problems that are not solvable by conventional mathematics. The multi-criteria nature of geological hazard zoning or urban planning implies that a straight-forward logical or mathematical solution procedure to evaluate these problems does not exist (Fedra and Loucks, 1985).

The integration of GIS and environmental models has been improved by the application programming interface IPDS. This integration provides a common interface and information sharing and transferring between the respective components (Figure 1) using a model built with the "C" programming language.

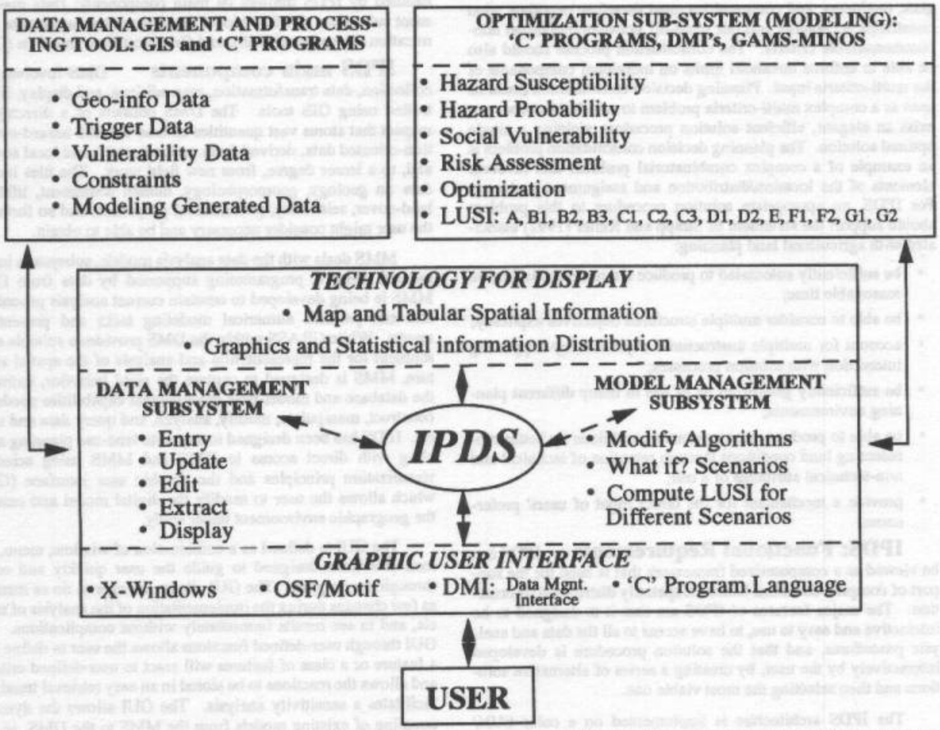


Figure 1: Major components of a decision support system, organized for the Integrated Decision Support System (IPDS). (Modified from Nevo and Garcia, 1993, and Berke and Stubbs, 1989).

To facilitate input of extensive data, the IPDS system is linked with GRASS (CERL, 1992) and with standardized interface. The X-Window System (MIT, 1990), and a number of interface-built tool-kits, make this an efficient integration. IPDS allows the user to select criteria (objectives and constraints), and arbitrarily decide whether the user wants to maximize or minimize them. McHarg (1969) describe some of the criteria that should be considered when setting out to derive an assessment of integrated planning decision and additional geomorphic studies are required to involve hazard assessment such as debris flow, floods, or subsidence hazard susceptibility. It should become obvious from examination of these criteria that they cannot all be measured by the same unit of measurement and that much of the information to be evaluated will be subjective and subject to uncertainty and preconception. The integrated planning consolidation process therefore must accommodate many non-commensurable criteria and objectives. Planners must accept that an individual perception of the land quality or constraints for social development may be quite different from a mathematical or logically derived state assessment. This study considers integrated planning decision as ***an approach of multi-criteria input factors*** to bring stability to urban planning projects.

Ideally, each individual's multi-criteria account statement (set of algorithms in IPDS) at the end of consolidation of the planning assessment should match the starting account goal. This obviously is an unrealistic expectation. Planners, sociologists, engineers, and communities must therefore negotiate what constitutes acceptable and fair trade-off between individual non-commensurable criteria. The consolidation process should also be able to enforce threshold limits on individual components of the multi-criteria input. Planning decision consolidation could be seen as a complex multi-criteria problem to which there does not exist an elegant, efficient solution procedure yielding a single optimal solution. The planning decision consolidation problem is an example of a complex combinatorial problem that involves elements of the location/distribution and assignment problems. For IPDS, an appropriate solution procedure to this problem should support the statement of Strapp and Keller (1992) associated with agricultural land planning:

- be sufficiently automated to produce alternative solutions in reasonable time;
- be able to consider multiple structured objectives explicitly;
- account for multiple unstructured objectives by supporting interaction with solution processes;
- be sufficiently generic to be of use in many different planning environments;
- be able to produce more reasonable solutions by better representing land conditions through retention of technical and non-technical attributes of a cell;
- provide a mechanism for the direct input of users' preferences.

IPDS: Functional Requirements

IPDS can be viewed as a computerized framework that is used for the support of complex decisions based on spatially distributed information. The major features of IPDS are that it is designed to be interactive and easy to use, to have access to all the data and analysis procedures, and that the solution procedure is developed interactively by the user, by creating a series of alternative solutions and then selecting the most viable one.

The IPDS architecture is implemented on a color SUN/SPARC-workstation running UNIX under the X Window System. The system can be ported to most UNIX workstations with a limited amount of effort. The development of IPDS followed two basic approaches: the first one is to develop it from the ground up, by writing the whole code for desired functionality from scratch. This step demands a tight integration with programmers. The second step is the creation and implementation of a GUI by putting together existing applications that provide the necessary tools.

IPDS: Structure

The interactive dialogue subsystem and the display and interactive use components are particularly critical for the effective use of the IPDS since they provide the interaction between user and machine. These features isolate the user from the technicalities of the computer and foster a dialogue based on the user's judgements, rather than imposing the hardware engineer's or computer programmer's discipline upon the user. These models of interaction permit a quick, low-cost examination of alternative solutions as well as the capability to modify assumptions and vary decision criteria. Moreover, the IPDS menu-driven approach was designed with the assumption that the user does not need a strong computer background. The user needs to have the capability to direct the flow of information and modeling effort towards a desired goal. This provides the user with a framework where the user creates individual applications and results using IPDS functionality, but never has to write the functions.

A solution approach to a complex environmental problem is handled by IPDS through its main components: Data management subsystem (DMS), Model management subsystem or optimization subsystem (MMS), and Graphical User Interface (GUI).

IPDS main components

DMS involves data collection, data transformation, map editions, and display, is controlled using GIS tools. The DMS consists of a directory or mapset that stores vast quantities of land use and hazard-evaluation-oriented data, derived from national, state, and local sources and, to a lesser degree, from new field work. The files include data on geology, geomorphology, human settlement, lifelines, land-cover, seismicity, geotechnical properties, and so forth that the user might consider necessary and be able to obtain.

MMS deals with the data analysis models, subsystem implemented using C programming supported by data from DMS. MMS is being developed to emulate current analysis procedures and can perform numerical modeling tasks and present the results. While GRASS within the DMS provides a suitable environment for the representation and analysis of the spatial structure, MMS is designed to capture the cited behavior, including the database and model-base management capabilities needed to construct, manipulate, modify, analyze, and query data and models. IPDS has been designed to expedite land-use planning modeling with direct access to DMS and MMS using scientific visualization principles and the graphic user interface (GUI), which allows the user to modify the digital model and emulate the geographic environment under study.

The GUI is defined as a combination of window, menu, and icon selections designed to guide the user quickly and easily through the program. The GUI allows the user to do as many or as few changes during the implementation of the analysis of models, and to see results immediately without complications. The GUI through user-defined functions allows the user to define how a feature or a class of features will react to user-defined criteria, and allows the reactions to be stored in an easy retrieval trend that facilitates a sensitivity analysis. The GUI allows the dynamic coupling of existing models from the MMS to the DMS, so that the GIS itself acts as a database source to the controlling program. GUI tools provide the user with complete control over the environment in a way not possible in the traditional geo-relational system. And, in this form, the GUI provides the ability to set up a more realistic and effective modeling environment than those that have been possible through simple GIS application. This feature provides the flexibility to interact with the user where the need for the interaction reduces the effort currently demanded by a single application.

While the architecture just described is in fact a collection of diverse, independent software tools, the IPDS interface is assembled in such a way that the analyst always has the impression that he/she is interacting with a single and coherent system. Each of the above-mentioned tasks has been implemented as part of the IPDS system. Each of these components is usually implemented using the already-described different types of technology.

User IPDS provides a framework that orients the user in conducting a planning decision process. The design of the IPDS system includes a wide variety of multi-criteria factors that can be increased, partially avoided, or at least orient the users to better solutions. A logical sequence of steps for the user in IPDS would be:

- Reach agreement on what criteria should be included in the planning decision process.
- Collect data for the above criteria and build a digital database using GIS software (GRASS).
- Examine the theoretical and historical patterns that lead to stability or instability conditions, and modify input data where necessary to meet professional and ethical concerns.
- Calculate and categorize all constraints to be included in an individual hazard assessment, including trigger factors selection such as: probable maximum precipitation (PMP), seismic iso-intensity lines (isoseismal), environmental modifications (land use), etc.
- Promote discussion of algorithms among concerned parties to develop a better and more popular planning decision solution.
- Enforce threshold limits on vulnerability and multi-criteria components. This is implemented by selection or grouping of urban elements such as human settlement, critical facilities and public assembly sites. This leads to a more acceptable risk assessment evaluation and zoning.

Interface Design The Screen Layout of the IPDS interface design, somewhat platform independent is formed by: (1)the ***Menu Bar*** on the top of screen; (2) the ***Control Panel*** on the right side of the screen; (3) the ***Message Box*** and ***Location information*** on the bottom of screen; and (4) the ***Display Window*** in the middle of the screen. Figure 2 shows one of many possible choices. It shows the different shades (colors on the screen) that indicate differences in elevation listed in the legend displayed to the right of the display window.

Hazard Assessment Methodology and Physical factors Geological hazards initially modeled in the study include subsidence, debris flows, and floods. Other models can be run having the data and the algorithm. The dynamic interaction with IPDS for hazard, vulnerability, and risk assessment is based on the assumption that the user has a good background in the required and available information within the database used by the system.

Hazard evaluation inputs are: ***(a) Susceptibility***, determined by a combination of physical factors such as slope (relief), surficial geology (mineralogy, weathering, erodibility and strength), tectonism, geomorphology (morphodynamic processes that modify the landscape and its stability, morphometry), type of soil and geotechnical characteristics, vegetation type and density, land use and land cover, hydrology, constraints, and many others. ***(b) Triggering factors***, determined from the combination of seismicity, precipitation (intensity and duration) evaluated as probable maximum precipitation (PMP), and land use as the human influence on activating disasters through environmental modification.

For each factor, an index of influence is determined through a reference value for every particular site through a specific weight. By multiplying and summing these values through the following equation, a relative Hazard (H) is determined:

$$\text{Hazard} = \text{Hazard Susceptibility} * \text{Trigger(s)} \tag{1}$$

Therefore, the equation suggested for debris flow hazard (Hdf) evaluation is defined as the product of debris-flow hazard susceptibility (Sdf) times the considered trigger factor, which can be precipitation (Tdf_p), seismicity (Tdf_s), or a combination of both (Tdf_ps).

$$\text{Hdf} = \text{Sdf}*[\text{Tdf\_p} \mid \text{Tdf\_s} \mid \text{Tdf\_ps}] \tag{2}$$

- **Hazard susceptibility assessment** The natural factors influencing hazards occurrence such as debris flow, can be modified in the field by engineering management activities, and relatively weighted to assess their projection through the IPDS system.

The preceding factors are evaluated and a relative rating of mass instability is given to each mapping unit. The following algorithm, as an example, is suggested to compute and assign a relative weight of each of the primary factors considered as a control on the susceptibility of a particular site to debris flows (Sdf) in the Glenwood Springs urban area (Colorado, USA). It can be interactively modified using the Hazard Susceptibility pull-down menu (Figure 3), pressing the Debris flow option causes the Edit Debris Flow Susceptibility pop-up. To interact with the model the user can modify Modified Algorithm and apply it. Similarly, Hazard can be interactively modified using the Hazard pull-down menu and pop-up window (Figure 4), following Equation 1.

$$\begin{aligned}\text{Sdf} = {} & ((\text{slopedf} * (\text{aspect}*7 + \text{usc\_casag}*4 + \\ & \text{sgmdf}*9 + \text{veg}*8 + \text{hgdf}*5 + \text{shrswell1}*2 + \\ & \text{erosK}*7 + \text{lusess}*3 + \text{wsbuf1}*8 + \\ & \text{femahist2}*10 + \text{isohyaa}*4)/67) + 9)/10\end{aligned} \tag{3}$$

Equation 3 (modified from Mejía-Navarro et al., 1994) describes slope susceptibility to debris flows and is basically a weighted average, with the relative weighting for each physical factor indicated by the numerical suffix of that factor. These weighting factors are subjective and may be modified by the operator through the GUI using the IPDS interface model (Mejía-Navarro and García, 1994).

The IPDS interface design is built in a way that the user applies the triggering factors directly through the Hazard pull-down menu, clicking on the hazard of interest. The result is obtained interactively by pressing the button for the user's interest, such as Debris Flow Hazards by both PMP and seismicity as trigger factors, then a pop-up editor comes to the screen.

- **Vulnerability data processing** To assess and be effective in vulnerability reduction for urban planning decision-making, we must be prepared to act within an interdisciplinary frame-work. Also, we must realize that the basic importance of our work is the measure of its projection into the improvement of human life. Therefore, we can say that geological hazard zoning of an area has importance and justification to the extent that we use it in planning decisions. Land use planning includes management of existing human settlement, and orientation of new settlement under 'stable' conditions. Environmental geology and geotechnical engineering are designed to be incorporated into the first steps of planning decisions, to give basic information to develop acceptable conditions for life under most geologic circumstances.

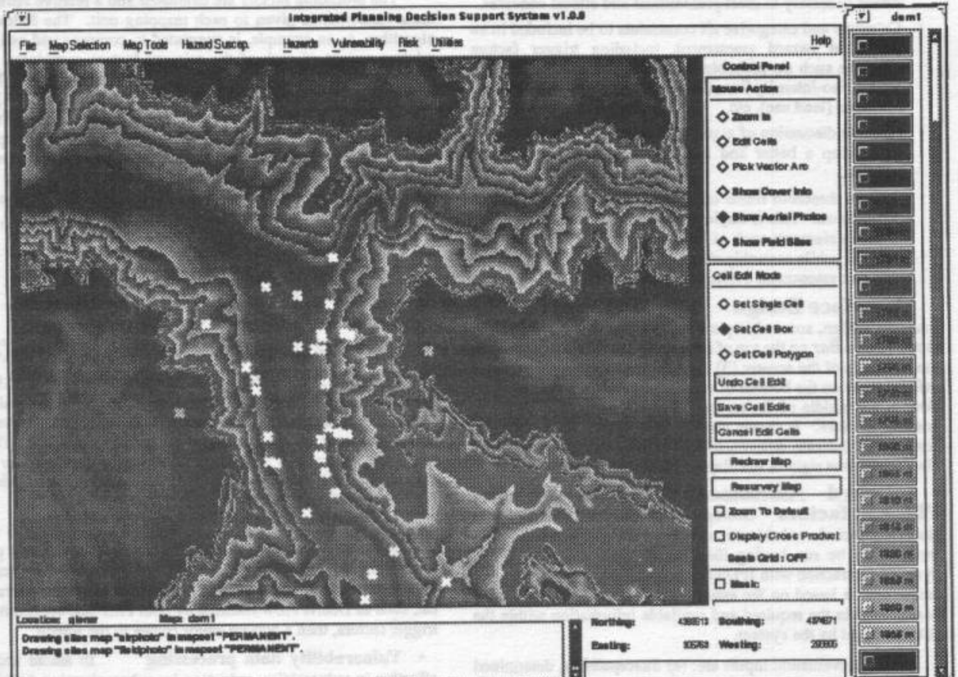
A team of consultants representing all of the disciplines associated with urban planning and development should include soil scientists, geologists versed in geomorphology and environmentalism, civil engineers, hydraulic engineers, design engineers, architects, landscape architects, sociologists, lawyers versed in social conflicts and land-use regulations, transportation engineers, and others. IPDS has been designed to facilitate and promote an easy and fast multi-criteria analysis avoiding a major part of this multi-professional agreement, in order to be more effective in hazard mitigation through productive planning and decision-making. Extensive analysis and definition of land cover and land use by classes should be made, describing density, development approach, traffic circulation and road requirements, flood protection, storm drainage, stream proximity use definition, and utility services. Additionally, extensive studies must be conducted of the preservation of open space available for recreation and time of contingency.

The influencing factors considered for vulnerability assessment and a relative rating of social features response to hazardous events are applied to build the vulnerability algorithm (Equation 4) Land use vulnerability (luseV) assessment is done with consideration of community infrastructure such as building designs and material used in construction and economic zoning, urban infrastructure such as channelization and structural works with special designs to control or mitigate hazards, and social infrastructure such as cultural conditions. Human density is based on census data per block or minimum cell size of the analysis. The lifelines factor considers the buffer area built around the road system network plus water, phone, and electricity lines.

$$\text{vulnerability} = (\text{human\_density}*10 + \text{luseV}*7 + \text{lifelines}*2)/19 \qquad (4)$$

IPDS, through the ***Vulnerability pull-down menu*** (Figure 5) allows the user to modify vulnerability considerations by inserting his/her opinions within the new algorithm which can compute the combination of ecosystem sensitivity (urban infrastructure), economic vulnerability (community infrastructure), and social structure vulnerability (cultural infrastructure).

- **Risk data processing** One particularly complete tool for presenting information on a community's hazard risk is a zoning risk map. Specific risk (Rei) zoning is a procedure of dividing a region into zones that indicate exposure to a specific hazard (Hi) such as debris flows, floods, rockfall, or subsidence. The interest of this type of zone mapping is to estimate the location,



Location: glenr   Map: dem1

Drawing sites map "airphoto" in mapset "PERMANENT".
Drawing sites map "fieldphoto" in mapset "PERMANENT".

Northing: 4366513   Southing: 4374871
Easting: 305763   Westing: 290905

Figure 2: Raster map showing elevation with site locations of field photo sites (Xs).

probability, and relative severity of future-probable hazardous events, so that potential losses can be estimated, mitigated, or avoided (Cluff, 1978). Hazard and risk zoning maps provide the basic information for applying land-use planning measures improved by structural and/or non-structural techniques to hazard or vulnerability mitigation. Risk is computed as function of hazard and vulnerability (socioeconomic and political issues):

$$Rei = f(Hi, Ve). \qquad (5)$$

In other words, risk can be understood as the geographical distribution of potential damages affecting elements at risk (Cardona 1988), or as the scenario of social and economic losses. The goals of a risk analysis are to: (1) reduce causal agents, (2) reduce vulnerability, (3) mitigate physical, economic, and mental damage, and (4) improve the process of planning. This study provides a model which calls attention to areas that demand fast and careful attention. This can be done by running different scenarios if conditions of vulnerability and/or hazard have been modified or mitigated by structural or non-structural implementations.

The Risk pull-down menu of IPDS allows the user to selectively evaluate the geographical distribution of potential damages affecting social features, selected when the user computes vulnerability for different types of hazards (Figure 6).

CONCLUSIONS

This DSS called IPDS is built on a decision-making process that community planners often tacitly use now. However, IPDS can help to provide a stronger rationale for the decisions made, particularly in terms of implementation feasibility and costs.

IPDS discusses the potential usefulness of land use planning techniques in relation to technical features such as geologic surficial processes, geotechnical characteristics of ground, environmental conditions, and social aspects. IPDS application allows planners to implement safer emplacements within a minimum time for decision making and the most information available applied.

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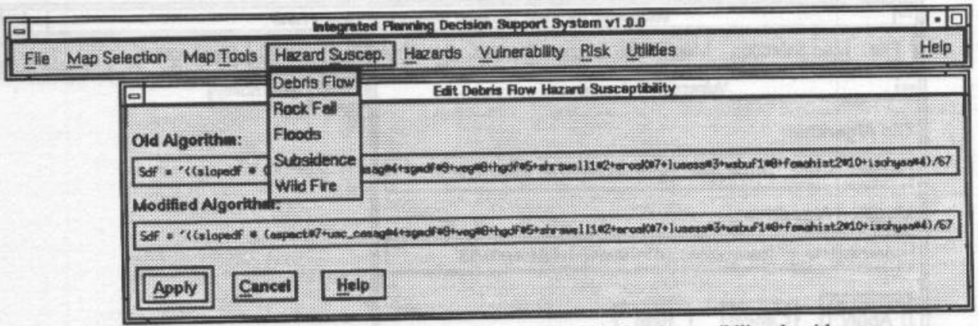
Physical factor abbreviations glossary Abbreviations have been normalized for main entries within algorithms used to compute hazard susceptibilities, triggers, hazards, and risks. These are designed to be close to the normal words, the length of which require abbreviation. The following are the meanings of the input factors in the algorithms described for this study.



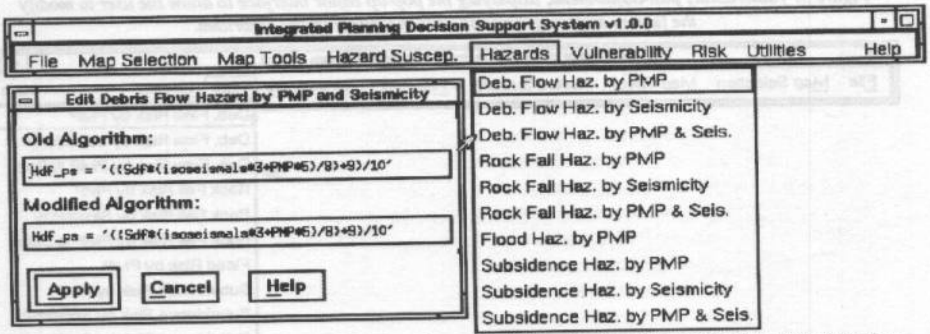
Old Algorithm:

```
Sdf = '((slopedf * (...sag#4+sgadf#9+veg#8+hgdf#5+shrswell1#2+erosK#7+luess#3+wsbuf1#8+fmchist2#10+ischyso#4)/67
```

Modified Algorithm:

```
Sdf = '((slopedf * (aspect#7+usc_casag#4+sgadf#9+veg#8+hgdf#5+shrswell1#2+erosK#7+luess#3+wsbuf1#8+fmchist2#10+ischyso#4)/67
```

Figure 3: Hazard susceptibility pull-down-menu, displaying Debris-flow Susceptibility algorithm pop-up editor



Old Algorithm:

```
}Hdf_ps = '((Sdf*(isoseismals#3+PMP#5)/8)+9)/10'
```

Modified Algorithm:

```
Hdf_ps = '((Sdf*(isoseismals#3+PMP#5)/8)+9)/10'
```

Figure 4: Hazard pull-down-menu, displaying Hazard by PMP and seismicity pop-up editor interface when user wishes to evaluate hazard involving both trigger factors.

slopedf: slope angles from 0°-89° (0%-800%) are divided into 10 classes, with the highest rating (10) given to those angles most characterized by debris flows.

aspect: slope aspect, with 360° = 0° = north-facing, 90° = east-facing, 180° = south-facing, 270° = west-facing.

sgmdf: debris flow susceptibility of surficial geologic material (slope cover). These include different exposed lithologic units - both bedrock and Quaternary deposits - differentiated and reclassified into 10 categories according to their susceptibility to and historic influence on related hazards.

hgdf: hydrologic soil groups used to estimate runoff from precipitation (Harman and Murray, 1992); these are classified based on infiltration rate, water transmission and speed of rise of internal pore pressure.

lusess: a zoning of land use features based on their relative negative influence on slope stability and flooding.

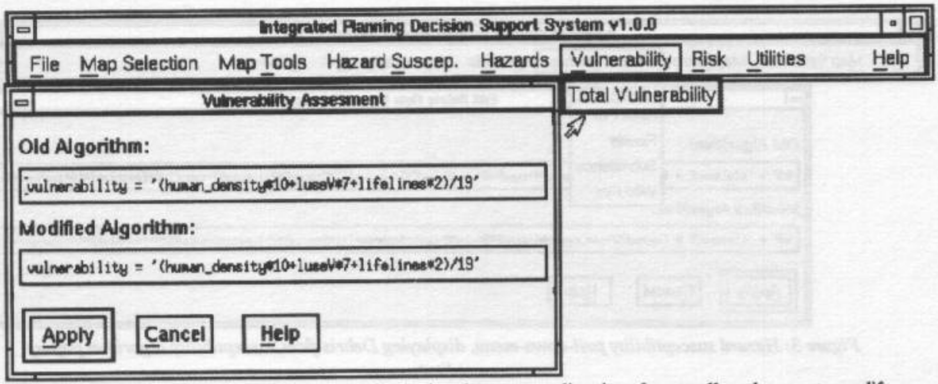
luseV: this factor considers land use reclassification by its vulnerability to be affected by a general natural hazard. This reclassification is based on cultural and economic conditions of the community, on urban infrastructure design of buildings such as zoning of wood versus brick and concrete constructions, urban infrastructure density which blocks or facilitates the passage of debris flows or floods, and proximity to the hazardous areas, and on hazard mitigation infrastructure such as channelizations and structural works with special designs to control or mitigate hazardous events.

femahist2: the data for this factor are the result of a cross-tabulation and reclassification of debris flow records on Quaternary geology maps, historical floods and debris flow records from newspapers during this century, and possible flooding areas estimated with HEC2 (Hydrologic Engineering Center, 1971) evaluations.

isohyaa: isohyets for average annual precipitation from weighting are assigned from 10 for areas with the highest precipitation values in millimeters to 1 for areas with the lowest value of annual precipitation.

Probable Maximum (PMP): isohyetal maps of 25, 50, or 100 year probable maximum precipitation obtained from climate centers. Weighting is assigned to each isohyetal area based on historical record of storms associated with destructive events and the areal distribution of each precipitation intensity on urban areas.

usc_casag: this factor combines (i) regolith texture according to the Unified Soil Classification System (USC), reclassified by grain-size distribution in terms of susceptibility to infiltration and internal structural collapse, and (ii) regolith



Old Algorithm:

```
vulnerability = '(human_density*10+luseV*7+lifelines*2)/19'
```

Modified Algorithm:

```
vulnerability = '(human_density*10+luseV*7+lifelines*2)/19'
```

Figure 5: Vulnerability pull-down-menu, displaying the pop-up editor interface to allow the user to modify the factors and weighting values in the vulnerability algorithm.

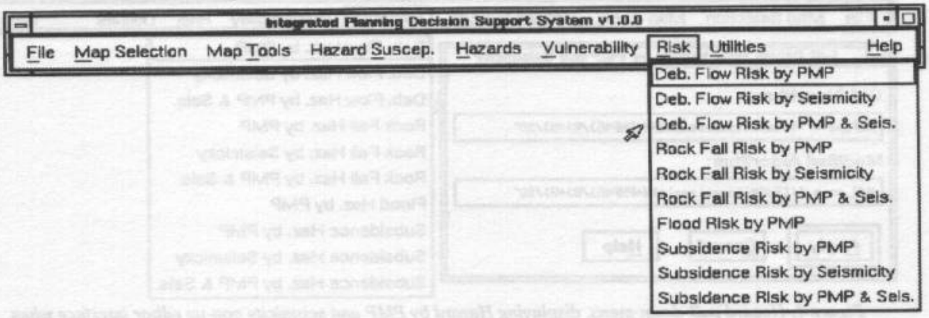


Figure 6: Risk pull-down-menu allows the user a selective estimation of scenarios.

matrix by its proximity to the Casagrande A line (Casagrande classification: Lambe and Whitman, 1969) on a plot of liquid limit versus plastic index.

shrswell: clay content and mineralogy in relation to shrink-swell potential (Harman and Murray, 1992).

erosK: sheet erosion potential using Universal Soil Loss Equation factor K, a measure of the susceptibility of the soil to erosion by water; soils having the highest K values are the most erodible, facilitating debris flows.

isoseismals: when this type of map does not exist, it is built based on seismic waves attenuation behavior empirically assigned to geologic units, in combination with a pattern of radiation of energy from known epicenters and fault planes to create an isoseismal map of expected seismic intensities in specified areas. This can be also considered as a predicted attenuation pattern of seismic waves

lifelines: the buffer area built around the road system network plus water, phone, and electricity lines.

veg: vegetative cover of slope, with categories as calculated for the study area by the Soil Conservation Service (Harman and Murray, 1992).

human_density: this factor is based on population census data per block or minimum cell size of the analysis.

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